THE DEVELOPMENT OF STRATIFICATION IN VEGETATED COASTAL SAND DUNES, SABLE ISLAND, NOVA SCOTIA.

By

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ABSTRACT

Sable Island is the emergent portion of Sable Island Bank, located on the edge of the continental shelf about 200 km from the mainland. The island is made up of wide, flat beaches, overwashed spits, brackish and freshwater ponds and vegetated and unvegetated sand dunes. The dunes are organized into a fairly continuous north ridge which is punctuated by blowouts and a less continuous south ridge which ring the island's main body and are vegetated predominantly with Ammophila breviligulata and a variety of woody species of the Shrub Heath community. The spits are covered with low hummock dunes vegetated primarily with Honkenya peploides.

A description of the stratification within the dunes provides a basis for an interpretation of the processes operating throughout their history. Particular importance is attached to the role of vegetation because each plant community has an associated set of structures which are the signature of deposition within, around, and in the lee of that group of plants. These sedimentologic signatures are combined to create a sequence which describes the history of deposition in the dunes. Distinct sequences are presented for morphologically different dunes.

There are two types of foredunes, which develop in place, that have their own sequence of sedimentologic signatures. Three types of dunes develop from the migration of dune ridges over an area. Of particular importance on Sable Island are the parabolic dunes which move through the

body of the island on a west-northwest to east-southeast axis. The structures in the dunes can be used to help explain the surface morphology.

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CHAPTER 1

INTRODUCTION

1.1 Aims of the Research

The primary goal of this thesis is to examine and analyze the morphology, internal structures, and sedimentary processes of vegetated dunes on Sable Island, Nova Scotia. The wider goal is to contribute to the body of knowledge of modern dune systems in order to develop facies models for vegetated coastal dunes, in particular, and sand dunes in general. This research also aims to investigate other aspects of aeolian sedimentation in coastal settings and to investigate the effect of different vegetation types and densities on aeolian transport, deposition and stratification.
The work is based on the hypothesis that it is possible to define a number of coastal dune types in which external morphology and internal structure are consistently the same. This suggests that it should be possible to make inferences about the original dune morphology from the stratification types and sequences within remnant dunes.

Facies models can be defined as a cyclical repetition of lithological, structural and organic aspects of a deposit which are detectable in the field and which will ultimately be given environmental interpretation (from de Raaf in Blatt et al. 1980). According to Walker (1984) they link modern and ancient environments and can be expressed as idealized facies sequences (block diagrams and vertical columns), graphs, and equations. He defined a facies model as a general summary of a specific environment, written in terms that make the summary useable in four ways. It must act as a norm for comparison, as a framework and guide for future reference, as a predictor in new geologic situations, and as a basis for interpretation of the environment or system it represents.

The thesis provides descriptions and genetic interpretations of the internal structure of the various types of dunes present on Sable Island which have developed under a range of vegetation conditions. These data are used to construct an idealized sequence of internal structures, which may be representative of vegetated coastal dunes in the broader, cool-temperate setting of northeast North America and Europe.

1.2 Present Form Of Sable Island

Sable Island was selected for the study because it has a relatively continuous, scarped dune ridge along the north shore and a less continuous ridge along the south shore of the island, both of which provide abundant natural exposures of the internal structures of vegetated dunes. There is also a wide range of sand sizes on the island and abundant heavy minerals which make it easier to differentiate between stratification units. The existence of a paleosol within some sections of the dunes also aids in the recognition of different phases of sedimentation. There have been many studies of the geology and sea level history (Medioli et al. 1967, James and Stanley 1968, Austin and Howie 1973, Stanley et al. 1973, Scott et al. 1984, Hoogendoorn and Dalrymple 1986, King and Fader 1986, Hoogendoorn 1989). A summary of these is contained in Appendix I.

The island exists as a crescent of sand on the outer portion of the Scotian Shelf (Fig. 1.1). Almost half of the surface is made up of unvegetated fine to medium-sand with heavy minerals. There is also some coarse to granule sized material and a scattering of cobbles which were once the ballast of ships which were wrecked off the shore. Wallace Lake occupies the south-central portion of the island. This brackish water body is separated from the ocean by a narrow barrier which is breached by storm waves. The vegetated portion of the island consists of sand dunes with a low species diversity, and the pond fringes where vegetation diversity is greatest.

The island consists of four physiographic parts: 1. the west spit, 6.4 km long and 300 m wide with an average elevation of 1.5 m.a.s.l; 2. the 17 km long, 300 m to 1.2 km wide, main body of the island which has 4 zones - a narrow north beach; a 24-26 m high northern dune ridge which is punctuated by blowouts; a central undulating zone of ericaceous heath, grass and sedge meadows, and fresh and brackish water ponds; and, a 9 to 12 m high southern dune ridge; 3. the wide, flat beaches on the south shore and the Wallace Lake sand flats which have developed over the last 150 years possibly as a result of

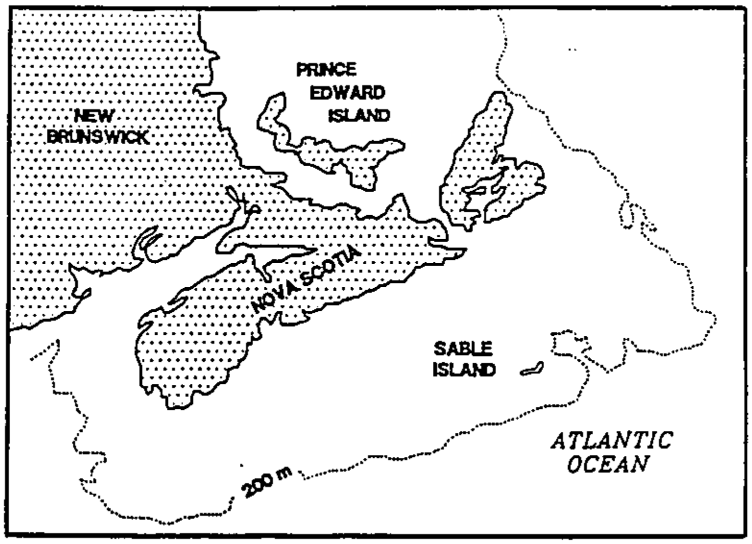


FIGURE 1.1. Sable Island is located on the edge of the continental shelf, about 198 km east of Halifax. Notice the location of a submarine canyon, The Gully, east of the island.

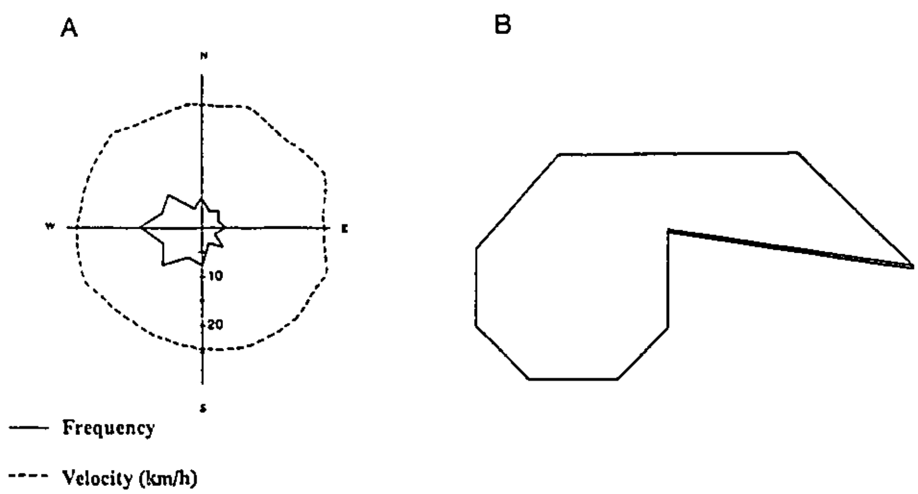


FIGURE 1.2. A: The wind rose for Sable Island. Frequency is shown in the inner line and velocity in the outer. The most frequent winds are from the west, while the strongest winds blow from all directions. B: Vector resultant for Sable Island. The resultant wind direction is shown by a double line.

lagoon infilling (Terasmae and Mott 1971, Hennigar 1984); and, 4. the east spit, 6 km long and 300 metres wide and varies in elevation from 1.5 to 3 metres. The two spits provide little area for vegetation development other than that of Honkenya peploides because they are subject to washover.

Dune types include low discontinuous mounds of sand deposited around Honkenya peploides on the terminal spits, incipient foredunes vegetated primarily with Ammophila breviligulata, and the established dune ridges which can be separated into north and south dunelines. The north duneline is nearly continuous along the north shore of the island except for areas in which blowouts have penetrated the ridge. The south dune line is much less continuous, being absent from the area to the south of Wallace Lake, and dissected by numerous large blowouts on the east end. A more specific morphological discussion will be presented in Chapter 3.

1.3 Vegetation

Freedman et.al (1981) described the vegetation of Sable Island, recognizing six terrestrial plant communities (Table 1.1). The first community, Sandwort, covers about 6% of the island in very exposed locations on the extreme ends (the spits). The dominant species in this community is Honkenya peploides. The second plant community is the Dense Marram community which covers about 8.7% of the island and occurs along the oceanic edges of vegetated terrain. The dominant species include Ammophila

SANDWORT	DENSE MARRAM	SPARSE MARRAM	SHRUB HEATH	
Ammophila breviligula	Achillea lanulosa	Achillea lanulosa	Achillea lanulosa	Myrica pensylvanica
Cakile edentula	Agropyron repens	Ammophila breviligulata	Ammophila	Plantago lanceolata
Honkenya peploides	Ammophila breviligulata	Anaphalis margaritacea	breviligulata	Platanthera lacera
Solidago sempervirens	Cakile edentula	Cakile edentula	Anaphalis margaritacea	Platanthera viridus
	Honkenya peploides	Festuca rubra	Anthoxanthum	Poa pretensis
	Lathyrus maritimus	Honkenya peploides	oderatum	Potentilla tridentata
	Rosa virginiana	Lathyrus maritimus	Arenaria laterifolia	Prenanthes trifoliolata
	Solidago sempervirens	Myrica pensylvanica	Aronia prunifolia	Rhinanthus crista-galli
		Poa pretensis	Aster novi-belgii	Rosa virginiana
		Rosa virginiana	Calluna vulgaris	Rubus hispidus
		Solidago sempervirens	Carex montanae	Rumex acetocella
			Carex silicea	Sisyrinchium angust.
			Cerastium vulgatum	Smilacina stellata
			Coptis trifolia	Solidago sempervirens
			Danthonia spicata	Spartina pectinata
			Empetrum nigrum	Spiranthes romanzoff.
			Euphrasia americana	Thalictrum polyganum
			Festuca rubra	Trientalis borealis
			Fragaria vesca	Trifolium repens
			Gnaphalium obtusata	Vaccinium angustif.
			Hieracium pilosata	Vaccinium macrocarp.
			Hieracium scabrum	Viburnum cassinoides
			Juncus balticus	Viola lanceolata
			Juniperus communis	Viola septentrionalis
			Leontodon autumnalis	
			Linnaea borealis	
			Luzula campestris	
			Lycopus uniflorus	
			Mitchella repens	

TABLE 1.1. Plant communities on Sable Island (From Freedman et al. 1981).

breviligulata, Lathyrus maritimus, Achillea lanulosa, and some Solidago sempervirens.

The third community is the Sparse Grasslands which is made up of the Sparse Marram community and the Marram Fescue community. This group covers about 22.5% of the island and is found where new dunes develop. The dominant species in the Sparse Marram community is Ammophila breviligulata, but there is also an important contribution by species such as Lathyrus maritimus and Solidago sempervirens. The Sparse Marram community is the first to establish on new dunes and may later be replaced by the Dense Marram type of vegetation. If an area remains stable over a longer time period, then the Marram Fescue community may develop. The dominant species within the Sparse Grasslands are Ammophila breviligulata and Festuca rubra, with other important species being Fragaria vesca, Achillea lanulosa, Rosa virginiana, Anaphalis margaritacea, Myrica pensylvanica, and Rumex acetosella. The Sparse Grasslands Community are combined in this thesis as the Sparse Marram Community.

The fourth community is the Shrub Heath community, covering about 4.3% of the interior locations of the island with the most important species being Empetrum nigrum, Juniperus communis, Myrica pensylvanica, Rosa virginiana, Vaccinium angustifolium and Calluna vulgaris. Associated with the Shrub Heath community is the Cranberry Heath, which is found in the intermittently wet areas in the interior of the island. It is made up of

Vaccinium macrocarpon, Juncus balticus, Myrica pensylvanica, Aster novi-belgii, Viola lanceolata and Calopogon pulchellus.

The fifth community consists of the Freshwater Pools and Borders, which are heterogeneous in composition and distribution at each pool. The sixth community is the Brackish Ponds. Both are the surface exposures of the large rainwater-fed freshwater lens that underlies Sable Island (Hennigar 1970). The wetland vegetation in this community changes transitionally to the Cranberry Heath as one moves from areas which are wet for long periods of time to areas which are wet for shorter periods. Changes in the type and abundance of plants are related to the following; 1) salinity; 2) abundance of moisture and length of periods of inundation; and, 3) variations in the use of pools by horses, gulls and terns. Together Freshwater Pools and Borders and Brackish Ponds cover about 3.0% of the island's surface.

1.4 The Wind Regime

In examining the changes in the winds over time for Sable Island, a number of factors must be considered. First the prevailing wind direction - the direction winds most commonly blow from - must be determined. These are usually not the strongest winds, but their frequency greatly influences the morphology of the dunes. Secondly, the strongest or dominant wind directions must be considered. Although these lower frequency winds do not affect the morphology on a day to day basis, they can be responsible for marked changes in the system which occur over the length of the wind event. Finally, the winds must be analyzed to determine the direction with the most effective sand moving capabilities. This analysis includes a calculation of the wind vector magnitudes for 8 compass directions and the determination of the resultant vector (Appendix II).

An analysis of the winds from 16 compass points for Sable Island shows that there is great variability in frequency of wind from different directions, but little variability in the strength of the wind. The rose diagram (Fig. 1.2A) indicates that the winds are always strong on Sable Island with an average velocity for all winds from all directions of 25.7 kmh^{-1}.

The analysis of the yearly winds shows that the prevailing winds range between south and northwest and account for 61% of the winds. Average velocity for these winds is 25.6 kmh^{-1}. The most frequent winds are from the west followed by the southwest and then the northwest. These account for 31.8% of the winds. The mean velocities for these directions are 25.6, 24.5, and 26.3 kmh^{-1} respectively. Winds from the southwest are slightly more gentle than those from the northwest and west.

The strongest (highest velocity) winds are from the east-southeast at 27.5 kmh^{-1}. These are the least frequent winds blowing for only 3.4 % of the time. The next strongest winds are from the west-southwest (27.1 kmh^{-1}) and then the west-northwest (26.7 kmh^{-1}). These are the fourth (8.2 %) and sixth (6.9 %) most frequent winds respectively (Tables 1.2 and 1.3). Therefore, on

TABLE 1.2. MEAN FREQUENCY
OF WINDS ON SABLE ISLAND, NOVA SCOTIA
1955-1980

DIR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	FOR THE YEAR
N	5.3	6.9	7.9	6.7	5.4	4.2	2.6	3.7	6.1	6.3	6.3	6.2	5.6
NNE	2.9	3.6	5.2	4.4	3.6	3.0	1.7	2.6	4.5	4.5	3.7	3.4	3.6
NE	3.6	3.5	6.8	5.5	5.6	4.3	2.5	3.7	5.9	4.2	4.7	3.8	4.5
ENE	2.9	3.1	3.7	3.6	4.5	3.1	2.0	2.5	3.9	2.1	3.8	2.3	3.1
E	5.8	5.4	4.9	6.5	4.6	3.7	2.[illegible]	2.9	4.7	4.1	5.1	5.1	4.6
ESE	2.9	3.4	3.3	4.2	3.7	3.9	2.8	2.9	3.2	3.4	3.0	3.7	3.4
SE	4.2	4.4	4.8	5.4	5.5	5.4	5.6	5.2	5.0	6.1	6.4	5.8	5.3
SSE	2.7	2.5	3.0	3.0	4.0	4.5	5.4	4.2	4.6	3.9	4.6	3.7	3.8
S	5.0	4.5	5.3	5.4	9.5	11.4	14.2	9.6	7.3	7.5	7.0	4.9	7.6
SSW	3.6	2.8	4.0	5.2	8.2	11.8	13.4	10.4	6.3	4.8	4.4	3.3	6.5
SW	5.7	5.7	6.6	10.0	12.6	19.0	22.8	18.9	11.7	8.0	6.4	5.2	11.1
WSW	6.0	6.9	7.0	8.4	8.5	8.9	10.0	12.4	9.2	8.7	5.9	6.0	8.2
W	17.2	17.1	12.7	10.9	9.4	6.6	6.4	9.5	10.9	13.9	13.7	17.2	12.1
WNW	12.1	11.1	7.6	5.7	4.8	3.1	2.4	3.4	4.9	7.1	9.0	11.6	6.9
NW	14.2	12.9	11.0	9.0	6.2	4.0	3.2	4.2	6.8	9.5	10.5	11.7	8.6
NNW	5.1	5.6	5.6	5.4	3.4	2.4	1.4	2.8	4.3	5.5	4.9	5.4	4.3
CALM	0.8	0.6	0.6	0.7	0.5	0.7	1.1	1.1	0.7	0.9	0.6	0.7	0.8

TABLE 1.3. MEAN VELOCITY OF WINDS ON SABLE ISLAND, NOVA SCOTIA 1955-1980

DIR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	MEAN VELOCITY
N	29.1	28.1	29.5	24.0	22.5	17.4	15.2	19.6	22.5	27.7	29.6	28.6	24.5
NNE	29.4	29.5	30.2	26.1	23.0	19.6	15.9	20.1	23.6	27.5	31.3	29.4	25.5
NE	30.6	27.0	31.4	26.7	20.9	18.1	18.9	19.2	21.1	23.6	29.1	29.4	24.7
ENE	33.2	33.4	29.0	25.3	24.2	21.1	19.8	21.8	19.7	24.4	28.6	25.8	25.5
E	28.5	28.8	31.8	30.2	25.7	22.8	20.3	18.0	18.5	21.0	27.7	26.5	25.0
ESE	33.7	35.0	33.4	28.6	25.8	22.1	20.7	18.8	21.3	26.7	29.9	33.9	27.5
SE	33.2	31.5	28.7	27.0	24.0	20.6	18.1	17.7	20.1	26.7	29.3	31.8	25.7
SSE	32.0	31.1	26.8	24.5	22.2	21.5	19.7	18.8	21.5	25.1	31.7	30.9	25.5
S	30.9	28.7	26.6	23.9	22.5	21.1	19.2	19.4	22.0	25.0	28.8	28.7	24.7
SSW	29.2	27.1	26.0	25.8	23.4	21.3	19.4	19.6	22.7	24.6	25.1	28.6	24.4
SW	29.2	28.0	27.7	25.1	22.7	21.1	19.4	19.3	21.8	23.5	26.7	29.5	24.5
WSW	33.3	33.2	32.4	27.0	23.8	21.3	19.1	20.5	22.0	26.7	30.5	34.9	27.1
W	33.6	31.9	31.3	26.4	22.9	18.3	16.7	17.5	20.2	25.6	28.9	33.6	25.6
WNW	34.0	33.2	33.4	27.3	23.8	18.5	15.6	17.7	23.4	28.1	31.6	34.1	26.7
NW	34.3	32.8	31.0	27.0	23.7	17.6	14.9	17.7	23.9	28.4	31.4	32.8	26.3
NNW	32.3	31.0	28.9	27.2	23.9	18.4	16.1	19.1	23.7	28.7	31.4	31.3	26.0

Mean Wind Velocity (for all directions) = 25.575 km/h

Sable Island, the strongest winds blow for a significant part of the year.

The resultant was calculated using the formula of Jennings (1957) adapted from Landsberg (1956) and Bagnold (1941). The vector diagram (Fig. 1.2B) shows that using all directions the resultant is toward 99° east of north, or blowing from 279° east of north. These are the most effective sand carrying winds. Thus these winds carry the sediment from the west end of the Island toward the east-south-east. This is also the average orientation of the blowouts on the north shore of the island.

1.5 Methods

To examine the structures and stratification within the dunes in three dimensional view, a series of pits were dug into the wind scoured vertical faces and large areas of these faces were cleared. The size of the pits and cleared faces depended upon the local stability of the sand. In some cases, the dunes were very stable and large pits and cleared faces could be examined. In other areas, the dunes were not stable due to variations in moisture, amount and type of vegetation and texture of the sand. In these sites smaller cleared sections were examined. In some instances, the dune slumped or collapsed before the cleared section could be logged.

In the more stable dunes the pits were usually 0.5 to 1 m square with a larger area around them cleared. Sections were examined immediately following clearing, when the sand was still moist, and then again when it had dried, and differences in grain size and packing could more easily be seen. Lateral variability of the stratification in each section was determined by cutting small trenches and faces adjacent to the main ones.

In some dunes it was difficult to determine the entire sequence because of the instability of the sand. Collapse occurred frequently on the cut faces before recording of the structures was completed. Thus there is not a full record of the structures of every dune examined.

In order to document the relationship between the plants and physical structures, the elements of stratification in the prepared natural sections were described. The basic types of aeolian stratification were defined and given a genetic interpretation, using the concepts outlined by Hunter (1977 a,b). The descriptive code established in Byrne and McCann (1990) was modified and is presented in Figure 1.3. This code was used to condense the large amount of information present in a natural section down to a more workable sequence which described the structures and strata associated with different vegetation covers.

Descriptive summaries of 18 specific sites in simple dunes, selected to show the main elements of the vegetational effects on deposition, are presented in the sedimentologic signatures in Chapter 4. They are illustrated in a descriptive fashion in order to portray the remnants of vegetation, grainsize and nature of the stratification at each site under the specific plant communities. Each sedimentologic signature portrays the sequence one would

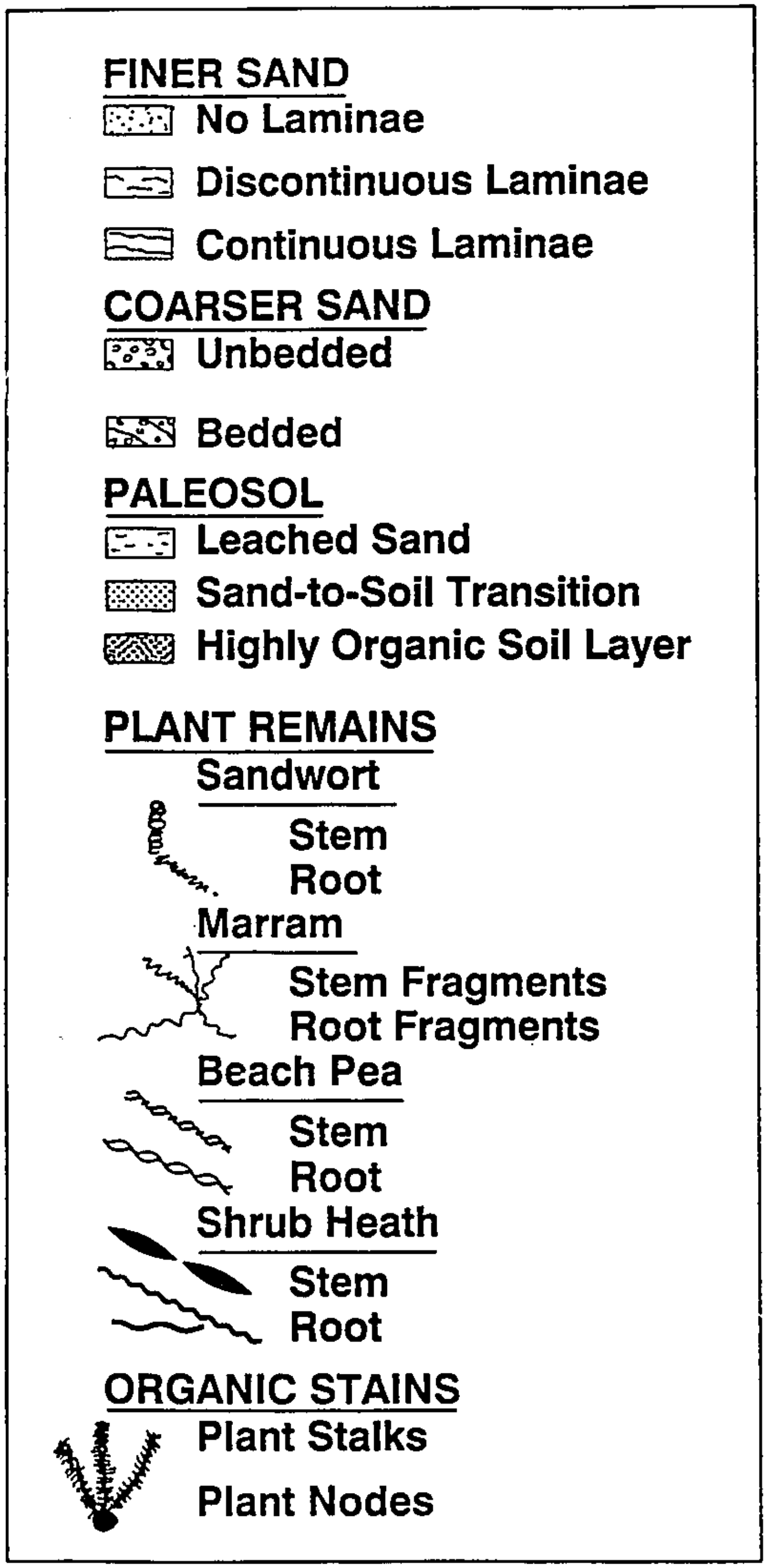


FIGURE 1.3. The descriptive code used to document structures in the dunes on Sable Island. The code accounts for both physical and biological aspects of the sand dunes.

expect to find below the plant community for which it is named and can be considered a facies for that community. Descriptive summaries of 19 larger sections in larger and/or more complex dunes, selected to show the overall structure of the dunes at each location, are presented in Chapters 5 and 6. The descriptions are followed by genetic interpretations of the mode of deposition of the different sedimentary units which can be identified as facies, and of the evolution of the dune.

Chapter 7 presents the sequences of structures which are present in secondary depositional features, shadow dunes, aprons and ramps. Chapter 8 presents a model which illustrates the deposition of the dunes of Sable Island in conjunction with the growth of vegetation. Also presented in this chapter is a discussion of the contribution of this work to coastal sand dune facies models. Chapter 9 lists the conclusions of the work.

CHAPTER 2

PREVIOUS WORK

2.1 Introduction

The literature dealing with the development and internal structure of sand dunes is varied and there is a large amount of information so this chapter will be selective. Topics covered are dune morphology and classification, aeolian stratification, the internal structure of sand dunes, and finally, aeolian facies models. The initiation of movement and sand transport are outlined in Appendix IV.

2.2 Morphology and Classification of Sand Dunes

2.2.1 General

Because coastal dunes are a subset of sand dunes, it is best to discuss sand dunes in general before discussing the coastal features. Aeolian dunes are found in a number of environments such as deserts, along rivers and on coasts. Wilson (1972) recognized four groups of aeolian bedforms existing in a continuum at all scales from larger dunes to smaller ripples. He identified these as draas, dunes, aerodynamic ripples and impact ripples. Draas are the very large sand bodies (wavelength of .5 to 5 km) found in sand seas or ergs.

These often have dunes (wavelength 10 to 500 m) superimposed upon them. McKee (1979) called them composite or star dunes. Their morphology will be discussed later. Aerodynamic ripples are long forms with low height to length ratios. Impact ripples can be either sand ripples or granule ripples which form under the impact of sand grains in saltation. Their wavelength is 0.01 to 10 m. Wilson stated that bedforms arise spontaneously by the interaction between surface form and airflow involving piecemeal material transfer between them. They grow until they reach a dynamic equilibrium and are simultaneously occurring and independent forms. Dune forms can be simple or very complex. The shape of the sand body is determined by the depositional environment. McKee (1979) has examined the growth and development of dunes and separated them into groups thus developing a classification. Simple dune types are a reflection of the following: wind strength, duration and direction; sand supply; vegetation; physical barriers; and the distance of the deposit from the source of the sediment. Various combinations of the factors are responsible for the development of different dune types (McKee 1979). A simple dune may be classified partly on its form and partly on the number of slipfaces which develop as a reflection of the above.

Simple dunes tend to form perpendicular to winds which have a single dominant direction. Some of the simple forms of dunes are: the crescent-shaped barchan dune which forms in areas with a limited supply of sand; barchanoid ridges which are rows of coalesced barchans that form in areas of less limited supply; and, transverse dunes which have parallel straight edges and form where sand supply is abundant. All of these have slipfaces in one direction and are representative of unidirectional winds. The three types occur in sequence downwind as supply decreases. Transverse dunes attain their maximum height at a balance between wind strength and sand supply (McKee 1979).

McKee (1979) identified another type of simple aeolian feature. These have no slipfaces and include sand sheets and stringers or streaks. These are not considered dunes because they are not mounds or ridges. They are, however, often found in desert areas. Other features which have no slipface are dome dunes. They are circular or elliptical in plan and may have internal slipfaces which indicate that they began as barchans which were subsequently bevelled off by high winds. Parabolic dunes and blowouts are dunes whose form is controlled by vegetation and moisture. They may have slipfaces sloping in one or more directions depending on the area of the dune which is free to migrate; the area not tied by vegetation. Their form depends more upon deflation than deposition.

The larger features described by McKee (1979) included the following dune types. Linear dunes, which are called seif dunes in Africa and Saudi Arabia, and longitudinal dunes elsewhere, are long straight ridges with slipfaces on both sides and are thought to develop in areas with bi-directional winds. Star dunes, which have multiple slipfaces, develop in areas which have a number of different wind directions. They have a high peak with three or more arms and grow vertically rather than laterally. Reversing dunes are those dunes which develop where two opposing winds have a balance of strength and direction. They may appear to be transverse ridges with a second slipface which develops from time to time directly opposite to the primary slipface.

Compound dunes are abundant in sand seas. McKee (1979) described them as two or more of the same type of dune which overlap or superimpose upon themselves. Examples of compound dunes include coalescing barchanoid ridges, coalesced star dunes with a pattern of arms and peaks, smaller barchan dunes superimposed on the flanks of the larger ones, small parabolic dunes between the arms of the larger ones, and major ridges covered by smaller linear dunes.

McKee (1979) identified complex dunes as two basically different types of dunes which grow together. Examples of such would include linear dunes in rows with stars on their crests. He called these chains of stars or strings of beads. Other examples of compound dunes would be small barchans in between linear dunes, blowouts on transverse dunes, and star dunes with superimposed barchanoid forms.

This classification is by no means exhaustive. There is a great variety of forms which have not been discussed. However, the basic forms have been described. Other types would represent a transition from one type to the next and would be the result of a change in the direction of the wind or variations in the supply of sand or a change in the physical obstruction around which the dune developed.

2.2.2 Coastal Dunes

Coastal dune morphology is influenced by the amount of sand available in an area; by the wind speed, duration, and direction; by vegetation; by tidal range; and, by the physiographic setting. These factors are reviewed by Goldsmith (1985) and Pye (1984).

Goldsmith (1985) suggested that there is no simple relationship between the distribution of wind velocity and dune development. The dominant or high velocity winds may move more sand per unit time than the lower velocity more frequent prevailing winds, but because prevailing winds occur for a greater period of time, they are more important. The orientation of the shoreline to the winds is also very important. The most efficient dune forming environments are those in which the shoreline is normal to the prevailing winds.

Vegetated dunes are the most common type of coastal aeolian structure in temperate areas. They are usually ridges of vegetated sand with flat to undulating upper surfaces and continuous, but irregular crests. The ridges are often interrupted by blowouts and washover passages. They may be stabilized parabolic dunes in a series of parallel ridges reflecting the accretional history of the area (Goldsmith 1985).

Goldsmith (1985) classified dunes using a genetic classification; a scheme to categorize dunes on the basis of development rather than form. The classification described vegetated, artificially induced, medanos, and parabolic dunes. Vegetated dunes are fixed in place. They develop around obstacles and are anchored by different types of vegetation. These usually have long elaborate root systems and rhizomes which grow along the surface. They greatly stabilize the dunes. Transverse dune ridges have no vegetation, but may be associated with vegetation. Precipitation ridges are those dunes which deposit sand in front of or migrate over any vegetation which may be in their way. The name is derived from the process of sand raining down. They are associated with tall vegetation at the downwind end of exposed sand. Medanos are high, steep, isolated sandhills. The wind moves sand up toward the summit from several directions. Goldsmith (1985) stated that they are distinctive to the coastal zone. According to Goldsmith parabolic dunes form behind them. The parabolic dunes have a slipface on the downwind, convex side and are open to the upwind direction. They otherwise resemble vegetated dunes.

Pye (1984) discussed the morphology of dunes in another manner. His classification was based on movement. Thus those dunes which were fixed in place by vegetation were called impeded dunes. These include shadow dunes and foredune ridges whose height depends upon wind energy and the rate of coastal progradation. These ridges are rarely very well developed on erosional coasts. Impeded dunes also included sand platforms, non-transgressive transverse ridges, hillock dunes and crescentic dunes. Few of these are well described in the review. The second category of dunes described by Pye (1984) were transgressive dunes which consists of those dunes which were not anchored. They are free to migrate inland. These transgressive dunes include barchans, transverse ridges (precipitation ridges), transgressive sand sheets, parabolic dunes and oblique dunes. Large coastal parabolic dunes are also called retention dunes. The arms are fixed by vegetation while the bow is open to the wind. They develop on a generally stable surface with a good supply of sand and unidirectional winds. The sand concentrates its attack on one area forcing that area to migrate while the vegetation holds the arms of the dune in place.

Pye's classification and discussion are unsatisfactory lacking descriptions of the types of dunes he lists. There is a duplication in that transverse ridges are both transgressive and impeded. In Goldsmith's classification a number of dune types are overlooked and others, such as the artificially induced dunes are inadequately described. Medanos, although distinctive to the coastal zone, are not a feature common to all beaches. Parabolic dunes are a subset of vegetated dunes, even though they are dependent more on deflation than deposition.

Davies (1972) classification defines primary dunes, which are derived from beach sand directly, and secondary dunes, which are the result of the erosion of primary dunes. Primary dunes consist of free dunes, in which vegetation is unimportant and impeded dunes in which vegetation is critical to their development. Free dunes are wind oriented and impeded dunes tend to be parallel to the rear of the source beach. Secondary dunes consist of transgressive dunes which develop normal to the constructing winds and remnant dunes which are the eroded remnants of vegetated primary dunes.

Primary free dunes develop along desert coasts, in areas where there is not enough moisture, or where sand binding flora does not grow. The most common primary free dunes are barchan dunes. Transgressive dunes which form perpendicular to the wind and gradually migrate downwind are also characteristic primary dunes. Davies (1972) stated that precipitation dunes are transitional between free and impeded dunes.

Impeded primary dunes form as a result of the interaction of wind and vegetation. They are produced where there is a sufficient supply of sand and where vegetation is competent enough in relation to wind strength and sediment supply to bind the sand. Impeded dunes are typically foredunes or frontal dunes which lie parallel to the beach. They are also represented by frontal dunes, sand beach ridges, and dune platforms.

Short and Hesp (1982) present a morphodynamic classification of surfzones, beaches and dunes of the microtidal, low to high energy southeast Australia coast. They classify beaches as dissipative, intermediate or reflective, depending upon the amount of deep water wave energy reaching the shore (wave attenuation) and wave refraction. They discuss beach-dune interactions and foredune morphology, present a classification of wave, beach and dune interactions and suggest some variations. Their classification is based upon dunes and beaches in microtidal settings with medium to fine sand. The following paragraphs summarize their classification.

Modally dissipative beaches have high wave energy, wide surfzones with parallel bars and troughs, low gradient wide beaches with low mobility, minimum windflow disturbance, high potential aeolian sand transport, and potentially large foredunes. There is an abundance of sediment over time, which leads to dunefields of the greatest sediment volume and extent. Intermediate beaches have moderate wave energy, complex surfzones with complex three dimensional rhythmic topographies and varying rip systems. They represent a transition from dissipative to reflective beaches with a decrease in rip spacing and size, a decrease in surfzone width, a decrease in beach width and increased beach gradient. There is a decrease in the potential foredune size with the transition from dissipative to reflective beaches. Reflective beaches have low wave energy, minimum surfzone widths, high gradient, narrow, low mobility beaches with high windflow disturbance and small foredunes.

In this classification, Short and Hesp (1982) stated that exposure is an important variable in dune development, but it is not as important as beach morphology, gradient and width in determining the rate of landward sand transport. They also stated that potential dune size increases with decreasing sand size.

In summary, Short and Hesp (1982) classify coastal dunes on the basis of foredune morphology and stability which parallel beach morphology. As the beach becomes more perpendicular to the dominant onshore winds foredune stability increases and transgression decreases. The initiation of dune instability is due to the waves and not the wind. Dunes become larger on high energy beaches because these receive a greater supply of marine sand than those in lower energy environments. Globally, the largest foredunes exist in the lee of high energy dissipative-intermediate beaches exposed to onshore mid-latitude westerlies. Moderate dune development occurs on moderate energy intermediate beaches along east coast swell and trade wind environments. Low dunes develop in low wind velocities and on reflective beaches of the tropics and polar regions and all other regions.

This classification can be used to explain a number of dune types. However, it ignores the critical variable of vegetation which can change the morphology of a dune with a change in species or with a change in plant morphology.

2.3 Basic Types of Aeolian Stratification

Hunter (1977) stated that there are three main depositional processes at work in the aeolian environment, tractional deposition which results from grains creeping; grainfall deposition which results from the settling of grains out of suspension and saltation; and, grainflow deposition which is associated with slumping. Each produces a different type of stratification. These are ripple deposits, grainfall lamination, and sandflow cross- stratification. As well there is quasi- planar, wet depositional adhesion stratification (Hunter 1980). These structures are the building blocks from which, sometimes with the aid of vegetation, all dunes are built.

Aeolian stratification produced by tractional deposition is called either climbing translatent stratification or rippleform lamination. These laminae form when wind ripples migrate under net sedimentation conditions (Hunter 1977). Rippleform lamination develops as wavy layering parallel to successive rippled depositional surfaces whereas, climbing translatent stratification exists as even layering parallel to the vector of ripple climb.

As the angle of ripple climb changes from subcritical to supercritical, the basic structure of the ripple changes. Critical angle of climb is the angle at which the vector of the ripple climb is parallel to the ripple stoss slope. Subcritically climbing translatent stratification has a complete lack of ripple foreset cross-lamination. The angle of ripple climb can dip from as low as horizontal to as high as 35° (42° where salt crust and moisture enhance grain cohesion). Hunter stated that this type of stratification is usually thin (2 mm to 8 mm, the height of most wind ripples) unless formed under high wind conditions or in coarse grains. As the angle of climb decreases, stratification becomes so thin that individual strata are difficult to see. This type of stratification is laterally extensive compared to its thickness and so it is highly tabular. Contacts are erosional and consist of inversely graded grain sizes. This inverse grading is produced by shear sorting. There is close grain packing due to tractional deposition. Therefore the surfaces are firm, low in porosity, and low in permeability. They retain moisture longer than other deposits and so appear dark in many exposures (Hunter 1977).

Cross-lamination in subcritically climbing translatent stratification is rarely visible. It is seen only in very thick stratification which develops in coarse grain sizes or by strong winds or in stratification whose angle of ripple climb is close to critical. When it is visible it looks like complete rippleform cross-lamination except for the truncation of one ripple by the overriding one.

Hunter (1977) also discussed supercritical climbing translatent stratification. In this type of strata the angles of ripple climb are steeper than critical (6°). There are gradational contacts rather than the sharp contacts which develop in subcritically climbing stratification. There is normal grain size grading in the thin gradational contact zones. It is accompanied by rippleform lamination which makes the direction of ripple climb easily visible. The surface commonly dips more than 15°. This type of stratification generally develops in zones which are in transition from subcritically climbing translatent stratification to grainfall stratification. Most often the angle increases until the deposit is covered by grainfall lamination.

Hunter (1977) also outlined rippleform lamination. This type of stratification looks like wavy grainfall lamination or wavy planebed. It develops parallel to the rippled depositional surface. As the angle of ripple climb increases the steepness of the ripple decreases. The ripples disappear as the angle of climb becomes close to vertical. As the ripples flatten the lamination grades into grainfall lamination. Thus this type of laminae represents a transition from tractional deposition to grainfall deposition.

The second main type of aeolian stratification is grainfall lamination (Hunter 1977), which occurs as a result of the settling of previously saltating grains in the zones of flow separation at dune crests. At the brink of the slipface there is a zone of flow separation where the saltating grains lose momentum and fall onto the dune lee slope. This results in a smooth topography that is intermediately packed. Grainfall laminae form best on steep lee slopes where avalanching is not occurring. It is the result of any grain-by-grain deposition on surfaces where wind stress is too low for ripple growth.

The internal structure of grainfall lamination consists of parallel, tabular beds. There is little grain segregation because sorting occurs during transport and deposition, but not after. Contacts are gradational making it difficult to see actual sets. Grading within laminae is difficult to recognize because the laminae are very thin and there is poor grain segregation. Porosities of samples range from 38 to 42%.

The third type of aeolian lamination, sandflow cross stratification, is produced by avalanching. It is much like Reineck and Singh's (1980) encroachment deposits or Allen's (1970) avalanche or foreset laminae. This type of stratification originates mainly by two mechanisms. The first, slump degeneration, is the gradual loss of cohesion between grains in a moving slump sheet of low to negligible water content. It is common in unvegetated dunes. The loss of cohesion and resulting destruction of stratification that had existed occurs from the shear surface upward. If the nose of the avalanching mass has to travel a long distance before coming to rest, degeneration of the low water content slump mass is more likely. Thus if the slipface is large, slump degeneration is more likely to occur (Hunter 1977).

The second mechanism of sandflow cross stratification is scarp recession which begins as a very small flow anywhere on the slipface. The mechanism which causes this to happen in unknown. Sand falls away from the initial break-away-scarp which then recedes and fans out upslope. This process occurs rapidly. Unlike slump degeneration in which a sheet of sand loses cohesion, scarp recession occurs by the fall of grains one by one, or by the detachment of very small sand masses. Most often the scarp continues to recede until it reaches the top of the slipface (Hunter 1977).

Slumping may also occur. By this mechanism the sediment mass maintains cohesion while sliding downslope along a clearly defined shear surface. It is the simultaneous beginning of movement and loss of cohesion of a mass of sand above a shear surface. It is occasionally observed in unvegetated coastal dunes, but is more commonly seen in vegetated dunes. It is very rare in deserts. The observances in unvegetated coastal dunes may be due to the fact that sand grains encrusted in salt have more cohesion than those in desert dunes (Morton 1957, Hunter 1977).

There are distinctive structures produced by these processes. Scarp recession produces a depositional cone which abuts the base of the slipface and an erosional trough which extends from the base to the top of the slipface. A sandflow that begins at the top of the slipface is more likely to form a tongue of constant width rather than a cone. Whatever the shape, it forms a single cross stratum in the deposit of a migrating dune. This stratum which dips from 28 to 34°, has a very sharp, straight or nearly straight upper contact. The basal contact is sharp, but non-erosional except at higher levels where it is erosional, straight and dips at a slightly lower angle than the underlying strata. This difference in dip of the upper and lower contacts causes the stratum to thin upward to a feather edge. Strata appear as lenses in a horizontal exposure and are thicker than other types of aeolian cross strata. Internally, sandflow cross stratification is structureless or subtly graded. Grading is more common closer to contacts because of the effects of shear sorting. Sandflow deposits are loosely packed making them highly porous and highly permeable. Porosity ranges from 44 to 46% (Hunter 1977).

The fourth type of aeolian lamination is quasi-planar adhesion stratification. This stratification results from the deposition of sand on beaches, dunes or other sandy surfaces which are wet, but not marked by adhesion ripples. Hunter (1980) studied deposition during rainfall and, although he documented the development of quasi-planar adhesion stratification, he could not determine the range of conditions under which it forms. The stratification is transitional between regular dry sand ripples and adhesion ripples in very wet sand. Strata are very faint, crinkly, and do not vary with changes in a vertical exposure.

Adhesion structures form by the adhering of dry, wind blown sand to a surface which is wet or damp (Hunter 1973, Kocurek and Fielder 1982). According to Kocurek and Fielder (1982) there are three types of adhesion structures: adhesion ripples, adhesion warts, and adhesion plane bed. The three types have the same basic origin, but are the result of different depositional conditions. They develop in areas where there is both a dry sand source and a wet depositional area and are common to tidal flats, beaches and aeolian interdune areas.

Adhesion ripples form on surfaces with a high water content. Individual adhesion ripples climb upwind over each other when winds are unidirectional and thus produce a set of pseudo-cross-lamination with foresets dipping in the downwind direction (Hunter 1973). Hunter (1977) later called these translatent strata. The ridges and troughs are oriented transversely to wind direction and reform easily as wind direction changes. Therefore, if asymmetry is present, the wind direction that formed the ripples can be determined from their structure (Hunter 1969). The angle at which the adhesion ripple climbs is a function of water content, wind velocity, and the angle between the path of the saltating grain and the surface of deposition (Kocurek and Fielder 1982).

Adhesion plane bed forms as grains cling to a surface which has not been marked by adhesion ripples or adhesion warts (Hunter 1980, Kocurek and Dott 1982). This type of bedding forms in areas where the water content falls below a critical level and sand adheres to the surface in very thin sheets. It can also form when the angle between the path of a saltating grain and the surface of deposition is perpendicular. The beds which develop are only a single grain to a few millimetres thick. the bed can be identified by its thinness, faintness, and crinkly appearance.

Adhesion warts are small ellipsoid bumps or domes which tend to be more randomly distributed than adhesion ripples. They form in strong winds that shift direction frequently. These shifts in wind direction prevent the structure from growing in any direction. They therefore grow by upward rather than lateral accretion.

2.4 Large-scale Stratification and Internal Structure of Sand Dunes

2.4.1 General

The internal structure of dunes is a record of the depositional history of the landform and environment. McKee and Bigarella (1979) established a link between the morphology of the feature and the internal structure. The main sedimentary structures are often medium- to large-scale foresets that dip downwind and are separated by bounding surfaces that are horizontal or inclined at low angles (McKee and Bigarella 1979). However, when the sediment supply exceeds the amount that can be moved up the dune slope, deposition occurs at the base. This action deposits low angle strata that dip windward. If the wind is strong or changes direction, earlier deposits may be partially eroded forming surfaces which are buried and become part of the sedimentary record of the dune.

McKee and Bigarella (1979) and Bigarella et al. (1969) described the structures common to most dunes. Medium- to large-scale cross-strata with leeward dipping, high angle (30 to 34°) foresets are common. These were originally angle of repose slipfaces. [illegible] common are planar tabular sets of cross-strata thinning upward in a vertical sequence which were once the deposition on the windward slope. Sloping laminae within sets tend to repeat the pattern in the thick basal set, but at lower angles. Bounding planes between individual cross-sets are horizontal or dip leeward at low angles.

There are structures which are characteristic of a particular type of dune. Barchan dunes have long even layers which dip 20 to 32° downwind in the middle of the dune. Lower on the windward slope, the truncated tops of these layers are covered by a veneer of laminae dipping upwind 5 to 7°. In the wings of the dune, strata dip at low angles in both directions (McKee and Bigarella 1979). Barchanoid ridges contain generally flat-lying planar tabular sets of cross-strata with foresets dipping downwind at 26 to 34°. Downwind, bounding surfaces become steeply dipping (20 to 28°) with foresets dipping 34°. In the crescents on the ridges, there are cross-bed sets with horizontal bounding planes. On the flanks, cross-beds and bounding surfaces dip outward at low angles. Individual cross-strata sets form wedges tapering toward the dune margins and foresets show dips of 12 to 23°.

Transverse dunes also have characteristic internal structure. They contain steeply dipping (30 to 34°) planar tabular strata within bounding planes that range from nearly horizontal to moderately high angle (20 to 26°) downwind. McKee and Bigarella (1979) found that large foresets in the lower part of the dune extended downdip, terminating as tangential curves at the dune base. In the upper part of the dune, cross-bed sets thinned and bounding planes became nearly parallel. High angle foresets were almost absent.

In parabolic dunes, foresets dip downwind on slipfaces. The stratification in the arms dips normal to the dune axis. As the rounded nose of the dune migrates it deposits foresets that are concave downward. Much of the stratification is warped by the growth of roots. The internal structure of a blowout has not yet been determined. However, McKee and Bigarella (1979) thought that it would be much the same as that contained in parabolic dunes. Retention ridges are much like parabolic dunes. They commonly contain topset and foreset in a single, continuous layer due to the abundance of sand and the low rate of movement. Sinuous sand layers at the lower part of these dunes are similar to the strata in dome dunes.

Dome dunes have their tops bevelled off by strong winds. They have no steep avalanche faces. The upwind portions contain planar tabular cross-strata with foresets dipping downwind 28° to 33°. In the downwind portion of the dune, foresets dip 14 to 27°. Normal to the dominant winds, there are horizontal strata or strata dipping slightly toward dune margins. Cut and fill sections can show a series of sand filled scours parallel to the wind. Desert domes contain uniformly dipping high angle foresets. These are lacking in coastal dome dunes (McKee and Bigarella 1979).

There are no documented examples of the sequences of internal structures contained in linear dunes (McKee and Bigarella 1979). However, hypothetically, these should contain high angled cross-strata in the upper half on both sides. On the lower flanks, there should be low angled (4 to 14°) cross-strata due to the accretional nature of the area.

In reversing dunes high angle foresets of lee deposits are scarce and therefore slipface deposits are rarely preserved. Leeside bedding underlies a veneer of windward deposits. The crestal areas contain thicker units which are more complex due to the back and forth movement of the sand with a reverse in the wind direction.

Star dunes have the most complex internal structure. The arms have slipfaces on one side which dip at 31 to 33° and a more gentle leeward side (17 to 21°). Cross laminae dip at high angles in three principal directions coinciding with seasonal wind movement. There is a wide spread in dip directions in the complicated internal structures (McKee and Bigarella 1989).

Gunatilaka and Mwango (1989) examined shadow dunes in Kuwait. These features are similar to those described by Hesp (1981), but they are larger and develop downwind of nebkhas. Their internal structures consist of bipolar azimuths and bimodal dip distributions of planar-tabular grainfall cross-strata with a chevron pattern in the crest and alternating reactivation surfaces which probably represent third-order bounding planes on slipfaces.

2.4.2 The Internal Structure of Vegetated Coastal Dunes

The existing literature on sand dune bedding contains a thorough investigation of the types of bedding in unvegetated small dunes (Hunter 1969, 1973, 1976, 1977, 1980). However, vegetation plays an intrinsic role in the development of large coastal dunes and dune systems. Bagnold (1941) and Ranwell (1958) recognized that vegetation adds complexity to the dune system and referred to it as a special kind of surface roughness. This surface roughness affects the manner in which sand is laid down (Hesp 1981). The bedding should therefore reflect the existence of vegetation as well as the processes by which sand is transported and deposited. Ranwell (1972) classified vegetated coastal dunes on the basis of their location and vegetation cover. Strandline dunes are located just above the reach of high tides and are vegetated with annual plants. These plants trap windborn sand and grow vertically and laterally becoming vegetated by perennial plants such as Agropyron junceiforme and Elymus arenaria in Europe and Uniola paniculata along the eastern seaboard of the United States. These plants propagate either by seed or by growth from rhizome fragments. Extensive horizontal and vertical rhizomes develop which have viable buds to 60 cm depth. These plants can withstand accretion of up to 30 cm per year and depend upon organic matter and sprayborne nutrients because they have no active roots below 60 cm depth and are thus independent of the water table. He called these embryo dunes.

Ranwell (1972) stated that it is unclear whether the pioneer grasses are overwhelmed by accretion rates, or whether the nutrient requirements are no longer met, or whether the presence of Ammophila shades out the pioneer grasses. However, Ammophila does take over as the predominant species on embryo dunes. These types of plants have potentially unlimited horizontal and vertical rhizome growth and can withstand accretion/burial up to 1 m per year in Europe and slightly less in North America. The roots shed every year and the vegetation causes the development of an inherently unstable form with a steep windward slope (Ranwell 1972). These are established dunes.

Ranwell (1972) further discussed the relationship between depositional patterns and vegetation by relating sand deposition to shoot development of

Ammophila. Depositional patterns can be determined by measurement of internodal lengths. Although his studies relate the deposition of sand to the presence of plants, little is stated about the patterns of bedding which develop as the sand is deposited around the plant. No statements were made regarding the presence or absence of beds or sets, nor about the magnitude and direction of dip. Therefore, although this account puts forward a good discussion of the primary deposition of sand in vegetation, it is lacking in the description and analysis of the internal structures and stratification of dunes after initial development.

McBride and Hayes (1962) discussed the presence of beds within dunes on Mustang Island, Texas. They measured 130 cross-bed azimuths and dips at 7 stations along an 18 km stretch of beach. They constructed rose diagrams of dip directions. A summary rose diagram revealed a bimodal distribution of dips. They attributed this distribution to the development of asymmetrical pyramidal dunes which have two faces that dip in the direction of the cross-bed modes. These dunes are an intermediate step in the transformation of barchan dunes to longitudinal dunes during the movement of sand inland.

Although this hypothesis describes the movement of sand inland and explains the existence of high angle cross-beds, further description of the beds would be useful to the reader. It is unclear exactly which beds the authors are measuring. There are only two pictures of the types of bedding which they were examining and there are no drawings of the sections which were measured. The authors concede that the number of measurements is few, but do not describe the size of sections in which the measurements were made. Their descriptions of sets is incomplete. They do not describe the laminae within beds nor the presence or absence of sets.

Bigarella et al. (1969) examined the coastal dunes of Brazil. They examined vertical sections parallel to and transverse to the average wind direction. They found that "cross-bedding" characteristics were similar between these dunes and those studied by McKee (1966) in the White Sands National Monument. The characteristics included high angled foresets, nearly horizontal bounding surfaces which become steeper in linguoid protuberances (large shadow dunes ?), a thinning of individual sets of cross stratification from the bottom to the top of the sections, and a dominance of planar sets. They also noted convex-upward foresets and contorted beds.

This study contains a wealth of information about the coastal sand dunes of Brazil. However, it is very difficult to understand the diagrams which are meant to simplify the bedding within the dunes. Also, these dunes are densely vegetated in places and little mention is made of the effect of the vegetation on the structures. The emphasis of the discussion is on bounding surfaces rather than the smaller features within the sets defined by them. An examination of the internal structures at a laminae-bed-set scale is warranted.

McKee and Bigarella (1972) also describe the deformational structures within coastal dunes in Brazil. The structures associated with deformation are well documented and considered to be more common in coastal than desert dunes. Slumping is common and there is greater cohesiveness of the sand. This is attributed to the higher moisture content in these dunes rather than to the combined effect of a higher moisture content and the presence of plants. Vegetation is only mentioned in the conclusions, with the statement that small roots of plants follow the lamination planes with little or no disturbance while dense thick roots disrupt and contort the stratification. No consideration is given to the fact that vegetation in this environment often grows up with accretion of sand, thereby often minimizing the effects of the plant on the bedding.

Goldsmith (1973) discussed the internal geometry of vegetated coastal dunes on Monomoy Island, Massachusetts. He measured the dip, azimuth and elevation of 301 cross-bed sets. All of the beds were planar or very slightly curved and were about 5 to 10 m long. The beds were little disturbed by roots. He attributed a "distinctive internal dune geometry" to the presence of vegetation. Goldsmith (1985) also compared his data with that of four other areas. He concluded that the dip distributions of aeolian cross-beds are bimodal and that the high angle dipping cross-beds ($>20^{\circ}$) have a bimodal azimuth distribution which is bisected by the vector mean of the prevailing wind direction. This results from the development of pyramidal shaped wind shadow dunes. He also concluded that the low angle cross-beds found on Monomoy Island are also present in the other locations. He stated that these form simultaneously with the upward growth of dune vegetation.

Goldsmith (1985) stated that the existence of low and high angle beds can be accounted for in coastal dunes. The low angle beds are the result of the interaction of wind, vegetation and sand. The high angle beds are the result of the interaction of the same factors with the added development of pyramidal shaped shadow dunes. He does not state why these dunes develop. Hesp (1981) has outlined the development of shadow dunes behind semi-circular, semi-permeable obstacles. Goldsmith does not refer to this paper nor does he explain why shadow dunes are not present on Monomoy Island. There is also a lack of illustrative material in the Goldsmith papers. Although there are numerous pictures of the dune surfaces, there are no photographs of the bedding contained within the dunes and there are no drawings of the sections in which cross-bed sets were measured. Also, no descriptions of the cross-bed sets are given. However, Goldsmith (1985) does state that low angle beds predominate in vegetated coastal sand dunes.

Hesp (1984) discussed foredune formation in Southeast Australia. He distinguished 2 types of foredunes - incipient and established foredunes. Incipient foredunes are those initial or embryo dunes formed by the trapping of sand within pioneer plant species. They are 2 to 5 m in height. These are similar to the embryo dunes of Ranwell (1972). Established foredunes are those foredunes colonized by shrubs and trees and range from 2 to 30 m in height.

There are four modes of foredune development proposed by Hesp (1984). The first (Type 1a) are those foredunes initiated by aeolian sand deposition within and in the lee of discrete plants. Type 1b foredunes develop within discrete zones of seedlings. Type 2a foredunes are incipient foredunes formed by deposition within laterally extensive colonies of seedlings. Finally, Type 2b foredunes form within laterally extensive colonies of rhizomes.

He further discussed the interactions of wind and plants in the development of morphologic differences along a section of dune. The variations in wind velocity create morphologic variations because transportation and deposition take place over a longer distance during high wind velocities than during low. As wind velocity increases, dune height decreases and width increases. If plant density is low and/or wind velocity is high, swales have less chance of forming or will be shallower because downwind distance over which sand deposition occurs increases as plant density decreases or wind velocity decreases.

Hesp (1984) therefore explained the morphologic variations which occur in foredune systems and classified the different types of foredunes which occur. However, the discussion of internal structures is short. He gives only one diagram and two photographs to support his ideas. He does state that the bulk of the foredune is dominated by low angle beds. This lends credence to Goldsmith's assertion that low angle beds are the result of deposition of sand simultaneously with upward growth of vegetation.

Thus, Bigarella et al. (1969) and McKee and Bigarella (1972) have examined structures and their deformation, but these papers were not written with a knowledge of the importance of vegetation in this environment. Ranwell (1972) considered the vegetation more than the dunes. McBride and Hayes (1962) and Goldsmith (1973, 1985) considered dip angles and orientation of beds, but not the beds themselves nor the laminae contained within them. Hesp (1981, 1985) has considered the importance of vegetation in the development of dune bedding and in influencing the morphology of the dune. However, he considers the internal configuration of the dune from a gross structural aspect rather than from a laminae/bed/set view. It is clear that the vegetated coastal dune literature is lacking in descriptions of internal structures and sequences. There is also a lack of documentation of sequences of structures and sets within this environment. Drawings and photographs of sections are necessary in order to convey the information more precisely. Such information should be available in a coastal dune facies model.

2.5 Aeolian Facies Models

2.5.1 General

Facies Models were defined in the introduction (section 1.1). Brookfield (1984) stated that aeolian facies models are based on the premise that migrating hierarchies of aeolian bedforms climb over each other and show different types and proportions of stratification. The assemblages of strata generated when these bedforms migrate can be compared to the actual sections of ancient sandstones to create facies models. He outlined six problems associated with the development of facies models for modern desert dunes. These include the following: 1) recent deposits rest on alluvium and are post-Pleistocene in age; 2) no thick deposits are forming at present. The ancient deposits show very thick accumulations of sand; 3) most large modern bedforms are not in equilibrium with modern winds because of the lag time associated with the size of the deposit adjusting to relatively rapid changes in wind circulation patterns; 4) the stratification types described by Hunter (1977) are for small coastal dunes and so are not the right order of magnitude to describe large desert dunes; 5) many models are based on studies by McKee in the White Sands National Monument. These dunes are made of gypsum which is more cohesive than quartz. Therefore one cannot compare directly between the two. These studies are useful form comparison of general morphology and style; and, 6) only the lowest parts of aeolian bedforms are preserved. Therefore it is difficult to reconstruct the size and shape of the larger bedforms from the small preserved portion of sand. Despite these problems, models have been developed for different desert environments. The models are associated with the migration of bedforms rather than changes in current (Brookfield 1984). As the bedforms migrate they leave behind bounding surfaces. In a large dune-draa system, first order bounding surfaces are flat-lying and are due to the migration of the largest features - the draa. Second order bounding surfaces lie between first order surfaces and dip downwind. They are the result of the smaller bedforms climbing over larger ones or moving laterally alongslope. Finally, third order bounding surfaces are the reactivation surfaces which are due to the erosion followed by deposition caused by local wind fluctuations.

2.5.2 Coastal

Hesp (1988) reviewed the relationship between morphology, erosional and depositional precesses and the construction of foredunes. He attempts to outline a facies model, in basic form, for vegetated foredunes. He stated that, in combination with observations from papers by Bigarella et al. (1969), Bigarella (1972), Goldsmith (1973), McKee (1979), and others, there is a basic facies model for foredunes and coastal dune terrains where relict foredune plains predominate. To this point an adequate model has not been proposed.

Hesp proposed that the facies comprise: 1) a boundary between swash (marine) and aeolian environments; 2) a predominance of simple, tabular to lenticular low angle beds; 3) a predominance of large-scale (> 6m) beds which are continuous across the top of the dune; and, 4) many windward sets of cross strata.

After presenting these as the basic facies types he tries to group them within five stages of development with distinct morphologic stages associated with specific facies assemblages. The model outlines some of the basic facies elements - a) the aeolian/marine boundary, b) low angle beds, c)continuous large-scale beds, and, d) the existence of windward cross strata. However, the description of beds is confusing because some cross-beds are simply beds. The morphologic link with a specific facies assemblage is also not clear. All dune stages have the same shape although there are different facies assemblages.

By the first definition of a facies from de Raaf, Hesp (1988) is accounting for structural and organic aspects of the deposit which he detected in the field and which can be given environmental interpretation. One can look at the sequences presented and say that they were deposited in an aeolian environment. However, there are no links between the modern and the ancient environments. In constructing a facies model both must be considered. Hesp ignores any possible ancient examples in his literature search. He also does not present an idealized sequence or block diagram. He presents the real sections which he examined, but does not distil away local variability to give a summary of the environment.

By Walker's (1984) definition, Hesp's model presents a general summary of a specific sedimentary environment. But, is it useable in four ways? Is it a norm for comparison? The area in which Hesp is examining these dunes is atypical of coastal dune environments. Australia is unique in many ways from other areas which have coastal dunes. Sea level change, wind regime, degree of shelter must be considered. The sea level is falling, wind regime is constant off shore and the dunes are in a fairly sheltered location.

2.6 Summary

Although coastal sand dunes appear to be simple sedimentary features developed along a shoreline, one can see from the preceding review of the literature that they are actually quite complex. The development of large coastal dunes depends upon sand supply, wind regime, the proper climatic conditions (precipitation and humidity), tidal range and beachface slope angle.

Tractional processes are important because, although large deposits are not laid down, this process is responsible for about one quarter of the total amount of sediment moved by aeolian processes. Ripples and other small scale features are ubiquitous in the coastal environment. Adhesion structures are indicative of a dry sand source nearby. Small shadow dunes form in the lee of obstacles and are indicative of an accretional environment. They are identified in a deposit by the higher-angled beds with a bi-modal dip direction.

Coastal dunes are a subset of sand dunes and thus many of the landforms are similar. However, because this environment reflects the influences of many sub-environments, there are forms which are unique along the coast. The main difference between temperate coastal and desert dunes is that on the coast, the dunes are vegetated. Vegetation is very important because it stabilizes the sand and allows the dune to grow vertically as well as laterally.

The bedforms which result from the accumulation of sand have unique morphologies. The internal structure of the bedforms must be examined in order to link it to the shape of the feature.

CHAPTER 3

MORPHOLOGY OF SABLE ISLAND

3.1 Surface Morphology

3.1.1 Present Configuration of Sable Island

Sable Island is composed of reworked outwash sediments, which form the underlying bank, the broad beaches and the dunes of the island. The dunes have a variable morphology. As stated in the introduction, the island consists of four physiographic parts - the west spit, the main body of the island, the wide flat beaches on the south part of the island and of Wallace Lake, and the east spit.

Five profiles were taken across the island to define its basic morphology and dimensions. These are presented in Appendix III along with an outline of the historical information on Sable Island. A short summary of the results is outlined here, followed by a discussion of dune morphology and a classification of the dunes, based on process, vegetation cover, and morphology.

The elevation of the dunes on Sable Island generally increases from west to east (Fig. 3.1). Peak elevation of the north dune ridge is toward the centre of the island and peak elevation of the south dune ridge is almost at the eastern

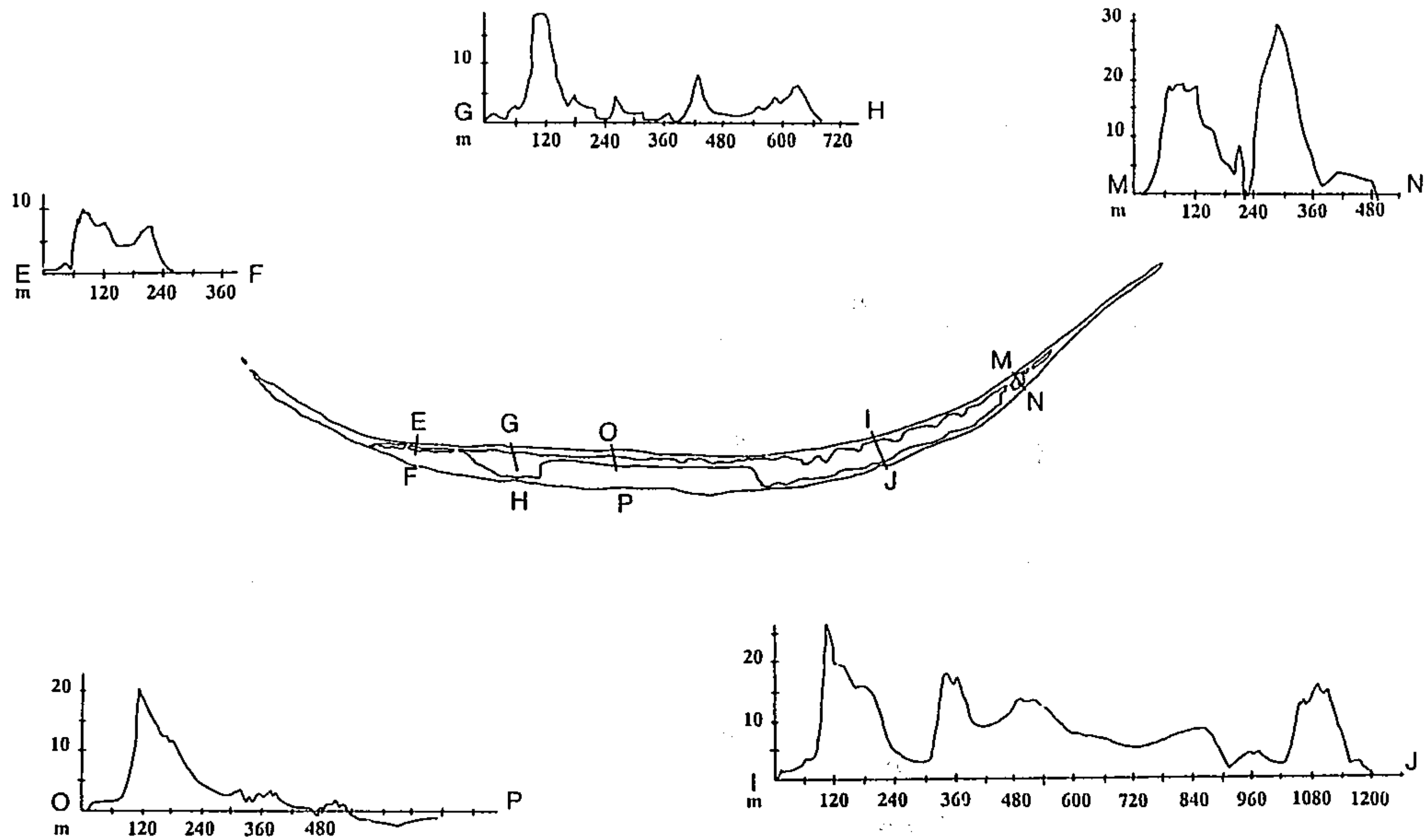


FIGURE 3.1. Profiles across the dunes on Sable Island show the morphological trends in the dunes.

end. The westerly winds move sediment along the length of the island, piling it on the eastern end and causing this to be the portion of the island with the highest elevation.

The island is widest in the central portion (around 1.2 km). The width of the dune belt is greatest to the west (Fig. 3.1, Profile G-H) and east (Fig. 3.1, Profile I-J) of the Wallace Lake flats. The dune belt behind the flats is very narrow (Fig. 3.1, Profile O-P). The width of the dunes and of the island are less the result of the winds than of the previous morphology. Wallace Lake is located in the position previously occupied by the lagoon in the earliest maps. The barrier between the Wallace Lake and the sea on the south is a remnant of the southern dune ridge which is perhaps growing again in the form of the vegetated hummock dunes near Three Mile Dune. The width of the dune system at profile I-J is related to the presence of the parabolic dunes which are migrating in accordance with the present wind regime. The average axis orientation of the parabolic dunes is in line with the resultant direction (See Appendix II).

Dune elevation is not related to the width of the dune system nor to the width of the island. This is especially true on the west end of the island. At profile E-F the dune system is narrow in comparison to the width of the island, but the elevation is also low in comparison to the east end. At profile G-H both the dune system and the island are wider and the north ridge is higher. The same is true for profile I-J. However, at profile M-N, the island is narrower and the dune system is narrow and maximum elevation for the island is attained.

In general the north-facing slopes are steeper than the south-facing slopes. This is true at all locations. The south facing slopes are steep when the slope is on the south beach.

3.1.2 Changes in the Dune System Over Time

Although Cameron (1965) examined the historical configuration of Sable Island, he did not detail changes which have occurred in the dune system (Appendix I). Therefore, the photographs which he used were re-examined. Two further sets of colour photographs were available (1971 and 1981). Tracings were made of the dune coverage from the photographs which best depicted the dunes on the island. The 1952 and 1955 sets clearly showed the configuration of the dunes at that time. However, there was a great deal of distortion in the photographs and so changes to the dune ridges are only relative. The 1963 photographs were not a complete coverage, nor were they well exposed. The traces from these photographs were then used to make a comparison with a map drawn from the 1981 photographs (scale approximately 1:20,000).

Maps were was made from this comparison. Figure 3.2 is a location key for the vegetation maps (Fig. 3.3 through Fig. 3.7). There is a map for change in vegetation cover for five areas - the spits, the west end, the Wallace

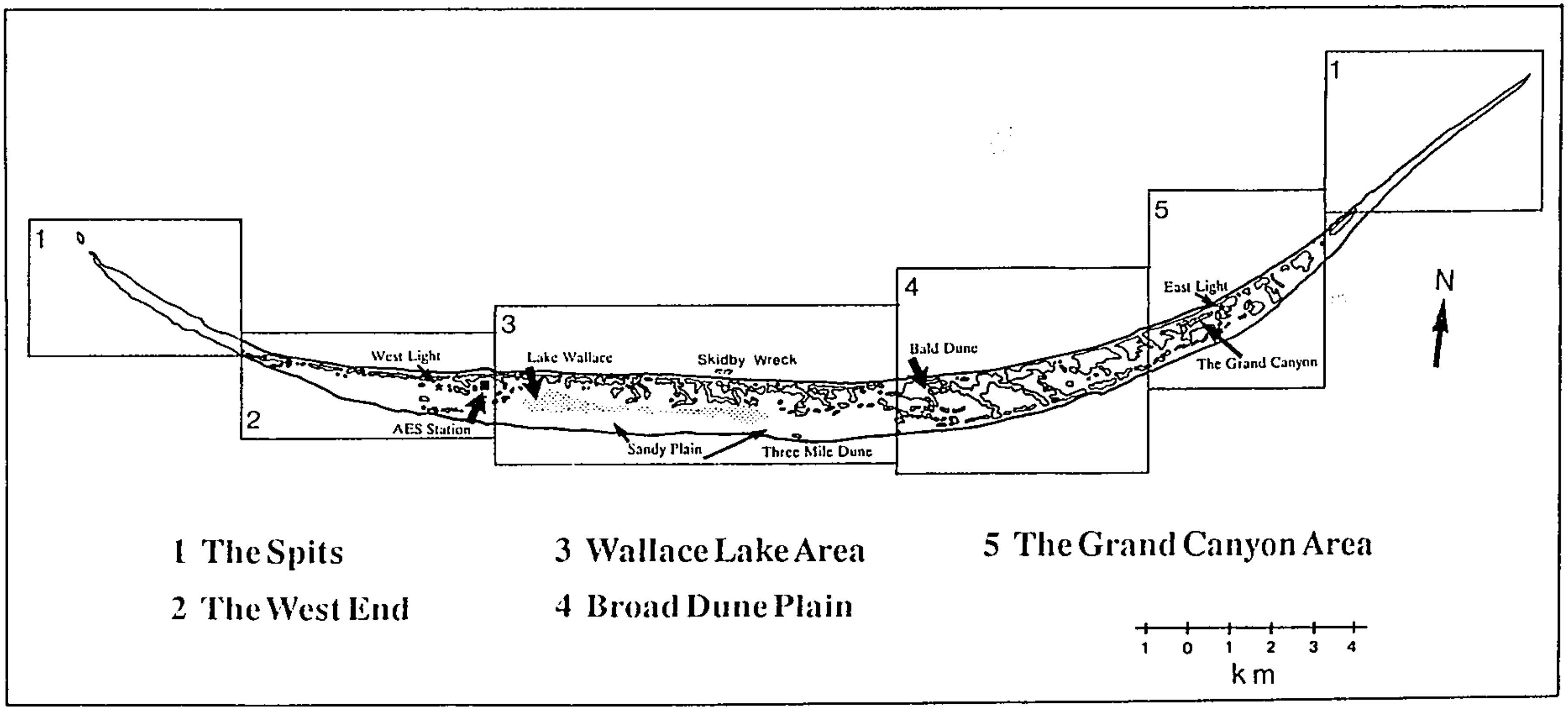


FIGURE 3.2. Locations of the vegetation maps which document the cover on the island.

FIGURE 3.3. West Spit. The dunes on this part of the island are dominated by the presence of <u>Honkenya peploides</u>, which is able to withstand the harsh conditions in such an exposed area.

