DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Economic Heavy Minerals in Sediments from an Offshore Area East of Cape Charles, Virginia

by

Gretchen Luepke[1]

Open-File Report 90-451

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

1990

ABSTRACT

The heavy-mineral suite in 23 vibracore samples east of Cape Charles, Virginia is dominated by pyroboles (pyroxenes and amphiboles), with notable percentages of garnet, staurolite, and epidote group minerals. Economic heavy minerals identified include ilmenite, leucoxene, rutile, zircon, monazite, and aluminosilicates (sillimanite and kyanite). In the samples from this study these minerals constitute an average of about 15 percent by weight of the heavy minerals in the analyzed sediment and an average of 0.23 percent of the bulk samples. Total heavy-mineral percentages in the samples range between 0.1 and 6.3 percent. The uppermost parts of all but 5 vibracores contain over 1 percent heavy minerals; 21 of 72 samples contain over 3 percent heavy minerals. Although the concentrations of the economic species are lower than in other samples taken nearby (Berquist and Hobbs, 1988), the presence of a significant number of samples containing greater than 3 percent heavy minerals plus the occurrence of the same heavy-mineral suite as previously described further supports the possibility of economic concentrations in this region.

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, 23 vibracores from an area 20 to 60 km east of Cape Charles, Virginia, have been analyzed for their heavy-mineral content.

The earliest heavy-mineral study in this area was done by Goodwin and Thomas (1973). Grosz and Escowitz (1983) included analyses of grab samples off the Virginia coast. Detailed heavy-mineral studies from both core and grab samples have been published by Berquist and Hobbs (1988).

Acknowledgments

Mark Brown performed some of the initial estimates of heavy-mineral percentages. Robert Oscarson performed analyses with the SEM and EDAX .

METHODS

Twenty-three vibracores were collected in June 1985 offshore of Cape Charles, Virginia (fig. 1). Table 1 lists the location and length of each core, and the water depth at which the core was taken. Core length averaged 484 cm, with minimum and maximum lengths of 172 cm and 614.5 cm, respectively.

Each core was split, photographed, described, and sampled. Based on lithological changes within the cores, 72 samples were taken, and each sample was split for repository, grain-size analysis, and heavy mineral content. Descriptions of grain-size analysis, core lithology and stratigraphy will be published later.

After the subsamples for repository and grain-size analysis were taken, the remaining sample was weighed and transferred to a 20-liter bucket to which a 5 percent solution of sodium hexametaphosphate (Calgon) was added for disaggregation of clay particles. This sample was then wet-sieved to remove any material less than 0.62 mm size. The remaining sample was again wet-sieved to remove the gravel-sized fraction (>2.0 mm).

The sand-sized fraction (2.0-0.062 mm) was dried in a convection oven at 100 degrees C. and weighed. These samples, ranging in weight from 163 to over 13,000 g, were separated into light- and heavy-mineral concentrates by using a Humphreys 3-turn spiral, following the wet-milling process described in Luepke and Grosz (1986). A quarter split of each heavy-mineral fraction was taken: half for geochemical analysis and half for repository. The analytical split was separated by magnetic techniques (Luepke and Grosz, 1986) into three paramagnetic subfractions: one strongly magnetic (separable by hand magnet or 0 amp), and two separable by an electromagnet set at 0.6 amp.

The remaining three-quarters split of each heavy-mineral fraction was separated into six paramagnetic subfractions: strongly magnetic, 0 to 0.2, 0.2 to 0.4, 0.4 to 0.6, 0.6 to 0.8, and >1.8 amp. Each magnetic fraction was weighed and examined using binocular and petrographic microscopes. Long-wave and unfiltered short-wave ultraviolet lights were used with other optical properties to detect zircon and monazite, respectively. Because of the extreme danger to eyesight when using short-wave ultraviolet light with a binocular microscope, examination of fractions for monazite was stopped as soon as one grain was positively identified. Selected mineral grains were examined using a scanning electron microscope (SEM) and an energy-dispersive X-ray analyzer (EDAX), to aid in confirming mineral identification.

RESULTS

The weight percentages of heavy minerals identified in the sediments (table 2) were calculated according to the method described in Luepke and Grosz (1986). Minerals identified in Cape Charles cores include, in approximate order of decreasing average abundance, pyroboles (pyroxene and amphiboles), epidote group, staurolite, ilmenite, garnet, zircon, magnetite, apatite, sphene, leucoxene, sillimanite and kyanite, tourmaline, rutile, and monazite. Pyrite, limonite, mica, chloritoid, and corundum occur mostly as traces and not in all samples. This suite agrees with that determined by Berquist and Hobbs (1988) along the entire Atlantic coastline of Virginia.

