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SEDIMENT YIELDS IN FIORDLAND

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ABSTRACT

Sediment yields from New Zealand catchments traditionally have been determined from hydrological data collected over a few decades. In this paper estimates of long-term average sediment yields for the Holocene are made from sedimentological data from Fiordland, South Island, New Zealand. Radiometric dating and seismic reflection profiling have been used to determine sedimentation rates and volumes of sediment fill. From these data sediment yields have been determined for three fjord catchments. The long-term, average yields range between 28 and 209 tonnes/km^2/yr, and are much lower than previously published rates derived from stream flow and suspended sediment ratings (13300 tonnes/km^2/yr). These large differences are difficult to explain, particularly as the fjord waters and bottom sediments show characteristics typical of a low sediment environment. While some sediment may be lost seaward out of the fjord systems, this is a small percentage of the total and can not account for the large disparity between the two techniques.

THE PROBLEM

Measurements of river flow and suspended load concentrations have been made in many New Zealand rivers. Unfortunately the records of suspended load are quite short, the number of observations sparse and only recently has the data base been adequate to derive some simplified estimates of catchment sediment yields (e.g., Adams, 1979; Thompson & Adams, 1979; Griffiths, 1979; Jowett & Hicks, 1981). Sediment yields vary greatly between catchments, which is not surprising in a country with such diverse geology and climate. Despite this, yields generally fall within the range estimated from similar environments in other parts of the world. However, Griffiths (1979) identified the Western Southern Alps as a unique zone in New Zealand, with extremely high sediment yields by global standards.

In the last fifteen years New Zealand Oceanographic Institute has carried out sedimentological surveys in several fjords, and glacially excavated and man-made lakes of the southern South Island. Results from this work suggest that in Fiordland sedimentation rates, and by inference sediment yields from the catchments, are low, and certainly not abnormally high. This paper presents data on estimates of long term sediment yields from Fiordland, and demonstrates techniques for determining sediment yields in catchments draining into confined basins.

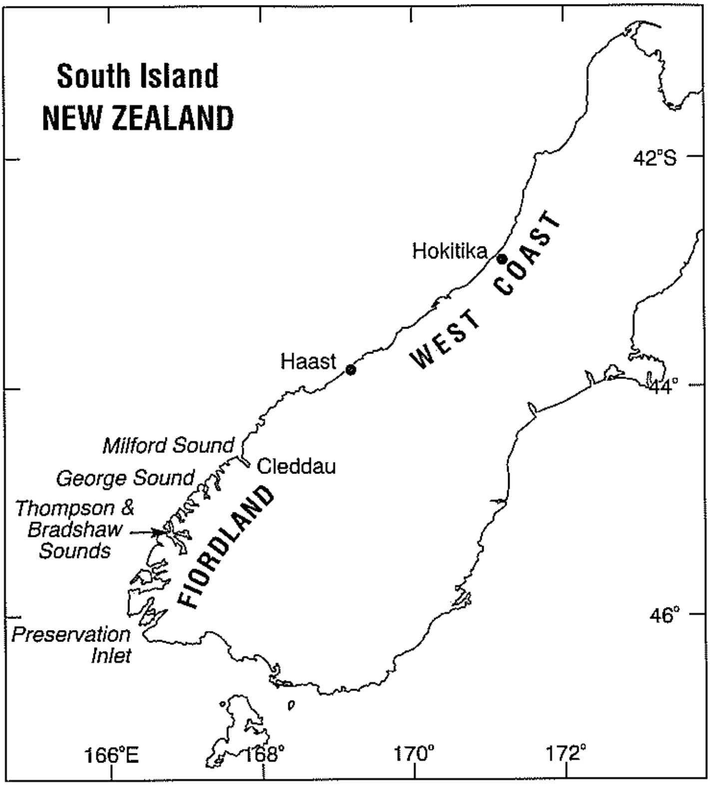

FIG. 1—Location of catchments and fjords referred to in the text.

BACKGROUND

In 1977 a reconaissance oceanographic and geological survey was made of all of the New Zealand fjords (Stanton & Pickard, 1981). The findings from this survey were used to select four fjords (Fig. 1) considered typical of the range of environments in the area: Milford Sound, George Sound, Thompson/ Bradshaw Sound and Preservation Inlet. Detailed studies were carried out in these four fjords during two cruises aboard *R V Tangaroa* in 1980 and 1983. Additional information is available from earlier studies in Caswell, Nancy and Milford Sounds (Glasby, 1978; Skerman, 1964). Measurements were made of the water properties: salinity, temperature, and concentration of suspended particulate matter. Composition of the suspended particulate matter was examined with a scanning electron microscope. Seismic reflection profiling was carried out with a hull-mounted 3.5kHz system aboard the ship, and with a EG & G *Uniboom* system operated from a small boat. Bottom sediments were sampled

