Reports

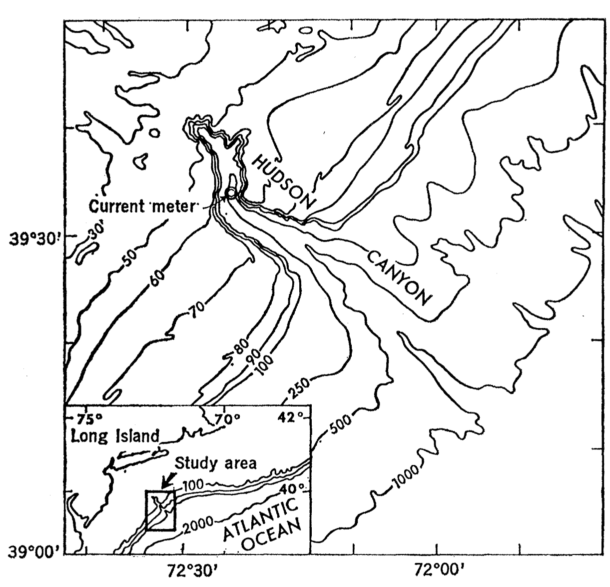
Bottom Currents in the Hudson Canyon

Abstract. *In-place measurements of the bottom currents in the Hudson Canyon reveal that the current regime is characterized by a pronounced reversal of flow up and down the canyon. Velocities are commonly of the order of 8 to 15 centimeters per second, reaching 27 centimeters per second on occasion in the upper and central portion of the canyon. Although a 2.5-day recording of currents showed a net transport upcanyon, a combination of 66 current measurements from the submersible* Alvin, *the analysis of sediment texture and organic carbon, and the determination of the benthic fauna–nutrient relationship indicate that over the long term there is a net transport of fine material through the canyon to the outer continental rise.*

Bottom current measurements in canyons off the east coast of North America date back to the early studies of Stetson (*1*) in the canyons on Georges Bank. More recently, a limited number of current observations have been made in Oceanographer (*2*) and Corsair (*3*) canyons off New England, and in Wilmington Canyon (*4*) east of the Maryland-Delaware border. Most of these recent studies have been based on either a series of observations of very short duration (minutes) from a submersible or interpretations of bottom photographs and video tapes. Fenner *et al.* (*5*) obtained a limited number of short-term measurements over a 3-day period in the Wilmington Canyon by using a free fall and return type of current meter (*6*). Stetson (*1*), although the only one to employ a bottom-mounted current meter, was held to roughly 30-minute observations at each station due to the station-keeping limitations of his ship. Bottom and near-bottom current activity has only been monitored to any extent in the canyons off southern California, where Shepard and Marshall (*7, 8*) recorded currents for periods up to 15 days, and in the submarine valley of the Var, off Nice, where Gennesseaux *et al.* (*9*) observed currents over a 25-day period. This report deals with a series of in-place measurements of bottom currents along the axis of the Hudson Canyon; the measurements were made during a 3-month period and ranged in duration from 1 minute to 2.5 days.

The Hudson Canyon, 220 km southeast of New York City, is the most pronounced of the east coast canyons, cutting from 200 to 800 m into the continental slope and extending approximately 370 km from the shelf edge to the deep sea (Fig. 1). Its axial slope is of the order of 23 m/km to a depth of 800 m, increasing to about 30 m/km out to 2000 m. Its overall appearance is that of a relatively broad (7 to 9 km wide), well-incised canyon which has been blanketed with fine-grained sediments throughout most of its length. Only in the canyon head area does erosion appear to be taking place. Within the central canyon (at depths of 400 to 1000 m) ridges of semiconsolidated silty clay trending both parallel and perpendicular to the axis rise as much as 70 m above the canyon floor. Indications are that some of the ridges crossing the canyon serve to restrict the movement of bottom water up and down the canyon. The overall physiographic aspects of the canyon and its relationship to the surrounding sea floor have already been described (*10*).

