Diel Migration of Sound Scatterers into, and out of, the Cariaco Trench Anoxic Water[1]

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ABSTRACT

Acoustic measurements at 25 kHz show that a well-defined sound-scattering layer in the Cariaco Trench migrates down in the early morning to the oxic-anoxic interface and splits into two components: one remains in oxygen-deficient water above the interface; the other penetrates several hundred meters into the anoxic hydrogen sulfide- and methane-containing region of the water column. During the afternoon, scatterers move up from this anoxic zone, join with the group that remained above the interface, and all then move to near the surface for the night. Strong circumstantial evidence suggests that *Bregmaceros* spp. are migrators into the anoxic zone.

Introduction. The Cariaco Trench is an anoxic depression in the Continental Shelf off the coast of Venezuela. It is nearly 1400 m deep in some spots, and its sill lies at depths of less than 150 m. Above 150 m, the Trench water can communicate freely with the rest of the Caribbean. Below about 375 m to 400 m, the Trench water is anoxic and contains hydrogen sulfide and methane (Richards and Vaccaro 1956, Atkinson and Richards 1967, Richards 1970).

During a cruise in April 1969 aboard the USNS Mizar (T-AGOR-11), two stations were occupied over the Trench. By means of a 12-kHz echo sounder and precision depth recorder (PDR), a prominent sound-scattering layer (DSL) was observed to migrate downward in the early morning each day and to fade out in the region of the oxic-anoxic interface (Fig. 1). Winkler determinations of the dissolved-oxygen concentration (DO) showed that less than 0.15 ml/l was present at the depth (400 m) where the echo-sounder trace disappeared. A strong odor of H_2S was always present in Trench-water samples that contained that amount or less of DO, and experience indicated that H_2S was also present in all deeper samples. Richards (1970) reported a peak sulfide concentration of about 30 μM near 900 m; this sulfide would occur almost

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entirely as H_2S and HS^-, chiefly the latter. Presumably the fading of the scattering-layer echo was a result of either depth compression of fish swimbladders, with a consequent reduction in the target strength at 12 kHz, or vertical dispersion of the scatterers near the oxic-anoxic interface. In any event, the echo reappeared in the late afternoon and indicated that movement of scatterers upward toward the surface was occurring.

On a cruise in May 1971 (MIZAR Cruise 71-11-02A), an identical migration pattern was observed with the 12-kHz echo sounder and PDR at a Cariaco Trench station. In addition, an "acoustic profiler", operating at 25 kHz, was used. The higher-frequency instrument showed that the migrating DSL split into two components at, or near, the oxic-anoxic interface. One component remained above the interface throughout the day while the other migrated deep into the anoxic water, where its echo faded out at 900 m to 1000 m. Quite surprisingly, however, the level of volume reverberation at 25 kHz began to increase during the afternoon in the region around 600 m, and what seemed to be a migrating component took shape and moved back above the interface, where its echo merged with that of the component that had not entered the anoxic zone. The whole group then moved upward, in the manner observed at 12 kHz, and merged with another layer that had remained throughout the day near 250 m.

Equipment and Procedures. The 12-kHz echo sounder was an EDO Model UQN-1C operated through a Westrex Mark V Precision Depth Recorder. Power to the transducer was approximately 800 watts, and the beam angle of the transducer was 30° at the 3-decibel-down point. The equipment was operated in the "long ping" mode, wherein the transmitted pulse was 20 to 30 msec long.

The 25-kHz acoustic profiler was built at the Naval Research Laboratory specifically for studying sound-scattering layers (Wilson et al. 1968). Like the UQN-1C, it is a downward-looking echo sounder, but it differs from the usual instrument in having a calibrated A-scan oscilloscope display, which shows directly the value of sound-scattering strength as a function of depth.[2] On this cruise it delivered 940 watts to an EDO Model EX 116 transducer, which has a beam angle of 18° at the 3-decibel-down point.

