NRL REPORT 3556

SOUND TRANSMISSION MEASUREMENTS AT 8 AND 16 KC IN CARIBBEAN WATERS, SPRING, 1949

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November 11, 1949

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ABSTRACT

Measurements of sound transmission at 8 and 16 kc have been obtained through the use of a submarine-mounted sound projector and a string of six hydrophones suspended at different depths from a surface ship. The use of a submarine-mounted projector thus provided a sound source of controllable depth, range, and frequency. Data were obtained in Caribbean waters on a cruise between Key West, Florida and San Juan, Peurto Rico during February and March, 1949. Essentially simultaneous measurements were made at 8 and 16 kc. The resulting mass of data was found to be most lucidly presented when plotted as transmission-anomaly cross-sections. These were found to have features only partially explainable from the ordinary bathythermograph trace.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem S02-03R
NR 522-030

SOUND TRANSMISSION MEASUREMENTS AT 8 AND 16 KC IN CARIBBEAN WATERS, SPRING, 1949

INTRODUCTION

In the years prior to 1935 a considerable volume of data on the transmission of sound in the ocean was accumulated, mostly in the form of direct signal and echo ranging data. Such early information revealed striking differences in sound conditions between different areas and even in the same area at different times. This early data, however, was of but only qualitative significance and only by 1935 had equipment and experience reached a stage where sufficiently accurate transmission measurements could be made so as to evaluate some of the different factors involved. In that year, Stephenson[1] at NRL carried out a systematic measurement program with the destroyer SEMMES and the submarine S-20, plotting direct signal level at 17 and 23 kc against range and obtaining rough values of absorption coefficient. In successive years, additional work by Stephenson at NRL[2,3,4] elucidated many of the factors now known to operate in determining sound ranges at sea. For example, from many transmission runs a formula $0.004 f^2 + .161 f$ for the attenuation coefficient in db per kiloyard as a function of frequency in kc was deduced. This finding is in surprisingly good agreement with the best information now available. Shadow zones had been observed many times, and were compared with the prediction of the ray diagram, and the reduction of range known as the "afternoon effect" was adequately accounted for. The effect on sound transmission of such things as temperature gradients, surface conditions, and conditions of sky, wind, and weather were known through observation and measurement at sea. Similar studies[5,6] were also made at about this same period by R. L. Steinberger in the Guantanamo, Cuba, area and in the North Atlantic. The extent of this pre-World War II work has not generally been realized.

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[1] *Stephenson, E. B., "Transmission of Sound in Sea Water," NRL Report S-1204 (Unclassified) October 16, 1935.*

[2] *Stephenson, E. B., "Absorption Coefficient of Sound in Sea Water," NRL Report S-1466 (Confidential) August 12, 1938.*

[3] *Stephenson, E. B., "Absorption Coefficients of Supersonic Sound in Open Sea Water," NRL Report S-1549, (Unclassified) August 2, 1939.*

[4] *Stephenson, E. B., "The Effect of Water Conditions on the Propagation of Supersonic Underwater Sound," NRL Report S-1670 (Unclassified) December 3, 1940.*

[5] *Steinberger, R. L., "Underwater Sound Investigation of Water Conditions, Guantanamo Bay Area, February 1937" (Confidential), Sound Laboratory Navy Yard, Washington D. C., May 1937.*

[6] *Steinberger, R. L. "Underwater Sound Investigation in Northern Waters, Cruise of USS SEMMES and ATLANTIS, August 1937" (Confidential), Radio Test Shop, Navy Yard, Washington, D. C., January 1938.*

The advent of World War II gave great impetus to further research on the subject, largely by University of California, Division of War Research, Columbia University, Division of War Research, and Woods Hale Oceanographic Institution. Extensive field studies were made, supported by elaborate instrumentation and thorough theoretical investigation,[7] that in the large part constitute our present knowledge of the propagation of sound in the ocean. Pressed by the problem of searching for enemy submarines with surface ships, a great many transmission runs were made using a surface source and a hydrophone at a variable depth. On the other hand, very little information was obtained on the transmission from a deep projector to a deep hydrophone.[8]

The present importance of submarine vs. submarine warfare lends emphasis to understanding the transmission of sound between two points deep in the body of the ocean, especially at moderate to long ranges, and at the lower sonar frequencies capable of achieving such ranges. Such studies have as an ultimate practical goal the determination of the best depth for evasion, detection and communication in this type of warfare. Again from a practical point of view, they also may provide means of estimating, through the echo-ranging equation, detection and communication ranges between a submarine and a submerged target.

The propagation of radio waves in the atmosphere has many points of similarity to the propagation of underwater sound. Transmission of electromagnetic energy from one point to another in air has been studied[9] to an extent beyond that of sound in the ocean, partly because of the comparative ease of making the radio measurements. One method of so doing is to employ an antenna mounted at a distance above the earth's surface, or suspended from a kite or balloon, and fly an aeroplane carrying a radio transmitter at a fixed height, and measure field strength as a function of range.

For underwater sound the analagous technique would utilize a single hydrophone or several hydrophones suspended from a surface ship, with a submarine to provide a sound source of controllable depth and range. That is, in essence, the method employed in the present study.

DETAILS OF MEASUREMENT TECHNIQUE

A string of six B-19H magnetostriction hydrophones was suspended from the surface vessel, E-PCS-1426. The lengths of electrical cable were such that, if the string hung vertically downward from the surface, the hydrophones would be at depths of 15, 30, 50, 125, 250 and 450 feet. Actually as a result of drift of the ship the string seldom hung straight downward; in fact, the entrance angle of the cable into the water was found to be as high as 50° to the vertical in a moderate to strong wind. The actual depths were determined by means of two variable-resistance depth gages, provided by WHOI, attached to the string. These yielded depth measurements of two points of the string, and by interpolation the hydrophone depths could be determined. The hydrophones were provided

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[7] "NDRC Summary Technical Reports," Division 6, Volumes 7 and 8, Committee on Undersea Warfare, National Research Council, 1946.

[8] "Transmission of 24 kc Sound from a Deep Projector," Report M-408, Sonar Data Division, UCDWR, March 1946.

[9] "Historical and Technical Survey, Vol.1," "Summary Technical Report, Committee on Propagation, NDRC, Washington, 1946.

