

A HYDROGRAPHIC INVESTIGATION OF WINYAH BAY, SOUTH CAROLINA  
AND THE ADJACENT COASTAL WATERS

A THESIS

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*Richard*  
Daniel R. Bloomer

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AND THE ADJACENT COASTAL WATERS

Approved:

*J H H*

*J*  
James Harding, Chairman

*M L*  
Robert Lovell

Herbert Windom

Date approved by Chairman: 7/9/73

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## ABSTRACT

Current measurements as well as temperature and salinity data were taken in the Winyah Bay estuary and the adjacent coastal waters. These data were accumulated over one year during five cruises. The current meters used were capable of recording current direction and speed at regular intervals of time so that several stations could be occupied simultaneously.

The data accumulated on the inner continental shelf strongly suggests that the water motion in this area is controlled primarily by the dominant wind conditions and secondarily by the tide. The evidence suggests that only during calm wind conditions (less than 10 knots) will the tidal effects alone be large enough to cause reversal of the shelf currents. There is evidence that an interaction between shelf and estuarine water motion may cause temporary interruptions in the otherwise smooth current variation following the change in the tide.

Data accumulated within the Bay indicate that the estuary may best be classified as partially mixed although these conditions may fluctuate greatly depending on position in the bay, stage in the tide, and rate of fresh water inflow. The Western Channel appears to be predominantly an ebb channel, particularly during periods of high runoff.

The limit of saltwater intrusion was found to proceed beyond the confluence of the Peedee and Waccamaw Rivers during average runoff. During high runoff the tip of the wedge intruded to the vicinity of station

R28. Even during high runoff the wedge was never completely expelled from the estuary.

## CHAPTER I

### INTRODUCTION

Over the past few decades the problems of pollution and its effect on the environment have become increasingly more important. Accelerated population growth and industrial development have resulted in substantial amounts of sewage and other waste being introduced into the nation's rivers and estuaries. The bulk of riverborne particulate and dissolved matter is usually confined to the estuaries and the inner continental shelf. Manheim, Meade, and Bond (1970) conclude that detrital particles contributed to the shelf are restricted to a narrow band ten miles wide adjacent to the coast. Any process which affects transportation and distribution within this coastal zone is therefore extremely important in determining the fate of pollutants introduced into this region. Water motion in the estuaries and adjacent waters is perhaps the most important factor to be considered.

To date, most of the data pertaining to circulation on the Atlantic southeastern continental shelf has been obtained by Haight (1942), Bumpus (1955), Bumpus and Lauzier (1965), Steffanson et al. (1971), and Blanton (1971). Haight (1942) presented current speed and direction data recorded at lightships along the eastern seaboard. Hourly data were recorded for one year at six lightships between North Carolina and Florida. Bumpus (1955), Bumpus and Lauzier (1965), Steffanson et al. (1971), and

and Blanton (1971) dealt primarily with coastal waters north of Cape Fear. Conclusions were based primarily on drift bottle studies and temperature and salinity data. In all of these studies, information pertaining to the waters south of Cape Fear was limited and conclusions regarding circulation in this area were tentative. Both Haight and Bumpus gave evidence that the general circulation south of Cape Fear reflects changes in seasoned wind conditions and fresh water input from coastal rivers. In addition Bumpus (1955) suggested that the waters immediately south of Cape Hatteras are affected periodically by intrusion of cold water from the north. Blanton (1971) suggested that occasional meanders in the Gulf Stream can cause onshore or offshore motion of shelf waters.

Literature pertaining to specific estuaries and their circulation characteristics has been largely restricted to major northeastern estuaries such as the Chesapeake Bay (see Schubel (1971)). On the basis of these studies, Pritchard (1955) has produced a general classification system by which estuaries may be categorized from a knowledge of circulation characteristics and salinity distribution.

At present, studies are under way to investigate near shore and estuarine water motion near the mouth of the Savannah River (Oertel, personal communication). Most of the work pertaining to major southeastern estuaries has been done by the United States Army Corps of Engineers Committee on Tidal Hydraulics (1961, 1964, 1972, Schultz and Simmons, 1957). These studies are preliminary and they deal primarily with problems associated with dredge spoil disposal, sediment distribution, or navigation. Meade (1969) presented evidence regarding sediment motion at

the mouth of major estuaries along the Atlantic coast.

Winyah Bay is the northernmost of several sizeable southeastern estuaries. There is a considerable amount of ship traffic within this bay and commercial fishermen gain access to the shelf through this harbor. In addition to this a large fraction of the pollutants and sediments introduced to the Pee Dee and Waccamah Rivers eventually enter this estuary. Work done by the Corps of Engineers in this estuary is preliminary and their conclusions with regard to classification based on Pritchard's work are tentative.

The present study was undertaken to determine circulation patterns and their dominant controlling factors in the Winyah Bay estuary and the adjacent coastal waters (Figures 1 and 2). Particular attention was paid to the nature of the circulation in the Western Channel as it was excluded from studies done by the Corps of Engineers. Also the nature of any interaction between estuarine and continental shelf circulation was of particular interest. Data accumulated within the estuary were used in conjunction with those compiled by the U. S. Army Corps of Engineers (1961 and 1964) in an effort to gain a better understanding of the type and extent of saltwater intrusion which occurs there. Hopefully conclusions regarding inner shelf circulation in this area can be extrapolated to areas to the south resulting in an increased understanding of near-shore circulation over the southeast Atlantic continental shelf in general.

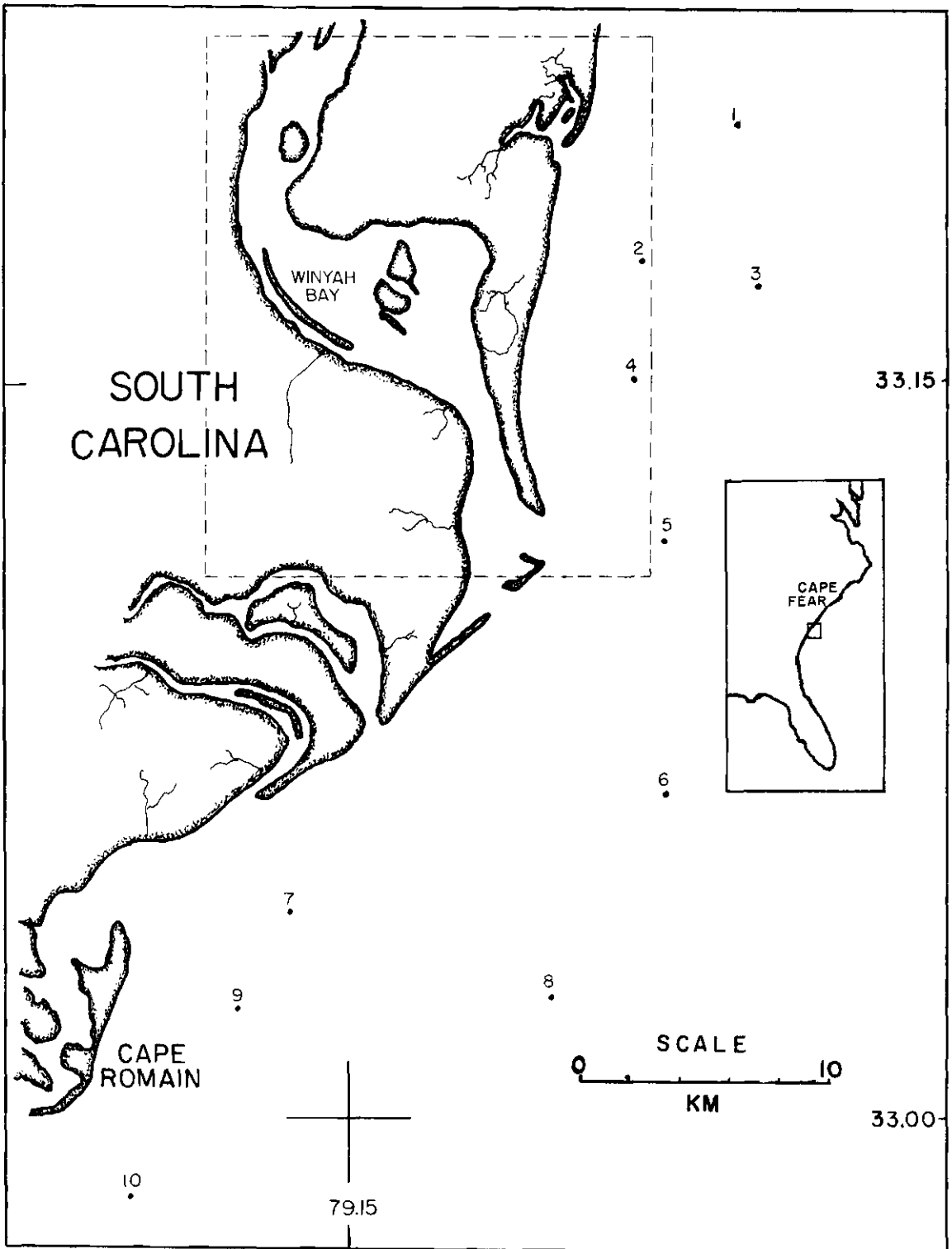


Figure 1. Station Locations on the Continental Shelf Adjacent to the Winyah Bay Estuary

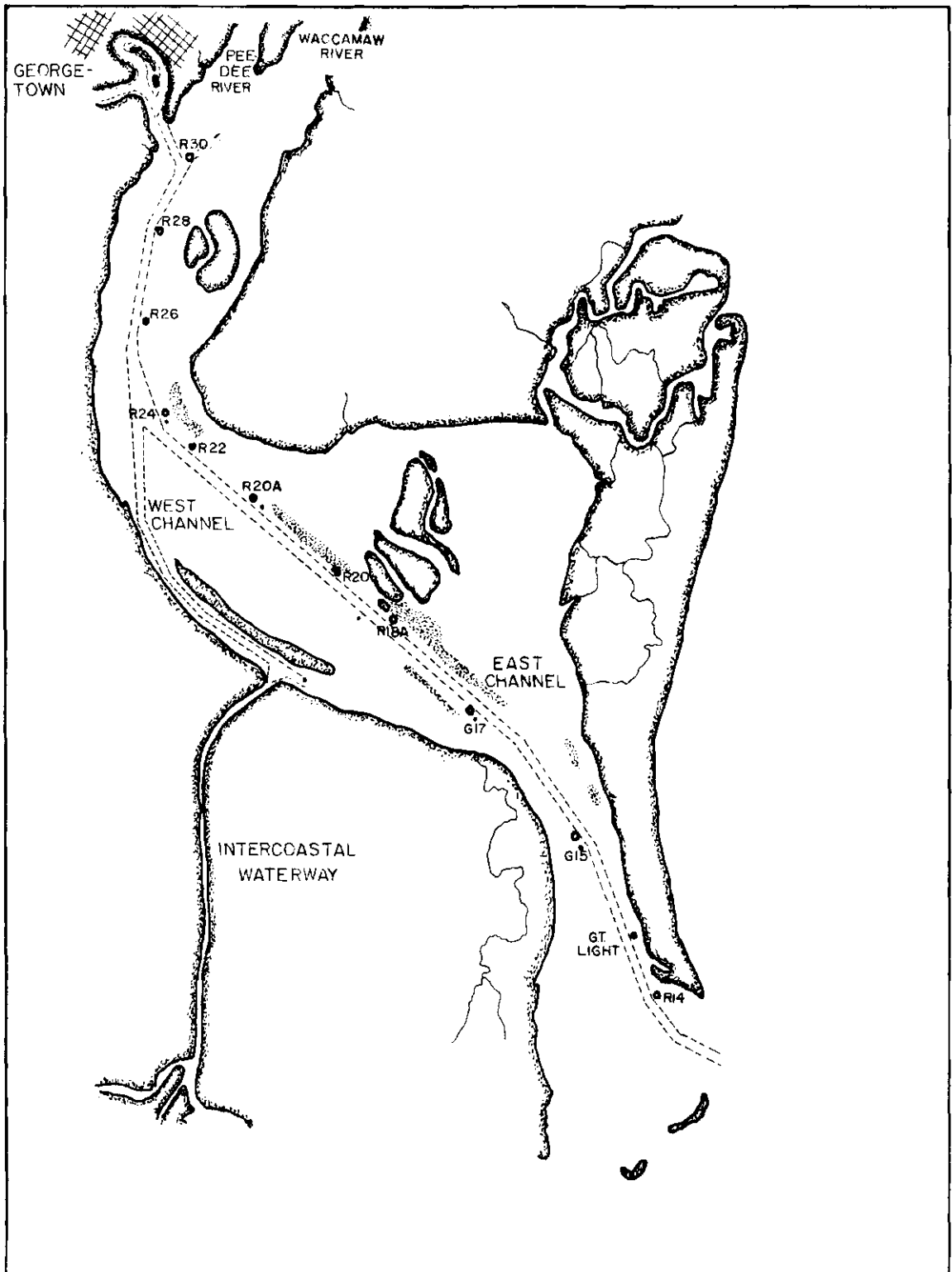


Figure 2. Station Locations within Winyah Bay (o = Salinity Measurement and • = Current Measurements)

## CHAPTER II

### INSTRUMENTATION AND EQUIPMENT

Current measurements were made with General Oceanics Model 2010 recording meters. The meters consisted of a buoyant polyvinyl chloride cylinder with two stabilizer fins attached to the exterior (Figure 3). Contained within each cylinder there were a super-eight cartridge camera, a light source, a directional inclinometer, and a watch. The camera was oriented such that it would periodically take a picture of the inclinometer and the watch simultaneously, thus recording the orientation, time, and degree of inclination of the meter. The system can be set so that it will record data at intervals of 10 seconds, 1 minute, 5 minutes, 15 minutes, 30 minutes, or one hour. The degree of inclination of the meter is directly related to the velocity of the water flowing past the meter.

The meters were attached to a wire cable by a snap hook restrained between two cable clamps (Figure 4). This simple system of mounting was easy to work with and the meter was able to respond freely to the water motion. The lower end of the mounting cable was attached to a 100 lb concrete or lead anchor with a shackle and swivel to allow the cable to twist without kinking. The upper end of the cable was secured to a fluorescent orange marker buoy by means of a half inch nylon leader.

Salinities were measured with a Beckman salinometer-temperature probe. The sensitivity of this instrument is better than 0.1 part per