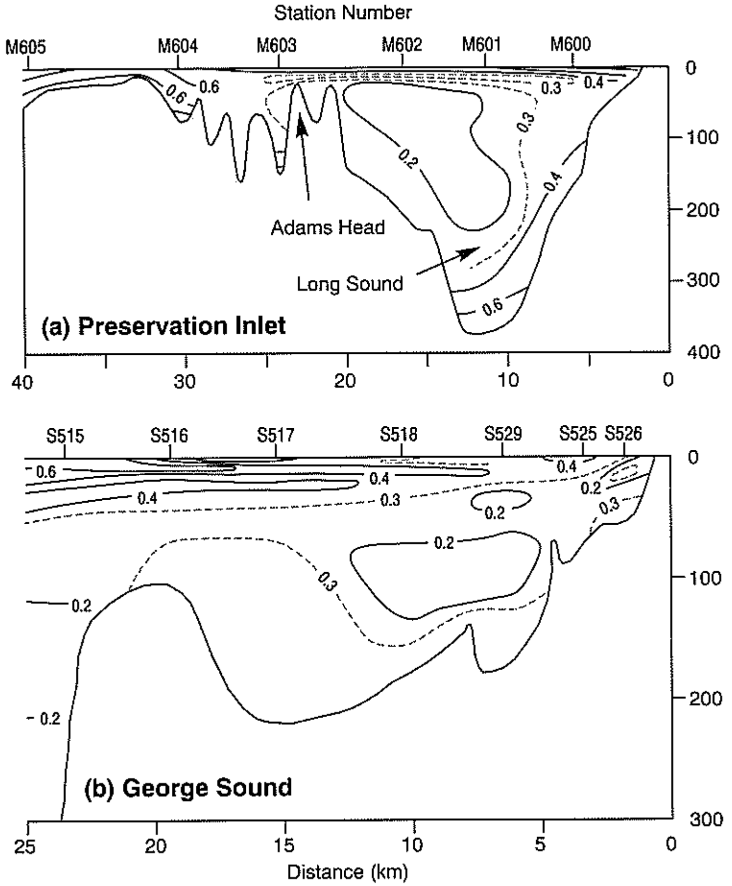

FIG. 2—Typical longitudinal profiles of suspended particulate matter concentration (mg/L) in the New Zealand fiords. (From Pickrill 1987). A. Preservation Inlet in spring (1980). B. George Sound in winter (1983).

using corers, grabs and underwater photography. Selected samples from the cores were submitted to the Institute of Nuclear Sciences DSIR for C^{14} dating.

From these studies circulation and depositional models have been developed (Stanton & Pickard, 1981; Pickrill, 1987), while the high-resolution seismic reflection surveys and bottom sampling have provided a longer term perspective of depositional processes (Pickrill *et al.*, 1992; Pickrill, in prep.). The two techniques compilment each other, the one providing a contempory dynamic perspective and the other a longer term geological perspective on the fjord systems. In this paper some of these data are used to determine sedimentation rates in the fjords and sediment yields in adjoining catchments.

CIRCULATION AND SUSPENDED SEDIMENTS

Most of the large rivers in Fiordland enter at the heads of fjords, where coarse bed-load sediments are deposited on deltas and the suspended load is jetted out over the surface of the fjord as a buoyant plume. The fjords have an estuarine circulation with fresh or brackish water flowing seaward at the surface, entraining and mixing with saline water from below (Stanton and Pickard, 1981). Saline water is replenished by a landward flow of oceanic water at depth, the renewal of which may be restricted by sills which mark the entrance of all of the fjords.

In most temperate-latitude fjords the brackish surface layer has highest concentrations of suspended particulate matter at the river mouth at the head of the fjord (e.g., 100-200 mg/L), decreasing seaward (e.g., 1-2 mg/L) as particulate matter is dropped out of suspension (Syvitski and Murray, 1981). Farrow *et al.* (1983) likened this process to a perforated conveyor belt, in which there is a rapid decrease in suspended particulate matter along the surface layer and with depth, which in turn creates a logarithmic down-fjord decrease in grain size and sedimentation rates.

The water circulation in the New Zealand fjords conforms to this model but sedimentation is quite different. Firstly, suspended particulate matter concentrations are very low, typically less than 0.5 mg/L (Fig. 2). Levels in all fjords are more characteristic of the open ocean than fjord estuaries (Pickrill, 1987). Secondly, there are no strong or persistant down fjord gradients in concentration away from the inflowing rivers (Fig. 2). Thirdly, concentrations in the brackish surface layers are only marginally higher than in the underlying saline water.

The composition of the suspended particulate matter is also rather surprising: grain counts on samples from Preservation Inlet show that terrigenous grains are an almost insignificant percentage of the total (Fig. 3). Levels are highest close to river mouths but still make up less than 35% of the total material. The predominant constituents are organic matter and marine phytoplankton. The suspended particulate matter surveys lasted for 17 days in spring and 10 days in winter during which time seasonal conditions were 'typical' for Fiordland (Pickrill, 1987). The circulation and settling of suspended particulate matter in the deep waters of the fjords is slow and, unlike rivers, conditions in the water column reflect conditions in the catchment for preceding days, weeks or months (Stanton & Pickard, 1981).

