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Some Investigations of Sound-Scattering Layers Near Key West, Florida

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CONTENTS

Abstract	ii
Problem Status	ii
Authorization	ii
INTRODUCTION	1
THE OPERATING AREA	1
SURVEY AND SAMPLING OPERATIONS	3
Navigation	3
Hydrographic Gear	3
Acoustic Profiler	3
Operating Procedure at Sea	5
LABORATORY ANALYSES	5
Particle Counts	5
Turbidity Measurements	5
Iron Analyses	6
RESULTS	6
Operation of February 23	7
Operation of March 3	16
Operation of March 4	21
DISCUSSION	26
ACKNOWLEDGMENTS	34
REFERENCES	34
APPENDIX A — Functional Description of the Acoustic Profiler	35

ABSTRACT

An attempt was made to correlate local variations in volume scattering near Pourtales Escarpment south of Key West with the nature and occurrence of particulate matter in corresponding regions of the water column. Sound-scattering strength versus depth was measured with an "acoustic profiler," which is described, and water samples were obtained by conventional cast. Despite frequent uncertainty concerning the actual depths at which samples were obtained, some good correlations were found between scattering strength, particle count, and particle size distributions determined with an electronic particle counter. The acoustic profiler revealed the presence of numerous scattering layers in the area and provided tentative evidence for rather narrow stratification in some instances. Abnormal concentrations of iron, apparently as ferric hydroxide, were found in discrete zones near the scarp.

PROBLEM STATUS

This is a final report on one phase of the problem; work on other aspects of the problem continues.

AUTHORIZATION

NRL Problem S01-26
Project SR 104-03-01-8136

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SOME INVESTIGATIONS OF SOUND-SCATTERING LAYERS NEAR KEY WEST, FLORIDA

INTRODUCTION

The existence of some unusual layers of yellowish, turbid water off the Continental Shelf near Key West, Florida, in January and March 1965 has been reported (1). The layers were found at depths of 600 ft to 1000 ft and appeared to be 100 ft to 200 ft thick with clear water above and below. The suspended matter producing the discoloration was found to be predominantly iron, apparently as ferric hydroxide, in the unusually high concentration of 2 or more mg dry weight per liter. Microscopic examination showed the material to be highly uniform with little evidence of microplankton.

The yellowish water sampled in March 1965 also was examined *in situ* with an experimental "acoustic profiler" and was found to be associated with a local increase in volume scattering (2). Other scattering layers were found in the same area, but the nature of the scattering centers was not determined. The occurrence and properties of sound-scattering zones are of fundamental importance to the Navy in connection with sonar design and performance, target classification, and underwater operations generally. Furthermore, the nature and occurrence of unusual concentrations of suspended matter in the sea are of considerable scientific interest.

This report describes survey operations in the same area from February 23, 1966 to March 4, 1966 to continue the search for sound-scattering zones and to collect samples for laboratory characterization of any associated particulate matter. The acoustic profiler was evaluated further and is now described in more detail.

THE OPERATING AREA

According to Coast and Geodetic Survey data reported by Jordan and Stewart (3) and Jordan, Malloy, and Kofoed (4), the Continental Shelf south of the Florida Keys is in the form of a broad terrace (Pourtales Terrace) sloping gently seaward at an average rate of about 25 ft per naut mi. The seaward edge of the terrace is marked by a rapid drop-off of about 600 ft in 1/2 mi to a depth of approximately 1800 ft, followed by a further gentle decline to the south. This scarp is the Pourtales Escarpment, and all our operations were conducted near and to seaward of this region (Fig. 1).

The two locations where turbid, iron-bearing water was found in 1965 are also shown in Fig. 1. On March 22 the turbid samples were obtained from two bottles, with a relatively clear sample taken between them. The January samples were obtained with adjacent bottles. Because of restrictions imposed by naval activity in the area, most of the 1966 operations were along or to the west of a line extending south from the Key West main channel. We were able to operate to the eastward of this line on one day only (March 3) and then no nearer the escarpment than approximately 6 mi. Track charts for each day's operation are included with the presentation of the results.

Note: D. F. Wilson is now in the Marine Biology Branch, Ocean Sciences Division.

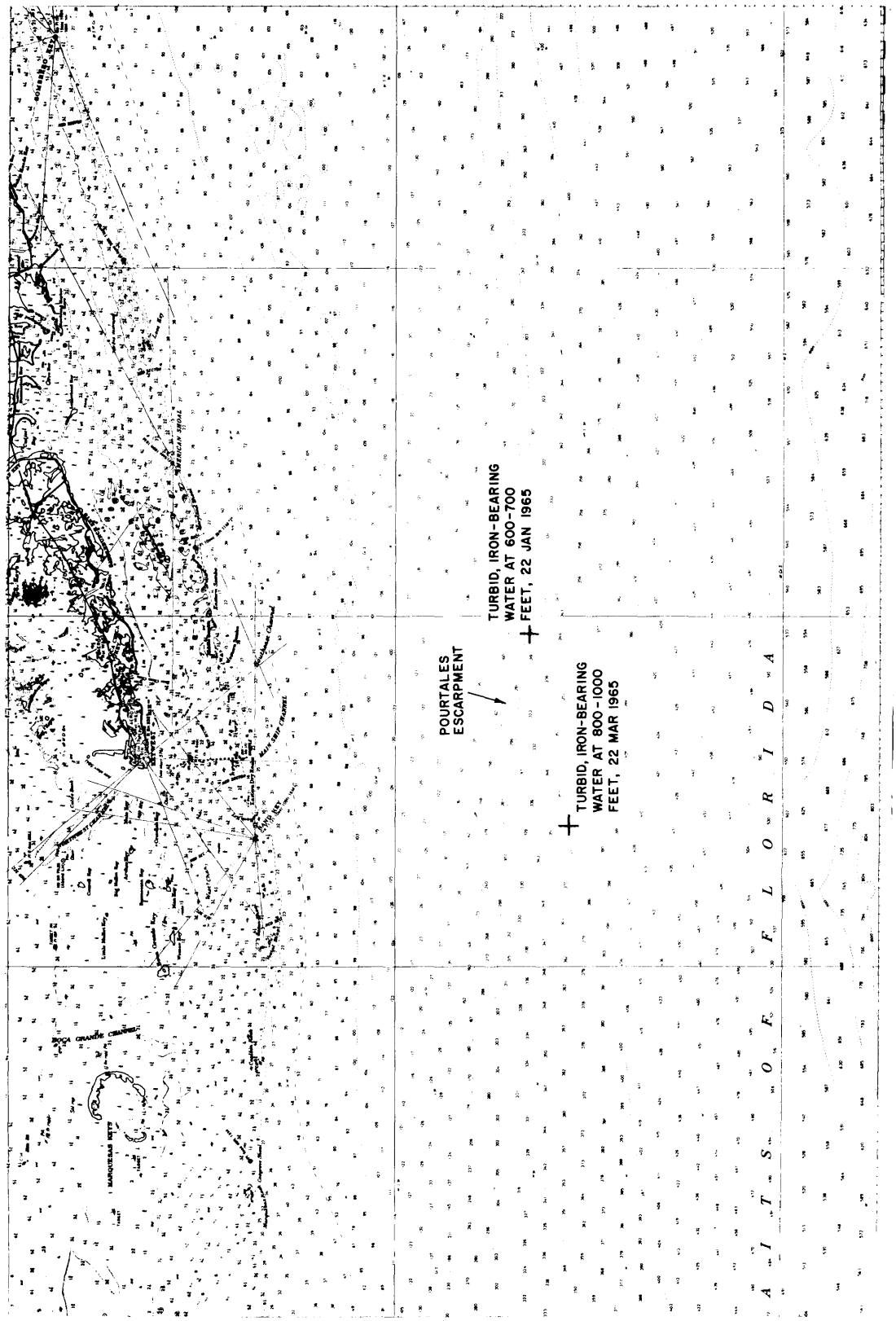

Fig. 1 - Operating area showing locations of the "iron layers" discovered in 1965

SURVEY AND SAMPLING OPERATIONS

The NRL Acoustics Division field party established a base of operations and laboratory in space provided by the NRL Cathodic Protection Field Laboratory, U.S. Naval Ordnance Unit, Key West. The Commanding Officer, Naval Ordnance Unit, provided a 63-ft underwater ordnance research boat (the UOR-125) for use during daytime only.

Navigation

Sand Key tower could not be seen from the escarpment by UOR-125's radar, so Loran A equipment was installed. It was recognized, however, that Loran A accuracy to better than 5 or 6 mi could not be expected in these waters, except for some single lines of position. Navigation at and beyond the edge of the Continental Shelf was, therefore, based entirely on a combination of dead reckoning, Loran data, and depth information provided by the acoustic profiler.

Hydrographic Gear

Special gear was installed in UOR-125, consisting of an A-frame and hand winch at the stern, for raising and lowering the 90-lb profiler transducer, and a reinforced davit and power winch mounted on the port side for handling the hydrographic wire. A 1700-ft length of plastic-coated stainless steel wire was run out through a meter wheel for the casts. We had twelve 1.25-liter Teflon-lined Nansen bottles without reversing thermometers. Bathythermograph data were obtained with a Wallace and Tiernan Model OC-3C/S BT operating to 900 feet.

Acoustic Profiler

The acoustic profiler was designed and built by one of us (L.C.R.) specifically for measuring the strength M_v' of volume scattering as a function of depth.* It is a 1-kW, highly directional, 19.5-kHz echo-ranging system operating from just beneath the surface downward, like a fathometer. The profiler differs from an ordinary echo sounder principally in the use of a narrow beam and an A-scan display. The system presently incorporates a transducer which cannot be towed. This necessitates stopping briefly at each profiler station to lower the transducer a few feet beneath the surface and observe the profile; 5 to 10 min are ordinarily required at such stations.

Figure 2 shows the profiler electronics installed below decks in the after compartment of UOR-125. Two display oscilloscopes are at the top of the main rack followed, in descending order, by a narrow power panel, the receiver section, and a panel containing the timing circuits, pulse-length generator, calibration oscillator, and log converter. The transmitter section and its power supply are at the bottom. To the left of the rack is a small test scope, an optical oscillograph, and a tape recorder. The Loran equipment is partly shown at the extreme right. A functional block diagram and description of the profiler are contained in Appendix A.

The oscilloscope display is recorded with a Polaroid scope camera. Figure 3 shows such a record. The strong peak at the origin is the transmitted pulse, and the strong peak at 2175 ft (on a 1000-yd scale) is the bottom echo. The equidistant curved lines

*M_v' is the ratio, in decibels, of the scattered intensity I_s at unit distance (1 yd) from a unit volume (1 yd^3) to the incident intensity I_0; viz., $M_v' = 10 \log I_s/I_0$. It is related to the volume-scattering coefficient m_v by the expression $10 \log m_v = 10 \log M_v' + 11$ dB.

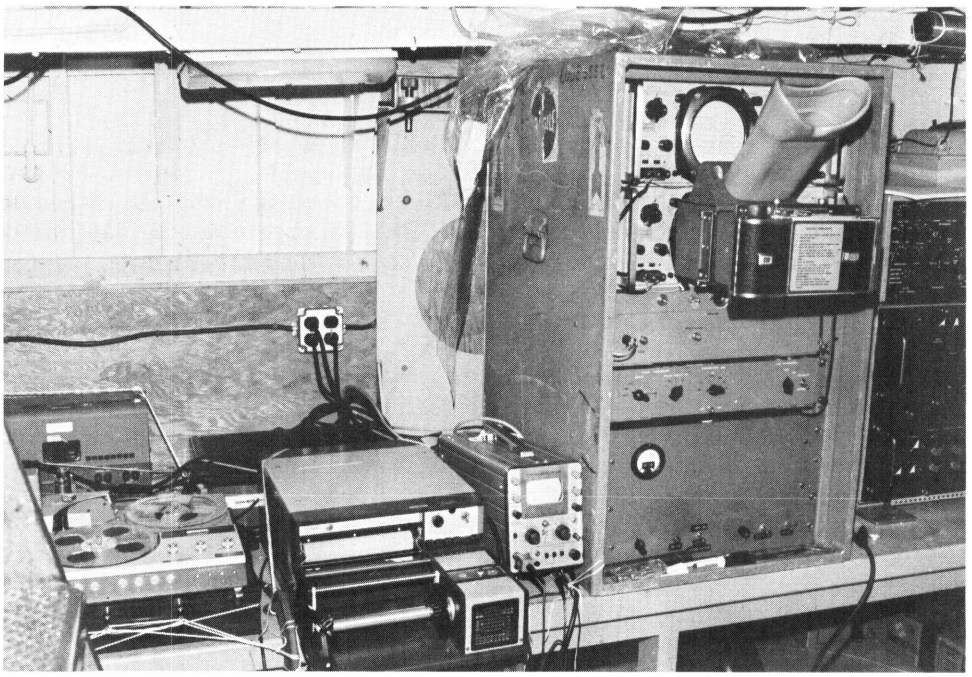

Fig. 2 - Acoustic profiler equipment installed in the after compartment of UOR-125 (port side)

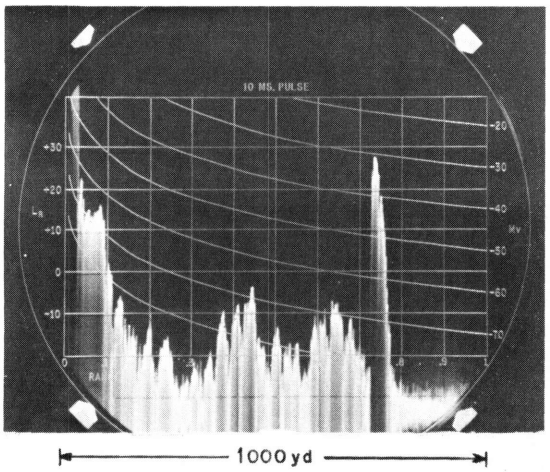

Fig. 3 - Example of scope-camera record of an acoustic profile. The profile is of Station 13, Feb. 23, 1966, taken at 1524. The range is 1 kyd, and the pulse length is 10 msec.

extending downward to the right are calibration lines of constant M'_v versus depth. Thus, on this particular scan, for example, M'_v = -67 dB at 200 ft, -95 dB at 800 ft, -68 dB at 1300 ft, -75 dB at 1500 ft, and -68 dB at 1900 ft. The left-hand ordinate L_R is used in display calibration.

Since profiles resulting from successive pulses cannot be recorded with the scope camera, an optical oscillograph is provided for continuously recording the output of the receiver section. This permits returns from successive pulses to be compared. An example of this type of record is shown in the Appendix (Fig. A4). A third type of record, on magnetic tape, is also described in the Appendix.

The profiler was conceived only as a rapid locator of major scattering zones. With use, however, it has become evident that the instrument has much to offer in the detailed study of water-column inhomogeneity. This report tends to emphasize its potential for such work, but the present accuracy of calibration, stability, and so on, necessarily reflect the original design specifications.

Operating Procedure at Sea

The usual procedure after arriving in the day's operating area was to examine the acoustic profile of the first station to determine the presence of scattering layers. A decision was then made whether or not to make a hydrographic cast.* If it was decided to seek a more favorable location, profiles were observed at intervals along a desired track until the proper conditions were found. The profiler was operated during casts to maintain a check on the boat's position relative to the layers, and a reference photo was taken at the approximate mid-time of the messenger's fall. A BT cast was usually made following recovery of the bottles.

LABORATORY ANALYSES

Particle counts and turbidity data were obtained at the shore laboratory in Key West. Iron analyses were performed at NRL using one of two samples drawn from each Nansen bottle. Iron analyses were made only on the samples from the March 3 and March 4 casts. Samples were also taken from the March 4 cast for salinity analysis.†

Particle Counts

Particle counts were made with a Coulter Model C electronic particle counter (Fig. 4). This is a 12-channel instrument with two aperture stands; each run produces counts of all particles exceeding sizes established by the aperture size and each of 12 sensitivity thresholds set by the operator. From these counts the number of particles falling into each of 11 contiguous size ranges can easily be computed by difference. Each sample was run using first a 30-μ aperture (50-μl aliquots) and then a 140-μ aperture (2-ml aliquots). This produced counts in 22 contiguous ranges including a small overlap between the two sets of counts. Counts were taken in replicate, and the results were averaged. The tabulated data are expressed as number of particles per milliliter in each range of equivalent spherical diameters.

All counts were made at laboratory temperature immediately after the samples were received on shore. Each sample was counted by immersing the aperture directly into the sample container after mild resuspension of the contents. Samples were kept on ice until shortly before arrival in port to minimize bacterial growth.