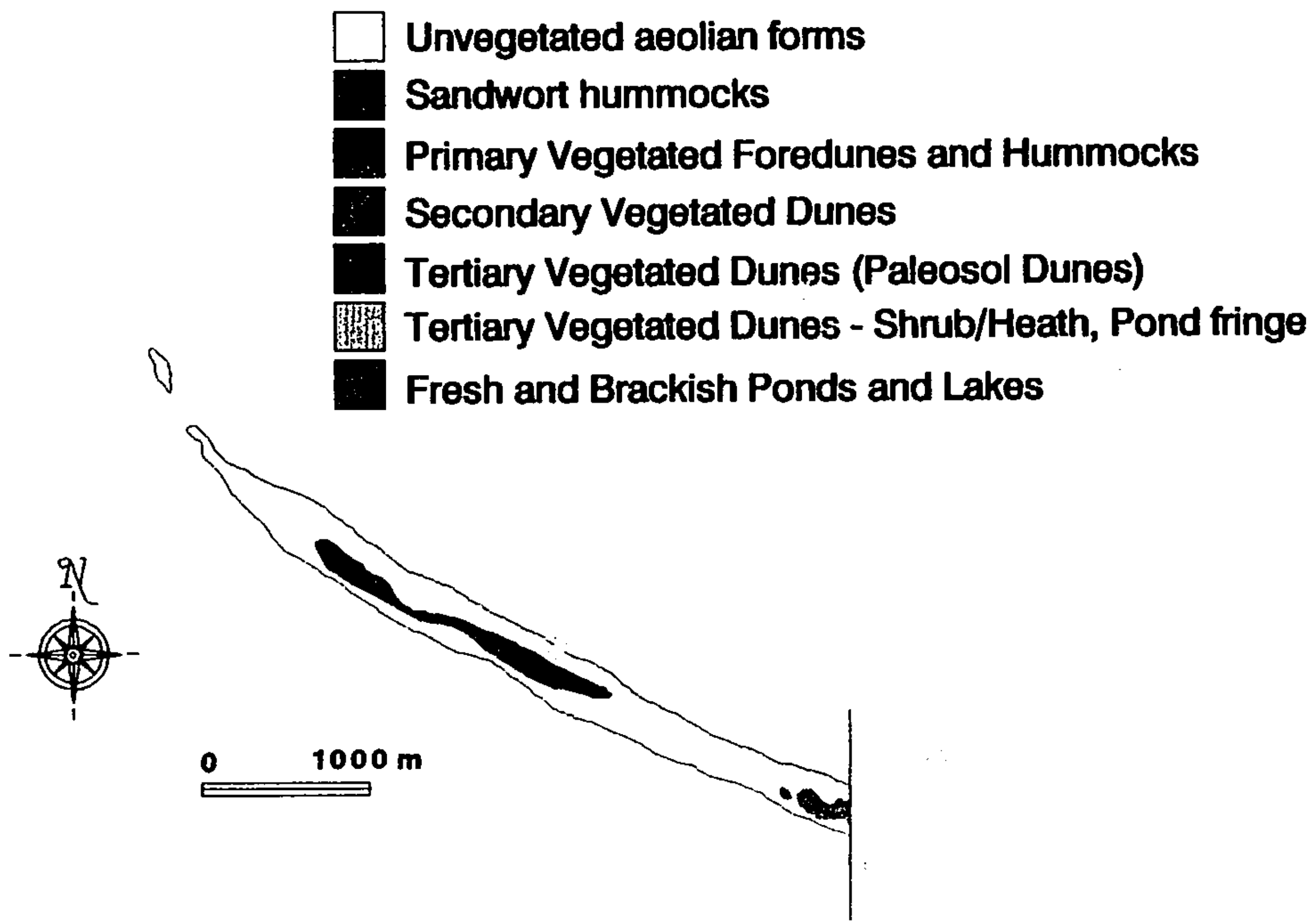
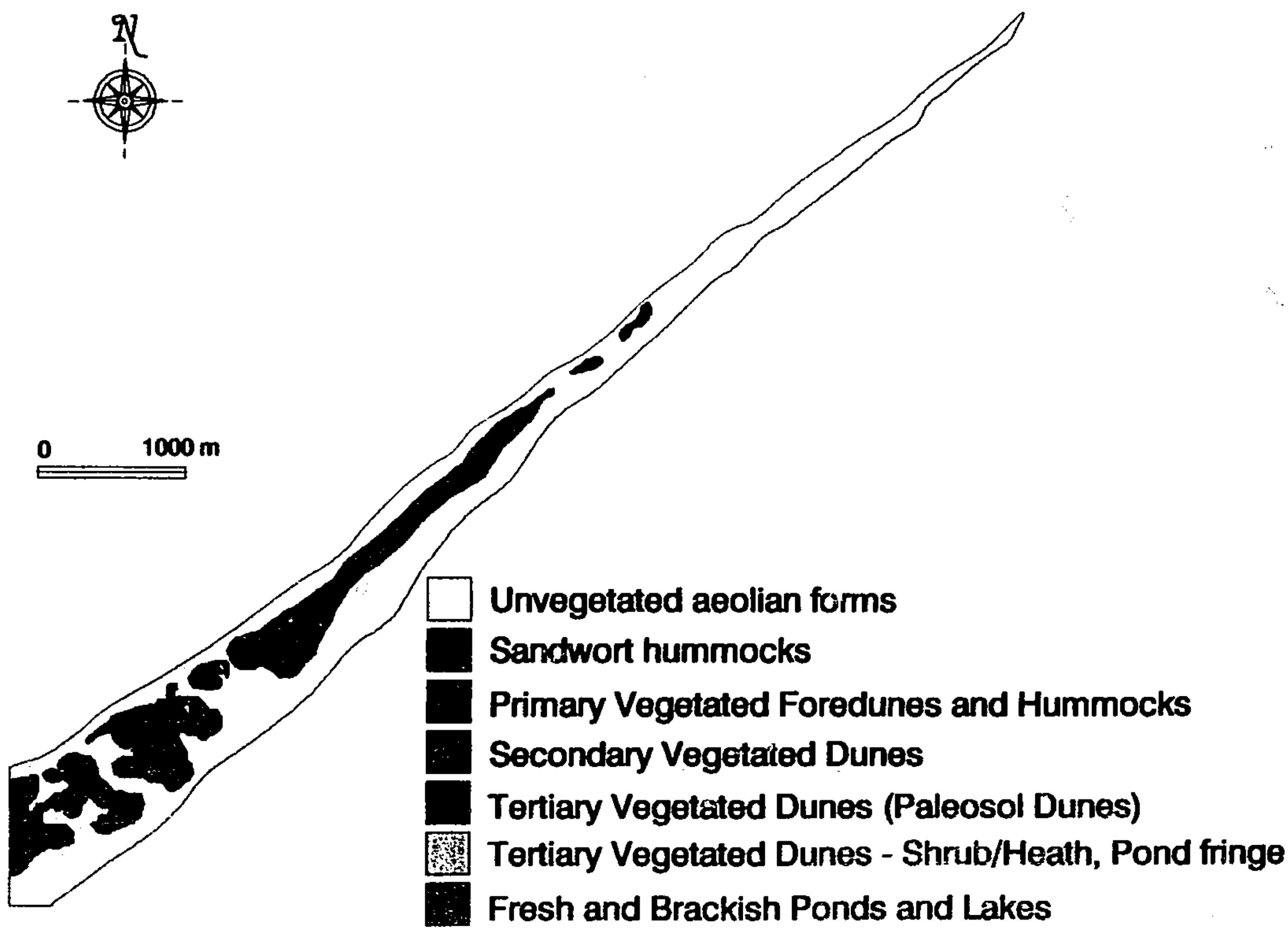

Unvegetated aeolian forms
Sandwort hummocks
Primary Vegetated Foredunes and Hummocks
Secondary Vegetated Dunes
Tertiary Vegetated Dunes (Paleosol Dunes)
Tertiary Vegetated Dunes - Shrub/Heath, Pond fringe
Fresh and Brackish Ponds and Lakes
N
0
1000 m

FIGURE 3.4. East Spit. The dunes here are again dominated by _Honkenya peploides_, however, they are much less extensive than the dunes on the West Spit.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Unvegetated aeolian forms
Sandwort hummocks
Primary Vegetated Foredunes and Hummocks
Secondary Vegetated Dunes
Tertiary Vegetated Dunes (Paleosol Dunes)
Tertiary Vegetated Dunes - Shrub/Heath, Pond fringe
Fresh and Brackish Ponds and Lakes

Lake area, the broad dune plain, and the "Grand Canyon".

The Spits (Fig. 3.3 and 3.4)

There are a number of remarkable changes which have occurred in the Sable Island dunes over the period of photographic coverage. Perhaps the most notable is the change in the length of the spits. The lengths were determined from the tracings of the 1:10,000 RCAF black and white images. There was distortion in the photographs and the tracings increased this effect. However, the actual lengths are not as important as the impression of change.

The 1963 photographs did not include good coverage of the spits. However, the 1971 and 1981 coverage is very good. In the 29 year period, the length of east spit decreased dramatically from 16.9 km in 1952 to 4.4 km in 1971 and then increased to 6 km by 1981. The west spit changed from 4.2 km in 1952 to 2.3 km in 1971 to 7.6 km in 1981, to about 6.4 km at present.

Although the length of the spits has changed dramatically, the surface cover has not. Small Honkenya peploides dunes are present on the surface today. Some of these were visible in the 1952 photographs. However, because these are such transient forms, it is difficult to distinguish the small-scale morphological changes which have occurred in them over time.

The West End (Fig. 3.5)

The section of the island from the west end of the dune ridge to Atmospheric Environment Service station consists of the main dune ridge and the western most pond system. On the north side of the ridge in the 1981 photographs, there are new foredunes which extend westward from the present Nova Scotia Energy Mines and Resources Camp. However, it is difficult to tell if these will be permanent features. They exist at the present time, protecting the once scarped dunes behind them.

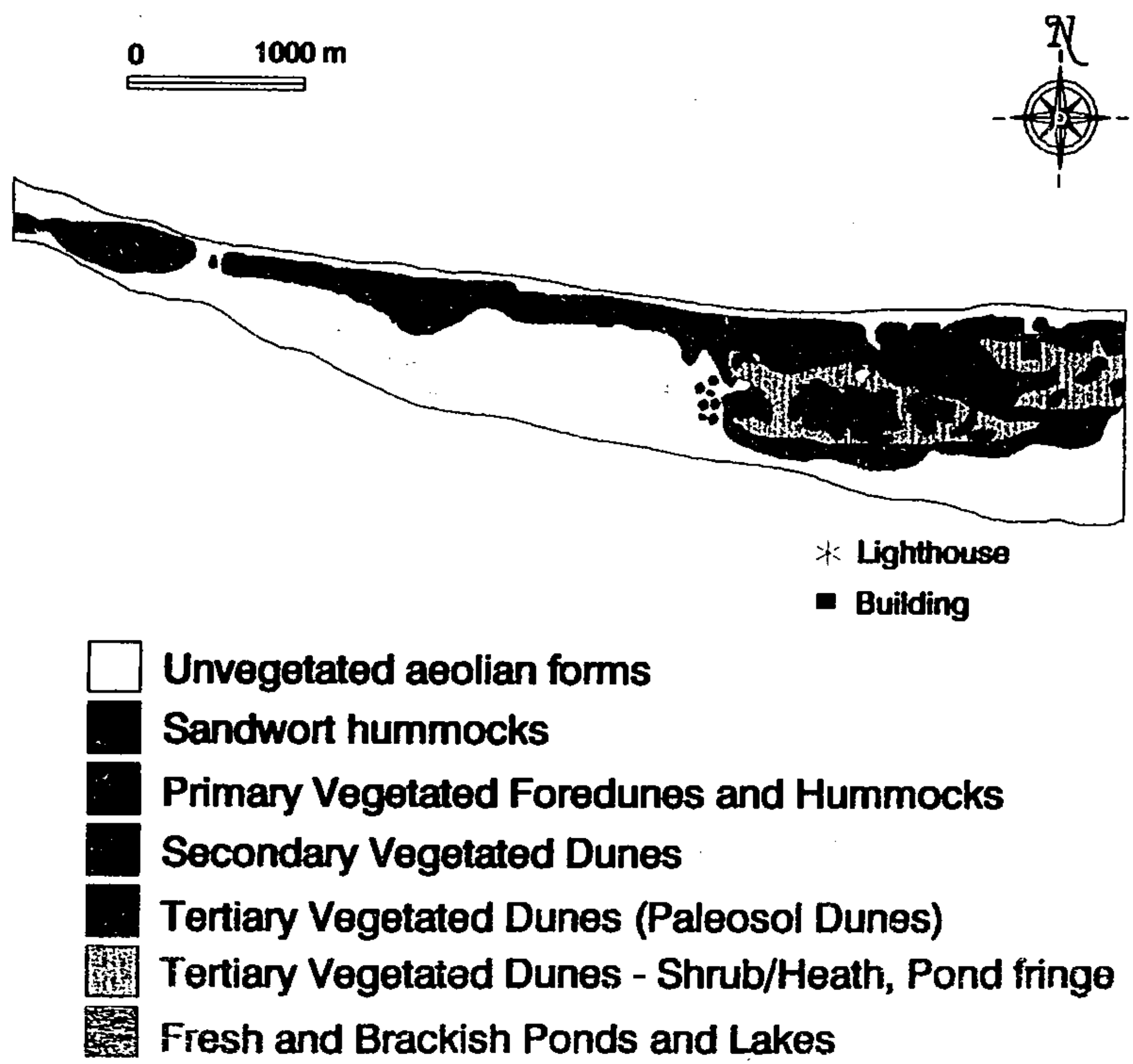
There is a notable change over time in the configuration of the dunes which separate the pond system from the south beach. In the 1971 photographs, the dunes had been breached allowing the storm overwash into the pond system. However, due to terrain management activity and the natural movement of sand, the breach has healed and water no longer flows into the ponds.

There is little else which is notable. There may be a recession of the dune line along the north shore, but it is difficult to determine with these photographs at this scale. Although there have been smaller scale changes - the infilling of one side of a blowout and the deflation of the other side, there has been no great change in the morphology of the ridge over the period of the photographic record.

Wallace Lake Area (Fig. 3.6)

The section of the dunes extending from the Atmospheric Environment Service station eastward to Bald Dune is made up of a discontinuous ridge of dunes which are separated by canyon-like blowouts and surround pond systems. South of the ridge is Wallace Lake which is separated from the sea by a wide berm.

FIGURE 3.5. The West End. The dunes in this sector become more complex with greater areal coverage and a higher elevation than the dunes on the West Spit. The topography is further complicated by the presence of the fresh water ponds south of the lighthouse.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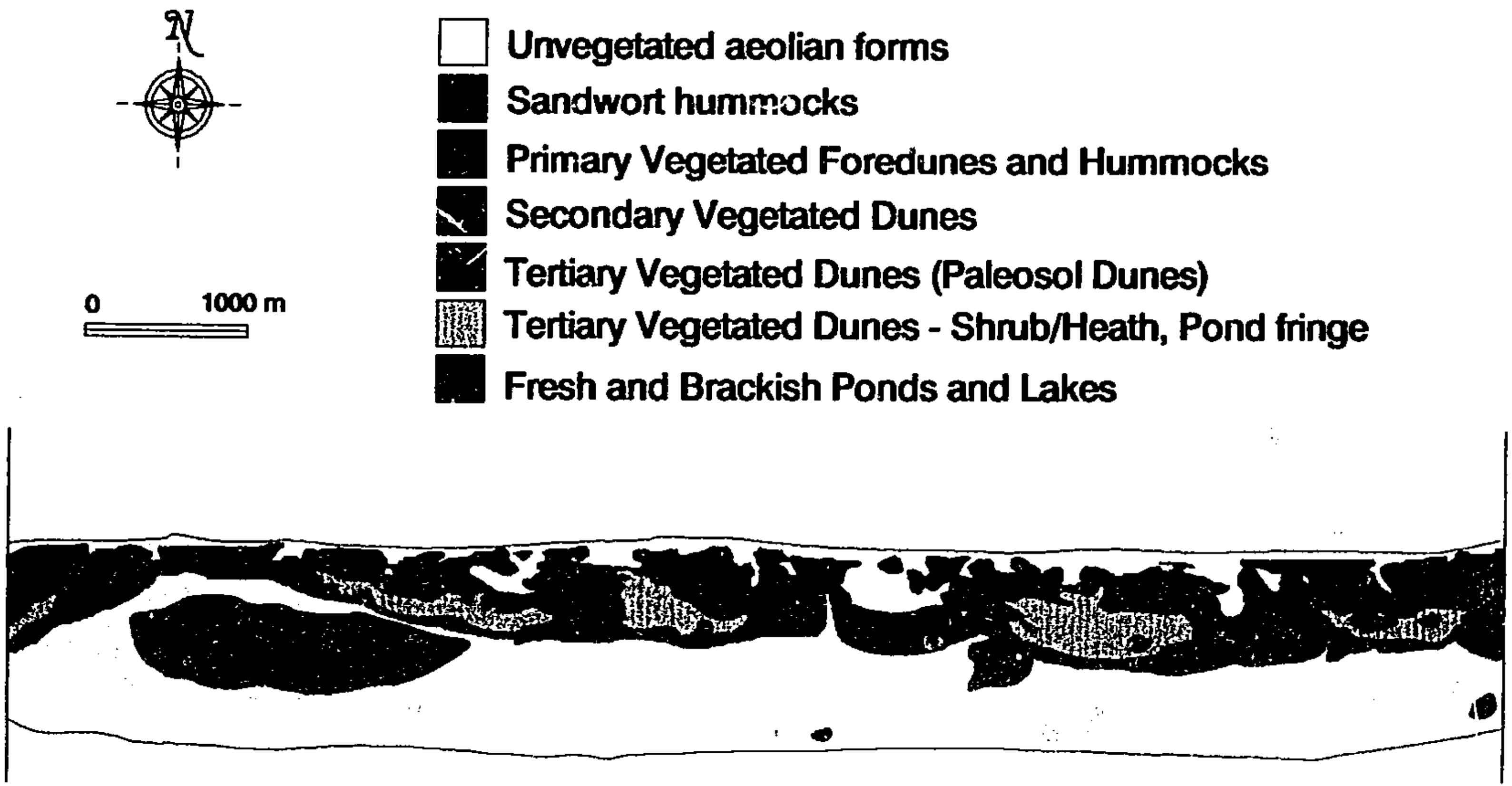
Lighthouse
Building
Unvegetated aeolian forms
Sandwort hummocks
Primary Vegetated Foredunes and Hummocks
Secondary Vegetated Dunes
Tertiary Vegetated Dunes (Paleosol Dunes)
Tertiary Vegetated Dunes - Shrub/Heath, Pond fringe
Fresh and Brackish Ponds and Lakes

FIGURE 3.6. The Wallace Lake Area is dominated by the presence of the Wallace Lake and the Sandy Plain. The dunes are complex with a mix of newly forming dunes and older dunes with a well developed paleosol. Small hummock dunes are currently forming on the Sandy Plain.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Unvegetated aeolian forms
Sandwort hummocks
Primary Vegetated Foredunes and Hummocks
Secondary Vegetated Dunes
Tertiary Vegetated Dunes (Paleosol Dunes)
Tertiary Vegetated Dunes - Shrub/Heath, Pond fringe
Fresh and Brackish Ponds and Lakes

Written accounts and the old maps depict the southern ridge on the barrier south of Wallace Lake as fairly continuous. In the 1952 and 1955 photographs, the ridge was discontinuous. It was made up of a series of discrete, vegetated hummocky dunes. Some had coalesced to form larger more densely vegetated forms, but for the most part these were only about 6 metres in diameter. In the 1971 photographs there are only about 7 of them left. By 1981, the only remnant of the southern dune ridge was Three Mile Dune.

Over the period of the historic record erosion has dominated on the barrier between Wallace Lake and the sea. The southern dune ridge all but disappeared. At the present time, hummock dunes are growing on the flats near Three Mile Dune. Perhaps the erosion phase for this part of the island is over for the present.

In the northern dune ridge the evidence from the aerial photographs shows that, overall, foredunes along the ridge have been eroded. Between 1971 and 1981, two large dunes east of Skidby were eroded. In other areas, there is infilling of the blowouts. The vegetation on the ridge is predominantly Ammophila breviligulata and it has advanced from the dunes at the back and on the west side of the blowouts to trap sand and cause infilling

The Broad Dune Plain (Fig. 3.7)

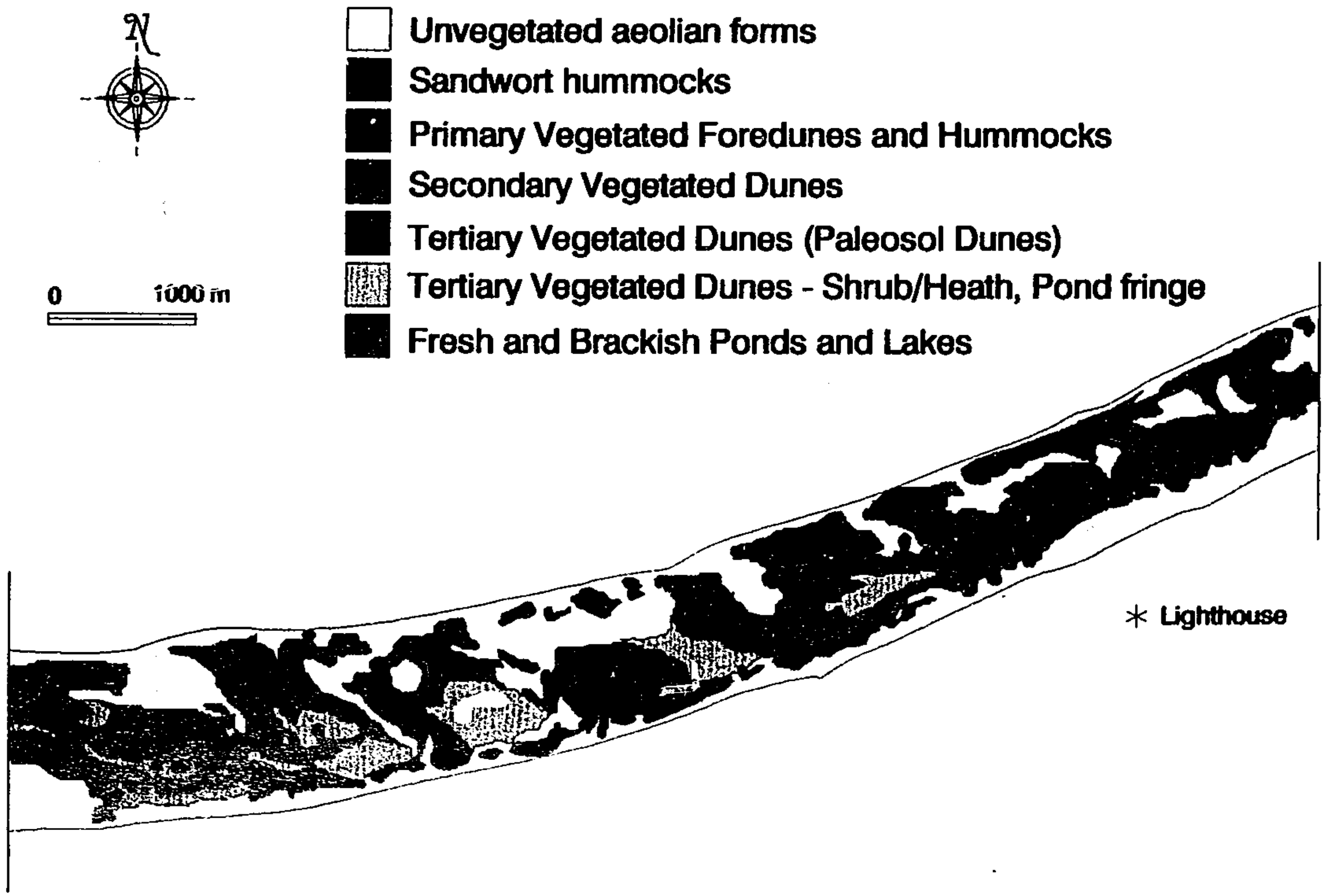
From Bald Dune to East Light the migration of parabolic dunes can be traced. There are many changes in the configuration of blowouts, some being infilled while new ones are eroded. In places the foredune is completely eroded and large areas of the established ridge deflated. In other areas there is growth of new ridges.

The parabolic dunes can be easily traced in the 1952 and 1981 photographs. At the present time there are parabolic noses which are avalanching over the vegetated dunes behind them. These are recognizable from the north beach as the bald dunes. The bald dunes are the result of wind from a number of directions moving sand up the slopes, however they respond to the force of the storm wind. They are therefore a combination of parabolic nose and dome dunes. The average orientation of the axes of the parabolic dunes is 296°. The resultant wind direction is 279°. The orientation of the dunes is close enough to the resultant to determine that the parabolic dunes are the result of the present wind regime.

In the 1952 photographs it was possible to see up to 3 phases of parabolic dune advancement. The nose of the oldest phase could be traced on the south beach while the nose of the current phase was moving east-southeast from the north beach. The most easily recognizable parabolic dunes were located at the east end of the sandy plain. They may be traced for about 6 km east of this location. They ranged in size from only about 100 m across to over a kilometre across the nose of the parabolic. This measure is taken across the width of the nose from the outside edges.

In the 1981 photographs, the pattern of parabolic dunes is more complex.

FIGURE 3.7. The Broad Dune Plain is made up of the most extensive cover of dunes on the island. Large parabolic shaped foredunes separate areas of secondary vegetation, and blowouts reach into the centre of the area. There are also large unvegetated dunes which are cascading onto the vegetation cover. The Grand Canyon area is at the east end of the island. It differs from the area just to the west in that the parabolic forms are much more difficult to discern and the topography is becoming less complex.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Unvegetated aeolian forms
Sandwort hummocks
Primary Vegetated Foredunes and Hummocks
Secondary Vegetated Dunes
Tertiary Vegetated Dunes (Paleosol Dunes)
Tertiary Vegetated Dunes - Shrub/Heath, Pond fringe
Fresh and Brackish Ponds and Lakes
* Lighthouse

Because these photographs are in colour, it is easier to recognize the noses of the parabolas and it is possible to trace parabolic dunes in the ridge north of Wallace Lake. The parabolic dunes also extended as far east as the end of the main dune ridge. The other main difference between the 1981 photographs and the earlier ones is that the parabolic dunes which are moving from the north beach toward the east-southeast are advancing over the older ones, cannibalizing them and using the sand stored within them. The older ones are held in place by the vegetation.

The Grand Canyon Area (Fig. 3.7)

The "Grand Canyon" is the trough-shaped interdune located at the east end of the island near the East Light. This feature is present in the 1952 and 1955 photographs as well as in the 1971 and 1981 photographs. In the earliest photographs, the lighthouse is located on a ridge of sand which forms the easternmost wall of the trough. In the 1950s, the lighthouse keepers house and outbuildings are present. By 1971, although the house still stands, the outbuildings have been destroyed by sand burial. The lighthouse is still in the same location. In the 1981 photographs, the lighthouse has been replaced by the present light which is located just northwest of the old light on the north dune ridge. The old light was undermined and toppled downslope (when?). In the 1952 and 1955 photographs, the north dune ridge extends from the blowout east of east light westward for about 4 km. It was relatively unbroken except for a few small blowouts. The trough was more broken. Ridges like the one the lighthouse was located on extended across the trough from the north to the south ridge breaking it into smaller troughs which could only be accessed from the north beach.

By 1971, the small blowouts had increased in width in the ridge. The troughs had also become more continuous, with steeply scarped walls and sharp crested, fairly regular ridges. The ridge on which the lighthouse was located was fairly wide, but was rapidly eroding. The floor of the canyon was wet indicating that deflation had reached the water table. There were some small dunes on the floor of the canyon, but these were very immature with a very sparse vegetation coverage.

In the 1981 photographs, there is a marked change in the amount of vegetation which covers the dunes, both in the established ridges and in the embryo and foredunes. The foredune on the seaward side of the north ridge is very well established and vegetated with a dense cover of Ammophila breviligulata and Lathyrus maritimus. Many of the ridges have been deflated allowing access from trough to trough without returning to the north beach. The blowouts have increased in width in the north ridge. The floor of the canyon is no longer wet indicating that there has been enough deposition to raise the level above the water table. The old light is gone and the new one has replaced it. The scarps which had been quite sharp in 1971 are blanketed by an apron of sand and the crests are more irregular indicating that erosion is occurring.

Overall, this part of the island reflects both erosion and deposition. There is deposition of sand in the depressions and erosion on the crests. Aprons of sand blanket the scarps bringing the steep angles closer to the angle of repose. Deposition is occurring on the seaward face of the north ridge. The sand here is quickly colonized by the Ammophila breviligulata and Lathyrus maritimus cover. The east-wall of the canyon is being eroded with sand being deposited on the south ridge.

3.2 Dunescape

The dunes on Sable Island exist as a complicated mix of vegetated and unvegetated sand in forms which may have undergone as many as three, if not more, changes in morphology and physical environment. The following section locates and describes the different dune types and presents a classification of the dunes which should make it easier to understand their development.

3.2.1 Location and Type of Dunes

There are many different types of dunes present on Sable Island. They range from small, simple unvegetated ripples and ridges to larger complex vegetated dunes and then to the great unvegetated domes which are called Bald Dunes. The ends of the island are unvegetated except for the Sandwort hummocks (Fig. 3.8 A/B). These dunes are small in comparison to other

FIGURE 3.8A. Sandwort dunes on the West Spit. These hummock-shaped dunes are low and often overwashed.

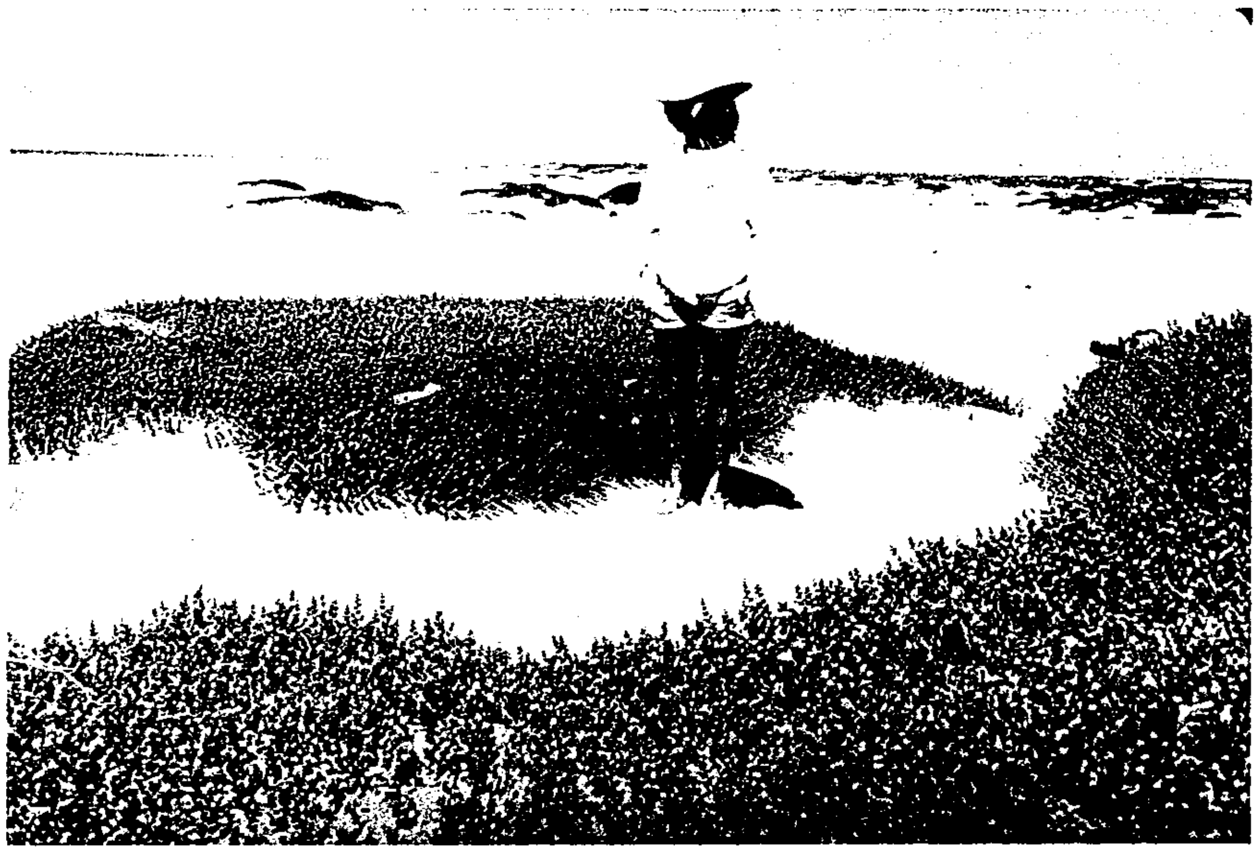


FIGURE 3.8B. Sandwort hummocks start as small dunes which grow by lateral spread of the surface vegetation.

dunes on the island and they are in constant change, easily trapping sand blown up from the exposed beaches, and just as easily eroded by the storm waves which frequently wash over them completely. More than 49% of the surface of the island is unvegetated. However, this does not mean that the surface is free of dunes. Usually, wind ripples cover the entire unvegetated area. Granule ripples develop in the unvegetated hollows between established ridges where the wind is accelerated (Fig. 3.9). The wind ripples are very flat in comparison to their length and are made up of fine to medium sand. The granule ripples are much taller in proportion to their length and consist of mostly granule sized particles, but there may be some very coarse sand (Fig. 3.10).

On the sandy plain between the end of Lake Wallace and Three Mile Dune, larger ripples develop. These may be as much as a metre in relief and are spaced 5 to 10 metres apart. They are oriented normal to the length of the island and appear on aerial photographs. Cameron (1965) noted their presence on his terrain map. They often have wind ripples superimposed on top of them. Other simple, unvegetated aeolian forms include sand sheets and strings which are carried by the wind over the surface of the beaches and plains, being deposited when the wind slows locally.

There are other complex, unvegetated, aeolian deposits which include aprons and ramps made up of sand deposited at the base of the established dune ridges in a zone of low flow velocity. Aprons may be as thin as a few

FIGURE 3.9A. Granule ripples in a dune hollow. These ripples develop where the wind accelerates through the passage in the dunes. This passage, located on the west end of the main dune ridge, is typical of many in which the ridges develop.

FIGURE 3.9B. A close-up of granule ripples in a blowout. These granule ripples have wind ripples migrating obliquely over them.

FIGURE 3.10. Granule ripples are not as flat as wind ripples and in this example have wind ripples migrating across their stoss sides. They are composed of granule sized particles, especially at the crests, and of coarse sand. Sunglasses are used for scale.

grains of sand or as thick as a metre or more. Ramps are usually much thicker and form at a lower angle than aprons. They assist in the movement of sand from a low area to the top of the established dune ridges. There are also large shadow dunes which are deposited behind obstacles such as small vegetated mounds or large dunes. The size of the shadow dune depends upon the size of the obstacle behind which it is deposited (Fig. 3.11).

Still larger, and more complex are the precipitation ridges and dome dunes which are not vegetated. They may however, bury over vegetation, but it is not absolutely necessary for their development. They are on the order of metres and tens of metres tall and located, for the most part, towards the eastern end of the island.

Roughly 50% of the island is vegetated. Of that, 38.51% is made up of dunes. The other 12.32% consists of pond and pond edge, and Wallace Lake. Upon first examination the vegetated dunes are quite complex. However, when taking a closer look, one can see that they can be subdivided into: 1) foredunes and marram hummocks which develop at the base of the established ridges, and depending upon the amount of wind shelter and inundation, will be continuous or divided into hummock forms; 2) ridges, which may be either transverse to, or parallel with the wind direction and are sparsely to densely covered with vegetation; 3) blowout infill and remnant dunes; 4) parabolic dunes; and, 5) undulatory dune ridges with a paleosol. Because it is so difficult to study these dune forms at first glance, it is grains of sand or as thick as a metre or more. Ramps are usually much thicker and form at a lower angle than aprons. They assist in the movement of sand from a low area to the top of the established dune ridges. There are also large shadow dunes which are deposited behind obstacles such as small vegetated mounds or large dunes. The size of the shadow dune depends upon the size of the obstacle behind which it is deposited (Fig. 3.11).

Still larger, and more complex are the precipitation ridges and dome dunes which are not vegetated. They may however, bury over vegetation, but it is not absolutely necessary for their development. They are on the order of metres and tens of metres tall and located, for the most part, towards the eastern end of the island.

Roughly 50% of the island is vegetated. Of that, 38.51% is made up of dunes. The other 12.32% consists of pond and pond edge, and Wallace Lake. Upon first examination the vegetated dunes are quite complex. However, when taking a closer look, one can see that they can be subdivided into: 1) foredunes and marram hummocks which develop at the base of the established ridges, and depending upon the amount of wind shelter and inundation, will be continuous or divided into hummock forms; 2) ridges, which may be either transverse to, or parallel with the wind direction and are sparsely to densely covered with vegetation; 3) blowout infill and remnant dunes; 4) parabolic dunes; and, 5) undulatory dune ridges with a paleosol. Because it is so difficult to study these dune forms at first glance, it is

FIGURE 3.11. Large shadow dunes which form in the lee of the established dune ridges. There are three shadow dunes in this photograph. The first extends from the dune in the centre of the photograph, the second extends from the top right to intersect the base of the first shadow, and the third is in the foreground.

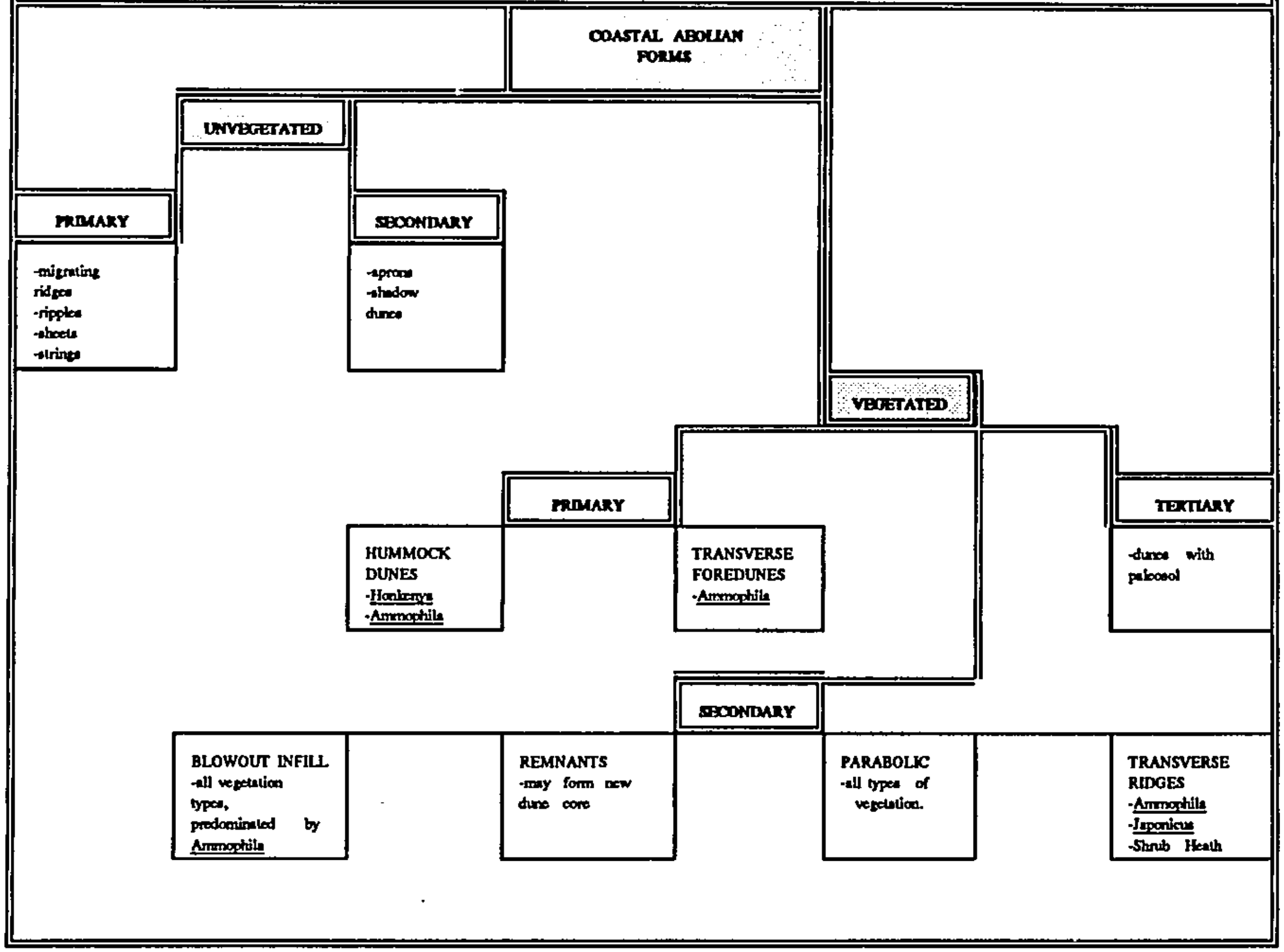
necessary to develop a classification scheme in order to determine the manner in which this landscape developed.

3.2.2 Dune Classification

A classification which combines processes with amount and type of vegetation and dune morphology is presented in Table 3.1. The Sable Island dunes are first divided on the basis of whether or not they are vegetated. Unvegetated forms include primary and secondary features. The development of primary features involves wind action and the movement of sediment over a surface. These features include ripples, both sand and granule, migrating ridges, sand sheets and sand strings. Migrating ridges and the sheets and strings develop as the wind moves over a large open stretch of sand such as the beach or large washover surfaces and the sandy plains. Development of the secondary features involves deposition of sand on or behind a pre-existing form or obstacle.

Secondary forms include aprons, ramps, shadow dunes, domes and precipitation ridges. Aprons and ramps develop at the base of larger established dunes masking wavecut or wind-scoured scarps. An apron is a thin (6 to 15 cm) cover of fine sand on a dune scarp. It develops as sand cascades downslope and comes to a rest on the scarp surface. Ramps also develop by the movement of sand downslope, but include slumped blocks of the dune which have moved downslope and have become buried. Ramps are thicker

TABLE3.1. Classification of Aeolian Forms on Sable Island, Nova Scotia



than aprons and build out from the dune base, eventually bringing the shape of the ridge closer to angle of repose after scarping.

Shadow dunes were first defined by Bagnold (1941) and their aerodynamics described by Hesp (1981). He found that these pyramid shaped forms develop best in the lee of semi-permeable, semicircular roughness elements which cause flow separation in the vertical as well as the horizontal plane. A cluster of Ammophila breviligulata or some other beach grass has this shape. The base of the shadow dune forms in an area extending from the plant (or obstacle) edges to some point downwind on the centreline. That point is the point at which the sand transport velocity is reached. Sand grains follow a semicircular path from the plant edge to the centreline. A linear ridge forms as a crest on the centreline because the vortices are fixed. Hesp (1981) observed that the height of the shadow dune is determined by the width of the plant (obstacle) and the angle of repose of the sand. Since dune growth stops when the sand transport threshold is reached, the core region diminishes in size with distance from the plant until the threshold is reached. At that point, flow becomes streamwise and sand is carried away downwind. Shadow dunes range in size from very small features behind plants or behind flotsam at the high tide line, to large permanent features behind dune ridges.

Precipitation ridges involve the deposition of sand on to vegetation. They are akin to the nose of parabolic dunes except that the nose of the parabolic dune consists of avalanching sand which need not be burying vegetation. Also, the precipitation ridge can be made up of sand which settles out of saltation (grainfall) rather than sand which has avalanched (grainflow). Whereas, the parabolic dune is usually made up of sand which avalanches down the nose. Dome dunes are associated with parabolic dunes. The exact mode of development for these is not known.

The second major division in the classification categorizes aeolian forms which are vegetated. This vegetated class may be broken down into primary forms which develop from beach sand during one phase of vegetal growth; secondary forms which involve a change in vegetation; and, tertiary forms in which changes in vegetation are associated with changes in the stability of the system, for example the development and subsequent breakdown of a paleosol beneath a changing plant cover.

Vegetated primary dunes are those which develop around primary colonizers like Cakile edentula and also around Honkenya peploides and sparse Ammophila breviligulata just above the storm line. When development occurs around a primary colonizer, the dune will exist only as long as the colonizer is alive. Once the plant dies, the sand blows away. However, if the form is invaded by another species, then it may continue to develop into a secondary, vegetated aeolian form. If the primary form develops around sparse or isolated marram clusters, then, if the location is favourable and sand supply is adequate, it will develop into a secondary aeolian form. Morphologically, the primary vegetated aeolian form may be divided into either transverse foredunes which develop at the base of pre-existing dune ridges or hummock dunes which develop in more open areas. These latter are a response to a different set of processes than the former.

Hummocks develop in more open locations where wind speed and direction are more variable and the form is subject to periodic inundation during storms. Such a location is the sandy plain near 3 Mile Dune (Fig. 3.2). The hummock shape can withstand inundation better than a continuous ridge shape because the breaks between hummocks allows the movement of wind and water around and between them. A single ridge must absorb the wind and wave energy and in so doing may be eroded significantly. For the most part the hummock shapes are vegetated with sparse Ammophila breviligulata. However, on the spits, the hummocks are vegetated with Honkenya peploides. Sandwort hummock dunes on the spits make up 1.05% of the morphology of the island, while marram hummocks make up 1.36%. Transverse foredunes develop in more protected locations, for instance where winds from only one direction are significant enough to erode the ridge, or where the ridge is protected from significant winds by another, larger ridge. This is the case along most of the north beach on Sable Island. The foredune ridges are dominated by a cover of sparse Ammophila breviligulata, but they may also be inhabited by other primary colonizers such as Cakile edentula and Honkenya peploides. Vegetated foredune ridges make up about 20.46% of the morphology of the island.

Secondary vegetated aeolian forms are more complex than the primary ones. They are a response to changing vegetation types which are a response to changing processes of erosion and deposition in a local area. Secondary forms include parabolic dunes and retention ridges, transverse ridges (established foredunes), blowout infill, and dune remnants. These make up about 12.20% of the morphology of the island.

Transverse ridges are a response to prevailing winds depositing sediment amongst the sparse to Dense Marram communities at the base of a dune ridge. Although there may be fluctuations in the wind regime, the prevailing winds are responsible for the linear morphology of the transverse dune which develops at the rear of the source beach. As accretion continues, the dune interferes with the flow of the wind over the feature and the amount of sediment deposited decreases. This change allows for other species of plants, such as those within the Dense Marram/Beach Pea communities and Shrub Heath communities, to invade, changing the morphology and sedimentary structures within the dune ridge. The dunes beneath a Sparse and Dense Marram community have an undulating topography with local highs located around plants or plant clusters. As the surface becomes vegetated with Lathyrus maritimus, the topography becomes less undulatory. Beneath a shrub heath canopy, the surface is almost planar.

When the force of the wind is concentrated in one area or when the vegetation cover is broken at a particular location, the dune ridge may become eroded locally. When this occurs deflation may continue downwind, developing into parabolic dunes or precipitation ridges, or a deflation basin may develop. Deflation basins are also known as blowouts. These are often bowl shaped and are common on Sable Island. They are particularly notable from the north beach southward into the dune ridge. The blowouts may deflate to the water table, but often the process changes from deflation to deposition as the wind changes direction with the changing seasons. When deflation ceases, the blowout may begin to infill and, if the infill becomes vegetated, the break in the ridge may heal. This change is reflected morphologically in a localized topographic low and sedimentologically by an arc shaped erosion surface with regularly shaped beds of sand deposited above it. Blowouts may occur in any vegetation type, but the marram communities are particularly susceptible to damage and deflation.

Parabolic dunes are a response to a dominant wind direction eroding the sand in the arc of the parabola while the arms of the dune are tied down by vegetation. These often result from a blowout migrating downwind. There are a series of parabolic dunes on the eastern half of the island. These are oriented with the nose moving in a southeasterly direction. In many of the dunes the central portion has been deflated to the water table leading to the formation of freshwater ponds. The nose of the parabola is either spilling onto the south beach or has been blown through to the sea.

Remnant dunes are those dunes which remain after the sand around them has been eroded. These dot the blowouts along the north shore of the island. Very often they are the remainder of a wall between two deflation basins. Depending upon their location, these pinnacle-shaped sand bodies either erode completely or become the core of a new dune. If they are in a particularly sheltered location, then it is possible that they would not be completely destroyed by the wind and deposition may occur burying the remnant and preserving this as the core of the dune.

Tertiary dunes are those in which vegetation change has slowed so as to be almost non-existent, the cover is stable and interrupts the air flow around and through it causing a change in the rate of sedimentation which causes renewed vegetation change. On Sable Island, these undulatory dunes contain a paleosol. They make up 3.45% of the surface of the Island. In these, vegetation change occurs and secondary vegetated dunes develop. With increased vegetation coverage the surface of the dune changes and receives decreasing amounts of new sediment. This creates a more stable environment and promotes the development of a paleosol. The paleosol is a layer of sand and concentrated organic material. Due to some driving force, rapid sedimentation occurs burying the paleosol under a blanket of sand. This blanket may be unvegetated, or it may be vegetated and take the form of a primary or secondary dune discussed above. This dune type is analogous to McKee's (1979) complex dune in which one or more simple dune types are superimposed or overlapped.

3.3 Summary

The vegetated dunes on Sable Island, Nova Scotia are a complex mix of dune forms and vegetation types. The morphology of the dunes is variable with elevation increasing toward the east and dune belt width changing along the length of the island with changes in the width of the beaches and the Sandy plain. Over the period of the historical record, the vegetation cover has changed locally with the growth and development of new foredunes and with the erosion of dune scarps.

Changes on the spits have been dramatic with alterations in their length which are on the order of 12 km of erosion. The west end is dominated by scraping of the seaward faces of the dunes and subsequent development of vegetated foredune ridges. The Wallace Lake area is dominated by erosion, with the disappearance of the southern dune ridge over the period of the historical record and the record of photographic coverage. Changes on the broad dune plain are the result of the passage of parabolic dunes through the area. This is marked by the changing position of Bald Dunes and blowouts. The Grand Canyon area is marked by changes in erosion and deposition which are associated with changes in vegetation cover.

The dunes are be classified based upon processes, vegetation and morphology. The classification is first divided on the basis of the presence or absence of vegetation. Unvegetated dunes may be primary or secondary. Primary dunes develop due to wind action and the movement of sediment over a surface. Secondary dunes involve the deposition of sand on or behind a pre-existing obstacle. Vegetated dunes may be primary, secondary, or tertiary, depending upon the type of vegetation, its frequency of change, and the stability of the dune.

CHAPTER 4

SEDIMENTOLOGIC SIGNATURES OF PLANT COMMUNITIES ON SABLE ISLAND

4.1 Introduction

This chapter documents the relationship between plants, plant clusters and plant communities, and the deposition within, around and in the lee of them, in order to document the influence that plants have on the physical structures in vegetated sand dunes on Sable Island. The chapter records the sequence of structures which is deposited as sand is laid down through a vegetation canopy. The vegetation canopies of the different plant communities (see Chapter 1.3) affect the manner in which the sediment is deposited because the plants are different morphologically. For example, the Sandwort community (Honkenya peploides) grows in tight hummocks or mounds on the most exposed portions of the island. There is little space between the plants in a mound and this is reflected in the surface which is preserved beneath the canopy. The Sparse Marram and Dense Marram communities are made up of plants which grow in clusters in less compact forms than those of Honkenya peploides. These grasses grow upright with little space between plants in a cluster, but with as much as a metre or more space between clusters in the

Sparse Marram community. The spacing between plant clusters is minimal in the Dense Marram community.

The Sparse Marram community is the first to establish on the sandy surfaces. Seedling establishment is rare, while propagation of new plants vegetatively by rhizome growth and tillering out is the most common and successful means of reproduction (Maun 1984, 1985). The plants within these communities interfere with the wind stream immediately above the cluster base causing increased deposition locally to the plant, while having little effect on the deposition of sediment over the surfaces between clusters. The result of this pattern of sediment capture is that there tends to be mounds of sediment which accumulate within and immediately around the marram clusters, while there is little increase in the depth of sediment between clusters. Because Ammophila breviligulata thrives with burial, there is a positive feedback between burial and plant growth. Over time the cluster sends out many rhizomes which tiller out into numerous plants which continue to capture sediment until a new dune develops. The dune may take the form of a hummock or a ridge depending upon other physical influences.

Over a period of time, the Sparse Marram community may be replaced by the Dense Marram community. This community is more lush and contains a higher species diversity than the Sparse Marram community. The differences between the Dense and Sparse Marram communities which are important in this study, have to do with the spacing of the plants and the dominance of certain species within the community. The plants and plant clusters within the Dense Marram are more tightly spaced than those within the Sparse Marram community. There is a greater ability to capture sediment over a wider area in the Dense Marram than in the Sparse Marram community. Also, although Lathyrus maritimus is present in the Sparse Marram community, it is a lesser species. In the Dense Marram community it is one of the important species. This is important because this plant has a different growth pattern than the Ammophila breviligulata. Lathyrus does not grow upright like Ammophila, instead it grows as a vine along the ground which results in deposition of beds which are more irregular than those deposited around the more upright Ammophila.

If the surface remains stable enough over a long enough period of time, then the cover may become that of the Shrub Heath community. This community is made up of woody species which grow upright and spread over a large area. Dominance of species varies from site to site and can be any of the following: Empetrum nigrum, Juniperus communis, Myrica pensylvanica, Rosa virginiana, Vaccinium angustifolium, and Calluna vulgaris. Because the surface is covered with the woody leaves and stems, there is an abundance of organic material available which stains the sand. The community spreads over a large area and so the deposits are relatively laterally continuous and tend to be horizontal.

The sedimentologic signatures of the different plant associations have been proposed. These consist of the plant or plants, their remains, and the structures and stratification around them. A plant itself consists of the organic material which is the result of the burial of stems (the main axis of a plant which bears the leaves, buds and flowers), leaves, roots (the organs which anchor the plant in the ground and do not bear leaves and buds), rhizomes (thick underground stems carrying buds from which new plants develop), and tillers (shoots arising from the base of the stem). This organic matter may be in the form of stains, fibres, or flakes of the original plant, and may occur as an amorphous stain or as the stain of the plant in growth position. Often the outer layer of the roots is removed, leaving only the inner potion which appears string-like in the deposit. This is the decorticated root. Woody plants are those which contain wood or lignin and non-woody plants are the herbaceous plants which are fleshy rather than woody. Often the nodes of plants are preserved. These are the points on the stem from which the leaves or lateral branches grow. The nodes can be used to determine growth rates as in Ranwell (1972).

Sand is deposited within the plant cover and in the lee of the plants in laminae and beds. Seventeen sections were examined. Their locations are portrayed in Figure 4.1. The structures which develop in each of the different plant communities are examined and are presented in the following sections (section 4.2 through 4.5). The sub-sections have been organized according to the name of the plant community and depict the structures and stratification

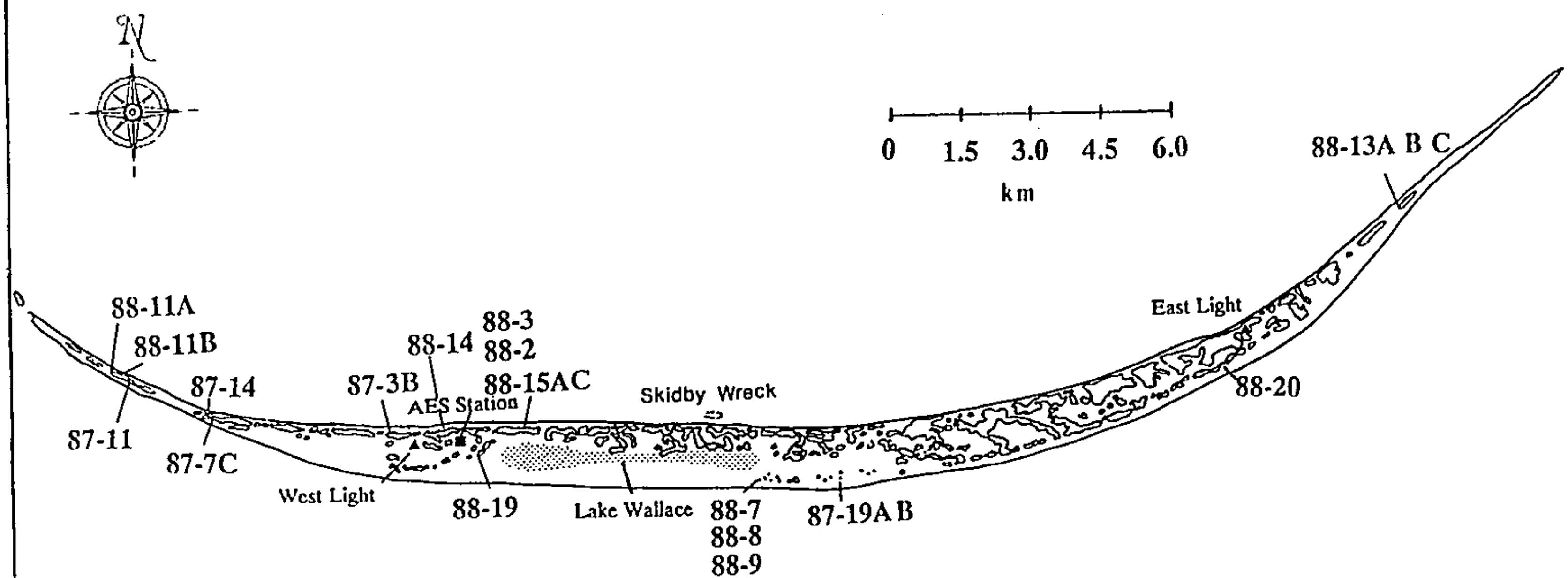


FIGURE 4.1. The locations of sections used to define the facies in the dunes on Sable Island.

which are unique to that community. The sub-sections are therefore the facies which represent the specific type of vegetation cover.

4.2 Sandwort Facies (Sites 87-11, 88-11A, 88-11B, 88-13)

Description

Site 87-11 (Fig. 4.2)

This site was located on the west spit and was dug into the Sandwort dunes which are periodically inundated by sea water. The dunes at this location seem to be in transition from purely Honkenya peploides to a combination of Honkenya peploides and Ammophila breviligulata. Individual clusters and mounds may be 10 to 20 cm above that surface. The basal portion of the dune consisted of low-angle beds of horizontal, parallel-laminated, fine sand with no evidence of vegetation. The beds truncated each other at low angles. At 25 cm from the section base, there was a 5 cm layer of un-laminated coarse sand. Topping this was a set of parallel-laminated, horizontal beds of fine sand which was about 10 cm in thickness. At that point the stalks and roots of Honkenya peploides were present within beds made up of parallel and wavy laminated fine sand with coarser pockets surrounding the roots of the plants. The amount of vegetation increased upward to the surface at about 70 cm.

Site 88-11A (Fig. 4.3A)

This section, located on the West Spit, consisted of a 25 cm set of beds

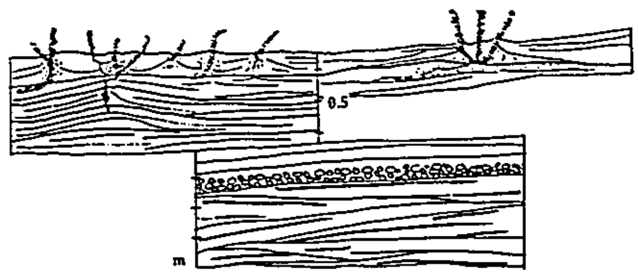


FIGURE 4.2. Site 87-11. This small sandwort dune was located on the West Spit. It was made up primarily of discontinuously laminated beds of fine sand with coarse lenses and layers. Beds warped upward around plants.

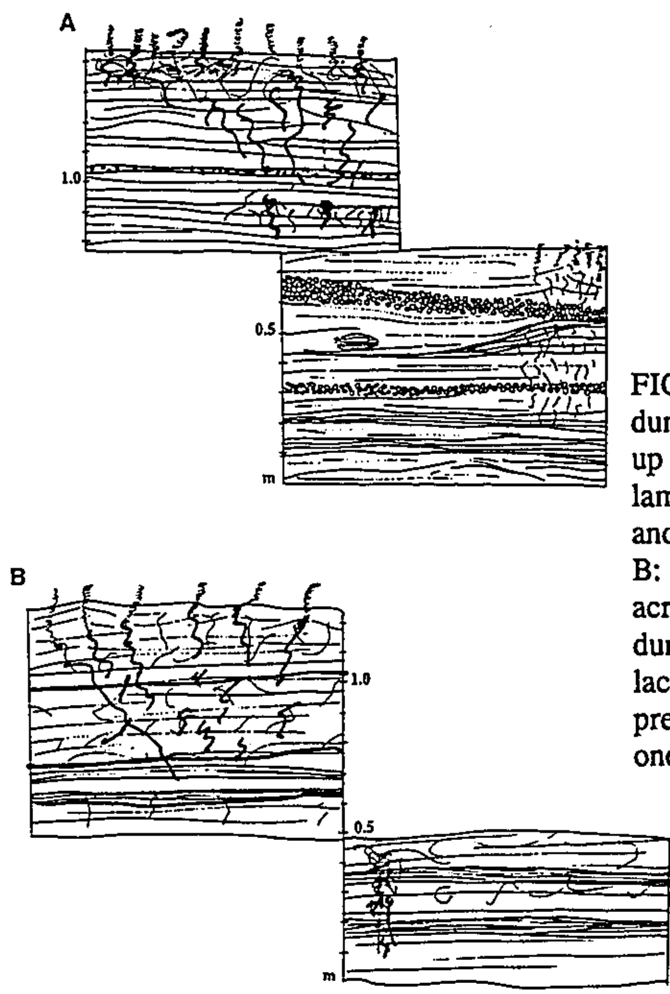


FIGURE 4.3A. Sandwort dune on West Spit made up of discontinuously laminated beds of fine sand and beds of coarse sand. B: Small sandwort dune across a blowout from the dune in 4.3A. This dune lacked the coarse layer present in the previous one.

of loosely packed sand separated by beds of very well packed sand. The basal low angle to horizontal bed of discontinuously laminated sand contained little evidence of vegetation. It extended from the base of the section to about 10 cm. A 5 cm bed of tightly packed parallel-laminated sand topped that bed. This pattern repeated once and was topped by loosely packed, laminated, uniform grain-size, fine sand containing decaying plant material. A 4 cm bed (at 30 cm) of coarse sand covered this surface. Above the coarse bed, was a bed of discontinuously laminated fine sand. In the left part of the section above the coarse bed at about 45 cm, there was a lens of heavy minerals and very fine sand buried within the section. In the right part of the section was a concentration of decaying plant roots and stems. Halfway across the width of the section at 45 cm, there was a mound shape buried within the dune. This mound was associated with the concentration of plant material. It was truncated by a 10 cm thick bed of coarse sand which extended across the width of the section. Above the coarse layer the style of stratification was similar to that which was below. The right side of the section extended to the surface of the dune while the left side continued through a thicker portion of the dune, through another pit to the surface. It was made up of beds of discontinuously laminated sand which were separated by beds of tightly packed sand. At about 1.12 m live roots were encountered. These could be traced to plants which were living on the present surface 25 cm above.

Site 88-11B (Fig. 4.3B)

This section, also located on the West Spit, was made up of couplets of discontinuously laminated beds of uniform grain-size, fine sand separated by thinner beds of tightly packed parallel-laminated beds of sand. The first couplet extended from the base of the section to 20 cm; the second to 35 cm; the third to 65 cm; and, the fourth to 73 cm. From the base to 75 cm there was an increase in the concentration of decayed plant material. From 75 cm to the surface the sand is deposited in association with Honkenya peploides. Live roots extended downward from the surface to about 100 cm from the section base. The deposit is discontinuously bedded and there is abundant decaying plant material.

Site 88-13 (Fig. 4.4)

This site was located on the east end of the island. The dunes here were much smaller than the dunes on the west end. Three pits were dug into the side of the dunes. Each spanned a section from below dune base to the top of the vegetation. The sand within the sections is extremely clean, having little visible coating of any organic material.

The basal portion of the first pit (Fig. 4.4C) was made up of two couplets which consisted of 8 to 10 cm of loosely compacted sand topped by 1 to 3 cm of tightly compacted, parallel-laminated sand which extended to 25 cm. The next couplet was similar in that it consisted of about 8 cm of loosely compacted sand. However the top of the couplet was truncated by another bed

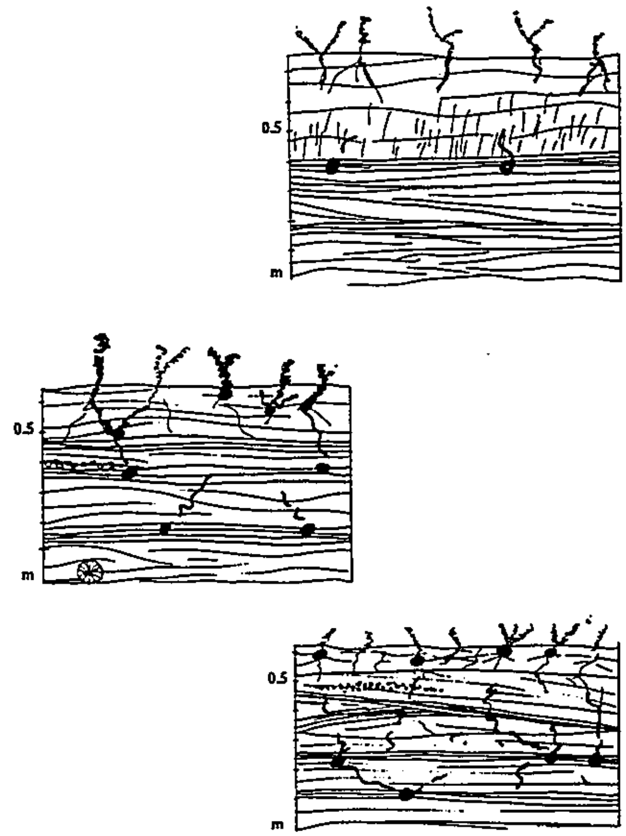


FIGURE 4.4. Site 88-13 was made up of three sections in small sandwort dunes on the East spit. These dunes were made up of couplets of sand which consisted of discontinuously laminated and discontinuously bedded, loosely packed, fine sand and more continuously bedded tightly packed sand, which were laid down in association with sandwort plants.

which was made up of tightly compacted parallel-laminated sand dipping toward 352° and which was in turn truncated by a bed of the same which dipped toward 172°. Topping this was a bed of discontinuously laminated sand which contained a lens of coarse material at the left side of the section. Some root material was present in this bed. This was overlain by a bed of discontinuously laminated sand laid down around the present surface cover.

The second pit was very similar (Fig. 4.4B). It was made up of a basal couplet of loosely compacted, discontinuously laminated sand which was topped by a bed of tightly packed, parallel-laminated sand. In the lower part of the section, there was the rotted remains of a buried branch. This was not in situ growth. The top of this couplet dipped 15°/262. Topping this couplet was 20 cm of wavy bedded, discontinuously laminated, loosely compacted sand. This was capped by 7 cm of parallel-laminated, tightly compacted sand. This, in turn, was overlain by a couplet of 8 cm of loosely packed, discontinuously laminated sand containing a lens of coarse material in the lets side of the section and 5 cm of tightly packed, parallel-laminated sand. The sand topping this couplet was deposited in association with the vegetation on the present surface. Beds were discontinuously laminated and broken up by the presence of plants. Laminae within the beds warped upward from all directions toward the plant. The top of the section was horizontal.

The third pit (4.3A) was slightly different. The bottom portion (0 to 45 cm) was made up of the loosely compacted, discontinuously laminated sand.

This was overlain by a set of discontinuous beds which deposited in association with dense Honkenya peploides vegetation, the remains of which were present in the section. The set was about 20 cm thick and changed gradually into the beds above. These were made up of laminated, loosely compacted sand in discontinuous beds with roots within them.

Interpretation

The Sandwort dunes on the east spit consist of sets of beds of grainfall and ripple lamination which are deposited around and within Honkenya peploides. The sections dug into these dunes revealed that the Honkenya peploides grew from a node at the surface. The sand buried that node to a certain level and then burial slowed (seasonally?). At that point the Honkenya peploides grew and spread over the surface. It was later buried to a second level. The portion of the plant between the two levels became internodal stem and then root. All the pits showed that the burial occurred first by predominantly grainfall and then by ripple migration.

The dunes on the west spit developed in a similar manner. Again there were sets consisting of beds of predominantly grainfall topped by ripple lamination. Often the ripple laminated beds contained an abundance of heavy minerals. At low densities, the Honkenya peploides had little effect upon the stratification. The sand simply buried the plant in situ. As density increased, the laminae within the beds began to warp upward around plant stems and often coarser grains were located adjacent to the stems.

The sand itself was remarkable. It was very clean and white reflecting the source. Sand in the Sandwort dunes is derived from the beach spits. It has been washed and abraded in the ocean before being deposited. In some of the larger dunes, the sand is often cannibalized from the foredunes which may have developed a paleosol. The sand grains would then be coated with organic material and be brown or yellow in appearance. Because these dunes tend to grow in hummocks, angles of dip increase from the horizontal underlying beach sand upward at the sides. Clusters of Honkenya peploides caused locally increased sedimentation and thus a mound of sand developed around the clusters. Beds at the edges of the hummocks have higher angles of dip than the centre of the hummocks. If the section is located within the centre of the hummock, then angles of dip may not increase from the base of the section to the top.

The sedimentologic signature of the Sandwort dunes consists of couplets of sand made up of sets of grainfall and ripple lamination. The couplets are relatively thin usually being less than 10 cm thick. They are laterally continuous for only a metre or so. The sand in the grainfall beds is very clean and white, while the sand in the ripple lamination may contain a high concentration of heavy minerals. If deposited within a sparse cover, the grainfall sets contain horizontally laminated beds. The laminae are very faint so as to be almost untraceable. As percentage cover increases, the likelihood of laminae within sets dipping at higher angles increases. The couplets may represent annual rhythms with the grainfall representing the spring and summer when an abundance of sediment is deposited by the more gentle winds within the growing Honkenya peploides, while the ripple lamination represents the winter when the plants are no longer growing and the winds are much stronger and so cannot trap the sand as effectively as in the summer months. The Sandwort Facies changes laterally into the Sparse Marram or Dense Marram Facies. The Sandwort Facies is illustrated in Fig. 4.5.

4.3 Sparse Marram Facies

The Sparse Marram Facies is divided into three sub-facies. All surfaces of the sections which were documented are covered with a Sparse Marram cover in which Ammophila breviligulata is dominant. The first sub-facies is the Marram Cluster which consists of sand deposited around isolated plants or plant clusters. The second sub-facies is the Marram Hummock which consists of larger groups of Ammophila breviligulata concentrated in an area. They are concentrated because the physical processes occurring in the area limit their spread. The third sub-facies is the Marram foredune facies which consists of linear bodies of sand laid down through the Sparse Marram vegetation.

4.3.1 Marram Cluster Sub-Facies (Site 87-3B, Fig. 4.6)

Description

This section was located above the paleosol in the sidewall of a blowout

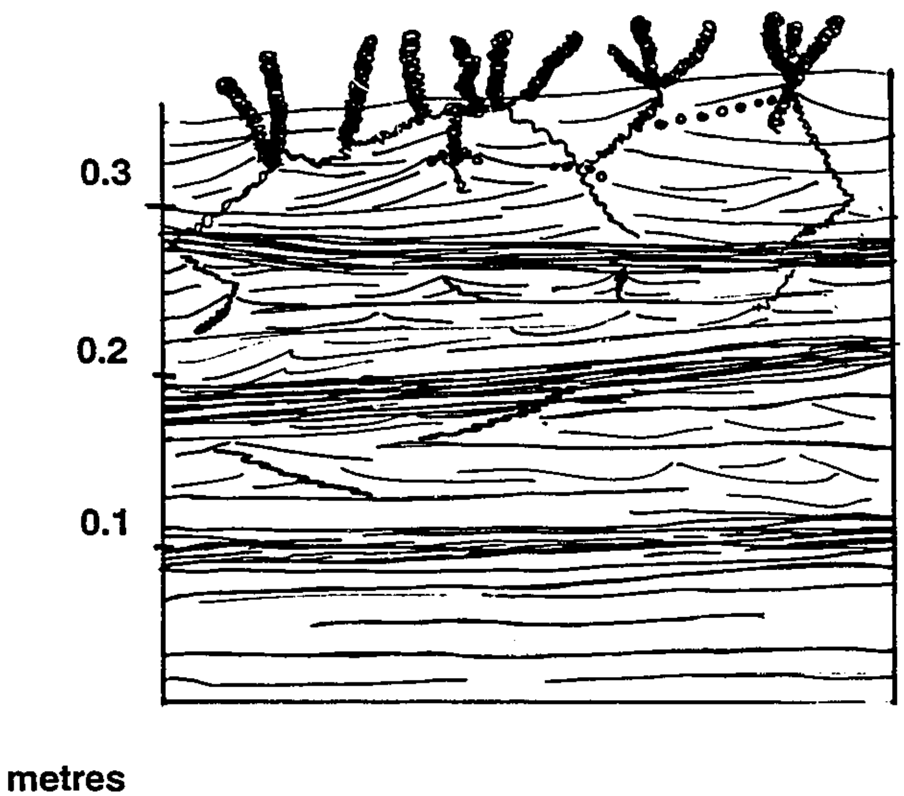
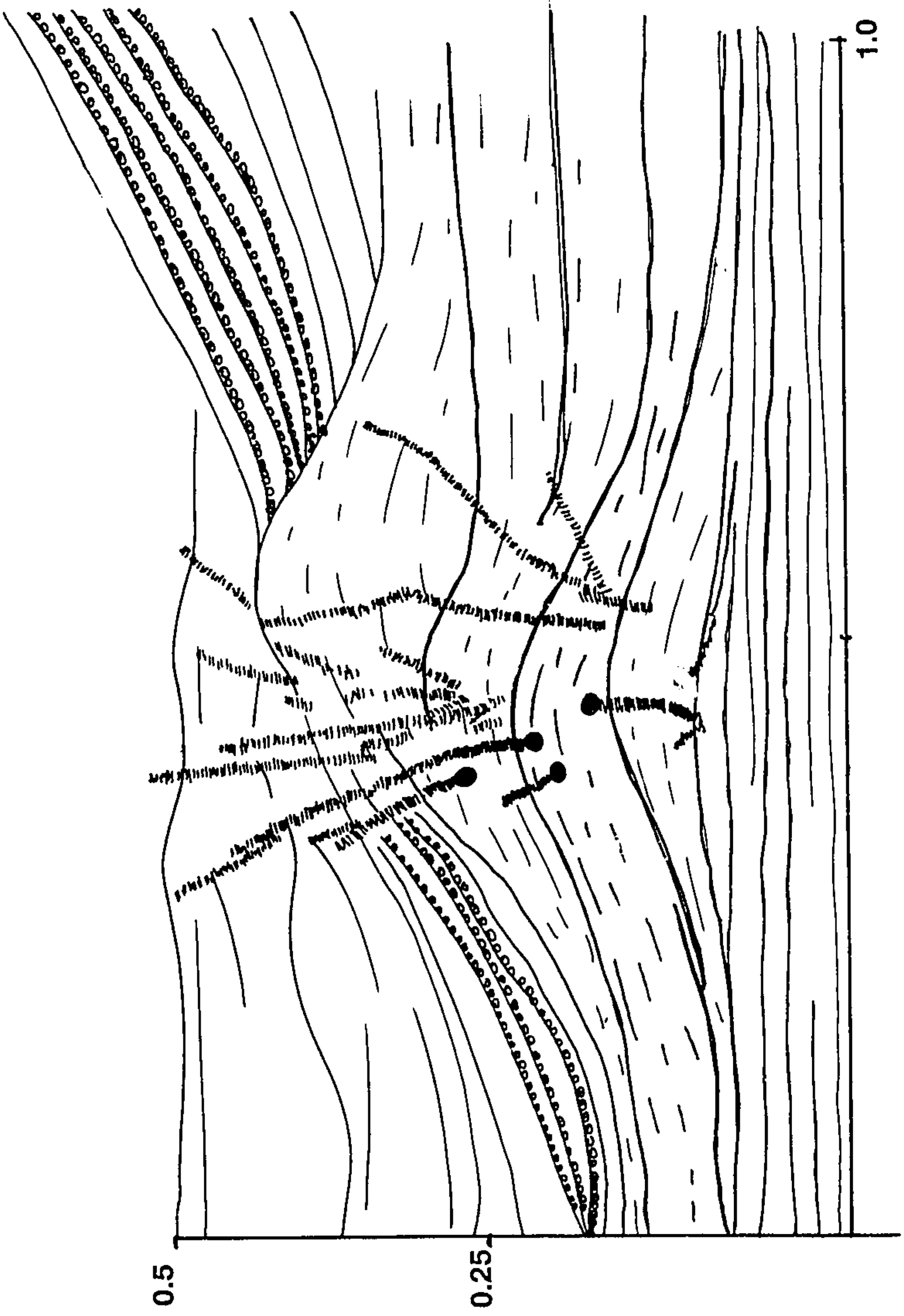


FIGURE 4.5. The Sandwort Facies consists of couplets of sand consisting of loosely packed, discontinuously laminated beds of fine sand and tightly packed, continuous beds of fine sand and heavy minerals. Root fragments were common and plants grew on the present surface. Beds warped upward to plant nodes and coarse grains were associated with previous surfaces.