Records from the acoustic profiler were made by photographing the oscilloscope trace and an overlying calibration bezel (Fig. 2). In these photographs, depth is indicated along the horizontal axis, increasing to the right from 0 to 1000 m; each vertical line thus measures off 100 m. The lines sloping downward to the right are lines of constant scattering strength, M'_v, expressed in decibels. The horizontal lines originating from the left-hand vertical axis,

2. The sound-scattering strength, M'_v, is the ratio, in decibels (dB), of the scattered intensity, I_S, at unit distance (one meter) from a unit volume (one cubic meter), to the incident intensity, I_O; viz., $M'_v = 10 \log (I_S/I_O)$.

labeled L_R, are for calibration purposes. A layer of increased volume-reverberation is seen as an envelope of signals whose amplitude, measured on the logarithmic scale of scattering strength, rises above that of the background on either side.

Range and amplitude calibrations of the display were checked prior to each series of photographs by means of calibration circuits built into the instrument. Each of the photographs shown in Figs. 2 and 3 was made with a pulse length of 10 msec. All were taken during "single-ping" operation to avoid introducing bottom echos from beyond the range of the display.

A single station, located at 10°38′N, 65°45′W, was occupied for approximately five days. All observations reported here were made while the ship was drifting on station. The 12-kHz echo sounder and PDR were operated continuously. Photographs of the 25-kHz profiler display were taken every few minutes during the periods of migration but were taken less frequently the rest of the time.

Dissolved-oxygen concentrations were determined by micro-Winkler titration (Carpenter 1965) of samples collected in nonmetallic water bottles.

Observations. On one hydrocast, all samples from 380 m and deeper showed no response to the starch indicator upon analysis for the DO concentration. On another cast, a DO concentration of 0.02 ml/l was found in samples taken from 375 m and 383 m. For the purpose of this paper, therefore, the oxic-anoxic interface is considered to be located at 400 m. Downward from about 325 m, however, the DO concentration was found to be below 0.15 ml/l. It is considered likely that H_2S, in amounts detectable by its odor in water samples, always existed from at least 325 m downward.

Figs. 2 and 3 show 18 oscilloscope camera records selected from a series of 53 photographs taken with the 25-kHz profiler on May 27. During the five days on station, a total of 185 such records was made, and on each day the migration pattern was the same.

Fig. 2a shows the scattering situation at 0500 h local (+4) time, just before the downward movement of the layer began, and Fig. 2b, taken at 0600 h, shows that the migration was proceeding. The first indication of the downward movement on the 12-kHz-PDR record appeared at 0512 h. This is the same time, almost to the minute, when the downward movement became apparent on the PDR record made in 1969 (Fig. 1). Fig. 2c, taken at 0640 h, shows an increase in the reverberation in the anoxic zone; this is the earliest evidence that a group of scatterers had entered the anoxic water. This time (0640 h) coincides closely with the time when the deepest 12-kHz trace disappeared, at approximately 400 m, on both the 1969 and 1971 records. The disappearance presumably resulted from the vertical separation of migrating-group components near and below the oxic-anoxic interface. The 1971 record shows a faint echo branching off and remaining visible for a short time at approximately 365 m, just as the main echo disappeared. Occasional faint reappearances of this layer occurred throughout the morning, particularly at 1000 h and again at 1130 h. Presumably this echo is from the group that remained just above the interface throughout the day. It was not seen in 1969, possibly because lower PDR gain settings were used then.

Fig. 2d, taken at 0705 h, shows that the deep group is clearly in the anoxic zone, and Fig. 2e, taken at 0830 h, shows it in the vicinity of 500 m. At 0905 h (Fig. 2f), the group was near 600 m, and by 1115 h (Fig. 2g), the group had reached the vicinity of 700 m. At this time there was an abrupt decrease in the echo amplitude. Fig. 2h, taken at 1229 h, shows only a faint echo in the 800-m-to-1000-m region, and by 1300 h (Fig. 2i), all traces of the group had disappeared. However, an elevated level of volume reverberation existed throughout the entire anoxic water column to the limit of the photographic record (1000 m), compared with the level that existed at 0500 h. This is taken to indicate considerable dispersion of the scatterers in depth throughout the range of the original group's movement.

