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Two oceanographic investigations were performed in the Persian Gulf, one to a location approximately 200 km west of the Strait of Hormuz in May 1976 and the other to the Strait of Hormuz in April 1977. Although these investigations were conducted under limited resources for the essential purpose of making a probing study, some interesting results have been achieved.

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In the month of May, the inflow from the Arabian Sea and the Gulf of Oman is detected at a point about 200 km inside the Persian Gulf and is found over the shelf off the Iranian coast within about 50 km from the shore. The adherence of the inflow to the Iranian coast is due to the Coriolis deflection. In the upper 30 meters of this shelf, the surface water essentially retains the characteristics of the unmixed surface water originating in the Gulf of Oman. However, the water at a 30-m depth has been mixed partially with the underlying denser and cooler water in the Persian Gulf. There are indications of progressively stronger mixing action with distance offshore. The temperature of the inflow appears to rise 5 to 7 °C while travelling a 200-km distance from the Strait to the study location off Kish Island.

The direction of the currents in this inflow off Kish Island was opposed to the anticipated general northwest trend at the time of this study. This is considered to indicate that, at this time of the year, during the month of May, the inflow is not sufficiently strong to overcome the opposing effects of local winds. The average speed in the surface 30 meters at this location was 0.38 knot.

In the southern half of the Strait of Hormuz, the water was stably stratified, consisting of three distinct water masses, located in the upper 30 m, the middle 20 m, and the lower 30 m. The upper layer exhibited identical water mass characteristics with the inflow from the Arabian Sea, and the lower layer with the outflow. The middle layer represented a product of mixing between the incoming surface water and the outgoing bottom water. The mixing appeared to take place as an upward entrainment of the outflow. The outflow on the bottom was about 30 m thick, approximately twice the thickness previously reported by the Meteor expedition.

Salinity and temperature extremes found in this study generally exceeded the historically reported data. The highest observed salinity and the lowest observed temperature both occurred in the bottom layer of the Strait of Hormuz, being 44.31 °/oo and 13.8 °C respectively. The highest observed temperature in this study was 29.8 °C at the nearshore surface off Kish Island in May 1976, and 26.3 °C at the surface of the Strait of Hormuz in April 1977.

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FINAL REPORT

OCEANOGRAPHIC STUDY IN THE STRAIT OF HORMUZ AND OVER THE IRANIAN SHELF IN THE PERSIAN GULF

FOR

OFFICE OF NAVAL RESEARCH
GEOGRAPHY PROGRAMS

FINAL REPORT

Contract Number
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OCEANOGRAPHIC STUDY IN THE STRAIT OF HORMUZ AND OVER THE IRANIAN SHELF IN THE PERSIAN GULF

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Arlington, Virginia

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ABSTRACT

Two oceanographic investigations were performed in the Persian Gulf, one to a location approximately 200 km west of the Strait of Hormuz in May 1976 and the other to the Strait of Hormuz in April 1977. Although these investigations were conducted under limited resources for the essential purpose of making a probing study, some interesting results have been achieved.

In the month of May, the inflow from the Arabian Sea and the Gulf of Oman is detected at a point about 200 km inside the Persian Gulf and is found over the shelf off the Iranian coast within about 50 km from the shore. The adherence of the inflow to the Iranian coast is due to the Coriolis deflection. In the upper 30 meters of this shelf, the surface water essentially retains the characteristics of the unmixed surface water originating in the Gulf of Oman. However, the water at a 30-m depth has been mixed partially with the underlying denser and cooler water in the Persian Gulf. There are indications of progressively stronger mixing action with distance offshore. The temperature of the inflow appears to rise 5 to 7 °C while travelling a 200-km distance from the Strait to the study location off Kish Island.

The direction of the currents in this inflow off Kish Island was opposed to the anticipated general northwest trend at the time of this study. This is considered to indicate that at this time of the year during the month of May, the inflow is not sufficiently strong to overcome the opposing effects of local winds. The average speed in the surface 30 meters at this location was 0.38 knot.

In the southern half of the Strait of Hormuz, the water was stably stratified, consisting of three distinct water masses located in the upper 30 m, the middle 20 m, and the lower 30 m. The upper layer exhibited identical water mass characteristics with the inflow from the Arabian Sea, and the lower layer with the outflow. The middle layer represented a product of mixing between the incoming surface water and the outgoing bottom water. The mixing appeared to take place as an upward entrainment of the outflow. The outflow on the bottom was about 30 m thick, approximately twice the thickness previously reported by the Meteor expedition.

Salinity and temperature extremes found in this study generally exceeded the historically reported data. The highest observed salinity and the lowest observed temperature both occurred in the bottom layer of the Strait of Hormuz, being 44.31 ‰ and 13.8 °C respectively. The highest observed temperature in this study was 29.8 °C at the nearshore surface off Kish Island in May 1976, and 26.3 °C at the surface of the Strait of Hormuz in April 1977.

ACKNOWLEDGEMENTS

The author would like to extend a sincere appreciation to the logistics support provided for this study by the Ministry of Court, Iran, for the 1976 expedition off Kish Island, and by the Development Council of the Sultanate of Oman for the 1977 expedition off Musandam Peninsula in the Strait of Hormuz. Mr. Kirk Agon, director of the Oman office of Tetra Tech, Inc., has provided most essential assistance in organizing difficult logistics for the 1977 study. Professor Harry Roberts of the Coastal Studies Institute, Louisiana State University, has volunteered to assist in the study in the Strait of Hormuz and has provided valuable assistance during the first half of the field operations. The author is also grateful to Dr. Li-san Hwang, Senior Vice President of Tetra Tech, Inc., for his authorization on using part of the company resources outside the limit of the project budget to complete the analysis of the data.

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1. INTRODUCTION

This report presents the summary of two field investigations performed in the shelf waters in the Persian Gulf. The first investigation was carried out in May 1976 off Kish Island, Iran, located at approximately 200 km west of the Strait of Hormuz. The second investigation was carried out in April 1977 off the west coast of Musandam Peninsula, Oman, in the Strait of Hormuz (see Figure 1.1).

The objective of these investigations was primarily to study the behavior of the shelf current on the southeastern coast of Iran. Specifically, the interest was focused on the surface current which enters from the Arabian Sea into the Persian Gulf through the Strait of Hormuz. The intense evaporation in the Persian Gulf gives rise to an inflow from the Arabian Sea which, being lighter in density than the highly condensed water of the Gulf, forms a surface current. As this current continues its way inside the Gulf, the Coriolis deflection forces it close to the Iranian coast. According to "Sailing Directions" of the U. S. Navy Oceanographic Office (1960), the inflow would appear to reach as far as the northern end of the Gulf during summer and approximately a half of this distance during winter (see Figure 1.2).

The first investigation in this study was planned as a probing attempt to intercept this inflow in the general area approximately 200 km inside the Gulf. The choice of the study site for this first investigation was primarily dictated by the logistics base on Kish Island which was made available for this study by the Governor of the Island. It had also appeared that in light of the descriptions appearing in the "Sailing Directions", the inflow could be readily intercepted in the general vicinity of Kish Island at all times.

During the investigation off Kish Island, a total of 28

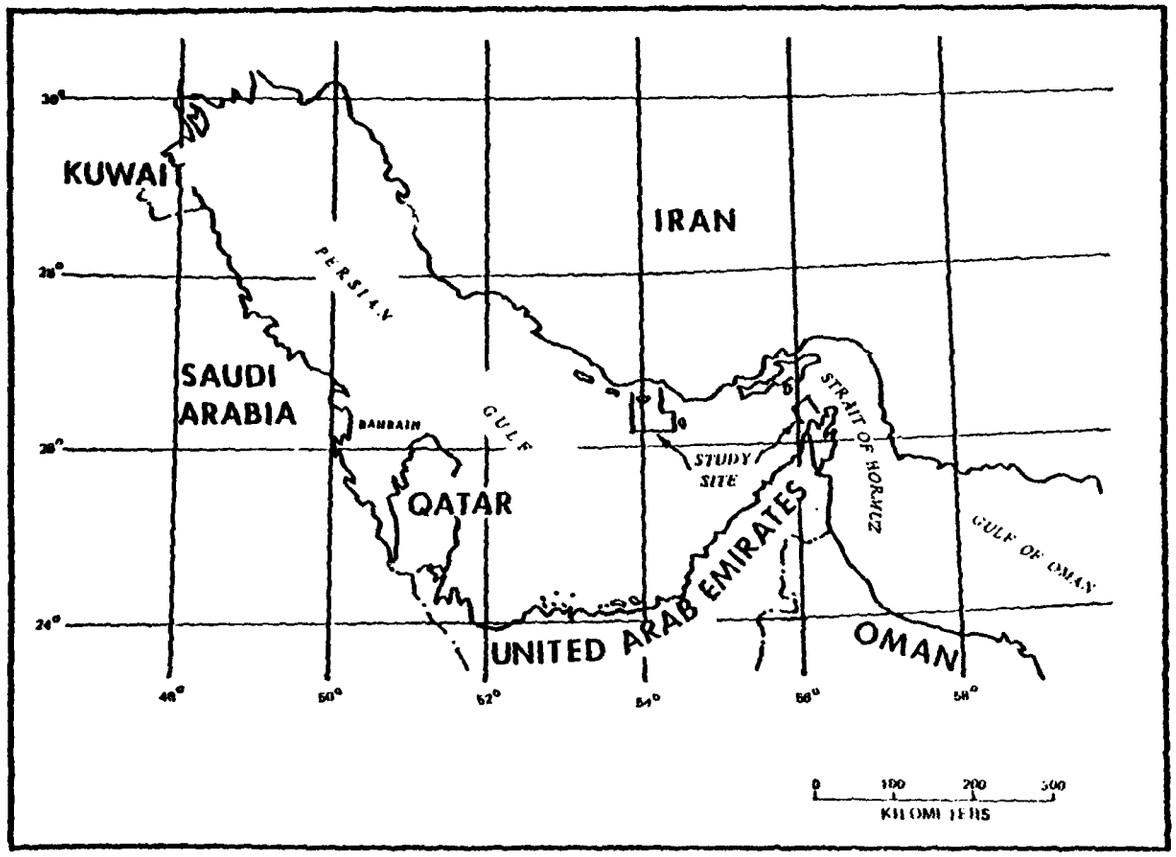
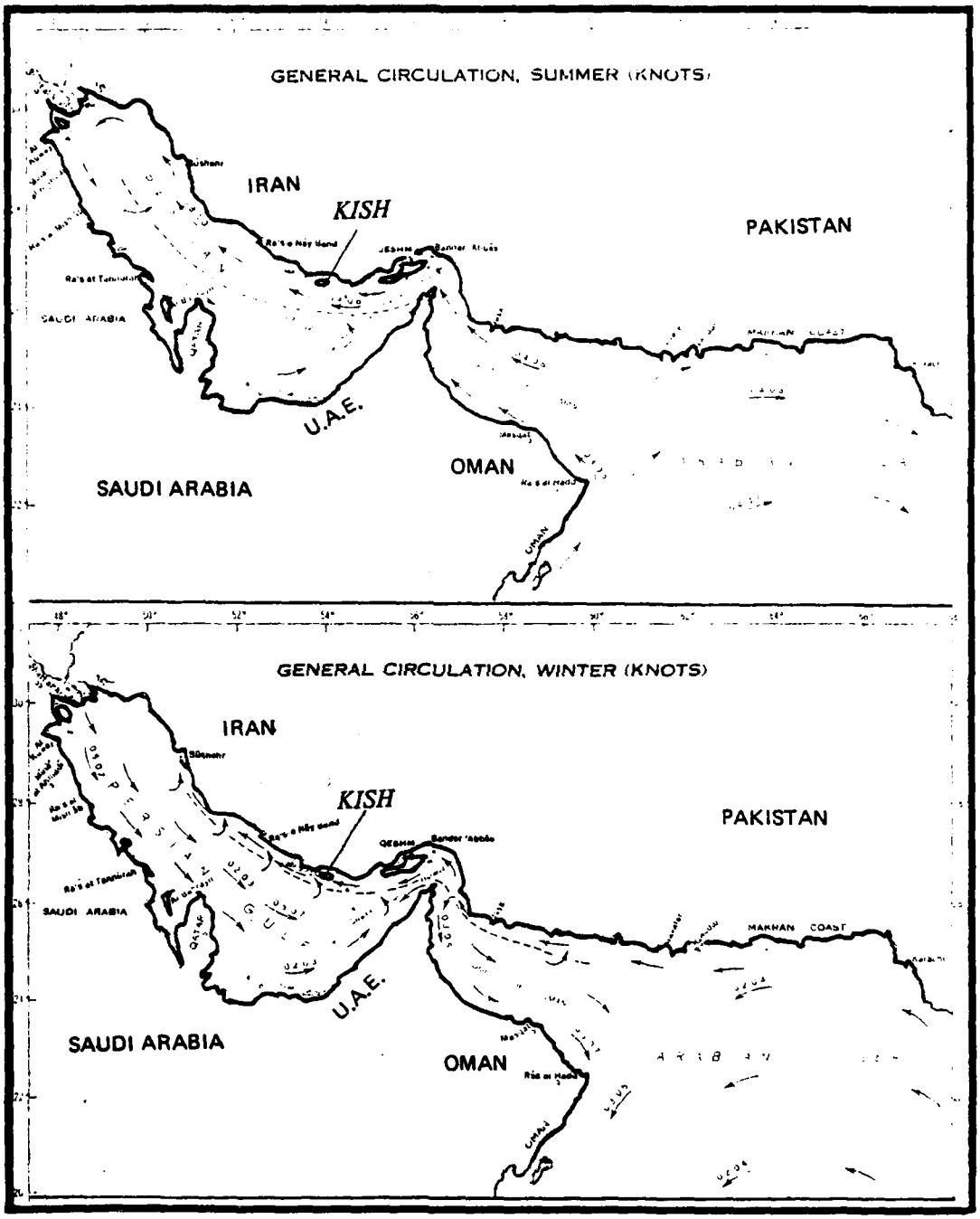


FIGURE 1.1 Study Locations



LEGEND:

---- APPROXIMATE BOUNDARY BETWEEN INFLOWING AND OUTFLOWING CURRENTS

—→ DIRECTION OF GENERAL CIRCULATION

FIGURE 1.2 General Circulations in the Persian Gulf (Source: U.S. Hydrographic Office "Sailing Directions").

stations, confined in a swath about 10 km wide and 50 km long in a due southward direction from the Iranian coast, were occupied in four cruises with a profiling current meter and a profiling temperature-conductivity sensor. Whereas current measurements were taken throughout the entire study, the temperature-conductivity measurements were possible only during two cruises to a depth of about 30 m.

The second investigation was planned in light of the results of the first investigation which had failed to produce convincing evidence of a strong northwesterly current off Kish Island. The site of the second investigation was located in the Strait of Hormuz, the point of entry of the inflow, where a total of 5 transects were occupied with a profiling current meter and a CTD. Two in-situ current meters taken to the field for this investigation were never deployed because of a threat of collision with the passing ships and possible vandalism. The second investigation has resulted in one good set of data on temperature and conductivity along a transect extending from the Oman coast to a mid-point of the Strait.

Although the data obtained from the two investigations are far short of meeting the original expectation, they appear to be of value in providing a general picture of water mass characteristics associated with the inflow through the Strait of Hormuz and its extension into the Persian Gulf.

2. OBJECTIVE

In the Persian Gulf, an annual evaporation is estimated to amount to 144 cm/year, or 326 km^3 /year from the total surface area of about 226,000 km^2. The Gulf receives a fresh water influx from precipitation and runoff amounting to about 70 km^3/year. Accor-

ding to a calculation by Koske (1970), the evaporation would cause some 3,000 km^3 of surface water in the Persian Gulf to be condensed from 36.6 ‰ to 40 ‰. In order to compensate for the net loss of water in the Gulf, the water from the Arabian Sea flows into the Gulf through the Strait of Hormuz. Considering that the Persian Gulf holds only about 8,000 km^3 of water, it follows that the water in the Gulf may be flushed in 2 to 3 years.

