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EVIDENCE OF LONGSHORE DRIFT IN BEACH SEDIMENT:

MANZANILLO, COSTA RICA

EVIDENCE OF LONGSHORE DRIFT IN BEACH SEDIMENT:

MANZANILLO, COSTA RICA

by

Jeffrey Martin Heikoop

A Thesis

Submitted to the Department of Geology

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AUTHOR:	Jeffrey Martin Heikoop
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ABSTRACT

The beach at Manzanillo, Costa Rica, is composed of a mixture of terrigenous siliciclastic and marine calcareous sediment. The most abundant siliclastic grains are magnetite and diopside. The most abundant calcareous grains are red algae and molluscan fragments. These grains are found in much greater abundance in the beach sediment then in their source areas as a result of their resistance to breakdown.

The distribution of the siliclastic minerals on the beach shows longshore drift to be from east to west. The main source of siliclastic sediment is the Rio Sixaola. Local rivers provide small inputs of sediment.

The trace element chemistry of the beach indicates the possibility that some elements may be absorbed on the surfaces of grains as opposed to being substituted for other elements in mineral lattices.

ACKNOWLEDGEMENTS

I would like to thank Dr. M.J. Risk for suggesting this study and for providing me with direction throughout (especially in Costa Rica when original plans needed to be changed drastically as a result of weather conditions).

I would also like to thank ANAI for their assistance in Costa Rica. Fiona van Wissen and Gwen French were a great help in the field.

Len Zwicker's preparation of thin-sections and Ota Mudroch's X-ray flourescence analysis of sediment samples were of great help in the completion of this thesis.

Lastly, I would like to thank all my friends here at McMaster, particularly Chris Martin and Ken Versteeg for an entertaining four years. Special thanks go out to those who helped me with the fish tank. I will beat it yet.

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CHAPTER 1 - INTRODUCTION

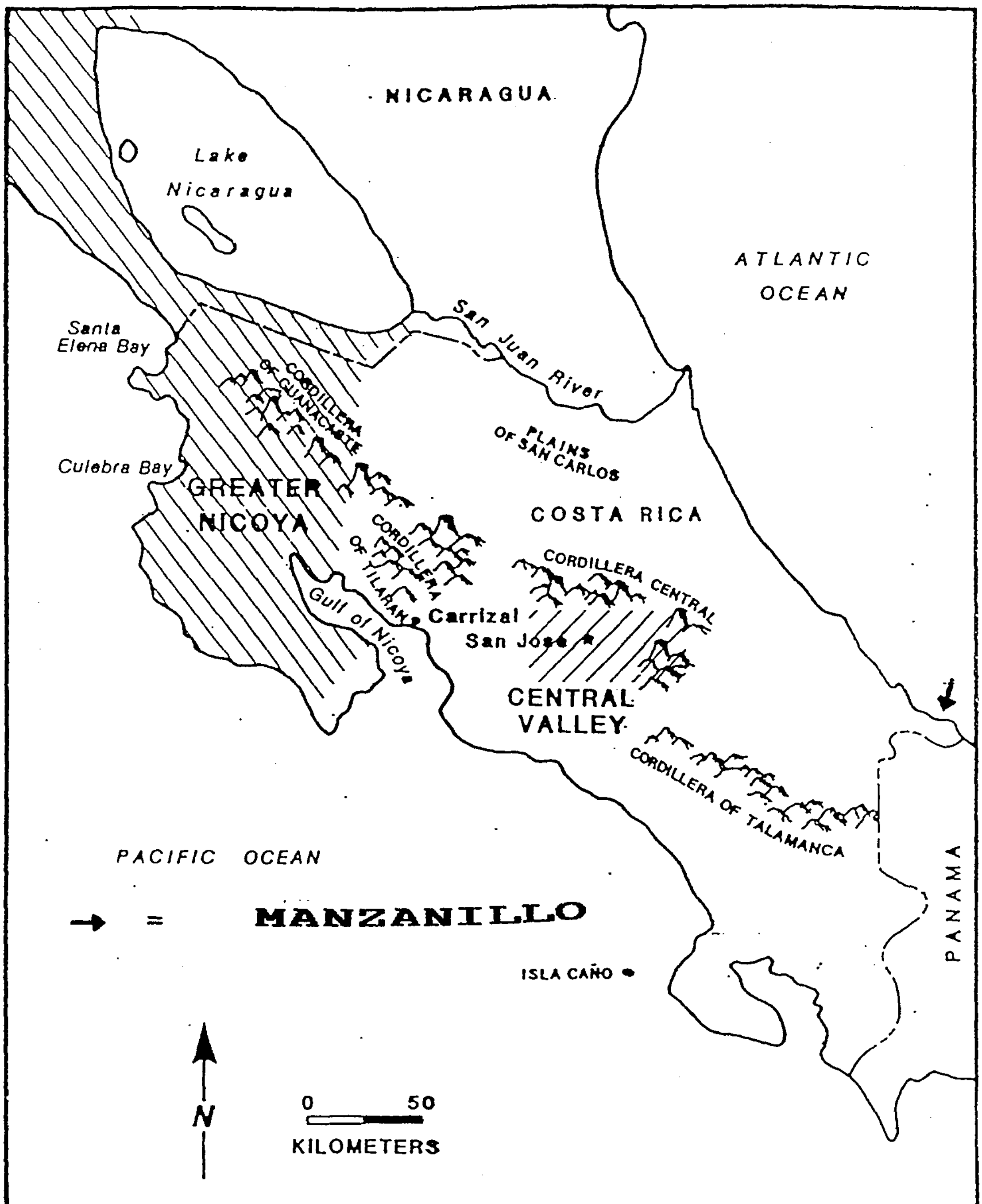
1.1 Introduction

The beach at Manzanillo, Costa Rica, is composed of a mixture of terrigenous siliciclastic and marine calcareous sediment. Manzanillo is located on the southeastern Talamanca coast of Costa Rica (Figure 1.1). The Caribbean coastline of Costa Rica is a low lying coastal plain. Several large rivers drain the central volcanic cordillera of the country and deposit sediment on the eastern coast. The mountainous central region is composed largely of basaltic-andesites, the source of the siliciclastic sediment.

The beach sediment was studied to determine compositional and granulometric properties. An attempt has been made to determine the sources of terrigenous sediment and the net direction of transport. This information could be valuable when assessing the effect of siltation on coral reefs (see Cortes and Risk, 1985).

Weather conditions were generally unsuitable for obtaining sediment samples from the reef and lagoon due to severe storms which occured just prior to the field studies of this thesis. The weather conditions did allow observation of local creeks during high flow and the direction of wave action on the beach following a storm. These observations helped determine the relative importance of local creeks for sediment supply and the direction of sand transport on the beach.

Figure 1.1 Map of Costa Rica showing location of study area.


NICARAGUA
Lake Nicaragua
ATLANTIC OCEAN
San Juan River
Santa Elena Bay
CORDILLERA OF GUANACASTE
PLAINS OF SAN CARLOS
Culebra Bay
GREATER NICOYA
COSTA RICA
CORDILLERA OF TILARAN
CORDILLERA CENTRAL
Gulf of Nicoya
Carrizal
San Jose
CENTRAL VALLEY
CORDILLERA OF TALAMANCA
PACIFIC OCEAN
PANAMA
→ = MANZANILLO
ISLA CAÑO
N
0 50
KILOMETERS

1.2 Materials and Methods

Sediment grab samples were obtained from the surf zone of the beach at 200 metre intervals from Punta Manzanillo to Punta Uva (Figure 1.2). Additional samples were taken at creek mouths and some distance up the small creeks found in the area. Two samples were obtained by SCUBA from sand patches around the reef north of Manzanillo (samples M06 and M02). Two samples were taken at Porto Viejo, north of Manzanillo (PVS2 and PVS4).

The mineralogy of the beach sand was determined through x-ray diffraction, thin-section analysis and visual identification through a binocular microscope. Samples were split where necessary through a microsplitter to obtain random sub-samples of the sediment. The carbonate component was analysed in thin section through a polarizing microscope and as grains through a binocular microscope.

The composition of the sediment was quantified in terms of mineralogy by point counting. Grains were mounted in epoxy resin and counted under the binocular microscope using a mechanical stage. Point counting should yield an area percent for each mineral species. Since most of the grains on the beach are equant, this should also be a fairly good representation of a volume percent.