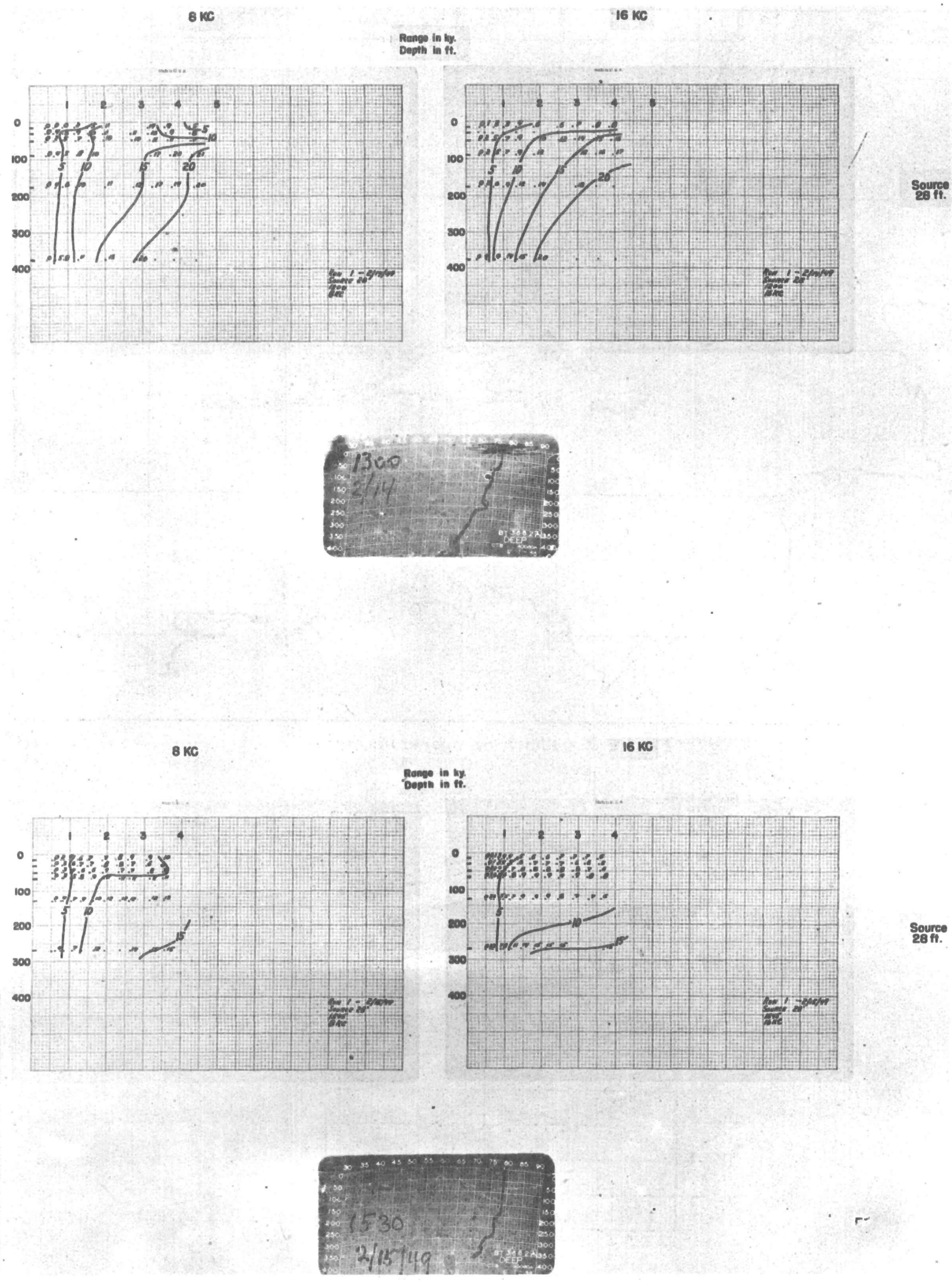

Figure 5 - Transmission anomaly cross-sections, dates 2/14/49 and 2/15/49 (depth in ft vs. range in ky)