The condensed water which is generated in the Persian Gulf is cooled during the winter and sinks toward the bottom, eventually exiting into the Arabian Sea and further south after passing through the Strait of Hormuz as a bottom current. Thus the Strait contains two opposing currents: An inflow on the surface and an outflow at the bottom.

The following excerpt from the "Sailing Directions" provides an overview of the general characteristics of these currents:

> It appears that there is an inflow of water along the northern shore and an outflow along the southern shore (in the Persian Gulf). The width of these bands of opposing currents varies with the seasons. The inflow appears broadest in summer, partly because large quantities of water of low salinity enter the gulf in order to replace water loss by evaporation, and partly because the Southwest Monsoon appears to pile water into the Gulf of Oman. During winter the width of the inflow is considerably reduced, and some water appears to escape at the surface through the Strait of Hormuz into the Gulf of Oman.

The currents in the Strait appear to vary considerably by the season. Chief among the factors which influence the currents in the Strait are the seasonal Southwest and Northeast Monsoons, the runoff from the Euphrates and Tigris which appear to occur during the months May-June (Schott, 1918), and the tides, as well as the evaporation. If we were to consider only the effect of evaporation

on the water exchange between the Persian Gulf and the Arabian Sea, very small values will be obtained to represent the velocities of this current. For instance, according to Privett (1959), evaporation in the Persian Gulf is at its annual maximum of approximately 6 $gm/cm^2/day$ in December and at its annual minimum of about 2 $gm/cm^2/day$ in May. Assuming that the monthly inflow in the Strait is proportional to the Gulf evaporation and further that the inflow occupies about 3 km^2 of its 4-km^2 cross-section (Koske, 1970), an average velocity of the inflow during the month of December is estimated to be about 4 cm/sec, a very small value compared with the velocities of the order of 60 cm/sec observed in the Straits of Gibraltar and Bab el Mandeb (Defant, 1961).

The adherence of the inflow to the northern (i.e., Iranian) shore of the Gulf is due apparently to the influence of the Coriolis deflection. At the outset of this study, the following two questions were considered to be of special interest:

1. How would this inflow interact with the denser Gulf water over the sloped Iranian shelf? Would it be possible that this shore-bound inflow may develop a trapped mode such as similar to the "coastal jets" which have been recognized off the lake shore as a baroclinic coastal boundary layer coupled with a "wedge-shaped" picnocline (Csanady, 1975)?

2. What would be the distance of penetration of the inflow? Our existing knowledge of the inflow away from the Strait is essentially based on either the interpretation of the water mass distribution or reports by vessels. No attempt had yet been made to measure the inflow directly.

3. SHELF CURRENTS

The shelf currents were investigated off Kish Island, Iran, which is located approximately 200 km west of the Strait of Hormuz (see Figure 3.1). The investigation was carried out between May 26 and 31, 1976. Four cruises were made during this period of time, occupying a total of 28 stations to a point as far as about 50 km from the shore. A profiling savonious current meter (Hydro Products Model 960S) with a deck readout was used aboard a chartered dhow (40 feet long). The dhow's anchor failed to stop the boat in a current in waters deeper than 100 feet. As an alternative, an anchored buoy was placed at each current meter station and the dhow was maneuvered into a stationary position alongside the buoy while taking the current measurements.

Figure 3.2 shows the velocity profiles taken from the four cruises off Kish Island. Each profile is numbered by the sequence of cruises (1 to 4) followed by the sequence of the stations occupied from nearshore to offshore (1 to up to 8). Current directions are indicated by arrows clockwise from the north. The observed speeds and directions, along with the east-west velocity components, are tabulated in Appendix A: CURRENT PROFILES.

Current Speeds

Table 3.1 summarizes the frequency of occurrence of the observed current speeds. The data are shown separately for two ranges of distance from the shore: those for nearshore stations extending to up to 35 km from the coast (maximum depth about 35 fathoms), and those for offshore stations ranging from about 40 to 50 km from the coast.

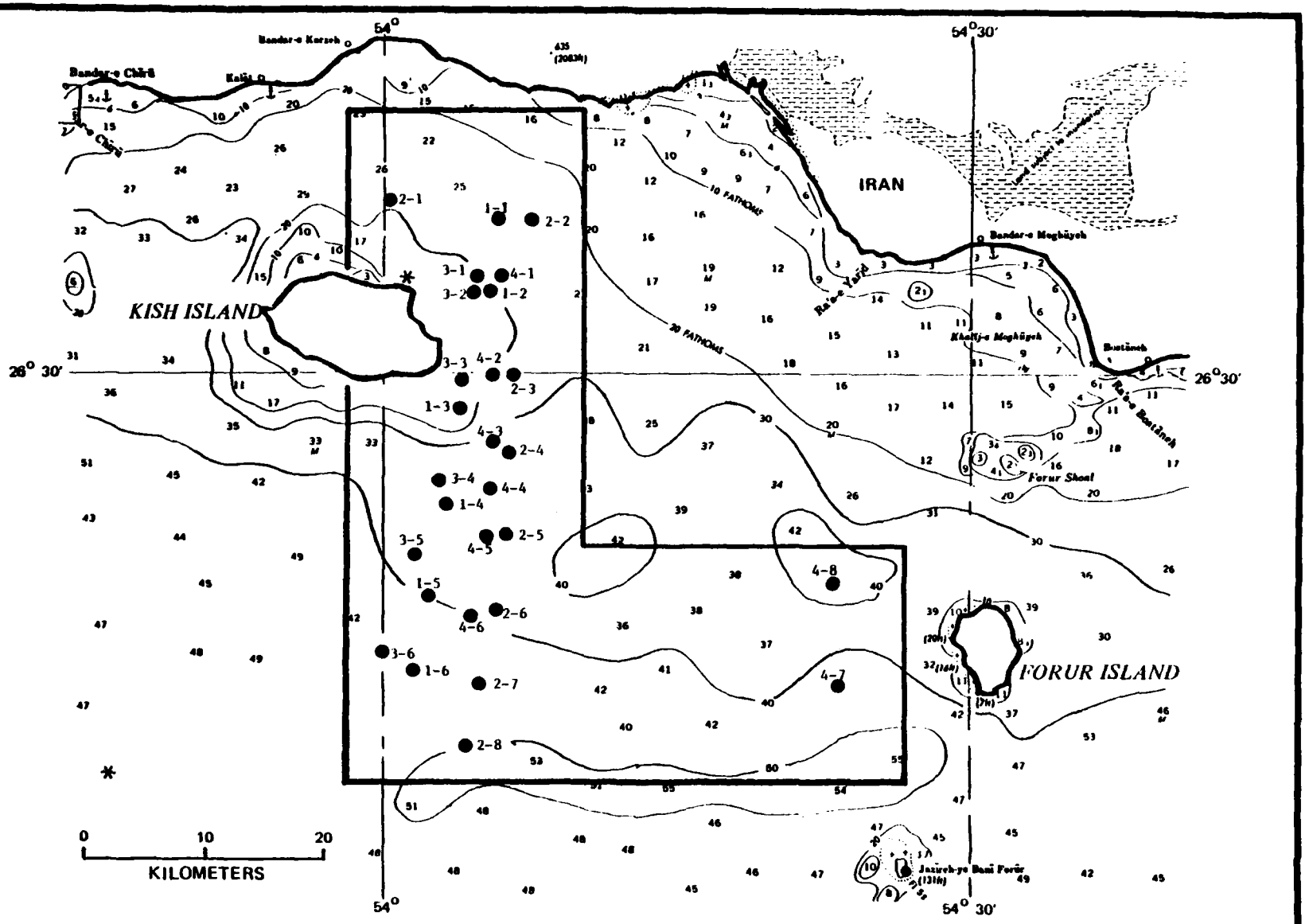


FIGURE 3.1 Site of 1976 Study off Kish Island

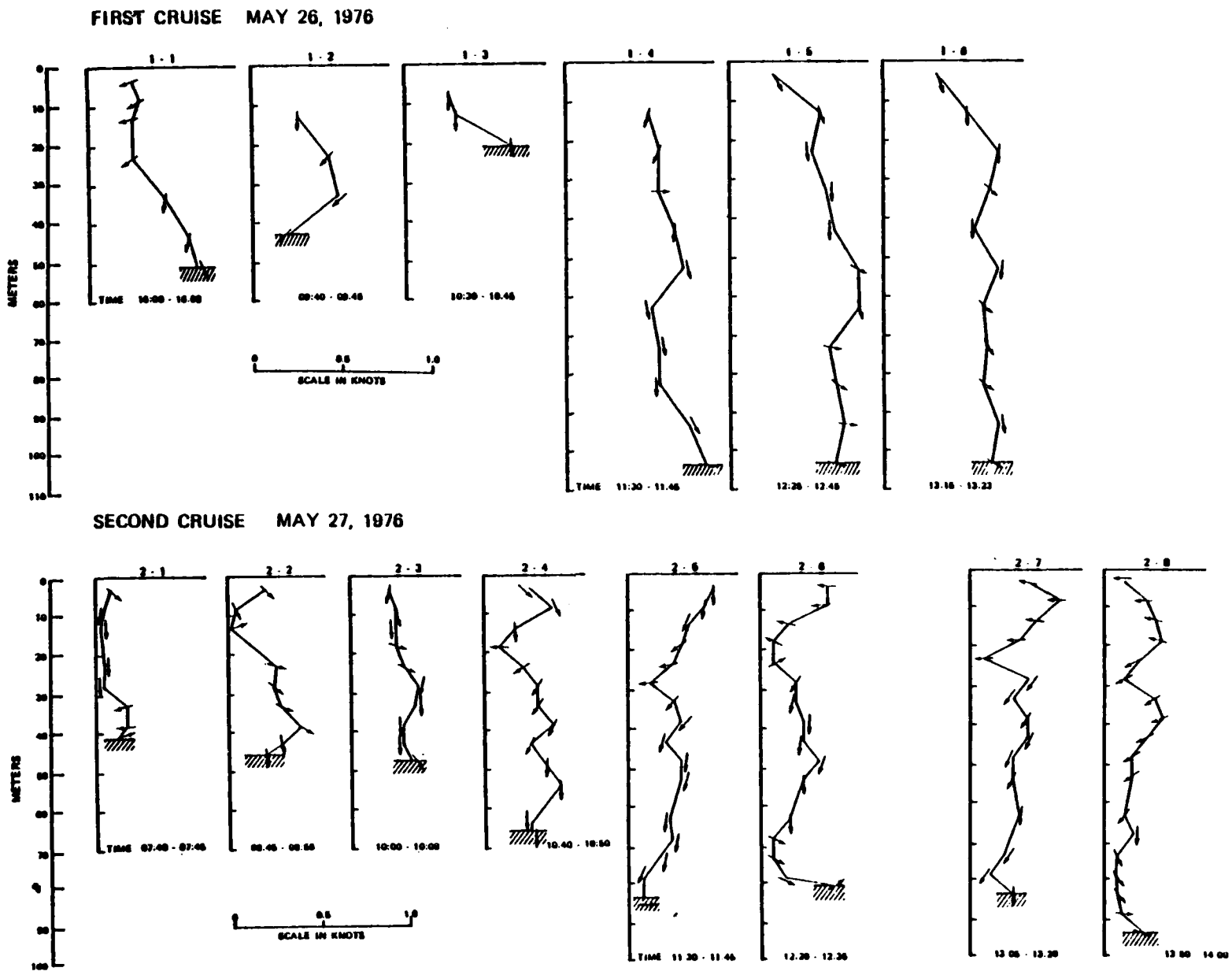
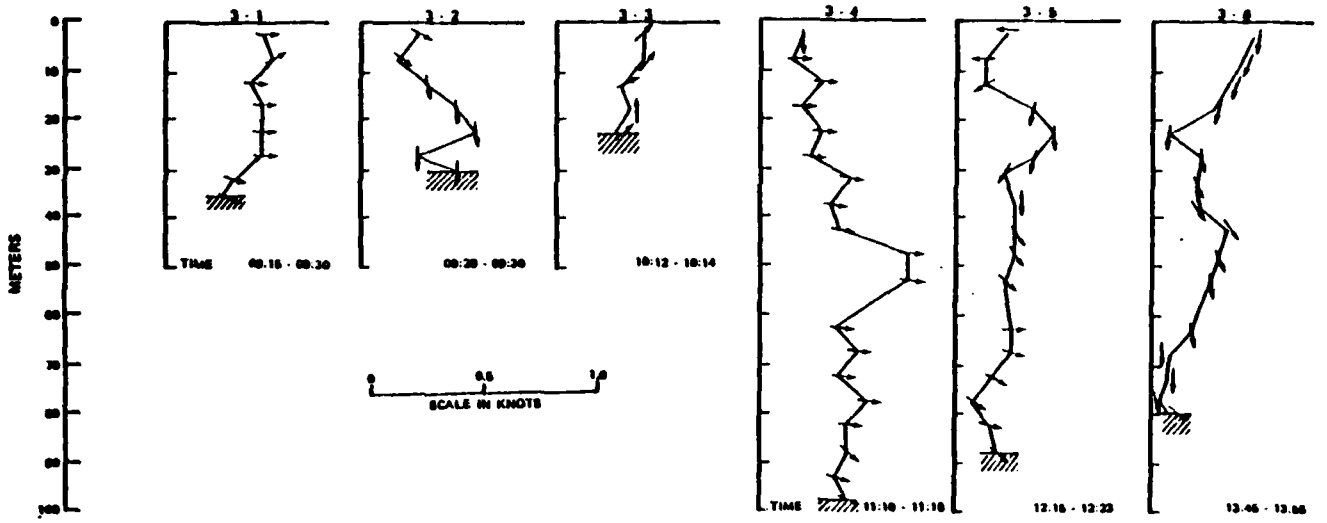


FIGURE 3.2. Current Profiles over the Iranian Shelf, 1976

THIRD CRUISE MAY 30, 1976



FOURTH CRUISE MAY 31, 1976

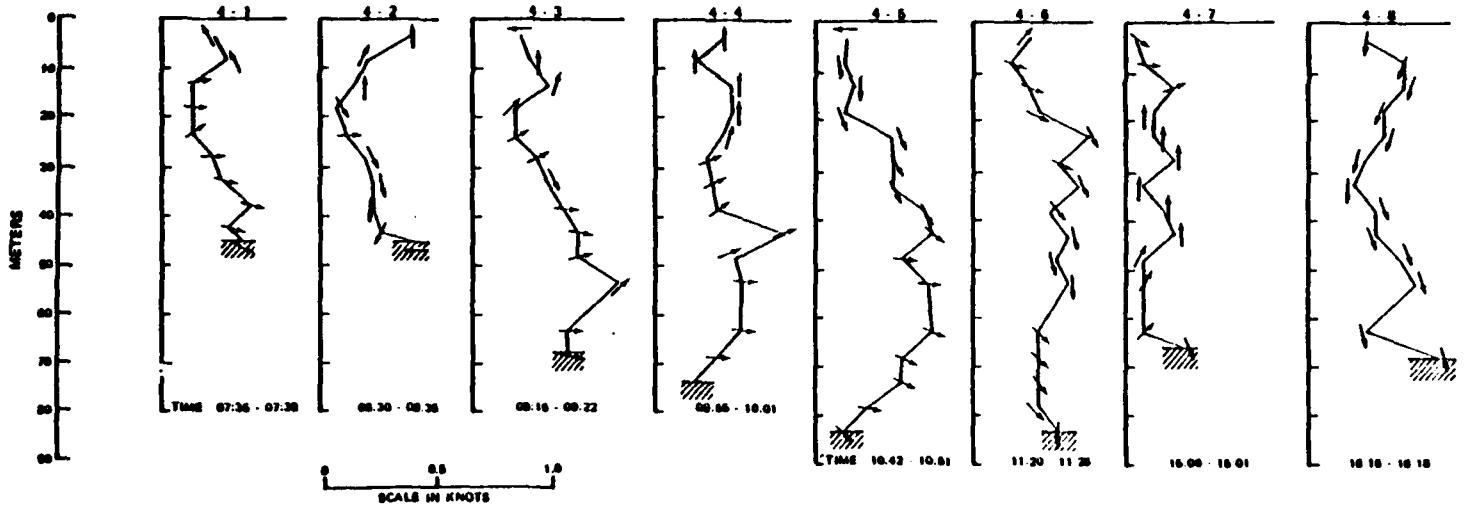


FIGURE 3.2 *Current Profiles over the Iranian Shelf, 1976 (Cont'd)*

Table 3.1 Statistics of Current Speeds

NEARSHORE STATIONS (0 to approximately 35 km offshore)