FIGURE 4.6. The Marram Cluster Sub-Facies was made up of physical and biological structures. The stain of the plant cluster in the centre of the diagram was made up of the organic material left after the decay of the plant. In some cases, there ware decorticated roots and the fragments of stems. In this instance, the nodes of the plants were visible. The physical structures consisted of discontinuously laminated beds of fine sand. The beds warped upward around the plant cluster creating the hummock shape. Around 0.25 m, the angle of the beds was steep enough for grainflow. Topping the cluster was deposition dominated by grainfall and ripple migration through the vegetation cover.


0.5
0.25
1.0

(the same blowout as 87-3a). The section consisted of sand which had been deposited around a cluster of Ammophila breviligulata. The cluster had decayed and the remains consisted of the nodes of the plants, organic stains of the stems and leaves, and some plant fibres. The plant cluster had occupied a space which at the base was about 12 cm wide and at the top, 0.5m from the base, was 40 cm wide. The sand below the plant was roughly planar. The beds of sand within the plant stains were irregularly shaped and those around the plant sloped away in all directions. Also, beds at the outermost portions of the section were higher angled than those within the plant cluster, dipping 24 to 35°. The irregularly shaped beds dipped only between 0 and 13°. The higher angled beds existed in couplets of finer and coarser layers.

Interpretation

Before plants established in this location, there was nothing to create an obstacle for the wind. Therefore, the beds laid down in the area were roughly planar. However, once a plant cluster became established, it interfered with the wind stream, creating a zone of zero velocity within the cluster. Therefore deposition took place within the vegetation. The beds laid down were affected by the movement of the plant in the wind and also by the growth of the plant. These beds were irregularly shaped and loosely compacted. As the plant grew a hummock developed around it. Once the hummock developed, the sand deposited in the lee of this obstacle built upward into steeper beds until avalanching could occur. Between periods of avalanche, grainfall on the face of the slope allowed for the development of one part of a couplet. Avalanche downslope would not remove all of the material and the actual grainflow left by the avalanche would be the other half of the couplet.

The sedimentologic signature of the Marram Cluster consists of the stain of a plant cluster surrounded by first coarser grains and then a mix of grain sizes. The beds beneath the cluster are often horizontal. However, as the plant or cluster grows, the laminae or beds may up-warp around the obstacle. If a hummock develops, then avalanche beds may be present. Over a longer time period, all organic evidence of vegetation will fade. Therefore, the structures around the cluster will be indicative of the vegetation cover. Horizontal beds overlain by increasingly thick sets in isolated locations leading to a hummock-like form. The hummock may be large enough to cause the overlying beds to reach angle of repose. If this happens then avalanche beds may be present (Fig. 4.6). Marram clusters are a portion of the Sparse Marram Facies.

4.3.2 Marram Hummock Sub-Facies (Sites 87-14, 87-19A/B, 88-7, 88-8, 88-9)

Description

Site 87-14 (Fig. 4.7)

This section was cut in a small hummock-shaped foredune on the north beach, located about 20 m from the main dune ridge and 30 m from the

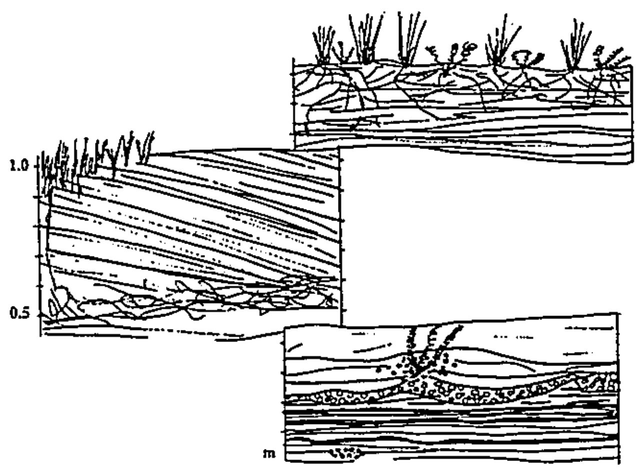


FIGURE 4.7. Site 87-14 was located on the north beach at the west end of the island. Coarse sand to granule sized sand were associated with the plant node and marked a previous surface. Plant fibres and decorticated roots were present throughout the section.

waterline. The dune was made up of 3 sets of laminated fine sand, granules, and plant material. The 20 cm basal set contained 4 beds of laminated fine sand with no remains vegetation. The remains of a single plant cluster occurred at about 30 cm associated with a bed of coarser (almost granule size) sand which pinched out away from the plant. Around the plant the sand was laminated and dipped away from the cluster in all directions. The second set began at 0.5 m. There was a 10 cm thick mat of decaying vegetation and roots overlain by about 40 cm of laminated sand which dipped 29°/90°. A rhizome connected the mat below to the plants which were living on the surface. The third set was toward the centre of the hummock where there was another 30 cm of laminated sand with an abundance of Ammophila breviligulata and Honkenya peploides roots within it. The dune was capped by a combination of the two plants.

Site 87-19 A/B (Fig. 4.8A/B)

These hummocks were located on the Sandy Plain just east of Three Mile Dune. Two hummocks which were less than 2 m in height and less than 5 m in diameter, were examined in detail. The first (87-19A) was about 1.5 m high. The structures at the base could not be logged in detail because digging caused collapse. At the base of the section there appeared to be a discontinuously laminated bed of fine sand which was topped by an irregular surface. At 10 cm a stain of a single plant was located in the left side of the section. Topping this was a bed of parallel-laminated, fine sand containing no

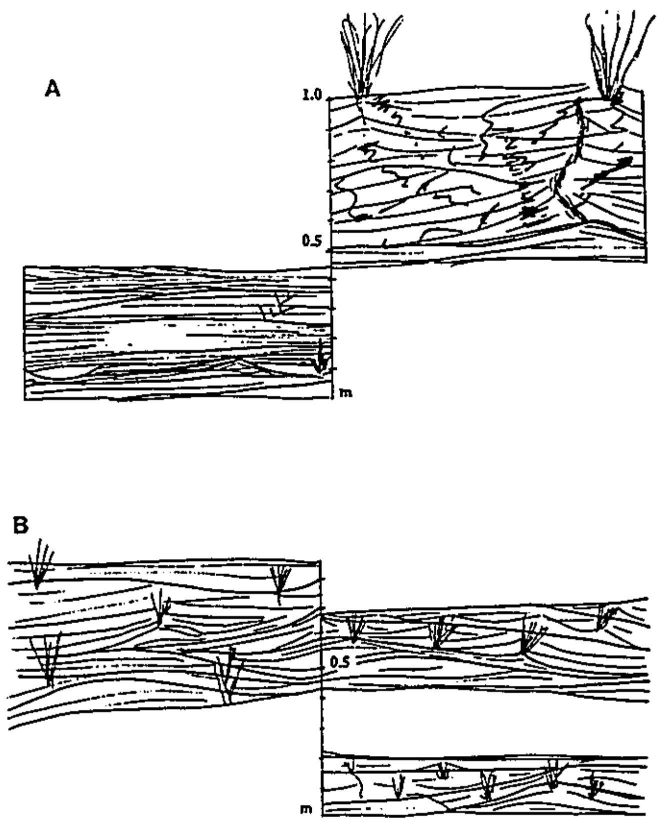


FIGURE 4.8A. Site 87-19A was one of two hummock dunes east of Three Mile Dune. It was made up of discontinuously laminated beds of fine sand containing fragments of decaying roots and broken pieces of plant stem and decorticated root material. Bedding planes marked periods of non-deposition (previous dune surfaces). B. This section was more well vegetated than the one above. It contained many pieces of plant material which had not yet decayed. The discontinuous beds rose from all directions toward the plants and were made up predominantly of fine sand.

evidence of vegetation which extended upward to 25 cm. From 25 cm to 50 cm, beds were more discontinuous. The stain of a decayed plant and some plant fibres were located at the left side of the section at about 30 cm. Beds truncated each other at angles ranging from as high as 21° to as low as only a few degrees. The sand was loosely compacted and faintly laminated. From 50 cm to the top of the section there was an increasing concentration of plant material. This consisted of the organic stains of stems and leaves, as well as plant fibres. The beds around the plants were discontinuous and wavy parallel, fine sand. A single plant stain could be traced from 55 cm to 95 cm. Beds warped upward around the plant and laminae followed the bedding planes.

The second hummock was more well vegetated than the first (Fig. 4.8B). The basal portion contained shells and plant debris. The structures, for the most part, were the same as those contained within the top of the first hummock, except for the bed between 20 and 40 cm which was made up of clean sand with few traceable laminations. Above and below this bed were beds of sand deposited in association with vegetation. Beds were wavy and parallel and laminae within the beds did not follow the bedding planes. There was an increase in the spacing of plant clusters from the base to the top of the section.

The Sandy Plain Sites (West of 3-Mile Dune)

These sites were located on the south side of the island on the Sandy Plain, just west of three mile dune. The dunes were small (usually less than 3.0 m in height and not more than 10 m in diameter) and were located in an area that was covered by water in the older photographs of the island. The dune at 88-8 was longer and wider than the one examined in site 88-7, but it was not as high. Site 88-9 was the smallest of the three examined in this location.

Site 88-7 (Fig. 4.9)

The section consisted of parallel-laminated horizontal beds at the base of the dune. These show no evidence of having been vegetated. The first evidence of plant growth occurred at 20 cm elevation. The base of a bed here contained a lens of sand around a plant node. There was increasing evidence of the presence of vegetation upward. Between 35 and 60 cm there was a series of four plant clusters. These were located in progressively higher beds. The beds were low angle and dipped in different directions. With increasing elevation the dip of the beds became less steep. The beds also become more continuous throughout the dune. Vegetation coverage became more dense upward.

Site 88-8 (Fig. 4.10)

Site 88-8 was made up of discontinuous beds of fine sand at the base. With increasing height, these became more continuous and evidence of

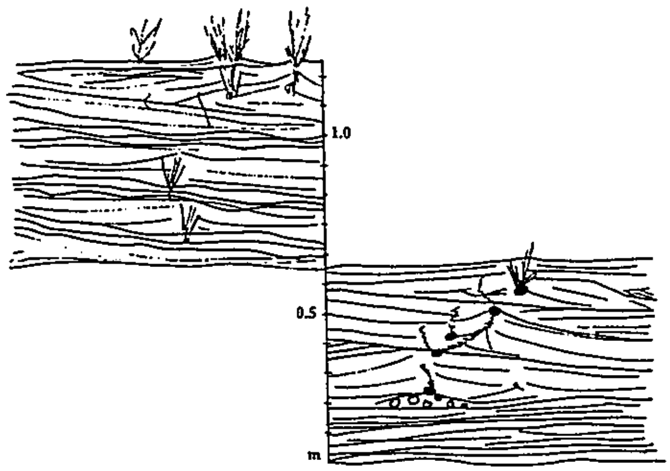


FIGURE 4.9. Site 88-7 was located on the Sandy Plain west of Three Mile Dune. It was made up of discontinuous beds of laminated fine sand deposited around plants and plant clusters. These were separated by more continuous beds of well compacted, fine sand. At 2.0 m a coarse lens was associated with the plant node.

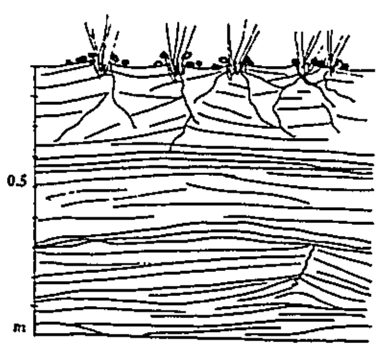


FIGURE 4.10. Site 88-8 was also made up of the discontinuous beds of fine sand separated by the more continuous beds of well compacted, fine sand. There was less vegetation cover and fewer plant fragments buried within the mound at this site than at the previous one.

vegetation occurred. There were couplets which consisted of a bed of uniform grain size, loosely compacted, parallel-laminated sand topped by a bed or beds of parallel-laminated tightly compacted sand. The surface was covered with Ammophila breviligulata whose roots penetrated about 20 to 30 cm into a bed of sand. Laminae within the bed dipped away from the stem of the plants. On the surface, there was a lens of slightly coarser sand around each plant.

Site 88-9 (Fig. 4.11)

This section consisted of discontinuously laminated, fine sand in beds laid down in association with vegetation. The beds were fairly horizontal, but the laminae within them dipped at various angles away from plant clusters. Evidence of plants was sparse. Between 20 and 30 cm a stain of a plant stem could be traced across the left side of the section. Above this the beds were more irregular with laminae dipping in various directions.

Interpretation

The structures in the hummock dunes are the result of the colonization of beach sand by plants such as Ammophila breviligulata. These plants take root and become obstacles to the wind, leading to the deposition of sand in the shadow area downwind. With changes in wind direction, the shadow area changes and the dune tail re-orients itself. The superimposition of the dunes over time leads to the development of the basal portion of the hummock. As the depth of sand around the plant increases, the dip of the surface beds

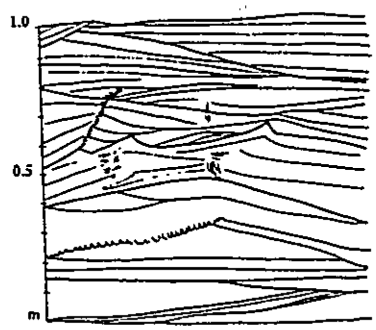


FIGURE 4.11. Site 88-9 was the most exposed of the hummocks being on the seaward side of the plain. The structures reflected the location of the dune in that there were truncations of beds by others being deposited by winds blowing from another direction.

increases. While that dip is below the angle of repose of the sand, the predominant processes depositing the sand are ripple migration (especially in the case of the heavy minerals) and grainfall. As the plant cluster grows, it spreads laterally and plant density increases. With increased density, the deposition of sand becomes affected by the presence of the plants. Beds and laminae become contorted around single plant clusters because these interfere with the wind velocity causing fluctuations which result in the variation of processes (ripple migration and grainfall) across the surface. Coarse layers and lenses are due either to the migration of granule ripples in areas where the streamlines are concentrated or to grainflow on slopes which are steep enough for this process to occur. With increased plant density, the sand surface is sheltered from the wind velocity and grainfall predominates. This leads to the deposition of more continuous beds of loosely compacted clean sand.

The Marram Hummocks are a sub-facies of the Sparse Marram Facies. This sub-facies consists of beach lamination at the base changing to aeolian deposition upward (Fig. 4.12). The aeolian deposition is associated with the presence of Ammophila breviligulata, and is composed of two units. The first unit is made up of sets of discontinuous beds of sand laid down around vegetation. There are coarse lenses of sand around the nodes of the plants with laminae of finer sand dipping away from the node in all directions. These are topped by continuous a bed of parallel-laminated, fine sand. This unit ranges from 20 to 40cm thick.

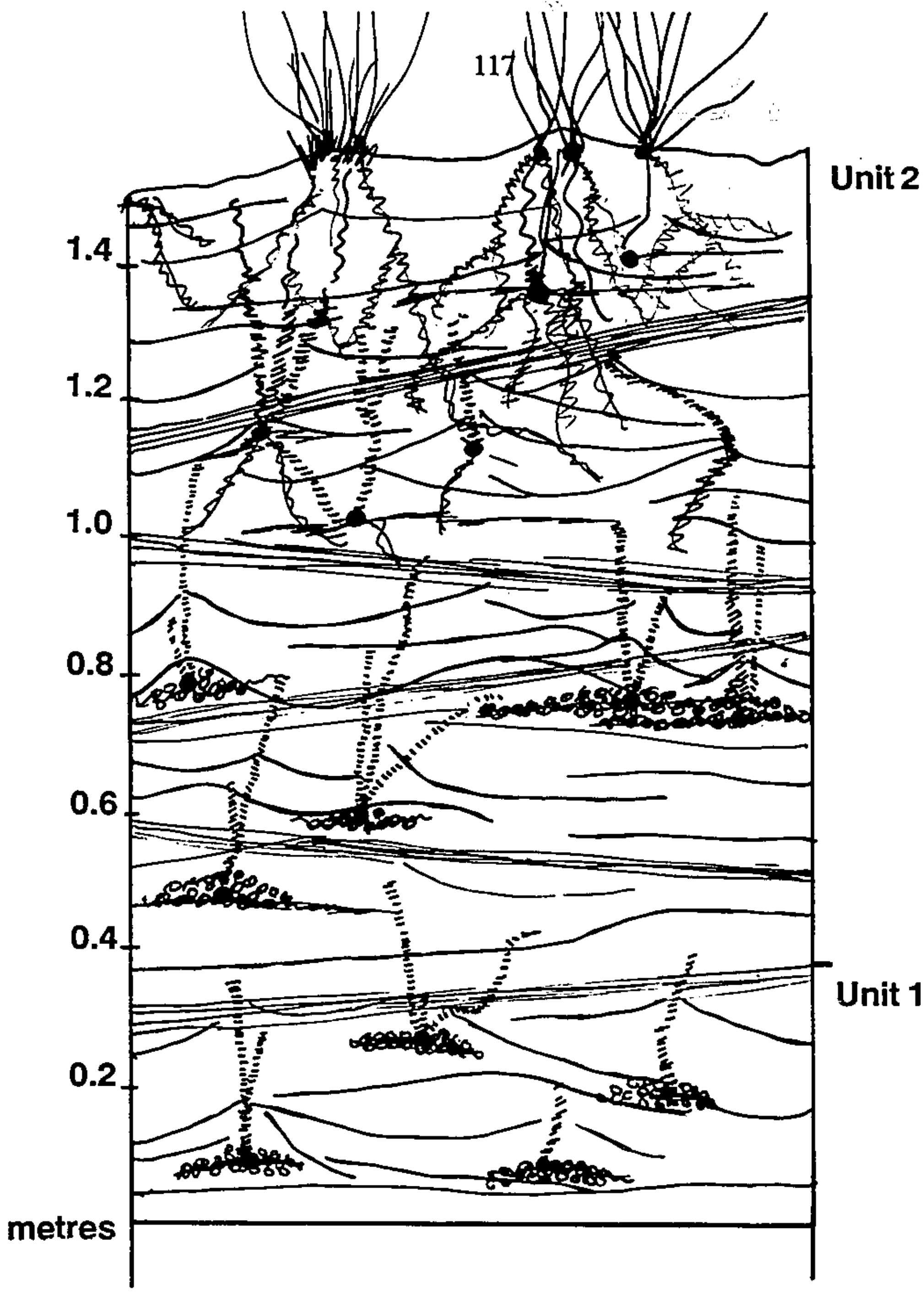


FIGURE 4.12. The Marram Hummock Sub-Facies consists of beds fine sand deposited around and in the lee of marram clusters and plants.

The second unit is made up of fine to medium sand laid down in alternating sets of tightly and loosely compacted sand. With increasing elevation in the dune there is an increase in plant density, an increase in the area vegetated, a decrease in dip at the centre of the hummock and an increase in dip at the sides of the hummock, and the deposition of more continuous beds. This unit may be a metre or more in thickness.

This sub-facies is located along the beach in areas where there is a strong influence from storm winds as well as the tides. It changes laterally into either Sparse Marram or Dense Marram facies.

4.3.3 Sparse Marram Foredune Sub-Facies (Sites 87-7C, 88-19, 88-15A)

Description

Site 87-7C (Fig. 4.13)

Site 87-7c was located on the western end of the established dune ridge on south beach. It was part of an old dune from which an apron extended onto the beach. The lowest portion (0.5 m) of the section was made up of discontinuous, parallel-laminated beds of sand with heavy minerals which dipped 29°/220. From 0.5 to 1.35 there were three beds of uniform grain size sand which ranged from 12 to 42 cm in thickness. Each was separated from the one below by a thin layer of more compacted sand, heavy minerals and coarse material. The bed at 1.0 m height contained the remains of a plant in growth position. The root system and the stem could be traced upward

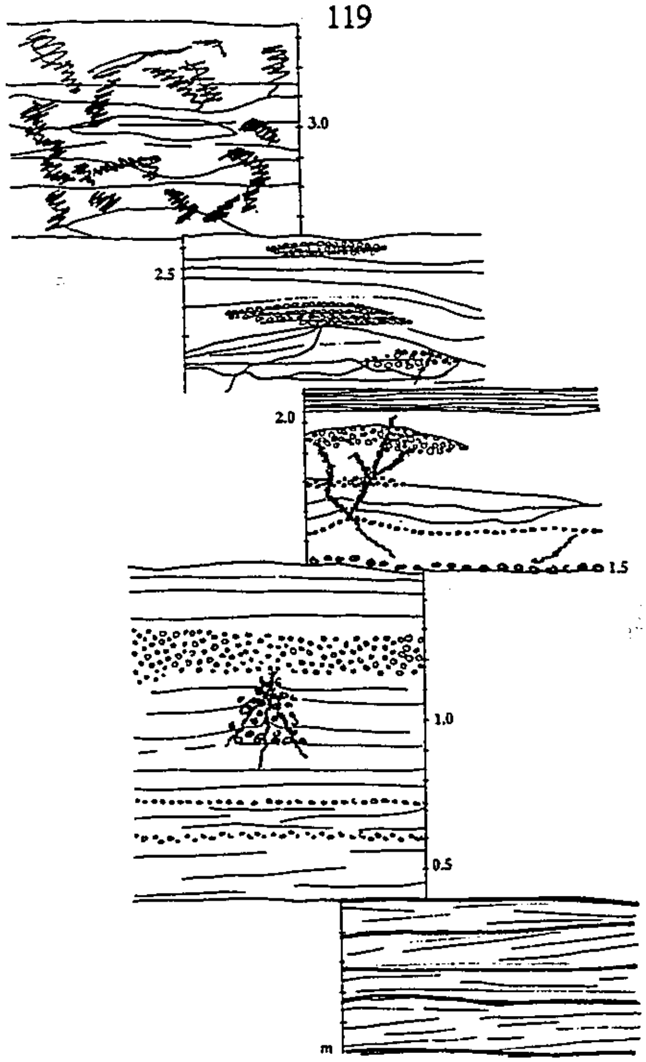


FIGURE 4.13. Site 87-7C consisted of beds of sand deposited in sparse marram cover. Coarse lenses were associated with the nodes of the plants. The presence of plants increased upward from minimal at the base to sparsely covered at the surface. Plant stains were common at the top of the section.

through the bed. However, at the bed boundary, the plant was no longer visible. The sand surrounding the plant was slightly coarser than the sand in the beds below. The bed at 1.4 to 1.6 m consisted of parallel-laminated beds of uniform grain size sand. From 1.6 to 2.73 the section was made up of beds of uniform grain size sand deposited around plants. Bed boundaries were marked by coarse layers. Lenses of coarse sand occurred at the nodes of plants. Individual plants could be traced for a metre or more. Plants existed singly or in clusters and were spaced at about 1 m intervals.

From 2.73 upward to 11.44 m the evidence of vegetation became more difficult to distinguish. Sets of discontinuously laminated beds of fine sand were deposited. These were highly organically stained and contained fragments of decorticated roots. Individual plants could not be detected, however, the influence of vegetation was pronounced in the organic colouring in the sets.

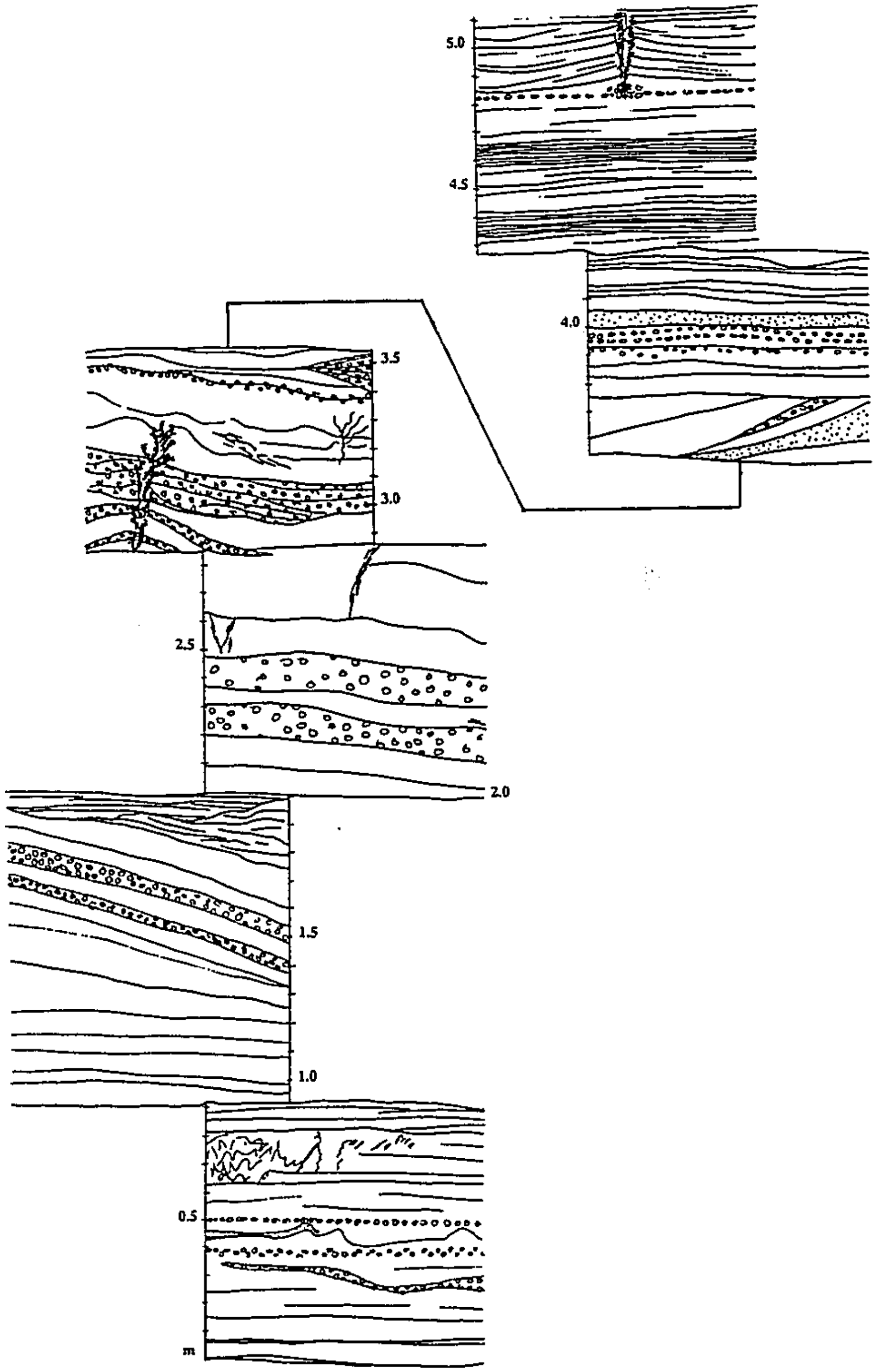
Site 88-19 (Fig. 4.14)

This site was located just east of the Atmospheric Environment Service Station entrance onto south beach within a large dune which was covered with Sparse Marram and had a well developed apron. The lowest portion of the dune (section base to 1.99 m) was made up of beds of sand of varying grain sizes with little evidence of vegetation. Coarse lenses and layers were present and slumped material from above had been buried within the section (65-82 cm). Dips ranged from 5° to 36° oriented toward 95 through 355°. From 1.99

to 3.54 m, there was abundant evidence of vegetation. Plant stains and fibres were in growth position. Discontinuously laminated sand was deposited with various dips (the general trend of the dip was less than 5°) around the plants. There was a change at 3.54 m. From here to 3.75 m a set of cross-beds of various grain sizes was deposited. Then from 3.75 upward to the top of the dune, the stratification style was similar. Sets of beds of discontinuously laminated sand were deposited around vegetation. A single plant was traced for a metre or more starting at 6.16 m. Sets were horizontal and the beds generally followed the set boundaries while the laminae within the beds were wavy around plants.

Site 88-15A (Fig. 4.15)

This site was located on the north beach about 0.5 km east of the Atmospheric Environment Service Station. The section was made up of parallel and wavy laminated beds. The first 12 cm consisted of parallel-laminated, horizontal beds capped by a layer of heavy minerals. From 12 cm to 32 cm, there was parallel-laminated sand at the base changing upward to un-laminated, coarse sand at the top. From 32 cm to 50 cm the deposit was similar to that immediately below, but was capped by laminated coarse sand. The contacts between beds were sharp, but non-erosive. From 50 to 80 cm there were parallel, horizontal laminations capped by discrete coarse layers. A plant node was located to the left of the exposure at the origin of a coarse layer. Above this (80 cm to 115 cm), the deposit was similar to that which


5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
m

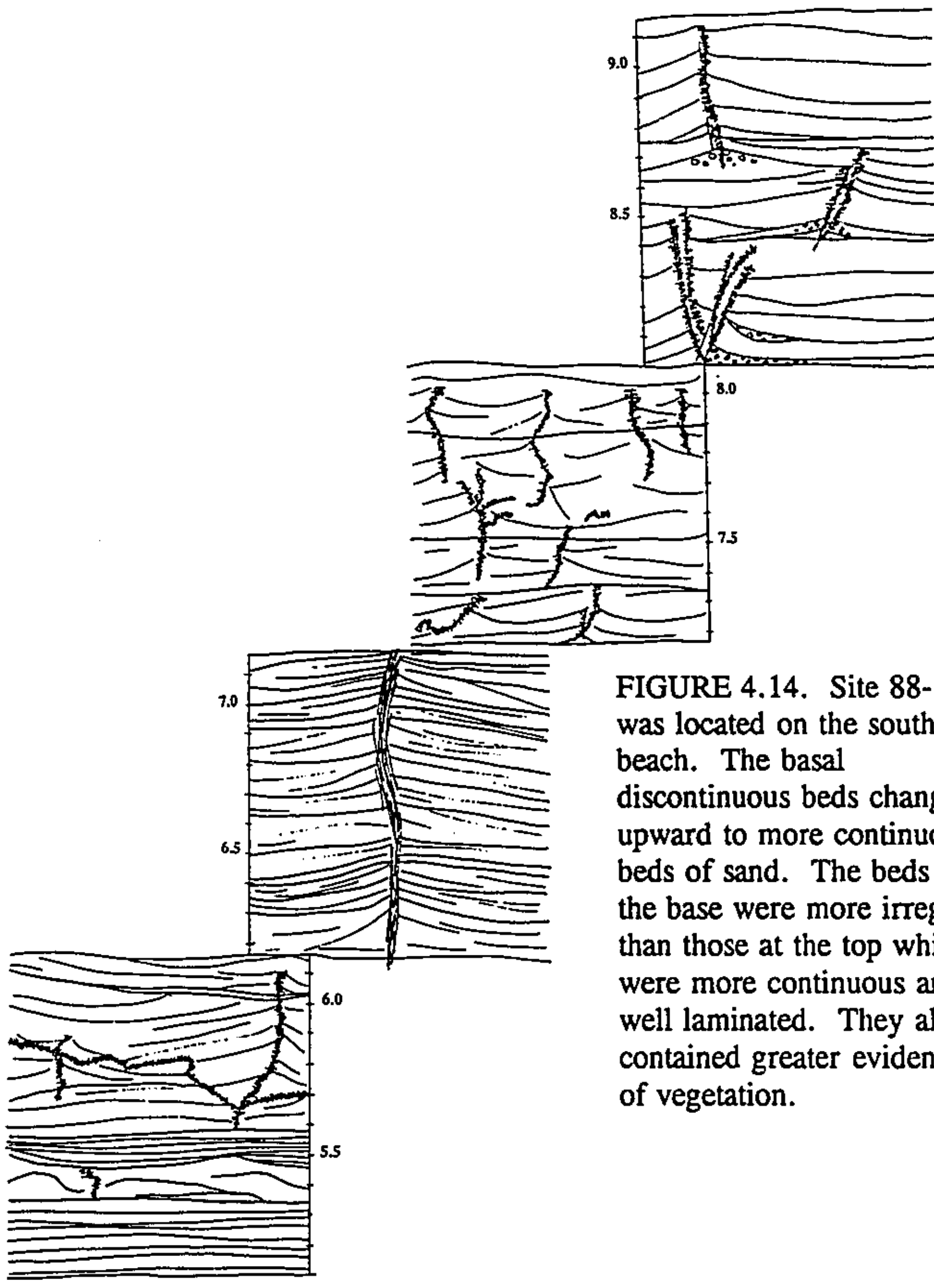


FIGURE 4.14. Site 88-19 was located on the south beach. The basal discontinuous beds changed upward to more continuous beds of sand. The beds at the base were more irregular than those at the top which were more continuous and well laminated. They also contained greater evidence of vegetation.

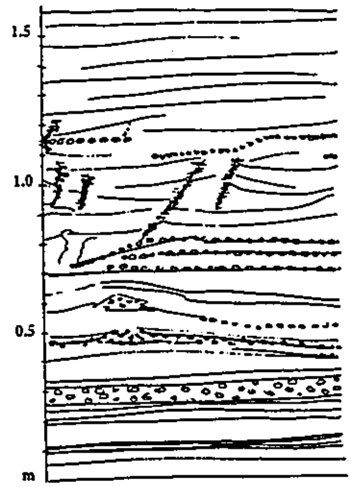


FIGURE 4.15. Site 88-15A is made up of fairly regular beds with a greater concentration of coarser material in the lower part of the section. Upward there is a greater concentration of evidence of vegetation and finer sediment.

was immediately below it, but with plants stains in association with coarse layers. From 115 to 158 cm there was a thick deposit of parallel-laminated, horizontal beds. There were no coarse layers visible. The top of the dune was at 218 cm. The 60 cm from 158 cm upward appeared to be a continuation of the same type of stratification. Because of the instability of the sand it could not be logged in detail.

Interpretation

In Site 87-7c, the first metre of the section (Unit 1) is made up of sand deposited in a relatively unvegetated area. Unit 2 consists of the next 2 metres of the section. Here vegetation is starting to be seen in the section, but it has made little impact upon the structures. Unit 3 is made up of that group of structures from 1.6 m to 2.73 m where the vegetation has made an impact on the structures. Laminae within the beds warp upward toward the plant stems and coarse lenses are associated with the roots and stems. The next unit (Unit 4) consists of the beds in which the stems of the vegetation are no longer traceable. There is plenty of decorticated root material present. The bed boundaries are not well marked and laminae are vague. The sand within the bed is stained a yellowish brown colour by the organic material present. In Site 88-19, there are only three units present. The basal unit is similar to Unit 1 above. This unit in which there is little evidence of vegetation extends to 1.35m. Unit 2 in which vegetation is just beginning to have an impact extends from 1.35 m to 2.85 m. The next part of the section (2.85 to 3.54 m), is Unit

3. From 3.54 to 3.75 m the sand is rapidly deposited with no evidence of vegetation. It is similar to the sand in Unit 1. Unit 2 is again present from 3.75 to 5.6 m. From 5.6 to 8.10 the vegetation has an impact upon the laminae within the beds and so this portion is Unit 3.

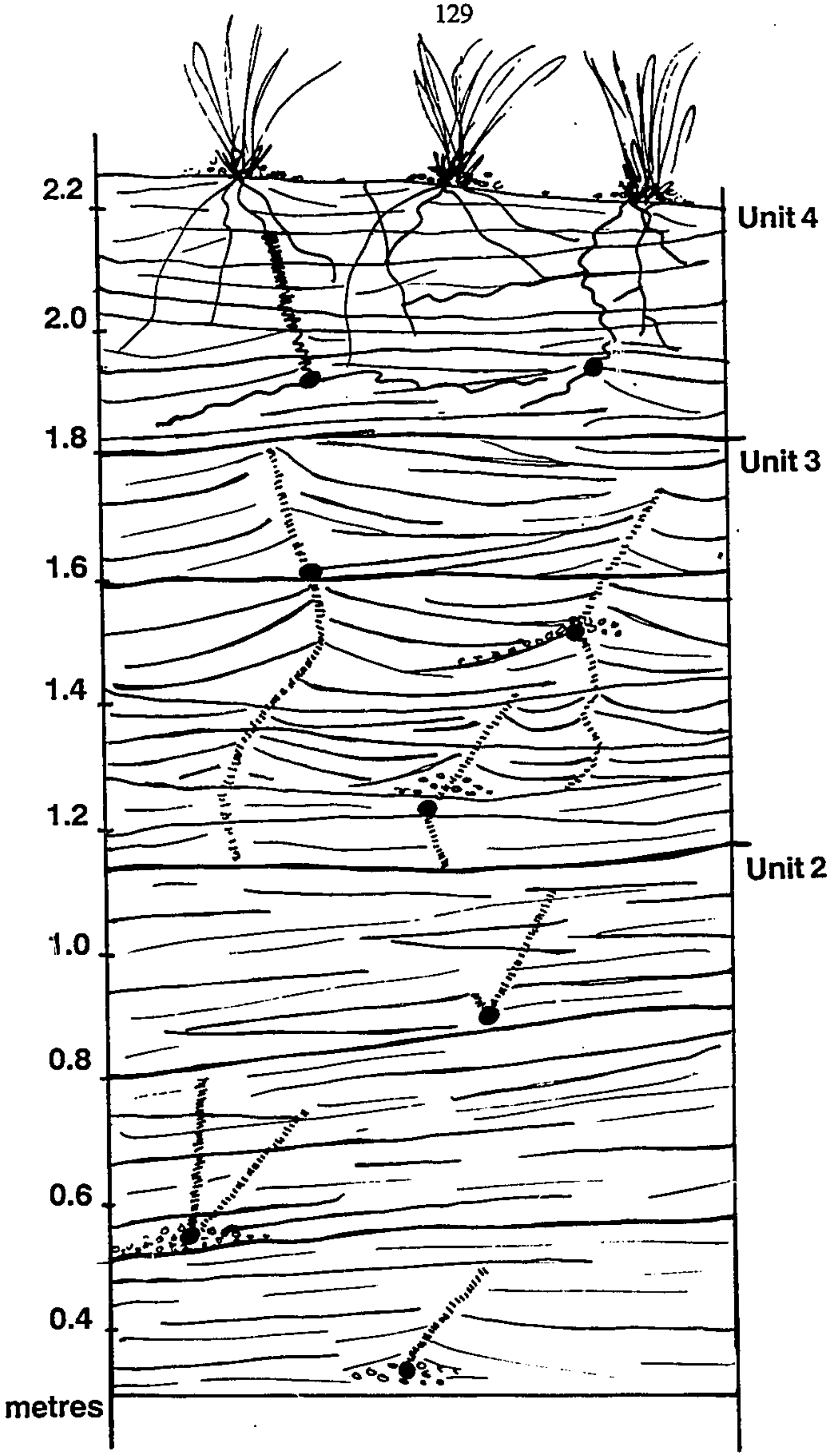
In Site 88-15A, there are only two units present. Unit 1 is the base of the section to 0.25 m. The remainder of the section is Unit 2. The sedimentologic signature of the Sparse Marram community is depicted in Figure 4.16. The sand deposited in Unit one is that which is laid down as the dune first forms. The obstacle behind which the sediment is deposited may be present laterally in the dune or it may have been an isolated plant cluster upwind of the beds examined. There are a variety of grain sizes present and, at Site 88-19, a block of slumped material which was buried and became part of the unit.

Unit 2 is the result of the deposition of sand around and within very sparse vegetation. Single plants may be more than 1 metre apart, or may exist as small isolated clusters at the same spacing. Sand is deposited within and around the plants in discontinuous laminae. The beds reflect the changes in process across a surface - grainfall close to plant clusters where the wind velocity is decreased by the presence of the plant, and a mix of grainfall and ripple deposition away from the clusters where the wind blows more freely. Beds of slightly coarser material may occur. These are predominantly the result of ripple migration. Laminae within beds are not affected by the presence of the plants. Bed boundaries mark the periods when deposition was at a minimum.

In Unit 3, the bed boundaries became more clearly defined. Laminae within beds are now disturbed by the plants which have become more closely spaced, being less than a metre apart. In some areas, clusters of Ammophila breviligulata (or the associated species in this community) may be spaced only centimetres apart. The spacing between individual clusters may be a metre or more, but the cluster itself is much larger (a metre or more in width) than in Unit 2. Sand deposited within the plant cluster is laid down in sets of laminae which warp upward to the plant. Closer to the plant cluster, the laminae are difficult to see, eventually fading out only centimetres from the stem. Often slightly coarser grains are present at this location.

In Site 88-19 there is a section which is not like the sediment in Unit 3. It located between 3.54 and 3.75 m. This set of cross-beds is the result of the rapid deposition of sand with no evidence of vegetation. This set was probably the result of a slump laterally on the dune surface which later allowed avalanche and then grainfall to bring the surface back to horizontal. From 3.75 to 4.0 m there was again rapid deposition with the migration of larger forms such as granule ripples which left behind the coarse layers. There was an abundance of sediment in very high winds before vegetation started to take hold once more at 4.26 m. Here Unit 2 is again present. The topmost part of the section is Unit 3.

FIGURE 4.16. The Sparse Marram Foredune Facies is made up of four units. The first represents the dune which developed in unvegetated sand, the second represents a very sparsely covered dune, the third represents the dune when vegetation has begun to spread over the surface, and, the fourth represents the dune in which some organic staining of the sand has occurred.


2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
metres
Unit 4
Unit 3
Unit 2

Although the portion of Site 88-19 from 5.6 m to the top of the section is all classified as Unit 3, there is a change in the style of stratification. From 5.6 to 6.16 m the sand was rapidly deposited while the vegetation kept pace with burial. The beds are large, being more than 40 cm thick, and the discontinuous laminae warp upward toward the plant stem. The sand within the beds is not tightly packed and the surface is unstable. From 6.16 to 7.16 m the rate of deposition slowed allowing the development of beds which were less than 10 cm thick and tightly packed. The surface is very stable. From 7.16 m to the top of the section there is a return to the rapid deposition which allows the dune to grow rapidly, but the form is unstable.

Typically, dunes covered by Sparse Marram consist of 3 to 4 units. The first unit is unvegetated and contains a variety of grain sizes and dip directions and orientations. The thickness of the unit is usually small in comparison to the height of the section. The second unit is of variable thickness and contains very sparse evidence of vegetation. The beds within are deposited around and within vegetation, but the discontinuous laminae within the beds are not contorted. Ripple migration is important in the movement of the sand, but grainfall leads to the thickness of the beds.

The third unit is again of variable thickness. Laminae within beds are discontinuous to continuous throughout the unit. They are often disturbed by the presence of the plants. Evidence of vegetation is more densely spaced than in Unit 2. Decorticated roots may be present, their presence increasing with increasing plant density. With a fairly constant accumulation rate, beds are thin, parallel and wavy laminated. The sand is tightly packed. When the accumulation rate is rapid or fluctuating, beds are thicker, more loosely packed and more contorted around plants.

Unit 4 may or may not be present. It usually exists where the dune has reached a stable equilibrium with a constant accumulation rate. It is made up of faint continuously laminated horizontal beds of organically stained sand.

The upper three units in the typical section then make up the Sparse Marram Facies. Unit 2 is the colonization/cluster facies which exists in areas in which the plant cover is a minimum to tie the sand in place. Unit 3 is the low density Sparse Marram Facies in which the plant cover is as described in Freedman et al. (1981) for the Sparse Marram community. Unit 4 is high density plant cover again. However, there is a greater contribution from the plants from the Marram Fescue community (Freedman et al. 1981). The Sparse Marram Facies changes laterally into the Dense Marram or Shrub Heath Facies.

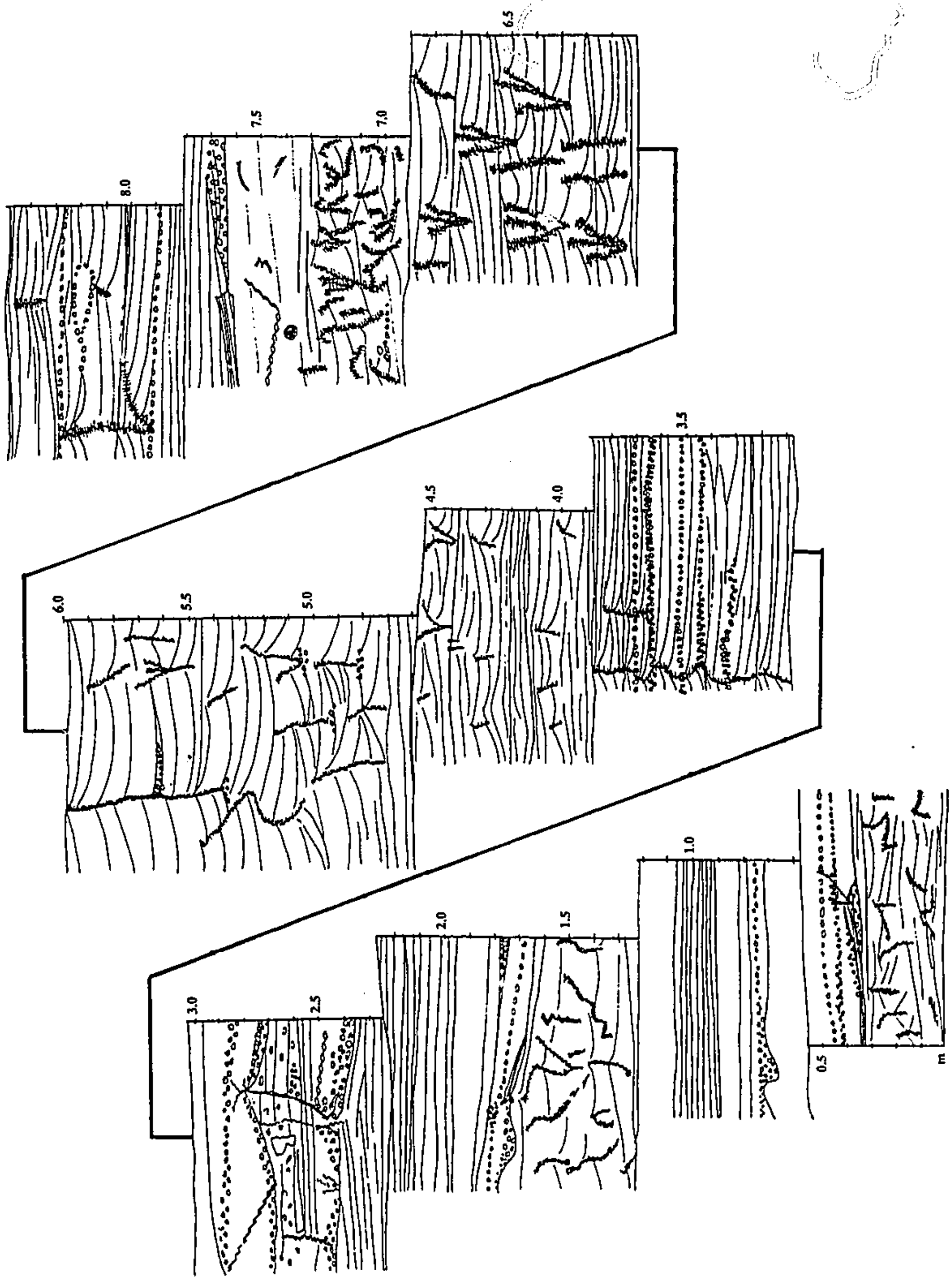
4.4 Dense Marram/Beach Pea Facies (Sites 88-2, 88-3, 88-14, 88-15C)

Description

Site 88-2 (Fig. 4.17)

This large dune was located just east of Atmospheric Environment Service station. It had a steep face and formed the wall of a blowout.

FIGURE 4.17. Site 88-2 contained structures which showed much evidence of deposition through the vegetation canopy. Plant stains were present and there were decorticated root pieces and stem fragments buried in the section. The beds warped upward toward the stem as at 1.5 m, 5.0 m, and 5.5 m.



8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
m

The base of the dune was fairly stable and masked by an apron of loose sand. Upward, the dune became more unstable. The lowest 20 cm of the section was made up of sand deposited around vegetation. At 35 cm there was a plant node associated with a collection of heavy minerals and a discontinuous patchy layer of coarser sand. There was a variation in grain size and in thickness of the heavy mineral laminae. The upper boundary was distinct, but not erosive. Above this was a set of beds which were laterally continuous, horizontal to sub-horizontal coarse and fine grained sand. This style of stratification continued upward to 1.21 m.

From 1.21 to about 1.75 m there was a set of indistinct beds of sand with abundant stains of plants. Laminae within the beds were indistinct. This was topped erosively by a set of beds of varying grain size and compaction which had no evidence of vegetation within them (1.75 to 2.4 m). Beds boundaries were marked by heavy mineral layers. Dip was 18°/350. From this point upward there was an increase in the amount of plant material within the dune. From 2.4 to 2.97 m the beds were contorted around plant stains. Lenses of coarse material were deposited in association with the nodes of the plants. Above the coarse layers the stain of the plant was associated with finer material. Laminae were contorted upward locally around plants. Lenses of grainflow cross-stratification were located at 2.7 m.

Upward in the section the beds became more horizontal. Laminae within the beds did not follow the bedding plane, but warped upward toward the stains of plants. Plant fibres were contained within the stains. These were the result of the incomplete decay of the plant. A single stain was traced through 80 cm of the dune starting at about 3 m. The nodes of the plant were visible. These were associated with the coarse layers which marked the boundaries of the beds. This type of stratification continued upward from about 3.8 to 5.9 m. However, the bedding became more indistinct upward and the amount of plant material and staining increased. Stains were traced sometimes for a metre or more. Columns of slightly finer sand infilled the holes where the stems once were. Beds averaged about 10 cm in thickness.

There was a change in vegetation at 5.9 m. The Ammophila breviligulata stains disappeared and were replaced with a woodier type of plant. Pieces of root and stem were visible in the section. Between 6.8 and 7.2 m there was a high concentration of organic material with many pieces of decaying plants. Upwards the type of plant material changed. The roots preserved at this level were smaller in diameter and were much more dense than those immediately below. There was also a high concentration of organic material within the section which stained the sand a darker brown than that which was above or below it. There was an indistinct boundary with the beds above this portion. This overlying material was cleaner sand with large leguminous roots preserved within it.

From 7.6 m to the surface of the dune the sand was deposited around vegetation. Decorticated roots could be traced along bedding planes and through beds. The sand around the vegetation was very clean, white and of uniform grain size within the bed. Bedding planes were often marked by a slight coarsening of the grain size. There was very little staining of the sand. Fibres of plants were present, usually in growth position. Beds averaged 30 cm in thickness. This type of stratification continued upward for about 4.5 m. The sand was very unstable and could not be logged in detail.

Site 88-3 (Fig. 4.18)

This section was located in a tall dune just about 1 km east of the Atmospheric Environment Service Station. The pits were dug into a relatively unstable, steep scarp on north beach. There was no paleosol. The section contained abundant evidence of the presence of vegetation during deposition. The present surface of the dune was covered with Lathyrus maritimus, but the structures within the dune reflected Ammophila breviligulata coverage. Plant clusters were easily identified and decayed stems could be traced through one or more metres of the section. Below 1.0 m, beds and laminae dipped away from plant clusters in all directions. However, laminae did not follow the bedding planes. Coarser layers occurred, usually in association with the node of the plants. Above 1.0 m the bedding became increasingly horizontal. A coarse layer at about 1.15 m was contorted and pinched out from left to right in the section. The thickness of beds decreased upwards. At the base of the section, the thickest beds were more than 40 cm thick. By the top of the section, the thickest bed was just over 20 cm thick. With increasing elevation,

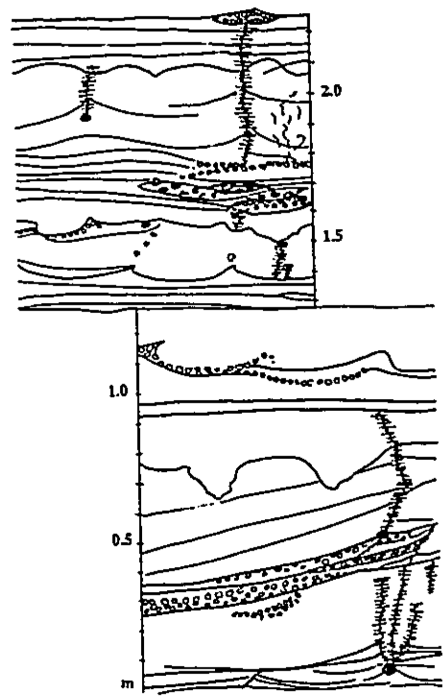


FIGURE 4.18. Site 88-3 consisted of irregularly shaped beds of fine to coarse sand. The coarse sand was deposited around the nodes of the plants or in layers on previous dune surfaces. There is evidence of plant growth through deposition, eg. upwarped beds at 2.0.

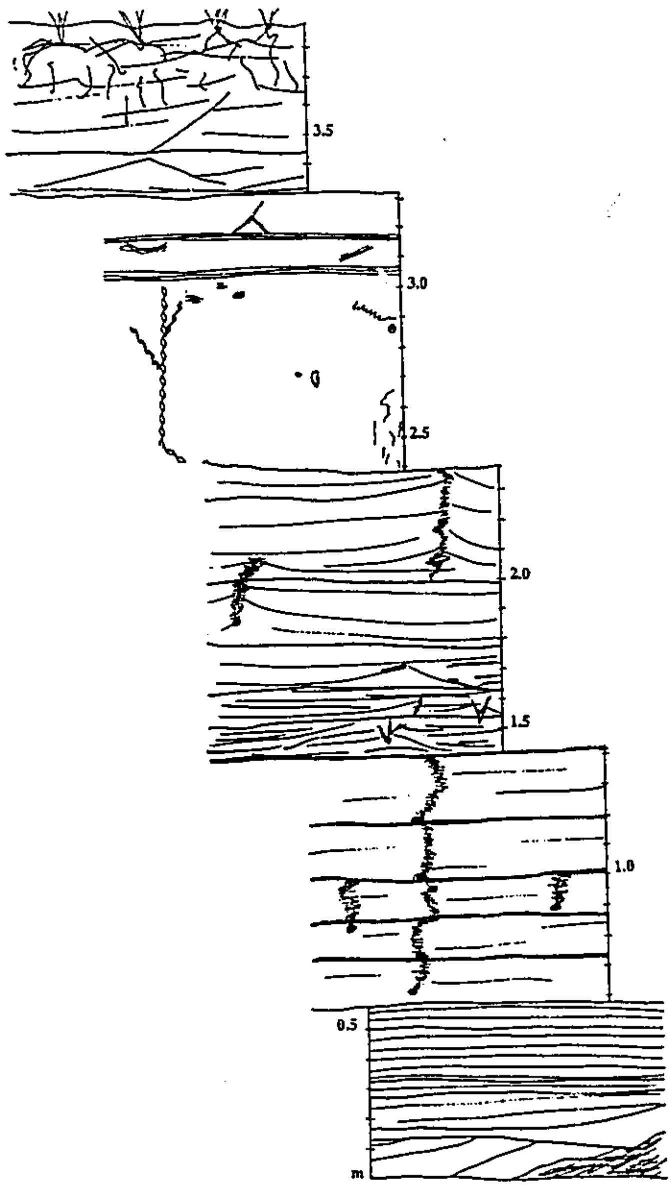
there was an increase in the amount of vegetation remains. Locally there were steeply dipping beds. Superimposed sand flows occurred in association with a plant cluster at about 1.7 m. The section could only be logged to about 2.3 m because with increasing elevation there was increasing instability.

Site 88-14 (Fig. 4.19)

This site was located in the dune scarp on the north beach just north of the Atmospheric Environment Service station. The present surface was densely vegetated with Lathyrus maritimus, some Ammophila breviligulata and Smilacina stellata. The basal portion of the section consisted of secondary deposition on the older dune. It was made up of alternating beds of loosely compacted and tightly compacted sand, deposited around a slump. It extended from the base of the section to 0.57 m.

From 0.57 to 1.8 m there were 8 beds of sand with vegetation remains. Each bed was topped by a very thin organic layer. There was a high concentration of organic material in the pit which caused the sand to have a yellow colour. All beds were horizontal with local variations in dip due to the presence of plants. Laminae were not visible in the lower part, but could be traced in the upper three beds. The uppermost bed (1.63 to 1.8) contained a higher concentration of organic material. Pieces of undecayed roots of Ammophila breviligulata were present.

From this point upward to 2.38 m, the sand was very clean and white in appearance. Sets were made up of laminated white sand topped by very



FIG\ ᵀE 4.19. Site 88-14 contained the signature of Dense Marram/Beach Pea. At 2.5 to 3.0 m elevation there were the remains of the Beach Pea plants. Physical structures are difficult to trace at this elevation, unlike the structures within the marram vegetation which is just below 2.5 m.

thin organic layers. Plant stains were visible and plant fibres were present. The organic layers were different from those below in that they were more like organic stains rather than collections of organic material. All beds were horizontal and laminae tended to follow the bedding planes with only slight up-warping around plants.

From 2.38 to 3.05 m there was one set which appeared massive. There was organic matter contained within it. At the left of the exposed section a single plant stain in growth position was traced from the bottom to the top of the set. Pieces of roots were present. Plant fibres were visible in the bottom right side of the exposed portion of the dune.

From 3.05 to 3.55 m there were 4 sets which were similar to those between 1.8 to 2.38 m. However, these were more loosely packed. They consisted of powdery sand arranged in sets below thin dispersed organic layers. The sets were horizontal and if laminae were visible, they followed the bedding planes. Leguminous roots were present. These were traced upward to plants which were living. The uppermost set extended from 3.55 to about 4 m. It was the presently accumulating layer. A dense cover of Lathyrus maritimus, Achillea lanulosa, Ammophila breviligulata and Smilacina stellata was on the surface with roots extending down into the sediment.

Site 88-15C (Fig. 4.20)

The face of this dune was covered predominantly with Lathyrus maritimus. The sand was extremely unstable and collapsed frequently. The

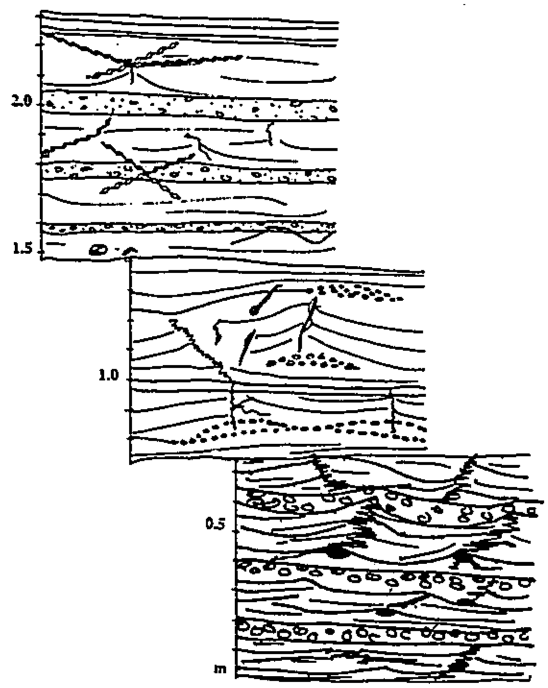


FIGURE 4.20. Site 88-15C contained evidence of Dense Marram vegetation at the base and the remains of Beach Pea in the upper part of the section.

base of the section was about 4 m above beach level. The bottom (0 to 0.74 m) of the section was made up of 4 beds. The lowest 13 cm was fine horizontal parallel-laminated sand with decayed plant material in growth position. The laminae rose very slightly toward the plant nodes. The bed was topped by a layer of medium to coarse sand with a distinct, but not erosive boundary above and below it. The next bed was the same style of stratification with a less sharply defined boundary between coarse and fine layers. The next two beds were a continuation of the same type of bedding. The amount of plant material increased upwards where there were fibres from plant stems present.

From 0.74 to 1.37 m the style of stratification was similar, but the coarse layers were not as concentrated. At first (below 1.0 m) beds were made up of parallel and wavy laminated sand deposited around Ammophila breviligulata clusters. Rhizomes could be traced from the plants upward into the beds above. There were coarse lenses associated with the nodes of the plants. Above 1.0 m the bedding was similar. However, the coarse lenses at plants nodes were made up of sand of larger grain sizes. From 1.37 to the top of the section (2.9 m), there were 5 beds, each consisting of 2 parts. The first was a thick deposit of fine to medium sand and the second was a thinner deposit of medium to coarse sand and heavy minerals. In all, there was a high concentration of Lathyrus maritimus root and some Ammophila breviligulata stem fibres. The laminae were not contorted around the plants, but simply rose up and buried them. The surface was covered in very dense Lathyrus maritimus, Ammophila breviligulata, and Achillea lanulosa. Leguminous roots were abundant.

Interpretation

In Site 88-2, there are four units. The first Unit (to about 2 m) represents a relatively stable period of deposition. The sand was laid down around dense vegetation, accumulating to the point at which the wind was no longer competent to move the sand over the top of the dune in great amounts. The pulses of sediment which were tightly or loosely compacted represent secondary deposition on top of the previously eroded surface. The secondary deposition made up the apron which was present on the lower portion of the dune.

After a period of initial stability, a change occurred. The second Unit was marked by the change in stratification style at 2.2 m. Here there was a change in the rate of sediment supply. The increase in supply led to the colonization of the surface by Ammophila breviligulata, a plant which can keep pace with burial. Upward growth of the dune with increased Ammophila breviligulata cover occurred until about 4.0 m (Unit 3). At this point the vegetation cover changed from predominantly Ammophila breviligulata with some Lathyrus maritimus to predominantly Lathyrus maritimus with some Ammophila breviligulata. Around 6 m (Unit 4) the vegetation changed again becoming much woodier (shrub heath). The woody cover represents a period of relative calm and slower burial. Above 7.5 m the rate of sedimentation increased again to allow the redevelopment of Lathyrus maritimus cover (Unit 3). This was the present surface of the dune.

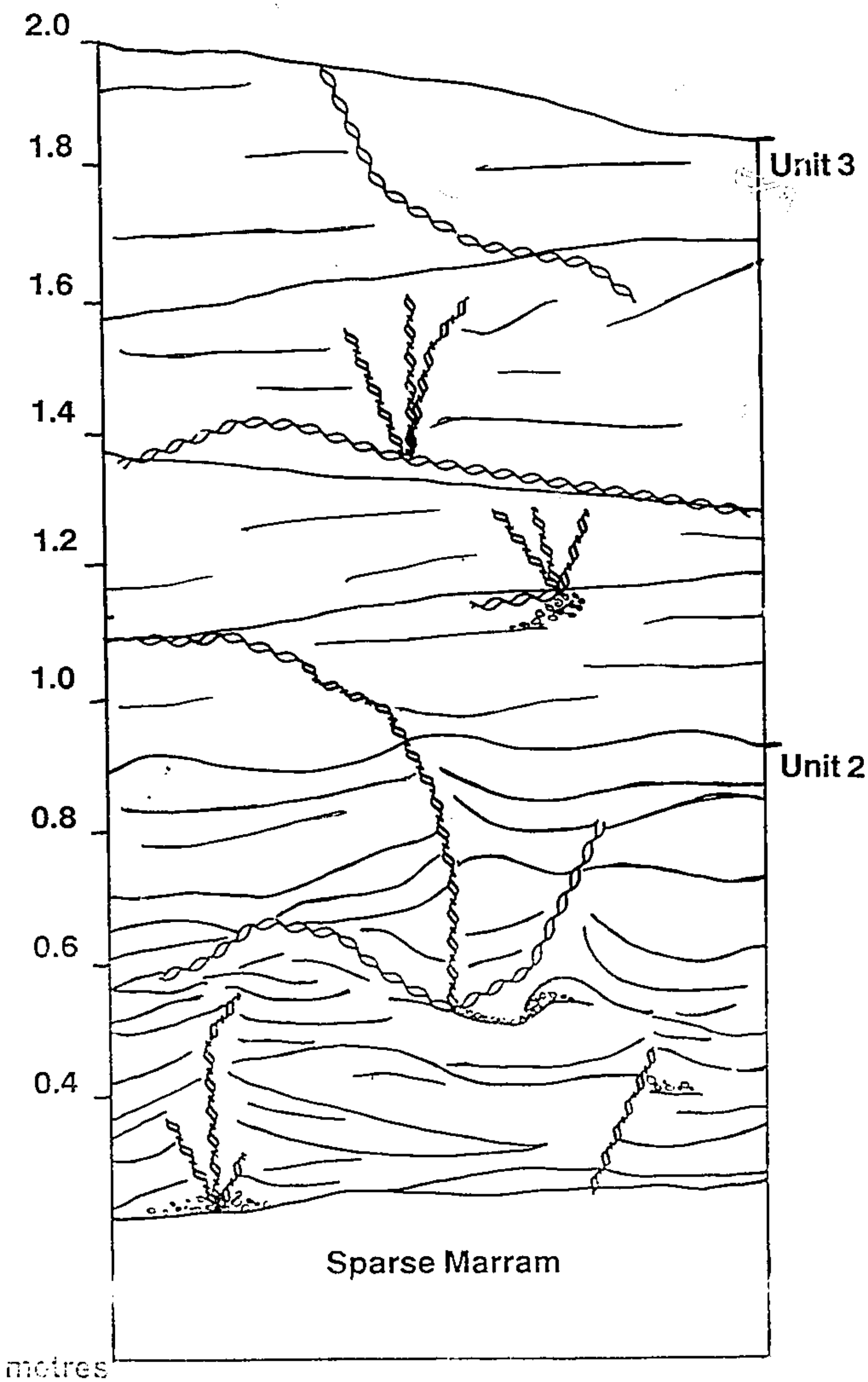
At Site 88-3, the structures are similar to the second Unit above. The vegetation cover was mainly Ammophila breviligulata, but there was a significant contribution from Lathyrus maritimus. Hence, the presence of Ammophila breviligulata stalks and nodes in the contorted bedding associated with Lathyrus maritimus. Site 88-14 was made up of three units. Unit 1 extended from the base of the section to 0.57 m, Unit 2 from 0.57 to 1.8 m, and Unit 3 from 1.8 m to the top of the section.

In Site 88-15C, there are only 2 units present. From the section base to 0.74 m is Unit 2a and from 0.74 m to 1.37 m is Unit 2b. Unit 3 extends from 1.37 to 2.9 m (top of the section). The first unit consists of the sand which is deposited in a relatively stable environment. It may be heavily vegetated like the pond edge vegetation. The sand bodies in this environment are relatively small, although persistent. Later, as the dune size grows, secondary deposition leads to the development of the apron on the side of the sand body.

Over time the environment changed, possibly by the transgression of a dune over the area. This change led to the deposition of Unit 2a. This unit consists of sand deposited within and around Sparse Marram. Unit 2b is associated with deposition through denser cover with a greater contribution from Lathyrus maritimus. The greater presence of the Lathyrus maritimus leads to the change of the beds from nearly horizontal to contorted around the plants. As Lathyrus maritimus makes a greater contribution to the vegetation cover, the surface becomes more regular, and the beds become more horizontal once more. The laminae within beds become harder and harder to see. Often bed boundaries are marked by organic layers. These may mark seasonal changes. With the die back of the cover in the fall and winter, organic material could accumulate on the surface and become buried. Over time this accumulation decays and leads to the organically stained surface. Laminae within beds are difficult to see because of the way in which they form. The Lathyrus maritimus cover is almost 100%. Therefore, it is difficult for the saltating grains to fall to the sand surface. The laminae are thus faint and discontinuous.

The fourth unit is the shrub heath unit. The formation of this unit will be discussed in the next section. The sedimentologic signature of the Dense Marram/Beach Pea dune is complex (Fig. 4.21). In the examples outlined above, there is a first unit which is the dune base. Here, they consist of small stable inland dunes. The second unit marks a change in the accumulation rate and in the environment. The first half of the unit is marked by Sparse Marram with a contribution from Lathyrus maritimus (Sparse Marram Facies). The second half consists of sand deposited within and around a dense cover which is a combination of Ammophila breviligulata and some Lathyrus

FIGURE 4.21. The Dense Marram/Beach Pea signature is made up of three units. The basal unit is the transition from the Sparse Marram community which lies below. This unit may be different if the Dense Marram developed from Marram Fescue. The second unit contains the irregularly shaped beds which are the result of the burial of the beach pea vines. The third unit is the sand deposited around the presently growing surface cover which contains leguminous roots and plants in growth position.


2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
metres
Unit 3
Unit 2
Sparse Marram

maritimus (low % cover, Dense Marram Facies). Beds are contorted with laminae not following the bedding planes. Coarse lenses and layers are present. These mark the migration of ripples through the areas in which vegetation is not dense enough to damp down the wind. Unit 3 is the Lathyrus maritimus facies, in which the surface is densely covered by Lathyrus maritimus. The beds are horizontal except for local variations which are due to rapid accumulation in specific areas. Laminae within the beds are faint and often discontinuous. Leguminous roots and fibres are present within the beds. Organic staining of bed surfaces is common. This facies changes laterally into either the Shrub Heath Facies or the Sparse Marram Facies.

4.5 Shrub Heath (Site 88-20, Fig. 4.22)

Description

This section was located on the east end of the island on the south beach in blowout which faced southwest. The present dune surface was densely vegetated with the shrub heath community. The lower section (section base to 2.96 m) consisted of thick (30 to 50 cm) beds of fine to medium sand deposited around dense woody vegetation separated by thinner (10 to 20 cm) beds of parallel-laminated sand and heavy minerals. The thicker sets were made up of discontinuously laminated fine to medium sand, containing either large stains from woody roots which have decayed, or the actual woody root. The thinner beds were made up of more or less continuously laminated sand

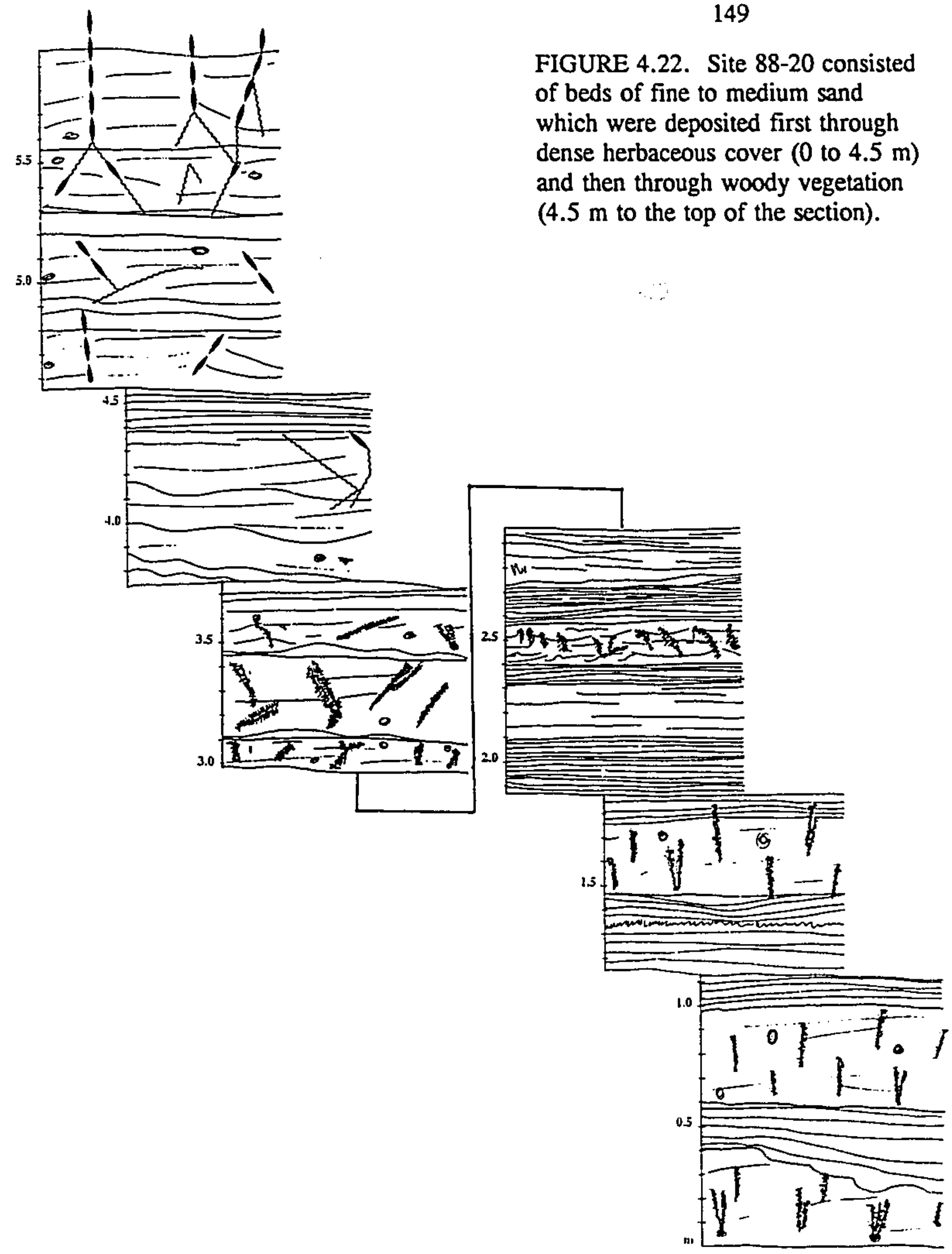


FIGURE 4.22. Site 88-20 consisted of beds of fine to medium sand which were deposited first through dense herbaceous cover (0 to 4.5 m) and then through woody vegetation (4.5 m to the top of the section).

which sat conformably above the thicker beds.

From 2.96 m to the 6 m (the present surface) beds of discontinuously laminated, organically stained sand with dense vegetation staining, sat conformably atop each other. At 4.9 m and at 5.2 m there were beds of clean sand which separated the beds of organically stained sand. The surface of the dune was covered with a dense blanket of Myrica pensylvanica, Arctostaphylos uva-ursi, Rosa virginiana, Smilacina stellata, Achillea lanulosa and Ammophila breviligulata.

Interpretation

Site 88-20 can be divided into two units. The first unit extends from the base of the section, which is just above the mean high water mark in elevation, to 2.96 m above the base of the section. The unit consists of beds of fine to medium organically stained sand with many plant stains and fibres present, which alternate with beds of parallel-laminated fine sand with an abundance of heavy minerals. The surfaces of the beds with the plant stains and fibres are often erosive. The parallel-laminated beds contain a wealth of heavy minerals which are a reflection of the source. The south beach is often covered with the heavy minerals which are carried to the dunes by the winter winds and by the stronger winds during storms in the summer. The organically stained portion of the couplets represents sediment laid down during a growing season. The vegetation cover is the sparse to Dense Marram community.

Unit 2 is made up of beds of sand deposited around larger woody roots and stems. The beds may be locally contorted, but are often laid down without disruption by the plants. The woody roots and stems are in situ and decay leaving a dark, organic stain. The roots and stems may be traced through as much as two metres. The lowest portions of the plant being decayed, while the upper portion on the surface is flowering. If the rate of sand accumulation slowed, then the accumulation of organic material would lead to the development of a soil horizon on this type of dune.

The sedimentologic signature of the shrub heath community consists of beds of faintly laminated sand laid down within and around woody stems and roots (Fig. 4.23). The stems later decay to stain the sand a dark brown to black colour. Over time, with a slower sand accumulation rate, organic material may collect and lead to the development of soil. If there is a more rapid accumulation of sediment, then the beds deposited around the roots and stems may be up to 0.5 m thick. These may be stacked in sections which can reach many metres in thickness. This facies changes laterally into any facies, although the most common is the Sparse Marram Facies.

4.6 Summary

The internal structures in the vegetated dunes of Sable Island can be classified on the basis of the characteristic deposits of 4 different plant associations into sedimentologic signatures (Table 4.1). Each of these distinctive deposits is a facies.

FIGURE 4.23. The Shrub Heath Facies consists of two units. The first is an organically stained set of discontinuous beds of fine, laminated sand (0 to 1.0 m). This is topped by a metre or more of discontinuous beds of fine laminated sand which is not organically stained, but which contains the roots of the present day surface cover.