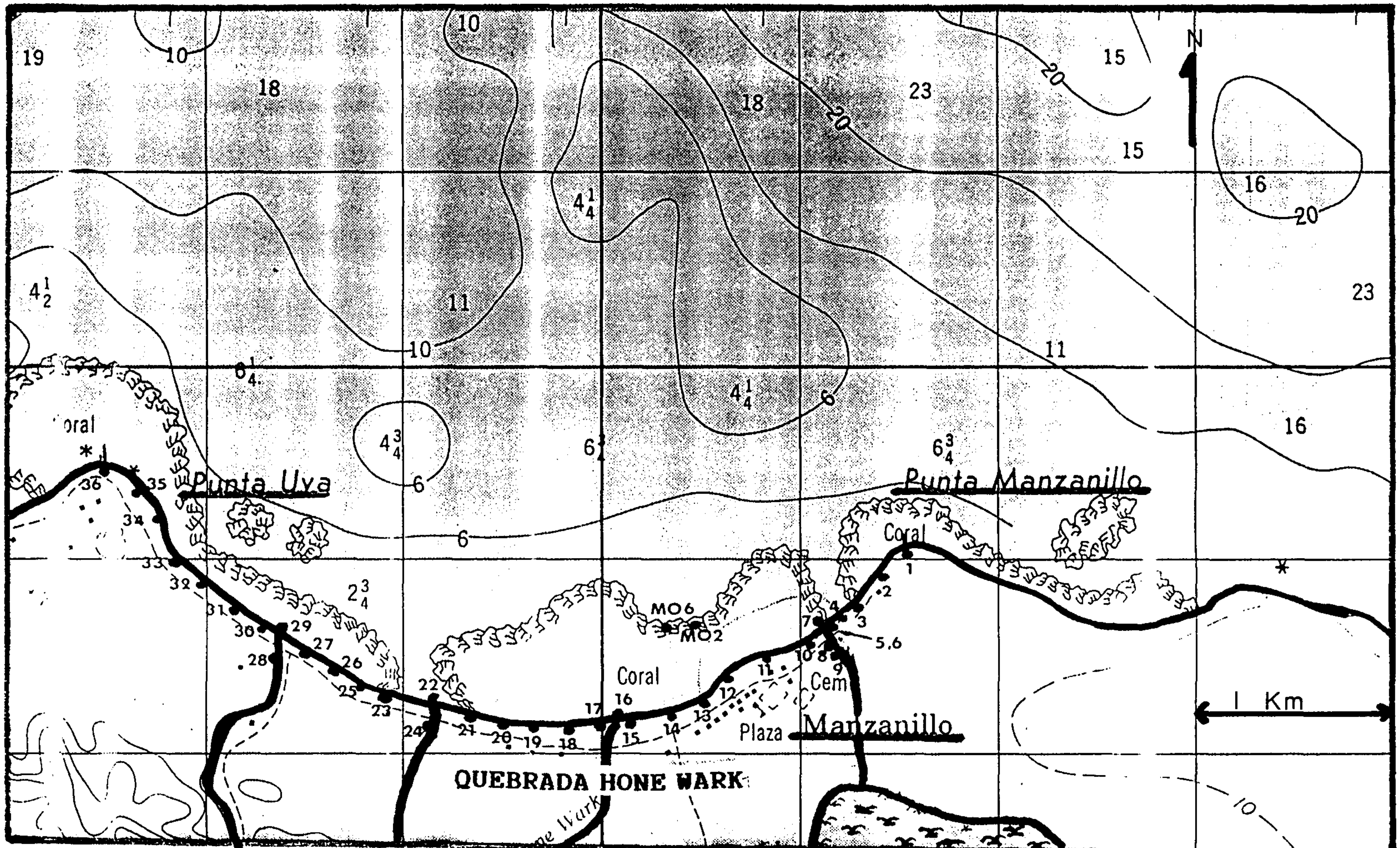
Counting involved 1000 points. Fifty points were counted horizontally across the slide with a point located every 0.6

mm. A random numbers table was then used to choose the next location for a horizontal transect. This process should eliminate any bias in the distribution of minerals on the slide caused by density differences. If a mineral species comprises thirty percent of the sample then at the 95.4 level of confidence the number of counts would fall between 290 and 310. This was chosen as an acceptable level of confidence for this study.

Granulometric analysis involved dry sieving sediment samples in a Ro-Tap shaker for fifteen minutes. The sand was separated into half-phi intervals and moment statistics were calculated. Each size interval was observed through the binocular microscope to determine the major mineralogical components.

Six samples were analysed by x-ray flourescence to determine major and trace element chemistry.

Figure 1.2 Map of Manzanillo, Costa Rica showing sample locations.



Punta Uva
Punta Manzanillo
Manzanillo
Plaza
Cem
Coral
Coral
Coral
MO6
MO2
QUEBRADA HONE WARK
N
1 Km

CHAPTER 2 - SEDIMENT COMPOSITION

2.1 Mineralogy

Thin sections of the beach sand reveal that the siliciclastic minerals present include pyroxene, magnetite, hornblende, plagioclase, garnet, quartz and biotite. X-ray diffraction showed the pyroxene to be diopside, the carbonate component to consist of aragonite and high magnesium calcite. Rock fragments are also present in this sediment. Many appear basaltic with glass and plagioclase matrices as well as magnetite. Some of the rock fragments have been serpentinized. The plagioclase was determined to be labradorite using the Michel-Levy test in thin section. There are two types of garnet found on the beach . West of Quesebrada Hone Wark the garnet is a much deeper red then the pink garnet found to the east.

2.2 Biogenic Grains

The biogenic grains in the sediment were very weathered and rounded. This made identification difficult through the binocular microscope. In every sample the predominate grains were equant and elongated white grains. Also present but to a lesser extent were equant orange grains. Microtextural characteristics in thin section reveal that most of the carbonate grains in the beach sediment are an articulating coralline algae, _Amphiroa_ sp. This algae is composed of high magnesium calcite. Also present but to a smaller degree are molluscan fragments identified by the cross lamellar structure. This is likely the identity of the orange weathered grains. Molluscan fragments are largely aragonitic although some shell structures contain calcite. Some of these white and orange grains have been slightly micritized around the margins.

Coral fragments are not found in the beach although they are present as larger clasts in the sands around the reef. Similarily, Halimeda is found only rarely in the beach sands. It is much more common in the sediment collected from the reef.

Forams are found in small amounts in the beach sand. Forams identified include milioloids, Amphistegina sp., Peneroplis sp., Elphidium sp., Marginopora sp., Cibicides sp., and an encrusting species of Homotrema. Other biogenic grains present in small quantities include sponge spicules, alcyonarean spicules, algal filaments, urchin spines and worm tubes. Some grains appear to have been cemented or encrusted by crustose coralline algae. Shell fragments and larval shells identifiable as being gastropods or bivalves are found.

CHAPTER 3 - MINERAL AND ELEMENT DISTRIBUTIONS

3.1 Mineral Distribution on the Beach

Table 3.1 shows the percentage of each mineral found in the beach sand samples. The major components of the beach sand are diopside, magnetite, rock fragments and biogenic carbonate grains. Figure 3.1 plots the abundances of magnetite and diopside while Figure 3.2 illustrates rock fragments and carbonate grains. The carbonate grains on the beach are rounded, frosted and quite abraded. The pyroxene and magnetite grains are sub-angular to sub-rounded. The rock fragments are rounded.

3.1.1 Diopside and Magnetite Distribution

Diopside and magnetite increase in abundance westwards from Punta Manzanillo. Magnetite is the more abundant of the two minerals until sample twelve where it reaches a maximum. Diopside then comprises a larger portion of the sediment over most of the remainder of the beach. Diopside reaches a maximum abundance in the beach at sample fourteen. The two detrital minerals decrease in abundance until west of Quebrada Hone Wark where they begin to increase again. A second smaller magnetite peak precedes a second smaller diopside peak west of the second creek. Magnetite and diopside then decrease in abundance and stay relatively low over the remainder of the beach. West of the last large creek there is

Table 3.1 Mineral Abundances by Volume

MINERAL ABUNDANCES BY VOLUME

SAMPLE	DIOPSIDE	HORNBLENDE	MAGNETITE	QUARTZ	GARNET	BIOTITE	ROCK FRAGS	PLAGIOCLASE	CARBONATE	TOTAL
1	0.60	0.40	6.30	0.50	0.10	0.10	4.00	0.30	87.70	100.00
2	0.50	0.00	2.40	0.00	0.00	0.10	2.60	0.10	94.30	100.00
3	0.00	0.00	0.30	0.00	0.00	0.00	0.90	0.00	98.80	100.00
4	0.40	0.10	2.60	0.00	0.00	0.20	8.50	0.00	88.20	100.00
6	4.00	0.30	4.10	0.60	0.00	0.00	4.70	0.20	86.10	100.00
7	14.70	0.80	21.80	1.50	0.60	0.10	4.60	0.00	55.90	100.00
10	21.90	1.30	49.90	2.00	0.40	0.00	3.90	0.10	20.50	100.00
11	12.20	2.00	74.70	1.00	3.00	0.10	3.90	0.10	3.00	100.00
12	50.80	1.70	26.50	3.00	0.70	0.00	4.90	0.40	12.00	100.00
13	54.00	1.70	26.70	2.10	0.60	0.00	3.40	0.20	11.30	100.00
14	54.80	1.30	26.40	0.50	0.30	0.00	4.00	0.20	12.50	100.00
15	43.60	2.10	18.10	3.20	0.80	0.10	7.10	0.90	24.10	100.00
16	20.70	0.60	21.70	1.20	0.30	0.40	13.70	1.70	39.70	100.00
17	13.20	0.60	9.30	4.30	0.50	0.20	14.90	1.80	55.20	100.00
18	18.30	1.00	10.00	3.70	1.30	0.20	15.50	1.90	48.10	100.00
19	18.00	0.70	22.10	2.30	0.50	0.00	13.40	1.20	41.80	100.00
20	26.20	0.50	5.90	2.60	1.50	0.30	11.10	1.50	50.40	100.00
21	35.40	0.30	13.40	1.90	0.50	0.10	11.10	2.30	35.00	100.00
22	20.90	0.10	12.60	4.80	0.50	0.30	15.10	2.50	43.20	100.00
23	8.70	0.10	5.10	2.80	0.20	0.00	16.10	1.00	66.00	100.00
25	5.60	0.20	4.40	2.00	0.00	0.00	12.70	1.20	73.90	100.00
26	5.40	0.00	2.30	1.90	0.40	0.10	13.30	0.90	75.70	100.00
27	5.60	0.00	1.80	1.80	0.20	0.10	14.40	2.20	73.90	100.00
29	2.30	0.00	1.30	0.70	0.20	0.00	15.50	0.60	79.40	100.00
30	5.00	0.00	2.50	1.30	0.00	0.20	13.70	1.40	75.90	100.00
31	18.10	0.10	4.20	0.90	0.70	0.00	14.40	1.60	60.00	100.00
32	1.60	0.20	0.80	1.00	0.30	0.30	12.20	1.00	82.60	100.00
33	1.40	0.00	1.30	0.60	0.10	0.40	14.00	1.00	81.20	100.00
34	0.80	0.00	0.50	0.70	0.00	0.80	15.40	0.40	81.40	100.00
35	0.30	0.10	0.30	2.10	0.00	0.60	15.70	0.20	80.70	100.00
36	1.20	0.00	0.90	2.70	0.30	0.60	11.40	0.60	82.30	100.00
AVERAGE	15.04	0.52	12.26	1.73	0.45	0.17	10.20	0.89	58.74	100.00

Figure 3.1 Diopside and magnetite distribution in beach sediment.