Speed Ranges knots	Depth Ranges (m) 0 -20 %	20 - 40 %	40< %	Sub-Total %	Exceedance %
0 - 0.2	20.4	8.3	2.2	10.4	100.0
0.2 - 0.4	53.1	58.3	24.4	45.8	89.6
0.4 - 0.6	26.5	27.1	48.8	33.9	43.8
0.6 - 0.8	0	6.3	22.2	9.2	9.9
0.8 - 1.0	0	0	0	0.7	0.7
Sub-total	100.0	100.0	100.0	100.0	
Av. Speed	.31	.36	.48	.39	

OFFSHORE STATIONS (approximately 40 km and offshore)

Speed Ranges knots	Depth Ranges (m) 0 -20 %	20 - 40 %	40< %	Sub-Total %	Exceedance %
0 - 0.2	25.1	13.8	22.5	21.0	100.0
0.2 - 0.4	41.7	44.4	39.4	41.2	79.0
0.4 - 0.6	30.6	30.6	16.9	23.8	37.8
0.6 - 0.8	2.8	11.1	18.3	12.6	14.0
0.8 - 1.0	0	0	2.8	1.4	1.4
Sub-total	100.0	100.0	100.0	100.0	
Av. Speed	.31	.36	.33	.36	

ALL STATIONS

Speed Ranges knots	Depth Ranges (m) 0 -20 %	20 - 40 %	40< %	Sub-Total %	Exceedance %
0 - 0.2	22.4	10.7	14.7	15.7	100.0
0.2 - 0.4	48.2	52.4	33.6	43.5	84.3
0.4 - 0.6	28.2	28.6	29.3	28.8	40.8
0.6 - 0.8	1.2	8.3	19.8	10.9	12.0
0.8 - 1.0	0	0	2.6	1.1	1.1
Sub-Total	100.0	100.0	100.0	100.0	
Av. Speed	.31	.36	.42	.38	

All the observed current speeds remained less than 1 knot. The maximum observed speed was 0.9 knot, and the average of all the observed speeds, 0.38 knot. About 50% of the observed speeds were less than 0.35 knot, and about 75% less than 0.47 knot. The "Sailing Directions" lists typical current speeds associated with the Gulf circulation at this location as 0.4 - 0.6 knot in summer and 0.8 - 1.0 knot in winter. Accordingly, the observed current speeds were somewhat less than the reported values.

Among other noticeable characteristics of the observed current speeds were (1) the lack of significant dependance on the water depth, (2) the lack of significant dependance on the distance from the shore, (3) the lack of significantly higher speeds near the water surface in spite of frequent sea-breeze actions with up to 10 knots, and (4) highly variable speeds from day to day.

Current Directions

Table 3.2 presents the frequency of occurrence of current directions. Again, the data are shown for separate groupings of nearshore and offshore stations. More than 50% of the time, the currents were directed to the south (S) and southeast (SE) sectors. The southerly (S) currents were most frequent, occurring 28.7% of the time. This was followed by the southeasterly (SE) directions with 25.6% and the easterly (E) directions with 17.0%. The average current directions were 128.7^{o} for the nearshore stations, 157.2^{o} for the offshore stations, and 142.6^{o} for all the stations. In particular, the southerly currents dominated the surface layers, occurring 27.0% in the 0 - 20 m layer and 29.4% in the 20 - 40 m layer. The southeasterly currents were most dominant in the bottom layer of 40 m and below, occurring 37.4% of the time.

Table 3.2 Statistics of Current Directions

NEARSHORE STATIONS (0 to approximately 35 km)

Current Direction	Depth Ranges (m) 0 - 20	20 - 40	40 <	Sub-Total
	%	%	%	%
N	15.1	2.0	0	6.2
NE	13.2	14.3	9.1	12.3
E	18.9	30.6	38.6	28.8
SE	13.2	12.2	15.9	13.7
S	24.5	26.5	31.8	27.4
SW	5.7	10.2	2.3	6.2
W	5.7	4 1	2.3	4.1
NW	3.8	0	0	1.4
Sub-Total	100.0	100.0	100.0	100.0
Average	119.1	132.2	128.9	128.7

OFFSHORE STATIONS (approximately 40 km and offshore)'

Current Direction	Depth Ranges (m) 0 - 20	20 - 40	40 <	Sub-Total
	%	%	%	%
N	2.8	11.1	1.4	4.2
NE	5.6	2.8	4.3	4.2
E	0	0	9.9	4.9
SE	22.2	27.8	50.7	37.8
S	30.6	33.3	28.2	30.1
SW	19.4	19.4	5.6	12.6
W	16.7	5.6	0	5.6
NW	2.8	0	0	0.7
Sub-Total	100.0	100.0	100.0	100.0
Average	185.1	157.5	142.7	157.2

ALL STATIONS

Current Direction	Depth Ranges (m) 0 - 20	20 - 40	40 <	Sub-Total
	%	%	%	%
N	10.1	5.9	0.9	5.2
NE	10.1	9.4	6.1	8.9
E	11.2	17.7	20.9	17.0
SE	16.9	18.8	37.4	25.6
S	27.0	29.4	29.6	28.7
SW	11.2	14.1	4.4	9.3
W	10.1	4.7	0.9	4.8
NW	3.4	0	0	1.0
Sub-Total	100.0	100.0	100.0	100.0
Average	149.2	142.9	137.7	142.6

The predominance of the southerly and southeasterly currents found in this study site was against the expectation that the inflow arriving from the Strait of Hormuz would set in the westerly or northwesterly directions at this location. As will be shown in the following section, the surface water at this location strongly resembled the water found in the Gulf of Oman, and undoubtedly the inflow had reached this area. The only explanation to this situation appears that the inflow at this time of the year is not strong enough to overcome the opposing effects such as those by winds. Prior to the cruises on May 26 and 27, and again to those on May 30 and 31, a strong westerly storm blew in this area. It is possible that the residual currents generated by the storm were still active at the time of the current measurements.

4. WATER MASS CHARACTERISTICS OVER THE IRANIAN SHELF

Temperature and conductivity were measured by means of a deck-mounted induction salinometer (Beckman RS5-3). These measurements could be performed only during Cruises 3 (May 30) and 4 (May 31) owing to the delay in clearing the customs at Dubai.

Figure 4.1 shows the offshore dependance of temperature, salinity and density (sigma-t) at the surface and a 30-m depth. Tabulation of the temperature, salinity and sigma-t data is presented in Appendix B.

At the surface, temperature increased toward offshore from about 27 ^{o}C to about 29 ^{o}C, while salinity remained generally constant at around 37 $^{o}/_{oo}$. At a 30-m depth, temperature decreased toward offshore, while salinity increased in the same direction. As will be shown in the discussion of water mass characteristics in the vicinity

of the Strait of Hormuz, the water found over the Iranian shelf off Kish Island represents a typical surface water of the Gulf of Oman partially mixed with the water of the Persian Gulf. The generally constant salinity at the surface around 37 $^{o}/_{oo}$ represents an essentially identical salinity to that of the surface water in the Gulf of Oman. The progressively increasing salinity toward offshore at a 30-m depth indicates that the inflow, while moving along the Iranian coast as a surface current, has been mixing with the dense Persian Gulf water underneath. Since the Persian Gulf water is cooler than the water in the Gulf of Oman at this time of the year, temperature at a 30-m depth should be cooler than that of the surface water as a result of the mixing, and should also decrease toward offshore as the mixing process is expected to be progressively more active away from the coast.

Figures 4.2 A, B, and C show cross-sectional views of temperature, salinity and density (sigma-t) distributions off Kish Island. The distribution patterns are conspicuously different between the two cruises which were made on two consecutive days, indicating that the characteristics of the conditions were highly dynamic. There are indications of a weak upwelling during Cruise 3, but this feature disappeared the next day during Cruise 4.

Figures 4.3 and 4.4 show water mass cross-sections taken in the same general area by the Meteor expedition in 1965 and the Atlantis II expedition of the Woodshole Oceanographic Institution in 1977. The locations of these cross-sections are indicated in Figure 4.5. It is noticed that the Meteor expedition took place in April, whereas the Atlantis II data were taken in February. Whereas these two sets of data exhibit a strong similarity with each other, they both show distinctly lower temperatures than those observed in this study. Furthermore, whereas the vertical temperature gradient in the upper 30 meters in the Meteor and Atlantis II data were

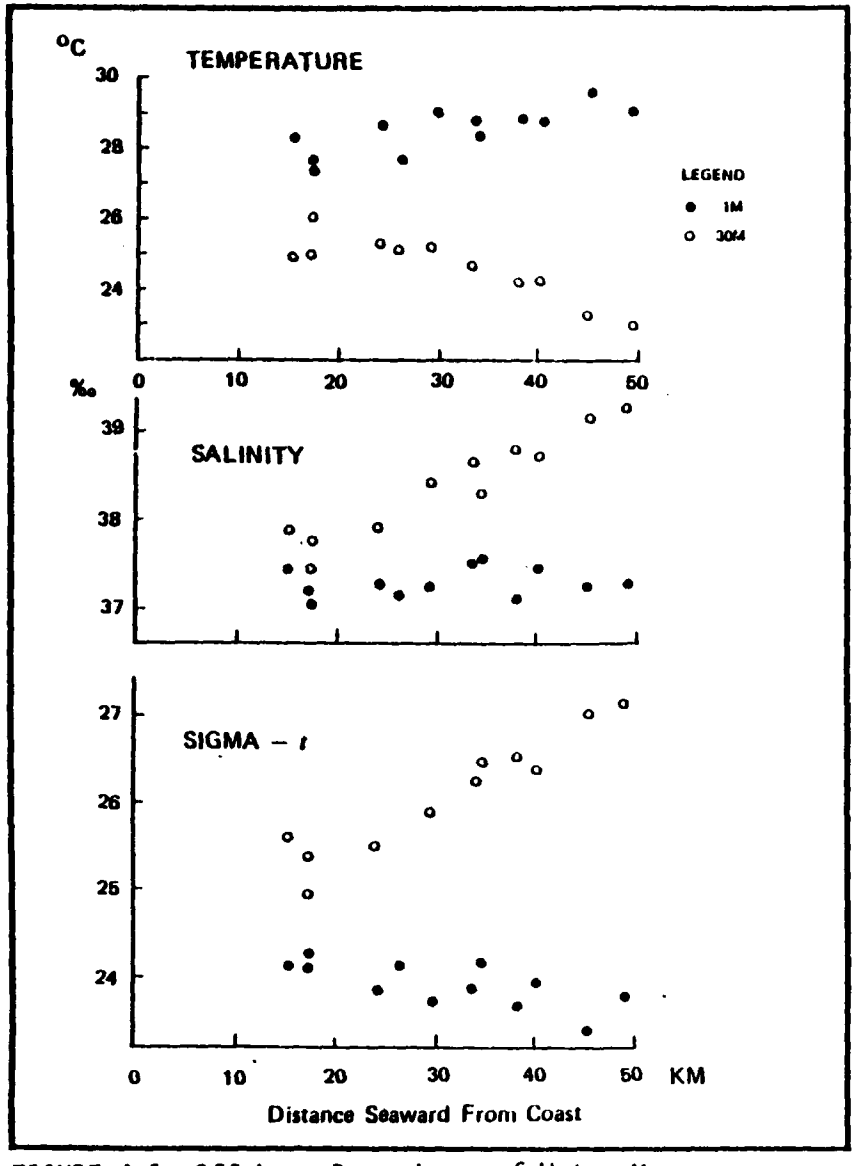


FIGURE 4.1 Offshore Dependance of Water Mass Characteristics over Iranian Shelf, 1976

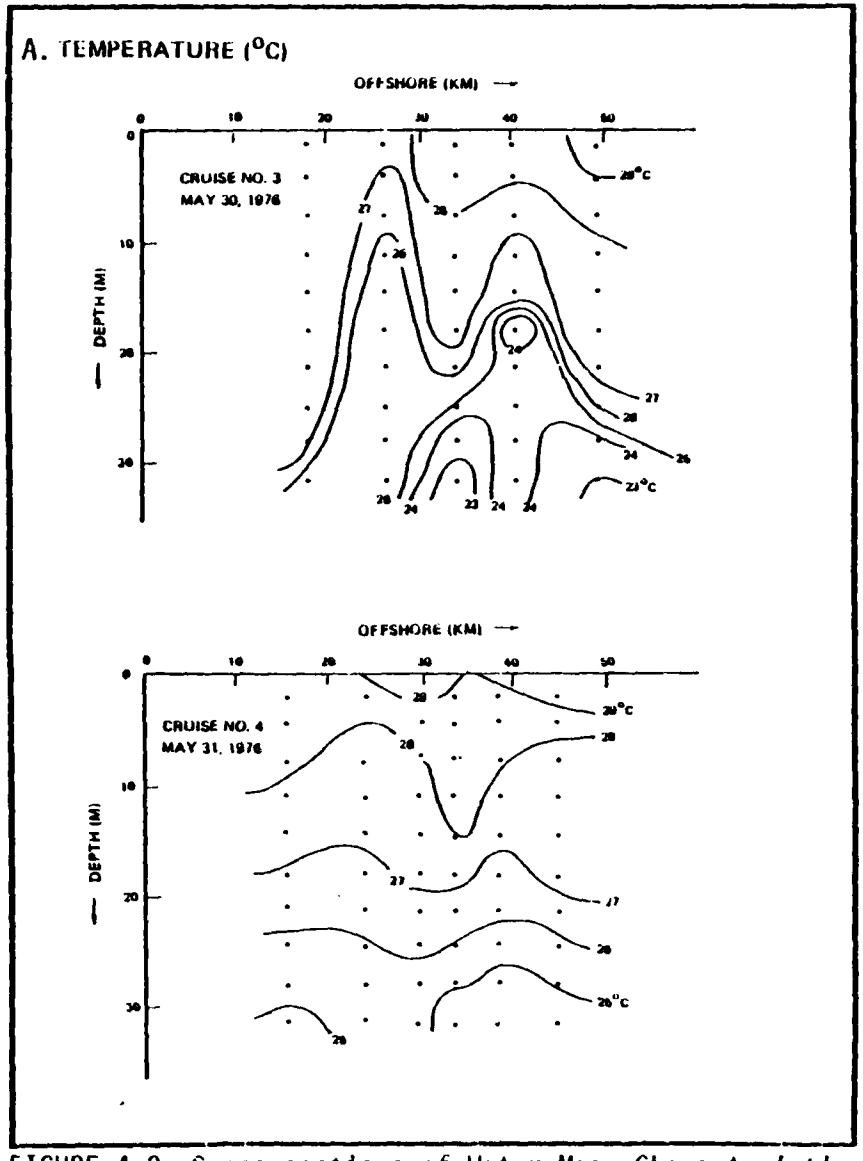
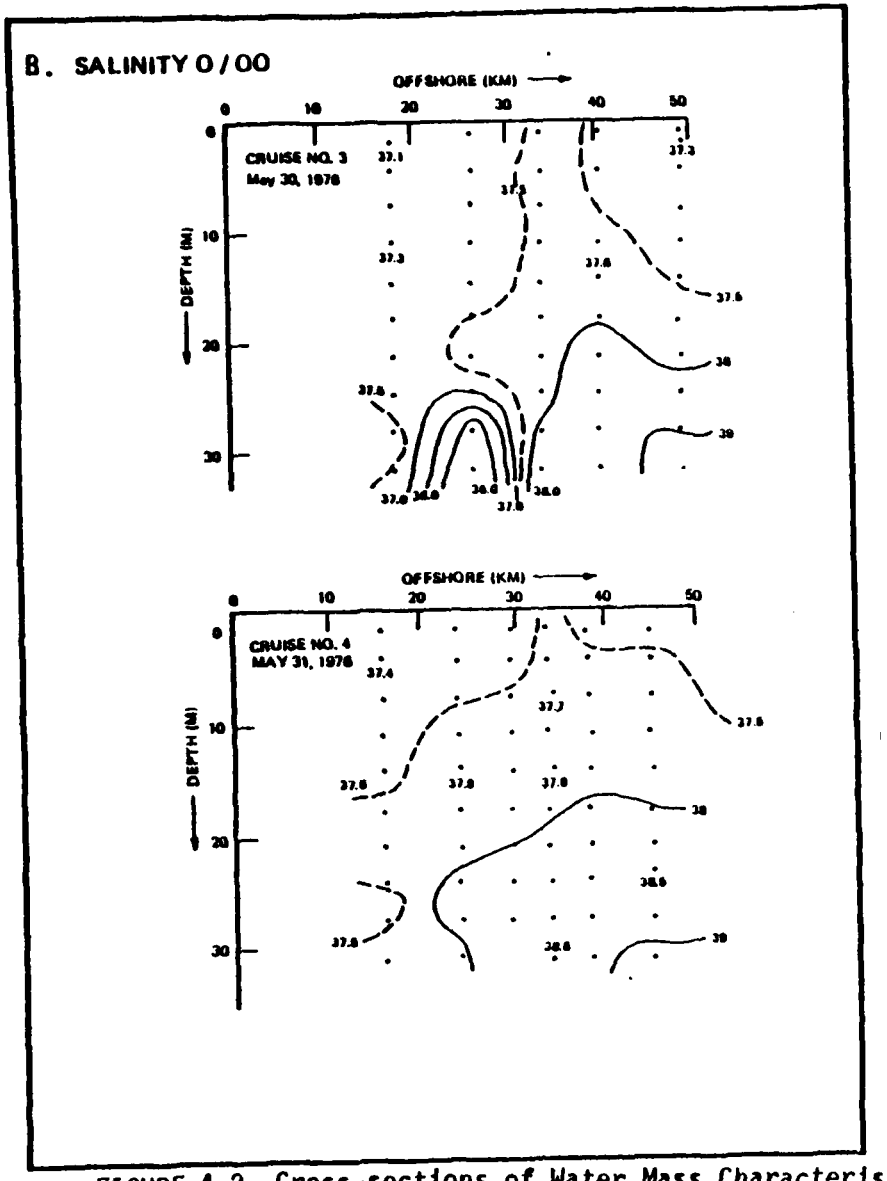


