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Larval and Juvenile Distribution of the Short-finned Squid (*Illex illecebrosus*) in Relation to the Gulf Stream Frontal Zone in the Blake Plateau and Cape Hatteras Area

by

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SPECIAL SESSION ON SQUIDS

INTRODUCTION

With the development of major international squid fisheries for Illex illecebrosus off the northeastern coast of the U.S.A. and Nova Scotia during the 1970's, and the parallel rapid increase in Canadian domestic landings in the inshore Newfoundland fisheries, ICNAF and its successor NAFO, recognized the need to develop a biological basis for management of the stock(s). Knowledge of the biology and distribution of Illex was then largely restricted to the period from roughly May through December of each year, when they are found in the on-shelf fishing areas, (Verrill 1882; Mercer 1969a, 1969b, 1970, 1973; Squires 1967; Lange 1980). Little was known for the period after November and December, when the large maturing male and females departed the fishing areas, until the following April and May, when small squid were again seen. Prior to the 1970's, only a handfull of fully mature females had been captured from as far south as Cape Henry (36°31'N 76°29'W) and as far north as Newfoundland (48°14N 59°46'W). Dawe and Drew (1981) reported on these and more recent captures. Neither spawning adults or egg masses have been encountered in nature, although spawning behaviour, characteristics of the egg mass, egg development, and hatching larvae have been described for captive animals by O'Dor and Durward (1978); Durward et al. (1980); O'Dor et al. (1980); O'Dor et al. (1981); O'Dor et al. (1982a, 1982b); and O'Dor (1983). Roper and Lu (1979) and Vecchione (1979) have described the Rhyncoteuthion type "C" larvae of *Illex illecebrosus* from plankton samples taken in the Mid-Atlantic Bight area off New Jersey and Virginia. Dawe and Beck (1982) have summarized previously reported distributional aspects of Rhyncoteuthion larvae in the Northwest Atlantic, from south of the Grand Banks as far east as 55° as well as previously unreported captures of type "C" larvae from the Blake Plateau between Cape Canaveral, Florida and Charleston, North Carolina.

Joint Canada/U.S.S.R. surveys in February 1979 provided the first large collections of *Illex illecebrosus* juveniles and suggested the possible importance of the Gulf Stream system in the life history (Amaratunga et al. 1980; Fedulov and Froerman 1980). Subsequent co-operative surveys under the general guidance of the NAFO *ad hoc* Working Group on Squid Research have greatly expanded our knowledge of larval and juvenile distribution, particularly for the area north of 38°N (Amaratunga et al. 1980; Amaratunga 1981; Amartunga and Budden 1982; Dawe et al. 1981a, 1982; Fedulov and Froerman 1980; Froerman et al. 1981; Hatanaka et al. 1982; Arkhipkin et al. 1983; Fedulov et al. 1984).

Trites (1983) examined and modelled the environmental factors and oceanographic processes likely to influence spawning and subsequent larval and juvenile *Illex* distribution in relation to one of the possible life-cycle scenarios developed by the *ad hoc* Working Group. He concluded that the critical area for a detailed search for the spawning area of *Illex illecebrosus* lay in the Shelf-Slope region southwest of Chesapeake Bay during the December-January period. The February 1983 research survey reported here was designed to sample the Frontal Zone between Gulf Stream water and Slope water in the area southwestward from Chesapeake Bay to Florida for fully mature or spawning adults as well as for larval and juvenile *Illex* concentrations and to determine their distribution relative to particular water masses and their dynamics.

MATERIALS AND METHODS

The survey was carried out during January 28 to March 2, 1983 aboard the Canadian research vessel "Alfred Needler". The survey focused on sampling along the northern edge of the Gulf Stream between 39°01'N, 72°48'W (in the northeast) to 28°43'N, 79°54'W (in the southwest). Most intensive sampling was carried out over the Continental Slope and Blake Plateau between Cape Hatteras, North Carolina and Cape Canaveral, Florida (Fig. 1, 2). Biological and oceanographic sampling was carried out along transects which generally extended across the landward edge of the Gulf Stream (the Western Boundary).

The survey was functionally divided into legs. During Leg I (January 28 to February 14) 71 complete stations (combined oceanographic and biological sampling) were occupied along 16 transects (Fig. 1, 2) as the vessel proceeded to the southwest. In addition, four complete stations were initially occupied at the northeastern extreme of the survey area before sampling along transects was initiated. Leg II (February 18 to March 2) comprised 41 complete stations along 11 transects (Fig. 1, 2) as the vessel departed port at Jacksonville, Florida, initially occupying the southern-most transects, and then proceeding to the northeast.

Generally, temperature and salinity profiles, using a Guildline portable STD system, were taken at 5-10 mile intervals along transects. Biological sampling varied greatly among stations. Generally a standard MARMAP-type oblique bongo tow was executed to sample for larval cephalopods, using 61 cm paired bongo samplers with 0.333 mm mesh. In Leg I, the majority of bongo tows were to the maximum planned depth of 300 m, whereas in Leg II they were consistently less than 200 m. Where possible plankton was sampled at sea surface using a Sameoto neuston net in 30-minute tows, although high winds prevented deployment of that sampler at many stations. Midwater trawling for juveniles was carried out using a Diamond IX midwater trawl with a 12 mm knotless nylon codend liner. During Leg I midwater trawling consisted of a 30-minute oblique haul from 300 m, whereas during Leg II the midwater trawl was towed for 30 minutes at a depth of 92 m, and then retrieved. Midwater trawling was less extensive than plankton sampling, but generally a midwater trawl set was executed on at least one station per transect.

Midway between complete stations along transects and while proceeding between transects XBT casts were made to help provide additional resolution of the temperature structure in the survey area. Temperature sections constructed onboard from XBT and STD operations were used to locate the Western Boundary.

Plankton catches were initially scanned for cephalopod larvae and residuals preserved in 10% buffered formalin. Plankton was later sorted on shore for remaining cephalopods and *Illex* sp. larvae. Midwater trawl catches were sorted onboard for cephalopods. *Illex* sp. juveniles were immediately measured to the nearest millimeter in dorsal mantle length. All cephalopods were initially fixed in 10% buffered formalin and then transferred to 70% ethanol. Larvae were identified in the laboratory and, where possible, dorsal mantle length measured to the nearest 0.1 mm.

GENERAL BIOLOGICAL AND OCEANOGRAPHIC FEATURES

Biological

Adults of *Illex illecebrosus* are seasonally widely distributed from the Gulf of Mexico to the Labrador Sea (Clarke 1966; Roper and Lu 1979). During the on-Shelf period of rapid growth and development, the greatest concentrations of adults are observed in the more northern areas of Georges Bank, the Scotian Shelf, the Laurentian Channel edge and inshore Newfoundland waters (Squires 1957; Mercer 1973; Lange 1980; Amaratunga 1981; Dawe 1981; Lange and Sissenwine 1983). Distribution within these areas of concentration appears to be influenced by temperature and abundance (Koeller 1980; Mohn 1981; Dupouy and Minet 1982; Rowell and Young 1984). While catches have been recorded from the surface to depths greater than 1,000 m (Rathjen 1981), the bulk of the population appears to concentrate over the shallower shelf areas, almost certainly in response to availability of prey species, and to be caught in areas where bottom temperatures are in the range of approximately 6-12°C (Dupouy 1981; Poulard et al. 1984).

Illex have not yet been aged, although concentric rings in the statoliths have been investigated and may ultimately provide a useful ageing tool (Lipinski 1978; Hurley et al. 1979). It is now generally believed that the life span is roughly one year (Squires 1967), however estimates of 18-24 month life-cycles have been proposed (Mesnil 1977; Lange and Sissenwine 1981). The bulk of the population is believed to result from a protracted winter spawning. Populations on the Scotian Shelf and areas northward are generally unimodal, although occasionally secondary and tertiary modes of smaller squid are seen in late summer and during the fall (Squires 1957, 1967; Amaratunga 1980; Dupouy 1981; Poulard et al. 1984). On Georges Bank and southern New England, several modes are usually seen (Mesnil 1977; Lange 1980; Lange and Sissenwine 1981) and the dominance of the winter spawned population is occasionally superseded by a cohort of late spring or summer spawned squid. In some years, the summer spawned component in this southern area has been estimated to make up as much as 86% of the autumn population (Lange and Sissenwine 1981).

When adult squid leave the northern shelf areas in late fall, the males are in an advanced stage of sexual maturity but the females are generally less advanced, suggesting some time remains prior to mating and spawning. During this period, tagging studies from inshore Newfoundland and Nova Scotia (Amaratunga 1981; Dawe et al. 1981b) indicate a general southwestward movement from Newfoundland waters and southwestward along the Scotian Shelf. One tag recovery indicates migration from the Newfoundland region to as far south as Maryland (2,000 km), representing, as a minimum, an average southwestward movement of 20 km per day (Dawe et al. 1981b). The sporadic fishery for *Illex illecebrosus* off Cape Canaveral and the high catches taken over the Blake Plateau by the Anton Dohrn in the fall of 1979 (Rathjen 1981) are evidence of large scale concentrations in this area. Unfortunately, there is little monitoring of this fishery and hence a lack of information on annual abundances, maturities etc. Of the seven mature Stage IV and V females captured in the field and reported by Dawe and Drew (1981), three of the four Stage V specimens were captured between Georges Bank and Cape Hatteras and all three had mated, as indicated by the presence of spermatophores in the mantle cavity. Laboratory experiments indicate that mating and spawning may be possible either on bottom or pelagically (O'Dor et al. 1981, 1982b). The gelatinous spherical egg masses are negatively buoyant, but water density changes of 0.004 g cm^{-3} have been sufficient to make them float (O'Dor 1983).

