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CURRENTS IN SAN GABRIEL CANYON

Simulation studies of sediment quality around a proposed deep outfall off Orange County in about 350 m of water, combined with measurements of midwater and near-bottom currents in the area, indicate that resuspension of organically enriched, outfall-related sediments will occur. These particles will be transported westward, with some fraction passing over San Gabriel Canyon.

The purpose of these ongoing San Gabriel Canyon current measurements is to determine whether particulates deposited in San Gabriel Canyon will be resuspended and, if so, whether these particles will be transported up-canyon onto the shelf, or down-canyon into San Pedro Basin. The study is funded by a grant from the National Oceanographic and Atmospheric Administration (NOAA) and complements other current measurements simultaneously carried out by NOAA and SCCWRP on the adjacent slope.

SUMMARY OF RESULTS

The currents within San Gabriel Canyon are weaker than the currents over the adjacent slope or on the nearshore shelf areas. In contrast to these areas, however, the strength of the currents within the canyon intensifies with proximity to the bottom. The variable components of the flows are substantially stronger than the net flows, with most of the variations associated with tidal or shorter periods. Fluctuations occur more rapidly with decreasing water depth. Tidal period fluctuations dominate at depths in excess of 395 m, but are augmented or replaced by shorter period oscillations (perhaps tidal harmonics) at lesser depths (132 and 302 m).

The net near-bottom flow appears to be down-canyon, with speeds of less than 1.5 cm/sec for the along-canyon component. The analysis is complicated by the apparent generation of secondary flows associated with the meandering of the canyon axis. The near-bottom currents are sufficiently strong to resuspend sediments containing total volatile solids (TVS) concentrations in excess of about 20% more than one-half of the time. Sediments with concentrations of about 13% will be resuspended about 10% of the time. Resuspended sediments will be transported primarily down-canyon, with limited up-canyon transport resulting from "diffusion-like" processes.

No episodic, intense, near-bottom flows have been observed during the 7 months of data analyzed to date. A short-duration (<30 min), cross-canyon flow that exceeded the recording range of the current meter (45 cm/sec) appears to have occurred at an elevation of 25 m above the bottom (in 397 m of water) in December 1983.

BACKGROUND

The width of the nearshore slope in the region between Newport Beach and Long Beach increases in two relatively abrupt transitions where the 100-m contour moves farther offshore. Both transitions are marked by the presence of submarine canyons--Newport Canyon at the eastern end of the area and San Gabriel Canyon at the left-hand transition (Figure 1).

The present Orange County outfall discharges on the outer portion of the nearshore shelf between these two transitions. The feasibility of constructing a new outfall discharging farther offshore in water depths of about 350 m has been the subject of a number of studies, including current measurements on the upper part of the slope (e.g. Hendricks 1982). These measurements, combined with sediment quality simulation studies (see Hendricks, this volume), indicate that if the outfall were constructed, the sediments would become organically enriched with effluent particulates (Figure 1). Sediment particles resuspended by physical and biological processes would, in general, be transported westward along the slope and across San Gabriel Canyon.

The dominant motions within a canyon usually take place along its axis, and hence are roughly perpendicular to the average motion along the adjacent slope area. If significant transport occurs along the San Gabriel Canyon axis, particles settling within the canyon or resuspended from the bottom of the canyon would be transported either up-canyon onto the shelf, or down-canyon into San Pedro Basin.

In water depths of less than about 510 m, San Gabriel Canyon actually consists of two major subcanyons. The heads of both subcanyons intercept the inshore shelf in water depths of about 45 m. In the

