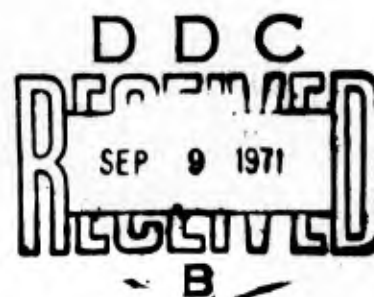


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DEEP SCATTERING LAYERS IN THE GULF OF MEXICO

R. C. Thompson, J. W. Caruthers, and T. J. Bright

Office of Naval Research
Technical Report 71-5-T

Contract N00014-68-A-0308-0002
Task Number NR 083-036

February 1971

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Department of Oceanography Texas A&M University, College Station, Texas 77843 Through Texas A&M Research Foundation		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP
3. REPORT TITLE DEEP SCATTERING LAYERS IN THE GULF OF MEXICO		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report		
5. AUTHOR(S) (First name, middle initial, last name) R. C. Thompson, J. W. Caruthers, and T. J. Bright		
6. REPORT DATE February 1971	7a. TOTAL NO. OF PAGES 64	7b. NO. OF REFS 40
8a. CONTRACT OR GRANT NO. N00014-68-A-0308-0002	9a. ORIGINATOR'S REPORT NUMBER(S) Reference 71-5-T	
b. PROJECT NO.		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		
10. DISTRIBUTION STATEMENT This document has been approved for public release and sale; its distribution is unlimited.		
11. SUPPLEMENTARY NOTES Details of Illustrations in this document may be better studied on		12. SPONSORING MILITARY ACTIVITY Office of Naval Research
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DEEP SCATTERING LAYERS

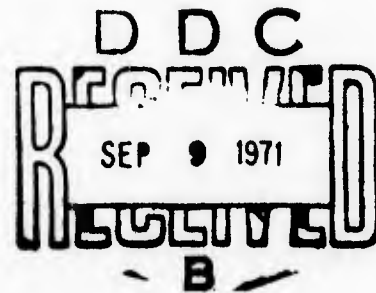
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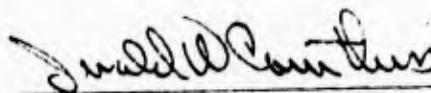
Reference 71-5-T



PREFACE

The following study was carried out primarily by Ronald C. Thompson as his Master of Science research under the direction of the undersigned. The work was partially sponsored by the Office of Naval Research through Contract N00014-68-A-0308-0002 Project 700-14 for which Dr. Thomas J. Bright is the principal investigator.

This report reviews the existing data, presents the state of knowledge, and discusses certain specific features of deep scattering layers in the Gulf of Mexico.



Jerald W. Caruthers

ABSTRACT

The deep scattering layer (DSL) in the Gulf of Mexico has been studied, over a period of three years, utilizing a precision depth recorder operating at 12 kHz. The DSL appears to be divided into four main daytime layers. The west-central Gulf shows little deep layering. No definite correlation of DSL and physical parameters was arrived at. The DSL was not found to be seasonally variable. There were some indications that the DSL shoals to the north. Maximum rates of evening ascent of 3.4 fm/min (6.2 m/min) and morning descent of 5.9 fm/min (10.8 m/min) were determined. The length of time for ascent (2 hr) and descent (3 1/2 hr) are arrived at. Examples of evening ascent, morning descent and the dawn rise are presented. Response of the DSL to a total solar eclipse and cloud cover are discussed.

ACKNOWLEDGMENTS

The authors would like to express appreciation to Dr. Davis Fahlquist for reviewing this manuscript and suggesting improvements.

We wish to thank Dr. Guy Franceschini and Prof. John Cochrane for making available portions of their cruises, (70-A-4) and (70-A-9), respectively, for this research.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
I. EARLY WORK	2
II. OBSERVATIONS OF GENERAL DSL CHARACTERISTICS.	8
A. Past Data	8
B. Recent Data	24
III. DISCUSSION OF SPECIFIC DSL BEHAVIOR.	28
A. Multiple Layering	28
B. Diurnal Migration	33
C. Dawn Rise	40
D. Reaction to Solar Eclipse	42
E. Response to Variations in Cloud Cover	43
F. Further Examples of the Character of the DSL.	46
1. The DSL over the Continental Slope	46
2. PDR Trace Compared for Ship Moving and Stationary	46
3. Scattering Groups.	48
IV. SUMMARY.	52
REFERENCES	54

LIST OF FIGURES

Figure		Page
1.	DSL observations during past three years	9
2.	Areal extent of deepest DSL layers	10
3(a).	Summer DSL observations.	12
3(b).	Winter DSL observations.	13
4.	Composite of cruise tracks for past three years. .	14
5(a).	Location of north-south and east-west cross sections for figures 5(b) through 5(i)	15
5(b).	DSL and general north-south temperature profile, summer.	16
5(c).	DSL and general north-south salinity profile, summer.	17
5(d).	DSL and general north-south oxygen profile, summer.	18
5(e).	DSL and general north-south σ_t profile, summer . .	19
5(f).	DSL and general east-west temperature profile, summer	20
5(g).	DSL and general east-west salinity profile, summer	21
5(h).	DSL and general east-west oxygen profile, summer .	22
5(i).	DSL and general east-west σ_t profile, summer . . .	23
6.	Location of DSL data from recent cruises	25
7.	Selected temperature profiles from cruise 70-A-9 showing prominent DSL	27
8.	Photograph of PDR trace for the morning of the total solar eclipse, relative receiver response is also shown.	29

Figure		Page
9.	Photograph of PDR trace showing multiple layering	31
10.	Photograph of PDR trace showing multiple layering in the southeastern Gulf.	32
11.	Composite morning descent and evening descent. . .	34
12.	Photograph of PDR trace showing an evening ascent	36
13.	Photograph of PDR trace showing an early portion of an evening ascent	37
14.	Photograph of PDR trace showing a morning descent.	38
15.	Photograph of PDR trace showing an early portion of a morning descent	39
16.	Photograph of PDR trace showing the morning descent the day of the total solar eclipse, also the dawn rise.	41
17.	Insolation curve and DSL response.	44
18.	Response of DSL to reduced insolation due to scattered clouds	45
19.	Photograph of PDR trace showing an observation of the DSL conforming to the bottom profile. . . .	47
20.	Photograph of PDR trace showing DSL while ship is stationary and underway	49
21.	Photograph of PDR trace showing an example of scattering groups	50
22.	Location of observed scattering groups	51

INTRODUCTION

The objectives of this study are to present the general characteristics of the deep scattering layer (DSL), in the Gulf of Mexico, in reference to;

- the distribution of the DSL during the past three years,
- average and maximum rates of ascent and descent,
- correlation between DSL motion during the total solar eclipse in March, 1970, and the change in light intensity,
- correlation of DSL motion and cloudiness,
- correlation of DSL with various parameters, i.e., temperature, oxygen, salinity, and density (σ_t),
- observations of the dawn rise,¹ and
- occurrence of scattering layer groupings.

Data presented are derived from an examination of precision depth recorder (PDR) records obtained during the past three years operation of a 12 kHz shipboard fathometer. The records include several sets for which the quality of the display of the DSL was the primary objective. Included in this later set is a three day record of the DSL at one point. The test period included the total solar eclipse of 7 March 1970.

The citations on the following pages follow the style of the Journal of the Acoustical Society of America.

I. EARLY WORK

The deep scattering layer (DSL) is a widely distributed marine phenomenon²⁻⁴ which most often appears as a midwater reflection on the trace of a precision depth recorder (PDR) when the recorder is used as part of an echo-sounding system. That this phenomenon is produced by the scattering of acoustic energy by marine organisms, which collect in horizontal layers, was first postulated by the University of California, Division of War Research, during the later part of World War II.⁵

The DSL ranges in depth from slightly below the surface down to at least 500 fm (914 m).⁶ Most of these layers migrate toward the surface near dusk, and return to the depths near dawn. While this is usually true, not all of the layers migrate. Some layers remain at their midday depth, or slightly above their midday depth, throughout the diurnal cycle.⁷⁻¹⁰

Layering is, generally, laterally uniform during the daylight hours; it has been observed in the Pacific Ocean to be present during an entire days run of the ship.³ Some shallow layering is observed at night; however, it is often obscured by the outgoing ping of the PDR.³

The DSL is thought to be composed of many different organisms including: euphausiids, copepods, myctophids, and siphonophores.^{4, 7, 8, 11-17} These organisms are, in most cases, good sound scatterers, and are, possibly, the primary agent of marine

sound scattering.¹⁸ There is, however, an apparent lack of correlation between the fishes and sound scattering in the upper 100 fm (183 m).¹⁹

Reflected sound from scattering layers is frequently associated with gas-bubbles. When gas-bubbles are insonified they are driven into oscillation and under certain physical conditions resonate. These conditions are determined by the relative impedances of the medium and the bubbles, the frequency of sound, and the shapes and sizes of the bubbles. Near resonance, the scattering cross sections of the gas-bubbles are much larger than their physical cross sections. The resonant frequencies of the gas-bubbles correspond to wavelengths much larger than the actual bubble diameters. Scattering layers have rather broad resonant peaks suggesting that they contain a distribution of gas-bubble scatterers of slightly different sizes.¹⁰

Resonant frequencies, generally, increase with increasing depth; this depth dependency is due primarily to changes in the physical characteristics of the gas-bubbles as the pressure (p) varies. If the gas-bubbles are spherical in shape, and free to compress or expand, then the resonant frequencies vary as $p^{1/2}$.^{4,20} If they are oblate spheroids, the resonant frequencies vary as $p^{1/2}$, $p^{5/6}$ or p , depending upon whether the sizes and the shapes of the bubbles are constant, or the gas-bubbles are free to compress or to expand while maintaining the major diameter constant, respectively.^{4,13,19}

It has been observed that as a layer undergoes diurnal migration its resonant frequency changes. Two cases of five-sixths power and one of one-half power frequency dependences upon depth have been reported for the western North Atlantic.^{4,20}

DSL exist over most of our world's oceanic areas--the exceptions being the polar regions. There are, however, marked regional variations:

- in the western Pacific layering has been observed at depths of 50 to 150 fm (91 to 274 m) and at 250 fm (457 m), the shallower layer being the most prominent;²¹
- one layer has been observed in the Bering Sea at 200 fm (366 m);⁷
- off the coast of Southern California two layers have been detected, the shallow less prominent one at depths from 85 to 135 fm (155 to 247 m), the deeper stronger one from 135 to 200 fm (247 to 366 m);⁷
- on an earlier cruise off Southern California, a prominent layer was found at 150 fm (274 m);²
- in the Atlantic Ocean south of New England, two layers have been found, one at 164 fm (302 m) and the other at 220 fm (402 m);⁴
- a prominent layer has been observed in the North Atlantic at 75 to 315 fm (137 to 576 m), with weaker layering from 315 to 465 fm (576 to 850 m) and dominant scatterers within 55 fm (100 m) of the surface at night;¹⁰

- three layers have been detected in the eastern Gulf of Mexico, at 55 fm (100 m) with a thickness of 20 fm (37 m), at 75 fm (137 m) with a thickness of 10 fm (18 m), and at 136 fm (248 m);²² and
- 35 mi (56 km) southwest of Key West, Florida, one layer was found at a depth of 200 fm (366 m) and with a thickness of 55 fm (100 m).²³

In general, the ascent rates of the layers are not consistent from one area to the next. Off Southern California, the maximum observed ascent rate was 1 fm/min (1.8 m/min).² North of Puerto Rico the maximum observed ascent rate was 2.5 fm/min (4.6 m/min).²⁴ In the eastern Gulf of Mexico ascent rates as high as 6 fm/min (11 m/min) have been observed.²²

The scattering strength²⁵ is of the same order of magnitude from place to place, but there is, however, some regional variability. The scattering strength in the western Pacific, as examined with a precision depth recorder (PDR) system operating at 12 kHz, varied from -106 to -61 db.²¹ Off the east coast of Nassau, the average scattering strength (averaged over the water column) was found to vary from -82 to -53 db for a frequency range of 1.6 to 20.0 kHz. This is, generally, about 10 db less than that found off Bermuda, thus indicating a denser population of organisms off Bermuda.¹³ South of New England, the scattering strength has been found to vary from -81 to -64 db for a frequency range of 6 to 20.5 kHz.⁴ In the eastern Gulf of Mexico the average

scattering strength has been found to vary from -69 to -51 db for a frequency range of 2.5 to 20.0 kHz.²²

The scattering strength, generally, decreases with increasing depth except in the DSL, where it is from 5 to 15 db higher than the local background.^{26,27} The average scattering strength appears to increase when the water column is insonified with higher frequencies.⁹ The scattering strength also appears to increase with increasing latitude, possibly due to a slow northward shoaling of the DSL.⁴

The majority of the data used in this paper are derived from precision depth recorder (PDR) records. Only a relatively few PDR records obtained in the past provide good data. Most cruises utilize the PDR as a means to delineate the bottom profile; the PDR is not adjusted to enhance midwater layering, such as the DSL. It is possible, through proper adjustments of the PDR gains, to produce a good trace of the DSL. But, still, the PDR is limited in what it detects as it operates at a single frequency; one layer is usually represented by a PDR trace which is considerably darker than those of the other layers at the same location. This darker layer may represent a layer of organisms that are resonant at or near the operating frequency of the PDR, while the other, apparently weaker, layers may be resonant at other frequencies. Thus, their lightness does not necessarily mean that they are not dense and well defined.

For the degree of darkening of the PDR trace that is observed,

it is not necessary that there be a high concentration of scatterers present. It is possible to get darkening of the PDR trace that is representative of a typical DSL if there are as few as 0.0006 scatterers/fm³ (0.0001 scatterers/m³) present.²⁸

The actual concentrations, as observed in situ, are substantially larger. Off Southern California, a population density of 0.22 scatterers/fm³ (0.036 scatterers/m³),⁷ and off the northern coast of Puerto Rico 0.50 scatterers/fm³ (0.082 scatterers/m³),²⁴ have been observed, while in the eastern Gulf of Mexico the density has been found to be 0.12 scatterers/fm³ (0.02 scatterers/m³).²⁹

The DSL of other oceanic regions is quite thoroughly studied; there is, however, a lack of information concerning the DSL in the Gulf of Mexico.³⁰ This dearth of knowledge, compounded by the fact that in the Gulf of Mexico the DSL is quite pronounced and interesting, has prompted this investigation.

II. OBSERVATIONS OF GENERAL DSL CHARACTERISTICS

A. Past Data

A summary of the areas of DSL occurrence in the Gulf, as obtained from a review of 7,000 hrs of PDR records taken aboard the R/V Alaminos using a 12 kHz echo-sounding system, is presented in Fig. 1. The PDR records were examined and data extracted consisted of depth, thickness, number of layers, time, place, extent and rates of motion of the DSL. The high concentration of points extending from off the Texas coast to the Yucatan strait is undoubtedly due to the high frequency of observations made in this area, rather than any real regional variability of the DSL. A review of the data reveals the following points concerning the DSL.

There appear to be four main, daytime, layering regimes in the Gulf: surface layers to a depth of 30 fm (55 m); relatively thin layers from 31 to 100 fm (55 to 183 m); another series of thin layers from 101 to 170 fm (185 to 261 m); and a thick layer from about 171 to 260 fm (263 to 476 m) (See Fig. 2). These layers were not present at all locations; usually the deeper layer was missing, and sometimes no layering could be found in the 101 to 170 fm (185 to 261 m) depth. No layering was found below 270 fm (494 m). The central and extreme southwestern Gulf appear to be areas of high DSL occurrence (the data for the southwestern Gulf were based on only a few data points). The

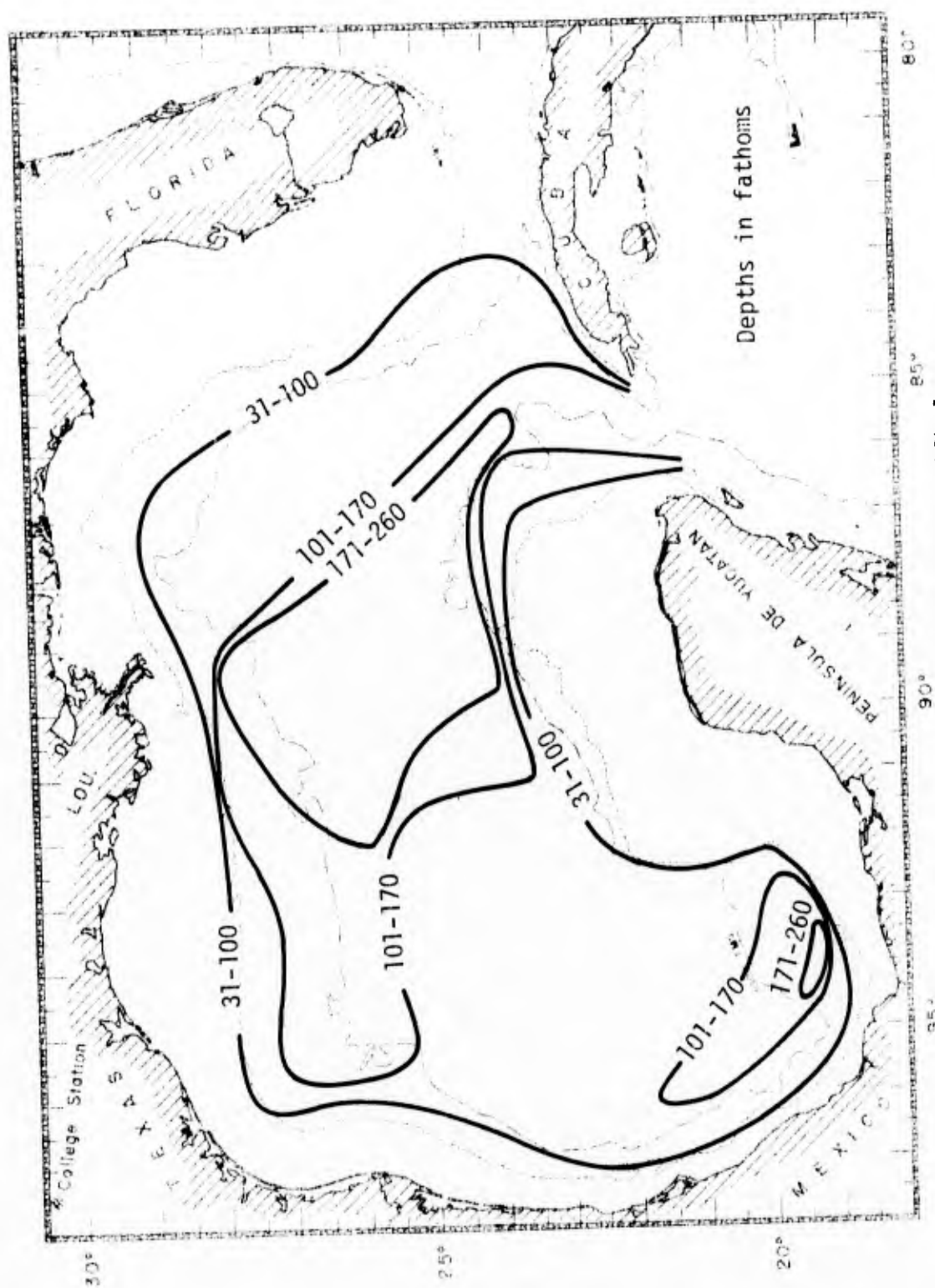


Fig. 2 - Areal extent of deepest DSL layers.

central portion of the western Gulf seems to have shallow layering only.

