

The role of modern sedimentation and particulate transport in the formation  
of the central submarine rises in the bathymetry of Puget Sound, Washington

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## Project Summary

Although many of the morphological features of Puget Sound were formed by repeated glaciation during the Pleistocene, there are several interesting bathymetric features that may be a product of modern sedimentation processes (Booth 1994). One of these features is the “W” shaped bathymetry found in three locations in Puget Sound, such as off West Point, in Possession Sound, and off Point Wells (Fig. 1). This study will focus on a cross Sound corridor between Pt. Wells and Jefferson Head (Fig. 2, Fig. 3). The proposed study location is the site of a dramatic example of the bathymetry type in question, and is also within the center of planned operations of the *R/V Clifford A. Barnes* during the study period. Although the W shaped bathymetric feature is both prominently developed and recurrent in the Puget Sound, its formation has not yet been explained.

It is possible that the W shaped bathymetry is due to regions of relatively low sediment accumulation flanking a central region with a high depositional rate. This accumulation pattern could be caused by a central region of relative quiescence near the bottom between stronger tidal currents nearer to the shoreline. A possible consequence of such a current distribution would be that the finest material carried in the water column wouldn't settle out in the high velocities present on the flanking regions of the feature, and would thus eventually be deposited in the center. Additionally, should flood currents in the Sound favor the western bank while ebb currents favor the eastern bank, the Coriolis force could play a role in deflecting currents on shore, thus discouraging the deposition of suspended sediments off the flanks of the central rise, and contributing to the formation of the marginal depressions.

Ebbesmeyer and Cannon (2000), describe a current regime off Point Wells that follows the pattern expected by the above hypothesis (Fig. 4). Although their results are encouraging, due to the probable importance of currents in the formation of this feature, this project would be remiss not to include a detailed study of the velocity structure within the lower 100 m of the water column along our selected corridor (Fig. 2). To that end, Shannon Maynor, a physical oceanography student, will be collecting ADCP data, together with CTD profiles, during both spring and neap tides along the chosen transect

(Fig. 2) in order to determine near bottom velocity structure during maximum flood and ebb as well as the sediment transport regimes present.

Along the same line, 3 box cores and 3 piston cores will be collected, one of each per sampling location. Accumulation rate will be determined from these samples using both  $^{210}\text{Pb}$  and  $^{137}\text{Cs}$ . Similar analyses performed using cores collected along the axis of the Sound by both Carpenter et al. (1985) and Lavelle et al. (1985, 1986) cause me to suspect that I will find the bioturbated layer to be between 10 and 30 cm thick, and that the accumulation rate will be less than  $1 \text{ cm yr}^{-1}$ . Accumulation rates obtained from radioactive isotope dating will either support or refute the hypothesis that accumulation is more rapid on the hump in the middle than on the lower flanks. Additionally, 9 Van Veen grab samples will be collected along the corridor (Fig. 2), which will then be analyzed for sediment grain size. Roberts (1974) found a generally inverse relationship between shoaling water and grain size in his study of the Puget Sound. However, if the currents are rapid enough to reduce or preclude the deposition of fine-grained material near the banks of the Sound, then the material settling in the deepest parts of the region should be coarser than the material settling on the central rise.

Whether the hypothesis is correct or not, valuable information about the relationship between currents and sediment deposition in the deepest parts of the Sound will be obtained. This insight could have implications on our understanding of benthic processes such as the transport of heavy metal laden sediments and other particulate pollutants associated with well known sources of industrial contamination.

