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ANALYSIS OF MICROTEXTURES ON QUARTZ SAND GRAINS OF TRIASSIC AGE, FROM THE MINAS BASIN - COBEQUID BAY AREA (BAY OF FUNDY), NOVA SCOTIA

ANALYSIS OF MICROTEXTURES ON QUARTZ SAND GRAINS OF TRIASSIC AGE, FROM THE MINAS BASIN - COBEQUID BAY AREA (BAY OF FUNDY), NOVA SCOTIA

By

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ABSTRACT

Triassic sandstones form rapidly eroding cliffs around much of the Minas Basin, Nova Scotia. The sand eroded from these cliffs is one major source of the modern intertidal sands. Wave erosion of the cliffs locally produces a small sand beach at the high tide level.

Eight samples were examined using the Scanning Electron Microscope: two from the Triassic sandstones, and six from the high-tide beach below the cliffs. All samples contained rounded, as well as subrounded and subangular, quartz grains in the 0.5 - 1.00 mm size fraction. As the samples originated in the cliffs, abrasion by strong tidal currents cannot account for the rounded grain shape.

All grains studied had suffered some degree of diagenesis in the form of a precipitation coat. This was generally thicker on the rounded grains than on the more angular ones. The Triassic sandstone grains generally illustrated upturned plates, semiparallel steps, conchoidal breaks and a fine V-shaped pattern. The high beach grains illustrated upturned plates, V-shaped patterns, conchoidal breaks, greater rounding of features present and arc-shaped steps. Wehrfritz (1973) studied quartz grains from intertidal sand bars in the Minas Basin. He concluded that grains were considerably rounded by intertidal processes, and the frequency of V-shapes increased with grain roundness.

Although some rounding of the beach sands was inherited, wave and tidal action aided in rounding the features further. The initial rounding of the sand grains within the sandstones may have occurred

during periods in the Triassic when they were exposed to wind or reworked in the lakes.

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CHAPTER I

INTRODUCTION

The major constituent of sand grains is quartz. When quartz grains leave their initial source, they may experience environmental forces, such as those produced by wind, water or glaciers. Each force, of sufficient intensity, will leave a mark on the grain's surface. However, the initial shape of the grain generally remains relatively constant. For example, if the grain was initially angular, the angularity will be visible to some degree through the subsequent modifications of the grain surface. The physical and chemical processes of diagenesis may also affect the surface form. These processes primarily include the solution and redeposition of silica. By studying the surface features of sand grains, with such instruments as a Scanning Electron Microscope (SEM), much information may be gained about the grain's history. Such studies can aid in the determination of both the provenance and depositional environment of a unit or sequence.

The intertidal sands on the macrotidal sand bars of the Minas Basin, Nova Scotia, have been derived largely from erosion of the low Triassic sandstones and pleistocene outwash sand cliffs surrounding the basin (Klein, 1970; Amos and Joice, 1977). Balazs and Klein (1972) attributed the well rounded nature of the intertidal sands to the high frequency of grain collisions which occur during bedload transport by tidal currents around the bars of the intertidal zone.

Wehrfritz (1973) studied the surface textures of intertidal sands, to further our understanding of the modification of quartz sand shapes in an intertidal environment and to test Balazs and Klein's (1972) hypothesis on sand grain rounding. This was followed up by Brisbin (1973) with a study of the surface textures of some of the glacial outwash sands, from which the intertidal sands were derived.

Balazs and Klein (1972) remarked particularly on the high degree of roundness of some of the modern intertidal sands, compared with the apparently low degree of rounding in the potential source materials, in the samples they studied. However, examination of the Triassic sandstones and the beach sands at the high tide level, that had been derived from the Triassic sandstones but had not been extensively transported by tidal currents, revealed the presence of well rounded quartz grains which were clearly visible even to the unaided eye.

The purpose of this study is, therefore, to complete the examination of the potential source materials for the modern intertidal sands, by a study of quartz sand grains: 1) in the Triassic sandstone cliffs flanking the Minas Basin, and 2) in the high tide level beaches found at the base of some of the Triassic cliffs. Description of the surface textures present on Triassic sands not only permits a comparison with the modern sands derived from the bars, but also suggests a possible origin for the Triassic sands themselves, and in particular for the well rounded Triassic grains.

As fieldwork was conducted in mid December (1977), the sampling locations were greatly restricted due to the time of year. Maximum low tides did not occur until late afternoon and several of the roads leading to the cliffs were closed. Also the number of samples studied was limited to eight due to the time available for this study and the temperment of the Scanning Electron Microscope used.

CHAPTER 2

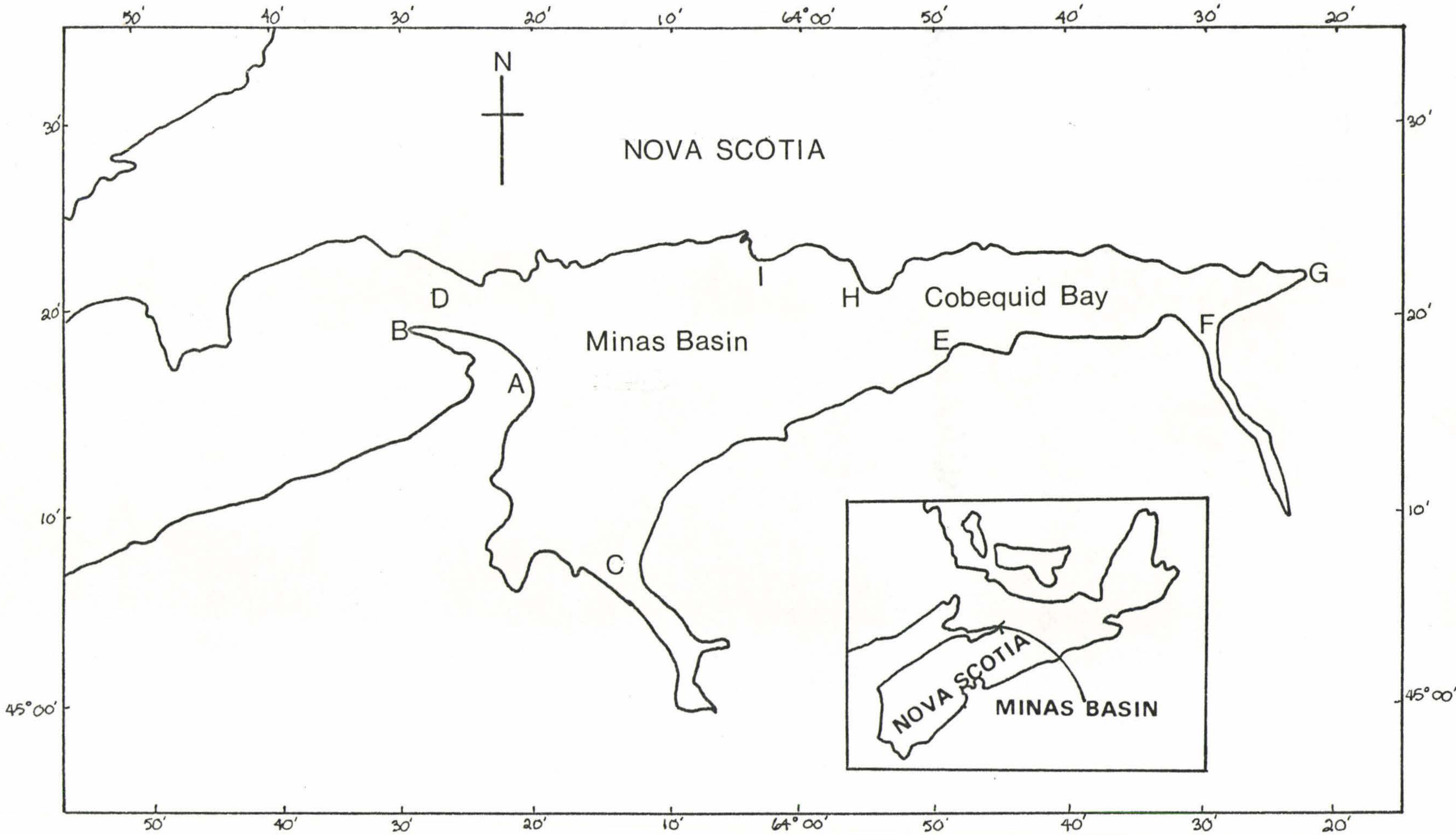
REGIONAL SETTING

The Minas Basin and Cobequid Bay form a triangular body of water at the northeast of the Bay of Fundy (Fig. 2.1). This is a macro-tidal embayment with a maximum length of 77 kilometers and width of 31 kilometers. The average depth below the lowest low water level is 15 meters and the perimeter of the enclosure is 320 kilometers (Amos and Joice, 1977). Extreme tidal ranges occur semi-diurnally throughout the system. During low tides, an extensive intertidal zone is exposed around the perimeter of the Minas Basin - Cobequid Bay system. This exposure may reach an area of approximately 200 to 300 square kilometers (Knight, 1977).