The individual layers, of the DSL, are often found to be patchy. This patchiness makes it difficult to follow any one layer over any appreciable horizontal distance. It was sometimes possible to follow a DSL complex (i.e., a number of layers, not, however, usually the same layers) through a number of diurnal cycles, both when on station and when underway.

An attempt was made to distinguish between summer and winter DSL layering (See Figs. 3(a) and 3(b)). Comparison of the two figures indicates a separation of the DSL into two regimes: the winter, with most occurrences in the eastern Gulf, and the summer, with most occurrences in the western Gulf. This apparent separation is not ascribed to seasonal differences but rather to the cruise pattern for the past three years (See Fig. 4). A seasonal variation is not, however, precluded. It may be necessary to examine the DSL, in a specified area of the Gulf, periodically over an extended period of time before a long term variation becomes evident.

Attempts were made to correlate the Gulf-wide distribution of the DSL with such parameters as the temperature, oxygen, salinity and density (σ_t);³¹ the data were such that no definite correlation could be established (See Figs. 5(a) through 5(i)). There does, however, appear to be a general northward shoaling of the DSL as is evidenced by data presented in Figs. 5(b)

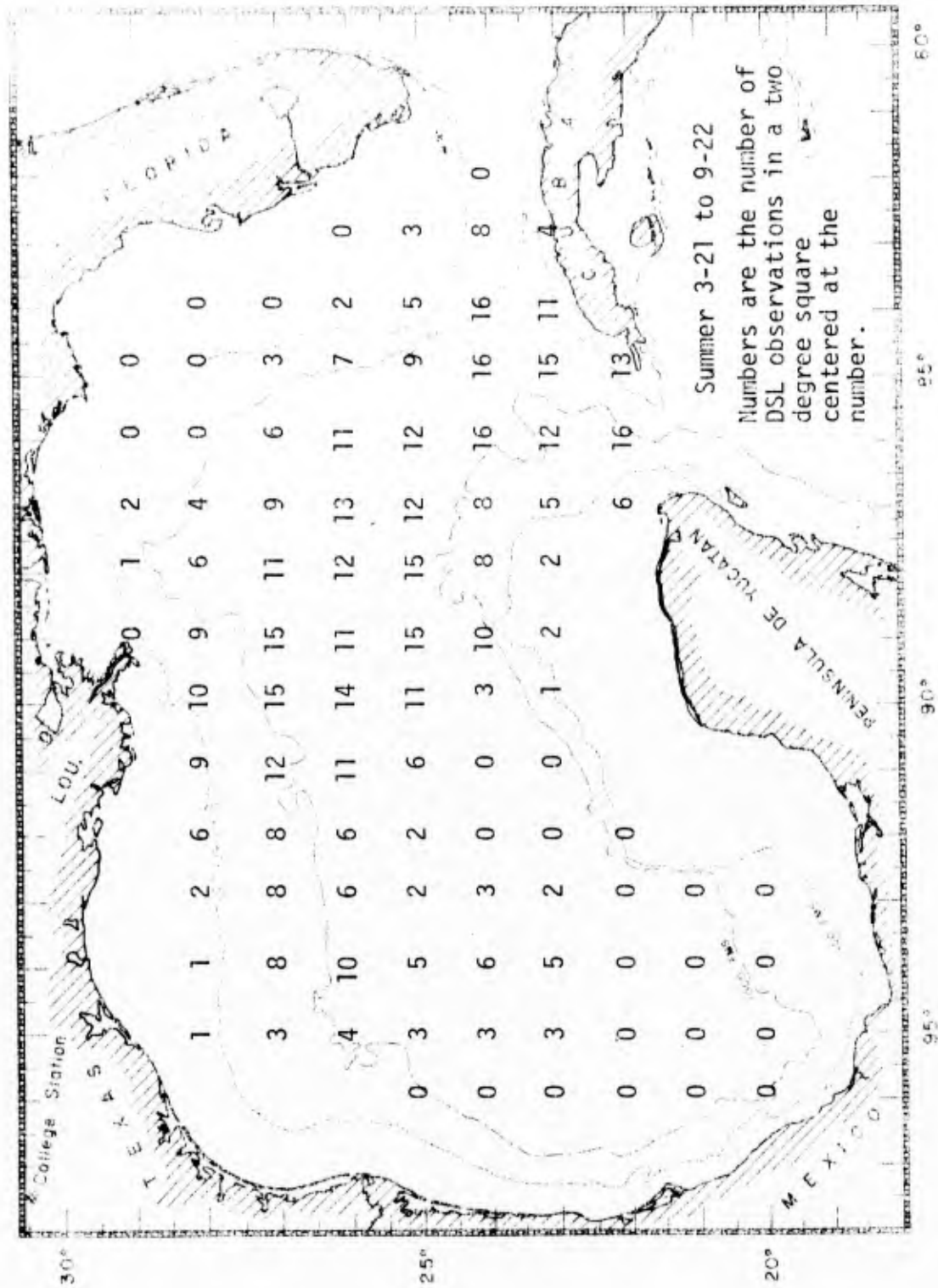


Fig. 3(a) - Summer DSL observations.

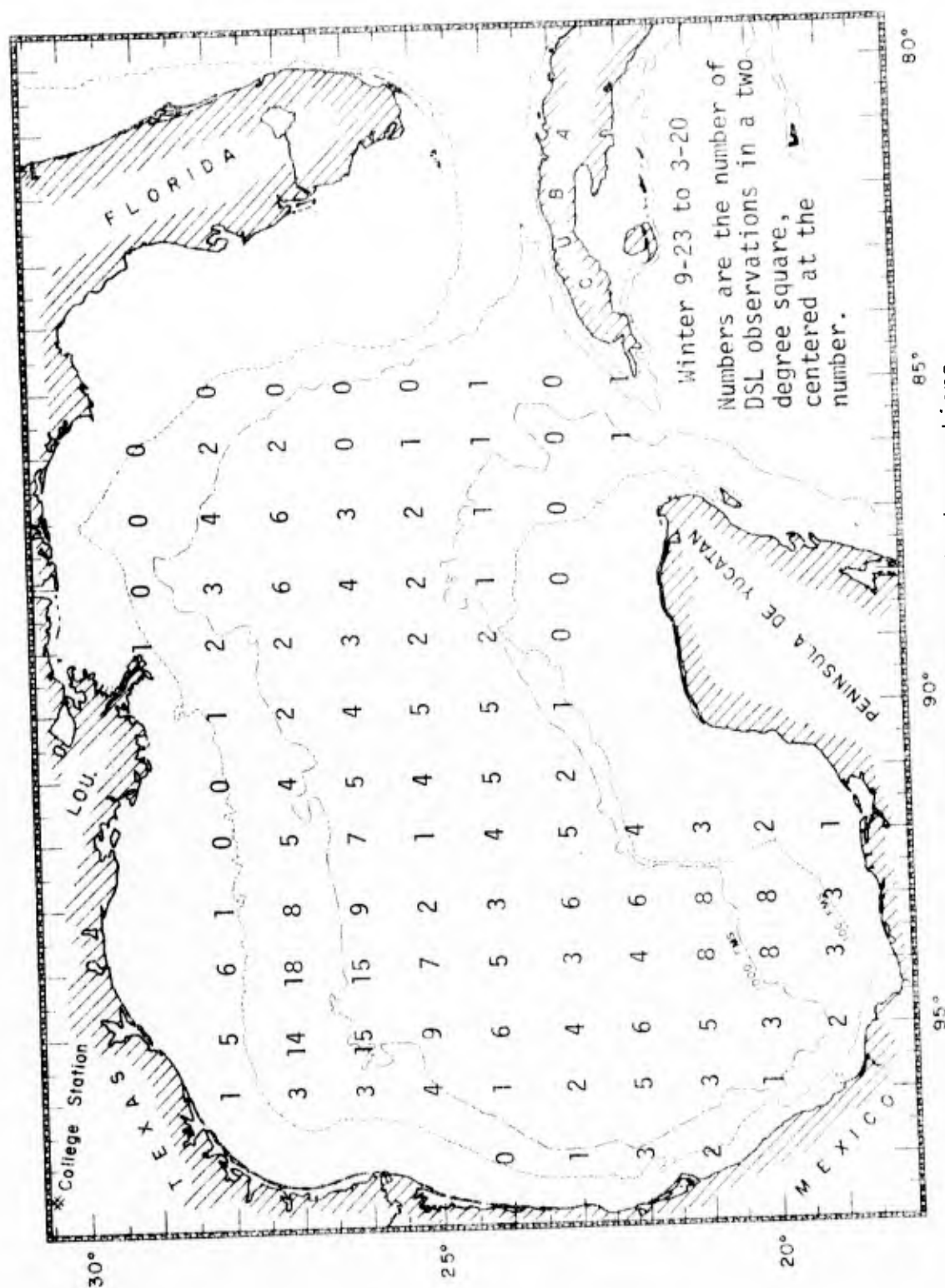


Fig. 3(b) - Winter DSL observations

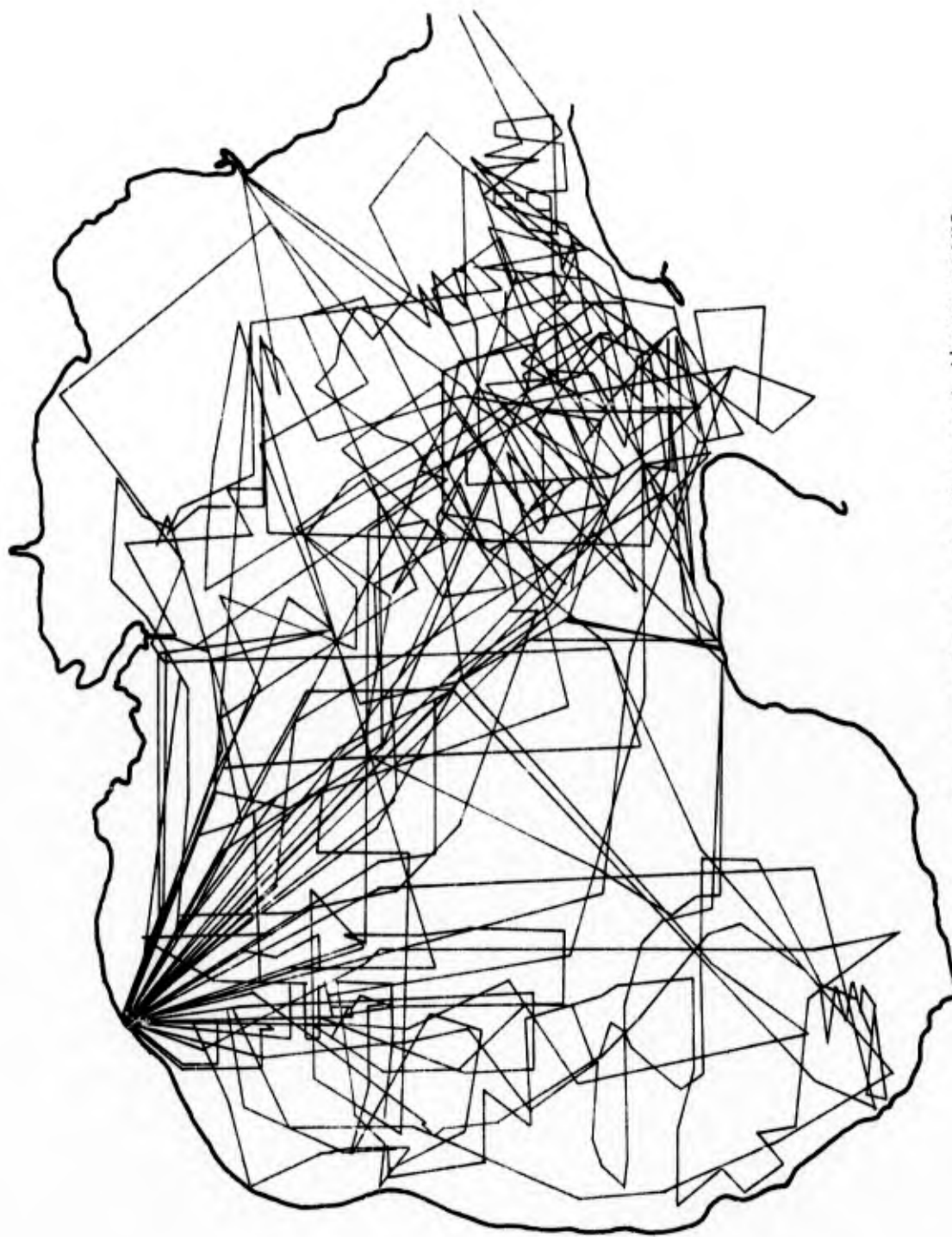


Fig. 4 - Composite of cruise tracks for past three years.

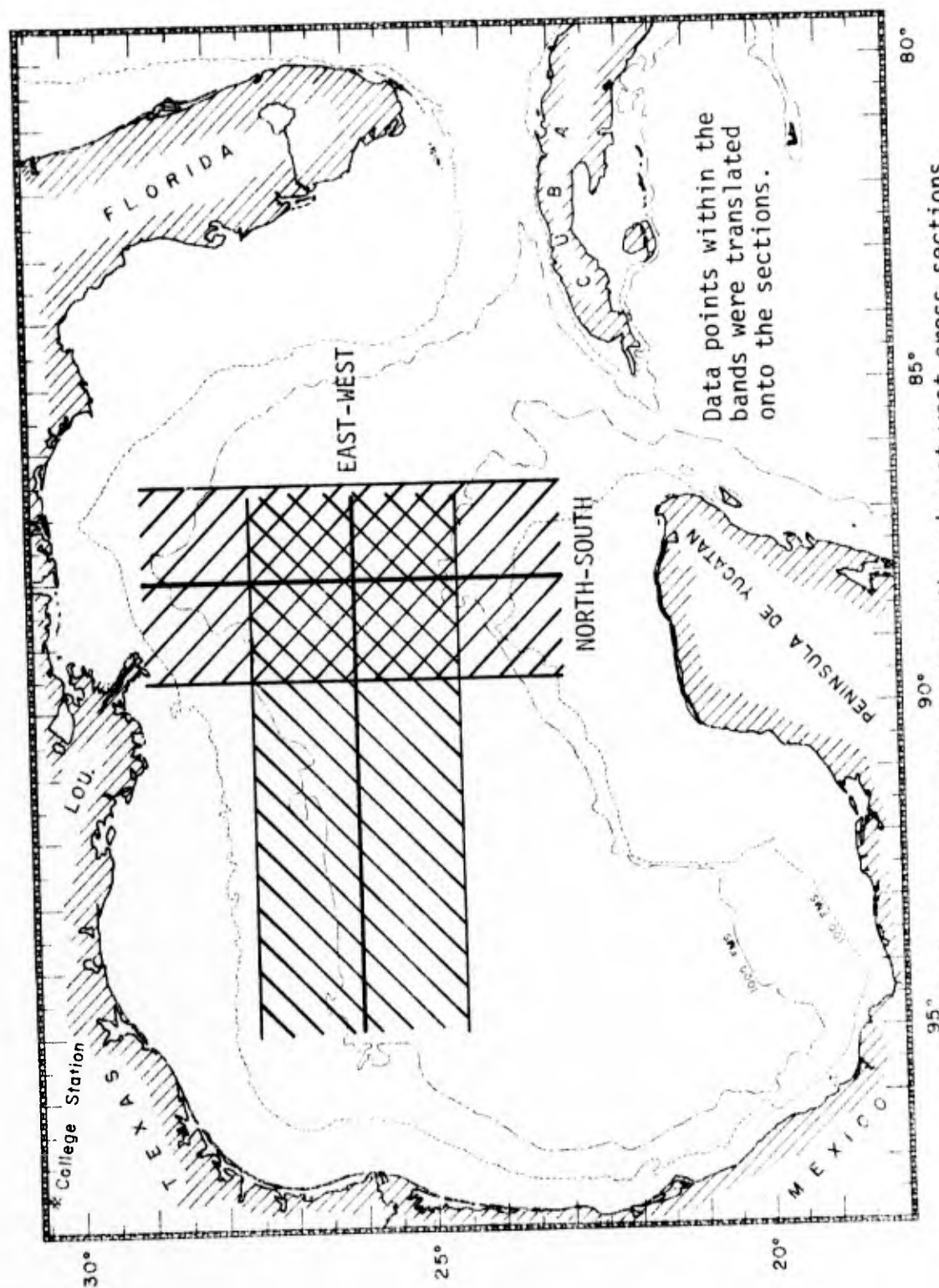


Fig. 5(a) - Location of north-south and east-west cross sections for figures 5(b) through 5(i).