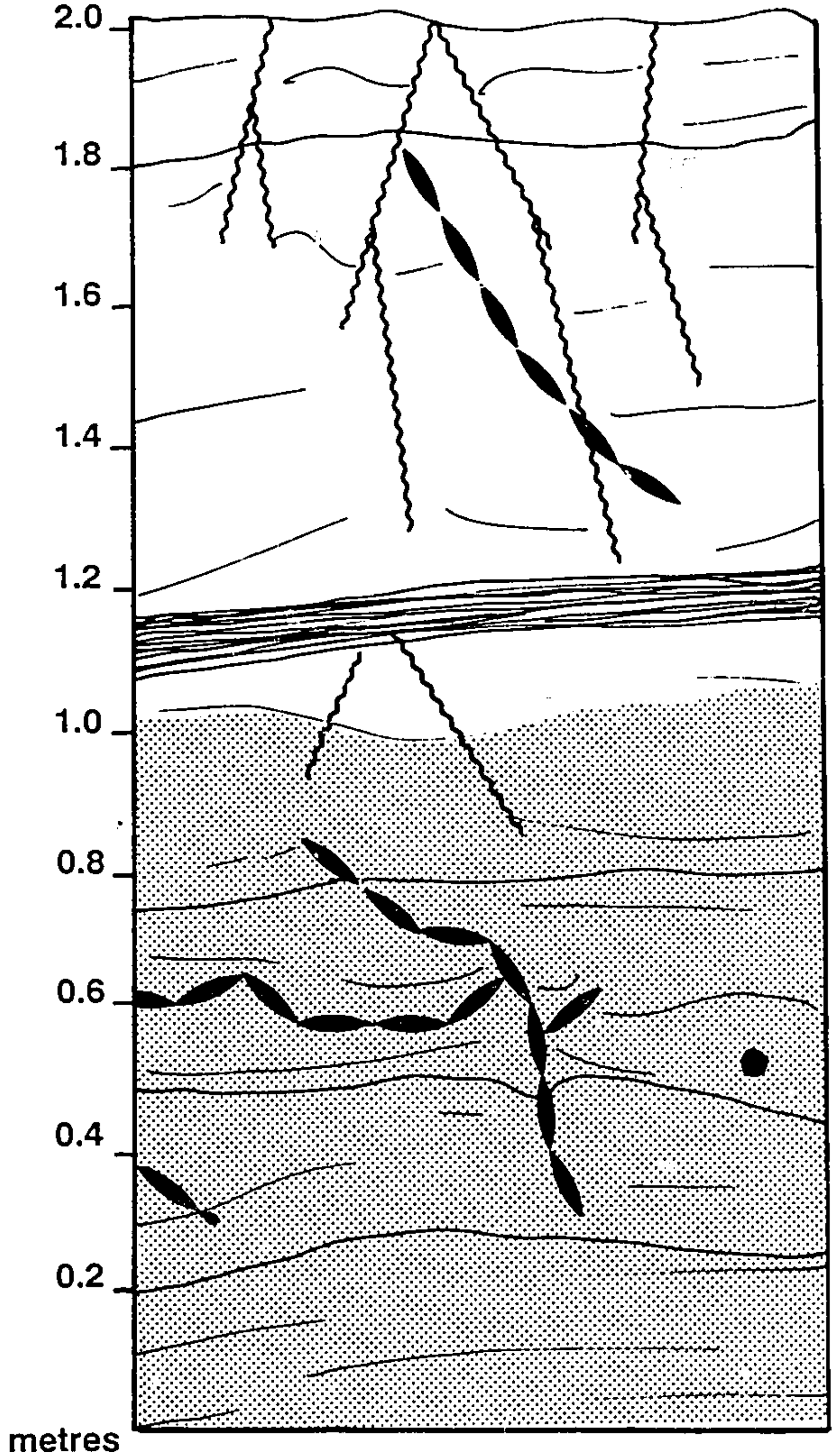

2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
metres

TABLE 4.1. FACIES FOUND WITHIN PLANT COMMUNITIES ON SABLE ISLAND, NOVA SCOTIA.

Facies	Sub-Facies	Site	Facies Location	Dominant Processes
SHRUB HEATH		88-20	sheltered	grainfall
DENSE MARRAM/BEACH PEA		88-2	established dunes behind a foredune or scarp	grainfall
		88-3		
		88-14		
		88-15C		
SPARSE MARRAM	Sub-Facies			
	HUMMOCKS	87-14	exposed beaches	grainfall grainflow traction (ripple migration)
		88-7		
		88-8		
		88-9		
	CLUSTERS	87-3B	sheltered areas with vegetation	grainfall grainflow traction
	FOREDUNES	87-7C	litter line to sheltered areas	grainfall traction
		88-19		
		88-15A		
SANDWORT		87-11	exposed beaches and spits	grainfall traction
		88-11A\B		
		88-13		

The first facies is the Sandwort Facies which is deposited in the more marginal areas on the island (spits and exposed beaches). The facies consists of couplets of sand made up of combined grainfall and ripple deposits in clean white sand which alternate with sets of parallel-laminated tightly packed fine to medium sand and heavy minerals. The couplets are laterally continuous for only about a metre and are influenced by the presence of plants. Sets average about 10 cm thickness. Upper and lower bounding surfaces are smooth except where disturbed by something such as a horse hoof print.

The next facies is the Sparse Marram Facies. It consists of three sub-facies. The first sub-facies is the Marram Cluster Sub-Facies which is associated with the colonizing plants such as Cakile edentula and clusters of Ammophila breviligulata. It is made up of discontinuous, truncating sets of parallel-laminated fine to coarse sand. Evidence of vegetation is sparse. Sets range in thickness from a few millimetres to 15 cm and are laterally continuous for a metre or less. Dips range from 5 to 20° and directions are variable. Coarse sand occurs either as parallel-laminated sets or as lenses or tongue-shaped deposits which are the result of the migration of granule ripples or of grainflows. The second sub-facies is the Marram Hummock Sub-Facies. This sub-facies consists of beach lamination covered by two units. The first is made up of sets of discontinuous beds of sand laid down around sparse vegetation. The second unit is made up of fine to medium sand laid down in alternating sets of tightly and loosely compacted sand. There is an abundance of vegetation with density increasing upwards. This sub-facies is located along the beach in areas where there is a strong influence from storm winds as well as the tides.

The third sub-facies is the Sparse Marram Foredune Sub-Facies which is made up of four units, the basal unit being made up of thin, cross-laminated beds which dip at various angles in various directions. This base is the deposition of tractional and grainfall deposition which occurs in an environment with a very sparse vegetation cover (Byrne and McCann 1990). Unit 2 is similar to the Marram Cluster sub-facies which exists in areas where the plant cover is a minimum to tie the sand in place. Ripple migration is important in the movement of the sand, but grainfall leads to the thickness of the sets. Unit 3 is the low density Sparse Marram Facies. With a fairly constant accumulation rate, sets are thin, wavy parallel-laminated. The sand is tightly packed. When the accumulation rate is rapid or fluctuating, sets are thicker, more loosely packed and more contorted around plants. Unit 4 was deposited in a higher density plant cover. However, there is a greater contribution from the plants from the Marram Fescue community. The Sparse Marram Facies is located on top of superimposed shadow dune structures and changes laterally into the Dense Marram or Shrub Heath Facies.

The sedimentologic signature of the Sparse Marram Foredune is similar to the signature of the Marram Hummock. It is different in that there is a lower concentration of coarser grains in the foredune signature. The beds are more continuous and plant remains are less concentrated. The dips of the beds are also less variable in the foredune signature. The deposits which result from ripple migration are not as extensive. Dunes covered with Marram Fescue have a similar sequence of structures, however, they are stained with organic material.

The third facies in the vegetated dunes on Sable Island is the Dense Marram/Beach Pea Facies. The sedimentologic signature of the Dense Marram/Beach Pea dune is complex. In the examples outlined above, there is a first unit which is the dune base. Here, they consist of small stable inland dunes. The second unit marks a change in the accumulation rate and in the environment. The first half of the unit is marked by Sparse Marram with a contribution from Lathyrus maritimus (Sparse Marram Facies). The second half consists of sand deposited within and around a dense cover which is a combination of Ammophila breviligulata and some Lathyrus maritimus (low % cover, Dense Marram Facies). Within the sets the beds are contorted with laminae not following the bedding planes. Coarse lenses and layers are present. These mark the migration of ripples through the areas in which vegetation is not dense enough to damp down the wind. Unit 3 is the Dense Marram/Beach Pea facies, in which the surface is densely covered by Lathyrus maritimus. The sets and beds are horizontal except for local variations which are due to rapid accumulation in specific areas. Laminae within the sets are faint and often discontinuous. Leguminous roots and fibres are present within the sets. Organic staining of set surfaces is common. This facies tops the Sparse Marram Facies and changes laterally into either the Shrub Heath Facies or, following disturbance, into a Sparse Marram Facies.

The fourth facies in the Sable Island dunes is the Shrub Heath Facies. The sedimentologic signature of the shrub heath community consists of sets of faintly laminated sand laid down within and around woody stems and roots. The stems later decay to stain the sand a dark brown to black colour. Over time, with a slower sand accumulation rate, organic material may collect and lead to the development of soil. If there is a more rapid accumulation of sediment, then the sets deposited around the roots and stems may be up to 0.5 m thick. These may be stacked in sections which can reach metres in thickness. This facies tops Dense Marram or Sparse Marram (Marram-Fescue) facies and changes laterally into any facies, although the most common is the Sparse Marram Facies.

CHAPTER 5

STRATIFICATION AND STRUCTURE OF IN SITU MULTIPLE PHASE FOREDUNES

5.1 Introduction

This chapter contains the descriptions and interpretations of sections located in the present day foredunes on the north side of the island (Fig. 5.1). The dunes are grouped into two types based upon the rate of growth, the sediment supply, and the development of the paleosol. The first group grew slowly and under conditions of relatively limited sand supply. Because of their slow growth rate, the organic material present in the vegetation cover collected to create a well developed paleosol. These dunes are presently eroding. The second group developed more rapidly under conditions of relatively unrestricted sediment supply, so the paleosol (or paleosols) are not well developed, consisting of organically stained sand rather than sandy, concentrated organic material. They have developed in an area in which there is accretion at the present time. The basic building blocks which are used to describe the sections are the facies which were outlined in chapter 4.

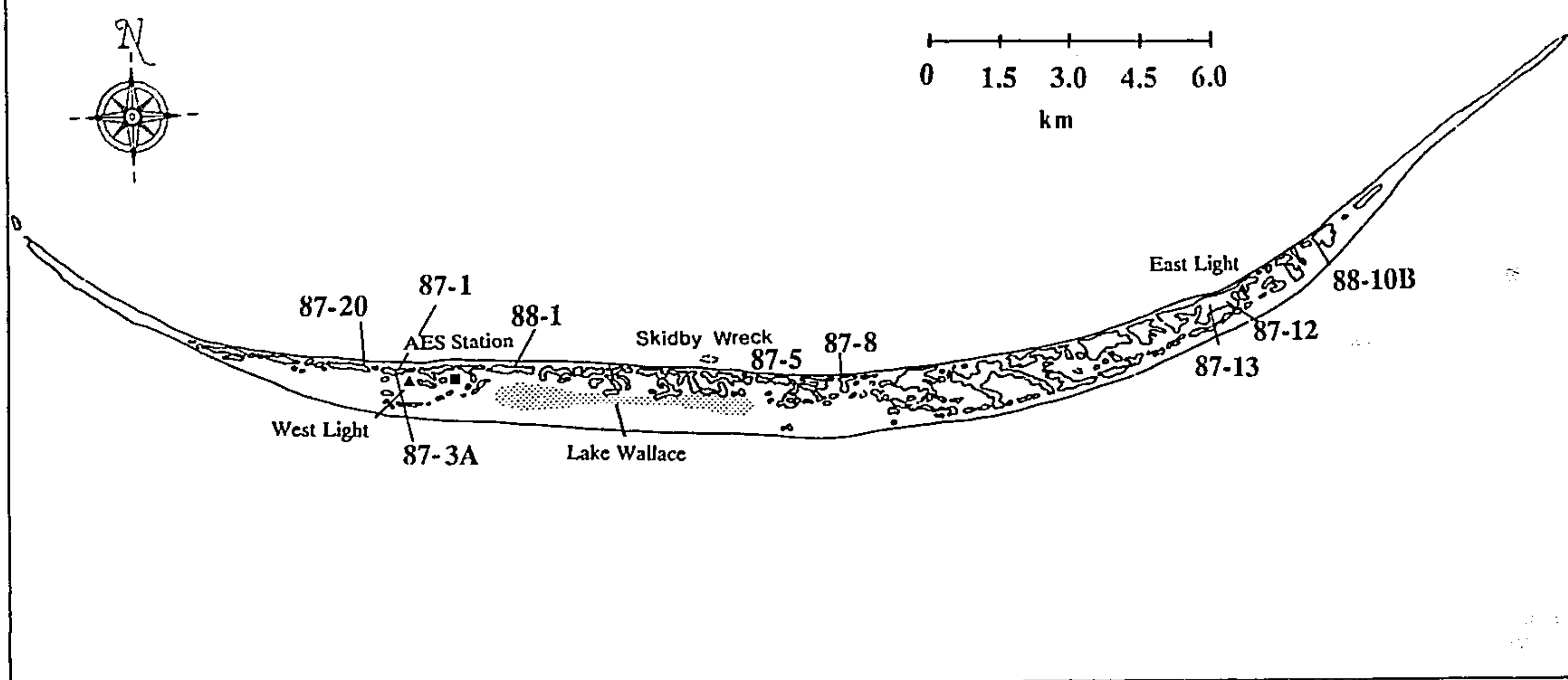


FIGURE 5.1. Location of the In Situ foredune sites.

5.2 Type I - Supply Limited Foredunes

5.2.1 Site 87-20 (Fig. 5.2)

Description

Site 87-20 was located about 0.5 km west of the BIO compound in a blowout which faces onto north beach. The lowest portion of the dune was buried by slumped material. Beds were planar from 2.0 m upwards to 3.8 m. Decayed vegetation was present and affected the patterns of deposition in the same manner outlined previously. From 2.0 to 2.7 m, there were 6 fining upward beds whose angle of dip increased from 15° in the lowest to 20° in the top bed. The base of the bed contained coarse sand to granule sized particles while the top of the bed contained fine sand. From 2.77 to 3.8 m, the beds were more irregular and dipped in an opposite direction to those below.

The paleosol extended from 4.1 m to about 4.7 m and consisted of a 35 to 40 cm grey sand layer, topped by two 10 cm thick layers of dark, sandy organic material containing decayed plant fragments, separated by a 5 to 10 cm layer of yellow sand.

Above the paleosol (4.75 to 6.0 m) there was very clean sand in which it was very difficult to see bedding. The lower beds were steeply dipping, about 24 to 27°, and changed gradationally from one discontinuous layer upward to the next. Toward 6.0 m, sets of beds of discontinuously laminated sand became more visible and less steeply dipping. Angles of dip were around 5°/180. This continued to the top of the exposed section, where beds and sets

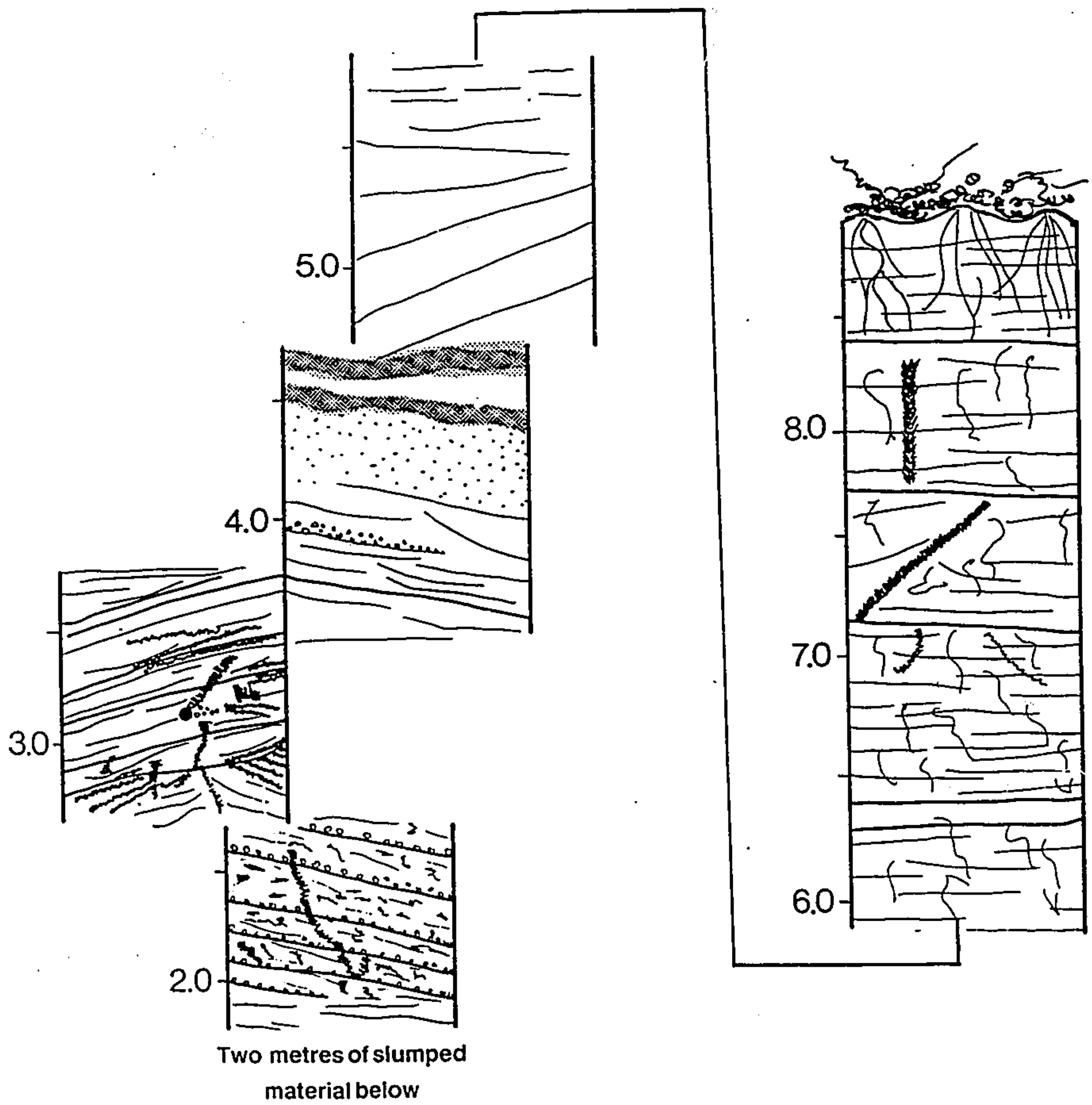


FIGURE 5.2. Site 87-20 contains structures deposited through first a sparse cover, then a dense cover which stabilized the surface to allow a paleosol to develop. This was then covered by beds deposited through dense marram and beach pea.

became more distinguishable. There were sets of somewhat wavy, but not rippled, beds (6.5 to 7.94 m) which were thicker toward the plant remains. Average set thickness was less than 1 metre and average bed thickness was 20 cm. The average dip decreased from 16°/135 at the bottom of the beds to 4°/211 at the top. This part of the section was dotted with the remains of vegetation, probably Lathyrus maritimus since this plant densely covers the dune at present.

From 7.94 to 8.87 (the top of the section) there were similar beds. However, all were nearly horizontal and contained a higher concentration of plant material. Bed boundaries were marked by discontinuities and there were breaks in the organic staining left by decayed plants. Again the section was covered by a thin modern soil layer.

Interpretation

The fining upward, planar beds with abundant organic staining at 2 to 3 m, indicate that the environment of deposition was one in which deposition of a sand of mixed grainsize occurred and then ceased. The surface of a bed was winnowed and a lag was left behind. Deposition began again and the rest of the fining upward bed was deposited. Perhaps this represents the deposition of smaller dunes which coalesced and became covered with Ammophila breviligulata which increased in density upwards. This portion of the section is therefore made up of the Sparse to Dense Marram Facies. It is covered by the paleosol which marks a period of stability when there was little sedimentation. Above the paleosol deposition occurred around sparse vegetation which is interpreted as Sparse Marram Facies to 6.0 m and then there is a change to Dense Marram Facies. Above 6.0 m there is abundant evidence of Ammophila breviligulata roots, and other plants such as Achillea lanulosa, Smilacina stellata, and Cladonia. The present surface is densely covered with Lathyrus maritimus and Ammophila breviligulata.

5.2.2 Site 87-3A (Fig. 5.3)

Description

Site 87-3a was normal to the waterline in the north foredune about 1 km west of the Atmospheric Environment Service station. The lowest 1.2 m contained an abundance of low-angle cross-beds, with little evidence of vegetation. There was a definite grain size segregation with the coarsest sand located between 0.8 and 0.9 metres. The lowest 0.8 m of the dune was made up of 8 beds of fine to medium sand which ranged in dip from horizontal to 12°/223. Coarse layers, 2 to 5 mm thick, often marked the bed boundaries these. From 0.8 m to 1.2 m there were 3 sets of bedded sand. The first set was made up of coarse sand to granule sized particles and was capped erosively by a discontinuously bedded set of fine sand. Overlying this was a second set of cross-beds, but these were uniform grain size, fine sand, rather than granule sized particles.

The structures changed at 1.2 metres. From 1.2 m to 3.0 m there were

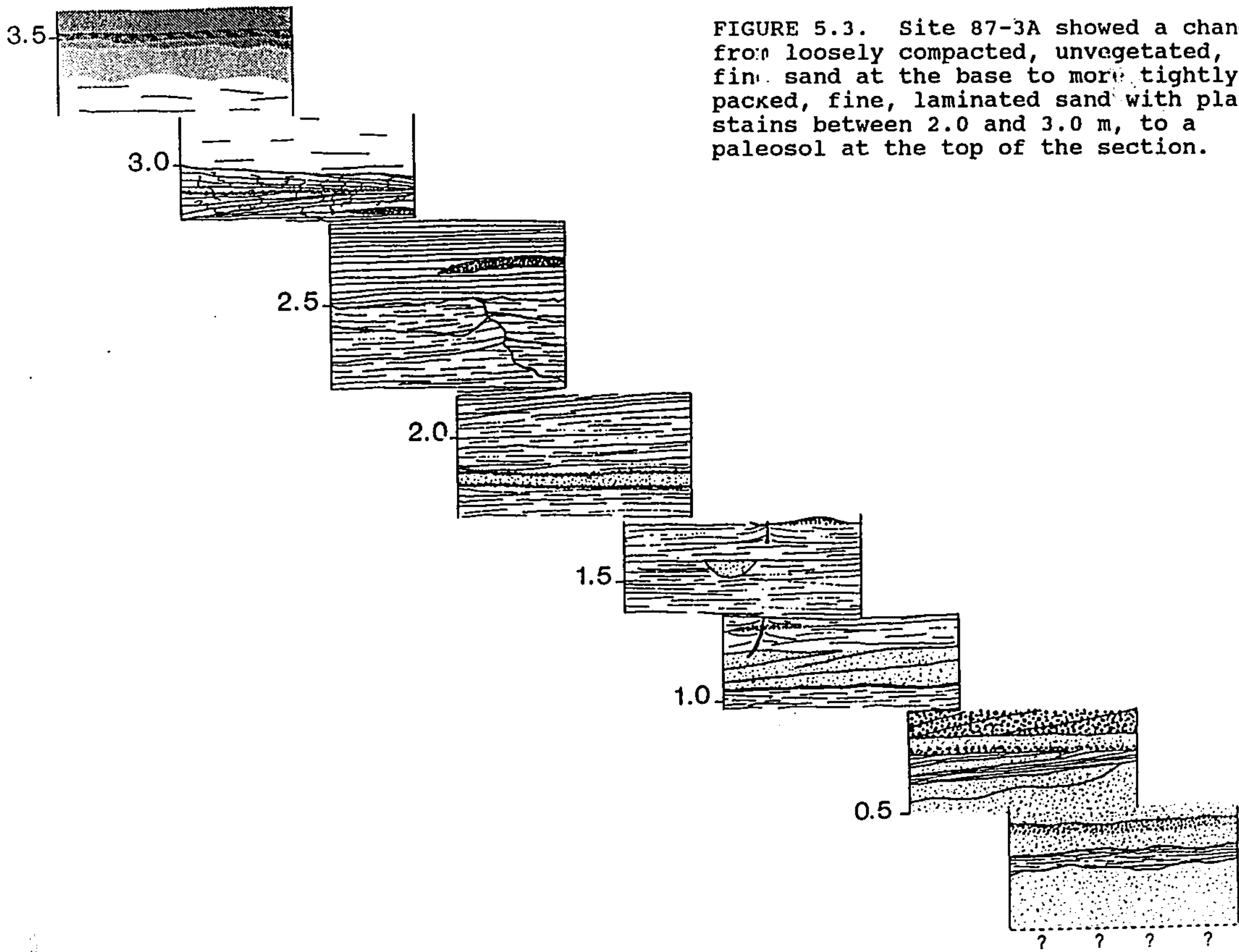


FIGURE 5.3. Site 87-3A showed a change from loosely compacted, unvegetated, fine sand at the base to more tightly packed, fine, laminated sand with plant stains between 2.0 and 3.0 m, to a paleosol at the top of the section.

5 beds of laminated sand with some evidence of vegetation. Bed 1 was about 0.6 m thick and contained two plant nodes (Fig. 5.4). which were connected to a stain from the plant in which the stem and node could be traced. A coarse lens was associated with the plant node and a coarse column infilled the stem hole. A 22 cm by 8 cm flat topped lens of less compacted sand was present. The bed was covered by a 1 cm thick layer of slightly coarser sand. Bed 2 was a 6 cm thick, uniform grain size, fine sand bed with no laminae, which was located between 1.8 and 1.9 m height and was covered by a 1 cm thick layer of slightly coarser sand. Beds 3 and 4 were similar to bed 1, however, there were no plant nodes. Beds were discontinuously laminated and were either horizontal or dipped less than 5°. Bed 3 contained a normal fault which is associated with slumping (Fig. 5.5). Bed 4 differed from bed 3 being continuously laminated. It extended from 2.5 metres to 2.8 metres and dipped 4°/8 It was mottled and dark in colour. Two coarse sand lenses had been deposited at 2.6 metres and at 2.8 metres. Bed 5 was located from 2.8 m to 3.0 m and contained a high concentration of root and stem fragments in two cross-beds that dipped 8° to 10°. There was a well defined boundary between the top of the second cross-bed and the sand above it.

The paleosol extended from 3.0 m to the top of the section. From 3.0 to 3.3 m the sand was light in colour and discontinuously, vaguely laminated with few plant fragments. The sand organic layer extended from 3.3 to 3.6 m and consisted of organically stained sand which contained increasing

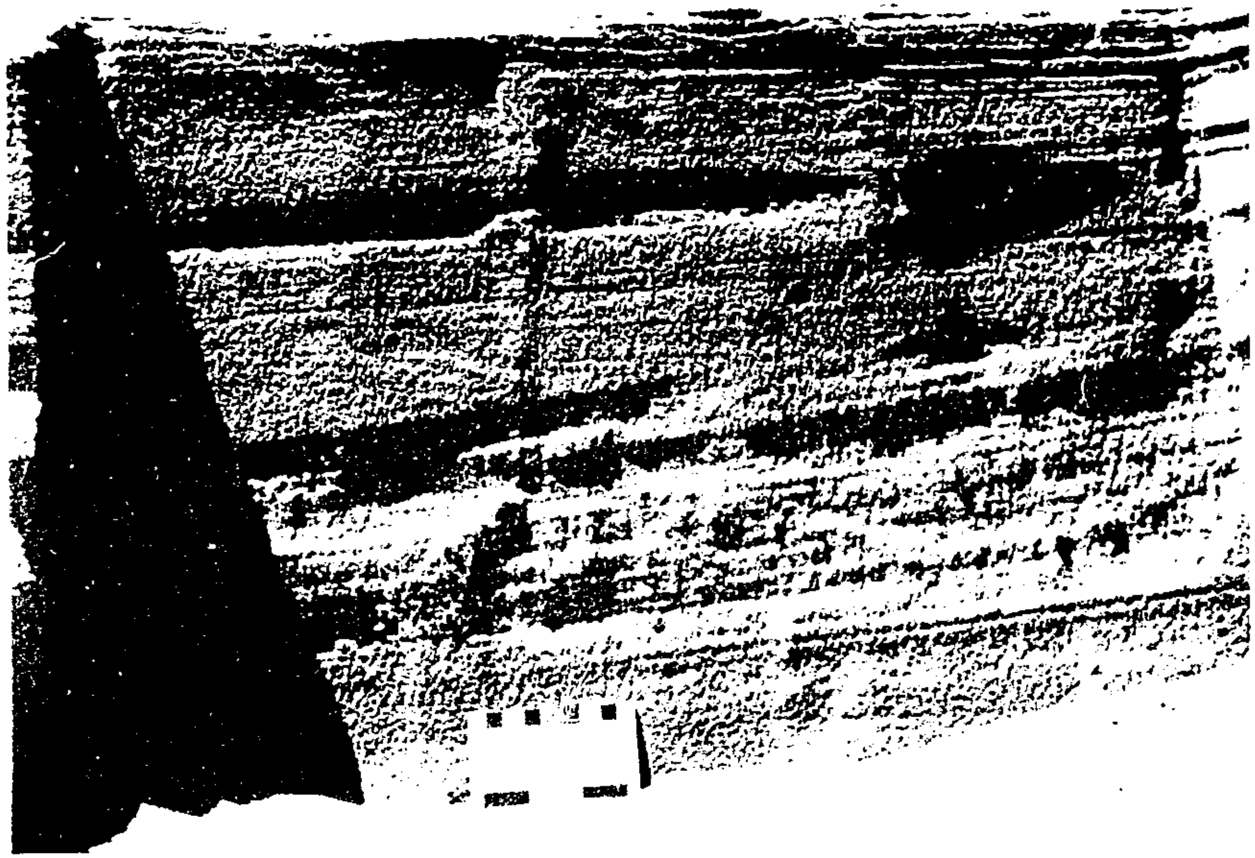


FIGURE 5.4. The burial of plants is illustrated in this photograph. A plant node, which is surrounded by coarser material, is located above the scale. A second plant node is located in the centre of the coarse lens above the first. There is a third plant node in the upper right hand corner which appears as a dark stain. The marram stem extending upward from the first node has grown with burial and is upright.

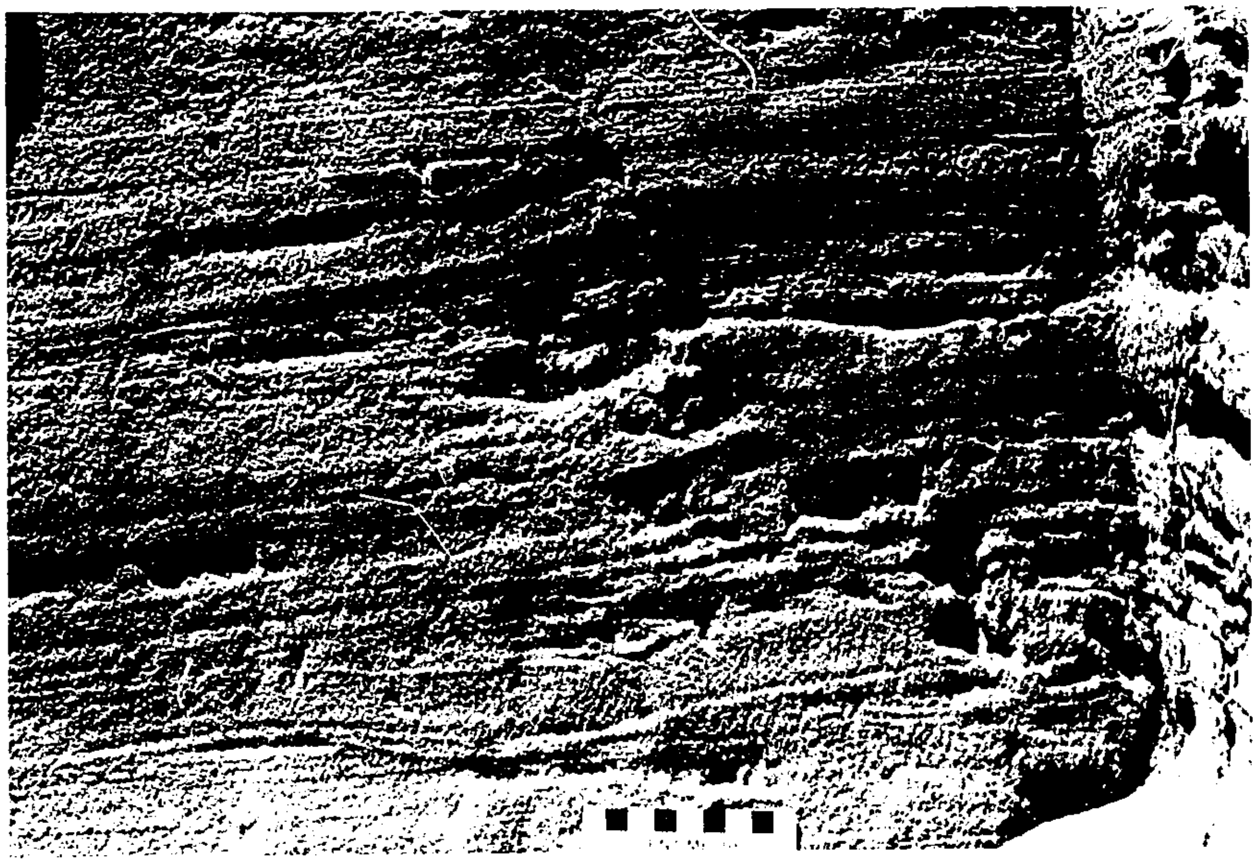


FIGURE 5.5. A fault in the dune is portrayed in this photograph. Beds and laminae can be traced across the fault. These types of features are common in the dunes on Sable Island.

concentrations of organic material upward to 3.5 m, and then a decrease in organic material. The sand overlying the paleosol was deposited around vegetation in a similar manner to other sites. However, because of the instability of the dune above the paleosol at this location, no pits were dug in this portion of the dune and structures could not be examined in detail.

Interpretation

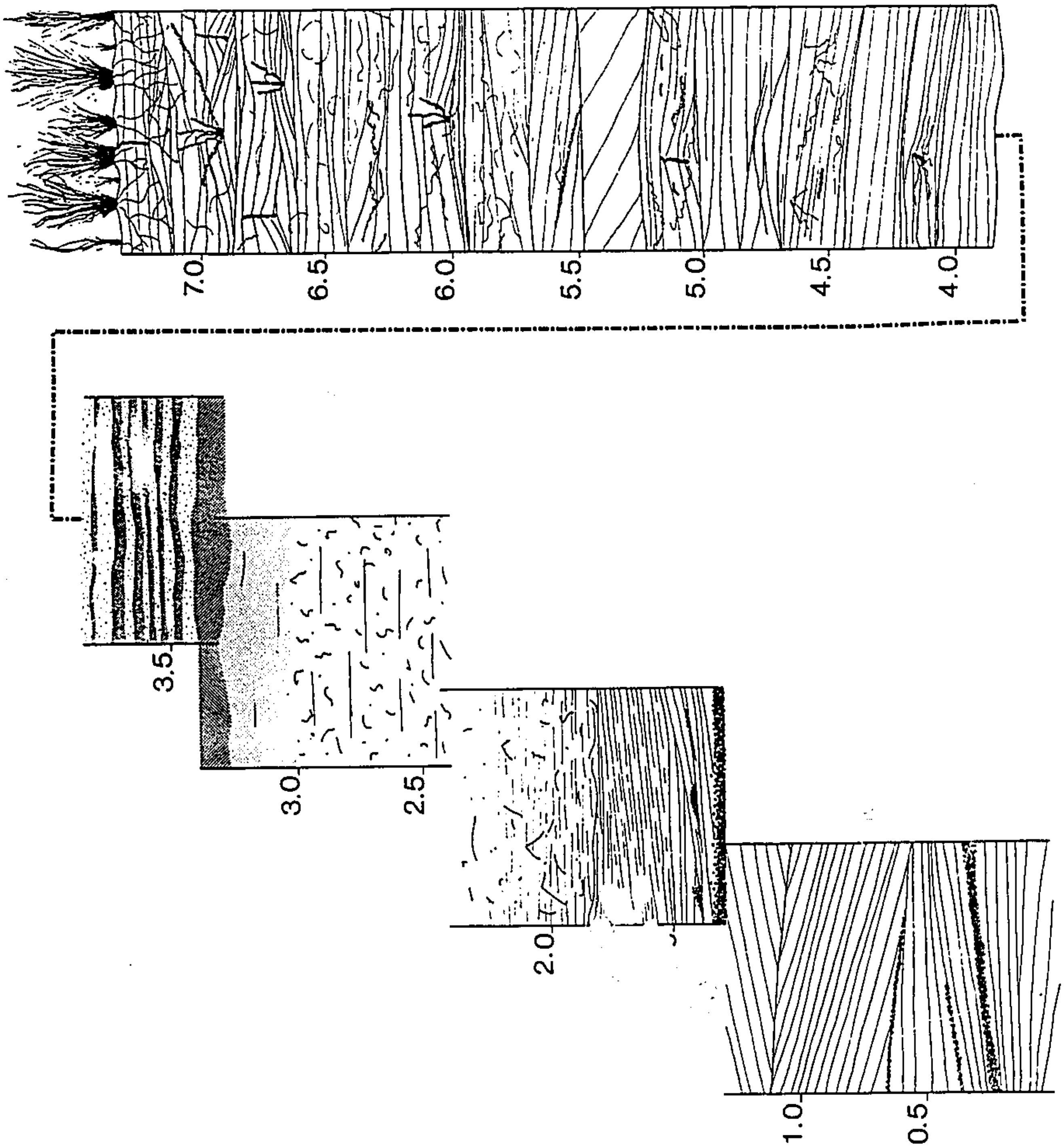
The base of the section is made up of structures which reflect a high energy environment in which there is little vegetation cover and a good supply of sand with a variety of grain sizes. This is the Sparse Marram facies in which small dunes have not yet coalesced. It is topped by a set of beds which reflect an environment in which vegetation plays a greater role. The increased vegetation cover (Dense Marram Facies) leads to a more stable surface and a decreased accumulation rate. This in turn creates an environment which is favourable to the development of the paleosol.

5.2.3 Site 87-1 (Fig. 5.6)

Description

At Site 87-1, located across the blowout from Site 87-3a, a 7.25 metre section was examined. The lowest 1.5 metres of the section consisted of 6 cross-beds of alternating direction which were made up of fine sand with coarse layers of less than 10 cm thickness contained within them. There was

FIGURE 5.6. Site 87-1 showed increasing evidence of vegetation from the base upward to the paleosol which marked a period of stability. Above the paleosol the sand is deposited within and in the lee of dense marram vegetation.


7.0
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6.0
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very little evidence of vegetation. The first bed dipped at a low angle and was topped by the second bed and a lag of slightly coarser sand which dipped 6°/315. This second bed was truncated by a third which contained variations in grain size and dipped 4°/260. Bed 4 truncated bed three, dipping 9°/60, and was covered by bed 5, a 6 cm thick layer of granule sized sand. Bed 6 was slightly more complex than the beds below, containing a layer of coarse sand to granule sized lenses. These averaged 15 cm in length and 1.2 cm in height. They were spaced between 15 and 25 cm apart and appeared to be climbing from left to right (north to south, away from the water).

The next portion of the section between 1.5 m and 3.0 m, contained an increasing concentration of decayed plant material. Between 1.5 m and 1.85 m there was a discontinuously laminated bed of uniform grain size, fine sand with very little evidence of decayed vegetation. This changed upward from 1.85 to 2.4 m where there was an increasing amount of plant fragments and staining. Laminae became less visible as the amount of plant evidence increased. From 2.4 to 3.0 metres the sand became increasingly mottled and grey and laminae all but disappeared. Although there was an abundance of evidence of vegetation at this site, the laminae within beds were not disturbed. Laminae parallelled the bedding planes and coarse lenses were rare.

The paleosol was 1.5 m thick consisting of 6 layers of dark, highly organic sediment which were separated by thin layers of well compacted, light coloured sand topping 75 cm of leached transition sand from the unit below.

Above the paleosol, at 2 m, the sand was loosely packed with increasing concentrations of plant material upward. The unit was bedded with definite boundaries between nearly horizontal beds which averaged about 15 cm thickness. Dip of the laminae within beds varied due to local plant growth resulting in parallel, wavy laminated beds. A thin modern soil topped the dune at this location.

Interpretation

The base of this section (0 to 1.5 m) reflects deposition of a wide range of grain sizes of sand in an environment in which there is little or no vegetation. Coarse layers represent the passage of coarse sand to granule ripples over the area. Granule ripples are preserved just below 1.5 m. From 1.5 m to about 2.5 m there is increasing evidence of vegetation in the form of roots, fragments and stains. From about 2.5 to 3.0 m the structures have all but disappeared due to leaching. The sand is greyish to yellow in colour and contains the stains of plants. From 3.0 to about 3.8 m the organic stained sand and sandy organic material which makes up part of the paleosol is the result of stable periods in which the dune surface was covered by a lush vegetation layer which led to the collection of organic material alternating with periods in which the supply of sediment was greater and resulted in the deposition of the light coloured sand.

From about 3.8 m to the top of the section (7.3 m), the sand was deposited around increasing concentrations of plant cover. Below 5.5 m the evidence of vegetation is sparse. There are some decorticated roots and fragments of Ammophila breviligulata, but these are widely spaced. Between 5.0 and 5.5 m there is a set of cross-beds of clean sand which show no evidence of vegetation which were deposited perhaps during a storm. From 5.5 m upward the vegetation density increased until, at the top of the section, a thin soil was developing.

5.2.4 Site 88-1 (Fig. 5.7)

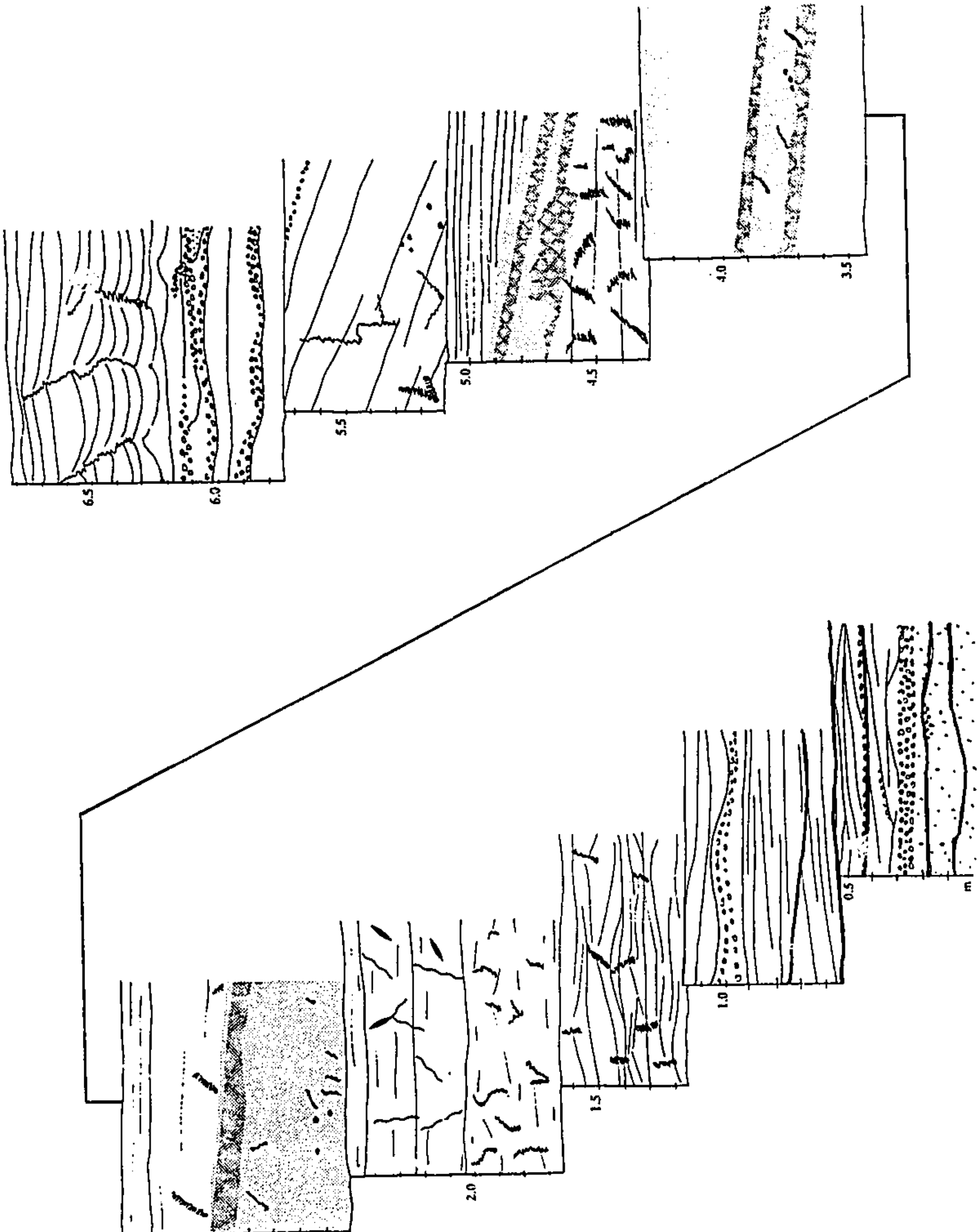
Description

Site 88-1 was a 6.9 m cleared section in a 14 m high dune behind north beach. The basal portion of the section (0 to 0.9 m) showed no evidence of organic matter or vegetation. There was a variety of grain sizes from fine to coarse in 7 beds each topped by a 1cm layer of heavy minerals. The lowest three beds were each about 7 cm thick and were fine, uniform grain size, unlaminated sand. Bed 2 had a lens of coarse material located in the centre top of the bed. Bed 3 was a coarsening-upward, laminated bed about 10 cm thick topped by bed 4 which was discontinuously laminated sand that was fine at the base and was capped by a coarse layer. Laminae could not be traced laterally for more than a few tens of centimetres. Beds 5, 6 and 7 were a continuation of this with a lack of coarse material and beds which were more continuous.

From 0.9 to about 1.0 m there was a bed of alternating coarse and fine laminated, undulatory, unvegetated fine sand. There began to be evidence of vegetation at 1.16 m in the form of plant nodes and the stains from stalks. Beds were laterally continuous but irregular around plant clusters. Laminae within the beds rose upward to the plants. This type of bedding extended upward to about 2.05 m.

The paleosol was located between 2.05 and 5.12 m. From 2.05 m to 2.51 the sand was very white and contained evidence of vegetation in the form of roots and stems. However laminae were either not visible or were difficult to trace. From 2.51 upward to 2.95 there was organically stained sand which contained roots and stalks of plants. From 2.95 to about 3.05 there was a layer of sandy organic material containing decayed vegetation and was overlain by a 1 cm thick layer of grey sand with roots in it. From 3.05 to about 3.7 there was a layer of yellow to grey sand with few structures. Laminae within this bed were very difficult to trace. At 3.7 m there was a 7 to 10 cm thick bed of sandy organic material topped by 10 to 12 cm of organically stained sand containing plant fragments and overlain by another 3 to 5 cm bed of sandy organic material. The sandy organic material was topped by a 35 cm thick layer of white-grey sand with brown organic stains which was capped by another 15 cm layer of organically stained sand. Above this was about 30 to 40 cm of mottled white sand and a cap of concentrated sandy organic material. It dipped 24°/335 and was separated from the final organic layer above by another layer of mottled organically stained sand. The final sandy organic layer was less than 10 cm thick and faded upward until the sand was no longer

FIGURE 5.7. Site 88-1 contained three separate paleosols which are located at 2.5 m, 3.7 m, and 4.7 m. The first capped a sequence of unvegetated fine and coarse sand which changed upward to discontinuously laminated, fine sand with vegetation fragments and stains. Between the paleosols were transitional sequences of discontinuously bedded fine sand with vegetation stains. Topping the third paleosol were beds of sand deposited in association with vegetation.



6.5
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m

organically stained.

The structures above the paleosol began at 4.92 m. From 4.92 to 5.1 m there was a discontinuously laminated bed of fine sand. It was capped erosively by a set of steeply dipping, discontinuous, vegetated cross-beds which extended to 5.76 m. These beds were traceable laterally for only a short distance and averaged about 10 cm in thickness. Above this the beds became horizontal and were made up of a wider variety of grain sizes. From 5.76 to 6.2 m was a set of alternating coarse and fine beds which were somewhat irregularly-shaped. From 6.2 m to the top of the section (6.8 m), discontinuous beds rose from all directions to plant stains. Beds averaged 9 cm in thickness and contained laminae which followed the bedding planes. The dune extended upward for about 3 or 4 m with a similar type of bedding, but due to instability it could not be examined in detail.

Interpretation

The structures at this site indicate a change in the environment of deposition from one in which there was abundant sand supply and little vegetation to one in which there was a decreased supply and a vegetation cover under which a soil could develop. Below 1.16 m there were small discrete dunes and sparse vegetation cover. From 1.16 m to about 2.0 m there was a change to a cover of grasses (Ammophila breviligulata). From 2.0 m to 2.8 m the surface was covered with a mixture of grasses and shrubs (Shrub Heath Facies) which stabilized the surface and led to the development of the paleosol.

The paleosol consisted of 6 layers of richly organically stained sand separated by leached sand layers. These were associated with the woody vegetation cover. The topmost portion of the section consisted of fine to medium sand deposited around sparse Ammophila breviligulata.

5.2.5 Site 87-5 (Fig. 5.8)

Description

At Site 87-5, only a relatively small section (2.7 m) parallel with the waterline could be examined because the sand was extremely unstable at this location. Also, the basal portion of the dune was blanketed with a thick ramp of sand which prevented digging through to the structures at the base of the original dune. The section began with the paleosol and so no structures below this were logged.

The paleosol consisted of two distinct groups of layers of concentrated organic material separated by about a half metre of laminated, well rooted sand. The first group consisted of a 10 cm concentrated sandy organic bed topping 24 cm of grey stained sand. It was fairly horizontal and was covered again by 48 cm of grey stained sand. This was topped by 10 cm of organically stained coarse laminated sand, 15 cm of laminated fine sand with plant remains, and 15 cm of interlaminated coarse and fine organically stained sand. The second group of beds of concentrated sandy organic material was at 1.24 m from the base of the section. It consisted of a 7 cm thick layer of

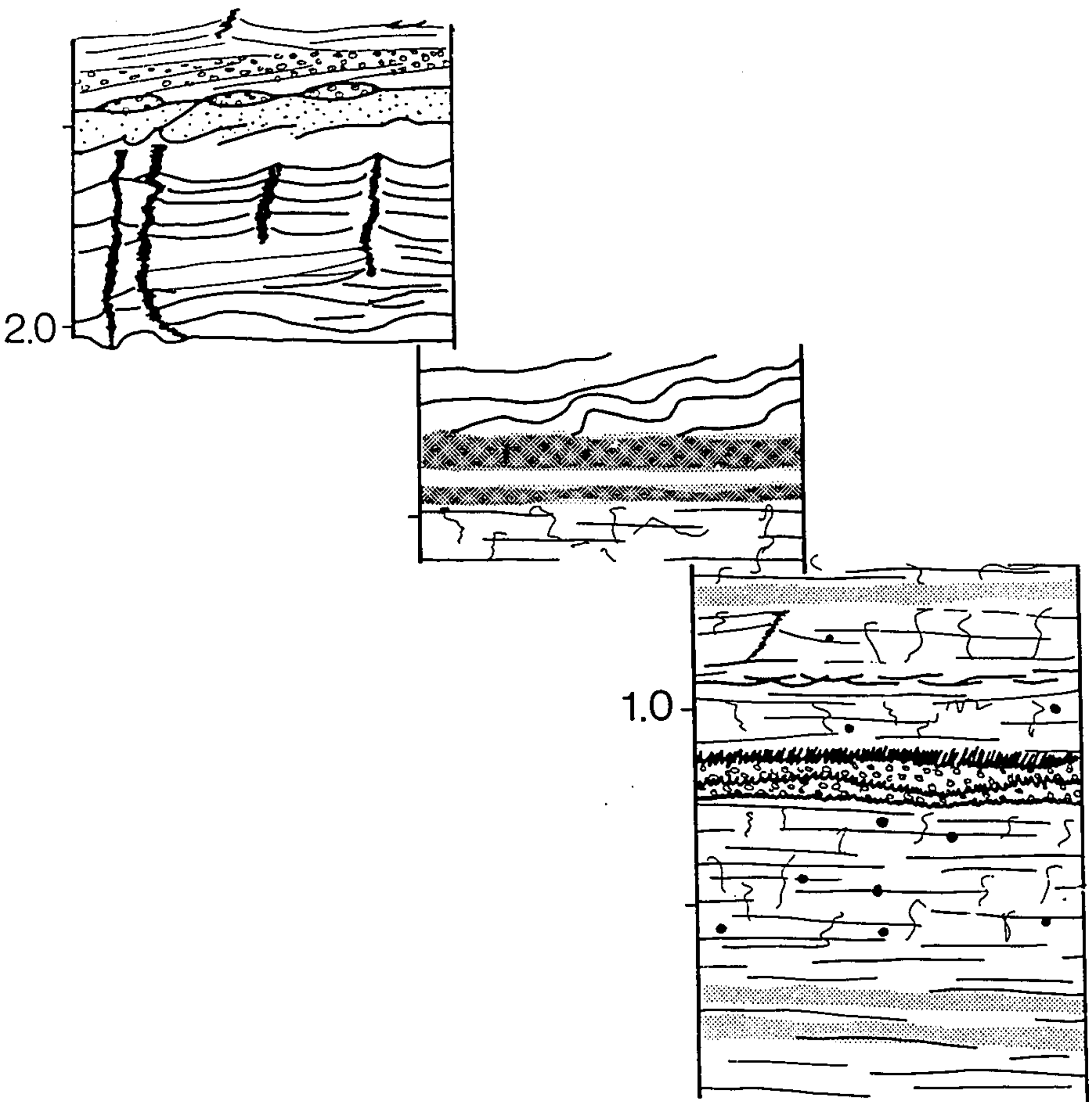


FIGURE 5.8. Site 87-5 is made up of sand deposited in association with vegetation. There is a paleosol at 1.5 m.

concentrated sandy organic material topped by 12 cm of discontinuously laminated, root stained, grey sand. A second 7 cm bed of concentrated sandy organic material and 5 cm of discontinuously laminated, root stained grey sand was located above this. A third horizontal, 10 cm concentrated sandy organic layer topped the discontinuously laminated sand. It was erosively overlain by clean white sand.

Sets of beds sat erosively above the paleosol at this site. There was striking evidence of vegetation as the stains from the decayed plants could be traced for as much as a metre in height and rhizomes could be traced laterally for 2 to 3 m. At about 2.4 m above section base beds could be seen with discontinuous laminae rising from all directions toward the base of the plants. At 2.5 m, lenses of coarse material were preserved which were between 5 and 10 cm long and 1 to 2 cm in height at their thickest points. A coarse layer was present at about 2.55 m. Above this was discontinuously laminated sand laid down around. However, due to the instability of this section, we were unable to closely examine this part of the section. It extended upward for about another 5 m.

Interpretation

The basal portion of this section of the dunes appears to have been the result of stable periods which allowed the accumulation of organic material and the beginning of the development of paleosol. However, slight changes allowed for periods of more rapid deposition of sand when the organic material could not collect in the concentrations necessary for development of the paleosol. However, this changed above the paleosol. Pulses of burial were interrupted by a period of rapid deposition with the growth of sand trapping vegetation (Ammophila breviligulata). The beds above the paleosol have very little organic material preserved within them.

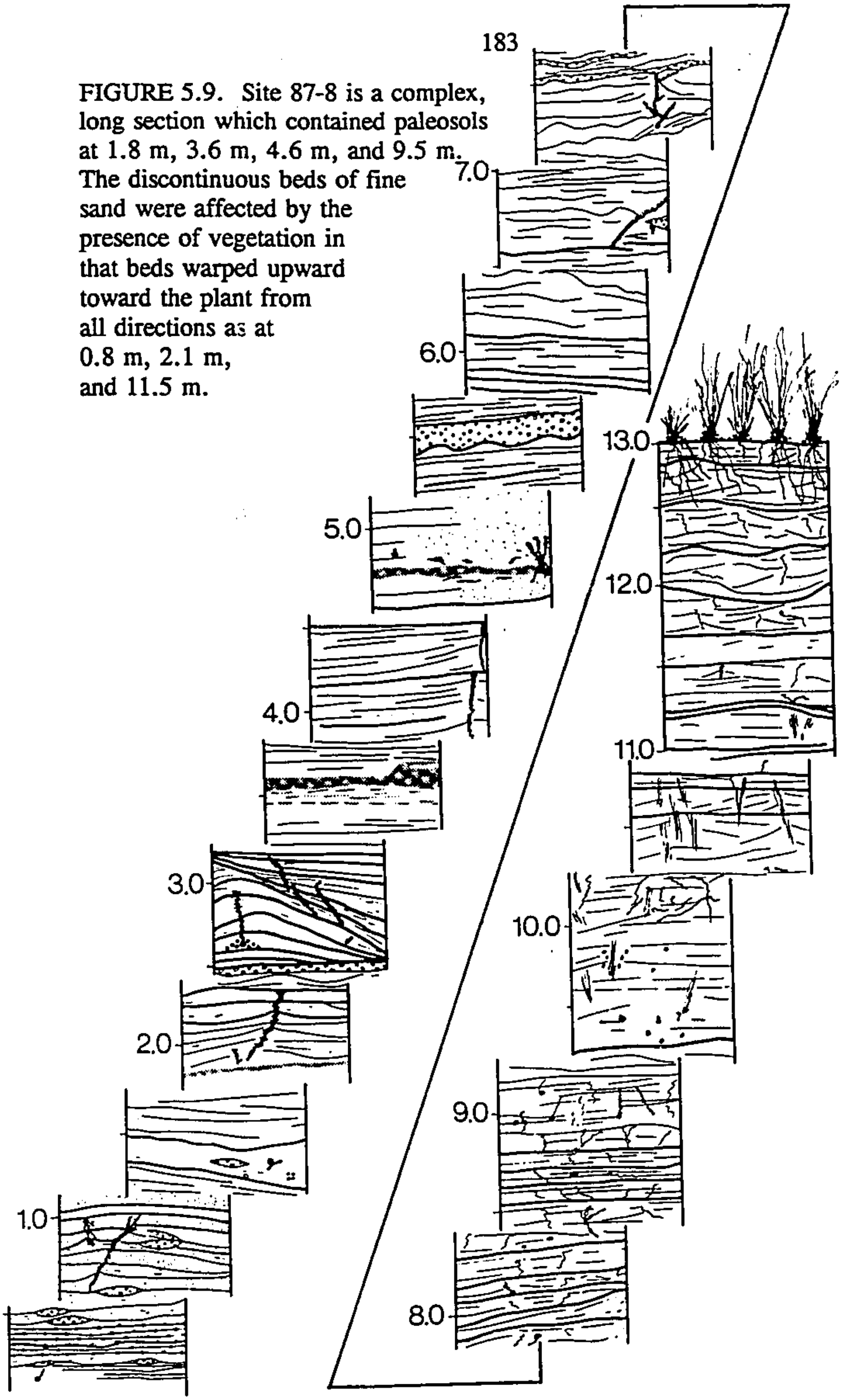
5.2.6 Site 87-8 (Fig. 5.9)

Description

This site was parallel to the waterline near the Skidby wreck. There was a 3.22 metre section dug below the paleosol. The basal section extended in height only to 0.54 m and consisted of three fairly tabular cross-beds decreasing in dip from 18°/136 to horizontal at the top of the section. Average bed thickness was about 25 cm. There was a variety of grain sizes and packing within the beds. Coarse lenses and layers were visible. A single plant node was present in the lowermost right of the section, but it did not seem to affect bedding.

From 0.54 m to 1.77 m, beds became more homogenous. There was more evidence of plant growth and beds were contorted around plant stains. However, the beds were continuous and made up of uniform grain sizes. Sand was alternately tightly and loosely packed from 0.54 to 1.14 m. A large plant stain was present in this section. Associated with the basal node of the plant was a lens of coarse sand 5 cm thick and about 20 cm long. A second set of

FIGURE 5.9. Site 87-8 is a complex, long section which contained paleosols at 1.8 m, 3.6 m, 4.6 m, and 9.5 m. The discontinuous beds of fine sand were affected by the presence of vegetation in that beds warped upward toward the plant from all directions as at 0.8 m, 2.1 m, and 11.5 m.



coarse lenses was associated with the lee of the top of the plant. These were similar in size to the lens at the base. Average bed thickness in this section was around 7 to 10 cm.

Above 1.14 m the beds were larger in scale. Laminae were less continuous and there was more organic staining. At 1.5 m there was a discontinuity dipping 14°/230. Laminae above and below this surface were similar. Although there was much organic staining, there were no plant stains visible in this section.

From 1.77 m to 3.22 m there was abundant evidence of vegetation. At 1.85 m there was an organic layer about 2 cm thick. From this a larger, very dark plant stain rose to 2.34 m. Bed thickness varied between 5 and 25 cm and laminae were contorted. It was not possible to measure dips in this section because they changed so much over a few tens of centimetres due to contortion by plants. Between 2.4 and 2.5 m there was a 3 cm thick horizontal coarse layer. Above this coarse layer were laminated beds of between 5 and 10 cm thickness with variable dips. Three large plant stains were contained within this section. At the base of each was a lens of coarser, slightly less compacted sand 1 to 2 cm thick and 15 to 20 cm long. By 3.1 m beds became more continuous and less contorted. There was abundant staining and more uniform grain size sand. From 3.22 to 3.38 m the beds became horizontal and were stained grey. The laminae within the beds could be traced for 20 to 40 cm and then were lost.

At Site 87-8, the paleosol was situated above discontinuously laminated sand and consisted of a layer of brown-stained, unlaminated sand (3.38 to 3.45 m) which changed upward to grey unlaminated sand, topped by a 10 cm thick hard organic layer, dipping 6°/243. This was capped by two thick discontinuously laminated vegetated beds (3.45 to 4.7 m) and then a second less well developed organic layer with plant stains extending from it.

There was a gradual change from the organic layer to the bedded and laminated sand above (4.7 to 5.5 m). Immediately above the organic layer the beds were indistinct and appeared not to be laminated. These were topped by a discontinuously laminated, horizontal bed of fine to medium sand. From 5.5 m to 5.65 m there was a bed of unlaminated, coarse sand. The lower contact was erosive, dipping 15°/239 and the upper contact was gradational, dipping 9°/278. Above the coarse layer there was again discontinuously laminated sand. This extended to 5.8 m where an erosive upper boundary dipped 21°/219. The discontinuously laminated sand continued upward to 6.65 m. At this point, there was a horizontal layer of organically stained sand less than 1 cm in thickness. A large plant stain extended from this layer. Laminae in the bed above rose up toward the plant stain. Contained within this bed was a coarse lens of sand which was 10 cm in height and about 20 cm long with a plant node at the left end of the lens. The bounding surface of this bedset was undulatory around the plant stains. Evidence of vegetation growth increased upward from this point. Beds were discontinuously laminated and had varying dips due to the presence of the plants. There was abundant evidence of plant growth in organic staining, root and stem pieces and contorted laminae. Dips of beds ranged from as low as horizontal to as high as angle of repose. The average thickness of beds was between 10 and 20 cm. Two beds were as thick as 40 cm. However, these were not the average. This type of deposition continued upward to around 13.00 metres.

Interpretation

The basal portion of the section reflects the growth of vegetation to a higher degree than that in Sites 87-1 and 87-3a. Beds are more continuous and have a greater variety of grain sizes. Perhaps this is due to the growth of a more dense vegetation.

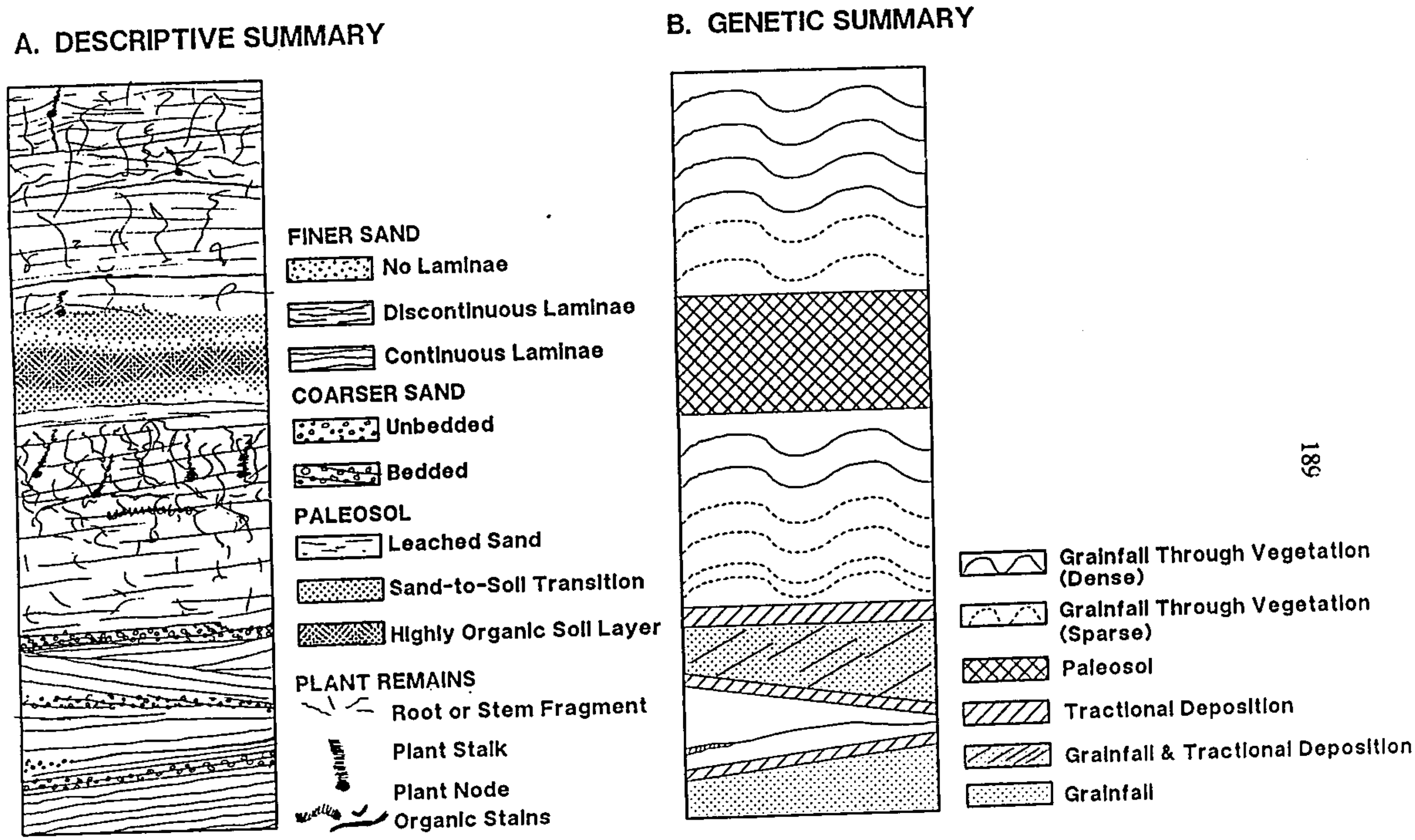
Organic layers are present and there is much organic staining of the sand. However, there is little evidence of plants in growth position other than Rosa virginiana roots. The different vegetation cover influenced deposition and led to a different suite of structures at this location. Evidence of vegetation increases rapidly upward from this point. Plants in growth position, which indicate rapid burial, are present below 1.35 m. Above this there is abundant evidence of vegetation. The laminae within beds can be traced across the cleared section. This is the result of a change in vegetation. Shrubby roots and stems are present at 3.3 m. These lead to the accumulation of the larger amounts of organic material and thus to the 5 organic layers between 4 and 5.1 m. Above this elevation, concentrated organic layers are deposited as paleosol.

At Site 87-8 there are two to three concentrated organic layers. The first is a set of two and is located at 3.4 to 3.6 m above section base. It is deposited on top of sand which accumulated rapidly around vegetation. The paleosol therefore represents a period of stability after a period when an abundance of sediment was available. This is overlain by another set of sediment laid down rapidly around vegetation. This episode was again followed by a period of relative stability and the development of the new paleosol. The structures above the paleosol here also lead to the inference that the sand was rapidly deposited around the vegetation. However, toward the top of the section deposition became more constant as the beds are of similar thickness and appearance.

5.2.7 Summary of Type I

Type I sites are all located west of the Skidby wreck. All are situated within the northern dune ridge, close to or facing on the north beach. Figure 5.10A is a descriptive summary of the structures contained within the sites and Figure 5.10B is the genetic summary. The section can be divided into 4 units. The basal unit is made up of beds which are not laterally continuous. They dip at various angles and show very little evidence of having been vegetated. The sediments were deposited by a combination of grainfall and traction around obstacles on a fairly horizontal base. At first the obstacles were the

FIGURE 5.10. The descriptive and genetic summaries of Type I In Situ dunes are portrayed in A and B above. At the base of the section, tractional and mixed tractional and grainfall deposition dominate. This is replaced by a dominance of grainfall deposition.



COLUMNS ARE APPROXIMATELY 5m HIGH

focus of sedimentation and small discrete dunes or dune ridges developed. Then, as supply was maintained, the ridges coalesced and became vegetated. This is the Marram Cluster Sub-facies of the Sparse Marram Facies.

The second unit is made up of sand laid down around vegetation. The first part of the unit is fairly continuously bedded with sparse evidence of vegetation. Vegetation cover would likely have been sparse Ammophila breviligulata. There is increasing evidence of vegetation upward through to the top of the unit. The predominant processes responsible for the deposition of this unit are grainfall through sparse and then dense vegetation cover. The base of the unit is the Sparse Marram facies and the top is the Dense Marram Facies.

The third unit is the paleosol. This unit was deposited under fairly stable conditions and marks a period in which there was very slow accumulation and an almost complete vegetation cover. A radiocarbon date of the sample showed it to be only 100 $\pm$ 70 years old. This age is not in agreement with that of Terasmae and Mott (1971) who dated peat balls from the island and stated that the paleosol was significantly older than 200 years. The paleosol developed under very slow accumulation conditions. There was not an abundance of sediment available during this time, but there are pulses of sedimentation which separate layers of concentrated organic material. The accumulation of organic material derived from a dense Ammophila breviligulata canopy is responsible for the development of these concentrated organic layers. The paleosol in this group is variable and rarely well developed. Often, the soil layers exist as pulses of organic material which reflect a system in a dynamic rather than a stable state.

The fourth unit consists of increasingly horizontal beds of parallel and wavy laminated sand deposited around an increasingly dense vegetation cover. Like unit 2 there is increasing evidence of vegetation with height in the unit. The surface is littered with plant remains and is well vegetated. This is the Dense Marram/Beach Pea Facies. The fourth unit represents a change from the slow accumulation to a period when there is a wealth of sediment which has been freed from some other point on the island or on the submerged portion of the bank.

The deposition of sand above the paleosol marks a change in the environment. A dune ridge developed on a flat surface and grew upward. A soil forming period was followed by a period when large amounts of sand were available and free to be moved. The rate of accumulation was at first rapid, but decreased with increasing vegetation cover. The first 3 units can be explained as normal foredune development. The environment was a high energy one similar to that of the beach at the base of the present day dunes. Small discrete dunes became vegetated and through time, they coalesced. The vegetation grew upward with burial enlarging the dune vertically and laterally. Accumulation rate slowed, organic material collected and a paleosol developed.

5.3 Type II - Sediment Abundant Foredunes

5.3.1 Site 87-13 (Fig. 5.11)

Description

Site 87-13 was located in the western end of the Grand Canyon in a newer dune which divided the blowout into two. The paleosol was located at 1 m above section base. From the base of the section to 0.2 m was a set of alternating coarse and fine beds of sand. The coarse beds ranged from 1 to 3 grain thicknesses and the fine beds were between .05cm to 2 cm in thickness. They dipped 10°/136. From 0.2 to 0.45 m there was discontinuously bedded, grey sand which contained an abundance of decorticated root material. The bounding plane dipped 12°/136. It was topped by a 60 cm bed of yellowed sand of uniform grain size. A 5 cm thick sandy organic layer dipping 10°/140, topped this. There was a second similar layer between 1.1 and 1.20 m which was separated from the first by a 15 cm thick layer of organically stained sand with decayed plant fragments within it. Between 1.3 and 1.6, there was little evidence of vegetation. For the most part it was made up of uniform grain size sand containing lenses of coarse grains. A coarse layer at 1.50 m was topped with a 5 cm thick layer of uniform grain size which was again topped by coarse sand.

From 1.6 upward to 2.8 m. there was evidence of vegetation as bed surfaces were laid down irregularly around plant stains and fragments. Plants were well preserved in growth position and laminae did not follow the bedding

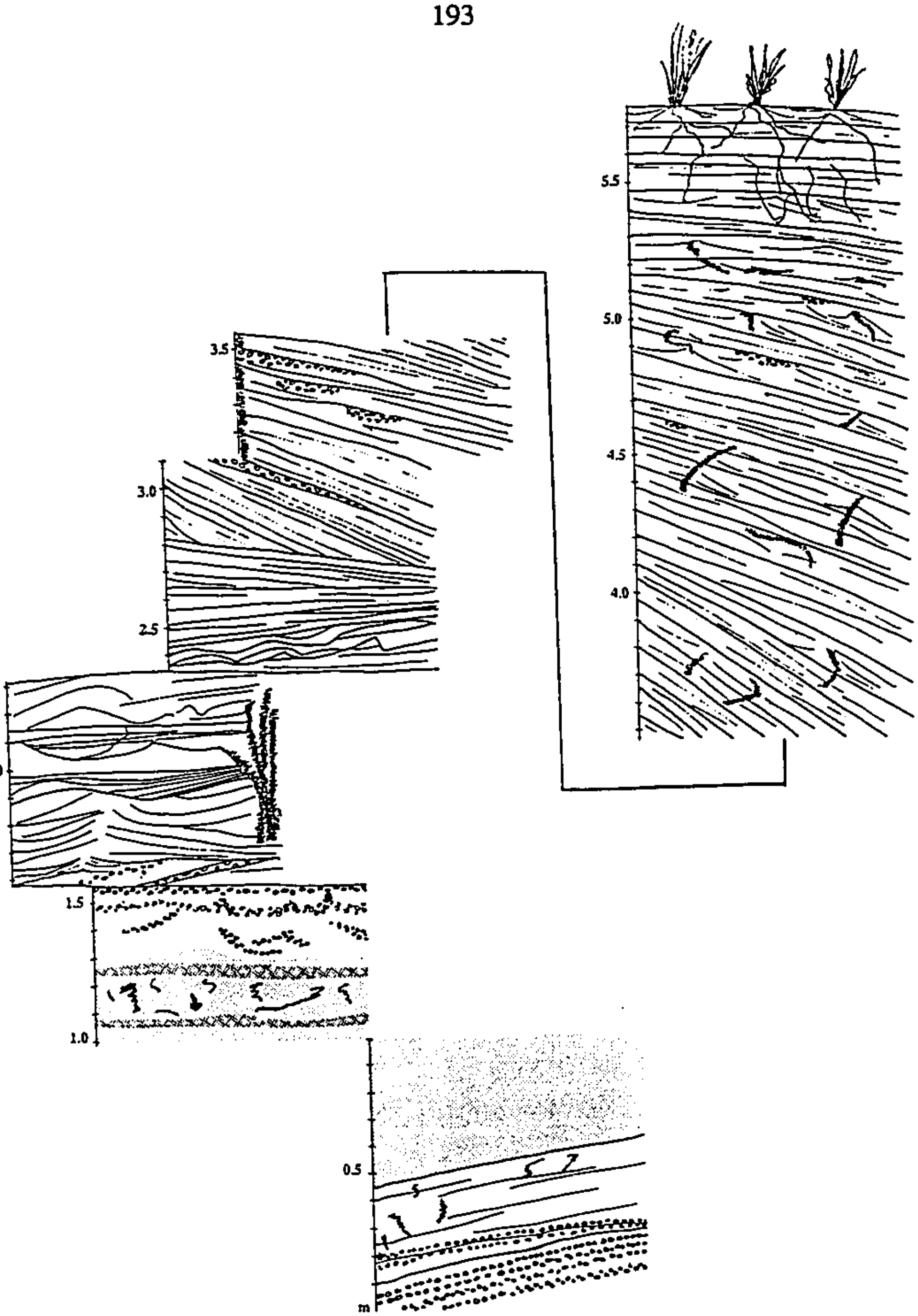


FIGURE 5.11. Site 87-13 had a paleosol at the base which was topped by increasingly vegetated, fine sand upward to the top of the section.

planes, but warped upward at plant locations. Coarse lenses were associated with plant nodes. At 2.8 m there is a change in bed dip and orientation. Below 2.8 m, beds dipped at angles less than 5° toward 140° while above 2.8 m, they dipped from 22 to 29° towards 285° before decreasing to horizontal at the top of the section. Beds averaged between 5 and 10 cm and contained many plant fragments, and abundant decorticated root material at the top of the section (5.85 m).