GENERAL GEOLOGY

The Geology in the Minas Basin - Cobequid Bay area, in ascending stratigraphic area, is as follows. The oldest rocks in this area belong to the Lower Ordovician Meguma Group. These shales, siltstones and sandstones are poorly exposed, tightly folded and well indurated (Dalrymple 1977). They lie beneath the Silurian-Devonian Cobequid, volcanic and shale complex. These rocks may be highly chloritized and severely sheared. The shearing in this complex and the folding in the Meguma Group may have occurred as a result of granitic intrusions during the Acadian Orogeny in the Late Devonian. The shearing in the Cobequid Complex may also have been caused by the Glooscap fault which forms the

RESEARCH AREA



A CAPE BLOMIDON

B CAPE SPIT

C AVON RIVER

D MINAS CHANNEL

E BURNTCOAT HEAD

F SHUBENACADIE RIVER

G SALMON RIVER

H ECONOMY POINT

I FIVE ISLANDS

Fig. 2.1 (AFTER AMOS AND JOICE 1977, P.5) southern edge of the Cobequid Mountains. This fault is of unknown displacement and tectonic significance (Dalrymple, 1977).

Both sides of the basin are underlain by Mississippian age sediments. These folded and well indurated rocks are believed to have been deposited in a fault-bounded graben (Dalrymple, 1977). The next unit in the sequence is the Horton Group of sandstones, conglomerates and shales. They are followed by gypsum, shale and sandstone of the Windsor Group.

The Pennsylvanian sandstones, conglomerates and coals lie directly above the Windsor Group. They were also deposited in the graben and are very similar to the Windsor except for a lack of evaporates. The Triassic sandstones conglomerates and siltstones of the Annapolis Group lie directly above. These very friable red sediments form the cliffs which flank the Minas Basin and Cobequid Bay. The unit is capped by the North Mountain basalt and dolerite flows of the Scots Bay Formation which form Cape Blomidon and Cape Spit, (Dalrymple, 1977, page 20).

As stated in Chapter 1, this study is directed to the Triassic sediments of the area. They include the Annapolis Group and the Scots Bay Formation, as mentioned above. During the late Triassic time the Maritime Provinces experienced a humid tropical climate, alternating with seasonal dryness (Klein, 1962). This is inferred from the evidence of flora and fauna present in the sandstones. The Blomidon Formation, of the Annapolis Group, is believed to be of lacustrine origin as the fossils present are restricted to a lake-type environment. The Scots Bay Formation is also believed to be lacustrine in origin, again due to fossils present and its similarity with the Blomidon Formation (Klein, 1962). Further reference will be made to the depositional environment of the Triassic sediments, in the discussion and conclusions of this investigation (Chapter 7).

GLACIAL GEOLOGY

During the Wisconsin, the Minas Basin - Cobequid Bay area was glaciated by a continential ice sheet which flowed from the north to the south-southwest. The bedrock was covered with glacial deposits and stream valleys were filled with outwash sediments. Approximately 12,000 years B.P. the ice mass began to retreat. As the ice melted, meltwaters transported outwash sediments through valleys to feed the prograding marine deltas which built upwards as the sea level rose.

The sea began to emerge when the eustatic sea level rise became less than the isostatic rebound rate. Outwash sediments were continually supplied by the retreating ice front. Rates of rebound slowed about 6,000 years B.P. (Knight, 1977).

RECENT SEDIMENT SOURCES

There are three active, modern sediment sources. They include: coastal erosion, basin bottom erosion and fluvial discharge. The cliffs surrounding the Minas Basin - Cobequid Bay area are, in most cases, a very friable red Triassic sandstone. Erosion of cliffs composed of Triassic sandstone, glacial-fluvial sediments, and Pleistocene fill is rapid. This is suggested by the following observations: broad wave or tidal cut benches flanking the margins; similar colour of the cliffs and the intertidal sediment; rapid rates of lateral shoreline erosion; and similar mineralogy between the coastal material and the sediment in the intertidal zone. Rivers entering the system are small and consequently contribute little sediment (Knight, 1977), Amos and Joice (1977); Klein (1970)).

CHAPTER 3

SAMPLE PREPARATION - PROCEDURE

The sample preparation method used for the Scanning Electron Microscope (SEM) specimen was very similar to the one described by Krinsley and Margolis (Carver, 1971). As the samples were too large to be sieved properly, they were first split in a riffle. After the riffled sample was weighed, it was sieved to determine the grain size distribution and to separate grains between 0.5 mm and 1.0 mm in size, for study under the SEM. The sieves selected ranged from -0.25 phi to +2.00 phi at 0.25 intervals. The samples were shaken on the Ro-Tap machine for ten minutes. After this each size fraction was weighed using a Mettler Balance.

Grains between 0.5 mm and 1.0 mm were then boiled; first in hydrochloric acid for 30 minutes to remove any surface debris, and then in a stannous chloride solution for 30 minutes to remove any iron stains. The sample was then thoroughly washed, with distilled water, and dried in an oven.

Once dry the quartz grains were separated from the sample with the aid of a binocular microscope and a fine paint brush, and placed on a black, gridded microscope slide. Unicrystalline grains were chosen over polycrystalline ones to avoid confusion when viewing under the SEM. When a sufficient number of quartz grains had been placed on the microscope slide, the horizontal rows of the grid on the slide were systematically scanned to obtain a representative sample. A random search may, in some cases, prove not to represent the sample. For example, if a grain was chosen from every other grid square, and in each case it was round, but the remaining grains were angular, the sample picked would not represent the population. Granted, the probability of this occurring is not very large. The chosen grains were then mounted, using a fine paint brush, in rows on aluminum stubs 12 mm in diameter, coated with Scotch Brand double coated conductive tape No. 410 (3M Company).

When approximately 20 to 25 grains had been placed on the stub it was placed under a binocular microscope and a reference map of the stubs surface was drawn (Fig. 3.1). Also at this time the grains were classified according to a Power's roundness scale (Blatt, Middleton and Murray, 1972, page 64).

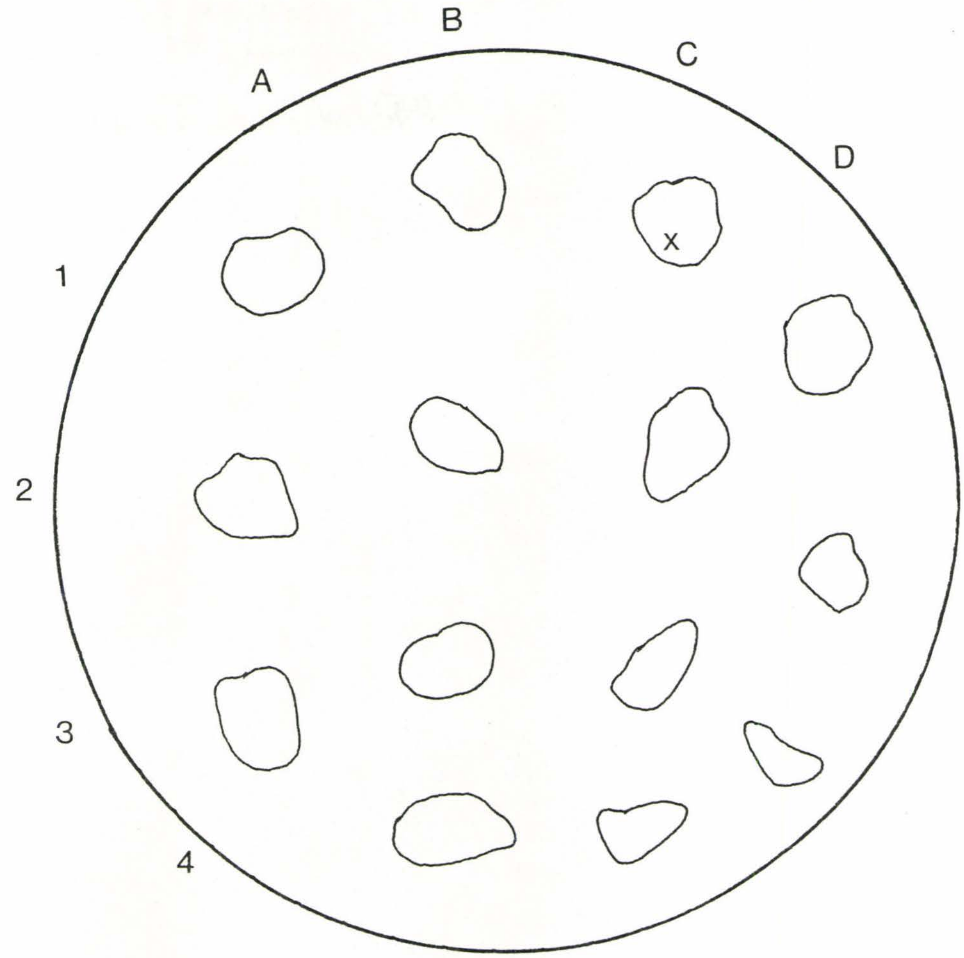
Each sample was then given a conductive coating of carbon and gold-palladium alloy by using a vacuum evaporator, to avoid a charge buildup on the specimen when being viewed with the SEM.

The gold-palladium coating on the grain surface was approximately 200 Angstroms in thickness. The stub was then ready for viewing with the SEM. The machine used was an AMR (American Metals Research) model 1000 SEM. Micrographs of the grains were taken using Ilford Pan F extra fine grained black and white safety film, with an ASA speed of 50.