## Introduction

Puget Sound, Washington, is a glacial fjord connected to the Pacific Ocean, most recently scoured 13,500 years ago in the Pleistocene. While the typical bathymetry of a given body of water is to plateau out at the deepest point, the Puget Sound in several regions displays a submarine central rise. This feature is commonly associated with a sudden constriction of the 100 m isobath, with locations including Possession Sound, off West Point, and between Pt. Wells and Jefferson Head (Fig 1). In Possession Sound, the feature is associated with a 100 meter isobathic constriction of 50% relative to a shoreline separation of 2 nautical miles. The western marginal deep is 48 m, the eastern marginal deep is 65 m, and the rise is 35 m. Off West Point, the feature is associated with a 100 meter isobathic constriction of 60% relative to a shoreline separation of 5.093 nautical miles. The western marginal deep is 273 m, the eastern marginal deep is 286 m, and the rise is 245 m. Off Point Wells, the feature is associated with a 100 meter isobathic constriction of 55% relative to a shoreline separation of 6.16 nautical miles. The western marginal deep is 158 m, the eastern marginal deep is 130 m, and the rise is 110 m. It is apparent from seismic reflection profiles from beneath the Sound that the glaciated material has long since been buried by younger sediments deposited due to erosion and tidal currents (Booth 1994). As the central rise occurs on the present seafloor, it would appear that this bathymetric feature is a function of the modern depositional regime. What, then, could be responsible for the location and formation of this curious bathymetry?

Because it is likely that the modern depositional environment has formed this central rise feature, it follows that its formation is associated with current-driven sediment transport and deposition. While there are several possibilities as to the types of currents responsible for the formation of the central rise, among them submarine landslides and slumps, this paper will test the possible formation of the rise by tidal currents. At present, relatively little is known about sediment transport dynamics in the Puget Sound. Roberts (1974) has produced several large scale sediment distribution maps of the Sound, and there are several other papers which give a broad idea of sediment accumulation rates in various regions of the Sound (Carpenter et al. 1984; Lavelle et al. 1985, 1986). However, despite these studies, a detailed understanding of

sediment transport in many regions of the Puget Sound has yet to be obtained. Nepheloid layer transport in particular may play a large role in the formation of the central submarine rise.

It is presently understood that the ebb currents moving into the Sound tend to prefer the eastern bank, whereas flood currents prefer the western (Ebbesmeyer and Cannon, 2000). It is thus possible that when currents are constricted, they are moving rapidly enough that the sediment load is being deflected back onshore by the Coriolis force, creating the marginal basins. However, in the center of the Sound current velocities near the bottom could be low enough to permit deposition of the fine-grained particles kept in suspension elsewhere. Were this the case, the marginal basins should contain sediment which is relatively coarse, heavy enough to facilitate settling through the strong currents. However, the rise should be formed of comparatively fine sediment, which has been deposited in the near bottom axial quiescent region unaffected by the strong currents. The settling of the fine grained material in this particular region has some interesting implications for the present understanding of sediment transport dynamics, particularly the fate of particulate pollutants.

The primary point sources of particulate toxics in Puget Sound are found in the industrial regions of Seattle and Tacoma. Whereas the majority of particulate pollutants which are released into the sound don't travel significantly outside the embayment on which the industrial sources are located, the sediment which does travel is the finest grained portion of the material, which only settles out in the quietest of water (Baker 1982; Baker et al. 1983; Curl et al. 1987). Hence, if these central rises are formed by quiet bottom water which permits the settling of fine grained material, they could be the location of high concentrations of industrial contamination.

## Proposed Research

In order to test the hypothesis that the central rise feature is a result of tidally created depositional environments, bathymetric grain size distribution, accumulation rate, and bottom current intensity will need to be investigated in a corridor across the “W” shaped bathymetry. For the purpose of this study, the sampling location will be on the submarine rise between Point Wells and Jefferson Head (Fig 2). In addition to being a dramatic example of the bathymetric feature of interest, the sampling location fits the constraints of available cruise time, allowing for maximum time on station. The samples will be collected at the locations outlined in fig. 2 during the week of the 29 March 2004 from the R/V Clifford A. Barnes (Table 1). Sample collection will correspond with a neap tide to facilitate the greatest possible accuracy in sample location. Van Even grabs will be taken on 29 March 2004 in nine locations, three in each depression and three on the axial rise. These samples will be used to analyze grain size distribution on both the central rise and in the marginal depressions. Box and piston cores will also be collected, one of each core type in both depressions, as well as on the axial rise. The box cores will be sub-sampled at 1 cm intervals and dated to determine accumulation rate on the rise and in the depressions, while the piston cores will be examined to determine any historical changes in depositional environment.

