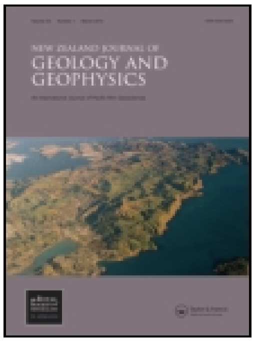

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Beach and nearshore morphology and sedimentation in Fiordland, New Zealand: a comparison between fiords and glacial lakes

R. A. PICKRILL
New Zealand Oceanographic Institute, DSIR
P.O. Box 12 346, Wellington

Abstract The morphology of 56 beaches from the Fiordland coast is described. Four groups of beaches are recognised: open coast sand beaches, fiord margin sand/gravel beaches, fiord margin boulder beaches, and bay head deltas. Fiord margin beaches and deltas have a shelf profile; on the fiord margin beaches this shelf is narrow and steep and is formed by local wind waves, and on the bay head deltas the shelf is wide and flat and the morphology is controlled by the rate of sediment supply. The ocean fiord beaches have a deep-water shelf.

On sheltered beaches sediments fine across the shelf, with a transition from sand to mud at the shelf break. The sediment distribution and morphology of the inner fiord beaches is similar to that on nearby glacial lakes and is a model of progradational shelf formation on the continental margins.

Keywords beaches; nearshore environment; fiords; glacial lakes; sediments; Fiordland; shore features; limnology

INTRODUCTION

Studies of fiord sedimentation within New Zealand and in other fiord systems around the world have concentrated on the deep fiord basins and entrance sills (e.g., Pantin 1964; Glasby 1978). The present paper describes shallow-water morphology and sediments of the beaches and deltas of the coast of Fiordland, New Zealand.

Recent studies of marine and limnic beach systems have drawn parallels between the 2 environments. Changes in stillstand of water level produce similar changes in beach morphology in the oceans as in the lakes (Dubois 1975, 1976; Pickrill 1978). Studies of nearshore bar systems (Davis & Fox 1972; Pickrill & Irwin 1978), beach morphology (Davis et al. 1972), and sediment distributions (Mothersill 1970) have shown oceanic and lacustrine systems to be analogous.

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In a recent paper, beaches around the glacial lakes of Manapouri and Te Anau were described (Pickrill 1978). Parallels were drawn between the sediments and morphology of the continental shelf and those of the limnic beaches; the shelf form of the limnic beaches was presented as a model for continental shelf formation. In the present paper comparisons are made between the limnic and nearby ocean fiord beach systems and the model for shelf development is extended and tested in the marine environment.

PHYSICAL SETTING

From Milford Sound in the north to Preservation Inlet in the south, the west coast of South Island is indented by 14 major fiords (Fig. 1). The deep, narrow, formerly glaciated valleys have been carved out of resistant gneisses and granites and have been altered very little by subaerial weathering since deglaciation.

The bathymetry of the fiords reflects their glacial origins. The narrow steep-sided inlets have a classical U-shaped cross section. In long profile the fiords have a shallow entrance (30–145 m); behind this sill the smaller fiords have just 1 deep basin (170–420 m) while the larger fiords have a series of deep basins separated by deep sills. Development of a continental shelf has been minimal (Brodie 1964). On average the shelf is less than 6.5 km wide, and off most of the fiords the entrance sill drops steeply into deep water (500+ m) (van der Linden & Hayes 1972).

Steep, forested cliff walls dominate the coastline. However, where the sediment supply is large, or the nearshore relief is not too steep, beaches have formed. At the head of the fiords streams draining the valleys of former tributary glaciers support the largest beaches. Beaches are also more numerous around the shallower fiord entrances and in re-entrants along the fiord walls where glacial moraine has accumulated and provided a source of sediment for beach development.

The Fiordland coast is exposed to high-energy swell and storm waves originating in unlimited fetch conditions south and west of New Zealand. However, the long indented nature of the fiords ensures that most of this energy is expended in the

