The Current Patterns on the Tortugas Shrimp Grounds [1]

F. F. Koczy, M. O. Rinkel and S. J. Niskin
The Marine Laboratory, University of Miami

Introduction

A study of the oceanographic environments of Florida Bay was started in January, 1959, in connection with studies of the life history of the pink shrimp (*Penaeus duorarum*) on the Tortugas fishing grounds. These studies have been carried out by The Marine Laboratory of the University of Miami, under contract with the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service. The results which are presented will be only preliminary. This work was planned on the following assumptions. The main nursery grounds for the pink shrimp are in Whitewater Bay. The migration from the nursery grounds is presumed to follow a path from Whitewater Bay along the Keys to the Dry Tortugas and then going towards the northwest into deeper water of the Gulf of Mexico. This assumption is based mainly on the size distribution of shrimp caught on the fishing grounds north of the Dry Tortugas in western Florida Bay. The young shrimp then move from the spawning area into Whitewater Bay. As shrimp larvae are not believed to be able to follow a fixed migration route, it was necessary to study the current system in this area to establish the fact that shrimp can be transported between the spawning and the nursery grounds. To cover and study intelligently the environment, observations were made of the distribution of oceanographic parameters such as temperature, salinity and phosphate.

Background Data

The general current system in the area is shown in Figure 1 (Wennekens, 1959). This figure is based on material published by Leipper (1954) and Chew (1955). The main feature of this system shows a current which enters into the Gulf of Mexico through the Yucatan Channel; part of it penetrates in a northerly direction depending on the general hydrodynamic and meteorological conditions in this area. This branch current may penetrate very far into the Gulf of Mexico or may make only a short loop before it turns to the east and south and leaves the Gulf of Mexico between the Dry Tortugas and Cuba to join the main current to become the Florida Current proper. One of the general features of the distribution of salinity is a low salinity pocket (Chew, 1957) stretching more or less parallel to the Florida west coast about in the position of the shelf edge (Figure 2). Passing from this salinity minimum toward the Florida coast, high salinities are found, but very close to the coast salinities are lower again. By studying the distribution of the high salinity water, it was concluded that this water originates in Florida Bay. The low salinity near the coast is created by the run-off from Florida. This salinity picture does not indicate a strong current passing from west to east in the region in which we are interested. However, as the previous investigations were carried out in the northern part of the eastern Gulf in the region in which Red Tide occurred, no conclusions could be derived about the current pattern close to the Dry Tortugas. The low salinity pocket was explained as run-off from the Mississippi River. Further and more

[1] Contribution No. 266 from The Marine Laboratory, University of Miami.

Contribution No. 122

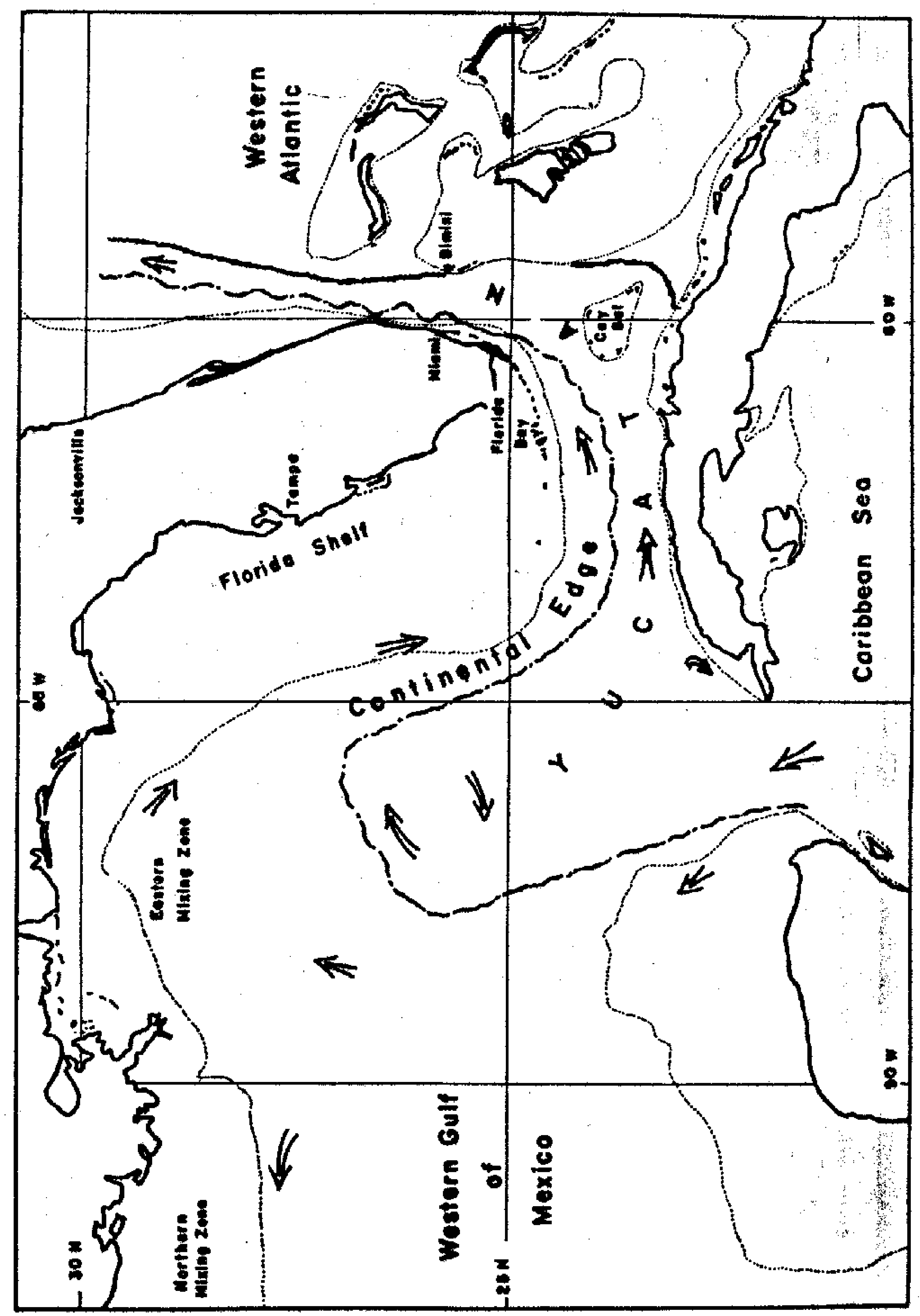

Figure 1. Boundaries of water masses of the Gulf of Mexico, Straits of Florida and Bahama Islands.