Fig. 3.1

Map of Sand Grains on the Stub

Sample No: 9



Grain Roundness

	A	B	C	D	
1	R	SA	VA	SR	
2	VA	SR	VA	VA	
3	SR	SR	VA	A	
4		VA	VA		

KEY

VA very angular

A angular

SA sub-angular

SR sub-rounded

R rounded

WR well rounded

X picture

CHAPTER 4

SAMPLE DESCRIPTION

Ten samples were collected from the Minas Basin - Cobequid Bay area. Samples 1 and 8 were collected by Dr. G.V. Middleton, while the remaining samples were collected by the author. The samples consisted of Triassic sandstones and of modern sand derived directly from Triassic cliffs. They were chosen in hopes of determining the characteristics of sand grains derived from the Triassic cliffs. It was hoped that the origin of the well rounded quartz grains, present in the samples, could also be determined. One sample was taken from the modern intertidal sand bars for comparison with the cliff and high beach samples.

Eight of these samples were studied under the Scanning Electon Microscope (SEM). Of the two samples which were not studied, one was too fine grained, while the other would not disaggregate because of the presence of a silica matrix. Five of the samples studied were from high beach areas, one sample was from a bar, and the remaining two were from the sandstone cliffs. Table 4.1 describes each sample location.

In addition to the SEM analysis several of the size fractions, such as -0.25 phi and +2.00 phi, were viewed both with the unaided eye and the binocular microscope. Table 4.2 summarizes the results. In general, all of the grains were coated to some degree with iron oxide. Under the binocular microscope this appeared as a powder dusting. Most of the samples contained several grains and artifacts coarser than -0.25

TABLE 4.1: SAMPLE LOCATIONS

Sample	Area
1.	A small beach at the south end of the Pleistocene cliffs, just south of Cape Blomidon. The sand is either Pleistocene or Triassic and strong wave action is not possible.
2.	A 'fluvial' sandstone from Economy Point.
3.	The base of a cobble beach at Cape Blomidon.
4.	The base of the cliff at Burntcoat Head where the wave action is strong.
5.	The centre bar at Economy Point.
6.	Sand from about 100 m from the cliff at Economy Point.
7.	Sandstone from the Blomidon Cliffs. This sample was not used as it was too fine.
8.	The sample was collected about 2.5 meters below high, high water level from the beach at Blomidon Provincial Park.
9.	A sandstone from the base of the cliff at Economy Point.
10.	A sandstone from about 1.5 meters from the base of the cliff (on the cliff) at Burntcoat Head. This sample was not used as it would not disaggregate.

TABLE 4.2: Binocular Microscope Observations

Sample	Power's Roundness	Iron Oxide Coat	Character of -0.250 Fraction	Character of +2.00 Fraction
1	subangular to subround	-light -gives orange tone	-small amount -size varies -few large particles present	-large amount of fines
2	Subangular to subround	-light -gives red tone	-very small fraction -grain size fairly constant	-large amount of fines
3	subrounded to subangular	-very heavy coating -gives dark red tone	-large fraction -all flat and of varying sizes	-large amount of very fine fines
4	angular to subangular to subrounded	-heavy coat -gives red tone	-fair size fraction -sizes vary -some very large pieces	-small fraction
5	subangular to subrounded to angular	-very light -gives orange tone	-medium size fraction -shells present plus some large fractions	-medium size fraction
6	subrounded to subangular to angular	-moderate to light -gives orange tone	-medium fraction -all fragments are flat and of varying sizes	-medium fraction
8	subrounded to subangular	-very heavy	-large fraction -fragments are flat, some are large	-large fraction -very fine
9	subrounded to subangular	-heavy -gives red tone	-medium fraction -variety of grain sizes -some of larger pieces have small ones adhering	

phi. The amount and size of these grains varied with the sample. Most of the grains were either subangular or subround, although well rounded grains did exist. The amount of very fine sand also varied with the sample.

Cumulative weight percent curves were drawn for each sample (Fig. 4.1). In each sample a bimodal grain size distribution is indicated by the curved lines. Histograms were also drawn for each sample (Fig. 4.2). Again, they indicate a bimodal distribution. This was expected for the beach sands, but it was unsure what the sandstones would show. The significance of this observation will become apparent when the SEM micrographs of surface textures are presented.

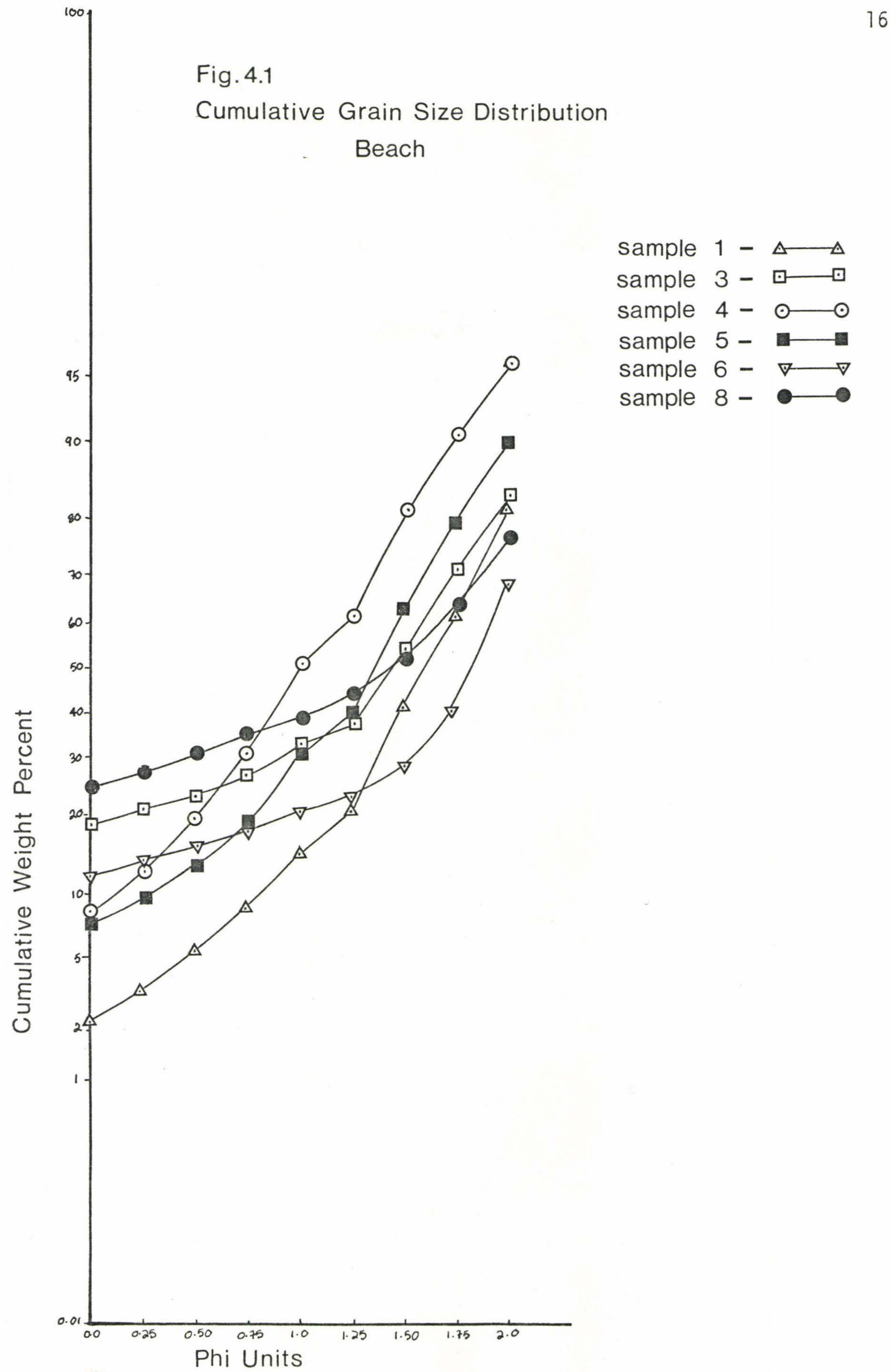


Fig. 4.1
Cumulative Grain Size Distribution
Beach
sample 1
sample 3
sample 4
sample 5
sample 6
sample 8
Cumulative Weight Percent
100
95
90
80
70
60
50
40
30
20
10
5
2
1
0.01
0.0
0.25
0.50
0.75
1.0
1.25
1.50
1.75
2.0
Phi Units