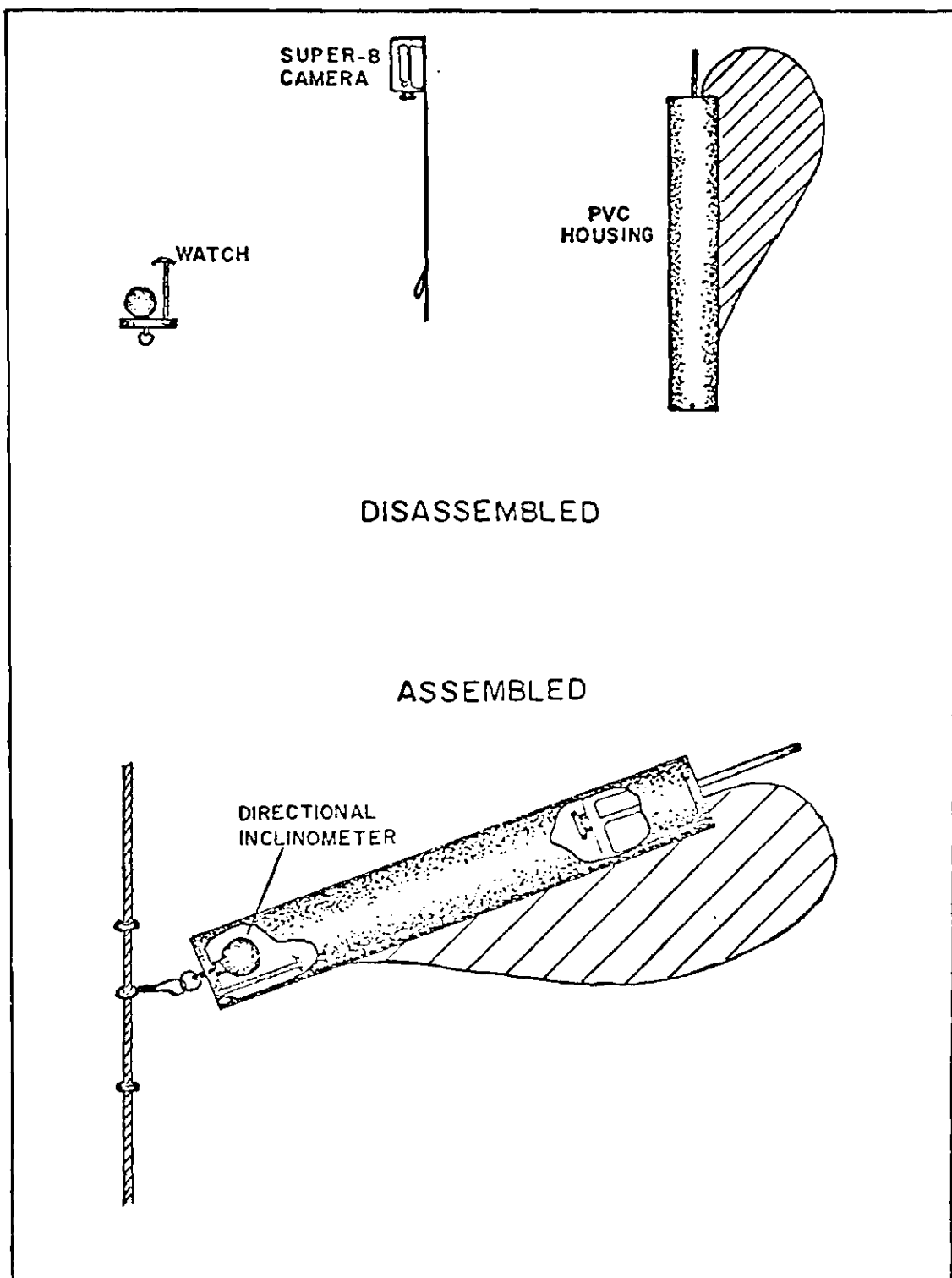


Figure 3. General Oceanics Model 2010 Recording Current Meter

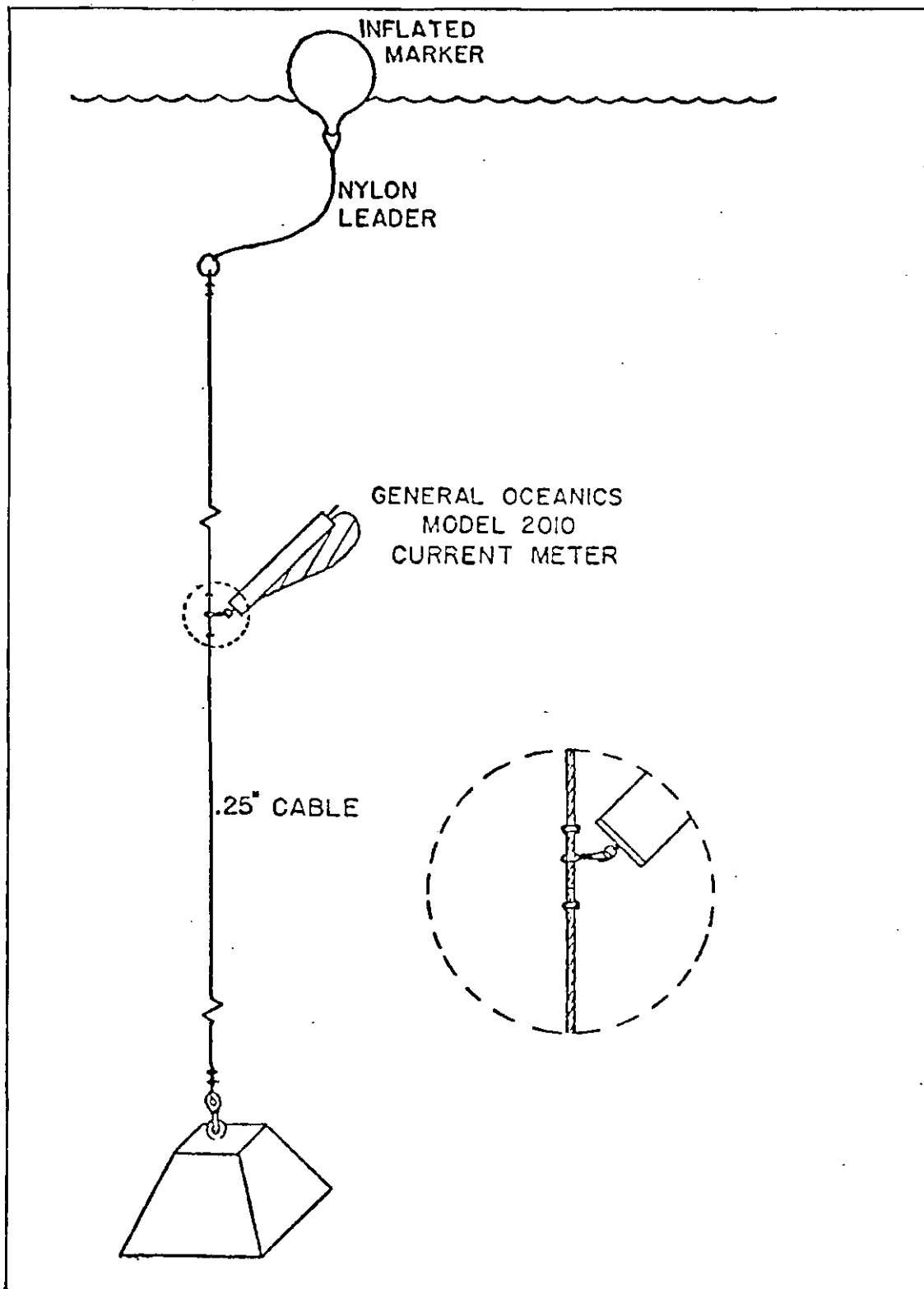


Figure 4. Current Meter Mooring System

thousand (ppt) which was sufficient for the purposes of this study.

Wind directions and speeds were measured using ship's compass and a hand held anemometer.

## CHAPTER III

### DATA ACQUISITION AND ANALYSIS

Data were accumulated during five cruises of approximately a week each aboard the R/V Golden Isles which is supported by the National Science Foundation. The cruises were scheduled for September 4-8, 1972, November 14-19, 1972, December 11-20, 1972, March 21-28, 1973, and May 14-21, 1973.

Stations on the shelf were occupied during the September, March, and May cruises. Current direction and speed were recorded at 5 and 15 minute intervals for at least one tidal cycle (one ebb and one flood tide) or approximately 13 hours. Each station was located using radar and dead reckoning. The November, December and the bulk of the March and May cruises were confined to the estuary.

Temperature and salinity were measured at one meter depth intervals at several stations within the estuary (Figure 2). An axial cross section was completed during the November cruise and four additional cross sections were completed during the March cruise. Current measurements were taken every five minutes for at least one tidal cycle at the surface mid-depth and bottom at the stations indicated by dots in Figure 2.

The current data on the shelf were vectorally averaged for each hour the meters were in the water. These data were then presented as progressive vector diagrams and current roses according to techniques described by Neumann (1968). Aliasing of the data resulting from sampling

frequency (Webster, 1964) was deemed negligible for the purposes of this study as most of the high frequency variation was of low amplitude and was eliminated in the vectoral averaging.

The current data within the estuary were presented as a plot of speed and direction versus time, so that the data could be separated into flood and ebb components. The velocities for each component were averaged over their duration. The difference between average velocity multiplied by the duration of each phase may indicate a dominant current component. Also, the areas under the velocity curves for both the ebb and flood components were measured, compared, and expressed as a percent total flow according to the methods of Shultz and Simmons (1957). This served as an additional indicator of the predominant flow component.

Volume runoff data were acquired through the United States Geological Survey, Water Resources Division. Volume runoff of the Peedee River at Peedee, South Carolina in cubic meters per second (cms) was directly related to total freshwater inflow into Winyah Bay (see Johnson (1970)).

Tide data were taken directly from the United States Coast and Geodetic Survey tide tables (1972-1973 edition). These data were corrected for location relative to gage and daylight saving time when necessary.

## CHAPTER IV

### THE RESULTS

#### Cruise Number One - September 4-8, 1972

This cruise took place during a period of low total freshwater inflow into Winyah Bay (85 cms or 3000 cfs). The average runoff is approximately 450 cms (16,000 cfs) (Committee on Tidal Hydraulics, 1964). Stations 1, 2, 3, and 4 (northern stations) were occupied on September 4-5, 1972 and stations 7, 9, and 10 (southern stations) were occupied on September 5-6, 1972 (Figure 1).

The data obtained at the northern stations consisted of current readings at 15 minute intervals of time. Meters at stations 1, 3, and 4 returned sets of data representing current measurements over a complete tidal cycle. The meter at station two returned a partial record representing five and one half hours of data on the morning of September 5, 1972. The results accumulated from stations 1, 2, 3, and 4 appear in Figures 5 and 6. The water motion over a tidal cycle roughly parallels the dominant wind direction for the period sampled (Figure 5). It is apparent from this diagram that the predominant direction of flow is north-northeast during periods of flooding tide and east-northeast during periods of ebbing tide. The hours during which the current was flowing north-northeast were characterized by slightly higher velocities. It appears that flooding tide enhances a northerly flowing current. Conversely,

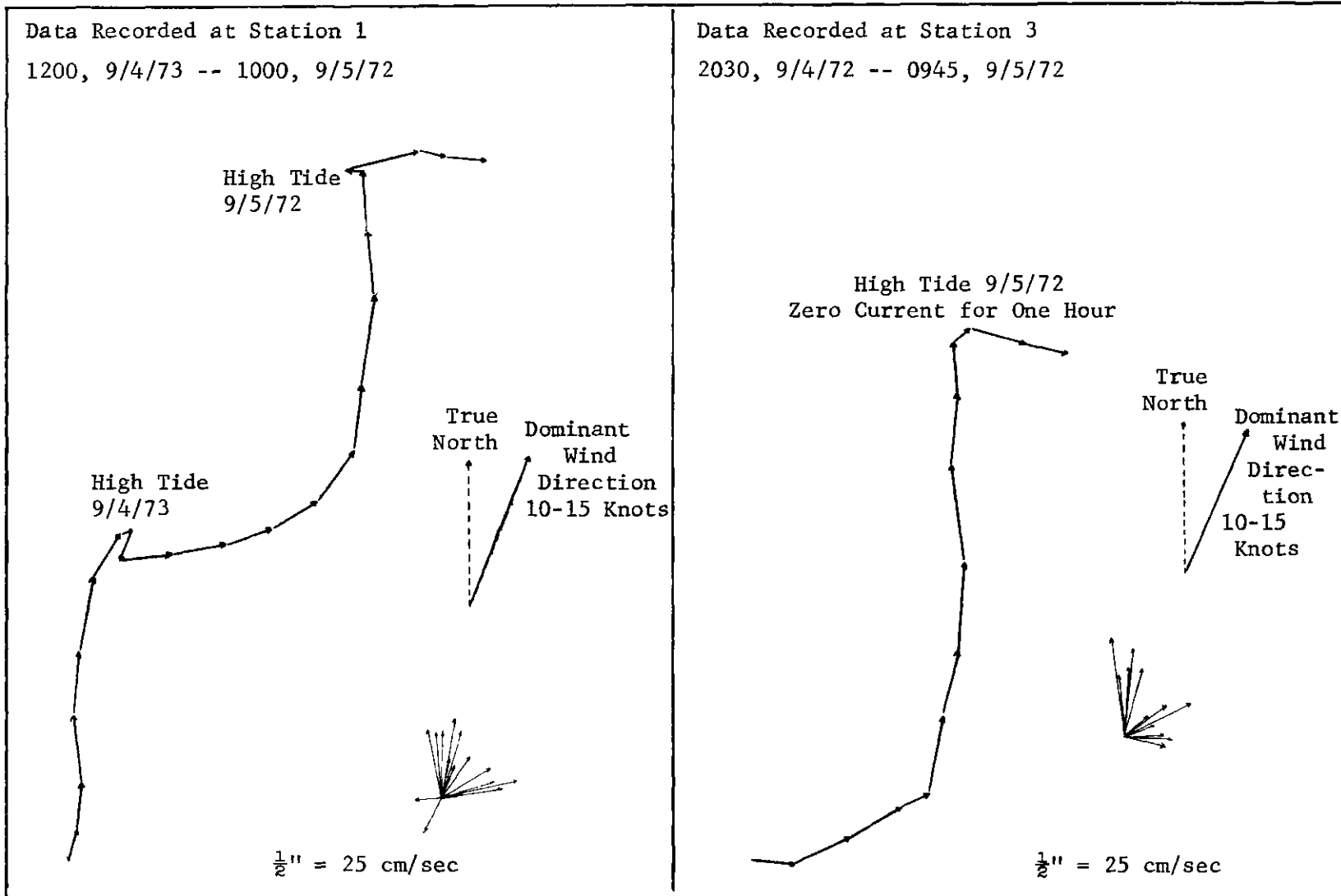


Figure 5. Progressive Vector Diagrams and Current Roses--Stations 1 and 3

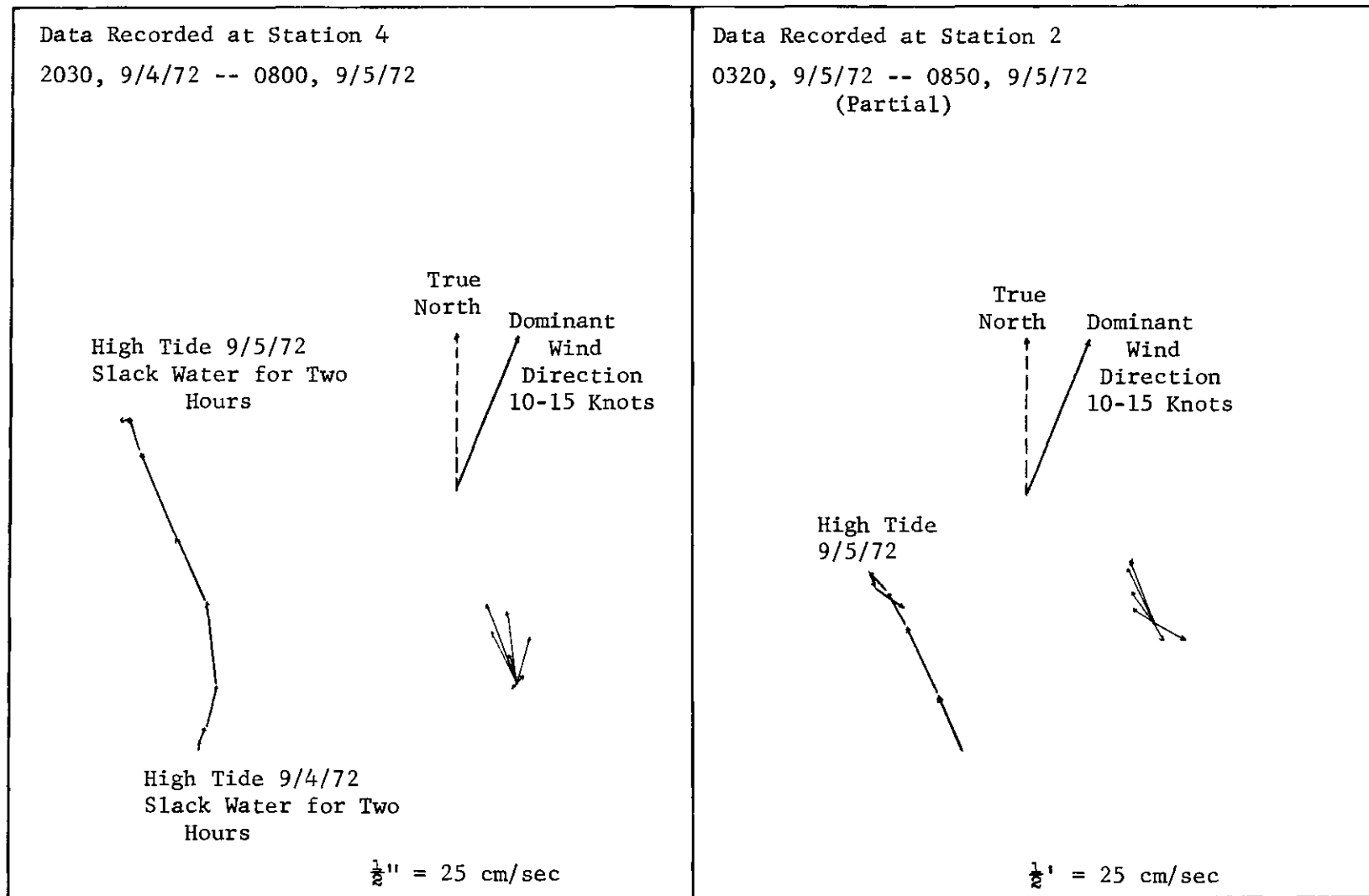


Figure 6. Progressive Vector Diagrams and Current Roses--Stations 4 and 2

one would expect that an ebbing tide would enhance a southerly flowing current or diminish a northerly flowing current.

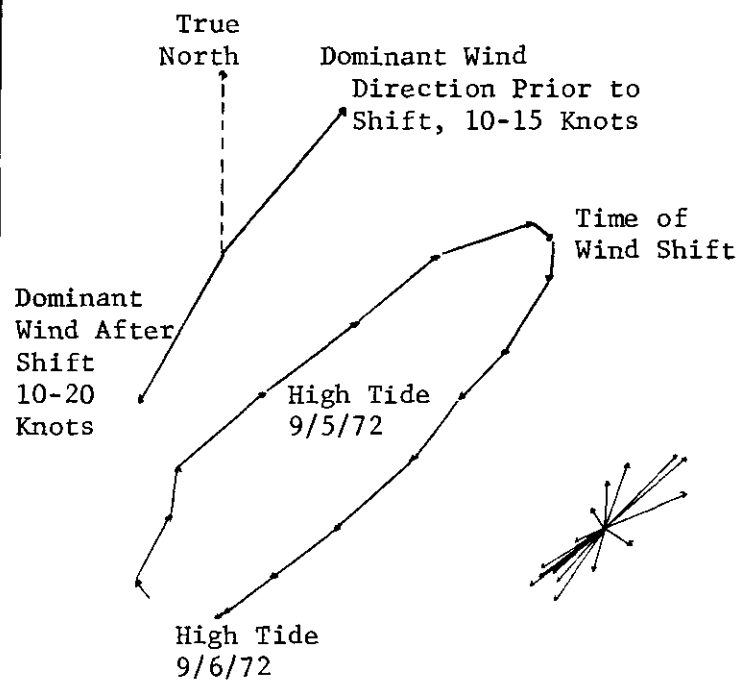
It appears from these data that the shelf waters at these stations at the times sampled tended to respond primarily to the dominant wind conditions (SW at 10-15 knots). The tidal effect was visible but was secondary to the wind driven currents. Finally, following high tide at each of the northern stations the otherwise smooth current variation is temporarily disrupted by a period of very slow-moving, randomly directed current. This condition may result from an interaction between estuarine and inner shelf circulation. This feature of the current pattern will be discussed in greater detail later.

The southernmost stations (7, 9, and 10) were occupied September 5-6, 1972 following recovery of the meters at the northern stations. All meters returned sets of data covering a complete tidal cycle. The regular variation in current direction with the tide, as reported for the northern stations, was obscured by a complete reversal in the current resulting from a 180 degree shift in the wind (Figures 7 and 8). The wind shifted from southwest to northeast in approximately one hour, and the water mass at the sampled stations responded quickly to the new wind conditions. The response of the water at all stations was similar.