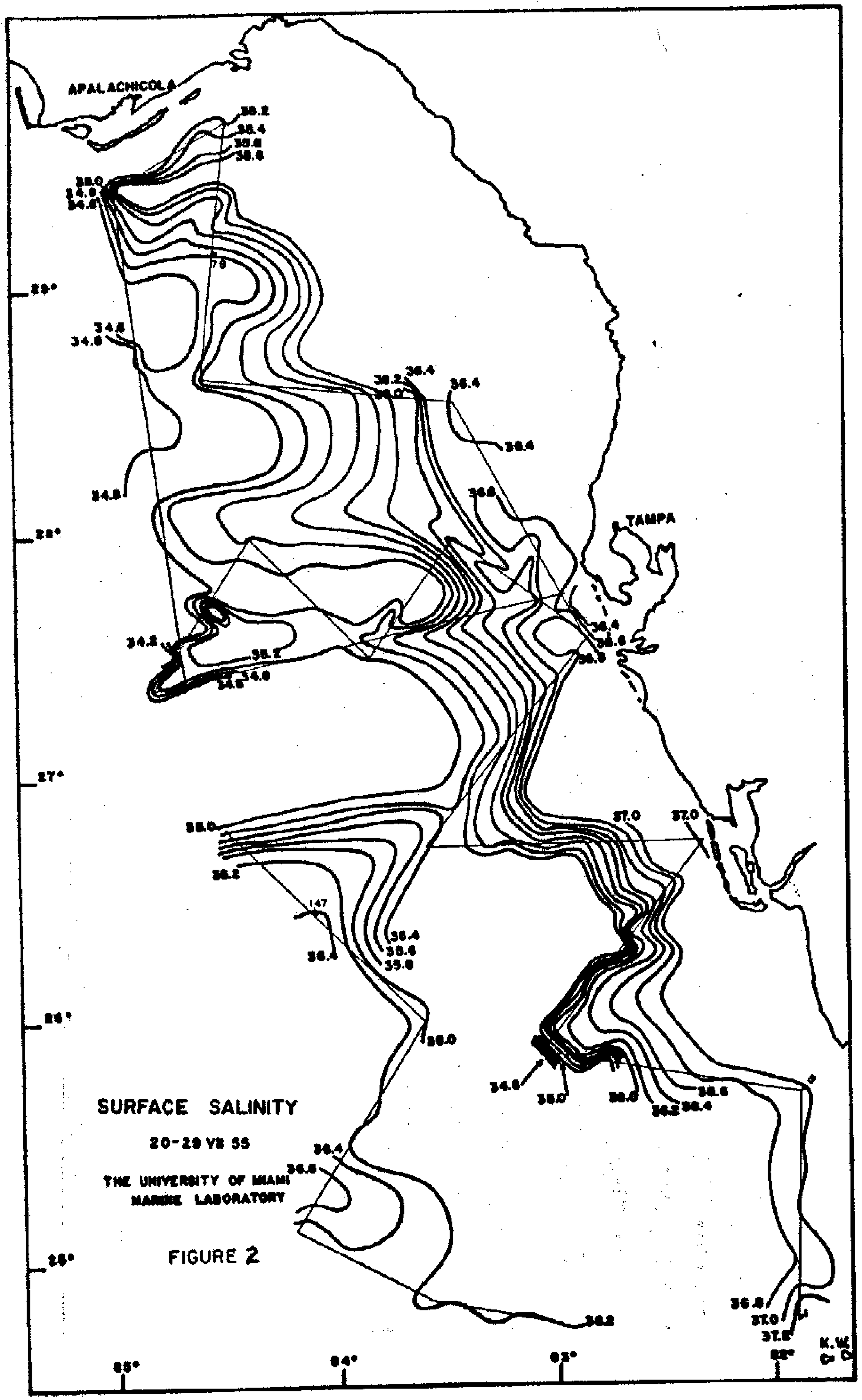

FIGURE 2. Surface salinities off the west coast of Florida.

intense studies about the permanency and the development of this low salinity pocket must be carried out before definite conclusions can be drawn. These investigations, based on a long term coverage of the area with a survey vessel and anchored recording buoys, would certainly contribute to the general oceanography of the Gulf of Mexico. On the other hand, it is believed that the influence of this special feature is not a serious one and that these preliminary conclusions, based on direct concrete observations, will be valid.