Turbidity Measurements

Turbidity data were obtained with a Coleman Model 9 Nepho-Colorimeter after the particle counts were made. This photometric instrument is calibrated in arbitrary "nephelos units" on a scale of 0 to 100, where 0 represents "absolute clarity" and 100 is a "visible turbidity." The instrument was calibrated daily before use and was checked after each measurement with a sealed "nephelos standard" provided by the manufacturer.

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*The shore laboratory could process the samples from only one complete (12-bottle) cast per day. This was due primarily to the time required for particle counting before significant aging of the samples occurred.

†These samples were analyzed at the Tropical Atlantic Biological Laboratory, Bureau of Commercial Fisheries, Miami, through the courtesy of Mr. J. W. Van Landingham and the Director, Dr. Thomas S. Austin.

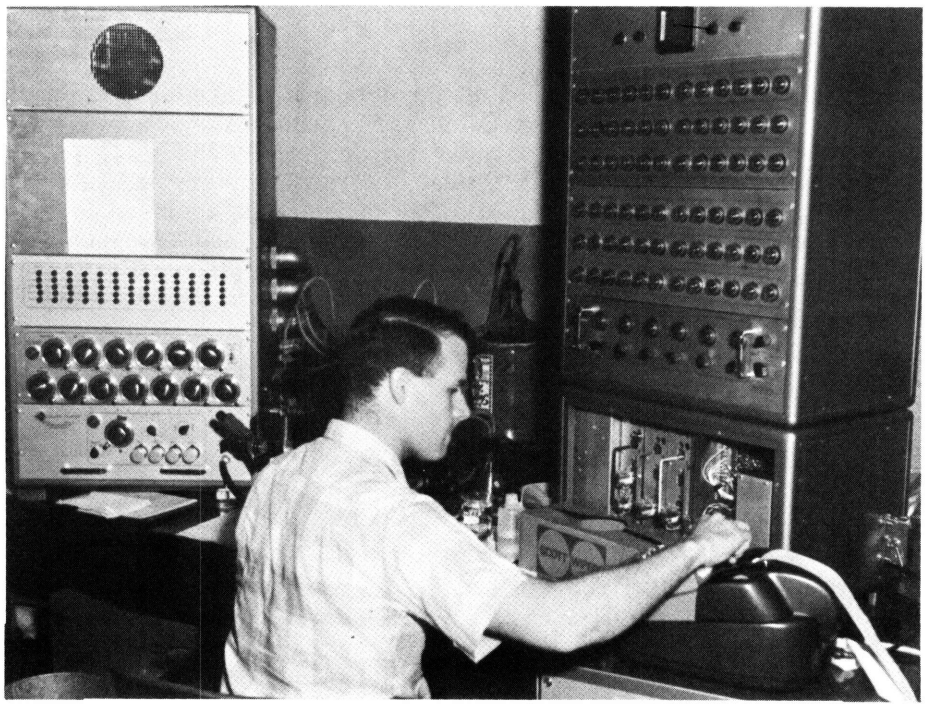


Fig. 4 - Coulter Model C electronic particle counter in the Key West shore laboratory

Iron Analyses

Since we were merely screening the samples for the occurrence of relatively heavy iron concentrations in discrete zones, only "HCl-reactive iron" (5) was determined. The procedure is simple when compared to the exhaustive digestion of samples with perchloric acid required for the determination of total iron. It was reported previously (1) that at least 60% of the total iron in the turbid water could be made reactive with dilute hydrochloric acid. In the present work, therefore, each 100 ml of raw sample was analyzed directly for reactive iron by the bathophenanthroline procedure without prior separation into particulate and dissolved fractions. Results are expressed as micrograms of iron per liter of sample.

RESULTS

Each day's operation is described separately. A track chart showing the position of each station occupied during the day is presented first. This is followed by BT data, the acoustic profiles, and the results of laboratory analyses. Finally, an attempt is made to correlate the acoustic data with data from the samples.

Because of the nonlinear relationship between M_v' and depth on the A-scope presentation, the interpretation of oscillographic records upon direct examination is sometimes difficult. Furthermore, a certain amount of inherent variability in the magnitude of the return signal exists from scan to scan, due to varying interference patterns and the transient presence of organisms. A more accurate presentation of the acoustic profile would be a composite graph of average M_v' versus depth prepared from multiple records for each station. Since we were usually surveying an area primarily to locate major

scattering zones, however, only a single photo was taken at most stations. This single record is shown for such stations. At stations of longer duration, particularly where casts were made, representative photos and a composite graph prepared from several (three or more) records are given.

The technique used to prepare these graphs was to pick off manually and record from each photo the value of M'_v at standard intervals (50 ft on the 1000-yd and 25 ft on the 1000-ft scales). All values for each depth interval were then averaged, and the result was graphed as average M'_v versus depth. Points on the graph are connected by straight lines; using such large depth intervals does not justify making any assumptions concerning the precise shape of the profile. The calibration bezel shown in all the photographs is valid only for the 1000-yd range scale with the 10-msec pulse. When the 1-kyd range scale is used with the 1-msec pulse, 10 dB must be added to the value of M'_v observed on the existing bezel. This was done, where required, in preparing composite graphs.*

Data are presented only for the operations of February 23, March 3, and March 4.

Operation of February 23

Thirteen stations were occupied along a track running approximately due south from the Key West sea buoy. Stations 1-7 were on the terrace, Sts. 8 and 9 were just off the scarp, and Sts. 10-13 were farther south (Fig. 5). All were acoustic profiler stations of 5 to 7 min duration except Sts. 1, 5, 8, and 13, which were also BT stations. The four BT records are shown in Fig. 6.

A 10-bottle cast was made at St. 6. We were then drifting rapidly into shallow water, however, and the two deepest bottles fouled on the bottom and failed to close. A second cast of three bottles was made at St. 13.

Acoustic Profiles — No camera records were made at St. 1, and the optical oscillograph was not yet operating. The profiles of Sts. 1-3 were similar, however, and the record for St. 3 is presented as generally characteristic of the first three stations. Figure 7 shows a single record for each of Sts. 3-8, including the cast reference photo at St. 6. Composite graphs for the Sts. 5 and 6 profiles are presented in Figs. 8 and 9, respectively. Figure 10 shows single photo records for Sts. 9-13, including the cast reference photo at St. 13. The composite graph for St. 13 is given in Fig. 11. The estimated depths from which samples were taken are shown on the appropriate graphs.

Bottom depths on the terrace (Sts. 1-7) ranged from 720 ft to 840 ft. Several diffuse regions can be seen in the records where the values of M'_v appear to be greater than those above and below and which stand out against what may loosely be termed the prevailing background reverberation level. Such zones are difficult to define on the basis of only one or two records. In spite of this, however, there seemed to be a zone between 110 ft and 200 ft, peaked near 150 ft, which can be seen consistently in the records of Sts. 1-5. This zone shows up most strongly in the record of St. 4. It does not show up well on any single record at St. 5 or 6, but it shows clearly on the St. 5 composite graph, and possibly corresponds, on the St. 6 graph, to the pair of small peaks at 150 ft and 200 ft. The BTs show a small temperature inhomogeneity near 100 ft at both terrace stations where BT casts were made.

*Doubtless a more accurate representation of a profile could be prepared by computer. The continuous output from the receiver, such as that now fed to the optical oscillograph and tape recorder, could be recorded on tape in digital form, for example, and used directly with an appropriate program for the computer analysis.

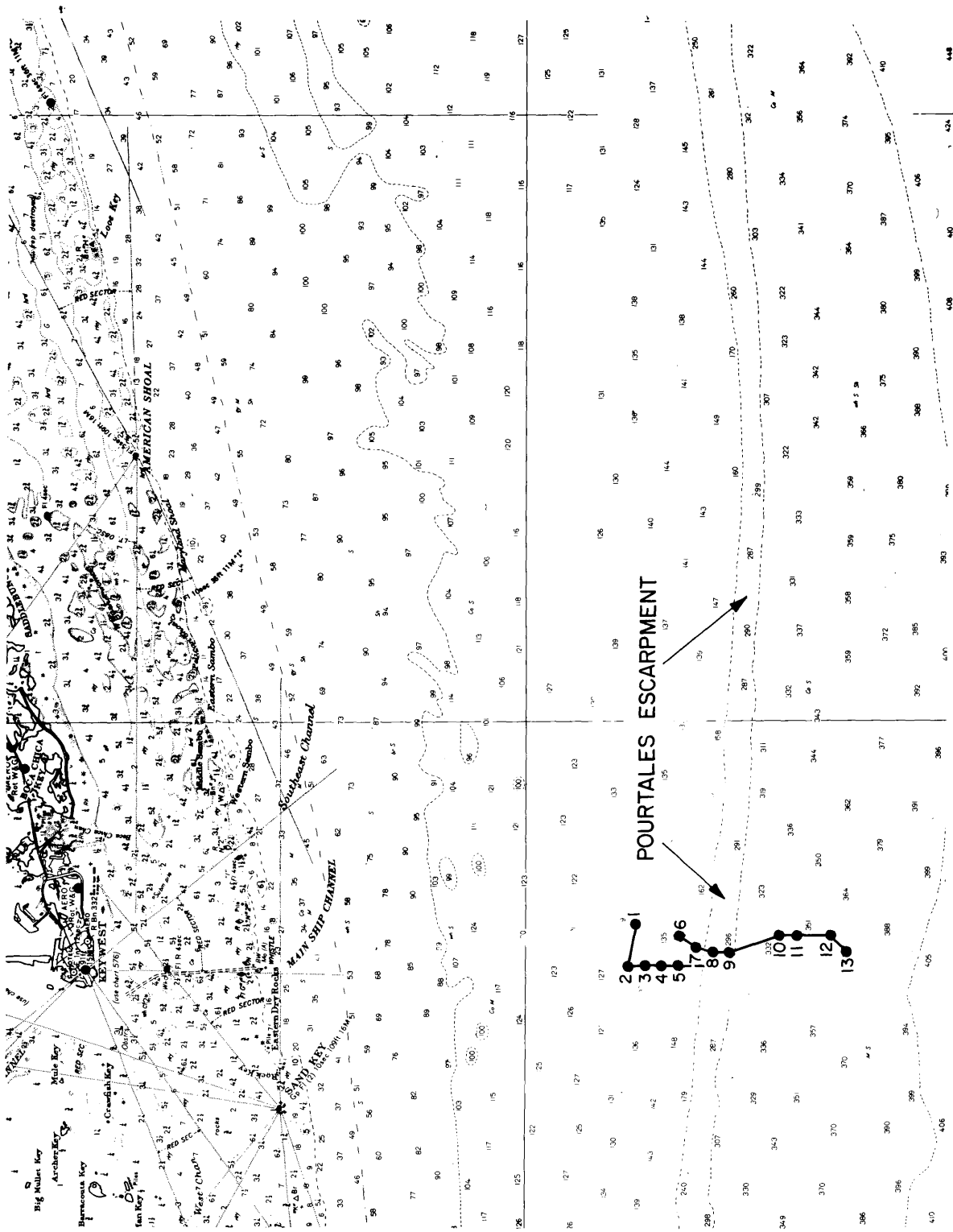


Fig. 5 - Track chart for the operation of Feb. 23, 1966

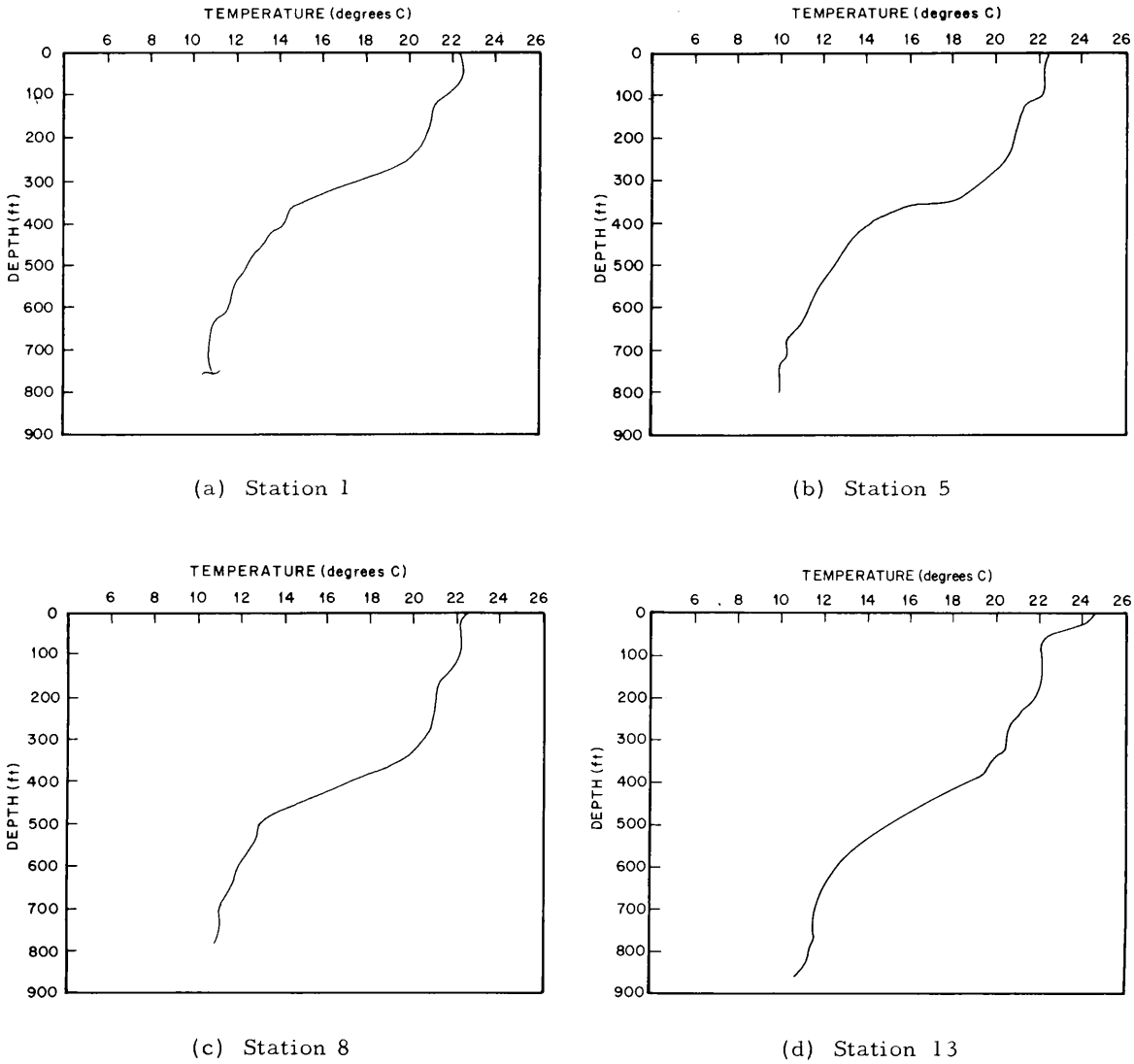
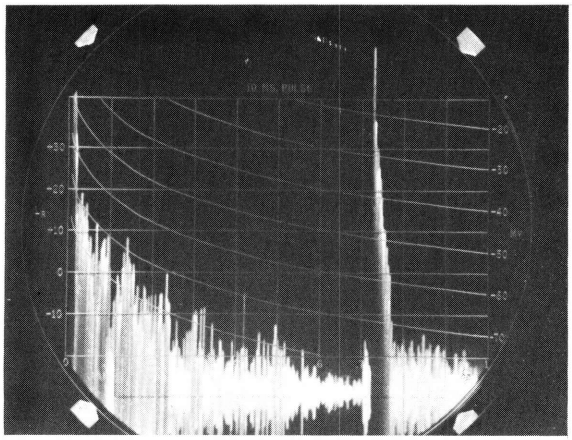


Fig. 6 - Temperature profiles for Feb. 23, 1966

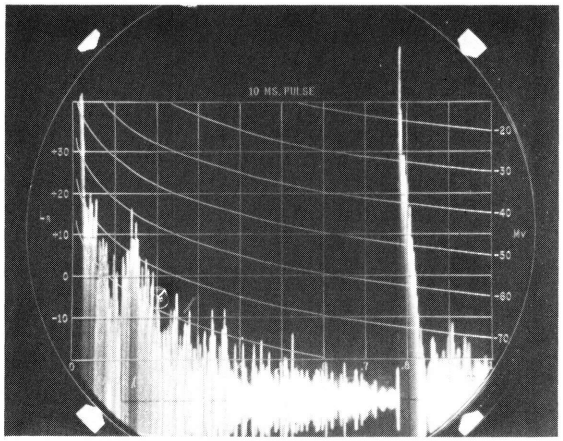
The strong reflection just off the bottom at St. 5 can be seen in all photos taken after the BT cast. It is presumed to be the reflection from sediment stirred up when the BT inadvertently hit bottom at an indicated 760 ft.