Even though the water column sampling has been limited, it is still surprising that the fjords have very low concentrations of suspended particulate matter and by inference a low input of terrigenous sediment. The surface waters in the fjords have poor visibility (Grange *et al.*, 1991) and, citing northern hemisphere examples, earlier researchers have assumed this to be created by high levels of suspended particulate matter (e.g. Pantin, 1964). However measurements by Peake (1978) and our own studies show low visibility is in fact created by 'gelbstuf', humic and fluvic acids dissolved in the water, rather than by sediments in suspension. Grange *et al.* (1991) measured the optical properties of the water in Doubtful Sound over an 18-month period and concluded that, for most of the time, light attenuation in the surface waters was comparable with that in oceanic and coastal waters elsewhere in the world. Similar humic-rich waters

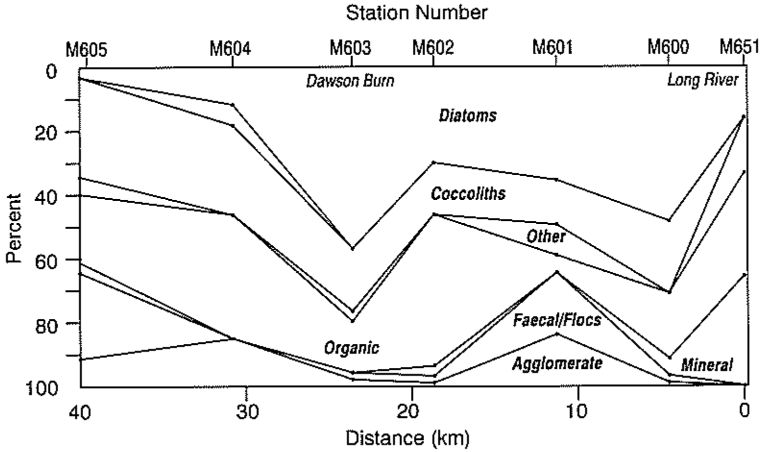

FIG. 3—Distribution of suspended particulate matter components at 2m depth in longitudinal profile during spring in Preservation Inlet. Station numbers correspond to those in Figure 2. From Pickrill (1987).

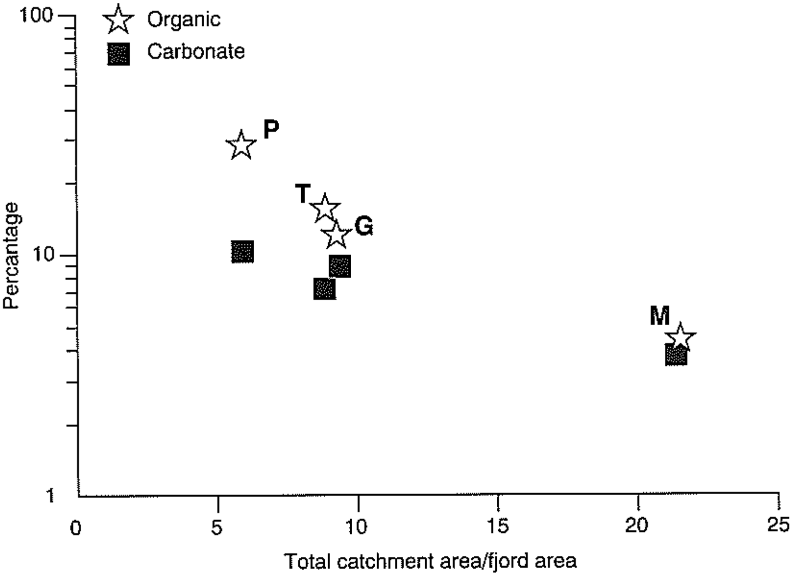

FIG. 4—Mean percent carbonate and organic content in bottom sediments from Milford Sound (M), Preservation Inlet (P), George Sound (G) and Thompson/Bradshaw Sounds (T) plotted as a function of the ratio of fjord catchment area to fjord area.

are characteristic of lakes draining forested catchments in other parts of the high rainfall zone of the West Coast South Island (Paerl *et al.*, 1979)

BOTTOM SEDIMENTS

In deep water, sediments are organic-rich muds. The sediment composition reflects the composition of suspended particulate matter in the water column, with large amounts of fibrous woody material, finer indeterminate organic matter, plankton, faecel pellets and a small terrigenous component (Pickrill, 1987). Sediment composition is indicative of the source area. Mineragenic sediments are derived from the surrounding catchments, biogenic calcareous sediments are derived *in situ* from pelagic and benthic organisms, while organic material originates both in the catchments and within the fjord waters. The ratio of catchment to fjord area is a measure of the size of the catchment, relative to the size of the receiving basin (Stanton & Pickard 1981). A logarithmic relationship between this catchment ratio and the percentage composition of *in situ* derived carbonate material (Fig. 4), reflects dilution of the carbonate sediment by mineragenic sediment from the catchments; organic matter content shows a similar trend (Fig. 4). This dilution effect has also been observed in the salinity structure of the surficial waters (Stanton & Pickard, 1981).

In northern hemisphere fjords there are down-fjord changes in grain size. Suspended particulate matter input by rivers at the fjord head is transported down fjord, and settling is size selective. No such trends are to be found in the New Zealand fjords. Coarse sand and gravels are deposited on steep foreset delta slopes, but soon give way to a uniform muddy drape just a few hundred meters down fjord (Pickrill, in prep). There are no textural trends in these muddy sediments.