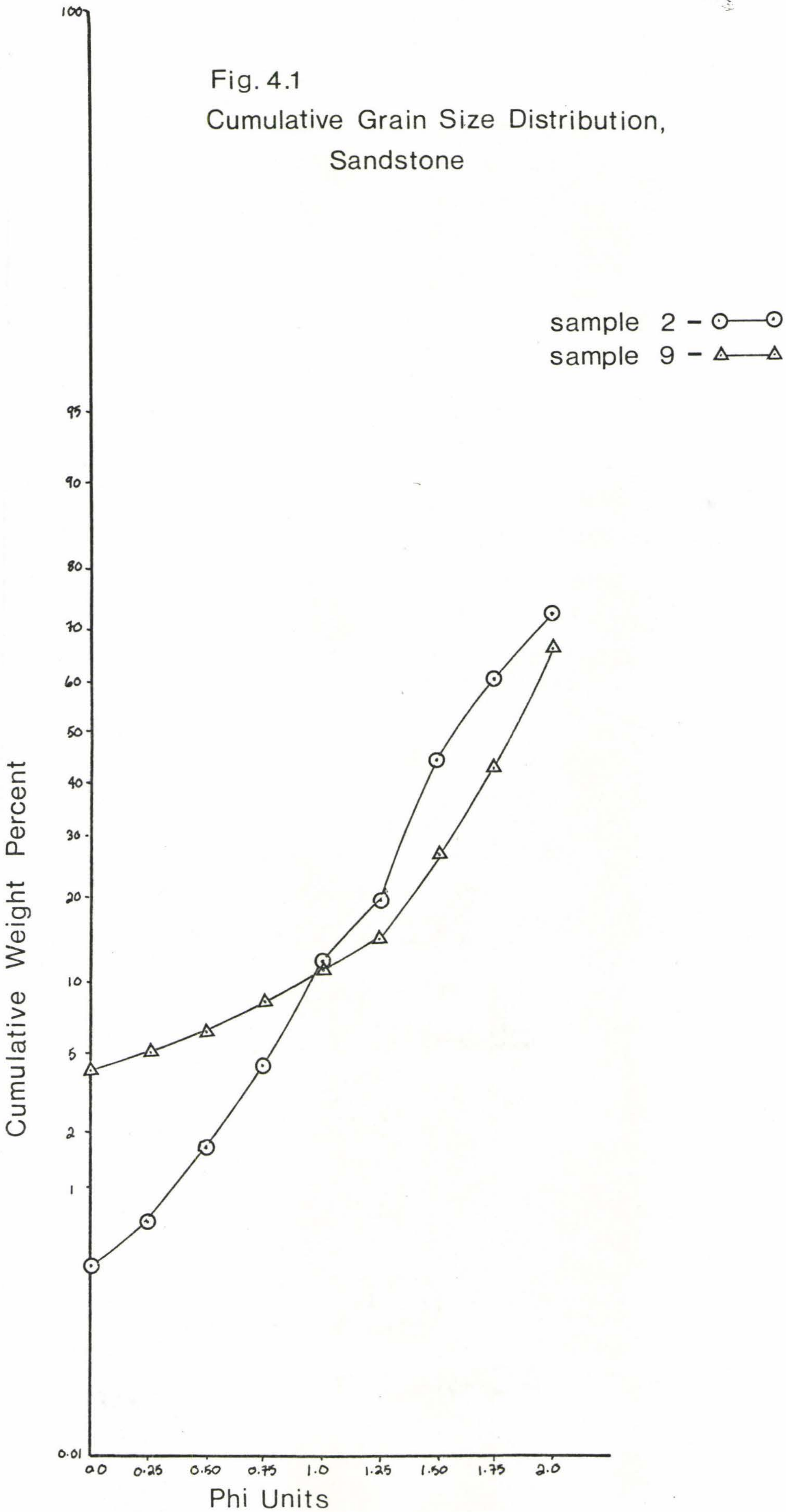


Fig. 4.1
Cumulative Grain Size Distribution,
Sandstone
sample 2
sample 9
Cumulative Weight Percent
Phi Units
100
95
90
80
70
60
50
40
30
20
10
5
2
1
0.01
0.0
0.25
0.50
0.75
1.0
1.25
1.50
1.75
2.0

Fig. 4.2 SAMPLE GRAIN SIZE DISTRIBUTION

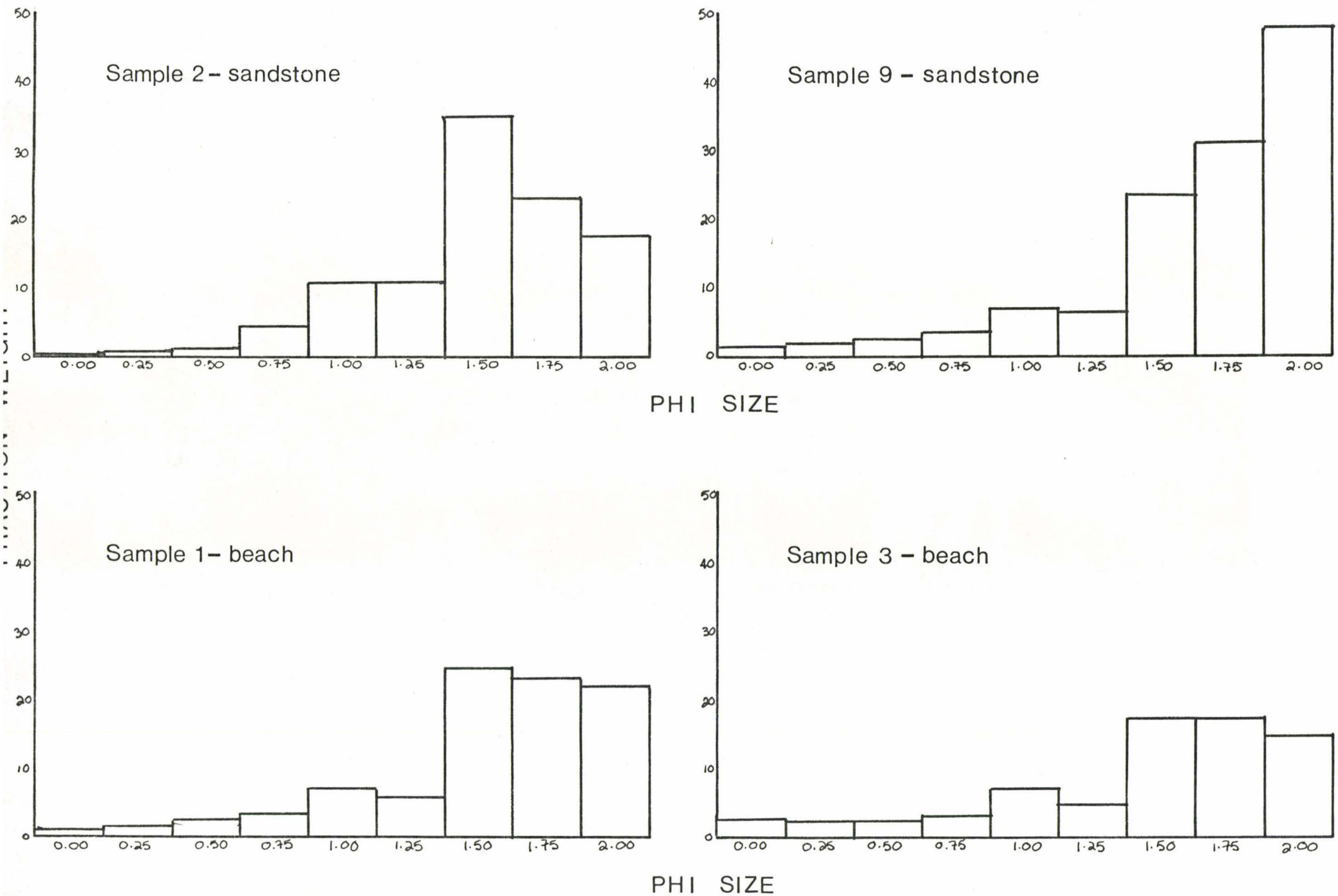
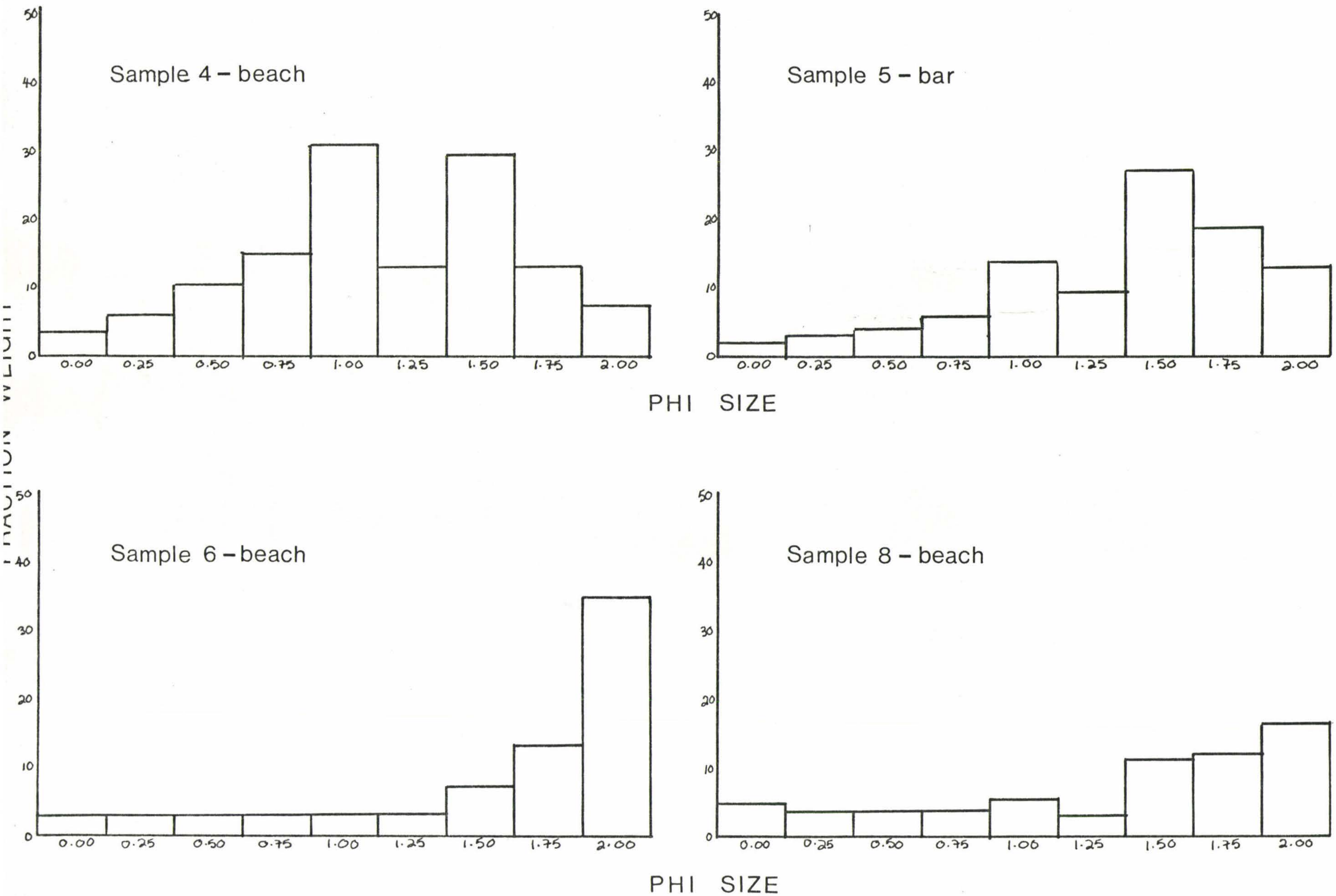