Beach Sediment Samples

Mineral Volumetric Abundances

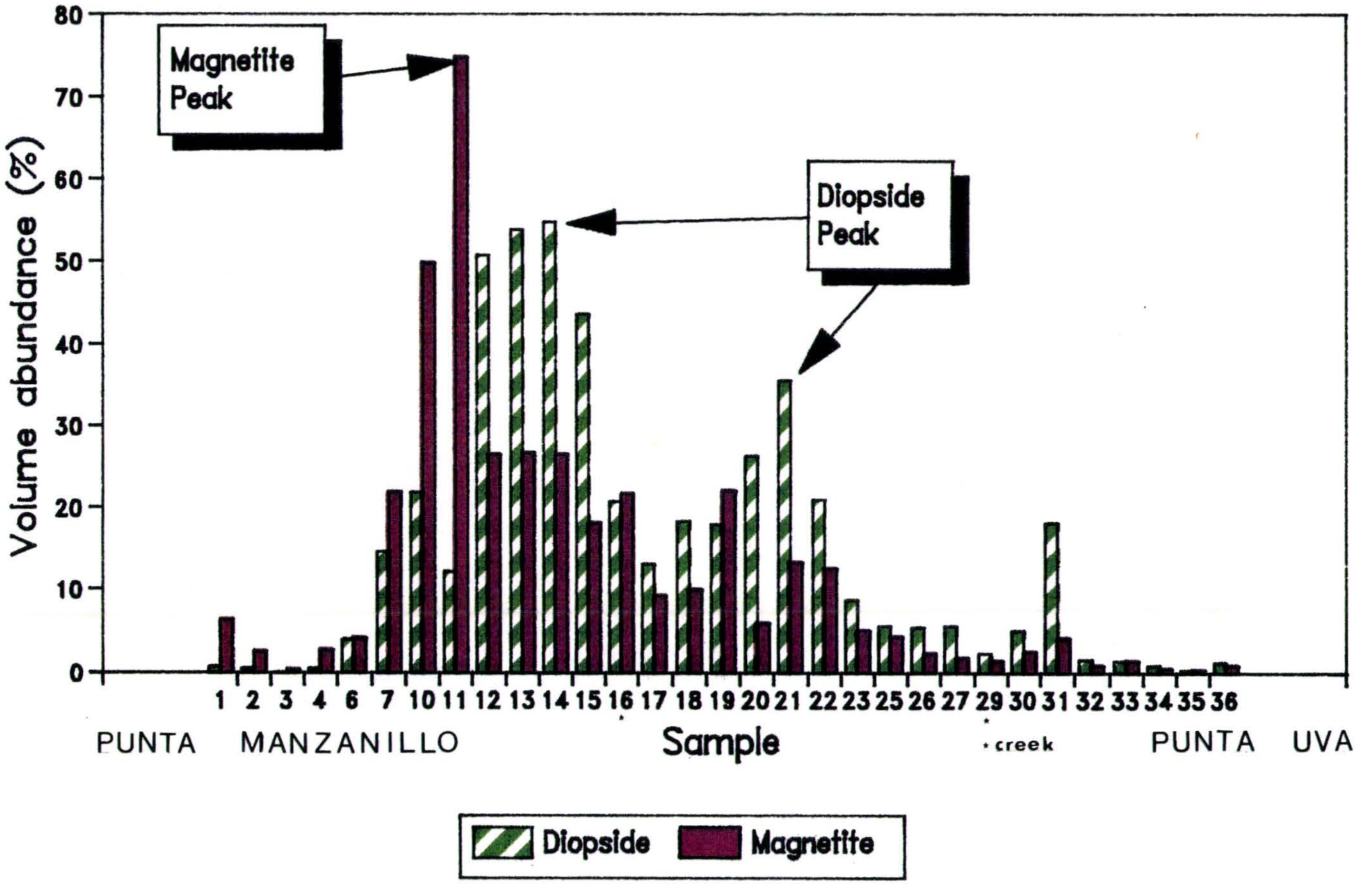
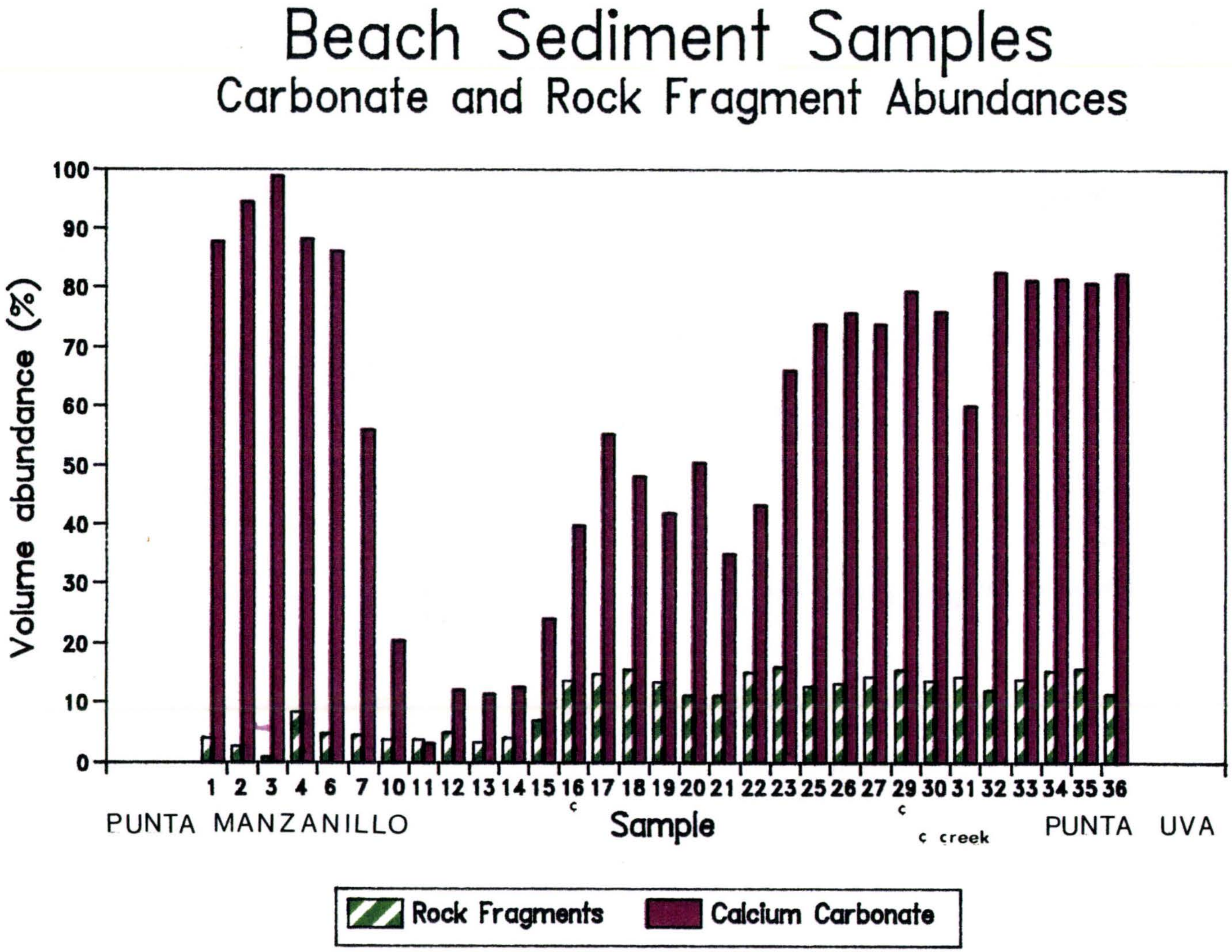


Figure 3.2 Rock fragment and carbonate distribution in beach sediment.


Beach Sediment Samples
Carbonate and Rock Fragment Abundances
Volume abundance (%)
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 6 7 10 11 12 13 14 15 16 17 18 19 20 21 22 23 25 26 27 29 30 31 32 33 34 35 36
c
c
PUNTA MANZANILLO
Sample
c creek
PUNTA UVA
Rock Fragments
Calcium Carbonate

another peak in pyroxene abundance at sample thirty-one.

3.1.2 Rock Fragment and Carbonate Distribution

Rock fragments are a relatively minor component of the beach east of Quebrada Hone Wark. West of this creek they increase in abundance to approximately fifteen percent and remain relatively constant over the rest of the beach.

The carbonate component is dominant close to Punta Manzanillo but decreases westwards to sample fourteen as the detrital minerals increase. West of sample fourteen the carbonate component of the beach increases. This increase continues interrupted ony by the peaks in detrital minerals mentioned earlier. The carbonate component comprises more then eighty percent of the sediment near the western end of the beach transect.

3.2 Average Mineral Abundances on the Beach

Table 3.1 shows the average mineral abundances for the entire beach. By volume, diopside and magnetite comprise approximately twenty-five percent of the beach with carbonate and rock fragments contributing about seventy percent.