As nepheloid sediment transport and near-bottom current velocities play a large part in the testing of the hypothesis, physical oceanography student Shannon Maynor will be collecting ADCP and transmissometer data in the same regional corridor (Fig. 2). By testing current strength at both spring and neap tide, she will determine the maximum and minimum currents in the region across the “W” shaped bathymetric feature. This will in turn yield the maximum grain size that the currents can carry, affecting expected depositional patterns (Fig.5) (Sternberg 1972). Shannon expects to find that the currents will be strongest along the western shore during the flood tide, and strongest along the eastern shore during the ebb. She will also be looking for the central quiescent bottom water which would support the hypothesis that tidally influenced depositional regimes are responsible for the formation of the central rise. The transmissometer data will indicate where the sediment load in the bottom water is located, which in turn will provide

valuable information on the depositional environment associated with central rise formation.

Previously collected data suggest that we will find bioturbated depths between 10 and 30 cm yr<sup>-1</sup>, with sediment accumulation rates no greater than 1 cm yr<sup>-1</sup> (Carpenter et al. 1985; Lavelle et al. 1985, 1986). Should these expected rates be accurate, accumulation rate will be available for at least the past meter of deposition using <sup>210</sup>Pb. In order to account for the formation of a central rise almost 100 m greater than the flanking depressions in the past 400,000 years (since Pleistocene glaciation), average accumulation rates must be .025 cm/year greater than that in the depressions. Although Carpenter et al. (1985) and Lavelle et al. (1985, 1986) did collect samples in the region between Pt. Wells and Jefferson Head, there has been no attempt thus far to sample both the depressions and the rise, let alone to compare accumulation rates. There have also been studies on grain size distribution performed in the Sound, most notably by Roberts (1974). The general conclusion of Roberts' grain size maps is that sediment generally fines as one moves away from shore, and that bands of constant grain size roughly parallel the topography. Although Roberts leads us to expect grain sizes on the order of silt and clay in the sampling region, no one has yet sampled and compared grain size distribution on both the rise and in the depressions of the "W" shaped bathymetric feature. Should the hypothesis of this paper be correct, it is expected that the sediment grain size will be coarser in the troughs and finer in the rise, reflecting the stronger currents expected to hinder deposition in the depressions and the quiet central bottom water which should permit the deposition of the suspended sediment load.

In order to determine grain size distribution in relation to the "W" shaped bathymetric profile, the Van Veen grab samples will be subjected to a standard phi size analysis. The piston core samples will likewise undergo standard phi size analysis to determine if there has been any change in the energy of the depositional environment over the past 400 years. The box core samples will undergo both <sup>137</sup>Cs and <sup>210</sup>Pb radiometric dating to determine the accumulation rate in both the troughs and the rise associated with the "W" shaped bathymetry. The method used will be one slightly modified from Nittrouer et al. (1979).

## Draft Budget

The total estimated cost of this project will be \$123.00. A breakdown of individual factors in the budget can be found in table 2.

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## Figure Legend

Figure 1: Map of the Puget Sound region illustrating the location of Possession Sound, West Point, and the study area shown in figure 2.

Figure 2: Central Main Basin of Puget Sound showing marginal depressions, together with the proposed sampling sites (see legend for sampler type) and the location of the depth profile shown in figure 2. Bathymetry contours are in fathoms.

Figure 3: Bathymetry profile across the central main basin of Puget Sound, showing the 'W-profile.' Location of the transect is shown in figure 1.

Figure 4: Net velocity vectors in the Puget Sound near the sampling region shown in Figure 2. From Ebbesmeyer and Cannon (2000).

Table 1. Sample type, station location, and sample depth.