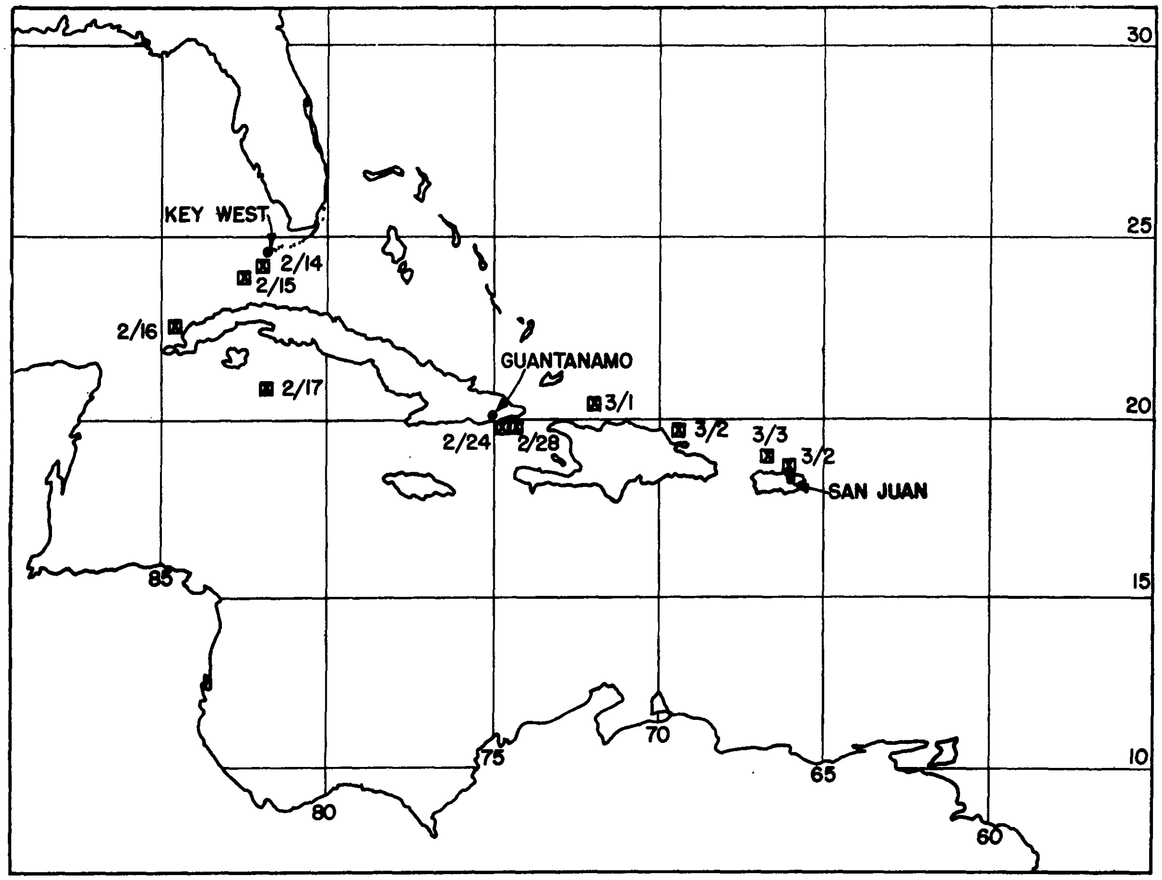

Figure 3 - Chart of operating areas

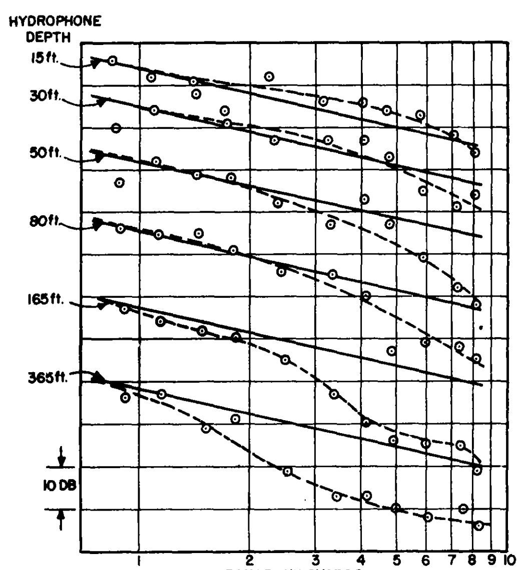

Figure 4 - Example of data reduction process for a typical run

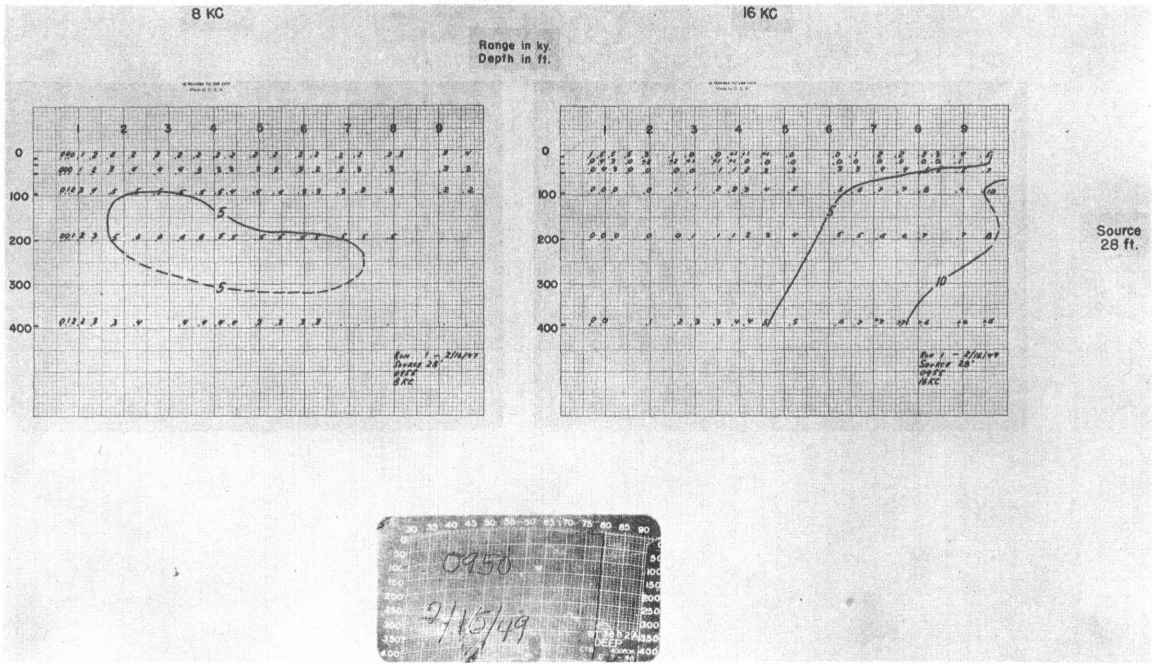

Figure 6 - Transmission anomaly cross-sections, date 2/16/49
(depth in ft vs. range in ky)

temperature gradients are present therein from time to time, nevertheless this layer is of sufficiently slight negative gradient that the velocity of sound still increases with depth. This means that in nearly all cases a surface-bounded sound channel 200 to 400 feet thick exists, in which a portion of the emitted sound is trapped between the surface and the lower boundary of the channel. In the channel sound rays are curved upward and sound travels to great ranges by successive reflections from the surface. This trapping results in transmission anomalies smaller than would exist in isovelocity water, and should be accompanied by long echo and listening ranges. In the propagation of microwaves such surface ducts are of common occurrence. To realize the full effects of such a channel, both source and receiver must be located in the channel a considerable distance apart.

In general, these statements are borne out by the data. For example, even at the comparatively short range of 5,000 yards, approximately one-half of the anomalies at 8 kc are equal to or less than would be found in isovelocity water, using the best present value for minimal attenuation coefficient. Some regions are observed, shown shaded in the cross-sections, where the sound level is greater than it would be even in an isovelocity, absorption-less medium. When either or both source and receiver are below the isothermal layer, large anomalies are observed. Near the surface where the water is subject to local heating and cooling, there are regions of extremely high and low anomaly especially when the source is near the surface. Such conditions must result from local and transient heating and cooling of the surface water.

Some systematic dependence of anomaly with hydrophone depth was found. When all source depths are averaged, the average anomaly plotted function of hydrophone depth is given in Figures 15 and 16 for several different ranges for 8 and 16 kc, respectively. The anomaly is seen to be somewhat greater at the deeper hydrophone depths.

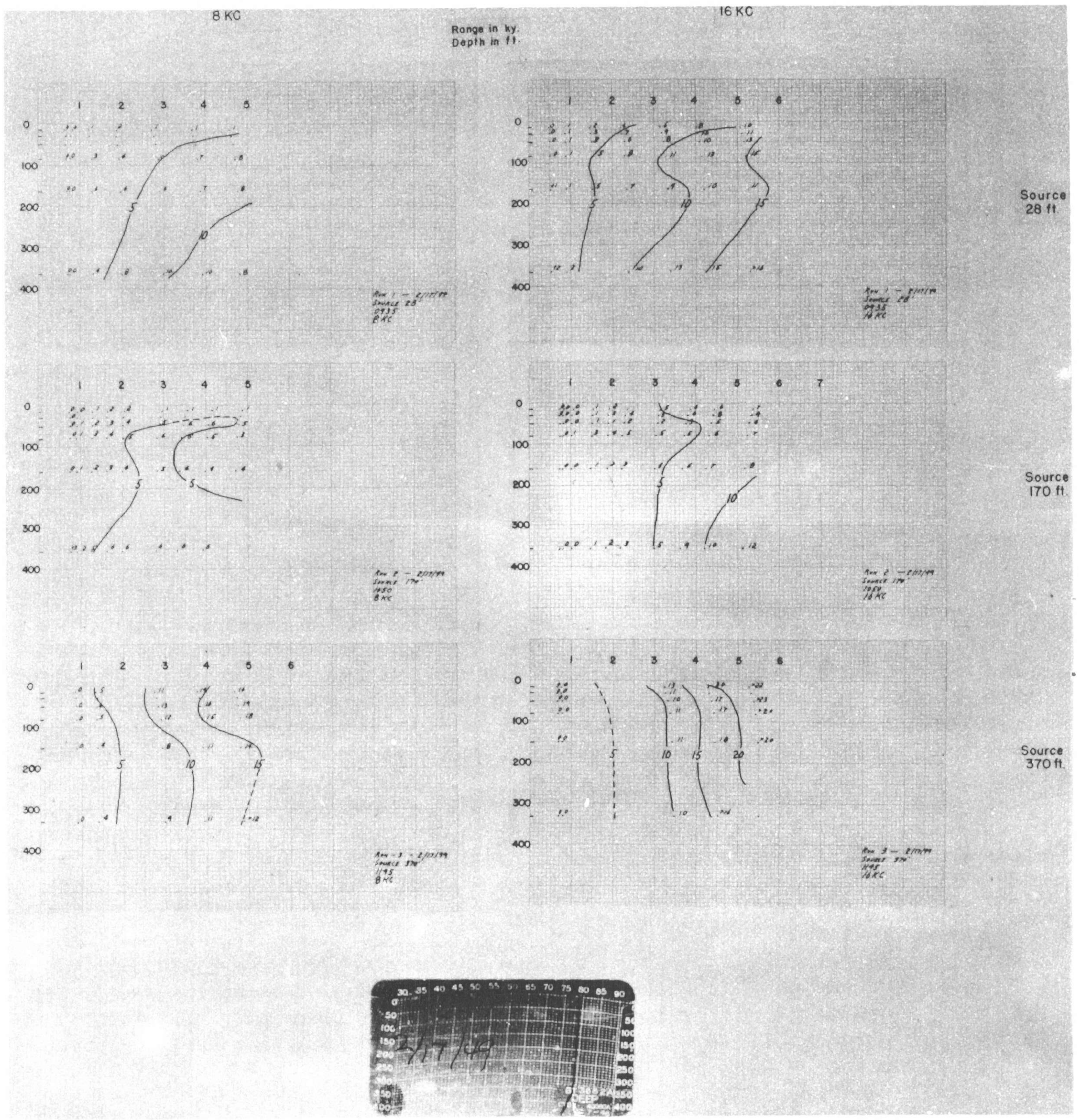

Figure 7 - Transmission anomaly cross-sections, date 2/17/49 (depth in ft vs., range in ky)