Fig. 4.2 CONTINUED



CHAPTER 5

REVIEW OF THE LITERATURE

Before 1962, sand grain surface textures were studied with the aid of a magnifying glass or a binocular microscope. The study was initiated by Sorby in 1880 (Soutendan, 1967). He observed a frosted surface on some sand grains and based a classification on this. Cailleux in 1942, using a binocular microscope, developed a sand surface texture classification scheme consisting of four types: 1) abraded; 2) well-rounded, shiny; 3) well-rounded, frosted; and 4) rounded, dirty (Soutendan, 1967). His investigations led him to the following conclusions: Firstly, the amount of well-rounded frosted grains present in a sample was a function of the intensity of wind action; secondly, frosting resulted from small percussion marks, produced during aeolian grain impact; thirdly, water transport results in a shiny lustre on the grain's surface.

The limited resolution and depth of focus of the binocular microscope proved very restrictive for this study. Detailed investigation of surface textures did not begin until the electron microscope was developed. In 1962 three independent studies were published by different authors on the electron microscopy of sand grain surface textures. The authors included Krinsley, Porter and Biedermann. The three papers suggested classification schemes which varied greatly. Porter (1962) proposed a classification with five surface textures. They include: 1) abraded, where the surface has a chipped or ground appearance; 2) lobate, where the surface has a distinctly cobbled appearance; 3) corroded, where the surface appears to be the result of material removed by solution; 4) smooth; and 5) faceted, where planes or facets are present and associated with the crystallinity Biedermann (1962) studied aeolian grains and water deposited grains. He found the former had irregular abrasion pits; and the latter had triangular crystallographically oriented pits formed by solution.

By far the most extensive of these papers were the three by Krinsley (1962, a,b,c). Krinsley and his colleagues studied grains from aeolian, glacial and littoral environments, as well as some experimentally abraded grains. The surface textures and environmental categories proposed by Krinsley will be described in detail in the following chapter. Also in 1962 Kuenen and Perdok concluded that wind had a strongly abrading effect on the sand grains it was transporting. They believed the mechanical impact of the grains causes a frosted appearance on the grain's surface.

Once these results were published, researchers began to apply them to their own studies. Krinsley continued his investigations and, in 1964, he concluded that the density of V's in the V-shaped pattern on beach sand grains was a function of the distance the grain had travelled. In 1968 Margolis investigated both natural sand grains with oriented etch features and sand grains which had been experimentally etched. He concluded that the best etching occurs where the pH levels of the solution exceed 9.0. Such solution conditions may be realized in an intertidal region where sea water on the grain's surface evaporates (Margolis, 1968).

In 1968 Krinsley and Donahue presented a more detailed description of environments and their characteristic surface textures. The same theme may be found in the following papers: Krinsley and Margolis (1969); Krinsley and Margolis in Carver (1971); Krinsley et.al. (1973); Krinsley and Doornkamp (1973); and Margolis and Krinsley (1974).

In 1969 Gees studied beach and dune sands. The textures he found were similar to those described by Krinsley. Also in 1969 Steiglitz published the first paper on sand grains seen under the Scanning Electron Miscroscope. Until that time electron microscopic work was restricted to the Transmission Electron Microscope. Steiglitz studied grains from a fresh-water environment and found, along with features Krinsley described as characteristic of this environment, pits, common to raised areas, with a variety of sizes and shapes.

The Scanning Electron Microscope (SEM) provides results that are much superior to those attainable with the Transmission Electron Microscope (TEM). In order for a grain to be viewed under the TEM a replica of its surface has to be made. This process is time consuming and requires skill. The SEM provides direct three dimensional viewing of the grains, which minimizes distortions and provides greater surface detail. As many as 40 sand grains may be mounted on a single SEM stub, thereby greatly reducing the number of changes necessary when viewing various grains. The stubs may also be tilted or rotated so that more of the individual grain can be seen (Krinsley and Doornkamp, 1973, page 4).

In 1971 Ricci Lucci concluded that a frosted or pitted surface was the result of shrinkage of surface layers which causes removal of chips without transportation or abrasion. He also concluded that grain-to-grain collisions during aeolian transport, along with this surface exfoliation, causes the grains to be highly rounded. Krinsley and Hyde (1971) suggested that the older the grain was, the greater would be the solution and reprecipitation of its surface. They also indicated that pre-Tertiary sand grains are generally lacking primary mechanical surface features due to their age.

In 1972 Setlow and Karpovich deducted that grains may illustrate 'glacial' features even if they had never been near a glacier. This fact was also stressed by Brown (1973).

Krinsley and Smalley (1973) found that the smaller the quartz particle is, the more plate-like it becomes, due to breakage of the grain by larger grains. They suggest that when a grain reaches a critical size of about 100 μm a cleavage-breakage mechanism is enforced. When the grain is larger less energy is required for failure by fracture and the cleavage tendency is suppressed.

Whalley and Krinsley (1974) studied sand grains from various glacial environments. These grains were from above, within and below the ice mass; plus grains from boulders over-ridden by ice, from meltwater streams and from moraines. They concluded that the inherited characteristics of quartz grains are of prime importance. These inherited characteristics include grain shape, and abundance of conchoidal fractures present on the surface.

In 1975 Tankard and Krinsley presented a paper on the diagenetic surface features of geologically young detrital sand grains. All samples studied possessed the same basic features: solution surfaces controlled by the crystallography and independent of internal symmetry, plus re-precipitation features.

Krinsley, et.al. in 1976 studied the aeolian transport surface textures on early Triassic sand grains. Four surface textures were common to the sand grains: 1) upturned plates; 2) elongate depressions; 3) smooth precipitation surfaces on smaller grains; and 4) polygonal cracks due to weathering.

In 1978 Hampton, Bouma and Torresan studied sand grain surface textures on grains from lower Cook Inlet, a tidal estuary in Alaska. This is the first paper written on such an area. The surface textures they observed were very similar to the ones observed on the intertidal sands of the Minas Basin. They will be described in detail in the following chapter.

The study of sand grain surface textures has come a long way since it began in 1880. However, it still requires a detailed descri-ption of all surface textures found, as well as more work on such environments as intertidal and subtidal marine environments. The remaining report is an attempt to describe the textures observed in the Triassic source sands and in a modern active intertidal environ-ment of a macrotidal area.

CHAPTER 6

THE SURFACE FEATURES AND ENVIRONMENTS

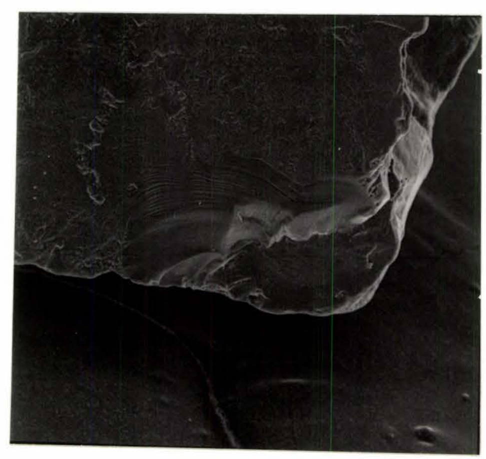
The easy recognition of textural surface features is of major importance. It may essentially be based on the presence, or absence, of several common fracture patterns. They include conchoidal breaks, flat cleavage plates, upturned plates, and alterations of these features (Krinsley and Doornkamp, 1973, page 4).