All the meters at the southern stations were recovered at approximately high tide on the morning of September 6, 1972. Consequently, any disruption of the current pattern following high tide was not recorded. There is some evidence, albeit weak, for a current disruption near the time of retrieval at station 10. A disruption did not occur following

Data Recorded at Station 10

1350, 9/5/72 -- 0805, 9/6/72



$\frac{1}{2}'' = 25 \text{ cm/sec}$

Data Recorded at Station 9

1500, 9/5/72 -- 0700, 9/6/72

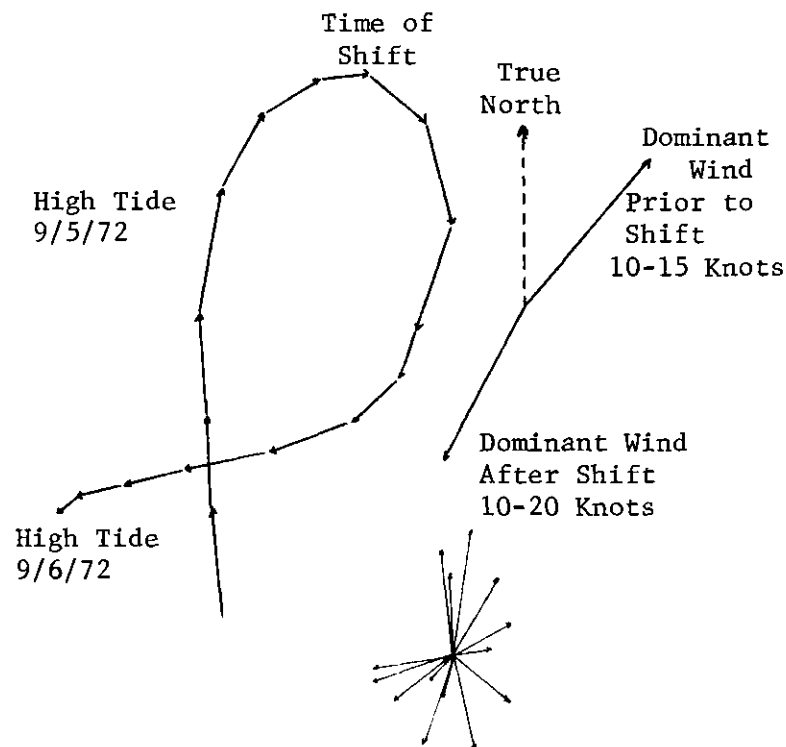


Figure 7. Progressive Vector Diagrams and Current Roses--Stations 9 and 10

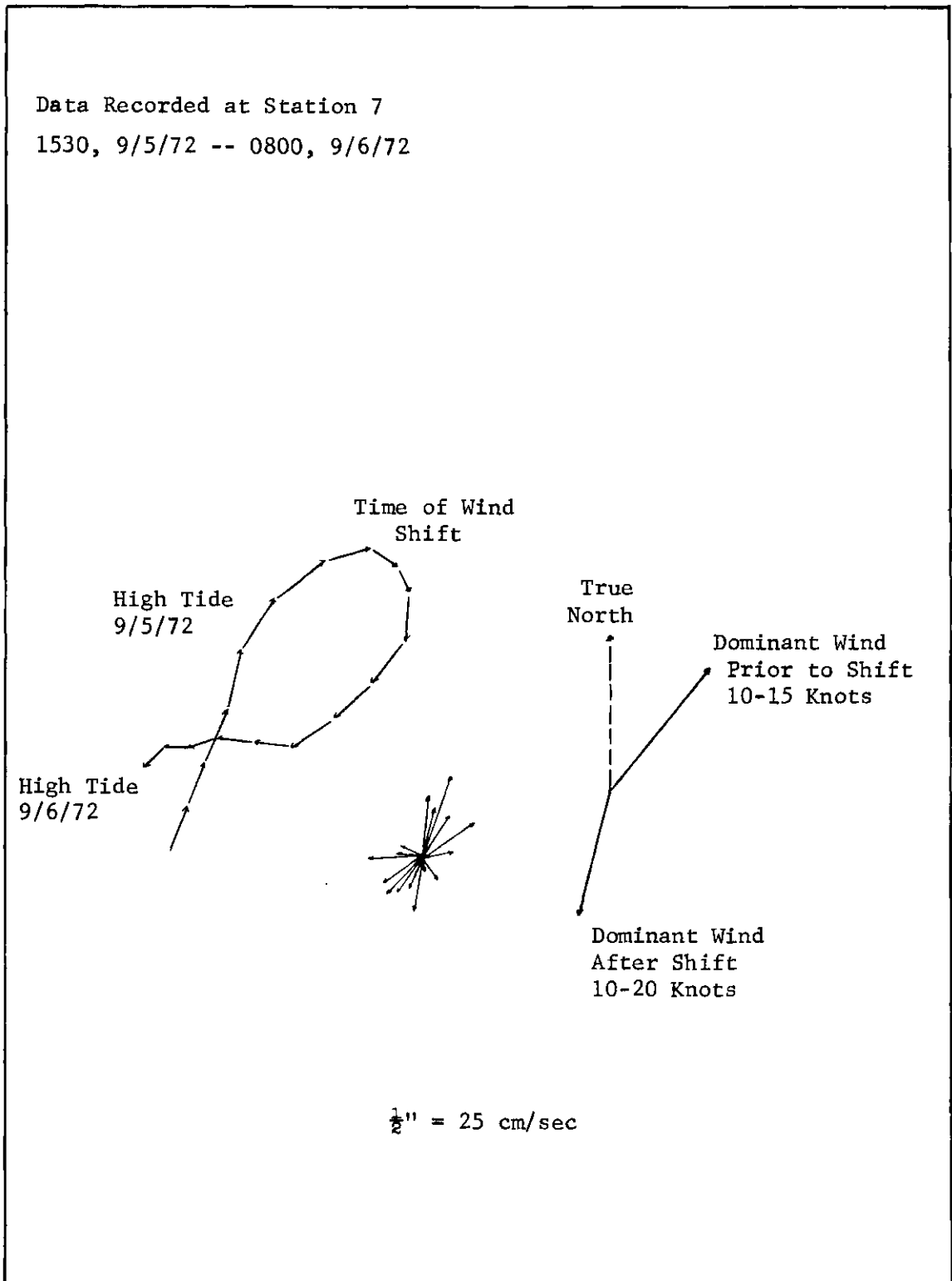


Figure 8. Progressive Vector Diagram and Current Rose--Station 7

high tide at the southern stations when the current was flowing northerly.

The data recorded at both northern and southern stations during this cruise suggest that the near shore shelf waters are controlled primarily by dominant wind conditions and secondarily by tides.

#### Cruise Number Two - November 14-19, 1972

This cruise was completely restricted to the estuary. The freshwater input into Winyah Bay, 140 cms (5000 cfs), was much less than the average (450 cms). The station in the Western Channel was occupied with two current meters mounted in tandem and current data were recorded simultaneously every five minutes throughout a tidal cycle. The upper meter, located one meter below the water surface, showed a predominance of ebb current over the flood current both in average velocity, duration, and percent total flow (Figure 9).

By comparing the time of the change in tide in the bay (Figure 9 and Figure 10) with the change in tide on the shelf as predicted from U.S.C.G.S. Tide Tables (1972-1973 edition), one can see that the change in the tide at the Western Channel station is two to three hours after the change in tide on the shelf.

Data from the lower current meter, located four meters below the water surface, indicate that flood currents predominate very slightly over ebb currents (Figure 10). The inclination of the meter averaged 55 degrees (approximately 39 cm/sec) for flooding currents and 50 degrees (approximately 36 cm/sec) for ebbing currents. The duration of each component at this depth was about equal. The percent total flow was 54 percent flood as compared to 46 percent ebb. At this depth in the Western

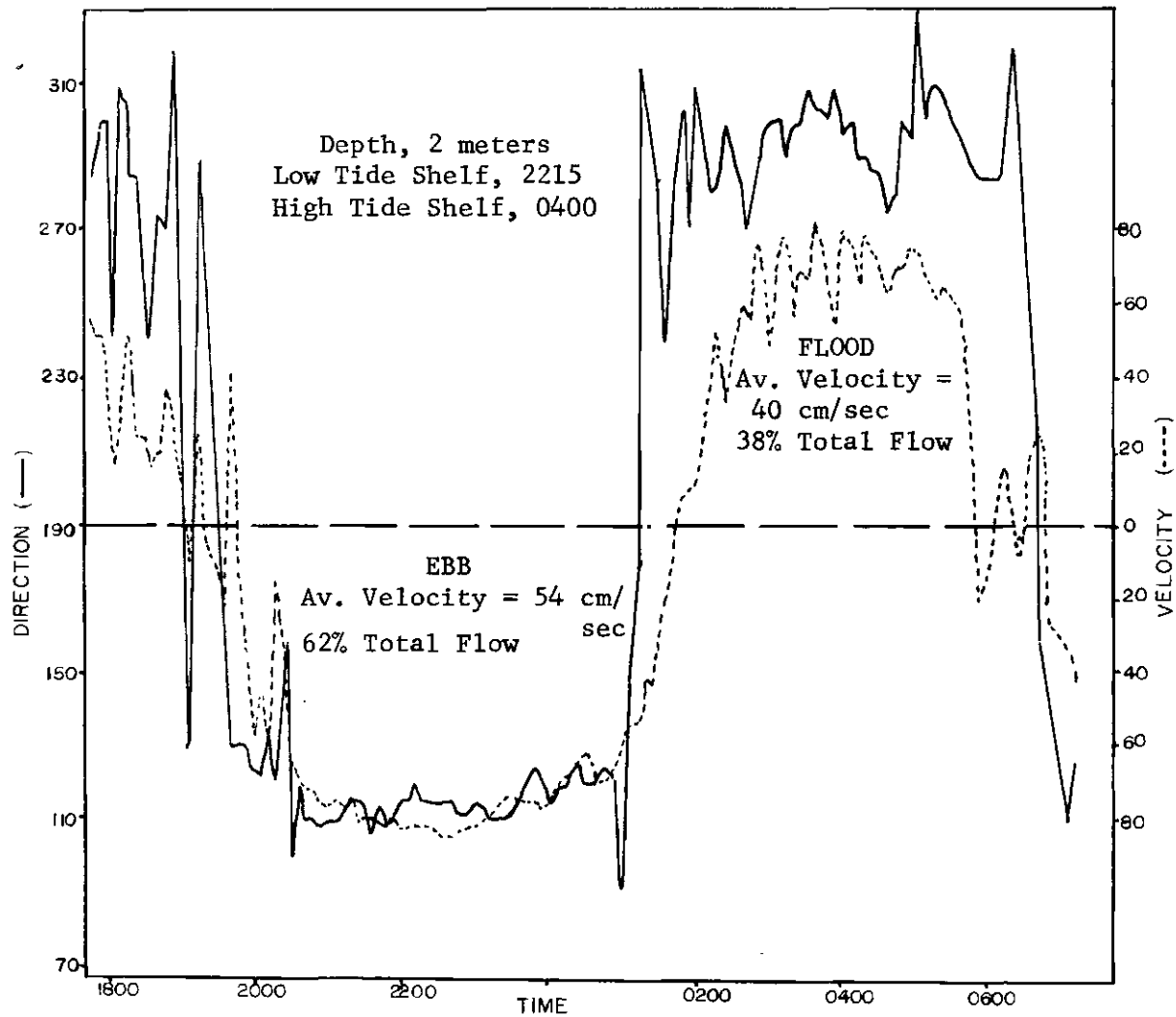


Figure 9. Current Data, West Channel--11/16-17/72, 2 Meter Depth

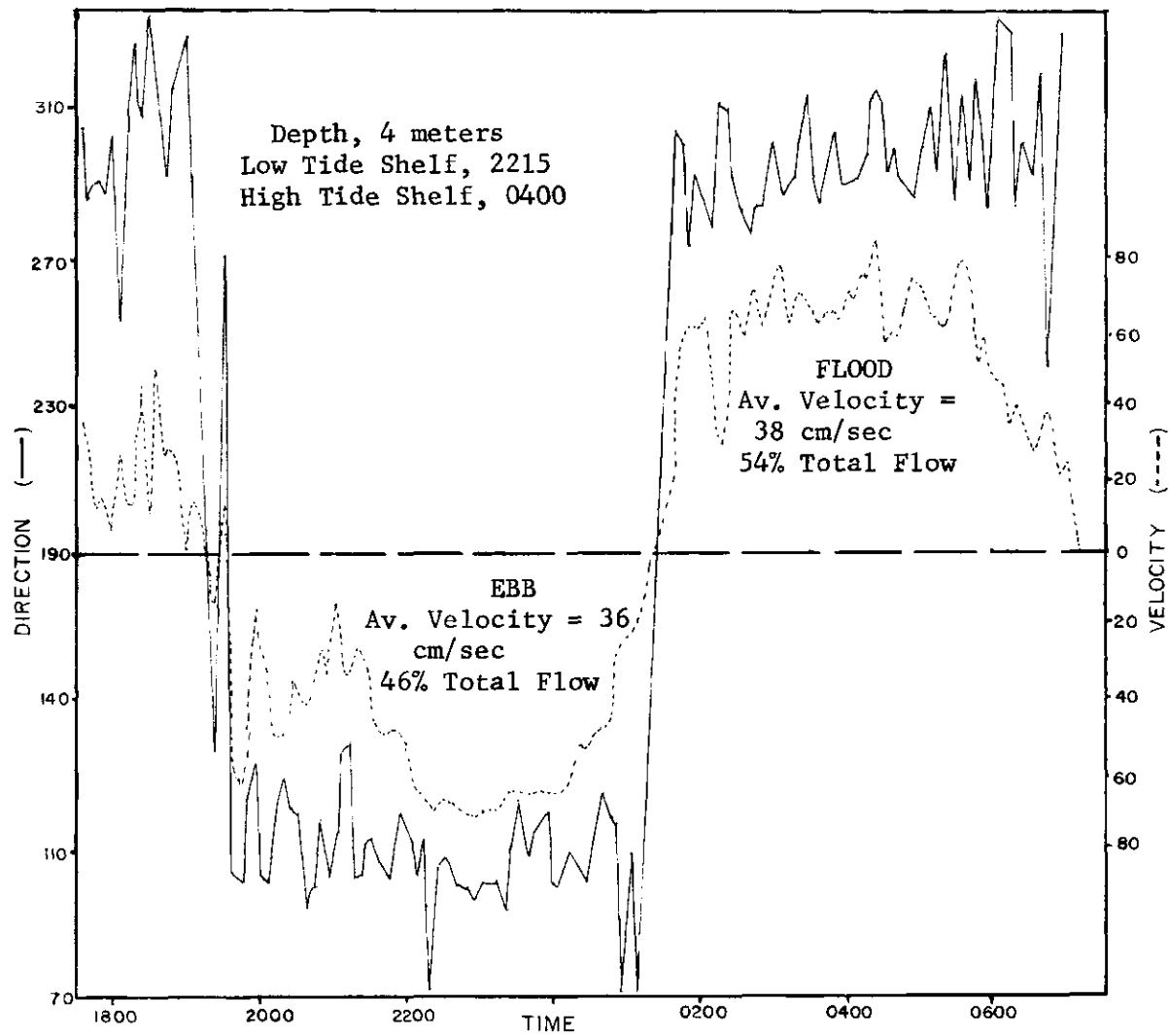


Figure 10. Current Data, West Channel--11/16-17/72, 4 Meter Depth

Channel the change in tide is roughly coincidental with the change in tide of the shallower depth.

Salinity measurements at this station were made while the tide was rapidly flooding and near the crest of high tide. The salinities were fairly high (approximately 30 ppt) with a very small gradient during flood tide. Following the crest of high tide, a layer of lower salinity (approximately 20-25 ppt) appeared at the surface.

The current data indicate a very slight predominance of flood current near the bottom of the Western Channel station. Salinity measurements indicate that the Western Channel may range from nearly homogeneous to somewhat stratified depending on the stage in the tide. Since freshwater runoff at the time of this cruise was substantially less than the annual average, it is conceivable that an increase in freshwater input into Winyah Bay might alter the observed situation. This possibility was the subject of investigation during later cruises.

#### Cruise Number Three - December 11-16, 1972

This cruise took place during a period of nearly average runoff. Like the November cruise, it was completely confined to the estuary. Station R20A was occupied with three current meters mounted in tandem. The meter nearest the surface (Figure 11) indicated a considerable predominance of ebb flow both in strength, duration, and percent total flow. The variability of the downstream flow at this depth was considerably less than the relatively weak flooding currents. As at the Western Channel station, occupied in November, the change in tide at Station R20A occurred two to three hours after the change in tide on the shelf. These general

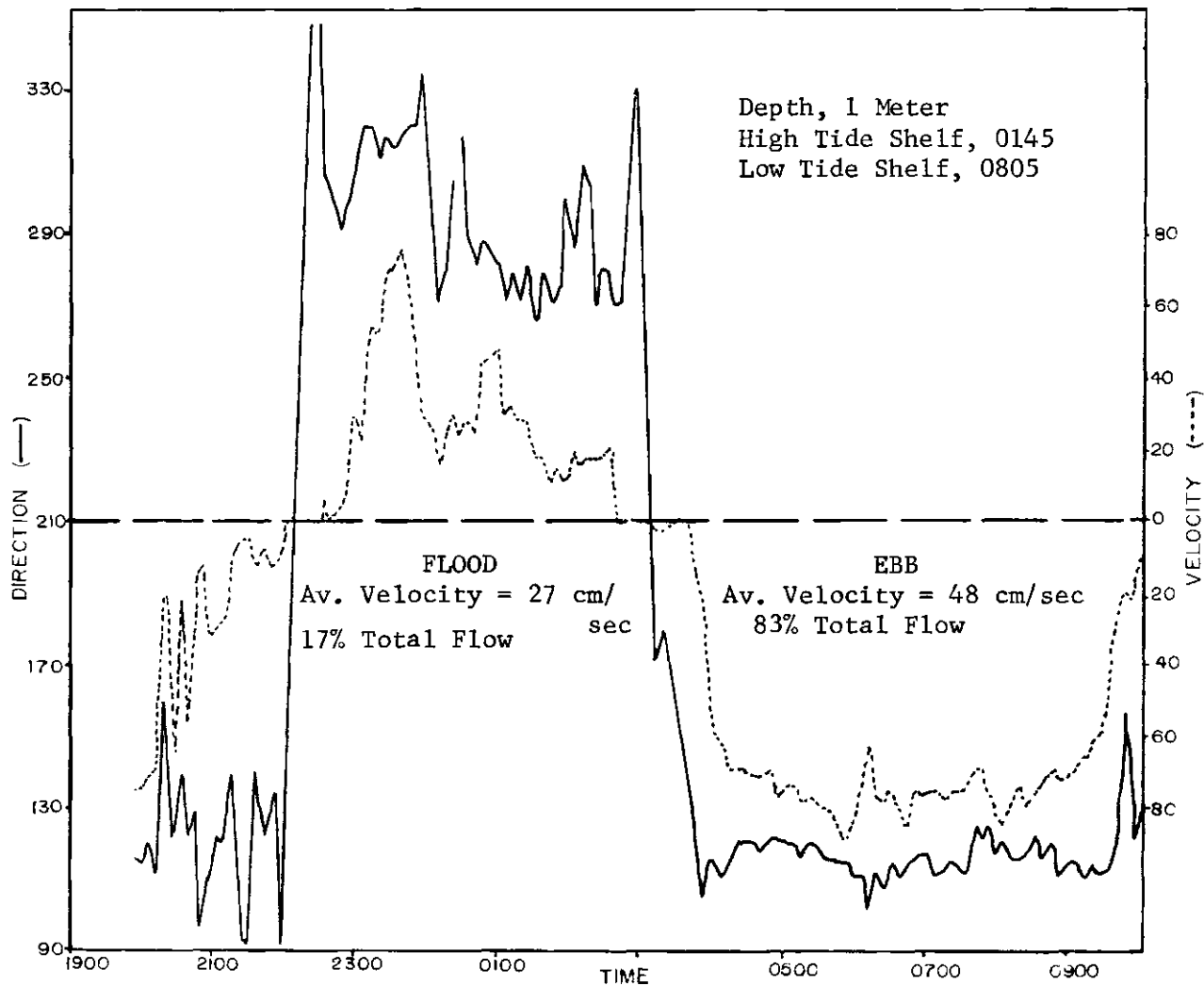


Figure 11. Current Data, Station R20A--12/13-14/72, 1 Meter Depth

characteristics of flow persisted at all depths except that the flooding currents became stronger and more stable with a slight increase in duration (Figures 12 and 13). Flood currents were not predominant at any of the depths at which currents were measured during this cruise. However, stations had to be located on the edges of dredged channels because ship traffic prohibited occupation of stations in the deeper central portions of the channels. It is conceivable that at greater depths than those measured there might have been a predominance of upstream flow. These areas would, for the most part, be restricted to the center of the dredged channels.