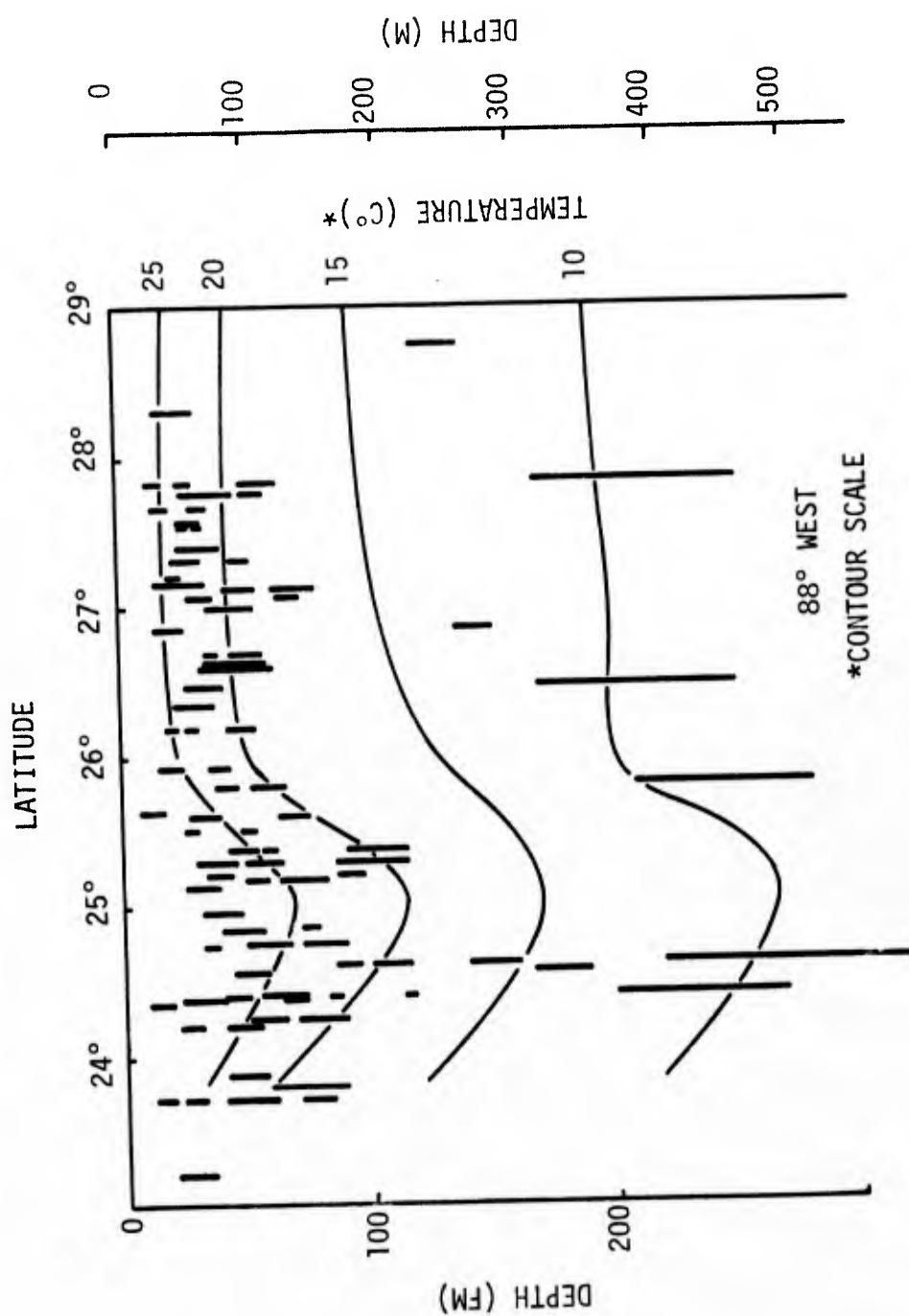


Fig. 5(b) - DSL and general north-south temperature profile, summer.

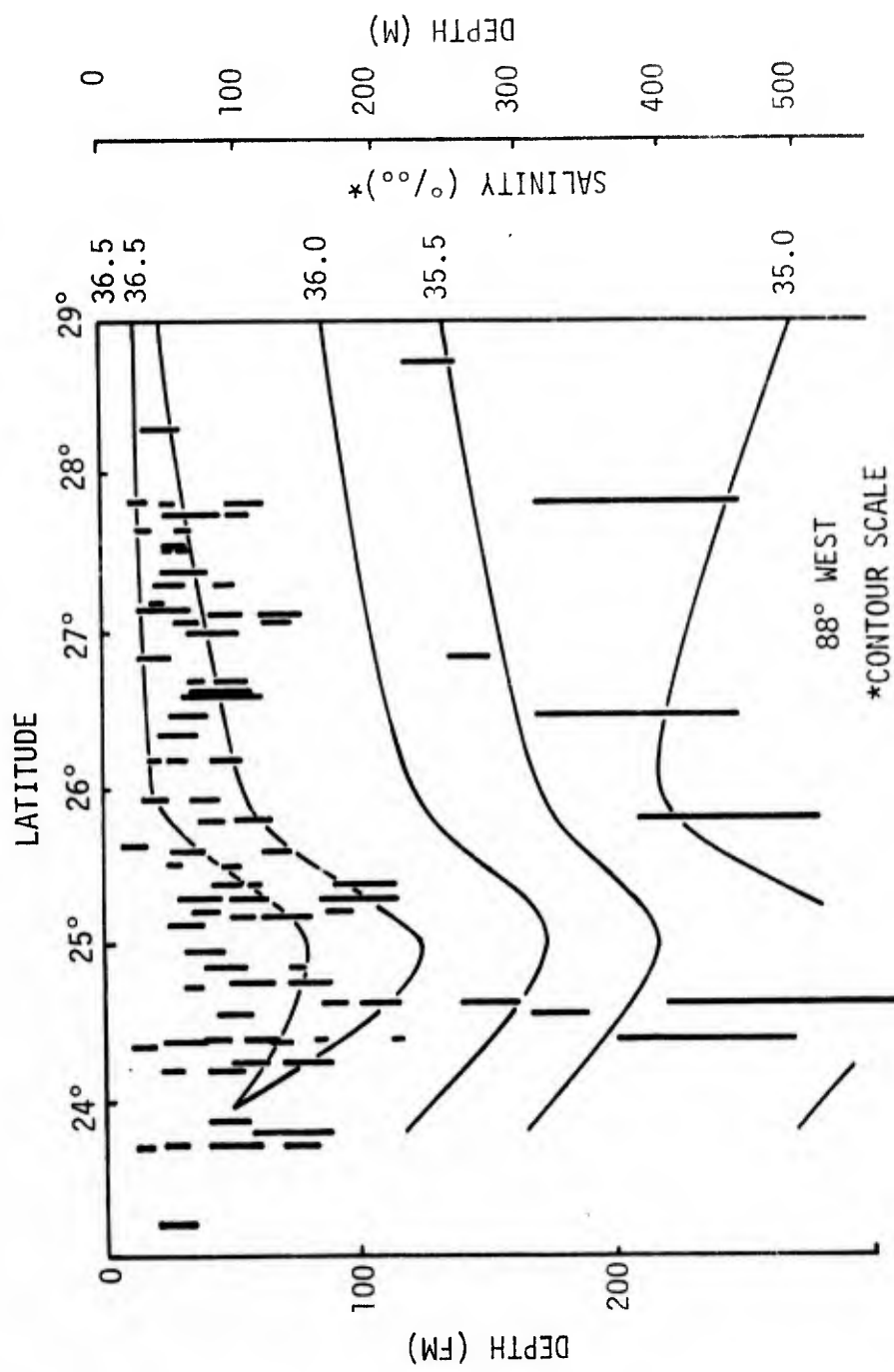


Fig. 5(c) - DSL and general north-south salinity profile, summer.

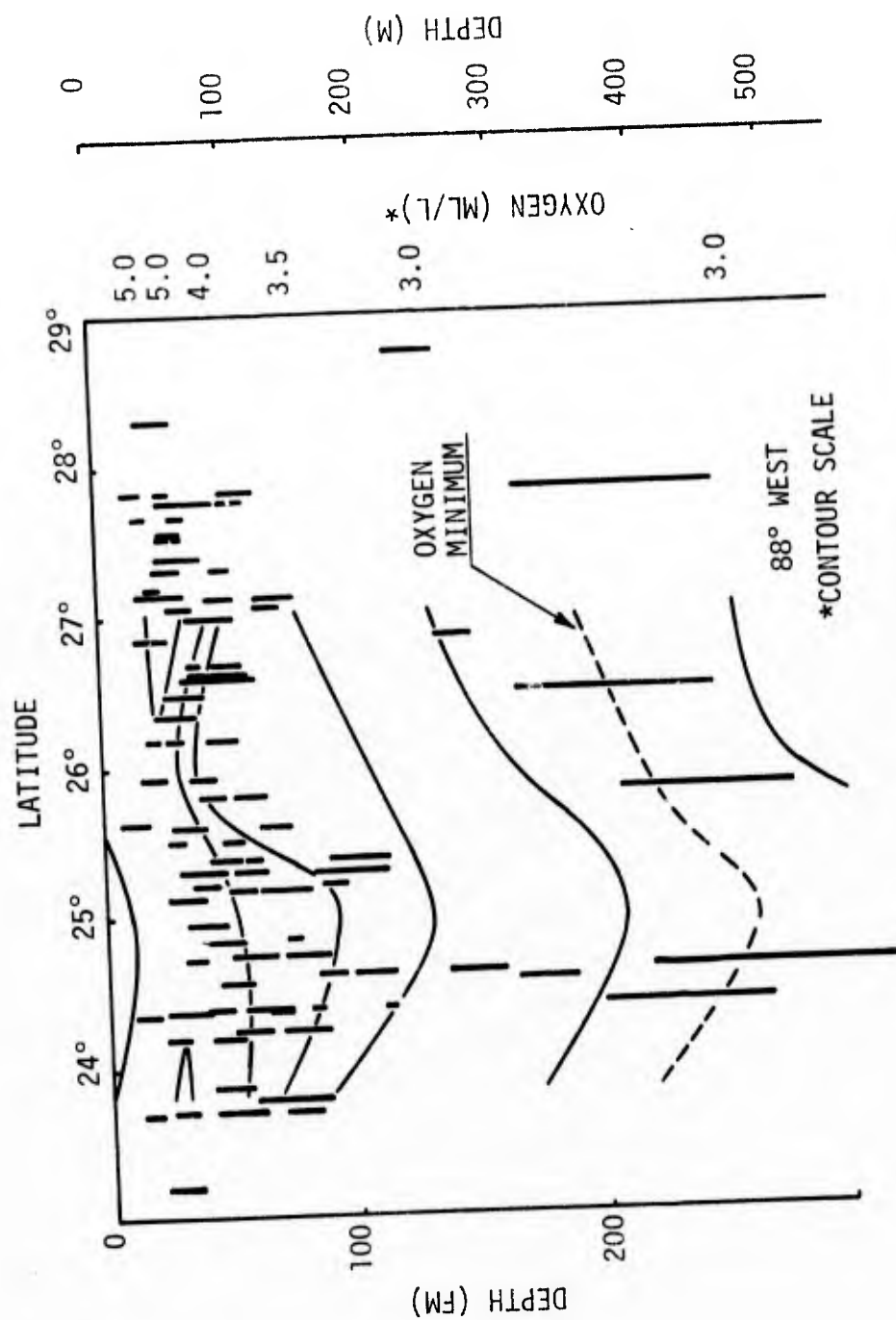


Fig. 5(d) - DSL and general north-south oxygen profile, summer.

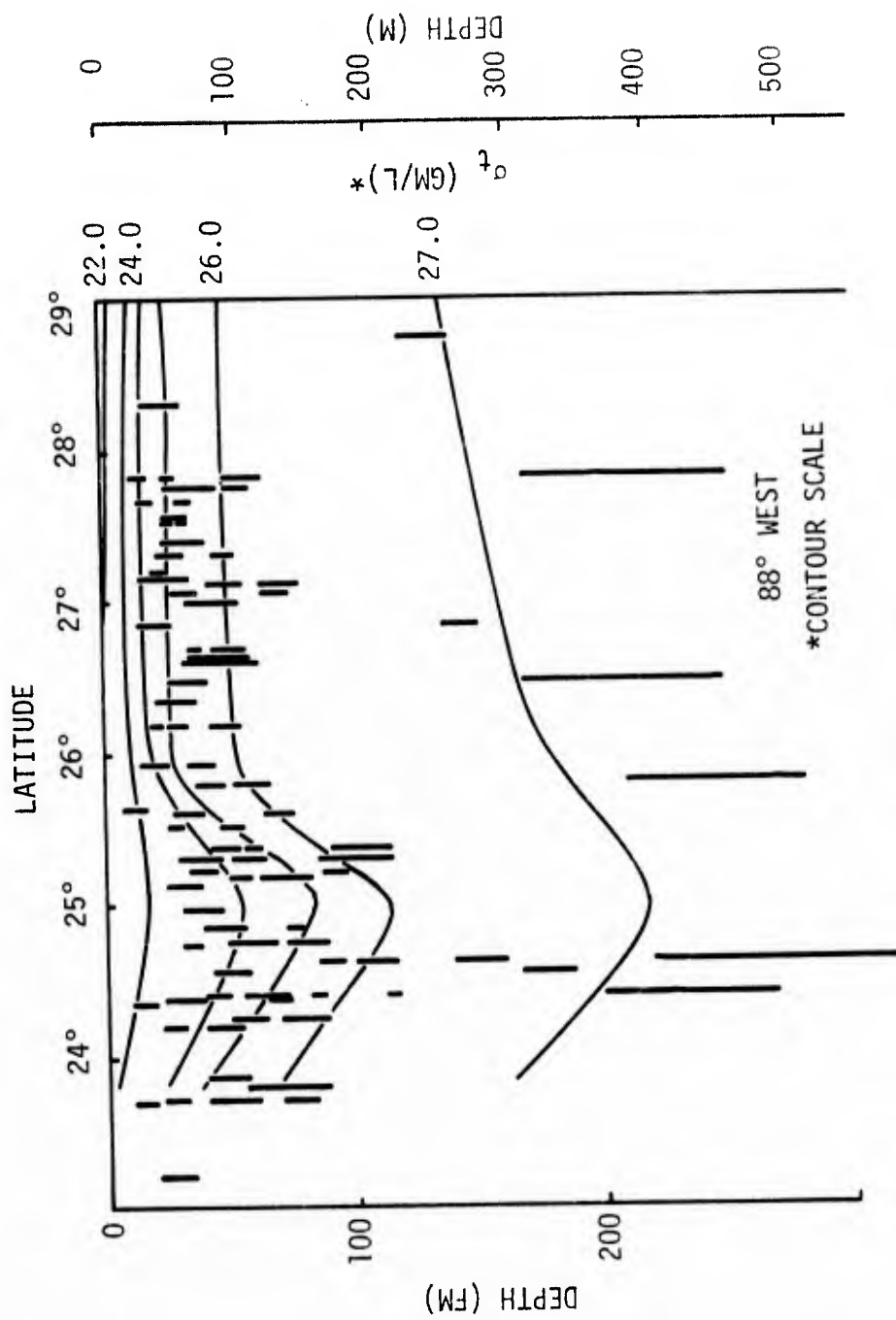


Fig. 5(e) - DSL and general north-south σ_t profile, summer.