Primary Fracture Patterns

A conchoidal breakage pattern results from circular or arc shaped fractures, and is found as either depressions or elevations. Their size and shape are highly variable due to the nature of the contact that produces the fracture. For example, compression between sand grains or between a single grain and a rough surface. Ideally, they are formed when pressure is applied in a uniform concentric fashion (Margolis and Krinsley, 1974).

Fig. 6.1

Large conchoidal fracture
Beach sand from a beach south
of Cape Blomidon (Sample 1)
200 x mag.



Flat Cleavage Plates are very flat areas on the grain's surface formed by "cleavage", and common to small sand grains. It is believed they represent "cleavage" parallel to the r or z face of quartz (Krinsley and Doornkamp, 1973, page 9). As quartz displays no true crystallographic cleavage, the term is here applied in a broad sense to a series of flat, parallel, fracture surfaces.

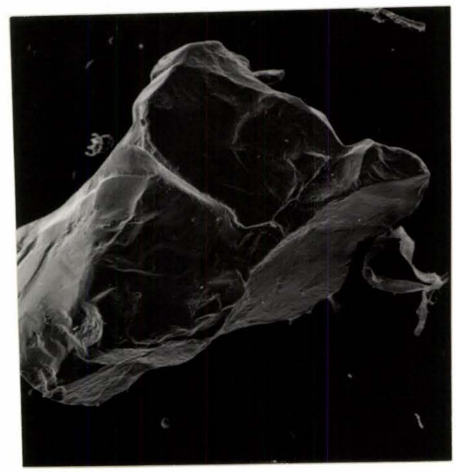


Fig. 6.2

Flat "cleavage" plates
Beach sand from a beach
south of Cape Blomidon
(Sample 1) 85 x mag.

Upturned "cleavage" plates are a common feature. They are either continuous or discontinuous and are oriented at an angle to the grain's surface. If unaltered they are jagged and of irregular height. The observed surface features are believed to be oriented along cleavage plane faces. The plates have a wide variety of appearances and there may be several varieties on a single grain. Mechanical abrasion along the cleavage plane traces produces rounded features resembling upturned cleavage plates (Margolis and Krinsley, 1974).

Fig. 6.3

Upturned "cleavage" plates
Economy Point Sandstone
(Sample 2) 950 x mag.

Alterations, in the form of silica precipitation or chemical modifications, greatly modify these features. A silica coat may form on the grain's surface, smoothing the relief and increasing the height and thickness of the grain's forms.

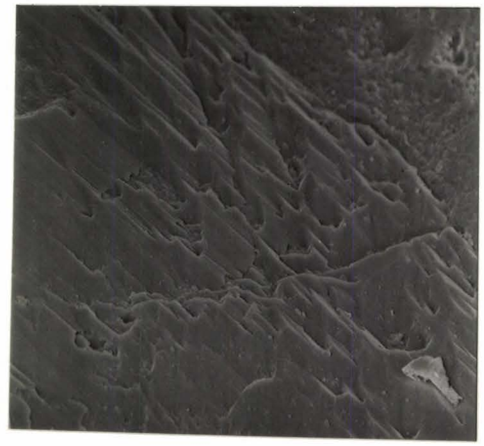
In general these alterations are produced by either mechanical or chemical means.

Secondary Alterations - Mechanical

One of the common mechanical features found on sand grains are V-shaped grooves and depressions cut in the top of cleavage plates. These roughly triangular shapes, with irregular sides and a central unevenly depressed area, are unique to a sub-aqueous environment. They are probably the result of gouging during grain collisions, with their size and shape a function of the energy present. In areas where the frequency of grain contact is high the resulting pattern is dense, irregular and non-oriented. On the other hand in areas where there is a low frequency of grain contact, the pattern becomes less dense and less random. Chemical etching on the surface may also occur. There is a continual gradation between the physical and chemical end members (Margolis and Krinsley, 1974; Krinsley and Donahue, 1968). Generally, mechanical V's range in size from 0.05 μm to 5 μm in length, approximately 0.1 μm in depth, and have a maximum density of about two V's per square μm (Carver, Chapter 8).

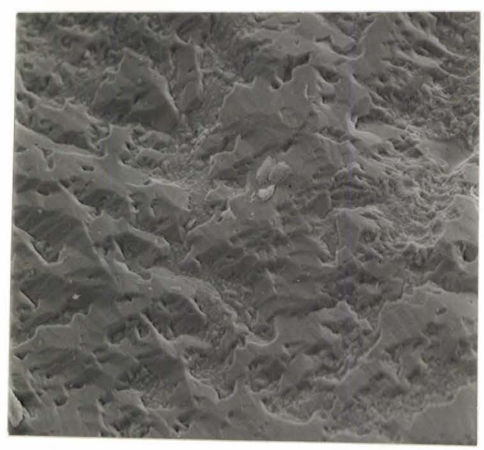
A single collision may produce more than one V-shaped pit. As the grains collide small splinters of the grain are removed. These slivers serve as active abrasive sources during later collisions, forming grooves and scratches. At low impact velocities the gouges are linear, but they begin to curve at higher collision energies. They range in length from two to 15 μm and vary in width. When the surface of the grain becomes totally saturated with depressions, new pits replace the old (Margolis and Krinsley, 1974).

Fig. 6.4



Oriented V pattern
Economy Point Sandstone
(Sample 2) 950 x mag.
In this example, the V pattern appears to be the result of the chemical action of sea water.

Fig. 6.5



Nonoriented V pattern
Economy Point Sandstone
(Sample 2) 490 x mag.
Again in this example, the V pattern appears to be the result of the chemical action of sea water.

Another mechanical feature, although rare, is chatter marks. These appear in a subparallel array of indentations, and are formed when one grain skips across another (Krinsley and Margolis, 1969).

Mechanically produced features need not be restricted to a subaqueous environment. Both glaciers and desert wind provide sufficient force to abrade sand grains actively. A high energy environment, such as a glacier, will produce highly angular grains. The degree of grain sorting will be small, which results in a large variation in particle size. High energies available for grinding lead to a high surface relief. Semiparallel steps develop from the shearing of one grain past another. They are roughly linear rises on the grain's surface, which are in a semiparallel step-like pattern. Arc shaped steps are similar to semiparallel steps in appearance, except for their semi-circular form. They are formed as a result of percussion fractures. As many of the grains have sharp edges, collisions between them produce parallel striations, or grooves, of varying lengths (Krinsley and Donahue, 1968). However, these features are not unique to glaciers. They will form in any environment where suitable conditions of abrasion exist (Brown, 1973).

Aeolian transport tends to round the surface of sand grains. A meandering ridge pattern develops from the intersection of slightly curved conchoidal breakage patterns, which, in turn, are due to grain collisions. The impact between grains wears away the breakage blocks and results in ridges. Graded arcs are another impact feature, very similar to conchoidal fractures. They are characterized by a concentric series of graduated arcs, formed by percussion fractures (Krinsley and Donahue, 1968).

Fig. 6.6

Arcshaped Striations: on a grain from the beach at Cape Blomidon. 1900 x mag. (Sample 1)

Fig. 6.7

Semiparallel Steps: on a grain from the sandstone at Economy Point. 1000 x mag. (Sample 9).

Secondary Alterations - Chemical

Chemical action on the grain's surfaces produces several distinct features. It may cause etching or the overgrowth of existing textures. Etching may produce crystallographically oriented pits or a non oriented pattern. Overgrowths may be continuous with, or completely obliterate, the pre-existing surface. In some cases the mechanical and chemical action will balance. That will be a function of such factors as the wind's strength, the number of storms in a certain period, the moisture content, the evaporation rate and the pH of the interstitial fluid (Margolis and Krinsley, 1974).

Etching produces irregular lines and a worn surface. Early in the process the pre-existing surface is clearly visible. However, with time the features become obliterated (Carver, Chapter 8). On tropical desert sands chemical etching or abrasion by fines replace the pre-existing surface with a flat pitted one (Krinsley and Margolis, 1969).

THE ENVIRONMENTS

Krinsley and his colleagues have conducted extensive research on the surface textures of sand grains from many environments around the world. They have suggested a set of grain surface textures unique to each of five environmental categories. The categories include: littoral (beach), glacial, aeolian, diagenetic and any combination of these (Krinsley and Doornkamp, 1973, page 9).

Littoral

A littoral, or subaqueous, environment includes any area where sand grains are transported, abraded and deposited by water. It may be a marine or a non-marine area. The process tends to round the grains and smooth the surface (Krinsley and Doornkamp, 1973, page 12). The resulting characteristic surface textures include: small V-shaped indentations, straight or slightly curved grooves, chatter marks and a conchoidal breakage pattern. It has been suggested by Krinsley that V-shaped indentations are formed more rapidly and with less energy than their glacial counterparts (Carver, Chapter 8).

Glacial

Sand grains originating from glacial tills or fluvial-glacial deposits tend to be very angular. Their edges may be unaltered both chemically and mechanically. This is a potentially high energy environment, and the characteristic surface features are: conchoidal breaks, a high surface relief, semiparallel steps, arc-shaped steps, and parallel striations (Carver, Chapter 8). The larger grains tend to have more conchoidal fractures than small grains, which also possess flat "cleavage" surfaces and upturned "cleavage" plates (Krinsley and Doornkamp, 1973, page 11 and 12).