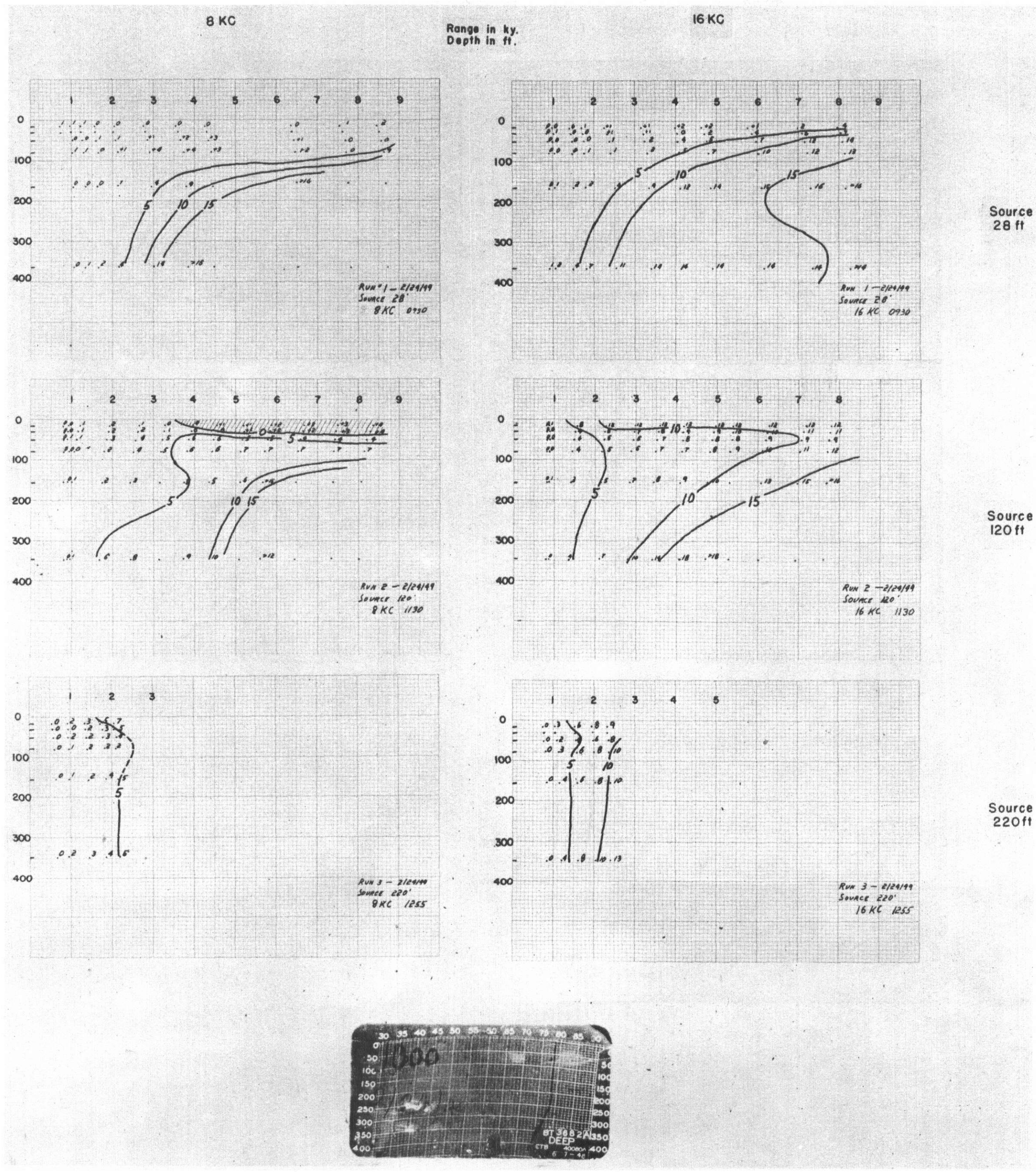

Figure 8 - Transmission anomaly cross-sections, date 2/24/49 (depth in ft vs. range in ky)

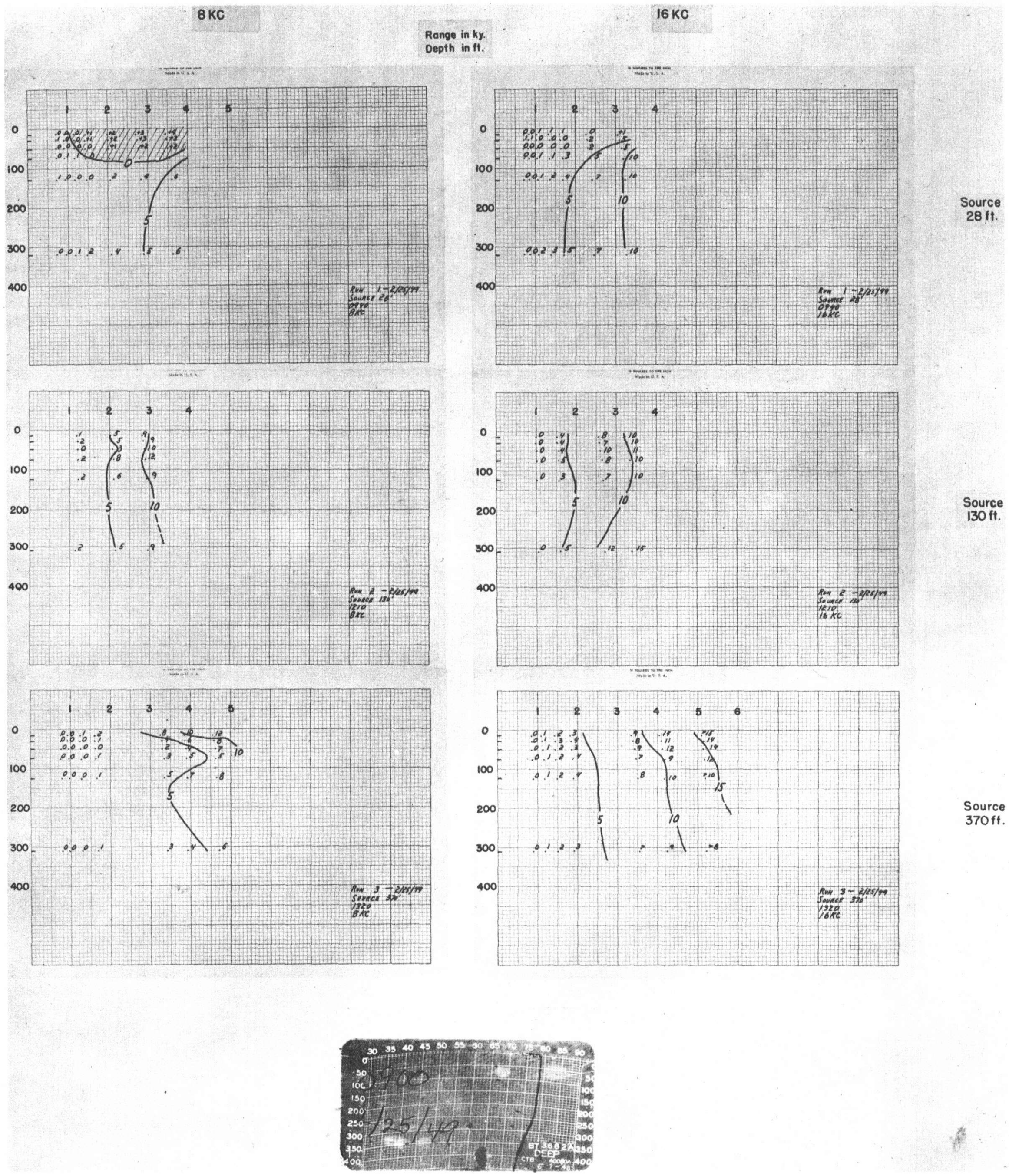

Figure 9 - Transmission anomaly cross-sections, date 2/25/49 (depth in ft vs. range in ky)