Interpretation

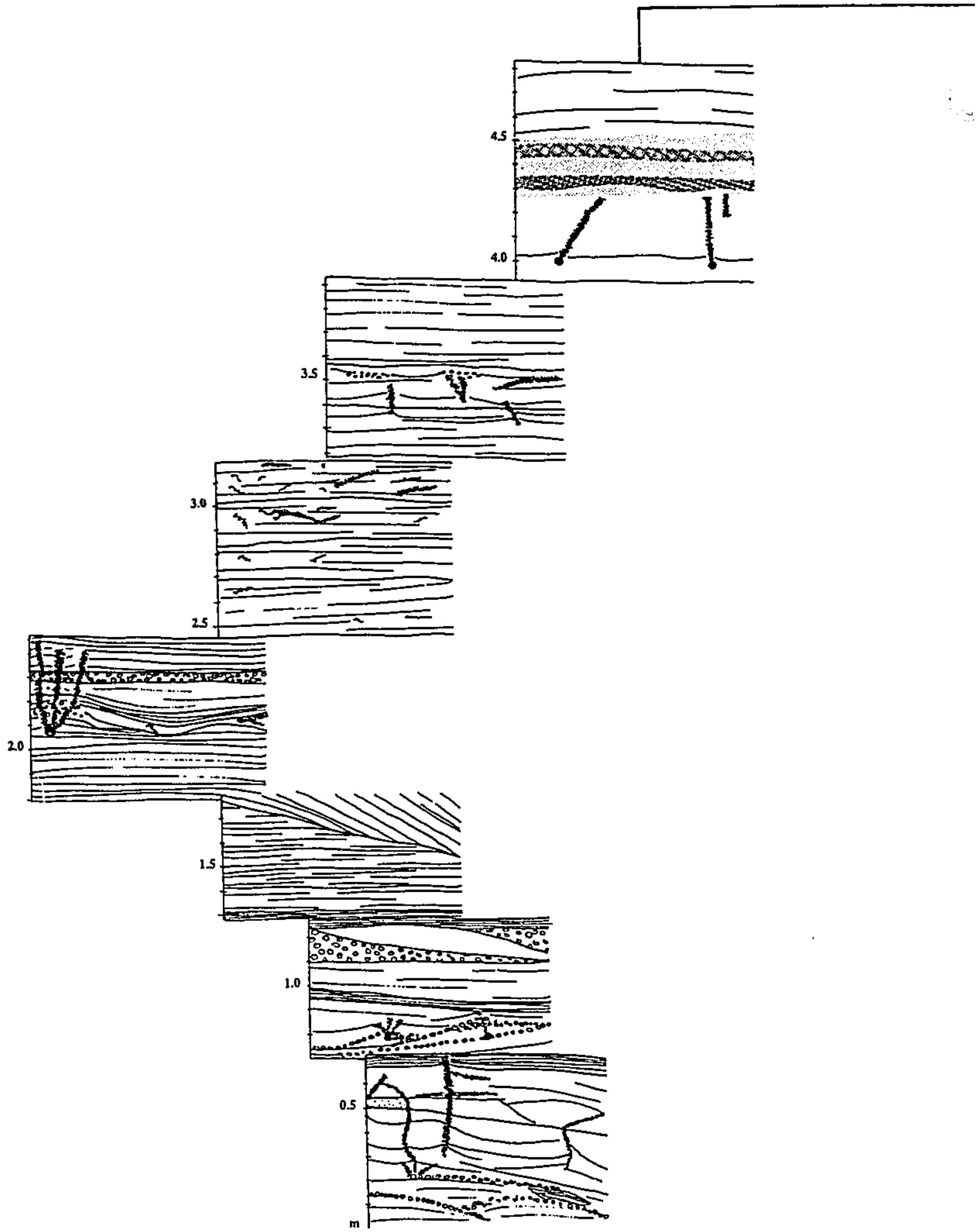
The basal portion of the section reflected an environment of deposition in which vegetation was important. There was abundant sediment supply of both fine and coarse sand. The migration of coarse sand ripples may have deposited the alternating beds of coarse and fine sand at the base. Vegetation took a strong hold on the sediment and organic material began to collect. A paleosol developed in this fairly stable environment. Then a change occurred which freed abundant sand. This was reflected by the layer of uniform grain size sand with coarse lenses. Deposition then slowed enough to allow vegetation to again take hold, but not to establish complete cover. A second pulse of rapid burial occurred between 1.97 and 2.27 m. Sediment supply increased upward. This was again followed by a slowing of deposition and the establishment of vegetation. Cover became more complete at this point as the beds became increasingly more horizontal. The present surface was covered by a sparse Ammophila breviligulata cover.

5.3.2 Site 87-12 (Fig. 5.12)

Description

Site 87-12 was located on the east end of the established dune ridge in an area known locally as the Grand Canyon. The basal portion (0 to 1.6 m) of the section at this location consisted of discontinuously bedded sand with abundant plant stains which were spaced more than 1 m apart. There was a variety of grain sizes, some plant stains and organic stains, and variably packed sediment. From 1.6 m to 2.1 m there was a section in which there was no evidence of vegetation. From 2.1 m upward there was again evidence of vegetation. Plant stains in growth position could be traced for about a metre. With increasing height, plant density increased. Clusters and individual plants were within 20 cm of each other. The beds were laterally continuous and averaged 8 to 15 cm in thickness. Bed boundaries were marked by compact layers of uniform grain size sand and many were erosive in that plant stains could not be traced from one bed to the next. Others sat conformably atop each other (plant stains could be traced through 3 or more beds).

At 3.48 m height, the bed boundaries were no longer distinguishable. Some individual plant stains could be identified, however, most had deteriorated beyond recognition. The sand was generally organically stained and plant fragments were common. From 4.3 m to 4.55 m the sand was clean, but yellow in colour - the beginning of the paleosol. The rest of the



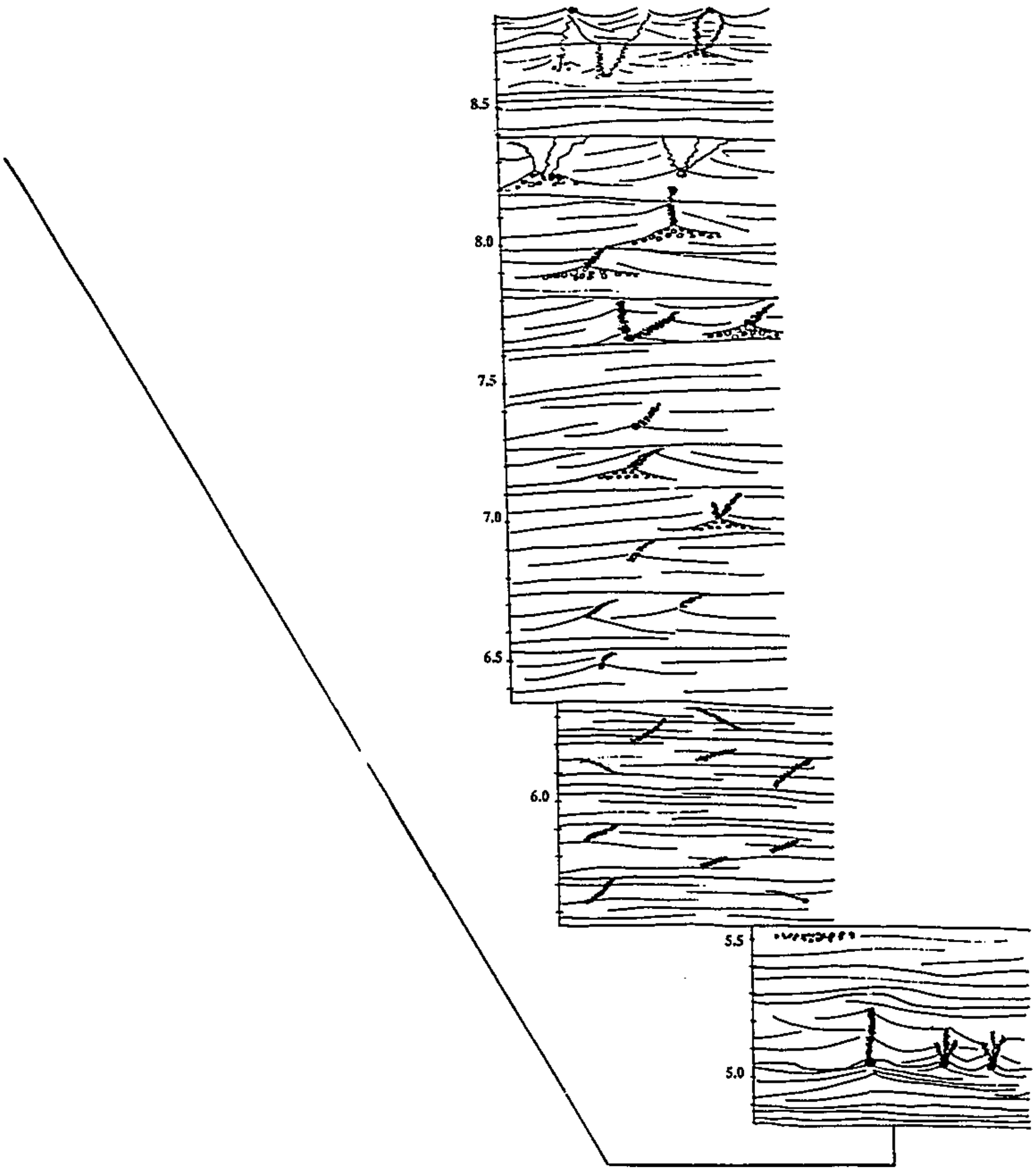


FIGURE 5.12. Site 87-12 contained a paleosol at 4.3 m. Below the paleosol was a sequence which changed from sparsely to densely vegetated. Above the paleosol the cover was dense to the top of the section.

paleosol developed in two layers. The first was at 4.6 m and the second at 4.7 m. The lower layer was about 10 cm thick and was capped by a 10 cm thick layer of grey sand. The upper layer of paleosol was covered by beds of discontinuously laminated sand.

From 5.8 to 9.0 m sand was deposited in discontinuously parallel and wavy laminated beds of sand and contained many stains from decaying vegetation. Vegetation density increased upward. Individual plants and plant clusters at 5.12 m were spaced more than 1 m apart. At the top of the section, they were spaced 20 cm or less. With increasing density there was an increase in the amount of preserved plant material and an abundance of decorticated root matter. Beds averaged between 10 and 20 cm thickness. Laminae within the beds followed the bedding planes at their bases and were more irregular at the tops. The plant material was for the most part, stains of the stems and roots. Some plant fibres were present increasing in occurrence upwards to the top of the section where fibres joined to the present surface cover.

Interpretation

The basal portion of the section was the result of sand being deposited around isolated clusters of Ammophila breviligulata and Cakile edentula. The clusters were spaced far enough apart for the wind to maintain velocity and to move larger sand grains. These were deposited in the lee of obstacles such as the plant clusters and resulted in the development of lenses of coarse material such as that at 15 cm. The vegetation density would be similar to that above the strandline at the foot of the first foredune. In this environment, granule ripples could develop and migrate. The coarse layer at 0.5 m was a preserved granule ripple. Coarse layers like those at 0.7 m were the result of the migration of ripples with a high content of coarser grains.

The 50 cm thick deposit of clean sand at 1.60 m was the result of a change in the rate of deposition. The rate increased beyond the capability of the vegetation to maintain growth through burial. Perhaps a series of migrating ridges moved through this area, burying the vegetated portion of sand and not allowing new vegetation to take hold. Eventually, the rate of deposition slowed and plants propagated most likely from stem pieces, or maybe from seed. Stability allowed the increase in vegetation cover and the development of a paleosol. Eventually, the rate of deposition increased again, but was slow enough for vegetation to keep pace with burial. The beds of horizontal wavy and parallel-laminated sand were deposited. Bed boundaries exist because of periods of non-deposition such as when the surface is frozen or when the plants die back and so are unable to catch sand. The vegetation cover increased upward from the paleosol. Plants and plant clusters influenced the deposition of sand in discontinuous laminae around them. Coarse lenses are associated with the nodes of the plants because the coarser material is left as a lag on the surface after the plants develop leaves which baffle the wind.

5.2.5 Site 88-10b (Fig. 5.13)

Description

This section, located east of East Light, was normal to the waterline and dug into the steep face of a dune with little apron on it. Although the sand was fairly unstable, an extensive cleared section extending from the base (about 2 m above sea level) to the top of the dune (16.82 m) was examined.

The basal section was made up of alternating, laminated horizontal beds of fine and coarse material. Average bed thickness was around 10 cm. At about 0.99 m there was a discontinuity which dipped 20°/92. Above the discontinuity beds were more steeply dipping (14°/272) and were made up of fine uniform grain size beds topped by a laminae of coarse material. Average bed thickness was 10 cm. This section was truncated by horizontal beds at 1.3 m, where a 5 cm thick layer of laminated coarse material formed the basal portion of the horizontally laminated bed of fine sand. It was topped by another bed of laminated coarse sand and a laminae of heavy minerals. The heavy mineral laminae dipped 3°/335. Above this were two 5 cm coarse laminated beds which alternated with 10 cm fine laminated beds. These were truncated by a surface at 2.04 m, which dipped 10°/21 and had an irregular surface. It was marked by two pits which were possibly once horse hoof prints.

From 2.04 to 2.14 m was a set of 2 to 3 cm beds of fine sand, each of which was capped by a laminae of coarse sand. Within this set was the first evidence of vegetation at this site. A single plant stain rose from the centre of the section upward for about 20 cm. Laminae rose toward the plant from all directions. From 2.26 to 2.36 was a bed of coarse laminated sand which was topped by a very tightly packed bed of fine sand that had a gradational lower boundary and an erosive upper boundary. This was topped by a thick set of laminated beds of sand. The set extended from 2.36 m to 3.13 m. Average bed thickness was around 4 cm. At 2.84 m was a lamina of coarse sand. There was another one at 2.96 m. From 3.13 m to 3.25 m there was a set of interlaminated fine and coarse sand.

From 3.25 upward there was increasing evidence of vegetation. From 3.25 m to 4 m there were no organic stains, however, the beds were contorted in a manner which suggests that there were plants present when the sand was laid down. At 3.4 m, a 2 cm coarse laminated bed separated two beds of uniform grain size, fine sand. The upper one extended to 3.7 m. At that elevation there was a lamina of coarse sand which dipped 26°/15. Above this was a thin deposit of fine sand capped by another coarse layer which illustrated the position of two nodes and an infilled stem hole. This was then covered with uniform grain size, fine sand which was truncated at 3.9 m by alternating coarse and fine thin beds (1 to 3 cm thick) which extended to 4.0 m. From here to 4.15 m the sand was laid down as thin beds of uniform grain size, fine sand.

At 4.15 m there was a thin bed (less than 5 cm) of unlaminated, coarse

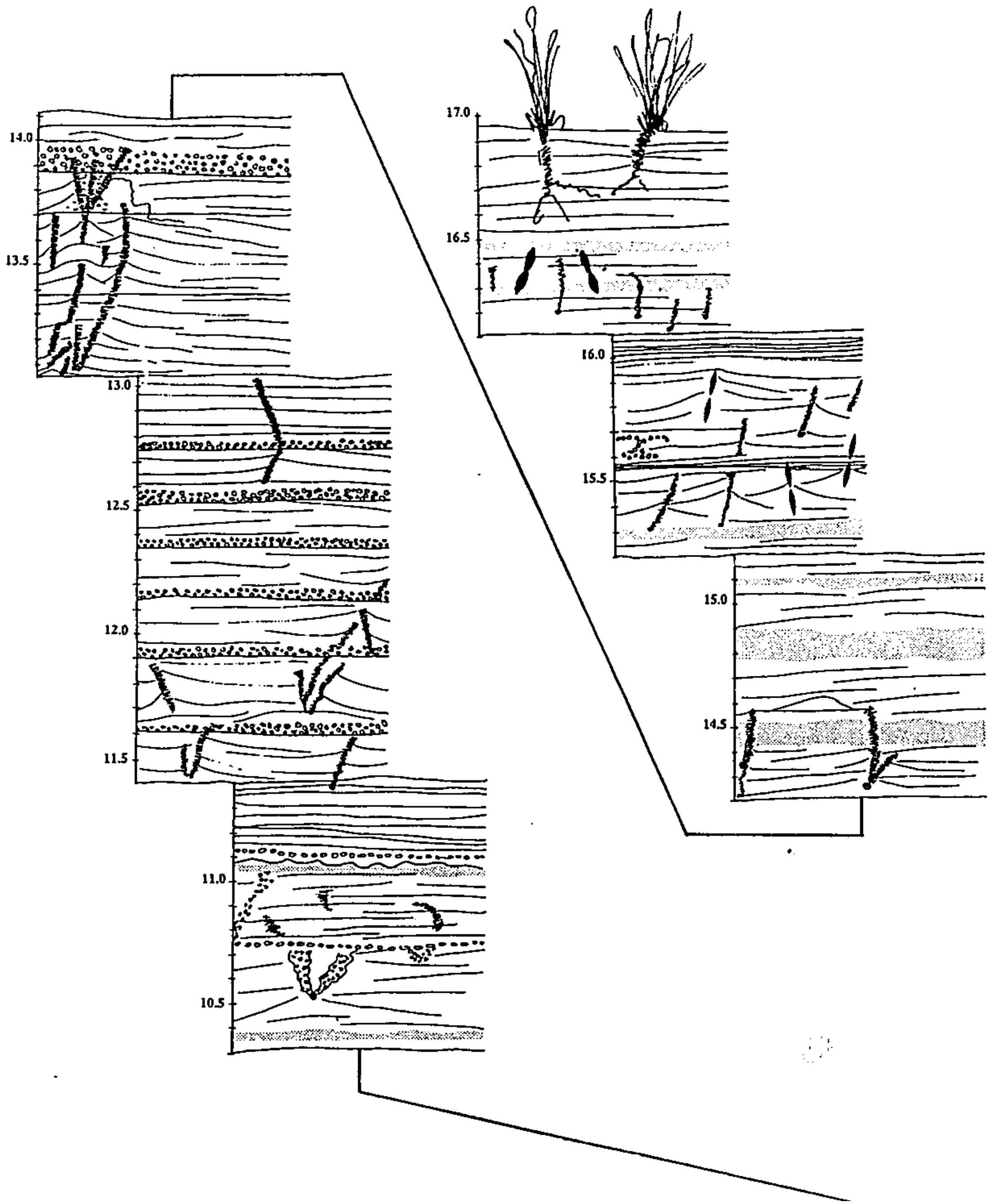
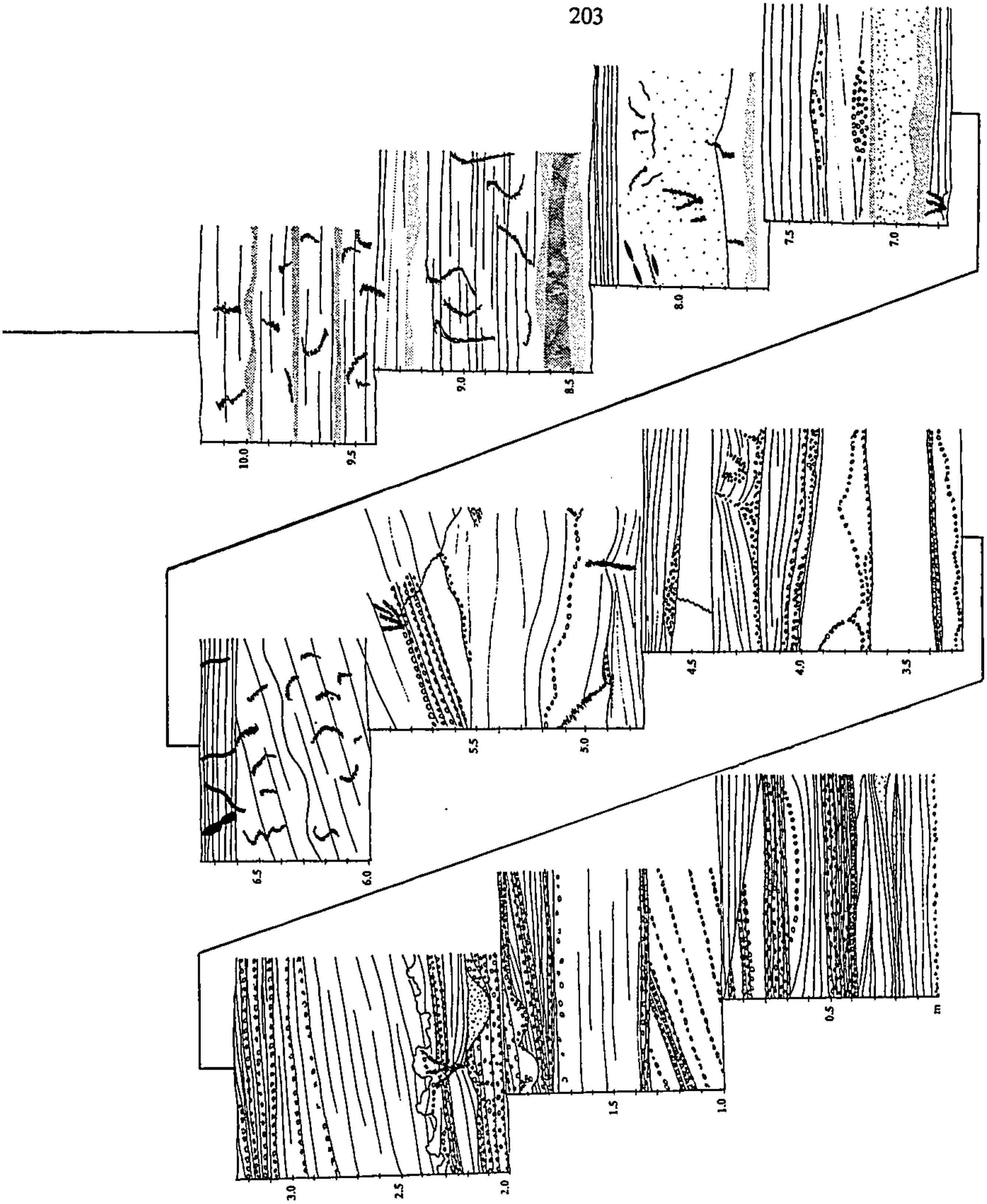


FIGURE 5.13. Site 88-10b was a very long section in which there were numerous organic stainings and paleosols. At the base of the section (from the bottom to about 4.0 m) there was an abundance of coarse sand. Upward the amount of coarse material decreased. The type of vegetation cover changed from herbaceous at the base to woodier at the top.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sand which had a distinct, but not erosive boundary with the bed below, but an irregular upper boundary. This surface was marked by two plant stains which rose up into the bed above. Upward to 4.4 m there was a set of unlaminated beds (around 3 to 5 cm thick) with abundant plant stains. Within the set was a crescent of coarse sand located between the two plant stains. The surface of the set was distinct and dipped 4°/340. From 4.4 m to 4.5 m a bed of unlaminated sand was deposited. Within it was a single plant stain which rose to a node in the set above that was surrounded by a lens of coarse laminated sand about 35 cm long and 7 cm thick. On top of this was a second set of unlaminated beds which extended to 4.69 m.

From 4.69 to 5.5 m three sets of discontinuously laminated beds were deposited around vegetation. Plant stains were present and nodes could be defined. The first set was about 20 cm thick and had an irregular surface. The second set was about 30 cm at its thickest point, contained two plant stains, an abundance of decayed plant material and was topped by a lamina of coarse sand. The third set was around 40 cm thick and contained a plant stain in the right side which rose through the set to a lens of laminated coarse sand at the top of the set. This set was topped by a discontinuity which dipped 15°/270.

From 5.5 to 6.7 m was a set of discontinuously laminated beds dipping 25°/235. These contained abundant decayed organic material. The lower portion of the set contained a bed (5.55 to 5.7 m) of coarse laminated sand deposited in the lee of a plant node. The set was truncated at 6.7 m by a 13 cm thick set of fine laminated sand.

Horizontal or near horizontal beds were deposited from 6.83 to 7.72 m (Fig. 5.14). Set thickness varied from 15 to over 30 cm and there was a variation in grain sizes. The lowest set was the thinnest and contained a plant stain in growth position at the left side of the exposure. To the right of the stain unlaminated beds of thicknesses between 2 and 5 cm were laid down with little effect by the plant. The next set was 20 cm thick and changed from loosely packed sand at the base to very tightly packed sand at the top. It was capped by a thin layer of organic material. The next set was 22 cm thick and contained a coarse lens in the centre of the set. It was 30 cm long and 10 cm thick. The rest of the set was made up of uniform grain size unlaminated, fine sand. From 7.43 to 7.44 was a bed of coarse sand ripple foresets. A single ripple was preserved in the centre of the bed. This was overlain by a 25 cm thick set of unlaminated, 5 cm thick beds. The paleosol was above this.

The paleosol (between 7.9 m and 8.8 m) was composed of a series of sandy concentrated organic layers separated by beds of yellow to grey sand. The first layer of organically stained sand occurred at 7.9 m. It was about 10 cm thick and had an undulatory transitional surface into the yellow sand above it. Plant stains rose from this layer into the clean sand above, the laminae in the sand being discontinuous upward to 8.3 m. From 8.3 to 8.4 m there was a set of parallel-laminated beds of fine sand which were topped by a bed of

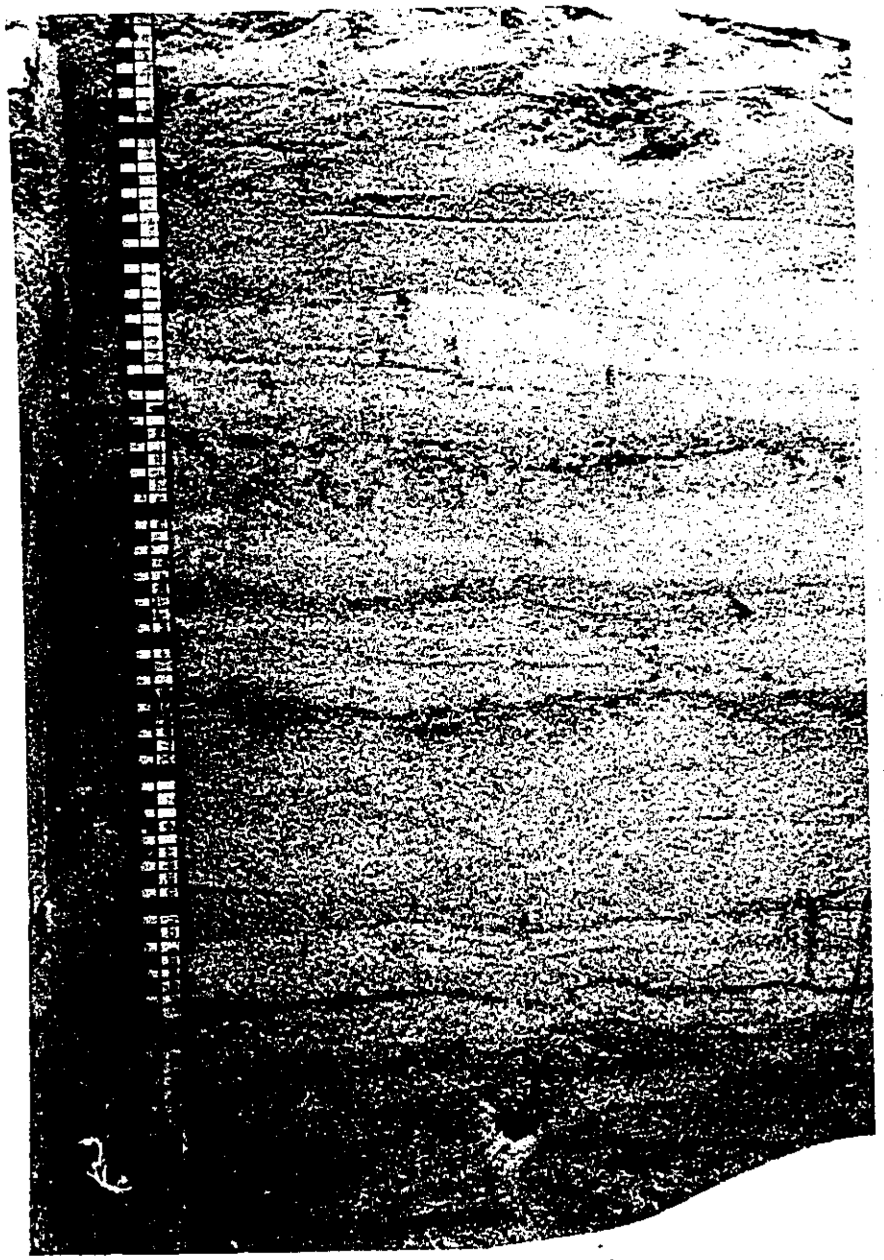


FIGURE 5.14. This photograph of a portion of Site 88-10b illustrates the nearly horizontal nature of the beds. In the bottom left of the photograph there is a lens of material which was deposited around the node of a plant. The stains of the stems of the plants can just be seen in the centre of the photograph at about 30 cm from the base of the pit. The bedding plane at about 35 cm from the base is marked by a collection of organic material. This is repeated at about 55 cm and at about 77 cm.

organic material. Roots could be seen and there were many root filaments. The most concentrated organic layer occurred at 8.5 to 8.6 m. Other layers (from 8.45 m to 8.5 m and from 8.72 m to 8.75 m) were either less concentrated or were not as thick as this layer.

Structures above the paleosol were made up of discontinuously laminated sand (Fig. 5.15, 5.16). From 8.7 to 9.24 m was a set of discontinuously laminated sand which contained root fragments and plant stains. The set was capped by a 2 cm thick organic layer. From 9.26 to 9.58 was a second set of the same type of bedding. There was a third extending to 9.77 m, a fourth extending to 9.98 m, and a fifth to 10.38 m.

The vegetation stains changed at this point. Laminae were still discontinuous and rose toward the plant from all directions, but sets were now capped by an erosive layer and then the next set began with a coarse lamina. The first set was 40 cm thick and the second 35 cm. The next set was made up of fine laminated sand and stretched from 11.1 to 11.41 m.

From 11.41 m to the top of the section (16.82 m) the vegetation stains were similar to those at around 9.0 m. Between 11.41 and 13.04 m there were sets of regularly alternating beds of fine sand laid down with abundant staining and thinner beds of coarse sand associated with plant nodes. Average fine bed thickness was 25 cm and average coarse bed thickness was 3.5 cm. The sets were horizontal. Plant stains within the sets were made up of the organic material from the decayed plant in the form of stains and fibres. The

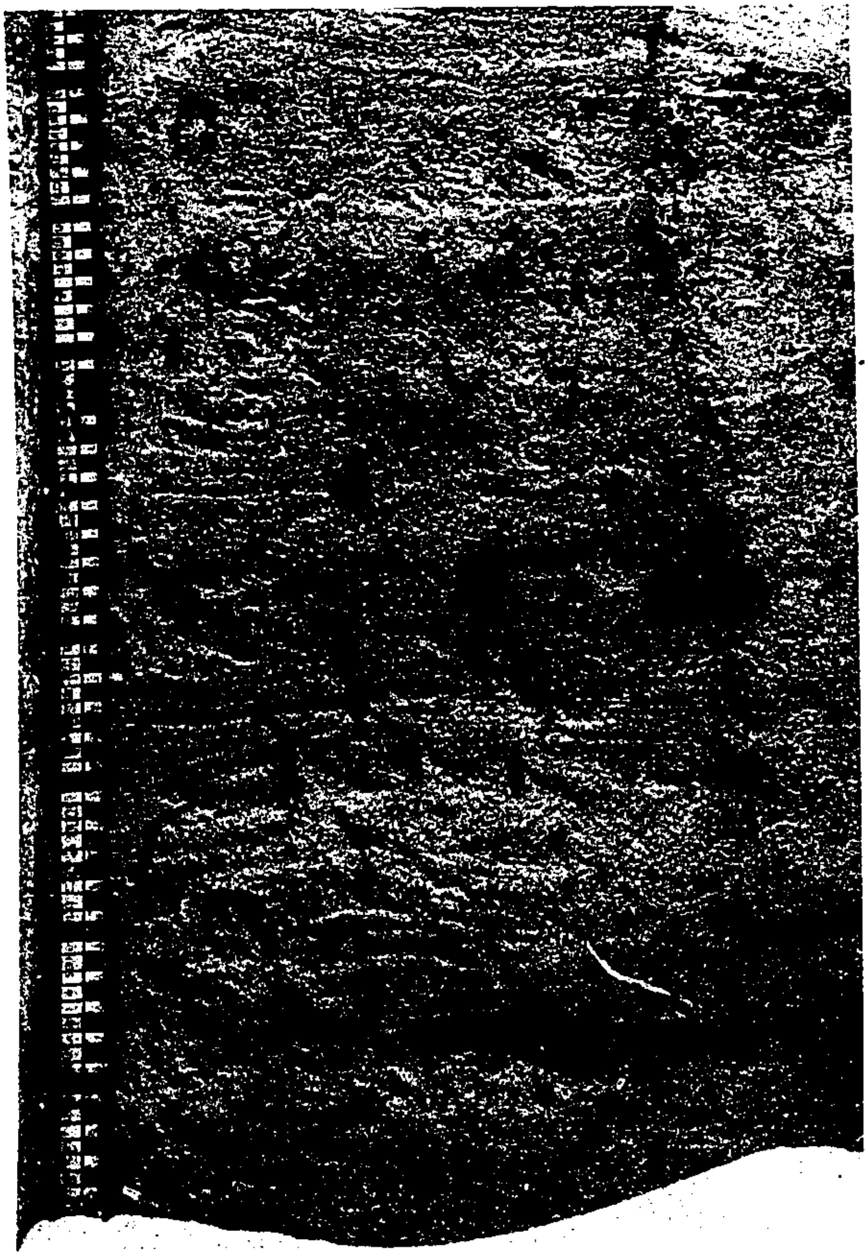


FIGURE 5.15. This photograph illustrates the structures deposited in a dense vegetation cover. A single marram stem left a stain in the right side of the photograph. It can be traced upward from a bed at about 12 cm to the top of the photo. The mottled appearance of the sand is due to the presence of the stains of many plants which have decayed. In some instance there are fibres of the plants present with the organic stain. Bedding planes can be recognized at 12 cm, 34 cm, 50 cm, and 65 cm.

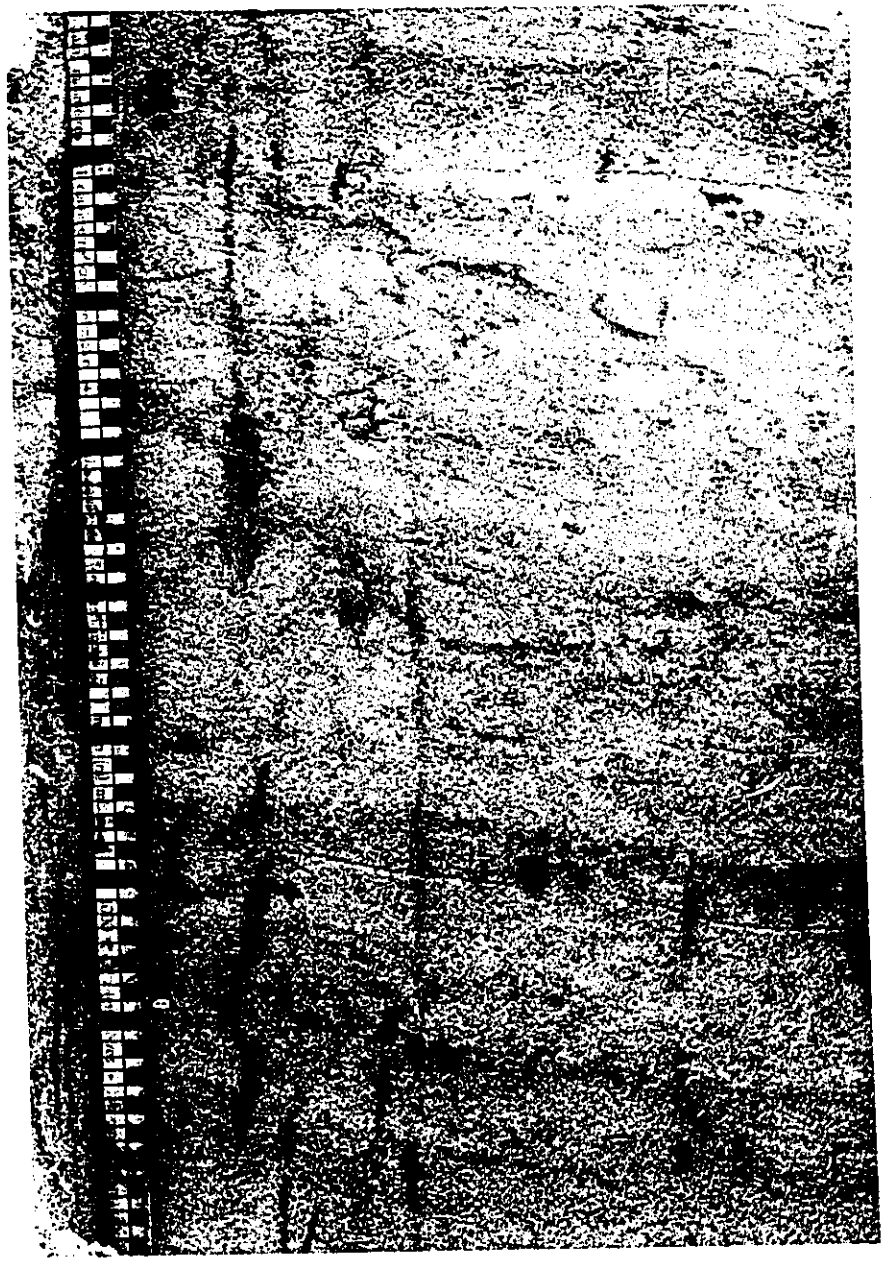


FIGURE 5.16. Marram stems are easily traced through this pit. Bedding planes are less easily defined. They exist at about 20 cm, 35 cm, 55 cm, and 80 cm.

coarse layers made up the base of the set and changed transitionally upward into the fine discontinuously laminated sand. From 13.04 to 13.9 m, the sets were similar in respect to the fine sand, however, coarse layers were absent. Set boundaries were marked by discontinuities in the laminae, but plant fibres rose upward from one set to the next.

From 13.9 to 14.0 m was a bed of unlaminated, coarse sand which was deposited with plants stains. From 14.0 m to 15.5 m there were alternations between fine sand laid down in discontinuous, irregularly shaped laminae with thin organically stained sand layers. The fine layers were between 20 and 40 cm in thickness and the organic layers were 2 to 5 cm thick and contained only organically stained sand with no plant fibres and no plant stains.

At 15.5 m there was a bed of horizontal, parallel-laminated fine sand with woody roots in situ. Above this to 16.0 m, there was discontinuously laminated sand with stains from woody and herbaceous plants that upwarped the laminae around them. From 16.0 to 16.1 m there was a bed of horizontal, parallel-laminated fine sand with no roots within it. A set of discontinuously laminated, horizontal, fine sand with vegetation stains capped by a thin organically stained fine sand bed extended from 16.1 to 16.3 m. A similar set extended to 16.5 m. From 16.5 m to the top of the section there was a set of discontinuously laminated beds of sand deposited in association with the roots and stems which made up the present cover of the dune.

Interpretation

The basal portion of the section was the result of sand being deposited around isolated clusters of Ammophila breviligulata and Cakile edentula and around small discrete dunes. The dunes were spaced far enough apart for the wind to maintain velocity and to move larger sand grains. The larger grains collected in areas which were locally protected and resulted in coarse pockets of sediment. Migration of ripples rich in coarse grains deposited a layer of coarse material. The dunes currently developing near this location are similar to those just described.

The convoluted beds with a high concentration of coarse material were the result of the rapid deposition of sediment around individual plants in a high energy environment (such as a pass through the duneline at the end of a dune ridge) where wind direction is variable. Beds are more continuous in this portion of the exposure indicating that the small discrete dunes had amalgamated by this point. Rapid burial continued upward. The unstable beds and sparse evidence of vegetation lead to this conclusion.

There was a change at around 6.0 m elevation. Here the beds became continuous and there was abundant evidence of vegetation. Perhaps this was due to a slowing in the rate of deposition or perhaps to a decrease in sediment supply. At 6.7 m there was again a change as the laterally continuous beds were truncated. There was very little evidence of vegetation for about a metre in elevation. At that point, woody roots were present. These Rosa virginiana roots were anchored within the fine sand which separated the organic layers in the paleosol. The presence of the paleosol indicates that the rate of deposition slowed substantially. It did not cease however, because the paleosol is complex, being made up of a number of organic layers.

Above the paleosol the rate of deposition increased again. Ammophila breviligulata in growth position was present in wavy parallel-laminated beds. With increasing height there was a change in the type of plant. At about 9 m the vegetation cover was dense enough to allow for the flattening out of the beds and the collection of organically stained sand layers. These alternated with deposits of fine sand around the plants. These organically stained layers represent periods of stability which last long enough for organic accumulation, but not for soil development. They are followed by periods of deposition. At 15.0 m there are woody roots present again, which indicate that the surface cover had become more dense. However, this dense cover could not last because it is topped by more mixed vegetation. The surface had a dense cover of Ammophila breviligulata, Achillea lanulosa, Lathyrus maritimus and lichen. There were woody roots present 20 cm below the surface, but no woody plants on the present surface.

5.3.4 Summary of Type II

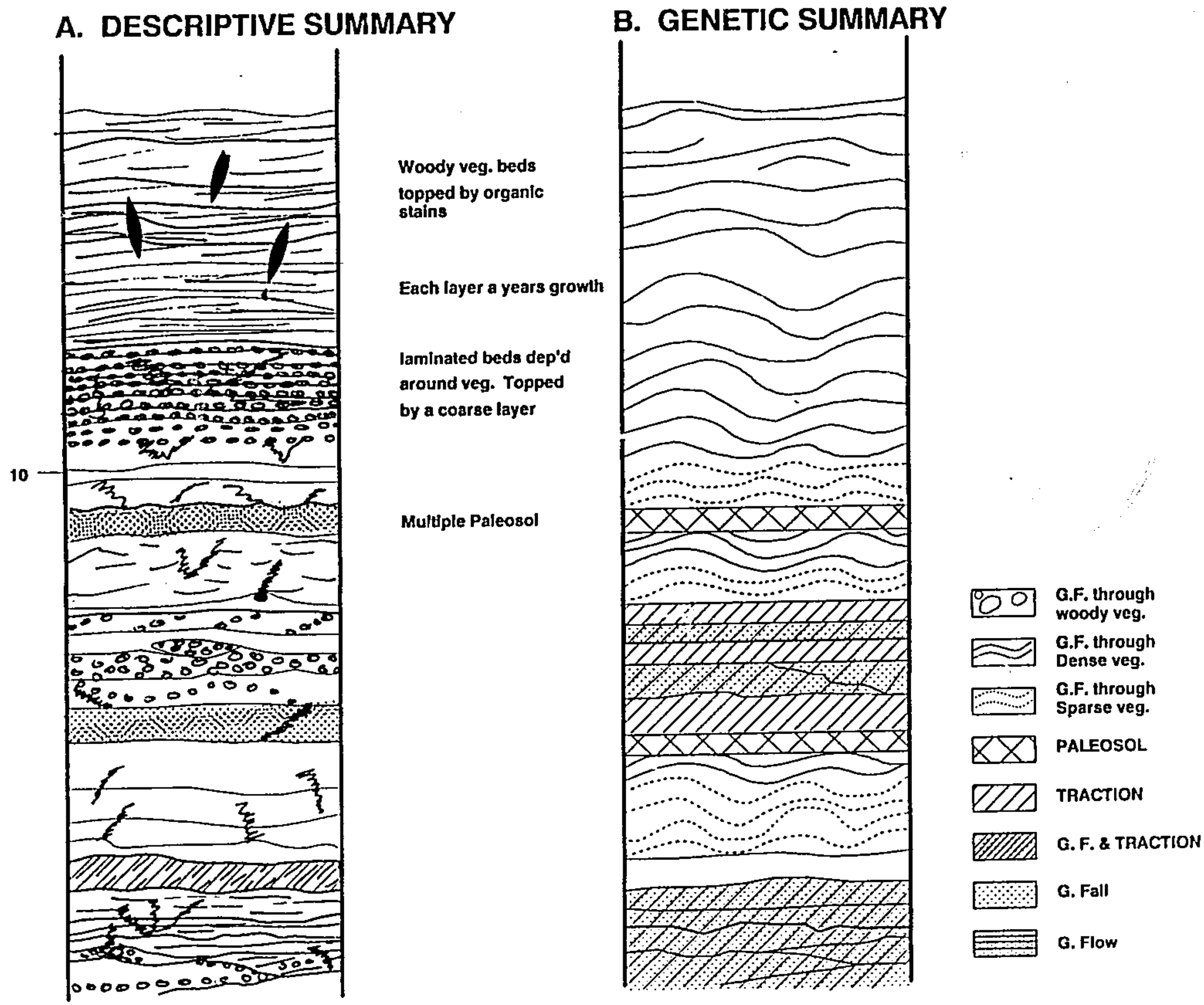
These sites are located toward the eastern end of the island. They represent the sequences developed in a foredune ridge where there is high energy capable of moving a large amount of sediment. The dunes at this end of the ridge are some of the highest dunes on the island. They often contain multiple paleosols scattered throughout the height of the dune. A descriptive summary of Type II is illustrated in Figure 5.17A. A genetic summary is shown in Figure 5.17B.

At the base of the section, tractional and mixed tractional and grainfall deposition combined in a high energy environment to lay down beds which were low angle and dipped in various directions away from plant clusters. Lenses and layers of coarse laminae result from the winnowing out of the fines at the surface of a bed. Plants contorted laminae, but had little affect on the configuration of the bed. This portion of the dune is combination of the Marram Cluster and Marram Hummock Sub-Facies of the Sparse Marram Facies.

An increase in the energy of the environment or a significant increase in the supply of sand to the location led to the deposition of the cross-bed sets which top the low angle beds at the base of the section. After that there was a decrease in the accumulation rate which allowed vegetation colonization. This changes rapidly from sparse to dense grasses and then to woody vegetation and with decreased accumulation to the development of the first paleosol. The facies change from the Sparse Marram Foredune at the base through the Dense Marram/Beach Pea to the Shrub Heath Facies at the top.

The paleosols in this group are not as thick nor as well developed as

FIGURE 5.17. Descriptive and genetic summaries of Type II In Situ dunes. They are more vertically extensive than the Type I dunes and contain greater amounts of woody material. There is usually more than one paleosol in the Type II dunes.



COLUMNS ARE APPROXIMATELY 20m HIGH

those in the other groups. One can infer from this that the soil forming period was neither as long nor the accumulation rate as slow as in other groups. The woody vegetation growing in the paleosol continued into the beds above. With an increase in the accumulation rate beds were laid down by a combination of grainfall through sparse woody vegetation and traction. This type of deposition continued upwards for about 4 metres. At that time there was a decrease in the accumulation rate and the development of another paleosol.

The second paleosol is very similar to the first in organic concentration and thickness of the deposit. Above the paleosol there are beds of sand which were laid down around first sparse and then dense Ammophila breviligulata. These were deposited by a combination of tractional and grainfall deposition. From about 12 metres elevation to the top of the section, there is an increase in the vegetation cover and a change to woody species. From 12 to 14 metres beds are laid down as couplets of laminated fine sand and a thin organic layer. These could represent one year's accumulation. Above that the beds of fine sand containing woody roots and stems as well as filaments and stalks of Ammophila breviligulata, become separated by thicker layers of organic material. These are the early stages of soil formation.

5.4 Summary of Multi-phase In Situ Foredunes

In situ foredunes are those dunes which have developed vertically in place. The structures and stratification examined in this type of dune are therefore not those one could expect to find within a dune which has migrated. These dunes build vertically as plants trap sand in place. The principal first colonizer is Ammophila breviligulata. With changes in the stability of the sand, other plants invade and colonize. However, that stability would not exist in the first place, without the presence of the Ammophila.

The Type I foredunes exist for the most part on the western end of the island where there is less sand available for dune building than throughout the eastern end. The growth of the dunes is limited in both vertical and horizontal extent. The basal portions represent a high energy environment as indicated by the presence of coarse layers and lenses and the preserved granule ripples. Over time the developing dune itself the wind flow over it and, with the introduction of vegetation cover, the environment changes from high to lower energy.

The Type II foredunes exist on the eastern end of the island. Here there is more sediment available and the structures reflect a higher energy environment with both coarse layers and high angle cross-beds. There is also a difference in the types of vegetation which grow in this type of foredune. The woody roots which were present in Type II dunes were not present in the dunes of Type I either because they had been eroded before the sections were examined, or because the vegetation cover never became as woody in Type I dunes as within the Type II dunes.

The patterns of sedimentation are similar in Types I and II foredunes in that different phases of sedimentation can be recognized. There are periods when embryo or incipient dunes can be seen in the basal portions of both types. Increased plant density leads to increased stability and possibly to the development of a paleosol. The differences between the two types of dunes are due to four factors. The first is sediment availability. Type I dunes develop on an eroding coast where sediment is scarce, while Type II dunes develop on an accreting coast where sediment is abundant. The second factor is sedimentation rate. On the Type I dunes the rate of sedimentation is slow while on the Type II dunes it tends to be much faster. The third factor is stability. The surface is stable enough for a paleosol to develop in the Type I dunes, but in the Type II dunes, as soon as a paleosol begins to develop, sedimentation resumes and the surface is buried. The final factor is wind energy. In the Type I dunes the shoreline is oriented in line with the erosive winds increasing the effect of the wind on the dune while the Type II dunes are built up by the storm winds.

CHAPTER 6

STRATIFICATION AND STRUCTURE IN MIGRATIONAL MULTIPLE PHASE DUNES

6.1 Introduction

The Migrational Multiple Phase dunes of Sable Island are located, for the most part, in the central portion of the island, away from the presently forming foredunes along the north and south shores (Fig. 6.1). They are interpreted as remnant dunes which developed during the passage of parabolic dunes across the area. The evidence of this interpretation is presented in the following chapter. Three types of migrational multiple phase dunes were defined on the basis of the sequences of sedimentary structures and the types of vegetation associated with the suites of structures. The first type is based upon three sections which were located landward of the present north foredune and contained well-developed paleosols. The second type is defined by structures in four sections in smaller dunes in the central portion of the island which also contain a well-developed paleosol which is not as highly organically stained as Type I dunes. The third type is based upon three section and is located toward the south side of the main dune ridge.

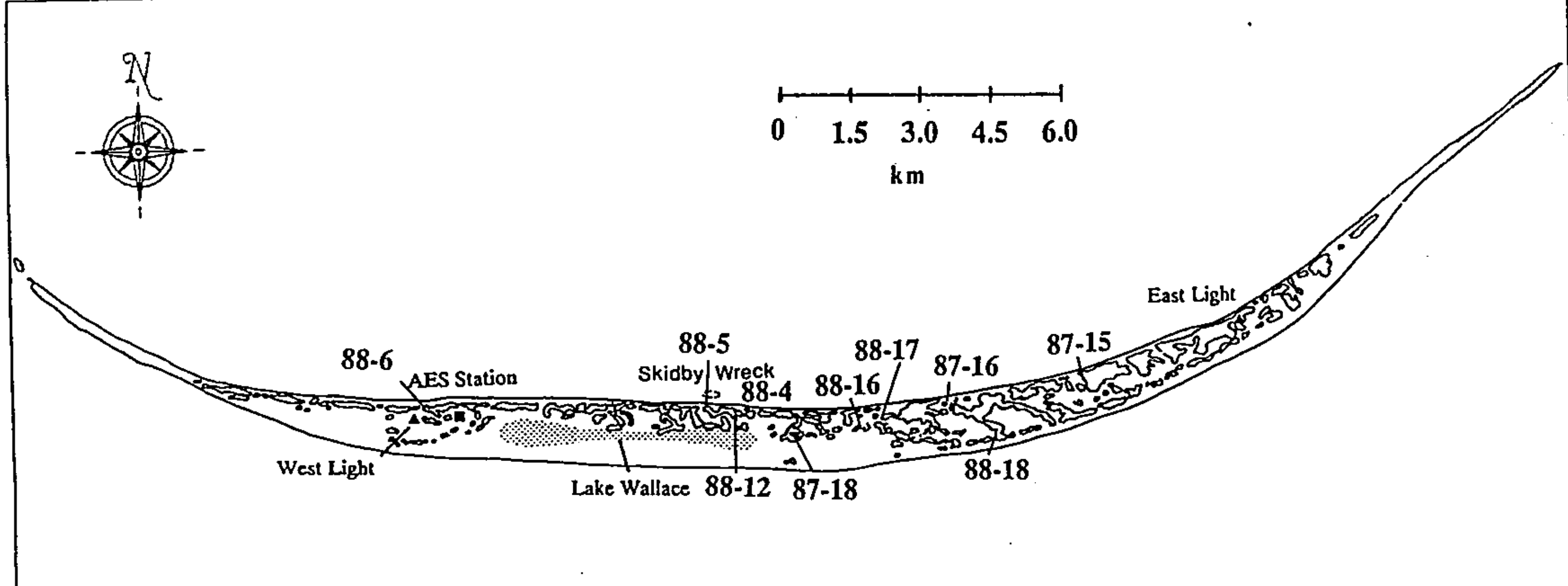


FIGURE 6.1. Location of the Migrational Multiple Phase dunes.

6.2 Type I

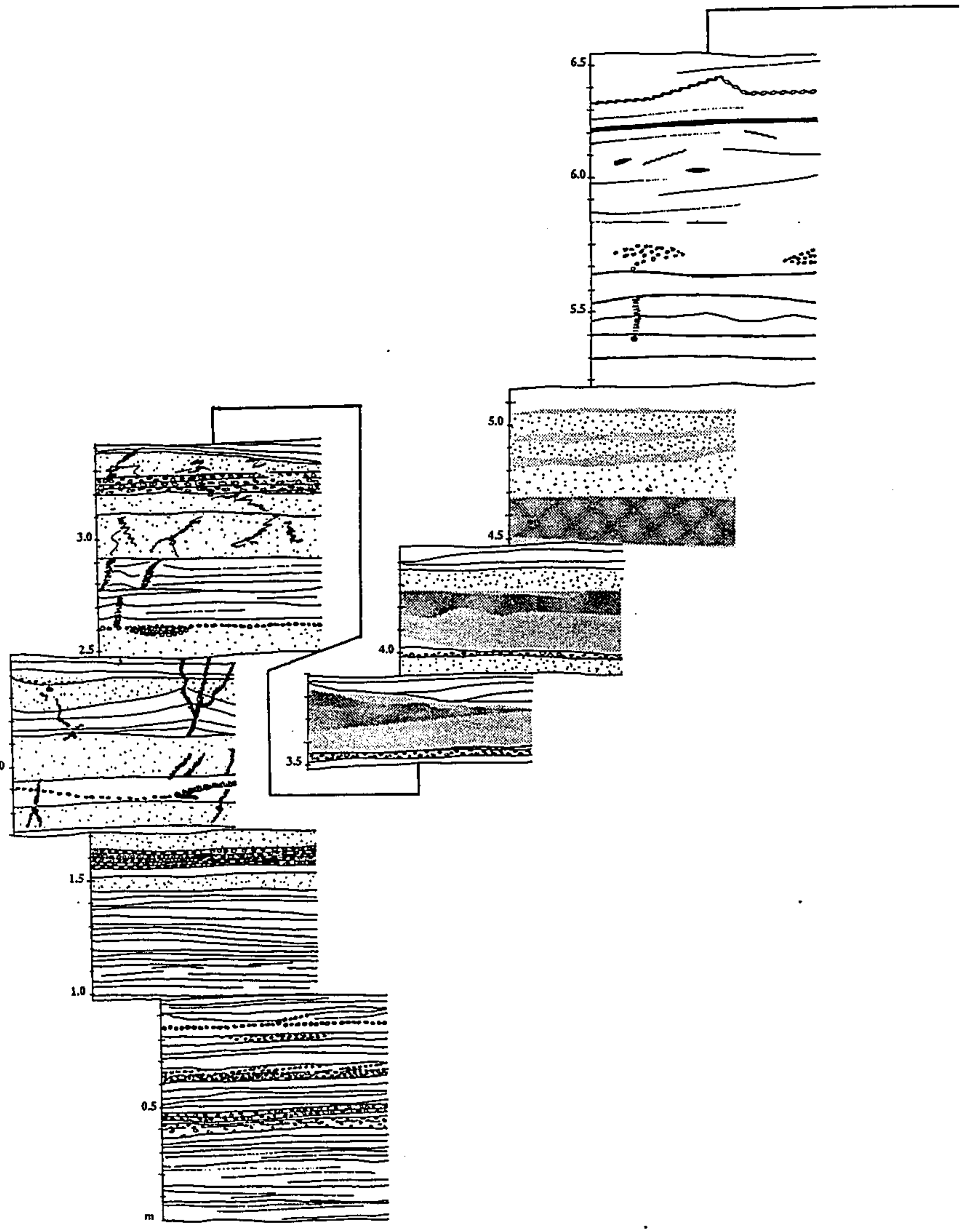
6.2.1 Site 88-16 (Fig. 6.2)

Description

This site was located in the first large blowout east of the Skidby wreck in a 10 m high dune made up of fine to medium sand with few coarse layers. There was a well-developed, complex paleosol in tightly packed sand 3.42 m above the base of the section.

Below the paleosol, there was a wide variety of grain sizes and few plant fragments. The basal sets of beds were horizontal to slightly dipping, planar tabular with dips oriented toward the south-southwest to the west-northwest. There was little or no evidence of vegetation and a variety of grain sizes (Fig. 6.3A). Below 0.4 m the beds were made up of laminated, fine sand which changed from 0.4 to 0.5 m to coarse laminated sand which was topped by a bed of laminated, fine sand. At 0.6 m there was a 5 cm thick set of laminated coarse cross-beds topped by 15 cm of fine laminated sand. At the top of this bed was a lens of coarse sand associated with a plant node.

From 0.97 m to 1.55 m there were sets of laminated beds of fine sand with no evidence of vegetation. Average set thickness was 15 cm and average bed thickness was 2 cm. From 1.55 to 1.65 m there was a set of coarse laminated sand with woody root pieces within it. From 1.71 to 2.49 m there was a change with increasing evidence of vegetation. Plant nodes and stains were abundant. Beds were laminated with



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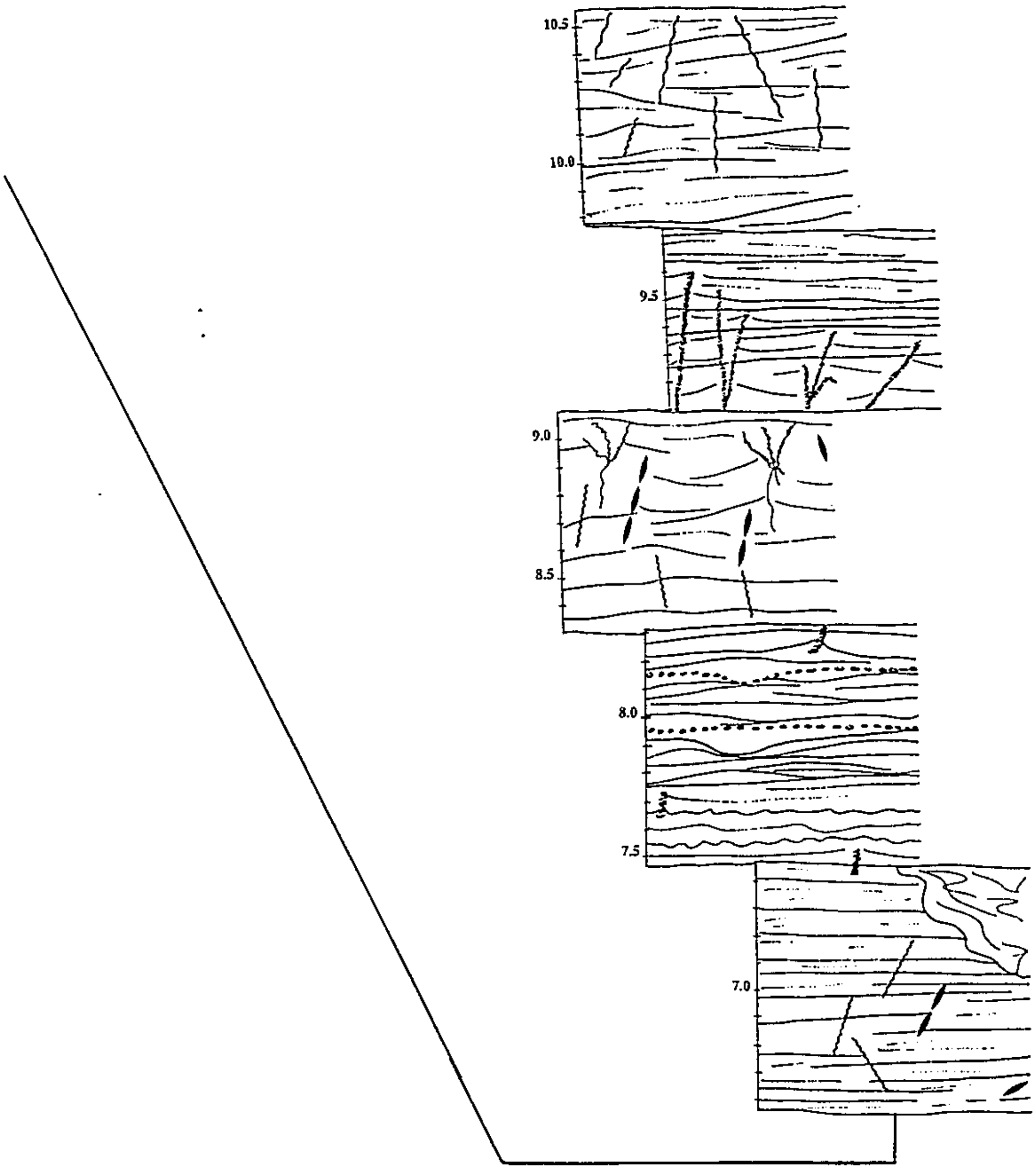


FIGURE 6.2. Site 88-16 contained complex paleosols between 3.5 m and 5 m. Below the paleosol there was the deposition of coarse material in beds which marked the previous surface. Evidence of vegetation increased upward to the paleosol(s). Above the paleosol(s) there was deposition of finer sand through increasingly woody vegetation to 9.0 m. At that point the vegetation became increasingly herbaceous to the top of the section.

FIGURE 6.3A. Base of 88-16 shows little evidence of vegetation. There is a plant node buried at 27 cm and the stain of a stem at the top right of the pit. The protruding beds are tightly packed, finer sand and the recessed beds are more loosely packed, coarser sand. There is also a lens of coarse, laminated sand at 53 cm.

laminae rising toward the plant from all directions. Dips of beds varied due to the presence of plants. From 2.49 to 3.42 there was increasing evidence of vegetation in that the sand was stained with organic material. However, beds were no longer convoluted. Plant stains were visible, but the laminae did not rise toward the plant. This was covered by the paleosol.

The paleosol consisted of three, thick, concentrated organic layers with associated stained transitional sands below them. The first layer, at 3.6 m, had an irregular surface because it had been eroded and buried. At 3.9 m there was a 2 cm thick layer of coarse laminated sand topped by an 18cm thick transition layer. This was overlain by an 8 cm thick concentrated organic layer. It was overlain by another layer of transitional grey stained sand (19 cm thick) and the third concentrated organic layer which was 21 cm thick and purplish in colour. Above it were 7 beds of fine, uniform grain size, unlaminated sand capped by thin organic layers which were 17, 10, 7, 18, 10, 10 and 26 cm in thickness respectively extending to 5.56 m. The first three beds were capped by 2 to 4 cm of organically stained sand, while the top 4 were capped by a very thin organic layer that was only a few grain sizes in thickness.

From 5.56 m to 6.56 m deposition occurred in association with woody vegetation in sets of clean white sand with beds which were difficult to trace laterally because the bedding planes were vaguely marked. The first set (5.56 to 6.22 m) contained two large dispersed coarse layers in the lowest part of the set and was capped by a 2 cm organic layer. Above this was the second set (6.27 to 6.56 m) which was made up of unlaminated, fine, clean sand. At 6.4 m was a layer of buried organic material which had not completely decayed (Fig. 6.3B).

From 6.56 to 8.59 m sediment was deposited in discontinuously laminated beds with vegetation stains. Between 6.56 and 7.46 there was a set of laminated beds with woody roots and stems and grass fragments. Average bed thickness was less than 10 cm. From 7.46 to 8.59 there were unlaminated to discontinuously laminated beds of fine sand with some vegetation staining. Between 7.9 m and 8.2 m there were two coarse laminae separated by discontinuously laminated fine sand.

From 8.59 to the top of the section (10.58 m) the sand was deposited in discontinuously laminated beds of fine sand which were upwarped around plant stains. Toward the top of the section undecayed pieces of vegetation were common. The dune was capped by Ammophila breviligulata, Achillea lanulosa, and some Myrica pensylvanica.

Interpretation

The beds at the base of this section (0 to 1.7 m) were the result of storm winds depositing sediment in the blowout. The location opens onto the north beach, toward the strong ENE storm winds.

Above this, sets of beds were laid down around vegetation in the Sparse Marram community. The sand was deposited around plants predominantly by

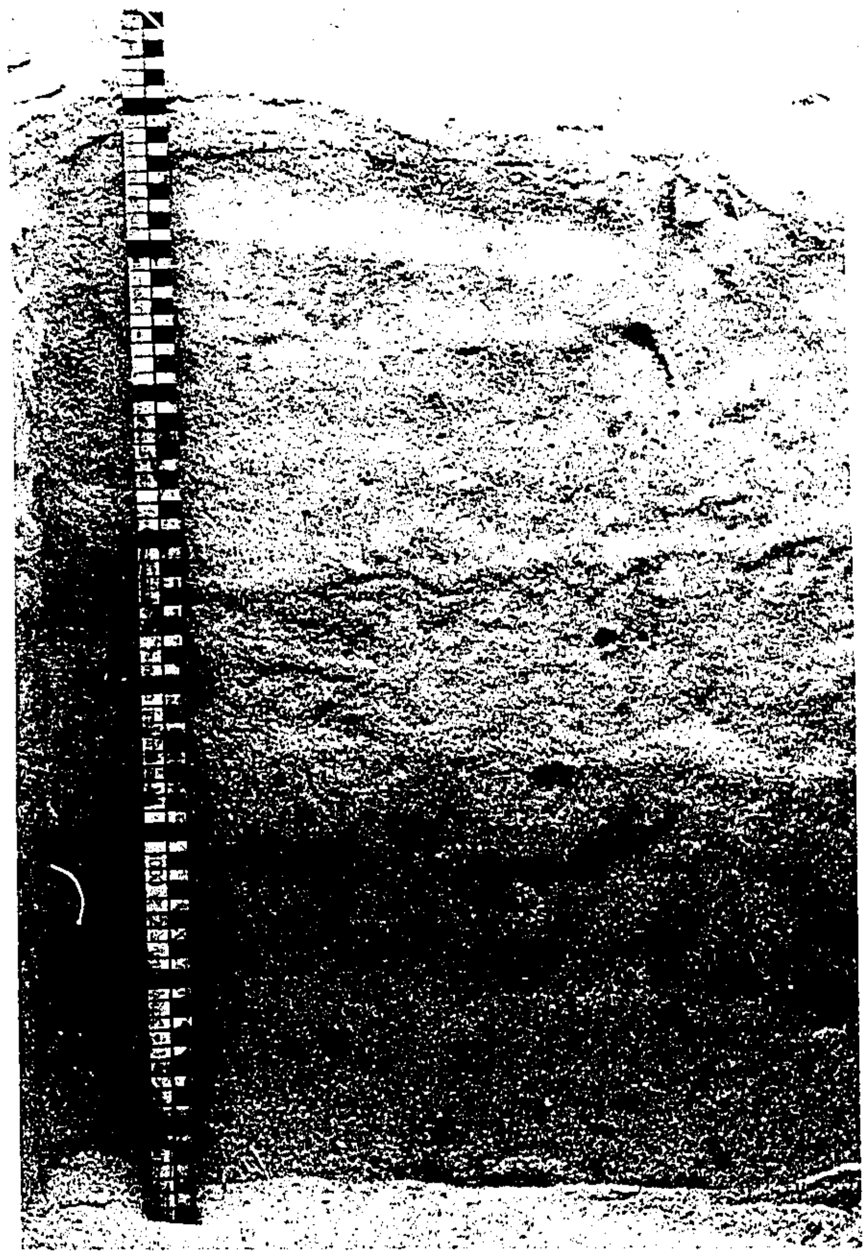


FIGURE 6.3B. Middle elevation of Site 88-16 in which partially decayed roots and stems are preserved as dark blotches at about 30 cm.

grainfall through the plant cover. However, because the cover of vegetation was sparse, there were bare patches in which there was tractional deposition. Therefore there was a lateral transition between grainfall deposition and ripple migration. This resulted in the deposition of the laminated beds around the plant stains. Close to the plants, the velocity was lower because the plant interfered with the windstream and greater amounts of sediment were deposited. Farther from the plants, wind velocity increased and ripples migrated, depositing thin parallel-laminae which warped upward to the plant (Fig. 6.3C). With increasing plant density, the wind velocity was baffled over a larger area, resulting in a decrease of ripple migration and an increase in the thickness of the beds locally. Beds became less contorted around plants as deposition became more even over the surface. Accumulation rate also decreased because, with increased height of the dune it was more difficult to transport the sand, and with increased cover, it was more difficult to transport the sand over the lateral distance of the dune. Although the dune was not very tall at this point, it was laterally extensive and the latter reason for accumulation rate decrease holds true.

With a decrease in the rate of accumulation, the vegetation cover changed in nature. Plants such as Ammophila breviligulata, which thrive on burial were replaced with those which can withstand some burial, but which do not need burial for healthy growth. Such plants would be those in the shrub heath community. The structures in this section reflect the growth of this

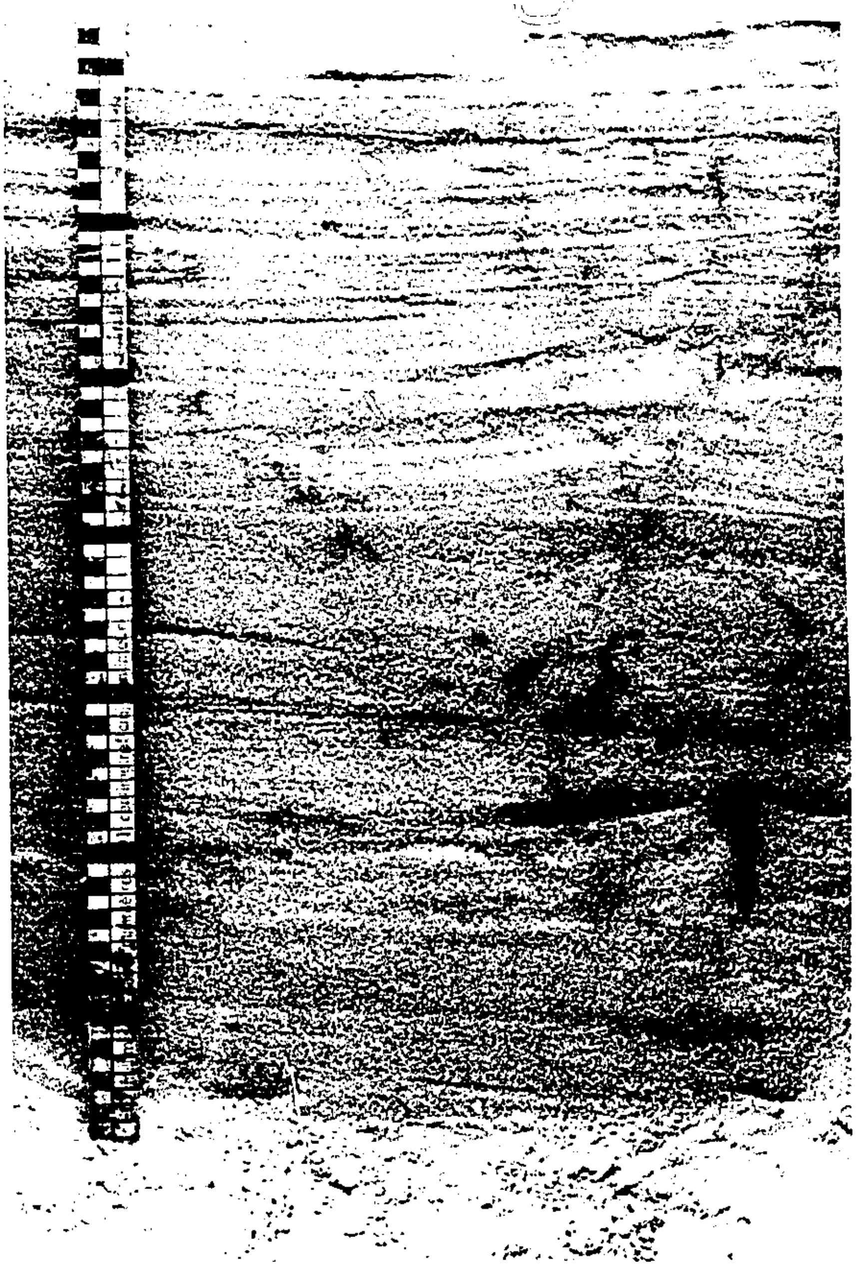


FIGURE 6.3C. Upward warping laminae deposited near plant stems are visible at about 22 cm and again at about 50 cm.

vegetation. Discontinuously laminated or structureless, leached sand was deposited around the woody stems, and the roots destroyed many of the other structures in their vicinity. Then, as the paleosol developed, the sand was leached, further destroying the structures.

The paleosol existed as a layer or layers of varying thickness made up of sand grains coated with organic material. It represented a stable period in which the organic material collected on the surface without being buried with large amounts of sediment. In this location the paleosol was complex, being made up of more than one layer. Layers of sediment separated the paleosol surfaces. With increasing height in the dune the paleosol decreased in thickness.

Beds of clean structureless sand containing woody roots overlay the paleosol. These developed as sand was deposited around Rosa virginiana and Myrica pensylvanica, slowly burying them. The plants later rotted away, rarely leaving stains, but often leaving portions of root or stem. Over longer periods of time these also would disappear.

At 6.5 m above the section base there was a change in structures which was due to a change in vegetation caused by a change in sedimentation rate. An increase in the rate of supply triggered a change in the vegetation cover. Although there were still woody roots and stems, there were also Ammophila breviligulata stains and pieces of Lathyrus maritimus root and stems. This type of cover remained to the top of the section.

