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Letter Section

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ABSTRACT

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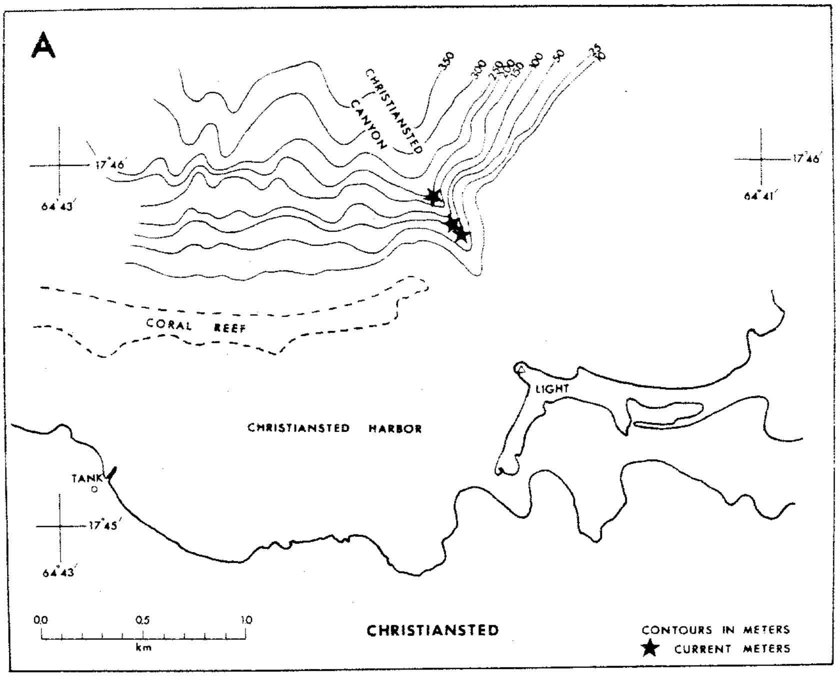
Currents in the heads of two canyons off the north shore of St. Croix, U.S. Virgin Islands are characterized by slow velocity with high-frequency alternations of direction and occasional periods of relatively strong downcanyon flows; the latter occurred during falling tides. The downcanyon flows appear to be density driven by pulses of saline water coming out of either the estuary or harbor located shoreward of the canyon heads.

INTRODUCTION

Along the north coast of St. Croix Island there are two well-developed steep submarine canyons that head near the shore. Their heads cut through the fringing and barrier coral reefs and receive tidal flow from the lagoon and estuaries behind the reefs. In June 1976, we placed current meters in the upper reaches of these two canyons. Scuba dives in the canyon heads off both Salt River and Christiansted Canyons (Fig. 1) revealed that occasionally there is a sudden build-up of downcanyon current flow which stirs up so much sediment that the visibility is greatly reduced. This flow is not throughout the water column but is concentrated at the bottom of the canyon. These observations stimulated interest in the overall long-term current regime of the canyons and prompted this study.

The area off St. Croix is of special interest for canyon-current studies because the region is subjected to very small tidal ranges, usually less than one foot. Previously Shepard (1976) had found that the range of tidal variation had an important bearing on the period of alternation of up- and downcanyon flows that appear to characterize virtually all current patterns in submarine canyons. The only earlier record of canyon currents in a virtu-


A
CHRISTIANSTED
CANYON
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300
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200
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50
25
10
17°46′
64°43′
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CORAL REEF
LIGHT
CHRISTIANSTED HARBOR
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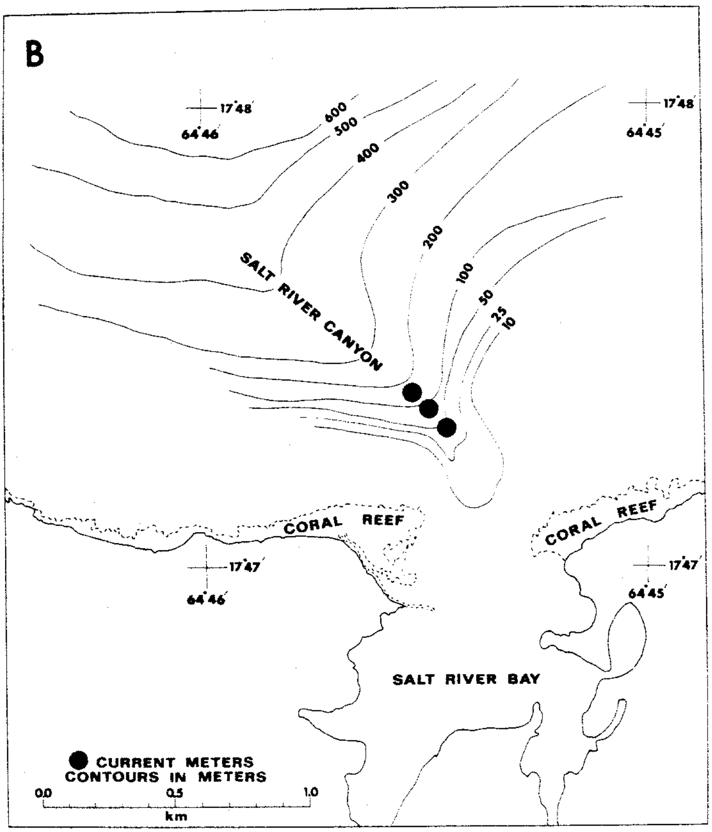
km
CHRISTIANSTED
CONTOURS IN METERS
CURRENT METERS