These features may be greatly altered by the action of solution and silica precipitation. The effect is, however, not as strong as in diagenesis. In any case, the grains become rounded. This may also occur by mechanical action in the outwash streams. The degree of alteration naturally depends on the chemical and mechanical conditions present in the environment (Krinsley and Doornkamp, 1973, page 12).

Although the above mentioned features are characteristic of glacial sand grains, they are not necessarily unique to them. They actually indicate a high energy environment with a large number of collisions between the grains.

The surface textures of glacial sand grains are somewhat a function of where they originate in relation to the glacier (Whalley and Krinsley, 1974). Supraglacial grains, which began in the cliffs above the glacier, show features inherited from the source rock. Modifications are then made to these features. Englacial grains fell into the accumulation area of the glacier and became buried. The amount of alteration is negligible as the grains are cushioned by water or ice and thus experience little grain-to-grain contact once in the ice mass. Subglacial grains are entrained from the rock beneath the glacier, and are strongly modified by glacial abrasion. In all instances the inherited characteristics of the source rock is of prime importance to the grain's surface texture (Whalley and Krinsley, 1974).

Aeolian

The aeolian, or wind, transport of sand grains produce meandering ridges and graded arcs, both of which are similar to conchoidal breaks. The breakage patterns are smaller and more uniform than their glacial counterparts, and differ from their littoral complements by the presence of curved sides (Carver, Chapter 8). The sand grains become rounded by abrasion, solution and precipitation. Naturally, the degree of rounding is a function of the energy of the environment.

Diagenetic

The diagenetic textural features are formed by mechanical and chemical processes which occur after the sand grains have been deposited and prior to any metamorphism. This excludes natural weathering. The most common form of diagenesis occurs with the solution and redeposition of silica. An inverse relationship arises: as the grain size decreases, the solution rate increases (Krinsley and Doornkamp, 1973, page 10 and 11).

Environmental Combination

In some areas several of the basic environmental categories will be combined. One example of this is the fluvio-glacial environment. In this instance the glacial grains are reworked by water. The sub-aqueous features are superimposed on the initial glacial ones.

Brief Comment on the Literature

Krinsley and his colleagues, because they have conducted such extensive research on the topic of sand surface textures, have dominated the field. They have put forth a relatively detailed classification scheme solely based on environment of deposition, rather than on the surface features present. Instead of relating grain surface textures to the processes which produced them, such as saltation of wind blown grains or movement on bed load by water, they have attempted to determine what combination of surface features is characteristic of a certain environment of deposition. Their classification is good but slightly rigid, as pointed out by Brown (1973). The features that Krinsley, and coworkers, have suggested as being characteristic of an environment may generally be valid. Nevertheless, several of the features may be produced in a variety of ways.

Further discussion and a comparison between the literature and results obtained in this study will be given in the next chapter.

CHAPTER 7

RESULTS, DISCUSSION, CONCLUSIONS

Results

A summary of the results for each sample may be found in Table 7.1. Generally, all the samples contained grains which varied in shape to some degree. Upturned plates were common to most grains, as well as some precipitation coating. This latter feature is indicative of diagenesis. It tended to be thicker on the rounded grains than on the angular ones. Associated with this coating was the silica plastering, or sticking of smaller grains to the surface. Conchoidal breaks, of varying sizes, and a non-oriented V-shaped pattern were a relatively common feature. The former being more common to the angular grains. In some cases the V-pattern was the result of grain impact while in other cases it was a diagenetic feature formed by the chemical action of sea water.

Several of the rounded grains illustrate dish-shaped concavities. Etching was not very common, although it was found on one grain. Figure 7.1 through Figure 7.7 illustrate the features found, which were not previously portrayed.

Table 7.1. Summary of Results

FEATURES PRESENT - IN GENERAL

Sample	Power's Roundness	Well Rounded	Rounded	Sub-Rounded	Very Angular	Angular	Sub Angular
1 (beach)	-majority of the grains are rounded to some degree -some are very round while some are very angular	-precipitation coat -some adhering particles -upturned plates-coated	-upturned plates -non-oriented V-shaped pattern -solution growth -conchoidal breaks	-some adhering particles -rounded breaks -non-oriented V-pattern -solution growth	-V-shaped indentations -non-oriented -sharp breaks -flat "cleavage" surface		-solution growth -adhering particles
2 (sandstone)	-majority of the grains are sub-angular to angular -rounded grains do exist		-very fine, non-oriented V-shaped pattern -irregular precip coat -silica plastering			-upturned plates -large conchoidal fractures	-precipitation surface -some solution growth -slightly rounded conchoidal breaks -etching -rounded breaks -oriented V-pattern -upturned plate
3 (beach)	-all but 2 of the grains studied were rounded or subrounded -the remaining two are angular		-upturned plates -dish-shaped concavities -some adhering particles	-rounded breaks -fairly deep, nonoriented V-shaped indentations -precipitation coat		-flat cleavage surface -some precipitation coat	

Table 7.1 (continued)

Sample	Power's Roundness	Well Rounded	Rounded	Sub-Rounded	Very Angular	Angular	Sub Angular
4 (beach)	-majority of grains studied were rounded or subrounded -several grains were angular	-very rounded features	-adhering particles in grooves and depressions	-small conchoidal breaks -rounded breaks -smoothed surface -silica plastering	-numerous conchoidal fractures-sizes vary -some parallel and arc-shaped steps	-precipitation coat over entire grain -angular breaks after coating	-solution growth -solution growth rounds edges -upturned plates - high relief
5 (bar)	majority of the grains are rounded -several are subangular	-precipitation surface	-upturned plates -few adhering particles -non-oriented V's.	-precipitation surface -some adhering particles -nonoriented V-pattern -upturned plates -dish shaped concavity		-uneven breaks -some adhering particles -small oriented V-pattern	-some adhering particles -unoriented V-pattern -evidence of conchoidal breaks -uneven breaks
6 (beach)	-a mixture of grain shapes		-adhering particles	-precipitation surface -some adhering particles rounded breaks -upturned plates -smooth surface -random V-pattern	-adhering particles -conchoidal breaks -upturned plates -nonoriented V-pattern -sharp breaks		-small round particles adhering to top half of grain (see Fig. 7.3) -silica plastering -rounded breaks -conchoidal fracture
8 (beach)	-majority of the grains are rounded	-upturned plates -precipitation coat -adhering particles	-upturned plates -adhering particles -precipitation coat	-dish shaped concavity -conchoidal fractures -upturned plates -precipitation coat - high relief			-conchoidal fractures -some adhering particles

Table 7.1 (continued)

Sample	Power's Roundness	Well Rounded	Rounded	Sub-Rounded	Very Angular	Angular	Sub-Angular
9 (sandstone)	-the grains are generally subrounded to subangular		-precipitation coating -upturned plates -adhering particles	-upturned plates -adhering particles -precipitation coat -rounded breaks		-adhering particles -upturned plates -semiparallel steps -i.e. Fig.6.7	-conchoidal breaks -adhering particles -upturned plates

Fig. 7.1

Etching on a grain from the sandstone at Economy Point. Upturned plates are also clearly visible. 500 x mag. (Sample 2)

Fig. 7.2

Silica plastering on a grain from the sandstone at Economy Point. 1900 x mag. (Sample 2)

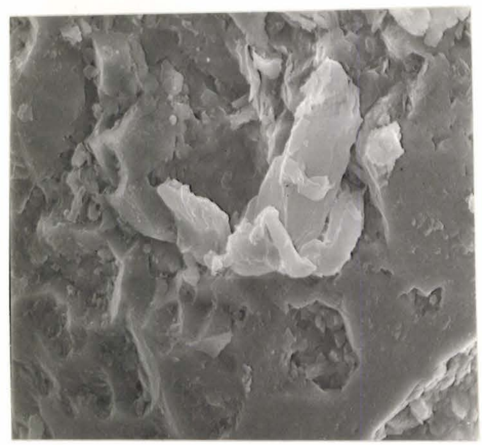


Fig. 7.3

Round adhering particles on a grain from the beach at Economy Point. 500 x mag. (Sample 6) Upturned plates and a Silica coat are also apparent.

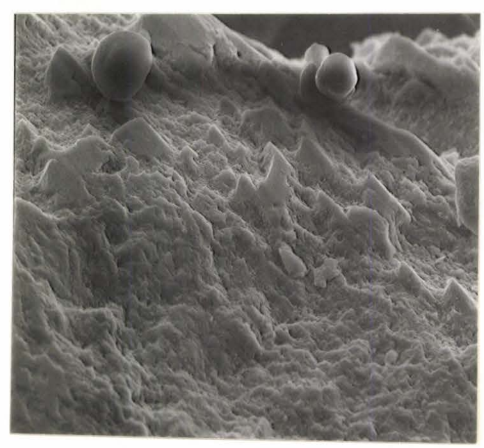


Fig. 7.4

Dish-shaped concavity on a sand grain from the beach at Cape Blomidon. 100 x mag. (Sample 3).

