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A BATHYMETRIC PROFILE ACROSS THE HUDSON SUBMARINE CANYON AND ITS TRIBUTARIES

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ABSTRACT

Echo soundings recorded continuously during a crossing of the Hudson Submarine Canyon system 200 miles southeast of New York Harbor show that the tributaries in 1200–1800 fathoms depth differ in profile and gradient from the Hudson Canyon proper. Because the recordings are distorted by instrumentation, the true bottom configuration is computed by using Schuler's method. In the area studied, the main Hudson Canyon has a steep V-shaped profile whereas the major tributary has more gently sloping sides and a flat bottom. Of the two minor tributaries crossed, the short one has a broad valley profile, the long one a narrow profile. Differences between these canyons are attributed to the number and size of the mudflows and turbidity currents which stream down them.

INTRODUCTION

An extensive survey of the Hudson Submarine Canyon (5) has shown that the deepest gorges are cut in the upper 1200 fathoms of the continental slope and again on the continental rise from 1700 to 2100 fathoms depth (19). Observations show that the Canyon extends 200 miles further seaward than that observed by Veatch and Smith (20), has several tributaries entering at grade, and continues into 2850 fathoms before it spreads out in a delta on the floor of the North America Basin. No “hanging valleys,” like those described in canyons off the California Coast (15), were found.

Subsequent study (4), (6), (7) has shown that great quantities of sand and shallow-water sediment have been transported down the Hudson Submarine Canyon system and have been deposited in a vast delta of coalescing fans at the Canyon’s mouth. These sedimentary deposits are attributed to submarine turbidity currents which started on the unstable continental slope and continued out to sea. Such submarine erosion processes have been described (8), (12), and laboratory experiments (11) have shown that turbidity currents have the power to transport sediment and deposit it in graded layers. De-

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etailed topographic profiles of the Hudson Canyon and its tributaries were obtained with the Edo sonic sounder UQN1B recording on a greatly magnified scale (Fig. 1) along a traverse of the canyon area from 1600–1800 fathoms depth (Fig. 2).

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METHOD

A continuous recording echo sounder, model UQN1B, manufactured by the Edo Corporation, College Point, Long Island, was used. Geographical positions were determined by hourly loran readings on two or more station pairs. Some canyon crossings were made with the instrument set on a scale of 0-6000 fathoms, a setting which gives no appreciable vertical exaggeration and obscures the smaller canyons. Other crossings were made with the instrument set on the 0-600 fathom scale; this same setting can be used also (Fig. 1) in 1200–1800 fathoms depth because the two pinging styli are mounted on a continuous moving belt so that the second stylus can record the first one’s outgoing ping, thereby doubling the scale. (An additional pen mounted halfway between the two will record the returning echo for intermediate scales of 600–1200, 1800–2400, 3000–3600, and 4200–4800 fathoms.) With this arrangement a vertical exaggeration of about 10/1, depending on the ship’s speed, is obtained. To the author’s knowledge, recordings of this type were made previously by B. C. Heezen in 1952 on the ALBATROSS III and ATLANTIS, by the author on the KEVIN MORAN (7), and by the Scripps Institution of Oceanography.

This method of surveying brings out the minor irregularities in the ocean floor over a continuous track of varying width under the ship, but it records only the least depths within a cone of sound whose diameter varies with the type of instrument and the depth of water (1). For the instrument used in these observations, the half angle of the cone of sound is designated as 30° by the manufacturer, but in deep water the effective cone is much narrower.

To obtain an accurate configuration of an ocean bottom from such a large area of returning echoes, Schuler (14) has worked out a relation between the angle subtended by the cone of sound and the length of the returning echo. Schuler considers water depths up to 300 fathoms. In one case he uses the known angle of the cone of sound and computes the expected echo length; in a second case he determines the effective
Figure 1. Echogram of the Hudson and some of its tributaries.
cone of sound from an observed echo length. Following suggestions by Dr. E. T. Booth, it was found that in much greater depths than those described by Schuler it is still possible to compute the effective cone of sound from a measurable echo length.

The area on the ocean floor from within which echoes are recorded on the instrument at a given gain setting can be computed from Schuler's equation: depth plus echo length = depth/cos φ, where φ is half the angle of the effective cone. Therefore, by measuring the depth and echo length from the record and by substituting these values in the equation, the effective cone of sound can be determined. For example, at B (Fig. 1) a depth of 1600 fathoms is indicated and the echo length is 50 fathoms. By substituting in the equation, φ = 14°; and by solving for the tangent φ, the diameter of the base of the effective cone at this depth and gain setting is 4800 feet.