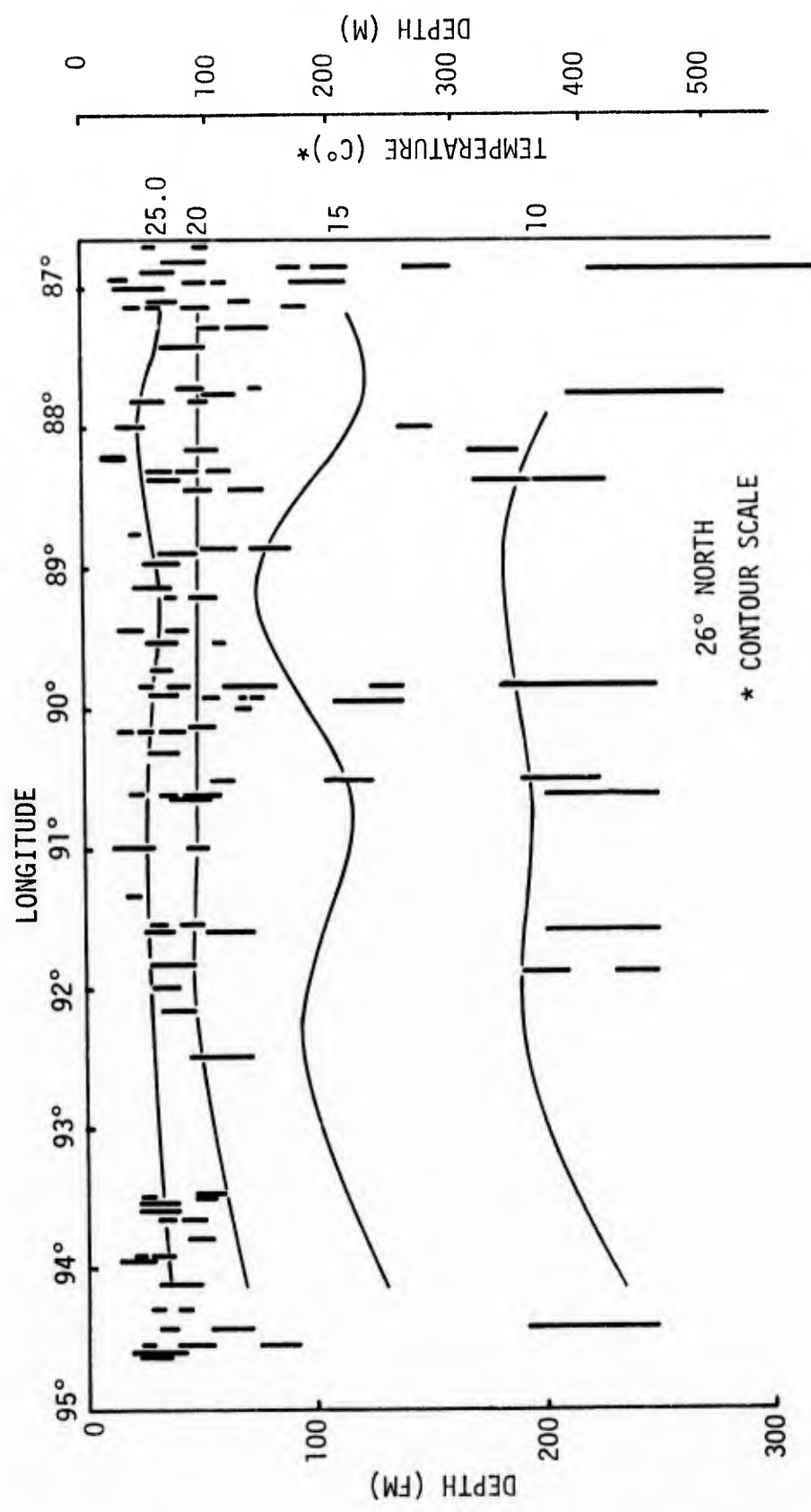


Fig. 5(f) - DSL and general east-west temperature profile, summer.

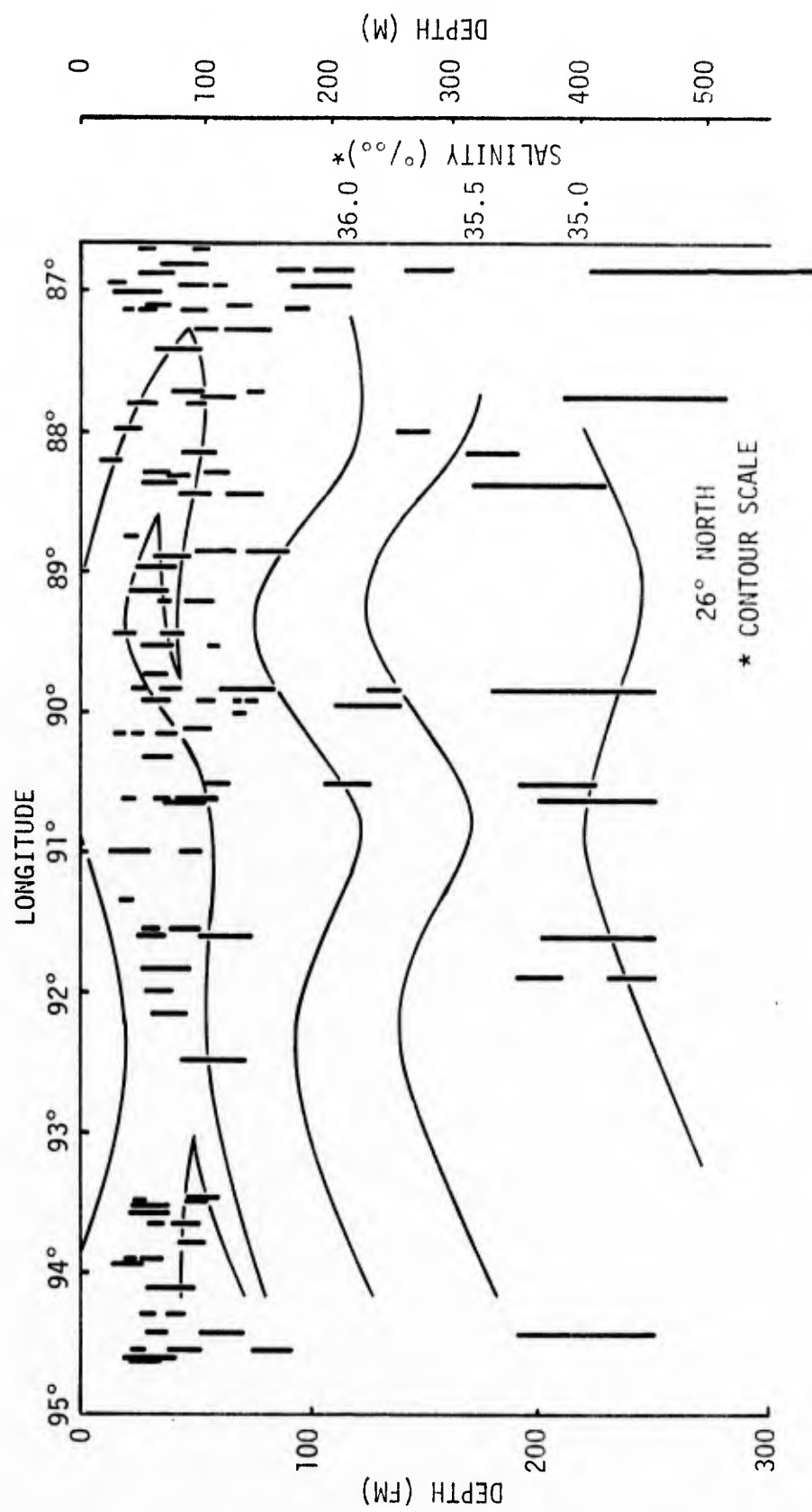


Fig. 5(g) - DSL and general east-west salinity profile, summer.

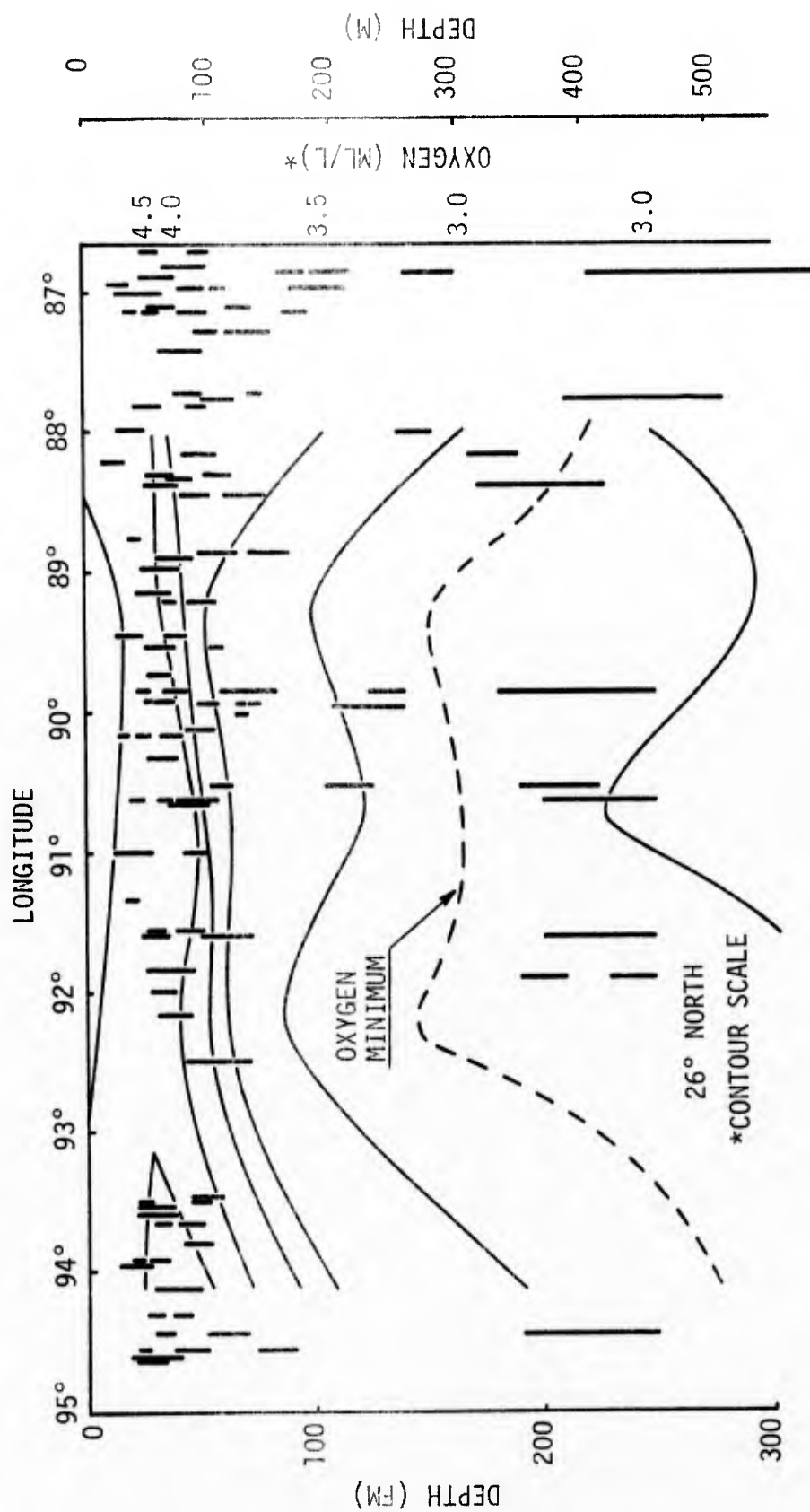


Fig. 5(h) - DSL and general east-west oxygen profile, summer.

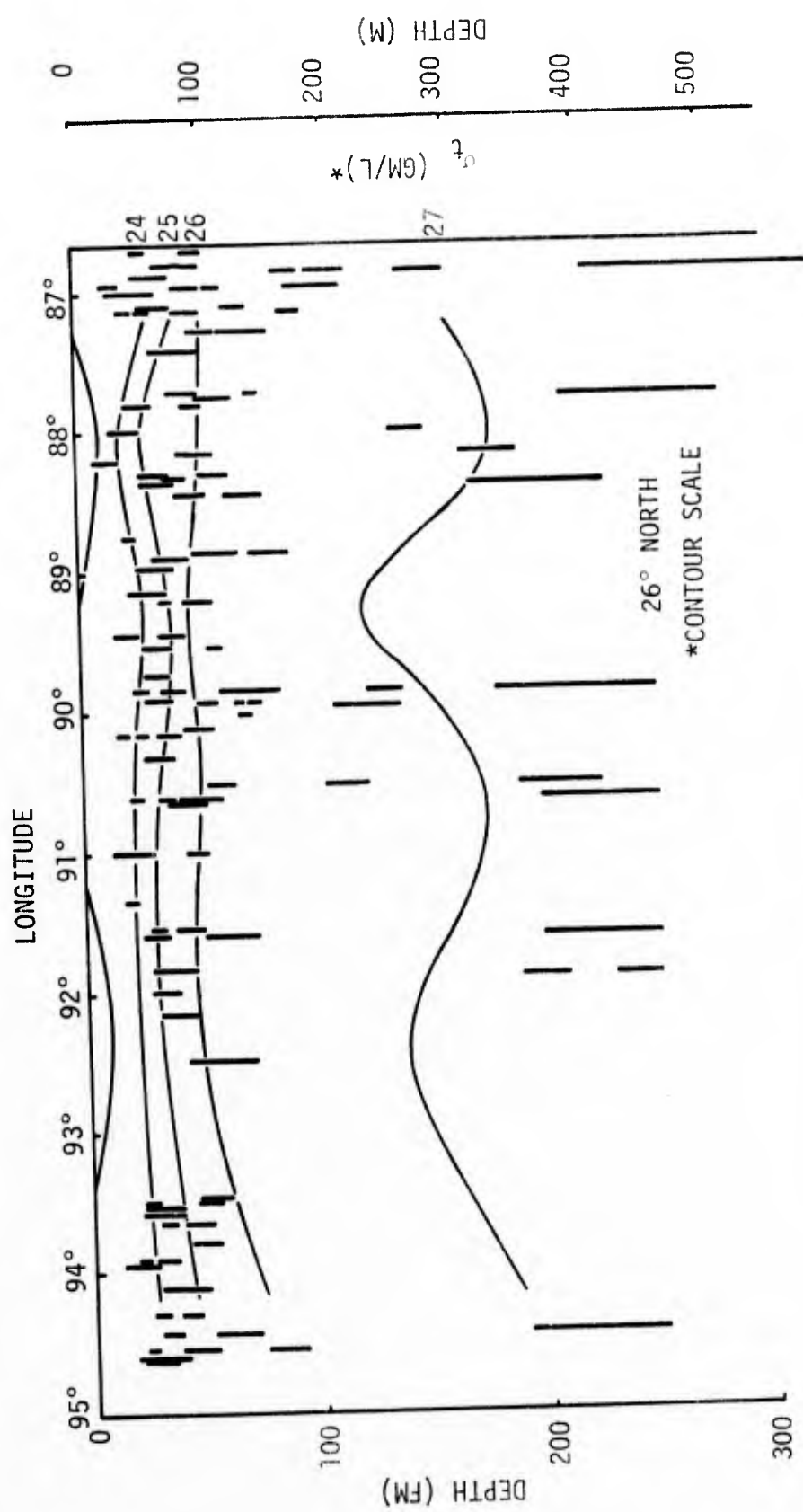


Fig. 5(i) - DSL and general east-west σ_t profile, summer.

through 5(e). The shallower (less than 100 fm (183 m)) DSL appear to conform to portions of the water column that are coexistent with rapid vertical change of such parameters as temperature, salinity, oxygen and σ_t . There is less pronounced correlation of the DSL with these parameters as shown on the east-west sections (See Figs. 5(f) through 5(i)), as compared with the correlated north-south sections (See Figs. 5(b) through 5(e)). This is possibly because there is a greater degree of variability in the east-west direction than in the north-south direction in the Gulf. The only conclusion that can be drawn, based upon the existing data, is that there is no definite correlation between the various physical parameters and the distribution of the DSL in the Gulf of Mexico. This conclusion will, it is expected, be altered as more, and better, data become available in the future.

B. Recent Data

On two recent cruises of the R/V Alaminos (70-A-4 and 70-A-9), observers were on board with the primary task of improving the DSL data (this was done by close control of the PDR system). A large volume of precision depth recorder tracings as well as some simultaneous magnetic tape recordings of the PDR signal were obtained. The location of specific DSL observations are presented in Fig. 6.

Data from these cruises were used in attempts to arrive at correlated DSL motion with temperature and temperature gradient.