The present study was undertaken to investigate the bottom current condi-



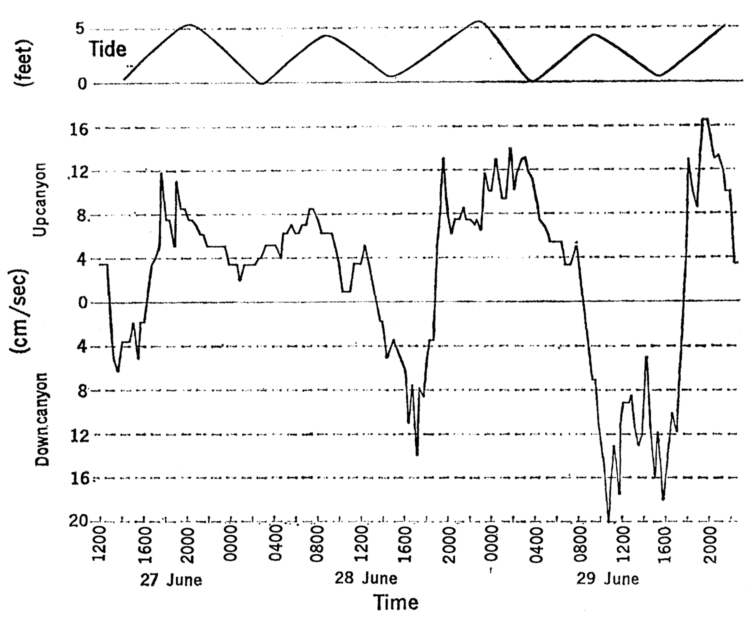


Fig. 1 (left). Generalized bathymetry and location of the Hudson Canyon. The contours are in fathoms (1 fathom ≃ 1.8 m). [Data from Coast and Geodetic Survey Chart 1108] Fig. 2 (right). Comparison of upcanyon and downcanyon flows measured by a bottom-mounted meter at 471 m. The tides for the same period predicted for Sandy Hook, New Jersey, are shown at top (1 foot = 30.48 cm).

tions in the Hudson Canyon, to relate these conditions to both the mass physical properties and flux of the sediment, and to determine the influence of the currents on the benthic fauna within the canyon. This report, however, deals primarily with the observed current regime.

Much of the study was conducted from the submersible *Alvin* during a series of 15 dives in the months of June and September 1972. Basic observations during the dives consisted of measurements of bottom currents with a Savonius type meter held 12 cm above the canyon floor, collection of suspended sediments, core and grab sampling of the bottom sediment, and almost continuous photographic coverage of the dive sites. The dive sites were located from the canyon head out to depths of 1826 m, and the average time on the bottom was 4 hours per dive. In addition to observations from the submersible, 30 camera and coring stations on the bottom, both in the canyon and on its banks, were occupied remotely from a surface vessel. To define the current activity, a bottom-mounted current meter (General Oceanics, model 2010) was placed in the axis of the canyon at a depth of 471 m during the dives in June and retrieved in September. In addition, a series of reference stakes were planted from *Alvin* in the vicinity of the meter to monitor possible sediment movement.

Although relatively few bottom current measurements have been made to date, it appears that flow reversal is a characteristic common to submarine canyons (*1*, *7*). Stetson (*1*) related such flow to tidal activity, but Shepard and Marshall (*7*), in a much more extensive study of La Jolla and Scripps canyons, could find no distinct tidal relationship.

Unfortunately, the bottom-mounted meter placed in the Hudson Canyon had a failure of its recording element after 2.5 days. Although the limitations of such a short observation period are obvious, the data obtained do serve to document the reversal of flow within the canyon (Fig. 2). During this period, upcanyon flow was of longer duration but usually at much lower velocities than downcanyon transport, for which currents as high as 22 cm/sec were recorded. Owing to the limitations of these data, it is difficult to assess the periodicity of flow reversals or any possible tidal relations. During the first 35 hours of observation, it appears that reversals occurred about every 12 to