Van Veen Samples				Kasten Cores			
Sample #	Lat (+47 deg)	Lon (+122 deg)	Depth (m)	Sample#	Lat (+47deg)	Lon (+122deg)	Depth (m)
1	45.3	25.8	300	1	45	25.65	315
2	44.95	25.51	300	2	45.35	24.84	215
3	44.63	25.21	270	3	45.44	24.3	235
4	45.42	24.89	215				
5	45.3	24.8	215				
6	45	24.72	215				
7	45.8	24.67	235				
8	45.5	24.39	235				
9	45.35	24.33	250				

Table 2: Draft Budget

Item	Unit Cost	Units	Time (d)	Total Cost (\$)
Barnes	\$1800/d	1	2	7200.00
Cs-137	\$500/ml	3	N/A	1500.00
Pb-210	\$40/ml	8	N/A	320.00
Box Corer	\$45/d	1	1	45.00
Piston Core(2'')	\$45/d	1	1	45.00
Core Liner (2'')	\$3.50/ft	20	N/A	70.00
Core Caps (2'')	\$.25 each	8	N/A	2.00
Van Veen	\$3/d	1	1	6.00

Total estimated cost: \$123.00

\*Ship costs covered by the School of Oceanography Academic Budget

\*\*These supplies will be donated by Prof. Chuck Nittrouer.