B
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SALT RIVER CANYON
CORAL REEF
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SALT RIVER BAY
CURRENT METERS
CONTOURS IN METERS
0.0
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km

ally tideless sea was off the Var River in the Mediterranean Sea (Gennesseaux et al., 1971). The canyon currents in that region had a continuous downcanyon flow, but they were measured during storm and flood conditions which apparently produced turbidity currents. The St. Croix canyons permit the measuring of canyon currents in an area of low tide range under normal conditions when storm-induced turbidity currents are not involved.

CURRENTS IN SALT RIVER CANYON

Salt River (Fig. 1) Canyon heads directly outside an estuary which has high saline water in the summer months (36‰ vs. 34 to 35‰ for oceanic water). The canyon walls are precipitous and narrow in its upper reaches but broaden seaward. Our five Savonius rotor current meters were placed in the canyon axis at 48 m by scuba divers and dropped from a surface boat to depths of 90 and 165 m using an echo sounder to locate the axis of the canyon. The records were only partly successful because of tangling of the vane in two cases and one failure of the counter that determines the current velocity. However, we measured significant currents with the working instruments.

We obtained a record from the 48-m station at 3 m above the bottom that showed slow currents with up- and downcanyon alternations at irregular intervals averaging about 30 minutes. These alternations were interspersed with several periods when the flow was predominantly downcanyon. The latter had a somewhat stronger current (Fig. 2). We found that these periods of relatively strong downcanyon current were all during falling tides. The contrasts between the two types of record are shown best by including a portion of the tapes (Fig. 3).

The record from 90 m was somewhat questionable although the first part looked to be operating correctly, but during the last part the fin was clearly tangled allowing recording of only small changes in direction. At 164 m the 3-m above-bottom record showed no velocity but did show alternating up- and downcanyon directions with irregular cycles of either about one hour or of a few hours. As in the 48-m record, there were periods of more than an hour with downcanyon flow. Some of these occurred about 3 hours after the relatively strong downcanyon flows in the 48-m axis station (Fig. 3). This suggests that the currents were initiated by an outflow of dense water from the salty estuary shoreward of the canyon head during falling tide and that some of these continued slowly down the canyon floor. The record 30 m above the bottom at 164-m axis depth lacked these downcanyon flows of consistent direction (Fig. 2) suggesting that the salty water had flowed down only nearer the bottom.

Fig. 1. Salt River Canyon (A) and Christiansted Canyon (B) off the north coast of St. Croix Island. Note that Salt River Canyon virtually dies out less than a kilometer from shore, whereas Christiansted Canyon continues seaward.