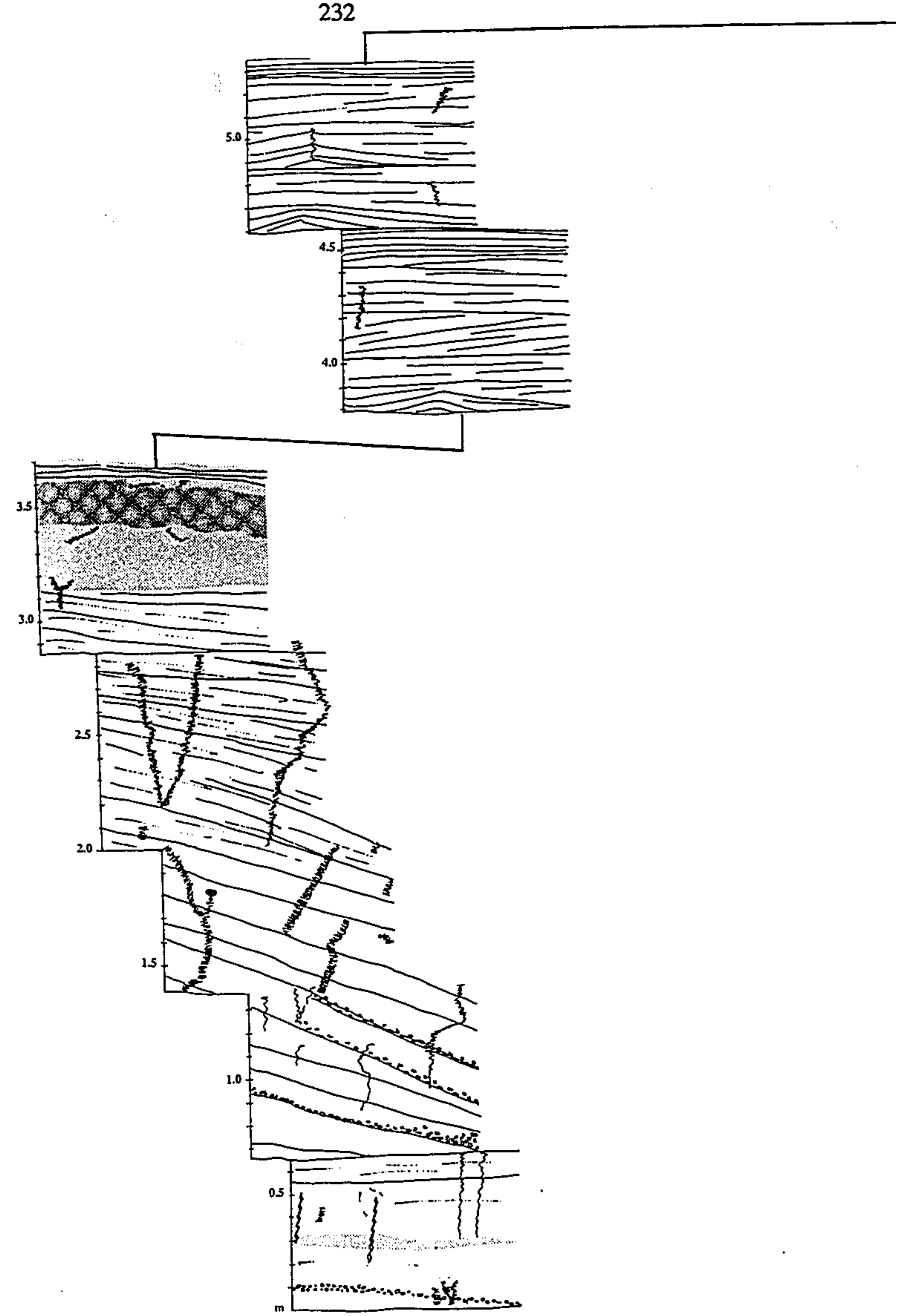
6.2.2 Site 88-17 (Fig. 6.4)

Description

At this site, the paleosol, exposed in a face which was normal to the waterline, outlined the shape of the paleodune within the present dune. The sand was well-packed and stable. There were 3 metres of sand below the paleosol, which was 45 cm thick and there were 6.64 metres of deposition above the paleosol.

There were a variety of beds of different grain sizes, with changing dips, below the paleosol. The basal portion (0 to 0.65 m) was horizontal changing upward to dips of 26° and then decreasing to 14°/227 in the paleosol (3.1 m). From the base to 0.65 m, many plant stains were present and an organic layer occurred at 0.3 m. From 0.65 to 3.1 m there were medium- to high-angle beds dipping toward 172°. Coarse layers existed downdip of plant stains, but the rest of the sediment was fine grained. Plant stains were abundant and extended through many beds which averaged 15 cm thickness. Laminae within the beds were unaffected by the presence of the plants. This was topped by the paleosol.

The paleosol was simple and very well-developed. It extended from 3.1 to 3.65 m and consisted of a 35 cm thick, lower layer of grey stained sand with vegetation fragments and a 20 cm thick upper layer of very concentrated organic material. From 3.65 to 5.29 m the sand was deposited in 8 nearly horizontal beds of fine to medium sand with abundant plant stains. Laminae



5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
m

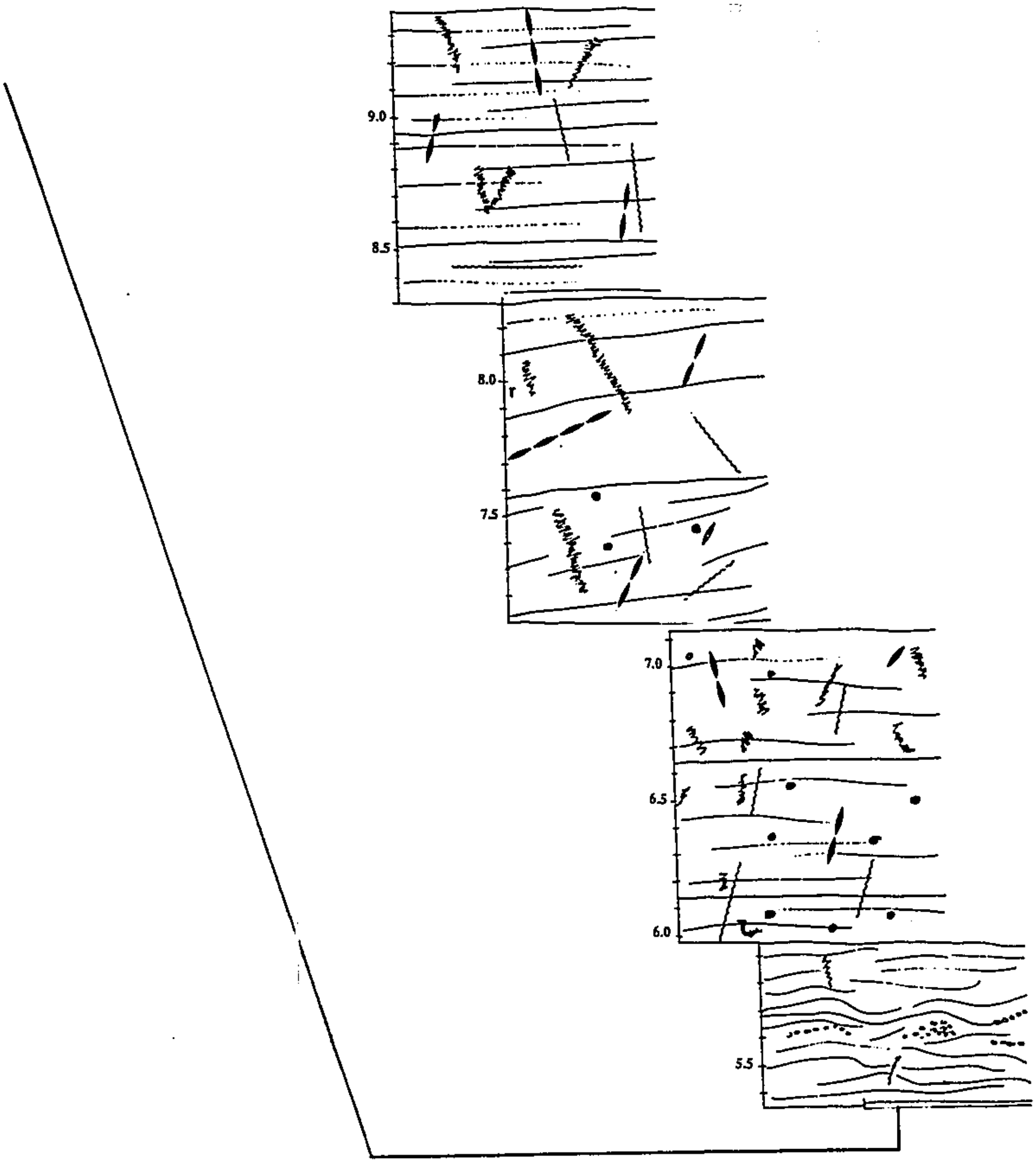


FIGURE 6.4. Site 88-17 contains a paleosol at 3.15 m. Below the paleosol there was a dune which had been vegetated by herbaceous vegetation. Above the paleosol, herbaceous vegetation gave way to woodier species which resulted in a more horizontally bedded deposit of sand.

rose toward plant stains from all directions. Dips of beds ranged from 5° to horizontal and varied in orientation from 78° to 314°, and averaged about 20 cm in thickness. From 5.29 to 6.0 m the beds became less continuous, more wavy and contained more coarse material.

From 6.0 m to 8.5 m there was a higher concentration of decayed plant material within the beds which had become more horizontal once again. Laminae within the beds were difficult to follow for more than a few centimetres and were arranged in beds which were between 30 and 40 cm in thickness. From 8.01 m to the top of the section the sand was stained grey. There was also a change to plant stains and a decreased concentration of woody plant remains.

Interpretation

This site is made up of two distinct dunes which are separated by the paleosol. The basal portion is the paleodune, below the paleosol, which is made up of tabular beds laid down around sparse Ammophila breviligulata. Above this, sets of beds are deposited around a denser vegetation cover with a greater variety of species than in the base. There are some woody plants toward the top of this section. Capping the paleodune is the paleosol.

The paleosol at this site was better developed than at any other site examined. The organic layer was thicker than most (20 cm as opposed to about 10cm) and had very high moisture retention capability. It overlaid a 35 cm thick, transition of leached sand which had originally been deposited around woody vegetation.

Overlying the paleosol was sand laid down within and around sparse Ammophila breviligulata vegetation. This resulted in bedding similar to that below the paleosol in 88-16. With increasing plant density and elevation, the cover changes to include increasingly more woody vegetation to the present surface which is covered with Rosa virginiana, Myrica pensylvanica, Ammophila breviligulata, Achillea lanulosa, and Lathyrus maritimus.

6.2.3 Site 87-15 (Fig. 6.5)

Description

This site was located on the scarped face of a dune at the back (landward side) of a blowout which faced onto north beach. The section was parallel to the waterline and consisted of well-packed, vegetation stained sand. From the base to about 0.4 m there were discontinuously laminated, irregularly shaped beds of fine sand with a plant stain in the left side of the exposure. From 0.4 to 0.45 there was a single, unlaminated, coarse bed of sand topped by a single, fine bed of sand which extended to 0.55 m. From 0.55 m upward to 2.7 m, beds were horizontal to gently dipping with discontinuous laminae, abundant plant stains and coarse layers associated with the plant nodes (0.7 and 0.8 m) and rhizomes. Within this section, from 1.45 to 1.6 m and from 2.0 to 2.3 m, there were two tabular sets of laminated beds, 10 to 20 cm thick, with irregular laminae and evidence of vegetation in the form of decorticated root material. From 1.6 to 2.0 m sand was deposited in discontinuously laminated beds of sand with plant stains. The bedding was similar from 2.3 to 2.7 m.

From 2.7 m to 3.35 m sand was deposited in beds which were unlaminated, but contained vegetation stains. Above 3.35 m, the beds became more continuous laterally, while laminae became less continuous, and there was a higher concentration of organic material and there were root pieces were present. At 3.7 m beds dipped 18°/215, at 4.0 m 14°/300, and then they increased in dip up to the paleosol. At 4.5 m and in three layers around 5.0 m, the beds were capped by 2 cm thick organically stained sand layers.

The paleosol was complex with concentrated sandy organic layers at 5.3 m, 6.35 m, 6.5 m, and 7.5 m. From 5.3 to 6.35 m the sand was deposited in 5 beds. The first was discontinuously laminated, 12 cm thick, and capped by an organically stained sand layer.The second was unlaminated, made up of fine sand, 12 cm thick and capped by a thin organically stained sand layer. The third extended to 5.95 m, was also unlaminated and capped by a organically stained sand layer. From 5.95 to 6.1 m the sand was unlaminated, but there was no organically stained sand layer present. From 6.1 to 6.35 m there was a discontinuously laminated bed of sand. The sandy organic layer at 6.35 m was separated from the sandy organic layer at 6.5 m by a discontinuously laminated, well stained sand layer. From 6.55 to 7.0 m there were two beds of fine sand. The first was unlaminated and contained vegetation stains and the second was vaguely laminated and contained abundant stains and decorticated root material. From 7.0 to 7.4 m there was organically stained sand and from 7.4 to 7.5 m there was the final concentrated sandy organic layer.

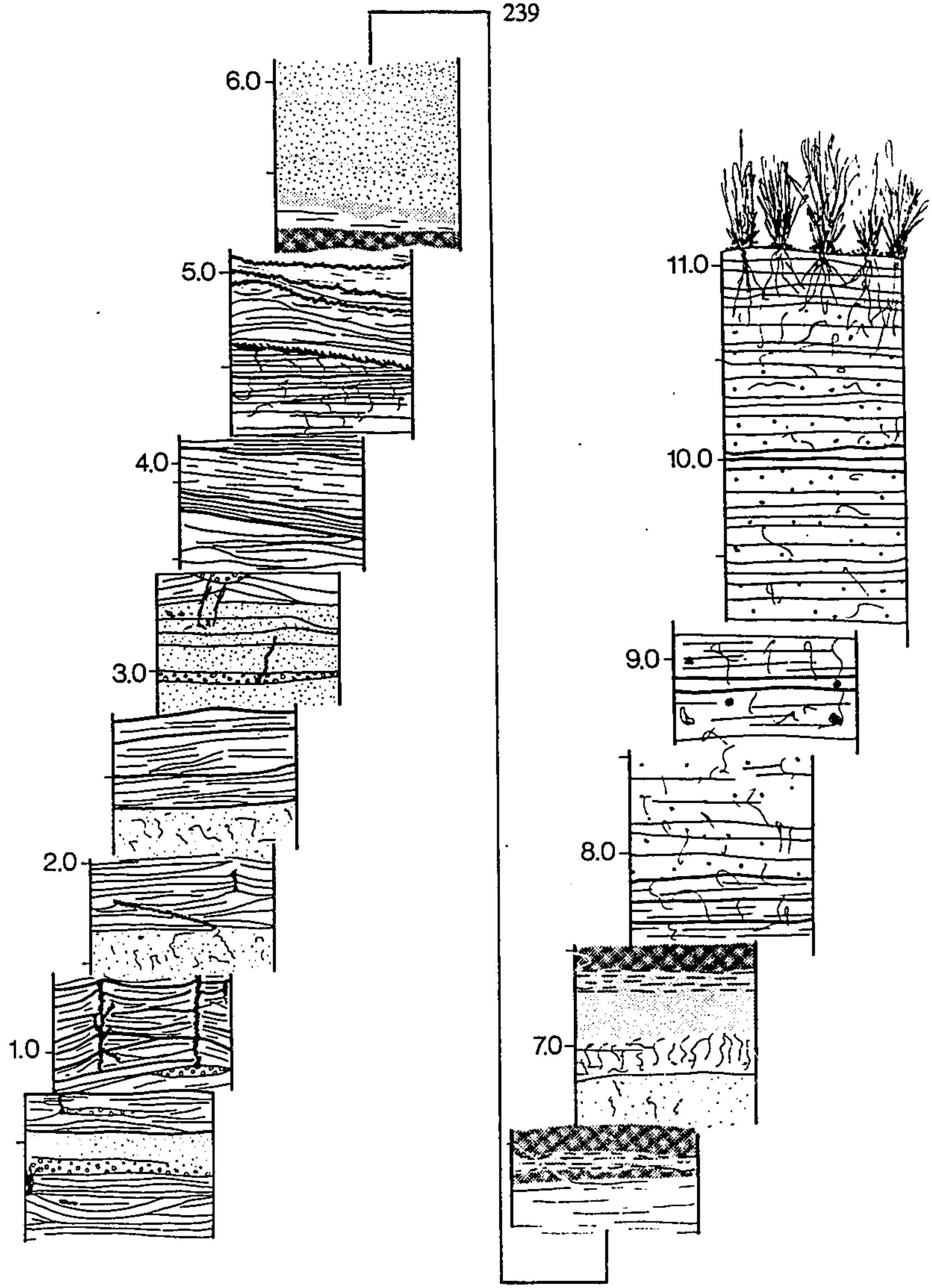
The structures above the paleosol consisted of discontinuously laminated beds of fine sand with vegetation stains and decayed vegetation. At 7.8 m the beds dipped 11°/140 to 13°/150. This dip decreased upward to 9.0 m to 10°/198 and then to horizontal at the top of the section. Average bed thickness was about 10 cm. Decaying woody roots and stems were contained within the section.

Interpretation

The basal section at Site 87-15 reflected an energetic environment with a variation in grain sizes deposited in a variety of bedding styles. These were the result of sand being deposited in discrete dunes which developed in the lee of isolated plant clusters. With increasing height in the section the dunes coalesced, resulting in the deposition of more laterally continuous beds of sand. There was increasing evidence of vegetation upward to the first paleosol.

The complex paleosol was the result of slow deposition through a woody canopy. It represented a relatively long period of stability as the paleosol is about 2.5 m in thickness. Above this the sand was deposited in fairly even beds of stained sand. These represented slow, steady burial with a constant sediment supply and winds capable of carrying the sediment up to the top of

FIGURE 6.5. Site 87-15 contained 3 paleosols located at 5.1 m, 6.5 m, and 7.0 m. Below the paleosol, sand was deposited through herbaceous vegetation while above the paleosol there were woody roots and stains.



239
6.0
5.0
4.0
3.0
2.0
1.0
11.0
10.0
9.0
8.0
7.0

the dune.

6.2.4 Summary of Type I

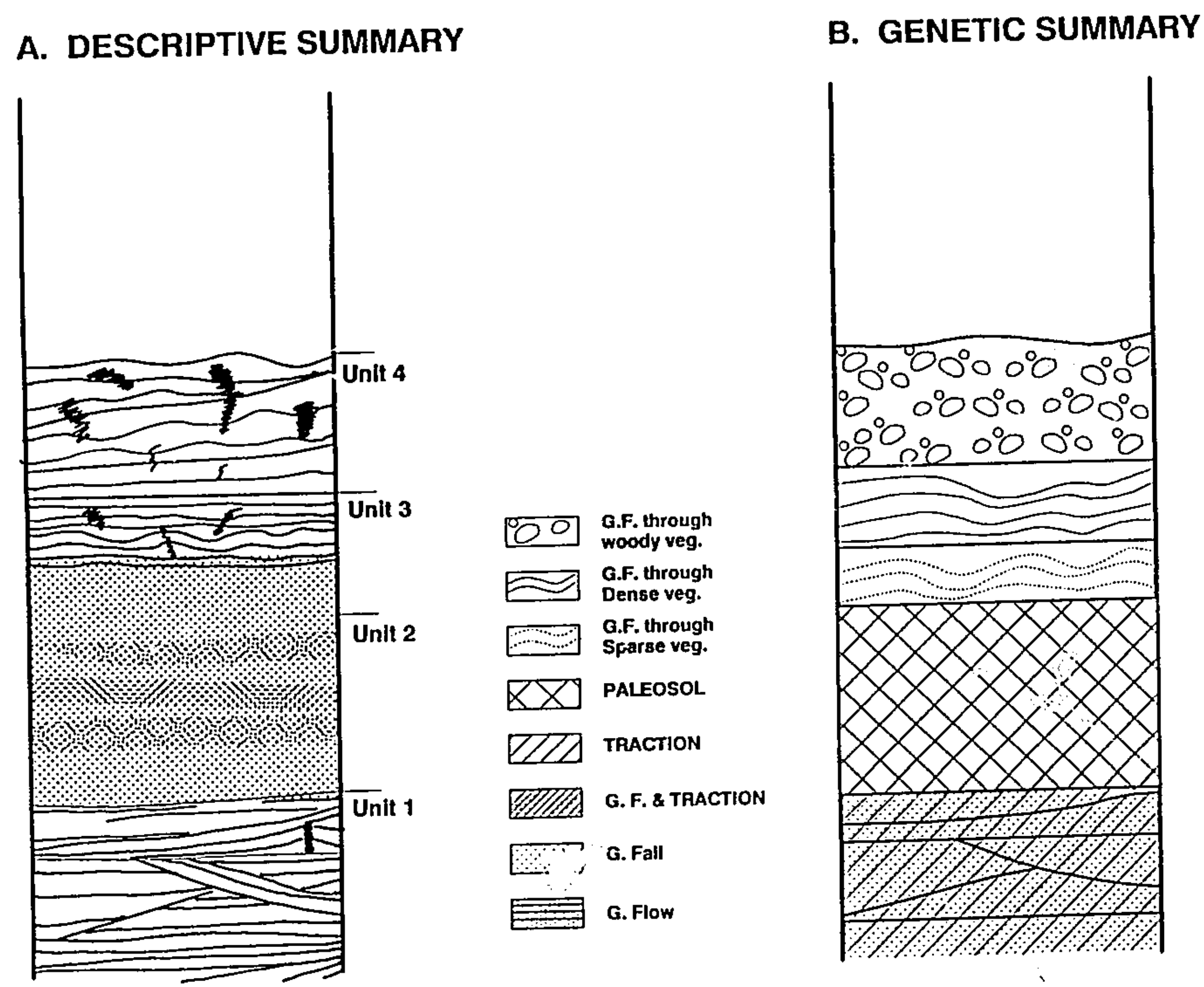
The Type I sites were located on the north side of the island, east of the Skidby wreck, in the dunes behind the currently forming foredunes. There are four units (Fig. 6.6A). The basal unit is made up of discontinuously laminated, horizontal to wavy parallel beds of fine to medium sand which contain some coarse lenses and layers. It represents a situation in which there was very little vegetation cover (Marram Cluster Sub-facies) where tractional and mixed tractional and grainfall deposition dominated, which changed upward to more laterally continuous beds of sand that were deposited in association with the colonization of the area by the Sparse Marram community (Fig. 6.6B). Unit 2 is made up of more laterally continuous beds of fine to medium sand in which there is abundant vegetation staining which increases toward the top of the unit to the paleosol. It is associated with the deposition of sand through the Dense Marram community leading to the development of the paleosol. The paleosol is contained within this unit because it is the extension of the dense marram cover through a stable period. The third unit consists of laterally continuous, horizontal and wavy parallel beds of sand which were deposited by grainfall through first sparse and then dense grass vegetation. The fourth unit is made up of thicker, laterally continuous beds of sand which were discontinuously laminated and contain decaying woody roots and stems and vegetation stains. It developed by grainfall through woody vegetation (Shrub Heath Facies).

Below the paleosol, the development was very similar to that of In Situ Type I dunes. However, the paleosol development was more complex, often with more than one phase of soil development. The concentrated organic layers had a greater moisture retaining capacity than those at other sites. They were also more cohesive, and contained more root pieces. Therefore when the paleosol was developing, vegetation cover was dense and the accumulation rate was very slow. The soil forming period was much longer in this location than at others on the island, because the deposit of organic material was much thicker and more concentrated than in other areas.

Above the paleosol, the dominant characteristics of the sand were the presence of woody roots and stems and the fairly constant rate of sand accumulation. The characteristic which identifies the different units is the changing plant associations through time. At first the stains indicate that the dune was vegetated with first the Sparse and then the Dense Marram communities. Later, woodier vegetation covered the area. The plants associated with the roots and stems can be identified as Rosa virginiana and Myrica pensylvanica. Sand deposited around the plants is very faintly or discontinuously laminated and often there is very little disturbance of the laminae where they come in contact with the plant.

The vegetation associations follc logically from a very active

FIGURE 6.6. Descriptive and genetic summaries of Type I Migrational Multi Phase Dunes on Sable Island. These columns are less vertically extensive than those of Type II In Situ dunes, and more vertically extensive than the Type I. They are capped by deposition through a woody vegetation canopy.



COLUMNS ARE APPROXIMATELY 10m HIGH

environment through a less active environment to a nearly stable paleosol forming environment and then through the cycle again. The present vegetation cover would be conducive to soil development if the accumulation rate was slower. An explanation for the location of this type of dune may be that the sites were located within the vegetated arm of a parabolic dune. The discontinuous beds at the base in Unit 1 were the result of the movement of ripples and granule ripples over the dune surface landward of the foredunes, where there is only a sparse cover of vegetation. This was a very active environment with the migration of large amounts of sand. With continued deposition and vegetation growth, the structures changed. Vegetation density increased as the cover changed from Sparse to Dense Marram which caused the beds to become more continuous. The rate of sand deposition increased because the vegetation was able to hold more of it in place in the laterally continuous, discontinuously laminated beds. As the amount of sand held in place increased, the dune was building in height, which in turn decreased the ability of sand moving winds to supply sand to the dune. This caused the vegetation cover to change and allowed the accumulation of greater amounts of organic material which led to the development of the paleosol.

To this point the growth of the dune was similar to that of the In Situ types of dunes. However, after the development of the paleosol in a stable period, the supply of sand is increased. This increase in supply was related to the passage of a parabolic dune over an adjacent area. This dune type was located in the arm of the parabolic dune. As the nose passed an adjacent area, it buried the structures beneath a precipitation type of dune. However, the arms of the dune received a smaller amount of sand, which allowed vegetation to keep pace with burial. The type of vegetation changed to suit the rate of burial. Therefore, the Sparse Marram community once again dominated the cover. As the nose of the dune passed the area completely, the rate of deposition decreased and the type of cover changed again to become more dense. With a further decrease in sand supply, woody species colonized the area leading to the deposition of the continuous, horizontal beds of vaguely laminated sand and woody remnants.

6.3 Type II

6.3.1 Site 88-6 (Fig. 6.7)

Description

This site was located in the blowout leading into the BIO house compound about 1 km west of the Atmoshperic Environment Service station. There was a well-developed paleosol exposed in a section normal to the waterline. The structures below the paleosol were made up of a variety of grain sizes and packing around plant stains (Fig. 6.8). Coarse layers and lenses were associated with nodes. The lowest 0.25 m of the section was a parallel-laminated bed of fine sand. At 0.25 there was a lens of coarse sand deposited around a plant node which was the width of the section (0.5 m) and

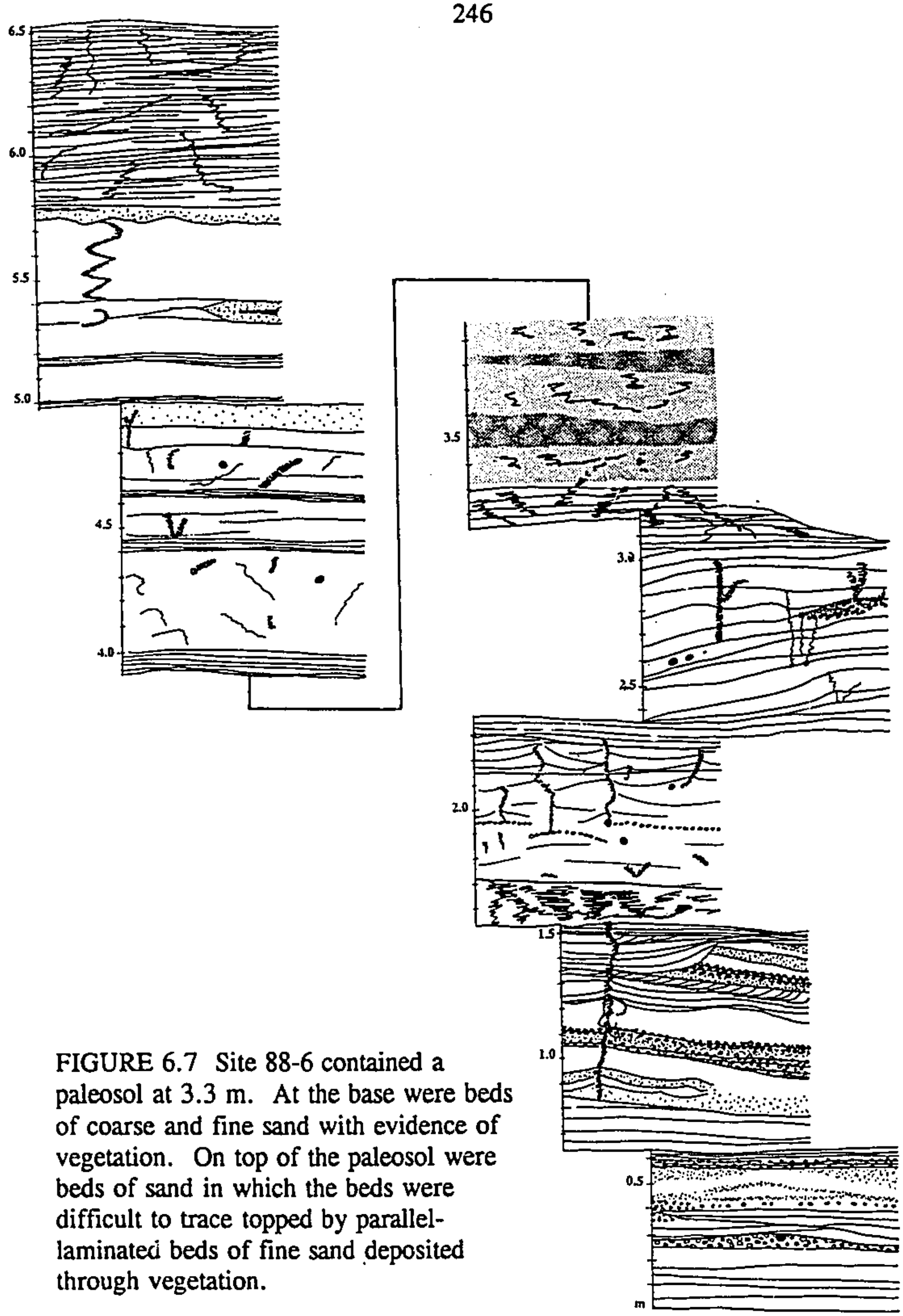


FIGURE 6.7 Site 88-6 contained a paleosol at 3.3 m. At the base were beds of coarse and fine sand with evidence of vegetation. On top of the paleosol were beds of sand in which the beds were difficult to trace topped by parallel-laminated beds of fine sand deposited through vegetation.

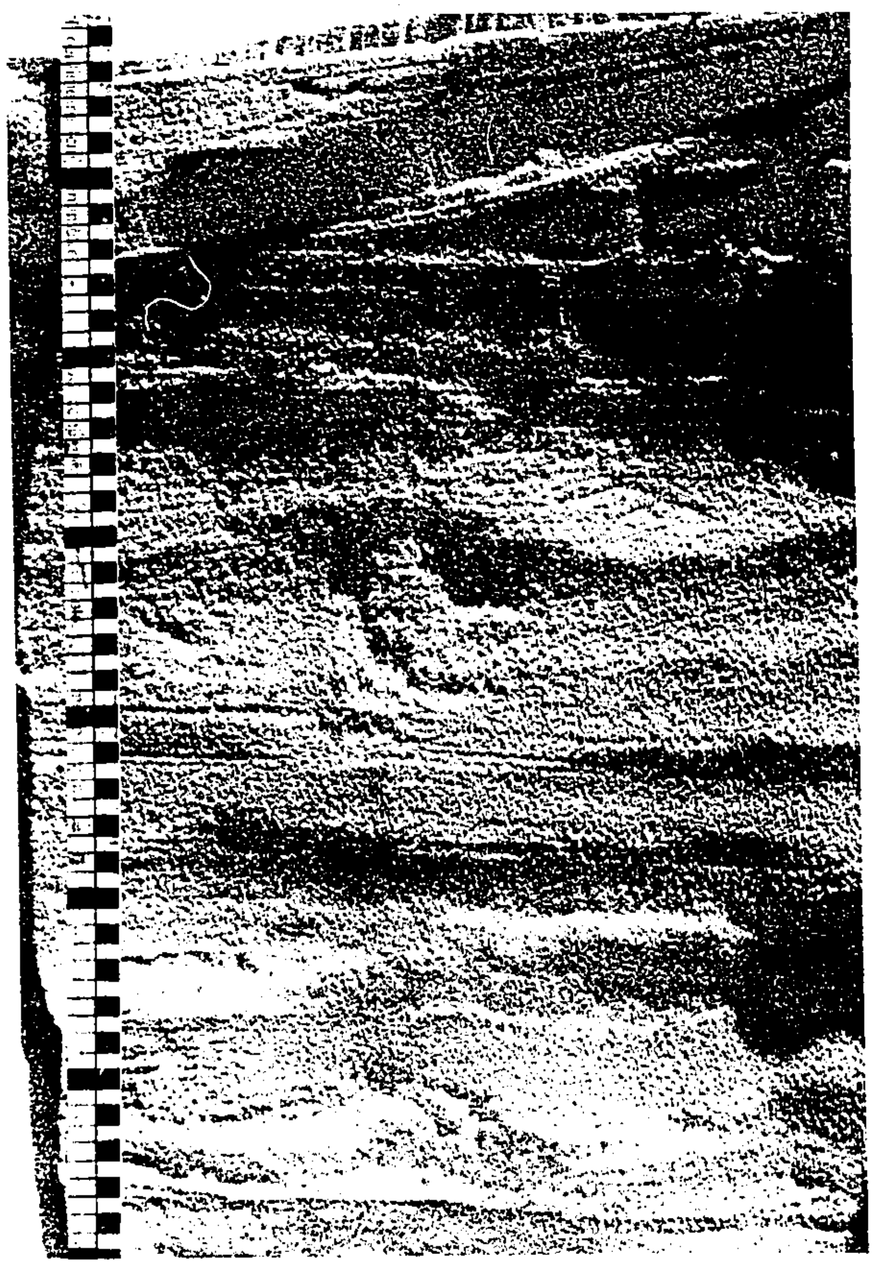


FIGURE 6.8. Photograph of the base of Site 88-6 showing the beds with coarser sand separated by the beds with finer sand. There is also the stain of a plant which can just be traced upward from about 10 cm in the centre of the picture. The base of the plant is marked by a bed which warps upward to the stem.

about 8 cm at its thickest point. It was overlain by a set of low angle, parallel-laminated beds, truncated by an erosion surface which dipped 3°/228. Above the erosion surface were parallel-laminated beds of sand topped by a coarse layer which was only a grain size thick. Above this, alternating, irregular layers of tightly and loosely packed sand were deposited. These extended to 0.57 m where there was a 3 cm bed of parallel-laminated coarse sand. This whole basal portion was topped by a 20 cm bed of parallel-laminated horizontal sand.

The next set of laminated beds extended from 0.8 to 1.5 m. It was made up of a 10 cm thick basal bed of tightly packed sand with a plant stain that extended to 1.5 m and was topped by a 5 to 10 cm thick bed of unlaminated, uniform grain size, fine sand overlain by 5 to 10 cm of horizontal, coarse laminated sand. Another tightly compacted, 2 cm thick layer of fine sand was deposited at 1 m and overlain by 2 cm of horizontal laminated coarse sand. The next bed in this set was a 10 to 15 cm thick layer of uniform grain size, fine, unlaminated sand with an irregular surface overlain by a laminated bed which followed the underlying surface. At 1.3 m a set of high angle cross-beds extended from a plant stain at the left of the section to the right (0.4 m). It was truncated at 1.35 m by a 2 cm bed of tightly packed sand which was overlain by a 3 cm bed of laminated coarse sand. Four beds of alternating tightly and loosely packed sand topped this, extending to 1.44 m. An erosion surface truncated these beds at this elevation on the right of the section. To the left it dipped (30°/333) down to 1.3 m at the plant stain. Laminated sand was deposited above the erosion surface.

The next set of beds, extending from 1.5 to 3.05 m, was made up of fine sand deposited in association with woody vegetation. There was a 0.5 cm layer of heavy minerals at 1.72 m which separated a lower bed of brown stained, unlaminated, uniform grain size, fine sand from a bed of faintly laminated, uniform grain size sand with stains, roots and stems. It contained a discontinuous laminae of coarse sand at 1.9 m. The top of the bed was at 2.15 m and was distinct but not erosive. The next bed extended to 2.3 m and contained laminae which upwarped around plant stems. The third bed extended from 2.3 m to 3.05 m and contained laminae which were irregular around plant stems and roots. At 2.7 m there was a lens of coarse sand which was associated with the nodes of several plants, the stains of which extended from it. This set was then capped by the paleosol.

At this location the paleosol extended from 3.10 to 4.0 m and consisted of 6 beds. The lowest bed was 15 cm thick and contained discontinuously laminated, brown stained sand. It was overlain by 10 cm of discontinuously laminated, grey organically stained sand with abundant pieces of decaying plant stems and roots. At 3.3 m the concentrated sandy organic layer developed. It was 13 to 15 cm thick with an irregular upper and lower surface. Above this was a 20 cm thick bed of mottled, grey stained, discontinuously laminated sand with abundant pieces of decayed plant material.

It was topped by a second bed of concentrated sandy organic material and another bed of mottled, grey stained, discontinuously laminated sand with decayed plant material within it.

The cleared section above the paleosol extended from 4.0 m to 9.45 m, however, the figure shows the section only to 6.6 m because it collapsed before detailed examination could be made. The structures consisted of horizontal to sub-horizontal, parallel and wavy laminated beds of vegetation stained sand. Bed boundaries were difficult to trace. There was a high concentration of decaying plant material within the section. The lower part consisted of couplets of horizontal beds made up of laminated sand overlain by the sand in irregularly-shaped beds with vegetation. The first couplet was 49 cm thick, the second 22 cm, the third 38 cm, the fourth 15 cm, and the fifth 15 cm. The fifth set ended at an elevation of 5.3 m.

Above 5.3 m there was a higher concentration of root clusters and root filaments. Laminae upwarped around stems, usually rising toward plants from all directions. Although the sand was well laminated, beds were difficult to discern.

Interpretation

The lowest 1.5 m in this section reflected an environment of deposition in which the surface was sparsely covered with Ammophila breviligulata. The environment of deposition was a high energy one because there was an abundance of coarse material in the sediment. From 1.5 upward, there was a decrease in the amount of coarse material supplied to the dune and an increase in the density of coverage. There was also a change in the type of cover. This was indicated by the dark brown organic staining of the sand. Perhaps there was a woodier cover at this elevation. This was also indicated by the development of the paleosol at 3.5 m. From the paleosol upward the structures indicated that the rate of accumulation increased gradually. Immediately atop the paleosol there was a section with some woody roots and an abundance of evidence of Smilacina stellata and Cakile edentula. With increasing elevation Ammophila breviligulata became the dominant species present. The predominant vegetation types on the present surface were Ammophila breviligulata, Cakile edentula and Smilacina stellata.

6.3.2 Site 88-5 (Fig. 6.9)

Description

This site, at the base of mount Skidby, was normal to the waterline. Structures below the paleosol and the paleosol itself were examined. The basal portion of this section contained a variety of grain sizes and packing. Vegetation stains were present with coarse layers and lenses associated with plant nodes. At 0.10 m there was a 5 cm laminated coarse bed of sand which capped an indeterminate thickness of uniform, fine to medium grain size sand. Above the coarse bed was another bed, 7 cm thick, of uniform grain size sand capped by a 5 cm bed of laminated coarse sand. A plant node was located

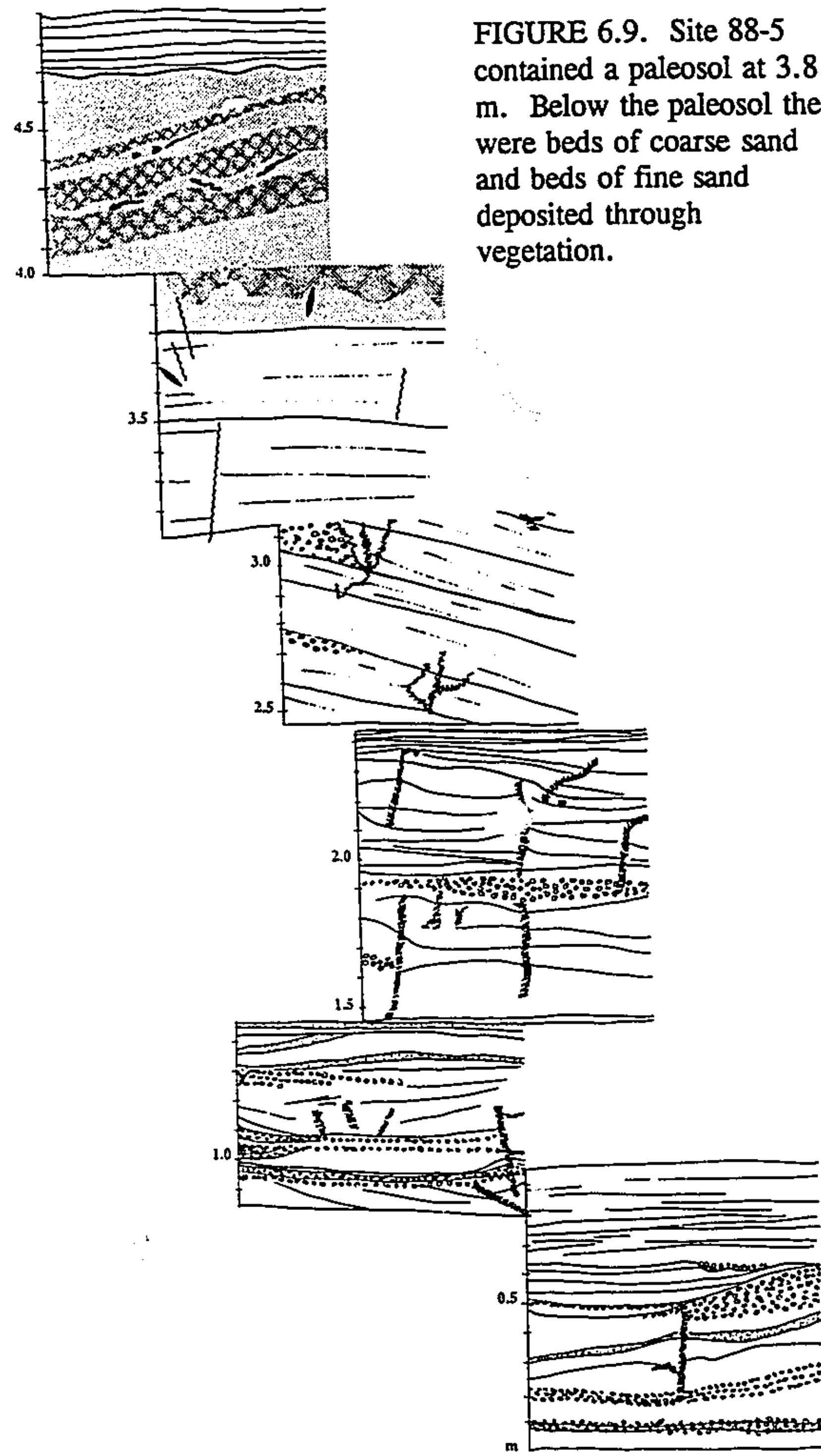


FIGURE 6.9. Site 88-5 contained a paleosol at 3.8 m. Below the paleosol there were beds of coarse sand and beds of fine sand deposited through vegetation.

within this bed. The stain from the plant rose from the node and stretched through the next 5 beds.

At 0.35 m there was a more tightly packed layer of sand which was only 2 cm in thickness. Above and below this was uniform grain size, fine sand. At 0.50 m there was a layer of coarse sand only a grain size thick. To the right of the plant were low angle cross-beds of coarse sand which dipped at various angles toward the plant stain. From 0.5 to 1.0 m there was a 30 cm bed of laminated fine sand which dipped 17°/65. There was no evidence of vegetation within this bed. There was a distinct, but not erosive boundary which separated this bed from the next one.

The next bed extended from 0.8 to 0.95 m and consisted of low angle cross laminae dipping at various angles toward a plant cluster located in the right of the pit. This bed was capped by a 7 cm bed of laminated coarse sand separated from a second bed of coarse laminated sand above by a 10 cm thick bed of uniform grain size, fine sand. An Ammophila breviligulata stain extended through the bed at the right side of the pit.

At the base of the next bed was a cluster of plant stains. These were surrounded by discontinuous beds of irregular laminae. At 1.3 m on the left side of the pit was a plant node. In the lee of this node were low angle cross-beds of coarse laminated sand. These beds were capped by a 1 cm thick layer of tightly packed sand. At 1.44 m there was a discontinuity which truncated a bed of uniform grain size sand and a 2 cm thick tightly packed layer.

The next set extended from 1.44 to 2.44 m and consisted of parallel and wavy laminated beds of fine sand with plant stains. The beds were irregularly shaped and laminae were discontinuous. Lenses of coarse sand occurred at 1.7 m and at 1.9 m. The first was small, only 2 cm in height and about 10 cm long. The second was large extending the width of the pit (.5 m) and was up to 10 cm in thickness. It was associated with three plant nodes. The beds above this were laterally continuous, but contorted. Plant stains were abundant.

There was a change at 2.44 m with the deposition of a new set of beds which were no longer horizontal, but dipped at angles up to 28°/290. Laminae were discontinuous and vague and bed boundaries were distinct, but not erosive. This set was topped by another set of laminated beds at 3.14 m where the beds were again horizontal. Laminae were still discontinuous and plant stains were abundant. This extended to 3.8 m where the transition to paleosol began.

The paleosol at this location extended from 3.8 m to 4.8 m. Between 3.8 and 3.9 m the sand was stained grey to brown and contained fragments of woody roots. Then a concentrated sand organic layer extended from 3.9 to 04 m. It had an irregular bottom surface and the upper surface was truncated by the present day surface. In a second cleared section the basal grey-stained sand was overlain by a concentrated sandy organic layer which dipped 17°/90 and was 10 cm thick. The upper irregular surface was capped by mottled grey sand containing roots. Between 4.25 and 4.32 m there was another concentrated sandy organic layer which was less concentrated than the first one and was capped by a 3 to 8 cm thick grey sand layer containing roots. A final concentrated organic layer capped the sequence. It was overlain by mottled grey sand. All the beds dipped 17o/90 and were truncated by an erosional surface which was horizontal.

Because the sand was so unstable the structures above the paleosol could not be cleared for examination at this location. A general examination revealed that the sand was laid down in beds around vegetation. These beds were similar in appearance to those at other locations.

Interpretation

The base of the section was made up of alternately tightly and loosely packed beds of fine to medium sand separated by and containing lenses of coarse material. This reflected an environment in which there was some vegetation, but there were relatively large spaces which were unvegetated. In the Sparse Marram community this is often the case. Clusters of Ammophila breviligulata which spread over a large surface (metres in width and breadth) were separated by areas which may be of the same size in which there were few or no plants. In such an area, there is a transition from predominantly grainfall at the perimeter to predominantly traction away from the baffling effect of the plants.

The contorted beds which rise toward plant stains, were a result of the increase in plant coverage. In this location a more limited local supply of sand caused a slower accumulation rate. When carrying little sediment, the wind scoured the areas between plants while depositing close to the plants. The resulting deposit contained beds which were warped upward around individual plants with coarse lags on surfaces. With increasing plant density, the scouring decreased and a more even bed was deposited.

The increasing plant cover caused a decrease in the amount of sand deposited and allowed a change in the type of vegetation. Woody plants colonized, increased the stability of the local area, and allowed for the development of the paleosol.

6.3.3 Site 88-4 (Fig. 6.10)

Description

This dune, located just east of Skidby wreck, contained structures below the paleosol which had a variety of grain sizes with many laterally continuous coarse layers and lenses. There was also a variety of grain packing and much evidence of vegetation.

Below 1.62 m there was little evidence of vegetation. Beds dipped 29°/335 at the steepest and 5°/335 at the flattest. Evidence of 2 plants existed in the very first bed of the section. Here a node and an organic stain were present. However, they had little effect on the surrounding beds. Coarse layers were between 1 and 10 cm in thickness and alternated with fine and

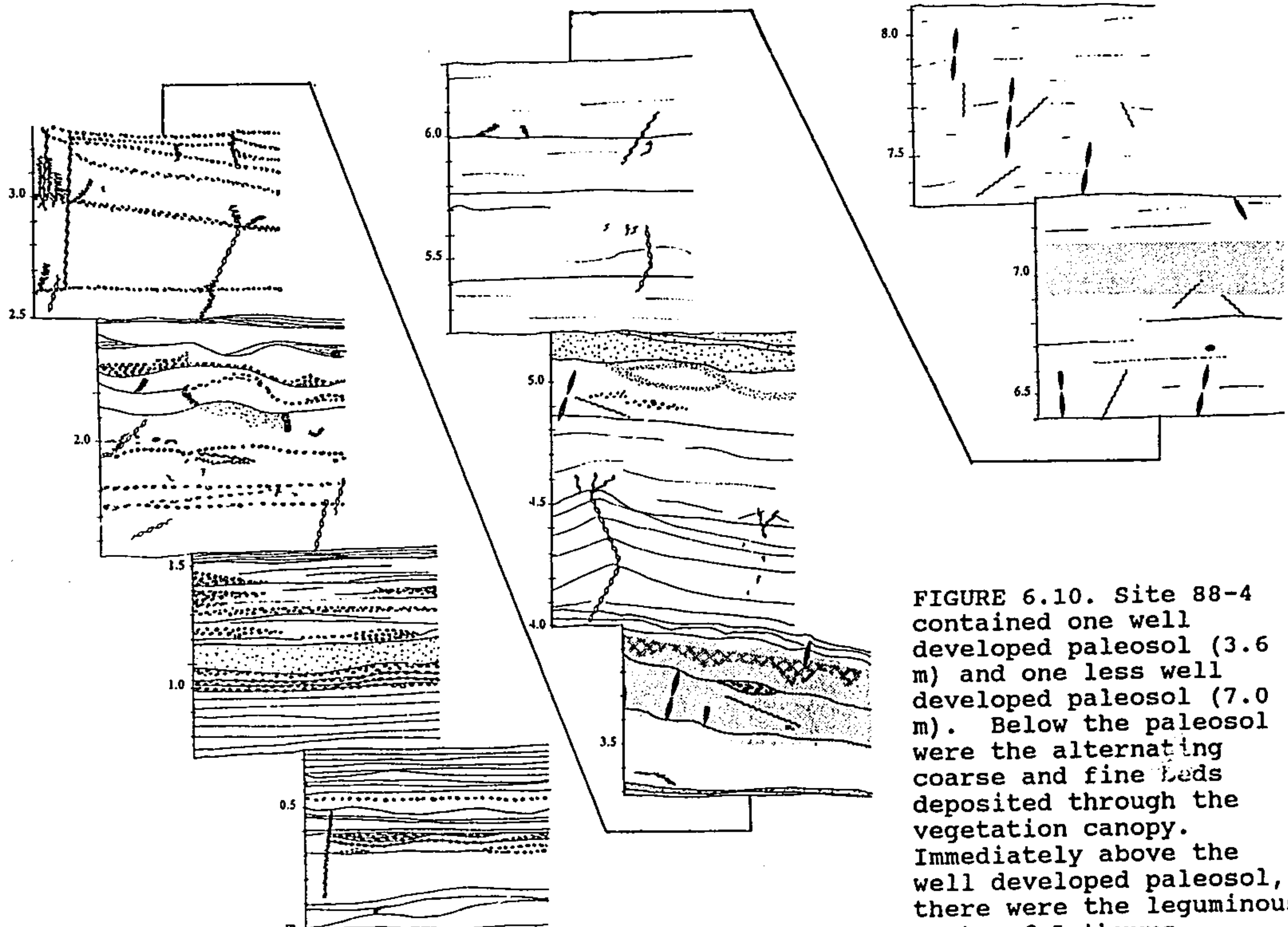


FIGURE 6.10. Site 88-4 contained one well developed paleosol (3.6 m) and one less well developed paleosol (7.0 m). Below the paleosol were the alternating coarse and fine beds deposited through the vegetation canopy. Immediately above the well developed paleosol, there were the leguminous roots of <u>Lathyrus maritimus</u>. This changed upward to a woodier cover.

medium sand layers. Lenses of coarse sand predominated from 1.1 to 1.5 m. Each lens was about 4 cm in height and between 10 and 20 cm in length.

Above 1.62 m there was increasing evidence of the sand having been vegetated. Fragments of decayed plants were abundant and decayed roots were present. From 1.62 to 1.84 there was a bed of unlaminated, fine, uniform grain size sand topped by a 1 cm coarse layer. This in turn was topped by low-angle cross-beds of medium to coarse sand with roots in it. The top of this bed dipped 6°/335. From 1.9 to 2.15 m was another bed of unlaminated, uniform grain size, fine sand capped by a coarse layer. The top of this bed was irregular and contained many organic stains. Another bed of uniform grain size sand was deposited between 2.15 and 2.25 m containing a large coarse lens in association with a fragment of plant stalk. A plant stain stretched from the bottom to the top of the bed. There were four more similar beds which were deposited up to 2.60 m. Each was capped by a more or less contorted coarse layer and each was made up of uniform grain fine size sand with plant stains.

From 2.60 to 3.5 the beds were more organized around plant clusters. Uniform grain size, fine sand was deposited around plant stems with coarse layers and lenses associated with the nodes of the plant. Beds were laterally continuous and averaged between 10 and 20 cm in thickness with the largest being around 40 cm thick. At 3.33 m there was a 1 cm thick layer of tightly packed medium sand. Above this was a piece of root in a bed of unlaminated, fine sand which extended upward to 3.62 m and the paleosol.

The paleosol at this location consisted of two sets of sand and organic material. The lower set was 20 cm thick and was made up predominantly of organically stained sand with root fragments and stem pieces within it. Near the top of the set was a 20 cm long 8 cm thick lens of coarse sand. There was a distinct boundary between the sets. The second set was made up of two beds. The first was grey-stained sand and the second was a concentrated sandy organic layer. Extending upward from this was a 2 cm in diameter piece of root.

Immediately above the paleosol were three sets of laterally continuous, but irregular beds of sand with plant stains and fragments. The first set was made up of fine sand at the base and medium to coarse sand at the top. From 4.0 to 4.9 m the beds were continuously laminated and warped upward around plant stains. From 4.5 to 5.2 m the laminae were less continuous and the beds became more horizontal. At 4.9 m there were two coarse lenses which were only about 5 cm in thickness and 5 to 10 cm long. Contorted layers of coarser sand were deposited between 5.0 m and 5.1 m. Between 5.1 and 5.2 m thick beds of coarse sand were deposited.

The second set extended from 5.2 m to 6.3 m and was made up of 4 beds of discontinuously laminated sand with leguminous root fragments. Laminae within the beds dipped at various angles due to the presence of vegetation, but the beds were horizontal. The third set extended from 6.3 m to 8.3 m and was made up of discontinuously laminated beds of sand containing woody roots and woody plant stains. From 6.9 to 7.1 m there was a bed of organically stained sand in which the laminae could not be traced. Above the organically stained bed, the bed boundaries could not be traced and woody roots were common.

Interpretation

The base of the section (0 to 3.3 m) was the same as that deposited at site 88-5. With an increase in plant cover, there was a decrease in the accumulation rate because it was harder for sediment to be carried to the surface. This resulted in a change in the type of cover. Woody species invaded and out competed the grasses. In this instance, the woody coverage resulted in a locally stable surface on which a paleosol developed. External forces then freed sediment which migrated over the area, burying the paleosol, smothering the woody vegetation and allowing the grasses to re-establish. This happened between 4 and 5 m elevation. From that point upward, there was a balance between the growth of woody plants (Rosa virginiana and Myrica pensylvanica) and grasses. Accumulation rate was fairly constant.

6.3.4 Site 88-12 (Fig. 6.11)

Description

Site 88-12 was located on the east face of an eroding dune about 200 m east of Skidby. The dune was over 13 m in height and a long section was cut into it. Below the paleosol there were coarse layers that were easily traceable to the beds outside the pit. The basal portion of the section consisted of sets of alternating finer and coarse beds of sand with vegetation stains. There was abundant evidence of vegetation with many plant stains. The basal set was continuous across the cleared section and consisted of parallel and wavy laminated beds of fine and coarse sand with irregular surfaces. Laminated beds of fine material were separated by beds of coarse sand. This portion extended to 0.85 m. Average thickness of the fine material was 17 cm and average thickness of the coarse material was 8 cm. Woody roots were present at 0.4 m.

From 0.85 m to 1.1 m there was a second set of fine beds separated by coarse material. The first bed extended from about 0.85 to about 0.95 and was made up of fine material which was also covered with a coarse layer, but was disturbed. In the centre of the exposure there was a break in the coarse layer. Ammophila breviligulata stains rose up from the coarse layer. To the right of the exposure, a lens of coarse sand was deposited in the lee of a plant stain. Above this was a bed of fine sand in which it was difficult to discern laminae. Topping this, extending to 1.53 m, was a bed of laminated coarse sand which pinched out in the centre of the pit.

From 1.53 to 1.8 m was another set of laminated beds which consisted of a 7 cm bed of laminated fine sand topped by a 13 cm bed of coarse laminated sand. This was overlain by a 5 cm layer of fine, unlaminated sand

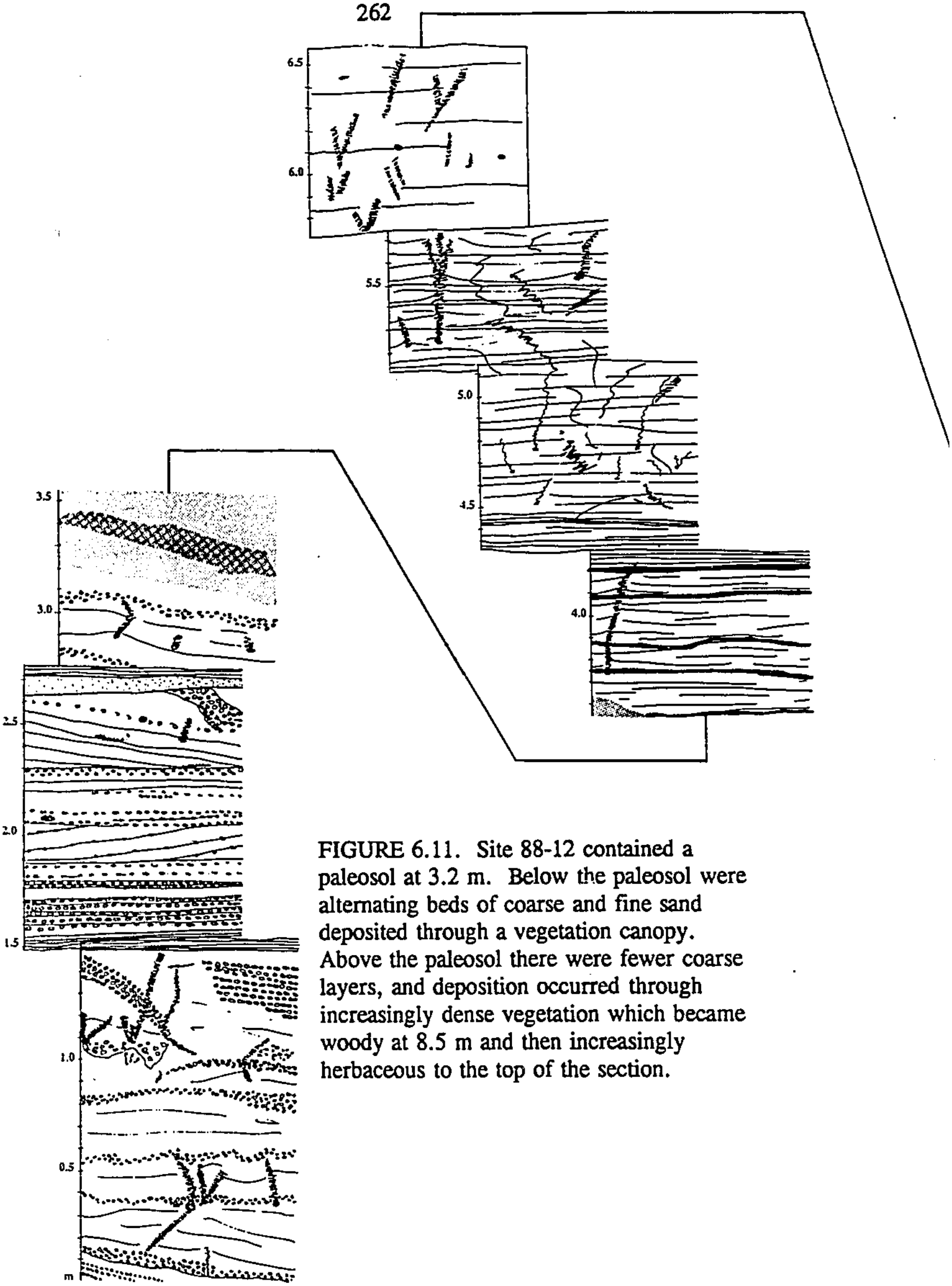
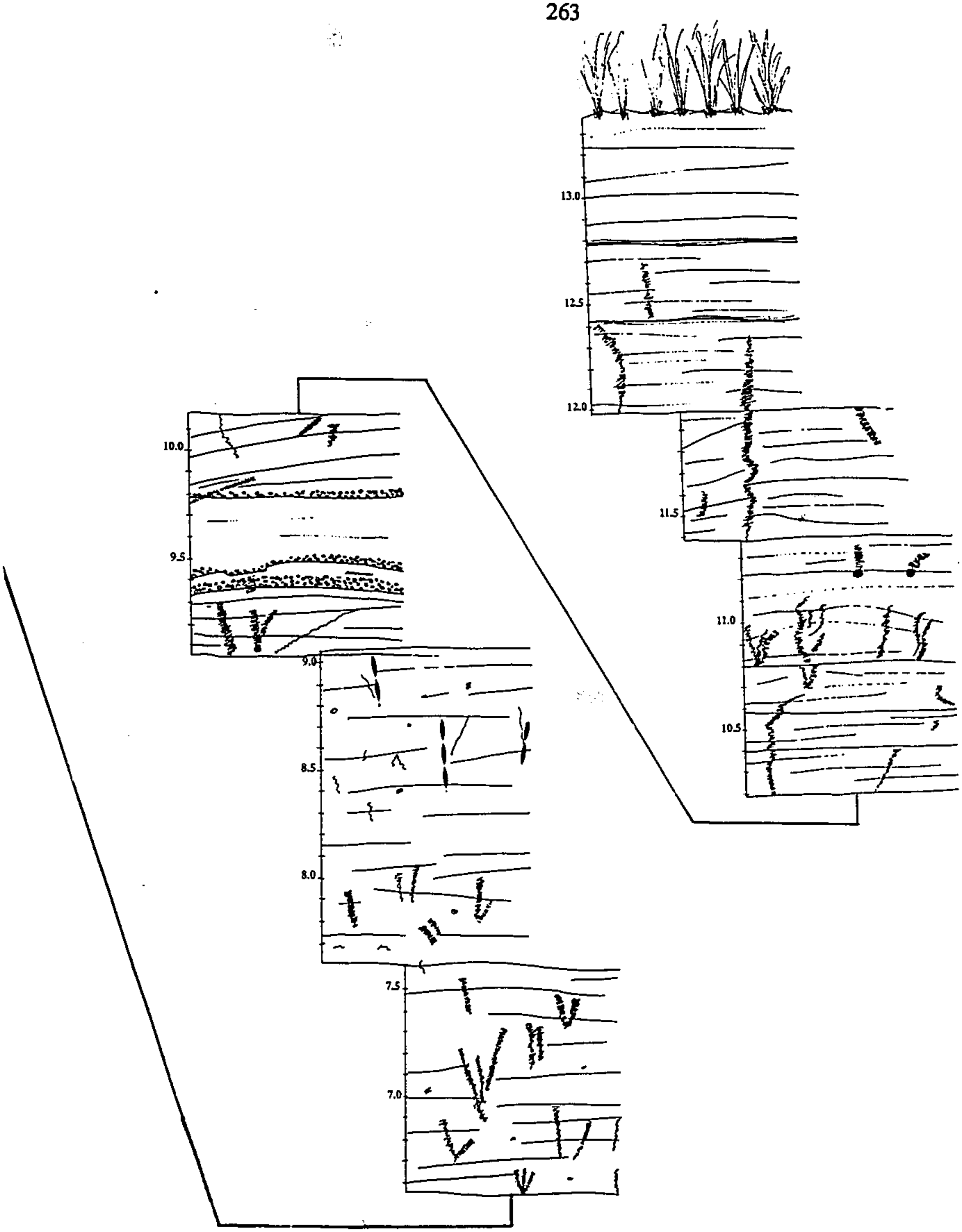


FIGURE 6.11. Site 88-12 contained a paleosol at 3.2 m. Below the paleosol were alternating beds of coarse and fine sand deposited through a vegetation canopy. Above the paleosol there were fewer coarse layers, and deposition occurred through increasingly dense vegetation which became woody at 8.5 m and then increasingly herbaceous to the top of the section.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and again by a 3 cm bed of laminated coarse sand. From 1.8 to 1.9 m were two beds of fine sand separated from each other by a lamina of coarse sand. From 1.9 to 2.05 m was a set of cross-beds of fine sand separated by a coarse lamina. The set dipped 10°/197 and was truncated by a coarse lamina which was overlain by another set of fine beds separated by coarse laminae. There was a very thin (only a grain size thickness) organic layer at 2.3 m. Above this was a 30 cm thick set of fine, laminated cross-beds with an average bed thickness of 5 cm, containing pieces of root material and stems. Also, contained within this set was a coarse lens which surrounded a plant stem. It was overlain by a 5 to 8cm bed of unlaminated, fine sand. Above this was the paleosol.

The paleosol extended from 2.76 to 3.6 m. At the base of the paleosol there was a set of beds which were the transition from the structures below. In this transition layer, the beds are difficult to trace and the laminae are hard to define. A 5 cm thick coarse bed was topped by a bed of discontinuously laminated fine sand containing many pieces of decaying grass roots and portions of woody roots. This was capped by a 5 cm thick, unlaminated bed of coarse sand. Above this the beds were discontinuously laminated and contained an abundance of organic material. At 3.25 m there was a 3 cm thick bed of organically stained sand (Fig. 6.12). It was covered by more discontinuously laminated sand and then the thicker concentrated sandy organic layer. This 10 cm organic layer dipped 21°/298 and was topped by 10 cm of

FIGURE 6.12. The paleosol at Site 88-12 contained a concentrated, sandy organic layer which topped leached sand.

grey stained sand.

Deposited on top of the paleosol were beds of discontinuously laminated fine sand separated by thin layers of organic material. Average bed thickness was 15 cm with the fine sand portion being 10 to 12 cm and the organic layer 3 to 5 cm thick. This pattern extended from 3.64 m to 4 m.

From 4 m to 5.75 m sand was deposited in horizontal to sub-horizontal, discontinuously laminated beds of fine to medium sand with vegetation stains. Laminae rose toward plant stains from all directions. Bed thickness varied between 3 and 15 cm (Fig. 6.13). At 5.75 m there was a change from grey and brown sand to clean white sand deposited in beds with woodier plant stains. Discontinuous beds were between 10 and 25 cm thick and were discontinuously laminated, extremely unstable sand. There were no clear sets. This type of structure extended upwards to 9.05 m.

At 8.5 m more roots were visible. From 9.3 to 9.5 m there were two coarse layers of sand associated with plant nodes which were topped by a 15 cm thick bed of unlaminated, uniform grain size, fine sand overlain by a 1 cm thick layer of coarse sand with a plant node in the left side. Above this were eight sets of discontinuously laminated sand deposited in discontinuously laminated, discontinuous beds of fine sand with woody vegetation stains. Sets ranged from 10 cm thick to 40 cm thick. Each set was capped by a 1 to 2 cm thick layer of organic material.

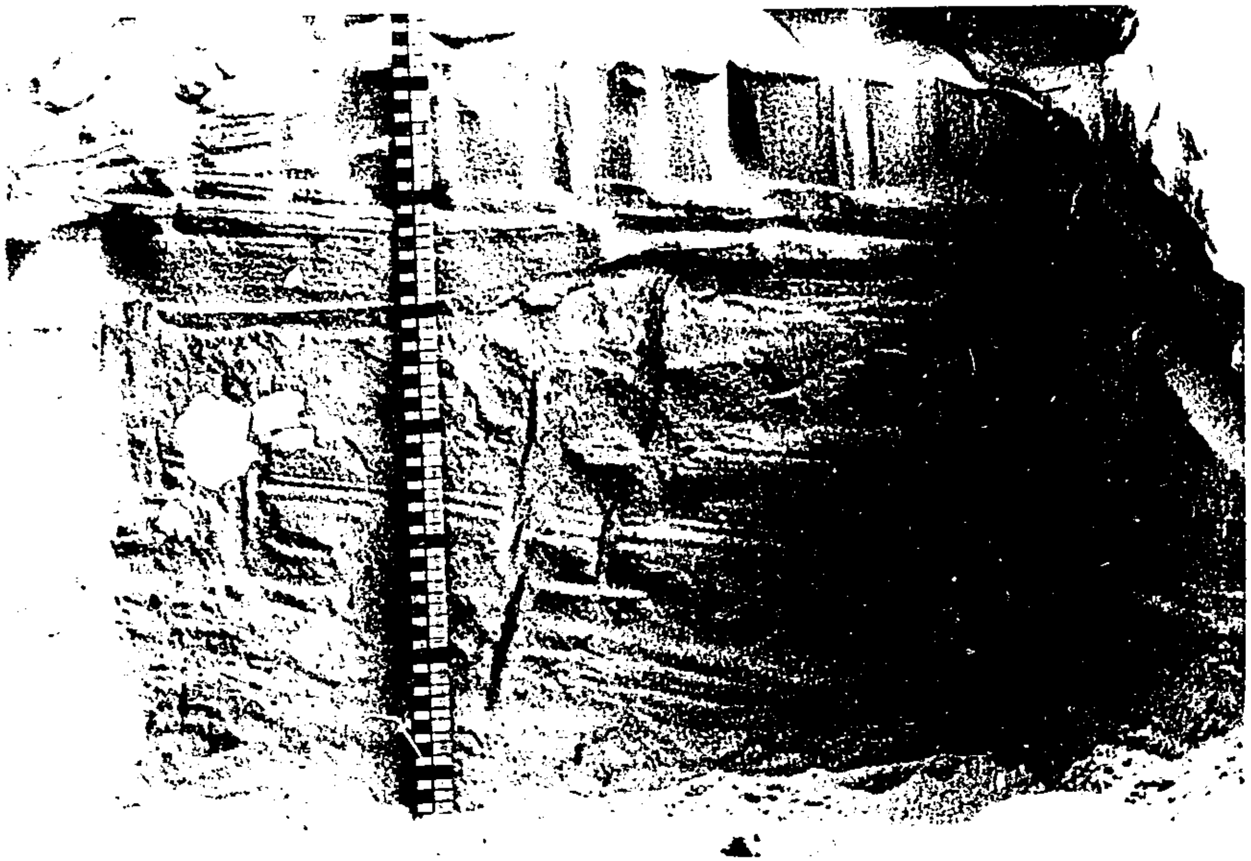

FIGURE 6.13. Photograph of a portion of Site 88-12 showing the beds which are deposited within Marram grass. The vertical lines in the centre of the photo are the stains and fibres of the plant. To the left of the scale is the stain and scour mark of another plant.

Interpretation

The base of the section upward to the paleosol developed in the same way as 88-5 and 88-4. The beds of fine laminated sand separated by coarse layers represents an environment in which there was some vegetation, but there were large enough spaces between clusters of vegetation to allow for the migration of ripples and granule ripples. This would have been the Sparse Marram community. As plant cover increased beyond this point, organic material could have accumulated which would allow the development of the paleosol. Above the paleosol there was a large (3.5 m to 5.75 m) section in which the predominant vegetation type was Ammophila breviligulata. This changed upward to become a cover of Ammophila breviligulata, Lathyrus maritimus, Smilacina stellata, Achillea lanulosa, and some Rosa virginiana. There was fairly steady accumulation from 5.75 m upward to the present surface.

6.3.5 Summary of Type II

The Type II sites are located within the north dune ridge, landward of the presently forming foredune. Figure 6.14A shows a descriptive summary of the group and Figure 6.14B the genetic summary. There are four units. The basal unit is made up of discontinuously laminated, discontinuously bedded sets of fine sand, capped by beds of coarse sand. These structures represent those which were deposited in the open area landward of the foredune ridge. The second unit consists of vegetation stained sand deposited in discontinuously laminated, horizontal to sub-horizontal beds in which laminae rise toward the plant stains from all directions. This unit represents the structures deposited as the area behind the foredune ridge was filled in with new sand and vegetation colonized. In some dunes there was a change from Sparse to Dense Marram and then to Shrub Heath vegetation, while in others the vegetation change was only to the Dense Marram community. This cover of vegetation allowed the development of the paleosol - Unit 3. The paleosol is neither very thick nor well developed, indicating that the stable, paleosol-forming environment did not last for a long time. Instead it changed into an environment in which there was a more rapid rate of deposition. Unit 4 reflects the deposition of continuous to discontinuous beds of laminated to faintly laminated fine sand within and around vegetation which changes from Sparse Marram (Unit 4a) at the base through to Dense Marram upward, and even to Shrub Heath in some cases (Unit 4b).

From the base to the paleosol, the development of the dune is similar to the others described previously. However, the thinness and crude development of the paleosol are the result of the changes in rates of deposition. Given enough time, the paleosol here could develop into a thicker layer, but the rate of sedimentation increased rapidly, cutting off the development of the soil. This type of dune develops when the foredune ridge began to migrate over the area behind it, becoming a blowout. The ridge continued to migrate through foredune ridge. The second unit consists of vegetation stained sand deposited in discontinuously laminated, horizontal to sub-horizontal beds in which laminae rise toward the plant stains from all directions. This unit represents the structures deposited as the area behind the foredune ridge was filled in with new sand and vegetation colonized. In some dunes there was a change from Sparse to Dense Marram and then to Shrub Heath vegetation, while in others the vegetation change was only to the Dense Marram community. This cover of vegetation allowed the development of the paleosol - Unit 3. The paleosol is neither very thick nor well developed, indicating that the stable, paleosol-forming environment did not last for a long time. Instead it changed into an environment in which there was a more rapid rate of deposition. Unit 4 reflects the deposition of continuous to discontinuous beds of laminated to faintly laminated fine sand within and around vegetation which changes from Sparse Marram (Unit 4a) at the base through to Dense Marram upward, and even to Shrub Heath in some cases (Unit 4b).

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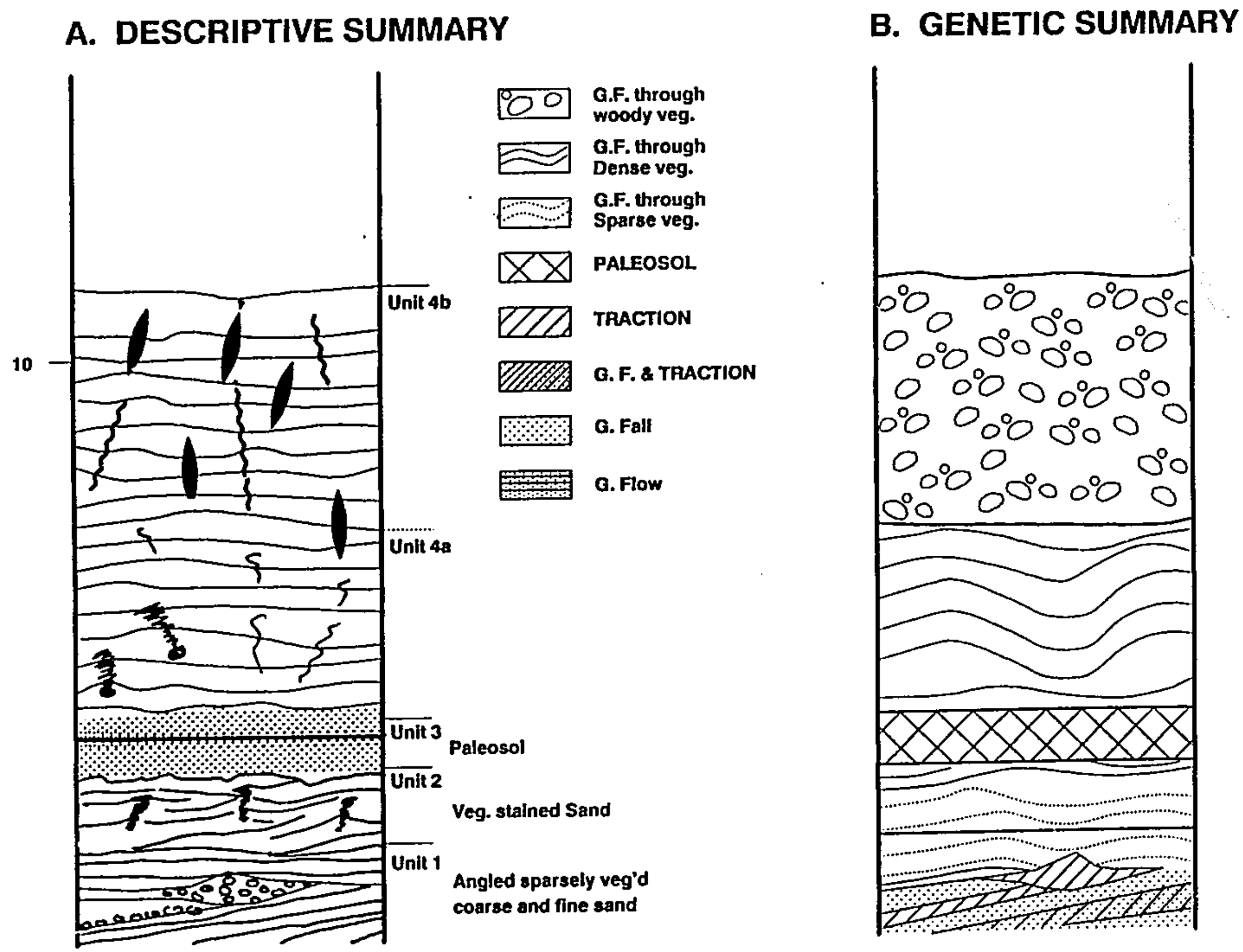
FIGURE 6.14. Descriptive and genetic summaries of Type II Migrational Multi Phase dunes. The base is marked by alternating beds of coarse and fine sand. Topping the section is woody vegetation which is marked by predominantly grainfall.