FIGURE 4.2 Cross-sections of Water Mass Characteristics over Iranian Shelf, 1976



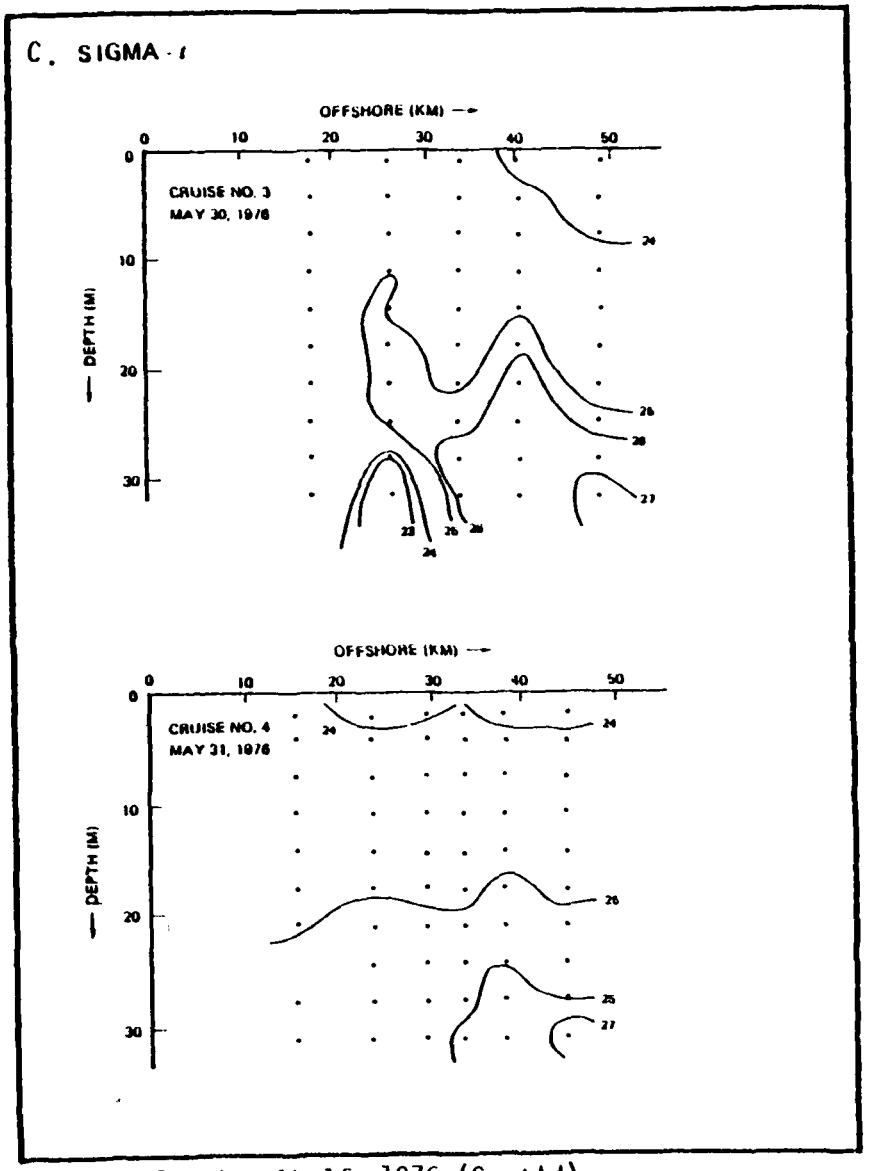


FIGURE 4.2 Cross-sections of Water Mass Characteristics over Iranian Shelf, 1976 (Cont'd)

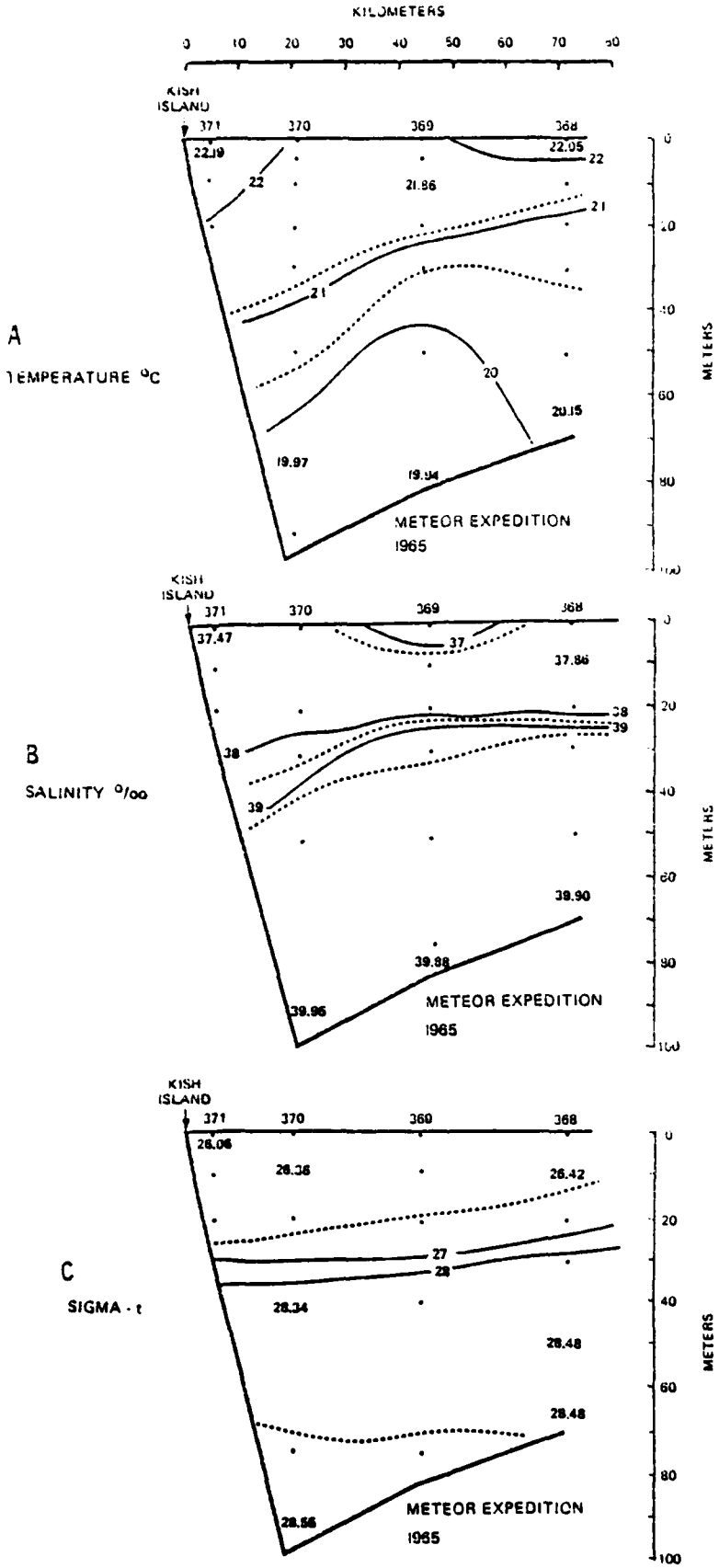


FIGURE 4.3 Cross-sections of Water Mass Characteristics from Meteor Expedition, 1965, off Kish Island, Iran

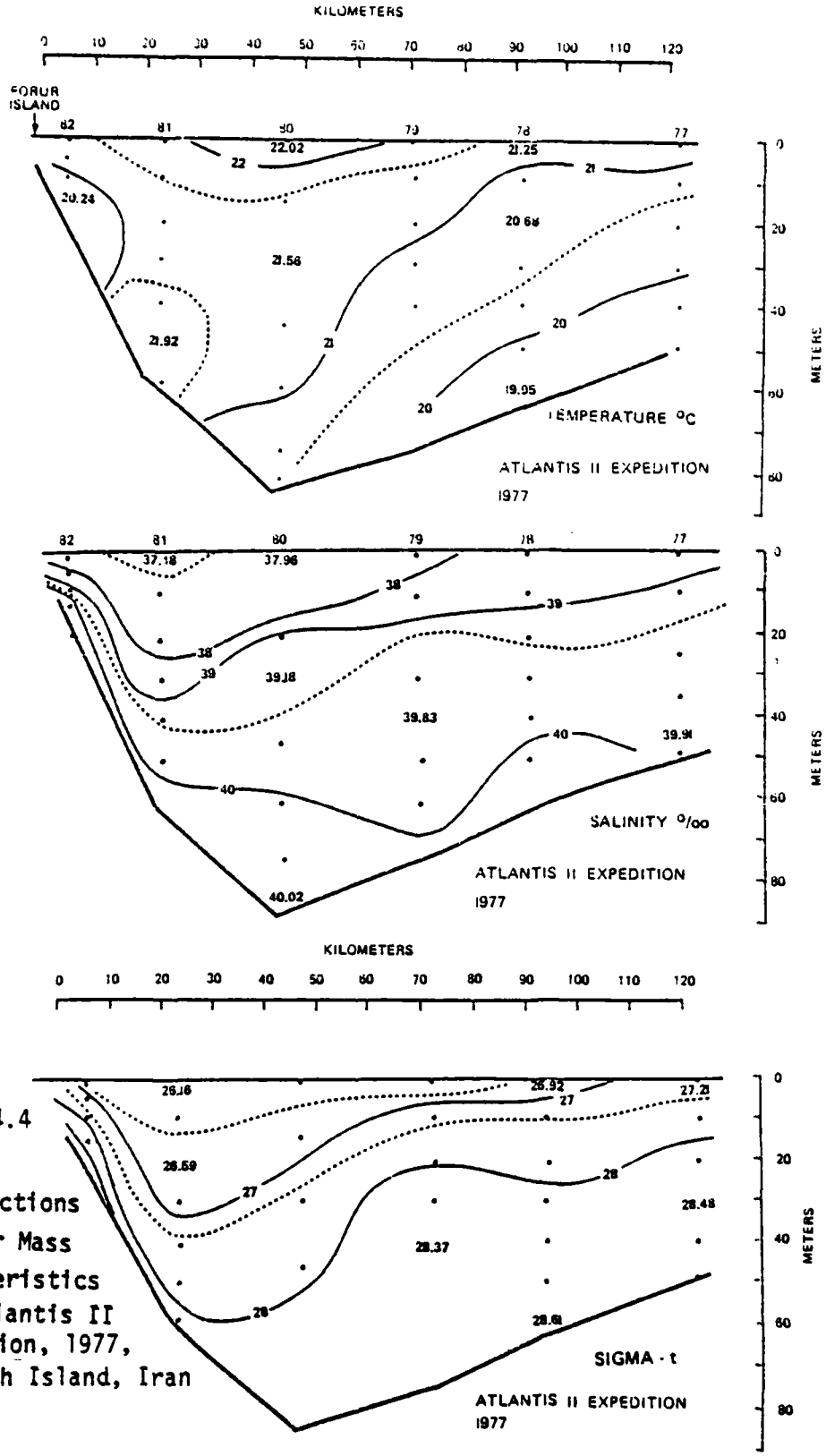


FIGURE 4.4

Cross-sections of Water Mass Characteristics from Atlantis II Expedition, 1977, off Kish Island, Iran