In addition to the current data, salinities were measured at one meter depth intervals at the stations indicated on Figure 14. The sampling time spanned two hours following the crest of high tide at the bay mouth. The salinity distribution near the mouth of the estuary appears nearly stratified. The general upstream trend, with ebb currents increasing, was for the salinity distribution to change from nearly stratified to partially mixed. The salinity distribution approached homogeneity towards the head of the estuary.

Measurable salinities were found to occur beyond station R30 while the current was ebbing hard. Apparently, during periods of average runoff, saltwater intrusion proceeds beyond the confluence of the Peedee and Waccamah Rivers.

#### Cruise Number Four - March 21-28, 1973

This cruise took place during a period when the runoff was about 1400 cms (50,000 cfs). Current data as well as temperature and salinity

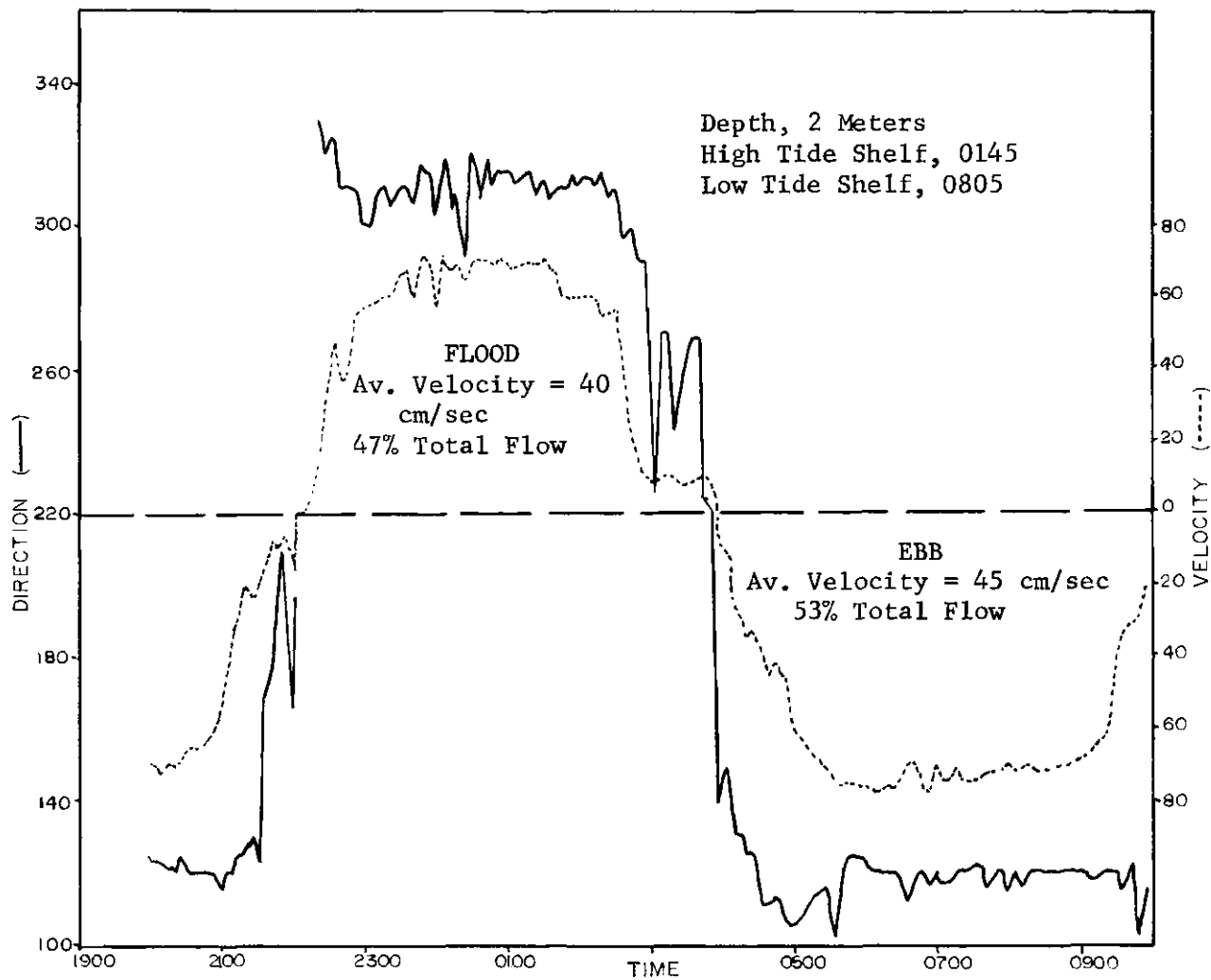


Figure 12. Current Data, Station R20A--12/13-14/72, 2 Meter Depth

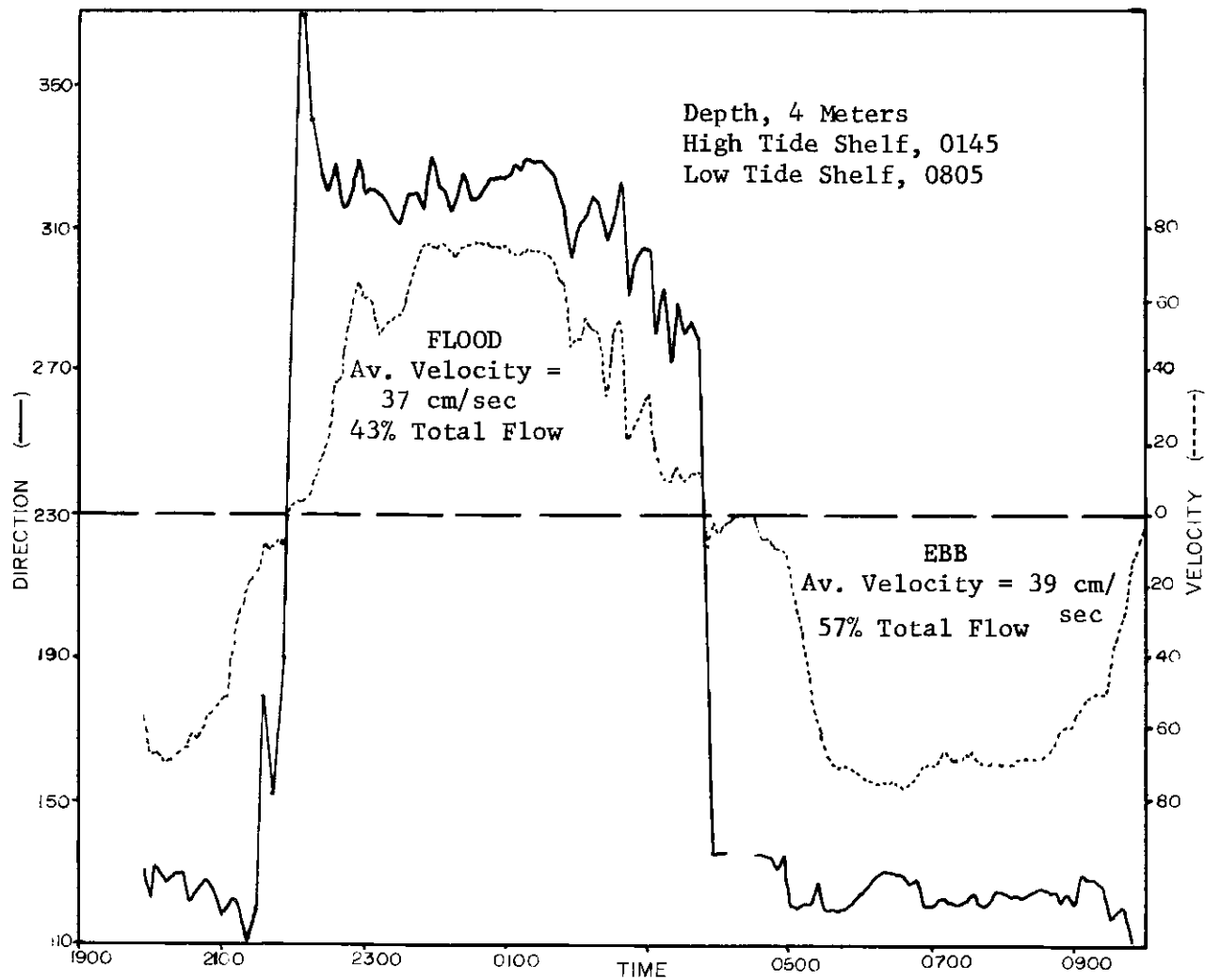


Figure 13. Current Data, Station R20A--12/13-14/72, 4 Meter Depth

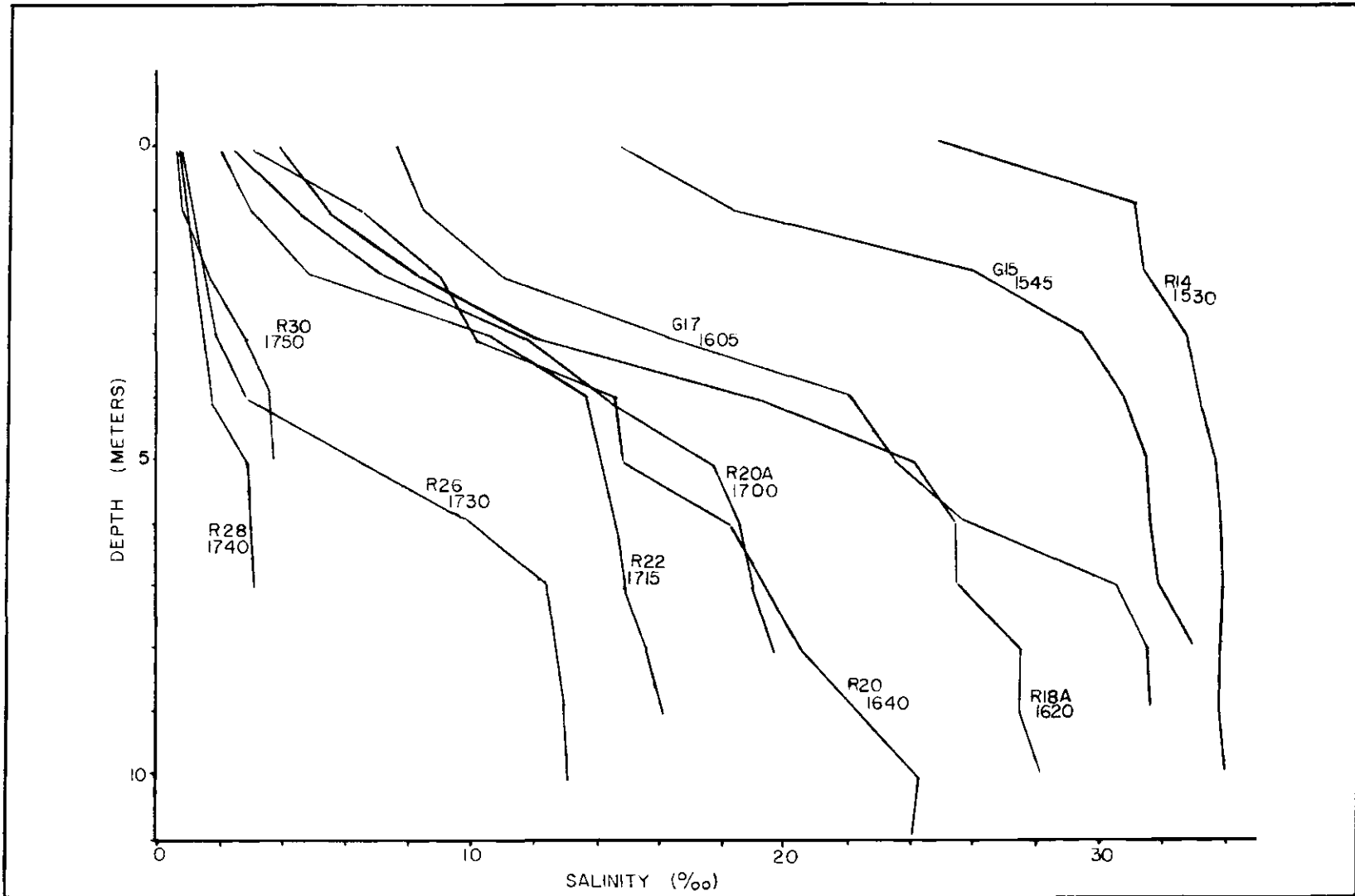


Figure 14. Salinity Cross Section, East Channel--12/13/72

data were recorded at a number of stations within the estuary and at two stations on the shelf. The salinity data were accumulated during five axial transects of the estuary at various stages of the tide.

A current meter was lost during recovery at station 8 reducing the number of exterior stations to one (station 5). The data recorded at this station support tentative conclusions resulting from data collected during the September cruise. Again the water tended to respond primarily to dominant wind stress (ENE at 10-15 knots). The tidal effects were secondary to the wind (Figure 15). The higher velocities were associated with ebbing tide, again suggesting that ebb tides enhance southerly flowing currents. The lower velocities associated with flooding tides suggest that flooding tide enhances northerly flowing currents and retards southerly flowing currents. This was also observed during the September cruise. The lowest velocities of all occur at high tide. No corresponding marked decrease in velocity occurs at the time of low tide on the shelf. This again suggests that there is some process, asymmetrical with respect to tide, occurring at the change of the tide on the shelf which tends to briefly disrupt wind drift current.

The general conclusions regarding the current patterns and dominant controlling factors appear to be the same for both the September and March cruises. This observation is particularly significant since these cruises took place during periods that were strikingly different with respect to runoff and wind conditions.

Current meter data were recorded within the estuary at stations G15, G17, R18A, R24, and in the Western Channel. These data are presented

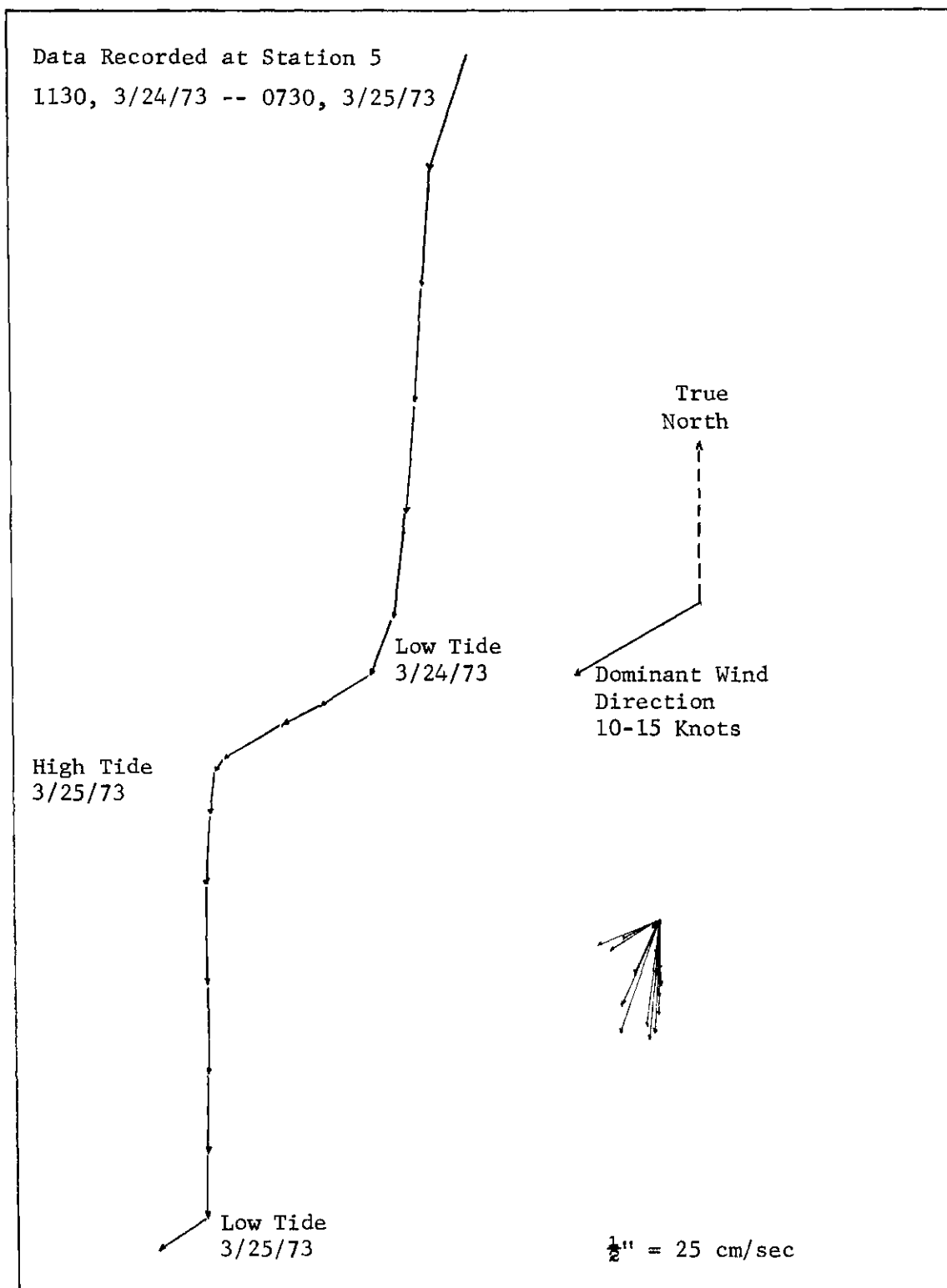


Figure 15. Progressive Vector Diagram and Current Rose--Station 5

in Figures 16 through 25. Ebb and flood components were nearly equal near the bottom at all stations in the Eastern Channel. There was perhaps a slight increase in the ebb component at the shallower depths particularly at stations nearer the head of the estuary. Data recorded in the Western Channel show a striking predominance of the ebb component particularly at the shallower depths, where flood velocities averaged less than 13 cm/sec (Figures 23 and 24). These data suggest that the Western Channel is primarily an ebb channel, at least during periods of high runoff.

The meter near the bottom at station G15 recorded data every minute rather than the normal five minute interval to allow estimation of aliasing effects produced by the sampling frequency (Figure 18). The data recorded at the two frequencies were very similar. The one minute recording frequency eliminated some of the abrupt variation recorded at five minute intervals; but there were changes in current direction and speed occurring in less than a minute, equal to those recorded at five minute intervals. Apparently the bulk of the variation recorded at five minute intervals is fairly high frequency, random, and of low magnitude relative to tidal variation. Therefore the aliasing effects of the sampling frequency were deemed negligible for purposes of this study.

Temperature and salinity data were recorded at the stations and at the times indicated in Figures 26 and 27. The times of sampling may be placed in the tidal cycle by consulting the current data recorded at nearby stations (Figures 16 through 25). Under high runoff conditions a flooding tide produces a more stratified situation whereas an ebbing tide tends to drive the Eastern Channel towards homogeneity.