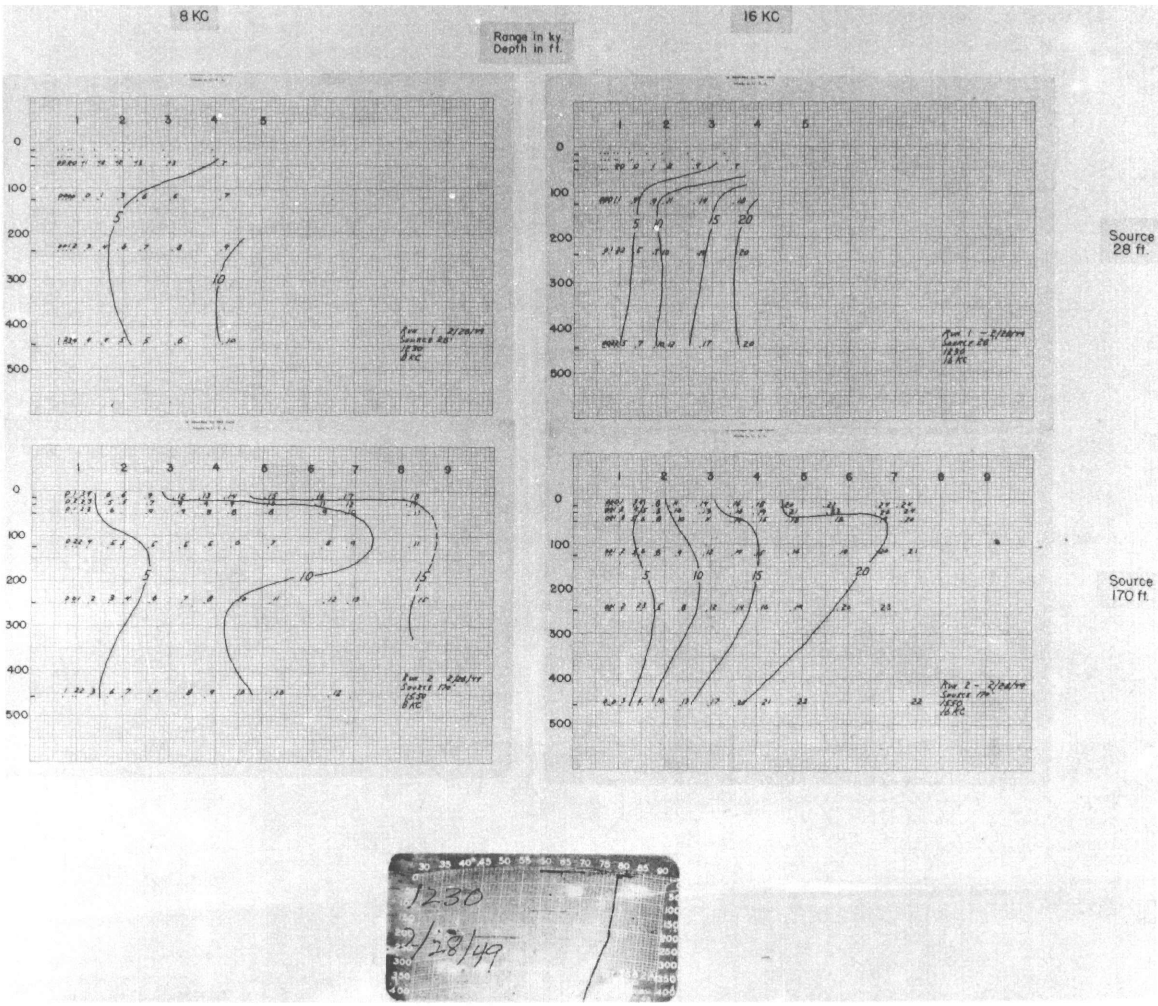

Figure 10 - Transmission anomaly cross-sections, date 2/28/49
(depth in ft vs. range in ky)

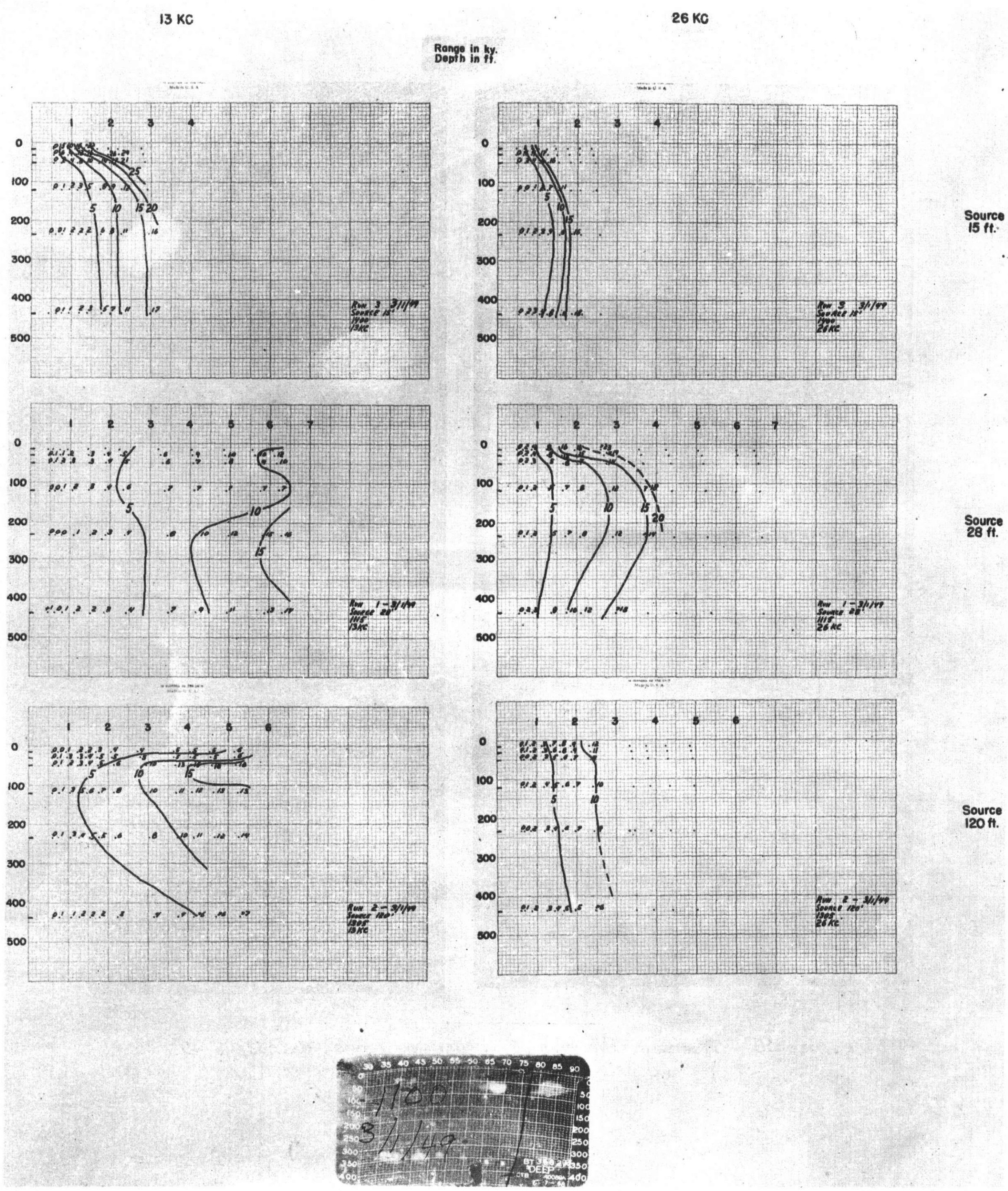

Figure 11 - Transmission anomaly cross-sections, date 3/1/49
(depth in ft vs. range in ky)

