HYDROGRAPHIC FRAMEWORK OF THE DOBOY SOUND ESTUARY AND SURVEYS OF THE OTHER TIDAL INLETS ALONG THE COAST OF GEORGIA

by

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ABSTRACT

Hydrographic and sedimentologic research was conducted during the summer of 1970 as part of a study to investigate the sediment budget at the entrance of the Doboy Sound estuary, Georgia.

The dynamic diversion of wind, wave and tidal currents results in a predictable sand-shoal geometry at the entrance of the Doboy Sound estuary. Patterns of diversion developed in response to seasonal fluctuations in wind and wave approach interacting with inlet tidal drains. Mutually evasive flow paths of ebb and flood currents influence the formation of shoals adjacent to inlets.

Shoals at the entrance to Doboy Sound are partially exposed at low water and exhibit two trends. Three shoals form an elongate-offshore orientation that extends several miles seaward of the entrance. A fourth elongate shoal is oriented parallel to the beach approximately one-quarter mile offshore. During the summer months, sediment is transported in a closed system within these shoals, and there is essentially no sediment by-passing at the inlet although some by-passing apparently takes place seaward of the entrance. This condition results in lateral and vertical expansion of shoals and in sediment "starved" areas adjacent to shoals.

Tidal inlets along the Georgia coast have many hydrographic and geomorphic characteristics in common. However, estuaries with large fluvial sources of water are distinctly different in form and hydrographic character from tidal inlets without fluvial sources of low salinity water. Sedimentation occurring in estuaries with large fluvial sources is generally a response to some form of bi-polar flow associated with a stratified water mass. The tidal inlets generally have large tidal drains that are diverted by mutually evasive tidal channels and inlet "water piles".

INTRODUCTION

Statement of the Problem

An understanding of sedimentary processes governing shoaling in nearshore waterways in important for the maintenance of navigation, the control of nearshore geometry and for understanding the pathways of pollutants. The relationship of sedimentary processes to the corresponding sedimentary record is also of significance for interpreting the development of barrier islands and for the general reconstruction of paleoenvironments.

Sedimentation around estuary entrances is the result of a complex interplay of numerous physical, chemical and biological parameters, however, the interdependent factors governing these parameters vary continuously in intensity. This study is an attempt to determine the principal interrelationships between the physical and chemical parameters functional in estuary entrance sedimentation at Doboy Sound, Georgia and is a summary of portions of a Ph.D. dissertation by the author. The study period was from July 1, 1970 to October 10, 1970, and the relationships are valid only for the summer weather conditions. A complimentary study by Mayou (1972) is concerned with the organism-sediment interrelationships in part of the study area.

Location

Doboy Sound is an estuary located on the central Georgia coast south of Sapelo Island (fig. 1). The shorelines of Doboy Sound are bounded on the north by Sapelo Island and on the south and west by a series of marsh islands composed principally of mud and Spartina alterniflora (Wolf Island). The main channel of Doboy Sound extends seaward for several miles beyond the coastline which is delineated by Pleistocene and Holocene barrier island complexes (Hoyt, 1967; Hoyt, Weimer and Henry, 1964).

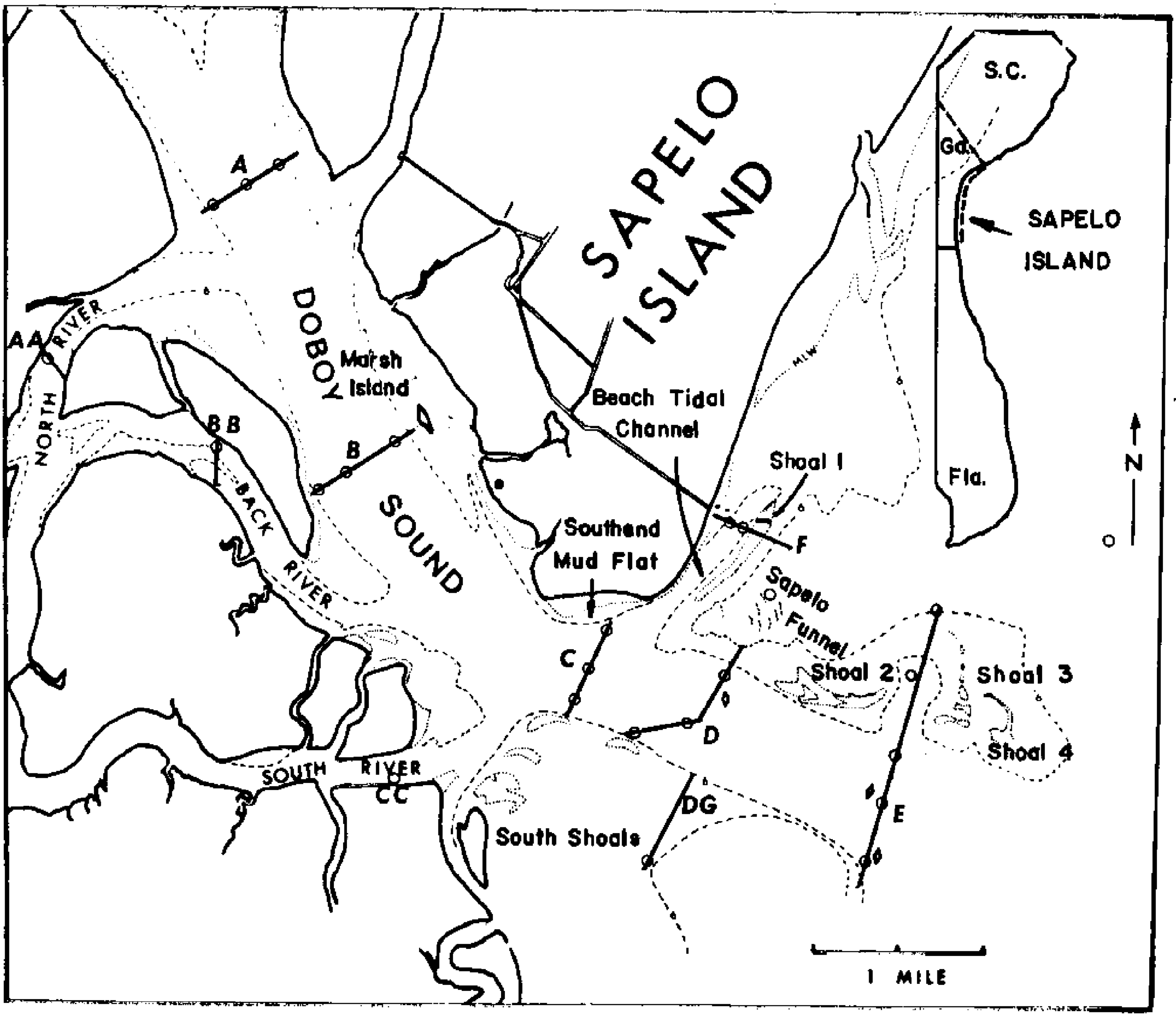

Figure 1. Map of Doboy Sound showing the locations of the 13 hour hydrographic stations (indicated by open circles) and bathymetric profiles (labeled with capital letters).

Previous Investigations

An early attempt at a multi-disciplinary evaluation of the estuary environment was presented in Estuaries (Lauff, 1967), in which each chapter was concerned with a different discipline of estuarine study. Many of the ideas and concepts presented in Estuaries (1967) are pertinent to portions of this study. However, the generalized sedimentary frameworks were too great an oversimplification for many of the individual estuarine systems along the Georgia coast.

Recently, intra-disciplinary studies of specific estuary systems have appeared in the literature. Of these, several informative papers dealing with sediment-hydrodynamic interrelationships relate to this study. Publications by Daboll (1969), Farrell (1970), Hartwell (1970), Kulm and Byrne (1966) and the Coastal Research Group, University of Massachusetts (1969) have investigated sedimentation as a response to hydrography, however little or no consideration was given to the area adjacent to estuary entrances.

Although a fairly extensive literature exists for sedimentation landward of estuary entrances, only a few studies have been concerned with the area around and seaward of entrances. In the late fifties, Bruun and Gerritsen (1959) provided a general framework of patterns of sedimentation at inlets. Subsequent work by Bruun and Gerritsen (1961) and Bruun and Battjes (1963) have added to the understanding of parameters affecting inlet stability, and patterns of sediment by-passing at inlets. Different patterns of sediment by-passing occur at different distances seaward of inlets. By-passing close to the inlet is generally accomplished by tidal currents while shifting sand bodies are generally more important seaward of estuary entrances on peripheral shoals. Bajorunas and Duane (1967), Ludwick (1970, 1971), Price (1963), Robinson (1966) and Scruton (1956) have related some characteristics of inlet hydrodynamics to patterns of sedimentation and shifting sand bodies.

At Doboy Sound, previous investigations of hydrography (Levy, 1968, Kuroda, 1969) have provided little insight to patterns of bedload sedimentation just seaward of the inlet. A preliminary study of the circulation and suspended matter budget of Doboy Sound (landward of the entrance) was conducted by Levy (1968). Howard (1969) described some of the bedforms present on the peripheral shoals in the research area. However, the relationship of bedforms to local hydrodynamic processes and bedload sedimentation was not discussed.

Hoyt and Henry (1965, 1967) and Hoyt, Weimer and Henry (1964) suggested a southward migration of Sapelo Island and the inlet to the Doboy Sound estuary. Their hypothesis is based on erosion on the up-current end of the barrier island and deposition on the down-current end of the barrier island. The present research indicated that the sedimentation system in the proximity of the Doboy Sound entrance is more complicated than is associated with migrating inlet and island complexes.

PROCEDURE

Methods for the Study of Physical and Chemical Hydrography

Salinity, temperature, suspended matter and current speed and direction were recorded at eight foot depth intervals for all station indicated on Figure 1. Measurements of these variables were recorded almost simultaneously at each station. A set of measurements was made within a one hour interval (½ hour before and ½ hour after) of mean high water, mean low water and during mid-ebb tide and mid-flood tide.

Hydrographic research was conducted from a 16½ foot boat, with special modifications to suit the project. The mobility and speed of this small but well equipped research vessel permitted complete sampling of cross-sectional profiles (consisting of 2 to 3 stations) within the one hour interval encompassing the four sampling times during the tidal phase.

Bathymetric profiles were made with a Raytheon DE-719 fathometer and a model 7245 transducer at positions indicated on Figure 1. After profiles were made, stations were positioned where samples could best evaluate circulation patterns in the study area.

Current measurements were obtained using a Gurley 665 direct reading meter and a Bendix-Q-15/233 meter system. Salinity and temperature readings were obtained with a Beckman RS 5-3 portable salinometer. A General Oceanics water bottle was used to collect 500 ml water samples which were analyzed in the laboratory for suspended matter content. The weight of particulate matter suspended in a liter of water was determined by using matched millipore filters and the procedure outlined by Levy (1968).

Readings were plotted on appropriate profiles in order that current velocity, salinity, temperature and suspended matter distribution could be correlated for mean high water, mid-ebb tide, mean low water and mid-flood tide.

METEOROLOGICAL AND TIDAL FLUCTUATIONS

Hydrographic conditions in an estuary system are subject to the influence of meteorological and tidal fluctuations. Increases in river flow increase the salinity stratification of an estuary (Pritchard, 1955), and an increase in estuary stratification enhances the capability of bottom flood currents to transport marine sediments into the estuary (Schultz and Simmons, 1957; Kulm and Bryne, 1966). Circulation around estuary entrances is also affected to a great extent by wind directions. Wind directions influence the directions of longshore currents and the patterns of wave refraction at inlets. Increases in wind velocity also increase the rate of turbid diffusion which results in the mixing of water masses and the breakdown of estuary stratification.

Levy (1968) demonstrated that monthly variations in precipitation at Sapelo Island had a negligible effect on the discharge of the Altamaha River (Table 1). This is probably because the Altamaha River receives most of its water from the Piedmont drainage basin where it heads. During the study period (July 1, 1970 to October 10, 1970), fluctuations in precipitation probably did not effectively influence estuary circulation. The North, Back and South Rivers are very small well-mixed branches of the Altamaha River system and fluctuations in these systems were probably more subtle. However, seasonal fluctuations in precipitation probably had a greater effect upon estuary circulation.

	ALTAMAHA RIVER DISCHARGE	PRECIPITATION ON SAPELO ISLAND	
	1967	1967	1970
JUNE	10,620 cfs	3.40"	trace
JULY	12,000 cfs	5.37"	5.66"
AUGUST	9,401 cfs	8.14"	7.36"
SEPTEMBER			0.79"

Table 1. Comparison of precipitation on Sapelo Island to the discharge of the Altamaha River.

During the study period, winds were generally out of the east, east-southeast and south-southeast (Table 2) and induced a weak longshore current that moved in a

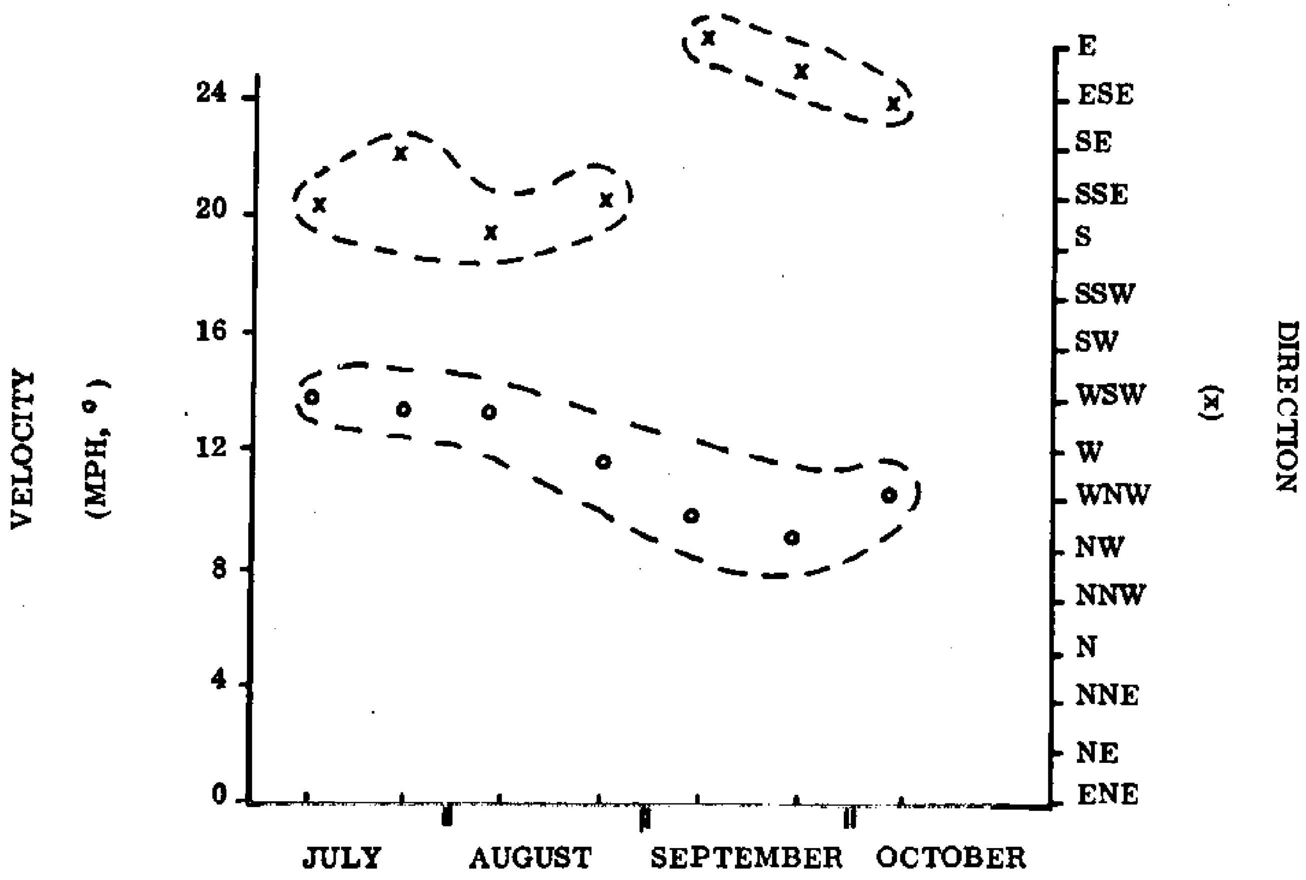

Table 2. Graph showing bimonthly averages of wind velocities (°) and directions (x) during the study period.

northerly direction. Refraction at the inlet caused a convergence of wave orthogonals toward the inlet. When wind velocities increased, the nearshore zone of shoaling waves expanded in an offshore direction over the shallow shoreface.