Table 3.2 shows the same data as table 3.1 but this time abundances are by mass. The specific gravity used to convert from volume to mass for each mineral is shown. Average abundances by mass are also shown. By mass diopside and

Table 3.2 Mineral abundances by mass. Specific gravity values used to convert from volume to mass are shown.

MINERAL ABUNDANCES BY MASS

SAMPLE	DIOPSIDE (3.2)	HORNBLENDE (3.2)	MAGNETITE (5.2)	QUARTZ (2.65)	GARNET (3.6)	BIOTITE (3.0)	ROCK FRAGS (2.8)	PLAGIOCLASE (2.6)	CARBONATE (2.0)	TOTAL
1	0.85	0.57	14.54	0.59	0.16	0.13	4.97	0.35	77.84	100.00
2	0.76	0.00	5.93	0.00	0.00	0.14	3.46	0.12	89.59	100.00
3	0.00	0.00	0.77	0.00	0.00	0.00	1.25	0.00	97.98	100.00
4	0.59	0.15	6.26	0.00	0.00	0.28	11.02	0.00	81.70	100.00
6	5.75	0.43	9.58	0.71	0.00	0.00	5.91	0.23	77.38	100.00
7	16.00	0.87	38.55	1.35	0.73	0.10	4.38	0.00	38.02	100.00
10	17.85	1.06	66.09	1.35	0.37	0.00	2.78	0.07	10.44	100.00
11	8.40	1.38	83.57	0.57	2.32	0.06	2.35	0.06	1.29	100.00
12	45.79	1.53	38.81	2.24	0.71	0.00	3.86	0.29	6.76	100.00
13	48.34	1.52	38.84	1.56	0.60	0.00	2.66	0.15	6.32	100.00
14	49.27	1.17	38.57	0.37	0.30	0.00	3.15	0.15	7.02	100.00
15	43.27	2.08	29.19	2.63	0.89	0.09	6.17	0.73	14.95	100.00
16	21.46	0.62	36.56	1.03	0.35	0.39	12.43	1.43	25.73	100.00
17	16.05	0.73	18.38	4.33	0.68	0.23	15.86	1.78	41.96	100.00
18	21.42	1.17	19.02	3.59	1.71	0.22	15.87	1.81	35.19	100.00
19	18.77	0.73	37.45	1.99	0.59	0.00	12.23	1.02	27.24	100.00
20	31.63	0.60	11.57	2.60	2.04	0.34	11.72	1.47	38.02	100.00
21	38.00	0.32	23.37	1.69	0.60	0.10	10.43	2.01	23.48	100.00
22	23.61	0.11	23.13	4.49	0.64	0.32	14.92	2.29	30.50	100.00
23	11.48	0.13	10.94	3.06	0.30	0.00	18.59	1.07	54.43	100.00
25	7.68	0.27	9.81	2.27	0.00	0.00	15.25	1.34	63.37	100.00
26	7.61	0.00	5.27	2.22	0.63	0.13	16.41	1.03	66.70	100.00
27	7.90	0.00	4.12	2.10	0.32	0.13	17.77	2.52	65.14	100.00
29	3.34	0.00	3.07	0.84	0.33	0.00	19.69	0.71	72.03	100.00
30	7.05	0.00	5.73	1.52	0.00	0.26	16.91	1.60	66.92	100.00
31	23.22	0.13	8.75	0.96	1.01	0.00	16.16	1.67	48.10	100.00
32	2.36	0.30	1.92	1.22	0.50	0.42	15.78	1.20	76.30	100.00
33	2.05	0.00	3.09	0.73	0.16	0.55	17.93	1.19	74.29	100.00
34	1.18	0.00	1.20	0.86	0.00	1.11	19.93	0.48	75.24	100.00
35	0.44	0.15	0.72	2.58	0.00	0.83	20.34	0.24	74.69	100.00
36	1.77	0.00	2.16	3.30	0.50	0.83	14.73	0.72	75.98	100.00
AVERAGE	15.61	0.52	19.26	1.70	0.53	0.22	11.45	0.89	49.83	100.00

( ) = specific gravity used to convert volume abundance to mass abundance magnetite comprise about thirty-five percent of the sediment while carbonate and rock fragments decline to approximately sixty percent.

3.3 Mineral Distributions in Other Samples

Table 3.3 shows mineral abundances from other samples taken in the study area. The two reef sand samples are almost completely carbonate. The samples from Porto Viejo are mostly carbonate and rock fragments although small amounts of detrital magnetite and diopside are present. Sample five is from the same location as sample six except further back from the surf zone. This is an area of accumulation of magnetite. The rest of the samples were taken upstream in the various creeks of the area. These samples show high abundances of diopside, magnetite and rock fragments.

3.4 Element Abundance

Table 3.4 shows major and minor elemental abundances determined by x-ray flourescence for five beach samples and one sample from the reef. The major element abundances correspond well with the abundances of the minerals they form. Silica, aluminum, iron, magnesium and calcium are the predominate major elements. The iron abundance reflects the magnetite abundance shown in table 3.2. Calcium and magnesium follow the trends shown by the carbonate grains. Aluminum and silica increase and decrease with the abundance of

Table 3.3 Mineral abundances by volume for samples not included in the beach transect.

MINERAL ABUNDANCES BY VOLUME (OTHER SAMPLES)

SAMPLE	DIOPSIDE	HORNBLENDE	MAGNETITE	QUARTZ	GARNET	BIOTITE	ROCK FRAGS	PLAGIOCLASE	CARBONATE	TOTAL
5	0.90	0.00	93.30	0.00	0.80	0.10	0.40	0.10	4.40	100.00
8	26.50	0.70	35.40	2.20	0.50	0.30	9.40	0.00	25.00	100.00
9	16.30	0.90	51.40	1.60	0.90	0.20	5.00	0.10	23.60	100.00
24	19.20	0.30	20.10	4.20	1.20	0.00	12.70	2.10	40.20	100.00
28	3.80	0.10	1.70	1.30	0.30	0.00	15.30	1.60	75.90	100.00
M06	0.00	0.00	0.20	0.20	0.00	0.00	0.40	0.10	99.10	100.00
M02	0.10	0.00	0.10	0.20	0.00	0.00	0.30	0.00	99.30	100.00
PVS4	0.80	0.00	7.00	6.30	0.00	0.70	15.30	0.80	69.10	100.00
PVS2	0.20	0.00	2.10	0.00	0.00	0.50	10.50	0.20	86.50	100.00

Table 3.4 Elemental abundances.

ELEMENTAL ABUNDANCES

Sample:	12	20	26	28	32	MO6
Major elements as oxides (percent by mass)						
Silica	33.91	36.10	34.75	34.48	31.14	26.88
Aluminum	3.76	5.70	5.74	5.53	3.47	1.12
Iron	16.70	6.09	3.69	2.17	0.44	0.17
Magnesium	5.83	5.78	4.55	3.99	3.90	3.84
Calcium	18.31	25.12	27.84	27.90	29.99	29.99
Sodium	2.82	1.00	2.14	1.01	1.49	0.43
Potassium	0.34	0.59	0.88	0.93	0.70	0.18
Titanium	2.70	0.72	0.42	0.27	0.12	0.04
Manganese	0.19	0.13	0.08	0.07	0.04	0.03
Phosphorous	0.24	0.22	0.15	0.13	0.10	0.09
Sulfur	0.28	0.10	0.21	0.12	0.36	0.35
Trace elements in ppm (by mass)						
Rb	8.5	12	18	20	17	8
Sr	526	981	1300	1390	1570	2350
Y	32	31	23	22	16	10
Zr	297	37	23	<3	<3	<2
Nb	22	11	4	4	<1	1
As	4.5	7	6	9	8	6
Co	70	11	9	5	3	2
Cr	158	57	38	11	10	11
Cu	28	25	24	21	12	11
Ni	35	37	19	19	13	13
Pb	3	5	12	5	4	<1
V	750	169	113	64	32	20
Zn	100	54	48	31	18	19
Ba	141	201	280	271	188	46

aluminosilicates such as diopside and plagioclase on the beach.

The trace elements will likely substitute for the major elements in the mineral lattices. Strontium for example, follows the carbonate distribution quite closely. Strontium atoms are likely substituting for calcium in the carbonate grains. This will be especially true of aragonite with its nine-fold coordination.

Some of the trace elements measured could substitute for iron in the magnetite lattice. Figures 3.3 and 3.4 plot trace element abundances as a function of distance from Manzanillo (sample 12). The magnetite abundance by mass at these distances is plotted for comparison. Chromium, cobalt and vanadium all follow the same trend as magnetite. These elements can readily substitute for iron. Lead and arsenic would not substitute for iron because of their ionic radii and charge. These elements show a gradual decrease with distance from Manzanillo. Copper, nickel and zinc do not reflect the abundance of magnetite although they could substitute for iron. They also show a gradual decrease with distance from the village.

The trace elements which do not follow the abundance trend of magnetite could be substituting in the lattice of some other minerals. With a more complete data set the trace element distribution over the entire beach could be compared

Figure 3.3 Trace element concentrations as a function of distance from Manzanillo. Magnetite abundance shown for comparison.