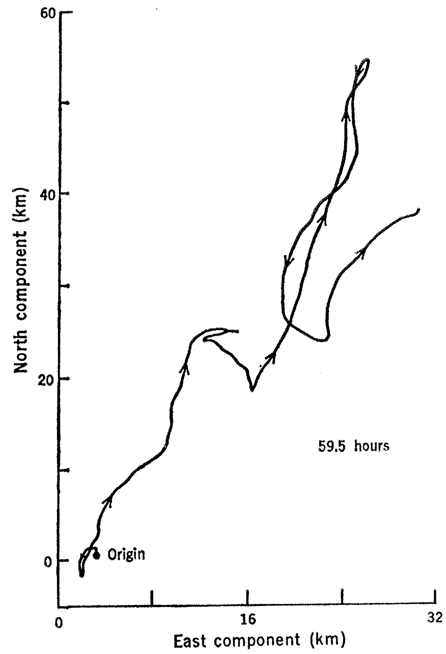


Fig. 3. Progressive vector diagram showing net transport during a 59.5-hour period, as determined from the bottom-mounted current meter at 471 m.

14 hours, closely approximating the tidal cycle recorded at Sandy Hook, New Jersey. During this time, downcanyon flow or minimum upcanyon activity appears to have coincided with periods of low tide at Sandy Hook (Fig. 2). Such a relationship, however, was not found during the last 24 hours of recording. Just how the current reversal is related to tidal activity is not evident from our observations. Internal waves generated by tidal currents impinging on the continental margin probably influence the current reversals to some extent and thus further complicate the overall relationship. A progressive vector diagram of the data from the bottom station reveals that during the 2.5 days of operation the net transport was upcanyon (Fig. 3); the canyon is oriented north-south at the current meter station. A bias in these measurements cannot be ruled out. In a relatively wide canyon like the Hudson, the tidal flow will be asymmetrically distributed at any one location between the zones of maximum flood and ebb, so that a single meter may show some degree of bias.

There are, however, strong indications that over the long term there may be a net transport downcanyon. During the two series of dives, 24 to 30 June and 7 to 14 September, approximately 66 bottom current measurements were made with a Savonius meter deployed from *Alvin*. The actual measurements were for periods of 1 to 2 minutes, but the duration and direction of flow was monitored throughout the dive. By compiling these determinations of direction and duration for the measured velocities during all the diving days, an attempt was made to roughly approximate the net transport. For the June period it was found that 61 percent of the flow was downcanyon, whereas the September dives showed 83 percent of the transport downcanyon. These are necessarily crude estimates of the net transport, but we believe that the short-period observations from the submersible do provide an important indication of current flow.

Based on the measurements from *Alvin*, it was found that relatively high velocities (20 to 27 cm/sec) commonly occurred in the upper and central portion (150 to 1000 m) of the canyon. Beyond 800 m, velocities were considerably less, commonly of the order of 2 to 5 cm/sec. These relatively few observations are far from adequate to document the bottom current conditions, but they do appear to present the generalized current regime along the axis of the canyon.

Our study of the sediments lends further support to the concept of long-term transport downcanyon. The sediments progress in texture from sand with well-rounded pebbles in the canyon head to silt and clayey silt to depths of 400 m and silty clay to the 2000-m isobath. Some silts and fine sands do occur in the deeper portions along the margins of the canyon.

The central portion of the canyon (400 to 1000 m) appears to be a unique zone of deposition. Sediments are very soft with a fluffy surface resembling accumulated dust. Cohesion in the upper 4 cm of this sediment is of the order of 5 to 9 g/cm^2, the lowest recorded in the canyon. The current velocities in this section of the canyon were as high as 27 cm/sec during one dive and averaged 10 to 15 cm/sec (Fig. 2). Although the sediments are fine-grained, one might have anticipated that at least the fluffy material would have been moved by these currents. This was not the case; no movement of bottom material was recorded. Observations of the bottom in the vicinity of reference stakes for an additional 3 months further indicated that no erosion or deposition was taking place. The fluff covering the canyon floor appears to be largely biological in origin and may in some way develop cohesion from the organic makeup of its various components. This portion of the canyon also happened to be a zone of very low visibility owing to a turbid water mass blanketing the bottom. The turbid suspension was concentrated in a zone 4 to 5 m thick, and often caused zero visibility. The suspension was largely made up of biological material of varying sizes and shapes, but a brown coloration seen from the backscatter of the *Alvin*'s lights indicated that sediment also comprised a large portion of the turbid mass. A comparison of the visibility conditions found throughout the canyon indicates that the zone of high turbidity is confined to this part of the canyon. The possible damming influence of ridges trending across the canyon in this area may account for the localization of these conditions. These turbid conditions were not related to the sea state at the time of observation (state 3), but are believed to have resulted from much stormier conditions some time before the dives.