The presence of ilmenite within the magnetite has been confirmed with X-ray diffraction; up to half of the "magnetite" may be titaniferous. Magnetite percentages within the core generally increase with depth, while ilmenite percentages generally decrease. Leucoxene occurs as individual grains and as alteration on ilmenite. The ratio of amphibole to pyroxene is usually 2:1 and can be higher.

Amphiboles are dominated by green and blue-green hornblende; rarer species are brown hornblende, basaltic hornblende, tremolite/actinolite, and riebeckite(?). Pyroxenes include hypersthene and augite, with rare titanaugite. Epidote includes clinozoisite and rare non-ferrian zoisite. Sillimanite is much more common than kyanite. Both brown and (rarer) blue varieties of tourmaline are present.

In many samples the percentage of staurolite exceeds that of garnet. This is opposite of the results obtained by Berquist and Hobbs (1988). However, when the averages of these two mineral percentages are totaled, the results of the present study and theirs are similar.

Apatite, included with "others" by Berquist (oral communication, 1989) and sphene occur in consistently subequal amounts; no immediate explanation for this is available. Zircon averages 4.6 percent and tends to increase with depth within the core. Rutile averages 0.4 percent. The presence of monazite in trace amounts must be seen as minimum amounts, because of the conservative manner in which the mineral was detected.

"Others" may include chloritoid and corundum, trace minerals (<0.5 percent) identified in grain mounts. The bulk of "others" are altered grains, which may be altered epidote and/or pyroboles. Mica occurs in trace amounts in some samples. Limonite occurs only in three cores, and only in the lowermost samples of two of these. This may indicate the penetration of older Holocene material. Pyrite, where identified, occurs as either framboidal organic pyrite or as interlayers with clays in fecal pellets.

Economic heavy minerals identified in the Cape Charles region are ilmenite, leucoxene, rutile, zircon, monazite, and the aluminosilicates sillimanite and kyanite. The summed percentages of these minerals (EHM/C) ranges from 8.2 to 26.7 percent; as weight percentage of bulk samples (EHM/T), they range from 0.1 to 0.68 percent. These values are lower than the values for core samples obtained by Berquist and

Hobbs (1988), who found 12-69 percent EHM/C; they did not calculate EHM/T. Among individual mineral species, only zircon averages higher in the present study, and the leucoxene percentages are nearly equal..

A comparison of the average values and standard deviations of the percentages of economic heavy minerals from the Berquist and Hobbs (1988) study and the present study are shown in Table 3. Berquist and Hobbs (1988) base their evaluation of the area's economic potential on minimum concentrations for a hypothetically economic land deposits as defined by Garnar (1978): ilmenite, 45 percent; leucoxene, 5 percent; rutile, 2 percent; zircon, 5 percent; monazite, 1 percent; sillimanite/kyanite, 7 percent; and a total heavy mineral concentration of 4 or 5 percent. By these standards, the average values for the minerals in Table 3 are lower than industry standards for mining on land.

Because no offshore production of a similar heavy-mineral suite exists within U.S. waters, Berquist and Hobbs (1988) were unable to make a direct economic comparison to Virginia's offshore mineral potential. However, they postulated an economic potential based on maximum values for the economic heavy minerals in 50 of their 390 samples, although total heavy mineral concentration may be low in some samples. Together with the results of Berquist and Hobbs, maximum values in the present study for leucoxene (5.5 percent in 1364-5), rutile (2.7 percent in 1368-1), and zircon (17.4 percent in 1360-4) further support the possibility of economic deposits in this region.

Possible reasons for the differences between Berquist and Hobbs (1988) and this study include sample distribution and number. Berquist and Hobbs' study represents 390 samples, 284 of which were vibracores, with heavy-mineral percents ranging from 0.41 to 9.26 (average 2.87 percent). Only 22 of the 284 samples (about 8 percent) contained less than 1 percent total heavy minerals, and 78 samples contained greater than 5 percent. These samples represent the entire Atlantic coastline of Virginia; nearly all samples lie within 9 km of land at depths ranging from 2 to 18 m.