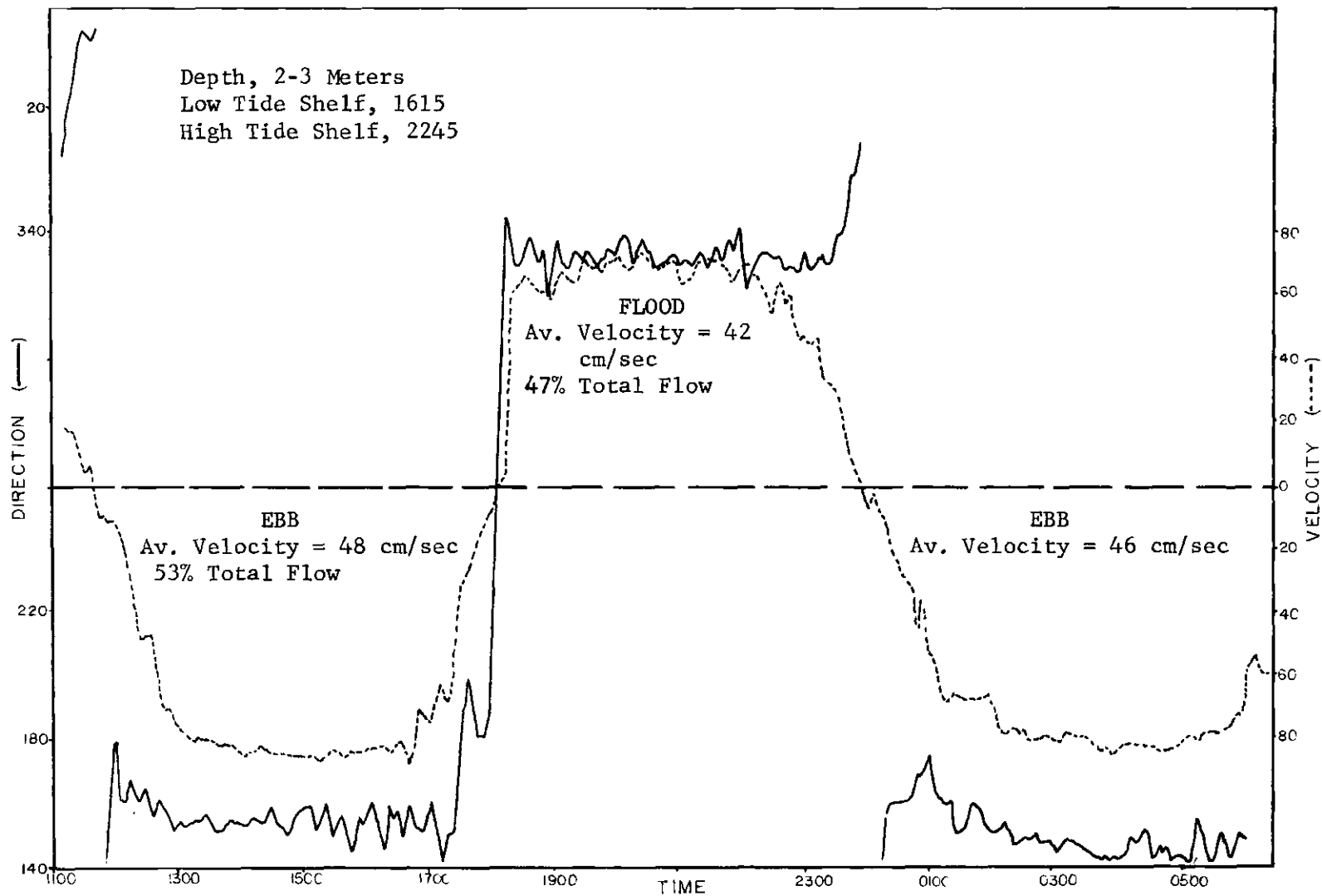


Figure 16. Current Data, Station G15--3/22-23/73, 2-3 Meter Depth

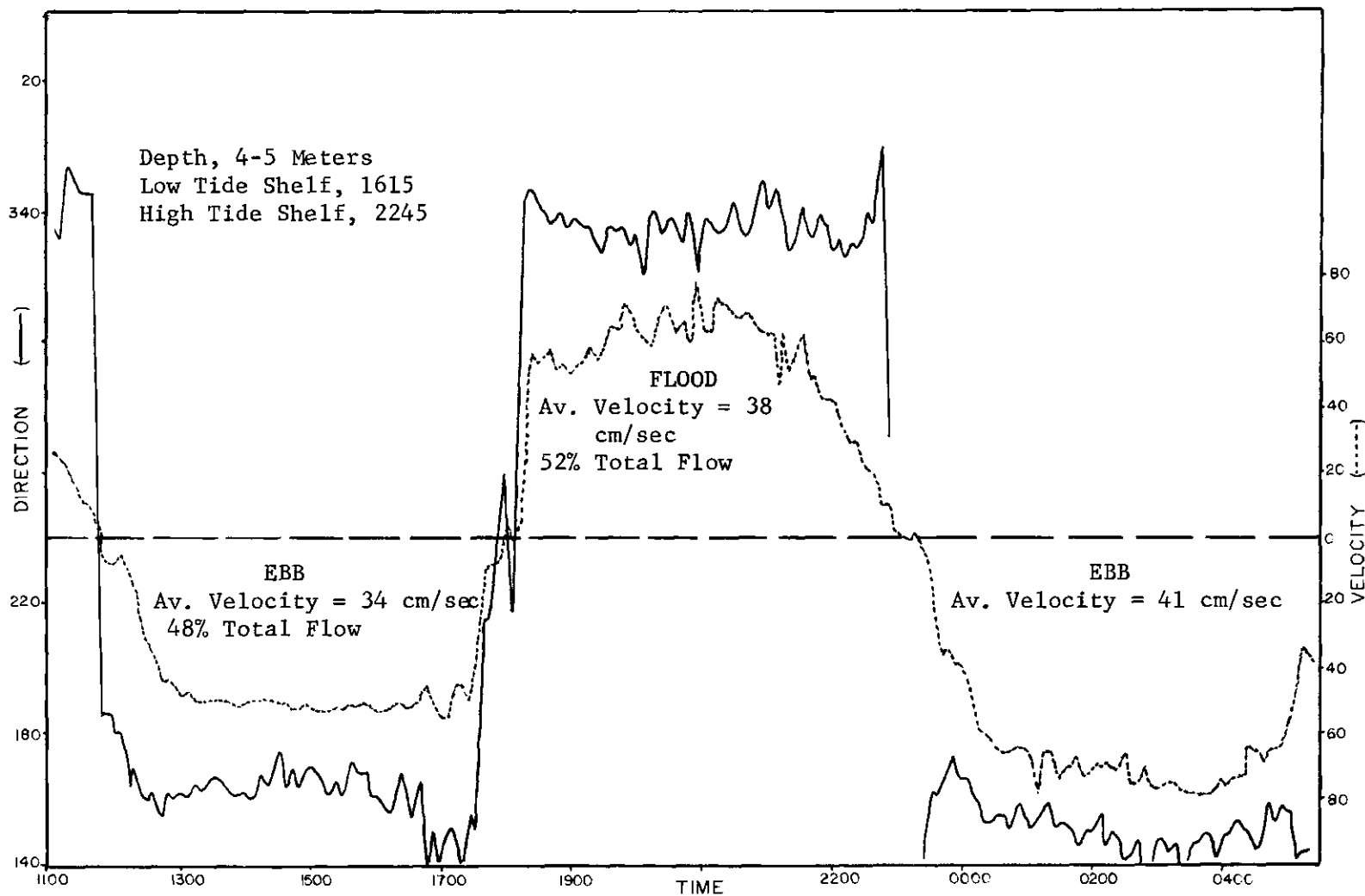


Figure 17. Current Data, Station G15--3/22-23/73, 4-5 Meter Depth

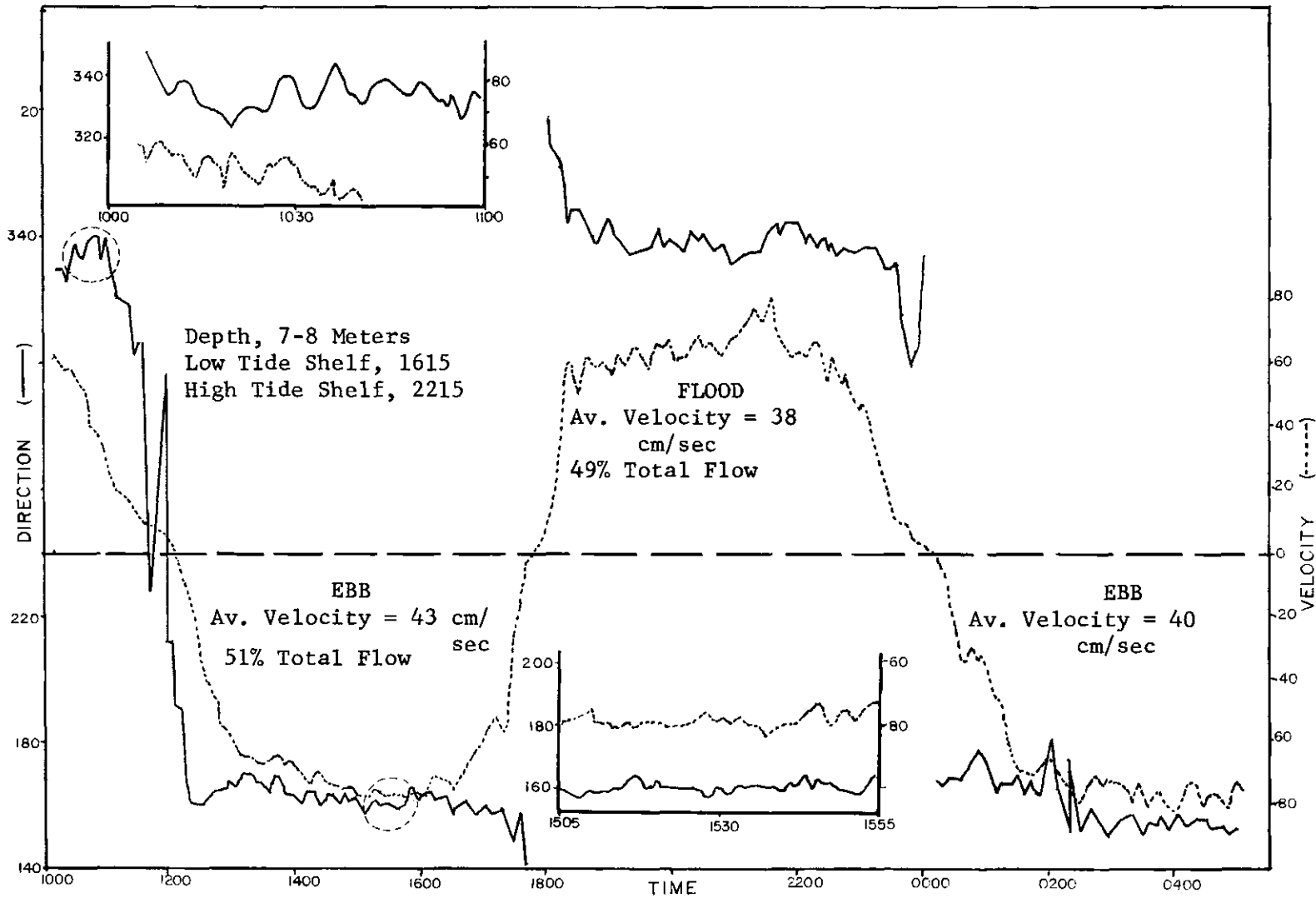


Figure 18. Current Data, Station G15--3/22-23/73, 7-8 Meter Depth

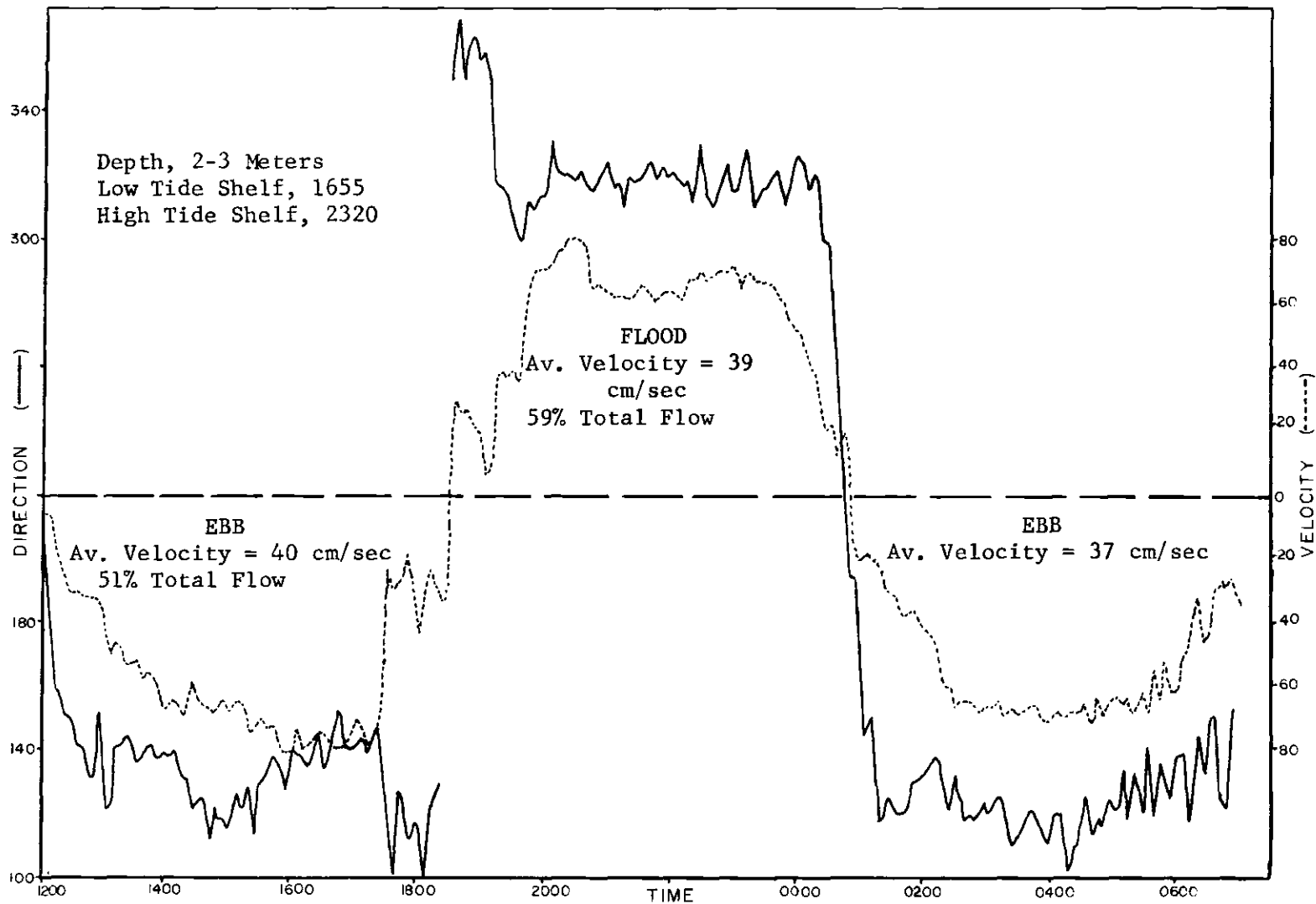


Figure 19. Current Data, Station G17--3/23-24/73, 2-3 Meter Depth

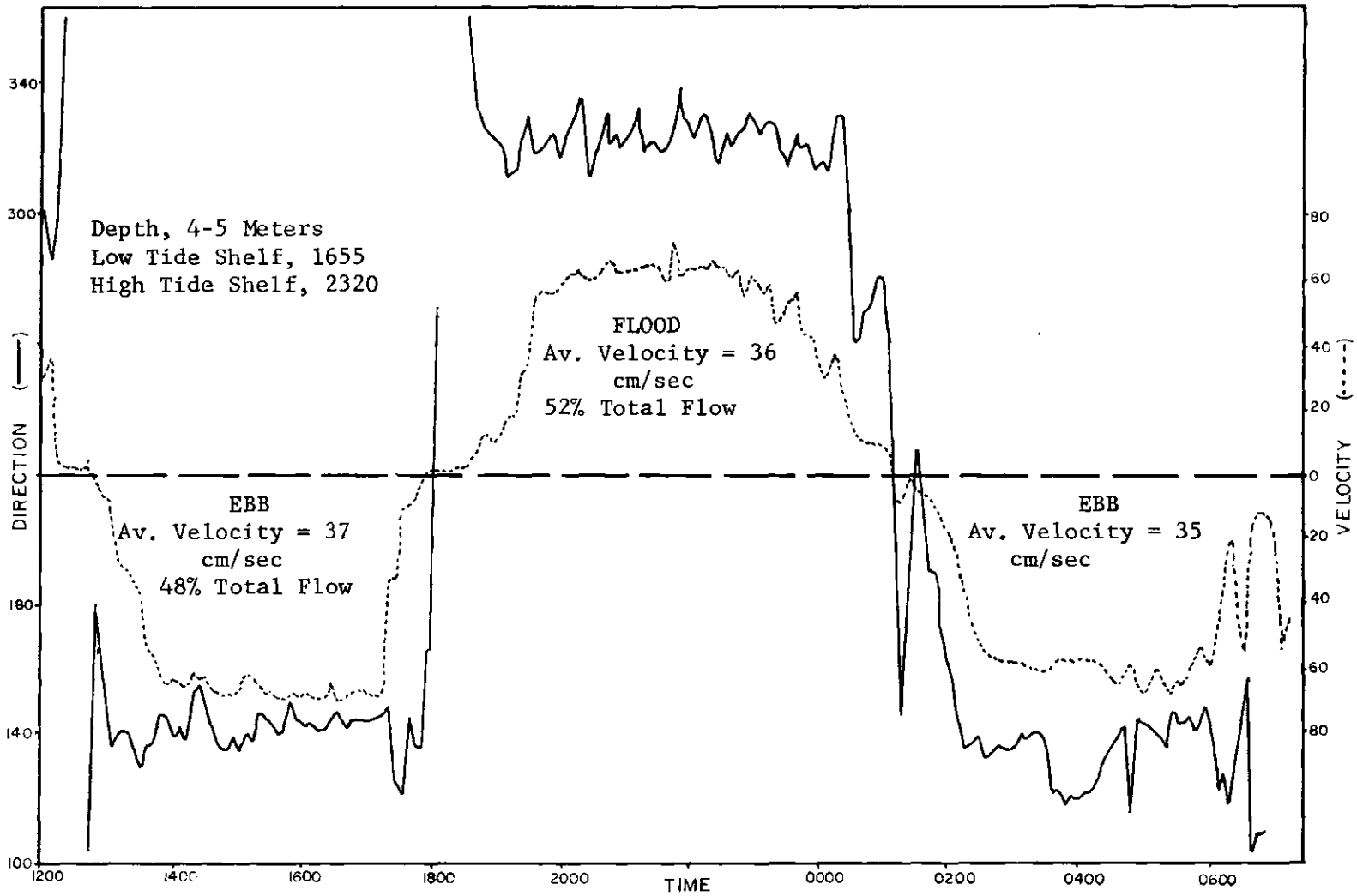


Figure 20. Current Data, Station G17--3/23-24/73, 4-5 Meter Depth

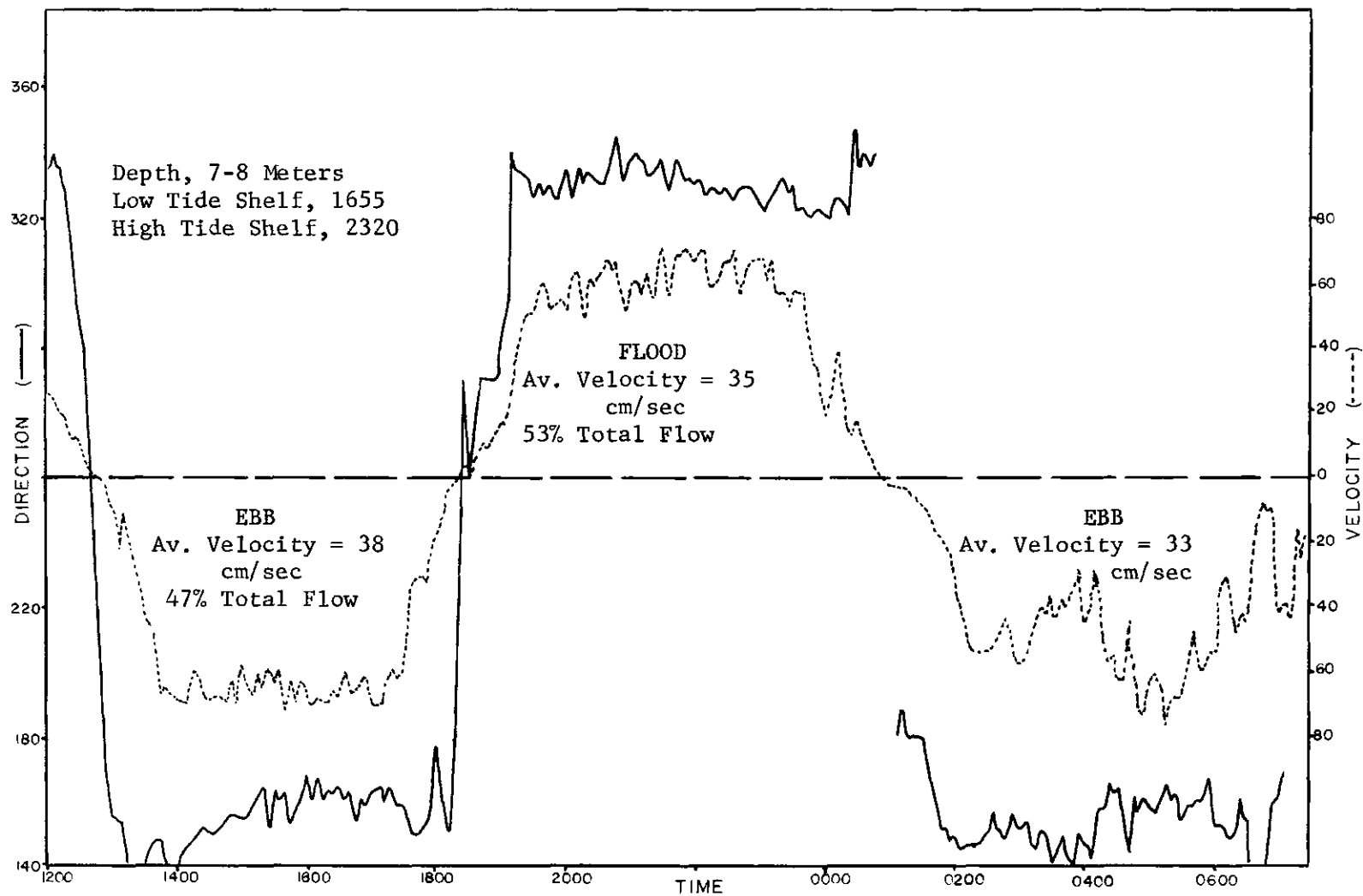


Figure 21. Current Data, Station G17--3/23/24/73, 7-8 Meter Depth

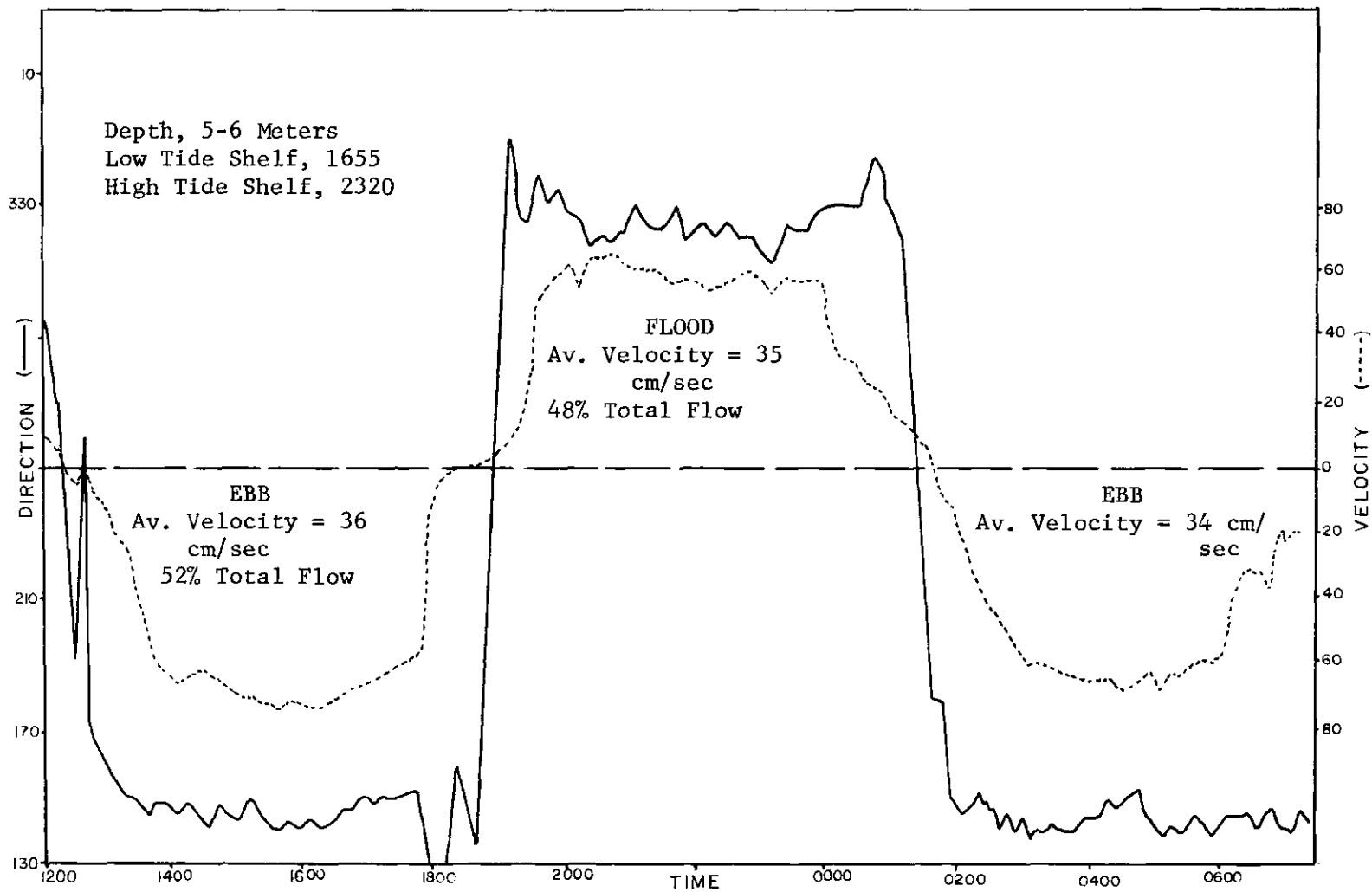


Figure 22. Current Data, Station R18A--3/23-24/73, 5-6 Meter Depth

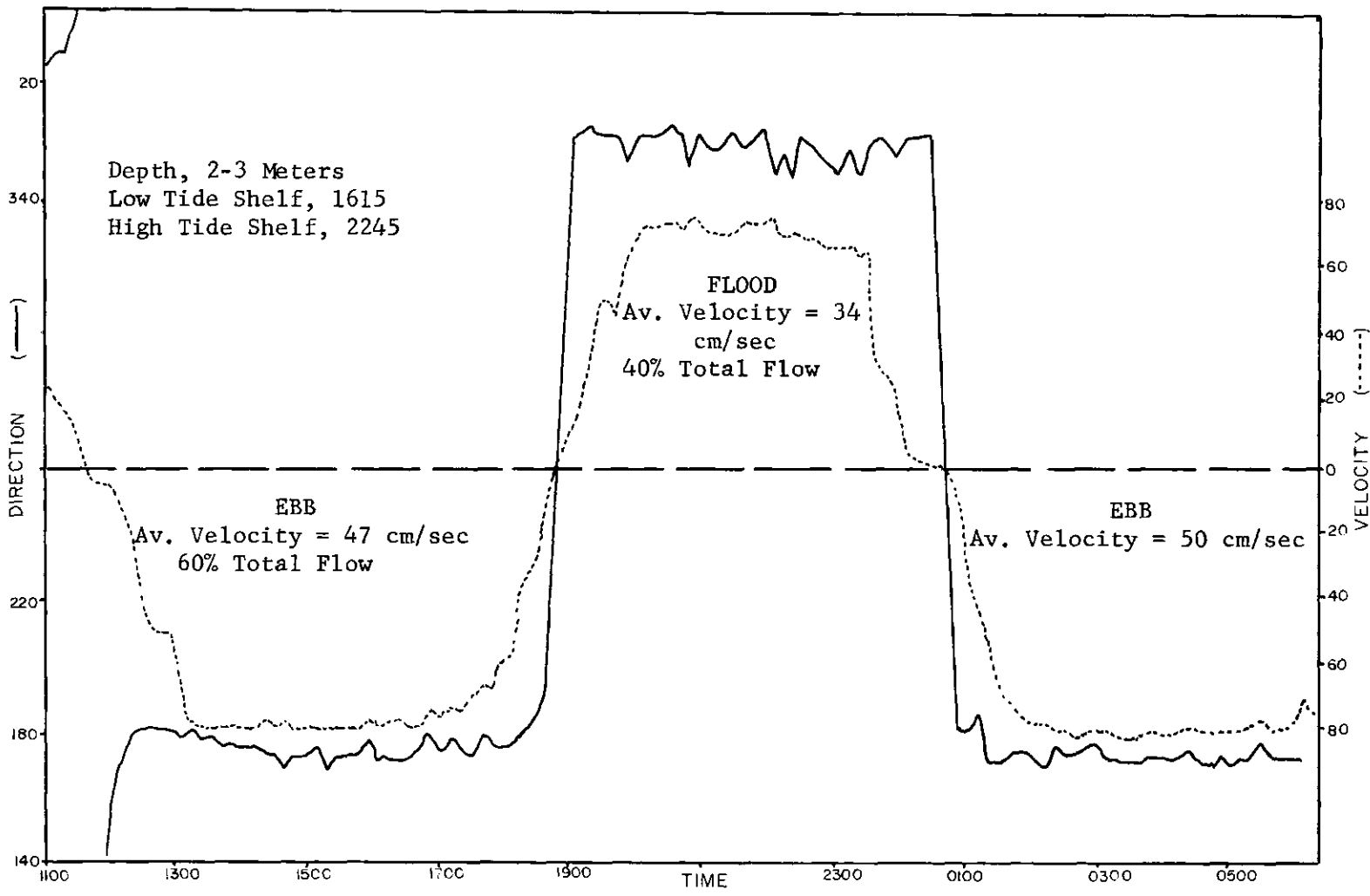


Figure 23. Current Data, Station R24--3/22-23/73, 2-3 Meter Depth

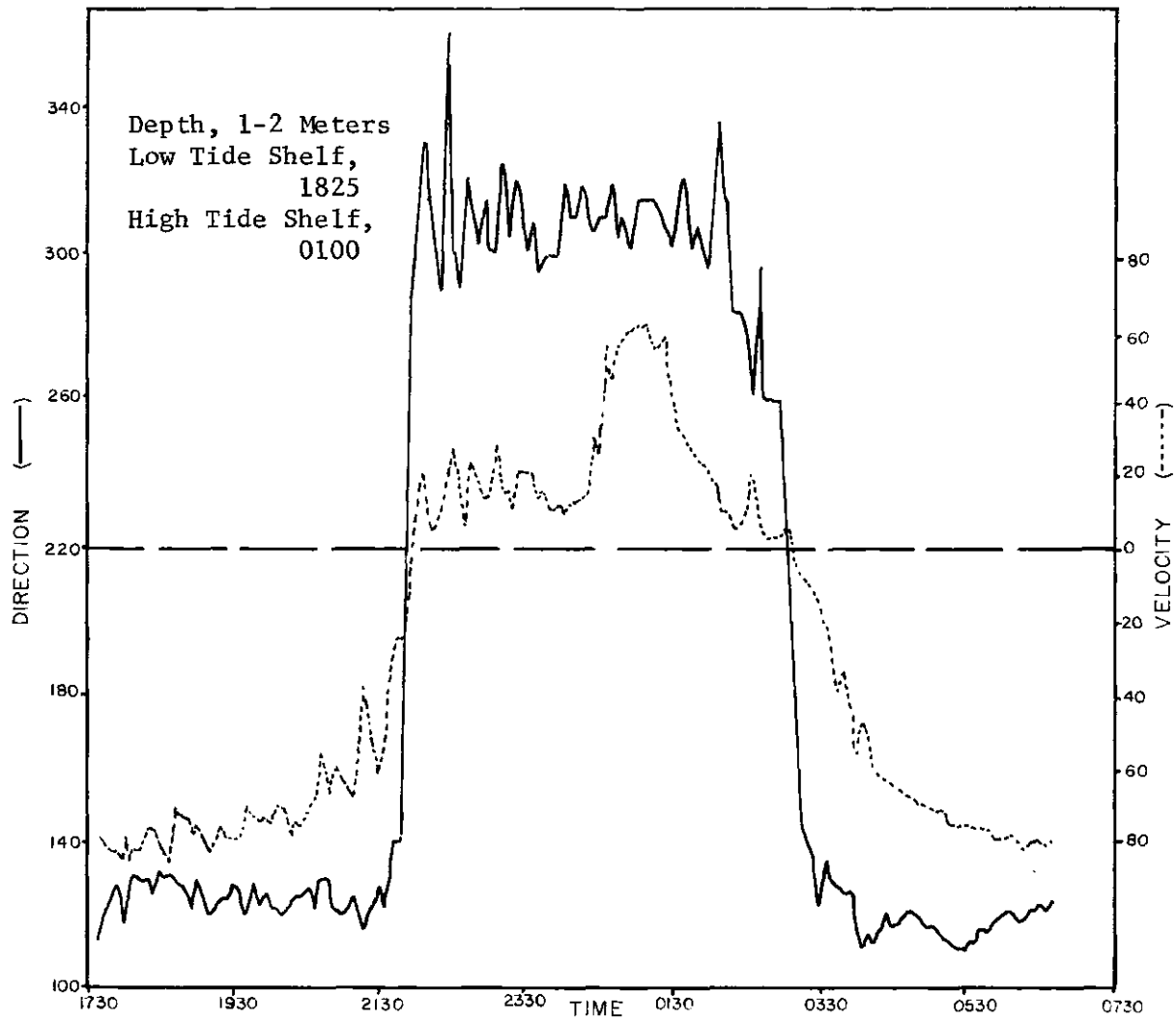


Figure 24. Current Data, West Channel--3/25-26/73,  
 1-2 Meter Depth

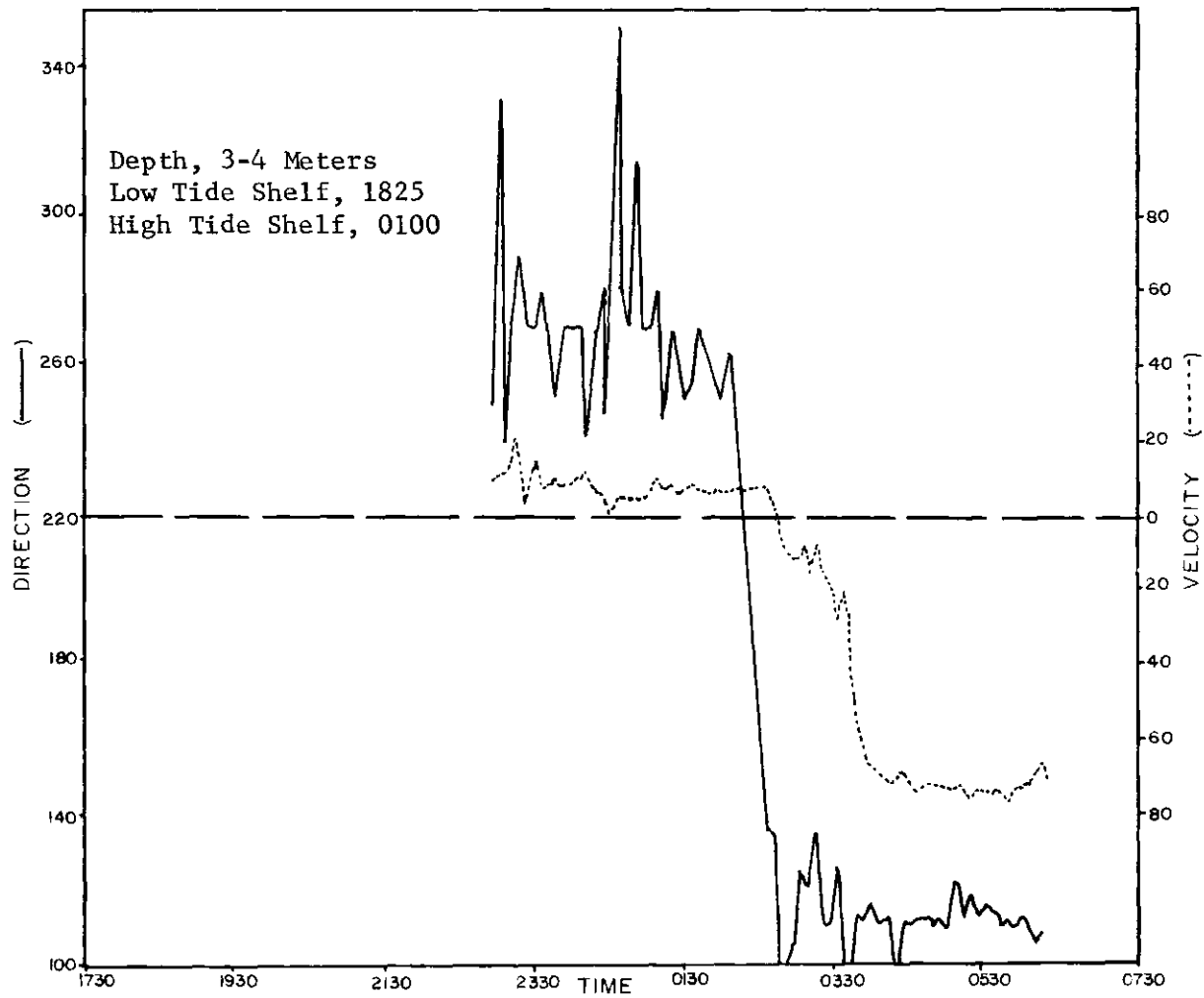


Figure 25. Current Data, West Channel--3/25-26/73,  
 3-4 Meter Depth

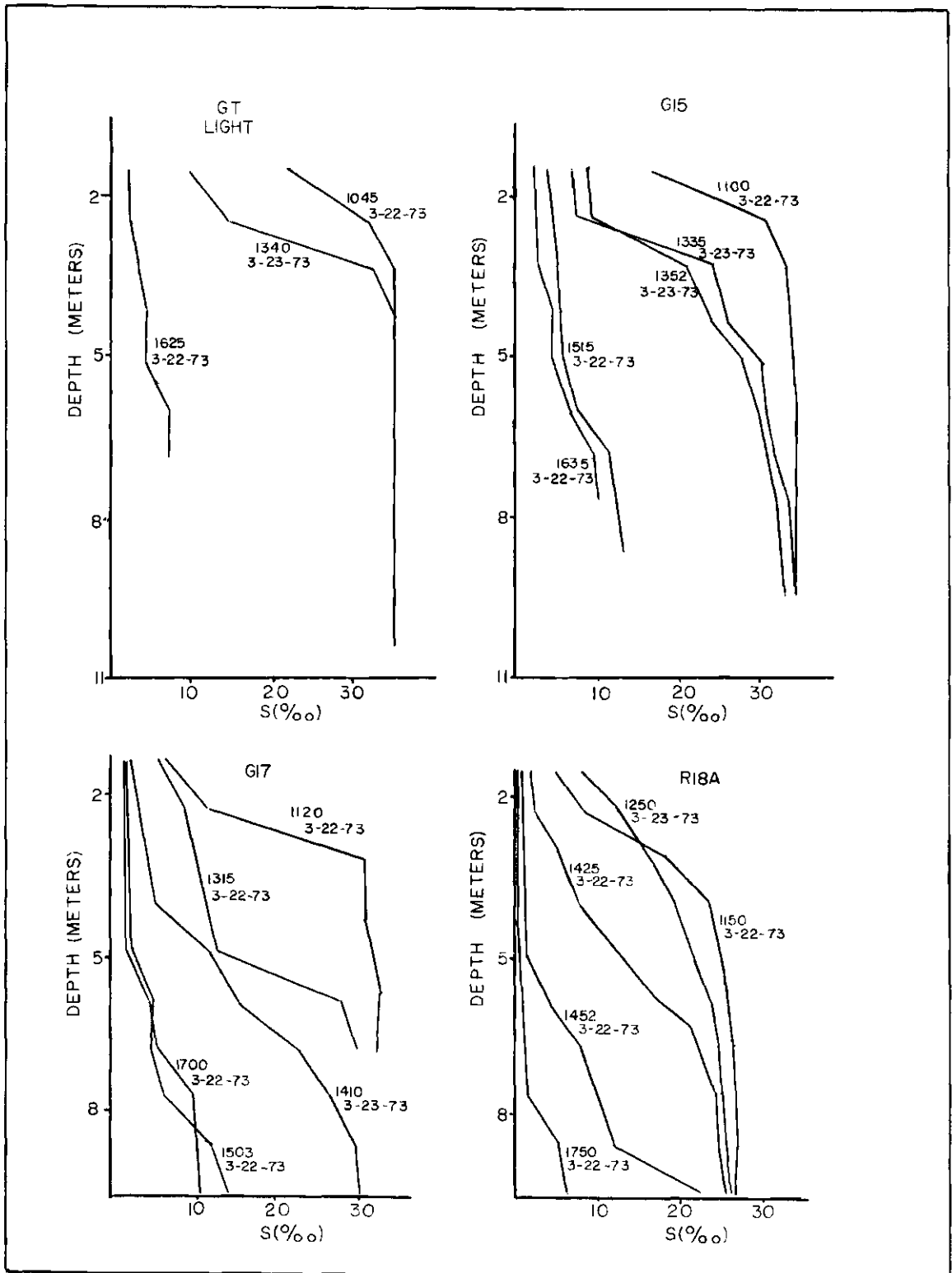


Figure 26. Temperature Salinity Data, 3/73,  
G.T. Light to R18A

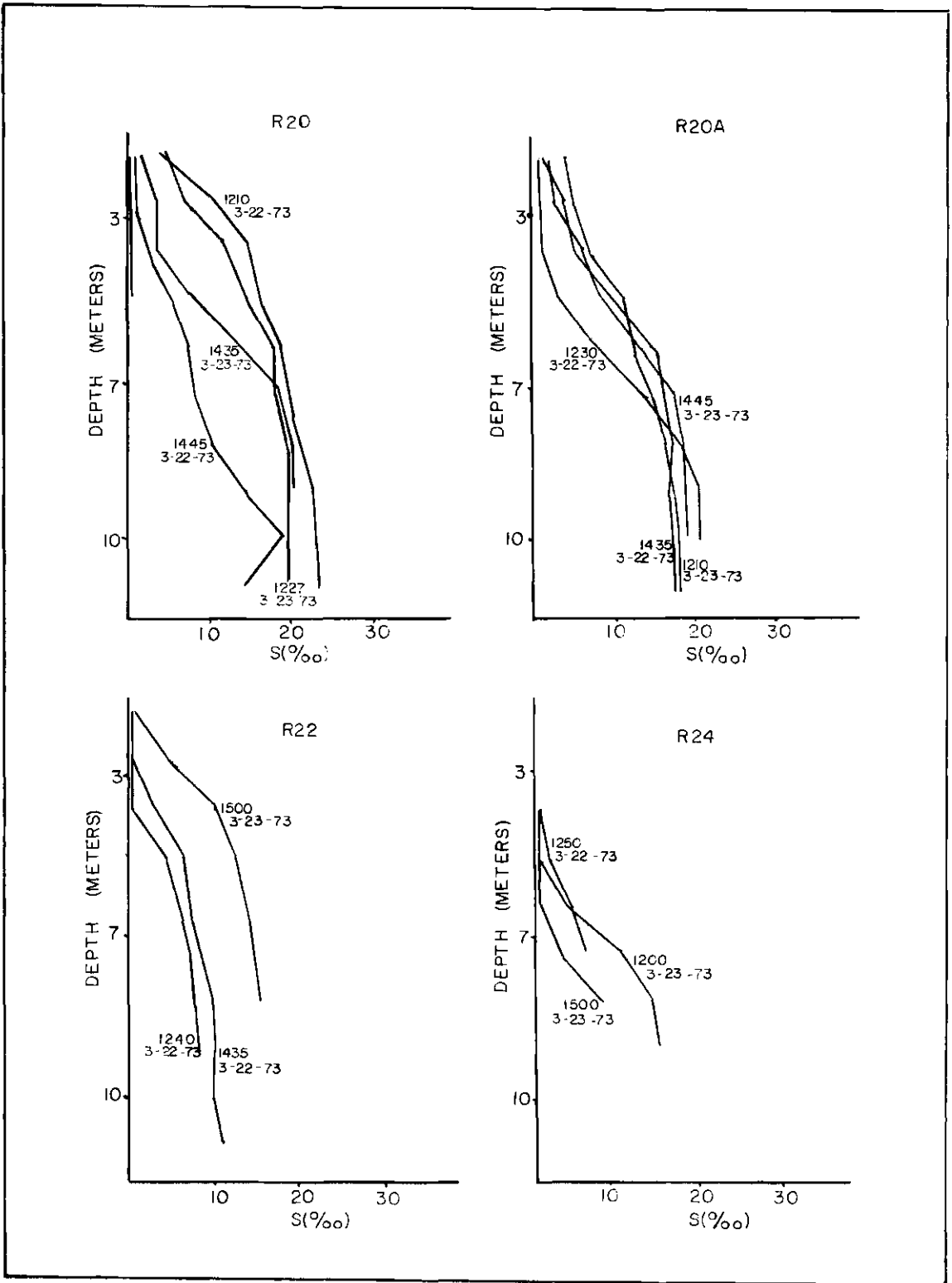