Fig. 3a shows the scattering situation at 1335 h. A group echo can be seen forming in the vicinity of 500 m to 600 m. By 1404 h (Fig. 3b), an upward movement toward that region and shallower was taking place. Fig. 3c, taken at 1433 h, shows a further increase in the volume reverberation of the upper part of the anoxic zone, and at 1500 h (Fig. 3d) a more specific upward trend was apparent. At 1550 h (Fig. 3e), movement across the interface began, and at 1650 h (Fig. 3f) it was well in progress. By 1800 h (Fig. 3g) the bulk of the scatterers had passed across the interface, and the reverberation level had dropped substantially in the lower part of the water column. At 1854 h (Fig. 3h), movement from below 400 m appeared to be complete, but the group was continuing to move toward the surface. The deep migrating layer did not reappear on the 12-kHz record until about 1820 h, at which time it was well on the way toward merging with the 250-m layer, which had started to move up at approximately 1635 h. The 12-kHz PDR record showed that movement of the entire group was completed at about 1925 h, and a 25-kHz profiler photograph taken at 2000 h (Fig. 3i) is essentially identical to the one taken at 0500 h (Fig. 2a).

Discussion. The acoustic evidence for the daily migration of part, but not all, of the DSL into the anoxic zone seems incontrovertible. The evidence for migration upward out of the anoxic zone is perhaps a little less clear, but only because the migrating group lacks the compactness seen during the descent. In the absence of an alternative explanation for the daily increase in, and the progressive upward enhancement of, volume reverberation in the anoxic zone, it seems inescapable that late-afternoon upward migration was occurring on a regular basis. This conclusion is strengthened by the timing of the upward movement; it began sufficiently ahead of the start of the upward movement by

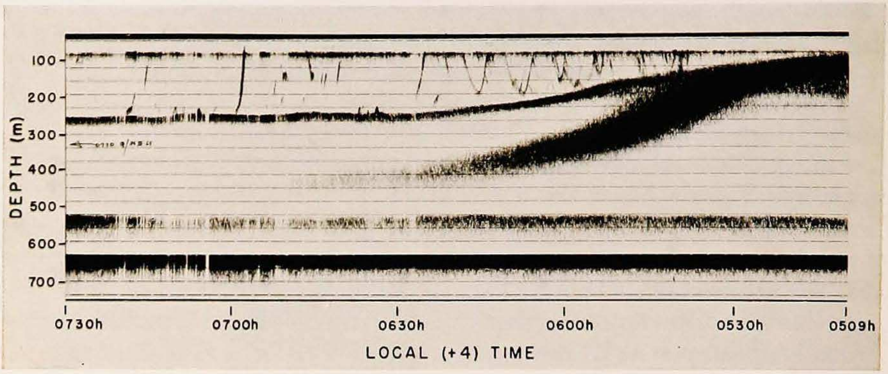

Figure 1. A 12-kHz PDR record of the scattering layers on April 26, 1969. The layer recorded at approximately 520 m is an artifact resulting from a second return from the bottom.