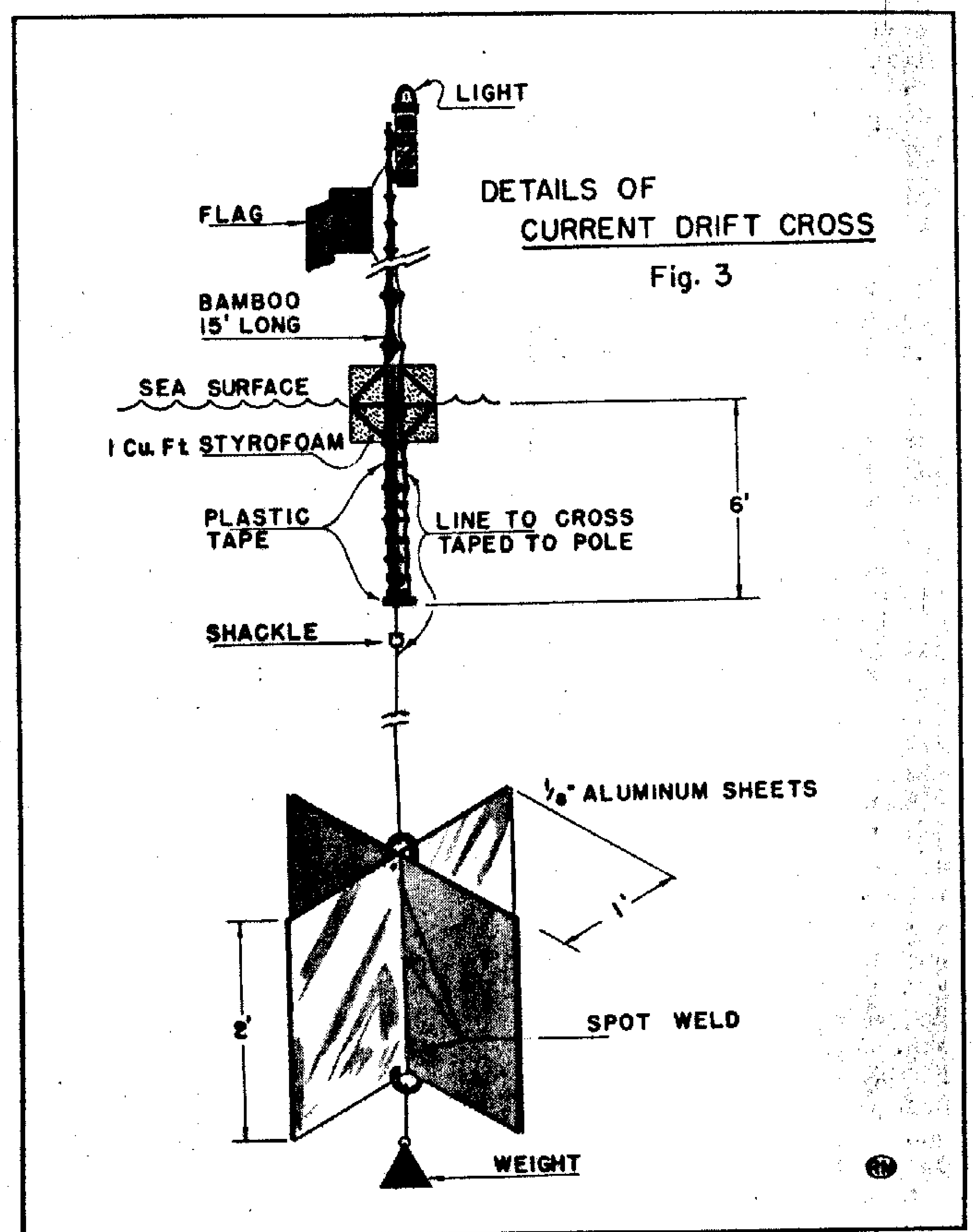

FIGURE 3. Details of current drift cross.

To attack the problem in the most efficient way and to achieve essential results applicable to fishery interests, an intense program of current measurements was organized; because, in general, the medium for the transport of the shrimp larvae is the water current. Of course it was necessary to study the distribution of salinity, temperature and density but it was felt that by developing a technique which gives adequate current data, the first logical assumption of the transport of the larvae could be proved or disproved. The main current in this region is the tidal current. Consequently at each current station a minimum of 1½ tidal cycles had to be observed to get the component of the permanent current. The best method to achieve this is to follow the paths of a water parcel over a given time period. Current crosses were utilized (Figure 3). The major problem encountered was the determination of the geographic position of the current crosses at half-hour time intervals.

Methods

After experimentation with several different methods, the following method for determining water movements was standardized. First a reference point, from which the geographical locations of the drifting current crosses could be ascertained, was established. This reference point was either a fixed navigation aid or an anchored radar reflector equipped "Hula Hoop" (Figure 4). Two aluminum 2 x 2 foot current crosses, equipped with flags and lights were then launched (Figure 3). One, a surface cross, was located 2 meters below the surface and the other, a bottom cross, usually 3 meters above the bottom. Using radar, a bearing and distance were taken at a time interval of one-half hour from each cross to the reference point.

When the distance between the crosses and the reference point reached about four miles, a second anchored reference "Hula Hoop" point was laid. This "leap frog" technique, as it was called, was extended as necessary to track the geographic location of the current crosses. Distance and bearing readings between the reference buoys were taken at time of laying and recovery. Based on cross checking of all bearing and range readings of the current crosses from any two reference "Hula Hoop" points, the largest geographical error recorded was 200 yards in distance and 10 degrees in direction at a cross reference point distance of four miles. The largest percentage of these multiple readings were much smaller in error. It is believed that the accuracy in the determination of the geographic locations of the current crosses is not in error by more than 200 yards in distance and 10 degrees in direction. It seems possible that a method error of 2 cm/sec can exist.

The "Hula Hoop" (Niskin, in press) consists of a ring 8 to 10 feet in diameter. This ring is formed from an 80 foot length of heavy walled 2 inch diameter polyethylene pipe wound round three times.

Its ends are joined with a standard 2 inch coupling of the same material. Twelve double nylon woven lines radiate inward from this ring to a brass hub. This hub is drilled to receive these nylon lines. The hub is milled to accept an aluminum mast 1¼ by 1¼ inches square and 20 feet in length. One third of this overall length is below the surface. Attached to the heel of the mast is a 30 pound heel weight. A 3-centimeter mesh universal life-raft type radar is attached to the head of the mast. An anchor line is made fast to the polyethylene ring and a 50 pound weight is used as an anchor.