Figure 27. Temperature and Salinity Data, 3/73, R20 to R24

Also, the head of the estuary tends to have more poorly defined salinity than those recorded at the mouth. Thus the estuary at the time of these measurements may best be classified as partially mixed (Pritchard, 1955), recognizing that this condition may fluctuate greatly depending on stage in the tide, location in the estuary, and the amount of freshwater inflow into the bay.

#### Cruise Number Five - May 14-20, 1973

The runoff during this cruise was about 560 cms (20,000 cfs). Three stations were occupied on the shelf. The meters placed at Cape Romain marker (station 10) and at station 6 returned sets of data spanning 20 and 24 hours, respectively. The meter placed in the vicinity of station 5 suffered a malfunction in the triggering mechanism, consequently, no data were returned from this station during this cruise.

Temperature and salinity data were recorded within the estuary at the Western Channel station and station R18A. These data were recorded at half hour intervals over one half of a tidal cycle (through an ebb tide) in an effort to determine any differences between the salinity structure of the Western Channel and the Eastern Channel.

The current data on the shelf were recorded at five-minute intervals, vectorally averaged and presented as progressive vector diagrams (Figures 28 and 29). The wind shifted gradually from the southwest through the west (variable for two or three hours) to the north during the recording period. The gradually shifting winds in addition to the tidal variation and possible estuarine effects resulted in fairly complex progressive vector diagrams. The water appeared to respond primarily

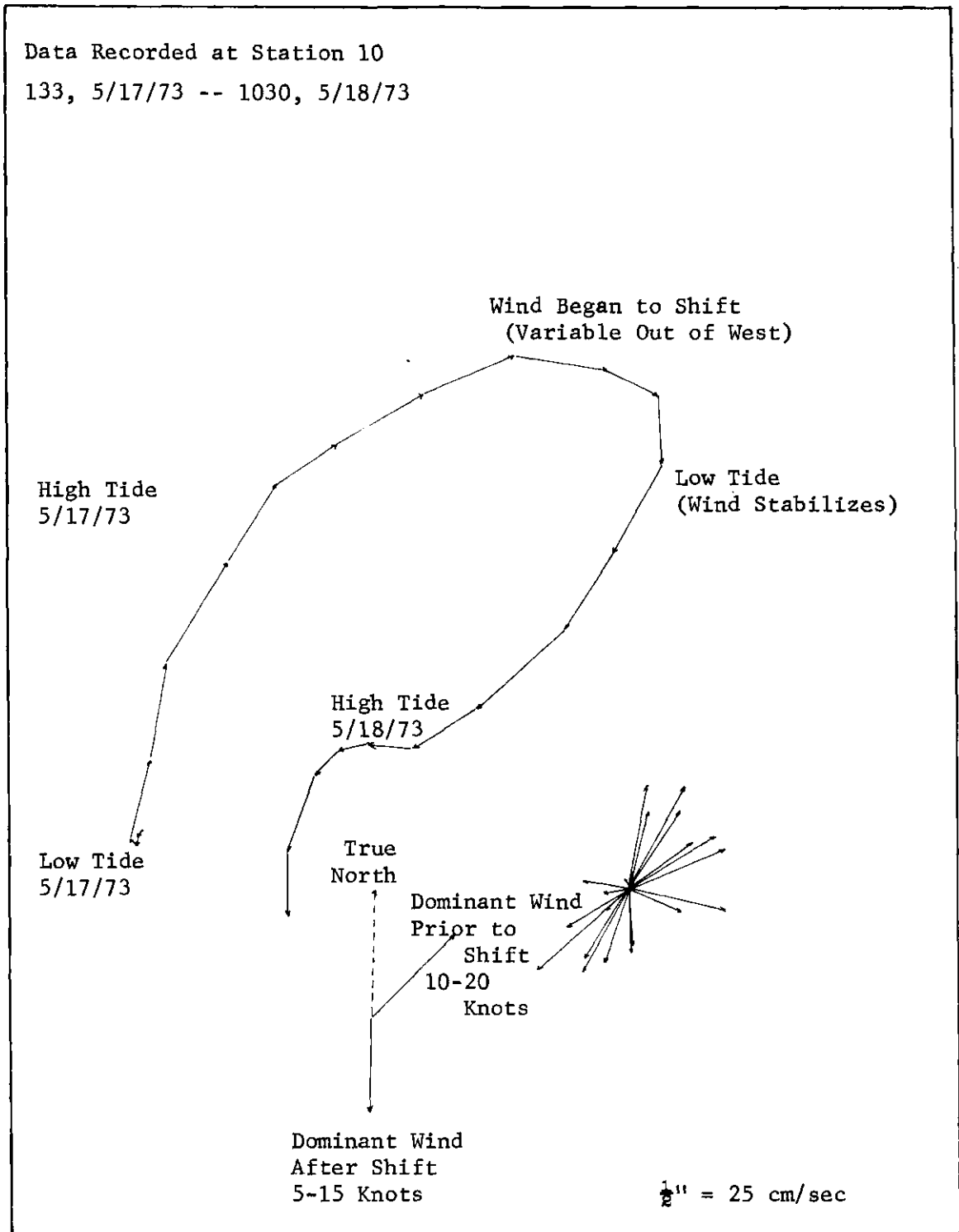


Figure 28. Progressive Vector Diagram and Current Rose, Station 10

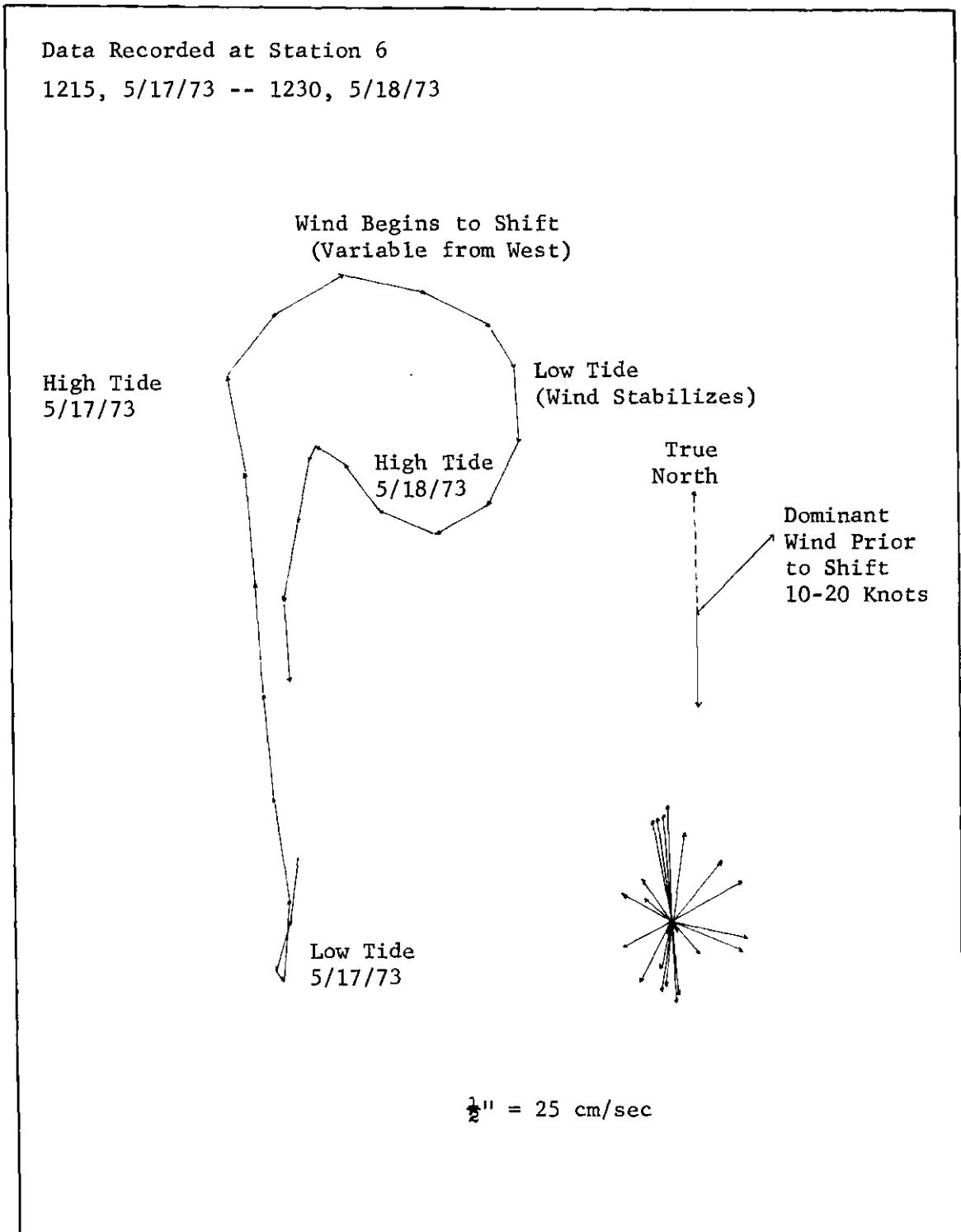


Figure 29. Progressive Vector Diagram and Current Rose, Station 6

to changing wind conditions and secondarily to the tide as previously observed. Also the diagrams show that a northeasterly flow accompanied a sustained southwesterly wind whereas southwesterly flow accompanied a sustained northerly wind. The complete shift in current direction could not be attributed to tide as the current reversal did not have the periodicity of the semidiurnal tide which exists in this area. As during previous cruises, the flooding tide produced a more westerly component to the dominant drift whereas the ebbing tide produced a more easterly component.