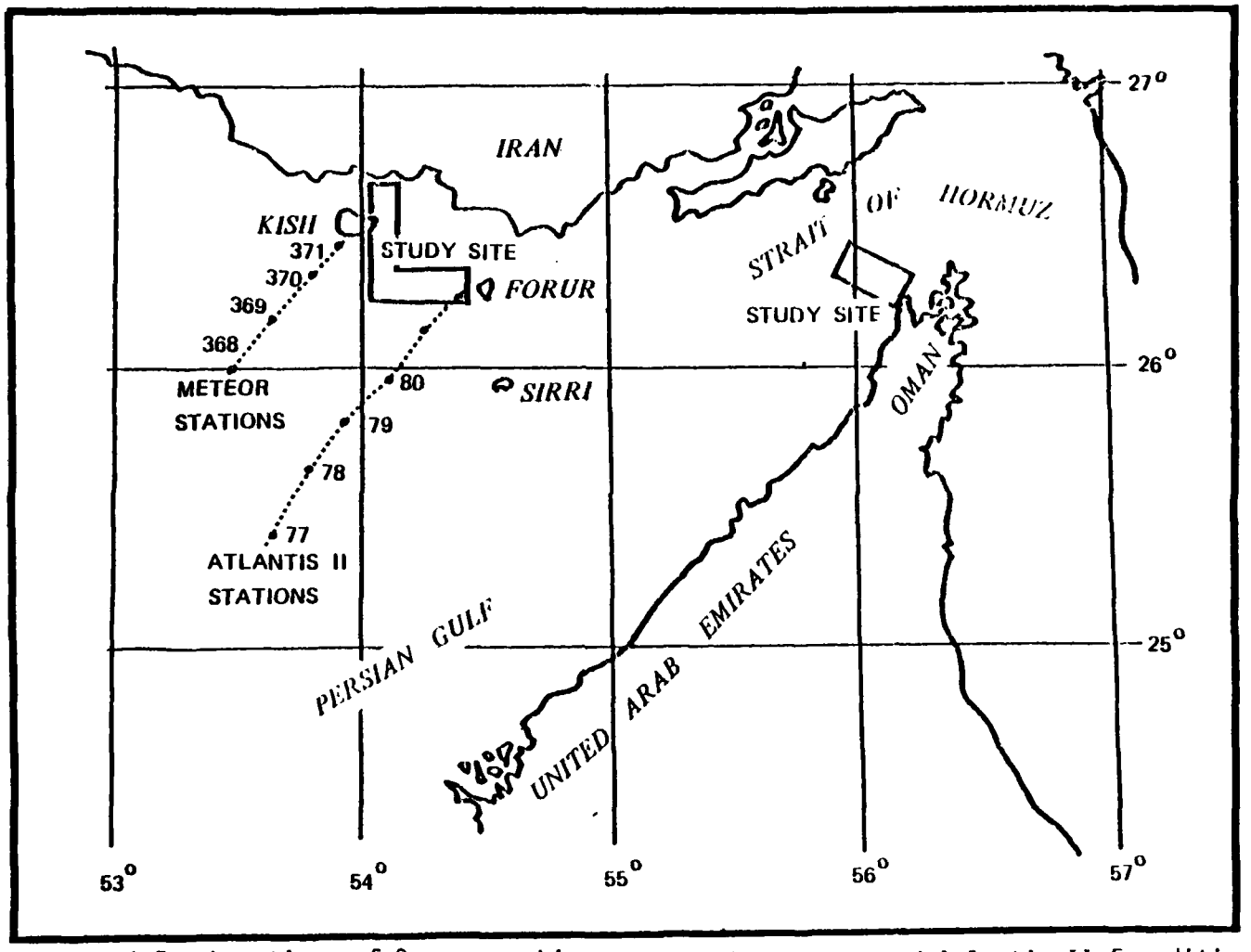


FIGURE 4.5 Locations of Oceanographic Stations for Meteor and Atlantis II Expeditions

only about 0.02 - 0.05 °C/meter, it was as much as 0.15 °C in this study. These differences would mean that the inflow grows by a quantum jump between April and May off Kish Island, with accompanying intensification of mixing with the cooler Persian Gulf water.

It is interesting to notice in both Figures 4.3 and 4.4 the presence of a warm-water lens on the offshore surface bounded by a 22 °C isotherm in an area approximately 30 - 50km from the shore. This warm-water lens may represent the core of the inflow and be responsible for the increase in surface temperature toward offshore as observed in this study. The presence of a similar warm-water lens is only partially indicated in the data of this study.

The three sets of data show a similar order of magnitude for salinity, except that a distinct halocline indicated in both the Meteor and Atlantis II data has not been revealed in this study which sampled the water only to a depth of 30 m. The presence of a lens of low-salinity surface water about 40 - 50 km offshore, shown in the Meteor data (Figure 4.3B), again is an indication of the core of the inflow at this location.

5. WATER MASS CHARACTERISTICS IN THE STRAIT OF HORMUZ

The investigation in the Strait of Hormuz was conducted during the latter part of April in 1977. It should be noted that this investigation was carried out on the Oman side of the Strait south of the international boundary, hence away from an area off the Iranian shore where the inflow is believed to be concentrated (see Figure 5.1). Temperature and conductivity were measured with a CTD meter (Martek model TDC) aboard a chartered dhow. Tabulation of the data is presented in Appendix C.

Figure 5.2A, B, and C show the cross-sections of temperature, salinity and density obtained in this study in the southern half of the Strait of Hormuz. Figure 5.2D shows a cross-sectional distribution of water types, based on a T-S analysis as shown in Figure 5.3. The data off Kish Island over the Iranian shelf obtained in the 1976 field study are also plotted in Figure 5.3 to allow comparison.

The water masses in the Strait are distinctly stratified, consisting of three types in terms of temperature, salinity and depth, as shown in Table 5.1.

Table 5.1

Water Types in the Strait of Hormuz

Layers	Thickness	Temperature		Salinity	
		Range	Gradient	Range	Gradient
	(m)	(°C)	(°C/M)	(°C)	(°C/m)
Upper	0 to 30	26-23	-0.60	35-38	-0.20
Middle	5 to 25	21-16	-0.20	38-40	-0.20
Lower	30 to 60	16-14	-0.03	41-44	-0.20

The upper layer featured relatively high temperatures above 23 °C and low salinities below 38 $^{o}/_{oo}$, and essentially represented the typical characteristics of the oceanic waters in the Arabian Sea. In the Strait, this water was found above a distinct thermocline which sloped steeply from a point about 30 km offshore

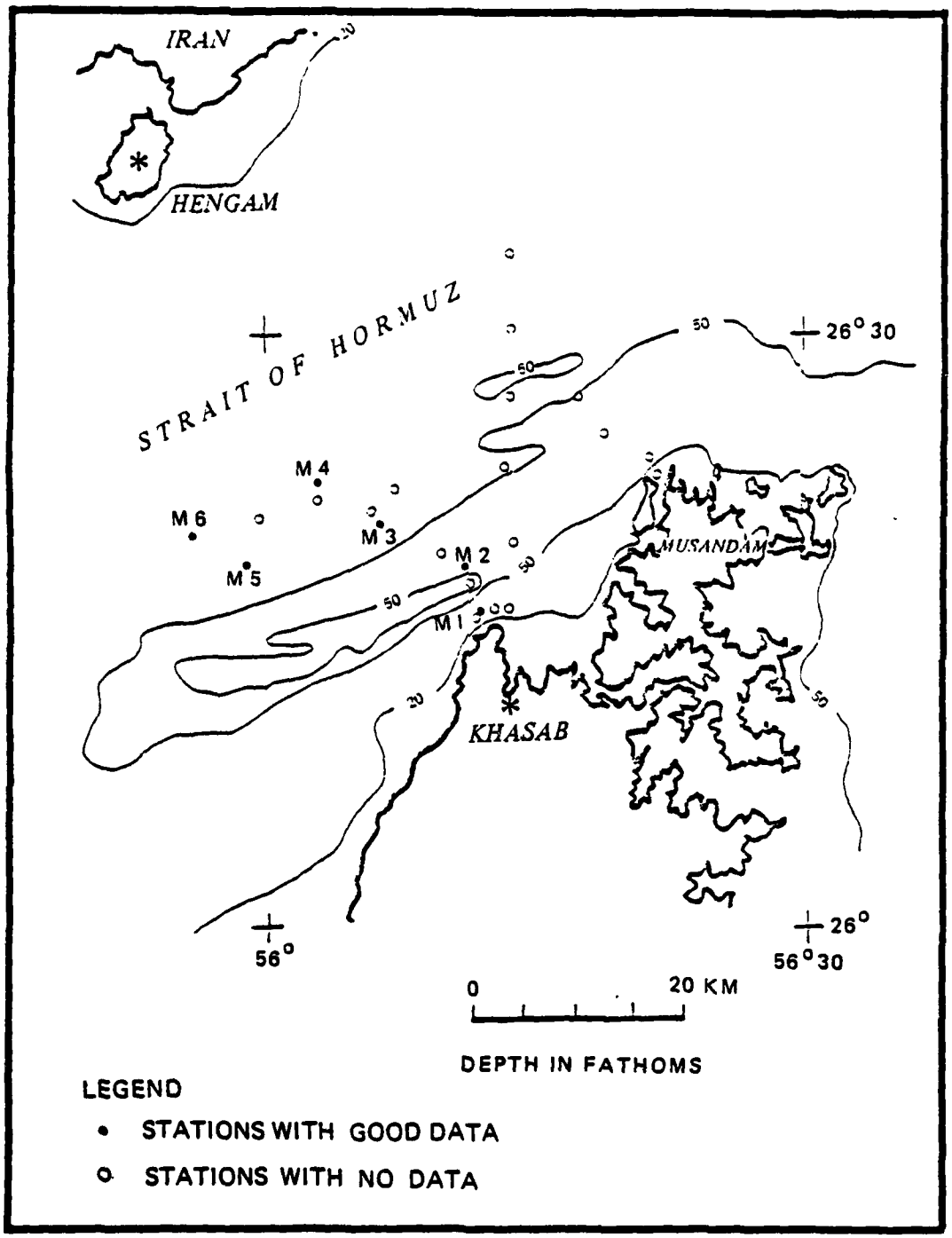


FIGURE 5.1 Oceanographic Stations in the Strait of Hormuz, 1977

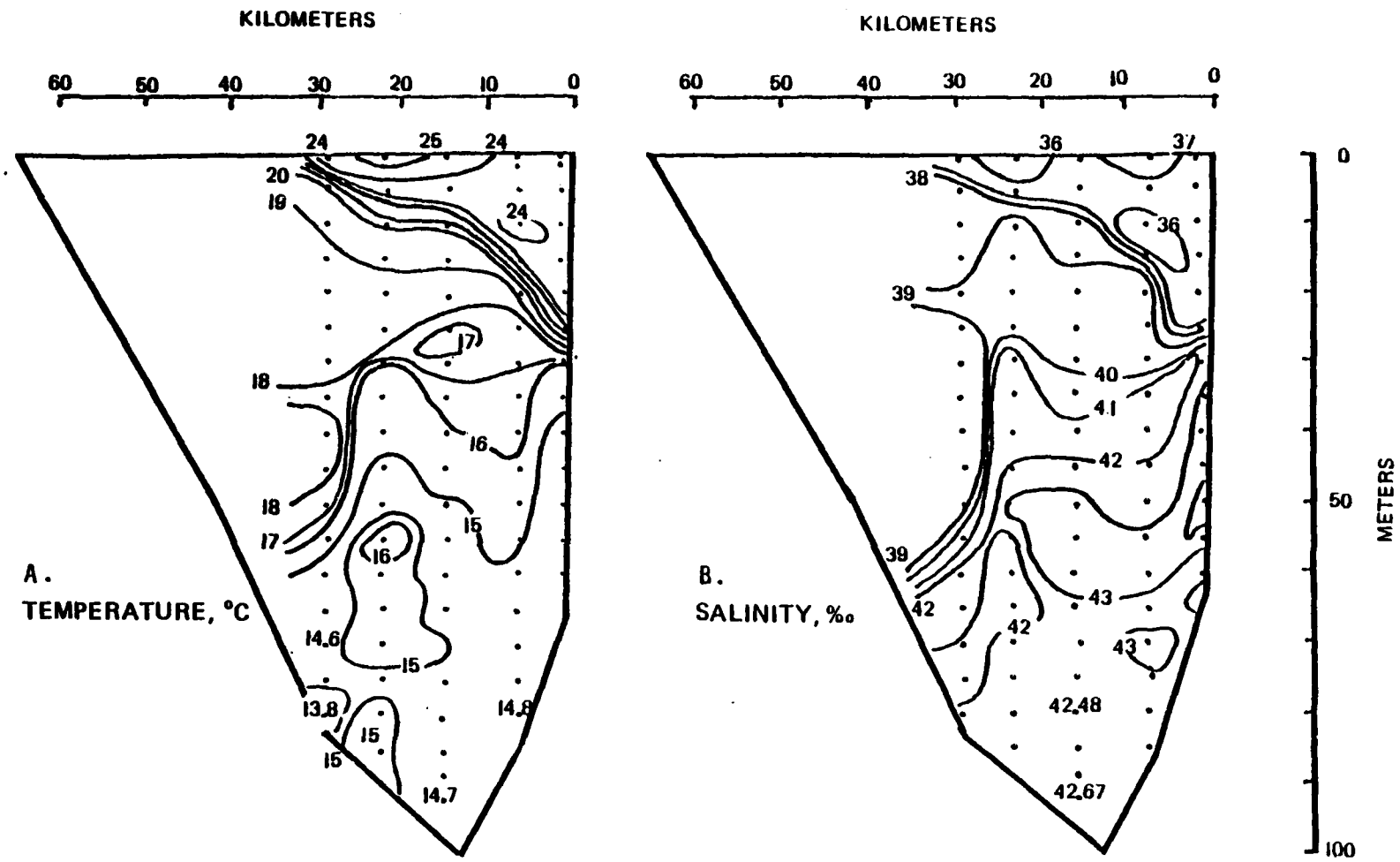


FIGURE 5.2 Cross-sections of Water Mass Characteristics in the Strait of Hormuz, 1977

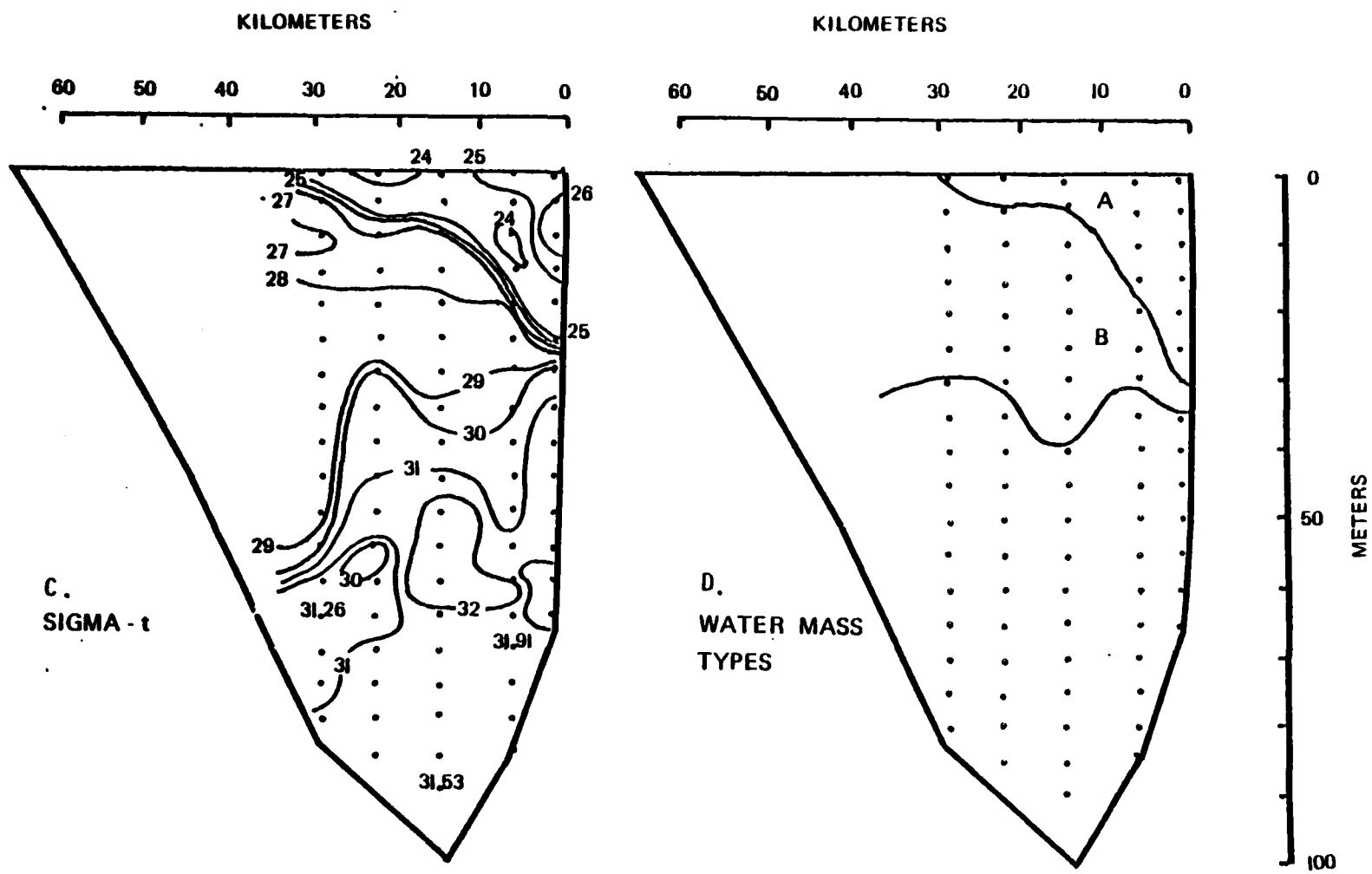


FIGURE 5.2 Cross-sections of Water Mass Characteristics in the Strait of Hormuz, 1977 (Cont'd)