The present study represents 72 samples whose weight percentages of all heavy minerals range from 0.11 to 6.26 (average 2.14 percent). Eighteen of these samples, or 25 percent, contained less than 1 percent total heavy minerals, and only 2 samples contained greater than 5 percent. However, 10 samples from cores between 16 and 30 m depth contained greater than 3 percent total heavy minerals. The sampling area is a relatively narrow east-west swath with a depth range of 9 to 35 m, the only minimal overlap occurring with the vibracores near Smith Island (Cores 1352, 1354, 1356, 1358, 1360, 1362, and 1425). This suggests that the area of the present study may represent a limit to the extent of high concentrations of economic heavy minerals on this part of the Virginia continental shelf.

CONCLUSIONS

The economically important heavy minerals identified in the Cape Charles region are ilmenite, leucoxene, rutile, sillimanite and kyanite, zircon and monazite. The weight percentages of these minerals (EHM/T column, table 2) constitute an average of 0.23 percent of whole samples, ranging from from <0.1 to 0.68 percent, or 6.2 to 25.7 percent of the heavy-mineral fraction (EHM/C column, table 2).

Although these values are lower than previously noted for the inner continental shelf of Virginia (Berquist and Hobbs, 1988), the facts that the heavy-mineral suite is identical, the thicknesses of the cores average nearly 5 m, and the samples were taken farther from shore further support the possibility of economic placer deposits in the Virginia offshore. These samples with lesser amounts of heavy minerals may represent a seaward limit to the extent of high (greater than 5 percent) heavy-mineral concentrations..

REFERENCES

Berquist, C.R., Jr. and Hobbs, C.H., III, 1988, Study of economic heavy minerals of the Virginia inner continental shelf: Virginia Division of Mineral Resources Open-File Report 88-4, 149 p.

Garnar, T.E., Jr., 1978, Geological classification and evaluation of heavy-mineral deposits: Georgia Geological Survey Information Circular 49, p. 25-36.

Goodwin, B.K. and Thomas, J.B., 1973, Inner shelf sediments off Chesapeake Bay, v. III, heavy minerals: Virginia Institute of Marine Science Special Scientific Report 68, 34 p.

Grosz, A.E. and Escowitz, E.C., 1983, Economic heavy minerals of the United states Atlantic Continental Shelf: in Tanner, W.F. ed., Nearshore sedimentology, Proceedings of the 6th Symposium on Coastal Sedimentology, Florida State University, Tallahassee, p. 231-242.

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.