In this analysis the width of the effective cone of sound is important because any difference in depth within the effective cone will be indicated as increased echo length on the record. As a declivity in the bottom is approached by the survey ship, the upper and lower boundaries of the trace will diverge.

Furthermore, these changes in the character of the trace will anticipate the survey ship by half the width of the effective cone. Thus the width of the flat-floored canyon is equal to the indicated width plus the radius of the effective cone of sound taken twice (Fig. 4). On the other hand, if the canyon is narrower than the effective radius, it will show not as an indentation on the record but only as a lengthening of the styli markings.

In order to solve Schuler's equation quantitatively, the recordings have to show considerable detail. For example, location CC is only two miles away from location C (Figs. 1 and 2). At CC the recorder was on the 6000 fathom scale and the Canyon is only barely discernable, whereas at C it was on the 600 fathom scale which brings out the flat floor and sloping sides of the Canyon.

HUDSON CANYON SYSTEM

The Hudson Canyon, a seaward extension of the Hudson Channel on the continental shelf, was mapped by early submarine physiographers (10), (17) and more recently by Veatch and Smith (20), who traced the Canyon out to 1200 fathoms. Its origin has been attributed to subaerial erosion, faulting, spring sapping, tsunamis, and more recently to turbidity currents. The arguments for or against these theses have been considered in detail by other workers (16), (18) and will not be examined here. However, the turbidity current is held by
some authors to be a most likely eroding agent. Daly (3) first attributed the submarine canyons to density currents formed in a time of lowered sea level. Recent geologic studies (4), (5), (6), (8), (9), (12), (13), (18) have brought out considerable evidence for a present-day environment on the continental shelf and slope which points to the action of mudflows and landslides which turn into turbidity currents. The characteristic V-shaped profile of the Hudson Canyon proper has led Kuenen (11) to think that this parent Canyon may have been developed by the Hudson River during the Pleistocene, a period of lower sea level, while the tributaries are due to later headward growth by turbidity currents which are still in operation.

The Hudson Canyon at A in Fig. 2 is shown to be a sharp V-shaped feature at A in Fig. 1 as compared with tributary C in Figs. 1 and 2. The indicated depth at the bottom of the V is 1670 fathoms. However, as the cone of sound moved across the Canyon it picked up echoes from both sides (Fig. 3) and thus made it appear shallower. This "crossover effect" is recognizable by the extending "tails" of the styli markings (A in Fig. 3) which meet at the true depth of the Canyon. The coalescing tails in A (Fig. 1) show the true depth of the Hudson Canyon to be 1715 fathoms, 200 fathoms below its banks. Sediment cored in the Canyon 20 miles downstream from this place and buried under 100 cm of gravel and foraminiferal clay contained pebbles up to 2 cm diameter (6) as well as shell fragments of the Pleistocene. This type of graded bedding in the Canyon floor, absent on its walls, indicates that the Canyon is the route of sediment transport by turbidity currents. The walls of the Canyon slope at 17° with the horizontal and are probably covered with the green pyritic clay that is so widespread in the region (4), (6).

Eight miles downstream the east wall of the Canyon is cut by tributary B (Figs. 1 and 2). Although this tributary was observed only five miles from where it joins the main Canyon "at grade" (19), it is a broad depression 2½ miles wide with sides sloping only about 0.5° with the horizontal. There is no apparent further headward extension of this tributary, so it evidently has encroached from the 1800 fathom main Canyon depth to its present location by a series of mudflows or landslides that keep entering the main stream at grade.