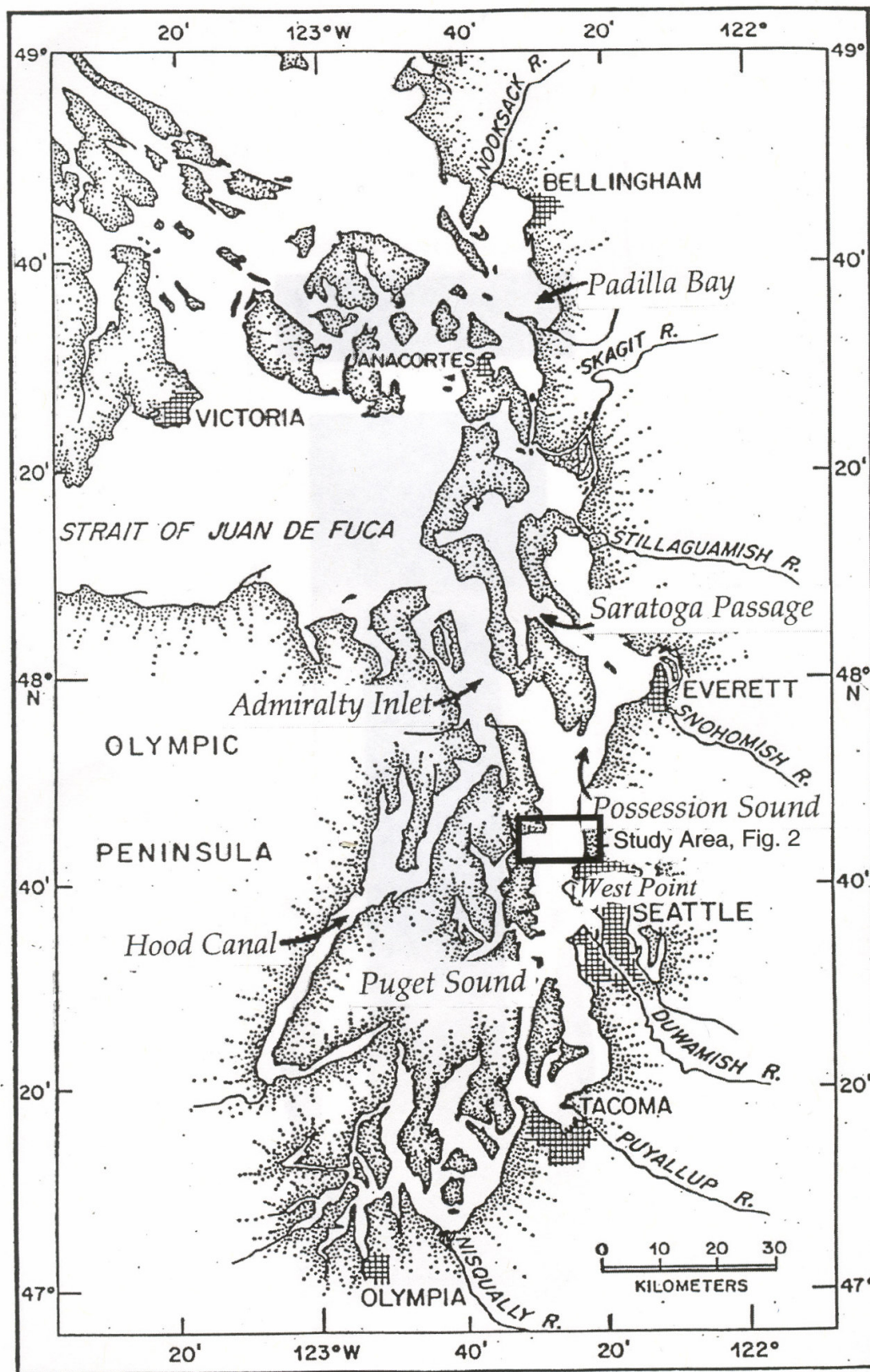


Fig. 1