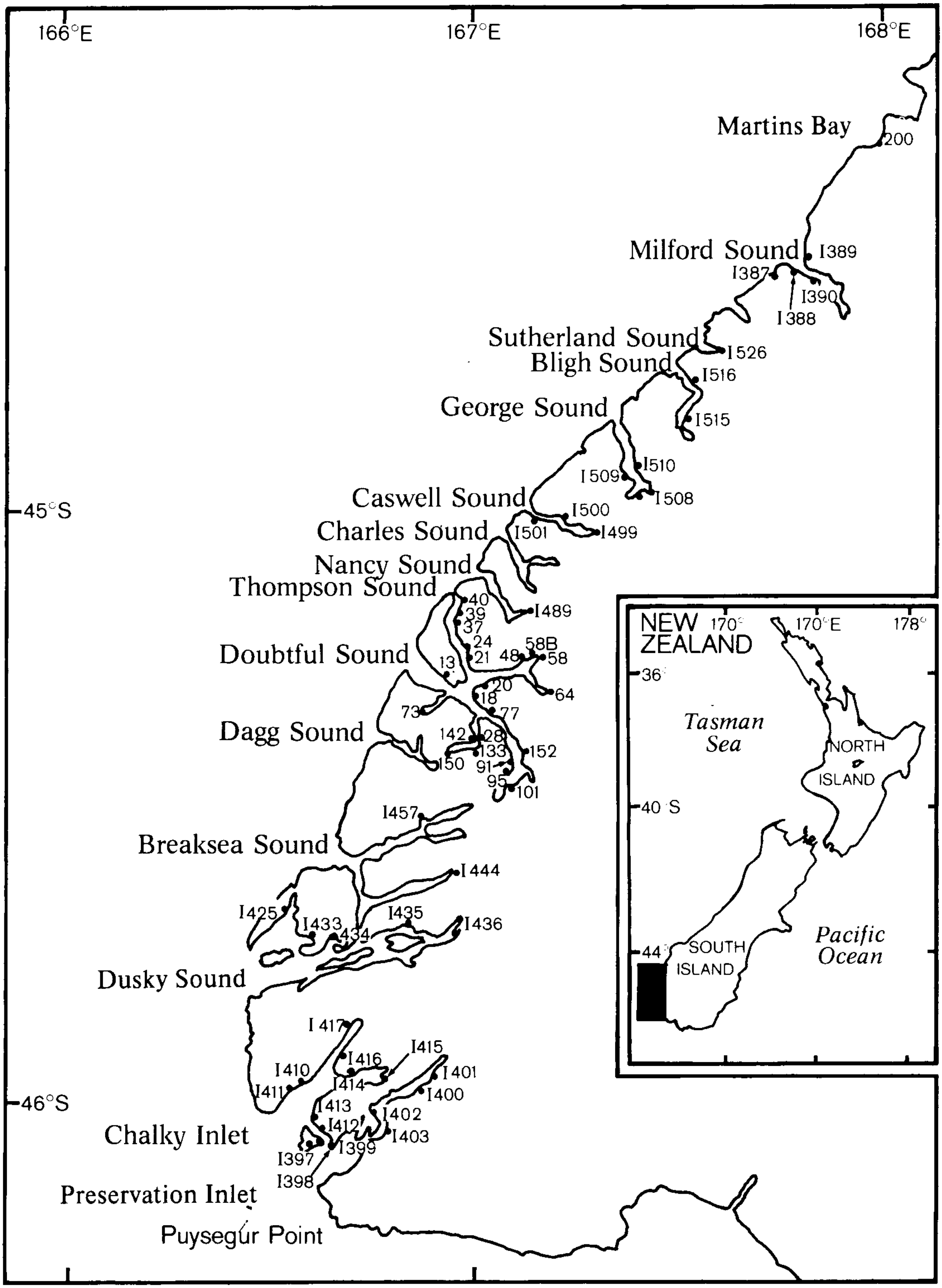

Fig. 1 Location of beach profiles surveyed in Fiordland.

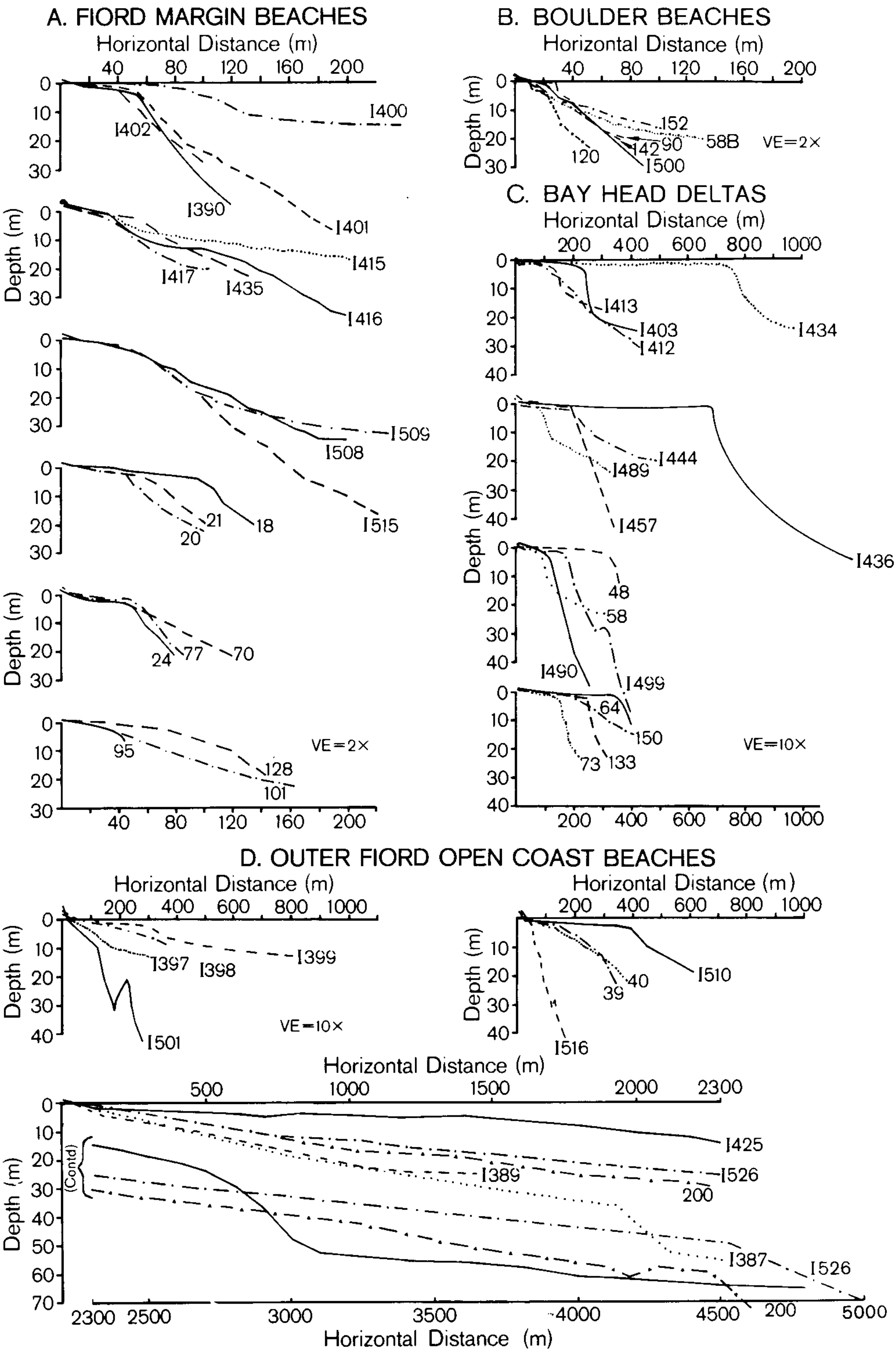

Fig. 2 Beach and nearshore profiles of the stations marked in Fig. 1.