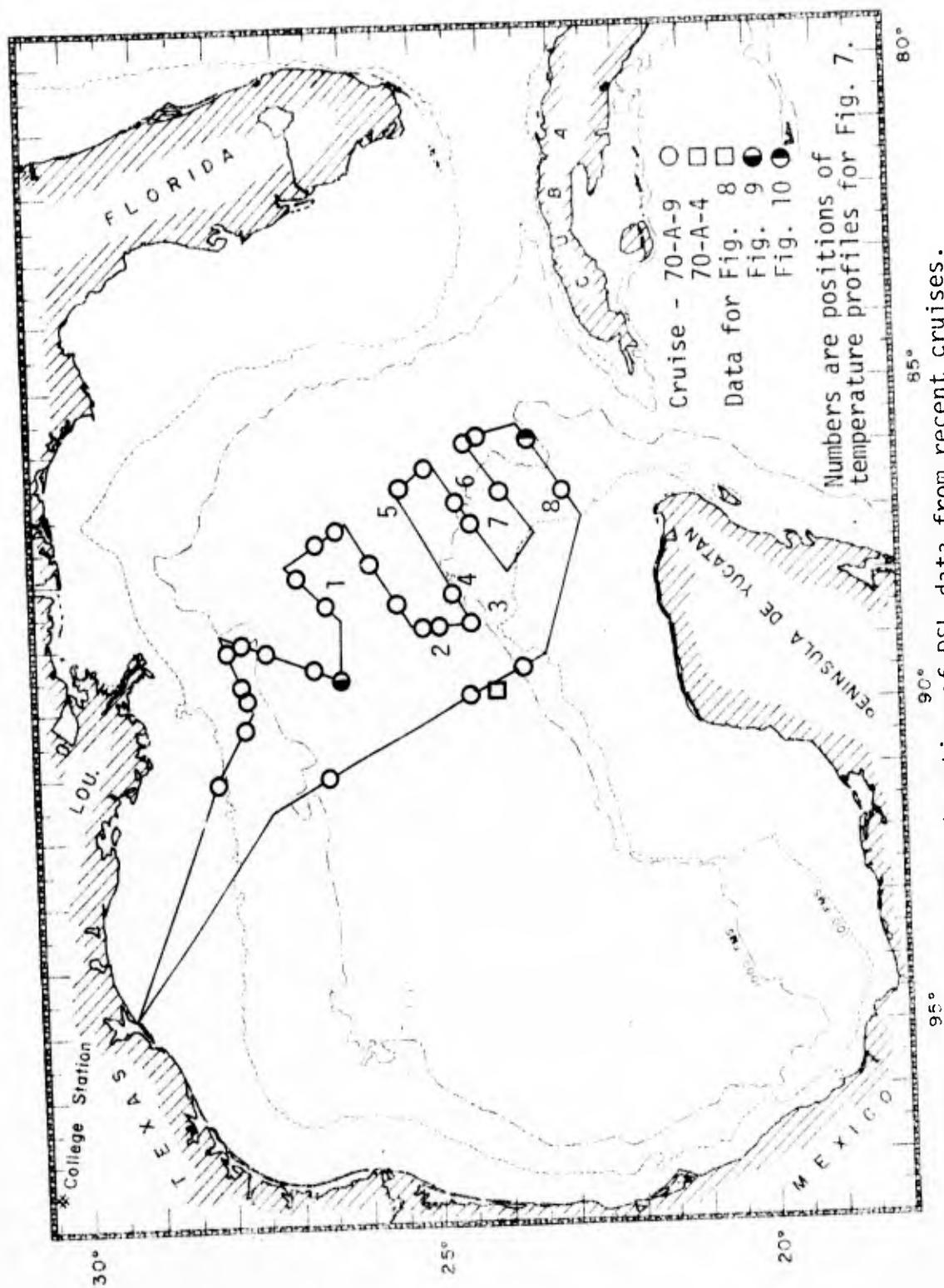


Fig. 6 - Location of DSL data from recent cruises.

There is the possibility that some degree of correlation exists between the vertical temperature structure and the depth of the DSL (See Fig. 7); however, no consistent set of data indicating such could be concluded.

Through the continuous monitoring of the PDR gains, the quality of the data was a marked improvement over that of past data, and, in general, the data confirmed the conclusions drawn from past data. Specific features, found in both recent and past data, are discussed in the following sections.

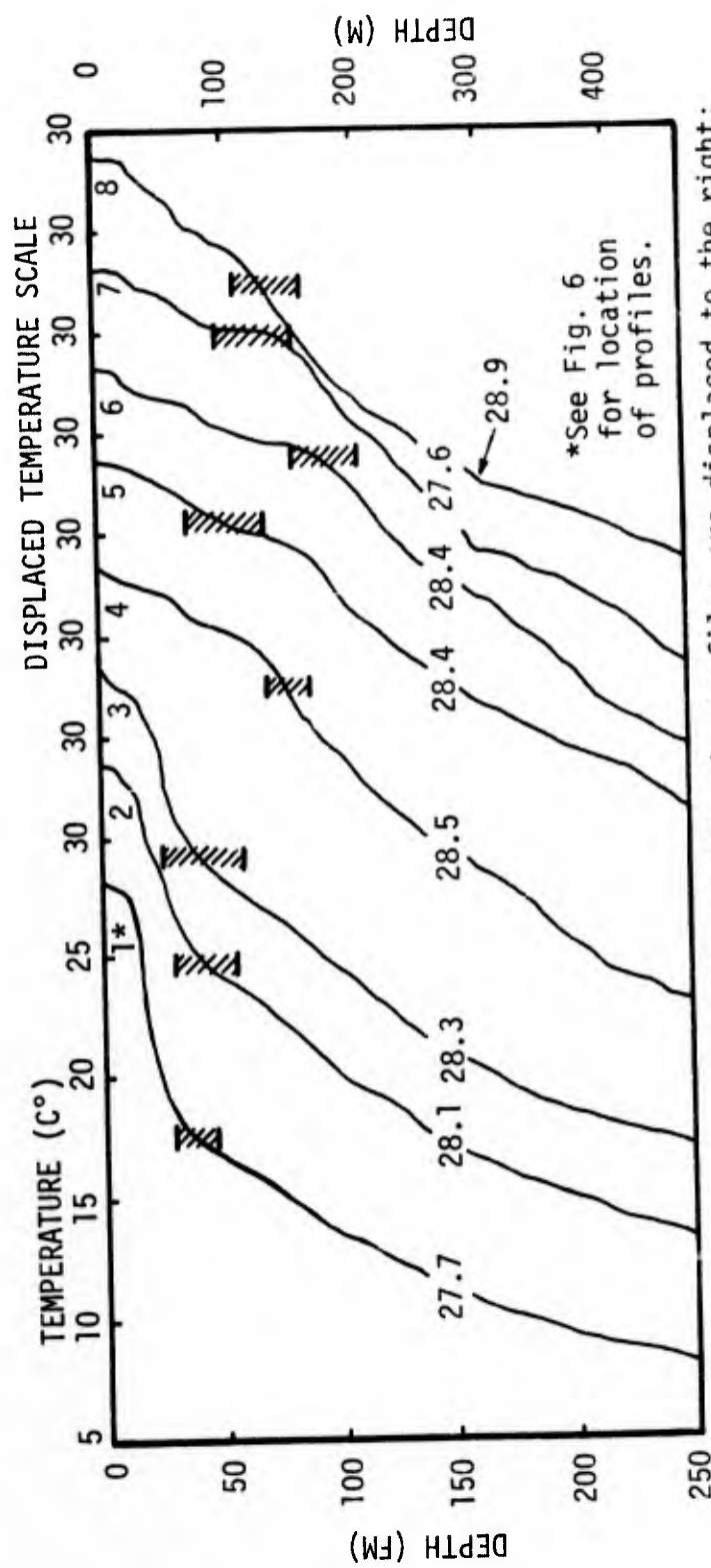


Fig. 7 - Selected temperature profiles from cruise 70-A-9 showing prominent DSL.

III. DISCUSSION OF SPECIFIC DSL BEHAVIOR

A. Multiple Layering

Multiple layering is often observed in the Gulf. On a cruise in March, 1970, while maintaining station, six distinct layers were observed at depths to 225 fm (412 m) (See Fig. 8), these layers were stable over the observation period of three days. Also shown in the figure are some volume scattering measurements taken utilizing the PDR system. The outgoing and returning pings were recorded on magnetic tape. The relative values of the intensity, as shown on the figure, are from averages of several pings taken from the magnetic tapes. Table I summarizes the layering as it was observed during the test period. The layers were continuous from morning to evening of the same day, and from one day to the next they appeared to be continuous.

On a subsequent cruise in June, 1970, multiple layering was observed on a number of occasions. Fig. 9 is a photograph of a PDR tracing showing an observation of five layers in the central Gulf; these layers range in depth to 180 fm (329 m). In the southeastern Gulf, on the same cruise, seven layers were observed (See Fig. 10) ranging in depth to 240 fm (431 m). As can be seen on the figure the shallow layers appear to be horizontally patchy.

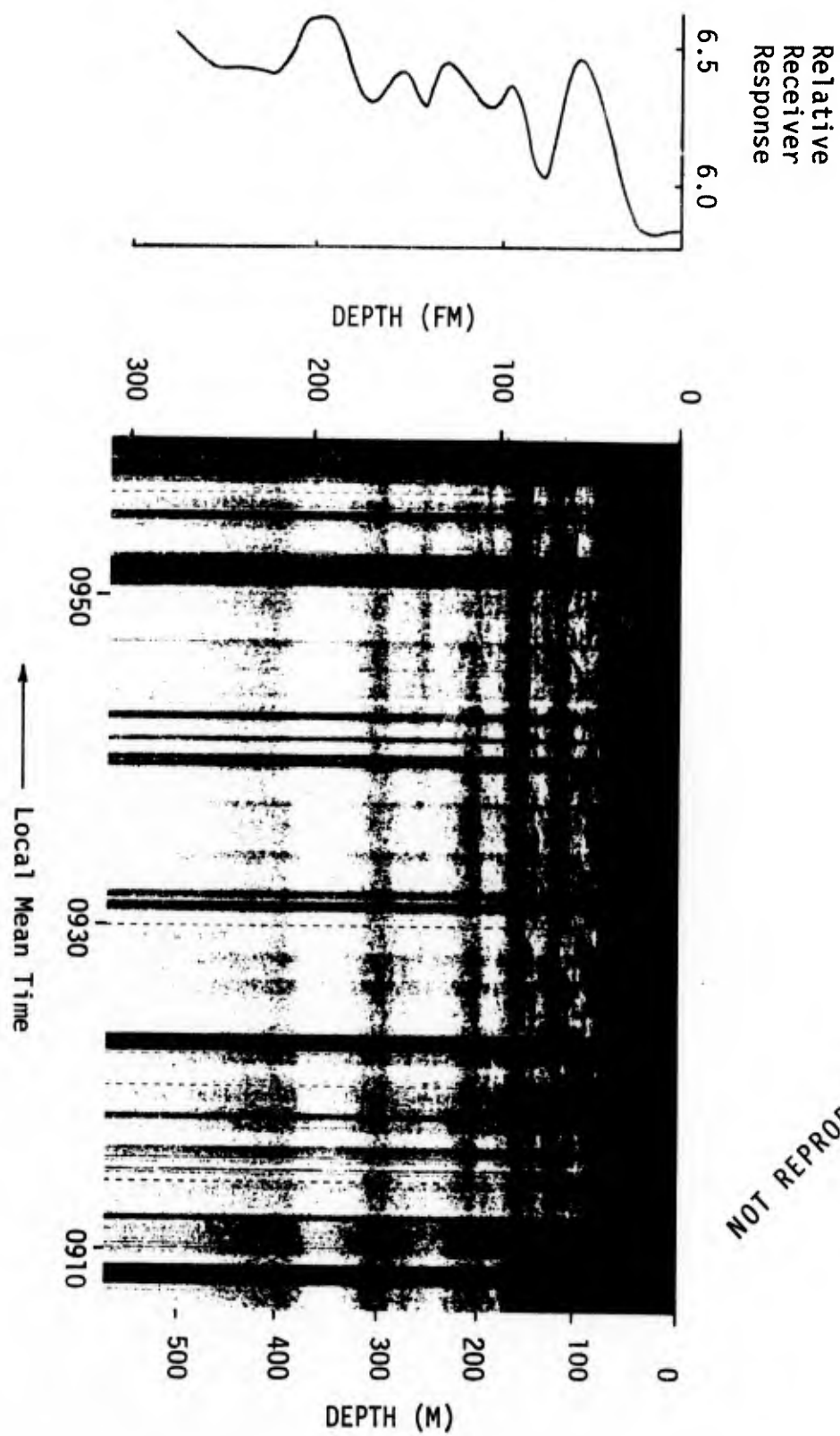


Fig. 8 - Photograph of PDR trace for the morning of the total solar eclipse, relative receiver response is also shown.

Layer Number	Afternoon ^a 3/6/70	Morning 3/7/70	Afternoon 3/7/70	Morning 3/8/70	Afternoon 3/8/70
1				35 Ms	30 Ms
2		65 Hm	^b	70 Mm	
3	90 Ls ^c	85 Hs	85 Ms	85 Mm	85 Ms
4		110 Hw		120 Mw	120 Mw
5		135 Hw			
6		160 Hw	150 Mw	160 Mw	160 Mw
7		220 Hw	220 Mw		210 Mw

^aNo specific times are assigned here since the layering was generally constant during these periods.

^bLayer broke up into individual scatterers.

^cCapital letters refer to relative gain settings (H, high; M, moderate); lower case letters refer to relative darkening of PDR record (s, strong; m, medium; w, weak).

TABLE I. Depth (in fathoms) of observed layers

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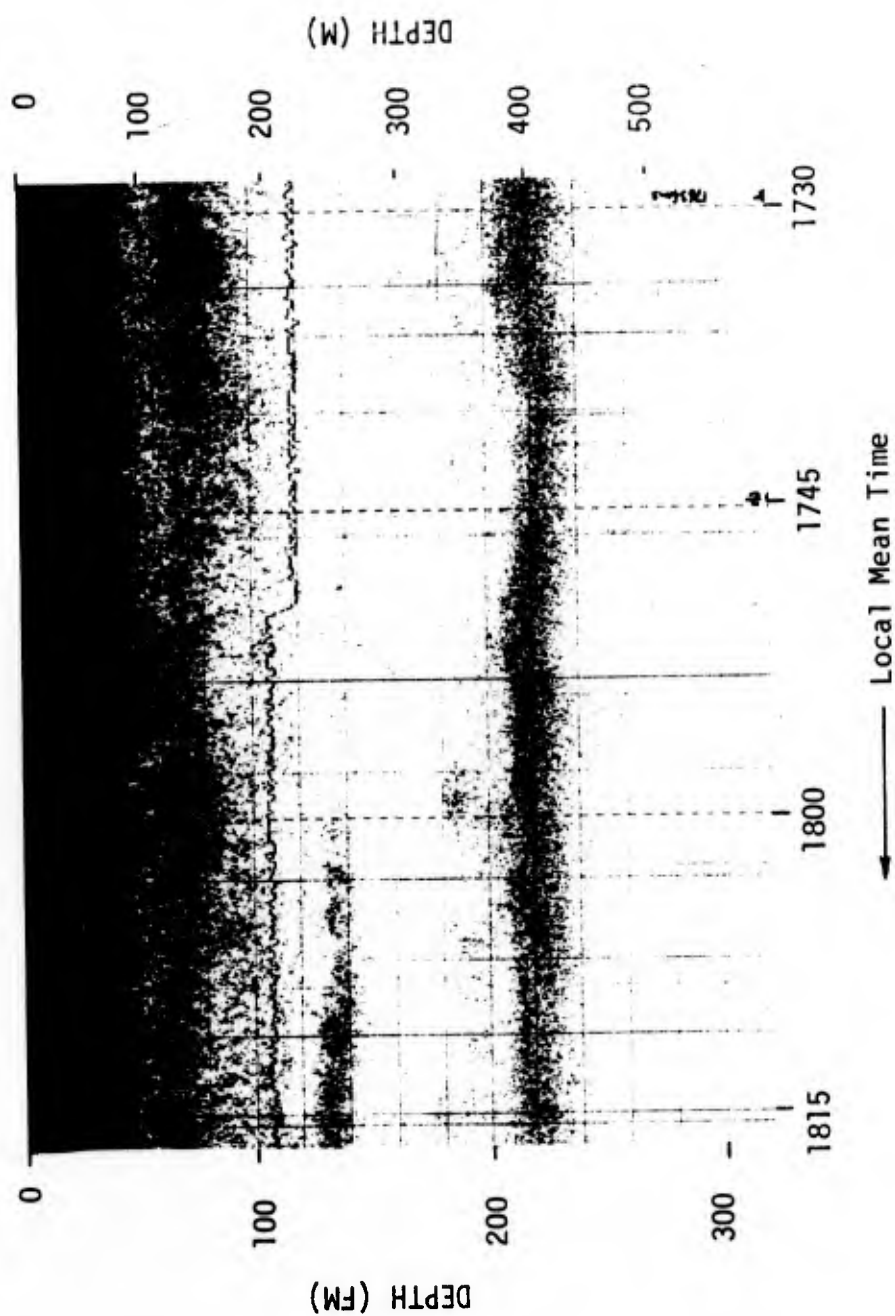


Fig. 9 - Photograph of PDR trace showing multiple layering.