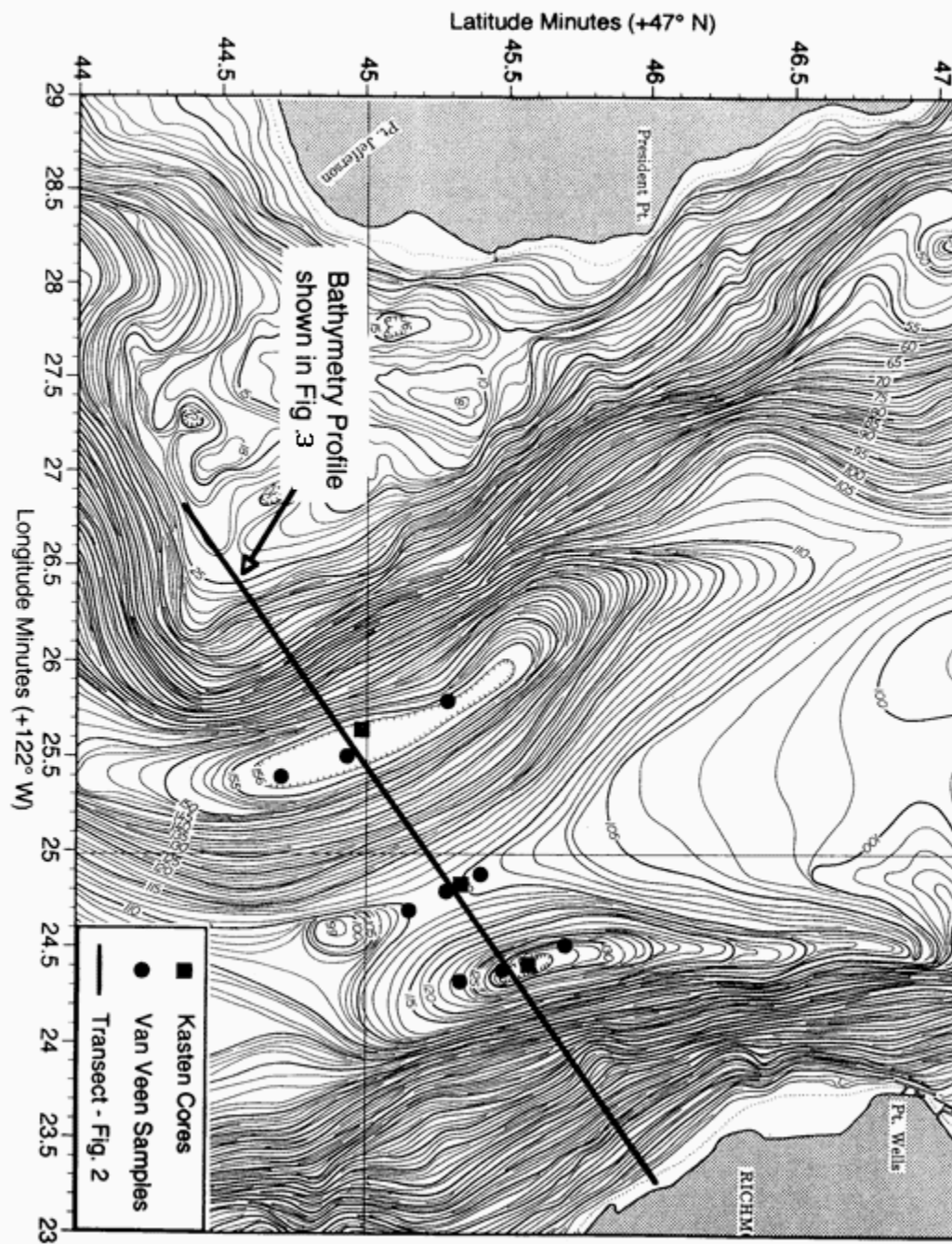


Fig. 2

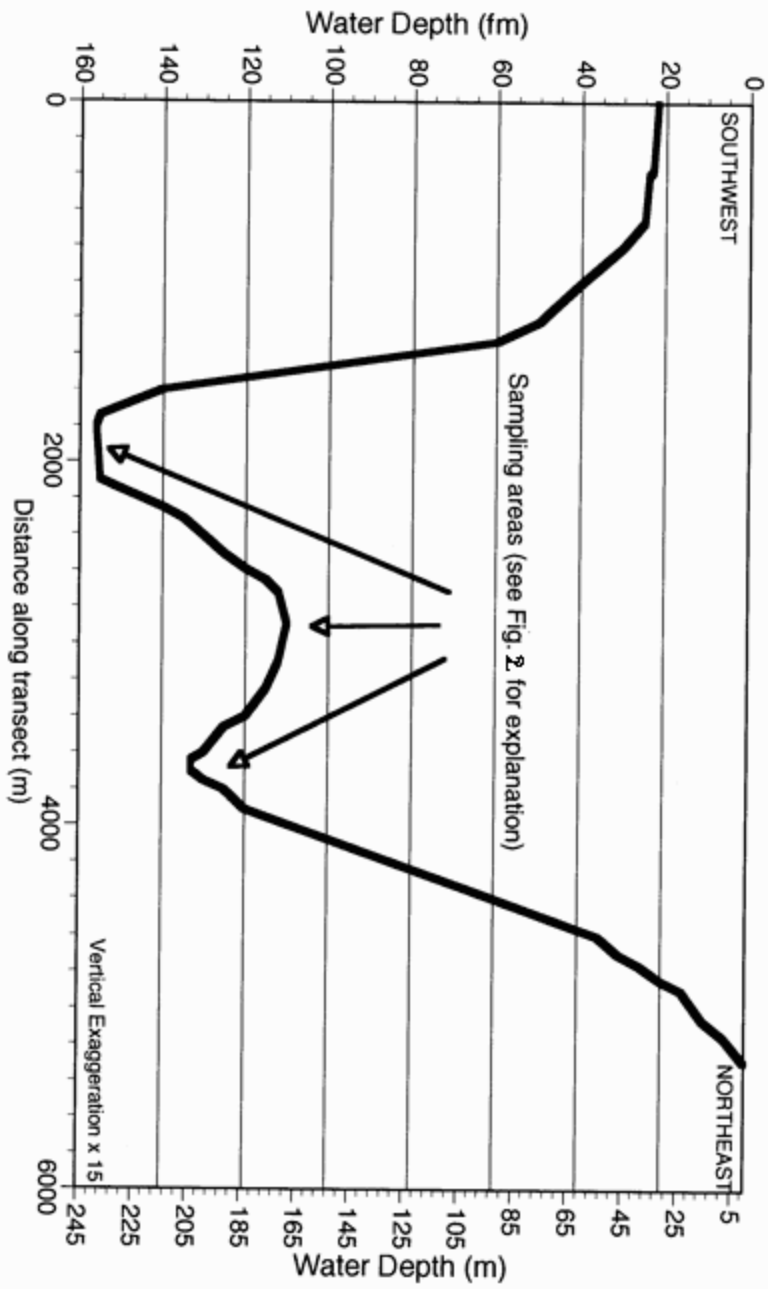