Decreases in wind velocities often corresponded with winds out of the northeast. However, winds out of the northeast produced the greatest wave activity as a result of the large fetch. For this reason, northeast winds were most effective in producing large waves capable of diffusing the estuary stratification seaward of the inlet.

Monthly tidal fluctuations also influence estuary entrance circulation. During spring low tides, there was a dramatic increase in exposure of the peripheral shoals as well as an increase in the tidal current velocities around the shoals. At low water, the depth of water over the shoals decreased by about 1.8 feet relative to the mean tide level. This change directly affected sedimentation processes by: 1) decreasing the ratio between water depth and the depth of wave influence, (which created a broader zone of littoral drift around the shoals) and, 2) by decreasing the depth of the water column over which tidal currents flow (which created an increase in shear stress and an increase in flow regime). Topographic shielding in the immediate vicinity of the shoals during the spring tide was also more pronounced as a result of increased ebb exposure.

HYDROGRAPHY OF DOBOY SOUND

General Bathymetry

The circulation of the protected part of Doboy Sound (landward of the entrance) is governed by the discharge of the North, Back and South Rivers and the influx of marine water through the sound entrance. The bathymetry of Doboy Sound was mapped by evaluating bottom-sounding profiles (fig. 1) and U.S.C. & G.S. chart 574. At profile A, the deepest part of the channel was centrally located and flanked by relatively steep sides. At about the 12' depth (mlw) there was a sharp break in the slope and the bottom (covered with megaripples) graded gently toward the marsh borders of the channel. At profile B, the deepest part of the channel was located in the southwest part of Doboy Sound. This trend continued seaward through the inlet of Doboy Sound. The north part of profile B was essentially horizontal at the 22-24' depth (mlw). At about the 20' depth, the bottom graded upward to a sandbar with a stable oyster reef core and a Spartina alterniflora marsh fringe. At the inlet to Doboy Sound (profile C), the northern part of the bottom profile had a bathymetric high with variable relief. This bathymetric high resulted from the influence of a flood delta which developed just outside of the estuary entrance (fig. 1). A small channel discernible on the extreme northern part of the profile represents the western most limit of the Beach Tidal Channel which curved around in front of the island (fig. 1).

Hydrologic Characteristics of Low Salinity Rivers Discharging into Doboy Sound, Georgia

Because of its proximity to the Altamaha River, Doboy Sound received a relatively large quantity of relatively low salinity water. The low salinity water was supplied to Doboy Sound through an interlacing network of tidal rivers in the lagoonal marshes behind the barrier beaches. The North, Back and South rivers were the three main suppliers of the relatively fresh water to Doboy Sound. The discharge of the North River enters Doboy Sound approximately half way between the head waters of the Sound and the inlet to the sea. The Back River enters the Sound approximately 1½ miles inside the entrance and the South River enters the Sound at the inlet. In effect then, low salinity water (19.9 ^{o}/oo to 26.6 ^{o}/oo) enters the Sound along most of its southern shore, and the circulation of the water mass inside Doboy Sound was largely influenced by the hydrologic character of these rivers, (the North, Back and South Rivers) which discharged into Doboy Sound at angles almost normal to the axis of the Sound (fig. 1).

North, Back and South Rivers

The North, Back and South Rivers are shallow tidal streams that receive fresh water from the Altamaha River. These rivers also experience the bimodal flow of tidal currents which enter through the entrance to Doboy Sound. The mixing of Doboy Sound water with Altamaha River water was easily delineated by turbid water and foam lines which were produced by the shear between the two water masses. During the flooding tide, narrow streams of water that were diverted from the Altamaha River were restricted to the shallow margins of the North, Back and South Rivers. During the average high and low tides, current velocities in North and Back Rivers were from 20 to 30 cm/s (Table 3). During the mid-tides, the average velocities in these rivers increased to approximately 50 to 60 cm/s. During all phases of the tide,

PROFILE	LOW WATER	FLOOD RACE	HIGH WATER	EBB RACE
AA	20.3	56.5	24.4	52.9
BB	24.4	64.0	34.6	67.1
CC	22.3	44.4	7.7	49.7

Table 3. Mean current velocities (cm/sec) for the water columns above profiles AA, BB and CC.

the maximum velocities were at the water surface and velocities decreased with depth. During high water, the distribution of currents in the South River (profile CC) indicated a bi-polar reversal in the direction of water flow from the water surface to the bottom.

This bi-directional water flow in the South River caused the apparent lowering of the average current velocities indicated in Table 3.

During the ebbing tide, the North, Back and South Rivers discharged water at oblique angles to the seaward ebbing discharge of Doboy Sound. The paths of these water masses can be delineated by the turbid water lines and foam lines (fig. 2). However, winds sometimes shifted the foam lines away from the actual points of shear between two water masses and foam lines were not always reliable indicators of the borders between two different water masses.

Low salinity gradients in the water columns in the North and Back Rivers indicate a rapid mixing between the lower salinity water coming from the Altamaha and the higher salinity water in Doboy Sound. A small salinity gradient was present in the water column at the mouth of the South River. Apparently molecular and turbulent mixing took place at a slower rate in this river, than it did in the North and Back Rivers.

At low water, the salinities in these rivers were in the mid to lower 20's ($^{o}/oo$) with the shoreward most river exhibiting the lowest salinity and the seaward most river exhibiting the highest salinity (Table 4). During the flooding tide apparently much of the higher salinity flood intrusion was diverted past the entrance to the South River and into the Back River. This high salinity by-passing across the entrance to the South River was apparent because, during high water and the mid tides, the

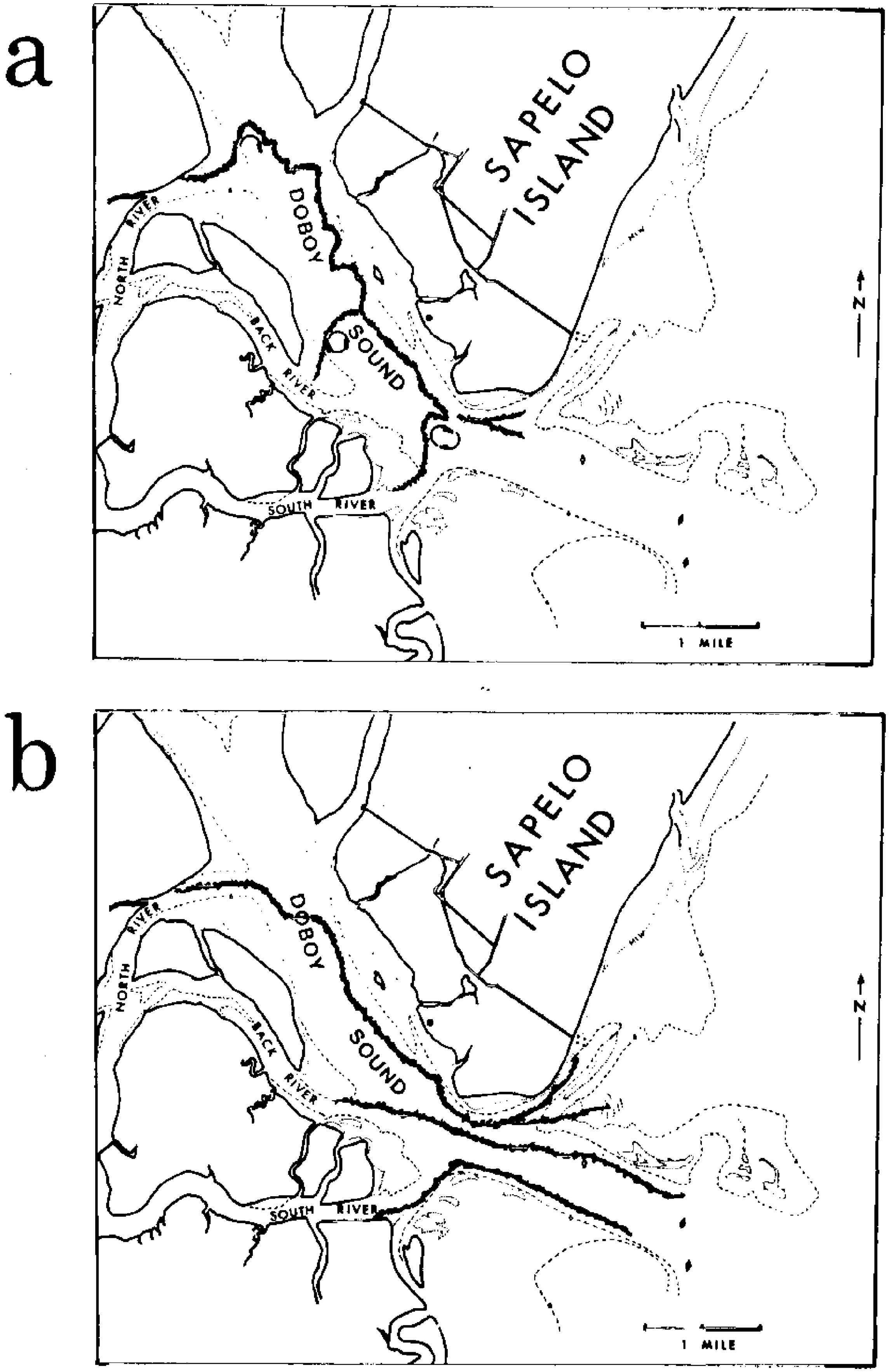

Figure 2. Map of Doboy Sound showing the distribution of foam lines during high water (a) and mid-ebb tide (b). Foam lines during mid-ebb tide are much straighter than the foam lines at high water. High water foam lines illustrate a westward deflection of river currents.

salinities of Back River were higher than the corresponding salinities of the South River.

PROFILE	LOW WATER	FLOOD RACE	HIGH WATER	EBB RACE	TIDAL CYCLE AVERAGE
AA	19.9	28.8	31.8	30.8	27.8
BB	23.6	32.9	33.0	31.7	30.3
CC	26.9	29.3	31.8	30.8	29.7

Table 4. Mean salinities ($^{0}/oo$) for the water column above profiles AA, BB and CC.

Suspended Matter

Suspended matter determinations for a complete tidal cycle (Table 5) indicated concentrations varied from approximately 50-250 mg/l. The North River carried the greatest load of the three rivers, and the suspended matter loads decreased for each consecutive river closer to the sea. The highest concentrations of suspended matter corresponded to the periods of highest current velocities (at mid tides) and lowest concentrations occurred during high and low water.

PROFILE	LOW WATER	FLOOD RACE	HIGH WATER	EBB RACE	TIDE CYCLE MEAN
AA	74.7	104.8	65.2	248.0	123.7
BB	81.9	87.3	51.8	95.7	79.2
CC	34.3	87.1	51.3	66.7	58.6

Table 5. Mean suspended matter content (mg/l) for the water column above profiles AA, BB and CC.

The concentration of suspended matter generally increased with depth. However, in some cases, high turbulence and vertical mixing displaced sediment laden water masses upward in boils. Increased turbulence and mixing developed best when winds were 180° out of phase with the surface current flow and a high stress on the water surface created closely spaced and high amplitude waves.

Temperature gradients in the North, Back and South Rivers were very subtle as a result of the high degree of mixing. Temperature averages for a tidal cycle were approximately the same for the North and Back River (Table 6); however, the temperature of South River water was consistently higher than temperatures recorded for the two rivers further landward.

PROFILES	MEAN TEMPERATURE	STANDARD DEVIATION
AA	29.0	.48
BB	28.9	.36
CC	29.7	1.10

Table 6. Mean and standard deviation of temperature (°C) for the tidal cycle above profiles AA, BB and CC.

Hydrologic Characteristics of the Doboy Sound Estuary

Low Water

During low water, a well-mixed water mass flooded through the inlet to Doboy Sound from the northeast (fig. 3c). This flood intrusion spilled across the central part of the main channel at an oblique angle, while the ebb flow continued to drain out of the inlet to the north and south of this flood intrusion (fig. 3c). During periods of strong onshore winds and large swells, the initial flood intrusion also occupied the northern most part of the channel. At low water, the salinity gradients at the entrance were low, and the salinities generally ranged from approximately 28 ^{o}/oo near the surface (at the south side of the inlet) to 30^{o}/oo near the bottom of the channel (at the north side) (fig. 4c). The gradient of suspended matter concentrations at the inlet was also low and concentrations varied between 10 and 20 mg/l (fig. 4h).

Landward of the inlet the initial flood instrusion occupied the southwest and bottom part of the channel. In the central body of the sound salinities get slightly lower and the salinity gradients indicate a very well-mixed water mass. Low salinity water occupied the surface of the channel adjacent to the point where the North River discharged into Doboy Sound. This low salinity water was apparently diverted from the Altamaha River.

The suspended matter concentrations landward of the inlet increased from 20 mg/l to 120 mg/l along the margins of the sound. The central axis of the sound generally had suspended matter concentrations less than 20 mg/l (fig. 4).

Seaward of the inlet, an ebbing current was confined to the upper part of the channel and flooding currents were confined to the lower part of the channel. The salinity varied from 29 ^{o}/oo to 32 ^{o}/oo and the best stratification was present at the seaward most profile (fig. 4). The suspended matter concentrations increased with depth and seaward of the inlet. The highest concentrations were located in the central portion of the channel and varied from 80 mg/l to 120 mg/l. Although the water in the bottom of the channel had relatively high concentrations of suspended matter, the concentrations at the surface were approximately 10 mg/l. This low concentration was relatively consistant with concentrations found along the entire central-surface of the Sound from 1½ miles seaward of the inlet to 3 miles landward of the inlet.

The distribution of the salinities along the axis illustrates two different salt-wedge intrusions enter Doboy Sound from two different directions during flood tide.