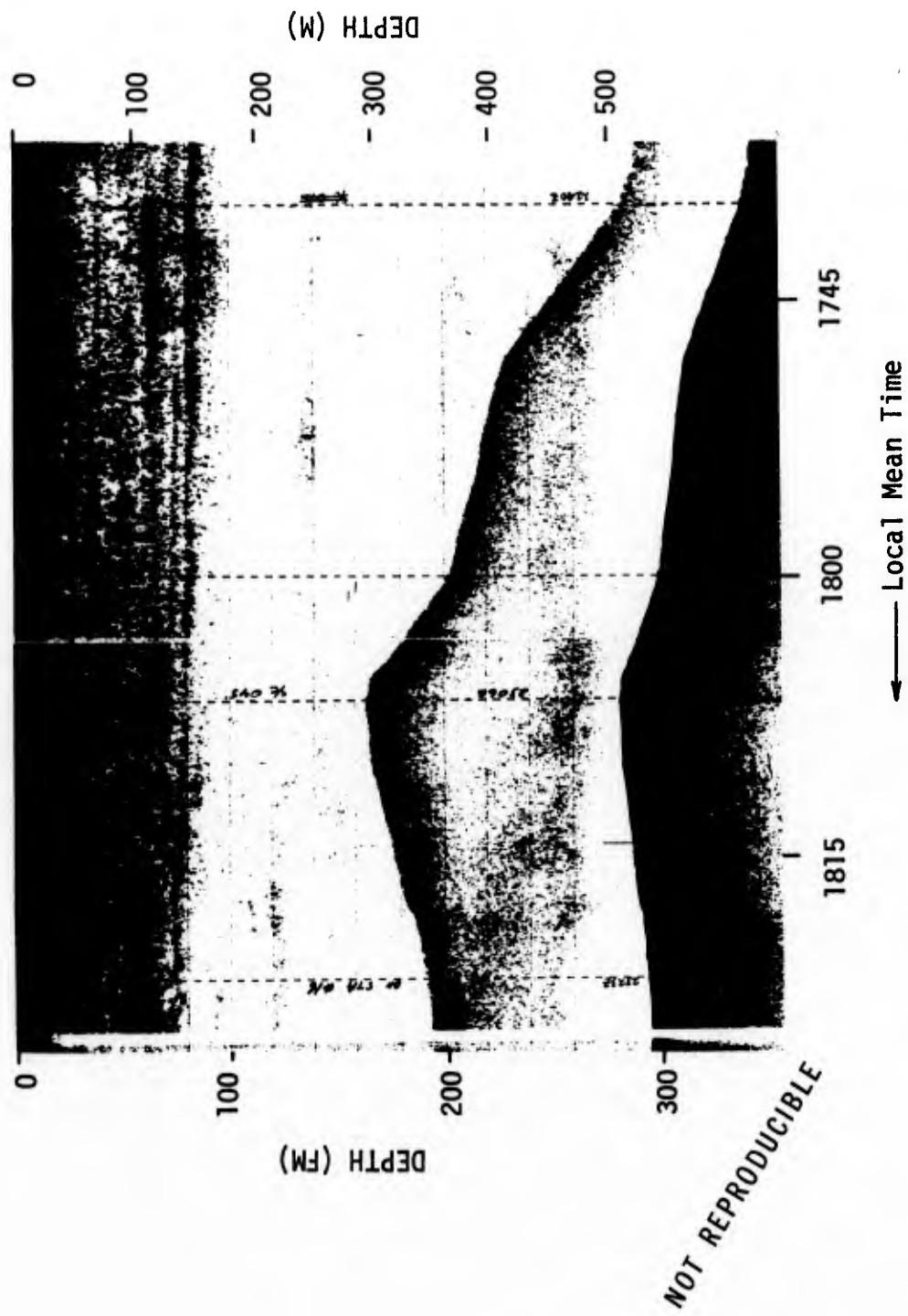


Fig. 10 - Photograph of PDR trace showing multiple layering in the southeastern Gulf.

B. Diurnal Migration

Fig. 11 is a composite diagram of individual evening ascents and morning descents; collectively, representing typical evening and morning migrations. There are a number of migratory regimes: the near surface, which undergoes little or no vertical migration; the intermediate, which descends to depths as great as 125 fm. (229 m); the deep, which descends to depths of the order of 225 fm (412 m); and, possibly, deeper layering.

As the layers descend they separate into other layers, usually undergoing further splitting prior to approaching a stable depth; ascent is similar to, but opposite, descent. While the downward migration of the deeper layers seldom takes longer than two hours, the upward migration takes as long as 3 1/2 hrs to complete--depending upon the initial depth of the layer; the deeper the layer the longer it takes to reach its near surface nighttime level.

The first portion of the evening ascent and the last portion of the morning descent are slow (less than a half a fathom a minute (less than a meter a minute)). During the last hour, the motion is fairly rapid (about 1.3 fm/min (2.4 m/min) for the ascent and about 1.8 fm/min (3.3 m/min) for the descent--the maximum rates being 3.4 and 5.9 fm/min (6.2 and 10.8 m/min), respectively). The layers start their rapid descent about an hour prior to sunrise; the rapid portion of the evening ascent starts

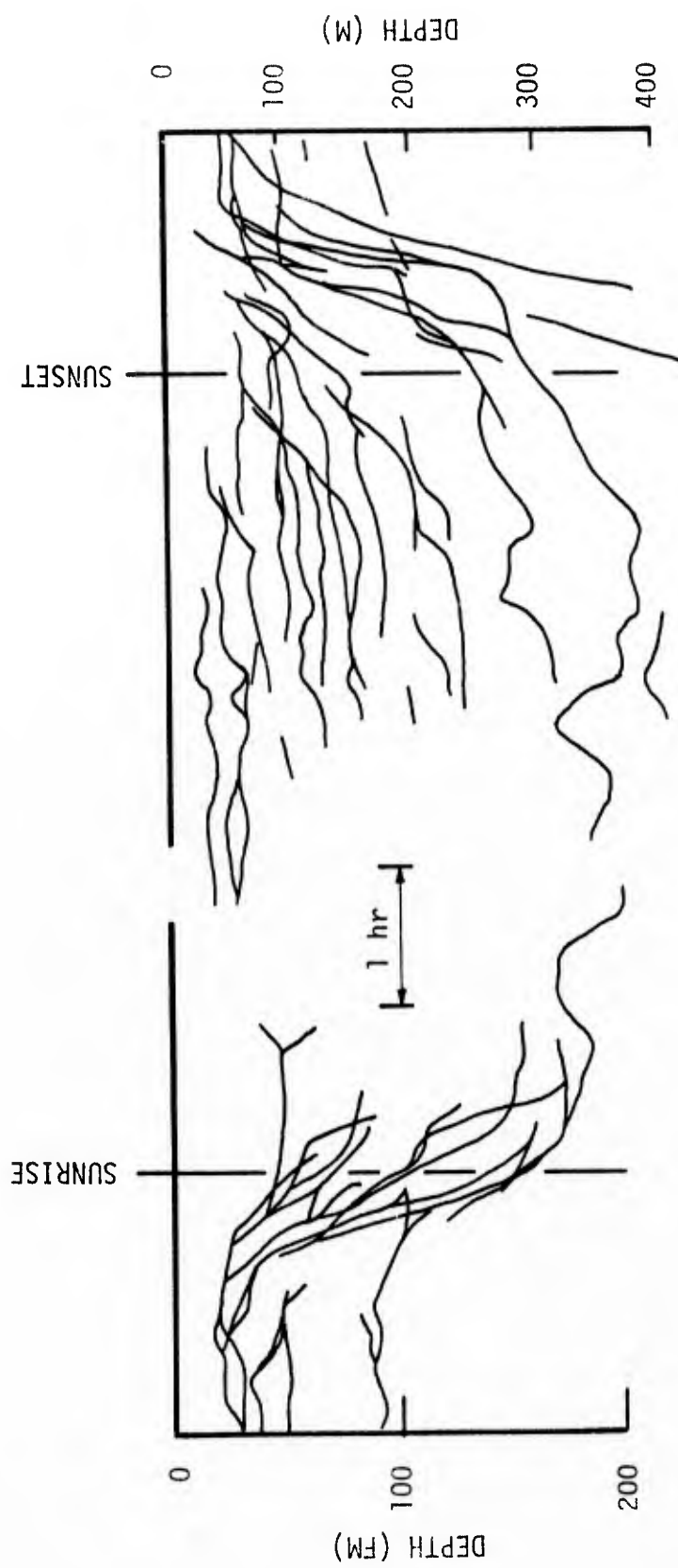


Fig. 11 - Composite morning descent and evening ascent.

about the same time interval prior to sunset. It is often difficult, with certainty, to follow the DSL throughout its period of vertical migration.

An example of the evening ascent is shown in Fig. 12. Not all of the layers start their evening rise or arrive at their shallowest depth at the same time. Prior to the beginning of the rise, at least three layers were present 60 (110), 105 (192) and 200 (366) fm (m) deep (See Fig. 13). The layer at a depth of 200 fm (366 m) could be followed into the rise, and seen to separate into two layers during the early portion of the rise.

Layers can often be seen to form during the descent (See Figs. 14 and 15). Often, while the layers are preparing to descend, they will first rise toward the surface; this "dawn rise" is discussed in a later section. Two layers are seen to descend; the deeper layer started down at about 0500 h LMT, the shallower about 0530 h LMT. The deeper layer ceased its rapid descent near 180 fm (329 m), but continued downward at a slower rate eventually reaching a midday depth of 200 fm (366 m). The shallower layer reached 100 fm (183 m) prior to midday and by early afternoon it was down to 105 fm (192 m). As the deeper layer descended, parts of it broke up into scattering groups (to be discussed in a later section).

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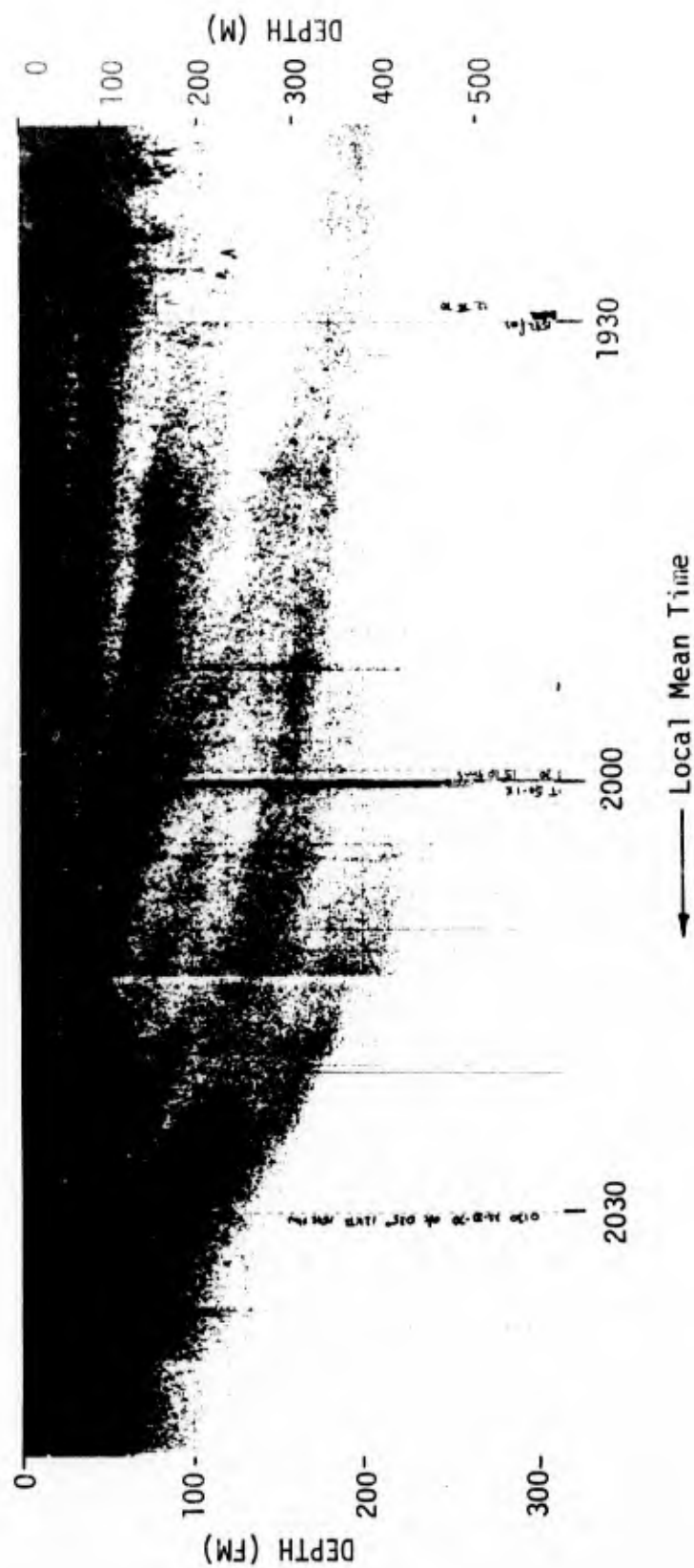


Fig. 12 - Photograph of PDR trace showing an evening ascent.

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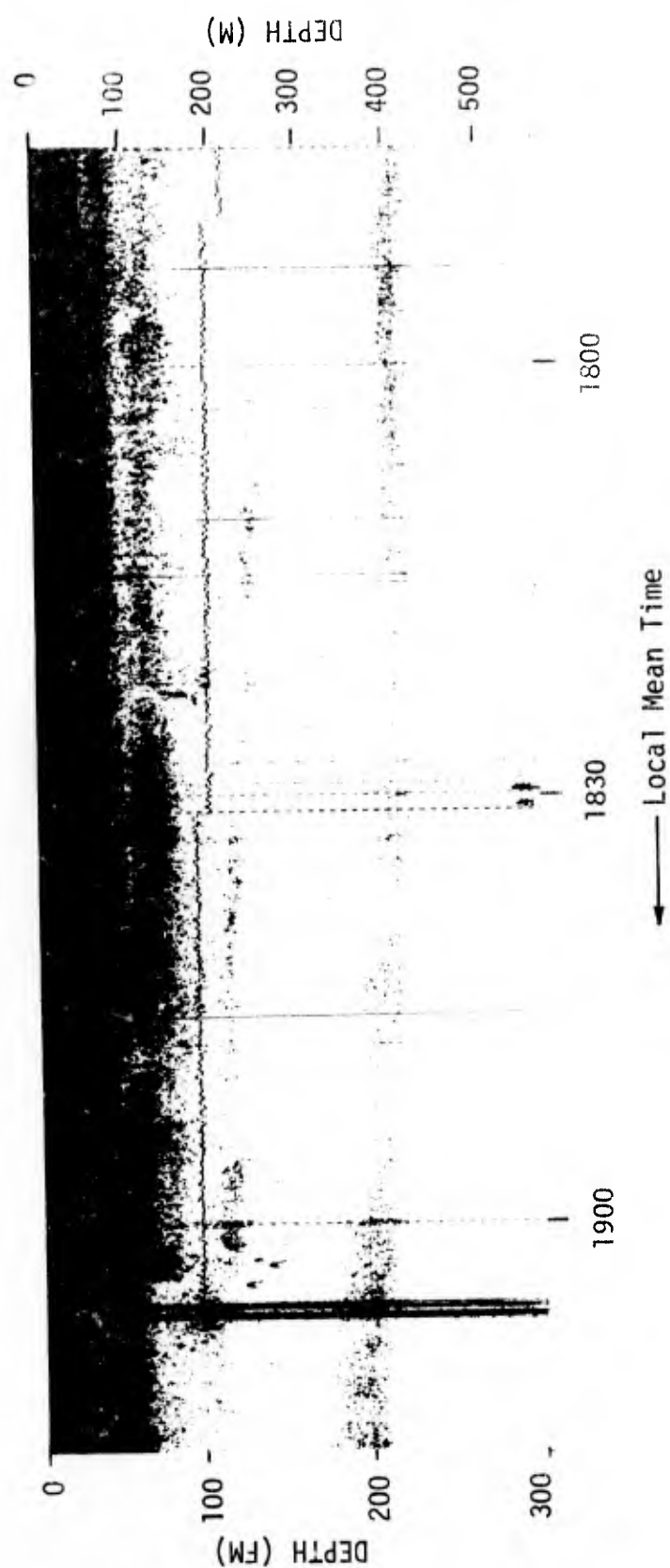


Fig. 13 - Photograph of PDR trace showing an early portion of an evening ascent.

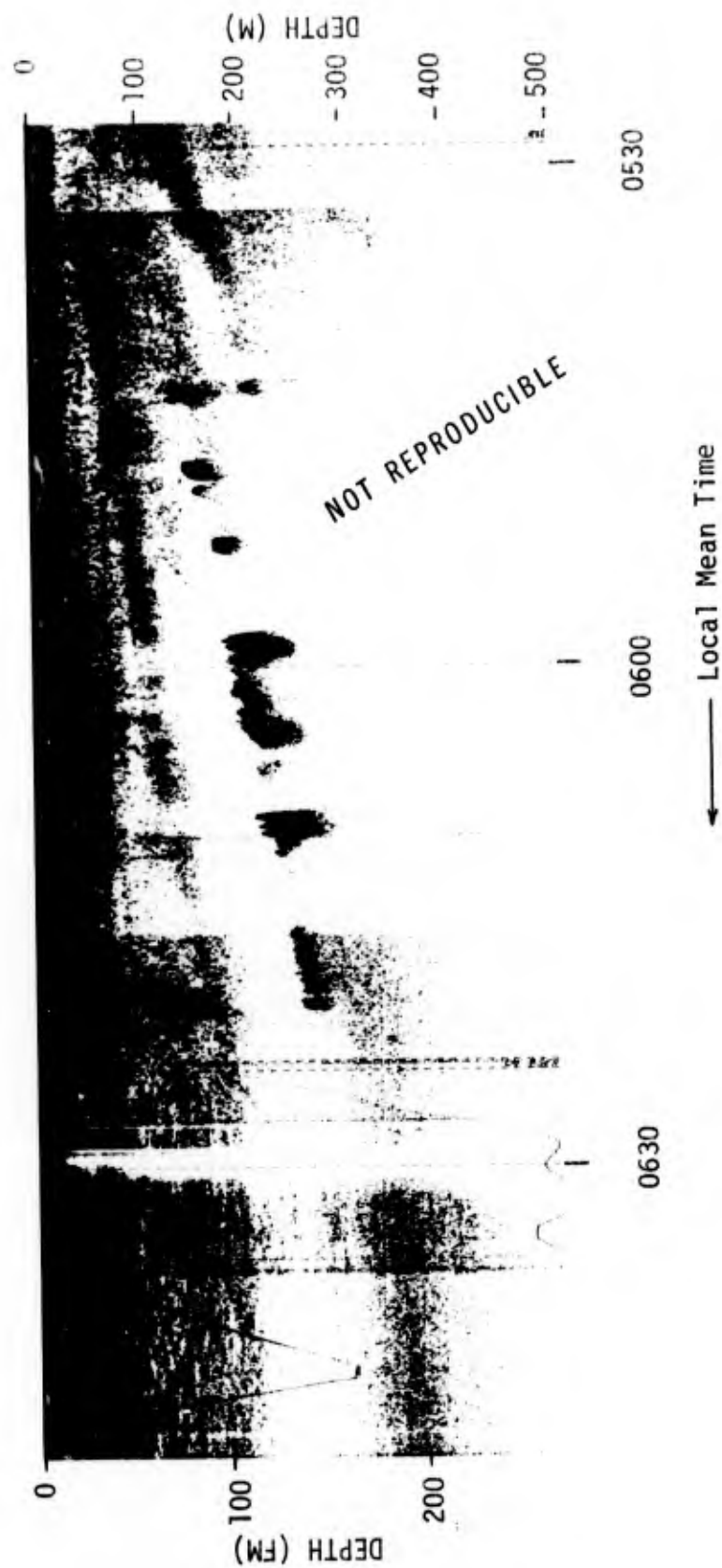


Fig. 14 - Photograph of PDR trace showing a morning descent.