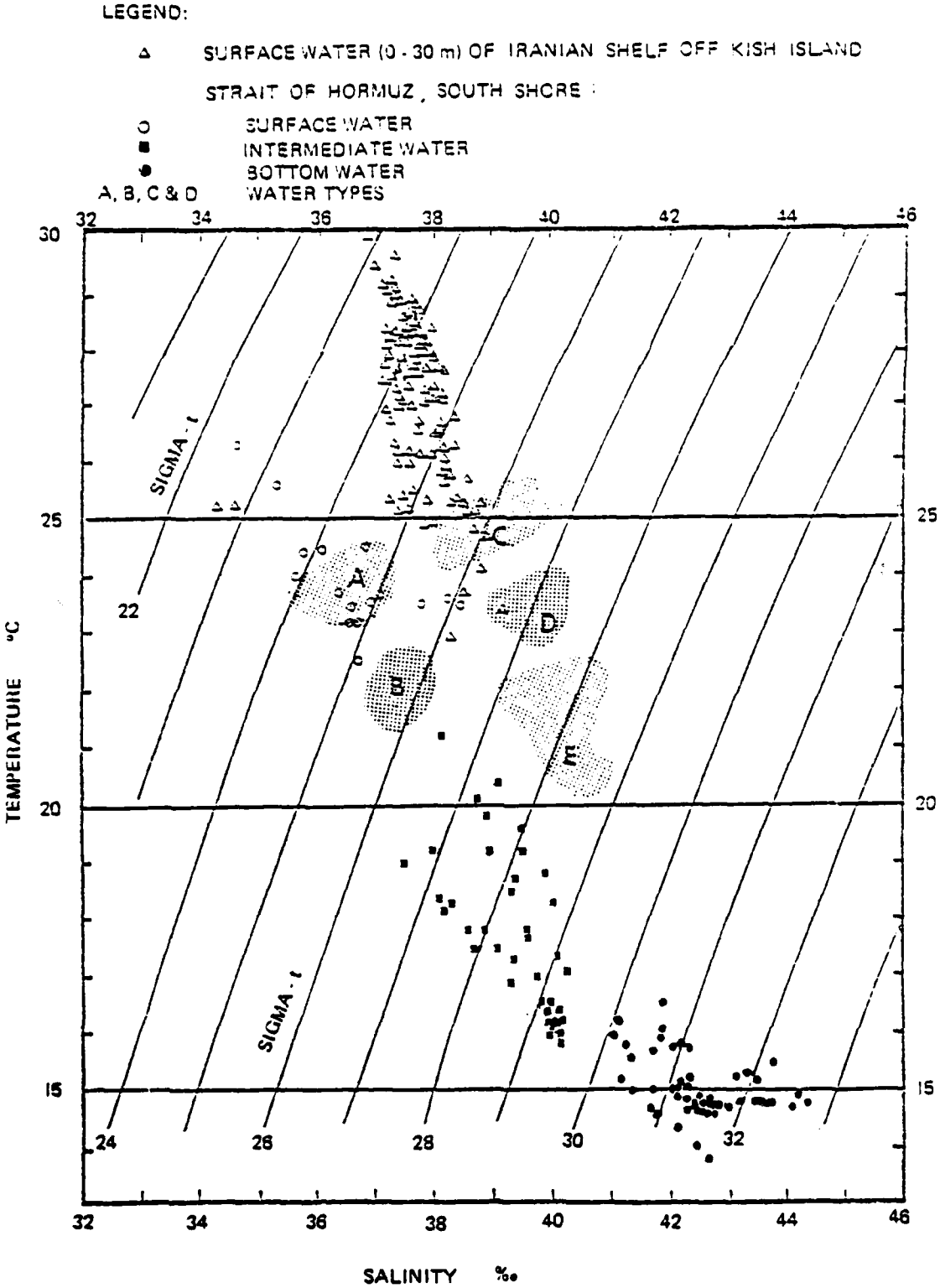


FIGURE 5.3 T-S Diagram

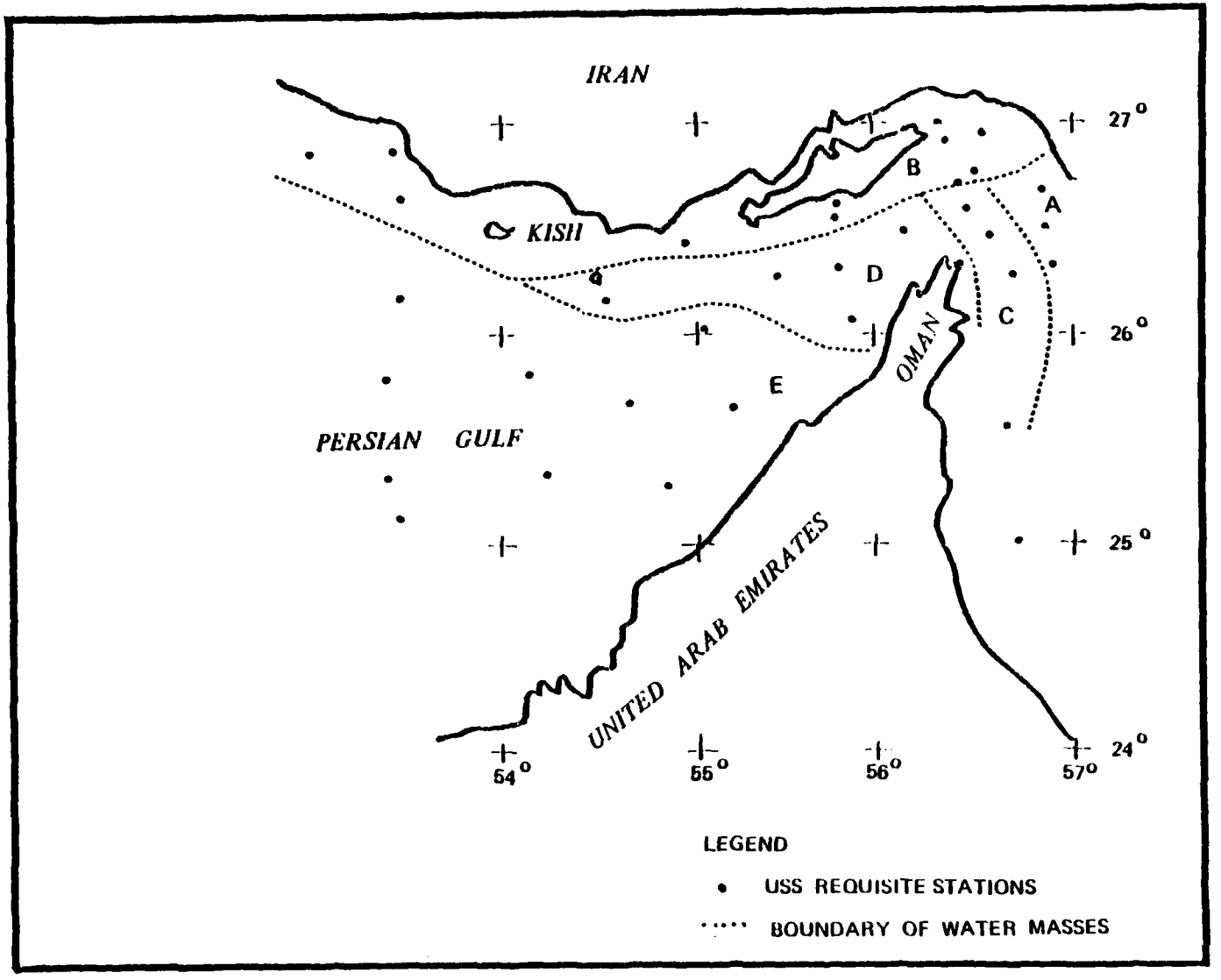


FIGURE 5.4 Distribution of Bottom Water Samples for 1961 USS Requisite Expedition

to a depth of about 30 m on the nearshore bottom.

The middle layer was wedged between the upper and bottom layers with thicknesses varying from zero at the nearshore bottom to about 25 m at a point about 30 km offshore. The T-S diagram in Figure 5.3 suggests that this layer is a mixing zone between the upper and the bottom layers. Temperatures in this layer ranged from about 21 to 16 °C, and salinities from about 38 to 40 ‰.

The bottom layer occupied a thickness as much as about 60% of the entire cross-section in the southern half of the Strait, whereas the upper and middle layers occupied only about 20% each. This situation was quite contrasting with the Meteor data which revealed only a thin bottom layer about 15 m thick. It is possible that the Meteor expedition employing sparsely distributed stations might have missed the core of the bottom layer. The water in the bottom layer in this study featured very low temperatures generally less than 16 °C and very high salinities generally above 40 ‰. The lowest observed temperature of 14.8 °C and the highest observed salinity of 44.06 ‰ were both located in this layer.

It is of interest to notice in Figures 5.2 that whereas the isopycnal boundary between the upper and middle layers is well defined, that between the middle and lower layers is relatively indistinct. This would mean that there exists an upward entrainment of the outgoing Gulf water from the lower to the middle layers.

In order to estimate the distribution of the water masses found in this study in the general vicinity of the Strait of Hormuz, the data on bottom water samples obtained by the USS Requisite expedition of the U.S. Naval Oceanographic Office (Peery, 1965) are shown in the T-S diagram of Figure 5.3 (see the range of data scatter

delineated by shaded areas named A, B, C, D and E). This expedition was carried out during January through March 1961. The location of the data is shown in Figure 5.4.

It is evident that some of the USS Requisite data fall in the same area of the data of this study in the T-S diagram (Figure 5.3). For instance, water type A, which occupies the Strait to its approximate mid-point (Figure 5.4), is essentially identical to the water found in the surface layer on the Oman (southern) side of the Strait in this study. This means that this water type, probably representing the core of the inflow from the Arabian Sea, which normally adheres to the northern (Iranian) shore while transiting through the Strait, was spilling over to the south (Oman) side during the time of our study in April. Water type B, which is found in a band elongated as far as Kish Island and beyond in the USS Requisite data (Figure 5.4), essentially represents the same characteristics with the intermediate water on the south side of the Strait found in this study (Figure 5.3). This water type is a product of partial mixing between the water from the Arabian Sea and that inside the Persian Gulf. Both of these water types A and B also appear in the Atlantis II data, type A covering the entire surface of the Strait of Hormuz and type B in an elongated band along the Iranian coast inside the Persian Gulf. Types C, D and E in the USS Requisite data failed to appear on the southern half of the Strait in this study.

Figure 5.3 also allows comparison between the waters off Kish Island which were investigated during the study in May 1976 and in the Strait of Hormuz in April 1977. The water off Kish Island is seen in this T-S diagram to represent an upward transition in temperature scale from the surface water in the Strait, while maintaining essentially the same level of salinity. This means that the inflow has been influenced by the warming trend in the Persian Gulf

while traveling from the Strait to the points near Kish Island, a distance of about 200 km. A downward transposition of the data for Kish Island by about 5 to 7 ^{o}C in the T-S diagram will produce an almost complete superimposition of the Kish Island data over the surface and middle layers in the Strait, indicating that the temperature rise due to the warming trend was approximately 5 to 7 ^{o}C, and that the waters in the upper 30 m found within about 50 km off Kish Island in May 1976 were essentially the same water found in the upper and middle layers (to 25 to 30 m in depth) in the Strait in April 1977.

6. DISCUSSIONS AND CONCLUSIONS

The Persian Gulf is known to generate one of the highest salinities of sea water in the world. Historically, the highest observed salinity on record was 42.6 $^{o}/_{oo}$ reported by Blegvad in the Bahrein Bay area (Blegvad, 1944). The 1961 USS Requisite expedition reported 42.08 $^{o}/_{oo}$ east of Qatar Peninsula in January. Emery (1956) reported a measurement of 42.4 $^{o}/_{oo}$ in the Kuwait and Bahrein Bays. A maximum salinity reported by the Atlantis II expedition in 1977 was 41.3 $^{o}/_{oo}$, and that by the Meteor expedition 40.61 $^{o}/_{oo}$.

A maximum salinity measured in this study, i.e. 44.31 $^{o}/_{oo}$, exceeds any of the historical highs reported. Out of the 55 readings taken in the bottom layer in the Strait of Hormuz in 1977, all but 5 readings exceeded 40 $^{o}/_{oo}$ in this study.

The lowest historical record of sea water temperature in the Persian Gulf was 12.3 ^{o}C south of Shatt al Arab in mid-February

(Schott, 1918). Other low temperatures reported in recent years were 17.68 °C by the Meteor expedition in 1965 (Brettschneider et al., 1970), 16.31 °C by the Atlantis II expedition (Brewer et al., 1978), and 17.30 °C by the USS Requisite expedition (Peery, 1965). The lowest observed temperature in this study was 13.8 °C, lower than all the historical lows except for the all-time low of 12.3 °C reported by Schott (1918). Of the 55 temperature readings taken in the bottom layer in the Strait of Hormuz in this study, all but 9 readings exhibited temperatures lower than 16 °C.

The highest observed sea water temperature in this study was 29.8 °C in the nearshore surface off Kish Island in May 1976, and 26.3 °C at the surface (1 m deep) in the Strait of Hormuz in April 1977.

Key conclusions of this study are summarized below:

1. In the month of May, the inflow from the Arabian Sea and the Gulf of Oman is detected at a point about 200 km inside the Persian Gulf and is found over the shelf off the Iranian coast within about 50 km from the shore. In the upper 30 meters over this shelf, the surface water is essentially an unmixed water originating in the Gulf of Oman. However, the water at a 30-m depth has been mixed partially with the water in the Persian Gulf. The temperature of this water was 5 to 7 °C higher than at the Strait, probably due to the warming trend in the Gulf at this time of the year.

2. The direction of the currents in this inflow off Kish Island was opposed to the general northwest trend at the time of this study. This is considered to indicate that at this time of the year (May) the inflow is not sufficiently strong to overcome the effects of local winds.

3. In the southern half of the Strait of Hormuz, the water is stably stratified, consisting of three distinct

layers in the upper 30 m, the middle 20 m, and the lower 30 m. The upper layer exhibits identical water mass characteristics with the inflow from the Arabian Sea, the lower layer with the outflow. The middle layer represents a product of mixing between the inflow and the outflow. The mixing takes places as an upward entrainment of the outflow.

4. The outflowing bottom layer observed in this study was approximately 30 m thick, about twice the thickness previously reported by the Meteor expedition.

5. Salinity and temperature extremes found in this study generally exceeded the historically reported data. The highest observed salinity and the lowest observed temperature in this study both occurred in the bottom layer in the Strait of Hormuz, being 44.31 $^{o}/_{oo}$ and 13.8 ^{o}C, respectively. The highest observed temperature in this study was as much as 29.8 ^{o}C at the near-shore surface off Kish Island in May 1976, and 26.3 ^{o}C at the surface of the Strait of Hormuz in April 1977.