If the egg masses are transported passively, current systems and the development time to hatching may greatly influence distribution of the newly hatched Rhyncoteuthion larvae. While the minimum temperature for fertilization has not been fully determined it is known that eggs fertilized at temperatures as low as 7°C will develop if the temperature is raised above 13°C. Full development of eggs does not occur below 12°C (O'Dor et al. 1982a), and rate of development to hatching increases with temperature; 16 days being required at 13°C and an estimated 9 days at 21°C. At hatching, the larvae have mantle lengths (ML) between 1.1-1.25 mm (Durward et al. 1980; O'Dor et al. 1982a; O'Dor pers. comm.). The smallest larvae previously captured (1.1 mm ML) were from the Blake Plateau in 1969 (Dawe and Beck 1982). The capture of Rhyncoteuthion "C" larvae as small as 1.5-2.0 mm ML (Froerman et al. 1981) as far to the northeast as 60°00'W, 40°30'N in the Slope Water/Gulf Stream Frontal Zone strongly suggest that, with passive transport of egg masses and larvae for periods of two weeks or more after spawning, the area of spawning might lay in the area of, or to the south of Cape Hatteras. Trites (1983) has described those oceanographic features and processes which might define possible areas of spawning and those which would act to transport egg masses and larvae to the northeastern areas where large concentrations of small juvenile Illex have been captured since 1979 (Amaratunga et al. 1980; Fedulov and Froerman 1980; Froerman et al. 1981; Amaratunga and Budden 1982; Dawe et al. 1982; Hatanaka et al. 1982; Arkhipkin et al. 1983; Fedulov et al. 1984).

In this northeastern area of the larval and juvenile distribution there is an indication of a progression in size of the juveniles as one moves further to the northeast (Dawe et al. 1981) and also as one moves from the Gulf Stream Frontal Zone towards the Shelf area (Froerman et al. 1981; Hatanaka et al. 1982). At the Frontal Zone juveniles are often in the range of 10-30 mm ML whereas shoreward they are progressively larger. Froerman et al. (1981) found that at about 40 mm ML juveniles have small amounts of food in their stomachs, indicating that at that size they are capable of significant movement. Evidence of multiple spawnings is also seen in the "delivery" to these areas of "packets of larvae", small juveniles being predominant in an area where larger juveniles were found weeks or months earlier (Fedulov et al. 1984). Highest catches of larvae and juveniles in the northeast have generally been associated with the Frontal Zone and periphery of Warm Core Eddies. Although a few larvae and juveniles have been found in the Gulf Stream or in the Sargasso Sea Water at the centre of Cold Core Eddies (Hatanaka et al. 1982), the bulk of the catches suggests they are not likely or originate either within the interior of the Gulf Stream or Sargasso Sea.

Oceanographic

The dominant oceanographic feature of the Shelf-Slope area between Cape Hatteras and the Florida Straits is the intense western ocean boundary current, which is part of the Gulf Stream system (Stommel 1965). Although Iselin (1936) introduced a well defined nomenclature for various parts of the Western North Atlantic current system, we will not strictly adhere to his terminology, but rather, refer to the high velocity current from the Florida Straits northward simply as the Gulf Stream. Off the east coast of Florida the shoreward edge of the Stream, on average, can be delineated approximately by the 200 m isobath. Further north, off South Carolina, the Stream tends to move further offshore, returning to about the 200 m isobath a short way south of Cape Hatteras. Analysis of sea surface temperature maps prepared and distributed by the National Oceanic and Atmospheric Administration (NOAA-NESS) reveals that the Stream has a meandering or wavelike characteristic, with the shoreward boundary consistently displaying a folded-wave pattern (frontal eddies). Frontal eddies of this type appear as tongue-like extrusions of Gulf Stream water, oriented upstream, nearly parallel to the Stream (and bottom topography), and often giving the appearance of "shingles" (Lee et al. 1981; Legeckis 1979; Bane et al. 1981). For the area between the Florida Straits and 32°N, there are relatively small lateral movements of the Stream (approx. 10 km) and the frontal eddies or filaments are narrow and very elongated. A rapid increase in the magnitude of the meanders downstream of a seaward deflection of the Stream off Charleston, South Carolina (Charleston Bump) may be as great as 40 km from the mean (Bane and Brooks 1979). The shoreward crest of the meanders appear to propagate downstream at speeds of 30-40 km/day (Legeckis 1979; Brooks and Bane 1981). Warm filaments tend to develop near the shoreward crest of the crest of the meanders and usually, though not always, grow rapidly in length. Chew (1981) reports that, although a filament is assumed to be part of the cyclonic vortex, the merging of the filament near its tongue has never been observed. Filaments are very shallow features typically less than 50 m in depth.

Velocity structure and transport in the Gulf Stream have been reported by a number of authors (e.g., Parr 1937; Worthington 1954, 1976; Knauss 1969; Richardson et al. 1969; Kirwan et al. 1976). Transport increases from about 30 Sverdrup (1 Sverdrup = $10^6 m^3 s^{-1}$) in the Florida Straits to about 80 at Cape Hatteras and reaches a maximum of about 150 south of Nova Scotia, thereafter diminishing in magnitude.

Maximum velocities in the core of the current in the Florida Straits to Cape Hatteras region appear to be generally in the range of 150-200 cm/sec with velocities gradually diminishing with depth. On a Lagrangian basis, Kirwan et al. (1976) reported a satellite tracked drifter (drogued at 35 m) launched in the Stream at 30°N was off Cape Hatteras 5 days later, and within 15 days was east of 60°W.

Although it is well established that as the Gulf Stream flows northward off the east coast of the United States its volume transport increases, it is much less clear as to the proportion supplied from various sources. Water mass analysis, treating temperature and salinity as consevative properties, is often useful in identifying water sources. In a water mass properties study of the Straits of Florida and related waters Wennekens (1959), identified two water masses in the southern Straits of Florida: Yucatan Water and Continental Edge Water.

The water that passes through the Yucatan Straits either passes around the western end of Cuba and directly into the Florida Straits or flows as the Loop Current in a clockwise direction in the eastern Gulf of Mexico before entering the Straits of Florida. According to Wust (1964) as well as Nowlin (1971), the water flowing through the Yucatan Straits is made up of Suptropical Underwater, characterized by a salinity maximum (36.6-36.8 ‰) at depths between 50 and 200 m. Below about 600 m Antarctic Intermediate Water is present and can be identified by a salinity minimum (less than 35 ‰) at depths between 800-1,000 m.

According to Nowlin (1971) the water beneath the surface mixed layer but warmer than 17°C is the only distinct water mass formed in the Gulf of Mexico. This water referred to as Continental Edge Water by Wennekens (1959) is characterized by an increase in salinity from about 36.00 ‰ to 36.45 ‰ between about 25°C and 18°C. Thus the salinity is considerably less for a given temperature than is the water referred to as Yucatan Water by Wennekens.

During 1965 and 1966 oceanographic sections across the Gulf Stream off Charleston, South Carolina, were run on 21 occasions on the ship Peirce of the U.S. Coast and Geodetic Survey (Hazelworth 1976) measuring temperature, salinity, dissolved oxygen, as well as determining near surface currents with a parachute drogue (Fig. 4). The water masses identified by Hazelworth (1976) for this section consisted of Continental Edge Water, Yucatan Straits Water, Antilles Current Water and Sargasso Sea Water.

Station mean T-S curves for the entire year of data, as reported by Hazelworth (1976) indicated that a nearshore or coastal water type of local origin was present at Stations 1 and

2, with Continental Edge Water present at Station 2 at 30-50 m depth. Stations 4 and 5 contained a mixture of Continental Edge Water and Yucatan Straits Water, with the latter type predominating (Fig. 5). Seaward of Station 6, water from the Sargasso Sea or Antilles Current predominates. It is not possible to differentiate between water passing through the Yucatan Straits, the Antilles Current Water, and the water from the Sargasso Sea between 18°C and 22°C. Also Antilles Current Water cannot be differentiated from Sargasso Sea Water between 18°C and 11°C.

The surface drogue movements indicated that the axis of the Gulf Stream was usually in the vicinity of Stations 5 or 6, but on occasion touched stations 4 and 7. Mean velocity at the core was 179 $cm.s^{-1}$, but varied from a low of 142 $cm.s^{-1}$ to a high of 219 $cm.s^{-1}$. Currents between stations 2 and 3 sometimes flowed with the Gulf Stream and sometimes in the reverse direction.

RESULTS AND DISCUSSION

Larval Distribution and Size

Stations at which bongo sets were made south of Cape Hatteras in Legs I and II, and those having catches of Ryncoteuthion type "C" larvae, are shown in Figure 1. North of Cape Hatteras there were an additional four bongos in Leg I, extending as far as 39°00'N, 72°48'W and five in Leg II, extending as far as 37°45', 72°21'W which yielded no catch.

Table 1 lists the number and sizes of larvae captured in relation to latitudinal position along the axis of the Gulf Stream. In Leg I, a relatively large number (25) of type "C" larvae were captured along the Fontal Zone between the Gulf Stream and Slope Water. Sizes ranged from 2.4 mm ML to the near transition length of 6.4 mm ML ($\bar{x}$ = 3.8 mm). In Leg II, only a few (5) type "C" larvae were captured; all in the most southern area of the survey. ML ranged from 1.0-3.0 mm ($\bar{x}$ = 1.8 mm).

Although there is no evidence of a progression in larval size from northeast to southwest during the Feb 4-12 period of Leg I, the larger number of larvae with ML > 4.0 mm appearing in the more southern catches suggests such a possibility.

Those larvae caputured during the February 19-22 period of Leg II were with one exception, considerably smaller than those of Leg I. This, coupled in Leg II with the complete absence of larval catches between February 23-25 in the northeastern area, suggests that two distinct larval broods were sampled, and that the larval brood sampled during Leg I had either been transported from the area or advanced to the juvenile stage in the 17-21 day period between samplings.

The larvae captured in Leg II appear to be very recent hatchlings and, in the case of the 1.0 mm ML individuals may have been precociously hatched. Durward et al. (1980) report hatching in captivity at 1.1 mm and O'Dor (pers. comm.) suggests that damage to the egg masses in the above studies may have led to such early hatching. He suggests 1.25 mm ML is more probably the size of hatching in undisturbed egg masses.

The size of the larvae and the mix of sizes, particularly in Leg I, captured over a wide range along the Gulf Stream Frontal Zone suggests that spawning itself may be widely dispersed in a direction roughly parallel to the Gulf Stream axis. It also suggests that there may be some mechanism for retention and eventual mixing of egg masses, larvae, and juveniles in the area despite the potential for rapid transport by the Gulf Stream. If spawning and retention of egg masses and larvae were occurring along the Frontal Zone, it is also possible that development to hatching and subsequent larval growth might be influenced by temperature clines or other variables.