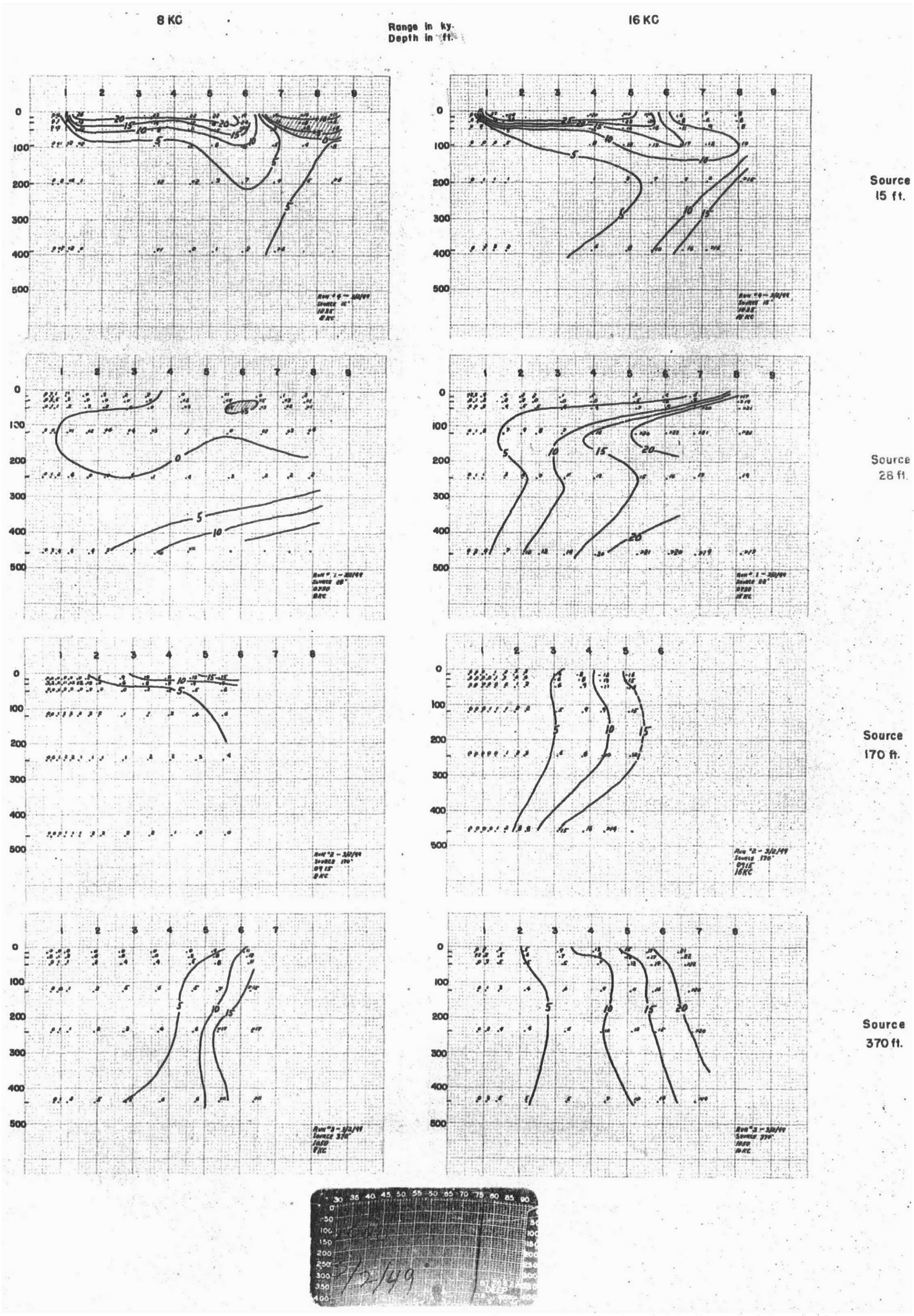

Figure 12 - Transmission anomaly cross-sections, date 3/2/49
(depth in ft vs. range in ky)

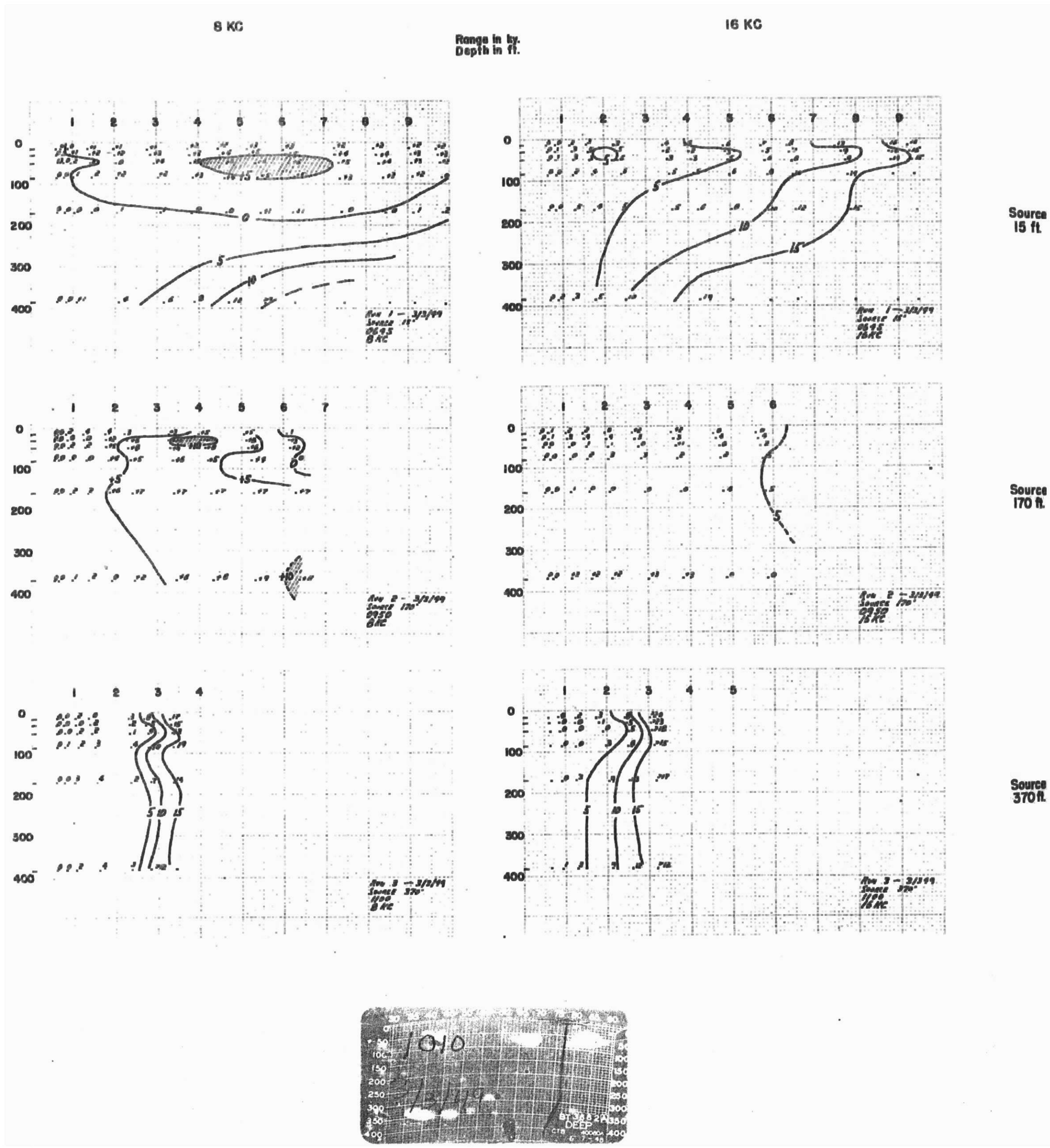

Figure 13 - Transmission anomaly cross-sections, date 3/3/49 (depth in ft vs. range in ky)