Table 1 Summary of beach/nearshore characteristics taken from the shore normal profiles in Fig. 2. Catchment areas, delta areas, and delta widths were calculated from Lands and Survey NZMS 1, 1:63 360.

Profile No	Effective Fetch Length (km)	Foreshore/Nearshore Width (m)	Foreshore/Nearshore Elevation (m)	Foreshore/Nearshore Slope (°)	Offshore Slope (°)	Catchment Area (km²)	Beach Type Sand (S) Gravel (G) Mixed (S/G)
FIORD MARGIN BEACHES							
I390	0.91	53	4.2	4.5	39.3	3.1	G
I400	3.70	85	4.0	2.2	11.0	17.0	S/G
I401	1.25	46	4.0	5.0	25.5	19.4	S/G
I402	3.07	45	4.2	5.3	36.1	1.2	S
I415	2.48	42	4.7	6.4	17.0	2.2	S/G
I416	1.45	37	4.8	7.4	32.3	5.0	G
I417	0.76	27	3.6	7.4	18.0	3.5	S/G
I435	2.85	60	5.5	5.2	26.1	13.7	G
I508	1.27	47	4.0	4.9	15.8	0.9	G
I509	2.61	54	4.6	1.1	20.5	1.6	S
I515	2.07	64	6.4	5.7	26.6	1.6	S/G
18	3.49	95	5.5	3.3	22.1	4.0	S
20	3.11	44	4.2	5.4	16.2	5.0	S/G
21	1.76	64	5.8	5.2	21.9	6.9	S
24	2.15	44	4.6	6.0	28.5	8.5	S/G
37	1.31	85	5.2	3.5	17.5	2.8	S/G
70	1.24	43	4.8	6.4	14.5	0.6	S/G
77	3.52	51	4.1	3.8	29.4	18.4	S
95	1.18	31	2.9	5.3	26.6	3.0	G
101	1.28	34	3.3	5.5	12.9	9.6	S
128	1.34	73	3.4	2.7	24.6	4.4	S/G
BOULDER BEACHES							
I500	0.85	No shelf	-		29.0	1.80	
58B	1.63	22	3.1	8.0	28.1	1.0	
90	0.92	21	3.5	9.5	30.5	3.5	
120	0.56	No shelf	-		29.9	0.3	
142	0.77	28	1.7	3.5	29.5	2.8	
152	0.91	No shelf	-		20.2	0.4	

Profile No.	Effective Fetch Length (km)	Foreshore/Nearshore Width (m)	Foreshore/Nearshore Elevation (m)	Foreshore/Nearshore Slope (°)	Offshore Slope (°)	Catchment Area (km²)	Delta Width (m)	Delta Area (km²)	Beach Type Sand (S) Gravel (G) Mixed (S/G)
INNER FIORD BAY HEAD DELTAS									
I403	2.63	238	3.3	0.8	27.9	26.5	500	0.119	S/G
I412	1.50	110	3.0	1.6	7.4	0.9	510	0.056	S/G
I413	1.21	128	3.0	1.3	17.3	24.4	500	0.064	S/G
I434	0.93	750	3.6	0.3	13.6	21.7	200	0.150	S
I436	1.69	680	1.2	0.1	19.7	251.3	1140	0.775	S
I444	1.00	196	2.3	0.7	8.2	35.5	420	0.082	S/G
I457	1.60	186	3.5	1.1	20.5	12.5	450	0.084	S
I489	0.60	83	2.3	1.6	14.2	15.0	200	0.017	S/G
I499	1.02	176	3.8	1.2	31.2	5.4	100	0.017	S
I490	1.40	110	2.0	1.0	23.5	7.8	250	0.027	S/G
48	1.71	325	1.0	0.2	24.8	22.9	500	0.162	S/G
58	1.33	87	1.9	1.2	23.5	55.1	550	0.048	S/G
64	1.06	365	2.2	0.3	17.6	125.4	750	0.274	S/G
73	1.14	129	2.0	0.2	20.1	16.9	600	0.077	S/G
133	1.34	244	2.1	0.5	32.3	21.7	650	0.159	S/G
150	0.74	125	2.0	0.9	7.5	7.1	200	0.025	S/G
OUTER FIORD OPEN COAST BEACHES									
I387	>1000	1940	37.0	1.1	5.1	55.5			S
I389	"	No shelf	-	-	-	3.8			G
I397	"	No shelf	-	3.2	-	2.0			S
I398	"	No shelf	"	1.8	-	1.0			S/G
I399	"	No shelf	"	2.9		1.7			S
I425	"	2540	20.0	0.4	4.9	0.3			S/G
I501	"	114	11.5	5.8	23.8	1.0			G
I516	"	45	4.4	5.6	28.6	14.1			G
I526	"	4600	55.0	0.7	21.8	160.0			S
39	"	319	15.5	2.8	13.7	21.7			S
40	"	365	20.9	3.2	11.0	23.0			S
200	"	4400	58.0	0.7	9.1				S

Profile numbers I388, I410, I411, 1433, I510, 13, 91 have been excluded from the morphological analysis as structural controls affect the morphology.

narrow fiord entrances. Beaches in the entrance to the fiords and on the open coast are built in response to this oceanic swell wave climate, while those inside the fiords are moulded by low-energy waves generated within the restricted fetch conditions of the inner fiords.