Dawe and Beck (1982) report 30 _Illex_ larvae and four juveniles being captured in February 1969 along the 183 m isobath over the Blake Plateau between Cape Canaveral and Charleston. These captures overlap the area of capture in our survey and, since the Frontal Zone of the Gulf Stream tends within narrow bounds to follow this isobath, it is likely the 1969 captures were made in similar water masses. The _Illex_ larvae and juveniles captured in 1969 ranged from 1.1-10.5 mm ML, with 22% having a ML less than 2.0 mm. Dawe and Beck (1982) also report a relatively large collection of 38 larvae of

2.4-5.4 mm ML from a transect at 56°00'W in February-March 1981 and a single Illex larvae of 6.6 mm ML from 55°00'W in 1980. The latter represents the most northeasterly capture of Illex larvae, and coupled with the large number of larvae captured between Cape Hatteras and the area of the Frontal Zone off the Scotian Shelf and Grand Banks (Roper and Lu 1979; Vecchione 1979; Amaratunga et al. 1980; Amaratunga 1981; Amaratunga and Budden 1982; Dawe et al. 1982; Hatanaka et al. 1982; Arkhipkin et al. 1983; Fedulov et al. 1984, suggests that spawning may be pelagic over an extended area along the Gulf Stream Frontal Zone and (or) that egg masses are transported over long distances from the Shelf edge areas either immediately north of Cape Hatteras or from the Blake Plateau. Some of the larvae captured in the area off the Scotian Shelf (at 66°00'N, 43°30'N) have been as small as 1.5 mm ML (Dawe et al. 1982) and must be very recent hatchlings.

Juvenile Distribution and Size

Stations at which midwater trawl sets (MWT) were made south of Cape Hatteras in Legs I and II, and those having catches of Illex juveniles, are shown in Figure 2. An additional three stations north of Hatteras in Leg II yielded a catch of two juveniles at the northernmost (37°79'N, 72°17'W).

Table 2 lists the number, median sizes and ranges (mm ML) for juvenile Illex captured in relation to latitudinal position along the axis of the Gulf Stream, and Figure 3A, B presents length frequencies for those MWT stations having catches of more than four juveniles.

There were no apparent differences in distribution of juveniles between the two Legs of the survey, other than that resulting from the further extension south of trawl stations in Leg II.

In Leg I, the juveniles had median sizes in the range of 10.3-47.0 mm ML and an overall size range of 7.0-72.0 mm ML. From northeast to southwest, the median size became progressively larger and the range in size also became larger. In Leg II, the juveniles were generally larger, having median sizes in the range of 22.0-44.5 mm ML and an overall size range of 14.0-92.0 mm ML. During this Leg, there was no evidence for progression in size along the Gulf Stream.

Table 3 lists those bongo (larvae) and MWT (juvenile) stations having catches, as well as those where bongo and MWT sets were paired on a particular station but resulted in no catch of either larvae or juveniles. The only two neuston catches are also shown in relation to bongo and MWT sets at the same stations. When the sets are compared, there is evidence for an overlap in distribution for a portion of the juveniles and larvae, and for another portion of the juveniles to have a distribution not associated with the larvae. All stations having bongos catching larvae also had juveniles captured in the MWT, but where the MWT caught juveniles, the paired bongos captured larvae in only 10 out of 16 sets (63%) in Leg I and two out of 11 sets (18%) in Leg II. In the southern group of stations of Leg II, where the only larval catches for this period were made, two out of six paired bongos (33%) captured larvae. The possibility that the smaller juveniles might have a greater distributional overlap with the larvae was considered, but examination of median sizes and ranges indicated no size differential between those juveniles associated with larval catches and those not associated. Additionally, examination of the ocanographic data revealed no difference in the water masses for the associated and unassociated catches of juveniles.

Oceanographic features in relation to distribution of larvae and Juveniles

Sea Temperatures in Survey Area

The aim of the program was to run a series of short transects across the Frontal Zone of the shoreward side of the Gulf Stream between Cape Hatteras and Florida. The 15°C isotherm, which is usually nested within a closely spaced set of isotherms on a temperature plot at 200 m depth (Worthington 1954; Webster 1961; Fuglister 1963) is frequently taken to indicate the geographic position of the high-velocity core of the Gulf Stream. Upstream from its seaward deflection off Charleston, South Carolina, the Stream may at times and places be shoreward of the 200 m isobath so that the water in the column is all in excess of 15°C. However, its position as judged from the surface thermal front, is usually close to the 200 m isobath and with a lateral movement generally less than 15 km (Bane and Brooks 1979). Figure 4 shows the approximate location of the XBT sections and the STD stations occupied during the January 31-13 February period of Leg I (A). Plots of temperature at the surface (B) and at 200 m (C) are shown as well The temperature plots have been progressively offset for visual convenience. Sites where either larval or juvenile catches were made are also shown on offset (C). It is noted that all squid catches in Leg I were located on the shoreward side of the 15°C (at 200 m) isotherm, which suggests that the bulk of the squid are probably found shoreward of the high velocity core of the Gulf Stream.

The temperature plot shown in Figure 4 should not be considered in any way synoptic or representing a mean temperature distribution over the 2-week period taken to cover the area. Only the individual transects which were completed within a matter of a few hours may be considered approximately synoptic. An indication of the dynamic nature of the sampling area, and the speed with which change may occur, in at least the surface layer, is given in the NOAA/NESS satellite derived oceanographic analysis maps, which are produced twice weekly (Wednesdays and Fridays). The location of the Gulf Stream/Slope Front has been extracted from these maps for the 1, 3, 8, and 10th of February, and shown in progressive offsets in Figure 6. A complex series of filaments or shingles were present at all times and varied in number, position, size and shape. Additionally the high velocity core of the Gulf Stream appears to have been moving further offshore in the 1-8 February period in the area downstream of the Charleston Bump. By 10 February the meander appears to have been moving shoreward again. Thus the time during which the ship was in the area downstream from the Charleston Bump (prior to 8 February) coincided with the major offshore deflection of the Stream and the developing filaments or shingles.

The general cruise track for the February 18-25 period of Leg II, along which XBT's, STD's, and sampling were undertaken, is shown in Figure 7A. Also shown, as progressive offsets, are the sea surface temperature pattern (Fig. 7B) and temperature at 200 m (Fig. 7C). The locations where a squid catch was made are shown in Figure 7C. Catches appeared to be taken most frequently in or on the seaward side of the high velocity core of the Gulf Stream. Exceptions were noted at Stations 27, 31, 84 and 86. This appears to contrast significantly from the Leg I sampling, where catch was confined to areas shoreward of the core of the Stream.

T-S Characteristics in Survey Area

T-S plots for stations on Leg I of the cruise where there were larval and/or juvenile catches, compared to those located further to seaward, generally show distinct differences in the upper 100-150 m (Fig. 8). T-S characteristics of the water mass in the upper 100 meters, where catches were made, are very similar to Continental Edge Water as defined by Wennekens (1959) whereas the water further offshore matches more closely that defined as Yucatan Straits Water. Curiously, for stations shoreward of where catches were made, the T-S curves seem to contain a mixture of both Continental Edge and Yucatan Straits Water, except that temperature is frequently lower in the upper layer. It may be that this feature is the residue of frontal eddy activity which would tend, at times, to place water from nearer the core of the Stream further shoreward as a filament of warmer, more saline water.

The T-S properties for the upper 50 m of the water column at stations where there was a catch are closely clumped (21-23.5°C, 36.3-36.8 ‰).

For Leg II of the cruise, T-S plots for stations where there was a catch, again tend to conform more closely to Continental Edge Water than to Yucatan Strait Water, although there is appreciably more scatter in the curves than was the case for Leg I stations (Fig. 9). However, if one plots the T-S curves for only the top 50 m, then the curves conform closely to Continental Edge Water. The envelope of the upper 50 meter T-S curves for all stations where there was a catch is shown in Figure 10. Although there is no way to identify the depth at which either the larvae or juveniles were caught, the close similarity in T-S properties for the upper 50 meters on both phases, suggests that the bulk of the catch may have been in the upper 50 m.

Sectional plots of temperature, salinity, and density anomaly, oriented more or less normal to the axis of the Gulf Stream, also confirm that the catch during Leg I was almost always shoreward of the core of the Gulf Stream, in the Frontal Zone area. Figure 11 shows two of the more southern sections. The sites where the catches were made is clearly in a water mass moving in the same direction as the core of the Stream. To be noted as well is the double core of high salinity water centered at just over 100 m depth. The inshore core has similar characteristics to Continental Edge Water while the offshore core is characteristic of Yucatan Straits Water. Squid catches were made at STD Stations 34, 36, 37, and 38 (Fig. 11A, B, C) which appear to be just on the shoreward side of the high velocity core of the Gulf Stream. An STD section further south (Fig. 11D, E, F) shows essentially the same oceanographic features as is seen in Figure 11A, B, C; i.e. the double core of high salinity water, and the squid catch restricted to the shoreward side of the high velocity core of the Gulf Stream.

Two of the sections occupied on Leg II of the cruise, and oriented approximately normal to the Gulf Stream, show the position of squid catches in relation to the temperature, salinity, and density anomaly patterns (Fig. 12). The estimated position of the high velocity core of the Gulf Stream is also indicated. Based on the density pattern (Fig. 12C, F) it appears that the water throughout both sections was moving in the same direction as that of the Stream similar to that observed in the sections for Leg I.

Spawning Events and Larval Broods

When the size differential and distributions of the larvae and juveniles between Legs I and II are considered, it appears that Leg I was sampling a population of larvae ($\overline{x}$ = 3.8 mm ML) and juveniles (medians of 10.3-47.0 mm ML) from earlier spawning events, whereas in Leg II, while the juveniles (medians of

22.0-44.5 mm ML) may have resulted from the same events), the larvae ($\overline{x}$ = 1.8 mm ML) are definitely newly hatched and represent a new brood. By the time of Leg II all evidence of the first larval brood(s) has disappeared, no larvae being captured in the northern stations and all but one of the larvae (ML = 3.0 mm) being smaller than the smallest (ML = 2.5 mm) captured in Leg I.

That the spawning period is protracted and is composed of a number of spawning events appear well documented from other studies. Fedulov et al. (1984) noted the occurrence of large numbers of Illex juveniles (30-35 mm ML) in March, 1983 and again in May of the same year. The regular appearance of modal groups of small squid (10-15 mm ML) also supports the hypothesis of a protracted spawning period with a number of spawning events of variable intensity.