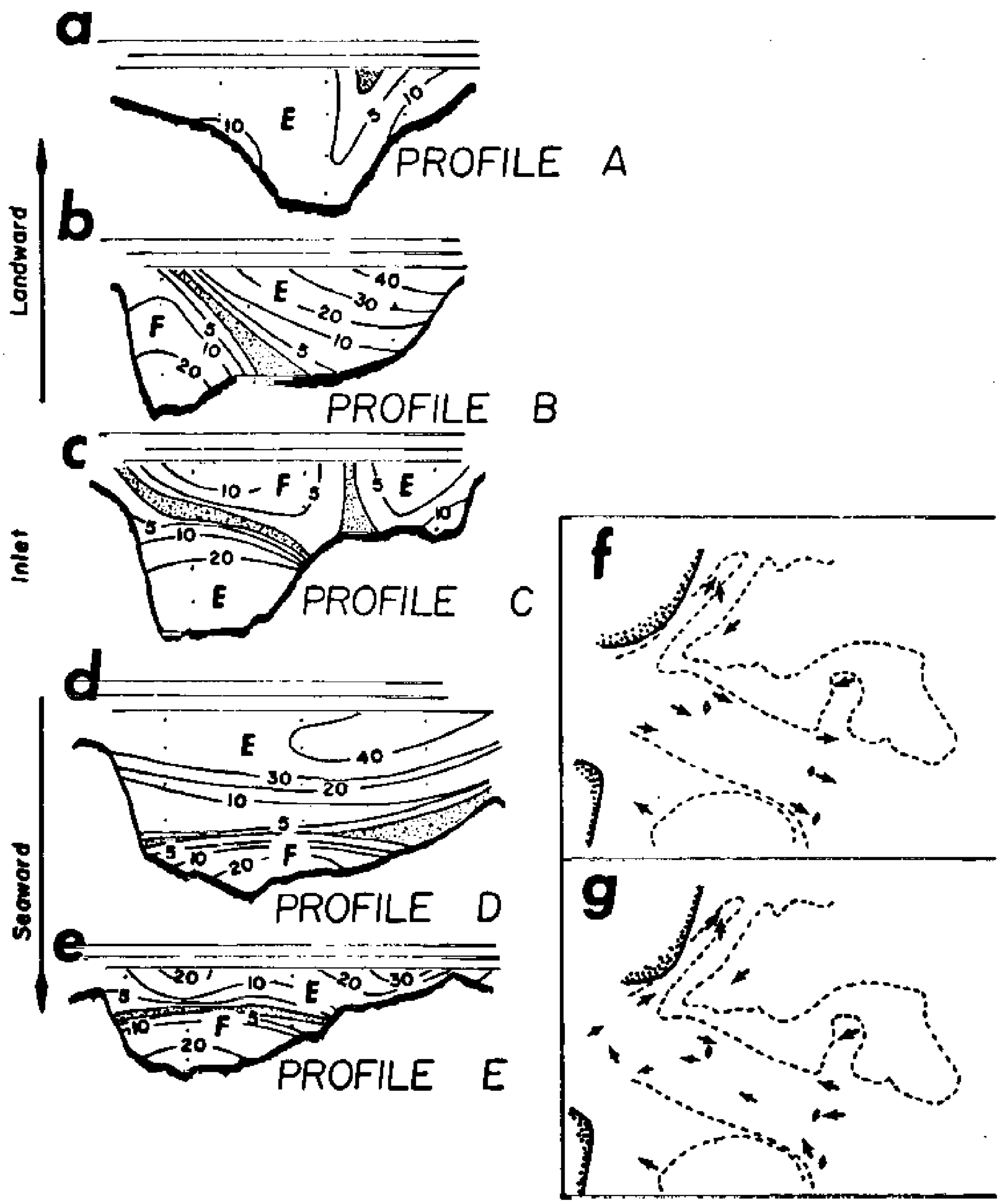

Figure 3. Cross sections of the Doboy Sound channel above bathymetric profiles A, B, C, D and E showing the distribution of current velocities during mean low water. Contours are 0, 5, 10, 20, 30...100 cm/s. Sample stations are indicated by solid black dots and were spaced at 8 foot intervals beginning 2 feet below the water surface. Inserts f and g are maps of the entrance to Doboy Sound showing the directions of water flow during mean low water at the surface (f) and at the bottom (g). Shaded areas represent the "slack water" zones in the water column. Flood and ebb flow is indicated by (F) and (E) respectively.

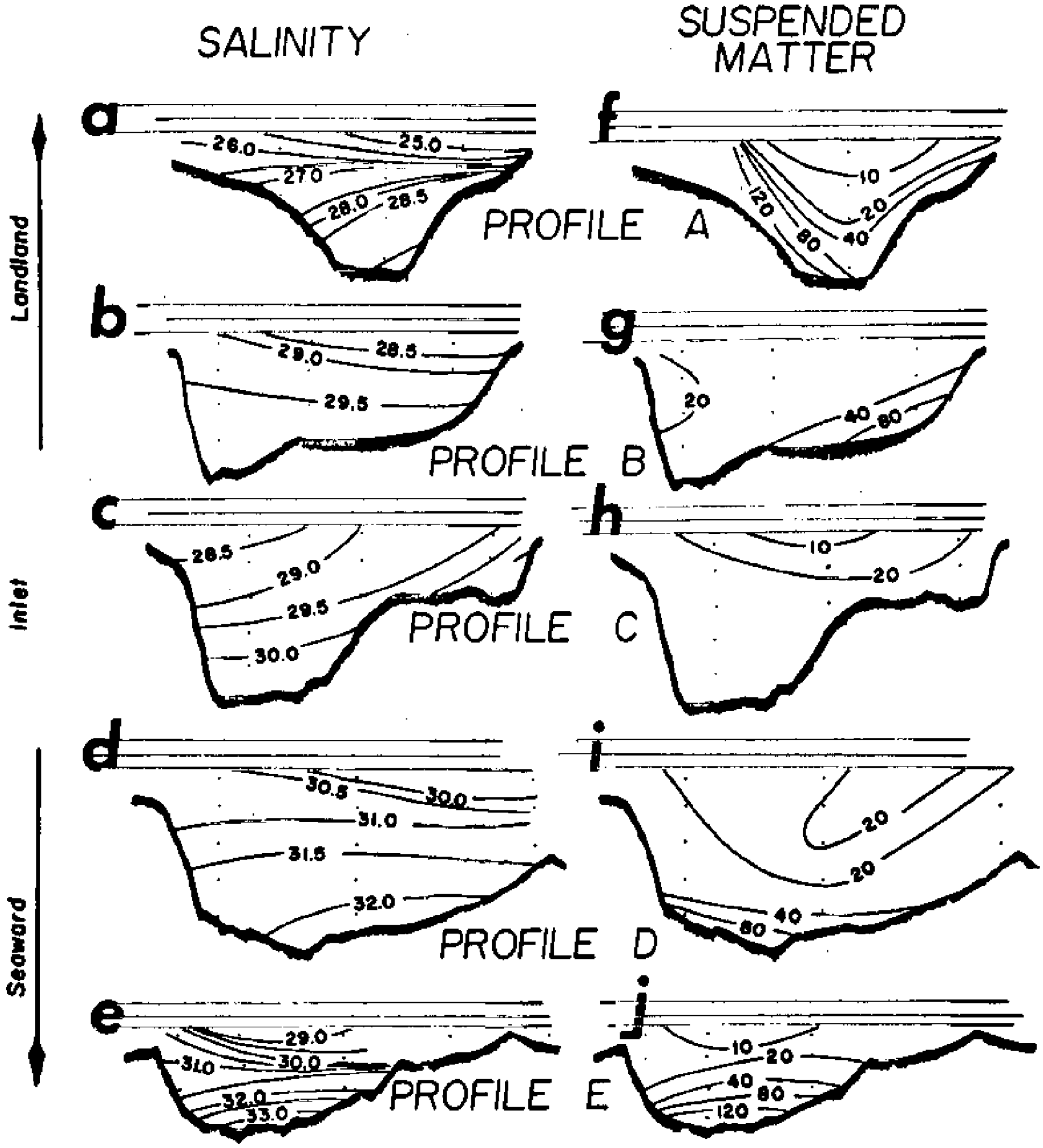

Figure 4. Cross sections of the Doboy Sound channel above bathymetric profiles A, B, C, D and E showing the distribution of salinities and suspended matter concentrations during mean low water. Sample stations are indicated by solid black dots and were spaced at 8 foot intervals beginning 2 feet below the water surface. The salinity contour interval is 0.5‰ and suspended matter concentrations are in irregular intervals (10, 20, 40, 80, 120, 200, 280, 360, 440, 520 mg/L).

The initial intrusion flooded across the inlet (profile C) from the Beach Tidal Channel and through the neck of the Sapelo Funnel (fig. 3 c). This intrusion would probably be classified as a Type D intrusion (Pritchard, 1955) because of the well-mixed nature of its unidirectional flow along a north northeast-south southwest axis (fig. 5a). Upon entering the sound, this salt intrusion spreads both landward and seaward along the main axis of Doboy Sound. The landward flooding salt intrusion forms a Type B intrusion (Pritchard, 1955, stratified estuary circulation) with the lower salinity water leaving the sound.

At profile E (fig. 4), the other salt intrusion had a 5 $^{o}/oo$ salinity stratification ($30^{o}/oo$ to 35 $^{o}/oo$) and was flooding along the bottom while the surface water continued to ebb (fig. 3d,e,f,g). This Type B intrusion (Pritchard, 1955) was associated with the salt-wedge that was advancing landward along the main axis of the Doboy Sound estuary (fig. 3e, 4e, 5b).

Mid-Flood Tide

During mid-flood tide, high velocity currents were present throughout Doboy Sound. All of the currents were flooding landward and maximum current velocities were along the central axis of the Sound (fig. 6). The high velocities (90-100 cm/s) were present at the surface of the channel near the constricted portion of the inlet, and the surface water along the southern portion of the channel, just inside of the inlet.

The salinities along the axis of Doboy Sound varied from 29 $^{o}/oo$ at the landward most profile (profile A) to 33 $^{o}/oo$ at the seaward most profile (profile E) (fig. 7,8). The salinities were highest at the bottom of the channels and lowest at the surface.

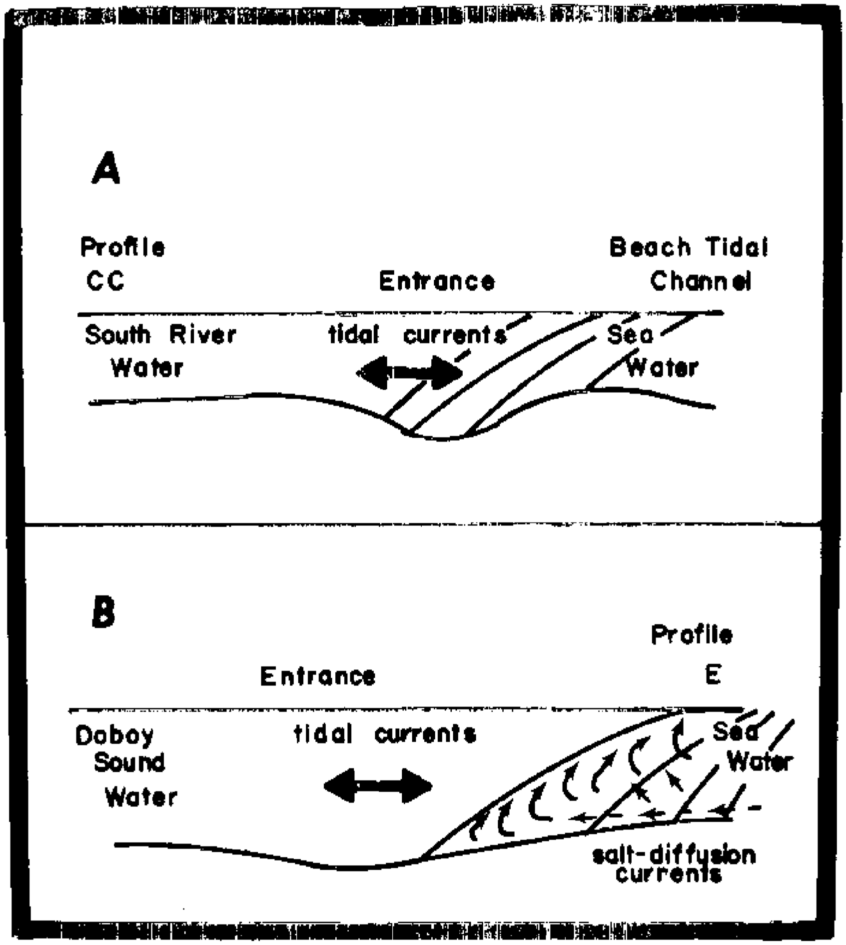

Figure 5. Cross sections through the axis of Doboy Sound across the longitudinal axis (A) and along the longitudinal axis (B) showing patterns of water flow. A type D (Pritchard, 1955) salt-wedge tongue moves along a northeast-southwest axis across the entrance of the Sound (A). A type B-type C (Pritchard, 1955) salt-wedge circulation (moderately stratified) moves along a northwest-southeast axis across the entrance to the Sound (B).

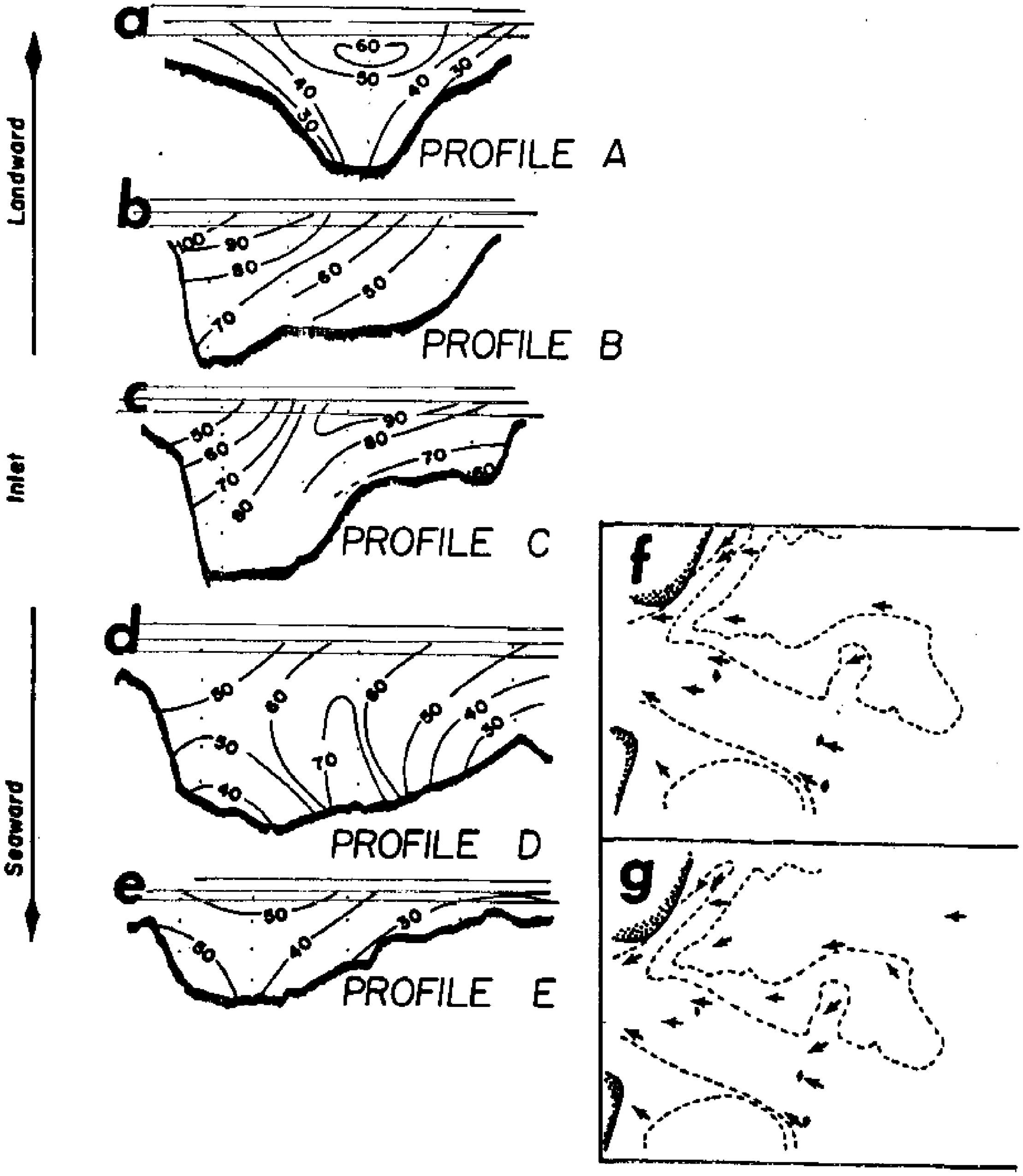

Figure 6. Cross sections of the Doboy Sound channel above bathymetric profiles A, B, C, D and E showing the distribution of current velocities during mid-flood tide. Contours are 0, 5, 10, 20, 30...100 cm/s. Sample stations are indicated by solid black dots and were spaced at 8 foot intervals beginning 2 feet below the water surface. Inserts f and g are maps of the entrance to Doboy Sound showing the directions of water flow during mid-flood tide at the surface (f) and the bottom (g). Shaded areas represent the "slack water" zones in the water column.