TRACE ELEMENT CONCENTRATIONS AS A FUNCTION OF DISTANCE FROM MANZANILLO

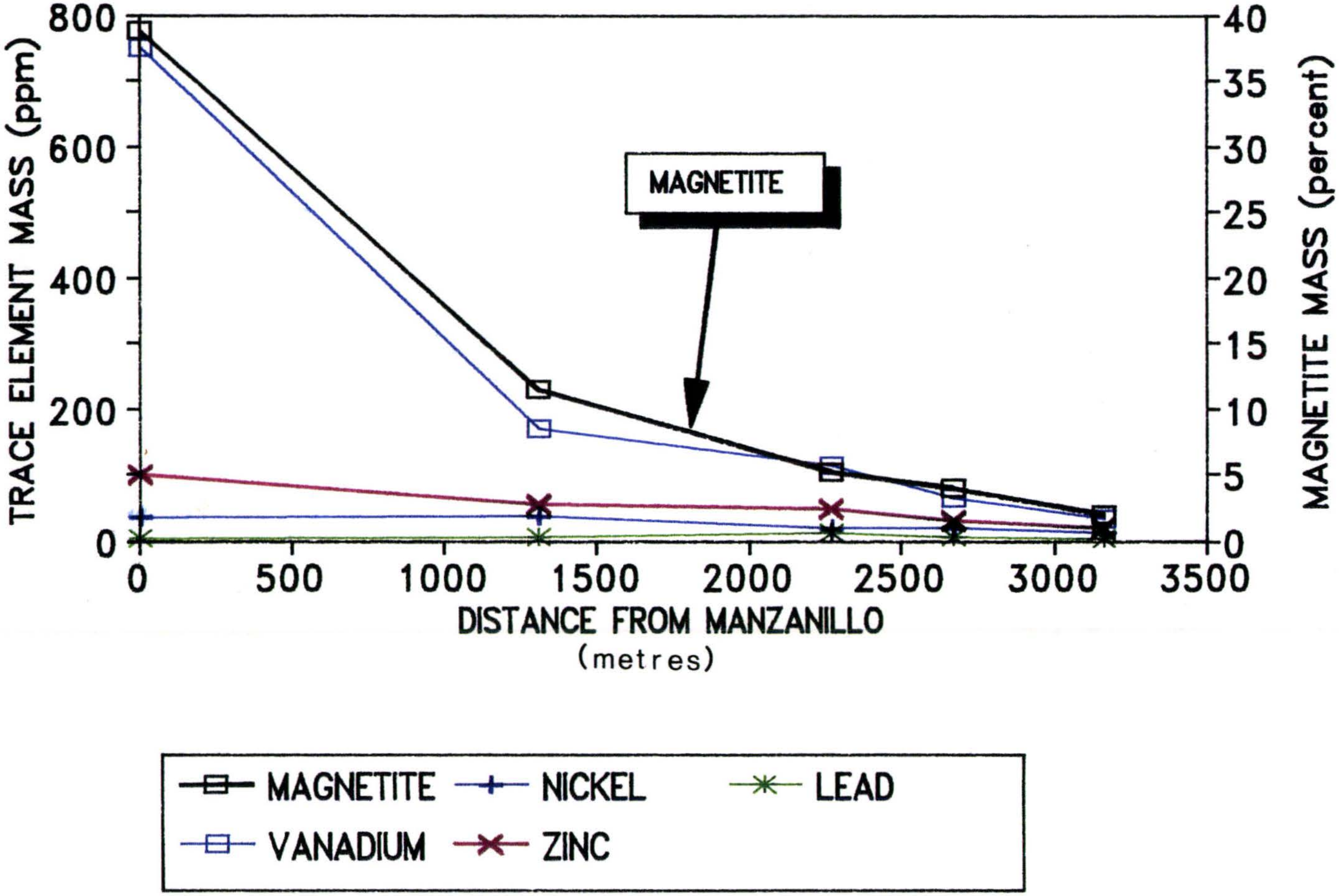
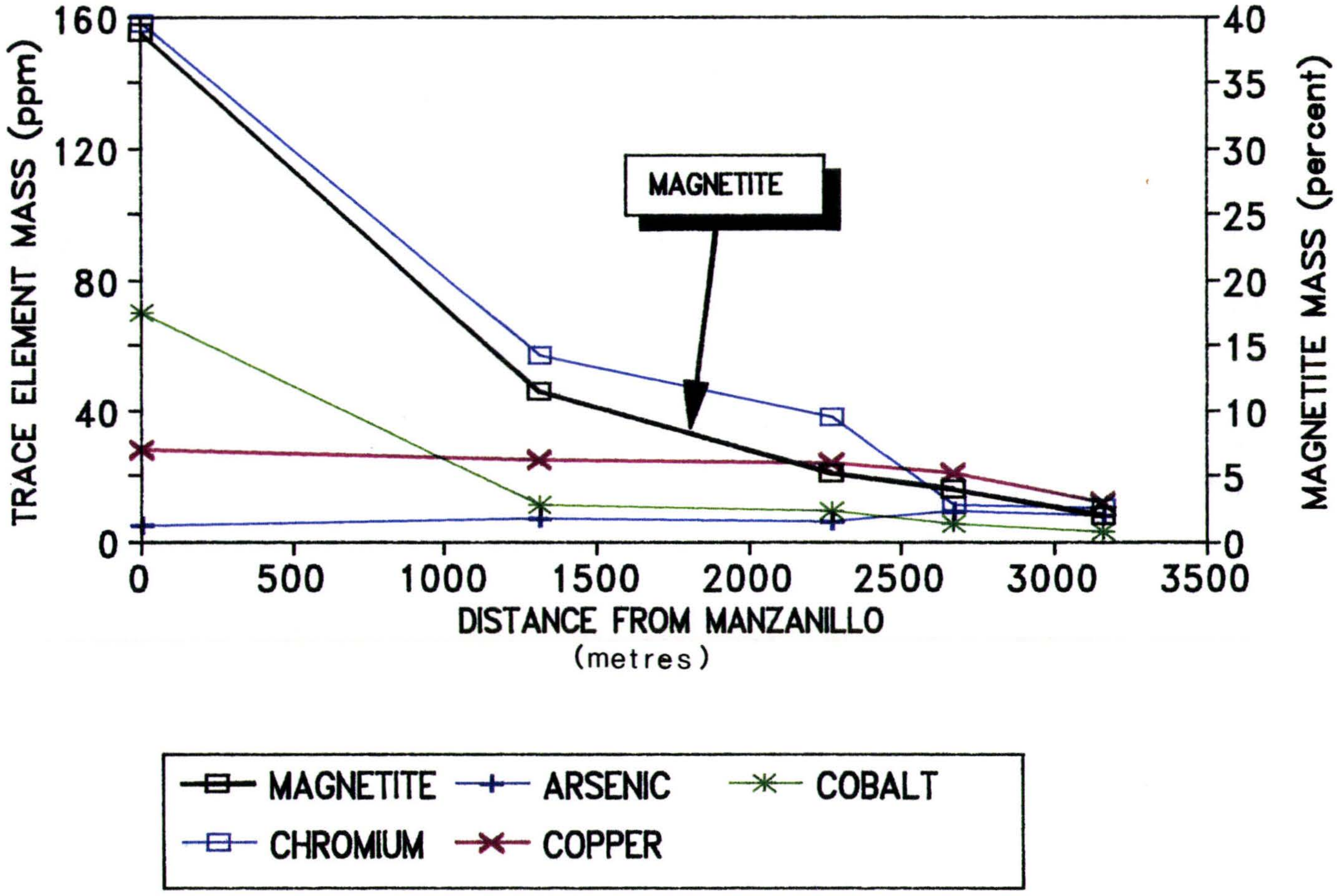


Figure 3.4 Trace element concentrations as a function of distance from Manzanillo. Magnetite abundance shown for comparison.

TRACE ELEMENT CONCENTRATIONS AS A FUNCTION OF DISTANCE FROM MANZANILLO



to mineral distributions. All the minerals show some fluctuation in abundance over the beach and any substitution of trace elements for major elements in these minerals should be reflected by similar fluctuations in the trace element distribution.

Some trace elements could be absorbed and transported on fine grained material or organics. These will be rare in a beach environment since the higher energy will winnow out fine grained material and likely abrade any organic coatings. Despite this, some of the trace elements which show a gradual decline in abundance with distance from Manzanillo, could represent absorbed material as opposed to substitution. Future studies could include chemical analysis of a greater number of beach sand samples. Analysis of local river and creek muds could also yield information since there will be greater concentrations of fine-grained and organic particles. Chemical tests are available which can remove absorbed elements from a surface and measure their concentration.

The elemental abundances do not add up to one hundred percent. The remaining mass of the sediment is likely comprised of carbon in the carbonate lattices, water (formational water and water absorbed on grains) and organic material.

CHAPTER 4 - GRANULOMETRIC PROPERTIES

4.1 Moment Statistics of Beach Samples

Table 4.1 and Figure 4.1 provide data on moment statistics calculated for samples located along the beach transect. The beach samples are well sorted. For most samples one standard deviation lies between 0.5 and one phi unit.

The average grain size given by the mean is much larger towards Punta Manzanillo. However, the large drop in average grain size at sample 10 does not reflect a change in energy conditions. The average grain size decreases because the mineralogy of the beach changes. At this point there is a large increase in the abundance of siliclastic grains which are much denser than carbonate grains. These dense grains can be hydraulically equivalent to much larger carbonate grains. Sample 3 is a gravel. This sample was comprised mostly of entire gastropod shells. The central region of the beach has an average grain size which is relatively constant between 2 to 2.5 phi (fine grained sand). Near Punta Uva the average grain size increases slightly by about one phi unit.

Most of the beach samples near Punta Manzanillo are positively skewed indicating a fine grained tail in the granulometric distribution. Near Punta Uva the sediment is negatively skewed indicating a coarse grained tail to the size

Table 4.1 Moment statistics for beach samples.