SUMMARY

Squid larvae and juveniles caught during this cruise continue to point to the Frontal Zone of the Gulf Stream/Slope Water as the preferred area of presence, and that larvae and juveniles are intermixed throughout the entire Frontal Zone. Such a mixing would arise if spawning occurred either pelagically or demersally all along the Shelf/Slope area south of Cape Hatteras. Alternatively it is also possible that spawning occurs in a relatively small area south of the area surveyed. If larvae and juveniles remain mostly in the upper 50 m of the water column, and are initially spawned in say the Florida Straits along the shoreward edge of the Gulf Stream, then many animals will be injected into the Slope Water area by the Frontal eddies. As the filaments dissipate and become reabsorbed into the Stream, older animals ejected earlier in the filament would become mixed with younger animals being carried by the Stream. The many and frequent development of filaments between the Straits of Florida and Cape Hatteras could easily be the principal mechanism for mixing animals of a wide size range. Animals which did not get ejected into one or more filaments during their downstream transport could travel from the Straits of Florida to Cape Hatteras in less than a week. Alternately

some of the animals which take the "filament" route might not have travelled more than a few hundred kilometers to the northeast, even after a month or more.

ACKNOWLEDGEMENTS

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Table 1. Number and size of Rhynchoteuthion type "C" larvae captured in relation to latitudinal position along the axis of the Gulf Stream and date in February.

Leg I					Leg II			
Station	Day	No. of Larvae	Mantle Length (mm)	Latitude	Mantle Length (mm)	No. of Larvae	Day	Station
				Northeast				
44	4	1	2.5	33°58.5'				
53	5	2	3.5,4.8	33°42.7'				
65	6	3	3.5,>3.5,3.9	33°22.1'				
66	6	1	3.5	33°19.4'				
69	6	1	3.0	33°03.9'				
82	8	1	3.0	32°46.2'				
83	8	2	3.0,4.9	32°42.5'				
95	9	2	>3.5,3.9	32°17.1'				
92	8	1	4.0	32°11.3'				
88	8	1	3.3	32°08.6'				
106	9	1	>3.5	32°06.2'				
107	9	3	2.8,3.2,6.4	32°01.6'				
108	10	3	>3.0,>5.0,5.4	31°57.5'				
122	11	1	4.8	31°23.7'				
				31°13.4'	1.0	1	22	51
131	12	1	>4.0	30°53.3'				
129	12	1	>4.0	30°50.7'				
				29°49.6'	3.0	1	19	8
				28°50.5'	1.0,2.0	2	20	27
				28°43.3'	2.0	1	21	33
				Southwest				

Median size = approx. 3.5 mm
Mean Size = 3.8 mm

Median size = approx 1.3 mm
Mean size =1.8 mm

Table 2. Medians and ranges (mm) of juvenile Illex for stations progressing from the northeast to the southeast along the axis of the Gulf Stream. Days correspond to dates (GMT) in February. Where stations in Leg I and Leg II were in close proximity, they are paired across the columns (i.e. Station 65 of Leg I and Station 70 of Leg II).

LEG I						LEG II					
Station	Set	Day	No of Juveniles	Median	Range	Range	Median	No of Juveniles	Day	Set	Station
					Northeast						
						23-30	26.5	2	27	M098	120
24	M001	1	38	13.3	9-18						
						14-86	32.3	126	24	M070	84
						24-43	31.0	3	24	M073	86
65	M004	6	7	16.0	13-27	16-30	23.5	20	23	M058	70
82	M007	8	5	24.0	21-53						
88	M008	8	4	12.5	9-13						
92	M009	8	34	10.3	7-30						
94	M010	9	15	13.0	7-30						
95	M011	9	4	19.5	19-23						
107	M012	9	1	29.0	-						
108	M013	10	1	24.0	-						
112	M014	10	5	22.0	14-24						
114	M015	10	5	47.0	44-56						
122	M016	11	4	22.5	11-27	19-76	44.5	4	22	M055	55
129	M018	12	5	20.0	15-37	20-68	43.0	7	21	M042	45
131	M019	12	29	31.0	13-72						
137	M020	12	359	30.9	9-66						
139	M021	12	1	36.0	-						
						20-51	35.0	4	19	M004	8
						-	22.0	1	20	M016	16
						19-92	31.5	64	20	M021	20
						32-37	34.5	2	20	M032	31
						18-35	22.3	13	21	M036	33
					Southwest						

Table 3. Individual bongo (larvae) and MWT (juvenile) stations having catches or where paired on a particular station. Catch in either bongo or MWT is indicated by horizontal bar. Linked catches are indicated by linking bar. Linked neuston set 32 is also shown. Numbers captured are indicated on bar. Number in brackets represents juveniles in bongo and larvae in MWT.

Station			Bongo			MWT
Leg I						
24			B013		38	M001
26			B014			M002
44			B021	1		-
53			B024			
			B025	2		M003
65			B028	3	7	M004
66			B029	1		-
69			B031	1		-
74			B035			M005
80			B038			M006
82			B040	1	5	M007
83	N032	1	B041	1		-
88			B043	1	4	M008
92			B045	1	32(2)	M009
94			B046		15	M010
95			B047	1	4	M011
106			B049	2(1)		-
107			B050	3(1)	1	M012
108			B051	3	1	M013
112			B053		5	M014
114			B054		5	M015
122			B059	1(1)	4	M016
124			B060			M017
129			B063	1	5	M018
131			B064	1	24	M019
137			B066		359	M020
139			B067		1	M021
141			B068			M022
Leg II						
8	N006	1	B005		4	M004
10			B007			M009
16			B014		1	M016
20			B019	(1)	64	M021
27			B027	2		
31			B030		2	M032
33			B034	1	13	M036
45			B041		7	M042
51			B048	1		
55			B054		4	M055
70			B056		20	M058
84			B068		126	M070
86			B071		3	M073
88			B074			M076
104			B082			M083
109			B087			M089
111			B090			M092
120			B096		3	M098

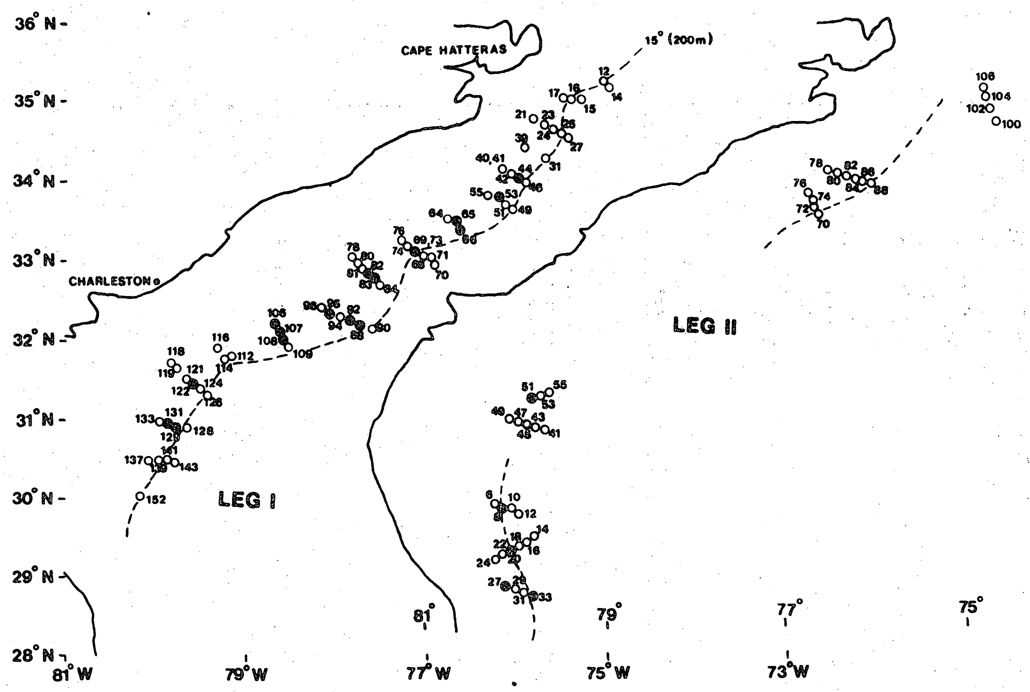


Fig. 1. Station locations at which bongo sets were carried out. Closed circles denote rhyncoteuthian type "C" larval capture, except at Station 20 of Leg II where a juvenile *Illex* was captured in the bongo. The approximate position of the Gulf Stream core, as indicated by 15°C at 200 m, is also shown.