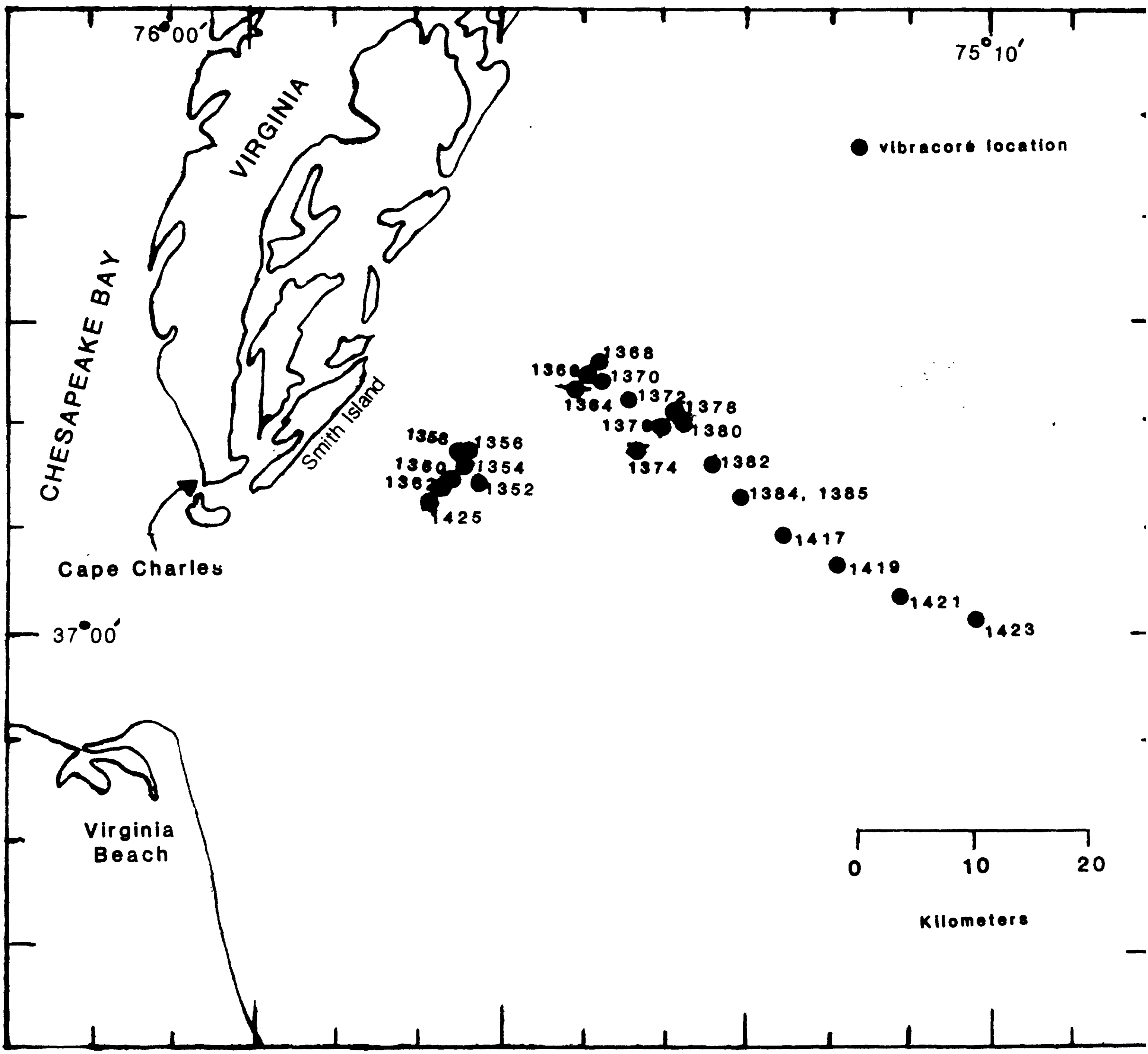

Figure 1. Index map showing location of vibracores taken near Cape Charles, Virginia. Map base from Berquist and Hobbs (1988).

Table 1. Location and depths of vibracore samples from Cape Charles area, Virginia. Latitude and longitude expressed in degrees to the nearest thousandth.

Core No.	Latitude, N.	Longitude, W.	Water depth, m	Core length, cm
1352	37.126	75.689	10.7	502
1354	37.135	75.696	10.9	603
1356	37.146	75.698	11.0	614.5
1358	37.146	75.707	10.9	588
1360	37.125	75.714	9.9	601
1362	37.119	75.724	9.1	553
1364	37.194	75.585	9.3	549
1366	37.206	75.574	9.3	314
1368	37.217	75.562	14.0	215
1370	37.202	75.559	15.3	409
1372	37.188	75.534	22.4	498
1374	37.146	75.526	15.1	402
1376	37.167	75.501	13.8	462
1378	37.179	75.485	16.1	360
1380	37.170	75.485	16.6	372
1382	37.135	75.478	23.5	570
1384	37.110	75.418	24.0	172
1385	37.110	75.417	24.0	599
1417	37.079	75.375	25.9	536
1419	37.056	75.321	30.5	517
1421	37.029	75.258	36.6	592
1423	37.009	75.180	39.6	520
1425	37.107	75.733	12.2	580

Table 2. Heavy mineral analyses of vibracore samples from Cape Charles area, Virginia. Mineral abundances are given in weight percent of heavy minerals.

[Abbreviations: hv. min.=heavy minerals; Sill/Ky=sillimanite and kyanite; MIN=Minimum value; MEAN=Mean value; MAX=Maximum value; St. Dev.=Standard deviation; dash(-)=not detected; EHM/C=sum of percentage of ilmenite, leucoxene, rutile, zircon, monazite, sillimanite and kyanite in the heavy-mineral concentrate; EHM/T=weight percentage of economic heavy minerals in total sample; T=trace (<0.5 percent)]

Epidote group includes epidote, clinozoisite, and zoisite
Pyroboles include pyroxenes and amphiboles
Others are mostly altered grains and may also include corundum, chloritoid, and unknown minerals.

Table 2. Heavy mineral analyses of vibracore samples from offshore area east of Cape Charles, Virginia. Mineral abundances are given in weight percent of heavy minerals.