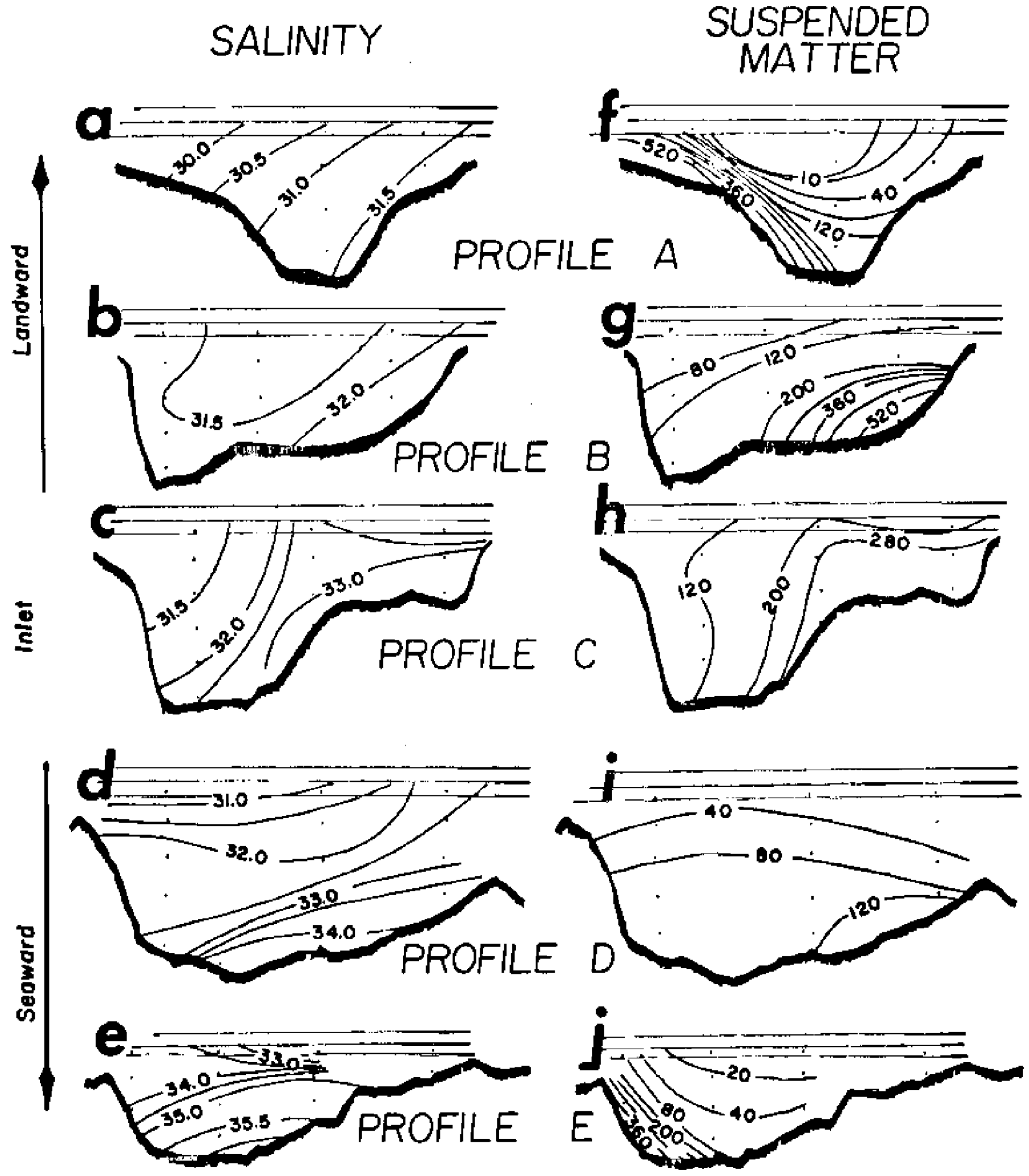

Figure 7. Cross sections of the Doboy Sound channel above bathymetric profiles A, B, C, D and E showing the distribution of salinities and suspended matter concentrations during the mid-flood tide. Sample stations are indicated by solid black dots and were spaced at 8 foot intervals beginning 2 feet below the water surface. The salinity contour interval is 0.5‰ and suspended matter concentrations are in irregular intervals (10, 20, 40, 80, 120, 200, 280, 360, 440, 520 mg/L).

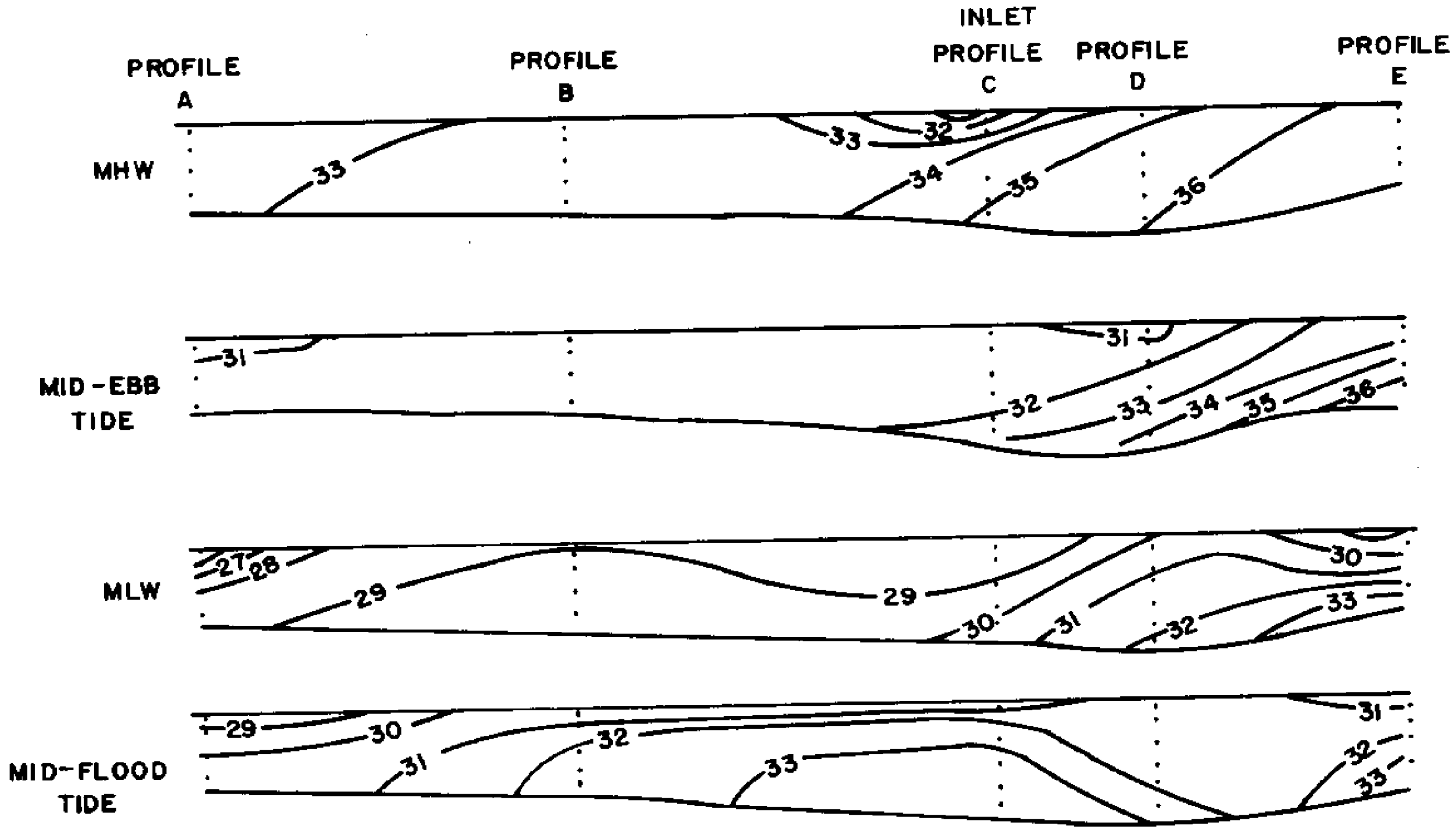

Figure 8. Distribution of salinity (^{o}/oo) along the longitudinal axis of Doboy Sound (in the deepest parts of the channel). Contour interval equals 1.0 ^{o}/oo.

Inside of the inlet, tongues of the salt intrusions moved into Doboy Sound where they experienced turbid and molecular diffusion with the lower salinity water mass of the sound. A normal pattern of diffusion along the estuary axis was complicated by the drainage of the Back and North Rivers. These rivers discharged low salinity water (Table 4), with a high concentration of suspended matter, (Table 5) normal to the direction of flood currents and type B (Pritchard, 1955) diffusion-circulation currents. As a result, turbulent mixing caused by river discharge was perpendicular to the direction of molecular diffusion, along the axis of the sound.

As North and Back River discharge was deflected landward by flood currents, water masses were subdivided further and mixed inside the sound. The northwest deflection of the North, Back and South Rivers created gyral currents which were highlighted by foamlines (fig. 2a). Shear between currents of high suspended matter concentration and currents of low suspended matter concentration created the turbid water zones and the foam lines.

The suspended matter concentration during mid-flood tide was generally between 10 and 40 mg/l except in the vicinity of the inlet (fig. 9). At the inlet, the suspended matter concentrations varied from approximately 80 mg/l at the surface to over 440 mg/l near the bottom. This high turbidity and water turbulence helped to delineate the limits of the well-mixed, marine intrusion that was spilling into the inlet from the northeast (fig. 7,9). High suspended matter concentrations (360-440 mg/l also were present in the alongshore tidal channel adjacent to the inlet (Beach Tidal Channel in Figure 1).

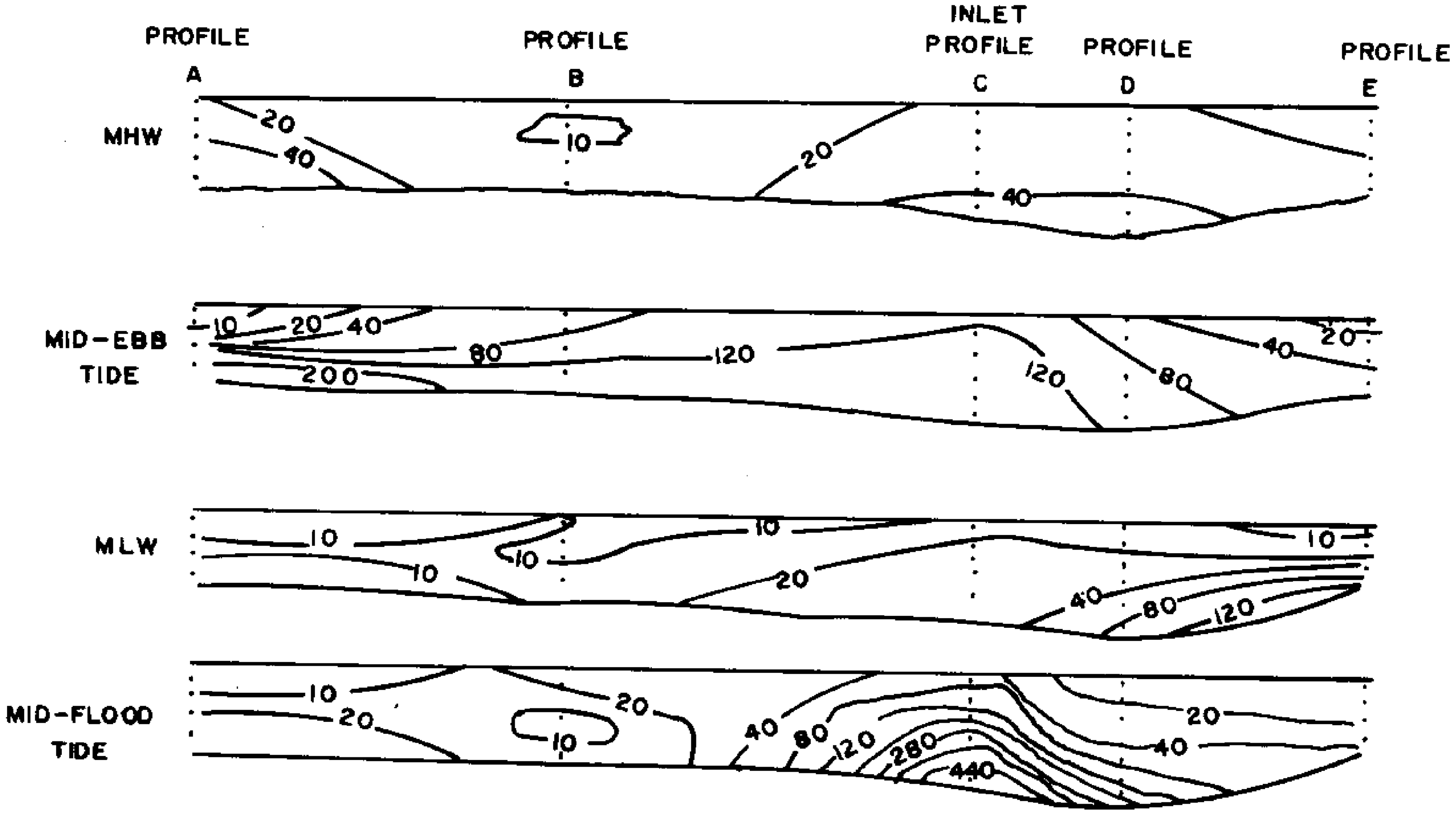

Figure 9. Distribution of suspended matter (mg/L) along the longitudinal axis of Doboy Sound (in the deepest part of the channel). Contours are irregular intervals (10, 20, 40, 80, 120, 200, 280, 360, 440 mg/L).

High Water

During high water, a gyral flow of water was present at the inlet. Most of the currents flowed in an onshore direction (flood) toward the estuary inlet, however, the initial northward ebb flow had begun through the tidal channel adjacent to the barrier beach (fig. 10g). At the constricted estuary inlet, the highest current velocities (60-80 cm/s) were present at the surface of the channel, and velocities decreased away from the inlet.

On the southside of the channel (at profile D) currents flowed eastward on the surface, while currents were diverted toward the north-northeast along the bottom and toward the south-southeast at mid-depth (Table 7).