At St. 6 there was a definite scattering layer lying between 550 ft and about 675 ft, peaked near 625 ft. The tall spikes seen in Fig. 7d (St. 6) are returns from the Nansen bottles. These can often be seen when the wire angle is small; their indicated depths are slant ranges within the beam.

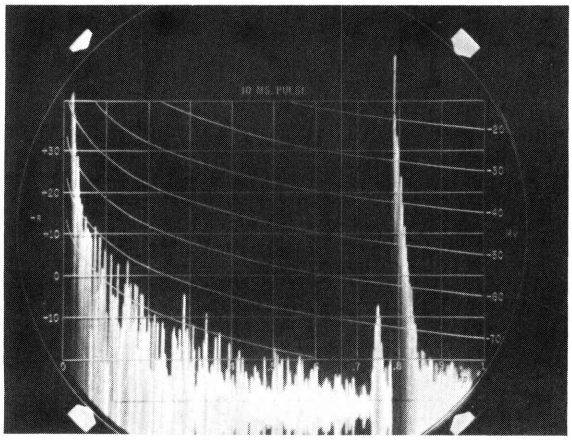
Bottom depths at stations beyond the escarpment ranged from 1950 ft to 2150 ft. A most interesting feature was a major scattering zone peaked at about 1350 ft immediately seen upon passing over the escarpment (St. 8). This zone was first seen as a single layer about 400 ft thick, but it seemed to separate into two zones a little farther out (or else a second layer subsequently appeared). One layer remained consistently near the initial depth (1350 ft), whereas the other layer sank deeper as the distance from the



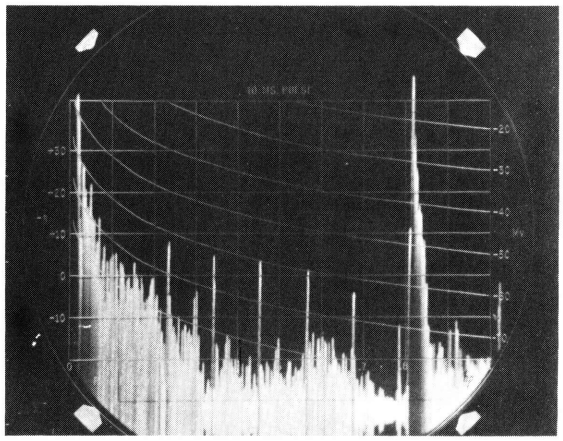
(a) Station 3 at 1022; 1 msec pulse length, 1000 ft range



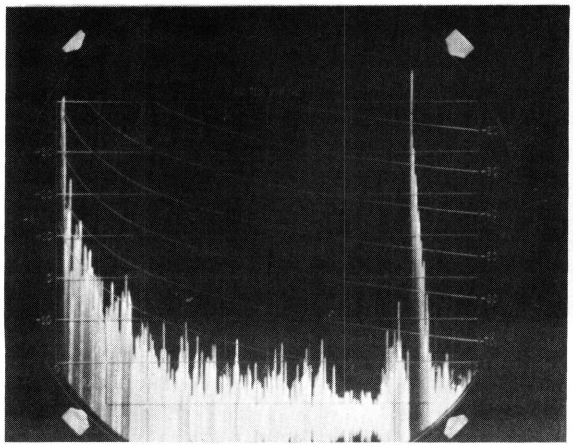
(b) Station 4 at 1029; 1 msec pulse length, 1000 ft range



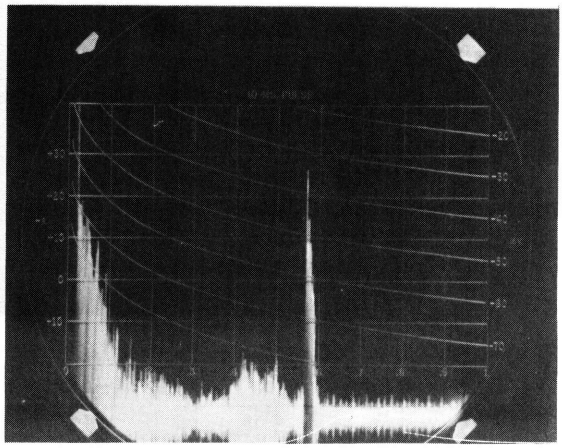
(c) Station 5 at 1037; 1 msec pulse length, 1000 ft range



(d) Station 6 at 1143; 1 msec pulse length, 1000 ft range



(e) Station 7 at 1222; 1 msec pulse length, 1000 ft range



(f) Station 8 at 1241; 1 msec pulse length, 1000 yd range

Fig. 7 - Acoustic profiles of Stations 3 through 8, Feb. 23, 1966

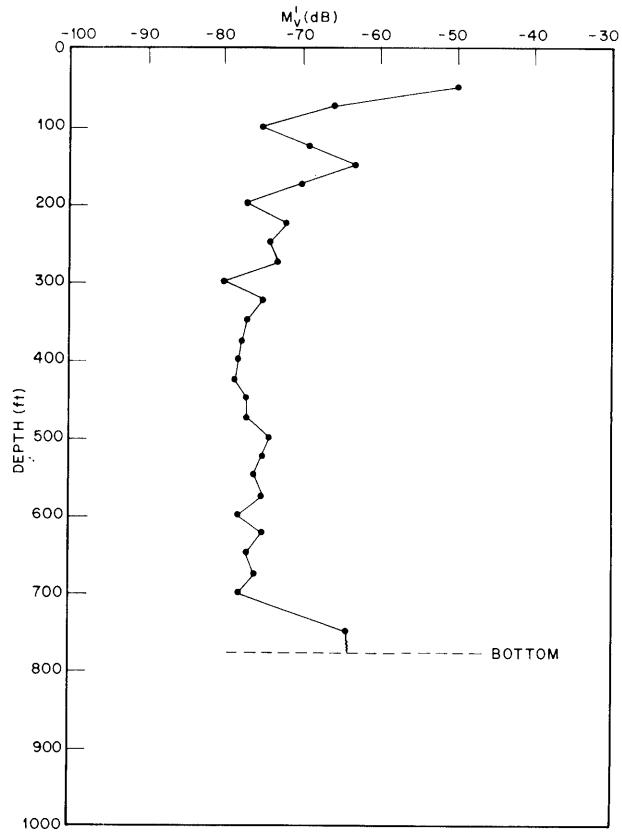


Fig. 8 - Composite acoustic profile of Station 5, Feb. 23, 1966

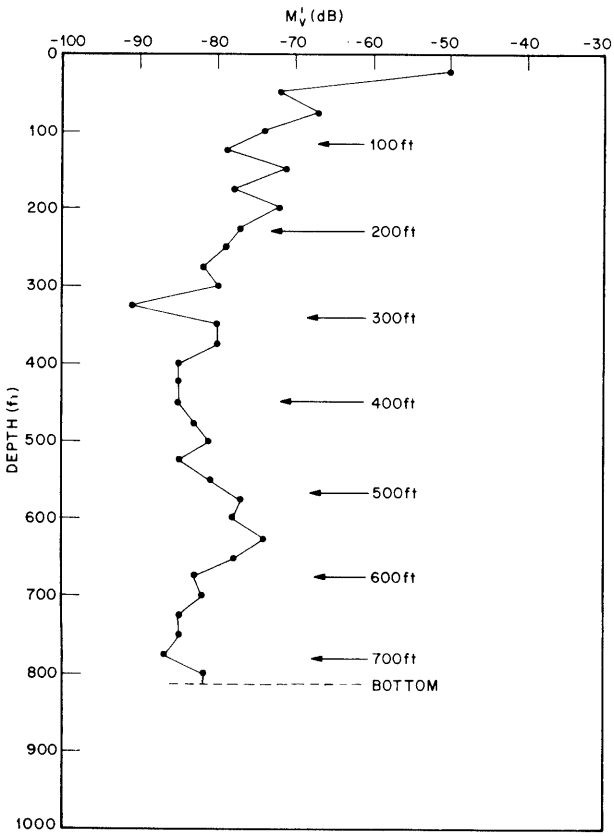
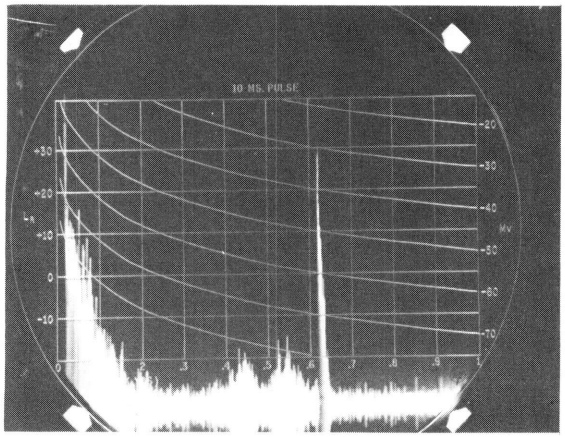
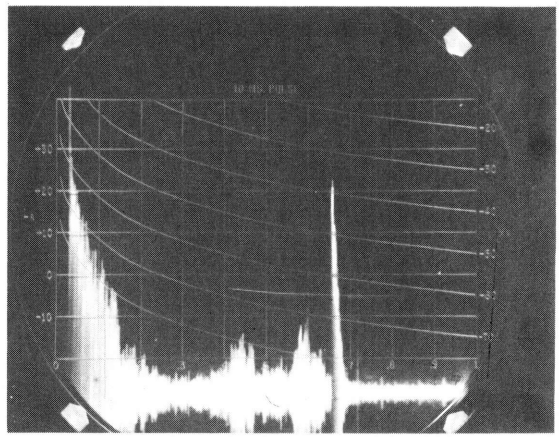


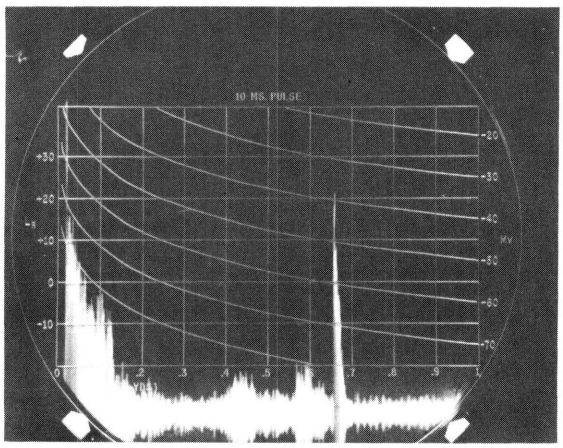
Fig. 9 - Composite acoustic profile of Station 6, Feb. 23, 1966



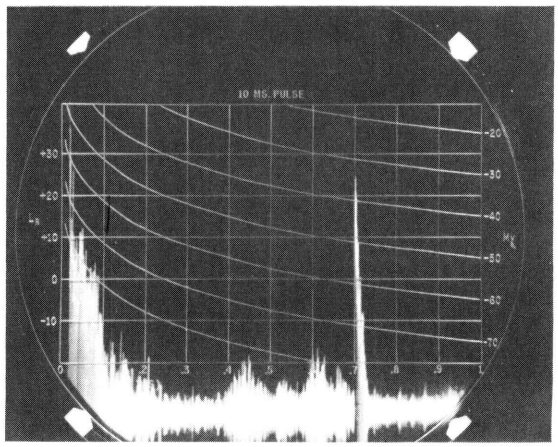
(a) Station 9 at 1310; 1 msec pulse length, 1000 yd range



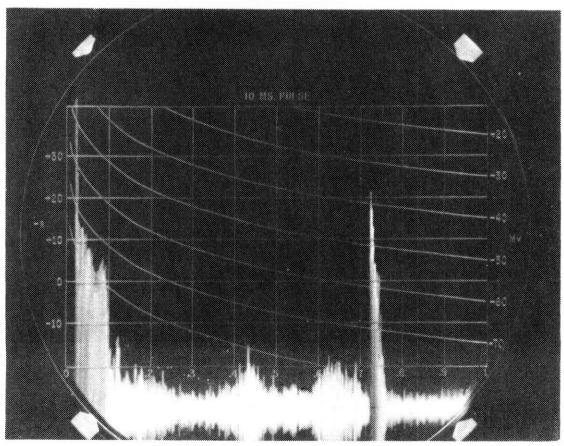
(b) Station 10 at 1322; 1 msec pulse length, 1000 yd range



(c) Station 11 at 1329; 1 msec pulse length, 1000 yd range



(d) Station 12 at 1337; 1 msec pulse length, 1000 yd range



(e) Station 13 at 1449; 1 msec pulse length, 1000 yd range

Fig. 10 - Acoustic profiles of Stations 9 through 13, Feb. 23, 1966

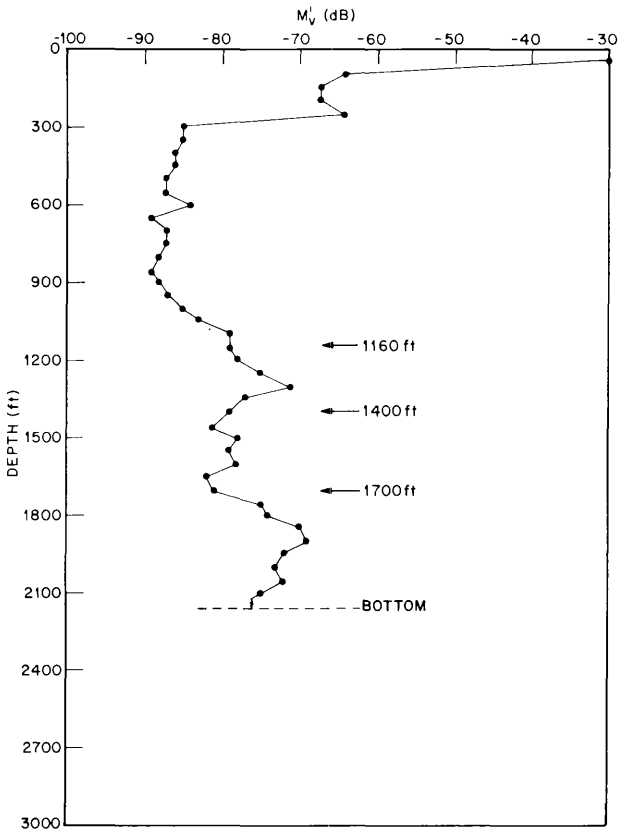


Fig. 11 - Composite acoustic profile of Station 13, Feb. 23, 1966

scarp was increased and touched bottom at St. 11 or 12 (about 2-1/2 mi from the escarpment). The upper zone was variously measured as 250 ft or 300 ft thick. The lower zone appeared to spread out somewhat with distance from the escarpment and was 300 ft to 400 ft thick when it reached the bottom. There was an indication of a middle zone 100 ft to 150 ft thick first distinguishable at St. 10. This latter zone tended to remain centered near 1500 ft. The original layer actually was first seen shortly after St. 5 while proceeding south over the edge of the terrace, and the cast was started at that point. This was approximately 1000 yd west of St. 8. While the cast was being lowered, however, a strong current set us to the northeast, so that when the messenger was dropped our position was that of St. 6, and the layer had disappeared from the acoustic profile. It was decided to explore the layer further using only the profiler. Unfortunately, power limitations dictated the use of a 1-msec pulse length at this time, and this produced poor records.

Nansen Cast and Samples — The total particle counts and the M'_v data corresponding to the estimated sample depths are summarized in Table 1 for both Sts. 6 and 13. Table 2 shows the distributions of particle counts in the various size ranges. The photonephelometer had not yet been put into operation.

At St. 6 the depths shown in the tables are based on the amount of wire out, with wire angle neglected ($< 5°$). In Fig. 7d, however, the profiler shows the bottles to be consistently 10-15% deeper than their positions on the wire would allow. This is interpreted as resulting from a corresponding error in the profiler display calibration. Due

Table 1
Summary of Data Obtained from the Operation of 2-23-66 at Stations 6 and 13

Depth (ft)	M'_v (dB)	Total No. Particles $\geqq 0.74\mu$ (ml^{-1})
Station 6		
2	—	393,450
100	-77	121,020
200	-77	213,007
300	-84	72,440
400	-85	31,353
500	-78	46,033
600	-83	25,845
700	-86	28,285
Station 13		
1160	-82	42,907
1400	-79	52,890
1700	-81	60,530

to large fluctuations in the power supplied from UOR-125, it was necessary to recalibrate the display frequently, although this was not realized at the time. Consequently it is now felt that the depths indicated in Figs. 7d and 9 should be about 10-15% shallower. To facilitate correlation of profile and sample characteristics, however, the profile and the sample depths were plotted in Fig. 9 as they were indicated by the profiler, but the sample depths were labeled to correspond to the wire depths by which the samples were identified and which are used in Tables 1 and 2. These wire depths should correspond closely to the true depths.