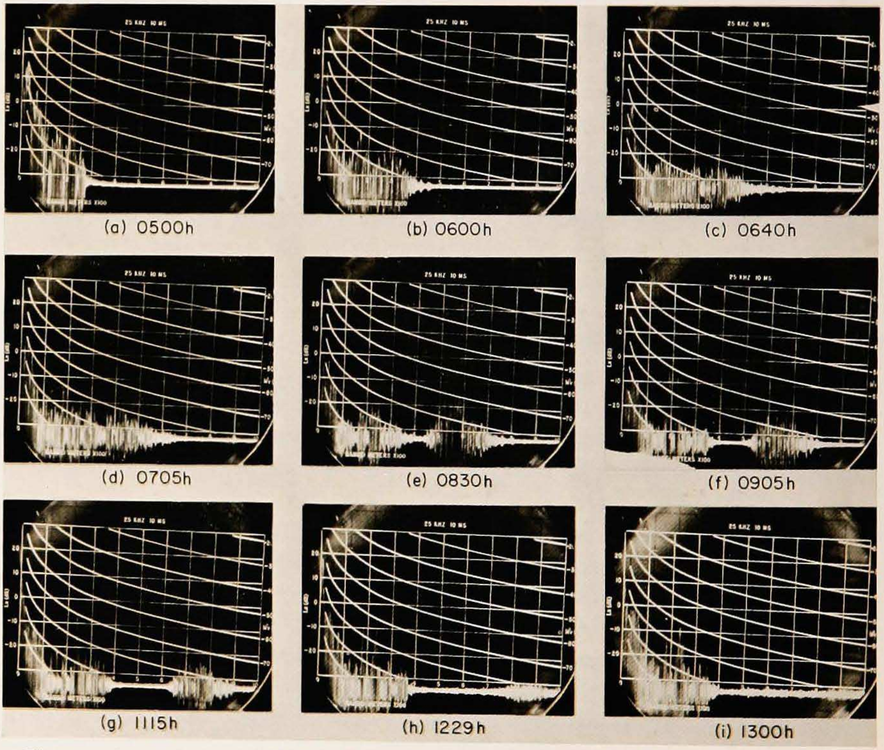

Figure 2. Some of the 25-kHz acoustic profiler records showing the descending DSL on May 27, 1971. Times shown are local (+4) time. See text for details.

the DSL component that remained above the interface so that all components merged into a single diffuse, but connected, group that again appeared as a trace on the 12-kHz record.

It is widely believed that organisms (other than certain anerobic bacteria) cannot survive in the sulfurous anoxic waters of the Cariaco Trench (Richards 1965, 1970, Heezen et al. 1959). Apparently this is not entirely the case; however, the acoustic findings necessarily leave the question of the migrators' identity unanswered. Mead (1963) made a single trawl in the anoxic zone, where he obtained 223 specimens of *Bregmaceros atlanticus* and virtually nothing else. He did not report any acoustic data, but his haul was made in the early morning at a depth of 400 m to 600 m. This would have put his net in close proximity to the downward-migrating group we observed with the 25-kHz profiler (his station was also in May). Unfortunately, we were not equipped to trawl for midwater fishes on this cruise. However, a messenger-actuated closing device was rigged on the cod-end bucket of a one-meter

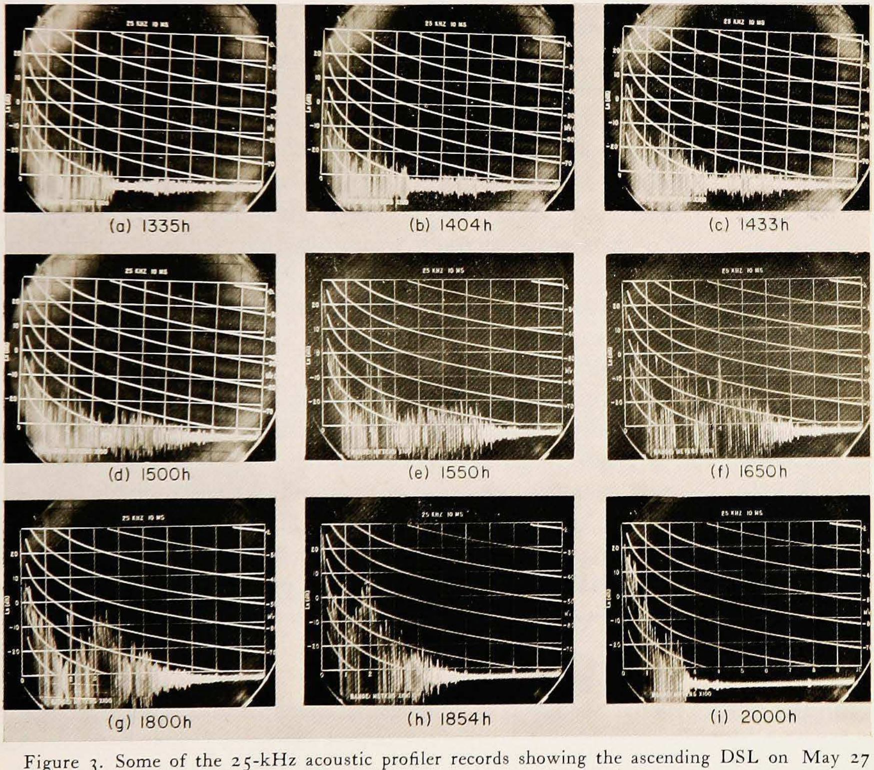

Figure 3. Some of the 25-kHz acoustic profiler records showing the ascending DSL on May 27 1971. Times shown are local (+4) time. See text for details.

plankton net, and a vertical tow was made from 800 m during the time of downward movement (see Fig. 2f, which was taken during the tow). The bucket was closed at approximately 500 m. Two specimens of *Bregmaceros* sp. were found in the closed bucket, and four more were in the net.