Sample Number	Interval, cm	Weight % hv. min.	Magnetite %	Ilmenite %	Leucoxene %	Pyrite %	Limonite %	Mica %	Garnet %	Staurolite %	Epidote %	Pyroboles %	Sill/Ky %	Tourmaline %	Sphene %	Apatite %	Rutile %	Zircon %	Monazite %	Other %	EHM/C	EHM/T
1352-1	0-403	3.69	8.7	3.9	0.8	T	-	T	7.1	5.2	14.2	42.4	0.5	1.0	2.0	2.3	0.2	5.5	-	5.9	10.9	0.30
1352-2	403-502	2.10	9.7	4.0	1.0	T	-	T	5.5	4.0	14.5	46.9	0.5	0.5	1.5	2.0	0.1	4.4	-	5.2	10.0	0.15
1354-1	0-162	3.70	6.0	6.6	0.8	-	-	T	6.9	4.9	7.9	47.6	0.5	3.4	2.0	2.2	0.2	4.4	T	6.5	12.5	0.31
1354-2	162-304	3.07	7.7	6.3	1.4	-	-	T	8.0	3.9	12.4	45.0	0.7	1.5	2.1	2.1	0.2	4.6	T	4.0	13.2	0.30
1354-3	304-466	2.29	9.4	5.8	1.0	T	-	T	6.6	4.8	11.1	43.1	0.6	2.6	2.2	2.4	0.2	5.2	T	4.9	12.8	0.22
1354-4	466-603	2.65	9.2	5.0	0.8	T	-	T	4.0	2.9	13.2	48.6	0.4	1.8	1.7	1.8	0.1	4.1	-	6.3	10.4	0.21
1356-1	0-86	1.53	2.4	12.3	1.2	-	-	-	6.6	6.3	9.5	49.6	0.5	1.5	1.9	1.4	0.5	3.4	T	2.9	17.8	0.20
1356-2	86-614.5	1.50	10.2	14.6	0.5	T	-	T	3.7	5.2	14.5	30.8	0.7	0.5	2.2	2.8	0.1	7.5	T	6.3	23.4	0.27
1358-1	0-128	4.71	5.9	5.8	1.3	-	-	-	5.5	4.1	16.2	47.5	0.4	0.6	1.6	1.7	0.1	3.8	T	5.3	11.4	0.41
1358-2	128-588	1.43	9.4	5.2	1.8	T	-	T	4.9	3.7	15.7	38.0	1.0	1.0	2.1	3.0	0.1	6.7	-	7.0	14.8	0.16
1360-1	0-42	1.48	8.8	8.5	1.5	-	-	-	4.2	6.1	18.1	43.8		part		of		sample		lost		
1360-2	42-109	5.06	12.1	5.6	0.8	-	-	T	4.0	5.6	18.4	37.1	0.7	0.6	1.6	2.5	0.2	6.0	T	4.5	13.3	0.49
1360-3	109-527	3.41	14.0	4.1	1.1	T	-	T	2.4	5.7	18.9	38.3	0.3	0.7	2.2	2.2	0.2	5.3	T	4.6	11.0	0.28
1360-4	527-596	0.94	13.3	3.3	1.2	-	-	T	2.0	4.4	10.8	28.6	1.7	0.7	2.6	7.0	0.3	17.4	-	6.7	24.0	0.16
1362-1	0-108	6.26	10.7	8.5	0.7	-	-	T	8.0	8.1	10.9	33.5	0.7	0.7	2.2	2.0	0.3	4.8	T	8.9	15.0	0.68
1362-2	108-254	4.38	11.6	4.3	1.0	-	-	T	4.0	4.0	14.8	36.0	0.7	0.7	2.4	2.2	0.2	5.2	T	12.9	11.4	0.37
1362-3	254-330	0.81	10.5	2.4	1.3	-	-	T	3.8	1.6	14.3	44.2	0.7	0.5	3.0	3.0	0.2	5.8	T	8.9	10.4	0.06
1362-4	330-553	2.16	16.3	1.7	2.2	-	-	T	4.3	4.3	15.9	38.7	0.7	0.4	3.2	3.0	<0.1	6.5	T	2.7	11.1	0.16
1364-1	0-17	0.89	2.1	16.8	1.0	-	-	-	8.4	8.4	9.5	47.4	1.0	<0.1	1.1	1.1	<0.1	2.1	T	1.0	20.9	0.12