STATION D_1

DEPTH (FEET)	CURRENT BEARING	
2	90°	East
8	130	
16	175	South-Southeast
24	175	
32	40	
40	35	North-Northeast

Table 7. Current-bearing variations with depth, at the south end of profile D (MHW).

At the landward most profile in Doboy Sound (profile A), a zone of "slack water" was present at mid depth in the channel. The current in the southwest part of the channel (above profile A) had a relatively high concentration of suspended matter

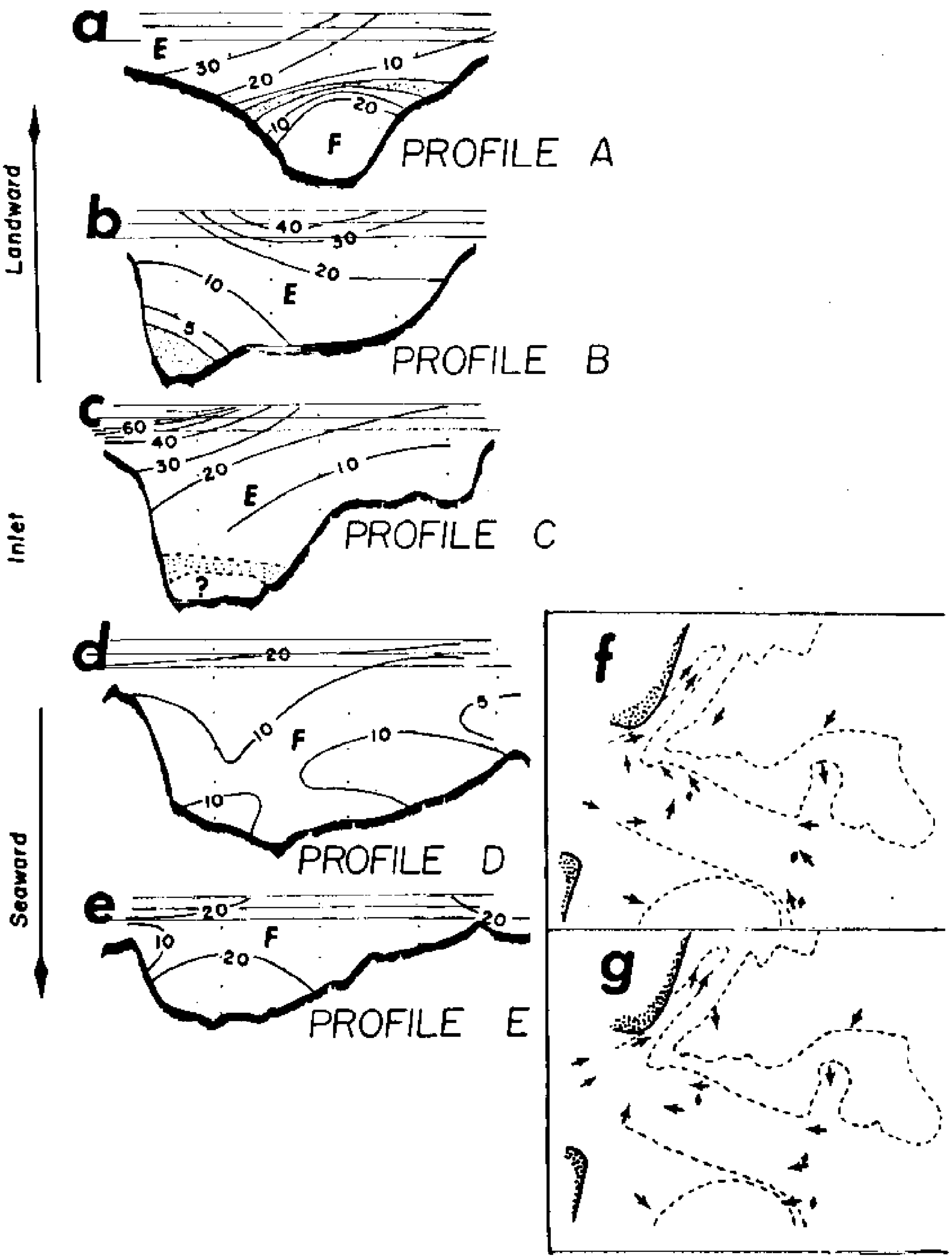

Figure 10. Cross sections of the Doboy Sound channel above bathymetric profiles A, B, C, D and E showing the distribution of current velocities during mean high water. Contours are 0, 5, 10, 20, 30...100 cm/s. Sample stations are indicated by solid black dots and were spaced at 8 foot intervals beginning 2 feet below the water surface. Inserts f and g are maps of the entrance to Doboy Sound showing the directions of water flow during mean high water at the surface (f) and at the bottom (g). Shaded areas represent the "slack water" zones in the water column. Flood and ebb flow is indicated by (F) and (E) respectively.

(40-120 mg/l), and a low salinity (31.5 $^{o}/oo$) (fig. 11) as compared to the rest of Doboy Sound at high water, (10-40 mg/l and 33-36 $^{o}/oo$). Because of these characteristics and the proximity of profile A to the North River, it is believed that this water (low salinity and high suspended matter) was diverted from the Altamaha River. The low velocity currents in the bottom part of the channel may be related to the waning surge of the flood intrusion along the bottom. However, the directions of water flow above and below the "slack water" zone at mid depth (fig. 10a) are speculative because a direction current meter was not available for this data collection.

The salinity gradient at the inlet (fig. 11c) during high water was approximately 4.0 $^{o}/oo$, while seaward of the inlet the water mass was well-mixed at 35 $^{o}/oo$ to 36 $^{o}/oo$. Salinities decreased with depth along the entire length of Doboy Sound, and the lowest salinities were generally present along the southwest-surface part of the sound (fig. 8).

The suspended matter concentrations are low throughout most of Doboy Sound, and concentrations along the central axis of the Sound vary between 10 and 40 mg/l (fig. 9). With the exception of profile A, suspended matter concentrations were slightly higher along the north side of the channel (fig. 11).

Mid-Ebb Tide

During mid-ebb tide, the maximum current velocities (100-120 cm/s) were at and just inside of the inlet (fig. 12). The highest velocities were generally located along the central and surface parts of the channel, and velocities decreased with depth and toward the margins of the channel. Two "slack water" readings were recorded at mid-ebb tide (fig. 12a,e). One "slack water" reading was made 3 miles

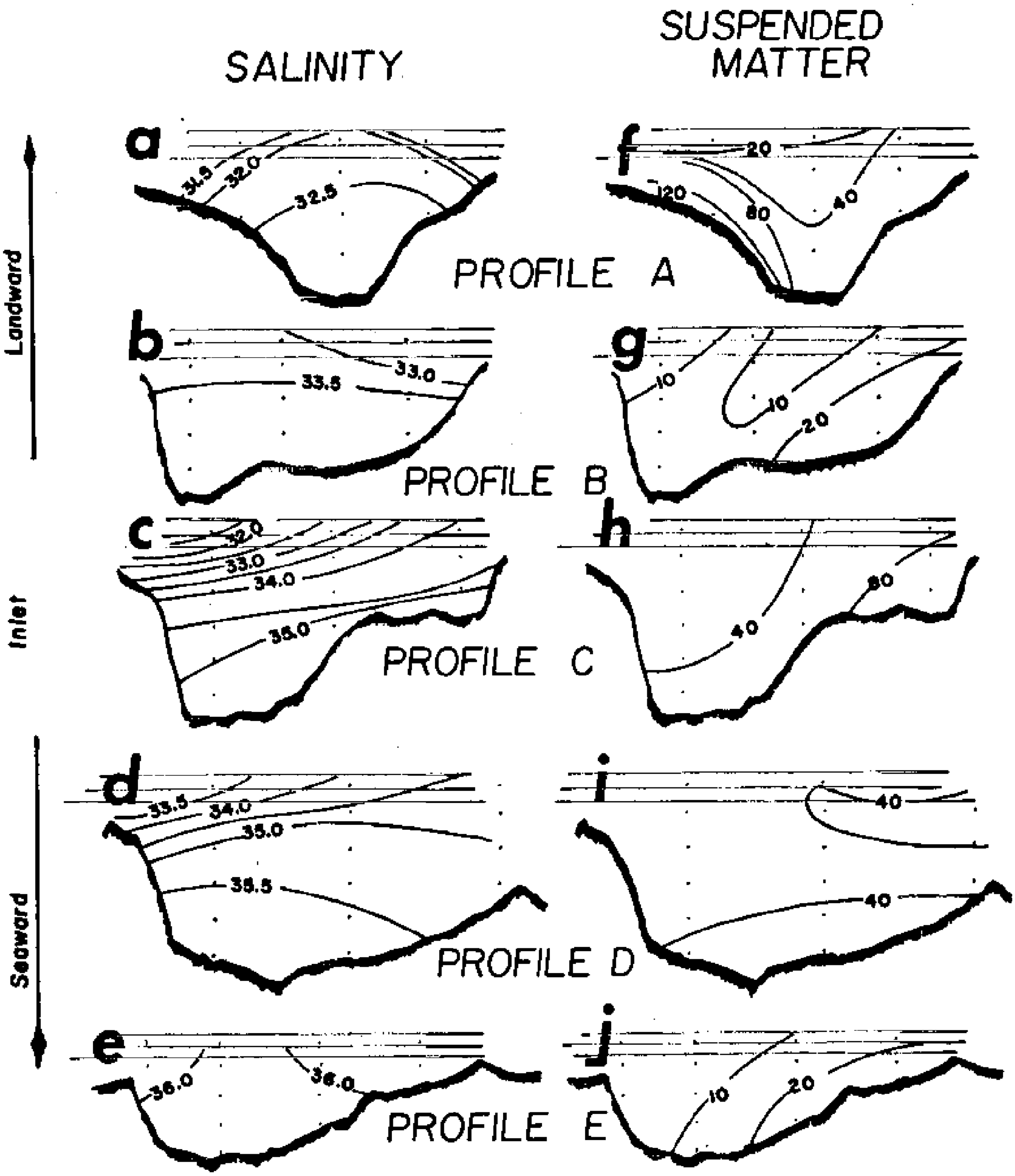

Figure 11. Cross sections of the Doboy Sound channel above bathymetric profiles A, B, C, D and E showing the distribution of salinities and suspended matter concentrations during mean high water. Sample stations are indicated by solid black dots and were spaced at 8 foot intervals beginning 2 feet below the water surface. The salinity contour interval is 0.5‰ and suspended matter concentrations are in irregular intervals (10, 20, 40, 80, 120, 200, 280, 360, 440, 520 mg/L).

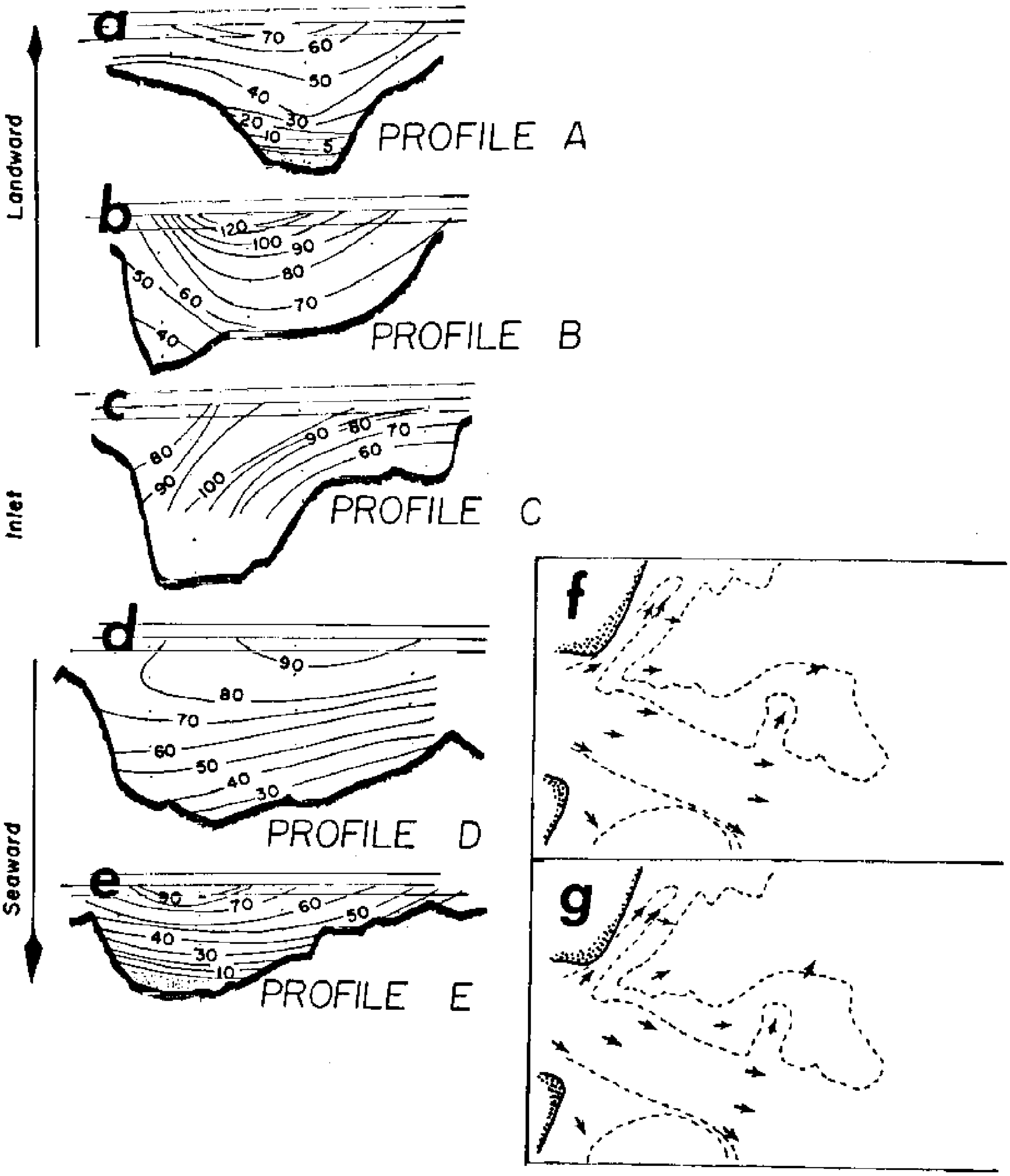

Figure 12. Cross sections of the Doboy Sound channel above bathymetric profiles A, B, C, D and E showing the distribution of current velocities during mid-ebb tide. Contours are 0, 5, 10, 20, 30...100 cm/s. Sample stations are indicated by solid black dots and were spaced at 8 foot intervals beginning 2 feet below the water surface. Inserts f and g are maps of the entrance to Doboy Sound showing the directions of water flow during mid-ebb tide at the surface (f) and at the bottom (g). Shaded areas represent the "slack water" zones in the water column.

landward of the inlet at the bottom of the channel (profile A) and another "slack water" reading was made $1\frac{1}{2}$ miles seaward of the inlet (profile E). However, there were apparently two different causes for these areas of "slack water". The "slack water" on the landward side of the inlet was apparently caused by a time lag between the ebbing of surface and bottom water. At profile A, a relatively high surface velocity (70 cm/s) was achieved before the water along the bottom of the channel began ebbing. Seaward of the inlet, salt-diffusion currents apparently were inhibiting the ebbing flow of bottom currents. A 5 $^{o}/oo$ salinity gradient between profiles D and E (fig. 13) indicated the presence of a small salt-wedge which could have been producing the landward flowing salt-diffusion currents. Landward of the inlet of Doboy Sound the water mass was well-mixed and the salinity varied between 30 and 32 $^{o}/oo$. The lower salinities were always located along the southwest and surface part of the channel (fig. 13).