Most of the canyon consists of much finer material than the surface sediments reported for the surrounding continental margin (*11*). Only in the canyon head, where sands apparently enter from the surrounding continental shelf, are textures similar to those on the adjacent shelf.

A study of organic carbon in the canyon sediments indicates enrichment by a factor of 2 to 3 relative to that reported for deposits on the adjacent continental shelf, slope, and rise (*11, 12*). The organic carbon contents of 3.0 to 3.5 percent commonly found in the canyon are similar to those reported for areas of upwelling (*13*).

A study of biomass concentration in the canyon sediments and the determination of available food for these organisms indicates that concentrations of food are considerably higher in the canyon than elsewhere in the North Atlantic. Since there is no indication that surface productivity is any greater over the canyon than in adjacent waters, the nutrient-rich material apparently is moving out into the canyon from a shelfward source.

Although all the data have not yet been fully analyzed, they lend strong support to the hypothesis of long-term net transport down the canyon. The sediment and biological data reveal the presence of a tongue of fine-grained, nutrient-rich material extending out to the continental rise through the Hudson Canyon. It is suggested that these sediments are primarily carried in suspension out across the continental shelf and into the canyon, where they are further transported downcanyon. Some of this material may also be derived from resuspension of sediment eroded from the shelf break.

During lower stands of sea level the canyon displayed much higher current activity than is found today. Coring of turbidite sequences not only in the canyon but from its outer terminus reveals that the canyon served as a conduit for the transport of coarse-grained material from the continental shelf to the deep-sea floor during the Pleistocene (*14*). Although coarse sands and gravels are present in the canyon head and are being transported locally by bottom currents today, there is no indication that this material is carried very far down the canyon. Despite strong bottom currents, the Hudson Canyon is relatively less active in funneling coarse-grained material or large volumes of finer sediment to the abyssal plain than it was in the Pleistocene, and less active than the canyons off southern California today.

Although the 2.5 days of continuous bottom current measurements in the Hudson Canyon revealed periodic reversals of flow as well as a net transport up the canyon, a considerable amount of other evidence indicates that the long-term net transport may be down the canyon. Not only did the majority of current observations from the *Alvin* show predominant downcanyon flow, but the sediment and biological studies indicate that the flux of fine-grained, nutrient-rich sediment is directed into the canyon from the coastal zone.

Coarse sediment is transported as a traction load only in the canyon head and does not appear to move very far down the canyon. Canyon sediments are mainly silt, clayey silt, and silty clay, which are apparently carried into the canyon in suspension. This fine-grained material is transported across the outer continental shelf, bypassing the canyon head and largely being deposited in the central part. The blanket of very turbid water plus sediments of low cohesion and density found in this portion of the canyon attest to relatively high rates of sedimentation taking place at this time. Beyond this zone, finer sediments are carried to the outer limits of the canyon.

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15. Funding for support of the submersible and surface vessel was provided by the Manned Undersea Science and Technology Office, National Oceanic and Atmospheric Administration. We acknowledge the significant contribution that the staff of the *Alvin* made to this study by their fine cooperation and unique capability.

4 December 1972; revised 19 January 1973

Cranial Anatomy of Oreopithecus

Abstract. *Reexamination of the 1958 skull of the late Miocene* Oreopithecus bambolii *revealed a cranial anatomy different from that widely accepted for this taxon. There is a sagittal crest, a high nuchal crest, a large gonial angle, and a high, rather vertical, occiput. This catarrhine was not a very large brained primate compared to known advanced hominoids.*

Oreopithecus, the late middle Miocene [10 to 12 million years ago; see Lorenz (*1*)] catarrhine primate from Tuscany, Italy, has been one of the most exciting fossil taxa. It has also been a most controversial problem for vertebrate paleontologists and physical anthropologists. This is primarily because of the alleged hominoid ties of this primate, which is nearly chimpanzee sized, and because of the crushed nature of the only existing cranium