Because the mast is suspended at the center of this large ring, it is very

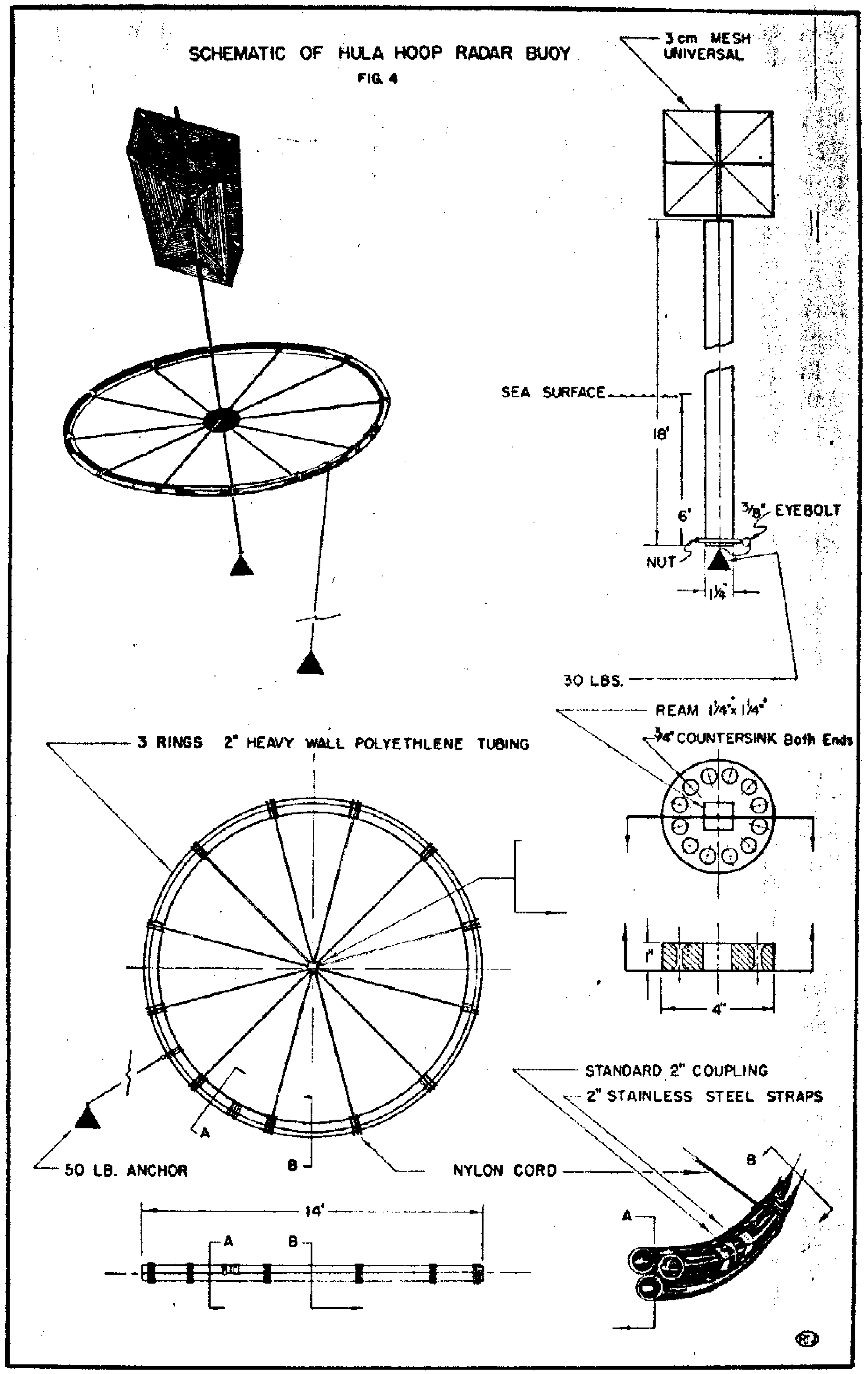

FIGURE 4. A schematic of the "Hula Hoop" radar buoy used as reference points on current stations.

effectively gimballed. The ring absorbs much of the vertical wave motion because the ring is flexible and the nylon spokes work and stretch. The above mentioned characteristics insure a maximum degree of vertical and overall stability of the mast.

The "Hula Hoop" has many other possible uses, i.e., surface current studies (minimum windage and cross suspension at the very surface of the water), suspension of surface instruments and gear, etc. The "Hula Hoop" is light (70 pounds, minus anchor and line), portable, easily launched and recovered and extremely seaworthy.

Results

The typical path of a surface current cross is shown in Figure 5. Each point gives the geographic position of the cross obtained at time intervals of usually one-half-hour. It is a classic example of a tidal elipse.

The average prevailing wind direction and speed is marked by arrows and is given in knots. On this occasion the water parcel seemed to stay stationary, except in the beginning of the observation, during which time it had a slightly southerly component. The permanent current was derived by assuming that the farthest point of the excursion either to the west or the east of the elipses, was the turning point of the tidal currents, and consequently should be at the same place in the absence of a permanent current. The times of the highs and

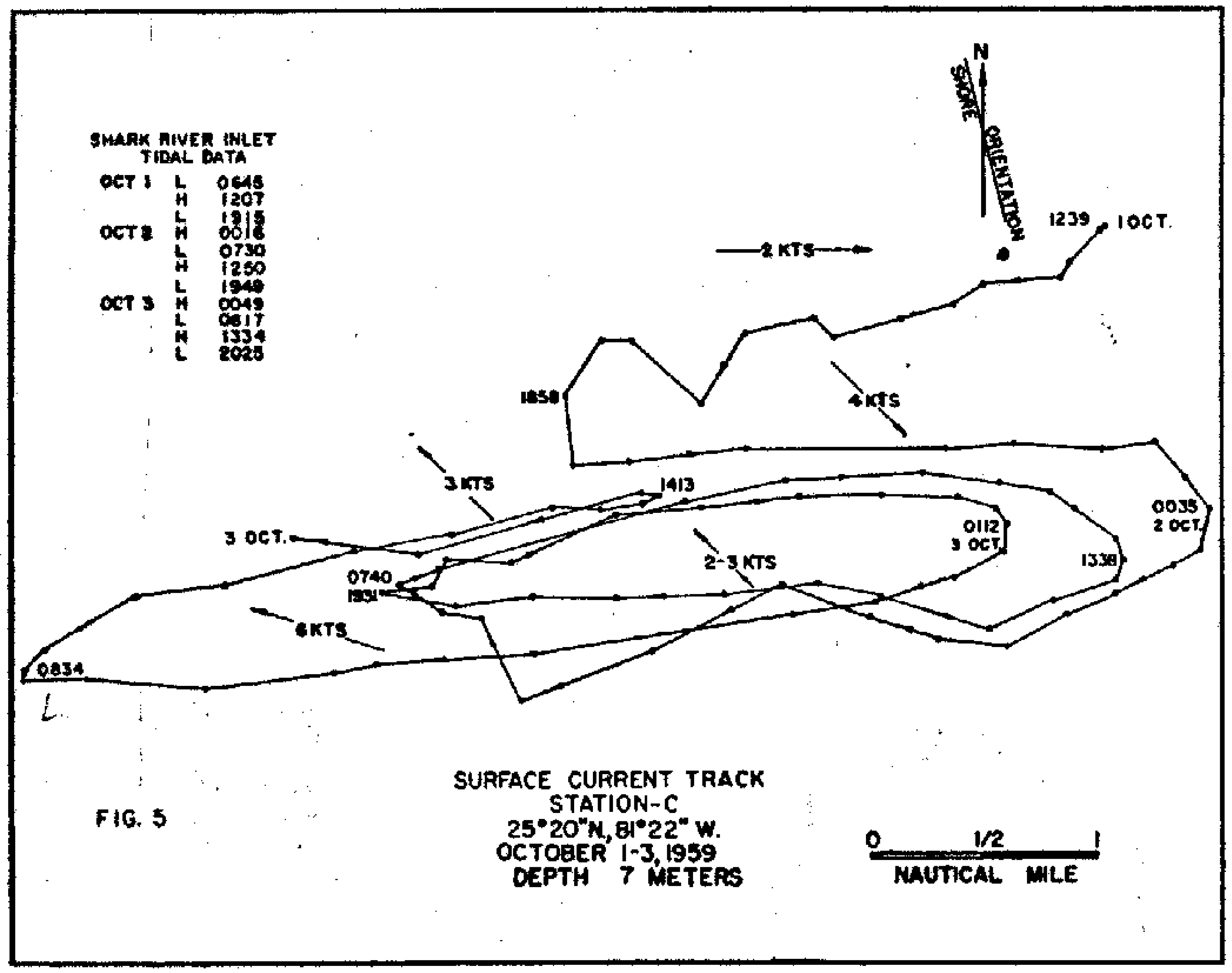

FIGURE 5. Current track of the surface drift cross at Station C. Direction of cross movement is indicated by arrows. Times of high and low waters for Shark River Inlet 11.5 miles from Station C are indicated in upper left corner.