The highest particle count, apart from the surface sample, was found in the 200-ft sample (M'_v = -77 dB). The total count (213,007 per ml) was nearly twice as large as in the 100-ft sample, almost three times as great as in the 300-ft sample, and better than four times larger than in any of the deeper samples. Examination of Table 2 shows that the 200-ft sample had a greater percentage of its particles in the 0.93μ to 1.17μ range than any of the other samples, including those from 100 ft (M'_v = -77 dB) and 500 ft (M'_v = -78 dB) where the scattering strengths were essentially equivalent. The 500-ft sample, however, shows more of a general trend to much larger particle sizes than any of the others. The 100-ft sample was probably shallow enough to be affected by surface reverberation (6). The 200-ft sample, from Fig. 9, appears to have been taken from the trailing edge of a small peak that may be related to the small scattering zone seen at 100 ft to 200 ft at all terrace stations.

Table 2
Operation of February 23, 1966. Particle Size Distributions in Samples Taken at Stations 6 and 13.

Estimated Depth (ft)	Number of Particles per milliliter of Sample Falling in the Size Ranges Indicated (in microns)*												Number of Particles per milliliter of Sample Falling in the Size Ranges Indicated (in microns)†										
	≧0.74	0.74-0.93	0.93-1.17	1.17-1.48	1.48-1.87	1.87-2.35	2.35-2.96	2.96-3.73	3.73-4.70	4.70-5.92	5.92-7.46	7.46-9.40	3.55-4.48	4.48-5.64	5.64-7.10	7.10-8.95	8.95-11.3	11.3-14.2	14.2-17.9	17.9-22.6	22.6-28.4	28.4-35.8	35.8-45.2
Station 6																							
2	393,450	329,170	42,040	10,160	4510	3720	1650	1110	580	270	150	40	452	216	91	34	31	15	8	4	3	2	1
100	121,020	91,193	17,134	5820	2760	1780	1026	640	367	140	80	40	262	130	59	22	9	4	2	1	0	1	0
200	213,007	147,407	44,080	13,027	4013	2307	1160	673	200	67	53	20	151	68	32	16	7	3	1	1	0	0	0
300	72,440	57,707	9200	2693	1140	747	506	240	114	46	34	6	68	27	16	4	1	3	0	1	0	0	0
400	31,353	20,113	5687	2620	1166	807	433	260	127	67	26	14	81	30	11	6	7	2	2	1	0	0	0
500	46,033	30,040	7940	3680	1893	1240	607	380	106	87	13	34	98	37	14	6	3	1	2	1	0	1	0
600	25,845	16,960	4430	1795	1170	720	420	155	90	50	25	25	84	33	24	10	8	5	3	0	1	0	0
700	28,285	18,570	5005	2425	1095	620	260	200	65	30	15	0	49	22	6	3	2	1	0	1	0	0	0
Station 13																							
1160	42,907	29,407	7073	2994	1580	900	486	287	93	60	0	20	56	25	7	4	1	0	0	1	0	0	0
1400	52,890	37,955	8000	3285	1670	1035	445	400	45	45	5	5	79	27	10	3	2	1	0	1	0	0	0
1700	60,530	34,380	11,530	6170	3360	2350	1500	670	320	160	50	30	224	96	34	16	6	2	1	0	0	0	0

*Counts made with 30-μ aperture
†Counts made with 140-μ aperture

The 500-ft sample, although low in comparison with the 200-ft sample, showed a somewhat higher particle count than did samples from immediately above and below it in the water column. This is well correlated with the correspondingly higher M_v' in that region, and Fig. 9 indicates that the sample was taken from the leading edge of the main scattering zone shown peaked near 625 ft (the true depth was probably nearer 565 ft).

On the other hand, the 300-ft sample (M_v' = -84 dB) showed a much higher particle count than the 500-ft sample but a substantially lower scattering strength. It can be seen from Table 2, however, that the size distribution of particles was quite different: 80% of the total count in the 300-ft sample was in the 0.74μ to 0.93μ range, whereas only 66% of the total count in the 500-ft sample lay in that range. Furthermore, most of the remaining particles in the 300-ft sample were concentrated in the adjacent small size ranges, whereas in the 500-ft sample there was a greater percentage of larger-sized particles.

The 700-ft sample came from the region of lowest scattering intensity (-86 dB) and, with the adjacent 600-ft sample, had the lowest particle count.

At St. 13 the depths shown were based simply on the amount of wire run out. Scattering strengths were similar (-79 dB to -82 dB) and not particularly well correlated with particle count. From Table 2 it can be seen that particle size distributions were very similar in the 1160-ft and 1400-ft samples. The 1700-ft sample, however, showed a slightly greater total count and a slight trend toward larger-sized particles.

Since no other analyses were performed on any of the samples, no conclusions can be drawn concerning the nature of the scattering material. It is possible, however, to point to some good correspondence between particle count, particle size distribution, and scattering strength.

Operation of March 3

Fifteen stations were occupied well south of the escarpment. All but Sts. 1 and 2 were to the east of a line extending south from the Key West sea buoy (Fig. 12). All 15 were profiler stations; BT and Nansen casts were also made at St. 12. Naval exercises in the area prevented us from working closer to the escarpment and the January 1965 position where iron-bearing water was found at 600 ft to 750 ft (Fig. 1). The St. 12 temperature profile is shown in Fig. 13.

Acoustic Profiles — The acoustic profiles, starting with St. 2, are shown in Figs. 14 through 16, and the composite graph for St. 12 is shown in Fig. 17. This graph also shows the estimated sampling depths. Bottom depths were near 2500 ft to 2600 ft at all stations.

A prominent feature observed at all 15 stations was a scattering zone, approximately 450 ft thick, at depths near 1200 ft to 1650 ft. The composite graph indicates that it contained two well defined maxima near 1350 ft and 1600 ft at St. 12. Most stations also showed a more diffuse zone lying between about 2000 ft and the bottom. Another scattering zone was centered around 600 ft at most of the stations, with indications at some that two adjacent zones might be involved.

We experienced several power failures and consistently poor voltage regulation during the cast, and it was not possible to obtain a usable reference photo when the messenger was dropped. Figure 15e shows the initial profile of St. 12 at 1258, and Fig. 16a shows a profile of poor quality taken at 1410 just before the cast was recovered. A record made at 1354 (Fig. 15f) shortly before the messenger was dropped provides evidence for the location of the Nansen bottles in the beam, although the definition of the profile is very poor due to the mandatory use at that time of a 1-msec pulse. Varying paper speeds

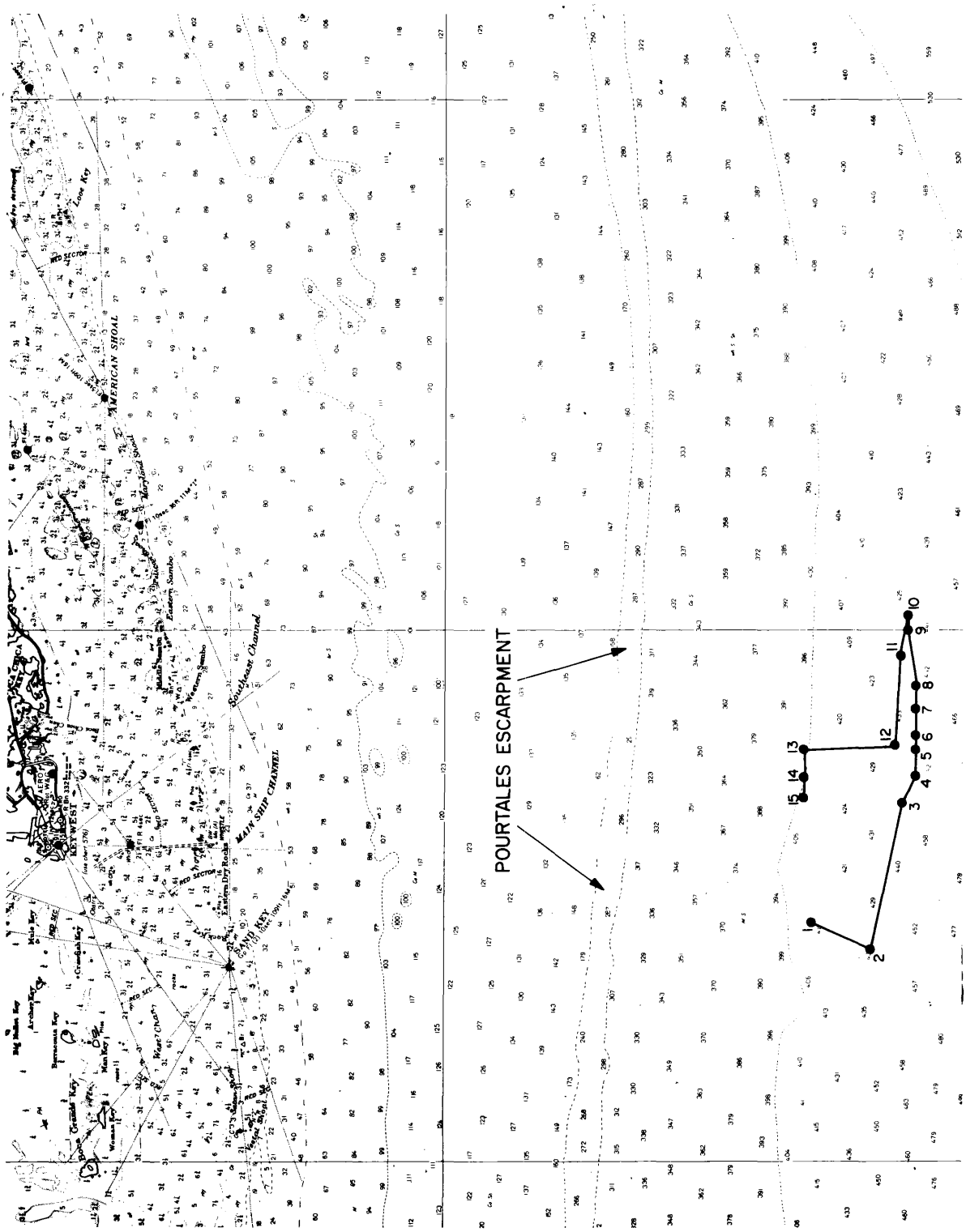


Fig. 12 - Track chart for the operation of March 3, 1966

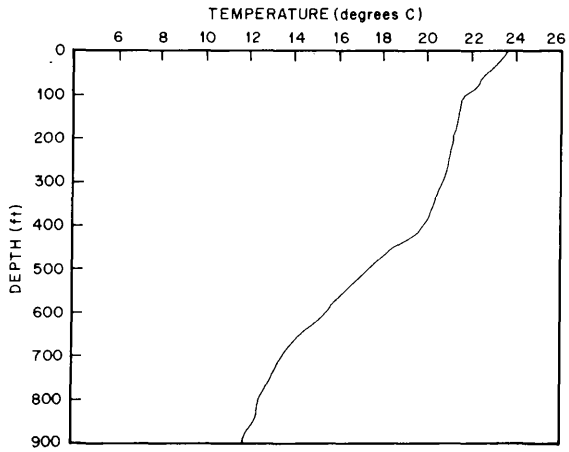


Fig. 13 - Temperature profile of Station 12, March 3, 1966

on the optical oscillograph during this period made oscillographic records useless for depth information.

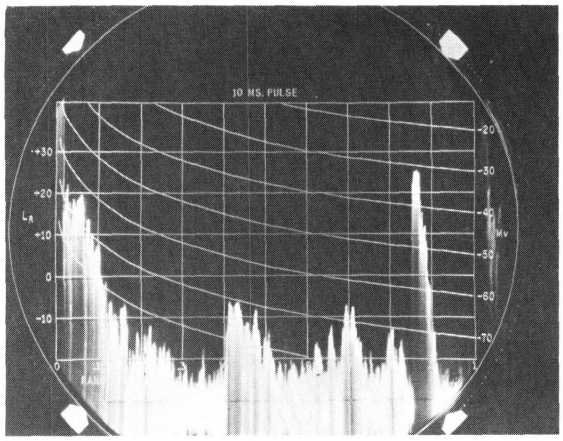
Nansen Cast and Samples — The cast was intended to bracket the major scattering zone. The attempt was quite successful in the light of indications obtained from the profile shown in Fig. 15f, although all bottles cannot be distinguished in any one record. Two bottles were put into the region around 350 ft to 850 ft, and a tall spike can clearly be seen at 400 ft on several of the 1-msec pulse photos. This would be almost exactly the proper depth for the upper bottle, on the basis of its location on the wire. Why there was no return from the second bottle is unexplained, unless the return seen was from a fish attracted to the vicinity of the upper bottle rather than from the bottle itself.

Table 3 summarizes the laboratory data, including total particle counts, and shows the value of M_v' at each estimated sampling depth. Table 4 summarizes the particle counts in the various size ranges.

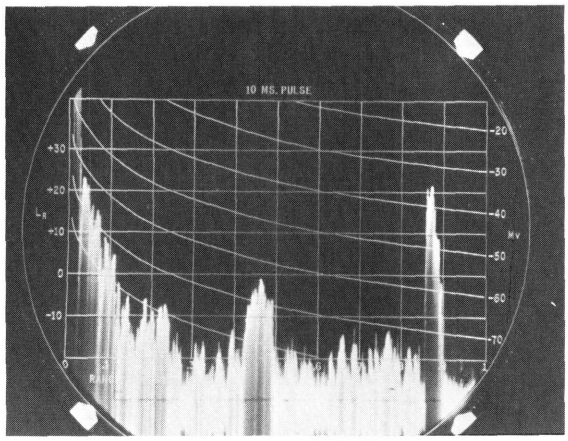
The profiler record indicates that the deepest bottle was located at 1565 ft or 1570 ft slant range in the beam — almost exactly where it should have been (1578 ft) on the basis of wire location alone. This was near the deeper of the two scattering maxima. If this indication is correct, then the seven bottles bracketing the zone were located with respect to the zone as shown on the composite graph (Fig. 17).

Table 3 shows essentially no relationship between total particle count and sound-scattering strength. Within the samples themselves correlation is fairly good between iron content and particle count, except in the 1414-ft sample. Turbidity does not correlate well with either particle count or iron concentration.

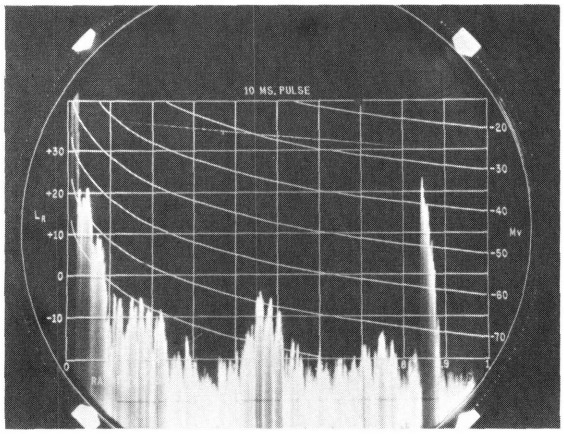
The higher iron values are associated with the higher particle counts at 401 ft and 1381 ft, where most of the particles fell in the smallest size range. The high count at 1513 feet is associated with an intermediate iron concentration, but here more of the particles lay outside the smallest size range. The 1479-ft sample, which is low in both iron and particles, shows a definite trend toward the larger particle sizes (Table 4). The 401-ft sample appears to have been taken on the leading edge of a poorly defined zone peaked somewhere around 550 ft to 600 ft.