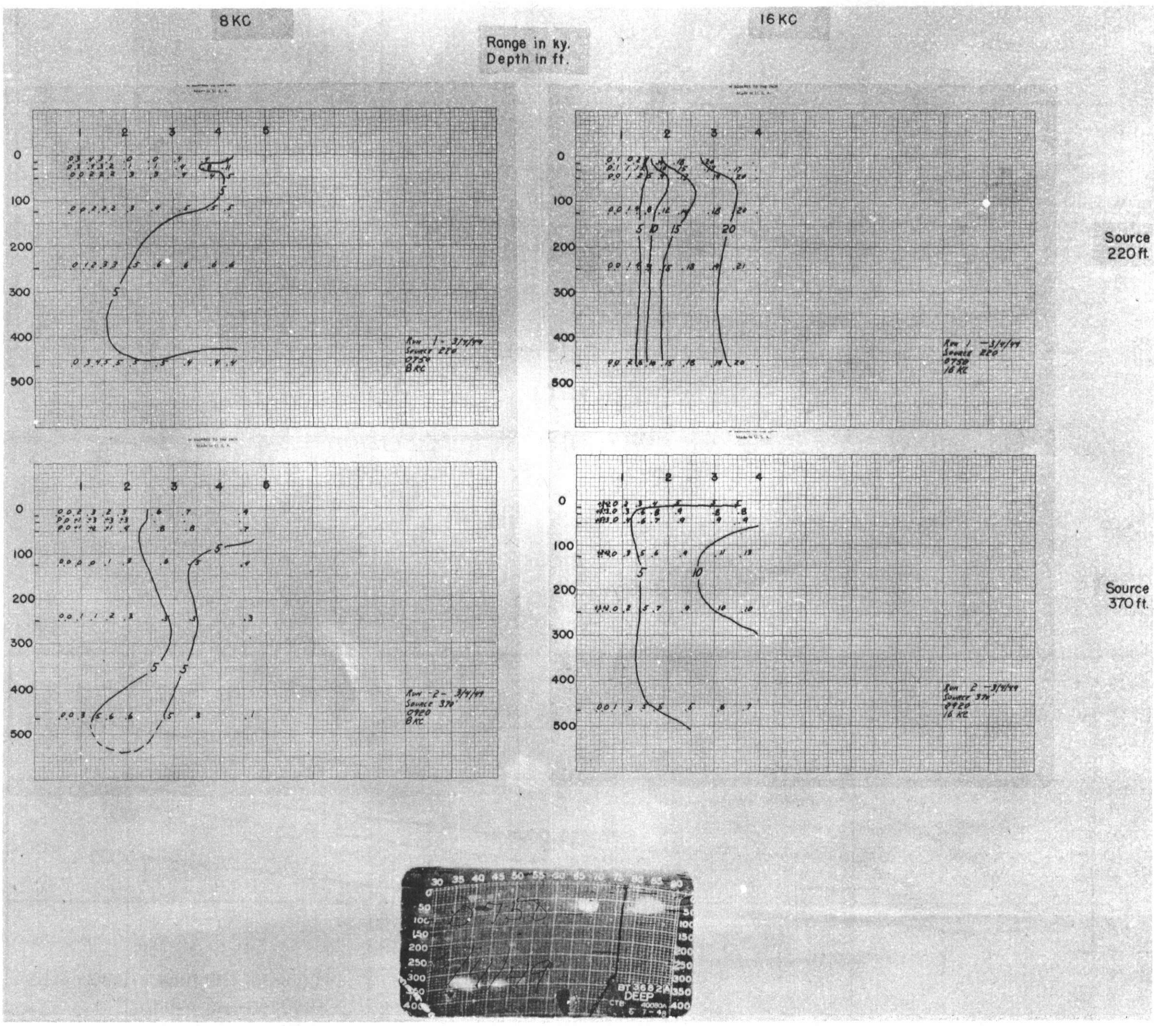

Figure 14 - Transmission anomaly cross-sections, date 3/4/49 (depth in ft vs. range in ky)

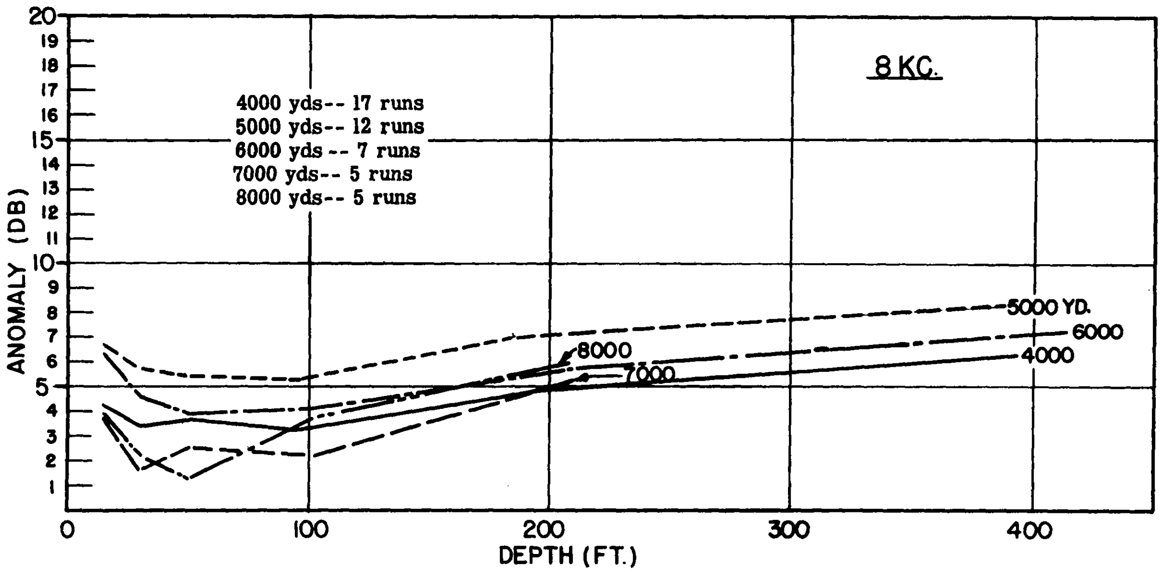

Figure 15 - Anomaly at 4,5,6,7 and 8 kiloyards as a function of hydrophone depth. All source depths averaged. Frequency 8 kc.