All of the sedimentological data, from both the water column and floor of the fjords, point to a low input of sediment from the catchments. None of the traditional indicators of high sedimentation, and by inference high sediment yields, could be found.

SEISMIC STRATIGRAPHY AND SEDIMENT THICKNESS

The basinal muds produce a transparent seismic signature with occasional parallel reflectors (Fig. 5). Cores from the basins show these sediments to be unstratified massive mud, with occasional sandy laminae deposited from slope failures on the fjord walls (Pickrill, in prep.). The base of this seismic unit is an unconformity above a highly reflective unit with few discontinuous sub-bottom reflectors (Fig. 5). In Preservation Inlet cores penetrated this contact; samples above and below the contact have been radiocarbon dated at 14250-18450 years BP (Pickrill *et al.*, 1992). For the purposes of this paper the age of the contact is assumed to be 16000 years BP, and to mark a transition in the catchment from glacial to ice-free conditions (Pickrill *et al.*, 1992). These basal sediments are late last-glacial blue-grey clays.

This contact between glacial and post-glacial sediments can be traced throughout the fjord, enabling an isopach map of the Holocene and late glacial sediment cover above the 16 ky contact to be produced (Fig. 6). Two features on the isopach map are particularly relevant to estimating sediment yields and understanding mechanisms of sediment transport. Firstly, sediment cover is quite

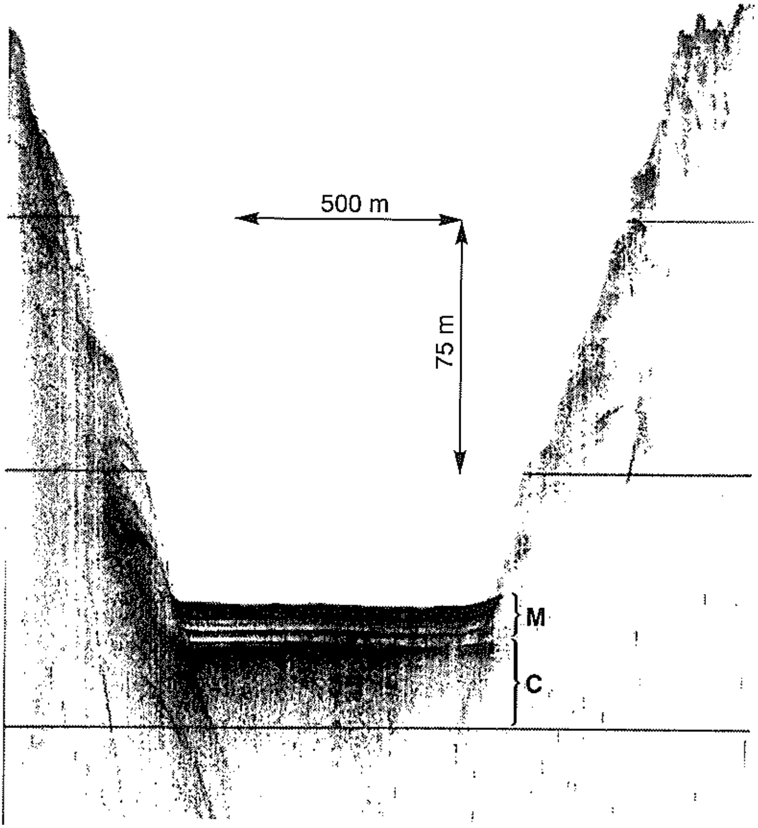

FIG. 5—Seismic reflection profile across Long Sound, Preservation Inlet, showing weakly bedded muds (M) overlying seismically opaque late-glacial clays (C).

thin (less than 16m). Secondly the sediment cover is relatively uniform, and surprisingly is thickest in deep water, becoming thinner toward the river mouths at the fjord head. There is no evidence from seismic reflection profiles or core stratigraphy for down-fjord thickening of sediments being generated by downslope flows or mass failure. These trends, however, are in accord with the findings from the suspended particulate matter and surficial sediment data, both of which indicate that sediment contribution from the fjord-head deltas is small, with river influence extending only a few hundred meters down fjord.

From the isopachs the total volume of fill within the fjord can be calculated. For the catchment above The Narrows Sill at the entrance to Long Sound, the total volume of sediment deposited in the last 16000 years is $0.205km^3$ from a catchment area, excluding the fjord itself, of $355m^2$. This equates to an annual sediment yield of $36m^3/km^2/yr$, or assuming a bulk sediment density of $1.27g/cm^3$, then approximately $46t/km^2/yr$.