METHODS

Shore-normal beach profiles were surveyed with a Quick Set Level and staff. These surveys were extended offshore with a 200 kHz Raytheon Survey Echo Sounder. Range poles on the beach were used to control the boat's course. Distances along the sounding line were measured with a tagged line tethered at the beach and paid out fom the survey boat. The sounder record was marked at 10-m intervals along this line. On some of the exposed beaches, where profiles were longer than 500 m or where landing was not possible, positions were fixed with a hand bearing compass and plotted on Lands and Survey 1:63 360 scale maps (NZMS 1).

Foreshore sediments were collected by hand. In deeper water, samples were collected with either a pipe dredge, Lafond Dietz grab (see Lafond & Dietz 1948), or gravity corer. The samples were washed, dried, and weighed before being treated with hydrogen peroxide to eliminate organic matter. Sand and gravel fractions were sieved at 0.5 ϕ intervals, the mud fraction being sized by pipette analysis. The percent dry weight organic matter and textural parameters of Folk (1968) were calculated.

BEACH AND NEARSHORE MORPHOLOGY

Beach and nearshore profiles for 56 beaches from Martins Bay in the north to Preservation Inlet in the south are shown in Fig. 2. Beaches exposed to the open coast can be separated from those of the sheltered inner fiords.

Sheltered inner fiord beaches

In the sheltered waters of the inner fiords the beach and nearshore systems have a distinctive shelf morphology with a downward sloping concave profile, steepest at the top of the beach, and decreasing in slope down the foreshore and across a shallow shelf (Fig. 2). At the outer edge of the shelf there is a sharp break in slope and a steep offshore face.

From nearby Lakes Manapouri and Te Anau a similar beach and nearshore morphology has been described (Irwin 1974a, 1974b, 1975; Pickrill 1978). In the lakes the profiles were divided into 3 slope facets, the foreshore, the nearshore shelf, and the offshore slope (Pickrill 1978). In the fiords tidal fluctuations make it difficult to draw sharp boundaries between the foreshore and nearshore shelf, and the morphology is divided into 2 slope units: a combined foreshore/nearshore shelf extending from the highest storm berm, offshore to the first break in slope, and an offshore slope extending seaward from this first break in slope*. From the profiles the average slope of these 2 facets and the width and elevational range of the foreshore/nearshore shelf were measured. Characteristics of the inner fiord beaches are summarised in Table 1. Three separate beach types can be distinguished.

1. *Bay head delta beaches:* At the head of most of the fiords, and on the fiord sides where large rivers enter the main fiord, the valley floor is infilled with fluvial Holocene sediments. The rivers draining these large headwater catchments have wide, flat, prograding deltas extending across the full width of the fiord. The foreshore/nearshore shelf is wide ($\bar{x}$ = 245 m) and nearly flat ($\bar{x}$ = 0.8°). The elevational range from the shelf edge to the top of the foreshore is small ($\bar{x}$ = 2.45 m)while the offshore slope is steep ($\bar{x}$ = 19.3°).

2. *Fiord margin sand and gravel beaches:* On the steep sides of the fiords beaches are rare, forming in isolated pockets of moraine trapped in re-entrants and on small deltas where tributary streams discharge into the fiord. On many of these smaller deltas the sediment is reworked alongside into re-entrants by wind waves blowing down the long axis of the fiords. The shelf on these beaches is narrow ($\bar{x}$ = 52 m) and gently sloping ($\bar{x}$ = 4.9°); the offshore slope is steep ($\bar{x}$ = 23.2°).

3. *Fiord margin boulder beaches:* Beaches supplied with coarse sediment unable to be reworked by wave activity rarely develop a shelf form. The beach is narrow and steep (8–10°), and the offshore slope is an extension of the subaerial morphology.

Exposed outer fiord and open coast beaches

On the exposed outer fiord and open coast beaches the shallow-water shelf morphology is replaced by a morphology more typical of a high-energy shoreline,

*The shelf break is a transition zone and not simply a clearly defined break point. Different methods of determining the break in slope on the outer edge of the continental shelf are discussed by Wear et al. (1974). They defined the shelf break by extending a straight line parallel to the surface of the outermost shelf. The point at which the bottom trace departs from this line is designated the shelf break. This technique has been used in the present study.