The average suspended matter concentrations during mid-ebb tide were generally high and in the same magnitude as the concentrations found during mid-flood tide. These concentrations were considerably higher than the concentrations at high and low water (fig. 9, 13). The highest concentrations of suspended matter (520 mg/l) were present along the margins of the channel inside of the inlet. Much of this suspended matter settled and was filtered out of the turbid water over the South-end Mud Flat (fig. 1) where sedimentation of suspended matter was enhanced by a large population of filter feeders (especially Onuphus microcephala) living in the mudflat. In general, turbid water with high concentrations of suspended matter bordered the entire southern margin of Sapelo Island from the beach to profile A. At the inlet, relatively high concentrations (280 mg/l) were present along the northeast

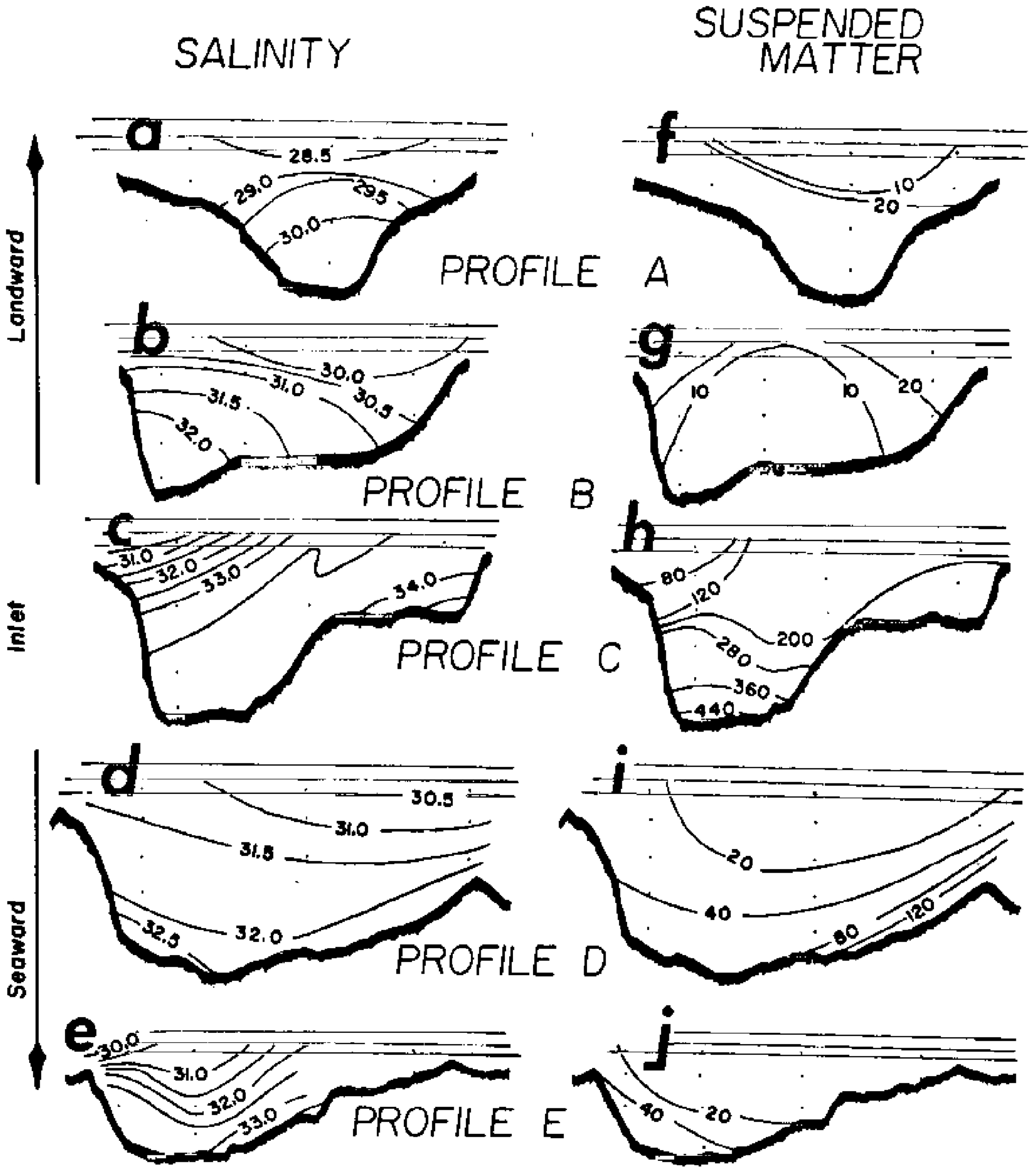

Figure 13. Cross sections of the Doboy Sound channel above bathymetric profile A, B, C, D and E showing the distribution of salinities and suspended matter concentrations during mid-ebb tide. Sample stations are indicated by solid black dots and were spaced at 8 foot intervals beginning 2 feet below the water surface. The salinity contour interval is 0.5‰ and suspended matter concentrations are in irregular intervals (10, 20, 40, 80, 120, 200, 280, 360, 440, 520 mg/L).

side of the inlet while relatively low concentrations, and concentration gradients were present just seaward of the inlet. Further seaward, at profile E, suspended matter concentrations increased to 360 mg/l near the bottom. This high suspended matter concentration was coincident with the position of the above described salt-diffusion currents and it appears very possible that the "slack water" associated with the tongue of the salt wedge was producing an accumulation of sediment in a manner very similar to that described by Schultz and Simmons (1957).

Temperature fluctuations for Doboy Sound were very small during mid-ebb tide, and periodic fluctuations in precipitation, wind velocity and atmospheric temperatures were not great enough to produce any long range temperature gradients.

During the mid-ebb tide, the seaward flow of Doboy Sound water completely overwhelmed the flow of river water, and turbid mixing of water masses increased in the center of the sound. Salinity and temperature gradients in Doboy Sound reached minimums just after the maximum ebb current velocities. Suspended matter gradients reached a maximum at this time and decreased rapidly as the ebb approached "slack water". Foam lines illustrated the positions of river drainage during the maximum ebb velocities (fig. 2b).

ESTUARINE CIRCULATION AND SUSPENDED SEDIMENT DEPOSITION

The circulation of Doboy Sound is complicated by the geometric relationships of land and water masses as well as the local hydrographic conditions. Table 8 shows several possible classification schemes for parts of the estuary, however, complicated patterns of water flow in Doboy Sound make it difficult to designate a simple classification for the entire estuary. Stratification and mixing vary along the

DOBOY SOUND ESTUARY CLASSIFICATION

Profile	Bowden, 1967	Pritchard, 1955	Pritchard, 1955
A-B	Vertically homogeneous with lateral variation	Type B-C	Vertically homogeneous with lateral variation in salinity
B-C	Two layer flow with vertical mixing	Type B-C	Moderately stratified to vertically homogeneous with lateral variation
F-CC	Vertically homogeneous laterally homogeneous	Type D	Vertically and laterally homogeneous
C-G	Two layer flow with entrainment, two layer flow with vertical mixing	Type B	Moderately stratified estuary

Table 8. Classifications for several portions of the Doboy Sound Estuary, based on schemes of Bowden (1967) and Pritchard (1955).

longitudinal axis of Doboy Sound as well as during different periods of the tidal cycle. In general, during the summer months Doboy Sound may be classified as varying from a moderately stratified estuary to a vertically homogeneous estuary with lateral variation (Pritchard, 1955).

Wind and wave generated currents caused the initial flood intrusions to enter the inlet through the funnel-shaped channel to the east northeast and the initial ebb flow to be diverted through the tidal channel adjacent to the beach.

During the mid-flood and mid-ebb tides, high velocity currents converged toward the constricted inlet to Doboy Sound. This general convergence of flow may produce a pile-up of water at the inlet. "Water-piles" such as these produce hydraulic currents (Johnson, 1919) and a gravitational flow of water called a "tidal drain" (Price, 1963) that spills away from the inlet. An unimpeded tidal drain flows away from a constricted inlet in a centripetal pattern. However, during the summer months, wind and wave currents at Doboy Sound produced a preferred diversion of the tidal drain (outside of the inlet) to the northeast. Hydraulic currents may also produce a stratified flow away from the inlets that is not controlled by salinity gradients, and this was apparently the case during high water; the surface water ebbed across the shoals, water at mid depth ebbed through the main axis of the sound, and bottom water ebbed through the tidal channel in front of the beach (Table 7). The high velocity currents associated with the tidal drains have been suggested to cause appreciable scour along the central troughs at the bottom of inlets (Price, 1963). The results of this type of scour is indicated at Doboy Sound by a thin veneer of cobbles that covers the floor of the scoured Miocene bedrock of the inlet trough.

As a result of the unique circulation patterns, much of the suspended load of the rivers discharging into Doboy Sound was deposited along the north side of the channel inside the entrance. Lenticular and flaser type bedding (Reineck and Wunderlich, 1968; Reineck, 1967) characterized the sedimentary structures in much of the sediment in the north central part of the sound. Part of the suspended loads of the North, Back and South Rivers was also deposited at the Southend Mud Flat where it was concentrated by current-deflection gyres during mid-flood tide.

Increased sedimentation of the suspended load above profile A was probably dependent on the settling lag and scour lag effects due to time/velocity asymmetry (Postma, 1954, 1967; Van Straaten and Kuenen, 1958) and by residual flood flow of bottom water (Shultz and Simmons, 1957; Meade, 1968, 1969).

Interpretations of suspended clays in Doboy Sound by X-ray studies (Levy, 1968) indicated four major sources of suspended material were: sediment from coastal plain rivers, reworking of material previously deposited in the salt marsh, organic detritus, and material transported landward from the nearshore continental shelf. Analysis of suspended matter data for the present study indicated that Doboy Sound had a net seaward transport of suspended matter (Levy, 1968). However, this net loss to the system is believed to be relatively minor in comparison to the amount of suspended matter deposited along the north margin of the sound.

The permanent load of oceanic water ranged from 1.5 mg/l ten miles offshore to approximately 5 to 20 mg/l five miles offshore, to an estimated 50 to 60 mg/l at profile E.

CURRENTS AND WATER CIRCULATION IN THE IMMEDIATE VICINITY OF ESTUARY ENTRANCE SHOALS, DOBOY SOUND, GEORGIA

General Bathymetry

Sand bars and intertidal ridges (King, 1959, p. 49) form peripheral shoals

(Price, 1963) on both sides of Doboy Sound seaward of the entrance. Shoals are topographic shields which deflect tidal and longshore currents and are dominant factors controlling wave refraction patterns around estuary entrances. Shoals are generally asymmetrical in cross-section with steeply sloping channel-ward sides which form submarine levees along the flanks of the channel (fig. 14). Shoals slope away from the channel at low angles characteristic of normal beach and foreshore slopes. The shoal complex on the north side of the channel is divided into four separate intertidal sand bodies. These sand bodies were designated as Shoals 1, 2, 3 and 4 (fig. 1). Asymmetrical sand waves in the funnel-shaped channel (Sapelo Funnel, Figure 1) showed a flood dominance, while bedforms along the Doboy Sound sides of the shoals illustrated an ebb dominance. Apparently the sand shoals helped to establish a shield between the preferred paths for the ebb and flood currents.

Similar preferred paths of tidal water flow have been described by Van Veen (1950), Robinson (1960), and Ludwick (1970, 1971). At Doboy Sound the establishment of mutually evasive paths of ebb and flood flow were apparently produced by the diversion of currents by the peripheral shoals and by other inlet currents. Todd (1968) described how the diversion of sediment laden longshore currents by inlet ebb jets produced shoals in the backwater area immediately downdrift of the inlet. Thus current diversion enhances shoal development and shoals help to produce current diversion.

At mid depth, the ebb jet observed at the inlet to Doboy Sound was confined to the main channel but the surface flow spilled centripetally away from the inlet as a tidal drain (Price, 1963). This centripetal drain away from the inlet has produced several small "spill-over channels" across the peripheral shoals (Price, 1963) or ramp-margin shoals (Oertel, 1973).

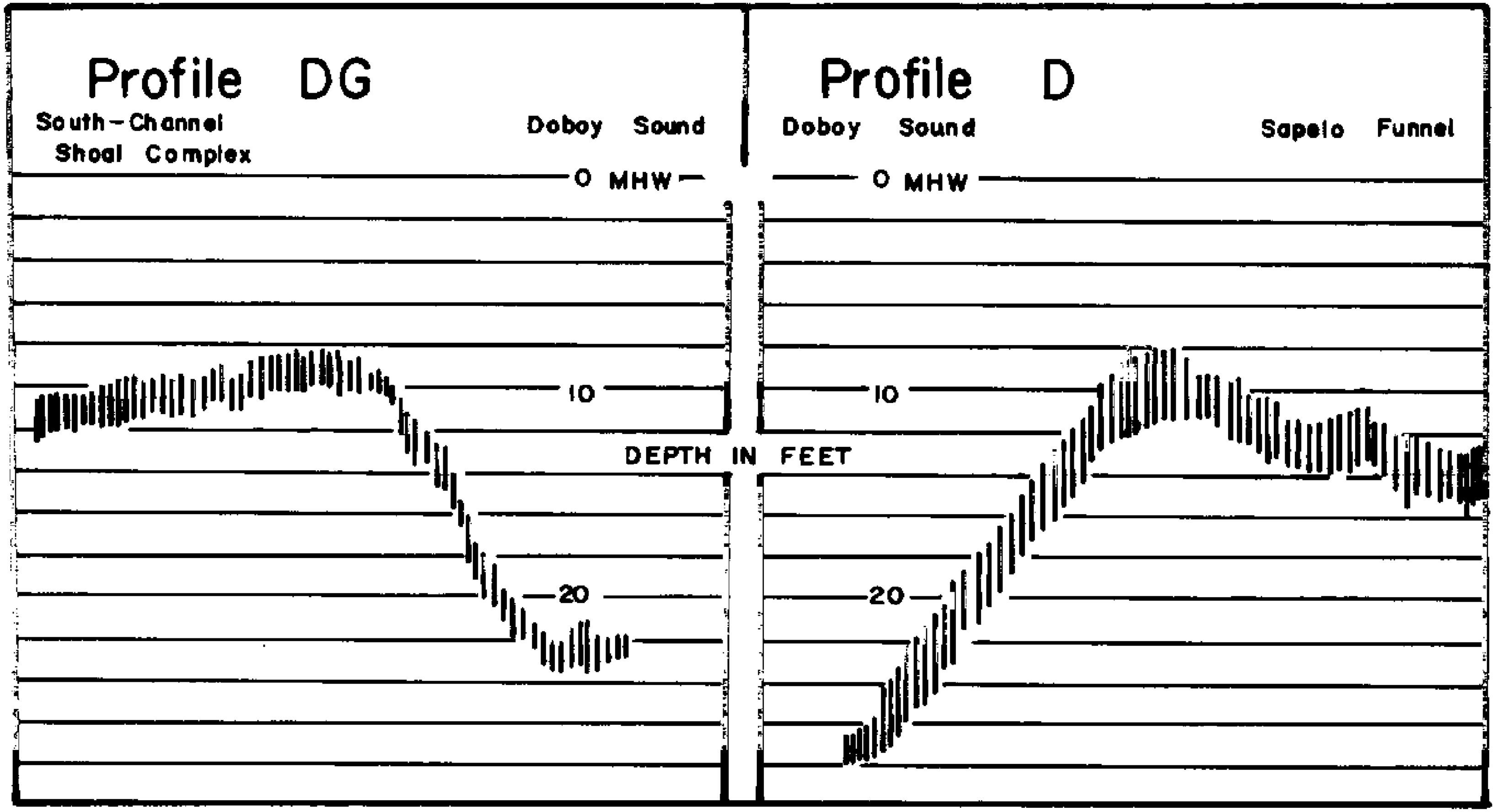

Figure 14. Sketch maps of the margins of Doboy Sound as depicted from bottom soundings at profiles D and DG.