lows for Shark River inlet (11.5 miles away) are given in the upper left hand corner of Figures 5 and 6 and indicate the possible error in determining the turning point. The distances between these points established the direction and the speed of the non-tidal displacement of the water. If the displacement between two successive tidal cycles was approximately the same, this current was taken to be a good estimate of the permanent current. On the other hand, it is realized that the tidal variations may give erroneous results because of the variation of the tidal currents from one period to another. It is obvious that very small permanent currents will be measured with a considerable error, but for the purpose of the investigation it was only important to achieve an indication of currents to the east of a rather high speed. It is believed that the accuracy of this method is sufficient to determine the possibility of shrimp larvae transport from the spawning to the nursery grounds. Furthermore, we believe this method is the most simple and gives the best results. Improvement could be obtained only by increasing the time period over which the measurement is carried out.

At the same station simultaneous current measurements were made near the bottom (Figure 6). The tidal turning points of the surface and bottom currents were determined to be simultaneous, at least within the accuracy obtainable by the necessity of alternately measuring the position of both current crosses.

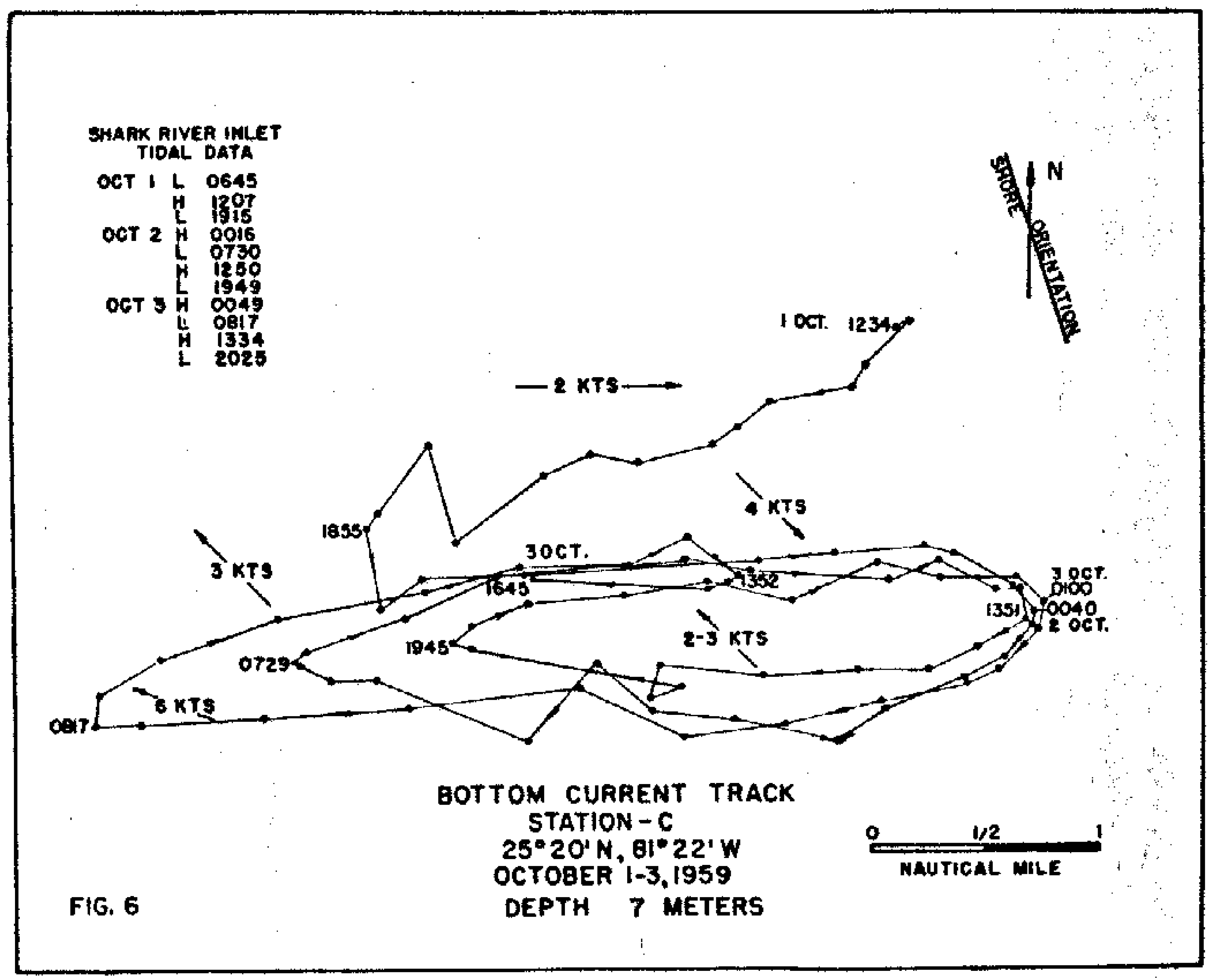

FIGURE 6. Current track of the bottom drift cross at Station C. Direction of cross movement is indicated by arrows. Times of high and low waters for Shark River Inlet 11.5 miles from Station C. are indicated in upper left corner.