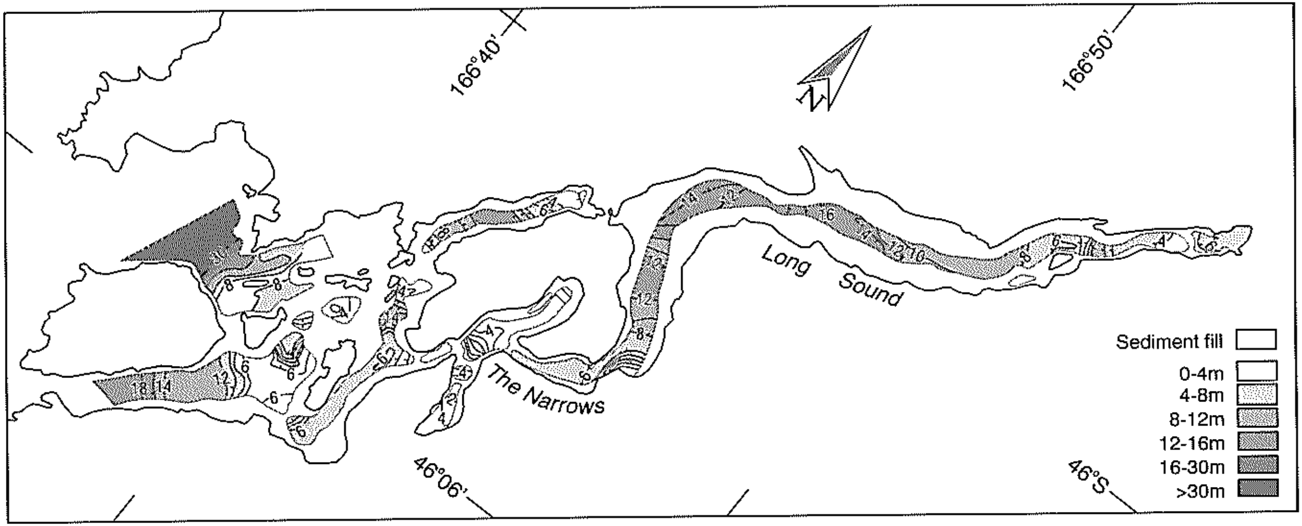

FIG. 6—Isopachs of sediment thickness (m) above the unconformity between post-glacial muds and late-glacial clays in Preservation Inlet.

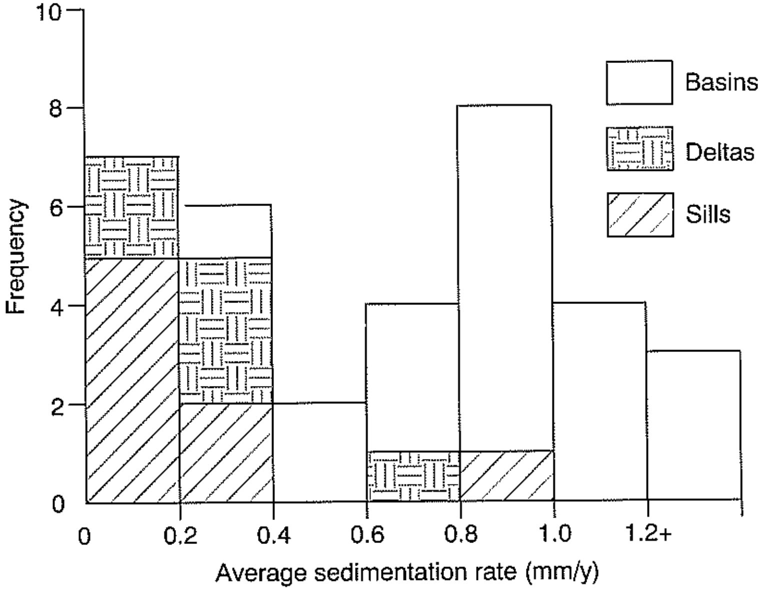

FIG. 7—Sedimentation rates derived from radiometric dating of core samples from basin, delta slope, and sill sediments from Nancy Sound, Thompson/Bradshaw Sounds and Preservation Inlet. Sample specifications are listed in Table I.

A similar unconformity can be identified in the seismic records from Thompson/ Bradshaw Sounds, where the sediment cover is slightly thicker at 15-25m. However, seismic coverage is inadequate to prepare isopachs and the age of this contact has not been confirmed by radiocarbon dating.

RADIOMETRIC DATING AND SEDIMENTATION RATES

The high organic carbon content of the sediments and occasional shell-rich laminae make most fjord sediments ideal for radiometric dating. Carbon dating has been carried out on core samples collected during the present study from Preservation Inlet and Bradshaw and Thompson Sounds, while samples have also been dated from Nancy Sound (Glasby, 1978). Table I presents a summary of 34 radiocarbon dates and sedimentation rates derived from the depth of burial within the cores. Dated samples can be divided into three groups; the basins, delta foreslopes and sills. Flows are concentrated over the sills and sedimentation rates tend to be very low (Fig. 7). While providing interesting information on the sedimentology in the fjords, this sill data is of little value in reconstructing a sediment budget other than to illustrate that sedimentation is focused on the basin floor.

Sedimentation rates in the different fjord basins are remarkably uniform, falling within a range of 0.4 to 1.4mm/year. The only exception is one sample from Nancy Sound (NZ1356) where the high sedimentation rate in Richards Basin may be either a result of gravitational mass movement or an artifact of core

TABLE 1 – Radiocarbon-dated core samples from the New Zealand fjords. Core numbers refer to NZOI Station Numbers. Data from Nancy Sound from Glasby (1978).