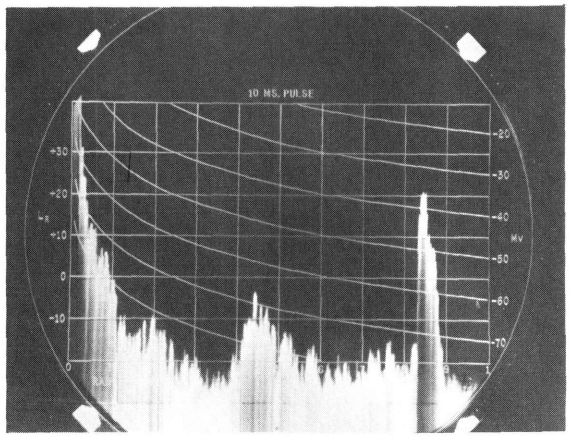
(a) Station 2 at 1051; 10 msec pulse length, 1000 yd range



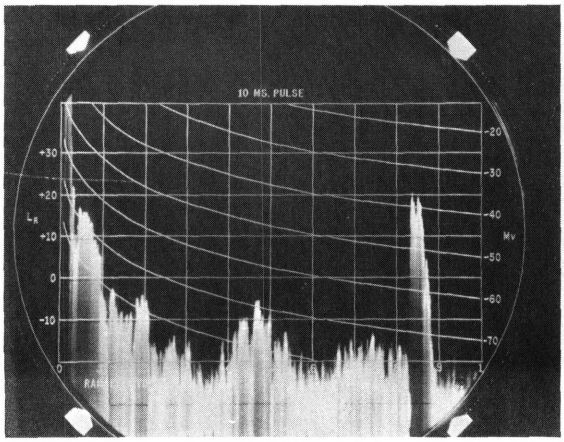
(b) Station 3 at 1116; 10 msec pulse length, 1000 yd range



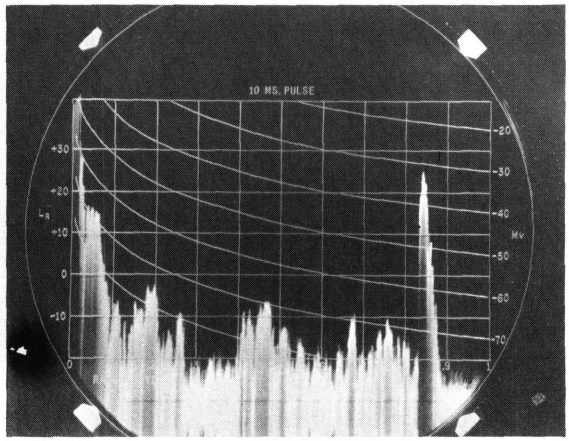
(c) Station 4 at 1128; 10 msec pulse length, 1000 yd range



(d) Station 5 at 1138; 10 msec pulse length, 1000 yd range

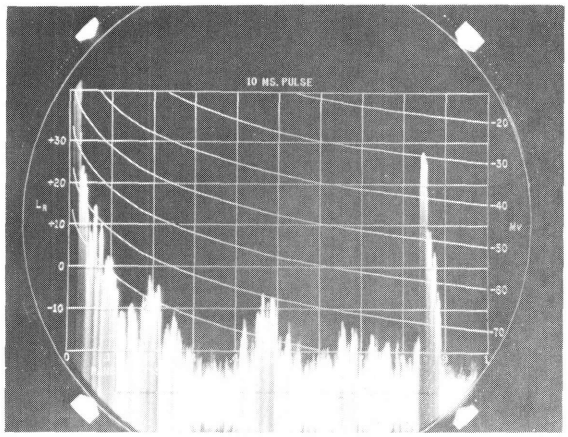


(e) Station 6 at 1148; 10 msec pulse length, 1000 yd range

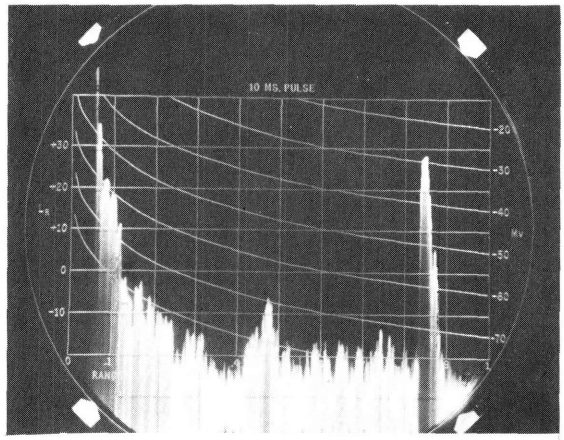


(f) Station 7 at 1159; 10 msec pulse length, 1000 yd range

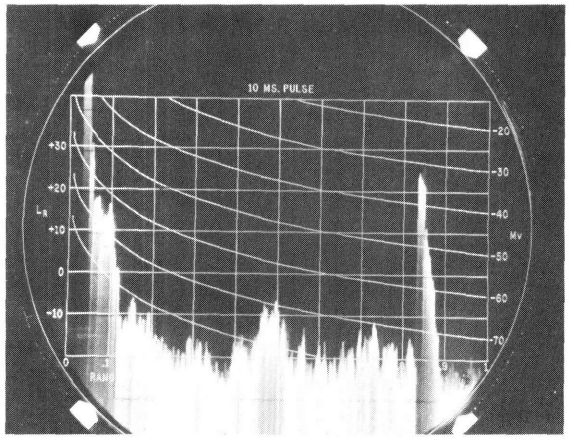
Fig. 14 - Acoustic profiles of Stations 2 through 7, Mar. 3, 1966



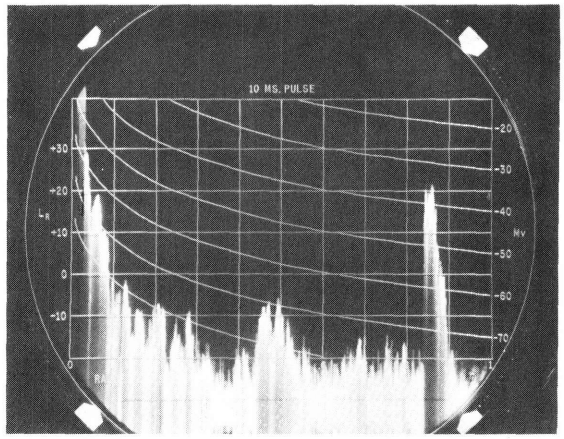
(a) Station 8 at 1212; 10 msec pulse length, 1000 yd range



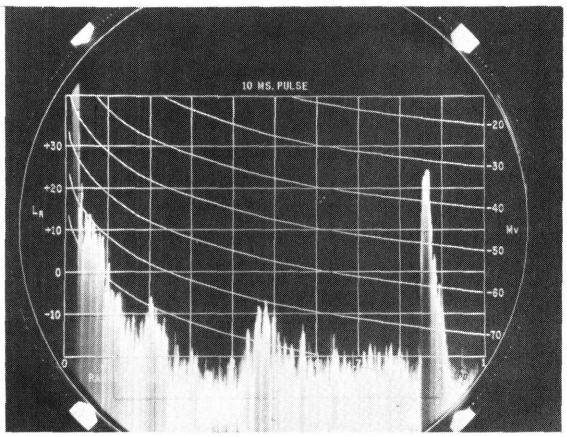
(b) Station 9 at 1222; 10 msec pulse length, 1000 yd range



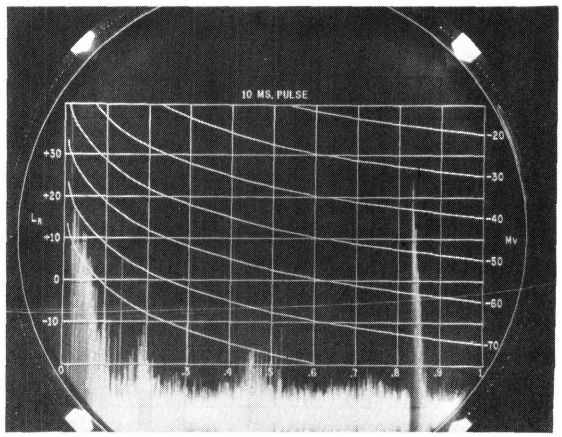
(c) Station 10 at 1232; 10 msec pulse length, 1000 yd range



(d) Station 11 at 1248; 10 msec pulse length, 1000 yd range

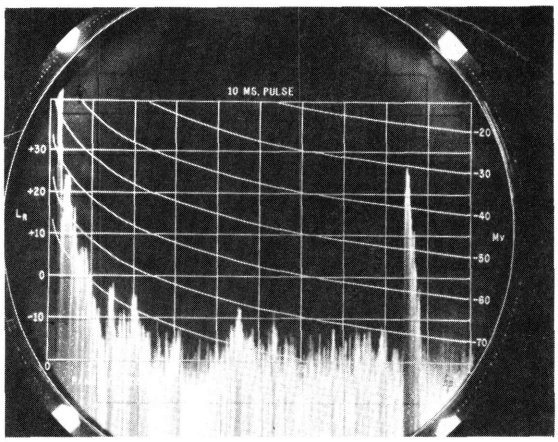


(e) Station 12 at 1258; 10 msec pulse length, 1000 yd range

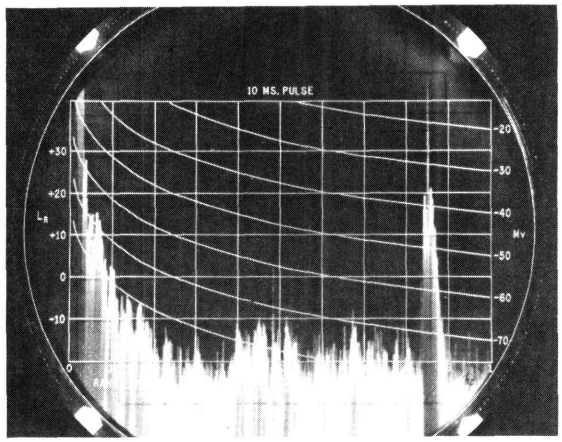


(f) Station 12 at 1354; 1 msec pulse length, 1000 yd range

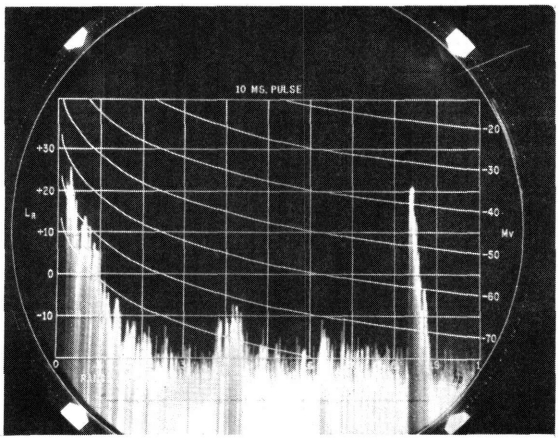
Fig. 15 - Acoustic profiles of Stations 8 through 12, Mar. 3, 1966



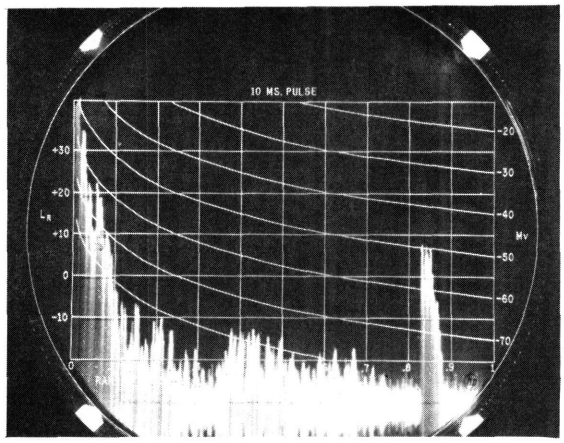
(a) Station 12 at 1410; 10 msec pulse length, 1000 yd range



(b) Station 13 at 1533; 10 msec pulse length, 1000 yd range



(c) Station 14 at 1543; 10 msec pulse length, 1000 yd range



(d) Station 15 at 1554; 10 msec pulse length, 1000 yd range

Fig. 16 - Acoustic profiles of Stations 12 through 15, Mar. 3, 1966

The valley and double maxima in the major zone occur, with slight variations in amplitude, in all photos. Other fine-structural variations in M'_v are indicated, and comparison of successive records suggests that not all of these may be due to interference phenomena. If this is indeed true, then differences between sound-scattering strength and particle counts (and other analyses) that occur between closely spaced samples, such as in the present case, may perhaps be real and due to fine-structural differences in the water column. Otherwise we can only attribute the observed differences to artifact, perhaps resulting from a considerable delay in getting the samples back to the laboratory, or to the presence of larger organisms not sampled by our water bottles.

Operation of March 4

Five stations were occupied during a half-day operation south and west of Key West near the escarpment. Station 1 was just north of the scarp, St. 2 was at the edge, St. 3

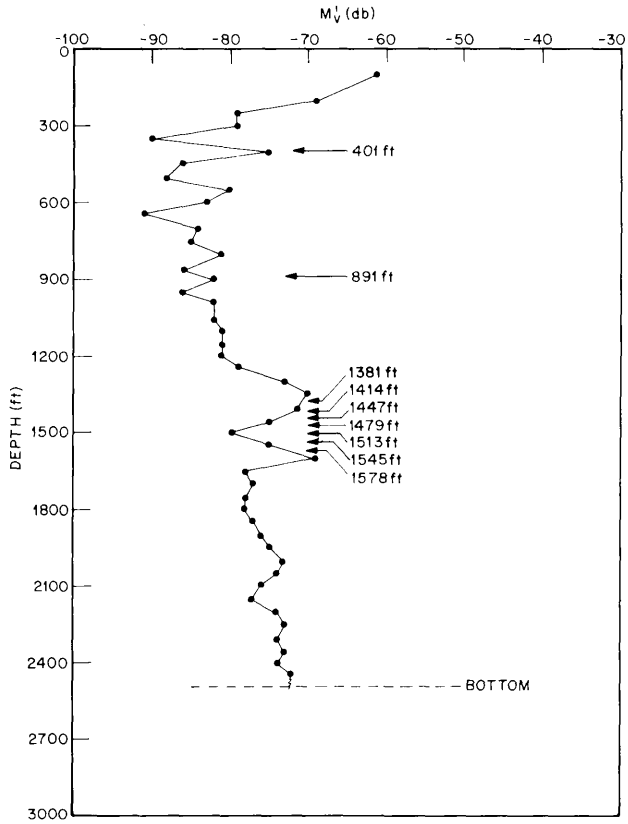


Fig. 17 - Composite acoustic profile of Station 12, Mar. 3, 1966

Table 3
Summary of the Data Obtained from the Operation of March 3, 1966 at Station 12

Depth (ft)	M'_v (dB)	Total No. Particles $\geqq 0.74\mu$ (ml^{-1})	Turbidity	Fe ($\mu g/l$)
2	—	164,224	16.0	1.0
401	-75	273,535	17.6	29.0
891	-83	70,087	17.2	1.0
1381	-71	141,275	17.5	31.0
1414	-72	30,169	16.3	13.0
1447	-74	114,004	16.5	5.0
1479	-77	80,687	16.9	3.0
1513	-79	185,785	16.8	22.0
1545	-76	94,100	17.0	2.0
1578	-72	67,586	16.6	2.0

Table 4
Operation of March 3, 1966. Particle Size Distributions in Samples Taken at Station 12.

Estimated Depth (ft)	Number of Particles per milliliter of Sample Falling in the Size Ranges Indicated (in microns)*												Number of Particles per milliliter of Sample Falling in the Size Ranges Indicated (in microns)†										
	≧ 0.74	0.74-0.93	0.93-1.17	1.17-1.48	1.48-1.87	1.87-2.35	2.35-2.96	2.96-3.73	3.73-4.70	4.70-5.92	5.92-7.46	7.46-9.40	3.55-4.48	4.48-5.64	5.64-7.10	7.10-8.95	8.95-11.3	11.3-14.2	14.2-17.9	17.9-22.6	22.6-28.4	28.4-35.8	35.8-45.2
2	164,224	99,752	40,636	13,520	4044	2856	1708	864	408	284	76	56	398	168	75	29	13	6	2	1	0	0	0
401	273,535	188,750	58,405	18,450	4715	1785	780	370	185	60	20	0	224	50	20	10	5	3	1	1	0	0	0
891	70,087	42,427	15,360	6427	2540	1606	940	454	180	73	60	20	238	51	24	10	2	1	1	0	0	0	0
1381	141,275	98,365	27,395	9130	2950	1700	940	495	190	70	25	15	162	47	21	5	3	1	0	1	0	0	0
1414	30,169	18,174	6647	2933	1070	744	314	170	83	17	14	3	105	37	19	7	3	1	0	0	0	0	0
1447	114,004	72,712	26,928	8776	2908	1460	620	364	108	60	40	16	125	50	19	11	5	4	1	1	1	0	0
1479	80,687	43,187	16,420	7687	4506	4007	2587	1380	640	153	73	34	395	105	39	13	5	4	2	1	0	0	0
1513	185,785	115,005	49,140	14,355	5015	1205	610	245	125	35	10	25	91	39	15	8	5	2	1	0	1	0	0
1545	94,100	42,380	39,490	7773	2073	1179	572	346	140	76	35	20	102	45	22	10	3	3	0	0	0	0	0
1578	67,586	36,363	18,942	6385	2723	1693	814	397	127	81	46	15	121	43	21	7	3	1	0	0	0	0	0

*Counts made with 30-μ aperture
†Counts made with 140-μ aperture

was just over the edge, and Sts. 4 and 5 were to the westward close to the scarp (Fig. 18). The first four were acoustic profiler stations only; BT and Nansen casts were also made at St. 5. Figure 19 shows the temperature profile at St. 5.