Mead found none of the known migrators, such as myctophids, in the overlying oxic waters of the Trench. He speculated that such fish might cross the sill at night and instinctively migrate down at daybreak to die in the sulfurous anoxic water. Pugh (in press) has expressed a similar view, although he has pointed out that Mead's station was too far from the nearest sill to allow fish entering from the outside waters to reach Mead's station by daybreak. The present data indicate, however, that some of the migrators cease their downward movement short of the oxic-anoxic interface whereas others continue down several hundred meters into the anoxic zone. It is apparent that those migrators that remain outside the anoxic zone spend the day in oxygen-deficient water. This is not particularly unusual, however, since Kanwisher and Ebeling (1957), Kinzer (1967), and others have reported that some scatterers elsewhere regularly spend the daytime hours in near-anoxic water. Our 25-kHz records of the downward movement (e.g., Fig. 2e and 2f) show at first a remarkably sharp separation between the components on either side of the interface, suggesting that, even though the DO concentration decreases with depth along a gradient commencing well above the interface (although local variations occur), a well-defined "physiological" interface exists. A likely parameter would seem to be the presence of H_2S.

It is possible that the upward "migration" seen acoustically could be an upward movement of dead or moribund fish buoyed up through some abnormal response of their swimbladders to the toxic gases. However, the timing of their return to the surface to coincide with the upward movement of the shallower components would seem to preclude this as an explanation. The evidence seems to support the idea of a true upward migration.

The evidence from both Mead's findings and mine tends to implicate *Bregmaceros* in these migrations. *Bregmaceros atlanticus* has been found by Mead (1963) and by Pugh (in press) in the overlying oxic water. Pugh reported that *B. atlanticus* was among the most abundant fish in catches from Trench waters but was sparse in catches from an adjacent Caribbean station. He also reported that the species was taken from depths where the DO concentrations were as low as 0.05 ml/l. Mead reported that the swimbladders of his *B. atlanticus* were analyzed for gases immediately after the trawl was recovered and were found to be "high in oxygen". According to our acoustic findings, his fish would have been taken shortly after the deep migrating group observed with the 25-kHz sonar would have crossed the interface into the anoxic zone. Mead felt that *B. atlanticus* could use the stored oxygen to remain for a time in completely anoxic water. In this same connection, large numbers of *Bregmaceros* sp. were seen from Deepstar 4000 to be prominently associated with a distinctive type of shallow sound-scattering layer in oxygen-deficient water off Cape Corrientes on the Mexican west coast (E. G. Barham, personal communication).

There is no way of telling, from the present evidence, whether the group observed during the downward movement consisted of one species or more than one species. The rate of downward movement was slow in the anoxic zone, approximately 1 m/min, and the increased level of reverberation behind the downward-moving group suggests that stragglers were remaining at shallower depths. The observation that the upward migrators first began to form a coherent group in the region of 500 m to 600 m shortly after the downward-moving group had reached 900 m to 1000 m suggests that the returning organisms might actually have been staying near the 500-m-to-600-m depth. The deeper group might then have consisted of different species or even dead organsisms sinking to the bottom. Speculation on this latter point is supported by the observation that there was a sudden and dramatic drop in the acoustic target strength after the vicinity of 700 m was passed (see Fig. 2 h). However, there is no way of knowing, on the basis of acoustic measurements at a single frequency, what may have happened to the swimbladders of any fish as a result of pressure changes and/or gas metabolism.

Thus, what seems to be a unique situation for the study of DSL ecology exists in the Cariaco Trench. The anoxic water barrier appears to limit the number of species that comprise migrating layers in the anoxic zone; at the interface, there is a clear separation between groups of migrators. Identification of the organisms involved should be easier than in the usual DSL situation where large numbers of species are aggregated together. Such identification would then open the door to important studies on physiological and ecological factors that influence the distribution of organisms in the water column.

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