The stability of tidal inlets is to a large extent controlled by the natural by-passing of sand across the inlets (Bruun and Gerritsen, 1959; Bruun and Gerritsen, 1961; Bruun and Battjes, 1963). At many tidal inlets, by-passing is produced by the combined forces of wave and tidal-current processes (Bruun and Battjes, 1963). Bajorunas and Duane (1967) and Todd (1968) have described some processes by which currents at inlets affect the diversion of water and sediment adjacent to the inlets. Bajorunas and Duane (1967) described how eddy currents at inlets formed gyral paths as they curved back in the lee of a "breakwater-protected harbor entrance". At Doboy Sound these eddy currents apparently also formed on the lee sides of the ramp-margin shoals.

Bathymetric shielding by ramp-margin shoals caused tidal flow to be diverted in the direction of the shoal trends and caused shoaling waves to be refracted toward the entrance of Doboy Sound. During flood tide, shoaling waves along sand-shoal margins spilled and the residual onshore wave surge apparently reinforced the on-shore flowing flood currents and during the ebb tide, spilling waves apparently inhibited the offshore flow of water. In the broad shallow areas adjacent to shoals (The Sapelo Funnel, fig. 1), waves began spilling at relative long distances from the shoal margins, and thus a large residual onshore surge of water was associated with these waves. Along the relatively deep-water margins of the shoals, waves "broke" at a narrow zone near the mean low water line.

Since the coastal currents along the Georgia coast are transient in direction and magnitude, there is no predominant updrift side of the inlet at Doboy Sound, (Oertel and Howard, 1972). However, by combining the concepts of inlet-eddy currents (Bajorunas and Duane, 1967), centripetal tidal drains (Price, 1963) and dynamic diversion (Todd, 1968) it may be seen how large sand shoals may form along both sides of the inlet to Doboy Sound. By-passing of small amounts of sand across the entrance to Doboy Sound was accomplished several miles seaward of this inlet by the combined forces of waves and tidal currents. The transfer of sand across the seaward portion of the inlet took place by bar shifting and by tidal-current processes described by Bruun and Gerritsen (1959). Approximately 4 miles seaward of the inlet, the shifting of offshore bars and tidal channels produced by-passing of sand across the distal shoals, while the combined forces of tidal currents and hydraulic currents produced by-passing across the seaward portions of the ramp to the sea (Oertel, 1972).

During mid-tides, waves which were refracted by the shoals crossed over the shoals from two different directions and interferred with each other (Oertel, 1972). Increased internal shear created by the interference of shoaling waves often produced wave-bores along the points of wave interference. These bores migrated across the shoal in a line which bisected the angle between the two directions of wave approach (fig. 15). Bores induced by wave interference flowed over the topographic highs on the shoals, whereas tidal currents flowed over the entire shoal surface or were restricted to the trough and runnels between swash bars and swash platforms.

Wave-induced currents and bores of interfering waves induced a pulsating flow of tidal currents over the shoals. Periodic surf surges from the two directions of wave advance momentarily neutralized the offshore flow during the ebb tide and momentarily reinforced the onshore flow during the flood tide. During the ebb tide, this action was especially important to the production of gyral patterns of sediment transport at shoals (Oertel, 1972).

During the waning stages of the ebb tide, when the depth of water over the

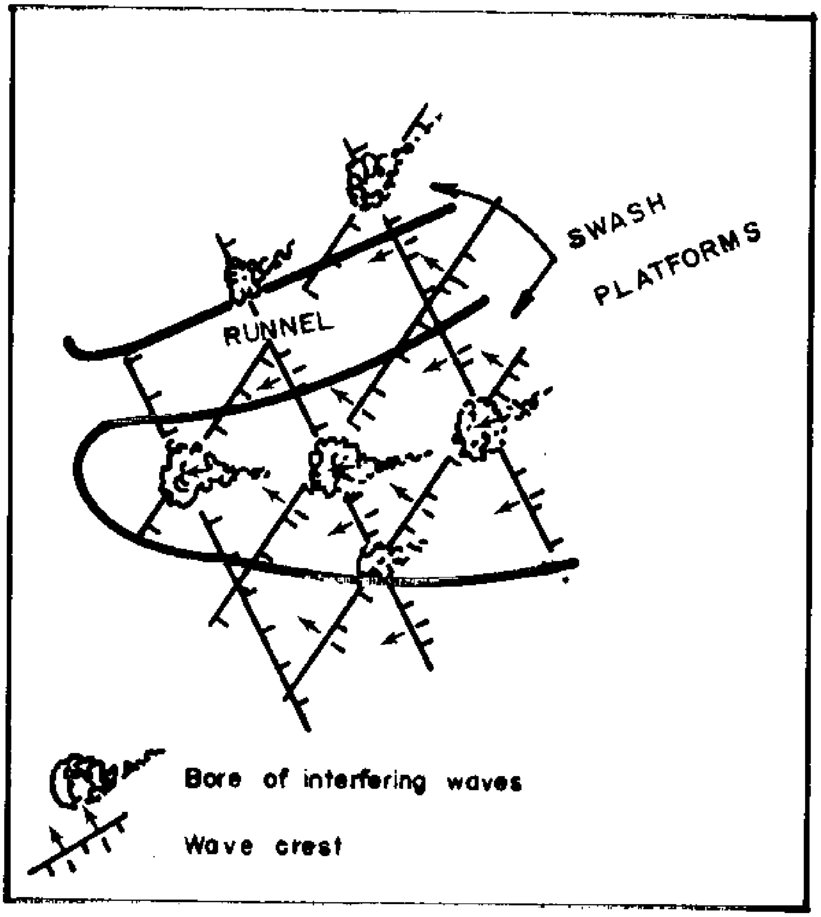

Figure 15. Sketch map illustrating the development of bores of interferring waves over swash platforms, but not over runnels (Adopted from Oertel, 1972).

shoals was reduced to approximately 20% of the high water depth, swash currents translated water westward over Shoals 3 and 4, and completely prevented the passage of ebb currents. These combined bathymetric and hydrodynamic shields deflected ebb currents toward the north through "spill-over" channels. Sedimentation associated with these deflected ebb currents produced extensions of the secondary longshore trends in the ramp-margin shoals (Oertel and Howard, 1972).

CONCLUSIONS:

SHOAL DEVELOPMENT AT THE ESTUARY ENTRANCE

Diversion of sediment-laden longshore currents by the ebb tidal drain of Doboy Sound caused deposition of sediment on the margin of the ramp to the sea. Shoal development at the entrance to the Doboy Sound estuary was in response to patterns of dynamic diversion (Todd, 1968) which were in turn controlled by flow gyres (Bajorunas and Duane, 1967) and the centripetal flow of the inlet drain (Price, 1963). Sedimentation on shoals was enhanced by mutually evasive tidal channels (Van Veen, 1950; Robinson, 1966; Ludwick, 1970, 1971). Under these conditions of flow diversion, sediment is "trapped" in the sediment system of the shoals and sediment by-passing across the inlet took place only several miles seaward of the entrance. Limited sediment by-passing is substantiated by the above described characteristics of the sediment on the ramp to the sea (Oertel, 1971).

The general pattern of sediment entrainment during the summer months was in two sediment gyres (fig. 16), which tended to accumulate sediment over shoal surfaces. This pattern of circulation at the entrance of the tidal inlet produced a deficit in the sediment budget along the mid-island shorelines of the barrier (Oertel

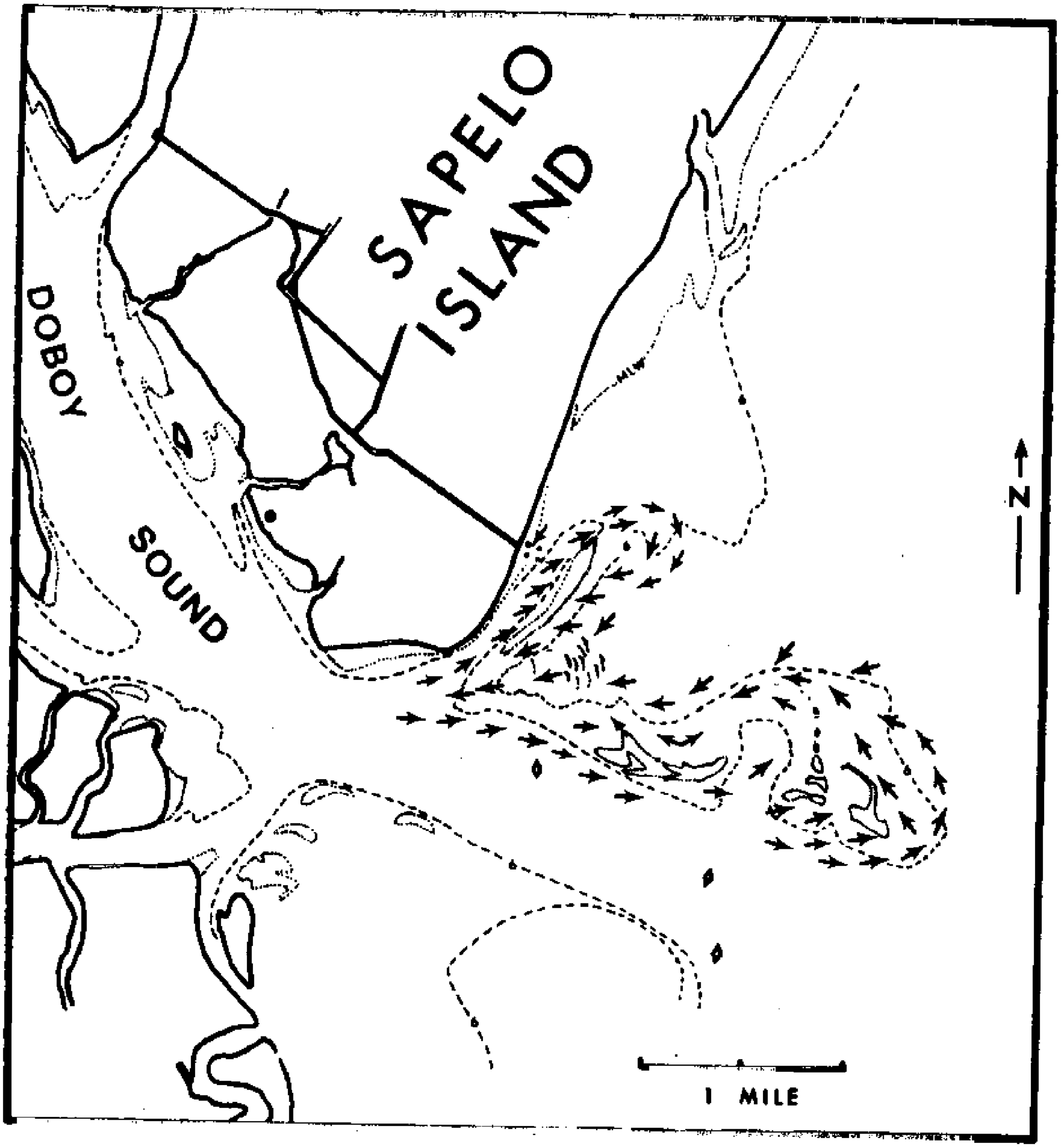

Figure 16. Sketch map illustrating gyral flow of sediment around estuary entrance shoals.

and Howard, 1972). Erosion of the mid-island shoreline is illustrated by washover fans that characterized the shoreline at Cabretta Beach (Frey and Howard, 1969; Mikesh, Howard and Mayou, 1968; Hoyt, Henry and Howard, 1966). Swift (1970), Dillon (1970) and Pierce (1970) have discussed how sediment starved barriers retreat intermittently by shoreface and shoreline erosion, however only the mid-island portion of the Sapelo Island shoreline appears to be retreating by overwash. This preferred location of erosion by overwash was characteristic of many of the other barriers along the Georgia coast (Oertel, in prep.).

Barrier islands along the Georgia coast develop differently than barriers with shorelines experiencing a predominant longshore drift (that overwhelms the force of ebb tidal jets). At Doboy Sound, tidal flow by-passing and bar by-passing (Bruun and Gerritsen, 1959) both take place a considerable distance seaward of the inlet.

It is apparent from the discussion of sediment by-passing that barriers and inlets on mesotidal coasts with low wave activity are not migrating in one down drift direction as was the case for the barriers described by Shepard (1960), and Hoyt and Henry (1967). Barrier migration adjacent to Doboy Sound appears to be more highly dependent on the nature of sediment accumulation on the peripheral shoals around the inlet, and upon the patterns of channel-shifting adjoining these shoals.

OBSERVATIONS OF HYDROLOGIC CHARACTERISTICS AT GEORGIA ESTUARIES

Estuaries along the Georgia coast fall into two groups. Most of the estuaries are basically <u>tidal inlets</u> (Price, 1963) with a very small source of fresh water. <u>Tidal inlets</u> generally have relatively deep (45-90 feet) axial troughs at the inlet. Four of the estuaries (St. Marys, St. Andrews, Altamaha and Ogeechee) along the coast are <u>fluvial</u>

estuaries and have rivers which supply fresh water to their respective sounds. The Altamaha and the Ogeechee Rivers have relatively large discharges of low salinity water (Table 9) and they generally exhibit a well-developed water stratification in their respective sounds. The low salinity water that discharged into the St. Marys and St. Andrews Sounds apparently mixed quite rapidly inside of the sounds (Howard, 1972). The fluvial estuaries had relatively well developed, stratified circulations (Altamaha and Ogeechee Rivers) and had relatively shallow inlet troughs (< 30 feet) (Table 10). The stratified circulation at the Altamaha and Ogeechee Rivers apparently enhanced shoaling at the inlets (Schultz and Simmons, 1957) and produced shallow ebb deltas seaward of the inlets. The tidal inlets (Price, 1963) that had deep inlet troughs probably had inlet circulation patterns which more closely fit the circulation pattern described for Doboy Sound. This circulation pattern enhances scour at the inlet, whereas a stratified circulation enhances shoaling. It was found that the ratio between the depth of the inlet trough and the average depths of the shoreface seven miles seaward of the entrance was a useful figure for distinguishing between estuaries with shallow ebb deltas and tidal inlets with deep inlet troughs. The estuaries with well developed salinity stratifications (Altamaha and Ogeechee Rivers) had ratios of less than .8, moderate to well mixed tidal inlets with moderate sources of fresh water (St. Andrew, St. Simons, Doboy and Wassaw Sounds) had ratios between 1.0 and 2.0, and well mixed tidal inlets (Sapelo and St. Catherines Sounds) had ratios greater than 2.0 (Table 10). Although the analysis of these ratios is only a crude method of comparison, it illustrates a relationship between entrance circulation and entrance sedimentation. These relationships are considered of greater importance to inlet stability in mesotidal coastlines with moderate to low wave activity, than they would be in areas having low tidal ranges and a predominant

AVERAGE ANNUAL DISCHARGE

River	Discharge	Location	Period Analyzed
St. Marys	683 cfs	Near MacClenny, Fla.	41 years
St. Andrews	2131 cfs	Near Atkinson, Ga.	44 years
Altamaha	13380 cfs	Near Doctortown, Ga.	39 years
Ogeechee			
Canoochee	451 cfs	Near Claxton, Ga.	
Ogeechee	2313 cfs	Near Eden, Ga.	
	2764 cfs		33 years

Table 9. Average annual discharges of the major rivers supplying fresh water to the Georgia coast.