Location	Water Depth (m)	N.Z. no.	Sample Depth in core (cm)	C^{14} Date years BP	Sedimentation rate (mm/yr)
A. BASIN FORESET SEDIMENTS					
Preservation Inlet					
Long Basin		NZ5344	100-109	1950± 70 (peat)	0.54
Core M612	369	NZ5345	370-376	4220±130 (peat)	0.88
		NZ5346	650-655	7430±140 (peat)	0.88
Otago Basin		NZ5358	100-105	1090± 55 (shell)	0.94
Core M638	195	NZ5353	165-167	1690± 75 (peat)	0.98
		NZ5352	165-167	2350±130 (shell)	0.71
		NZ5354	216-226	1810± 75 (shell)	1.16
		NZ5355	216-226	2040± 90 (peat)	1.08
		NZ5356	270-275	2140± 80 (shell)	1.27
		NZ5357	270-275	2370±150 (peat)	1.15
Bradshaw Sound					
Bradshaw Basin		NZ4738B	91-100	1230± 65 (peat)	0.77
Core 1478	443	NZ4736B	157-164	1990± 70 (peat)	0.80
		NZ4735B	171-176	2040±130 (peat)	0.85
Thompson Sound					
Lyall Basin		NZ4740B	58-63	2610±470 (peat)	0.24
Core 1479	300	NZ4737B	382-388	5360±130 (peat)	0.71
Thompson Basin		NZ4742B	140-146	3110±130 (peat)	0.46
Core 1480	339	NZ4741B	466-473	3520±100 (peat)	1.33
Nancy Sound					
Heel Basin		NZ1354	105-110	1260± 73 (peat)	0.84
Core H264	99	NZ1355	116	1135± 75 (peat)	1.02
Richards Basin					
Core H266	201	NZ1356	484-486	1135±154 (peat)	4.26
B. DELTA SEDIMENTS					
Preservation Inlet					
Revolver Bay		NZ5350	105-110	9510±290 (peat)	0.11
Core M633	34	NZ5349	201-210	10150±200 (peat)	0.20
		NZ5351	235-240	10450±200 (peat)	0.23

Table 1, continued

Location	Water Depth (m)	N.Z. no.	Sample Depth in core (cm)	C^{14} Date years BP	Sedimentation rate (mm/yr)
Bradshaw Sound					
Gaer Arm		NZ4715B	82-97	12800±0250 (shell)	0.07
Core 1477	107	NZ4750B	302-308	11800±450 (shell)	0.26
Shoal Cove					
Core 1476	31	NZ4752B	52-60	814± 79 (peat)	0.71
C. SILL SEDIMENTS					
Preservation Inlet					
Entrance Sill		NZ5348	80-85	2560± 80 (shell)	0.32
Core M626	29	NZ5347	180-195	2230± 60 (shell)	0.84
Whale Sill		NZ7243B	145-149	9440±220 (shell)	0.16
Core S490	118	NZ7351B	159-163	11950±350 (peat)	0.13
		NZ7377B	196-200	14250±650 (peat)	0.14
		NZ7375B	206-210	18450±1650 (peat)	0.11
Narrows Sill		NZ5343	60-65	7920±130 (shell)	0.08
Core M609	45	NZ5342	200-201	8690±140 (shell)	0.23

disturbance (Glasby, 1978). Within individual fjords the radiometric dating shows sedimentation rates are lower off the deltas at the head of the fjords (Revolver Bay in Preservation Inlet, Gaer Arm/Shoal Cove in Bradshaw Sound) than in the basins, confirming the trend shown by the seismic data that sediment fill is thickest in the basin and thins to the head of the fjords. Core recovery was variable, the longest at 6.6m gave the oldest date from basin sediments (Table 1 NZ5346, 7430 ± 140 yrs B.P., Long Basin in Preservation Inlet). Most other basin samples gave dates in the range of 1000-4000 yrs B.P. Where more than one sample was dated from a core, rates of accumulation are often slightly lower at the surface, possibly reflecting a decrease in sedimentation in the last 2000 years. In some cores, dates are juxtaposed either as a result of sediment reworking (Entrance Sill, Preservation Inlet) or by dating two different materials within a small slide deposit originating from the fjord wall (Otago Basin).

Radiometric data have been used to calculate mean sedimentation rates in the basins of Nancy Sound, Thompson/Bradshaw Sound and Preservation Inlet (Table 2). Basin areas have been measured and used in conjunction with mean sedimentation rates to estimate total annual volumes of sediment fill (Table 2). This is the minimum fill, i.e. assuming sediment settles only on the basin

TABLE 2—Catchment conditions and sediment yields derived from radiocarbon dating and isopach reconstruction in the fjord basins. Sediment yields derived in this study include the total volume of sediment deposited, both marine and terrestrial. Catchment areas exclude the fjords themselves (from Stanton and Pickard, 1981). Sediment yields from Griffith (1979) for other West Coast catchments. Mean sedimentation rates have been extrapolated from these yields.