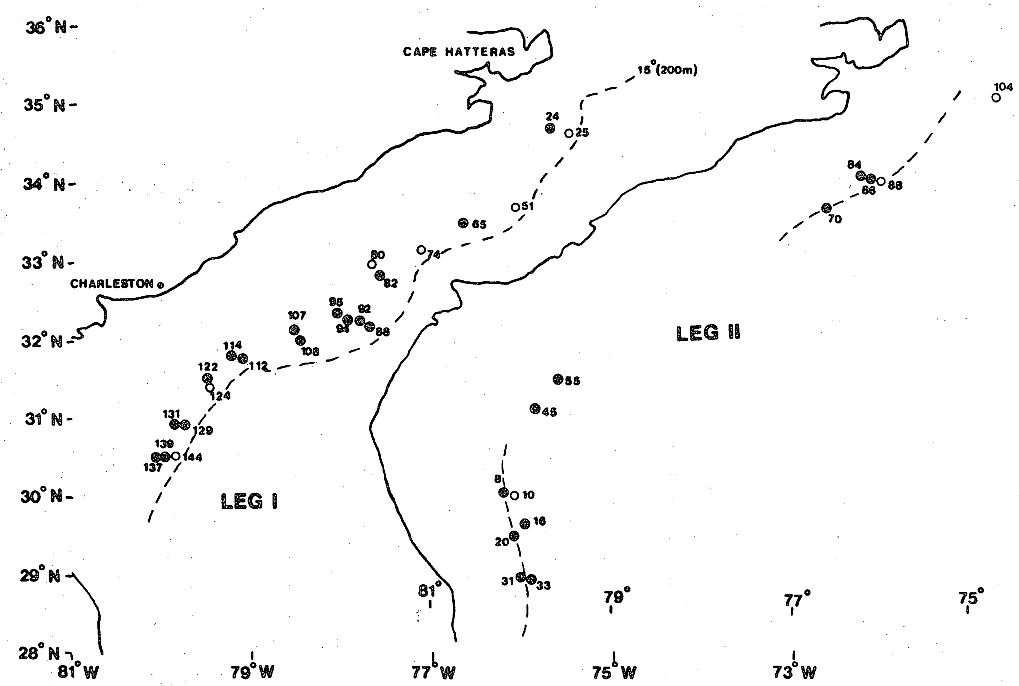
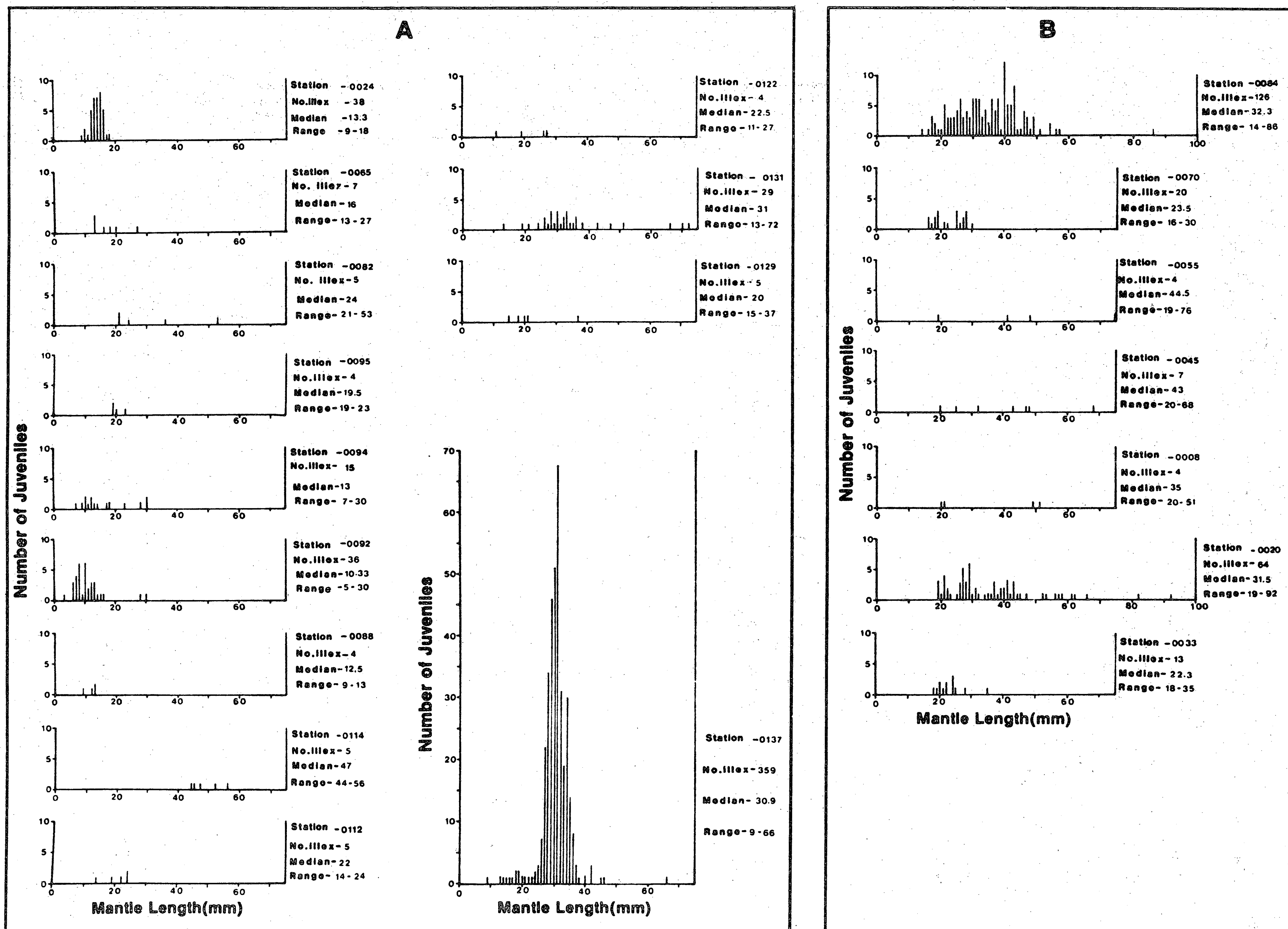


Fig. 2. Station locations at which MWT sets were carried out. Closed circles denote juvenile *Illex* capture. The approximate position of the Gulf Stream core, as indicated by 15°C at 200 m, is also shown.



LEG I

LEG II

Fig. 3A, B. Length frequency, number, median size, and size range of juvenile *Illex* at all stations having captures of four or more individuals. Histograms in Fig. 3A (Leg I) and 3B (Leg II) are arranged from top to bottom in order of progression from northeast to southwest along the axis of the Gulf Stream.

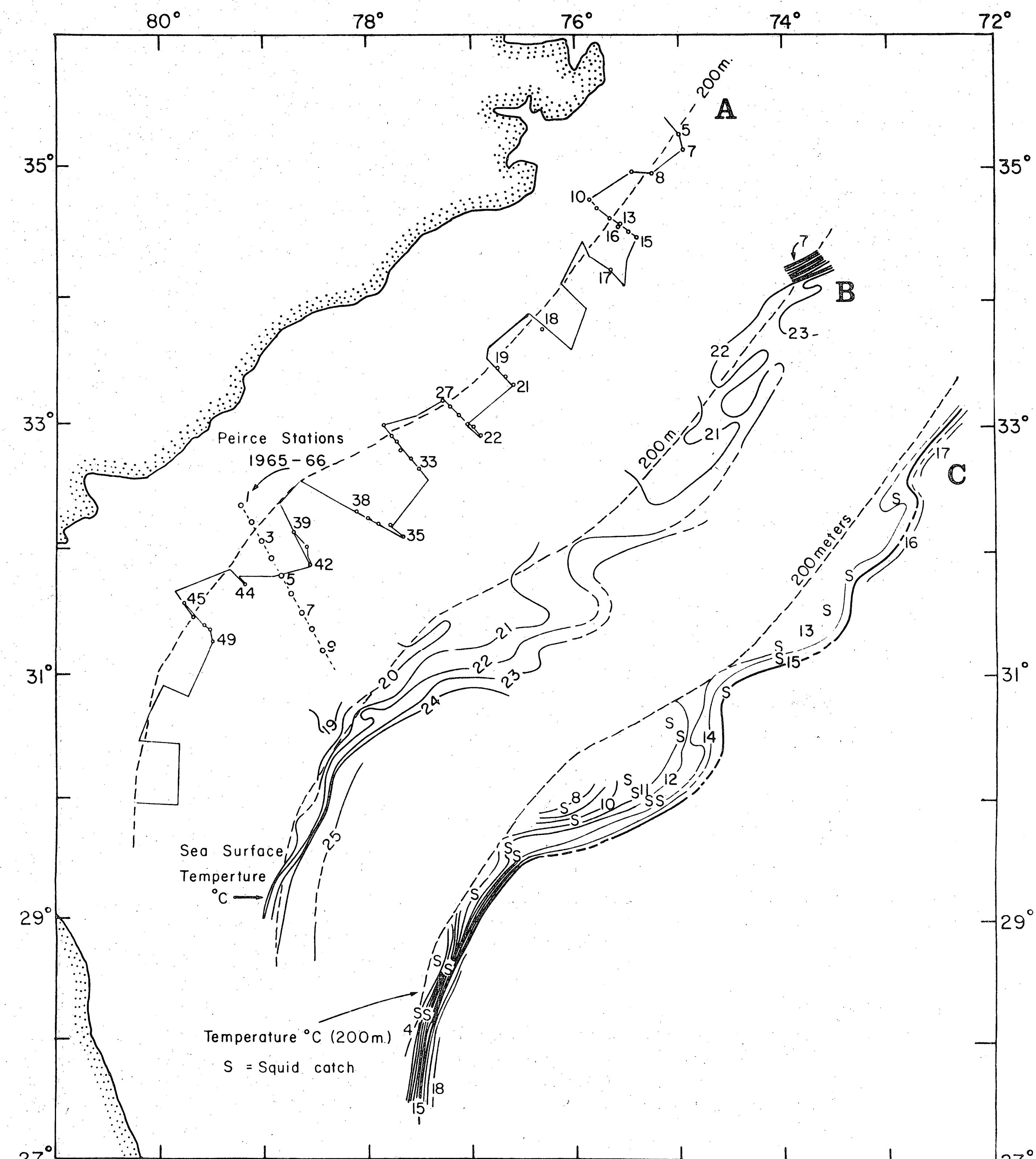


Figure 4. Map of the survey area showing: A) cruise track for 31 January - 13 February 1983, where XBT's were taken, station numbers of STD's and section line off Charleston where Peirce stations were occupied in 1965-66; B) sea surface temperature in °C as determined from the XBT's and STD's, and C) temperature in °C at 200 M for the period, including locations at which squid larvae and/or juveniles were caught. Figures B and C have been progressively offset for visual clarity.