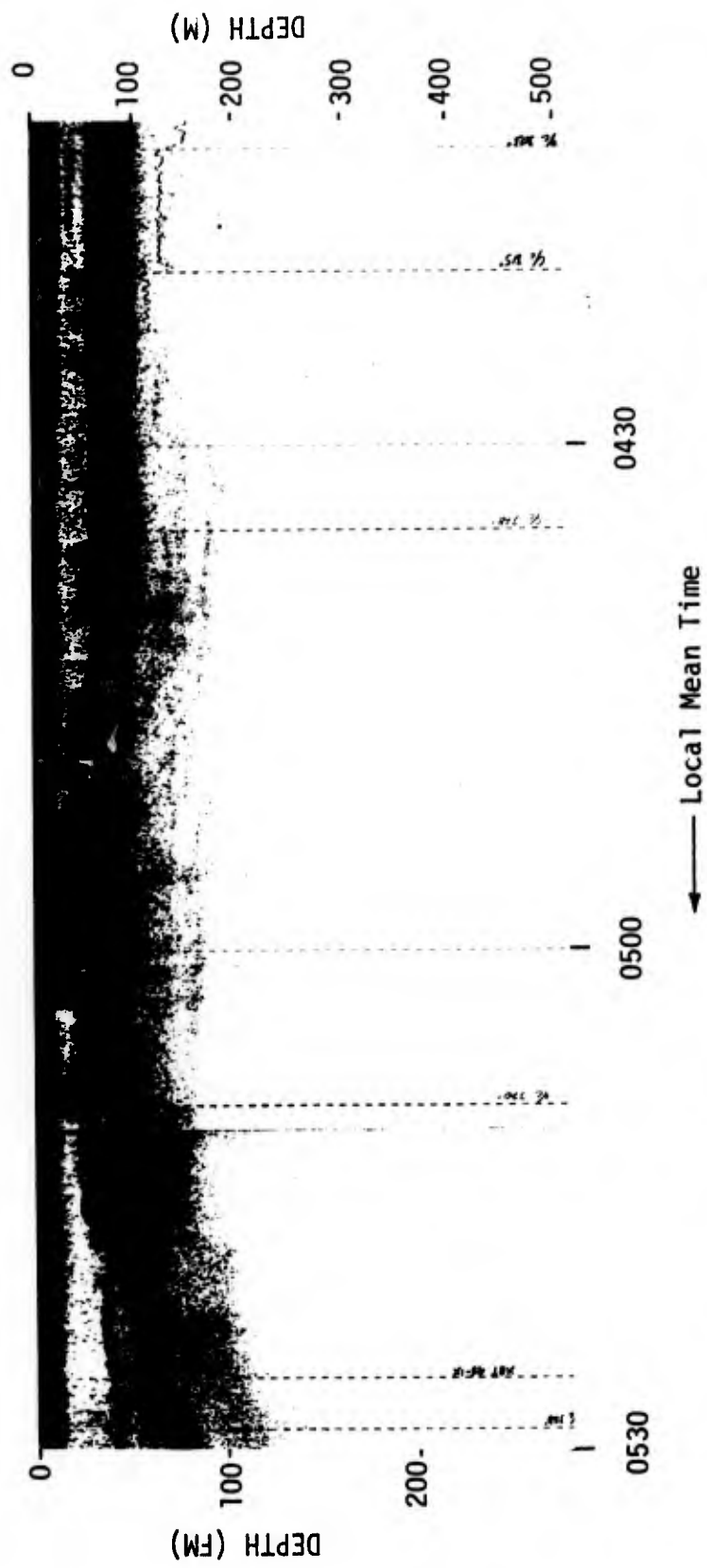


Fig. 15 - Photograph of PDR trace showing an early portion of a morning descent.

C. Dawn Rise

The organisms composing the DSL do not all remain at, or near, the surface throughout the night; many of them undergo a gradual settling.^{32,33} The primary stimulant causing the diurnal vertical migration of the DSL appears to be light. There is the possibility, however, that organisms within the DSL are only following smaller organisms that are responding to the change in light intensity. It is probable that there is some optimum range of light intensity to which a member of the DSL responds positively (i.e., toward increasing light intensity). Upward migration is in response to a falling off of the light intensity reaching the layer. Then, as the sun sets and the light intensity falls below the optimum value, some components of the layers settle slowly primarily because of random movement of the organisms in the absence of any stimulus to respond to.³⁴ Toward dawn, they once again start their rise, seeking their optimum light value. Then, as the light intensity continues to increase, the organisms start an active descent due to negative stimulus (i.e., away from increasing light intensity).

Two examples of the dawn rise are presented: the first observed while maintaining station, the second while underway. Fig. 16 shows a definite rise of a layer which formed before 0530 h LMT, at a depth of 70 fm (128 m), and migrated upward between 0540 h LMT and 0600 h LMT. The dawn rise was also observed

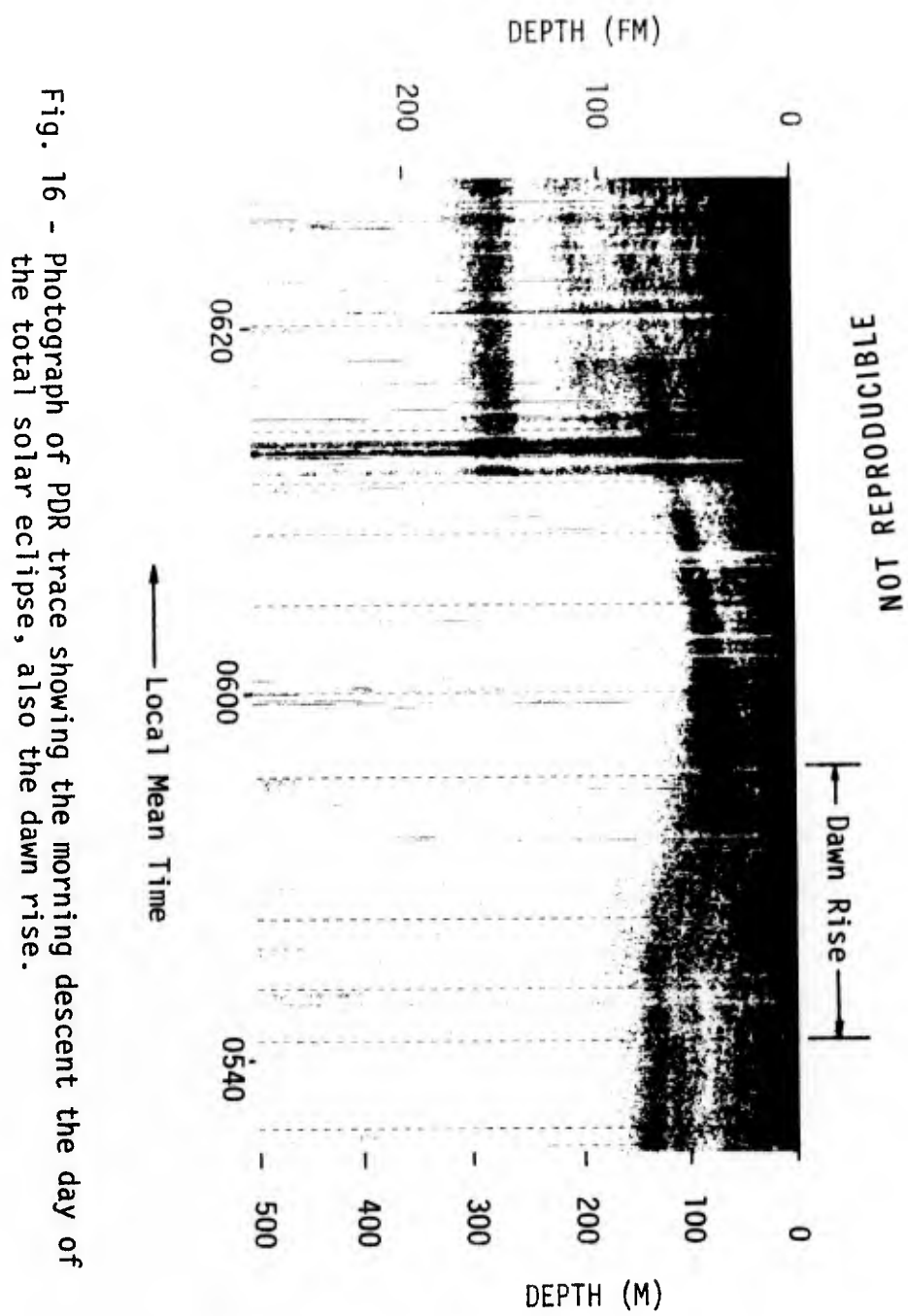


Fig. 16 - Photograph of PDR trace showing the morning descent the day of the total solar eclipse, also the dawn rise.

on the following morning. A later cruise, in June 1970, produced a good example of the dawn rise (See Fig. 15); a layer formed prior to 0435 h LMT at a depth of 30 fm (55 m) and started its dawn rise at about 0440 h LMT.

This phenomenon is apparently widespread as it has been reported often in literature on the biological layering as interpreted from net tows.^{34,35} No detailed acoustic reports, however, have been written concerning the dawn rise. In at least one instance the dawn rise was noted and discussed but not specifically identified as such.³⁶

D. Reaction to Solar Eclipse

Reported here are the results of observations of the DSL in the Gulf of Mexico during a three-day period which included the day of the total solar eclipse (TSE), March 7, 1970. The test site, 89° 31' W and 24° 01' N, was off the northern edge of Campeche Bank in 1910 fm (3495 m) of water. This point was selected because totality occurred at approximately local solar noon thus producing a maximum observable effect of solar radiation and depth of the DSL. On the day of the eclipse, occultation of the sun lasted for 2 h and 44 m (beginning at 1036 h LMT) and the total solar eclipse lasted for 3 m and 5 s (beginning at 1156 h and 35 s LMT).

Several layers seemed to have responded to the TSE but the most pronounced response occurred for the layer centered at

85-90 fm (156-165 m) (See Fig. 17). This layer migrated upward about 4 fm (6 m) arriving at its shallowest depth about 23 minutes after the TSE began.

Net tow experiments also seemed to indicate a vertical migration of the zooplankton in the upper 20 fm (37 m) in response to the TSE.³⁷

The migration of the DSL was quite complicated during the afternoon of the eclipse, and it is not certain to what extent the migration could be attributed to the eclipse. Several periods of heavy overcast occurred that afternoon, as is evident in the insolation curve given in Fig. 17. Much of the confused behavior of the layering was probably attributable to this cloudiness. It is clear that the DSL response to the TSE was small.

E. Response to Variations in Cloud Cover

There is some evidence to indicate that the deeper layers of the DSL respond to cloud occultation of solar radiation. It was noticed, on a number of occasions, that layers moved up when the sun was occulted by a passing cloud. This vertical motion was observed following the TSE (See Fig. 17) and on a subsequent cruise a few months later (See Fig. 18). The light intensity at the surface fell off some 80% while a DSL rose some 15 fm (23 m).

These measurements are the only insolation data known to have been taken that can be directly correlated to DSL motion.

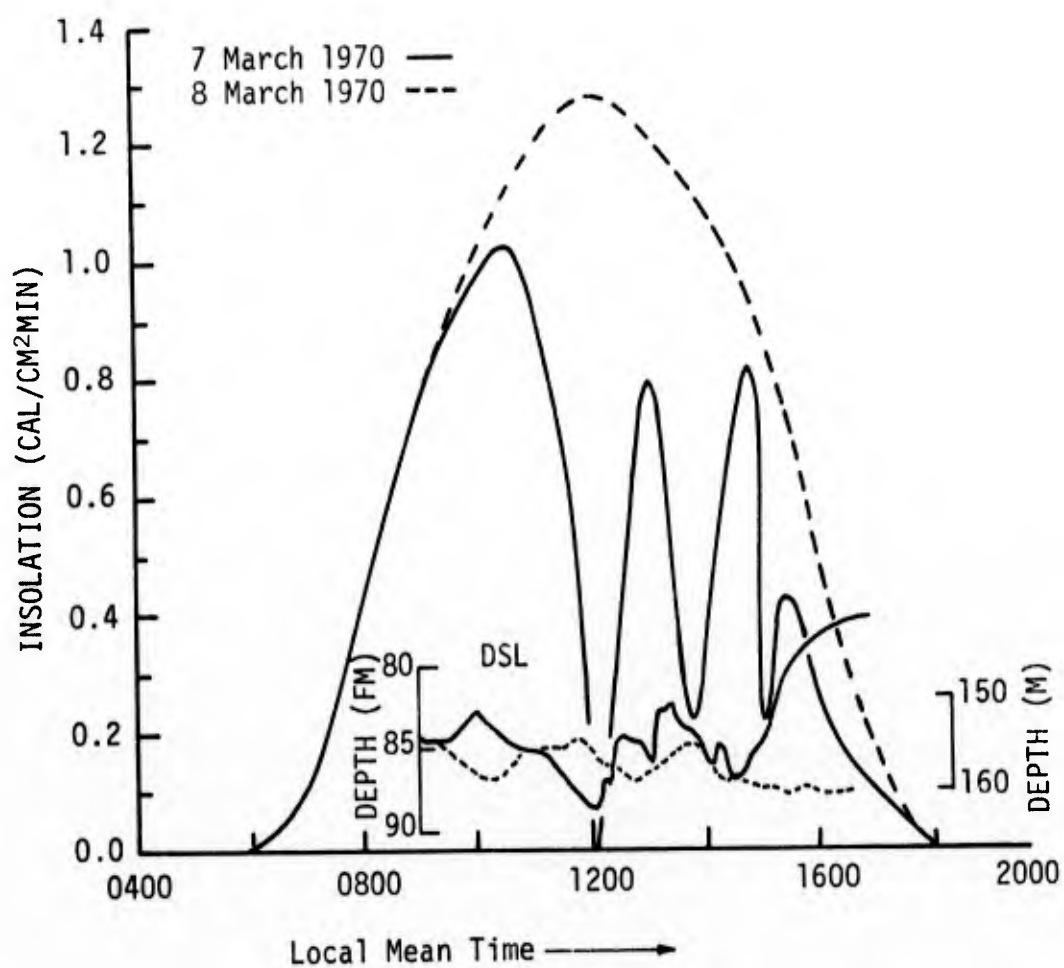


Fig. 17 - Insolation curve and DSL response.

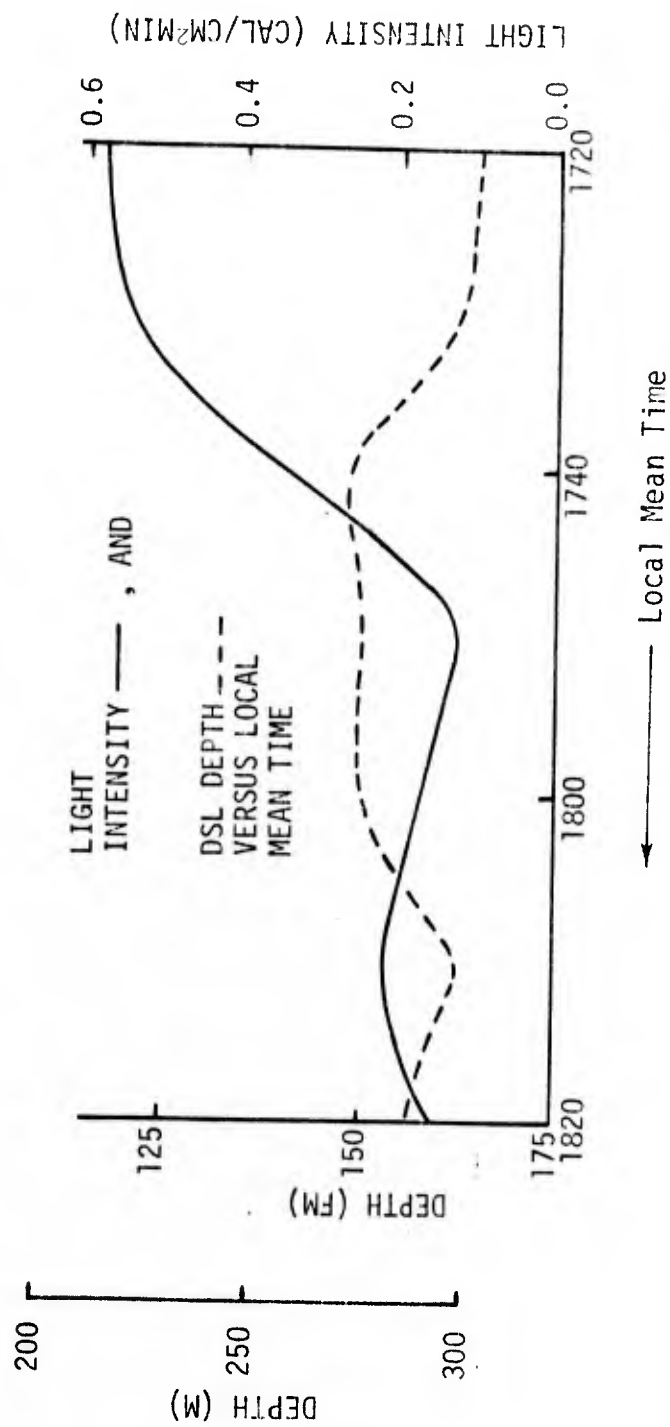


Fig. 18 - Response of DSL to reduced insolation due to scattered clouds.