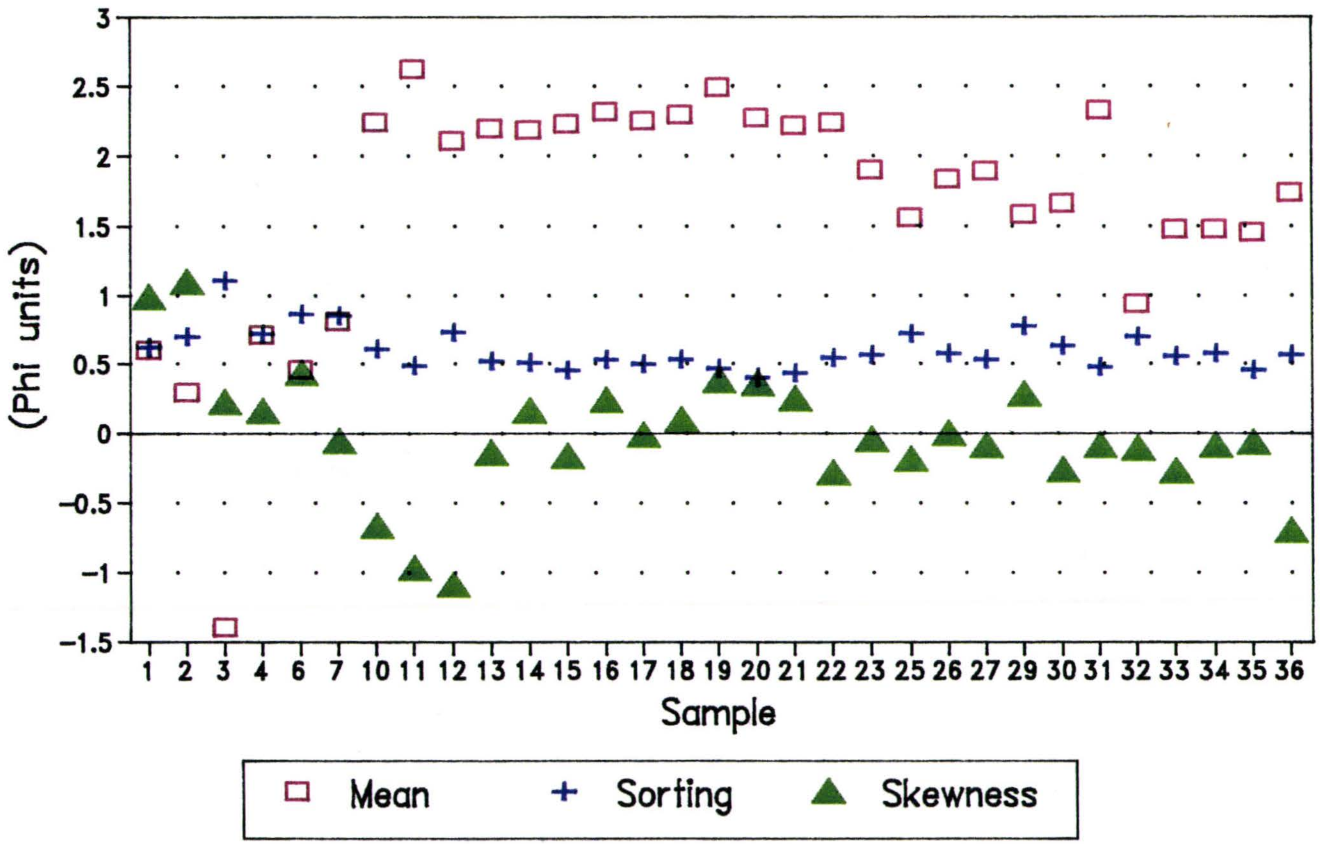
MOMENT STATISTICS FOR BEACH SAMPLES

SAMPLE	MEAN	SORTING (PHI UNITS)	SKEWNESS
1	0.602	0.622	0.984
2	0.295	0.695	1.109
3	-1.392	1.110	0.227
4	0.710	0.718	0.161
6	0.461	0.860	0.435
7	0.809	0.850	-0.048
10	2.243	0.617	-0.662
11	2.628	0.491	-0.969
12	2.113	0.733	-1.092
13	2.199	0.522	-0.140
14	2.184	0.511	0.168
15	2.231	0.463	-0.159
16	2.319	0.533	0.241
17	2.256	0.503	-0.012
18	2.301	0.536	0.101
19	2.494	0.473	0.389
20	2.273	0.408	0.361
21	2.223	0.434	0.249
22	2.242	0.549	-0.287
23	1.907	0.566	-0.047
25	1.565	0.724	-0.183
26	1.842	0.576	-0.002
27	1.890	0.538	-0.087
29	1.589	0.781	0.281
30	1.665	0.630	-0.258
31	2.325	0.486	-0.083
32	0.945	0.701	-0.111
33	1.480	0.556	-0.268
34	1.475	0.577	-0.086
35	1.460	0.458	-0.066
36	1.741	0.564	-0.700

Figure 4.1 Moment statistics of beach sediment samples.

Beach Sediment Samples

Moment Statistics



distribution. In the central area of the beach between the two points the skewness is less well defined with some samples being positively skewed while others are negatively skewed. The beach as a whole is almost entirely sand sized sediment grains. Some granules and pebbles are present. A silt fraction comprises less than one tenth of one percent of most samples.

4.2 Moment Statistics of Other Samples

Table 4.2 and Figure 4.2 illustrate moment statistics for other samples from the study area. The Porto Viejo samples are well sorted, negatively skewed sand of medium grain size. The sediment from around the reef is very coarse sand. One sample is less well sorted with a coarse tail to the size distribution. The other sample is well sorted and positively skewed. The river samples are well sorted, fine grained sand which is either negatively skewed or skewed very little.

4.3 Mineral Distributions Within Different Size Fractions

Each sediment sample was split into half-phi size distributions. The mineralogy of each size interval was determined in an effort to explain the mineral distributions on the beach.

4.3.1 Beach Samples

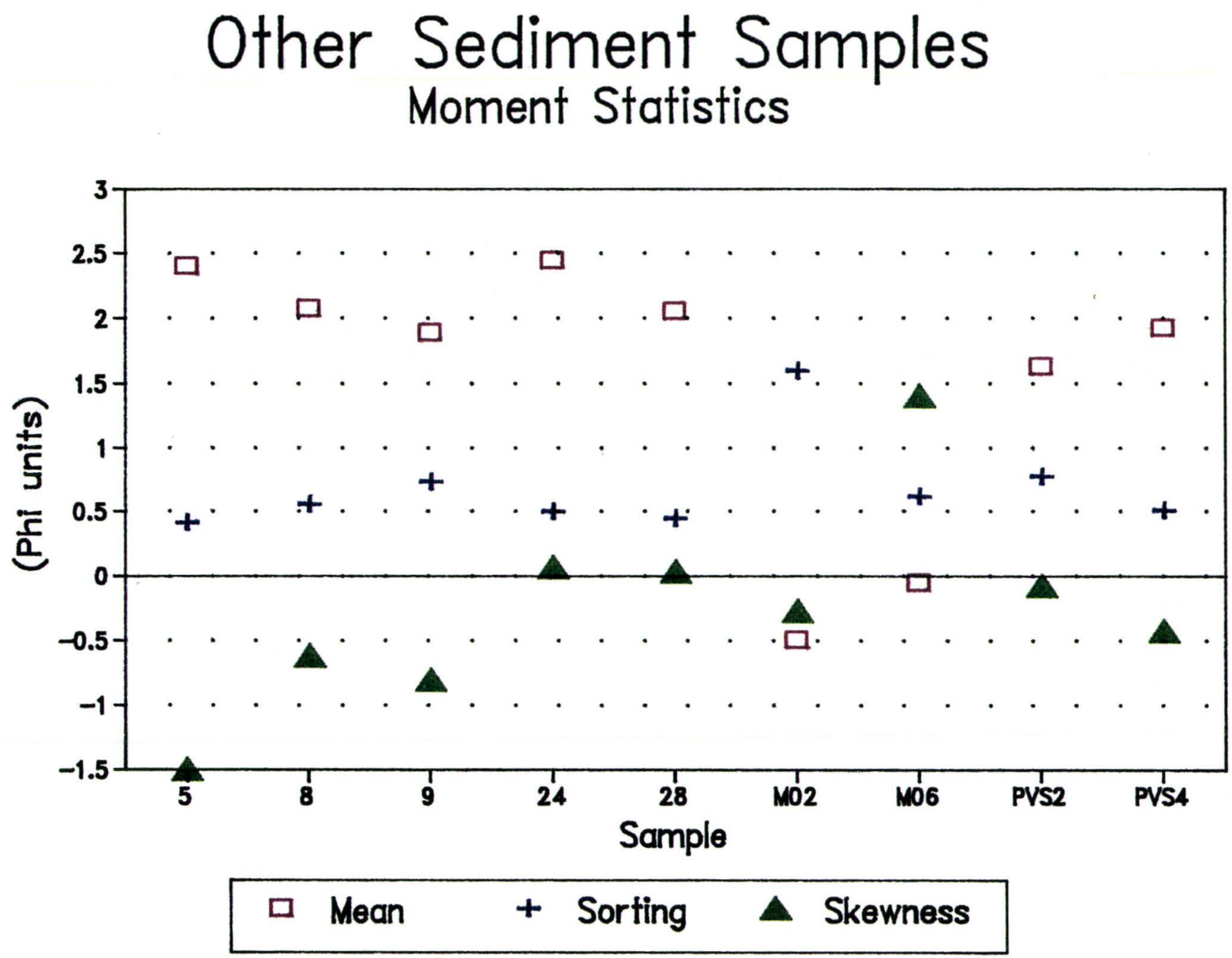
Carbonate grains are found throughout all size fractions although they are predominate in the coarse sand fractions of samples with a high detrital mineral content. Some of the

Table 4.2 Moment statistics for samples not included in the beach transect.