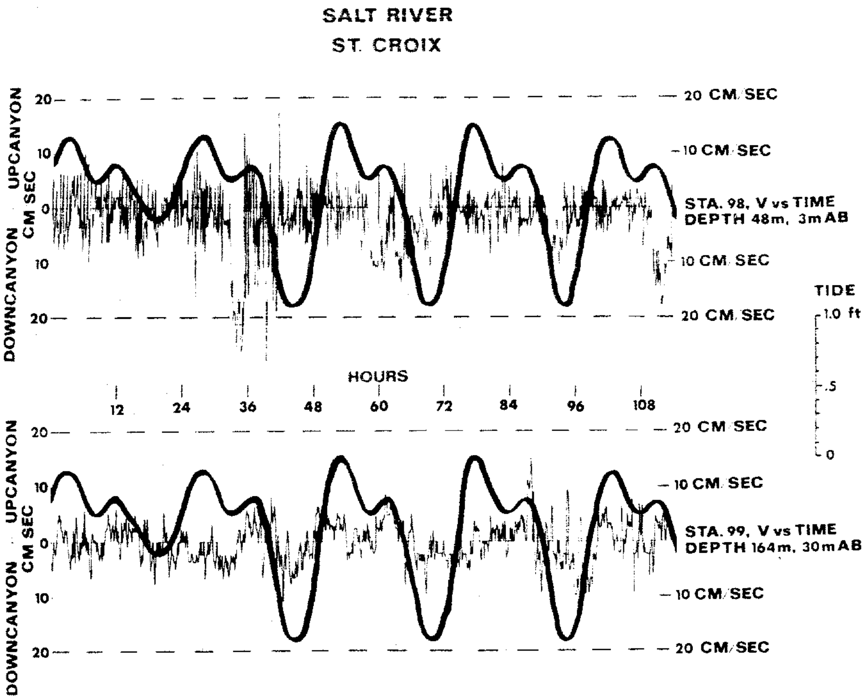

Fig. 2. Showing a result of very small tides related to high frequency alternations of up- and downcanyon currents at a 48 m axial depth in Salt River Canyon off northern St. Croix Island. Somewhat lower frequency is shown below from the currents obtained at 164 m in the same canyon. Note that at 48 m the highest velocities occur downcanyon during falling tides, probably the result of the highly saline water escaping from the estuary of Salt River (see also Fig. 3).

Diver observations show that occasionally there is a sharp water-mass boundary in depths of between 30 and 45 m in Salt River Canyon during ebb tide. The turbid water from the estuary shoreward of the canyon flows as a sheet of 20 to 30 m thick dirty water out over clear, colder underlying water occupying the bottom of the canyon. This interflow can be seen on an echo sounder as a "scattering layer" and flows along the coast in a westerly direction after it is no longer contained by the walls of the canyon. Occasionally divers are able to observe and feel internal waves on the interface between the lower boundary of this turbid lagoonal water layer and the underlying cooler clear oceanic water. The difference in index of refraction between the upper and lower layers is sufficiently large so as to cause a "shimmering", the visual distortion of objects viewed through this boundary.

The movement of water masses above and below the narrow boundary are shown to be different when they are tagged with fluorocene dye. The sharp "micro-oceanographic" boundaries viewed in shallow water by divers may explain the variations recorded remotely by the current meters that

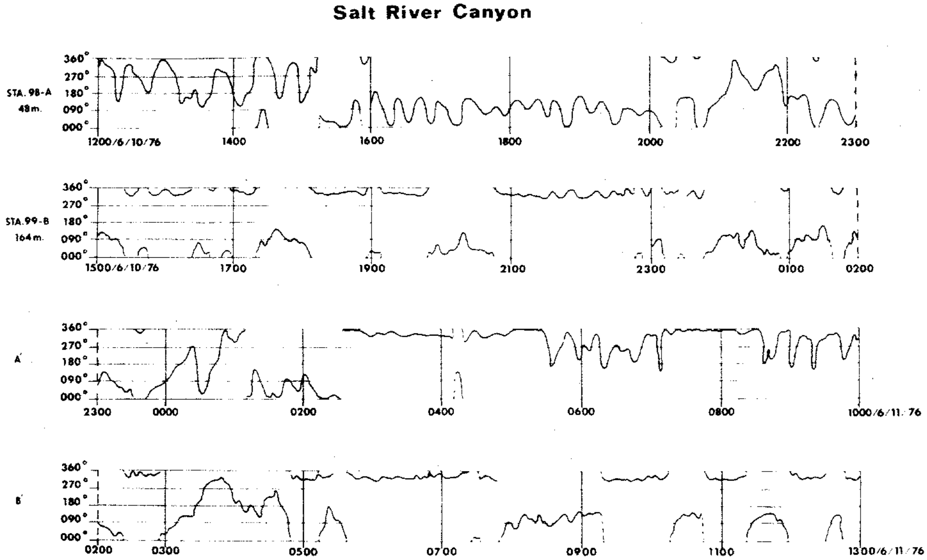

Fig. 3. Portion of current-meter records from Salt River Canyon showing the almost continuously changing directions at the depth of 48 m (3 m above the bottom) and the somewhat more constant up- and downcanyon direction at 164 m (also 3 m above the bottom). Note that two of the periods of downcanyon direction with fairly constant direction in the 48 m record may be matched about 3 hours later in the 164 m record.

were placed below diver observation depths. Not enough is known about the nature of the water masses and their movements in canyons in deep water to fully explain all the variations. Probably such an understanding will only come by making observations from a small research submersible at a future date.