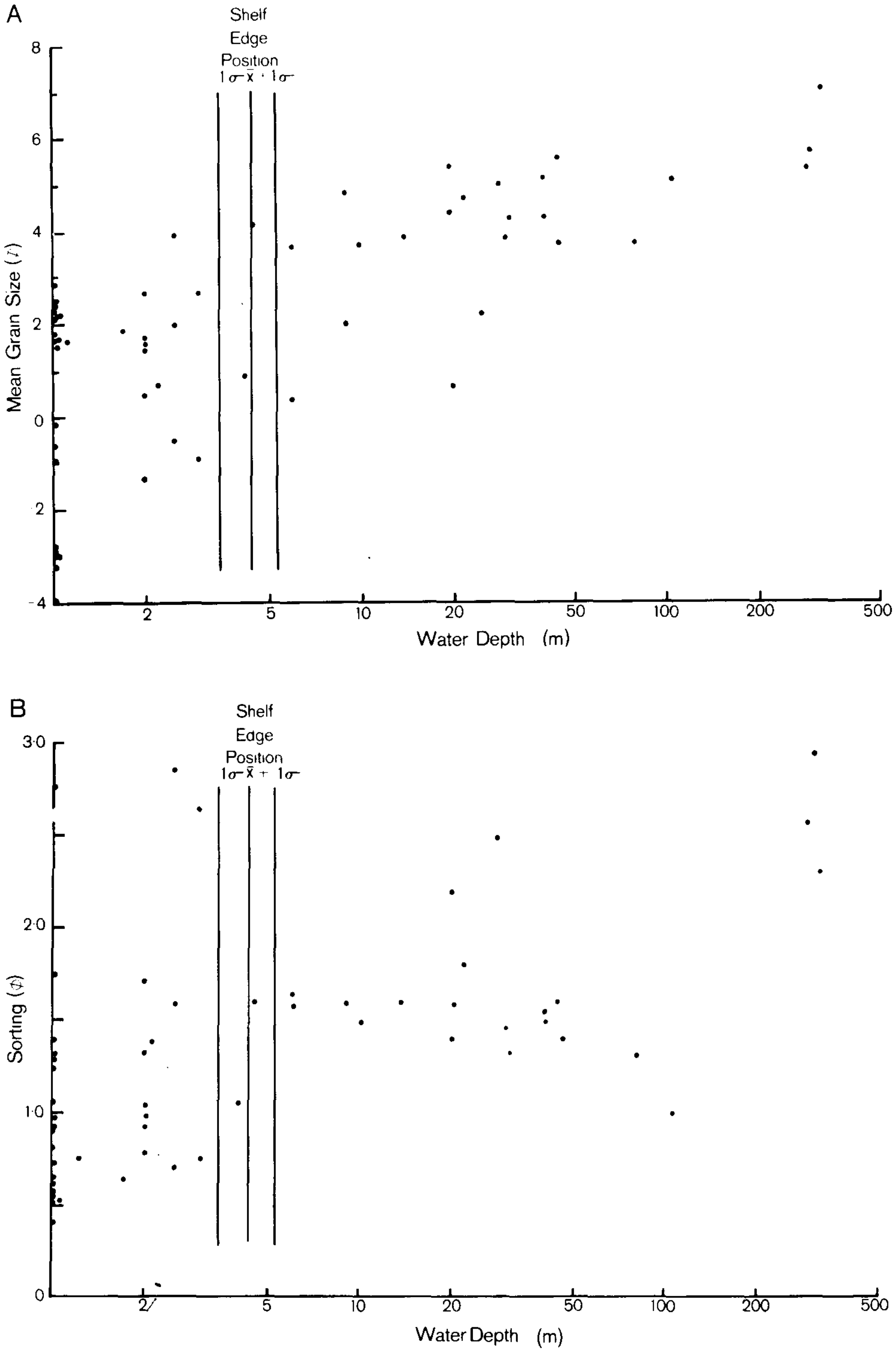

Fig. 3 A Bivariate plot of mean grain size against depth for the sheltered inner fiord beaches. **B** Bivariate plot of sorting against depth for the sheltered inner fiord beaches.

that of wide flat beaches (Fig. 2, Table 1). On beaches prograding into deep water inside the entrance sills (Fig. 2, profiles 39, 40) a deep-water shelf morphology is found, with a shelf 300–400 m wide and a shelf break in 15–20 m of water. In the wide, shallow entrance to Preservation and Chalky Inlets, where the sill depths are only 30 and 45 m respectively, the shelf profile has not developed (Fig. 2, profiles I397, I398, I399) and the beaches grade evenly onto the shallow sill. Martins Bay and Sutherland Sound are 2 former fiords closed off from the sea by barrier spits (Fig. 1). The barriers have been built across the shallow entrance sills. On these profiles the shelf break is probably controlled by the underlying bedrock rather than by wave processes. In these bays the shelves are respectively 4.4 and 4.6 km wide with shelf breaks in 55 and 58 m of water. The sample size is too small and the structural limitations too numerous and varied to enable a vigorous definition of the morphology of the exposed Fiordland shelf.

BEACH AND NEARSHORE SEDIMENTS

Inner fiord sediments

While there are obviously large differences from beach to beach the plot of grain size against depth (Fig. 3A) shows the general pattern of shore normal trends in texture. There is a wide range of foreshore sediments, from fine sand through to gravel (Fig. 3A). Sediments become finer down the shallow nearshore shelf as the coarse gravel fraction is eliminated. Shelf sediments are medium to fine sand. The shelf break marks a transition to muddy sand and sandy mud, but there is no obvious size grading down this steep offshore slope and only occasionally are coarse to medium sands found.

These shore normal trends in size are paralleled by shore normal trends in sorting coefficients (Fig. 3B). As on most ocean beaches, the sand and gravel foreshore sediments are well to moderately well sorted, while bimodal mixed sand–gravel beaches are made up of 2 well sorted sub-populations. Sorting deteriorates across the shelf; the muddy sand and sandy mud of the steep offshore slope are unimodal and poorly sorted.

Sediments from the steep offshore slope and deep basins are rich in organic matter, with most samples containing 10–20% organic material by dry weight, while some contain up to 83%. Shelf and foreshore sediments are free from organic material, except on some of the nearly flat bay head deltas, where plant remains may accumulate in shallow depressions.

These shore normal trends in texture are found on both fiord margin and bay head delta beaches. They are clearly defined on individual cross sections across the beach/nearshore system (Fig. 4).