The temperature and salinity data recorded within the estuary in the Western Channel and at station R18A show that the average salinity in the Eastern Channel during an ebb tide was higher at any given time than the Western Channel (Figure 30). However, the higher salinities in the Eastern Channel were found below the five meter water depth. The Western Channel is only slightly greater than five meters deep at mean low water and these two stations are roughly the same distance from the mouth of the estuary. Therefore it can be deduced that the higher average salinity in the Eastern Channel is a result of the saltwater intrusion being largely confined to the dredged channels where depths exceed five meters at mean low water. As previously mentioned, data recorded in March support the hypothesis that the saltwater intrusion may be mainly confined to the deeper areas of the estuary associated with dredged channels. Near the end of ebb tide the salinities in the Western Channel were lower than even the shallower waters in the Eastern Channel. Therefore the data recorded in the estuary during this cruise suggest, as

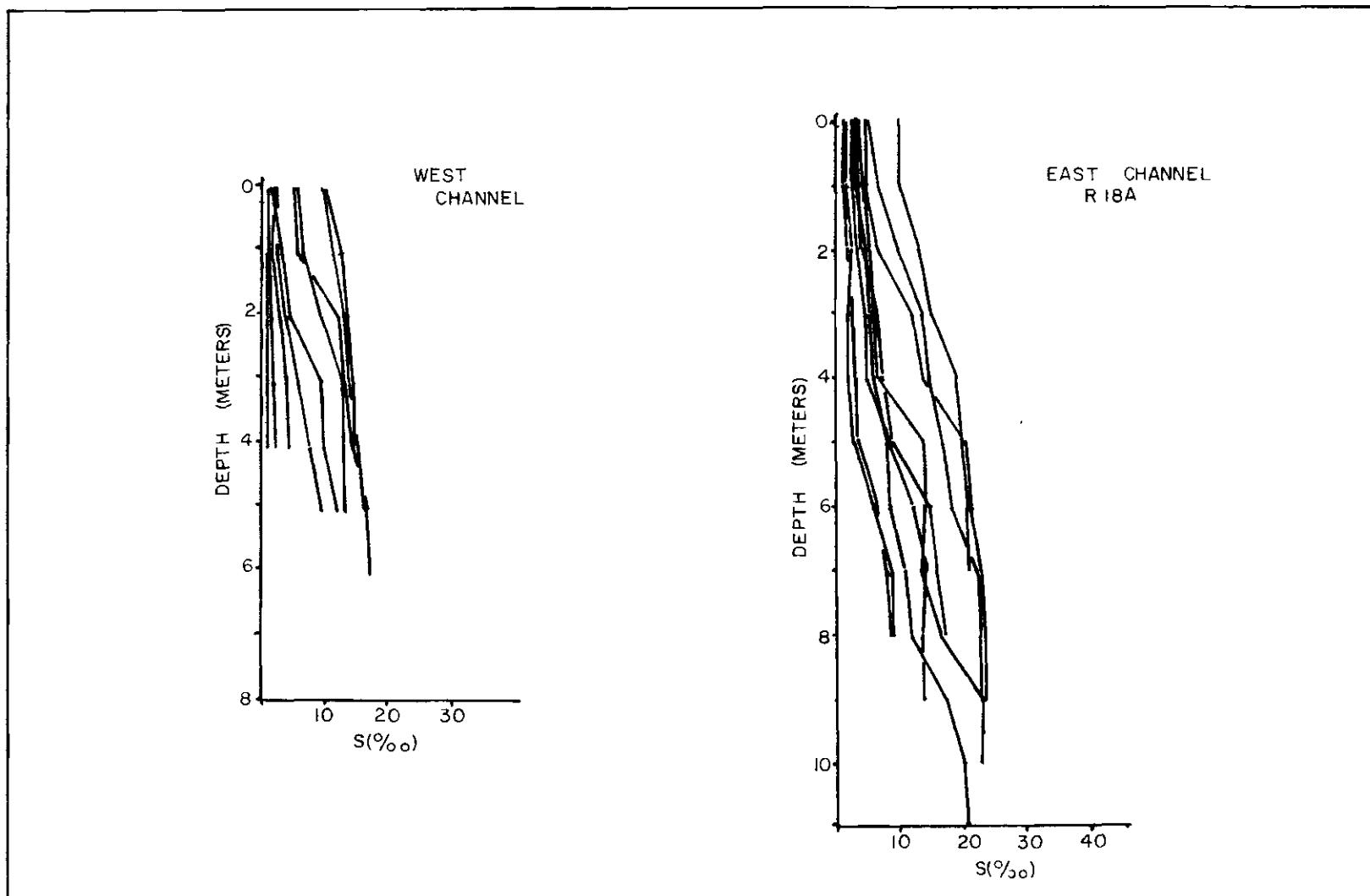


Figure 30. Temperature and Salinity Data, 5/15/73

during the March cruise, that the Western Channel is predominantly an ebb channel, particularly during periods of average to high runoff.

## CHAPTER V

## DISCUSSIONS AND CONCLUSIONS

The Inner Shelf

The data concerning inner shelf circulation were accumulated during the September, March, and May cruises. Fourteen stations were occupied and reliable data were returned from 12. The data were recorded over a wide range of conditions with regard to freshwater runoff and wind direction. Despite these widely varying conditions, some general characteristics of the water motion in the Winyah Bay area remained constant during all these cruises. The predominant drift appeared to be primarily due to dominant sustained winds. The tidal effect was secondary in that it generally modified the dominant drift direction with either a more onshore or offshore component.

At most stations a fluctuation in velocity was noted which could be associated with tidal variation. These velocity fluctuations suggest that a flooding tide enhances a northerly flowing current whereas an ebbing tide enhances a southerly flowing current.

The data indicate that no reversals of a tidal period occurred during any of the cruises and the sustained winds never fell below 10 knots. Therefore only at some wind speed less than 10 knots will be tidal currents be strong enough relative to wind driven currents to cause reversals.

Current data suggest that a tide related interruption in shelf circulation exists. The lowest speeds were recorded at times shortly

following the changes in the tide. At stations closest to the mouth of Winyah Bay, these times were often characterized by fairly shortlived and abrupt reversals in current. When all other conditions were constant, this phenomenon appeared to occur only following high tide or low tide but never both. The phenomenon appeared to have a period of 13 hours (assuming constant wind conditions) (Figure 5).

These anomalous current variations may possibly be explained by an interaction between estuarine and shelf circulation. It has been reported that the change in tide in the bay occurs two or three hours after the change in tide on the shelf during periods of low to average runoff. That is, upstream or downstream motion in the bay persists for two or three hours following the change in tide on the shelf. Therefore, following high tide on the shelf, there may exist a divergence of sorts near the mouth of Winyah Bay (Figure 31). This situation would result from the upstream motion in the bay following high tide on the shelf and the offshore component of flow on the shelf associated with the newly ebbing tide. Conversely, there may exist a convergence near the mouth of the bay following low tide on the shelf (Figure 31). This situation would result from the downstream flow in the bay following low tide and onshore motion on the shelf associated with the newly flooding tide.

A divergence near the mouth of Winyah Bay could result in water motion from north and south of the bay into the vicinity of the divergence (Figure 31). A convergence would have an opposite effect in that water would move north and south away from the vicinity of the convergence. Therefore, following high tide on the shelf, there would be forces tending to draw water southward, north of the estuary and northward,

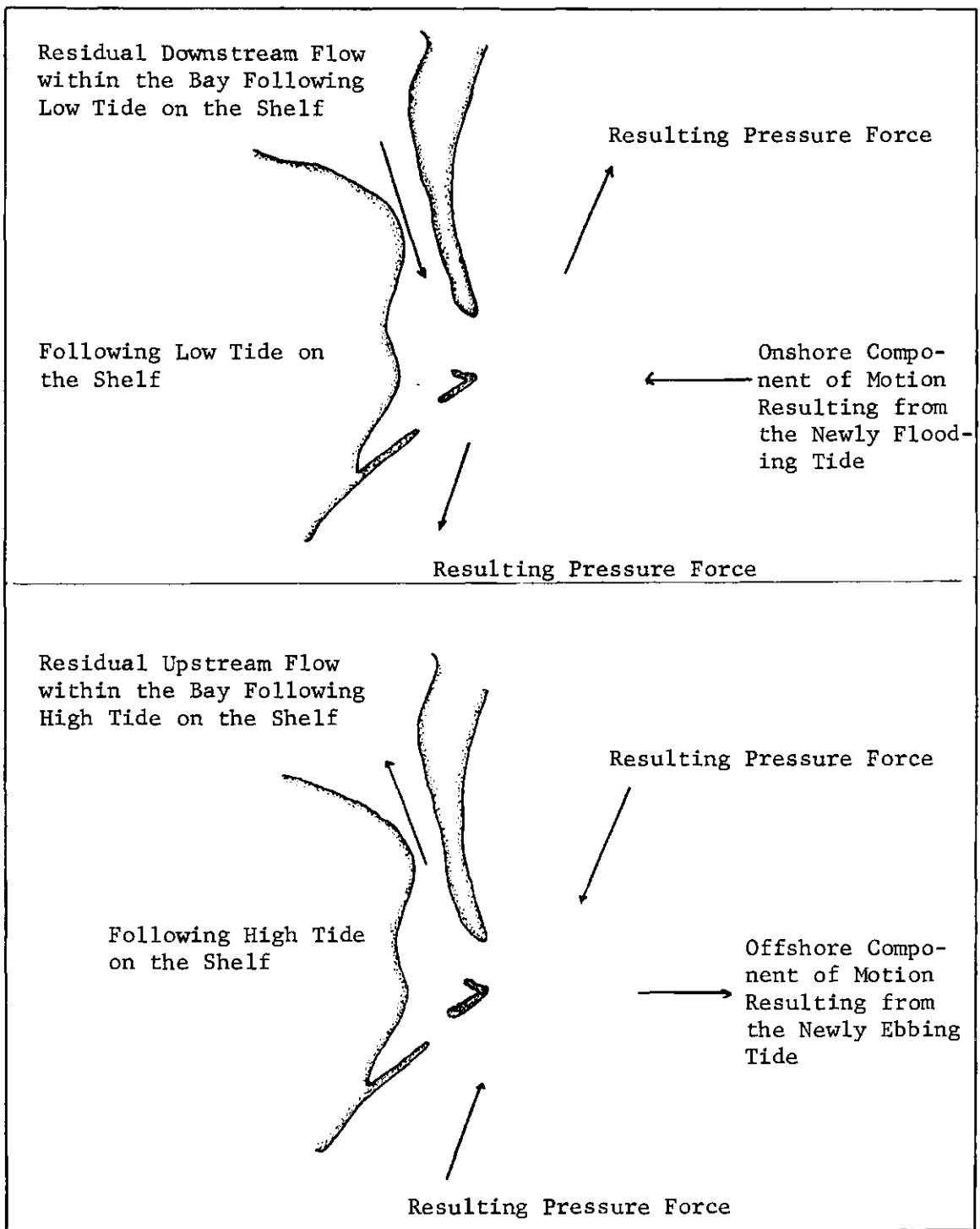


Figure 31. Schematic Diagram of the Proposed Interaction between Estuarine and Shelf Circulation at the Change in the Tide

south of the estuary (Figure 31). These conditions would be reversed following low tide. Therefore, depending on direction of dominant drift and station location relative to the bay mouth, the dominant drift may be temporarily accelerated, retarded, or reversed following the change in tide on the shelf.

Consider station one (Figure 5) for example. Following low tide on the shelf there would hypothetically be a convergent situation at the mouth of the bay acting to accelerate a northerly current at station one. According to the proposed model, no interruption in the current pattern is expected to occur at station one at this time. However, following high tide, a divergent situation would exist at the mouth of the bay. This is expected to have a retarding effect on a northerly current at station one and the current pattern should be temporarily disrupted. Figure 5 shows that the current pattern at station one fits the proposed model. Most of the observations made on the shelf support the existence of this type of phenomenon.

It is recognized that this model is overly simplified and may not be completely adequate to explain the short-lived disruptions that periodically occur in the otherwise smooth current pattern. It would require a more extensive study to verify the existence of this mechanism.

The principal conclusion that can be taken from data accumulated on the shelf is that the water motion is primarily dependent on dominant wind. Therefore, by consulting local wind conditions, one could make a reasonably accurate guess as to the fate of the water and thus the suspended and dissolved material exiting Winyah Bay at any given time.

General wind conditions in the Winyah Bay area are primarily dependent on season. The Summer months are characterized by predominantly southerly winds whereas Winter months are characterized by northerly winds (Haight, 1942). Therefore, dominant long term drift over the shelf in the Winyah Bay area should be northerly during the summer and southerly during the winter. During the Spring and Fall the winds are more variable; therefore, direction of dominant drift is less apparent. Probable yearly drift predominance for this area may be obtained by consulting local yearly wind data.

#### The Estuary

Data regarding salinity distribution and circulation characteristics within the estuary were compiled during the cruises made in November, December, March, and May. During these months there was a wide range of conditions with respect to freshwater inflow. Significant flood predominance was not observed at any stations occupied during any of the cruises. However, the deepest station occupied was approximately six meters deep at mean low water. It is conceivable that flood predominance did exist at the greater depths which occur within the dredged channels.

The salinity measurements indicated that the mouth of the estuary may range from nearly stratified to partially mixed depending on stage in the tide. The head of the estuary may range from nearly homogeneous to partially mixed again depending on the stage of the tide. The central portions of the estuary (stations G17 - R24) appeared to be nearly always partially mixed. These general characteristics remained unchanged over a wide range of freshwater inputs (140 cms - 1400 cms). Therefore, it

appears that this estuary may best be classified as partially mixed, recognizing that this condition may fluctuate greatly, particularly at the extremes of the estuary.

The main effect of changing freshwater input was to change the distance over which saltwater intrusion occurs. It was found that during average runoff conditions, the saltwater intrusion proceeded beyond the confluence of the Peedee and Waccamah Rivers. During periods of high runoff the tip of the wedge intruded slightly beyond the northern most confluence of the Western and Eastern Channels. Naturally during ebb tide the wedge moves seaward, but it was never found to be expelled completely from the estuary.

The Western Channel has a maximum depth of approximately six meters. Therefore, as the evidence previously presented suggests, it is predominantly an ebb channel at high runoff.

All of these conclusions regarding characteristics of estuarine circulation and particularly water motion over the shelf are based on a limited amount of data accumulated over a single year. However, it is believed that any further investigations in this area and in the areas to the south will support the major conclusions reached during this study.

## CHAPTER VI

### RECOMMENDATIONS

The greatest number of problems was encountered during location and recovery of meters at stations on the shelf. Adverse sea conditions occasionally resulted in dangerous situations when attempting to retrieve the heavy, bulky anchoring systems. Therefore, it is recommended that the anchors be made in the form of concrete cylinders with handles (Figure 32). A cylindrical shape has fewer sharp edges and handles will facilitate handling on deck. The low cost of concrete will make it economically feasible to dispose of the anchor during retrieval. The mooring line should consist of 3/8 inch nylon rope except for the section on which the meter is mounted. Nylon is considerably less expensive and easier to work with. The strength of nylon is sufficient unless the station is to be occupied for an extended period of time. It is also recommended that a small float be attached above the meter to hold the mooring line straight below the meter (Figure 32). The attachment rings located at the base of the meter should be replaced often as failure of this ring would result in the loss of valuable data and equipment.

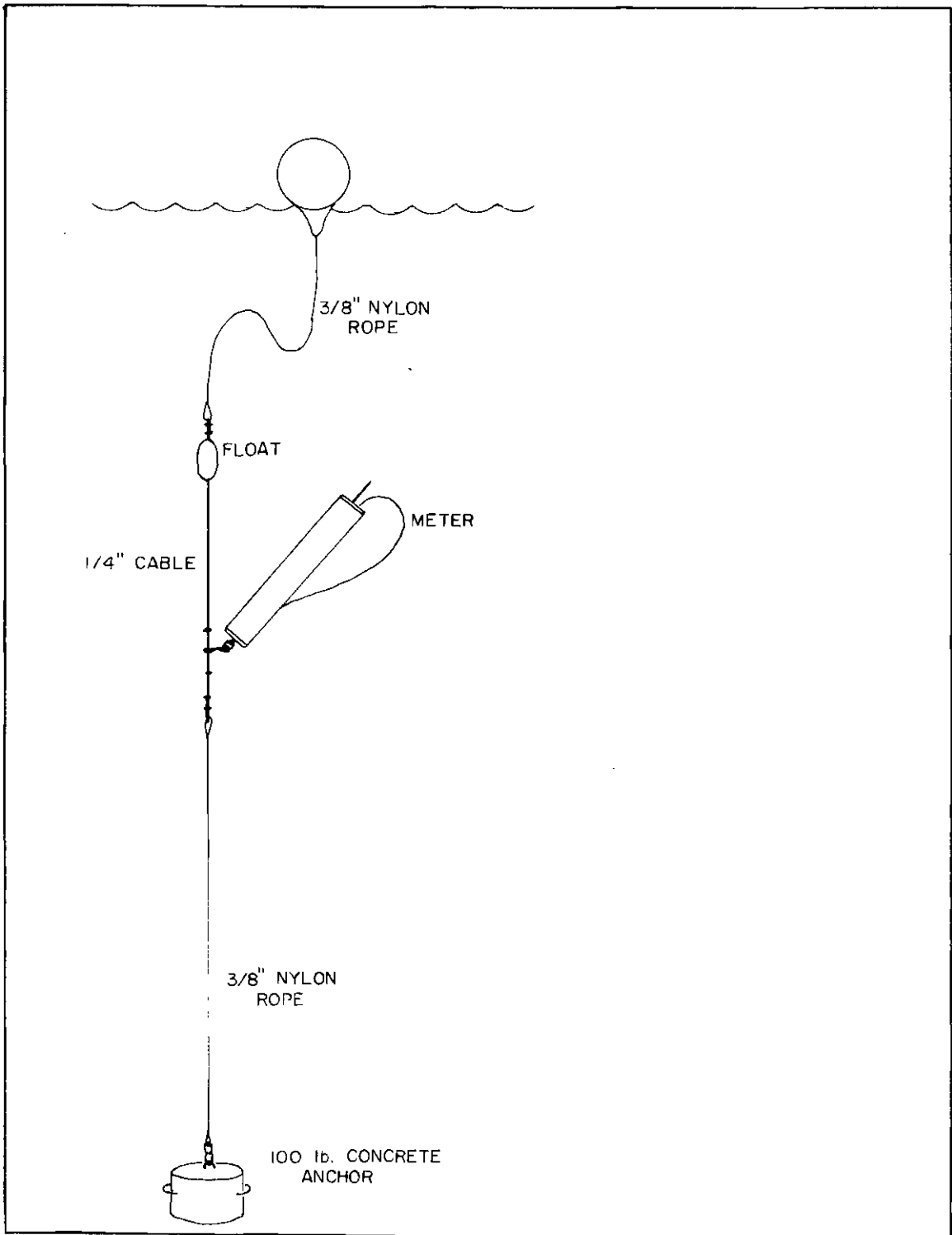


Figure 32. Recommended Current Meter Mooring System

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