MOMENT STATISTICS FOR OTHER SAMPLES

SAMPLE	MEAN	SORTING (PHI UNITS)	SKEWNESS
5	2.400	0.419	-1.500
8	2.082	0.559	-0.617
9	1.895	0.733	-0.804
24	2.445	0.502	0.063
28	2.053	0.453	0.033
M02	-0.491	1.600	-0.269
M06	-0.055	0.624	1.397
PVS2	1.630	0.777	-0.080
PVS4	1.919	0.517	-0.420

Figure 4.2 Moment statistics of other samples.



Other Sediment Samples
Moment Statistics
(Phi units)
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
5
8
9
24
28
M02
M06
PVS2
PVS4
Sample
Mean
Sorting
Skewness

carbonate grains are actually granules or pebbles. The rock fragments and plagioclase are found in the coarse to very coarse sand fraction of the samples. Quartz grains are found in the medium grain sand fraction. Garnets are generally located in the very fine sand of the beach.

Of the two main siliciclastic minerals in the beach sand magnetite is found over a wider range of sizes than diopside. Towards Punta Manzanillo magnetite is found in medium to very fine sands. Over the rest of the beach however magnetite can be found in the silt fraction of the sediment as well. Magnetite tends to be predominate or at least occur in its greatest concentration in the very fine sand interval. Diopside is predominate or at its maximum concentration in the fine sand fraction. Diopside occurs almost solely in this narrow size range.

The silt fraction contains magnetite, carbonate, pieces of what appear to be sponge spicules and some unidentified blue mineral. In most samples, the siliceous spicules and magnetite predominate in this fraction.

4.3.2 Other Samples

The river samples follow the same pattern as the beach samples. The reef samples are almost all carbonate grains with some very coarse rock fragments. The small percentage of siliciclastic minerals present in the reef samples occur in the same size fractions as they did on the beach. Magnetite is present over a wider range of sizes than diopside in these samples as well. Sample five, the magnetite accumulation back of the surf zone, is almost all magnetite but there are some carbonate and rock fragments in the coarsest size fraction. The Porto Viejo samples are similar to the Manzanillo samples, except that quartz and magnetite are found over almost the entire size range in those samples.

CHAPTER 5 - DISCUSSION

5.1 Source of Siliciclastic Minerals

The detrital mineralogy of the beach likely reflects erosion and subsequent deposition of basaltic-andesites from the central cordillera of Costa Rica. Pyroxenes and plagioclase are major components of these rocks while magnetite, quartz and garnet are accessory minerals (Ehlers and Blatt, 1982). Pyroxenes and calcic plagioclase are high temperature minerals which will be unstable at surface pressures and temperatures. Magnetite, on the other hand, is more resistant to weathering then pyroxenes or plagioclases (Ross, 1989).

Although magnetite is only a minor component of the rocks being weathered, it will tend to be concentrated in sediment. The averages in Table 3.1 illustrate that magnetite is much more volumetrically abundant in the beach sediment than it would have been in the source rock. Since magnetite is more resistant to weathering it can occur as sand sized grains. Pyroxenes, on the other hand, may be weathered down to smaller size fractions which would be winnowed out of a beach environment. Magnetite may also be present as larger phenocrysts in the rock to begin with while the pyroxene and plagioclase may comprise a finer-grained matrix. This will also facilitate magnetite comprising a larger fraction in the beach than it did in the unweathered source rock since it can occur as sand-sized grains which will be stable in a beach environment.

5.2 Mineral Provenance

The detrital mineral input is likely going to be from a large river draining the central highlands. This will give a large drainage area to provide a lot of sediment as well as a longer transport distance to increase the ratio of magnetite to other minerals.

5.2.1 Magnetite and Diopside Distributions

To the east of Manzanillo the largest river is the Rio Sixaola while to the west the largest river is the Rio Estrella. From the mineral distribution on the beach it appears likely that the source of the detrital sediment in the study area is the Rio Sixaola. Evidence from this comes from the distribution of diopside and magnetite on the beach. These heavy minerals will be moved along the beach by longshore drift. Magnetite peaks in abundance to the east of diopside in the beach sediments. This reflects the density difference between the two minerals and indicates net longshore drift from east to west.

Magnetite is denser and will be deposited earlier than diopside grains of approximately the same size. The distribution of minerals within different size classes revealed that most of the pyroxene grains occur in a narrow size class. This size class is found within the range of sizes for magnetite. If there was an infinite number of grains of an infinite number of grain sizes, then the pyroxene and magnetite abundances at any location on the beach would be equal. The magnetite grains would occupy smaller size classes than the pyroxene grains.

Since the size distributions for each mineral are limited and are quite similar, diopside and magnetite will not be in hydraulic equivalence. Diopside, being lighter, will accumulate further along the direction of net transport.

The sand fraction of the Sixaola sediment discharge will be deposited on beaches along the coast. It can then be moved by longshore currents between the mouth of the Sixaola and the beach at Manzanillo to the west. This would help concentrate the magnetite fraction since high energy beach environments would tend to wear down other minerals into finer grains which could then be winnowed out and transported offshore. Only the sand size pyroxene and plagioclase grains would remain to be deposited with magnetite further along the coast.

Punta Manzanillo is a rocky point with no sediment accumulation. Sediment from the east would have to be transported around the headland by wave refraction. This would help explain why the first half kilometre of beach west of Punta Manzanillo is predominately carbonate grains. This area is sheltered by the point and siliciclastic grains from the east do not accumulate until further down the beach. Waves refracting around the point diverge away from the headland creating a shadow zone within which siliciclastic grains are not deposited. The carbonate component in this zone is likely worked onto the beach from sources nearby. This sediment is largely molluscan fragments.

Large storm events, creating strong longshore currents will be responsible for moving most of the siliciclastic grains around the headland. These grains will tend to accumulate close to the headland, rather than being distributed across the beach. Normal energy conditions will be unable to transport these grains any great distance along the beach so they will remain close to Punta Manzanillo. Winnowing of carbonate grains in the high energy beach environment may accentuate the concentration of siliciclastic minerals. Both minerals decrease in quantity to the west with pyroxene being more abundant.

The peaks in diopside and magnetite abundance occur to the west of a creek which could be a source of sediment. This creek however, drains a large swamp area. It is highly unlikely that magnetite grains could be moved any significant distance through such a calm environment.

The rate of dilution of the heavy mineral assemblage in a beach can be used to determine the direction of net longshore drift (Komar, 1976). The heavy mineral assemblage as a whole becomes less abundant to the west in the study area indicating longshore drift in that direction. Not only the heavy mineral assemblage as a whole, but the individual minerals in the assemblage, indicate longshore drift from east to west. Beaches in which the heavy mineral assemblage occurs in a restricted grain size will tend to show a pattern in which the minerals peak in abundance according to density differences. In this study area, magnetite, being the heaviest, peaks first, followed by diopside. If the grain sizes were extremely variable then the entire heavy mineral assemblage would have to be considered as a unit to determine transport directions. While field work for this study was being carried out the waves were approaching the beach in an oblique sense from east to west. This would create the direction of longshore drift which has been proposed. Headlands can also give evidence of longshore drift. Sand will accumulate on the updrift sand of headlands while the downdrift side will be characterized by erosion (Komar, 1976). This evidence was observed around Punta Manzanillo.

When volcanic terrains such as the Central Cordillera of Costa Rica are being weathered, it is more likely that the grain sizes which can accumulate in beach sediment will be more restricted. Volcanic rocks tend to be very fine-grained so only the fine sand sized grains will accumulate in a beach environment.

To the west of Quebrada Hone Wark the same sequence of magnetite peaking in abundance before diopside is seen again. This time the source of the extra magnetite and pyroxene is likely Quebrada Hone Wark. The study was done at the beginning of the rainy season and the creeks in the study area appeared to be at bankfull flow. They would be draining the local uplands south of Manzanillo and could be a sediment source. The appearance of a different type of garnet in the sediment west of Quebrada Hone Wark also suggests that it could be a sediment source for the beach. The sediment would be deposited on the beach then worked westwards by longshore drift with the lighter pyroxene being deposited further to the west. When standing in the surf zone a definite current to the west could be felt. The strongest longshore currents develop in surf zones (Blatt, Middleton and Murray, 1980).

The same trend is again recorded in the beach sediment to the west of the large creek near Punta Uva. The peaks in magnetite and pyroxene abundance are not as pronounced but here almost all the detrital sediment is likely coming from the local creek while the effect of the Rio Sixaola would not be as strongly felt.

The magnetite to pyroxene ratio is still fairly high in the sediment deposited by these local creeks even though the highlands they drain are only a couple of kilometres away.

With less transport distance a greater amount of pyroxene and plagioclase might be expected. Most of the weathering however, likely occurs in the soil environment before any transport begins. The plagioclase may be so low because the average grain size is too small to accumulate on the beach. Most of the rock fragments are made of a very fine-grained plagioclase matrix.

Figure 5.1 shows an idealized distribution of siliciclastic minerals in the study area. This figure emphasizes that longshore drift is from east to west with mineral input around Punta Manzanillo and from local creeks.