Acoustic Profiles — Scope-camera records of the single observation made at each of Sts. 1-4 and the Nansen cast reference photo for St. 5 are shown in Fig. 20. The composite graph for St. 5 is presented in Fig. 21. Also shown are the estimated depths from which samples were taken.

At St. 1 the bottom was near 900 ft. A zone of higher scattering strength lay between roughly 620 ft and 860 ft. Other zones were suggested, as is usual on the terrace, but they could not be defined.

A broad zone of increased scattering strength was found between approximately 1100 ft and 1600 ft at all stations south of the terrace. It consistently showed maximum scattering strength (about -60 dB) near 1300 ft. The zone lay about 200 ft off the bottom (1800 ft) at St. 4. At St. 5 (bottom 1625 ft) the composite graph suggests that there may have been a small valley between peaks at 1250 ft and 1350 ft, which was not apparent in any one photo. After a decrease the intensity again rises near the bottom. Additional minor zones seem to exist, but the data are insufficient for any definite conclusions.

Nansen Cast and Samples — Strong and variable currents were encountered just off the escarpment; at St. 4 the set was 120° T, and at St. 5 it was 071° T. The wire angle varied greatly during the cast, and the depth estimations are based on the wire angle (30°) existing at the moment the messenger was dropped. The vessel probably was closer to the scarp than the navigational data indicated, since a bottle at 987 ft appears to have struck against the scarp at some time during or after lowering. The valve was jammed with sediment and failed to close completely, and the partial sample obtained showed a much greater content of larger particles than was found elsewhere. The sample is discounted as a valid indication of the natural state of the water column at that depth.

Table 5 summarizes the laboratory data obtained from analysis of the samples, including total particle count, and also shows the value of M'_v at each depth corresponding to the estimated location of a Nansen bottle. Table 6 shows the particle counts in the various size ranges.

It can be seen that there is good correlation between the various analyses performed on the samples. Concerning correlations between the acoustic profiles and the samples, however, few substantive conclusions can be reached, as anticipated, because of great uncertainty about the depths actually sampled. Some suggestions of correlations can be found, nevertheless, which should be considered in future work.

From Table 5, for example, it can be seen that the highest particle count, turbidity, and iron content were found in the sample estimated to have come from 1221 ft. Figure 21 shows that this depth would be well up on the leading edge of the broad scattering zone centered near 1300 ft. On the other hand, the 1299-ft sample, which should be at the peak of this zone unless the trough suggested by the composite graph represents a real drop in volume reverberation, contained substantially fewer particles, showed less turbidity, and contained virtually no iron. The situation was similar in the 1377-ft sample.

Table 6 shows that the bulk of the particulate matter in the 1221-ft sample fell in the smallest size ranges measured — predominantly in the 0.74μ to 0.93μ range. In the 1299-ft sample, however, the particles tended to be larger, with the majority in the 0.93μ to 1.17μ range. In the 1377-ft sample, the majority again fell in the smallest ranges, but there were proportionately more particles in the larger size ranges as well. The level of M'_v was similar at all three depths, although it was definitely weaker at 1221 ft.

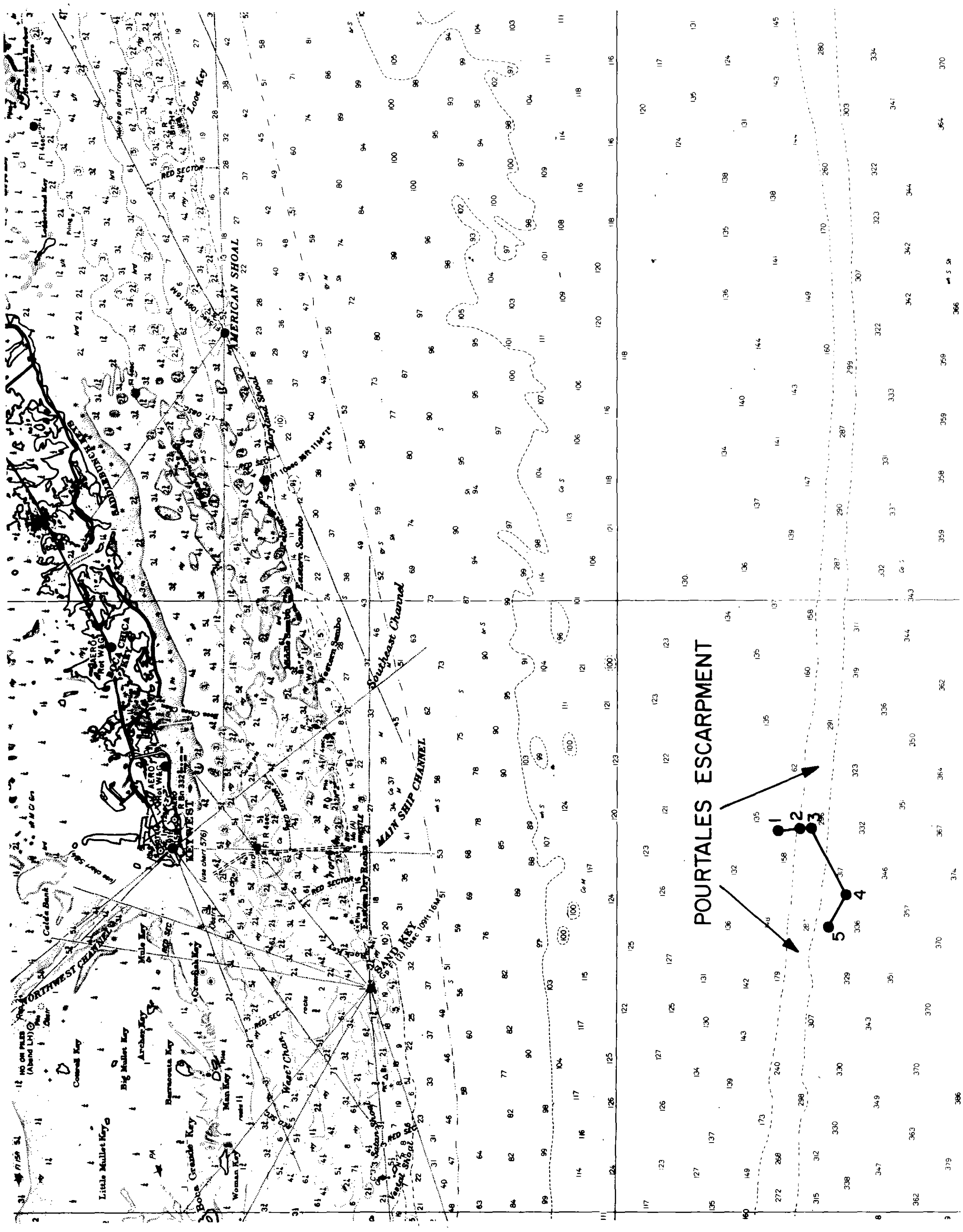


Fig. 18 - Track chart for the operation of Mar. 4, 1966

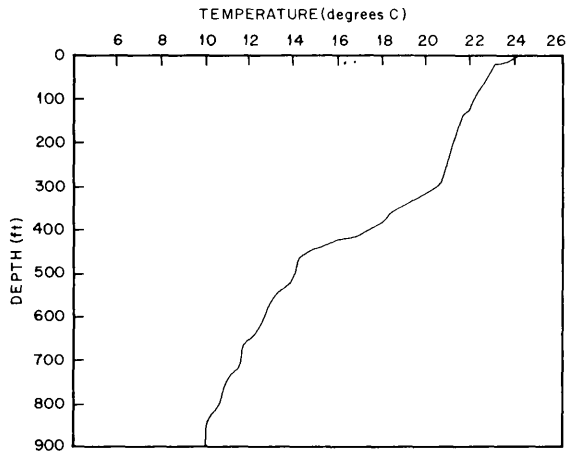


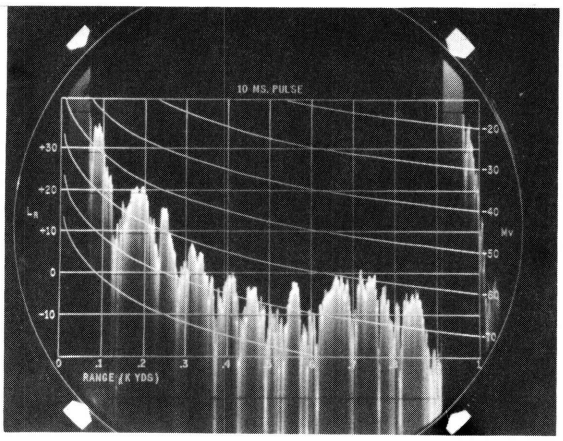
Fig. 19 - Temperature profile of Station 5, Mar. 4, 1966

Electron micrographs were prepared from the March 4 samples and are being published separately (7). A sample micrograph (Fig. 22) of the 1221-ft sample shows the characteristic fine particles (shown here in loose aggregates) which always dominate the field whenever there is a substantial concentration of iron. None of the characteristic iron material was seen in the two deeper samples (Figs. 23 and 24), which were found by chemical analysis to be low in iron. The unidentified material comprising the suspended matter in the two deeper samples consists, in both cases, chiefly of larger particles. Micrographs of the 1299-ft sample contained much debris and broken diatom shells.

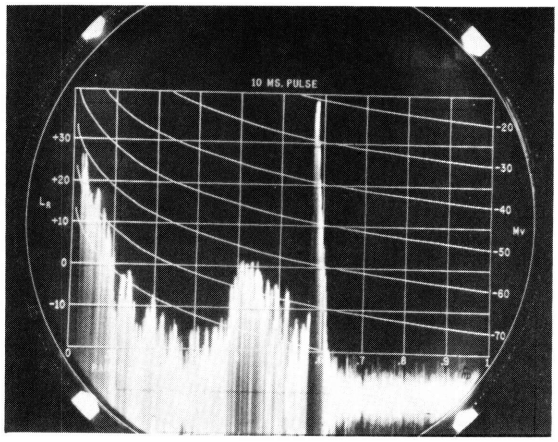
Another sample high in iron with high particle count and turbidity is the one from 779 ft. This depth falls in a region of low scattering strength, although it is near a small peak. The sample from 1065 ft, which comes from a region of essentially identical scattering strength, has a low particle count, little iron, and relatively low turbidity. Table 6 again shows the tendency toward larger particles in the 1065-ft sample and particles predominantly in the smallest ranges in the 779-ft sample. This again is well correlated with observations with the electron microscope.

DISCUSSION

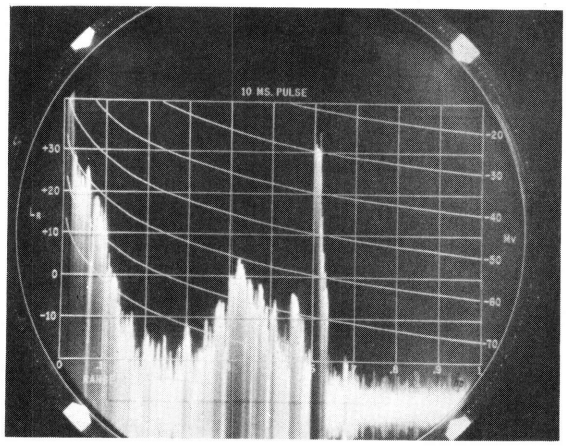
The major objective of this operation was to attempt to correlate localized increases in volume reverberation with the occurrence and nature of any suspended matter in the corresponding regions of the water column. Such a correlation requires that samples be identified unambiguously with the particular regions of interest "seen" by the acoustic profiler at the time of sampling. This was *a priori* obvious, but it must be strongly emphasized in the light of the present experience. Particularly where scattering zones are relatively thin, as many now appear to be, it is apparent that very much better information on the actual depth of each sampler is required than can be obtained from length of wire and wire angle at the surface, even in relatively calm and shallow water. Thermometric depth information, even if it had been available, probably would not have provided sufficient improvement at these depths, except perhaps on March 4 when the wire angle was large and variable. Fortunately, we were occasionally able to obtain information on bottle depth from the profiler; this cannot always be relied upon, however, and independent depth information is also desirable as a check on profiler performance. Thus, our analysis of the data gives a picture of seemingly good correlations in some cases and absolutely none in others. Without much better knowledge of the location of the water



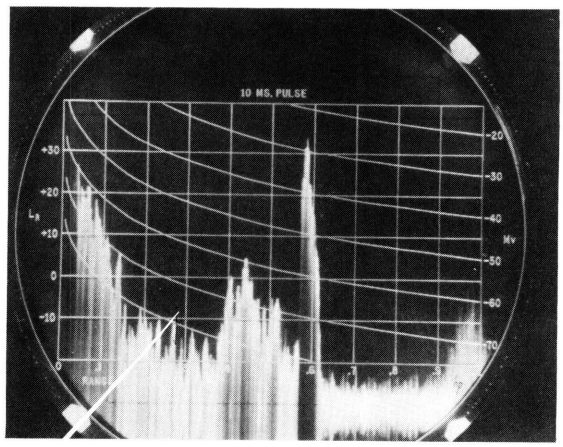
(a) Station 1 at 0851; 10 msec pulse length, 1000 ft range



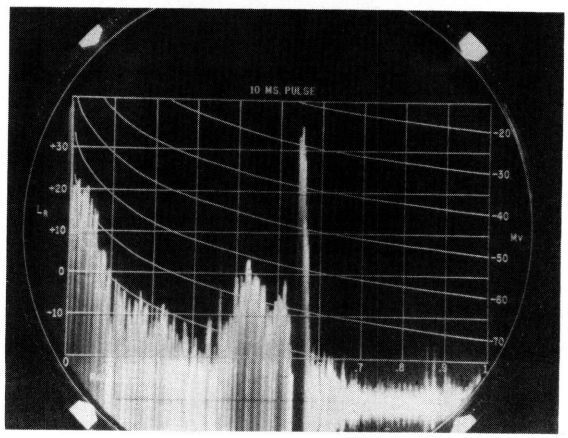
(b) Station 2 at 0908; 10 msec pulse length, 1000 yd range



(c) Station 3 at 0923; 10 msec pulse length, 1000 yd range



(d) Station 4 at 1004; 10 msec pulse length, 1000 yd range



(e) Station 5 at 1040; 10 msec pulse length, 1000 yd range

Fig. 20 - Acoustic profiles of Stations 1 through 5, Mar. 4, 1966

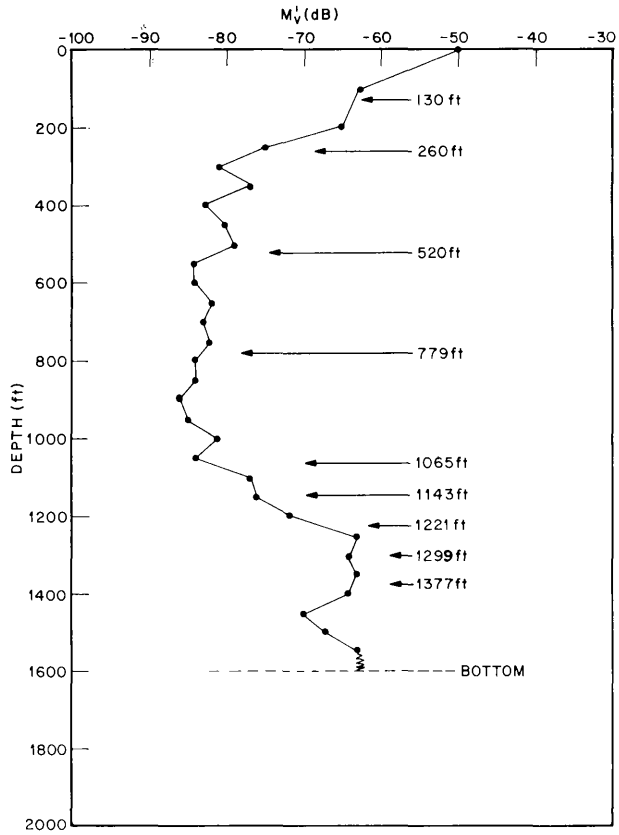


Fig. 21 - Composite acoustic profile of Station 5, Mar. 4, 1966

Table 5
Summary of the Data Obtained from the Operation of March 4, 1966 at Station 5

Depth (ft)	M'_v (dB)	Total No. Particles $\geqq 0.74\mu$ (ml^{-1})	Turbidity	Fe ($\mu g/l$)	Salinity (‰)
2	-50	176,310	16.4	10.6	36.30
130	-64	172,485	15.6	1.6	36.56
260	-76	491,575	18.7	125.8	36.56
520	-81	43,743	15.2	15.1	35.76
779	-83	439,267	17.6	130.3	35.29
1065	-82	80,890	15.3	39.4	35.13
1143	-76	273,882	18.0	35.1	35.12
1221	-68	792,707	20.0	189.9	35.08
1299	-64	251,584	14.9	2.2	35.07
1377	-64	379,288	15.2	5.7	35.08

Table 6
Operation of March 4, 1966. Particle Size Distributions in Samples Taken at Station 5.