	This Study				Griffith (1979)		
	Long Sound Preserv. Inlet A	 B	Thompson/ Bradshaw Sound	Nancy Sound	Milford Sound (Cleddau River)	Haast River	Hokitika River
Fjord catchment area (km^2)	355	-	393	78	517 (155)	-	-
Fjord area (km^2)	27.0	-	49.3	13.9	25.3	-	-
Fjord basin floor area (km^2)	8.8	-	15.8	4.5	13.4	-	-
Mean sedimentation rate (C^{14}) (mm/yr)	0.90	-	0.91	0.93	214-404[2]	-	-
Volume of sediment fill[3] (m^3/yr)	7,900 24,300	-	14,400 44,900	4,200 12,900	5,414,000[2]	-	-
Sediment Yield $m^3/km^2/yr$	22-68	36	37-114	54-165	10,500[1]	10,000[1]	13,400[1]
$t/km^2/yr$	28-86[1]	46	47-145[1]	69-209[1]	13,300	12,700	17,100

A. From C^{14} dating
B. From isopach mapping
1. Assuming a bulk sediment density of 1.27 g/cm^3
2. Sedimentation rate and volume of fill derived assuming an input of 13,300 $t/km^2/yr$ from the fjord catchment and 100% trapping efficiency.
3. The range of volumes assumes deposition only on the basin floor and evenly across the whole of the fjord area.

floor. Seismic data suggests this is largely true, nevertheless some sediment does settle on the fjord margins and a second estimate is presented on the assumption that sediment settles evenly over the entire fjord area (Table 2). Volumes of sediment fill probably lie at the bottom end of this range. These volumes of infill include calcareous and organic material which, for the most part, are not erosional products from the catchments. Sediments yields derived from these volumes range between 28 and 209 t/km^2/yr (Table 2) and must be considered average yields for the Holocene. Data from these three fjords suggests there is a decrease in sediment yields towards the south. In Preservation Inlet these rates are comparable with those determined for the last 16 ky from isopach mapping of the seismic discontinuity (Table 2).

DISCUSSION

The accumulated oceanographic data, measurements of suspended particulate matter concentration and composition, basin sediment composition and seismic stratigraphy all point to sediment input to the fjords being low. Isopach reconstruction of sediment fill above dated seismic discontinuities and radiometric dating of sedimentation rates both show that long-term sedimentation rates are small and that by inference sediment yields from the catchments are low.

Comparison of sediment yields derived in this paper with those of Griffiths (1979) for the south West Coast South Island shows a large disparity (Table 2). The two studies approach the problem of estimating sediment yields using very different techniques; one measuring river flows and sediment loads directly at a few points in time to extrapolate to the long period record, the other measuring the time-averaged product of these flows as recorded over several thousand years in the receiving basins. Griffith's rates are ". . . enormous . . . (rates for the Hokitika River) . . . are 2.4 times higher than that of the Ching River in China, quoted as having the largest measured specific yield of major rivers of the world." Rates for the Cleddau draining into the head of Milford Sound are not much lower (Table 2). By contrast rates derived in this paper are lower than previous estimates for the West Coast South Island and closer to those derived from the Maimai, a mountainous catchment with moderate rainfall in the northern South Island (O'Loughlin *et al.*, 1978, 20-110m^3/km^2/yr), and much lower than the world average for mountain terrain, estimated to be 1300 tonnes/km^2/yr (Griffiths, 1979).

Griffiths derived his highest sediment yields from the Hokitika, Haast and Cleddau catchments. Estimates from the geological data have been derived from catchments south of Milford Sound. There are significant changes in vegetation cover, physiographic setting and bedrock geology between Haast and Milford Sound. The southern catchments are largely forested, do not contain glaciers in the headwaters and have been cut in resistant gneisses and granites of the Fiordland Complex. In contrast many of the northern catchments contain glaciers, have formed in erodible schists and have experienced the impacts of man over recent historical time. As such sediment yields should be higher on the West Coast than in Fiordland. The post-glacial record of sedimentation provides indirect evidence for this, West Coast fjords having been infilled with sediment and fronted by a prograding coastal plain since deglaciation, whereas in Fiordland the fjords have been altered little since deglaciation and remain as overdeepened basins. In a review of South Island sediment yields Griffiths grouped the West

Coast and Fiordland into a single region, whereas the data presented here suggests that Fiordland should be considered a separate region, of significantly lower yields than the West Coast.

The more northerly fjords of Thompson/Bradshaw Sound and Nancy Sound are similar to Milford in terms of climate and catchment conditions; Preservation Inlet in the south has lower rainfall. Sediment yields are dependent on rainfall such that a moderate decrease in rainfall gives a large decrease in yield (Griffiths 1979); this in part may explain decreasing sediment yields towards the south. However, the magnitude differences in sediment yield between Milford, derived by sediment rating, and the other fjords, derived from sediment budgets, can not be a product of climate and catchment conditions. Why is there such a disparity in the sediment yields derived by these two different techniques? The data base used by Griffiths (1979) to develop a suspended sediment rating curve for the Cleddau River at a point upstream of its entrance into Milford Sound was limited. Data obtained were from relatively low peak discharge, high frequency floods, which when extrapolated to high flow rates can generate significant errors in estimating suspended sediment load over a period of several years. Similarly the estimate of total sediment input to Milford Sound, derived by simply prorating the input from the Cleddau River to the total area contributing to the fjord, may not be valid if there is significant variability in the total catchment, and particularly if there is substantial storage upstream, as could be the case in Milford where Lake Ada on the Arthur River would act as a sink for much of the sediment generated in the upper catchment.