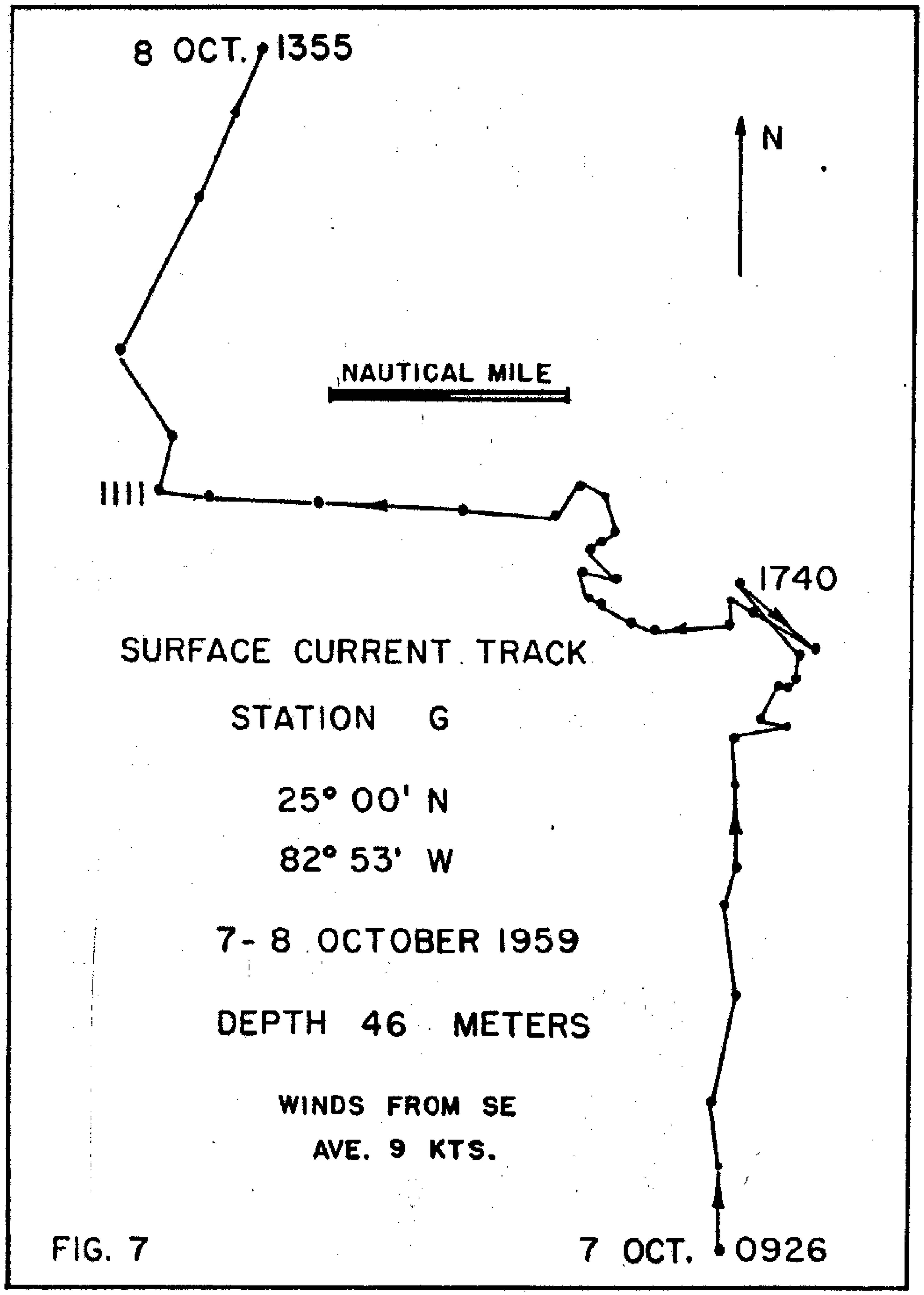

FIGURE 7. Current track of surface drift cross at Station G. Direction of cross movement is indicated by arrows.

The total tidal excursion between any two tidal turning points was about five miles at this station, which gives a tidal current of a little less than one knot in a nearly east-west direction. The smaller axis of the elipses was very small, less than mile. The permanent current at this station was determined to about 1/20th of a knot.

The situation given above is typical throughout the sampled area with the exception of three stations. At two of them, the bottom current was not similar to the surface current although both currents showed tidal characteristics. On the other station (Figures 7 and 8) no well developed tidal currents were found. Bottom and surface movement was slightly different. This may be explained by the fact that the bottom current cross was at greater depth than all other stations (50 meters), and in a slightly different water mass as shown by the difference between surface and bottom salinity of 0.6‰. The general trend of the movement of the surface buoy is at about 45 degrees to the right of the wind. The variations from a straight course do not seem to correspond to tidal excursions when compared with the nearest tidal data from the Dry Tortugas. The bottom current was, in the beginning of our series of measurements, about in accordance with the surface, but did show a marked decreased water parcel movement.

In total, eleven stations were occupied of which two were repeated as given in Table 1. The calculated permanent currents are shown in Figure 9. It is clear that these data are only preliminary, because of the scarcity of stations and of seasonal and yearly coverage.

The general trend of measurement of permanent currents from the surface and bottom current crosses indicates the existence of a pronounced westerly