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APPENDIX A

CURRENT PROFILES
THE IRANIAN SHELF
MAY 1976

STATION 1_ 1

D[M]	V[KTS]	C[DEG]	X	Y
3	0.30	[illegible]	[illegible]	[illegible]
8	0.35	[illegible]	[illegible]	[illegible]
13	0.50	250.00	[illegible]	[illegible]
23	[illegible]	[illegible]	[illegible]	[illegible]
33	0.60	200.00	[illegible]	[illegible]
43	0.65	200.00	[illegible]	[illegible]
51	0.70	135.00	0.495	[illegible]

STATION 1_ 2

D[M]	V[KTS]	C[DEG]	X	Y
13	0.50	180.00	0.000	-0.500
33	0.55	145.00	0.315	-0.451
43	0.25	135.00	0.177	-0.177

STATION 1_ 3

D[M]	V[KTS]	C[DEG]	X	Y
8	0.30	180.00	0.000	-0.300
13	0.35	185.00	-0.031	-0.349
21	0.70	165.00	0.181	-0.676

STATION 1_ 4

D[M]	V[KTS]	C[DEG]	X	Y
13	0.54	185.00	-0.047	-0.539
23	0.60	300.00	-0.205	-0.564
33	0.60	90.00	0.600	0.000
43	0.70	180.00	0.000	-0.700
53	0.75	165.00	0.194	-0.724
63	0.55	170.00	0.096	-0.542
73	0.60	170.00	0.104	-0.591
83	0.60	180.00	0.000	-0.600
93	0.80	135.00	0.566	-0.566

D[M]: Depth in meters. V[KTS]: Speed in knots.
C[DEG]: Direction to, in degrees clockwise from N.
X: in knots, (t) to east, (-) to west.
Y: in knots, (t) to north, (-) to south.

CURRENT PROFILES (cont'd.)

STATION 1_ 5

D[M]	V[KTS]	C[DEG]	X	Y
3	0.30	150.00	0.150	-0.260
13	0.60	150.00	0.300	-0.520
23	0.55	170.00	0.096	-0.542
33	0.65	180.00	0.000	-0.650
43	0.70	180.00	0.000	-0.700
53	0.85	120.00	0.736	-0.425
63	0.85	170.00	0.148	-0.837
73	0.65	100.00	0.640	-0.113
83	0.70	145.00	0.402	-0.573
93	0.75	110.00	0.705	-0.257

STATION 1_ 6

D[M]	V[KTS]	C[DEG]	X	Y
3	0.35	160.00	0.120	-0.329
13	0.55	170.00	0.096	-0.542
23	0_75	190.00	-0.130	-0.739
33	0.70	135.00	0.495	-0.495
43	0.60	180.00	0.000	-0.600
53	0.75	190.00	-0.130	-0.739
63	0.65	120.00	0.563	-0.325
73	0.75	145.00	0.430	-0.614
83	0.65	130.00	0.498	-0.417
93	0.75	170.00	0.130	-0.739

STATION 2-1

2_ 1

D[M]	V[KTS]	C[DEG]	X	Y
3	0.10	140.00	0.064	-0.07[illegible]
8	0.05	220.00	-0.032	-0.030
13	0.03	135.00	0.021	-0.021
23	0.05	180.00	0.000	-0.050
28	0.05	180.00	0.000	-0.050
33	0.20	250.00	-0.188	-0.068
38	0.20	260.00	-0.137	-0.035
41	0.15	45.00	0.106	0.106

CURRENT PROFILES (cont'd.)

STATION 3L 1

D[M]	V[KTS]	C[DEG]	X	Y
3	0.25	130.00	0.192	-0.161
8	0.05	170.00	0.009	-0.049
13	0.02	70.00	0.019	0.007
18	0.30	100.00	0.295	-0.052
23	0.30	145.00	0.172	-0.246
33	0.35	135.00	0.247	-0.247
38	0.46	150.00	0.240	-0.414
43	0.35	170.00	0.061	-0.347
46	0.25	180.00	0.000	-0.250

STATION 3L 3

D[M]	V[KTS]	C[DEG]	X	Y
3	0.25	190.00	-0.043	-0.246
8	0.30	170.00	0.052	-0.299
13	0.30	180.00	0.000	-0.300
18	0.30	130.00	0.230	-0.191
23	0.35	160.00	0.120	-0.329
28	0.45	220.00	-0.154	-0.403
33	0.45	180.00	0.000	-0.450
38	0.35	180.00	0.000	-0.350
43	0.35	180.00	0.000	-0.350
47	0.40	140.00	0.257	-0.306

STATION 3L 4

D[M]	V[KTS]	C[DEG]	X	Y
3	0.30	125.00	0.246	-0.172
8	0.45	145.00	0.258	-0.369
13	0.20	120.00	0.000	-0.200
18	0.10	270.00	-0.100	0.000
23	0.25	220.00	-0.192	-0.121
28	0.35	210.00	-0.175	-0.303
33	0.35	210.00	-0.175	-0.303
38	0.45	210.00	-0.225	-0.390
43	0.30	210.00	-0.150	-0.260
48	0.40	180.00	0.000	-0.400
53	0.50	180.00	0.000	-0.500
63	0.30	180.00	0.000	-0.300
65	0.30	180.00	0.000	-0.300

CURRENT PROFILES (cont'd.)

STATION [illegible]

D(M)	V(KTS)	C(DEG)		
3	0.35	180.00	0.000	[illegible]
8	0.50	[illegible]	[illegible]	[illegible]
13	0.40	210.00	[illegible]	[illegible]
18	0.15	140.00	[illegible]	[illegible]
23	0.20	150.00	[illegible]	[illegible]
28	0.15	140.00	[illegible]	[illegible]
[illegible]	0.10	110.00	[illegible]	[illegible]
[illegible]	0.10	100.00	[illegible]	[illegible]
40	0.15	115.00	[illegible]	[illegible]
45	0.15	115.00	-0.201	[illegible]
[illegible]	0.15	100.00	[illegible]	[illegible]
[illegible]	0.17	100.00	[illegible]	[illegible]
[illegible]	0.19	100.00	[illegible]	[illegible]
[illegible]	0.20	100.00	[illegible]	[illegible]
[illegible]	0.10	100.00	[illegible]	[illegible]
80	0.10	90.00	0.100	0.000

STATION [illegible] 6

D(M)	V(KTS)	C(DEG)	X	Y
3	0.45	275.00	-0.448	0.039
8	0.45	260.00	-0.443	-0.078
13	0.20	280.00	-0.197	0.035
18	0.10	315.00	-0.071	0.071
23	0.10	45.00	0.071	0.071
28	0.25	215.00	-0.143	-0.105
33	0.25	190.00	-0.043	-0.246
38	0.30	180.00	0.000	-0.300
43	0.30	190.00	-0.052	-0.295
48	0.40	215.00	-0.229	-0.328
53	0.30	180.00	0.000	-0.300
63	0.20	180.00	0.000	-0.200
68	0.10	110.00	0.094	-0.034
73	0.10	135.00	0.071	-0.071
78	0.18	135.00	0.127	-0.127
80	0.50	180.00	0.000	-0.500

CURRENT PROFILES (cont'd.)

STATION 2_ 7

D[M]	V[KTS]	C[DEG]	X	Y
3	0.40	260.00	-0.394	[illegible]
8	0.60	270.00	-0.600	0.000
13	0.45	280.00	-0.443	0.078
18	0.35	270.00	-0.345	-0.061
23	0.10	300.00	-0.098	-0.017
28	0.40	225.00	-0.283	-0.283
33	0.30	225.00	-0.212	-0.212
38	0.40	220.00	-0.257	-0.306
43	0.38	215.00	-0.218	-0.311
48	0.30	215.00	-0.172	-0.246
53	0.30	215.00	-0.172	-0.246
58	0.35	190.00	-0.061	-0.345
63	0.30	190.00	-0.103	-0.295
73	0.25	190.00	-0.043	-0.246
78	0.15	200.00	-0.051	-0.141
83	0.30	180.00	0.000	-0.300

STATION 2_ 8

D[M]	V[KTS]	C[DEG]	X	Y
3	0.15	270.00	-0.150	0.000
8	0.30	270.00	-0.300	0.000
13	0.35	290.00	-0.329	0.119
18	0.38	290.00	-0.357	0.130
23	0.25	225.00	-0.177	-0.177
28	0.15	225.00	-0.106	-0.106
33	0.35	203.00	-0.137	-0.322
38	0.40	203.00	-0.156	-0.368
43	0.30	203.00	-0.117	-0.276
48	0.20	206.00	-0.094	-0.177
53	0.20	238.00	-0.170	-0.106
63	0.15	210.00	-0.075	-0.130
68	0.20	180.00	0.000	-0.200
73	0.10	150.00	0.050	-0.087
78	0.08	150.00	0.040	-0.069
83	0.09	150.00	0.045	-0.078
88	0.12	110.00	0.113	-0.041
92	0.25	130.00	0.192	-0.161

STATION 3_ 1

D[M]	V[KTS]	C[DEG]	X	Y
3	0.50	90.00	0.500	0.000
8	0.55	55.00	0.451	0.315
13	0.45	80.00	0.443	0.078
18	0.50	90.00	0.500	0.000
23	0.50	90.00	0.500	0.000
28	0.50	90.00	0.500	0.000
33	0.35	80.00	0.345	0.061
36	0.30	80.00	0.295	0.052

CURRENT PROFILES (cont'd.)

STATION 3_ 2

D[M]	V[KTS]	C[DEG]	X	Y
3	0.30	100.00	0.295	-0.052
8	0.30	140.00	0.129	-0.[illegible]
13	0.35	170.00	0.061	-0.147
18	0.50	170.00	0.087	-0.[illegible]
23	0.60	170.00	0.104	-0.[illegible]
28	0.30	180.00	0.000	-0.300
31	0.50	180.00	0.000	-0.500

STATION 3_ 3

D[M]	V[KTS]	C[DEG]	X	Y
3	0.45	40.00	0.289	0.145
8	0.45	30.00	0.325	0.190
13	0.35	45.00	0.247	0.247
18	0.38	0.00	0.000	0.180
23	0.30	45.00	0.212	0.212

STATION 3_ 4

D[M]	V[KTS]	C[DEG]	X	Y
3	0.20	180.00	0.000	-0.200
8	0.15	90.00	0.150	0.000
13	0.30	90.00	0.300	0.000
18	0.20	100.00	0.197	-0.035
23	0.30	100.00	0.295	-0.052
28	0.25	100.00	0.246	-0.043
33	0.45	100.00	0.443	-0.078
38	0.35	100.00	0.345	-0.061
43	0.40	100.00	0.394	-0.069
48	0.75	100.00	0.739	-0.130
53	0.75	100.00	0.739	-0.130
58	0.40	100.00	0.394	-0.069
68	0.50	100.00	0.492	-0.087
73	0.40	100.00	0.394	-0.069
78	0.55	100.00	0.542	-0.096
83	0.45	100.00	0.443	-0.078
88	0.45	135.00	0.318	-0.318
93	0.40	120.00	0.346	-0.200
98	0.45	450.00	0.450	0.000

CURRENT PROFILES (cont'd.)

STATION 3_ 5

D[M]	V[KTS]	C[DEG]	X	Y
3	0.35	270.00	-0.150	0.000
8	0.15	270.00	-0.150	0.000
13	0.15	225.00	-0.106	-0.106
18	0.35	130.00	-0.061	-0.145
23	0.50	180.00	0.000	-0.500
28	0.40	110.00	-0.137	-0.306
33	0.25	225.00	-0.177	-0.177
38	0.20	180.00	0.000	-0.200
43	0.30	150.00	0.150	-0.260
48	0.30	150.00	0.150	-0.260
53	0.25	140.00	0.161	-0.192
58	0.30	90.00	0.300	0.000
68	0.20	115.00	0.254	-0.113
73	0.18	120.00	0.156	-0.090
78	0.10	115.00	0.071	-0.07[illegible]
83	0.18	125.00	0.147	-0.103
88	0.22	140.00	0.141	-0.169

STATION 3_ 6

D[M]	V[KTS]	C[DEG]	X	Y
3	0.50	190.00	-0.087	-0.492
8	0.45	210.00	-0.225	-0.390
13	0.38	195.00	-0.098	-0.367
18	0.30	195.00	-0.078	-0.290
23	0.08	190.00	-0.014	-0.079
28	0.25	170.00	0.043	-0.246
33	0.22	165.00	0.057	-0.211
38	0.25	145.00	0.143	-0.205
43	0.38	140.00	0.244	-0.291
48	0.35	145.00	0.201	-0.287
53	0.30	150.00	0.150	-0.260
63	0.22	150.00	0.110	-0.191
68	0.10	180.00	0.000	-0.100
73	0.08	180.00	0.000	-0.080
78	0.05	155.00	0.021	-0.045
80	0.10	135.00	0.071	-0.071

STATION 4_ 1

D[M]	V[KTS]	C[DEG]	X	Y
3	0.25	325.00	-0.143	0.205
8	0.32	325.00	-0.184	0.262
13	0.15	68.00	0.139	0.056
18	0.15	100.00	0.148	-0.025
23	0.15	45.00	0.106	0.106
28	0.25	90.00	0.250	0.000
33	0.30	95.00	0.299	-0.026
38	0.45	100.00	0.443	-0.078
43	0.32	120.00	0.277	-0.160
45	0.40	100.00	0.394	-0.069

CURRENT PROFILES (cont'd.)

STATION 4_ 1

D[M]	W[KTS]	C[DEG]	X	Y
3	0.48	360.00	0.000	0.480
8	0.25	10.00	0.125	0.217
13	0.20	360.00	0.000	0.200
18	0.10	150.00	0.074	-0.044
23	0.15	90.00	0.150	0.000
28	0.25	135.00	0.177	-0.177
38	0.30	180.00	0.000	-0.300
43	0.35	200.00	-0.120	-0.329
45	0.50	270.00	-0.500	0.000

STATION 4_ 2

D[M]	W[KTS]	C[DEG]	X	Y
3	0.25	270.00	-0.250	0.000
8	0.30	360.00	0.000	0.300
13	0.40	30.00	0.200	0.346
18	0.22	50.00	0.169	0.141
23	0.22	60.00	0.191	0.110
28	0.33	60.00	0.286	0.165
33	0.40	135.00	0.283	-0.283
38	0.50	100.00	0.492	-0.087
43	0.55	100.00	0.542	-0.096
48	0.55	80.00	0.542	0.096
53	0.75	60.00	0.650	0.375
63	0.50	90.00	0.500	0.000
67	0.50	100.00	0.492	-0.087

STATION 4_ 4

D[M]	W[KTS]	C[DEG]	X	Y
3	0.35	360.00	0.000	0.350
8	0.22	360.00	0.000	0.220
13	0.40	360.00	0.000	0.400
18	0.40	360.00	0.000	0.400
23	0.35	20.00	0.120	0.329
28	0.27	60.00	0.234	0.135
33	0.30	50.00	0.230	0.193
38	0.32	50.00	0.245	0.206
43	0.67	50.00	0.513	0.431
48	0.42	55.00	0.344	0.241
53	0.45	90.00	0.450	0.000
63	0.45	90.00	0.450	0.000
68	0.32	90.00	0.320	0.000
73	0.20	90.00	0.200	0.000

STATION 4_ 5

D[M]	V[KTS]	C[DEG]	X	Y
3	0.15	170.00	-0.150	[illegible]
8	0.15	170.00	0.042	-0.14[illegible]
13	0.20	150.00	0.000	-0.200
18	0.15	150.00	0.07[illegible]	-0.1[illegible]
23	0.40	150.00	0.[illegible]	-0.14[illegible]
28	0.40	150.00	0.300	-0.14[illegible]
33	0.40	150.00	0.130	-0.14[illegible]
38	0.55	-0.00	0.154	-0.41[illegible]
43	0.50	120.00	0.[illegible]0	-0.100
48	0.45	120.00	0.190	-0.12[illegible]
53	0.50	120.00	0.494	-0.1[illegible]
63	0.60	120.00	0.460	-0.18[illegible]
68	0.45	125.00	0.11[illegible]	-0.1[illegible]
73	0.45	125.00	0.11[illegible]	-0.1[illegible]
78	0.37	120.00	0.21[illegible]	-0.1[illegible]
80	0.15	140.00	0.051	-0.141

STATION 4_ 6

D[M]	V[KTS]	C[DEG]	X	Y
3	0.30	50.00	0.230	0.191
8	0.30	120.00	0.173	-0.100
13	0.30	130.00	0.230	-0.19[illegible]
18	0.35	140.00	0.225	-0.250
23	0.60	160.00	0.305	-0.564
28	0.45	150.00	0.325	-0.390
33	0.55	150.00	0.275	-0.47[illegible]
38	0.42	135.00	0.297	-0.297
43	0.50	150.00	0.250	-0.43[illegible]
48	0.45	150.00	0.225	-0.390
53	0.50	170.00	0.087	-0.4[illegible]
63	0.35	150.00	0.175	-0.303
68	0.35	150.00	0.175	-0.303
73	0.35	160.00	0.120	-0.329
78	0.35	160.00	0.120	-0.329
83	0.45	180.00	0.000	-0.450

STATION 4_ 7

D[M]	V[KTS]	C[DEG]	X	Y
3	0.05	135.00	0.035	-0.035
8	0.10	120.00	0.087	-0.050
13	0.25	50.00	0.192	0.161
18	0.15	360.00	0.000	0.150
23	0.15	360.00	0.000	0.150
28	0.25	360.00	0.000	0.250
33	0.10	360.00	0.000	0.100
38	0.20	360.00	0.000	0.200
43	0.25	360.00	0.000	0.250
48	0.10	45.00	0.071	0.071
53	0.10	45.00	0.071	0.071
63	0.10	45.00	0.071	0.071
66	0.30	135.00	0.212	-0.212

CURRENT PROFILES (cont'd.)