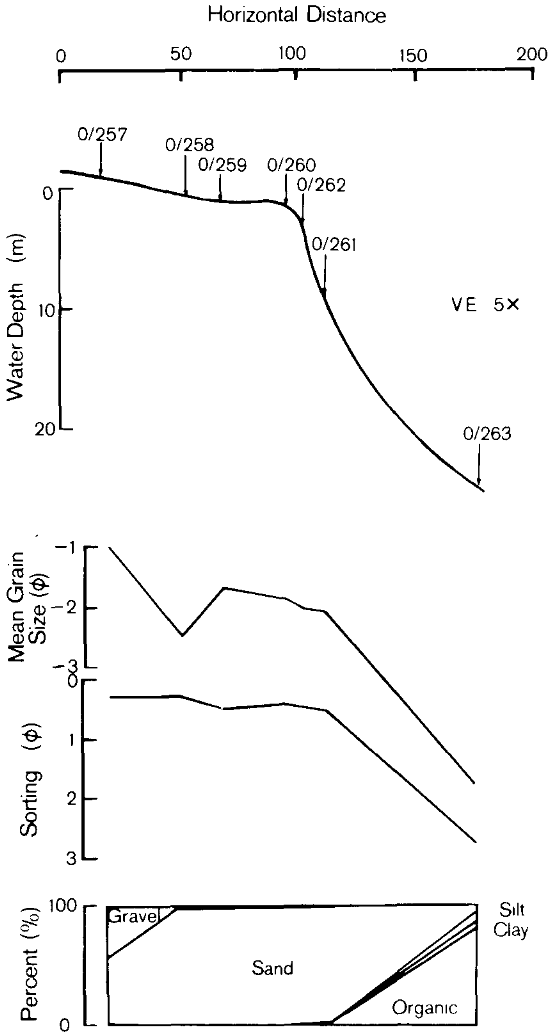

Fig. 4 Beach/nearshore profile across a typical fiord margin sand beach showing shore-normal textural patterns.

Outer fiord sediments

Most of the exposed Fiordland beaches sampled are composed of medium to find sands. Unlike the sheltered beaches of the inner fiords, there is no general fining of sediment across the shelf, and shelf sediments are also medium to fine sand (Fig. 5A). However, there is a shore normal decrease in sorting, and for any given depth, sediments are better sorted than on the sheltered beaches inside the fiords (Fig. 5B).

Unlike the inner fiord beaches there is no sharp change in sediment characteristics across the shelf break. Sediments on the offshore slope are sandy, free from organic matter, and not so well sorted as those on the shelf. A typical section across the shelf is shown in Fig. 6.

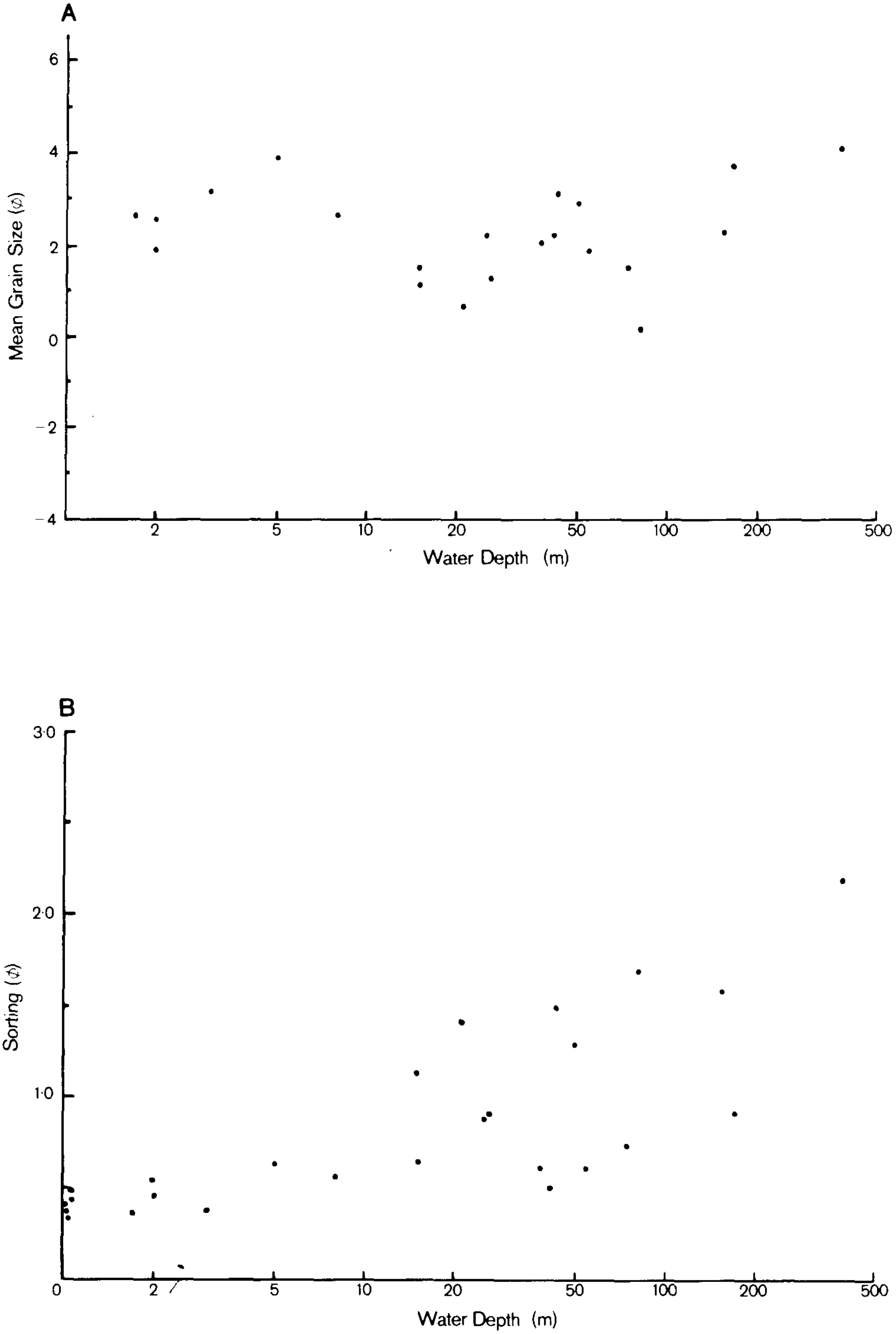

Fig. 5 **A** Bivariate plot of mean grain size against depth for the open coast fiord beaches. **B** Bivariate plot of sorting against depth for the open coast fiord beaches.