COLUMNS ARE APPROXIMATELY 10m HIGH

becoming a parabolic dune, leaving behind the structures on either side of the blowout. These structures are the Type II Migrational dunes. There is no evidence of the migration of the dunes - the avalanche beds - because these have been eroded away as the nose of the parabolic moved through the area. As the parabolic dune passed over, it buried the ridge beneath the paleosol, and continued in its path allowing deposition at a rate great enough for the Sparse Marram community to develop. Over time the rate of deposition decreased and the cover changed to the Dense Marram community and in some cases to Shrub Heath.

6.4 Type III

6.4.1 Site 87-18 (Fig. 6.15)

Description

The dune was located on the southern side of the main dune ridge, north of three mile dune. The paleosol was about 1/3 of the way from the top of the dune. North of the dune was a blowout which reached the watertable. There was another paleosol on the floor of the blowout.

The section consisted of 7 sets of laminated beds of sand and of organic material. The first set was made up of 9 beds of parallel, tabular, horizontal or slightly dipping, laminated uniform fine sand. Laminae generally followed the bedding planes which were nearly horizontal at the base and dipped 8°/135 at the top. There was the stain of a single plant stalk in growth position which

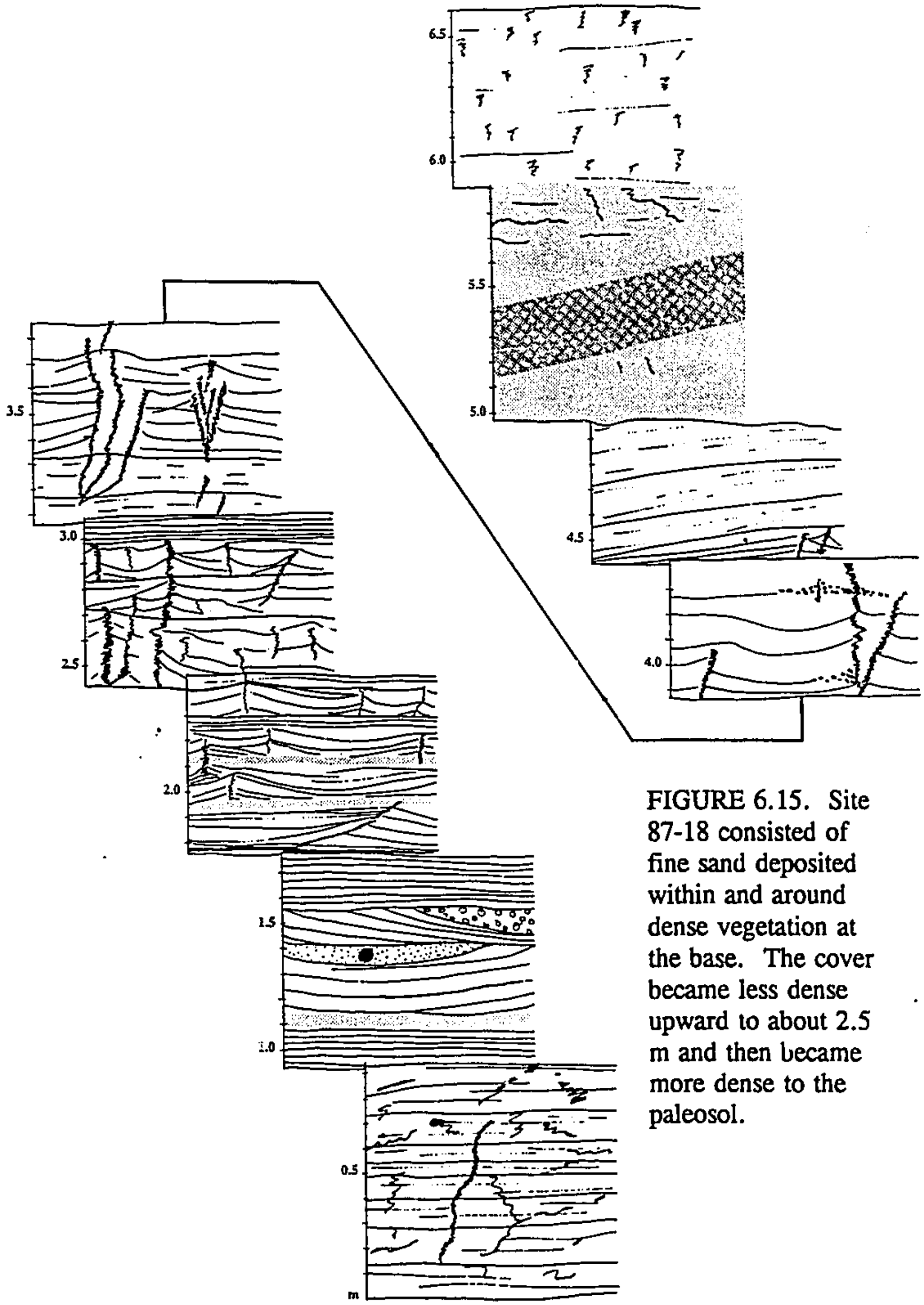


FIGURE 6.15. Site 87-18 consisted of fine sand deposited within and around dense vegetation at the base. The cover became less dense upward to about 2.5 m and then became more dense to the paleosol.

began in the second bed and extended upward through the seventh bed. The sand was brown and contained many transported fragments of vegetation. Set 1 was topped by a 1-3 cm thick layer of organically stained sand.

Set 2 was made up of laminated beds. The first consisted 25 cm of gently undulating parallel-laminated fine sand dipping 5°/205. The second bed was thinner (about 8 cm), lens shaped, coarser and more loosely packed than the first, with a stain of a single plant in the centre of the lens. The third bed had laminae dipping 14°/45 and bedding planes dipping 5°/205. The fourth bed (at 1.45 m) was about 10 cm thick, lens shaped and coarser. The fifth bed was planar-tabular, horizontal fine laminated sand and the sixth bed was a thin bed (2 to 5 cm) of parallel-laminated fine sand dipping 34°/276.

The third set of laminated sand began at 1.8 m. The eight beds in this set were made up of fine sand deposited around vegetation and ranged from 10 to 25 cm thick. The bedding planes were roughly horizontal while the laminae within beds rose toward single plants or small plant clusters. There was very little change in grain size throughout the set. The first and second beds were topped by a 2-3 cm thick layer of organically stained sand. Plant stains and fragments were common. These were often in growth position. Dips of the beds ranged between 12 and 19° and were oriented between 135 and 245°. The next six beds did not have organically stained sand topping them. Bed 5 (2.4 to 2.7 m) was thicker than the other beds, but contained the same discontinuous laminae as the others in the set. Topping the set at 3.0 m was a

10 cm thick bed of parallel-laminated, fine sand with no staining in it.

The next set of laminated beds extended from 3.1 m upward to about 4.5 m. The set contained abundant vegetation staining and a variety of grain sizes from fine to coarse. The vegetation was a different type than in the set below with plant stains that stretched through as many as 4 to 5 beds. In the set below this, the plants were present in only 1 to 2 beds. There were also two different types of stains, the first consisted of straight stalk stains or cylindrical fragments of stalks, while the second type of plant remains were woody and branched. The sand deposited around the plants was arranged in laminated beds. Bedding planes were horizontal or sub-horizontal. They were continuous, although it was difficult to trace them near plants and the laminae within the beds did not follow the bedding planes, rising toward plants or plant clusters from all directions. There was very little grain size segregation. As the laminae rose toward plants they became more indistinct and often faded completely. The sand closest to the plant clusters was often less well-packed than that which was farther away. Towards the top of the set (beds 12 and 15), there were two lenses of slightly coarser sand. These were associated with nodes of the plants.

The fifth set was the paleosol and the associated transition to the paleosol. The sand was a yellowish grey colour and was mottled with the stains and fragments of woody roots and stems. The transition layer of bedded, fine sand with vague laminae was located between 4.61 and 5.0 m and the organically stained sand was located between 5.0 and 5.1 m. This was overlain by the concentrated sandy organic layer. In this location it was slightly different than the organic layer in other locations. It was very thick (25 cm) and more sandy and thus, more permeable than in other locations. The sixth set in the section was made up of greyish mottled, discontinuously laminated, unbedded sand.

Interpretation

The basal section reflected a protected location in which the sediment was moved slowly and accumulated around plants while they grew upward. This was similar to the interior portion of the island. In many places there had been a blowout which was now healed. The area behind the blowout was protected from the strongest winds by the taller dunes around it. Sparse Marram often grows in this type of location.

There was a change in the second set to a more active environment. Perhaps the blowout was breached once again allowing a new supply of sand to be deposited on the Sparse Marram covering the area. With continued accumulation the density of cover increased causing difficulty for sand transport. This would then cause a decrease in the accumulation rate which would allow the woody vegetation to take hold. Over time the paleosol developed.

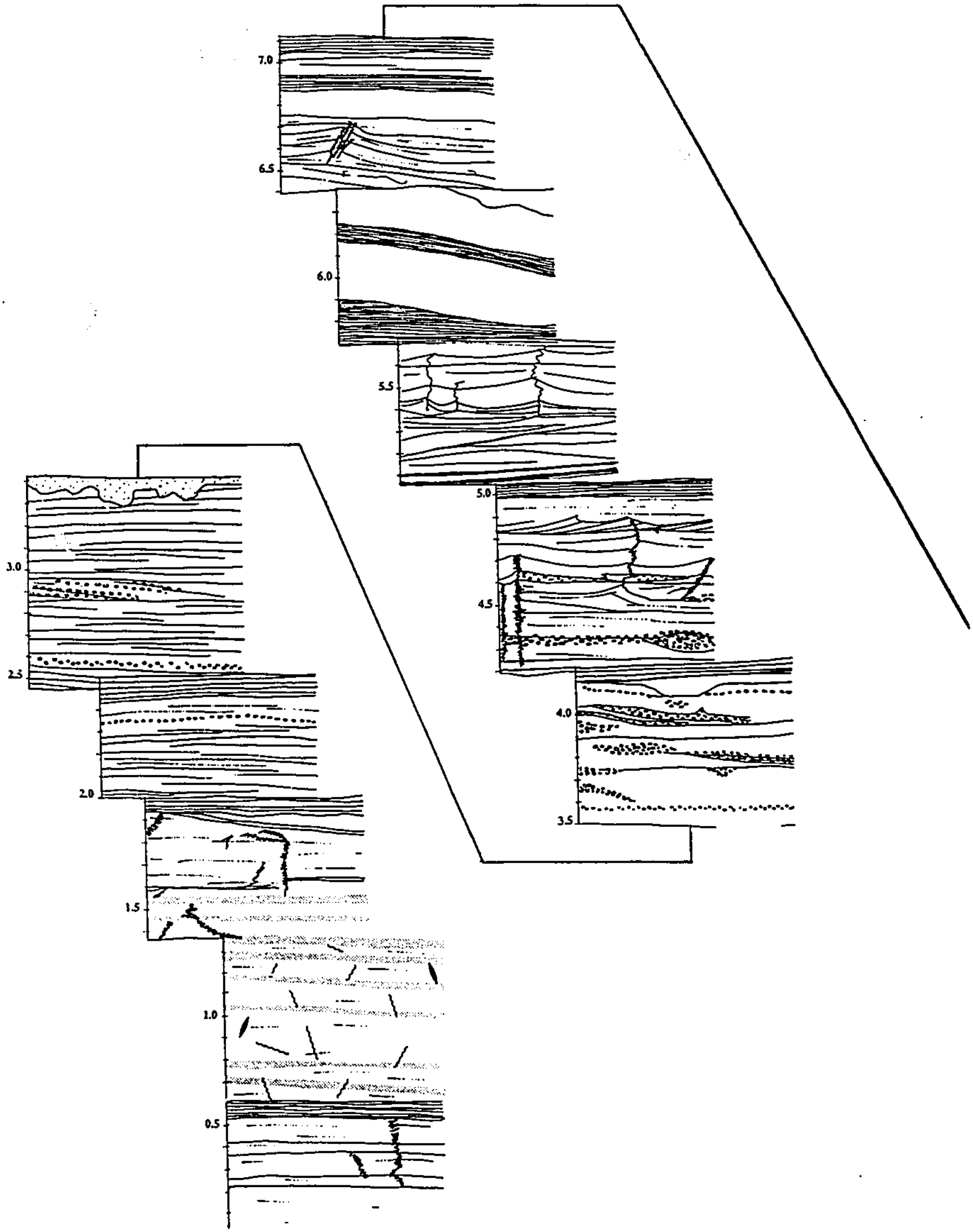
Then there was renewed sedimentation at a slower rate above the paleosol. The structures deposited consisted of laminated, greyish mottled sand containing fragments of in situ woody roots. This indicates that there was a slow but steady accumulation over a long period with the shrub cover growing upward with burial.

6.4.2 Site 88-18 (Fig. 6.16)

Description

Site 88-18 was located in the west face of a blowout facing onto the south beach at the end of profile I-J. There was a paleosol below the base of the section with an abundance of large (5 to 10 cm diameter) woody root and stem pieces. The paleosol was not a single concentrated layer of organic material, but was scattered over a vertical height of about a metre as thin (< 5cm) layers of organically stained sand. Roots could be traced for about 2 m below the examined section. The sand was deposited in beds which were separated by changes in grain packing - thicker uniform grain size, fine sand covered by a thin layer of well compacted sand. The beds of uniform grain size were unlaminated to vaguely laminated.

From 0.61 to 1.36 m the same style of sedimentation around large woody roots and stems continued. However, the uniform grain size beds became increasingly organic upward, the boundaries of sets marked by highly organic layers. They differ from the paleosol in other areas in that the organic concentration was lower. From 1.36 to 1.99 m there was increasing evidence of changing vegetation. The woody roots and stems were joined by evidence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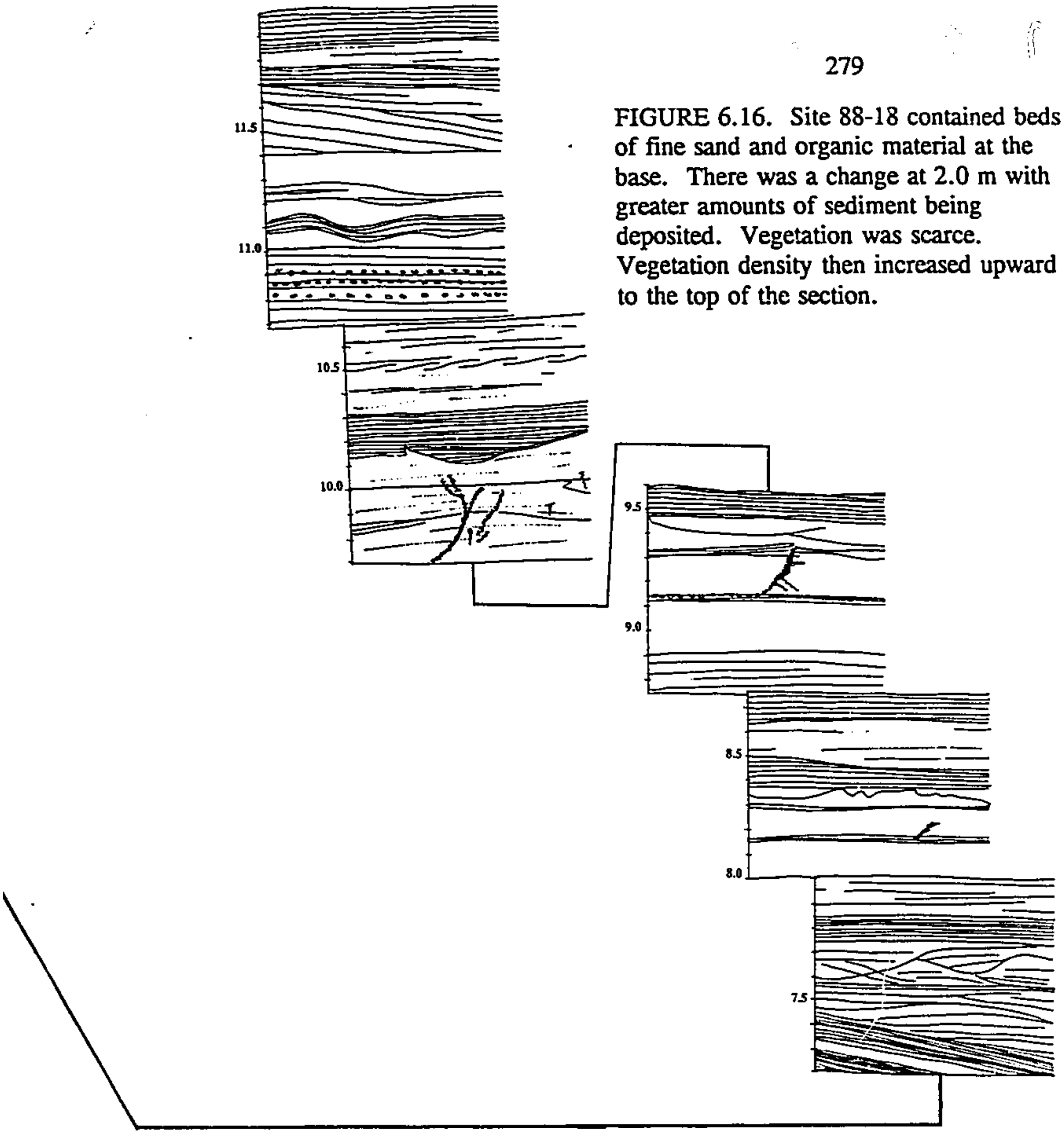


FIGURE 6.16. Site 88-18 contained beds of fine sand and organic material at the base. There was a change at 2.0 m with greater amounts of sediment being deposited. Vegetation was scarce. Vegetation density then increased upward to the top of the section.

of less woody species. By 2.0 m height in the section, the evidence of vegetation was sparse. There were local pockets of coarser material and thin layers of coarse sand deposited along with discontinuously laminated beds of fine sand. At 3.0 m there was a 10 cm thick set of coarse cross-beds which was deposited between discontinuous beds of fine laminated sand.

With increasing height in the section there was increasing evidence of grasses and the loss of evidence of woody vegetation. With the change in vegetation, the bedding became more disturbed (3.7 m). Locally contorted beds with pockets of coarse sand were associated with the nodes of the grasses. From 4.0 to 5.0 m there was evidence of vegetation in the form of stains which stretched through a number of beds. Plant nodes were associated with coarse layers and lenses. The beds were discontinuously laminated with the laminae rising toward the plant from all directions. There were also increasing concentrations of heavy minerals which blanketed the boundaries of sets with thin (1 to 2 mm thick) planar beds. At 5.0 m height, the layers of heavies were as thick as 15 cm (Fig. 6.17). Between 5.7 and 5.9 m there was another layer of parallel-laminated sand and heavy minerals. It was topped by 27 to 30 cm of fine, unlaminated sand with no vegetation stains, and a second 10 cm thick bed of parallel-laminated sand and heavy minerals and a 20 cm bed of unstained, unlaminated sand (Fig. 6.18).

Vegetation staining again appeared in the beds from 6.5 to 6.7. These beds are continuous and discontinuously laminated. From 6.75 to 6.87 there is

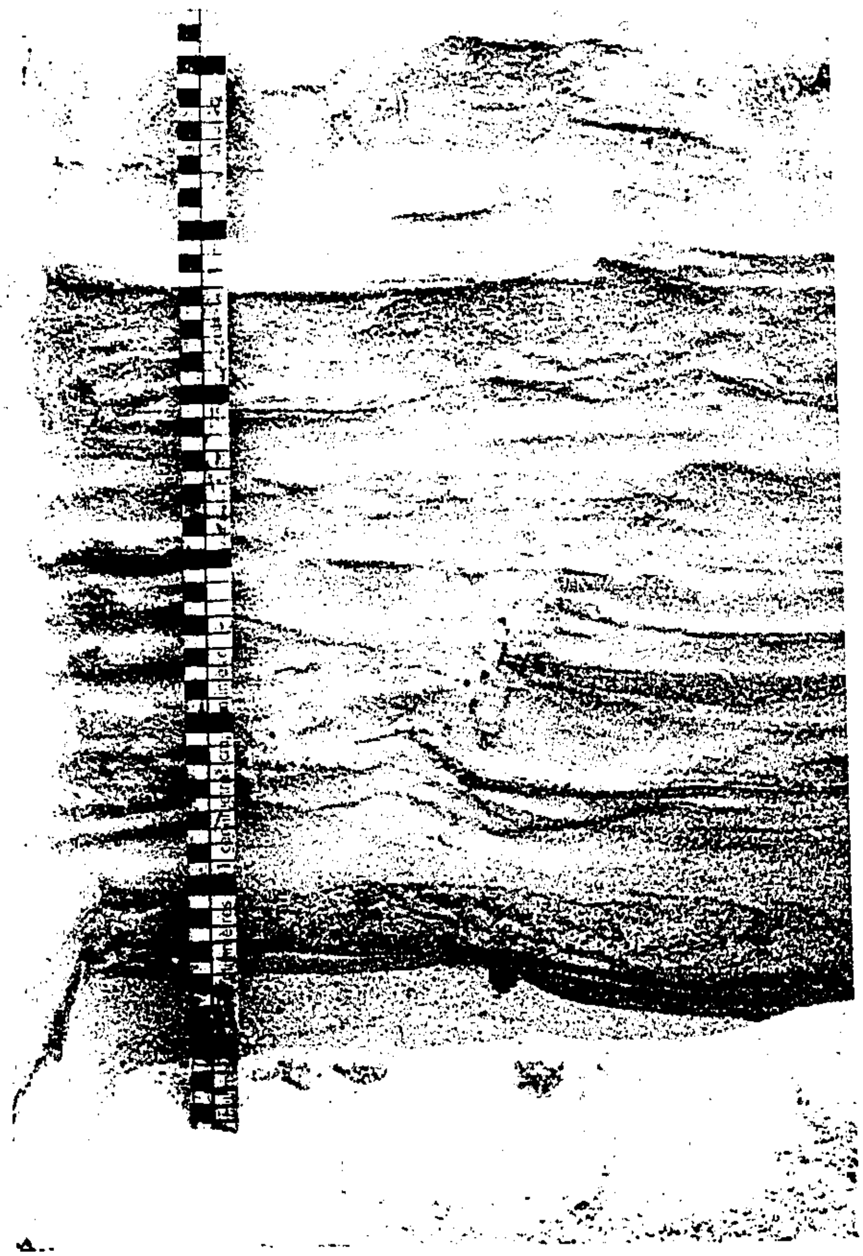


FIGURE 6.17. Photograph of a portion of Site 88-18 shows a plant stain curving upward from the centre of the bottom of the photograph to the right. A heavy mineral and sand layer is located at the bottom of the pit.

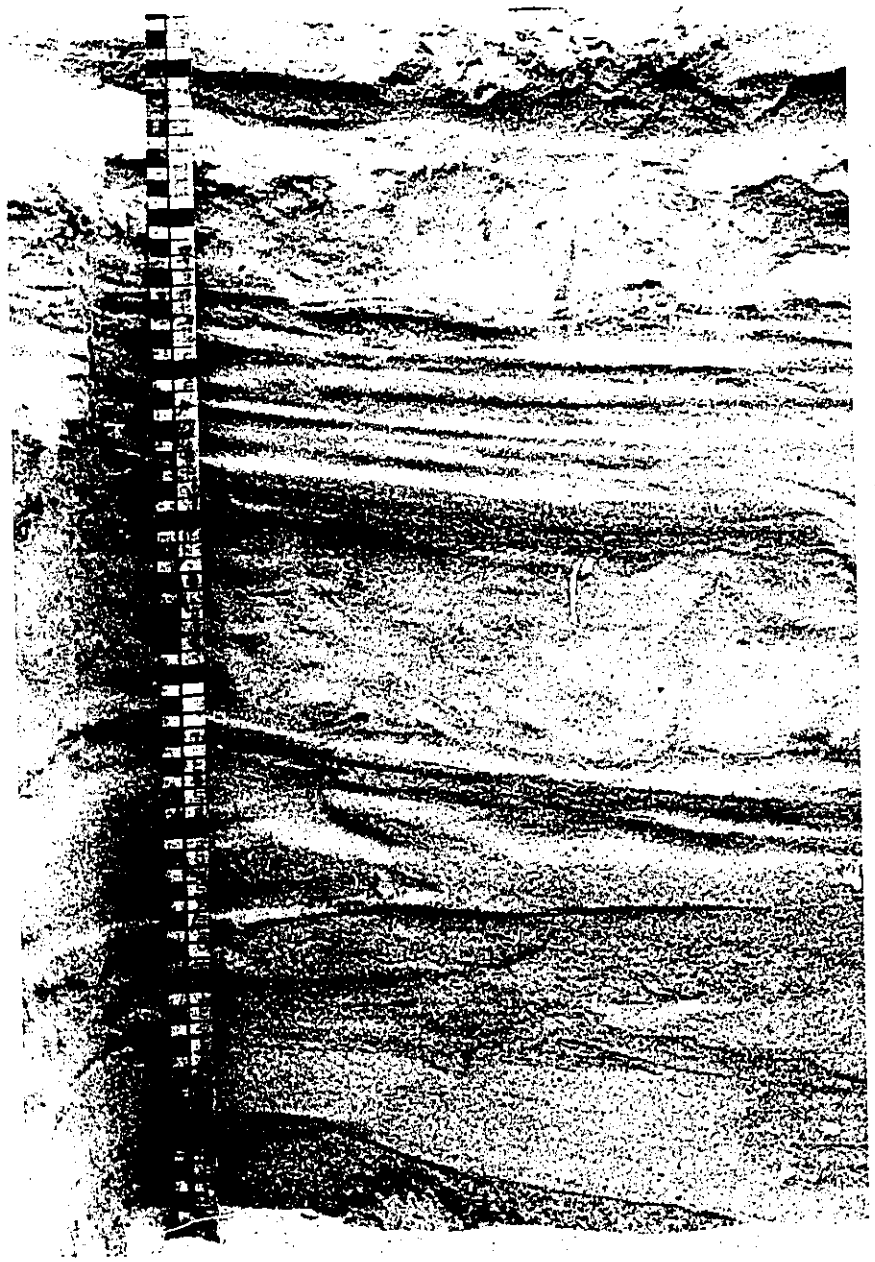


FIGURE 6.18. Photograph of a portion of Site 88-18 showing parallel laminated beds of fine sand and heavy minerals. The first bed is located at the base of the pit. The second bed is about 5 cm above, separated from the first by a bed of parallel-laminated fine sand.

a single, unlaminated bed of fine sand with no stains. This is topped by an 8 cm bed of parallel-laminated, fine sand and heavy minerals, a 7 cm bed of discontinuously laminated, clean sand, a 10 cm bed of parallel-laminated, fine sand and heavy minerals, another clean sand bed, and finally a 10 cm bed of fine, parallel-laminated sand and heavy minerals. From 7.5 to 8.0 m there is a deposit of fine sand which is organized into four beds. The first extends up to about 7.58 m and is made up of discontinuously laminated fine sand with few vegetation stains. From 7.58 to 7.74 there is a bed with contorted laminae and no vegetation stains. The third bed extends up to 7.85 and consists of parallel-laminated, fine sand and heavy minerals. The fourth bed, 7.85 to 8.0 m, is made up of discontinuously laminated, horizontal sand.

From 8.0 to 10.3, there are beds of clean sand separated by parallel-laminated beds of fine sand and heavy minerals. Staining is minimal until 9.6 m where there is a marram cluster in discontinuously laminated fine sand. At 10.5 m a set of ripple foresets are preserved. These are covered by discontinuously laminated fine sand. At 10.8 m there is an interlaminated bed of coarse and fine sand which is capped by a 7 cm bed of parallel-laminated fine sand, 7 cm of clean unlaminated, unstained sand, and then a 9 cm thick bed of undulatory, parallel-laminated fine sand and heavy minerals. Topping this, between 11.1 and 11.2 m, is a bed of clean sand topped by a discontinuously laminated bed which extends to 11.28 m. This is overlain by a 12 cm thick bed of clean, unlaminated, fine sand. From 11.4 to 11.63 there is a set of parallel cross-beds which show no evidence of having been vegetated. Topping this is a bed of discontinuously laminated fine sand, a bed of parallel-laminated fine sand and heavy minerals, a second bed of discontinuously laminated fine sand, and finally, a bed of parallel-laminated fine sand and heavy minerals which extends to the top of the section at about 12 m. The present surface is covered with the Sparse Marram community.

Interpretation

The basal portion of the section represents a period of transition from a stable environment where woody plants could flourish to one in which deposition increased to the point where woody plants could no longer survive. Perhaps this was an interdune, like the centre of the island, which was then covered by the migration a precipitation dune. The change was gradual because the woody stems could be traced for such long distances and could also be found in association with the grasses which flourished under net sedimentation conditions. Once the grasses established, they grew with burial. They kept pace with sedimentation to the top of the section. The present day cover is Sparse Marram and the types of structures within the top of the dune are consistent with this type of cover.

6.4.3 Site 87-16 (Fig. 6.19)

Description

This site consisted of two sections in remnant dunes which were located

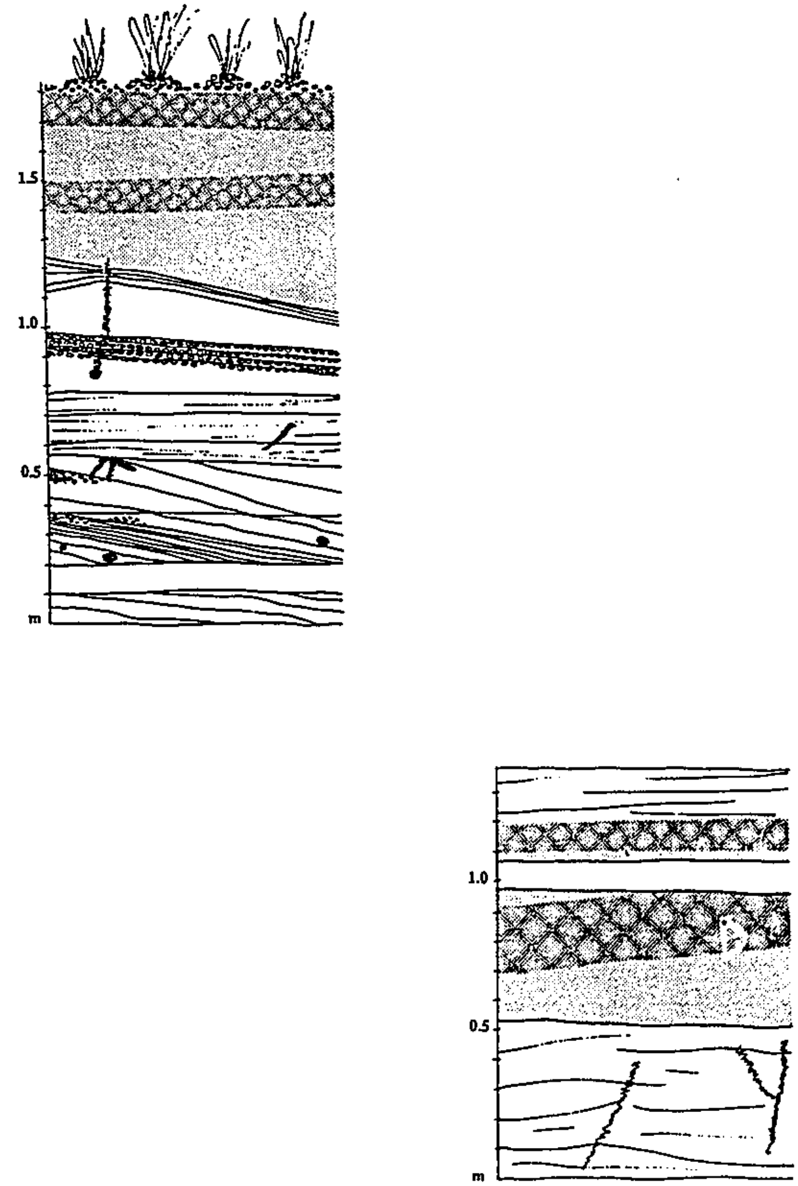


FIGURE 6.19. Site 87-16 consisted of two sections, each of which contained a paleosol.

in a blowout on the east central portion of the island. The first was a small remnant which was capped by a paleosol. It had a lag at the surface and within it the beds were wavy, parallel and deposited around plant clusters. Basal low angle cross-beds were erosively capped with 10 cm of discontinuously laminated, uniform grain size, fine sand. This was erosively capped with 30 cm of higher angle (15 to 20°) beds of fine sand with pieces of woody roots incorporated within the beds. Dips increased to 29°/130 and then decreased to 24°/125. From the base upwards there was an increase in organically stained sand giving the section a mottled appearance. There was an erosion surface at 0.57 m. Above this surface, the beds were horizontal. There was a second erosion surface at 0.77 m. Beds dipped more steeply above the second surface.

A layer of coarse sand was located at 0.8 m. Above this the sand was stained yellow and then grey. Bed boundaries became increasingly indistinguishable above the coarse bed. There was also an increase in the amount of organic material and decorticated root matter. The paleosol which began at about 0.64 m, consisted of two dark grey beds separated by a 17 cm thick bed of unlaminated white sand. Topping the paleosol was a layer of coarse sand which was deposited around the plant clusters.

The second remnant was similar in that the sand below the paleosol reflected increasing organic content to the paleosol. Again the paleosol consisted of two layers of concentrated organic material, sand grains and fragments of woody roots and stems. This remnant was topped by about 20 cm of sand deposited around the plants which grew upward with deposition.

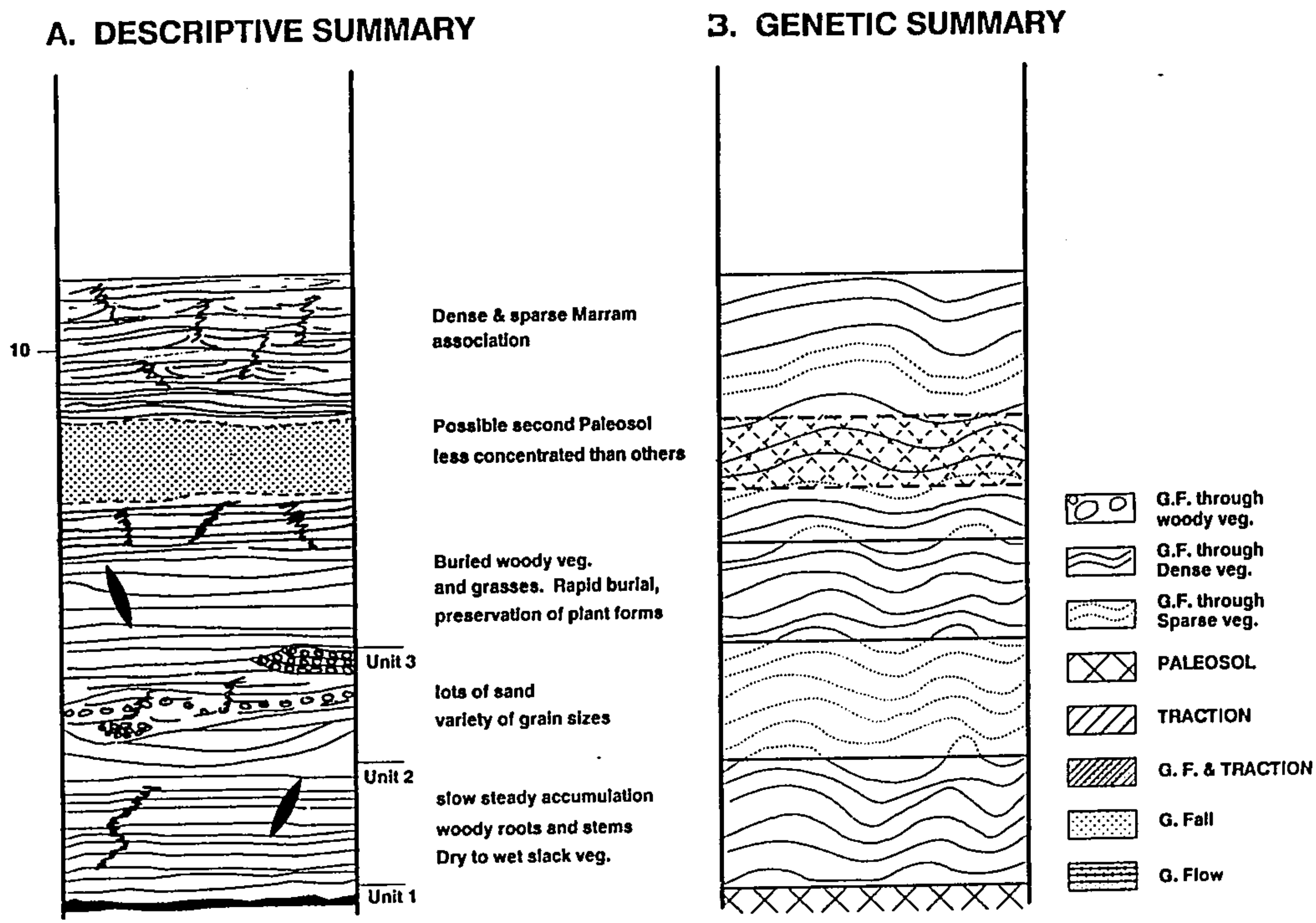
Interpretation

The sequences which are present in the remnants at 87-16 developed in the relatively quiet backdune area. Sand deposited in the slack slowly buried the woody vegetation which covered the surface. Accumulation of organic material led to the development of the paleosol. The paleosol was at the surface of the first remnant, while an increased local accumulation rate buried the paleosol at the second remnant under a few centimetres of sand.

6.4.4 Summary of Type III

The Type III sites were located on the south side of the north dune ridge or within the centre of larger blowouts. There are four units (Fig. 6.20 A/B). The basal unit is made up of continuous beds of fine sand which represent the relatively stable surface of the dune slack, with beds deposited within various types of vegetation (including woody vegetation) that decay and organically stain the sand. The environment of deposition is relatively low energy. There may or may not have been a paleosol present representing differing periods of stability or instability. This is overlain by units which are the result of an increasing accumulation of sand, reflecting an increase in the energy of the environment of deposition. The predominant processes active were grainfall through first dense and, with increasing accumulation rate, then sparse

FIGURE 6.20 Descriptive and genetic summaries of Type III Migrational Multiple Phase dunes.



COLUMNS ARE APPROXIMATELY 10m HIGH

Ammophila breviligulata (Dense Marram to Sparse Marram Foredune Facies). With increasing elevation in the section, there was again a decrease in the energy in the environment of deposition, a slowing in the accumulation rate and an increase in the vegetation cover with the type of vegetation changing to woodier species (Shrub Heath Facies). A second paleosol may be present illustrating that the dune had again become stable. Above the paleosol there was an increase in the accumulation rate to the present surface. Periods of soil forming were interrupted by periods of accumulation when supply of sediment was available.

6.5 Summary

The multiple phase migrational dunes are the remnants of a number of other dune types, the composite of which makes up a new dune form. The In Situ dunes, previously discussed, are dunes which grew in place. These dunes are the result of the passage of other dunes over the area. Evidence for this hypothesis can be gained by examining the vegetation associations, and the type of environment under which they develop. Usually, evidence of the migration of the dunes exists in the high-angle avalanche beds which result from the deposition of sand on the leeward face of the nose of the parabolic dune. This evidence has not yet been seen on Sable Island. Perhaps it exists within the large bald dunes. These could not be examined because the sand simply flowed into any trenches which were dug into the faces of these large dunes. Within the vegetated dunes which were examined, the nose of the parabolic dune passed through long ago and is no longer present on the surface of the island, having migrated into the ocean off of south beach.

The Type I Migrational dunes are similar to Type I In Situ dunes below the paleosol. The paleosol itself is different in Type II dunes. It developed in an area of slow accumulation through a dense vegetation cover over a longer period of time than in the In Situ dunes. Above the paleosol there is a greater concentration and a greater variety of woody plants. The vegetation associations change from those which grow in a high energy environment through those which grow in a low energy environment to a stable soil forming period. The cycle then repeats.

In Type II Migrational dunes, the paleosol is neither well-developed nor very thick. The soil forming period was not very long, and there was a scarcity of vegetation to contribute to soil forming processes. The change in type of environments is not gradual in these dunes. They change rapidly from those in which a soil can form to those in which there is an abundance of sediment available to deposit on the surface.

The Type III Migrational dunes develop where there is an abundance of sediment available to maintain the vertical growth of the dunes. Sediment is deposited at intervals which interrupt soil forming episodes.

CHAPTER 7

STRUCTURES WITHIN SECONDARY DEPOSITIONAL FEATURES ON SABLE ISLAND

7.1 Introduction

This chapter outlines the structures found within the small shadow dunes which develop behind obstacles and the aprons and ramps on established dune ridges. These are secondary forms because they result from some other obstacle or dune form interrupting the windflow and causing deposition. These dunes develop on the wind scoured faces and scarps of dunes and are present in blowouts which are healing. Locations of sites are illustrated in Figure 7.1. Therefore, they are features which are present in many parts of the dunescape. The structures within small shadow dunes will be outlined first and then aprons and ramps will be discussed.

7.2 Small Shadow Dune Facies (Sites 87-17AB, 87-10, 88-15, 87-2,87-4)

7.2.1 Description

Site 87-17 A/B (Fig. 7.2)

These small shadow dunes were located behind small sandwort dunes on the west spit. The first dune was 170 cm long, 60 cm wide, and 22 cm in height. The lowest 10 cm was uniform grain size loosely compacted sand. It

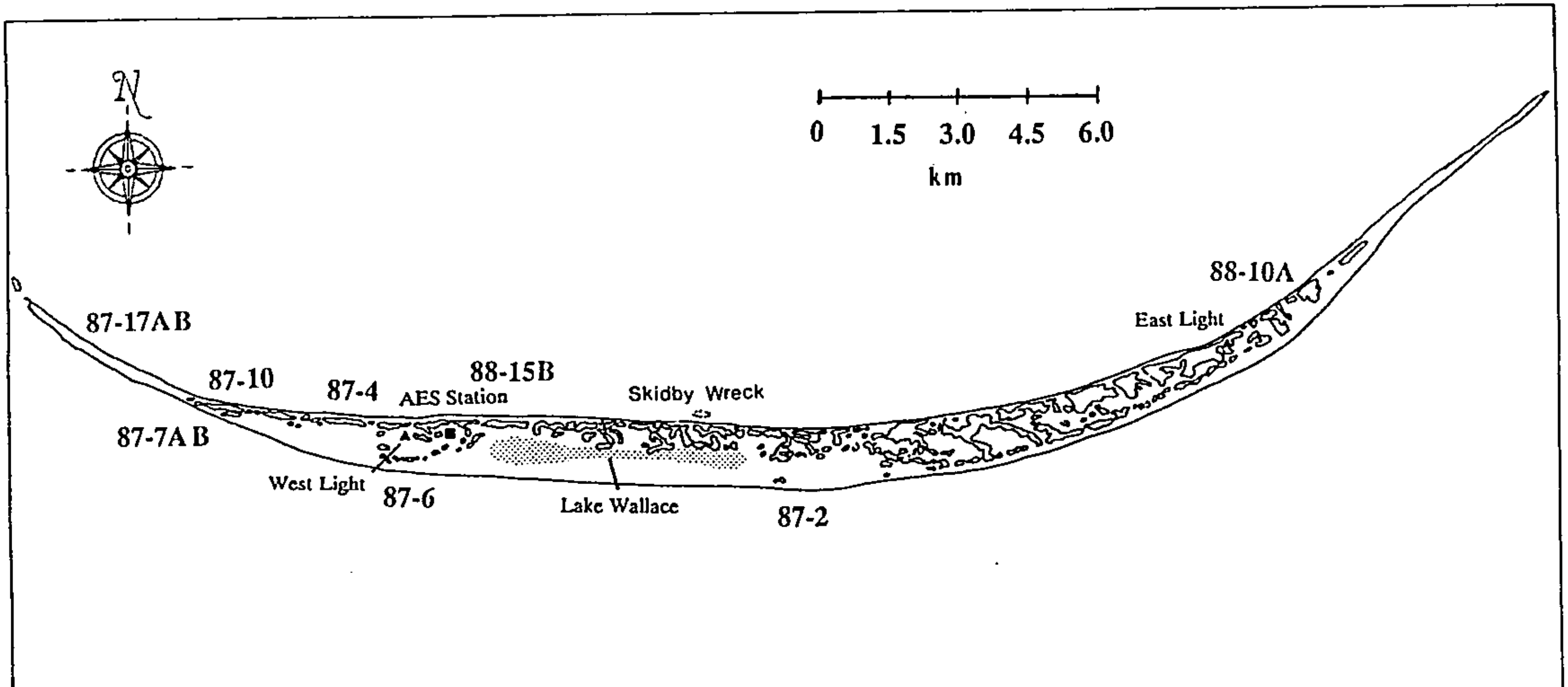


FIGURE 7.1. Locations of Sites of shadow dunes, aprons and ramps.

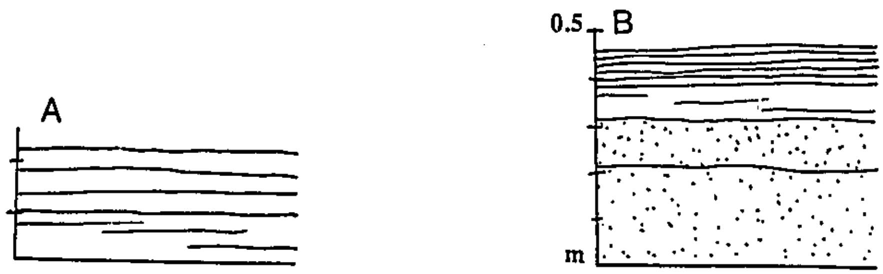


FIGURE 7.2. Site 87-17 consists of structures in small shadow dunes.

was capped by a 2 mm lens of heavy minerals and then three beds of loosely compacted sand separated by an erosional layer. The beds flowed easily when touched. The second shadow was much larger. It contained a coarse layer which dipped 25°/280. The dune was oriented toward 240. There were 4 beds. The coarse layer was in the first which was 21 cm in thickness. The second was 10, the third 7, and the fourth 8. The fourth bed was made up of tightly compacted parallel-laminated sand. The others were more loosely compacted.

Site 87-10 (Fig. 7.3)

This section was in a large shadow dune accessible from north beach on the west end of the island. The dune was about 4.0 m tall at the obstacle end and was pyramidal in shape. It extended out from a blowout in the established dune ridge, onto the area between the old dunes and the new sparse marram foredunes at the rear of the beach. The crest was fairly straight near the obstacle, but became somewhat sinuous where it came in contact with the cross winds in the swale between the established ridge and the new foredunes. The dune trended on an axis of 139/319°. The surface sediment was coarser on the lower slopes and finer near the crest. However, beneath the surface layer at the crest was a coarse, almost granular layer. Eight surface samples were taken which illustrated that the sediment coarsened downslope along the sides and fined downwind at the surface. Four pits were examined in the side of the dune. A fifth was attempted at the crest, but because the sand was so

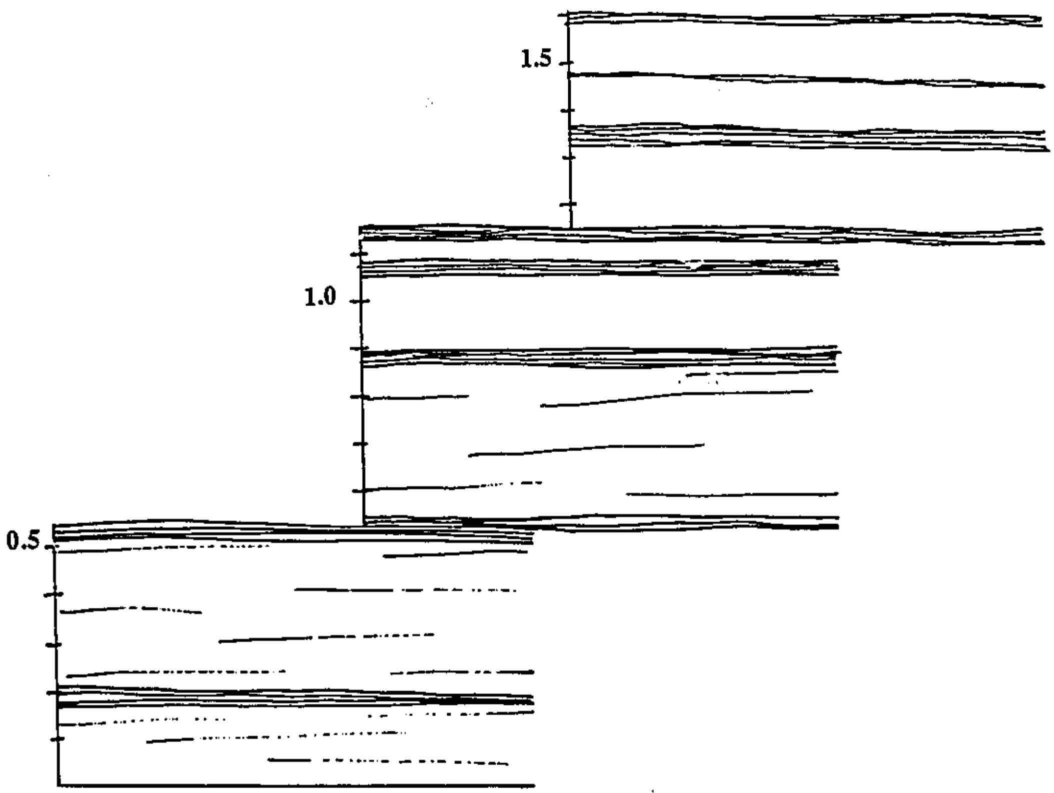


FIGURE 7.3. Site 87-10 was made up couplets of sand consisting of loosely packed beds and tightly packed beds with no evidence of vegetation.

dry it caved in.

The lowest 0.53 m was made up of two similar sets of 2 beds. Set 1 contained a lower 17 cm thick, bed of uniform grain size, fine sand topped by a 2 cm thick bed of parallel-laminated fine sand and heavy minerals. Set 2 contained a lower bed that was 32 cm thick and an upper bed which was 2 cm thick. This pattern continued from 0.53 to 3.62 m. Sets and beds dipped downwind from the obstacle and away from the crest.

At 1.4 m there was an erosion surface. The pattern of deposition were the same above and below it, the only change being in the dip of the beds. Below the discontinuity, the dips were low angle, between 5 and 10°, while above it they approached 0°. The beds were truncated by the present surface of the dune which was a 10 to 20 cm thick mantle of dry sand.

Site 88-15B (Fig. 7.4)

This section was dug in an infilled blowout in a new dune ridge on north beach about 1.5 km east of the Atmospheric Environment Service compound. The section showed a 1.74 m high deposit of cross-bedding. The beds were visible due to changes in grain size and heavy mineral marking. There was no evidence of vegetation until the top of the section. Throughout the section there were low-angle truncations and changes in dip angle which were non-erosive. Contained within the lower portion of the pit was decayed plant material which had once blown around the beach and then became buried. The marking at 0.51 m was the result of the break down of horse dung and

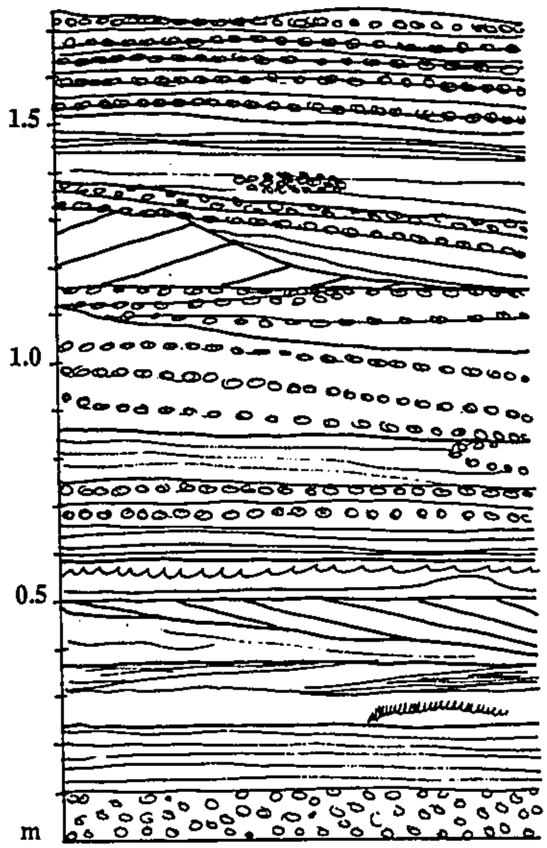


FIGURE 7.4. Site 88-15b was made up of alternating beds of coarse and fine sand with no evidence of vegetation.

urine. Below 0.81 cm sand was predominantly fine while above it the sand was predominantly coarse.

Site 87-2 (Fig. 7.5)

This site was located on the south side of the island in a 14 m wide shadow dune which extended about 30 m toward 75° from 3 mile dune. A 7.29 m long and 46 cm deep trench was dug on a 340° axis through the tail. Generally, the dune consisted of horizontal and low-angle beds of alternating fine uniform grain size, unlaminated sand and parallel-laminated sand. The parallel-laminated sand was often more tightly compacted than the uniform grain size, unlaminated sand and was often topped by a layer or more of concentrated heavy minerals.

More specifically, the section was divided into three sets of laminated fine sand. Set 1 was 21 cm thick and consisted of 1 to 2 cm thick beds of uniform grain size sand topped by very thin grain thickness to 1 cm thick beds with a wealth of heavy minerals. Set 2 was 8 cm thick and consisted of three beds, each being made up of a thick layer of uniform grain size, fine, unlaminated sand topped by a more densely packed, thinner layer of parallel-laminated, fine sand and heavy minerals. Unit 2 was separated from Unit 1 by an erosion surface and extended from about 21 cm upward to 28 cm. Unit 3 sat conformably on Unit 2. It was similar in appearance to Unit 1 - thicker beds of uniform grain size unlaminated, fine sand, topped by thinner beds of parallel-laminated sand and heavy minerals. The beds were extensive,

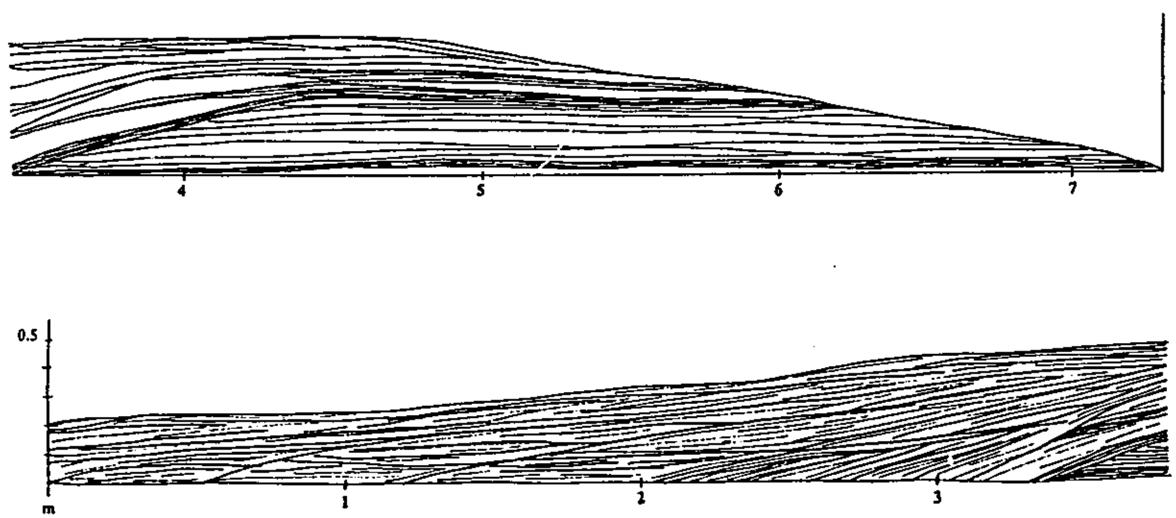


FIGURE 7.5. Site 87-2 consisted of a trench through a large shadow dune behind a remnant dune. There was no evidence of vegetation in the structures.

spreading laterally over the surface of the dune and draping downward at the sides of it.

Site 87-4 (Fig. 7.6)

This site was located about 1 km west of the Atmospheric Environment Service station on the south beach. The dunes which were examined extended from the hummock dunes developing seaward of the established ridge. Five dunes were examined, however, only three revealed stratification. Two of the shadow dunes deflated before they could be examined.

Generally, the shadow dunes consisted of sets of unlaminated and laminated beds of fine sand, which arched upward from the parallel-laminated sediment below. Each set consisted of a bed of uniform grain size, (fine or medium) unlaminated sand topped by a bed or group of beds of tightly compacted parallel-laminated fine sand and heavy minerals.

More specifically, the first dune which was trenched is depicted in Fig. 7.6A. The section was 50 cm thick and was made up of alternating wet and dry fine sand. The dry sand was generally uniform grain size, unlaminated, fine sand and the wet sand was more tightly compacted parallel-laminated sand. The surface of the dune was made up of sand which had become cohesive due to the presence of a salt crust. The second section, illustrated in Fig. 7.6B, was more complex than the first. It was 50 cm thick at its thickest point. The dune consisted of 1) a 12 cm thick basal set of clean parallel finely laminated fine sand, 2) a 7 cm thick set of horizontal planar lamination with a

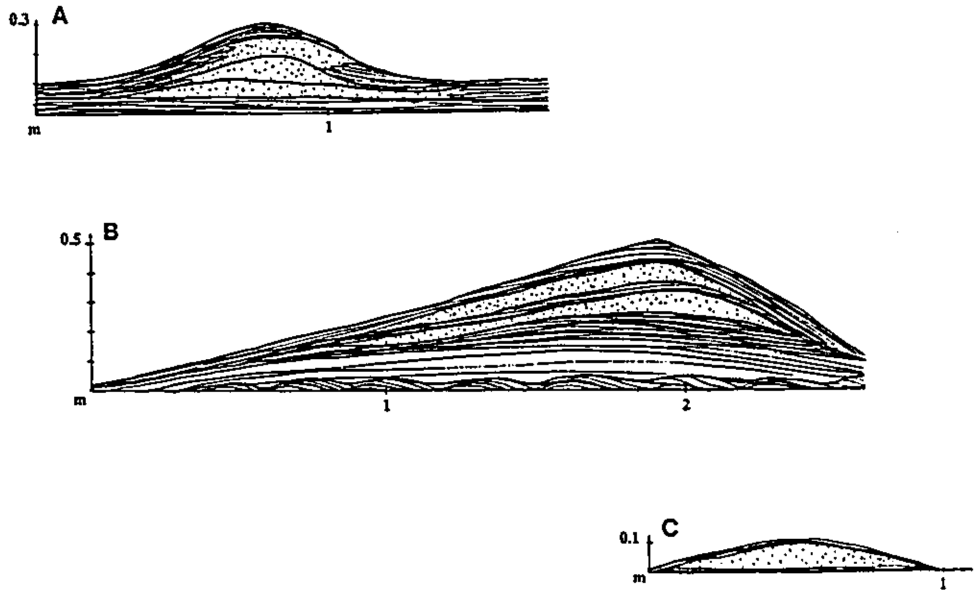


FIGURE 7.6. Site 87-4 was made of trenches through three shadow dunes. There was no evidence of vegetation.

wealth of concentrated heavy mineral layers, 3) a 9 cm thick lens shaped packet of unlaminated, dry uniform grain size, fine sand capped by a 2 to 5 cm thick packet of well compacted parallel-laminated sand and heavy minerals,and 4) a 9 cm thick lens shaped packet of unlaminated, dry, uniform grain size sand which was again overlain by well compacted fine sand and heavy minerals. This 6 cm thick layer makes up the surface of the dune.

Finally, the third section (Fig. 7.6C.) was very simple, consisting of a 10 cm thick packet of uniform grain size (fine to medium) unlaminated sand overlain by a layer of parallel-laminated sand which was only 2 to 3 grains in thickness. All of this was topped by thin salt crust.

7.2.2 Interpretation

In the first section at Site 87-4, the packets of dry, uniform grain size were the result of grainfall deposition behind the hummock. The maximum zone of deposition was immediately downwind of the vegetated hummock in the location of the crest of the shadow dune. In cross section this crest looked like the section depicted in Fig. 7.6A. Successive grainfall layers were offset due to variations in wind direction at the time of the depositional event. These layers are separated by more tightly compacted, layers of parallel-laminated sand which retain moisture. These were the result of the migration of ripples over and along the shadow dune. A crinkly layer of cohesive sand was often contained within or topped a ripple deposit. This layer was the result of salt crusting.

Section 2 (Fig. 7.6B.) showed similar patterns of deposition. The layers of uniform grain size deposited by grainfall deposition were separated by layers of tightly compacted parallel-laminated sand. The thicker layers of parallel-laminated sand at the base of the section were the result of ripple migration (subcritically climbing translatent stratification). At the very base of the section was a layer of rippleform lamination which developed under conditions of abundant sediment supply.

In Site 87-2, the alternating beds of uniform grain size and parallel-laminated sand in the first unit represent packages of sand deposited by grainfall topped by ripple deposits (subcritically climbing translatent stratification). The second unit represents a period when the sand supply and wind regime resulted in more rapid deposition of sand. Thus a thicker deposit of climbing translatent stratification was preserved over thicker beds of uniform grain size, unlaminated sand. The erosion surface between the first two units indicated a period of change - possibly a storm - when sedimentation was interrupted and the surface of Unit 1 was planed off. With a change in wind regime or sediment supply, the amount of deposition decreased and sediment was again deposited through grainfall and ripple migration. A series of events of grainfall topped by ripple migration led to the development of Unit 3.

By examining the total cross section of the dune, one can see the units clearly (boundaries marked by the arrows). The basal unit was a portion of a shadow dune oriented toward 90°. The location of the crest cannot be determined by the portion preserved. Unit 2 represents a change with the orientation the dune more toward the northeast (45°). Unit 3 was again a change of orientation with the beds dipping up toward 135°. The surface of the dune to the right of the crest dipped up toward 15°.

The whole of the section in Site 88-15B reflected the superimposition of several shadow dunes. The beds were visible due to changes in grain size and heavy mineral marking.The marking at 0.51 m was the result of the break down of horse dung and urine. The more loosely compacted beds are predominantly the result of grainfall while the more tightly compacted beds are primarily the result of ripple migration.

The pattern of uniform grain size sand topped by finely parallel-laminated fine sand at Site 88-10, was the result of periods of grainfall deposition separated by periods of ripple migration. Erosion surfaces developed with changes in wind direction. The whole shadow dune re-oriented itself with a shift in wind direction. The migration of ripples under these conditions caused the development of beds of differing dip. As the shadow re-adjusted to changes in wind direction, the sides of the dune were planed off, truncating the beds previously deposited and mantling them with layers of loose sand. The loosely compacted sand in the sections at Site 87-17AB were primarily the result of grainfall through the flow separation, which was described by Hesp (1981), behind the obstacle. The more compact beds which contained heavy minerals were primarily the result of the migration of ripples over the surface. Coarse layers were the result of the burial of isolated granule ripples.

In summary, the shadow dune facies consists of sets of parallel-laminated sand which are loosely compacted and alternate with thin sets of parallel-laminated, tightly compacted sand (Fig. 7.7). Coarse layers or laminae which result from the migration of ripples, may be present. In thicker sections (0.5 m or more), sets of beds of alternating tightly and loosely compacted sand may be separated by low angle truncations and may contain transported plant debris. In thinner sections, the sets are continuous from one side of the shadow to the other and often have coarse pockets of sand at the crest. In some cases there may be crinkly surfaces preserved within the ripple beds. These are the result of the development of a salt crust on the surface of the dune which is exposed to salt spray or fog.

7.3 Apron and Ramp Facies (sites 87-7AB, 87-6, 88-10A)

7.3.1 Description

Site 87-7A (Fig. 7.8)

This section, located at the western end of the island at the rear of south beach, was 1.5 m in height and consisted of beds of planar, parallel-laminated sand and heavy minerals which dipped seaward. There were 7 beds ranging in

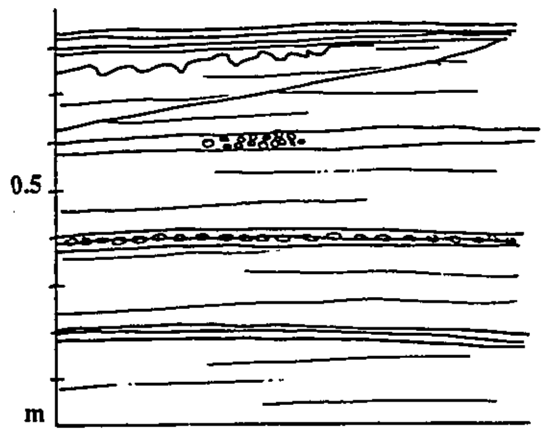


FIGURE 7.7. The shadow dune facies contains no evidence of vegetation. It is made up of alternating loosely packed and tightly packed beds of fine sand. The tightly packed beds often contain heavy minerals and are parallel-laminated. The beds increase in dip upward due to the piling-up of sand behind the obstacle. Dip orientation is downwind and away from the obstacle. Low angle truncations are the result of shifts in wind direction which changes the orientation of the dune.

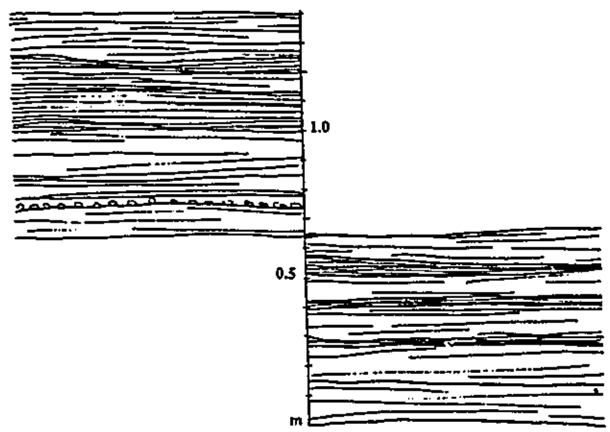


FIGURE 7.8. Site 87-7A consists of beds of discontinuously laminated sand and heavy minerals which dip seaward (225° to 257°) at angles between 23° and 35°.

thickness from 7 to 18 cm. These were made up mostly of clean parallel-laminated sand. Some coarser layers and lenses were present. The beds were separated by layers of more firmly compacted sand and concentrations of heavy minerals. Dips ranged between 23 and 35° toward 225 to 257°.

Site 87-7B (Fig. 7.9)

This 7.72 m section was located just east of 87-7a. The section consisted, for the most part, of parallel-laminated sand and heavy minerals. The lower portion of the section (below 1.5 m) was different from the upper portion. Fifteen centimetres from the base of the section was a discontinuity - an erosion surface. However, sedimentation above it was the same as that below it. From the base to 0.7 m, all beds dipped toward 210° and consisted of packets of fine uniform grain size, laminated sand capped by a thin layer of heavy minerals. There were four such packets below 0.4 m. At that point the heavy mineral portions became larger.

From 0.7 to 0.85 m was a packet of unlaminated, fine uniform grain size sand. It was capped erosively by another packet of fine uniform grain size, unlaminated sand which contained two lenses of coarser, less well packed sand. The topmost lens occurred in a layer dipping 24° toward 175°. This was topped by faintly laminated, fine uniform grain size sand.

There was an erosion surface at 1.2 m. Above the erosion surface were beds of laminated sand. These were topped by a packet of sand similar to that at 0.5 m - 2 to 5 cm thick layers of concentrated heavy minerals and fine

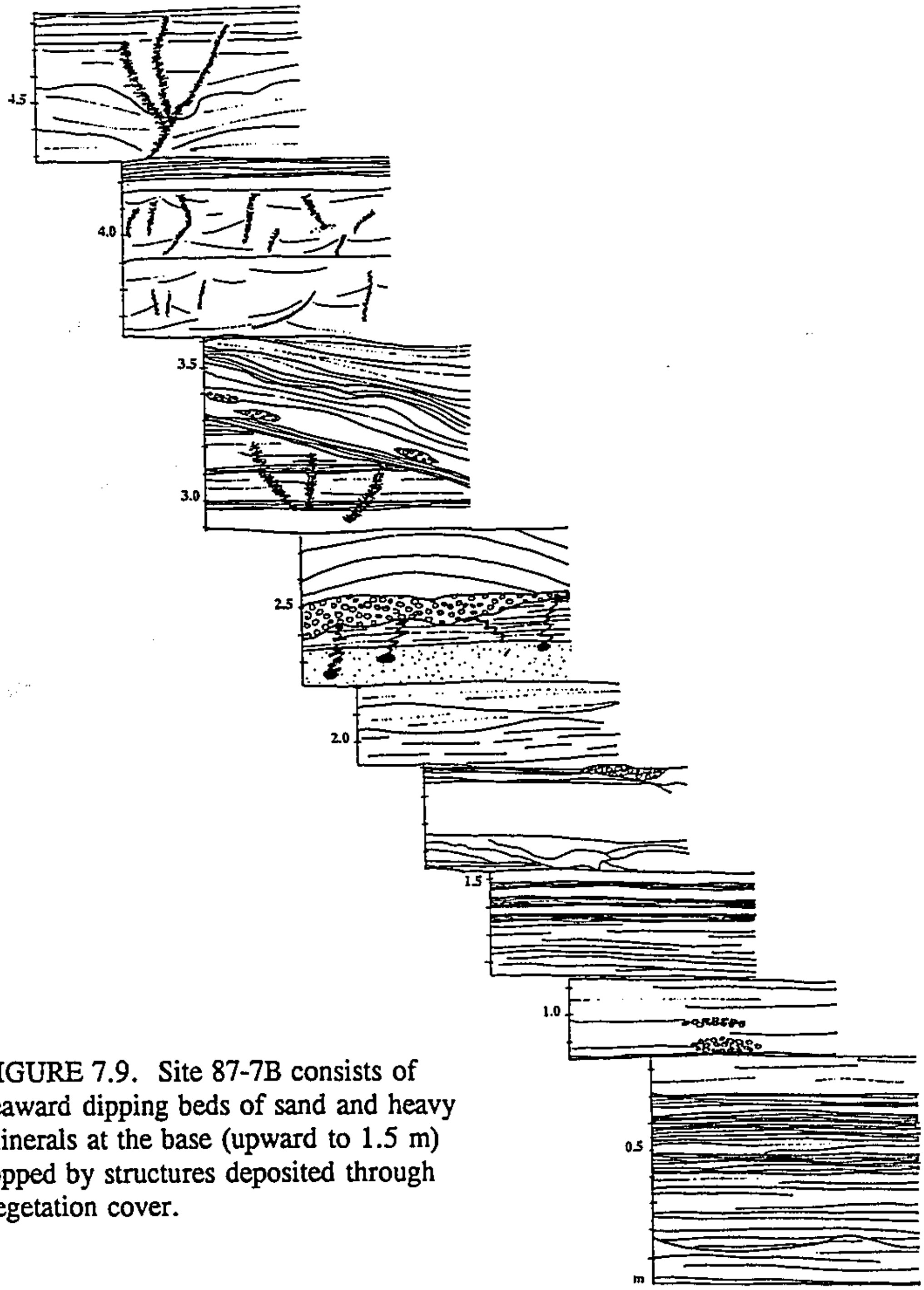


FIGURE 7.9. Site 87-7B consists of seaward dipping beds of sand and heavy minerals at the base (upward to 1.5 m) topped by structures deposited through vegetation cover.

uniform grain size, laminated sand. From 1.52 to 1.65 m were some contorted beds. They may be the result of slumped material which had been buried, or they may be a salt crust breccia. The lower surface dipped 31°/213 and the upper surface 15°/213.

From 1.65 to 1.85 m there was fine uniform grain size, unlaminated sand topped by finely laminated sand and heavy minerals. There were two coarse lenses at 1.91 m. These were associated with the remains of a marram plant. From this point upward, the section was no longer the apron, but part of the older established dune behind the apron. The beds were much different than those below. They were more contorted and contained plant fragments and a greater abundance of coarse lenses and layers. From 2.17 to 2.30 m the sand contained an abundance of plant fragments. However, there was little evidence of lamination. Perhaps these were destroyed by plant growth. From 2.30 to 2.50 m the sand was discontinuously laminated and capped by a 2 to 8 cm thick bed of unlaminated, coarse sand. From 2.5 to 2.74 m, a set of low-angle beds was deposited. These dipped away from the central portion of the pit. Plants remains in growth position were located from 2.74 m to almost 3.0 m. These were surrounded by three sets of beds of unlaminated sand capped by a more tightly compacted layer of sand. These beds were nearly horizontal. Above this point the sets dipped at higher angles (nearing angle of repose). From this point to the top of the section the sand was deposited around vegetation.

Site 87-6 (Fig. 7.10)

The site was located on south beach east of Site 87-4. It consisted of an apron on an old dune with a shadow dune which extended onto the south beach. The basal portion of the dune (first 0.32 m) was made up of horizontal sets which contained a thicker bed of fine uniform grain size sand, topped by a thinner bed of parallel-laminated, well compacted sand. From 0.32 to 0.64 m there were three sets of well compacted, parallel-laminated sand. This was topped by a set of uniform grain size and parallel-laminated sand. The beds of parallel-laminated sand contained a high concentration of heavy minerals.

From 0.83 to 1.52 m there were five sets of parallel-laminated beds of fine sand and heavy minerals which dipped between 10 and 27°. The first three sets were oriented toward 210°, but the last was oriented to 42°. All of the sets were truncated by the present day surface which dipped 27°/210. This continued upward to the top of the section at 2.53 m.