5.2.2 Rock Fragment Distribution

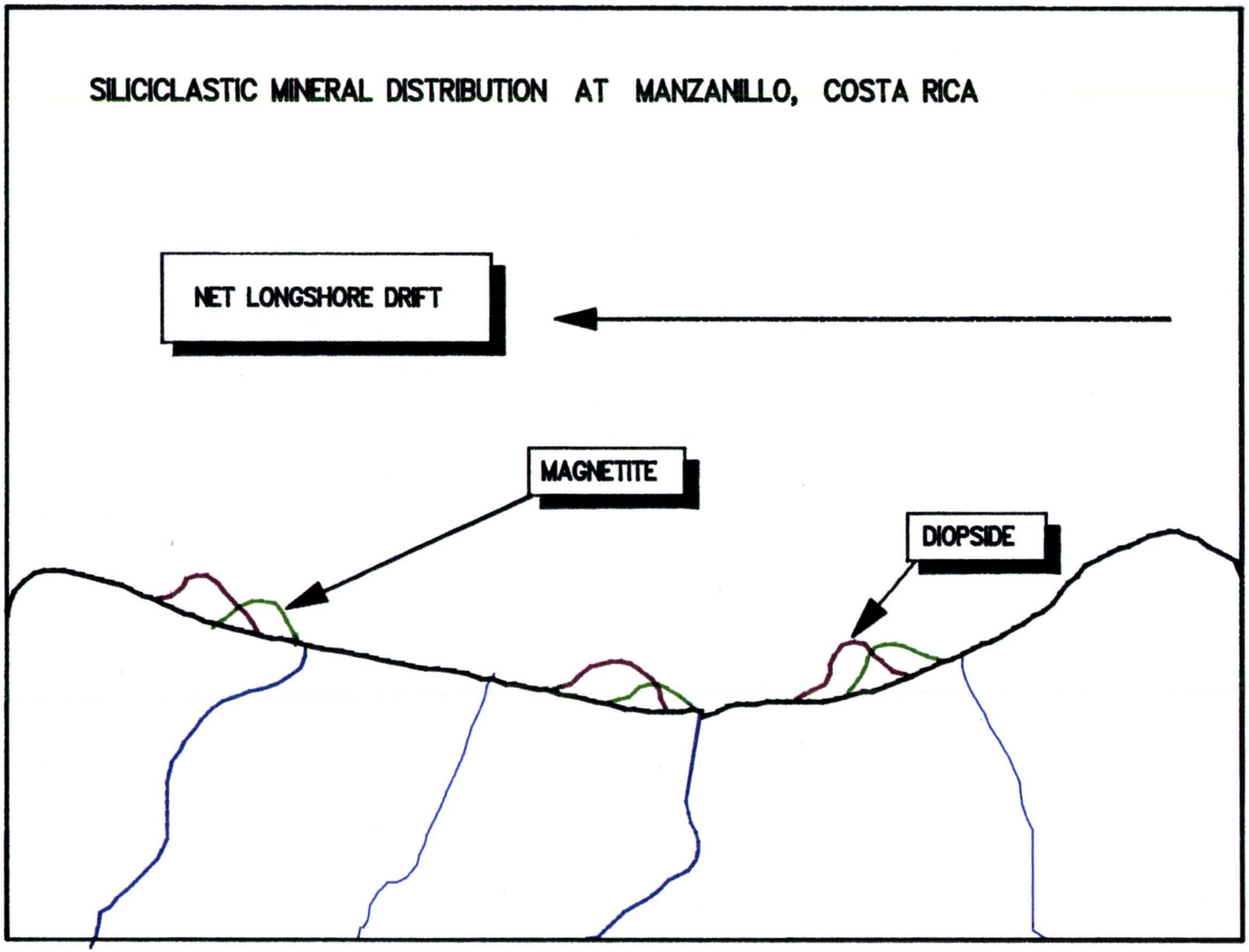
Rock fragments also become much more abundant west of Quebrada Hone Wark. For rock fragments to exist without having been weathered into the individual mineral components it is likely that they are relatively proximal to their source. The small creeks in the study area likely transport the rock fragments from the nearby highlands and deposit them on the beach.

The detrital mineral component decreases along the beach transect towards Punta Uva. This likely reflects the decreasing influence of the sediment from the Rio Sixaola. The carbonate component of the beach predominates instead.

5.3 Mineral Distribution in Other Samples

The samples from around the reef environment are very low

Figure 5.1 Idealized distribution of siliciclastic minerals in the study area. This type of density distribution will occur when the grain sizes of siliciclastic minerals are restricted.


SILICICLASTIC MINERAL DISTRIBUTION AT MANZANILLO, COSTA RICA
NET LONGSHORE DRIFT
MAGNETITE
DIOPSIDE

in siliciclastic minerals. The detrital minerals are generally only in the smaller size fractions. Most grains are likely transported out from the local rivers or transported off the beach during storm conditions.

Porto Viejo, further north up the coast from Manzanillo, also has mixed siliciclastic and carbonate sediments. The detrital minerals could be from further longshore drift working sediment up the coast with added inputs from rivers in between Manzanillo and Porto Viejo. The sediments contained fewer detrital minerals than the east end of the beach at Manzanillo. If longshore drift was largely responsible for transporting the detrital minerals, then it is to be expected that much has been winnowed away by the time the sediment reaches Porto Viejo. Insufficient samples were taken to conclude whether or not similar processes are working at the two study areas.

The various creek samples have high detrital mineral and rock fragment abundances, as would be expected if they are transporting sediment from local source areas. Sample five represents an area of the beach landward of the surf zone where the energy is much lower and detrital minerals deposited by large storm waves could accumulate without being moved as much by longshore currents.

5.4 Carbonate Composition of the Beach

The carbonate grains on the beach may have been transported from the east by longshore currents with the detrital minerals. Carbonate grains will not be as resistant to mechanical erosion as detrital mineral grains so it is unlikely that sand sized grains would last long enough in a beach environment to be transported long distances by longshore drift.

It is more likely that the carbonate grains in the beach sediments at Manzanillo are derived from the adjacent reef. These grains would be worked up onto the beach during constructive periods such as during calm weather (Blatt, Middleton and Murray, 1980). They would then be abraded in the surf zone by the swash, eventually to be winnowed out and carried to deeper, calmer water.

If a coral reef is the major proximal sediment source then the carbonate component of the beach might be expected to contain numerous coral and Halimeda sp. fragments. This is not the case in this study area. These types of fragments are found in the sand patches around the reef but they do not survive to be worked up onto the beach in sand sized grains. Mechanical breakdown and bioerosion by organisms such as parrotfish, urchins and boring sponges will reduce the size of these grains (Scoffin, 1987). Halimeda sp. has internal intertwined tubes which make the skeleton more open. This will increase the rate of mechanical erosion. Similarly, coral skeletons are quite porous and will break down more easily. Cliona sp. sponge boring will reduce coral fragments down to four to six phi (Scoffin, 1987). This is too small to accumulate in the high energy beach environment. Coral skeletons often tend to break down into their constituent aragonite needles so they will not be able to form sand grains (Bathurst, 1975). Microborers such as endolithic algae and fungi will also cause a lot of bioerosion of carbonate grains (Scoffin, 1987).

With mechanical erosion Halimeda colonies will first be broken into whole segments, then chips, then finally dust. In the beach environment a fragment of this algae will not survive very long. Whole segments are found in the sand around the reef but even there they are rare. This likely reflects the high energy of the nearshore environment at Manzanillo.

The large percentage of molluscan and red algal grains found in the beach sediments reflects the resistance of these grains to breakdown. Molluscan grains are among the most resistant to breakdown (Scoffin, 1987). The structure of red algae does not contain the hollow tubes of Halimeda. so it will be less quickly broken down. This will allow this algae to accumulate preferentially in the beach setting. These red algae occur in the middle of a scale of resistance to breakdown given in Scoffin (1987). They are more resistant than many other algae species.

The differential resistance to both mechanical and physical breakdown has determined the composition of the major biogenic components of the beach.

5.5 Sedimentological Properties of the Beach

The skewness and sorting of the samples reflect fairly well the expected properties of an ocean beach environment (see fig 3-16 Blatt, Middleton and Murray, 1980). The samples are well sorted as a result of the constant swash of the waves in the surf zone. Some samples are positively skewed, which is contrary to expectations for the beach environment. Perhaps a mixed sediment of this type with such large density differences will not conform entirely to expectations. The grains may not all be in perfect hydraulic equivalence which would confuse the results; on the other hand, the mineralogy of the various sand size fractions does differ greatly, suggesting that some degree of hydraulic equivalence is obtained.

The larger average sediment size reflects higher energy conditions at Punta Manzanillo. This is supported by the fact that there is no beach around the point. The lagoon behind the reef will be narrower at this point so there is less chance for energy to be attenuated. The very small silt fraction in the sediments of the beach and the reef itself support the conclusion that this is a very high energy environment. The high energy and the prescence of a heavy mineral suite are responsible for some of the structures observed on these beach. The beach sediment is laminated. Dark laminae of heavy minerals and lighter carbonate laminae were clearly visible in pits dug in the beach. Rhomboid ripple marks are also an abundant feature in the study area.

CHAPTER 6 - CONCLUSIONS

The beach environment at Manzanillo, Costa Rica, is characterized by a mixed siliciclastic and carbonate sediment. Of special interest is the presence and concentration of magnetite in this sediment. The magnetite, which is a minor component in the source rocks becomes concentrated as a result of its resistance to weathering and becomes a major component of the beach.

The detrital sediment appears to be transported from the east and is likely derived from the Rio Sixaola. If the reef at Manzanillo was found to be under siltation stress, then activities in the drainage basin of this river could be responsible. Local rivers also provide a small contribution to the sediment of the beach. If any of the trace elements in the beach sediment turned out to be absorbed onto grains, then an understanding of the source of the grains could help identify the source of comtamination.

The carbonate sediment on the beach is likely derived from the reef just offshore. Articulating red algal grains and molluscan fragments are concentrated in the beach environment as a result of their resistance to mechanical and biological degradation.

The heavy mineral assemblage can be used to determine the direction of longshore drift. If the grain sizes of the heavy mineral assemblage are restricted, then the minerals will be sorted to some degree according to their densities. This could be of use in the geological record as paleocurrent and provenance information.

The magnetite accumulations in this study area are not likely of any economical value, but if the source area contained precious metals such as gold, then a setting like the one described could form a placer deposit.

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