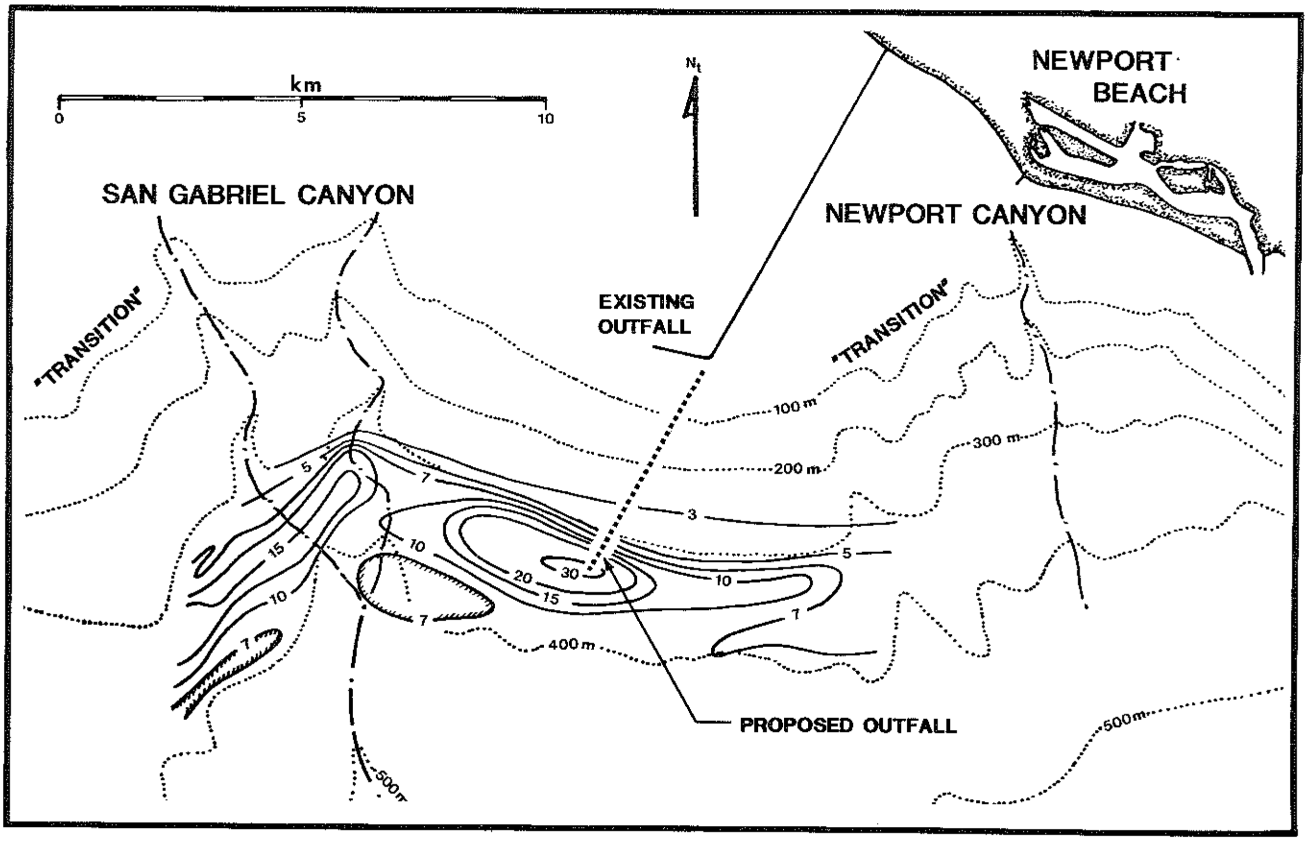

Figure 1. Relation between the predicted sediment TVS concentrations and San Gabriel Canyon. The existing and proposed Orange County outfalls are given in relation to water depths (subsurface currents are predominantly westward). The dark isolines show the TVS in the surface sediments predicted by the Hendricks sediment quality model if the deep outfall were placed in operation.

intervening depths, they cut across the upper portion of the slope in a tortuous fashion. Most of our measurements were made in the eastern branch of San Gabriel Canyon since this branch is likely to receive the bulk of the resuspended particulates passing over the canyon.

MOORINGS, EQUIPMENT, PROCEDURES

Two current meter moorings are used in this study. One of these moorings is a "permanent" mooring (Station P1 in Figure 2) and is situated on the axis of the canyon in about 397 m of water. This location corresponds approximately to the across-canyon extension of the 350-m isobath on the adjacent slope; the other mooring is rotated among five stations (Stations R1-R5 in Figure 2). Stations R1, R2, R4, and R5 are intended to supply information on the changes in the