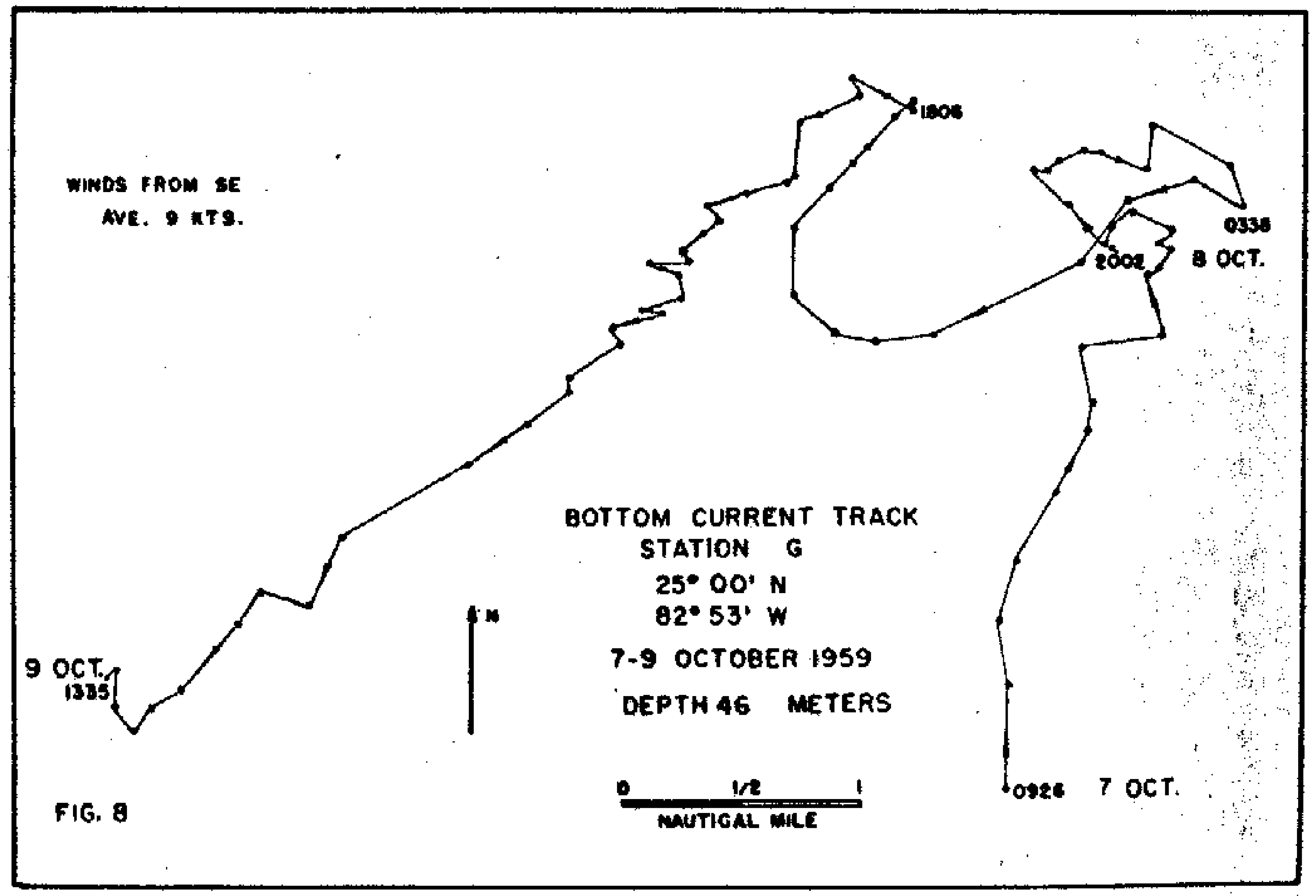

FIGURE 8. Current track of bottom drift cross at Station G. Direction of cross movement is indicated by arrows.

TABLE 1

RESULTANT CURRENTS FOR CURRENT STATIONS FLORIDA BAY SURVEY

Station	Lat. N.	Long. W.	Month Occupied	Depth to Bottom (m)	Depth of Bottom Cross (m)	Surface Direction	Surface Velocity*	Bottom Direction	Bottom Velocity*
A	24° 45′	82° 42′	Jan. '59	31	29	210°	9.2	190°	6.2
B	24° 46′	82° 06′	Jan. '59	18	16	226°	12.1	223°	19.4
SG	25° 00′	81° 15′	Feb. '59	6	4	088°	2.0	070°	1.9
R-16	25° 40′	81° 39′	Mar. '59	7	5	299°	4.0	294°	2.1
WR	24° 57′	81° 46′	Mar. '59	15	7	050°	5.6	017°	5.4
			June '59	15	12	017°	7.3	027°	5.0
C	25° 20′	81° 22′	June '59	7	4	255°	5.8	262°	5.3
			Oct. '59	7	4	261°	6.1	252°	4.6
E	24° 30′	82° 38′	June '59	14	9	340°	7.3	326°	6.6
F	25° 10′	81° 45′	June '59	15	9	227°	2.1	114°	1.9
D	25° 10′	82° 14′	Oct. '59	29	20	291°	8.8	288°	8.1
G	25° 00′	82° 53′	Oct. '59	46	37	340°	9.4	279°	3.8
AB	24° 43′	82° 35′	Oct. '59	29	20	300°	11.4	286°	7.6

*Velocity in cm/sec and denotes average velocity through major tidal cycle.

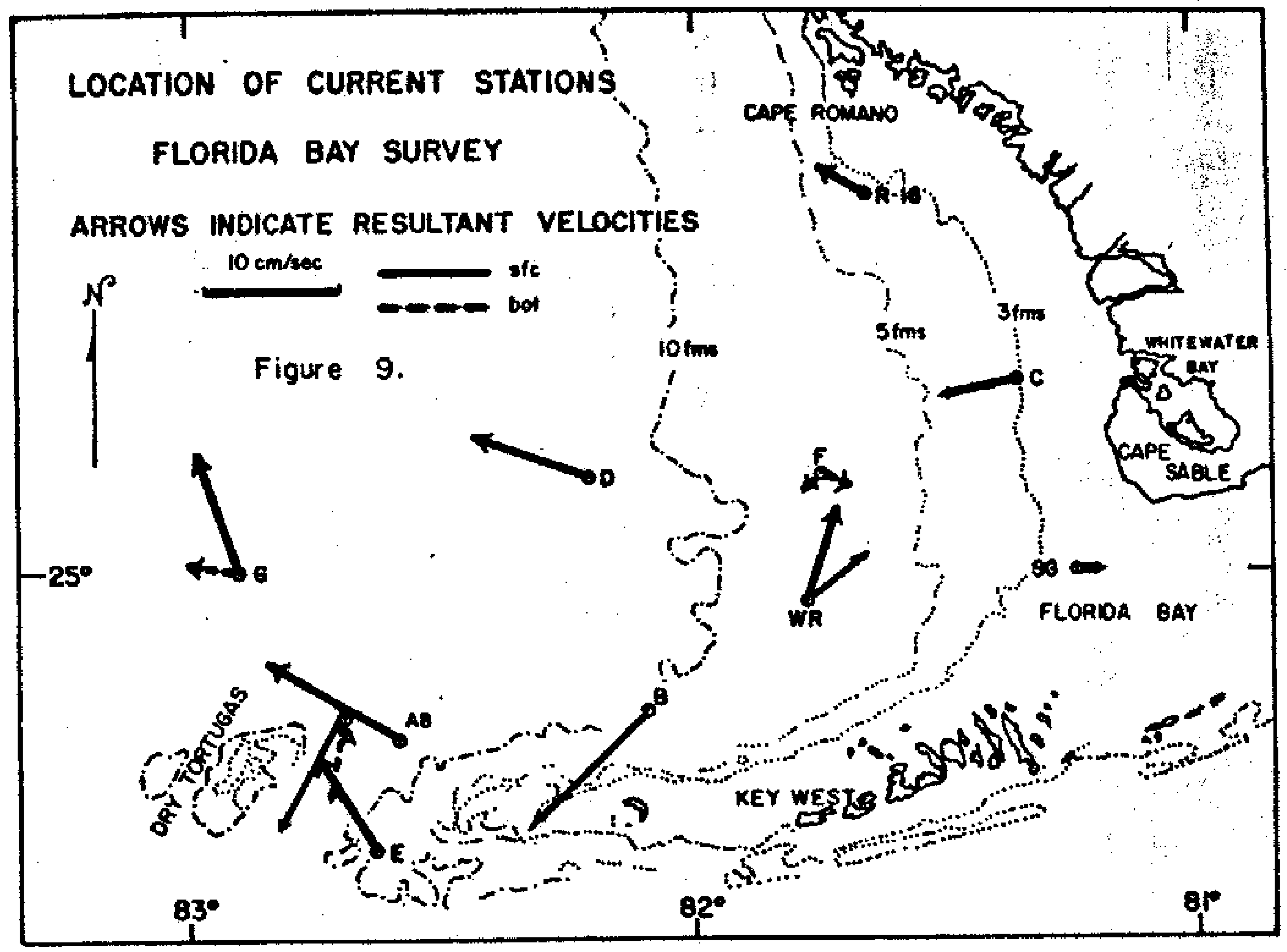

FIGURE 9. Location and resultant velocities of current stations Florida Bay Survey. Unless surface and/or bottom currents were markedly different, arrows represent average surface currents.