Fig. 3

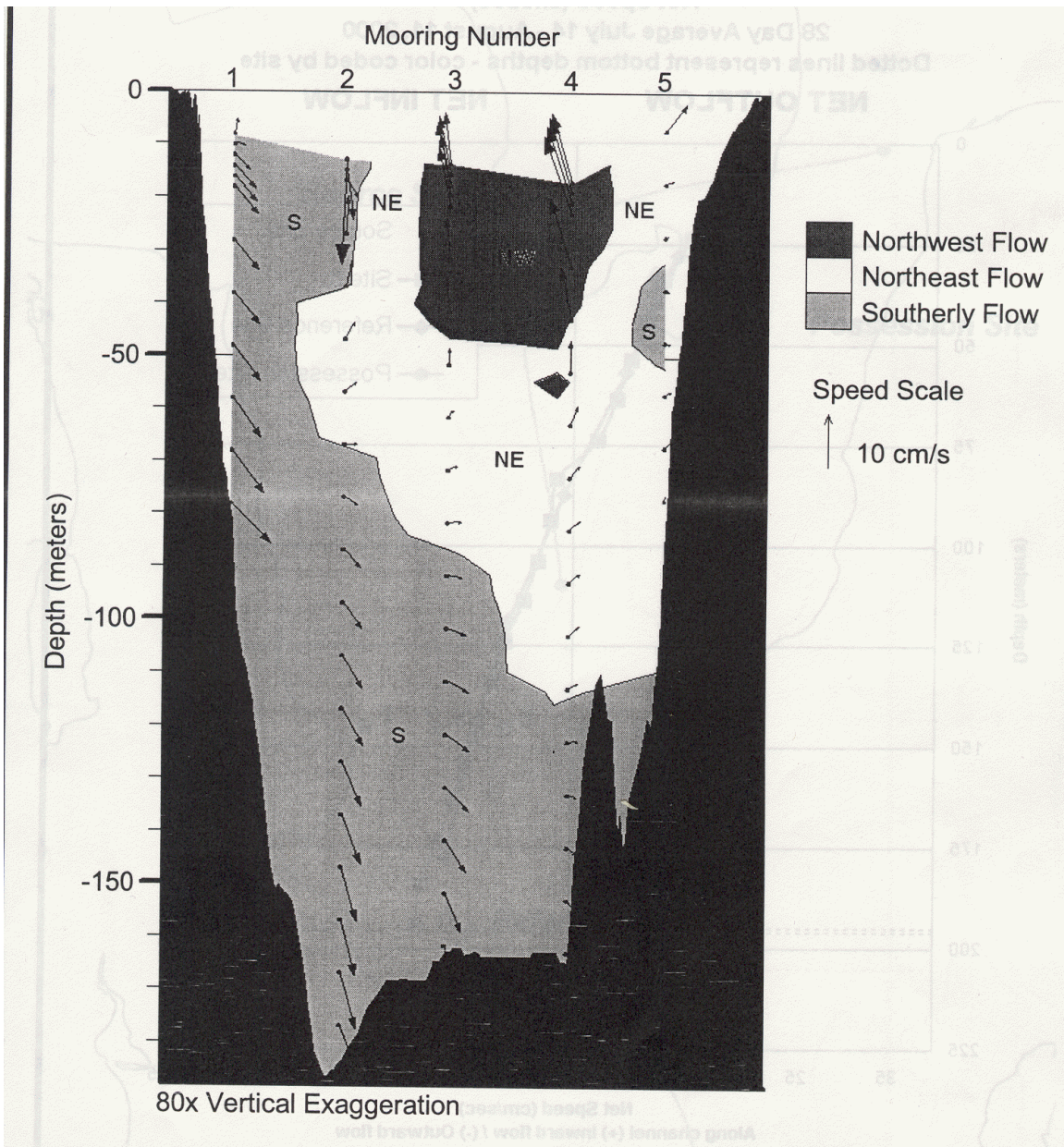


Fig. 4