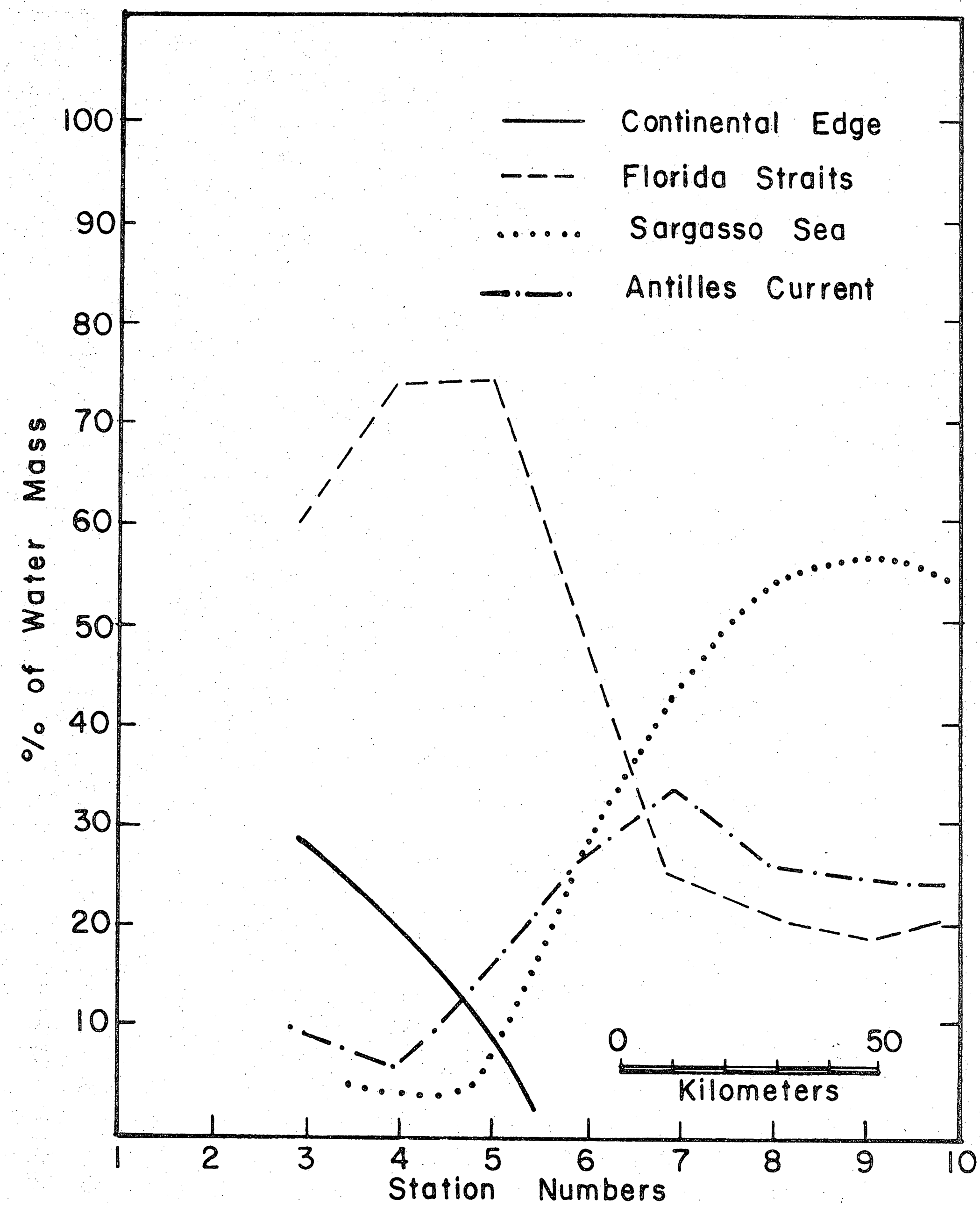


Figure 5. Percentage of Continental Edge Water, Florida Straits (Yucatan) Water, Antilles Current Water, and Sargasso Sea Water, as determined by Hazelworth (1976) for section occupied by the Peirce off Charleston, South Carolina in 1965-66. (Adapted from Hazelworth, 1976).

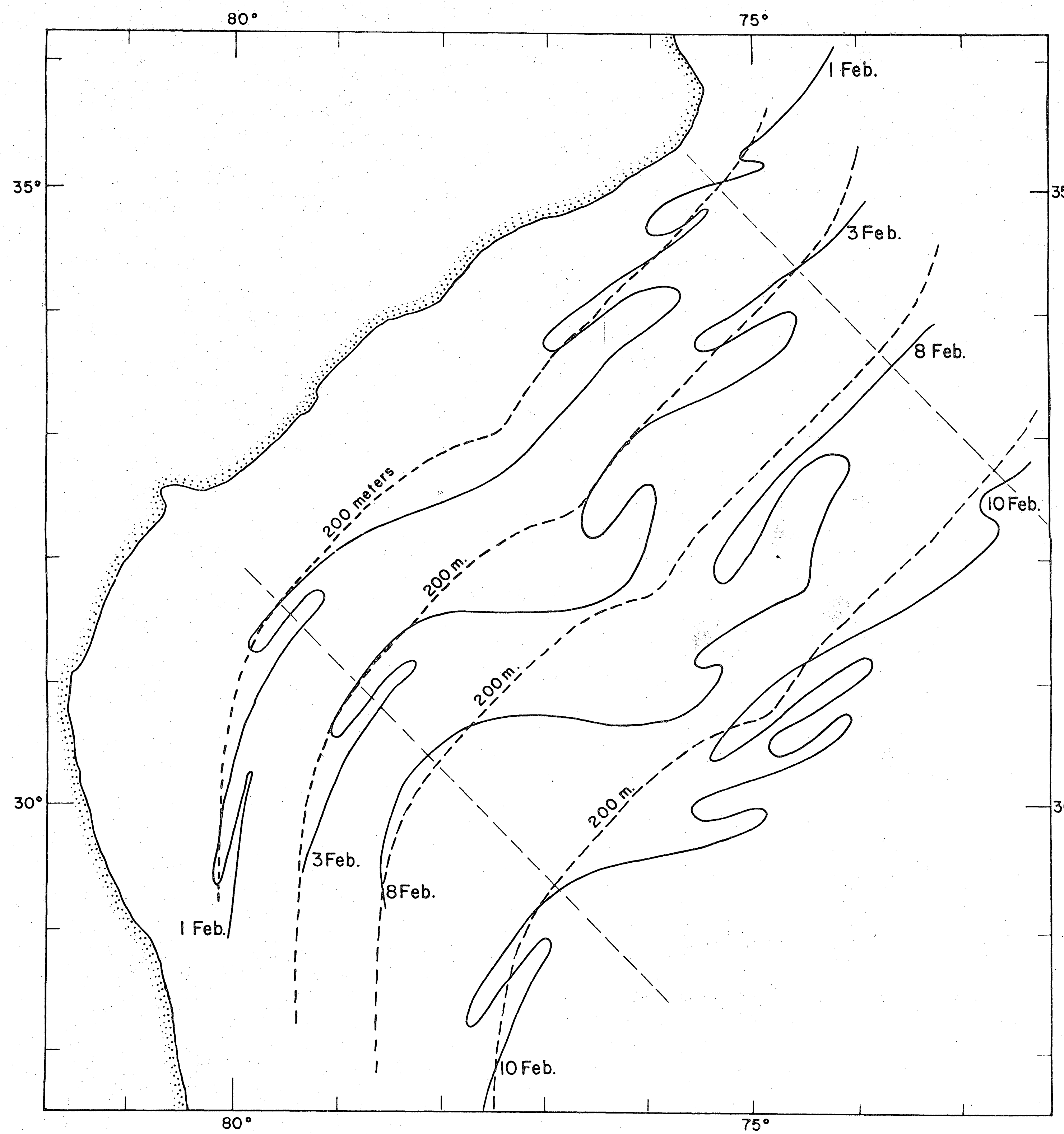


Figure 6. Location of Gulf Stream/Slope Front, as given in the NOAA/NESS satellite-derived oceanographic analysis maps for the 1, 3, 8, and 10th February 1983. The Front is progressively offset for each date for visual clarity.

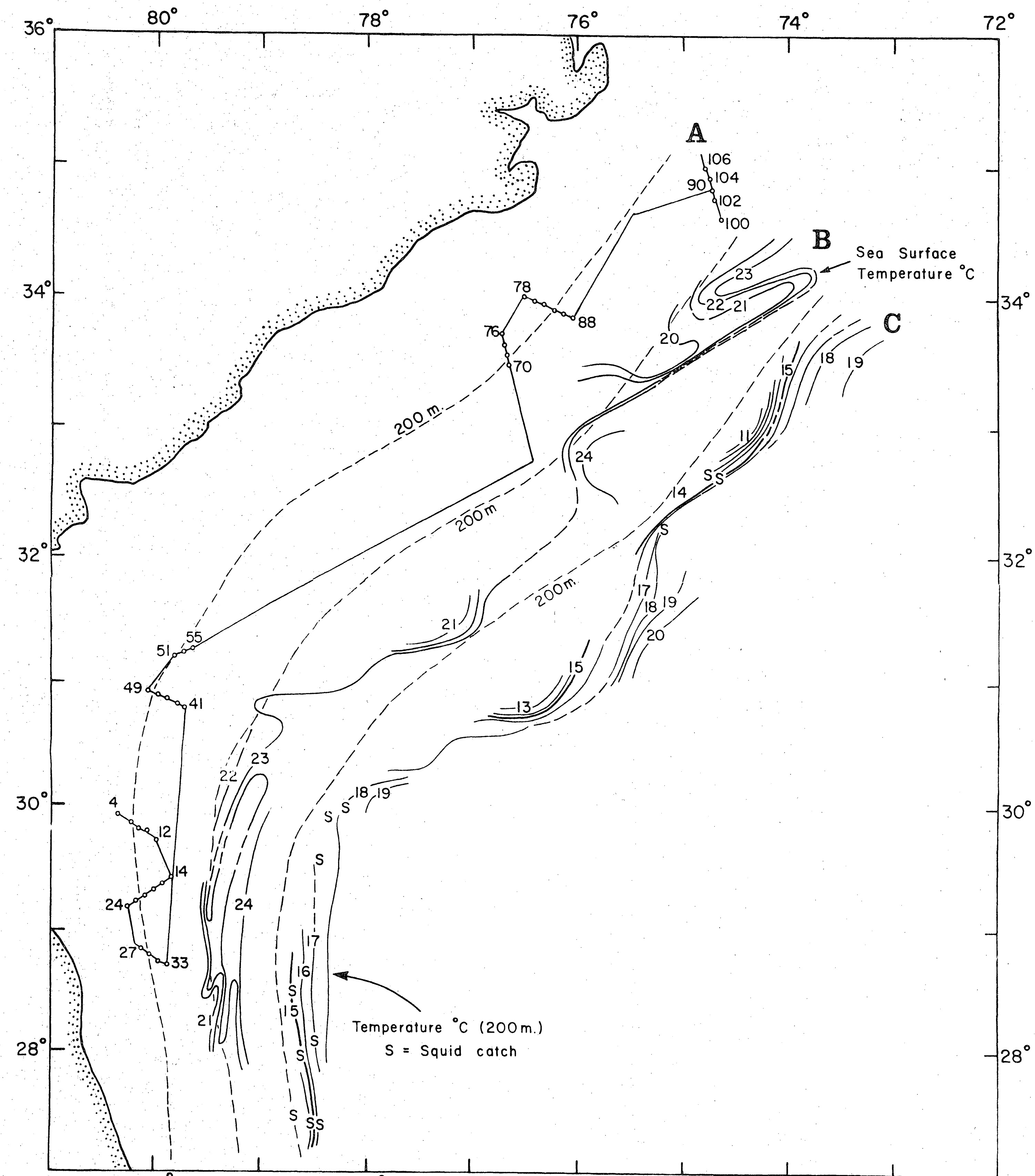


Figure 7. Map of the survey area showing: A) cruise track for 18-25 February, 1983 along which XBT's were taken and station numbers of STD's; B) sea surface temperature in °C, and C) temperature in °C at 200 M. Figures B and C have been geographically offset for visual clarity.