CURRENTS IN CHRISTIANSTED SUBMARINE CANYON

Christiansted Canyon heads in the pass through the barrier coral reef at the entrance to Christiansted Harbor (Fig. 1). In this canyon we deployed current meters at 49, 60, and 190 m. The two meters at 49 m both operated as did the one at 60 m, but at 190 m the records were both confusing in that they had only a rather long period of direction changes and showed little relationship to the assumed direction of the canyon axis and no recorded velocities. It is possible that there was no strong current in the canyon during the time of the measurements and the random direction was only a reflection of the directional vane wandering.

At the two shallow stations, the low-velocity currents alternated at intervals of about one hour (Fig. 4) but were quite variable in direction and period. At the end of the run during a time of falling tide, there was an increase of velocity and a downcanyon current at both stations. The down-

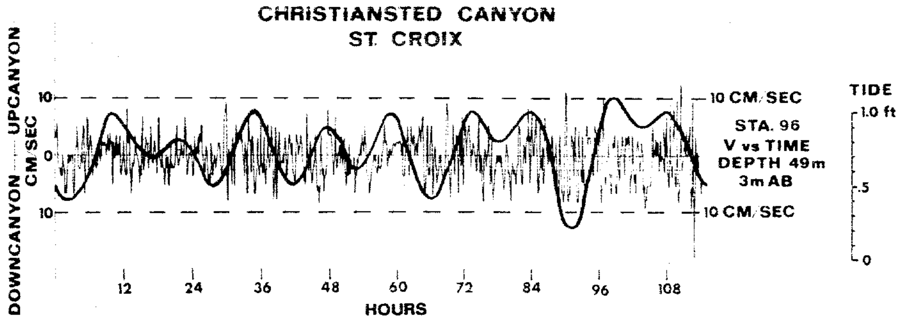

Fig. 4. Additional evidence of the effect of small tidal ranges in causing high frequency of up- and downcanyon currents at 49 m in Christiansted Canyon off St. Croix. Apparently there is no relationship between the currents and the tides, with the exception of a relatively strong downcanyon flow during falling tide near the end of the record.

canyon flow at the 60-m station occurred about 15 minutes later than at 48 m. The two stations were actually in close proximity about 100 m apart so that these relatively strong flows during a falling tide appear to be due to the introduction of dense water from Christiansted Harbor like the strong flows in Salt River Canyon where the stations were somewhat farther apart (approximately 150 m).

DISCUSSION

The currents flowing along the floors of Salt River and Christiansted Canyons are strikingly different from the usual currents in other submarine canyons and sea valleys observed to date. During most of the time covered by our St. Croix records, the currents were very slow, rarely exceeding 10 cm/sec, and the directions were changing so frequently that it was difficult to show them in the usual up- and downcanyon velocity diagrams as in Figs. 2 and 4 so that they are more clearly indicated by copies of the current-meter records (Fig. 3).

The currents in general show no relation to the tides. However, there are relatively short periods, particularly in Salt River Canyon during falling tides, when the currents have velocities of the order of 20 cm/sec and remain fairly constant in direction. In both canyons these periods of currents with relatively high velocity can be traced with some uncertainty down the axis between stations. The reason for the stronger flows appears to be that a mass of dense salty water has developed inside the shallow-water lagoons shoreward of canyon heads due to high summer evaporation and lack of rain runoff. During falling tides these pockets are tapped by the tidal currents and introduced into the canyon heads where they create a turbid density current that flows down the axis.

The almost constant change in direction observed in the records during most of the time is in keeping with the high frequency of cycles of up- and downcanyon currents in the inner canyons in other areas where the tide has a small range (Shepard, 1976). These appear to be related to internal waves as discussed previously (Shepard, 1975).

The high-frequency alternations of currents that characterize the area are probably related to the very small tidal fluctuation. Elsewhere with tides somewhat greater we also found high-frequency up- and downcanyon alternations at the shoaler stations. Thus we seem to have provided evidence that the alternating up- and downcanyon flows operate even with very small tides. It would be interesting to determine whether the canyons influenced by equally small tides in the Mediterranean have similar oscillations.

ACKNOWLEDGEMENTS

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