1364-2	17-212	3.66	8.4	7.8	0.9	-	-	T	5.4	11.6	13.4	35.5	1.6	0.5	3.0	3.4	0.2	7.3	-	0.9	17.8	0.48
1364-3	212-295	0.66	4.4	4.2	1.7	T	-	T	4.2	8.2	14.6	53.4	0.8	0.3	1.3	1.6	0.2	3.6	T	1.5	10.5	0.05
1364-4	295-378	1.99	7.7	6.5	4.7	T	-	T	2.0	6.5	13.9	40.2	1.6	0.6	4.0	3.9	0.6	6.3	-	1.5	19.7	0.32
1364-5	378-549	1.53	10.3	6.3	5.5	T	-	T	1.3	4.4	13.2	40.7	1.8	0.7	4.3	3.0	0.2	6.8	T	1.4	20.3	0.26
1366-1	0-32	0.34	1.5	19.7	1.0	-	-	-	7.6	8.0	4.5	43.4	0.5	<0.1	1.5	1.5	1.0	3.5	-	6.1	25.7	0.06
1366-2	32-132	2.13	5.0	4.0	1.4	-	-	-	5.5	7.8	6.3	50.1	1.0	0.6	2.3	2.2	0.5	4.0	-	9.3	10.9	0.17
1366-3	132-162	0.37	3.1	8.1	1.9	-	-	-	3.9	8.1	6.9	49.4	0.8	0.8	1.5	1.5	0.8	4.2	-	8.9	15.8	0.04
1366-4	162-314	1.50	1.6	6.6	1.7	-	-	T	4.4	9.4	11.9	46.4	0.8	1.4	1.6	1.2	0.9	3.2	-	8.9	13.2	0.15
1368-1	0-20	0.35	0.9	12.5	0.9	-	-	-	12.5	8.0	2.7	45.5	1.7	1.8	1.8	0.9	2.7	4.5	T	2.7	22.3	0.06
1368-2	20-116	2.41	0.7	8.6	1.3	-	-	T	11.3	10.3	4.4	51.0	0.6	1.3	1.4	1.1	1.0	3.1	T	3.7	14.7	0.26
1368-3	116-130	0.33	T	9.2	1.0	-	-	-	12.2	11.2	5.1	52.0	1.0	<0.1	1.0	1.0	1.0	3.1	T	2.0	15.3	0.04
1368-4	130-141	0.35	1.6	3.2	0.8	-	-	-	4.8	7.1	7.1	56.3	0.8	1.6	1.6	1.6	0.8	3.2	T	9.5	8.8	0.02
1368-5	141-162	0.42	0.6	8.0	0.6	-	-	-	8.6	11.7	5.6	48.8	1.2	0.6	1.2	1.2	1.2	4.3	T	5.6	15.3	0.05
1368-6	162-215	2.50	3.3	2.8	1.2	-	-	T	7.4	10.8	9.2	52.3	1.1	1.0	1.8	1.6	0.7	4.6	-	2.0	10.4	0.19
1370-1	0-119	0.96	2.4	7.9	1.4	-	-	T	7.3	7.3	7.2	53.3	0.8	0.7	1.6	1.2	0.4	3.0	T	5.5	13.5	0.09
1370-2	119-343	2.32	4.2	4.3	0.8	T	-	T	4.2	8.4	5.1	55.9	0.8	0.6	1.2	1.2	0.2	3.1	-	10.0	9.2	0.15
1370-3	343-409	2.06	7.0	2.7	2.1	0.5	-	T	4.0	5.7	5.0	56.9	1.0	0.6	1.9	1.6	0.2	4.0	T	6.7	10.0	0.15
1372-1	0-445	1.30	5.5	7.7	1.8	0.5	-	T	3.9	11.5	10.1	46.3	0.7	0.7	1.5	1.2	0.2	3.6	T	4.8	14.0	0.13
1372-2	445-498	1.06	0.8	13.2	1.3	-	-	-	2.3	6.7	8.3	53.7	0.6	0.6	0.7	1.4	0.3	3.0	T	6.6	18.4	0.14
1374-1	0-202	1.44	0.7	12.7	1.6	-	-	T	10.1	12.8	5.6	45.2	0.6	1.1	1.3	1.0	0.8	2.8	T	3.7	18.5	0.20
1374-2	202-322	1.97	1.6	14.0	1.4	-	-	T	7.1	10.8	8.4	45.8	0.7	1.0	1.4	1.1	0.4	3.1	T	3.1	19.6	0.29
1374-3	322-402	2.25	2.3	3.7	1.6	-	-	T	3.8	7.5	9.2	61.1	0.8	0.7	1.7	1.3	0.3	3.5	T	2.4	9.9	0.16