Estimated Depth (ft)	Number of Particles per milliliter of Sample Falling in the Size Ranges Indicated (in microns)†												Number of Particles per milliliter of Sample Falling in the Size Ranges Indicated (in microns)‡										
	≧ 0.74	0.74-0.93	0.93-1.17	1.17-1.48	1.48-1.87	1.87-2.35	2.35-2.96	2.96-3.73	3.73-4.70	4.70-5.92	5.92-7.46	7.46-9.40	3.55-4.48	4.48-5.64	5.64-7.10	7.10-8.95	8.95-11.3	11.3-14.2	14.2-17.9	17.9-22.6	22.6-28.4	28.4-35.8	35.8-45.2
2	176,310	128,227	25,393	9951	4763	3543	2047	1101	554	390	194	103	570	271	161	79	44	17	8	1	2	1	1
130	172,485	105,990	45,229	12,027	3929	2487	1524	657	325	177	105	15	397	122	58	26	12	5	3	1	0	1	0
260	491,565	279,523	121,963	54,583	21,335	9733	2838	818	365	285	48	33	359	127	66	27	15	4	3	1	0	1	0
520	43,742	27,555	8130	3932	1782	1300	542	298	114	40	27	10	166	40	19	7	5	2	1	1	0	0	0
779	439,267	293,477	110,400	28,720	4634	1067	484	247	117	47	44	23	110	38	21	8	3	1	1	1	0	0	0
987*	319,753	117,060	77,386	51,160	25,020	20,520	12,054	8493	4227	1980	1020	486	3442	1575	801	319	149	51	18	2	0	1	0
1065	80,890	21,807	37,454	13,357	3276	1954	1300	947	453	224	70	27	394	138	59	19	9	4	1	1	0	1	0
1143	273,882	198,577	58,615	12,197	2382	1110	515	335	47	70	29	10	125	29	15	4	3	0	1	1	0	0	0
1221	792,707	415,177	249,474	88,253	28,840	9144	1210	383	101	60	37	14	93	44	24	6	4	1	1	1	0	0	0
1299	251,584	81,127	146,747	19,970	1940	1220	200	273	37	56	0	4	91	26	14	3	2	0	0	1	0	0	0
1377	379,288	244,264	117,463	9865	3041	2176	1085	674	393	171	104	38	358	135	66	28	11	4	1	0	0	0	0

*This bottle apparently struck the escarpment and filled with sediment (see text).
†Counts made with 30-μ aperture
‡Counts made with 140-μ aperture

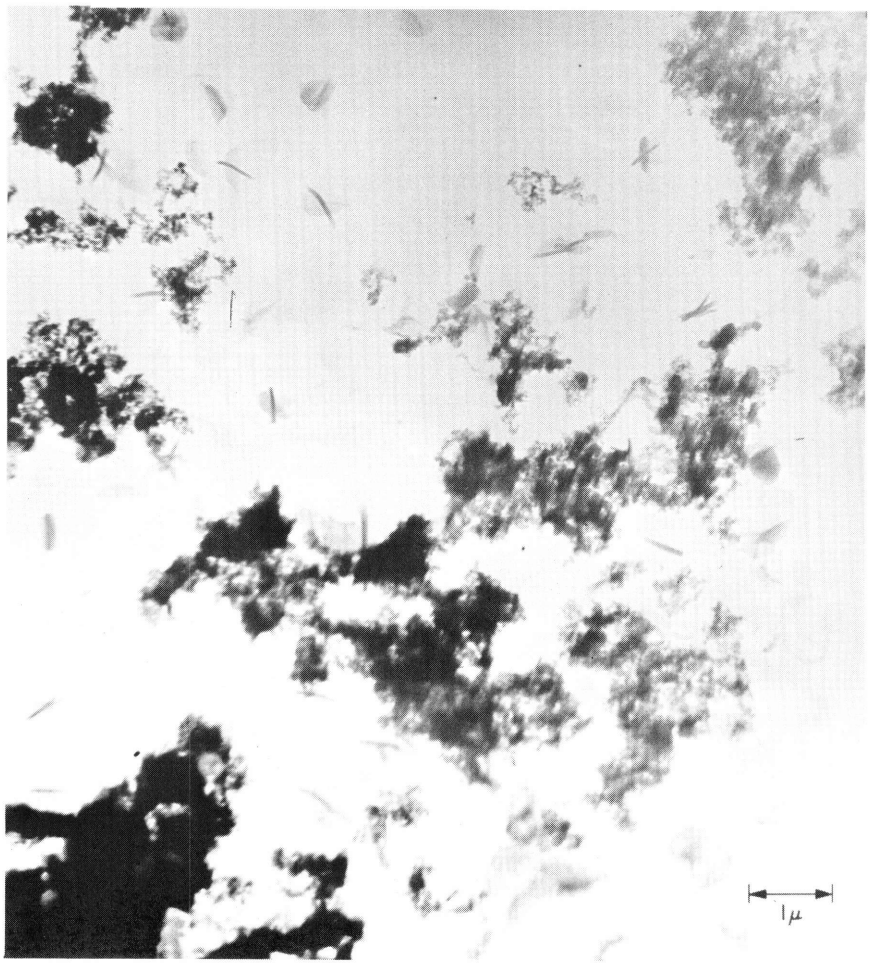


Fig. 22 - Electron micrograph of 1221-ft sample from Station 5, Mar. 4, 1966

bottles, it is quite impossible to decide, for example, whether the lack of a positive correlation resulted from failure to obtain corresponding samples or was due to the nature of the material involved.

It is apparent from studying the acoustic profiles themselves that scattering zones were widespread. In particular, a major zone lying near 1400 ft seemed to occur over large areas. Whether or not a "classical" biological deep-scattering layer was involved is not known. Peak scattering strengths were a little greater than those reported by Batzler and Vent (8) for scattering layers in the Western Pacific. Also, the average depth of the major zones did not correspond particularly well to the depths reported by Batzler and Vent for their layers, nor did it fit the depth characteristics reported by Hersey and Backus (9) for deep-scattering layers in the Western North Atlantic. It is possible, however, that proximity to the terrace may have resulted in deviation from more common depths. In the present work no observations were made near dusk or at night. Observations by one of us (D.F.W.) in June 1966, during a cruise (Undaunted-4) with the Bureau of Commercial Fisheries Miami Laboratory, showed basically the same acoustic profile patterns during the day with a major zone near the same depth. Although a single station was not occupied during both day and night, there was a strong indication

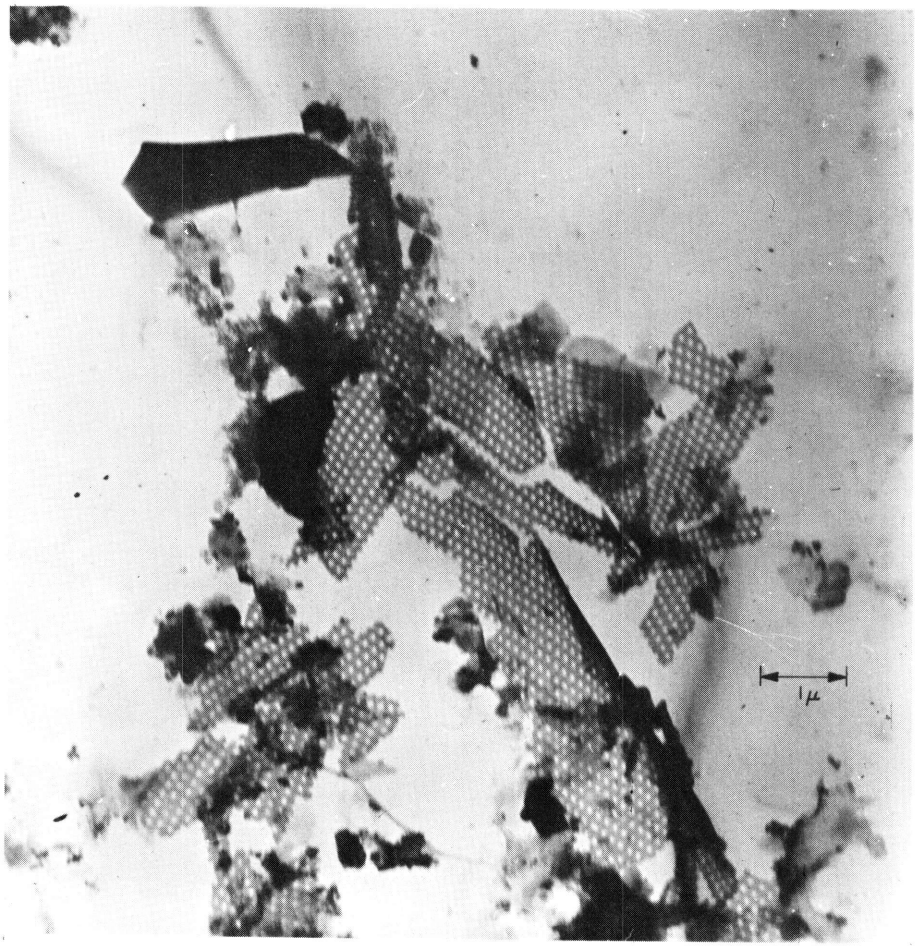


Fig. 23 - Electron micrograph of 1299-ft sample from Station 5, Mar. 4, 1966

that the general reverberation pattern in the area did change after dark. The principal zone seen in observations near midnight was then peaked near 1000 ft, with one or two narrower zones in the region of 1300 ft to 1500 ft. Near dawn the principal zone seemed to occur near 1200 ft. No biological sampling was done at any time.

The question of whether or not our principal zone was indeed a biological deep-scattering layer is further complicated by the observations of February 23 on the "splitting" layer just off the escarpment. One component remained at the depth at which it was first seen near the scarp (1350 ft) whereas the other main component descended rather sharply to bottom at about 2-1/2 mi from the escarpment. Since we obtained no samples or other measurements from these scattering zones, it is not possible to do more than speculate on the nature of the scattering centers. One possibility is that outflow from the Floridan Aquifer (10) lying behind the escarpment was involved. In such an event, lighter or more finely divided sediment components might remain suspended at about the exit depth and be transported outward from the scarp, whereas the heavier or more flocculent components would tend to settle out. This is reminiscent of the situation found with the March 1965 turbid, iron-bearing water samples (1). The uppermost of those samples was essentially a colloidal suspension and remained turbid for many days when left undisturbed in the laboratory. The lower sample contained more material per

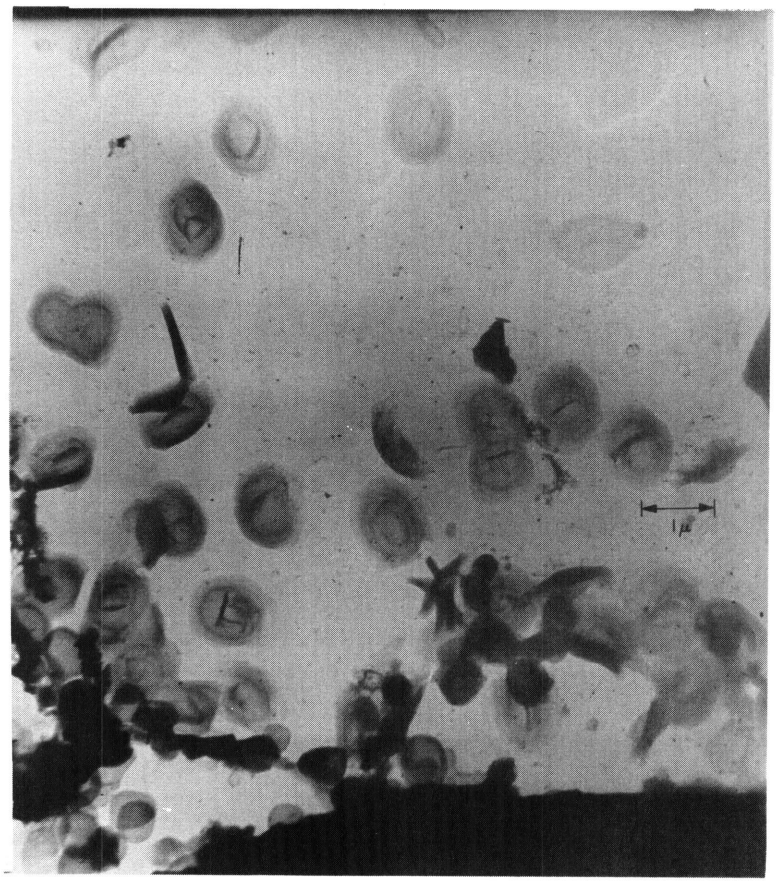


Fig. 24 - Electron micrograph of 1377-ft sample from Station 5, Mar. 4, 1966

unit volume, it was more flocculent, and the suspended matter settled out overnight. Both samples consisted of essentially the same kind of material, however.

The complication stems from the fact that the upper zone occurred at the same depth and had the same general appearance in the profile as the major scattering zone seen throughout the area. If it did involve a sediment layer, the layer was widespread. If it was not sediment *per se* that was causing the scattering, then outflowing water could still have been involved by controlling the layering depth of scattering organisms. This could occur, for example, through nutrient enrichment of the ocean water, leading to a zone of increased biological productivity. Increased productivity has been positively correlated with increased scattering by Batzler and Vent (8). It seems too much to expect, however, that one layer was an abiotic manifestation closely resembling in depth and scattering properties a nearby biological layer without there being some cause-and-effect relationship between them. The question is clearly unresolved at this time.

Thus, this early attempt to correlate acoustic profiles and sample characteristics has produced no clear-cut data bearing on the nature of the observed scattering zones. This is due, at least in part, to reasons we have repeatedly emphasized. An increased content of particulate matter certainly seems to be closely associated with increased scattering strength in at least some of the cases. Hiller et al. (2) have suggested, on the

basis of discrepancies between values calculated according to Rayleigh scattering theory for the observed small particle sizes and the scattering strengths actually observed with the profiler, that microbubbles may also be involved. We have produced no evidence bearing on this point, nor have we any evidence bearing on the nature and occurrence of microorganisms in the samples.

Furthermore we were unable to investigate any relationship between density profiles and acoustic profiles due to lack of precise enough temperature and salinity data. This is particularly unfortunate, since it is now well known that vertical distributions of temperature and density can be very heterogeneous. Stommel and Federov (11), for example, obtained data from continuous salinity-temperature-depth profiles showing vertical thermohaline inhomogeneities as thin as 2 m but extending horizontally for several kilometers. Some results based on high-precision classical analyses have led Cooper (12) to essentially the same conclusions concerning stratification in the ocean. More sophisticated analysis of records from successive scans will be necessary, however, before we can determine the reality of suggested profiler responses to narrow layering in the water column.

The iron concentrations found were well within the limits reported by investigators at the University of Miami (13) for Florida inshore waters, except for the three high values obtained in the cast of March 4. Although we have too few data for any generalizations, these findings together with those of 1965 suggest that abnormally high concentrations of iron can be found in discrete layers near the escarpment. No conclusions can be drawn concerning distances from the terrace where such zones may occur. The evidence obtained to this point in our work indicates rather clearly that abnormally high concentrations of iron, apparently occurring as small flocs of ferric hydroxide, produce large particle counts in the smallest size range and are associated with a distinct increase in volume reverberation. The degree of scattering does not appear to be as great, however, as that produced in volumes containing some other kinds of particulates. Many of these latter tend to be larger than the iron-bearing material and, in some cases at least, seem to be associated with higher volume reverberation levels when they are present in lower concentrations than the iron-bearing material. The substances involved are totally unidentified; iron determinations were the only chemical determinations performed, and the electron micrographs of the March 4 samples constitute the only other available source of information.