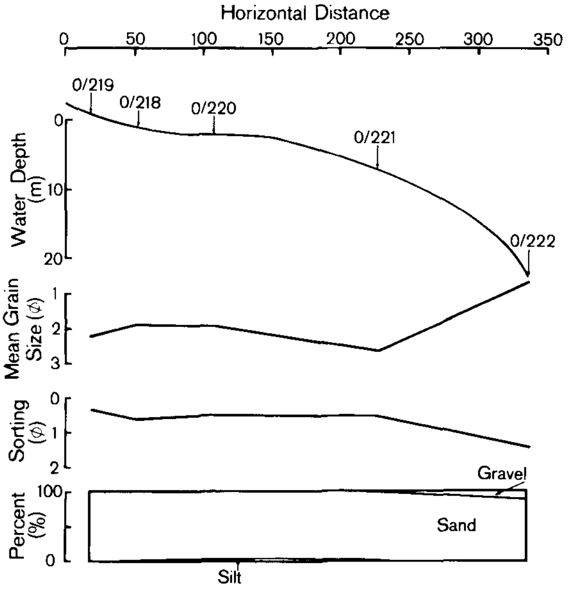

Fig. 6 Beach/nearshore profile across a typical open coast fiord sand beach showing shore-normal textural patterns.

SIMILARITIES AND DIFFERENCES BETWEEN OCEAN AND LIMNIC FIORD BEACHES

The ocean fiords of the South Island west coast are very similar to the glacial lakes Manapouri and Te Anau on the eastern side of the main divide in that both types of coast have been formed by the same erosive glacial processes, and both have similar fiord structures, with long, narrow, steep-sided inlets and deep basins separated by shallower sills. The ocean fiords are saline with a semi-diurnal tidal range of approximately 2 m (Marine Division, Ministry of Transport 1977). The natural range of water level in the freshwater lakes is 4.8 m in Manapouri and 3.9 m in Te Anau. However, for 80% of the time the range is less than 2.0 m in both lakes. Thus, while the ocean fiords are subjected to daily rhythmic fluctuations in water level, the limnic beaches are subjected to irregular fluctuations dependent on freshwater inflow and outflow. Tidal currents in the fiords are weak (Stanton 1978) and although there are no comparable currents in the lakes they are probably not important as agents of sediment transport in the littoral zone. In the lakes, and in the inner fiords, locally generated wind waves are the dominant hydraulic process affecting the shorelines.

The morphology of the fiord margin beaches is identical to that of the lakes (see Table 2). Student *t* tests show there are no differences between the shelf characteristics of the fiords and the 2 lakes at the 0.01 confidence level.

Beach nearshore sediments from the inner fiord and limnic systems exhibit similar shore normal trends. In both, sand becomes finer and more poorly sorted across the nearshore shelf, and the shelf break marks a textural as well as a morphological boundary with a change from clean well-sorted sand to organic-rich poorly sorted sandy mud or muddy sand.

INNER FIORD BEACHES AS EQUILIBRIUM SHELF MODELS

Fiord margin beaches

While the fiord margin beaches all have a similar shelf form there are systematic differences between the shelf characteristics which suggest that these beaches have developed as dynamic forms in equilibrium with wave processes. Correlations (Table 3A) between the shelf characteristics show there is an inverse relationship between the shelf width and slope, and a positive correlation between the width and elevation. These relationships suggest that at one extreme there are wide, flat beaches with high storm berms and at the other extreme relatively narrow steep beaches with a small elevational range between the storm berm and shelf edge.

In the nearby limnic systems similar relationships between the shelf characteristics have been described (Pickrill 1978). The shelf develops as an equilibrium form in response to wind wave activity. As the exposure to wind waves increases the shelf gets wider and deeper and the slope decreases (Pickrill 1978). Effective fetch length (U.S. Army Corps Engineers 1962) has been taken as a measure of exposure to wave activity, and relationships between this and the fiord shelf characteristics have been examined.

On the fiord margin beaches only 1 statistically acceptable relationship was found (Table 3B). The width of the shelf increases as a function of fetch length. The weaker relationships in the fiords may be a function of the limited range of fetch lengths rather than simply not fitting the equilibrium hypothesis developed for the lake shelves. In the fiords the mean fetch length is short and the range narrow compared with the much longer fetch lengths and larger standard deviations on the lakes (Table 2). This small range produces a correspondingly narrower range of shelf morphologies. In limited fetch conditions such as these other processes affecting the beach system (e.g., the size of the sediment and the rate of sediment supply) are probably more important in controlling small variations in morphology. Despite these limitations linear regression fitted between the foreshore/nearshore characteristics and effective fetch length

Table 2 Summary of beach/nearshore characteristics in the fiords and Lakes Manapouri and Te Anau. The lake data are derived from Pickrill (1978, table 1).

	Foreshore/nearshore shelf						Offshore slope (°)		Effective fetch (km)	
	Slope (°)		Elevation (m)		Width (m)					
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Ocean Fiords	4.9	1.6	4.4	0.9	51.9	17.4	23.2	7.7	2.04	0.92
Lake Te Anau	5.8	1.8	4.7	1.3	50.4	26.4	29.0	4.6	5.36	2.53
Lake Manapouri	6.2	2.3	4.4	1.3	46.2	23.0	35.6	13.3	3.37	1.85

Table 3 **A** Correlation coefficients between the beach /nearshore variables for the fiord margin beaches and bay head deltas. **B** Correlation coefficients between the beach/nearshore variables and effective fetch length.