The sediment budget approach does have potential to underestimate sediment yields. The fjord basins are not 100 percent efficient as sediment traps. Sediment can be exported from the fjords in the seaward-flowing surface flow. Trapping efficiencies of less than 1%, however, would be required to match the estimates of Griffiths (Table 2). Or, put another way, sediment yields predicted by Griffith for Milford Sound would result in mean sedimentation rates of 214-404 mm/yr (Table 2, assuming 100% trapping efficiency). The sediment concentration measurements in the rivers were made mostly during relatively low peak discharge, high-frequency floods that are considered to transport approximately 75% of the total sediment load. During floods the seaward-flowing surface layer would be strengthened and the residence time of the brackish water would be lower, allowing more sediment to be lost to the fjords. Unfortunately we do not have any measurements of suspended particulate matter concentrations under flood conditions. However, if this were the case then the effects would be a down-fjord logarithmic decrease in sedimentation rate and grain size, and high sedimentation rates with predominantly terrigenous sediment; this is not observed. Fjords are long; the shortest is 10km and the longest 44km. A sediment-laden river entering the quiet water at the head of a fjord as a surface plume could not travel these distances down-fjord to the open coast, and retain most of the sediment in suspension, without leaving some evidence in the sedimentary record in the fjord basins. The geological evidence from the fjords, and studies of deltaic systems elsewhere around the globe, suggest that fjords are in fact very efficient sediment traps (e.g. Syvitski *et al.*, 1987). Efficiencies are probably greater than 80%. Sedimentation rates consistent with the large volumes of sediment predicted to enter the fjords from the hydrological data are not found in any temperature latitude fjords, most of which have much larger ratios of catchment to receiving basin than in New Zealand. Such high sedimentation rates are confined to small areas close to the face of active glaciers (Syvitski *et al.*, 1987, Hicks *et al.*, 1990).

By comparison, the highest basin sedimentation rates in large New Zealand lakes are 10-15 mm/yr in Lakes Tekapo and Pukaki (Pickrill, 1987). In contrast to the fjords, glacial input to these lakes is high, the catchments are largely unvegetated, erosion is severe and trapping efficiencies are high. The lake sediments and water properties show all the characteristics of a high sediment input with high suspended particulate matter concentrations (5-25 mg/L), and thick semi-annual varves deposited on the basin floor. In the fjords, if sediment yields are as high as suggested by Griffiths (1979), suspended particulate matter levels, sedimentation rates and core structures should show similarities with those in the lakes rather than with those typical of a low sediment regime.

Hydrological data from the remote Fiordland coast are sparse and sediment yields will probably remain in doubt until a larger data base has accumulated. More measurements of suspended sediment need to be made in the rivers of Fiordland. However, the data available from marine studies suggest that sediment yields are probably much lower than those estimated from the hydrological data and not extreme by world standards. The results discussed in this paper show that evaluating sediment yields from catchments draining into estuarine or lake basins which form efficient sediment traps may be a cost-effective alternative to the more traditional techniques requiring long-term records of stream flow and sediment rating curves.

These techniques are not new, sediment yield estimates commonly have been derived for man-made and natural lake basins from rates of sediment accumulation. In man-made lakes the prefill sediment surface can often by identified by coring and the volume of sediment fill above this surface determined (e.g. Phillips & Nelson, 1981; Pickrill *et al.*, 1984; Pickrill & Irwin, 1986). In basins where the rate of sedimentation has been rapid, surveys of the bathymetry can be compared with prefill surveys to determine volumetric changes (e.g. Hicks *et al.*, 1990; Pickrill & Irwin, 1980; Thompson, 1978; Thompson & Adams, 1979). All of these studies rely on accurate dating of the former surface underlying the lake bed, and in most cases sediment yields have been derived for artificial lakes where the prefill surface can be easily mapped and dated.

Accurate knowledge of the former lake-bottom surface is not necessarily required to derive sediment volumes. In Fiordland radiometric dating and identification of the transition from glacial to post-glacial conditions proved to be the most effective way to determine a reference frame. In other environments different but equally useful natural markers can be used to determine a chronology. For instance, in the North Island, airborn tephras can be identified in cores and produce distinctive seismic signatures from which isopachs can be mapped (Pickrill, in press). In glacialy-fed lakes of the South Island annual and interannual varves are deposited; age of the varves can be confirmed by isotopic dating and isopachs of sediment thickness mapped from seismic records (Pickrill & Irwin, 1983). If sediment yields are to be assessed accurately the problem still remains to determine the efficiency of the lakes in trapping sediment. However, it may be easier to make long-term predictions of sediment loss from measurements at the lake outlet, after the flood peaks and most of the sediment load has been smoothed out of the river hydrographs, than embark on a long-term measurement programme on the rivers themselves.

Techniques described in this paper provide a different perspective on the problem of deriving sediment yields for New Zealand catchments and their use should be encouraged.

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