Fig. 7.5

Silica plastering on a sand grain from the beach at Burntcoat Head. 445 x mag. The silica coating has rounded the upturned plates (Sample 4).

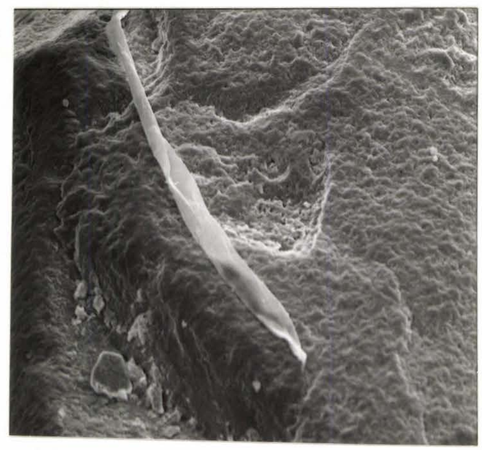


Fig. 7.6

A well rounded sand grain from the sandstone at Economy Point. 120 x mag. Upturned plates, a smoothed precipitation surface and adhering particles are all visible. (Sample 8).

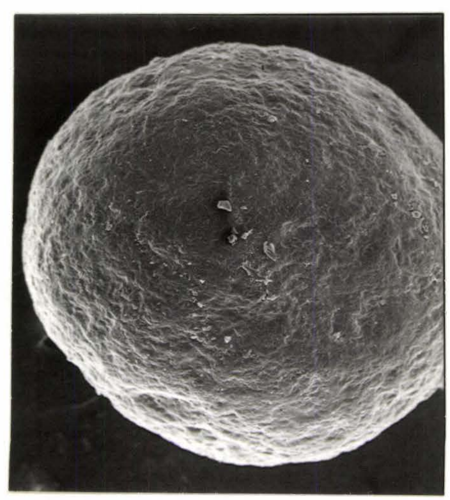


Fig. 7.7

A rounded sand grain from the beach at Burntcoat Head. The small light coloured dots surrounding the upper concavity are probably a feature resulting from the carbon and gold-palladium coating. They are not adhering particles. 94 x mag. (Sample 4).

DISCUSSION

From the results it may be noted that a great variety of grain shapes exist in the samples. The angular ones have evidently originated in an environment where the frequency of collisions was high. They are relatively immature grains, that is they have not had a chance to become reworked by either wind or water. In Krinley's terms they are glacial. However, they originated from the Triassic, which was a warm, lacustrine environment (Klein, 1962). Therefore, a glacial origin may definitely be ruled out. These angular grains did show evidence of diagenesis with a precipitation coating, and adhering, or plastering, of silica particles. Features such as non-oriented V-shaped indentations, sharp breaks, conchoidal fractures, arc-shaped steps and semi-parallel steps indicate a high degree of mechanical abrasion. The mechanical abrasion occurred prior to the diagenesis, in most cases, as the precipitation coating tends to round the features to some degree. The degree of diagenesis which affected the grain naturally varied.

The rounded grains have been produced, in most cases, by the action of water. In general they possess such features as upturned plates, a mechanical non-oriented V-shaped pattern, rounded breaks, a precipitation coat, and a plastering of silica to the surface. Again, a period of diagenesis, after the surface features were formed, is indicated. The precipitation coat is fairly heavy in most cases, and may either obscure the pre-existing surface, or build on it forming a high relief. The conchoidal breaks and mechanical V-shaped pattern are the result of high velocity collisions in an aqueous medium.

The two sandstone samples (numbers 2 and 9) are similar to each other. Their grains are either rounded, subrounded, angular or subangular. Upturned plates, a precipitation coat and adhering particles are common to most grains. Therefore diagenesis is evident to some degree. The angular grains illustrate conchoidal fractures.

The six beach samples are again roughly similar to each other. They illustrate the general features described above for rounded and angular grains. Etching was found on a subangular grain from sample 2 (Fig. 7.1). According to Margolis (1968) etching is achieved in solution where the pH exceeds 9.0. These conditions occur in an intertidal region where the sea water is evaporated on the grain's surface (Margolis, 1968). As the study area is intertidal, and sea water has a fairly highly pH level (8.2), these conditions are credible.

Wehrfritz (1973) studied quartz sand grains from an intertidal sand bar, in the Minas Basin, to make a check on Balazs and Klein's (1972) theory that sand grains from intertidal sand bars in the same area, show well developed rounding. He concluded that mechanical abrasion, solution abrasion and silica redeposition are three possible rounding processes in an intertidal environment. He noticed a pattern: the rounder the grain the greater the frequency of V-shapes and the less the frequency of glacial features. Wehrfritz concluded that Klein's theory was valid, grains are considerably rounded by intertidal processes. However, he suggested that the rounding may be inherited, as rounded grains, due to their smoother surface, would adopt intertidal textures with greater ease than angular grains.

Although, only one bar sample was studied in this project (Sample 5), the results are in agreement with Wehrfritz (1973). The majority of grains were round. A precipitation coat, upturned plates and V-shaped pattern predominated. The angular grains illustrated some V-shaped areas, conchoidal and uneven breaks.

Brisbin (1974) compared intertidal sands and Pleistocene source material sands to test Balazs and Klein's (1972) theory of grain rounding. He concluded that intertidal sands were more rounded than the Pleistocene sands. He found, as Wehrfritz did, that the greater the rounding in the intertidal sands, the fewer the glacial features. Therefore, the intertidal sand bodies are in equilibrium, rounding the grains while obliterating any glacial surface textures previously present.

In early 1978 Hampton, Bouma and Torresan published the first paper on the analysis of quartz sand microtextures from a tidal estuary in Alaska. Their observations were, in some respects, very similar to those in this study. In general they found that the resulting surface textures of the grains were due to some combination of glacial, mechanical impact, and chemical solution or precipitation action. The glacial grains are highly angular and illustrate a high surface relief, varying sizes of conchoidal fractures, parallel and subparallel steps, upturned plates and flat cleavage faces. Mechanical impact between the grains results in rounded edges, V-shaped patterns, breakage features and upturned plates. Chemical action results in both precipitation and solution forms. The resulting surface may be either smooth or rough, pitted or etched (Hampton, Bouma and Torresan, 1978). According to Krinsley's classification scheme, the grains studied by Hampton et.al. (1978) fall nicely into the glacial category.

In this study, although many of the angular grains illustrate typical "glacial" features, they have not had a glacial origin. Instead they are more likely the result of mechanical and solution abrasion. Gees (1969) suggested that solution abrasion was an important force in disordering the surface layer of quartz grains along with grain impact. This soluble, weakened layer is then hydrated by sea water (Gees, 1969; Margolis, 1968).

Two possible hypotheses may be inferred from the data regarding the nature of the high tide level beach grains; 1) the grains are continually being rounded and modified by intertidal abrasion, as suggested by Klein (1962), or 2) the grains have interited their rounded nature.

Hypothesis 1 is suggested by the fact that the majority of angular grains show rounded features. However, the angular grains also illustrate a diagenetic precipitation coat which aids in the rounding process. Therefore, this hypothesis is not in all cases true.

Hypothesis 2 is suggested by the fact that the majority of grains have adopted the intertidal surface textures on top of their pre-existing ones. A precipitation coat has also modified the original surface. But, in most cases, the primary surface may be visible.

The Triassic sandstones were deposited in a lacustrine or alluvial fan environment (Klein, 1962), as mentioned earlier. Due to the nature of this environment, the grains are possibly multi-cycle and may have been subject to aeolian activity at one time. Although no relict aeolian features were visible on the grains, it may be possible that the rounded grains originated during aeolian transport, followed by reworking in lakes. The angular grains in the Triassic are possibly also due to high velocity impact during aeolian grain contact. After the grains were deposited in the shallow lacustrine environment, they experienced diagenesis.

CONCLUSIONS

1. The sand grains from the Minas Basin - Cobequid Bay area, both high beach and sandstones, are the result of fluvial, mechanical impact, and chemical solution or precipitation forces.

2. The beach samples are better rounded and have heavier precipitation coats than their sandstone counterparts. They have had the opportunity to become exposed to the action of the water for a longer period of time than the sandstone grains.

3. The main characteristics of the Triassic sandstones are: round, subrounded, angular or subangular grains; upturned plates, diagenesis in the form of a precipitation coat and adhering particles; few conchoidal fractures.

4. The main characteristics of the high beach samples are: diagenesis in the form of a precipitation coat and adhering particles; V-shaped patterns; sharp and rounded breaks, conchoidal fractures; arc-shaped steps; semi-parallel steps; and upturned plates.

5. Although glacial-type features exist in the high beach samples it is believed they are due to high velocity impact during grain collision rather than glacial action.

6. The high beach samples were inherited from the Triassic sandstones. Their features are primarily the same but have naturally been reworked by the intertidal waters.

7. Balazs and Klein's (1962) theory holds true. The intertidal sands illustrate extensive reworking of the initial surface features.

8. The Triassic deposition in a lacustrine environment is clearly demonstrated on the grains, and is carried with them into the intertidal regions.

9. It would have to be totally wrong to follow Krinsley et.al.'s environments and corresponding characteristic features. If such had been done the conclusion would have been an initial glacier or glacial-fluvial environment!

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