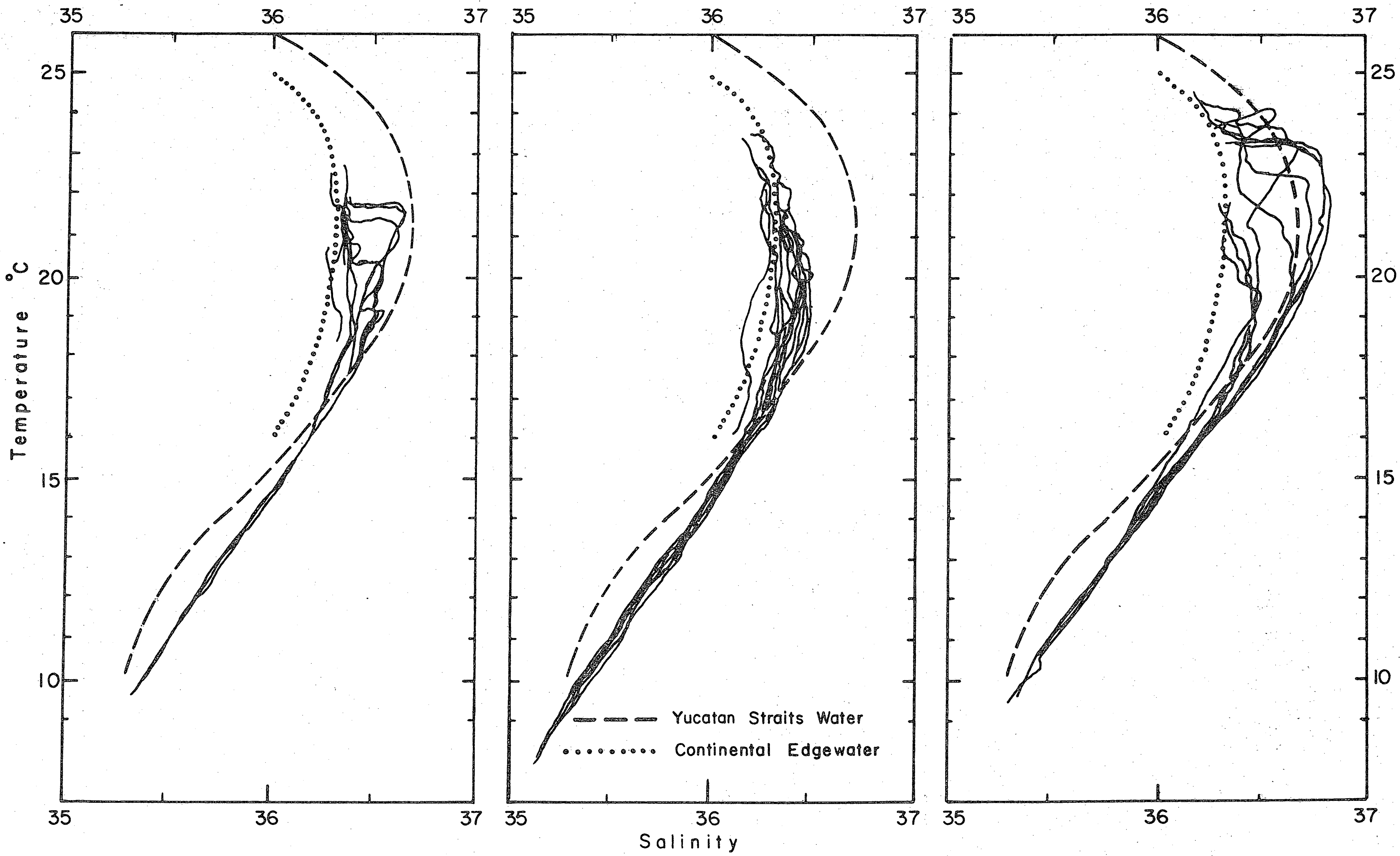


Figure 8. T-S plots along section lines occupied on Leg 1, where larvae and/or juveniles were caught at one or more stations; A) stations shoreward from those with catch; B) stations with catch, and C) stations seaward of the catch.

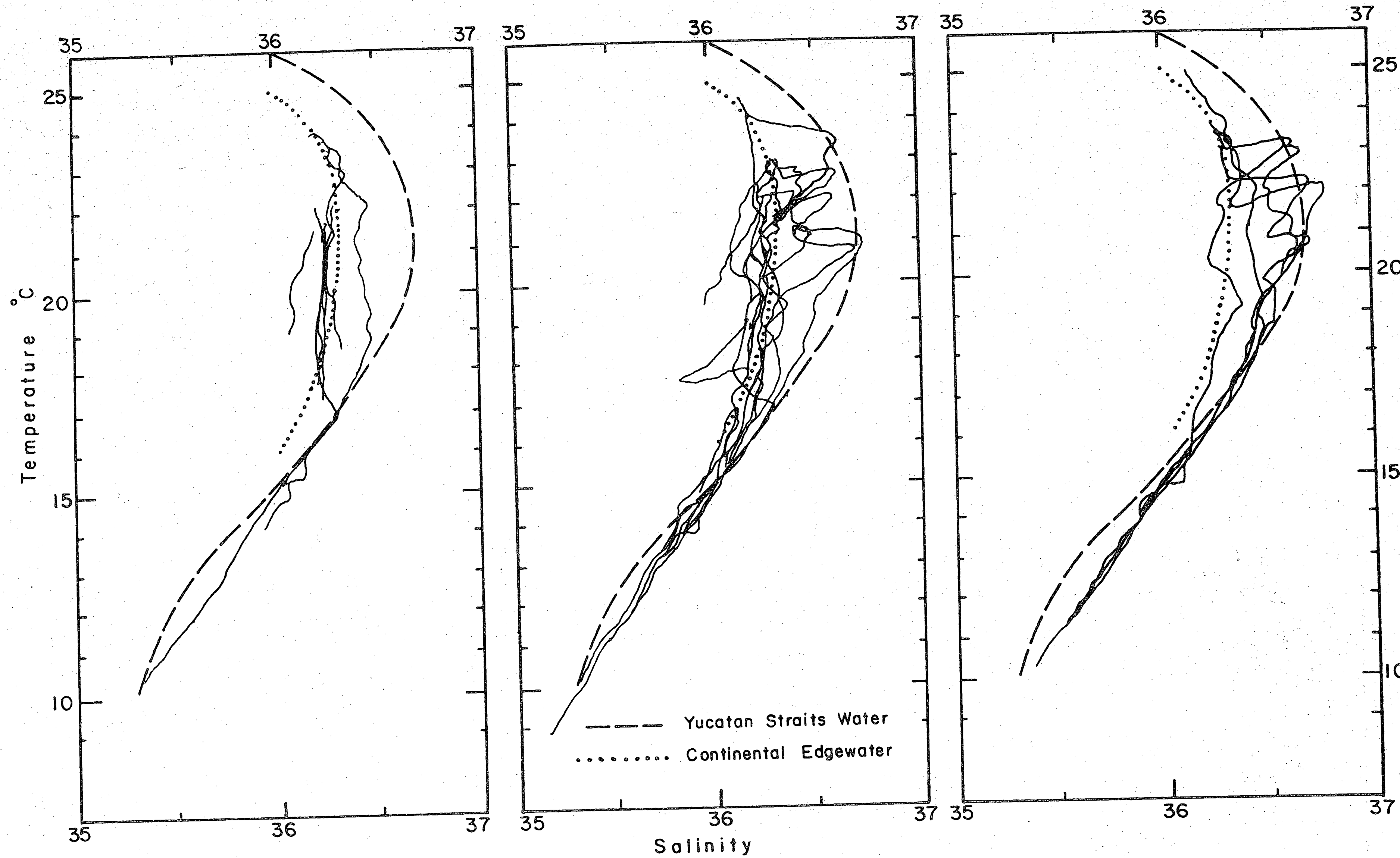


Figure 9. T-S plots along section lines occupied on Leg 2 where larvae and/or juveniles were caught at one or more stations in the section: A) stations shoreward from those with catch; B) stations with catch, and C) stations seaward of the catch.