component in this region. There are only a few stations with easterly current. Moreover their speeds are so small, compared with the overall accuracy of the method, that it would be more appropriate to attribute a zero velocity to these stations. Generally this is true for all inshore stations. The inshore currents measured fall more or less within the range of accuracy of our method. The existing westerly currents cannot transport the larvae from the spawning area towards the shore, a distance of 100 miles in an easterly direction. Furthermore, even if the current direction were reversed, the distance could only be traveled in about 1000 hours or roughly six weeks, precluding the arrival at an inshore nursery ground.

All measurements have been carried out under essentially easterly and southeasterly wind conditions. This limits the results to weather of this type, which is the prevailing one throughout the year. During a westerly wave (westerly wind conditions) occurring during winter, the current flow pattern may be reversed.

Discussion

These preliminary results indicate that the prevailing current pattern cannot be responsible for the transport of larvae to Whitewater Bay. It was not possible to investigate other mechanisms which may be responsible for the transport. One could be a bottom current, as currents very close to the bottom may have escaped detection, since the method employed can only give the movement of a rather thick water mass. Current crosses had to be positioned at least 2 feet above the bottom because of bottom irregularities.

Therefore, any bottom current transporting larvae in an easterly direction must be less than 2 feet thick. Theoretically it is possible that such a current exists; however, we do not believe it is probable. If such a current does exist, its speed is probably so small that it could not serve as a transportation medium for the larvae. However, in future work a study of the bottom currents will be included. It has been suggested that the shrimp larvae may have the ability to use the inshore leg of the tidal current for their movement. In order to do that, they need only to attach themselves to the bottom during the six hours the current is going towards the sea and float in the water during the inshore movement. As one tidal excursion is five miles in six hours, the larvae could make the whole distance in about four days. This problem is a purely biological one and has not been studied during our investigation.

Another possible explanation of the shoreward transport of larvae would be under easterly wave conditions, where for a short period of time a strong current could exist to the east. It is the authors' belief that under conditions like this the current is of short duration and the current speed could seldom reach values necessary to transport young shrimp into Whitewater Bay. However, this possibility has to be kept in mind during further investigations and a coverage of this area under all weather conditions has to be achieved. The best way to study this phenomenon would be by automatic current recording stations.

The rather high speed of the tidal current causes an intense mixing of the water masses resulting in a high value of the eddy diffusivity in this area. Preliminary calculations, which are based on diffusion constants in the Biscayne Bay and Florida Current, lead to the conclusion that the distribution of larvae has to show a very high gradient from the spawning grounds toward Whitewater Bay to allow the transport of the required amount of larvae to support the population of shrimp on the fishing grounds. Also in this case the time element would still be in the order of several weeks before the larvae could reach Whitewater Bay, a time period too long to substantiate this explanation. Before final conclusions about this possible solution can be derived, the distribution of larvae in this area has to be known both seasonally and yearly.

It is certainly premature to make any definite statements at the moment, but by summarizing these results, it seems virtually impossible to verify the mechanism by which larvae are transported to inshore areas from the conditions originally assumed. Thus, the assumptions postulated in the beginning of this paper will be again briefly discussed. These two basic assumptions made are:

1. Whitewater Bay is the primary nursery ground for all the larvae of the stock of shrimp in the Dry Tortugas area.
2. The larvae entering Whitewater Bay are produced in a spawning area about 100 miles off the western coast of Florida.

The first assumption is substantiated only by the high concentration of young shrimp in Whitewater Bay. Lacking knowledge of other possible nursery grounds, it cannot be stated that Whitewater Bay is the only existing one. Therefore, a part of the future study must include an investigation of potential nursery grounds of the shrimp. The conclusion that the principal spawning area is located to the northwest of the Dry Tortugas is based on the findings that the shrimp size increases from Dry Tortugas northward and that mature shrimp have to be found in this area. That may be true, but the occurrence of mature shrimp in near-shore areas could be a satisfactory basis for the assumption that shrimp spawning near shore are the main source of shrimp larvae in Whitewater Bay.

This investigation has been organized according to the principle for fishery hydrography investigations as outlined by Koczy and Idyll (1957). We defined first, with help of the accessible data and the most logical conclusions, the problem and attacked it in the fastest possible way. As our primary assumptions are now doubtful, we must redefine the oceanographic problem with the help of new biological investigations. We hope by proceeding according to the given principle, we will be able to solve the hydrographic aspects of both the fishery and the biological problems posed by the shrimp fishery in the Dry Tortugas area.

This work was partially supported by the Office of Naval Research under contract Nonr 840 (01).

LITERATURE CITED

CHEW, F.

1955. "On the Offshore Circulation and Convergent Mechanism in the Red Tide Regions Off the West Coast of Florida," Transactions of the American Geophysical Union, Vol. 36, No. 6, pp. 963-974.

1957. "Red Tide Studies," mimeo, pub., The Marine Laboratory, University of Miami, No. 57-18, pp. 1-14.

KOCZY, F. F. AND C. P. IDYLL

1957. "Oceanography and Fisheries," Proceedings of the Gulf and Caribbean Fisheries Institute, Tenth Annual Session, pp. 107-112.

LEIPPER, D. F.

1954. "Gulf of Mexico—Its Waters, Origins and Marine Life," Fishery Bull. Fish and Wildlife Service, Vol. 55, pp. 119-141.

NISKIN, S. J.

"A New Type of Marker Buoy for Oceanographic Research," (in press).

WENNEKENS, M. P.

1959. "Water Mass Properties of the Straits of Florida and in Related Waters," Bull. of Mar. Sci. of Gulf and Caribbean, Vol. 9, No. 1, pp. 1-49.