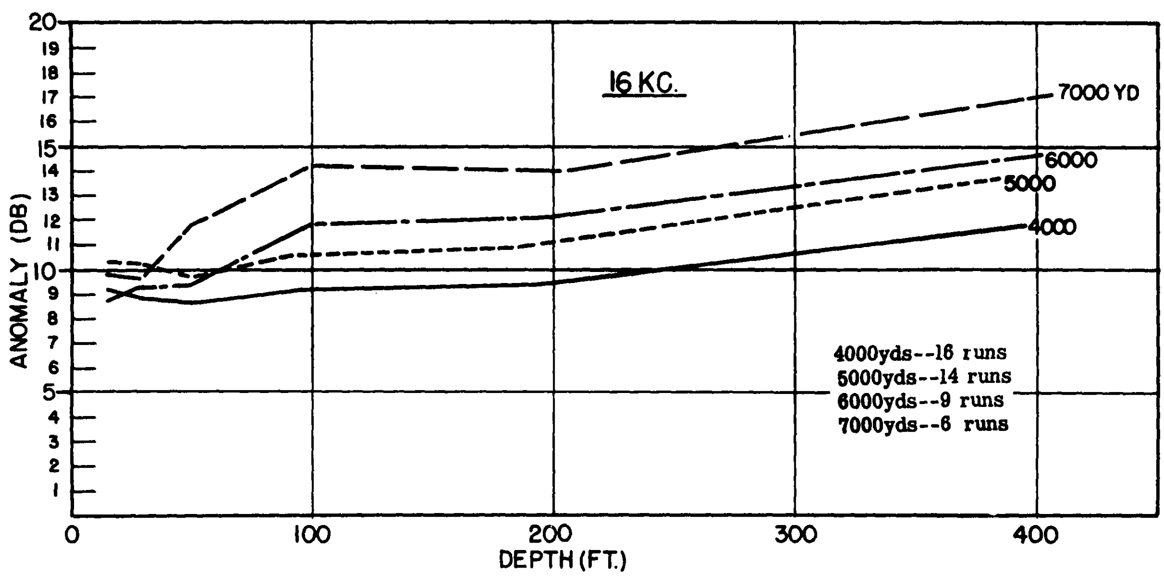

Figure 16 - Anomaly at 4,5,6 and 7 kiloyards as a function of hydrophone depth. All source depths averaged. Frequency 16 kc.

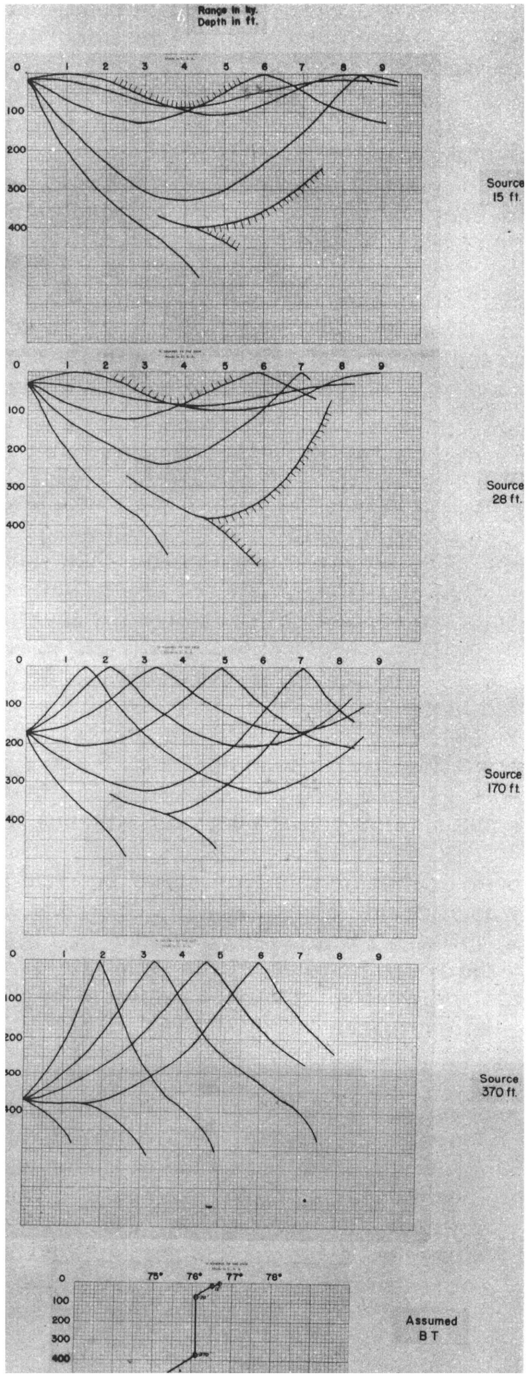

Figure 17 - Ray diagram corresponding to Figure 13 of 3/2/49 (depth in ft vs. range in ky)

The transmission anomaly is ordinarily thought to result from the combined effects of two independent causes. One is the loss due to absorption and scattering, and is for the most part dependent only on frequency. At the present time it is not believed to be dependent upon thermal and salinity gradients, except possibly in a subsidiary manner. The other is the loss due to refraction, resulting in a redistribution in space of the emitted sound. The refraction loss is normally determined by the bathythermograph and is commonly considered to be independent of frequency. Comparing the anomaly for 8 and 16 kc we should then find a difference which depends only on range, and not to a first approximation upon water conditions, and which represents the difference in loss due to absorption alone. Using values of 1.0 db per kiloyard at 8 kc and 2.8 db per kiloyard at 16 kc[10] we should expect an anomaly difference of 1.8 db for each kiloyard in excess of the reference range of 750 yards. Thus at 5,000 yards, the 8 and 16 kc plots should differ by 7.8 db in all cases, and be independent of depth. Those runs which extend to 5,000 yards actually show an average anomaly of 3.3 db at 8 kc and 9.8 db at 16 kc, a difference of 6.5 db.

The discrepancy between this last value and 7.8 db may represent some systematic error in the data, or else an indication that absorption is somewhat less in Caribbean waters than in waters where previous data have been obtained. Also it should be mentioned that the average anomalies at 5,000 yards are smaller than would be given by the best currently available values of attenuation coefficient alone, indicating that a divergence loss less than spherical (upward refraction) prevailed for the runs extending to 5,000 yards or beyond.

Occasionally there are more striking differences in the anomalies at 8 and 16 kc. For example, on March 2, 1949 (Figure 12) with the source at 28 ft. the level dropped off much more quickly at the shallow hydrophones between 6 and 8,000 yards at 16 kc than at 8 kc. Conversely in the same figure, with the source at 170 feet, the level at the shallow depths fell off with range more quickly at the lower frequency than at the high.

A ray diagram has been drawn for this particular day, and is shown in Figure 17, with the actual BT, as closely as it could be read, simulated by the BT shown at the bottom of the figure. A comparison with the actual measurements of Figure 13 shows that the ray diagrams elucidates only the rough features of the sound field. For example, the low intensity zone at 4,000 yards and the high intensity region at 8,000 yards near the surface for a source depth of 15 feet are borne out by the ray diagrams.

Some error in drawing the ray diagram is caused by the difficulty in reading slight gradients from the BT, and the impossibility of determining the temperature distribution accurately with a single BT over a distance of several miles during the period needed for a run. More frequent observations, from both ends of the acoustic path, with a more sensitive temperature or velocity measuring device are needed to specify the velocity distribution more completely. However, the ray diagram, since it ignores phase relationships between rays, treats all frequencies alike and cannot explain the difference between 8 and 16 kc mentioned above. Of greater utility in such cases is the normal mode theory, which so far has not been applied extensively to the propagation of sound in deep water.

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[10] *NDRC Summary Technical Report, Division 6, Vol. 7, Figure 50, p. 57.*

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