Table 2. Heavy mineral analyses of vibracore samples from offshore area east of Cape Charles, Virginia. Mineral abundances are given in weight percent of heavy minerals.

(cont'd)

Sample	Interval	Wt.% hv.	Magnetite	Ilmenite	Leucoxene	Pyrite	Limonite	Mica	Garnet	Staurolite	Epidote	Pyroboles	Sill/Ky	Tourmaline	Sphene	Apatite	Rutile	Zircon	Monazite	Other	EHM/C	EHM/T
1376-1	0-153	2.03	0.6	10.1	1.6	-	-	-	10.2	10.2	5.7	50.1	0.8	1.0	1.5	1.2	0.9	3.5	T	2.6	16.9	0.25
1376-2	153-303	2.80	0.7	5.2	1.1	-	-	-	10.4	10.4	7.1	51.8	0.7	0.8	1.4	1.1	0.6	3.3	T	5.3	10.9	0.23
1376-3	303-462	2.23	1.1	10.2	1.5	-	-	T	7.5	11.5	9.8	47.5	0.8	0.8	1.4	1.1	0.7	2.7	T	3.3	15.9	0.27
1378-1	0-148	2.05	0.6	10.6	1.1	-	-	-	13.6	11.2	5.6	49.6	0.7	1.2	1.8	1.1	0.5	2.3	T	0.1	15.2	0.22
1378-2	148-334	3.06	1.2	4.7	1.7	-	-	-	9.8	11.1	7.5	53.5	0.8	1.1	1.6	1.2	0.4	3.0	T	2.4	10.6	0.25
1378-3	334-360	4.27	2.4	3.9	1.9	-	-	T	7.4	11.5	9.3	52.2	0.9	0.8	1.4	1.5	0.1	4.1	-	2.5	10.9	0.35
1380-1	0-136	3.42	1.2	13.0	0.3	T	-	T	13.2	18.2	4.8	42.7	0.3	0.3	0.6	0.6	0.5	2.2	T	2.0	16.3	0.42
1380-2	136-372	3.23	1.2	12.5	1.0	-	-	0.9	8.3	12.8	4.1	50.5	0.6	0.3	1.2	0.9	0.3	3.3	T	2.0	17.7	0.42
1382-1	0-256	3.25	0.9	12.2	1.0	T	-	0.9	8.0	12.3	6.5	49.5	0.5	0.4	1.1	1.1	0.2	2.4	T	2.9	16.3	0.40
1382-2	256-463	3.72	1.5	13.8	1.0	T	-	0.6	3.2	7.3	11.5	56.6	0.3	0.5	1.1	0.5	0.1	1.1	T	0.8	16.3	0.44
1382-3	463-570	3.20	1.0	11.2	1.1	T	-	T	7.5	11.3	10.1	48.7	0.7	0.3	1.3	1.3	0.2	2.5	T	2.8	15.7	0.36
1384-1	0-172	3.62	2.4	10.5	1.6	-	-	T	3.5	7.2	10.6	47.7	1.5	0.4	1.8	2.1	0.2	4.8	T	5.7	18.6	0.51
1385-1	0-153	2.99	2.4	7.4	1.4	-	-	T	5.2	7.3	9.2	52.3	1.2	1.0	1.9	2.4	0.2	5.8	T	2.2	16.0	0.36
1385-2	153-306	3.72	2.3	10.7	1.1	T	-	T	5.3	10.8	7.0	48.4	1.2	0.6	1.8	2.4	0.4	5.3	T	2.6	18.7	0.32
1385-3	306-459	1.84	1.2	11.4	1.0	T	-	T	5.2	7.5	6.3	50.6	1.6	0.8	2.1	3.1	0.3	7.7	T	1.2	22.0	0.30
1385-4	459-599	1.17	1.4	7.3	1.6	-	-	T	10.8	14.5	4.1	40.6	2.0	0.8	2.9	4.0	0.4	8.6	T	1.0	19.9	0.17
1417-1	0-400	1.98	0.5	8.0	1.2	-	-	T	7.2	8.5	8.9	54.5	0.8	0.6	1.6	1.4	0.5	4.1	T	2.2	14.6	0.22
1417-2	400-536	1.48	1.0	4.4	1.1	-	-	T	6.7	7.4	7.8	59.6	0.9	0.8	1.6	1.4	0.2	4.1	T	2.7	10.7	0.12