STATION 4_ 8

D[M]	V[KTS]	I[DEG]		
3	0.30	190.00	-0.052	-0.135
8	0.50	210.00	-0.150	-0.4[illegible]
13	0.50	210.00	-0.250	-0.4[illegible]
18	0.40	210.00	-0.200	-0.14[illegible]
23	0.40	210.00	-0.200	-0.14[illegible]
28	0.30	210.00	-0.150	-0.1[illegible]
33	0.25	180.00	0.000	-0.1[illegible]
38	0.35	135.00	0.247	-0.147
43	0.35	150.00	0.175	-0.30[illegible]
48	0.47	135.00	0.332	-0.332
53	0.55	140.00	0.354	-0.421
63	0.30	135.00	0.212	-0.212
68	0.65	135.00	0.460	-0.460

APPENDIX B

WATER MASS PROFILES ON THE IRANIAN SHELF MAY 1976

STATION 3L 1

DEP [FT]	SAL	TEM [C]	DEN
3	37.10	27.70	24.[illegible]
10	37.10	27.50	24.[illegible]
20	37.10	27.50	24.[illegible]
30	37.10	27.30	24.[illegible]
40	37.10	27.30	24.[illegible]
50	37.10	27.30	24.[illegible]
60	37.10	27.10	24.[illegible]
70	37.30	27.10	24.[illegible]
80	37.50	27.10	24.[illegible]
90	37.50	26.[illegible]	24.44

STATION 3L 2

DEP [FT]	SAL	TEM [C]	DEN
3	37.20	27.45	24.25
10	37.40	27.40	24.[illegible]
20	37.32	27.34	24.[illegible]
30	37.45	27.24	24.51
40	37.45	27.24	24.51
50	37.43	27.18	24.51
60	37.47	27.16	24.[illegible]
70	37.55	27.08	24.53
80	37.35	26.85	24.56
90	37.75	25.30	25.35

STATION 3L 3

DEP [FT]	SAL	TEM [C]	DEN
3	37.18	27.70	24.15
10	37.30	26.84	24.52
20	37.25	26.24	24.58
30	37.40	25.53	25.01
40	37.35	25.51	24.98
50	37.50	25.41	25.12
60		25.25	
70	37.33	25.20	25.06
80	34.60	25.20	23.00
90	34.18	25.20	22.68

DEP [FT]: Depth in feet. **SAL:** Salinity in °/₀₀.
TEM [C]: Temperature in °C. **DEN:** Sigma-t.

WATER MASS PROFILES (cont'd.)

STATION 3L 4

DEP [FT]	SAL	TEM [C]	DEN
3	37.53	33.70	24.[illegible]
10	37.55	33.15	24.[illegible]
20	37.71	27.32	24.31
30	37.45	27.43	24.[illegible]
40	37.51	27.35	24.45
50	37.[illegible]	27.12	24.50
60	37.47	26.70	24.91
70	37.46	26.50	25.[illegible]
80	37.[illegible]	27.47	25.[illegible]
90	37.[illegible]	21.96	25.44

STATION 3L 5

DEP [FT]	SAL	TEM [C]	DEN
3	37.45	29.83	23.09
10	37.40	28.00	24.11
20	37.50	27.98	24.10
30	37.56	26.93	24.63
40	37.63	26.19	24.98
50	37.97	23.88	25.44
60	38.39	24.22	26.16
70	38.50	24.11	26.29
80	38.66	24.27	26.35
90	38.73	24.37	26.37

STATION 3L 6

DEP [FT]	SAL	TEM [C]	DEN
3	37.30	29.05	23.80
10	37.33	29.95	23.85
20	37.30	23.95	23.83
30	37.36	27.08	24.49
40	37.50	27.27	24.54
50	37.50	27.15	24.57
60	37.75	27.00	24.71
70	38.47	25.90	25.70
80	38.90	23.88	26.65
90	39.27	23.00	27.19

WATER MASS PROFILES (cont'd.)

STATION 4-1

DEP [FT]	SAL	TEM [C]	DEN
3	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]
30	[illegible]	[illegible]	[illegible]
40	[illegible]	[illegible]	[illegible]
50	[illegible]	[illegible]	[illegible]
60	[illegible]	[illegible]	[illegible]
70	[illegible]	[illegible]	[illegible]
80	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]

STATION 4-2

DEP [FT]	SAL	TEM [C]	DEN
3	37.35	28.77	21.35
10	37.31	27.00	24.44
20	37.40	27.83	24.[illegible]
30	37.58	27.53	24.86
40	37.[illegible]	27.[illegible]	24.[illegible]
50	37.57	27.17	24.[illegible]
60	37.35	26.15	25.15
70	38.12	25.85	25.46
80	38.17	25.61	25.56
90	37.93	25.30	25.48

STATION 4-3

DEP [FT]	SAL	TEM [C]	DEN
3	37.35	29.00	23.78
10	37.38	28.17	24.13
20	37.55	28.00	24.[illegible]
30	37.57	27.96	24.36
40	37.31	27.56	24.37
50	37.85	27.06	24.37
60	38.03	26.41	25.21
70	38.18	26.11	25.42
80	38.42	25.32	25.85
90	38.41	25.34	25.86

WATER MASS PROFILES (cont'd.)

STATION 4_ 4

DEP [FT]	SAL	TEM [C]	DEN
3	37.57	28.79	24.09
10	37.67	28.65	24.21
20	37.70	28.55	24.27
30	37.72	28.35	24.35
40	37.83	28.10	24.51
50	37.95	27.34	24.95
60	38.05	26.60	25.17
70	38.20	25.75	25.66
80	38.47	25.13	26.14
90	38.66	24.70	26.22

STATION 4_ 5

DEP [FT]	SAL	TEM [C]	DEN
3	37.15	28.90	23.73
10	37.54	28.45	24.18
20	37.49	28.10	24.26
30	37.76	27.55	24.52
40	37.92	27.14	24.89
50	38.06	26.58	25.18
60	38.33	25.36	25.48
70	38.57	25.26	25.96
80	38.83	24.62	26.37
90	38.80	24.25	26.46

STATION 4_ 6

DEP [FT]	SAL	TEM [C]	DEN
3	37.25	29.53	23.60
10	37.50	28.25	24.21
20	37.52	27.77	24.39
30	37.62	27.48	24.56
40	37.95	27.72	24.73
50	38.00	27.60	24.80
60	38.28	26.69	25.31
70	38.53	25.63	25.83
80	38.55	25.25	25.97
90	39.16	23.35	27.00

WATER MASS PROFILES (cont'd.)

STATION 4L 7

DEP [FT]	SAL	TEM [C]	DEN
3	37.11	24.05	23.7[illegible]
10	37.11	24.33	23.7[illegible]
20	37.11	23.10	23.[illegible]
30	38.06	27.58	24.[illegible]
40	38.13	27.13	25.06
50	38.05	27.04	25.02
60	38.11	26.55	25.[illegible]
70	38.25	26.35	25.[illegible]
80	38.23	25.16	25.[illegible]
90	38.25	25.11	25.11

STATION 4L 8

DEP [FT]	SAL	TEM [C]	DEN
3	36.80	29.83	23.16
10	37.00	29.35	23.47
20	37.15	23.38	23.[illegible]
30	37.19	28.25	23.[illegible]
40	37.28	26.95	24.[illegible]
50	37.32	26.63	24.53
60	37.25	27.35	24.54
70	37.30	25.40	24.62
80	37.20	26.27	24.44
90	37.35	25.15	25.09

APPENDIX C

WATER MASS PROFILES IN THE STRAIT OF HORMUZ APRIL 1977

STATION A-1 STRAIT OF HORMUZ

	DEPTH (M)	TEMP (DEG C)	CONDUC (MMHO/CM)	SAL (PPT)	SIGMA-T
1)	0	23.5	55.4	37.39	25.69
2)	5	23.6	56.2	38.41	26.04
3)	10	23.5	56.2	38.50	26.13
4)	15	23.5	54.2	36.97	25.01
5)	20	23.2	53.5	36.63	24.89
6)	25	22.5	52.8	36.72	25.12
7)	30	15.8	51.8	42.16	30.39
8)	35	15.2	52.5	43.43	31.98
9)	40	14.9	53.0	44.21	32.63
10)	45	15.5	53.2	43.73	32.13
11)	50	14.8	53.0	44.31	32.73
12)	55	15.3	52.3	43.13	31.73
13)	60	15.8	51.8	42.15	30.89
14)	63	16.0	51.8	41.94	30.68

WATER MASS PROFILES (cont'd.)

STATION M-2 STRAIT OF HORMUZ

	DEPTH (M)	TEMP (DEG C)	CONDUC (MMHO/CM)	SAL (PPT)	SIGMA-T
1)	0	23.7	54.6	37.11	25.06
2)	5	23.7	53.7	36.43	24.56
3)	10	24.4	53.7	35.86	23.93
4)	15	24.0	53.1	35.73	23.95
5)	20	18.7	51.9	39.37	28.11
6)	25	17.5	50.2	39.06	28.18
7)	30	16.4	50.0	39.95	29.11
8)	35	16.2	51.0	41.03	29.96
9)	40	16.5	52.3	41.87	30.51
10)	45	15.7	51.8	42.26	30.99
11)	50	15.7	51.8	42.26	30.99
12)	55	15.3	52.5	43.31	31.87
13)	60	14.8	52.3	43.67	32.25
14)	65	14.7	51.0	42.59	31.47
15)	70	14.8	51.8	43.21	31.91
16)	75	14.8	51.0	42.48	31.36
17)	80	14.8	51.2	42.66	31.50
18)	82	14.8	51.1	42.56	31.43

WATER MASS PROFILES (cont'd.)

STATION M-3 STRAIT OF HORMUZ

	DEPTH (M)	TEMP (DEG C)	CONDUC (MMHO/CM)	SAL (PPT)	SIGMA-T
1)	0	24.5	55.2	36.90	24.67
2)	5	23.2	53.4	36.61	24.84
3)	10	20.1	52.7	38.74	27.27
4)	15	19.2	52.0	38.99	27.70
5)	20	18.5	51.6	39.31	28.11
6)	25	17.7	51.0	39.56	28.50
7)	30	16.9	49.8	39.29	28.50
8)	35	16.2	50.5	40.59	29.63
9)	40	15.7	51.2	41.72	30.59
10)	45	15.2	51.3	42.33	31.16
11)	50	14.8	52.2	43.58	32.19
12)	55	14.7	52.6	44.06	32.56
13)	60	14.8	52.1	43.49	32.12
14)	65	14.7	51.0	42.59	31.47
15)	70	15.0	51.0	42.26	31.16
16)	75	14.8	51.0	42.48	31.36
17)	80	14.7	51.0	42.58	31.46
18)	85	14.7	51.0	42.58	31.46
19)	88	14.7	51.1	42.67	31.53

WATER MASS PROFILES (cont'd.)

STATION M-4 STRAIT OF HORMUZ

	DEPTH (M)	TEMP (DEG C)	CONDUC (MMHO/CM)	SAL (PPT)	SIGMA-T
1)	0	25.6	54.3	35.36	23.20
2)	5	23.5	53.8	36.57	24.79
3)	10	20.4	53.5	39.12	27.47
4)	15	19.6	53.1	39.53	27.89
5)	20	18.8	52.6	39.87	28.45
6)	25	18.8	52.3	39.61	28.26
7)	30	16.0	51.7	41.86	30.62
8)	35	14.9	50.8	42.20	31.13
9)	40	15.2	50.0	41.16	30.29
10)	45	14.8	50.8	42.30	31.23
11)	50	14.8	51.6	43.03	31.78
12)	55	16.4	51.2	41.00	29.89
13)	60	15.8	50.8	41.25	30.22
14)	65	15.6	50.7	41.37	30.35
15)	70	15.0	50.8	42.08	31.02
16)	75	14.8	51.0	42.48	31.36
17)	80	15.1	51.1	42.25	31.12
18)	85	15.0	51.0	42.26	31.16

WATER MASS PROFILES (cont'd.)

STATION M-5 STRAIT OF HORMUZ

	DEPTH (M)	TEMP (DEG C)	CONDUC (MMHO/CM)	SAL (PPT)	SIGMA-T
1)	0	26.3	54.2	34.76	22.54
2)	5	21.2	53.1	38.08	26.49
3)	10	19.2	52.6	39.49	28.07
4)	15	17.8	51.1	39.55	28.47
5)	20	17.3	50.3	39.34	28.44
6)	25	16.5	50.1	39.94	29.08
7)	30	15.0	50.0	41.37	30.49
8)	35	14.7	50.0	41.68	30.79
9)	40	16.0	50.1	40.43	29.56
10)	45	17.3	51.2	40.11	29.01
11)	50	17.1	51.2	40.31	29.20
12)	55	15.0	50.4	41.72	30.76
13)	60	16.0	50.3	40.60	29.69
14)	65	17.0	50.5	39.79	28.84
15)	70	16.2	50.4	40.49	29.56
16)	75	16.1	50.4	40.59	29.66
17)	80	16.3	50.5	40.48	29.52
18)	83	16.2	50.5	40.57	29.62

WATER MASS PROFILES (cont'd.)

STATION M-6 STRAIT OF HORMUZ

	DEPTH (M)	TEMP (DEG C)	CONDUC (MMHO/CM)	SAL (PPT)	SIGMA-T
1)	0	24.5	54.2	36.16	24.12
2)	5	19.8	52.5	38.35	27.44
3)	10	19.2	50.5	37.99	26.96
4)	15	17.8	50.3	38.36	27.96
5)	20	16.5	50.0	39.35	29.01
6)	25	19.0	50.0	37.50	26.65
7)	30	18.2	50.0	38.23	27.39
8)	35	17.8	50.0	38.60	27.77
9)	40	18.2	50.0	38.23	27.39
10)	45	18.4	50.1	38.13	27.26
11)	50	17.5	49.8	38.71	27.92
12)	55	15.9	49.7	40.17	29.39
13)	60	14.0	50.0	42.42	31.50
14)	65	14.3	50.1	42.18	31.26
15)	70	14.5	50.0	41.77	30.89
16)	75	14.6	50.0	41.77	30.88
17)	80	13.8	50.0	42.63	31.70