A

BAY HEAD DELTAS	FIORD MARGIN BEACHES: Width	Elevation	Slope
Width		0.406*	-0.713**
Elevation	-0.05^{NS}		-0.106^{NS}
Slope	-0.682**	0.45*	

B

	Width	Elevation	Slope
Bay Head deltas: Effective Fetch	0.11^{NS}	0.01^{NS}	-0.07^{NS}
Fiord margin beaches: Effective Fetch	0.54**	0.32^{NS}	0.25^{NS}

*Significant at 0.05 level, ** significant at 0.01 level, NS - not significant.

produce similar descriptive relationships in the fiords as in the 2 lakes; this suggests that both environments develop equilibrium shelf forms in response to the local wave climate.

BEACH/NEARSHORE WIDTH

Lake Manapouri = 24.5 + 6.33 effective fetch **
Lake Te Anau = 15.0 + 6.61 effective fetch **
Fiord margins = 31.5 + 9.86 effective fetch **

BEACH/NEARSHORE ELEVATION

Lake Manapouri = 3.13 + 0.36 effective fetch **
Lake Te Anau = 2.44 + 0.42 effective fetch **
Fiord margins = 3.83 + 0.29 effective fetch NS

**Significant at 0.01 confidence level, NS–not significant

Bay head deltas

Student *t* tests show that fiord margin beaches and bay head deltas are different in terms of slope, width, and elevation. While the morphology of the fiord margin beaches is an equilibrium shelf form developed in response to local wind waves, the characteristics of the bay head deltas bear no relationship to the fetch conditions (Table 3), because the form of the bay head deltas is controlled by fluvial rather than marine processes. The deltas are all fed by rivers draining large valleys at the head of the fiords. The size of these catchments, and by association the resultant sediment loadings, appears to be a major control of the area, width, and slope of the deltas (Table 4). By contrast, the fiord margin beaches have small catchments and the morphology appears to develop independent of catchment controls in response to the local wave climate (Table 4).

FIORD AND LIMNIC BEACH SHELVES AS MODELS OF THE CONTINENTAL SHELF

In describing the morphology and sediments of Lakes Manapouri and Te Anau an analogy was drawn between the development of equilibrium size graded shelves in the limnic and ocean environments (Pickrill 1978).

The development of an equilibrium shelf on the continental margins is a complex process, the morphology and sediment distribution being in part predetermined by relict shorelines and sediments from previous low stands of sealevel (see Lewis (1974) for a review of shelf formation). However, in an ideal situation of stable sealevels and tectonic stability, an equilibrium size-graded profile, with 2 sedimentary facies, could be expected to form, with a seaward fining wedge of sand in the nearshore modern sand prism and a modern mud blanket on the steep shelf slope.

Table 4 Correlation coefficients between the beach/nearshore variables of the fiord margin beaches and bay head deltas and catchment areas.

		Width	Elevation	Slope	Area
Catchment Area:	Deltas	0.61**	-0.45^{NS}	-0.50*	0.95***
	Fiord Margin Beaches	0.19^{NS}	-0.11^{NS}	-0.19^{NS}	-

* Significant at 0.05 level, ** significant at 0.01 level,

*** Significant at 0.001 level, NS - not significant.

Despite the large differences in scale the shelf morphologies and associated sediment distributions in the glacial lakes and continental margins are similar. In both the prograding wedge of nearshore sands fines to the outer edge of the shelf and the shelf break marks a transition from sandy to muddy sediments as a result of a change in the processes of sediment transport (Pickrill 1978). As such, the limnic shelves can be considered models of progradational continental shelves. In view of the similarities between the lake and fiord beaches the sheltered ocean fiord shelves also fit this model.

The continental shelf off the Fiordland coast is narrow and steep. On exposed beaches, prograding into deep water in the fiord entrances, a deep-water shelf morphology has developed. The sediment distributions across these shelves are indicative of an actively prograding shelf, as yet to gain an equilibrium profile form. The development of these shelves might be likened to the development of an initial continental shelf on a steep continental margin.

A transitional morphology might be expected between this high energy, deep-water shelf and the low energy, shallow-water shelves of the inner fiords. Given suitable conditions a hierarchy of shelf morphologies could be expected to develop, ranging from the wide, flat, deep-water shelves of the continental margins through to the narrow, steep shelves developed in restricted fetch conditions. In most of the fiords there is very little translation of wave energy up the inlet from the open sea, the entrances being too narrow and deep. However, in the entrance to Thompson Sound, this transition can be traced (Table 1, profiles 40, 39, 37; Fig. 2)—the shelf narrows, the shelf slope steepens, and the elevational range of the shelf/beach system decreases as the exposure to open ocean swell decreases up the fiord.

CONCLUSIONS

The beaches of Fiordland have a distinctive shelf morphology.

1. Beaches exposed to open ocean swell develop a deep-water progradational shelf form.

2. In the sheltered fiords a shallow-water shelf develops. On the sheltered fiord margin beaches the shelf is narrow and gently sloping. The shelf morphology and shore normal sediment distribution has developed in response to locally generated wind waves. On the large deltas at the head of the fiords the morphology is controlled primarily by sediment input from the catchment, and the shelf is wide and flat.

3. The morphology and sediments of the sheltered ocean fiord beaches are similar to those on the nearby glacial lakes of Manapouri and Te Anau. Both systems have developed an equilibrium form in response to the local wave climate, and both can be considered as models of progradational continental shelves.

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