Tributary C, also on the east wall of the Hudson Canyon, lies 14 miles downslope from B (Fig. 2). It has a flat bottom and is 120 fathoms deep (C of Fig. 1). The fathogram indicates that the flat floor of this canyon is ½ mile wide, but distortion due to the effective cone of sound moving over the canyon's walls ahead of the ship has made it appear too narrow (Fig. 4). If the indicated width of the
FIGURE 2

BATHYMETRIC CHART OF
HUDSON SUBMARINE CANYON
AND ITS TRIBUTARIES

CONTOUR INTERVAL
100 FATHOMS

SHOWING SELECTED TRACKS
BY JOHN NORTHROP

CONTOURS TO 1200 FATHOMS
FROM
VEATCH AND SMITH (1939)

CONTOURS GREATER THAN 1200
FATHOMS MODIFIED FROM A
PRELIMINARY CHART OF THE
HUDSON SUBMARINE CANYON BY
BRUCE C. HEEZEN AND
IVAN TOLSTOY

SOUNDING VELOCITY 4800 FT.
PER SECOND
SCALE, ONE MINUTE OF LATITUDE
EQUAL ONE MILE

Figure 2. Index map showing the location of the profiles.
flat floor is \( \frac{1}{2} \) mile wide, then the actual width must be \( \frac{1}{2} \) mile plus the radius of the effective cone of sound taken twice. This diameter can be calculated from the equation:

\[
depth + \text{echo length} = \frac{depth}{\cos \phi},
\]

\[
1705 + 30 = \frac{1705}{\cos \phi},
\]

\[
\phi = 11^\circ 30'.
\]

Then by solving the right triangle the diameter of the effective cone at this depth and gain setting is 4,152 feet, making the true width of the canyon \( 1\frac{1}{4} \) miles. The canyon’s walls slope at 6° with the horizontal. The slope of the southeast wall appears to be the same as that of the northwest wall, though the northwest rim is five fathoms higher, this discrepancy being due partly to the fact that the ship’s track is up the continental rise. Downstream from this crossing the tributary turns south and thence southeast to run parallel with the main Hudson Canyon for about 100 miles with an average gradient of 40 feet per mile; it then joins the main Canyon at 2300 fathoms, where it may form one of the series of coalescing fans that build out the Hudson Canyon delta (4), (6).

That this tributary has a flat floor at 1705 fathoms while the main Hudson Canyon is V-shaped at 1715 fathoms may be due to the fact that the Hudson Canyon has a gradient of 60 feet per mile while tributary C has one of only 40 feet per mile. The tributary’s lower...
gradient is probably not sufficient to transport sands or gravel as in the main Canyon, where both arenites and lutites are transported out into deeper water, leaving only the larger pebbles behind. The capacity and eroding power of the turbidity currents coming down the main Canyon would be greater than those in the tributary because the turbidity currents in the former have a greater area in the upper reaches of the Canyon in which to gather material and momentum.

Tributary D (Figs. 1 and 2), also on the east side of the main Canyon, was crossed 11 miles further downslope from tributary C. The bottom of this tributary is 15 fathoms below the southeast bank and 30 fathoms below the northwest bank. In other words, the up-slope side is 15 fathoms higher, which indicates that the continental rise is steeper here than at C. However, this illusion may be caused by the fact that the ship's track was more normal to the regional contours in the former case.

It is difficult to compute the true shape of this canyon because the instrument's gain was increased after the cone of sound entered the canyon. Working with the record from where the gain was increased, the effective cone (by the equation) is 14°, which gives an effective base diameter of 4,484 feet. Inasmuch as the bottom of the styli markings shows a rounded contour compared to the V shape of the upper terminus, the width of the canyon is less than the effective width.
Figure 5. The rounded bottom edge of the echogram is due to the canyon’s width being less than the diameter of the effective cone of sound.

diameter of the cone of sound and hence the true depth is greater than that shown (Fig. 5). No further computations can be attempted because of the change in gain setting of the instrument.

CONCLUSIONS

Although the Hudson Submarine Canyon can be traced headward to the continental shelf, its tributaries, like B, C, and D of this report, seem to stop short of the continental shelf. The Hudson Canyon has a deep V-shaped profile where it cuts into the continental rise while its major tributary canyon has a flat bottom. It may be that the main Canyon was better developed during a time of lower sea level than the tributaries, which have no bona fide parent river and which owe their shape to submarine slumping and turbidity currents alone. However, erosion by turbidity currents would be much greater in the main Canyon because it is a trunk stream, and any contributing turbidity currents would flow toward and then down the main Canyon, by-passing downstream tributary canyons. Thus the main Canyon would be the route of larger and more numerous currents and could be cut deeper. Turbidity currents can erode only the bottom of the Canyon. Material slumping down off the walls has modified the steepness of the Canyon walls and has started small tributaries, like B of this report, which are very short. As this process continues, a
tributary would elongate and encroach headward, although its channel might be filled with sediment left by weaker currents, as in tributary C of this report.

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