It is apparent that eliminating many of the sources of uncertainty in this work requires that particle counts and size distributions be obtained at sea. The increase in the number of bacteria, for example, between the time of collecting a sample and the time of making particle counts is a function of the initial number of bacteria, the temperature at which the samples are stored, and the delay in counting. This multiplication of bacteria can be arrested with a preservative, such as chloroform, but this could be done only in the face of certain alteration in the state of particle aggregation caused by the chemical itself. Furthermore, there is an inevitable natural alteration with time in the abiotic particulate matter when its environment is changed. The extent of this in any given instance is not known, but the phenomenon has been amply demonstrated in our laboratory and, no doubt, elsewhere. The only realistic solution is to perform particle counts at sea at the time of sampling or, preferably, *in situ*. In this latter connection an *in situ* type of particle counter is now being developed for this kind of work by the Coulter Corporation at the suggestion of NRL (2).

With further improvements in the profiler, reliable depth indication at the samplers, and better facilities for the rapid analysis of labile material (on board ship or *in situ*), better progress can be made in the study of water-column heterogeneity and its relationship to volume reverberation. Such study will be greatly facilitated by more use of both the light and electron microscopes, quantitative plankton-sampling techniques, and a continuous salinity-temperature-depth profiler.

ACKNOWLEDGMENTS

This work was done under the general direction of A. J. Hiller as part of his research program on the distribution and nature of particulate matter in the sea in relation to sound scattering. LCDR R. C. Anderson USN was in charge of the Navy boat crew and provided navigational data. Marlin Hildenbrand performed the particle counts, and E. A. Abbott made the turbidity measurements. J. E. Roberson, W. T. Wood, C. W. Hughes, L. G. Galli, and B. J. Culverhouse assisted with various aspects of the operation both at sea and ashore.

We also appreciate the cooperation of KWESTEVDET and NOU for furnishing the UOR-125 and space to set up our shore laboratory.

REFERENCES

1. Wilson, D.F., and Zillioux, E.J., "An Iron-Bearing Nepheloid Layer Near Key West, Florida," Nature 211:506-507 (1966)

2. Hiller, A.J., Mathes, R.H., and Ricalzone, L.C., Report of NRL Progress, September 1965, pp. 37-40

3. Jordan, G.F., and Stewart, H.B., Jr., "Submarine Topography of the Western Straits of Florida," Geol. Soc. Amer. Bull. 72:1051-1058 (1961)

4. Jordan, G.F., Malloy, R.J., and Kofoed, J.W., "Bathymetry and Geology of Pourtales Terrace, Florida," Marine Geology 1:259-287 (1964)

5. Strickland, J.D.H., and Parsons, T.R., "A Manual of Sea Water Analysis," Fisheries Research Board of Canada Bulletin 125 (1960)

6. National Defense Research Committee, Summary Technical Report, Division 6, Vol. 8, "The Physics of Sound in the Sea," 1946

7. Beckett, R.C., and Hiller, A.J., "Electron Microscope Observations of Oceanic Particulates in a Depth Profile," NRL Report in preparation

8. Batzler, W.E., and Vent, R.J., "Volume-Scattering Measurements at 12 Kc/Sec in the Western Pacific," J. Acoustic Soc. Amer. 41:154-157 (1967)

9. Hersey, J.B., and Backus, R.H., "Sound Scattering by Marine Organisms," M.N. Hill, ed., in "The Sea," New York:Interscience, Vol. 1, pp. 498-539, 1962

10. Kohout, F.A., "A Hypothesis Concerning Cyclic Flow of Salt Water Related to Geothermal Heating in the Floridan Aquifer," Trans. N. Y. Acad. Sci. 28(2):249-271 (1965)

11. Stommel, H., and Federov, K., cited in Undersea Technology, Vol. 8, No. 8, Aug. 1967, p. 31

12. Cooper, L.H.N., "Stratification in the Deep Ocean," Science Progress 55:73-90 (1967)

13. Institute of Marine Science, Univ. of Miami, "Investigations of American Tropical and Subtropical Seas," Progress Report 64-4, 1964

Appendix A

FUNCTIONAL DESCRIPTION OF THE ACOUSTIC PROFILER

Figure A1 will be used in describing the acoustic profiler's operation. The timing circuits provide keying intervals for ranges of 200 ft, 1000 ft, 1 kyd, 2 kyd, and 4 kyd. The circuits also trigger the pulse-length generator to provide pulses of 0.5, 1, 5, and 10 msec and, in addition, provide range calibration and synchronization pulses to the display oscilloscopes. The output of the pulse-length generator is used to key a 19.5-kHz oscillator and a 1-kW driver.

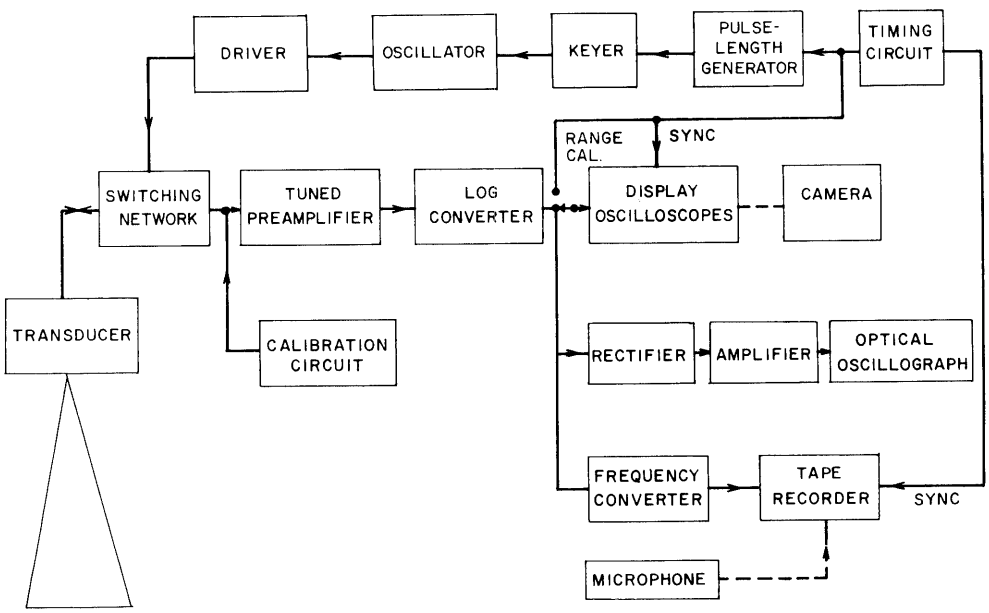


Fig. A1 - Block diagram of acoustic profiler

The driver is coupled through a diode switching network to an NRL type XP-1A transducer to produce acoustic pulses at a source level of 119 dB referenced to a sound pressure of 1 μbar. The transducer has a 12-in.-diameter active face which produces the beam pattern shown in Fig. A2. The side and rear lobes are very small. The beam-width at the 3-dB-down points is 15 degrees; this produces a directivity index of -21 dB. The weight of the transducer is 90 lb in air.

A frequency near 20 kHz was desired as a compromise between a transducer size which would allow easy handling and acceptable range reduction due to the absorption of sound by seawater. A transducer resonant at 19.5 kHz was available which had excellent characteristics for the desired application; consequently, 19.5 kHz was selected as the operating frequency. This frequency provides good returns from relatively weak acoustic reflectors to depths of over 1000 yd. The use of much higher frequencies could enhance

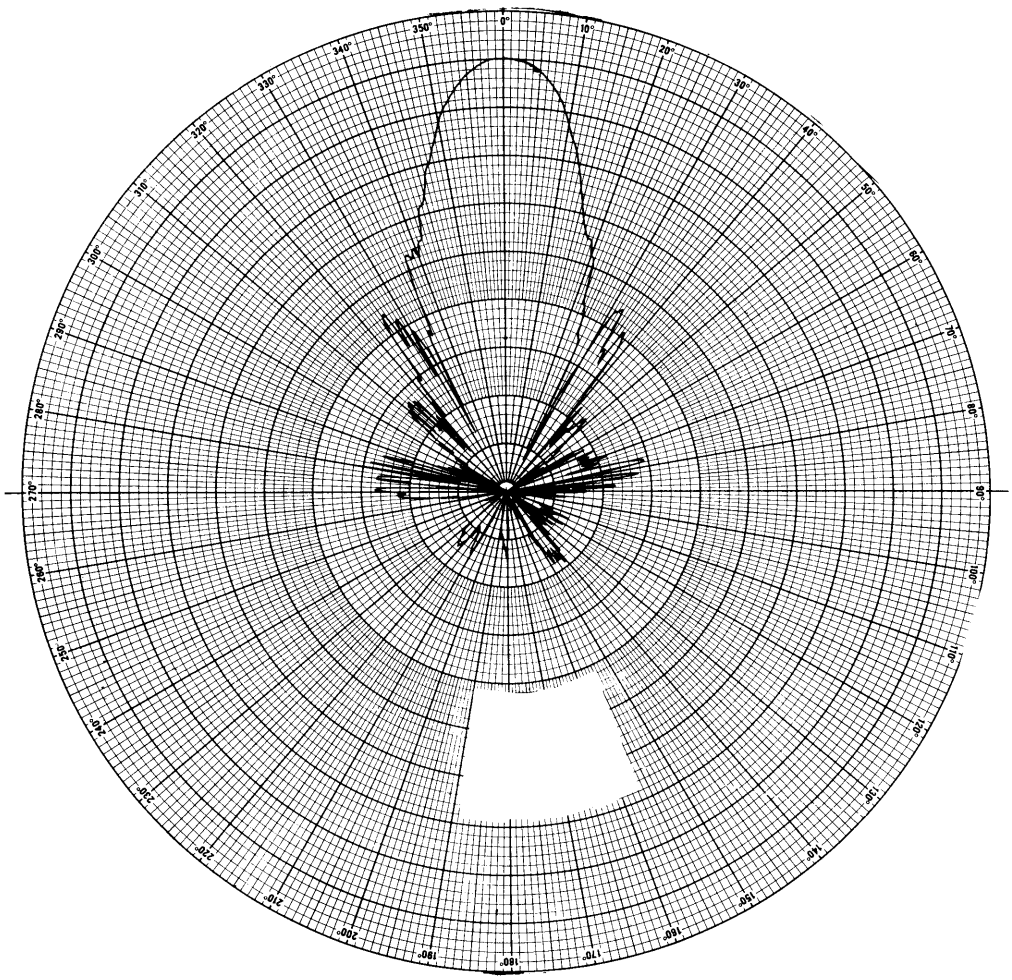


Fig. A2 - Beam pattern of NRL XP-1A transducer

the effect of small particles, but this would also result in larger absorption losses, which would reduce the range. Such equipment would be useful for special purposes, however, and a profiler operating at 220 kHz has been built and is now being evaluated.

The receiving portion consists of a tuned amplifier also coupled to the transducer through the diode switching network. This linear amplifier has a gain of 80 dB and a bandwidth of 2 kHz and is designed to match a commercial logarithmic voltage compressor ("log converter") to produce a logarithmic output calibrated directly in sound pressure level at the face of the transducer. A calibration oscillator and attenuator are included to permit proper calibration of the various displays. A linear calibration scale (L_R) of -20 dB to +40 dB referenced to 1 μbar is provided on the oscilloscope display.

Three different data recording methods are provided: (a) the oscilloscope display may be photographed at intervals using a Polaroid scope camera, (b) the data may be plotted continuously on an optical oscillograph, and (c) the data may be recorded continuously on a portable tape recorder together with range synchronization pulses and voice comments. Data are recorded using frequency modulation to overcome irregularities and losses often encountered with amplitude modulation (the "dropout" problem). Since the response of the FM mode is limited to 2 kHz at a tape speed of 7-1/2 in./sec,

the 19.5-kHz signal is converted to 1.9 kHz for recording. This limits the usefulness of the tape recording method to the 5-msec and 10-msec pulse lengths.

The output of the log converter is rectified and filtered before being applied to the optical oscillograph. A recording galvanometer having a flat response to 1 kHz is used which permits recording all pulse lengths except that of 0.5 msec. Various paper speeds up to 64 in./sec can be used to provide different degrees of range resolution and expansion. The optical oscillograph permits recording the profile from each pulse in sequence. This is not possible with the Polaroid camera but is needed in studying pulse-to-pulse variation.

Special bezels for the oscilloscopes and overlays for the oscillographic recorder are made up from the known parameters of the system to read M_v' directly in decibels. A different bezel is needed for each pulse length and range scale combination.

Figure A3 is a photographic record illustrating the return obtained from a scattering layer near the bottom using the bezel for a range interval of 1 kyd and a 10-msec pulse length. Figure A4 shows the same type of layer structure recorded with the optical oscillograph using an overlay for the 10-msec pulse length and a paper speed of 4 in./min. Figure A5 is a profile reproduced in the laboratory from a tape recording. It can be seen to agree closely with a similar profile photographed from the primary display. Figures A3, A4, and A5 are from profiles taken at nearly the same time. The range discrepancy is due to power line frequency variations on board UOR-125.

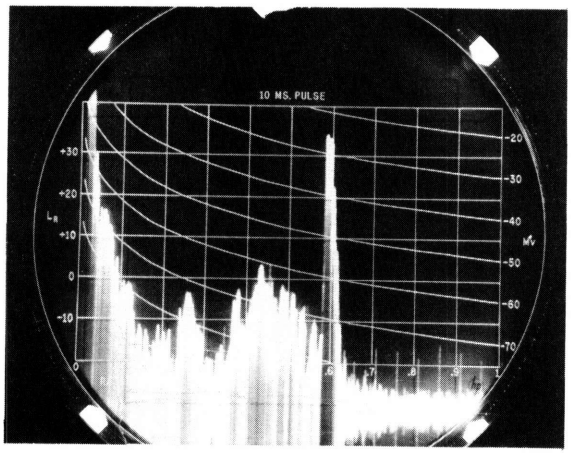


Fig. A3 - Scope camera photograph of oscilloscope display

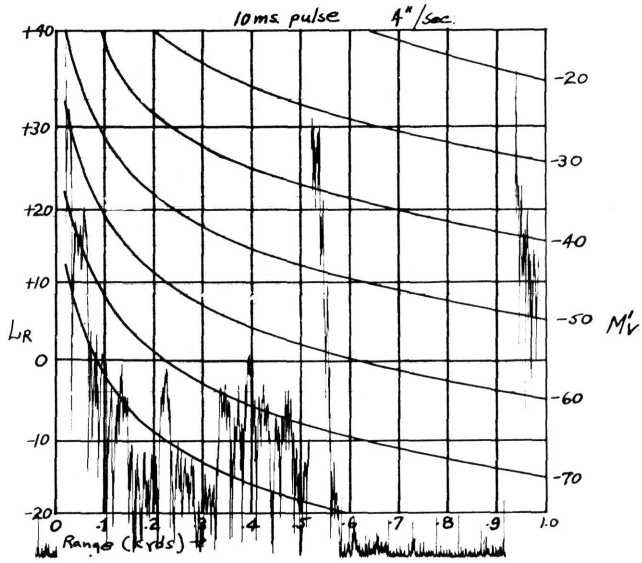


Fig. A4 - An acoustic profile recorded by the optical oscillograph

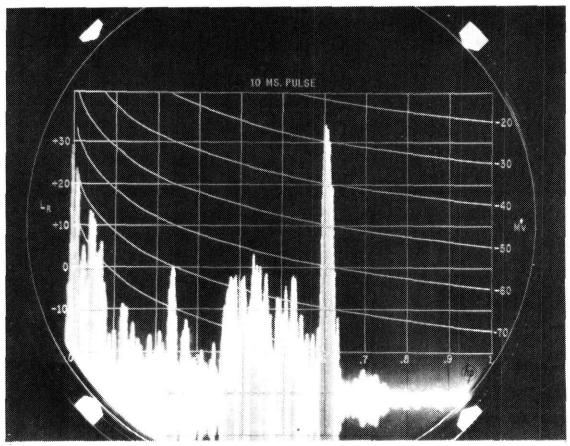


Fig. A5 - Reproduction of a profile recorded on magnetic tape

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

A final report on one phase of the problem; work on other phases continues.

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13. ABSTRACT

An attempt was made to correlate local variations in volume scattering near Pourtales Escarpment south of Key West with the nature and occurrence of particulate matter in corresponding regions of the water column. Sound-scattering strength versus depth was measured with an "acoustic profiler," which is described, and water samples were obtained by conventional cast. Despite frequent uncertainty concerning the actual depths at which samples were obtained, some good correlations were found between scattering strength, particle count, and particle size distributions determined with an electronic particle counter. The acoustic profiler revealed the presence of numerous scattering layers in the area and provided tentative evidence for rather narrow stratification in some instances. Abnormal concentrations of iron, apparently as ferric hydroxide, were found in discrete zones near the scarp.

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Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Volume scattering						
Suspended particles						
Sound-scattering strength						
Scattering layers						
Underwater sound						
Sonar						
Iron concentrations						
Particle size distributions						