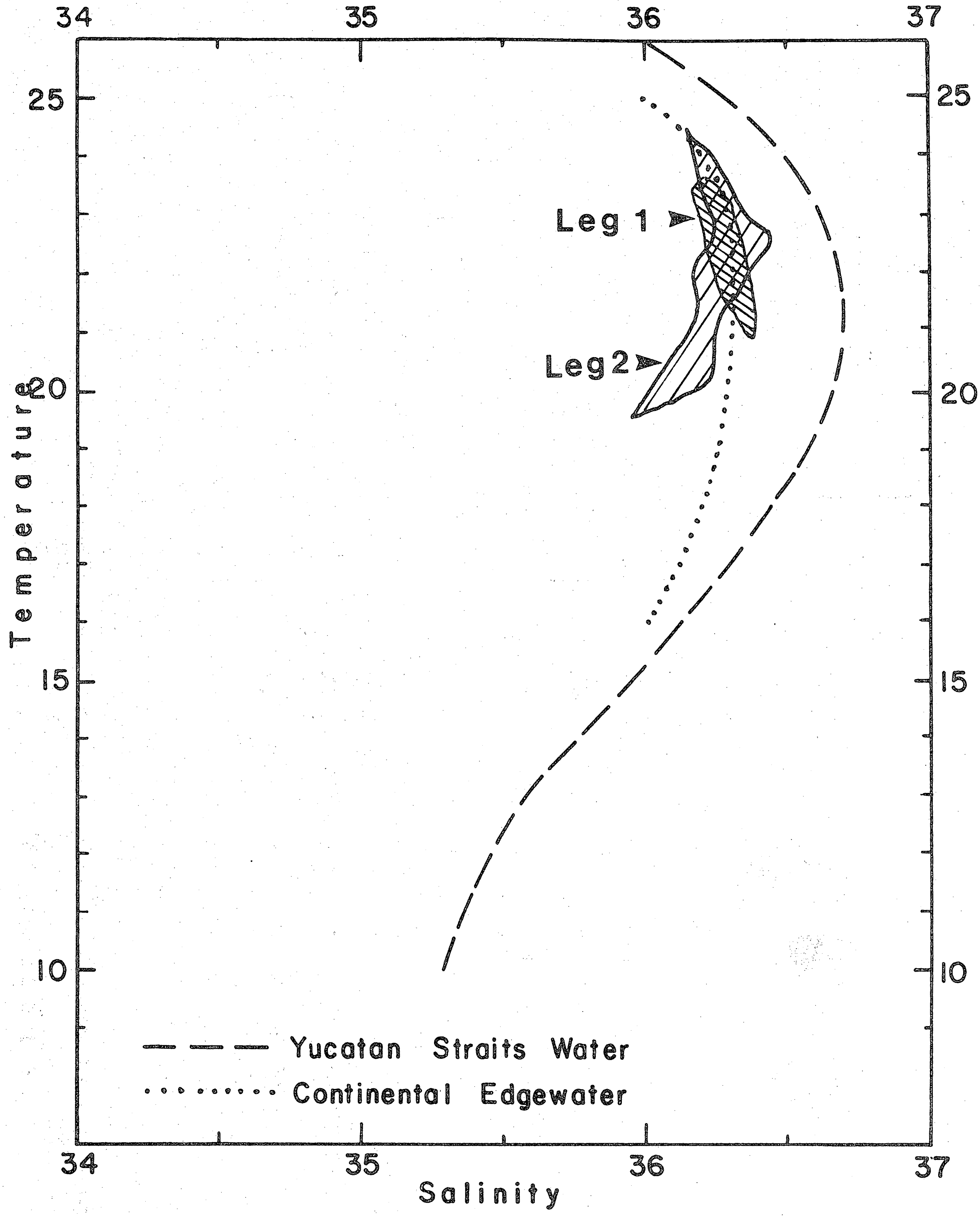


Figure 10. Envelopes of T-S curves for upper 50 meters that incorporate all stations from which squid larvae and/or juveniles were caught during cruise.

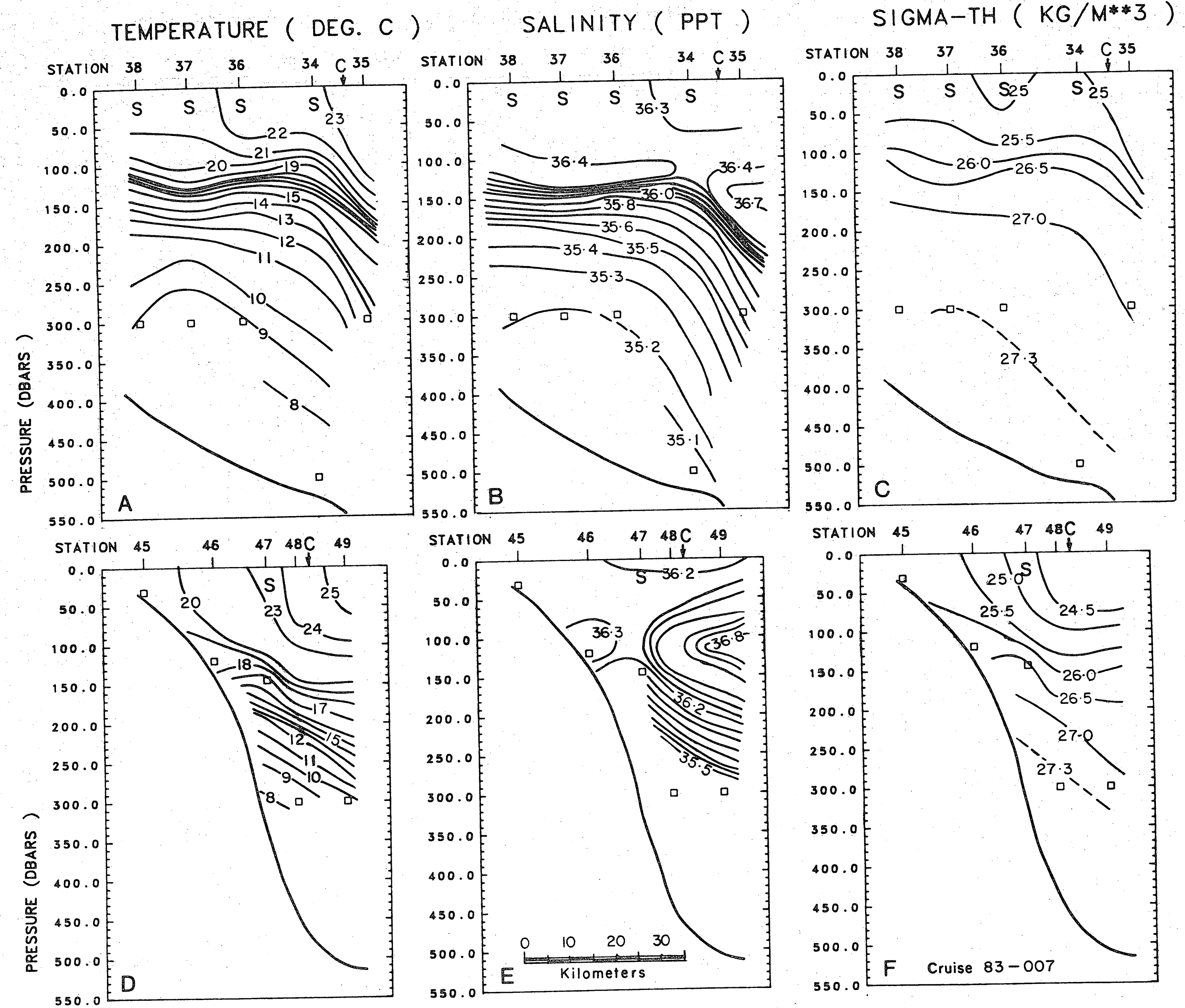


Figure 11. Cross section of temperature, salinity and density anomaly for two of the more southern sections occupied during Leg 1 of cruise. Stations with catch are marked with an "S" and the estimated location of the core of the Gulf Stream is marked with a "C".

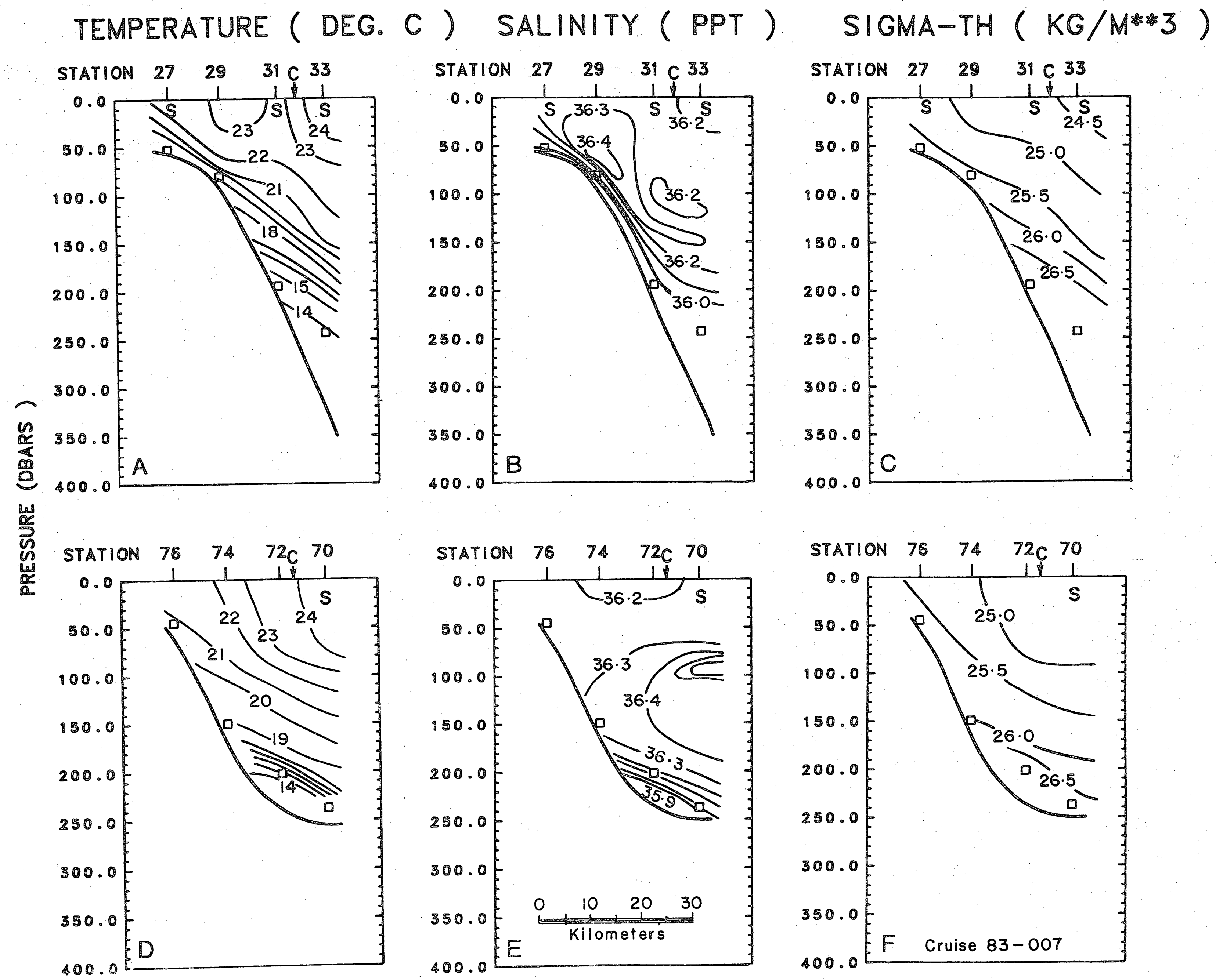


Figure 12. Cross section of temperature, salinity and density anomaly for two of the more southern sections occupied during Leg 2 of cruise. Stations with catch are marked with an "S" and the estimated location of the core of the Gulf Stream is marked with a "C".