Inlets	Inlet Trough	Shoreface	Ratio
St. Marys	50 :	33.1	1.51 : 1
St. Andrews	55 :	33.1	1.66 : 1
St. Simons	56 :	33.1	1.69 : 1
Altamaha	20 :	33.1	.60 : 1
Doboy	55 :	33.1	1.66 : 1
Sapelo	75 :	33.1	2.27 : 1
St. Catherines	90 :	33.1	2.72 : 1
Ossabaw	26 :	33.1	.79 : 1
Wassaw	45 :	33.1	1.36 : 1

Table 10. Ratio of the maximum depths of inlets (mlw) to the average depth of the shoreface seven miles seaward of the shoreline.

longshore drift.

Hydrographic Investigations

Subsequent to the relatively detailed investigation of Doboy Sound, studies were conducted at the remaining estuaries along the Georgia coast (St. Marys Sound, St. Andrews Sound, St. Simons Sound, Altamaha entrance, Sapelo Sound, St. Catherines Sound, Ossabaw Sound, Wassaw Sound). This research was done under the direction of Dr. J. D. Howard, Skidaway Institute of Oceanography, who was assisted by G. H. Remmer (State University of New York, Stony Brook, New York), T. Walker (Captain R/V Striker, Marine Institute, Sapelo Island, Georgia), R. Philosky, J. Garell and M. Indianer (Antioch College, Yellow Springs, Ohio). Hydrographic profiles for St. Marys, St. Andrews, St. Simons, Altamaha, Sapelo, St. Catherines, Ossabaw and Wassaw Sound were presented as part III of a final report for the U. S. Coastal Engineering Research Center Grant DACW-72-68-C-0030. Most of the data presented on Table 11 is a summary of data obtained from part III of this final report. A complete description of the thirteen hour fluctuations of current velocity, salinity, temperature, suspended matter and bedload are illustrated in the Howard (1972) report. Locations of the sampling stations for these data are indicated on Figure 17, and each station was analyzed over a thirteen hour tidal cycle. A description of the procedures is also presented in part III of the final report to the U. S. Army Corps of Engineers. The discussion in part III of the final report, noted that much of the water current data was collected without the knowledge of the flow directions and the assumption was made that subsurface water flow was equivalent to what was observed on the surface. Based on the observations at the entrance to the Doboy Sound estuary, this was probably a very poor

		St. Marys Sound	St. Andrew Sound	St. Simon Sound	Altamaha River Entrance	Doboy Sound (2)	Sapelo Sound	St. Catherines Sound	Ossabaw Sound	Wassaw Sound
Temperature Gradient °C		22.8 to 2.1 20.7	22.1 to .9 21.2	21.6 to 1.4 20.2	17.2 to 2.9 14.3	28.8 to .7 28.1	22.5 to 2.5 20.0	16.0 to 1.5 14.5	17.8 to .7 17.1	18.9 to 1.8 17.1
Salinity Gradient ‰ (6 hours)		35.0 to 4.5 30.5	32.0 to 5.0 27.0	33.0 to 7.4 25.6	25.2 to 22.7 2.5	35.5 to 7.0 28.5	32.8 to 2.6 30.2	31.0 to 2.0 29.0	31.0 to 5.0 to 26.0 10.8 (3)	32.6 to 2.6 31.0
*Discharge 10^4 cu ft	N	223.247·10^8 (F)	1637.9 (E)	231.45 (E)	51.2 (F)		608.9 (E)	300.6 (E)	138.0 (E)	51.1 (F)
Net Ebb (E) (1)	M		22.5 (F)	93.21 (F)	172.4 (F)	—	294.7 (E)	1060.8 (E)	112.4 (F)	1136.7 (E)
Net Flood (F)	S	239.411·10^7 (F)	1309.5 (E)	995.16 (E)	277.1 (E)		1329.6 (E)	112.1 (F)	408.3 (E)	386.9 (E)
Net. Suspended mg/l										
Load concentration	N	30. (E)	31. (F)	4. (E)	15. (F)		14.0 (F)	19.0 (E)	40.0 (E)	16.0 (E)
Net Ebb (E)	M		9. (F)	39. (E)	18. (F)	—	12.0 (F)	51.0 (F)	41.0 (E)	108.0 (E)
Net Flood (F)	S	193. (E)	6. (E)	5. (E)	14. (F)		13.0 (F)	8.0 (E)	40.0 (E)	387.0 (F)
Net Bedload g										
concentrations	N	1724.000 (F)	350.0 (E)	318.00 (F)	394.5 (E)		410.0 (F)	61.0 (E)		8220.0 (E)
Net Ebb (E)	M		325.0 (E)	24.00 (E)	252.5 (F)	—	76.0 (E)	315.0 (F)	425.0 (F)	357.0 (E)
Net Flood (F)	S	3420.000 (E)	325.0 (E)	26.00 (E)	80.6 (E)		495.0 (F)	20.0 (E)	280.0 (E)	407.0 (F)
Location of deepest part of channel and closest station		M/-	S/S	S/S	M/M	S/S	S/M	M/M	N/N	S/S

N = North Station
M = Middle Station
S = South Station

(1) These data are subject to scrutiny because a large part of the current data was not directional

(2) Data from Oertel, 1971

(3) Greer, in prep., found a gradient of (26.2 ‰ - 15.0 ‰) = 10.8 ‰

Table 11. Hydrographic data for nine estuaries of the Georgia coast, data predominantly obtained from Howard (1972) and in part from Oertel (1971) and Greer (in prep.).

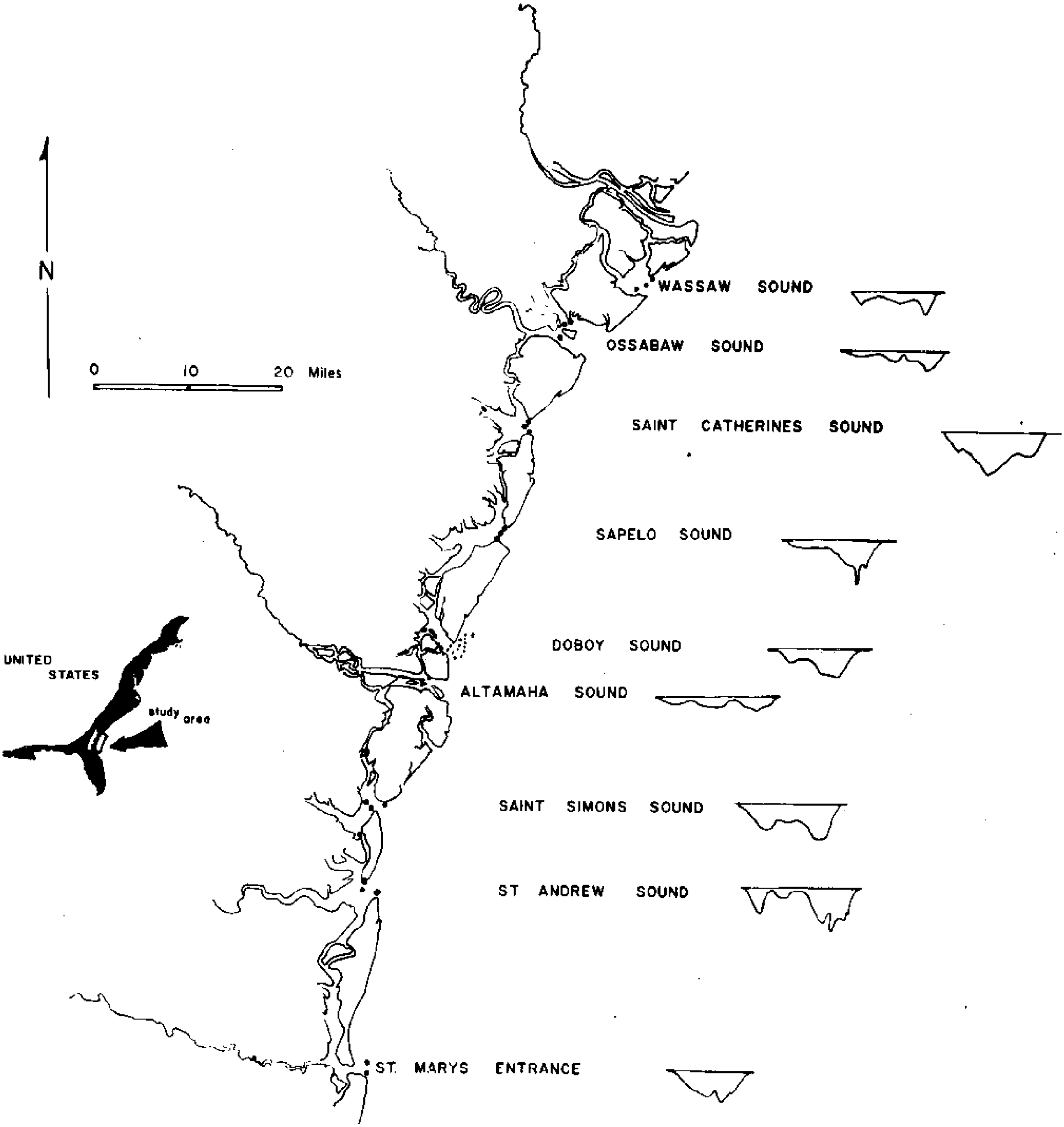

Figure 17. Location map of Georgia coast showing 13-hour sampling stations at locations studied by Howard (1972). Black dots illustrate station locations.

assumption. Vertical and lateral changes in flow directions were observed at Doboy Sound during large portions of the tidal cycle.

Temperature

Along the Georgia coast, temperature gradients across estuary inlets were between .7° C and 2.9° C. These gradients were low enough in magnitude to be overshadowed by changes induced by daily climatic fluctuations. In general, thermal mixing of the estuarine water masses was very rapid. Temperatures in the surface portions of channels were consistently higher than bottom temperatures. Lateral temperature fluctuations seem to vary from one estuary to the next without a consistent pattern.

Salinity

The salinity gradients above inlet profiles were quite variable and ranged from 2.0 ‰ at St. Catherines Sound to 22.7 ‰ at the Altamaha River entrance (Table 11). The estuaries with fluvial sources of discharge (St. Marys, St. Andrews, Altamaha and Ossabaw) had relatively high stratifications and as would be expected, the Altamaha and Ossabaw estuaries illustrated the most pronounced salinity stratifications as a consequence of their large fluvial discharges (Table 9). St. Simons and Doboy Sound also received relatively large quantities of low salinity water, and these entrances also had relatively well developed salinity gradients (7.4 ‰ and 7.0 ‰, respectively). Some of the low salinity water from the Altamaha River apparently was diverted to the north and to the south and was discharged into Doboy and St. Simons Sounds through the interlacing network of tidal rivers behind the barriers. The greatest amount of flow was probably diverted through the Intracoastal Waterway which is maintained for navigation by the U. S. Corps of Engineers.

The highly stratified water masses of the Altamaha and Ossabaw Sounds were observed several miles landward of the inlets (Kuroda, 1969 and Greer, in prep.). At Doboy Sound, maximum salinity stratification developed just seaward of the inlet during mid-ebb tides. This trend was also observed at Sapelo Sound by Kuroda (1969). Analysis of these initial observations indicates that there was a preferred location of stratified water masses seaward of tidal inlets (Price, 1963) and a preferred location of stratified water masses landward of fluvial estuary entrances.

Water Flow Budgets Through Inlets

Data presented by Howard (1972) illustrated that all of the estuaries (with the exception of St. Marys) had relatively large net ebbs of water. However, as was also pointed out in part III of the final report (Howard, 1972) the direction data used to compute net discharges were based on the assumption that subsurface water flows were equivalent to surface flows. The directions of surface and subsurface flow at Doboy Sound were variable and this is more than likely the case for the other estuaries along the Georgia coast.

Although the net directions and volumes of discharge presented by Howard (1972) should be used with scrutiny, the absolute values for current velocities are useful for determining the scour and sedimentation rates during a tidal cycle.

Suspended Matter

In order to determine the net flow of suspended particulate matter through an inlet, it was necessary to multiply the quantity of suspended matter during the ebb, times the volume of water during the ebb, and subtract this value from the quantity of suspended matter during the flood, times the volume of water during the flood. The resulting figure gave Howard (1972) what was believed to be the net flow of suspended matter through an inlet. However, as was previously stated,the values for discharge are based on a poor assumption and the values for the net volumes of suspended matter passing an inlet were also based on the original poor assumption.

Values for net concentrations of suspended load over a thirteen hour period (without discharge volumes) (Table 11) were analyzed in hopes of eliminating poor assumptions from the reduced data of the Howard (1972) final report; however, analysis of these data also failed to illustrate any trends of suspended matter flow that were common to all of the inlets. This was anticipated because of the complicated flow paths and the apparent mutually evasive channels found at the entrance to Doboy Sound. In general, the maximum concentrations were in the lower portions of the channels. These relatively high concentrations were also in the same magnitude as the concentrations determined at Doboy Sound. If it is valid to use Doboy Sound as a framework for the other tidal inlets, then it may be assumed that the standing suspended matter load throughout an entire tidal cycle was greatest at the entrance to the tidal inlet. However, three dimensional frameworks of the other inlets are needed before a valid comparison could be made.

Bedload

Analysis of bedload concentrations illustrated that most of the entrances had preferred locations for flood or ebb dominated flows of bedload. However, the positions of these preferred locations were not consistent for all of the respective estuary stations and no patterns of bedload flow at entrances could be effected from the data. The grain characteristics (size, shape, composition) also were not related to any portion of the tidal cycle or any station in the channel and it appeared that bedload transport patterns were different for each estuary entrance. Some of these differences could have been a result of sampling techniques since the quantity of material collected by the Arnham bedload sampler was greatly influenced by the local submarine topography. At Georgia estuary entrances the topography of the bottom was generally quite variable and was commonly characterized by a large number of large sand waves. A bedload sampler placed on the crest of one of these bedforms would collect different quantities of sand than if it were placed on the bedform's slip face or in a trough between bedforms.

CONCLUSIONS

Upon initial examination of hydrographic profile data, it was concluded that each estuary entrance had a unique pattern of suspended and bedload transport. However, since most of the estuary entrances had a great number of bathymetric similarities, it was speculated that the analysis of the reduced data did not produce similar sedimentary trends for some other reasons. Some of these reasons were indicated in the final report by Howard (1972) "It is clear from the data shown in the foregoing discussion that the picture of sediment circulation at the entrances is complex and variable. This is because of the variations in the synodic tidal cycle, seasonal wind variations, influence of seasonal flood from mainland rivers, the marsh storage area and the variability of water movements within the water mass at the estuary entrance."

Besides the above described problems with respect to the lack of direction, data for current readings and the problems with setting bedload samplers, the locations of sampling stations with respect to entrance topography were inconsistent for many of the entrances (fig. 17). These inconsistencies alone could produce the differences in data. Similarities in submarine topography at each inlet were related in shape, but not necessarily in size or orientation. For this reason it was difficult to locate stations at equivalent positions at each respective inlet. In order to relocate respective stations in an equivalent submarine, geomorphic setting, it would have been necessary to conduct a complete and detailed bathymetric survey of each entrance. There was insufficient time to do this, and the positioning of stations was also often determined by the degree of protection a thirteen hour station had from the occasional northeast storms.

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