Measurements have been made, however, utilizing a submarine photometer off the coast of San Diego³⁸ and New England.³⁹

F. Further Examples of the Character of the DSL

1. The DSL over the Continental Slope

This observation was complicated by a bottom multiple; also, this PDR trace was taken during the early portion of an evening rise. At the edge of the continental shelf, the DSL tends to conform to and rise with the bottom topography. Three layers were seen to exist: one at a depth of 60 fm (110 m) as well as two lower layers 3 and 6 fm (5 and 11 m) above the bottom, respectively (See Fig. 19). The lower layers appeared to remain a few fathoms above the bottom as the bottom profile changed; however, as the bottom dipped into a canyon the layers remained at stable depths across the canyon. As the bottom shoaled, on the far side of the canyon, the layers once again rose with the bottom.

The DSL were apparently prevented from being at their normal depth by the shoaling bottom; they appeared to prefer a shallower depth over that of drifting downhill to what would be their normal depth.

2. PDR Trace Compared for Ship Moving and Stationary

The character of the DSL, as obtained on PDR tracings, is strongly dependent upon whether the ship is moving or stationary.

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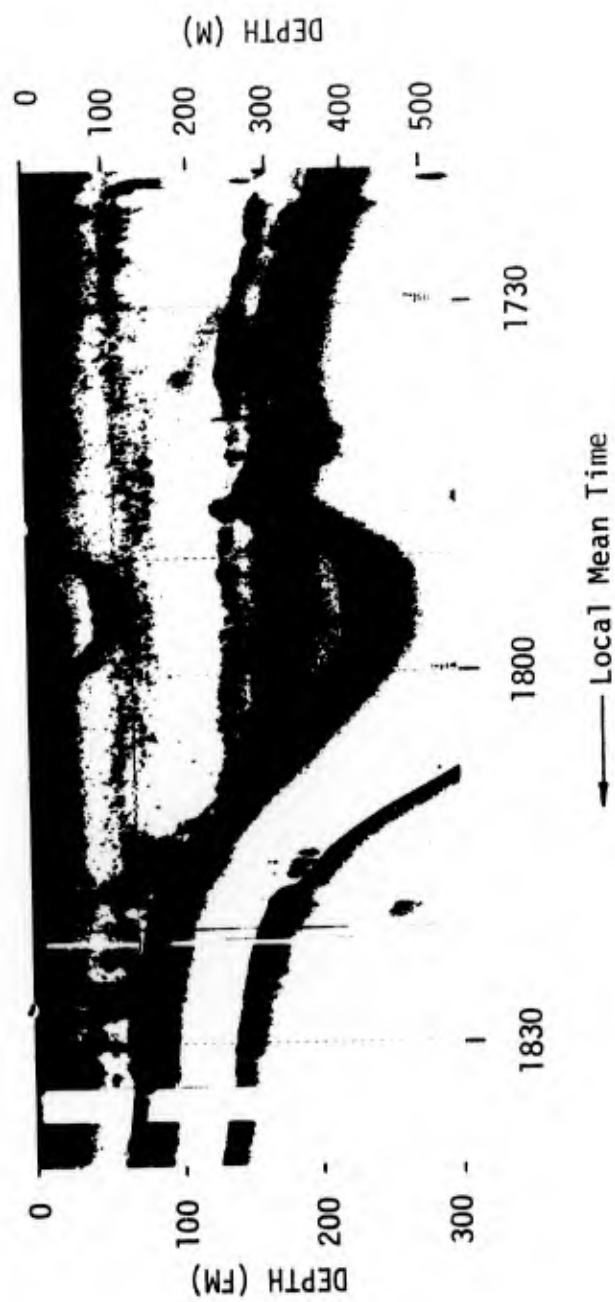


Fig. 19 - Photograph of PDR trace showing an observation of the DSL conforming to the bottom profile.

Fig. 20 is a trace of the near surface DSL as a moving ship comes to a stop. The character of the DSL, when the ship is underway, is such that the trace of the DSL is composed of many small, somewhat irregular, tent (hyperbolic) shaped spots. As the ship stops these spots become drawn out and the total number appears to decrease. These drawn out spots are probably due to the presence of individual organisms; the motion of the organisms through the cone of sound emitted by the PDR produces the tent shaped trace.⁴⁰

3. Scattering Groups

Quite often scattering groups are seen on the PDR trace obtained on crossings of the continental slope (See Fig. 21) and in the open sea (See Fig. 22). These groupings probably consist of schools of organisms such as fish, squid, etc. Another possibility is that they are composed of organisms grouped together because of physiological reasons, e.g., the particular volume of water they are occupying is the most comfortable or advantageous to their existence.

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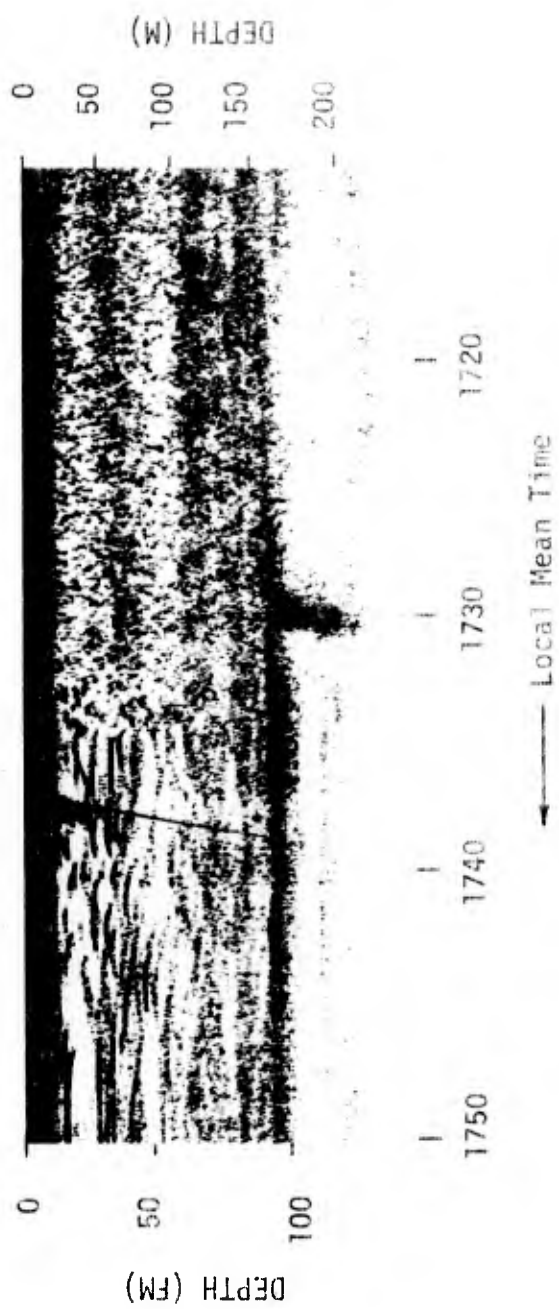


Fig. 20 - Photograph of PDR trace showing DSL while ship is stationary and underway.

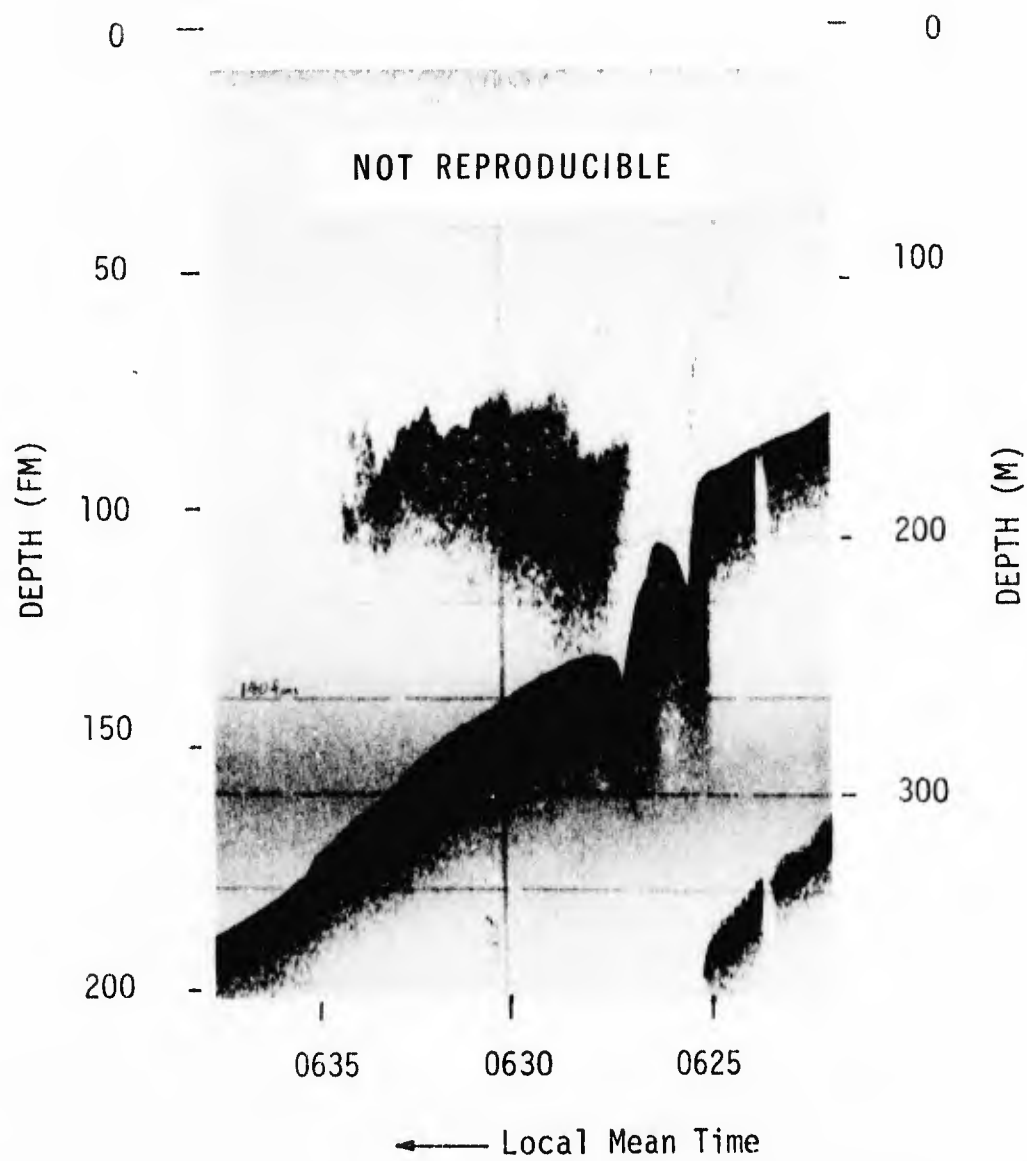


Fig. 21 - Photograph of PDR trace showing an example of scattering groups.

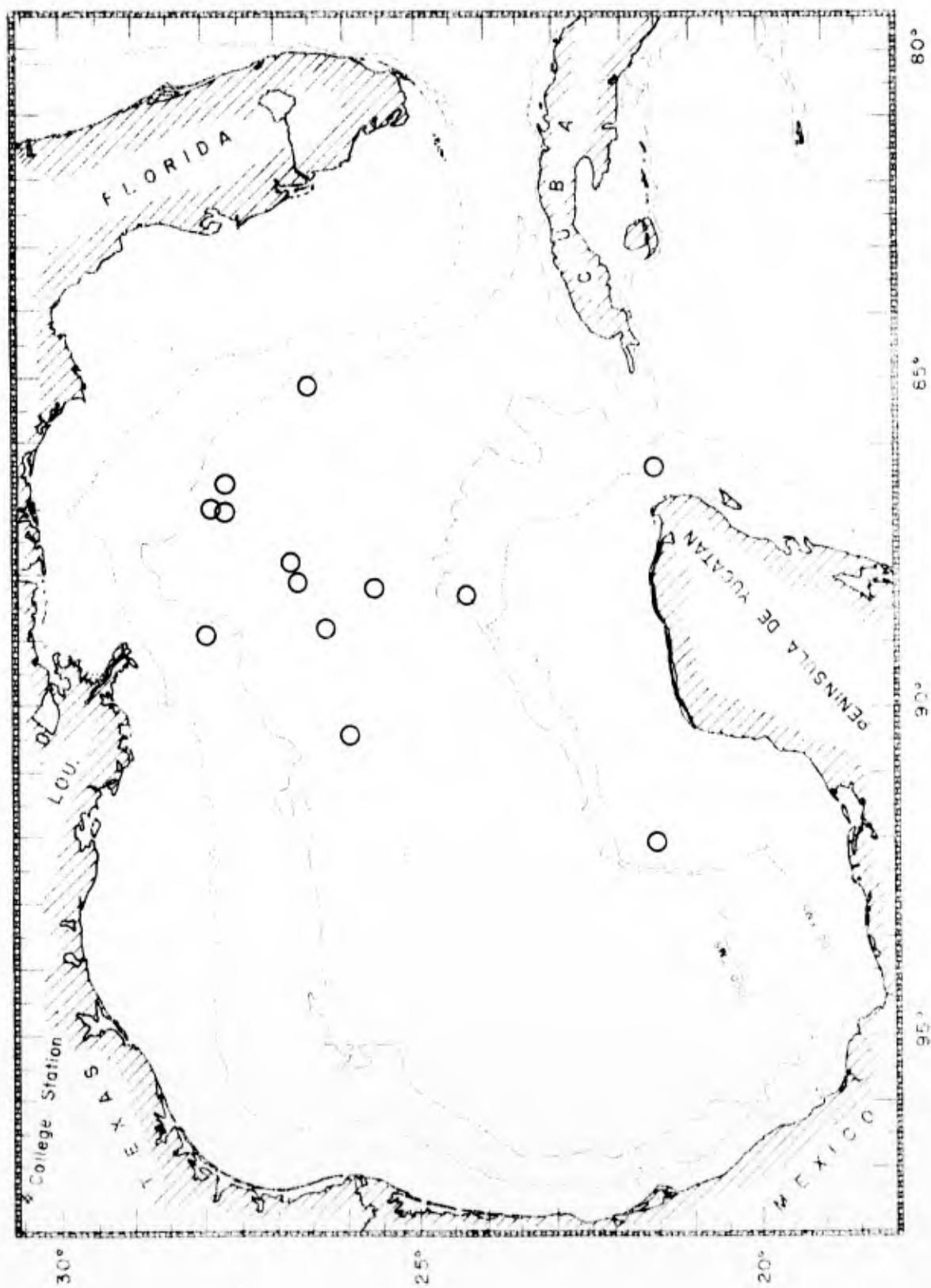


Fig. 22 - Location of observed scattering groups.

IV. SUMMARY

Observations of the DSL in the Gulf of Mexico over an extended period of time have produced the following results:

- documentation of the existence of widespread layering in the Gulf, including multiple layering in most cases, at depths to 260 fm (476 m);
- average descent rate of 1.3 fm/min (2.3 m/min), average ascent rate of 1.8 fm/min (3.3 m/min), and maximum rates of 3.4 and 5.9 fm/min (6.1 and 10.8 m/min), respectively--a slow descent follows the morning rapid descent, and, conversely, a slow ascent precedes the evening rise;
- the available data tends to indicate that there is little or no correlation between the DSL and various physical parameters, either on a regional basis or localized;
- the dawn rise was seen and noted on a number of occasions;
- a response of the DSL to a total solar eclipse is reported--there is some question, however, as to whether this response was due to the solar eclipse or to the scattered clouds present at the time of the eclipse;
- data were obtained which tend to indicate that the deeper layers of the DSL respond to occultation of the sun by clouds;
- the scattering layers, as recorded by the PDR, do not always consist of what could be called layers--often the tracings

are of a discrete nature, and most likely represent single organisms, or aggregates of organisms; and

- one observation of the DSL in the vicinity of the shelf edge indicated that it conformed to the local bottom topography in this region.

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