Site 88-10A (Fig. 7.11)

This site was located at the east end of the island on the north facing exposure of a large older dune. The pit was dug into an apron which consisted of buried slumps. There were many granule ripples which were migrating across the surface of the apron. The granule ripples deposited beds of laminated coarse sand - 10 to 15 cm in thickness at this site - whose upper surface was smooth, but whose lower surface followed any surface irregularities which had previously existed. The laminae were 1 to 2 grain

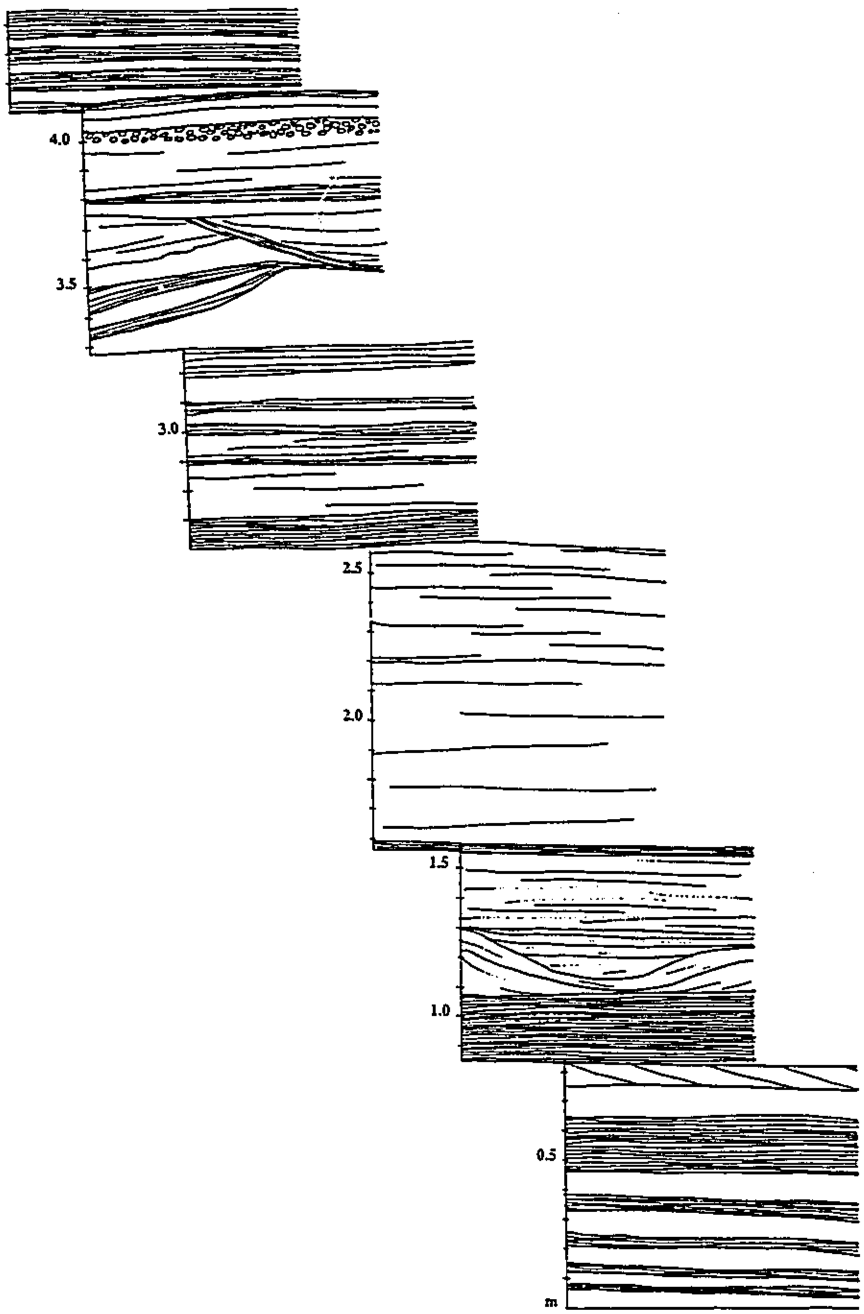


FIGURE 7.10. Site 87-6 is a 4.35 m section in an apron on south beach. It consists of beds of tightly packed, parallel-laminated fine sand and heavy minerals which are separated by beds of more loosely packed fine to medium sand. There is no evidence of plant growth.

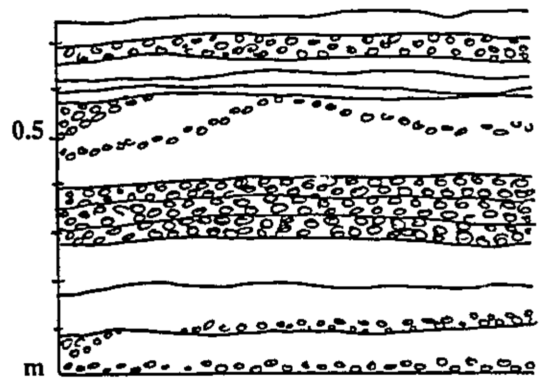


FIGURE 7.11. Site 88-10A was a very unstable section which collapsed easily. It consisted of alternating beds of coarse and fine sand.

sizes in thickness. The section consisted of coarse laminated sand interbedded with beds of fine to medium sand. Fragments of vegetation were transported in and buried. The beds were interpreted as packets of grainfall (medium sand) separated by packets of sand deposited by granule ripple migration (coarser sand).

7.3.2 Interpretation

The bottom 0.32 m of the section at Site 87-6 resulted from periods of grainfall lamination separated by combined grainfall and ripple migration. From that point upward the deposit was the result of a more variable wind speed and direction. Periods of grainfall and ripple migration occurred simultaneously. The result was the alternating beds of heavy minerals and fine sand. The two processes acting in unison resulted in the lamination of the sets.

At Site 87-7B, the section below 2.17 m consisted of the apron of sand deposited on the older dune. The sand was deposited in packets of grainfall and combined grainfall and ripple lamination. There was an abundance of heavy minerals within the ripple sets. Coarse lenses were associated with grainflows. These were lens shaped in cross section and tongue shaped in long section (along the avalanche slope). The brecciated layer at 1.52 m marks the top of the apron. Above this point there was evidence of vegetation other than that which could be associated with slumped material.

The vegetated portion of the section shows periods of stable growth interrupted by erosional episodes. The sand deposited at 2.3 m was similar to that deposited in dunes in which a paleosol had developed. However, there was no evidence of a paleosol here. Perhaps it began development and was eroded away. The cross-beds deposited at 2.70 m mark an episode of rapid deposition which slowed enough to allow plant growth at 2.80 m. This stable development was again interrupted when steep beds of clean sand were deposited between 2.80 and 3.10 m. A more or less stable environment was maintained from this point to the top of the section.

At Site 87-7a sand is deposited in packages which consist of 1) thicker, clean parallel-laminated sand, 2) thin, well compacted sand and heavy minerals, and, 3) thin coarser layers. The thicker layers of parallel-laminated sand were the result of discrete periods of grainfall from the dune above to the apron surface. The times when no grainfall was occurring were marked by the lamination planes. The more well compacted layers with an abundance of heavy minerals were the result of the migration of ripples over the surface. The heavy minerals are derived from the beach and deposited on the base of the dunes. The coarser layers were the mark of grainflows.

Aprons of sand mantle most of the dunes on the island. Their sedimentologic signature (Fig. 7.12) consists of wedge planar packages of sand dipping between 23 and 35° which are made up of: 1) sets of thicker, clean parallel-laminated sand; 2) sets of thinner well compacted beds of uniform grain size, fine sand and heavy minerals; 3) thin coarse beds which are the

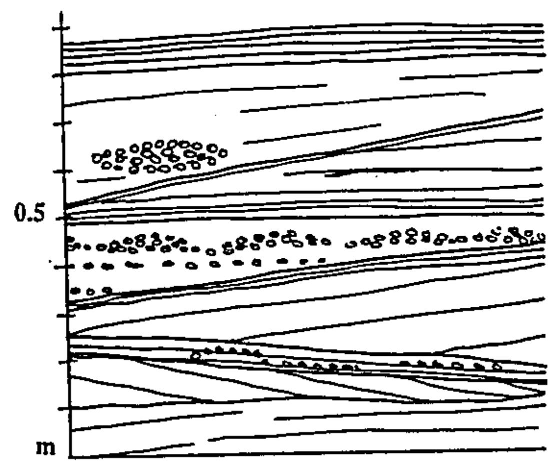


FIGURE 7.12. The sedimentologic signature of the aprons and ramps is similar to that of the shadow dunes in that tightly and loosely packed beds alternate. In the aprons and ramps, there are greater numbers of low angle truncations which result from the changes in wind direction. Also, angles of dip are greater and there are grainflows downslope which result in grainflow cross-stratification.

result of the migration of granule ripples or of grainflows. The migration of granule ripples results in the deposition of coarse laminated sand whose upper surface is planar, but whose lower surface follows the underlying topography. Sets are 10 to 15 cm thick. Grainflows deposit lens or tongue shaped packages of sand which are mantled by coarser material; and, transported fragments of vegetation which are either the result of slumping and later burial or are transported in by the wind.

7.4 Summary

The Small Shadow Dune Facies consists of sets of parallel-laminated sand which are loosely compacted and alternate with thin sets of parallel-laminated, tightly compacted sand. Coarse layers or laminae which result from the migration of ripples, may be present. In thicker sections (0.5 m or more), sets of beds of alternating tightly and loosely compacted sand may be separated by low-angle truncations and may contain transported plant debris. In thinner sections, the sets are continuous from one side of the shadow to the other and often have coarse pockets of sand at the crest. In some cases there may be crinkly surfaces preserved within the ripple beds which are the result of the development of a salt crust on the surface of the dune exposed to salt spray or fog.

Finally, the Apron and Ramp Facies sedimentologic signature consists of wedge planar packages of sand dipping between 23 and 35° which are made up of: 1) sets of thicker, clean parallel-laminated sand; 2) sets of thinner well compacted beds of uniform grain size, fine sand and heavy minerals; 3) thin coarse beds which are the result of the migration of granule ripples or of grainflows. The migration of granule ripples results in the deposition of coarse laminated sand whose upper surface is planar, but whose lower surface follows the underlying topography. Sets are 10 to 15 cm thick. Grainflows deposit lens or tongue shaped packages of sand which are mantled by coarser material; and, transported fragments of vegetation which are either the result of slumping and later burial or are transported in by the wind.

CHAPTER 8

THE SABLE ISLAND SUMMARY

8.1 Introduction

This chapter presents and discusses the Sable Island vegetated coastal sand dunes facies summary. The summary will be presented in the first part of the chapter, the contributions which the summary makes toward explaining the development of the island will be discussed in the second part and the contributions to the general facies literature will be outlined in the third part.

8.2 The Summary

The Sable Island Facies model consists of five sub-models which define the characteristics in the principal dune types on the island (Table 8.1).

TABLE 8.1. Model of Dune Types on Sable Island.

SUB-MODEL	IN SITU	MIGRATIONAL
A	TYPE I	
B	TYPE II	
C		TYPE I
D		TYPE II
E		TYPE III

Each of these sub-models has been presented in Chapters 5 and 6 and summarized in a series of diagrams (Figures 5.10, 5.17, 6.6, 6.14, and 6.20). These diagrams are now combined in Figure 8.1 (A-E), in a general locational context. Each sub-model diagram consists of three columns - a descriptive summary of the sequence of structures which would be present in a particular location, a genetic summary which illustrates the process by which the sand was deposited, and a summary of the facies which result from the processes. The facies codes are represented by the first letters of the code names. Marram Cluster facies is represented by MCF, Sparse Marram Facies by SMF, Dense Marram Facies by DMF, Paleosol Facies by PF, and Shrub Heath Facies by SHF. These can be used to explain the development of the island. However, it must be noted that the sections were interpreted with a knowledge of the historical development of the island (Chapter 3, Appendix III, Cameron 1965) and that the explanation is based upon more than the information present in the structures of the sand dunes. The profile information and the historical documentation combined with the sedimentologic information allow the reconstruction of the development of the island.

The five sub-models in Figure 8.1 reflect the changes which take place over time as the changes in morphology and the vegetation cover affect the flow of wind over the surface. The Type I In Situ foredunes are located primarily at the west end of the island. They reflect decreasing rates of deposition from the base of the sections upward to a paleosol and then increasing rates with renewed sedimentation to the top. The amount of wind energy increases from the paleosol upward until the dune begins to erode.

At the opposite end of the island is the Type II In Situ foredune. This feature begins in a high energy environment with deposition through the vegetation. The energy of the environment of deposition decreases with increasing vegetation density and increasing elevation until a paleosol begins to form. The source of the sediment is the erosion of the rest of the island which is upwind of this site. After the formation of the paleosol, the rate of deposition once again increases through a woody canopy. With increasing height there is a decrease in availability of sediment because the wind is no longer able to move it over the height of the dune, and a second paleosol develops. This pattern may repeat upward many times. At present there is a decreasing rate of deposition to the top of the dune. Perhaps the dune has reached an elevation at which the wind can no longer lift any sediment to the top of the dune. Only with a rise in sea level or an erosion of the dune could deposition once again increase.

The Type I Migratory dunes represent an area in which established dune ridges have been overrun by parabolic dunes. The original dune ridge developed to the point at which it became covered with the paleosol in a manner similar to the In Situ dunes. This ridge was most likely a low dune ridge similar to those on the landward side of the dunes at the west end of the island. With a change in the environment - a greater sand supply, increased erosion of sand at another place on the island, pressure from a rising sea level - more sand became available and the parabolic dunes began to migrate over the area. Little is visible of the avalanche face of these dunes. However, the vegetation which tied down the arms of the dune created a more stable environment which allowed the colonization of the area by the woody species. At present, the accumulation rate is too fast for these plants to thrive and there is the beginning of a change to more grassy cover.

The migration of the parabolic dunes can also be used to explain the development of the Type II Migratory dunes. The parabolic dunes began to migrate and passed over an area which was once dry slack, and continued to migrate downwind. After the parabolic nose had passed, the area was colonized by grasses and woody vegetation resulting in a thick deposit of sets of faintly laminated beds which are of fairly even thickness. Over time the woody vegetation which was more suited to a quieter environment, colonized the area and resulted in the present cover which makes up the fourth unit in the summary.

The Type III Migratory dunes make up sequences which were present before and after the passage of the parabolic dune through what was once wet dune slack. As the parabolic dune began to migrate, a large amount of sediment was free to move. Some of this available sediment buried the wet slack depositing a variety of grain sizes. Over time there was colonization first by the grasses and then by the woodier species. This may even have led to the development of another paleosol. The organic matter in the paleosol differs from other parts of the island in that it is less concentrated. There is more sand mixed in with the organic material. Topping this are sets of beds laid down through grasses, reflecting an environment of increasing energy with more rapid sedimentation. Perhaps this is the re-mobilization of the parabolic dunes.

8.3 The development of Sable Island Dunes

Periods of development of the island can be outlined by and examination of the literature and an analysis of the internal structures of the dunes. The first period is the post glacial development of the island. There are still many questions about this period of time which are not the focus of this thesis (Appendix I). Of importance to this thesis is the fact that the island developed in conjunction with a rising sea level which winnowed fine material out of the sediments on Sable Island Bank and led to the development of dunes.

The second period is that of dune growth. The development of the dunes was probably synchronous with the development of the island. At the end of the last glacial period, the island was much larger - probably as large as the Sable Island Bank (extending to the 100 m contour). The surface would have been covered by dunes much like those on the south beach. With the colonization of the area with different types of vegetation cover, the dunes would have stabilized and become more like those which cover the central portion of the island.

The third period of development is related to the Holocene rise in sea level which occurred and is still occurring today. As the sea level rose, the dunes were forced to migrate to the centre of the island creating higher ground (Cameron 1965, Ruffman et al. 1985). The migration of the dunes over the pre-existing dunes would have created sequences of structures like those of the Migrational Multi Phase Dunes in Chapter 6. The migration would have taken place in the form of parabolic dunes which result from the dominant winds pushing sand freed by erosion at sea level.

The last period of development is controlled by slowing sea level rise and a decreasing supply of sediment. There is new foredune growth at the eastern end of the island which is fed by the erosion of the foredunes at the west end. The sand is eroded and carried with the prevailing winds from the west to the east. Also, new parabolic dunes are developing and cannibalizing the vegetated arms of the old dunes. The result is the ultimate migration of the island in a north easterly direction.

The last two periods of development are of greatest significance to this thesis. The dunes of Sable Island have been classified into different sequences which can be used to tell the story of the island's development. The In Situ dunes are located at the back of the beach and were likely the first to form on the island. These dunes grew upward in place by the increased deposition of sand in the area. Over geologic time these dunes migrate landward. However, using human frames of time, these dunes do not change location.

There is erosion of the seaward side of the dune by wind and storm wave erosion which creates a dune scarp. There is also deposition on the islandward side of the dunes. This deposition increases the width of the foredune ridge.

Once the ridge forms it is subject to destruction by the winds which formed it. As the ridge increases in height, the ability of vegetation to thrive decreases (Ranwell 1972). As the plants lose vigour, they can no longer bind the sand effectively and the dune begins to erode. A chance occurrence of the loss of vigour and concentration of wind energy at that point in the foredune ridge may lead to deflation in a local area. If unchecked by the spread of vegetation into the area, this deflation may continue until there is a blowout in the ridge. If the blowout is aligned with the resultant wind direction, then the bowl of the depression enlarges and the backwall may begin to migrate and become a parabolic dune. The nose of this dune then migrates across the island, cannibalizing sand from the interior and growing larger as it crosses the surface. Over a number of years, the nose may migrate across the surface of the island from the northwest to the southeast until the sand in the nose gets deposited into the sea.

The explanation of the development of the island is based upon the knowledge of the historical development from maps and aerial photographs as well as the information from the sections. There is little evidence of the passage of the noses (avalanche faces) of the parabolic dunes in the sections examined. However, these sections are the extremes of what is present on the island, being either older and eroding on the northwest part of the island, or presently forming on the south east part of the island. There may be preserved avalanche faces present in the dunes in the central portion of Sable Island, but it was not possible to dig sections in them and there were no natural exposures. At this location the dunes are very well vegetated, making examination of the structures very difficult. Because there were no natural exposures, the internal structures could not be examined because it may have resulted in destruction of the surface cover and re-mobilization of the dunes.

Because the parabolic dune is made up of a migrating nose which is associated with blowout migration, it is difficult to determine the structures associated with it. These structures have been eroded away with the passage of the nose. However, the arms of the dunes are held in place by vegetation and the structures associated with them remain. These parabolic dunes can be seen in the vegetation maps of Chapter 3 (Fig. 3.6 and Fig 3.7). On these maps the green colour represents primary vegetation. This vegetation is the first type of vegetation cover to develop and is associated with the Sparse Marram Community. The axes of primary vegetation which reach into the centre of the island are the axes of orientation of the migration of the parabolic dunes. Once the dune has passed, the area is re-vegetated with Sparse Marram. The red colour on the figures represents secondary vegetation which colonized the arms of the parabolic dunes, and the pink colour represents Tertiary vegetation which is stable and has not been subject to the passage of the nose of a parabolic dune. On Figure 3.7 there are presently forming parabolic dunes which show as yellow arcs in the foredune ridge on the western end of this portion of the island. In this part of the island there is actually a series of parabolic dunes which are nested within each other.

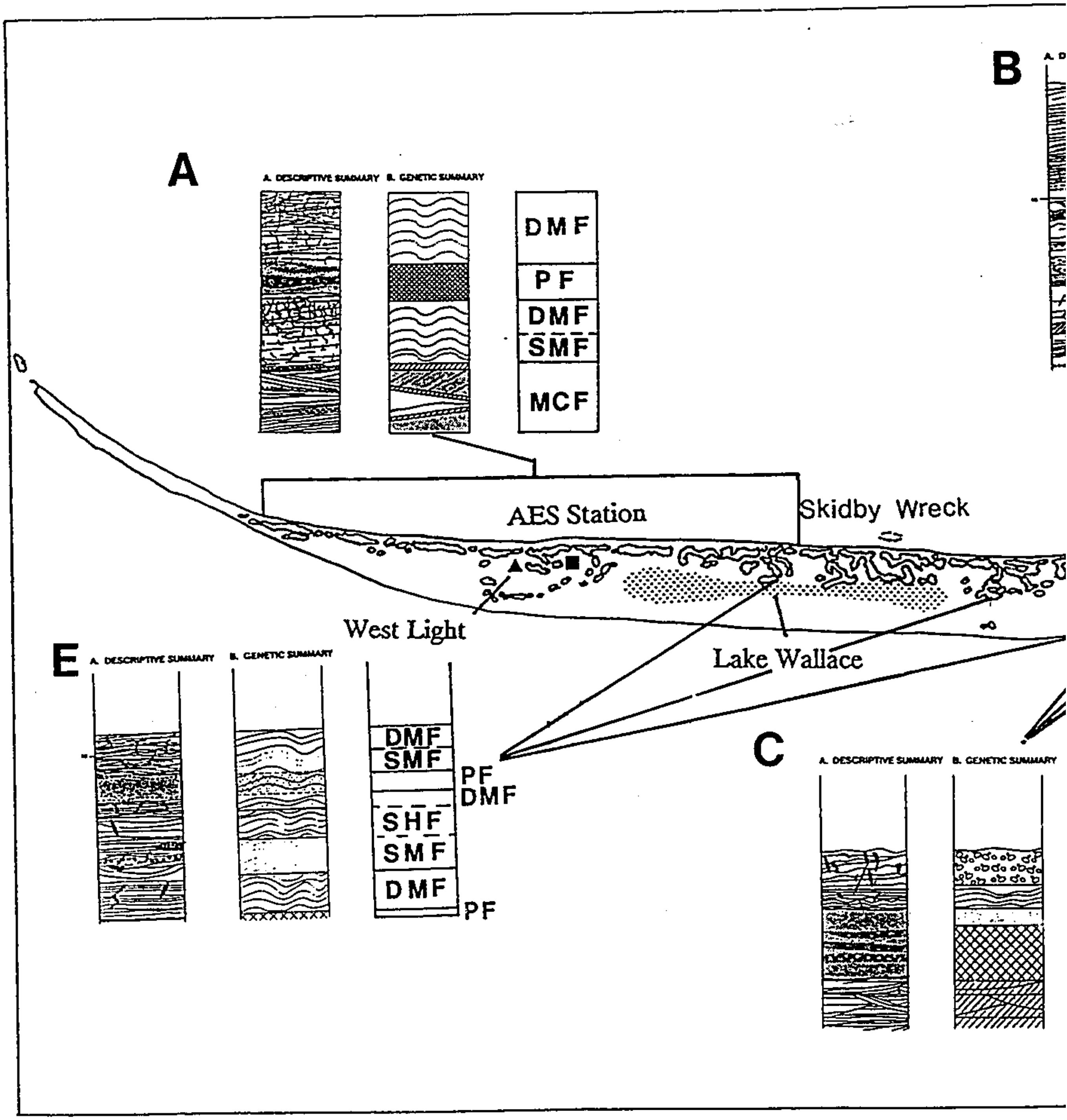
The internal structures of the parabolic dunes reveal that the Type I Migrational dunes develop first. They are a combination of an In Situ foredune at the base and the results of the migration of a parabolic dune at the top. This Type of dune developed as the blowout migrated inland. These dunes were located within the vegetated arm of the parabolic dune. Large amounts of sand blew by in the nose of the parabolic dune while the In Situ dune continued to grow in this area. Immediately beside the blowout, erosion and deposition occurred with changes in wind direction and intensity throughout a season and throughout a year. As deflation continued sand accumulated at the developing parabolic nose. The dune immediately beside the nose received more sand than the areas further away allowing the vegetation to remain vigourous as it kept pace with burial. The Sparse Marram Community dominated the area. Later, the nose of the dune passed, deposition rates decreased and the type of cover changed from Sparse to Dense Marram and then to Shrub Heath. Slightly further away, the In Situ dune developed until it reached an equilibrium and a paleosol formed.

The Type II Migrational Dunes developed at the same time as the Type I Migrational Dunes, but they are in a different location. The Type I

Migrational Dunes begin in the foredune ridge while the Type II Migrational Dunes begin development in the area behind the foredune ridge (toward the interior of the island, dry slack). Paleosol development is cut off by the rain of sand over the area as the nose of the parabolic dune passes. Once the nose of the parabolic has passed, the rate of grainfall slows, and the development of dense vegetation cover occurs rapidly by a lateral spread of the vegetation from the communities nearby. The rapid change in plant density is related to the sheltered location of this type of dune behind the foredune ridge. There is therefore the change from a paleosol to Dense Marram to Shrub Heath in this type of dune.

The Type III Migrational Dunes are located either on the south side of the island or on the southern part of the dune ridges. They are associated with the passage of the parabolic dune over an area of Tertiary vegetation (Pond Fringes). The base of the dunes is characterised by accumulation of organic material. This type of accumulation is occurring on the present surface in the Pond Fringes. With increasing supply of sand the density of the plants decreases as evidenced by the change from a paleosol to the Dense Marram Facies to the Sparse Marram Facies. The supply of sand increased until the nose of the parabolic dune passed. Once this had happened, the rate of sand supply again decreased, allowing the Shrub Heath community to spread laterally into the dune. It is associated with the Dense Marram Facies and a paleosol. With increasing height in the dune again there is a change to a

FIGURE 8.1 The Sable Island Model consists of 5 sub-models - A: In Situ Type I, B: In Situ Type II, C: Migrational Type I, D: Migrational Type II, E: Migrational Type III. Each sub-model is summarized in this diagram by three columns which provide a descriptive summary of the physical structures and the vegetation, a genetic summary which defines the processes, and a sequence of the facies which are the result of those processes: MCF - Marram Cluster facies, SMF - Sparse Marram Facies, DMF - Dense Marram Facies, PF - Paleosol Facies, and SHF - Shrub Heath Facies.


B
A
A. DESCRIPTIVE SUMMARY
B. GENETIC SUMMARY
DMF
PF
DMF
SMF
MCF
AES Station
Skidby Wreck
West Light
Lake Wallace
E
A. DESCRIPTIVE SUMMARY
B. GENETIC SUMMARY
DMF
SMF
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SHF
SMF
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C
A. DESCRIPTIVE SUMMARY
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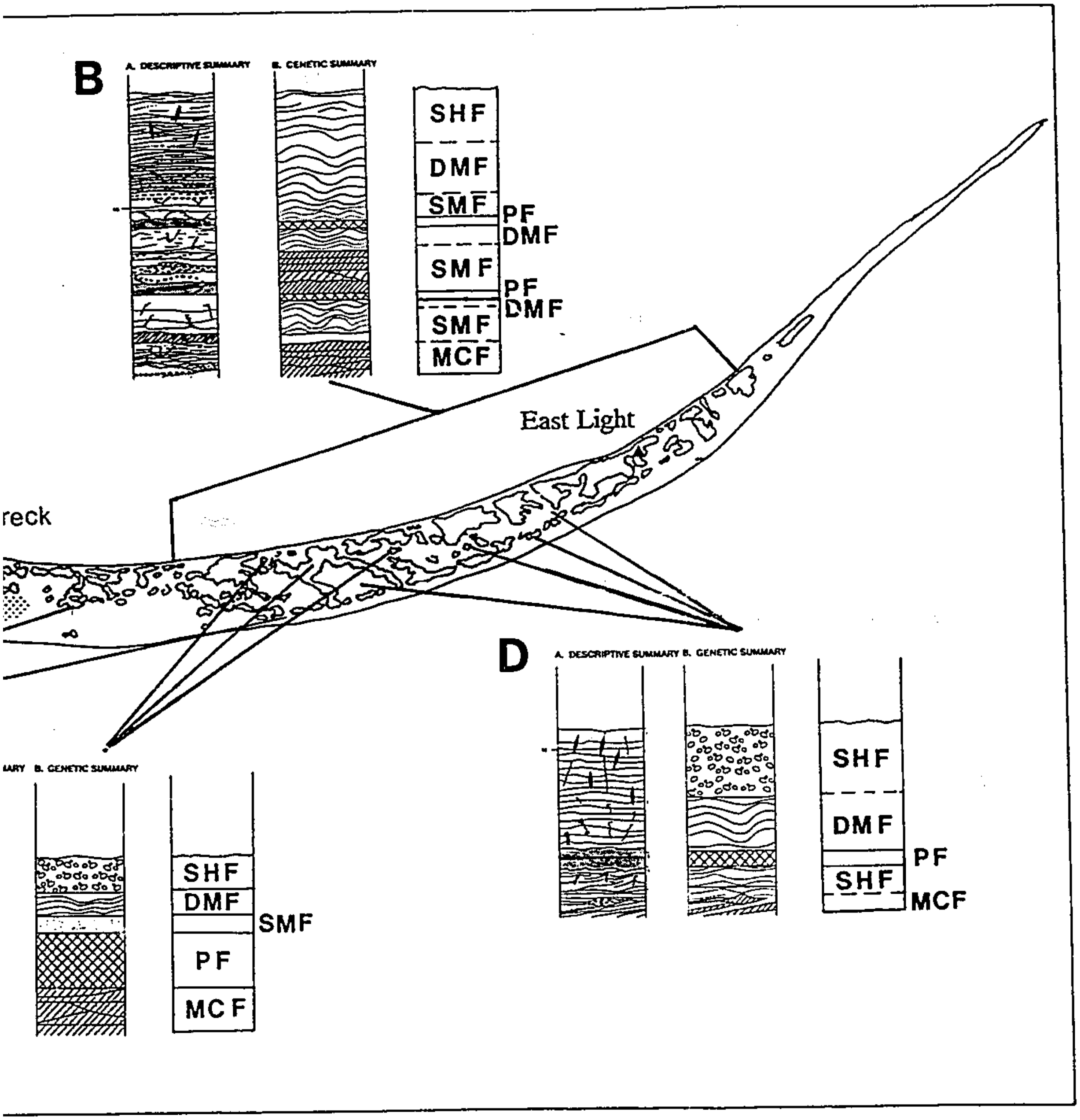

B
A. DESCRIPTIVE SUMMARY
B. GENETIC SUMMARY
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SMF
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DMF
SMF
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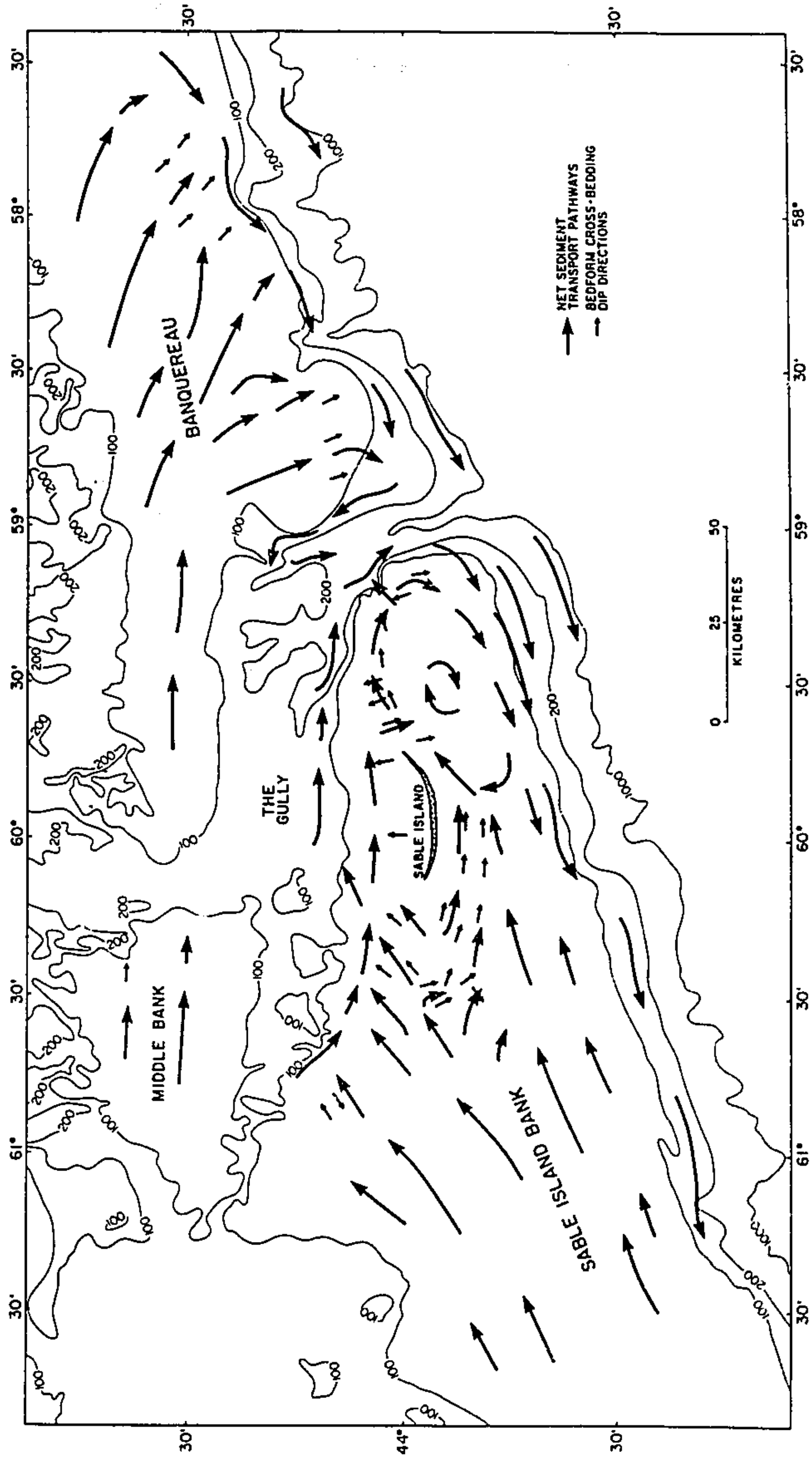
greater rate of accumulation (Sparse Marram Community) as a second parabolic dune migrated by and then a decrease in supply as marked by a change to Dense Marram cover.

There is a slow net movement of Sable Island north-eastward with sediment being added on to the east spit and the eastern end of the dune ridges. The surface sediments are blown into the dunes, and in the summer months when the sand is most free to be moved, the winds blow predominantly from the west to the east. Storms capable of moving great amounts of sand in short periods of time, shift the sand from the northwest to the southeast. The resultant direction of sand moving winds is toward the east-southeast. Therefore most sand is blown across the island from the northwest to the southeast. This direction is parallel to the average orientation of the large parabolic dunes which act as paths of movement of the sand. The large avalanche faces are blown through into the water off south beach. Once deposited into the water, currents carry the sand northeastward to the edge of the Gully and then parallel to the isobaths, eventually southwestward, away from the island (Fig. 8.2). Thus Sable Island is in a net degredational state.

8.4 Contributions to the Facies Models Literature

Although vegetated coastal dunes are an integral part of sandy shoreline systems, there are relatively few studies of vegetated dunes. Many which have been done concentrate on the ecology and management of the dunes rather than

FIGURE 8.2. The paths of sediment movement on Sable Island Bank based upon sediment grain-size trends and the orientation of bedforms (from Amos and Nadeau 1988).


BANQUEREAU
THE GULLY
MIDDLE BANK
SABLE ISLAND
SABLE ISLAND BANK
NET SEDIMENT TRANSPORT PATHWAYS
BEDFORM CROSS-BEDDING DIP DIRECTIONS
0 25 50
KILOMETRES
58°
59°
60°
61°
44°
30'
100
200
1000

on studies of their internal structures. Studies of internal structures of dunes tens to be centred on desert dunes rather than on coastal dunes and these are largely unvegetated. They reflect the physics of grain movement unhindered by the presence of vegetation. It is important to study vegetated coastal dunes in order to understand the interaction of the sand movement and vegetation dynamics.

The facies presented in earlier chapters are the result of the examination of vegetated dunes on Sable Island. However, the sequences of structures found within these dunes should be the same as those of dunes in other locations which have the same type of plant associations. The facies represent end members of transitions from low plant density, mobile environments of deposition, to high plant density, stable environments of deposition. They are therefore artificial end members representing the range of depositional environments on the island. However, they serve as documentation of recognizable points of change in the surface cover of the dunes.

The ideal order of the facies would be from unvegetated through Sparse and then Dense Marram to Shrub Heath and then the development of the paleosol. This represents a sequence from a high energy, dynamic environment of deposition, to a lower energy, more stable environment. This sequence should happen in any vegetated coastal dune environment. Variations would develop with contributions from different plant associations such as Beach Pea or Marram Fescue.

The above order is based on the changes which occur in vegetation cover. Facies order could also be altered by sudden physical change due to alterations in wind regime, increases or decreases in sand supply, or inundation by sea water. Coastal dunes are an inherently unstable form in which there is a cycle of development of growth, instability, erosion, and migration. The facies which are based upon deposition through vegetation cover would change with these changes in the physical environment.

Dickinson et al. (1972) stated that sand dunes in the ancient have been interpreted on the basis of sets of large scale cross-beds, that other physical properties of the dune sands are not unique to this environment, and that it is difficult to recognize preserved dunes because the physical structures are destroyed by growth of vegetation. However, most dune vegetation grows with burial, and therefore the structures are not destroyed by vegetation, but are deposited in association with it. There are unique physical structures associated with different plants and plant communities which are indicators of the coastal dune environment.

Sand dunes have traditionally been studied on the basis of their external morphology. In this study it has been shown that the external morphology of dunes may reflect the present environment, but may not illustrate the history of the dune. Different sequences of structures may exist in dunes which have the same external morphology. This study also shows that internal structures in vegetated coastal dunes can not only be recognized, but classified and given environmental interpretation illustrated by models of idealized sequences.

In a broader context, Sable Island is a shallow shelf sand which is storm dominated. Amos and Nadeau (1988) divided the submarine surface sediments of Sable Island Bank into several zones depending upon the types of bedforms and texture of the sediment. Sable Island itself was classified as Zone A which is a relatively featureless plain of well sorted, medium sand above the 20 m isobath which is predominated by shifting sand and current scouring from breaking waves and tidal currents. They stated that the processes operating in this zone were more like those in a barrier island setting than in a shallow shelf situation.

In North America the most famous barrier islands are in the Gulf of Mexico including Padre Island, Galveston Island, and Mustang Island. There are also numerous islands which fringe the eastern seaboard of the United States and Canada. Many of these are transgressive, experiencing rising sea level which pushes the islands landward, depositing a thin layer of barrier sands over lagoonal muds and being capped by nearshore sediments. Sable Island is similar to these in that it is experiencing a rise in sea level. However, the rise is not pushing the island landward, it is causing it to build upward. Cameron (1965) stated that the portion of the island east of the end of the Sandy Plain was a maintaining a constant position, suggesting that the island was building vertically with sea level rise. The result would be a wedge shaped deposit beneath the island in which subaerial barrier beach and dune sands were covered by nearshore sediments as the level of the water rose and the shoreline moved in toward the centre of the island.

With regard to the vegetated coastal dune literature, this study is an important contribution. There is a large and varied literature on structures within sand dunes, but there is a scarcity of information about structures within vegetated coastal dunes. McBride and Hayes (1962) found a bimodal distribution of the azimuth of dip angles in vegetated coastal dunes which they attributed to the migration of dunes with slipfaces dipping at oblique angles to the direction of the wind. They found that 10% of the beds measured dipped at angles higher than 34° and 27% dipped at angles higher than 30°. Goldsmith (1973) examined the internal geometry and origin of vegetated coastal sand dunes on Monomoy Island off Cape Cod. This examination consisted of a measurement of dip angles and azimuths. He found that there was an abundance of low angle cross-beds which formed as sand accumulated around dune vegetation. Higher angle dips were related to the presence of shadow dunes. He also found that all measured beds were either planar or very slightly curved.

The dunes on Sable Island are different from those of McBride and Hayes (1962) in that there is a scarcity of high angle beds with most of the measurements made being less than 25°. This agrees with Goldsmith's findings. There is also a wider distribution of dip angle azimuths on Sable Island than on either Mustang Island or Monomoy Island. Perhaps this is due to the occurrence of strong winds from all compass directions. Neither McBride and Hayes nor Goldsmith discussed the structures further, nor did they examine the sequences of structures within the coastal dunes.

Bigarella et al. (1969) examined the internal structures within coastal dunes in Parana, Brazil. They found that the dunes had high foreset angles, horizontal bounding surfaces, individual sets of cross-strata that were thinner and flatter near the top of vertical sections, and that the dunes were dominated by planar-tabular sets. They also stated that convex upward foresets at the dune's brink are characteristic of coastal dunes. The dunes on Sable Island also are marked by horizontal bounding surfaces, but there is a lack of the high angle foresets in the dunes. Perhaps the high angle of the Brazilian dunes is related to the humidity present in the region which is lacking on Sable Island. The types of vegetation are not discussed and this would have an influence on the types of structures which are deposited. The convex upward foresets which characterize the coastal dunes of Brazil are not seen on Sable Island. Perhaps this is due again to the different types of vegetation which colonize the dunes.

The coastal dunes on Sable Island do not consist of single barchans or barchanoid ridges, nor are they organized into duneforms with bottomsets, foresets, and topsets, stoss sides and lee faces. They exist as vegetated ridges with an irregular surface topography that are the result of the superimposition of many types of dunes. At the base the dunes are characterized by a lack of vegetation and a variety of grain sizes. Once vegetation takes hold in an area, shadow dunes begin to develop (Hesp 1981). With increasing vegetation density the shadow dunes begin to overlap and superimpose increasing the height of the dune and allowing for the development of beds which dip in a variety of directions over a short area (Byrne 1986). Once a number of dunes superimpose, the vegetated surface becomes more and more extensive and increasingly horizontal with hummocky irregularities. Therefore, the standard terminology regarding stoss and lee faces and topsets, foresets and bottomsets is no longer applicable.

McKee and Bigarella (1972) examined deformation structures in Brazilian coastal dunes. They found that deformation structures are more common in coastal dunes than in desert dunes. They also found that slumping is characteristic of the coastal dunes; that the types of structures in coastal dunes reflect the higher degree of cohesiveness of the sand; that faults and breccias are common, especially in wetter sand; and, that small roots follow laminae, but larger roots disrupt laminae. The dunes on Sable Island are similar in that slumping is common. However, the slumping is associated more with the binding of the sand by vegetation rather that solely to the moister nature of the coastal dune sand. The sand within the dunes on Sable Island is exposed to salt spray and salt wash, but it is not more cohesive than sand away from the coast. The structures present within the dunes are not the result of cohesiveness of the sand. They are the result of the interference of the wind stream by the plant and the deposition of sand in the wind shadow. Faults and breccias are seen in the dunes on Sable, but they are more rare than those in Brazil. Perhaps this is due to the fact that the temperatures are cooler on Sable Island and the sand does not dry out to the same extent as in the dunes in Brazil. Therefore, salt crusting is not as common as in the Brazilian dunes and the break up of the salt crust to form the breccias cannot happen. The major difference between the two locations is the relationship between plant roots and physical structures. In Brazil smaller roots follow bedding planes while the larger roots disturb the beds. On Sable Island, the vegetation grows upward with burial. As the plants are buried, the old stem becomes the new root. Roots do not reach downward into the sand and so they do not disrupt beds. Instead, the beds are laid down in conjunction with the growth of the plants and a pattern of grain size change takes place with the largest grains being deposited closest to the plant and the smaller grains further away.

Hesp (1984, 1988) examined the structures within vegetated coastal dunes. In the 1984 paper, Hesp examined foredune development in southeast Australia stating that foredunes grow upward from isolated shadow dunes with bimodal dip directions with medium magnitudes of dip to Spinifex dominated dunes which have more continuous beds of lower dip. The same is true of the dunes on Sable Island. However, the dominant species is no longer Spinifex, but Ammophila. The dip directions of the basal shadow sets are not bimodally distributed because of the occurrence of strong winds from a number of directions.

In the 1988 paper Hesp examined the internal structures to a greater degree than in the earlier paper. He recognized four facies in the dunes in Australia. The first is a boundary between the marine deposited backshore laminae and aeolian deposited laminae that is a simple tabular or wedge-shaped set of interfingering very low angle cross-strata; the second facies is predominantly low-angle beds which are often simple tabular to lenticular cross-strata; the third facies is dominated by large-scale (> 6 m) beds, which are commonly continuous from stoss slope to crest and crest to lee slope; and the fourth facies is made up of many windward sets of cross strata (Hesp 1988). These facies described by Hesp are similar to some on Sable Island. However, although these are deposited in association with vegetation, there is little mention of the effects of vegetation on the physical structures. Hesp's first facies is like the deposits on Sable which are below the vegetated portions of the dunes. The second facies is similar to the sandwort facies found on Sable. Hesp described large-scale beds which are more or less continuous as the third facies and windward sets of cross-strata as the fourth facies. These facies are similar to the Sparse and Dense Marram Facies and the Shrub Heath Facies described on Sable. The difference lies in the fact that the Facies on Sable Island consider the presence of the vegetation and its effect on the physical structures as well as the sequence of the physical structures themselves.

The internal structures in the dunes of Sable Island are similar to the types of structures found in coastal dunes in other locations. This study is significant in that it examines the sedimentology giving consideration to the plants and plant communities which are responsible for the development of the physical structures.

CHAPTER 9

CONCLUSION

The specific aim of this thesis was to examine and analyze the morphology, sedimentary processes and internal structures within vegetated dunes on Sable Island, Nova Scotia. This goal was met by analyzing a range of dune types developed under different vegetation associations and determining the sedimentary characteristics which were unique to each type of dune. The unique sedimentary characteristics were then combined in sequences which summarized the series of structures present in different larger sections, showing that it is possible to determine facies and to outline sedimentary models which describe and explain the dunes on Sable Island. The principle conclusions are listed below:

1) Vegetation is important in coastal dunes because it grows with burial, affecting the physical structures deposited. Over time all evidence of the vegetation fades, but characteristic physical structures remain. Therefore, it is possible to identify the types of vegetation present on the surface when the dune developed by examining the physical structures.

2) The physical structures deposited in association with vegetation can be

identified and organized into recognizable, and repeated, patterns. These facies were presented as sedimentologic signatures in Chapter 4.

3) Facies in vegetated coastal dunes can be organized into models which describe the patterns of sedimentation present in different locales. Chapters 5 and 6 presented the models for different types of dunes on Sable Island. Chapter 7 presented facies which result from secondary sedimentation - deposition associated with vegetation, but not the result of it. These are contained within the models in Chapters 5 and 6.

4) The models for different locations can be combined to create a facies model which can be used to describe the sedimentation patterns present for Sable Island. This model was presented in Chapter 8.

In addition, a general examination of the morphology of Sable Island was carried out (Chapter 3). The sediment models were used in conjunction with the results of morphological analysis to determine that the parabolic dunes on the island are not like those European parabolic dunes described by Landsberg (1956) and Jennings (1957). They are more like the nested parabolic dunes which exist on Cape Cod. These parabolic dunes are not the result of local disturbance, but are a natural stage in the development of a landscape. They act as means of movement of sand in the direction of the dominant storm winds.

Also, the dunes on Sable Island are in a dynamic state and will continue to be that way as long as there is a supply of sediment to maintain the island. The movement of sand on the surface of the island is from northwest to southeast during storms and from west to east during the summer months when the sand is free to be moved. The resultant direction is to the east-southeast. The combination of the wind and current directions results in a situation in which the surface morphology is most likely to continue to change, the consequence of which is a dynamic, ever-changing landscape of patchy vegetation and sand.

Appendix I

Geological Background

Sable Island Geology and Sea Level Change

Sable Island is the emergent portion of Sable Island Bank, part of a series of sand banks on the Atlantic continental shelf which stretch from the head of Baffin Bay in the north to the Gulf of Maine in the south. The total thickness of sediments on the Nova Scotian shelf and slope is greater than 5 km (Berger et al. 1965, Austin and Howie 1973). The area at one time was the centre of hydrocarbon exploration resulting in a wealth of drill hole data which shows that the sediments are Jurassic to Tertiary aged coastal plain deposits. These are overlain by Quaternary sediments which include glacial deposits (Austin and Howie 1973, Stanley et al. 1973, King and Fader 1986).

According to King and Fader (1986) maximum glaciation occurred 75 Ka BP to 50 Ka BP resulting in the coverage of ice to the shelf edge. A rise in relative sea level associated with crustal depression due to the weight of the ice, led to a thinning of the ice margin and the beginning of a glacial retreat in the Middle to Late Wisconsinan. The Scotian Shelf Drift represents the deposits laid down during that retreat. From 45 Ka BP to 32 Ka BP, the ice on the outer shelf was grounded and wet based while the central shelf was an ice shelf. At this time Facies A of the Emerald Silt was deposited. The final retreat phase occurred between 32 Ka BP and 16 Ka BP. During this time the ice shelf retreated and the central shelf area changed to one of proglacial deposition. During the retreat of the ice shelf, Facies B of the Emerald Silt was deposited. By 30 Ka BP, isostatic rebound was complete over the outer and central shelf. This is marked by a terrace at 115 to 120 metres whose constant depth indicates that the crust had almost totally adjusted to the absence of the ice. This low-stand is marked by the Sambro Sand which is restricted to the immediate vicinity of the terrace. At maximum sea level lowering, the sea level first fell and then rose. Finer material was winnowed out and deposited as the Le Have Clay. The coarser material left behind is the Sable Island Sand and Gravel. The gravel is generally on the western portion of the bank while the finer material is in the vicinity of Sable Island (King and Fader 1986). Sea level rise has occurred in the area for the last 10 Ka BP (Hoogendoorn 1989). For the last 7 Ka BP, the rate of rise has been uniform (Scott et al. 1984). During this time, Sable Island has aggraded vertically with the centre of the island at a roughly constant elevation with respect to mean sea level (Scott et al. 1984). According to Medioli et al. (1967) the lateral extent of the island has diminished over time.

James and Stanley (1968) stated that a key to the preservation of the island may be a cyclical movement of sand around the island. Wind currents and the tides drive bottom currents in a pattern which circles the island. Large sand waves, small sand waves and ripples were used to determine that south of the island, sediment moves from the east to the west, while north of the island it moves west to east. Farther offshore, sediment moves from the west to the northeast and from the east to the southwest (James and Stanley 1968, Stanley et al. 1973). This pattern is augmented by a seasonal variation in sediment movement to and from the island. During the autumn and winter large amounts of sand are blown from the island into the sea. These are returned to the island in spring and summer as bars weld onto the beaches.

Hoogendoorn (1989) carried out an examination of the sedimentology and dynamics of the shoreface-attached ridges of Sable Island Bank. The sand waves described by Stanley et al (1968) are actually shoreface-attached ridges (Hoogendoorn and Dalrymple 1986). Hoogendoorn (1989) countered this theory by stating that the sediment transport directions were not controlled by the tidal currents, but by currents generated by winter storms. Therefore storm generated currents move sediment in an east to northeast direction. This direction of sediment transport is also indicated by the angle of convergence of the ridges with the shoreface on both sides of the island (Hoogendoorn and Dalrymple 1986). According to Hoogendoorn and Dalrymple (1986), there is a wind set down and an obliquely onshore bottom current on the south side of Sable Island. The onshore transport of sediment due to this current may be in part, responsible for the subaerial exposure of Sable Island throughout the Holocene transgression.

Appendix II
Calculation of Wind Resultant

Table 1. Vector Magnitudes and Resultant for Winds from Eight Directions, Sable Island, Nova Scotia.

Vector Magnitude (b)	Vector Direction	Cos of Angle	Sin of Angle	YI	XI
80.33	N	1.00	0.00	80.3300	0.0000
59.10	NE	0.71	0.71	41.9610	41.9610
71.75	E	0.00	1.00	0.0000	71.7500
63.31	SE	-0.71	0.71	-44.9501	44.9501
61.65	S	-1.00	0.00	-61.6500	0.0000
106.18	SW	-0.71	-0.71	-75.3878	-75.3878
200.71	W	0.00	-1.00	0.0000	-200.7100
131.02	NW	0.71	-0.71	93.0242	-93.0242
			Sum =	33.3273	-210.4610
			Resultant = 213.0833		

In order to determine the resultant of the winds on Sable Island, the x and y components of the wind were calculated by multiplying the vector magnitude by the cosine of the direction angle for the y component, and by the sin of the direction angle for the x component. The x and y components for each direction were summed and then added together. The square root of this number is the resultant. The vector magnitude was calculated using the Landsberg (1956, Method B - equation 2) equation which accounts for the force of the wind and the threshold of sand movement.

Appendix III

History of Sable Island and Profile Morphology

Horse and Human Disturbance

Any study carried out on Sable Island cannot ignore the presence of the wild horses. These creatures have been the subject of many legends and much study. Christie (1980) presented a history of their probable origin and presence on Sable Island. The following is a summary of her history.

There are many stories about the origin of the Sable Island horses. Some say that the early Portuguese fishermen placed the horses on the island. However, the Portuguese fishermen would have no need for horses. They placed horned cattle and pigs on the island in 1553, both for food for fishing vessels. However, they had no need for horses, so it is unlikely that any were placed by the Portuguese.

In 1598, some sheep may have been left on the island by the Marquis de la Roche who had aspired to settle the island by leaving a group of convicts there. However, these men merely survived there for a few years before being rescued. There were no horses on the island at their rescue.

In 1633, the Acadians and New Englanders began to remove and slaughter the Portuguese animals. Again no horses were reported. In 1738, Le Mercier of Boston in partnership with Thomas Hancock, and others also of

Boston, tried to establish a lifesaving station on the island. Their venture failed in 1753. However, they had brought horses to the island in 1737. It is likely that some of these were abandoned on the island. With the expulsion of the Acadians from 1755 to 1762, there were many animals abandoned. Hancock is likely to have bought many of them (horses, cattle, sheep and hogs) and brought them to Sable Island for later transport to Boston. They were transported to Sable Island because it was illegal to trade between New England and New France. During this time there had been no reports of the wreck of Spanish ships from which the horses may have swum to the island.

The animals which had been landed on Sable Island were quite a valuable commodity, especially to raiding ships from both sides during the American war of Independence (1775-1783). During this time all of the cattle were removed for food. The island's hogs were also killed for food. A later severe winter likely killed off the remainder. Many horses were taken for mounts for soldiers. However, not all could be captured and they wildly roamed the island.

In 1801, the first lifesaving stations were established by the Nova Scotia government. They used the island's horses to aid in the rescue of shipwreck victims. The horses were ideal for the job because they were very sure footed in the deep sand of the beach and dunes. The horse herds were then managed, with stallions being brought from the mainland to improve the quality of the breed. These were then rounded up (twice a year) and exported to the mainland. This continued into the 20th century.

After the roundups ceased, the horses were allowed to roam the island freely. There have been thoughts that they overgraze the grass and lead to the destruction of the vegetative cover and thus to the increased erosion of the dunes. However, the horses only graze heavily during the winter when food is hard to find. During the summer, they simply graze the tufts of grass from the top of the stalks (Christie 1980). So it is likely that the amount of increased erosion on the island is due to the activities of those who tried to settle the island rather than the horses.

There is a well defined link between the history of the horses on the island and the history of European presence. Early visitors had no interest in bringing horses to the island. However, later ones not only brought the horses there, but, also returned to the island in order to collect some of the horses for use on the mainland. After the establishment of the Lifesaving stations, the sale of the Island's horses was a means of making money to help to keep the stations going.

European settlement has undoubtedly had a greater influence on the dune disturbance than the presence of the horses. Early attempts at agriculture not only disturbed the surface cover, but aided in the rapid depletion of the rudimentary topsoil. This in turn led to a decrease in the amount and type of cover which could establish at the dune base leaving the dunes susceptible to deflation. This combined with the cumulative trampling by both humans and horses has triggered greater sediment mobility in an environment which would otherwise be in a dynamic equilibrium.

Historical Maps and Photographic Evidence

According to Cameron (1965) Sable Island has been known to Europeans since its first sighting by John Cabot in 1497. The Baron de Lery is said to have left half of his cattle on the island in 1518. The island was first charted as Santa Cruz by Reinel in 1505. It was again included under the same name on a Portuguese map in 1521, and on Diego Homem's map of the world in 1544 as I. da Crus. Gastaldi charted the island in 1550, and Zaltieri in 1566, calling it Isola della Arena (Patterson 1894). It was first referred to as I. de Sable by Freire in 1546. The first account of the island came in 1633 when De Laet published that the island was situated 44°N and 30 leagues from the mainland. Patterson (1894) recounted that De Laet recorded the island to be 15 leagues (over forty miles) in circumference and much longer than wide. The sea surrounding the island was said to be very shallow with no harbours on the island. Other than one small pond, there was no water source on the island and the soil was naked or slightly covered with grass. This description, although discounted by Patterson as being incorrect, is very similar to the appearance of the island at the present time.

The oldest map available for this project was published by Des Barres in 1767. It shows an island with a central lagoon. There is an entrance to the lagoon off the north shore at the western end of that water body about 9 miles from the end of the island. The island is just over 29 miles long. The northern dune ridge is continuous except for the break at the entrance to the harbour. There is also a continuous southern ridge with naked sand hills spilling into the sea on the southeast part of the island. South of the lagoon there are two places where the dune ridge is broken. These are within a mile east of the entrance to the lagoon and about 4 miles to the east of that. There are ponds located amongst the dunes at the east end of the lagoon.

Accompanying the map is a manuscript entitled Remarks on the Isle of Sable which described the dunes as being so low that overwash occurred in many places along the length of the island. Des Barres stated that a dune called the Ram's Head was the highest on this island, but did not give a figure for the height. He stated that the Naked Sand Hills were 146 feet above the high-water mark and that Gratia Hill was 126 feet above high-water mark. He also stated that the island was much lower in elevation at the west end as compared to the east end.

Little more information exists about the next 100 years on the island. There are accounts of sealers and fisherman as well as pirates, shipwrecks and ghosts. In 1801, the first lifesaving station was established on the island and from that point to the present there is a good history in the form of superintendents' reports.

Patterson (1894) recounted that the early charts of the coast published in

1775 showed that the island lay between 60° 05' and 60° 45' W longitude (40 miles long and 2.5 miles wide). A special survey in 1799 located the island between 60° 01' and 60° 32' W (31 miles long and 2 miles wide). A survey in 1808 stated that the island was 30 miles in length and 2 miles wide with hills from one hundred and fifty to two hundred feet in height. A chart in 1815 shows the island to lie between 60° 03' and 60° 32' (29 miles in length). In 1829 the island was reported to be only 22 miles in length. In 1851 the island was again surveyed and reported to lie between 50° 45' and 60° 08' W. All of these reports emphasize the wasting away of the west end of the island.

The lifesaving station's superintendents' reports also outlined changes in the island's morphology. Reports stated that the main station was moved a total of 14 miles to the east between 1801 and 1833. Gales are also reported to have caused large-scale erosion on the west end of the island in the years 1881 and 1882. One map was a part of the superintendent's report in 1803. It shows no entrance into Wallace Lake and refers to this body of water simply as Salt Water Pond. It has little other information except that the naked sand hills are clearly marked on the east end.

Patterson also reported changes which have taken place along the shores of the lake. He stated that there was an opening into the lake from the north some time before the establishment of the first government on the island. But by 1808 there was no trace of this opening. Some years later there was an opening from the south which had been caused by a large storm. This was closed by another storm in 1836. When the government was first established, the lake was 15 miles long, but in 1881 a severe storm opened a "gulch" in the east end of the island which drained it, decreasing its length to only 8 miles. The map in Patterson's report shows the island was about 28 miles long and had two openings on the south side into Wallace's Lake.

The ridge which separated the lake from the sea on the south side was also subject to erosion from storms. Patterson recounted that the ridge was originally half a mile wide with hills 50 feet or more in height, but that it had been so eroded that it was scarcely 100 yards wide and overwashed in severe storms. He also reported that the winds were very destructive quickly eroding whole dunes and redepositing them in another location as a dune or spread over a whole area in a sheet.

In his introduction, Patterson (1894) described the island as the summit of the Sable Island bank. He stated that the island was about 85 miles from the nearest point on the mainland. In his account the island was less than 20 miles long and about 1 mile wide. The east end was located at 43° 59' N by 59° 49' W and the west end was at 45° 56' N by 60° 08' W. He described the island as two parallel ridges of loose grey sand separated by an 8 mile long lake. The dunes on the west end were about 20 feet high rising to the east to about 80 feet, before falling off again.

There is no documentation which describes the morphology of the island until Cameron (19__) constructed a terrain map. He divided the island into areas of stabilized sand, unstabilized sand, shallow water, deeper water, and grass cover. He also depicted the sand ripples which develop on the south beach and the buildings. He stated that although the stabilized dunes are the major topographic feature of the island, they do not reach more than 85 feet in height. In those which are not grass covered on top, there are root layers from previous coverage.

From the information contained within the Patterson report and other earlier sources, as well as the available aerial photography, Cameron (1965) drew a series of seven outline maps to show the changes in shape, size and position of the island over a time of 200 years. He determined the east end of Wallace Lake to be a point which is constant and superimposed the maps. The changes amount to a loss of 9 miles on the west end of the island and a gain of eleven miles on the east end. He concluded that: 1) the changes are due to wave and current action eroding the west and depositing sediment in the east; 2) serious erosion is due mainly to the action of severe storms and occurs periodically; 3) erosion may be accelerated by hurricanes tracking over the island; and, 4) with the present rise in sea level of 0.5 inches per century, the island will be reduced to base level in 3000 years.

Profile Morphology

In order to describe the morphology of the sand dunes on the island, profiles were taken across the width of the island. Three of these (A-B and C-

D on the west end, and I-L on the east) were taken on the spits. Five others were taken across the island at locations approximately equal distances along the length of the island. First the profiles on the spits will be described, and then the remainder of the profiles will be discussed.

A series of profiles were taken on the spits in order to gain insight into the changes to the dunes over a summer season. Profile A-B was taken at the westernmost end of west spit and profile C-D was taken at the end closest to the established ridge. Surveys were taken four times, June 24, July 7 and 24, and August 8. These allow a good record of the changes. However, because of differences in tidal levels, the waterline is not constant. Although the surveys were corrected for changes in tidal cycle, other factors such as tidal surge and passing weather fronts were not accounted for. Also, it was difficult to pinpoint the exact profile location form survey to survey because of changes in vegetation and beach topography. Stakes pounded in as markers were not useful because they were either kicked over by horses or moved by seals. Despite these limiting factors, the profiles are useful for documentation of the relative changes in the dune morphology over a summer season.

Profile A-B is approximately 420 m wide from north waterline to south waterline. Of this width, only 80 m are vegetated. The vegetation is primarily Honkenya peploides, but there is some Cakile edentula and Ammophila breviligulata. The natural morphology of the dunes trends towards hummocks, however, there has been some effort at establishing dunes on the spit by erecting fencing. This changes the morphology to a linear form. Overall, the shape of the dunes changes little over the summer season. Vegetation spread further toward the waterline and grew taller. There is a ridge at 120 m from north waterline which appeared to build vertically over the two months. While a ridge at 240 - 260 m deflated. The central portion changed little.

Profile C-D is only about 260 m wide. Only 60 m of this width is vegetated. The vegetation cover is similar to that in profile A-B, however, there is a greater cover of Ammophila breviligulata within the Honkenya peploides. There is little change in the shape of the ridge over the two months.

Profile K-L is on the east spit. There is very little vegetated dune coverage on this spit compared to the length of the sand body. The profile is approximately 220 m in width, of which 50 to 60 m is vegetated dunes. The vegetation coverage is also different from the west spit in that there is little Ammophila breviligulata and Cakile edentula. Over the summer months there appears to be little change in the dune ridge. Notable is the infilling of the trench on the south side of the ridge, creating a ramp to south beach.

Profile (E-F) was taken across the sand dunes just east of the old Main Station. The Nova Scotia Government Camp is located at this position. The second profile (G-H) was taken just east of the Atmospheric Environment Station. The third (O-P) was taken east of the A Frame house. Profile I-J was taken just east of the large Bald dune on north beach and just east of the end of Sandy plain on the south. Profile M-N was taken at the east end of the island. It included the cascading dune on the south beach.

Profile E-F

The dunes are narrow in comparison to the width of the island at Profile E-F. At this location, the dunes reach just over 10 m in height on the north and just over 7 m on the south. They are densely vegetated with Ammophila breviligulata and Lathyrus maritimus. The total width of the dune system at this point is only about 200 m whereas the width of the island at this point is roughly a kilometre. North beach is narrow (less than 100 m wide). A small sparsely vegetated foredune exists at the base of the established ridge. It is only 1.5 m in height and about 10 m in width. It extends along the base of the established ridge from dead horse cut almost to the BIO blowout. At that point blowouts begin to punctuate the established ridge and the foredune disappears. This foredune is an annual feature. It develops in the late spring as the plants colonize this portion of the beach which is no longer ravaged by the winter storm waves. Materials thrown up at this location by those waves make excellent focal points for sediment deposition. The dune builds in height over the milder summer and early autumn months and is then wiped out by the storm waves in the winter and early spring.

Behind the foredune is a runnel like trough where little vegetation grows. Perhaps this is due to the channelling of the wind in this area or by the deposition of sediment which has moved downslope from the established dune. In any case, there is a topographic low here.

The established dune ridge is actually a complex of many smaller dune ridges which are plastered together and built up on top of each other. The ridge may be divided into two sections. The first is the north section which is about 120 m wide. The north face is vegetated and rises to 8.8 m in elevation and then dips down to 8.0 m before rising again almost to 10 m in elevation. This is the highest point in elevation at this location. The top of this section of the established ridge is undulating with waves of sand tied down by vegetation. Elevation decreases to the south to 7.8 m and then rises to 8.2 m at the upper edge of the north section and then falls quickly to 2 m. The south section is shorter in elevation and less complex than the north section. It consists of a single ridge of vegetated sand and a concave up swale. The swale begins at the edge of the north section. There is a decrease in elevation from 2 to 3.9 m in about 30 m of distance. Elevation then increases up to 7.2 m elevation at 220 m from the waterline on north beach. Elevation then decreases down to the level of the sandy plain to the south of the dunes at this location. The sandy plain is fairly featureless and about 500 m in width.

Moving eastward from this point the dunes get wider and a pond system develops between the north and south sections. This system is located between the BIO/coastguard compound and the AES compound. In this location the dunes are well developed on the south beach being about 10 to 12 m in height and vegetated with a sparse to dense Ammophila breviligulata cover. The north dune ridge is suffering greater erosion than the south dune ridge, although it is still well established. Vegetation cover changes from Dense Marram/beach pea on the top of the north ridge to marram/heath toward the centre of the island. It changes again from marram/heath to pond fringe vegetation in the areas surrounding the ponds. In this location north and south beach are both very narrow.

Profile G-H

East of the AES compound the dunes narrow once more (profile G-H). To the south of the dune system is a sandy plain and Wallace Lake. There is little permanent dune development on the sandy plain. Some small shadow dunes develop around flotsam and jetsam deposited on the beach during storms. However, these are not tied down by vegetation and so are easily eroded by even the relatively gentle winds of the calmer periods. The vegetated dune system is about 600 m wide. At this point it is roughly half the width of the island. Maximum elevation has also increased to this location. In all but one of the dune peaks in this profile the north face is steeper than the south face. Only at the southernmost part of the profile does the dune have a steeper south face. The highest dune is 18.69 m tall and is the seaward portion of the north dune ridge. The seaward face of this dune is free of vegetation and is blanketed in an apron of fine sand. This face is very steep being greater than or equal to angle of repose for the upper two thirds of the dune face. The face may be steeper than angle of repose because the sand is tied together by the sand binding flora. The side of the dune facing the centre of the island is covered with dense Ammophila breviligulata at the top and sparser Ammophila breviligulata on the downslope over the upper third of the dune. Below this, the face is too steep and the dune is unvegetated. This dune ridge would be equivalent to the ridge in the north section of the previous profile.

There is a trough-like low at the southern base of this dune and then a small peak (5 m tall) which is covered with marram heath vegetation. There are two more troughs and peaks which stretch over the next 200 m. Each peak is successively lower in elevation (7 and 2.1 respectively). The troughs are just above water table. Bordering this region of marram/heath is a larger dune peak (reaching 8.1 m in elevation). The north face of this dune is free of vegetation and blanketed by fine sand similar to the larger dune on the north face of the system. The south face is vegetated by sparse to dense Ammophila breviligulata. South of this ridge is a concave upward swale which is about 0.9 m above sea level. It is separated from the sandy plain and Lake Wallace by a 5.9 m tall sparse Ammophila breviligulata dune.

Profile O-P

The dunes again narrow eastward to profile O-P. This profile is markedly different from profile G-H. It is simpler in that it has only one predominant peak, the elevation of which is 20.59 m. The north face is unvegetated and covered by an apron of fine sand. The south face is vegetated by dense Ammophila breviligulata at the top and sparse Ammophila breviligulata downslope. There is an undulating topography of heath vegetated ridges from 300 to 420 m south of the north waterline. From 420 m to about 500 m south of the north waterline is a freshwater pond surrounded by pond fringe vegetation. South of the pond system is a small (2.5 - 3 m) sparse Ammophila breviligulata dune. This dune separates the pond from the sandy plain to the south. South of the small dune the sandy plain is actually below sea level. Farther to the south the elevation increases and hummock dunes develop. However, these are not included in the profile because they were too difficult to tie into the survey profile.

Profile I-J

East of profile O-P the dune system widens. Profile I-J was taken across the widest point of the island. From waterline to waterline the width of the island is 1204 m. The dune system occupies about 1150 m of this width. The dunes may be divided into two halves with the north half being higher than and having steeper faces than the south half. The maximum elevation is 26.76 m at top of the north face of the northern dune ridge. The northernmost dune ridge is covered by dense Ammophila breviligulata. It is separated from the next ridge by an unvegetated area. The second dune ridge is vegetated with dense Ammophila breviligulata and separated from the third ridge by an unvegetated area. The third ridge is very gently sloping to the south and relatively gently sloping to the north. The gentle south slope gives way to the undulating grassy meadow which makes up the central portion of the dunes in this part of the island. At this location it is about 400 m in width. The meadow is vegetated primarily with dense Ammophila breviligulata and is predominated by Lathyrus maritimus.

The south dune ridge in profile I-J is more well developed and so more complex than at other locations. The maximum elevation is 15.66 m and the ridge is about 150 m in width. North of this ridge is a blowout which is healing. The area was once excavated almost to the water table, but now has a 5 m tall dune growing within it. The backface of the blowout is the southern portion of the grassy meadow.

Profile M-N

From profile I-J eastward the dune system narrows. At profile M-N, the width of the dunes is just over 400 m. The island at this point is about 420 m wide. Again there are two ridges. However, at this location the south ridge has the maximum elevation. This is also the maximum elevation for the island (29.05 m). South of this peak is an unvegetated dune which is currently cascading into the sea. It is between 2 and 4 m high, 20 m wide and about 100 m long. It is separated from the south ridge by a trough which dips down to about 1.5 m elevation. The lower portions of the south ridge are unvegetated, but covered with an apron of fine sand which has moved downslope from the vegetated top portion of the dune. North of the ridge is a trough which extends to 0.45 m below sea level. North of the trough is a small peak which reaches 8.05 m elevation. It is about 200 m south of the north waterline. North of this peak elevation falls to 3.45 m elevation and then rises again in a series of steps to the maximum north elevation of 19.25 m. The north ridge is covered with the Dense Marram community predominated by Lathyrus maritimus. The north face of the ridge is very steep and vegetated with dense Ammophila breviligulata. The north beach is very steep and narrow.

Appendix IV

Initiation of Movement and Sand Transport

A grain of sand begins to move when the shear force exerted by the wind on the surface becomes greater than the forces of gravity, friction, and cohesion acting on the sand. According to Bagnold (1941), air flow over a sandy surface experiences a frictional drag. The decrease in wind velocity due to this drag is transmitted up the air column in the same way as the decrease in stream velocity in water over a bed. This velocity gradient applies a force to the surface sand grains. This force is the shear velocity of the wind (u_*). It increases with increased wind speed or with increased surface roughness. When shear velocity increases past a critical value (u_*crit) the surface grains begin to move. Bagnold (1941) stated that the critical value depends upon the square root of grain diameter. The grains of critical size are the first to begin to move. These roll or slide along the surface and bump into larger grains which are, as yet , immobile. The force of the impacts sends the grains of critical size into the air. They begin to saltate (Pethick 1984).

When sand grains saltate, they bounce off stationary grains. As they rise into the air they come into contact with higher velocity winds which shoot the grains forward until they move as fast as the wind at that height and then they begin to fall. Their impact with surface grains causes the movement of more grains in the same manner (Bagnold 1941). The bouncing grains slow the wind speed because they become entangled in the air. Saltation continues, not because the grains are moved directly by the drag of the wind, but by the force of the grains on impact. The wind now accelerates the grains as they bounce into the air. The threshold velocity to maintain saltation is around 5 ms^{-1}.

A second process by which grains move is creep. When the grains fall out of saltation they may hit other grains which are too large to be sent into saltation. They react by jerking forward. Grains as much as six times the saltating grain's diameter can be moved in this manner (Bagnold 1941). Only one quarter of the sand in motion moves by this process, but, since it sorts the grains, it is very important. The grain size segregation occurs because finer grains saltate, moving further downwind, while the larger grains creep, moving more slowly and for shorter distances (Bagnold 1941, Pethick 1984). Fryberger and Schenk (1988) use the grain size sorting process of migrating ripples to explain the development of pin stripe lamination in modern and ancient aeolian deposits.

Bagnold (1941) and Hsu (1973) have shown the amount of sand transported per unit beach width per unit time to be related to the shear velocity or the actual wind velocity. Pethick (1984) stated that the amount of sand transported is extremely responsive to the variations which occur in wind velocity. Slight decreases in wind velocity cause deposition of large amounts of sediment and slight increases cause great amounts of erosion.

There is an interaction between the bedform and the airflow. Bagnold (1941) noted that there exists an energy balance between the force exerted by the wind on the surface and the loss of energy associated with impact with the ground. Because softer surfaces absorb more energy, there will be a reduction in the amount of sediment transported as a cloud of saltating grains passes over a soft sandy surface. If the cloud of saltating grains passes over a hard surface, less energy is absorbed by the surface, transport capability increases, and the surface may be swept clean of many loose sand grains. As a cloud of saltating grains passes over a smooth surface, the surface will be altered by the passing grains. If an irregularity exists on the bed, having greater angle of incidence with the grain paths than the bed itself, the windward side of the obstacle receives the impact of more grains than the leeward and, consequently, more grains are set in motion from that point. This effect extends a few more times before fading out under random influences, and thus zones of light and dense bombardment are created. These develop into alternating zones of erosion and deposition. This process continues until ripples develop and begin to migrate.

There are two types of aeolian ripples. Sand ripples consist of well sorted medium to fine grained sand while granule ripples are composed of coarse sand or granule size particles. The latter often exist as isolated ripple forms. The coarsest or heavy mineral grains collect on the crest rather than in the trough. Aeolian ripples have large ripple indices (wavelength divided by ripple height) and symmetry indices (ratio of the horizontal projection of the stoss to that of the lee) between 2.0 and 0. Granule ripples tend to be asymmetrical while sand ripples can be either asymmetrical or symmetrical.

Goldsmith (1985) stated that sand ripples develop on the sides of dunes with their long axes parallel to the slope. However, these may develop with long axes perpendicular to wind direction. They contain the same grain size as the substrate beneath and often form in areas of sand accumulation. They are good indicators of wind direction and the complexity of wind currents. Sand ripples form on the wind shadows and on the lee sides of dunes (Goldsmith 1985).

Granule ripples often form adjacent to areas of coarse lag deposits. They develop in a range of areas from the interdune lows to the high tide swash line and look much like barchan or parabolic dunes in form and structure. They are larger, more symmetrical, and move more slowly than sand ripples. They appear to form by surface creep driven by saltation impact under high wind velocity conditions.

Ellwood et al. (1975) noted that small aeolian ripples with a wavelength of 1 to 20 cm and larger ripples with a wavelength of 20 cm to 20 m develop by the grain impact mechanism outlined above. They also stated that because the wavelength corresponds to the mean path length of a grain jump (Bagnold 1941), differences in wavelength are due to differences in the grain size distributions of the sediments. Therefore, in fine grained unimodal sands, ripples will become increasingly flatter as wind speed increases. Ellwood et al. (1975) believed that these eventually disappear because ripple relief becomes so low that it cannot act as a nucleus to which the sand clings. If a coarse fraction exists in the grain size distribution, a higher threshold velocity is needed to initiate movement and ripple relief becomes greater. Therefore, when there are strong winds, ripples with very large wavelengths can develop.

Small vegetated coastal features also exist. Hesp (1981) discussed the development of shadow dunes. He found that these pyramid shaped forms develop best in the lee of semipermeable, semicircular-shaped roughness elements which cause flow separation in the vertical as well as the horizontal plane. A cluster of Ammophila breviligulata or some other beach grass has this shape. The base of the shadow dune forms in an area extending from the plant (or obstacle) edges to some point downwind on the centreline. That point is the point at which the sand transport velocity is reached. Sand grains follow a semicircular path from the plant edge to the centreline. A linear ridge forms as a crest on the centreline because the vortices behind the obstacle are fixed. Hesp (1981) observed that the height of the shadow dune is determined by the width of the plant and the angle of repose of the sand. Since dune growth stops when the sand transport threshold is reached, the core region diminishes in size with distance from the plant until the threshold is reached. At that point, flow becomes streamwise and sand is carried away downwind. Shadow dunes range in size from very small features behind plants or behind flotsam at the high tide line, to large permanent features behind dune ridges.

The grains of sand are now moving and can be deposited. The processes by which they move and the manner in which they are deposited result in the type of stratification which is left behind. The basic types of aeolian stratification will now be discussed.

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