1419-1	0-54	3.17	0.3	7.5	0.9	-	-	T	11.7	14.4	5.5	48.1	1.1	0.7	1.7	2.1	0.7	4.1	T	1.2	14.3	0.35
1419-2	54-517	1.59	1.9	3.7	1.5	-	-	T	3.8	5.3	8.0	52.0	1.5	1.0	2.3	3.1	0.2	7.4	T	8.0	14.3	0.16
1421-1	0-127	0.38	1.4	4.8	1.4	-	-	T	11.1	14.7	10.8	41.4	1.1	1.0	1.7	2.2	0.4	5.4	T	2.6	13.1	0.04
1421-2	127-431	0.64	0.4	7.6	0.6	-	-	T	8.4	12.1	14.8	43.3	0.8	0.8	1.4	1.1	0.4	5.0	T	2.3	14.4	0.07
1421-3	431-489	0.11	1.3	14.0	0.7	-	4.0	-	10.7	8.0	20.7	28.0	0.7	<0.1	1.3	1.3	1.3	4.0	T	3.3	20.7	0.02
1421-4	489-592	0.11	3.4	2.2	0.6	-	23.6	-	2.8	4.5	11.8	42.1	0.6	1.1	1.1	0.6	0.6	2.2	-	2.8	6.2	<0.01
1423-1	0-212	1.09	3.0	17.0	0.9	-	1.9	-	7.9	5.1	6.5	44.4	0.9	1.2	1.3	1.4	0.4	5.3	T	2.8	24.5	0.19
1423-2	212-390	0.66	3.6	5.5	1.3	-	1.3	T	7.2	5.8	13.6	49.3	1.1	1.1	1.2	1.3	0.3	5.1	T	2.4	13.1	0.06
1423-3	390-520	0.44	7.7	3.9	1.1	-	19.0	-	3.9	2.9	8.5	43.8	0.6	0.8	0.8	0.8	0.4	3.5	T	2.1	9.5	0.03
1425-1	0-162	4.39	6.7	5.9	1.2	-	-	-	6.7	7.1	8.7	45.0	1.0	2.5	1.8	2.1	0.3	4.9	T	6.0	13.3	0.44
1425-2	162-306	4.46	7.6	5.0	1.1	-	-	-	5.8	5.9	9.3	45.2	1.2	1.8	2.0	2.5	0.3	6.5	T	5.8	14.1	0.49
1425-3	306-468	2.11	8.0	2.8	1.5	-	-	T	5.6	5.7	8.4	40.3	1.8	2.7	2.7	3.6	0.3	7.9	-	8.6	14.3	0.22
1425-4	468-580	0.69	8.0	3.6	1.5	2.5	0.5	T	4.6	4.6	9.3	48.3	0.7	1.6	1.5	1.5	0.2	3.3	-	8.2	9.3	0.04
MIN		0.11	T	1.7	0.3	0	0.0	0	1.3	1.6	2.7	28.0	0.3	<0.1	0.6	0.5	<0.1	1.1	0	0.1	6.2	<0.01
MEAN		2.14	4.6	7.6	1.3	-	-	-	6.5	8.0	9.3	46.5	0.9	0.9	1.8	1.9	0.4	4.6	-	4.4	14.8	0.23
MAX		6.26	16.3	19.7	5.5	2.5	23.6	0.9	13.6	18.2	20.7	61.1	2.0	3.4	4.3	7.0	2.7	17.4	T	12.9	25.7	0.68
St.Dev.		1.37	4.9	4.1	0.7	-	-	-	2.9	3.3	4.1	6.8	0.4	0.6	0.7	1.0	0.4	0.4	O	2.8	4.3	0.15

Table 3. Comparison of abundance of economic heavy minerals from this study with values of Berquist and Hobbs (1988). Mineral abundances are given in weight percent of heavy minerals.

Mineral	Berquist and Hobbs (1988) [284 samples]		This study [72 samples]	
	Average	Stan. Deviation	Average	Stan. Deviation
Ilmenite	24.0	10.7	7.6	4.1
Leucoxene	1.7	1.2	1.3	0.7
Rutile	1.4	0.5	0.4	0.4
Sillimanite/ Kyanite	2.2	1.3	0.9	0.4
Zircon	3.8	1.5	4.6	0.4
Monazite	0.08	0.2	<0.5	---
Total heavy minerals(%)	2.87	1.66	2.14	1.37