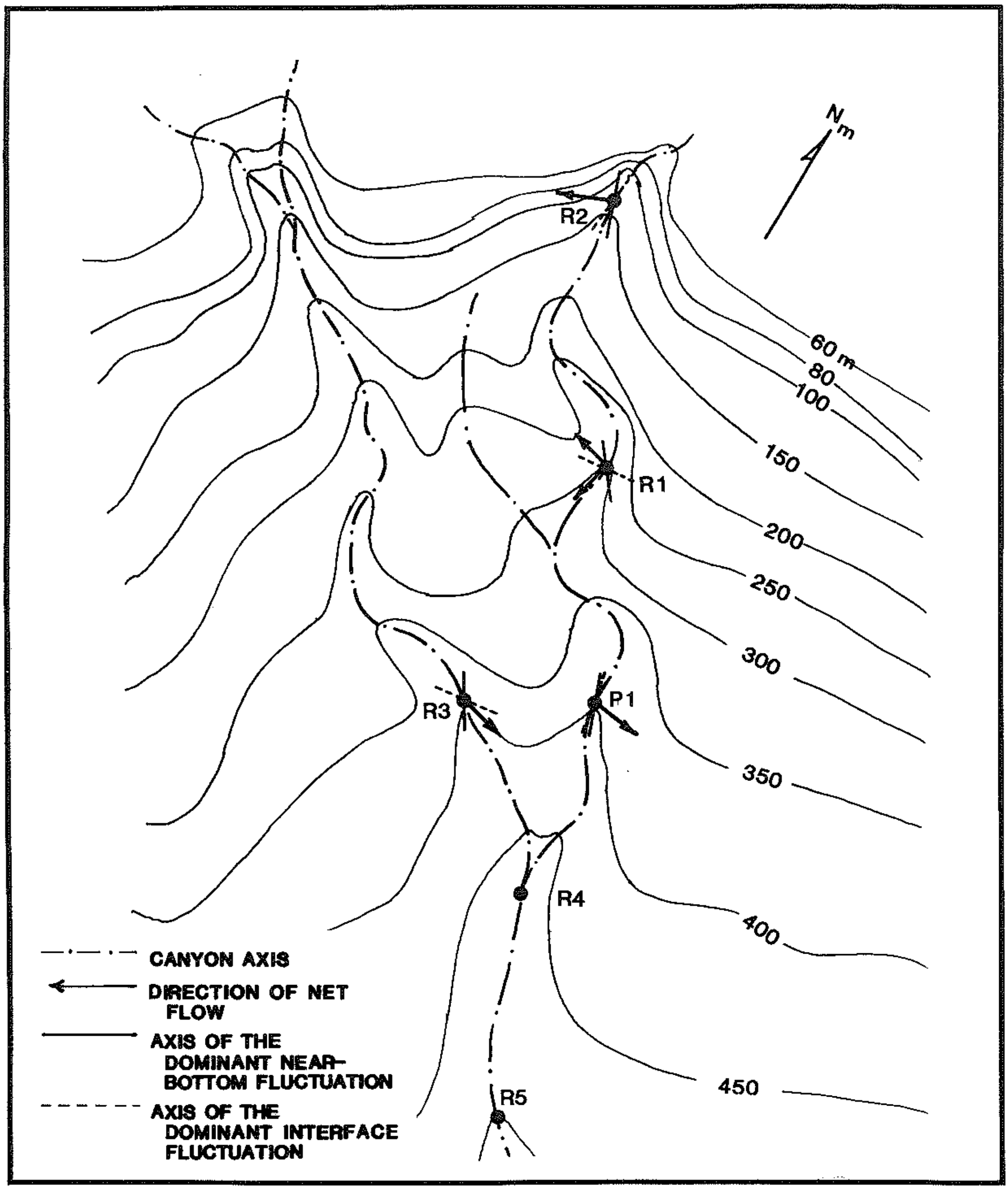

Figure 2. San Gabriel Canyon mooring locations and directions of flows. P1 is the "permanent" mooring (397 m); R1-R5, the "roving" moorings. The net flow and direction of the dominant variations are indicated by the arrows and lines at each station. The calculated net flows generally do not follow the canyon axis, but the primary axis of variation appears to parallel the axis (within the probable error associated with the bathymetry of the area).

properties of the currents at various depths; in addition, they can be used in combination with the measurements at Station P1 to determine the coherence or correlation between the various stations. Station R3 is used to determine if the properties of the currents in the west branch are similar to those in the more intensively studied east branch. The water depths at the moorings range from 132 m to about 500 m.

Each mooring includes three SCCWRP-designated, tiltmeter-type recording current meters. The lowest ("near-bottom") of the three meters is positioned 2 m above the bottom and is intended to provide information on the resuspension of canyon particulates and their subsequent transport. The middle ("intermediate") meter is positioned 25 m above the bottom (except at R5); these measurements are used to estimate the transport of particulates settling within the canyon, as well as to provide insight into the flow patterns within the canyon. Elevation of the upper ("interface") meter varies with the local depth of the canyon relative to the surrounding slope area. The elevation, chosen to approximately correspond to the interface between the "canyon water" and "slope water," varies from 25 m (R5) to 75 m (R2).

The meters are serviced at approximate 1-month intervals. Current measurements were made at 15-min intervals, but analyzed at 45-min intervals--except for the lowest meters; for these, measurements made at water depths of less than 397 m (and some of the P1 measurements) were analyzed at 15-min intervals. Collection and analysis of current meter data at Stations R4 and R5 (along with the simultaneous measurements at P1) are still in progress.

RESULTS

Speeds

The distribution of observed current speeds collected by the various meters is shown in Figure 3a (near-bottom currents) and 3b (midcanyon measurements). The strongest currents occurred at Station R1, in 302 m of water. This was not completely unexpected, since the canyon is narrower and deeper at this station than it is at any of the others. The near-bottom speeds in 132 m of water (R2) were almost as strong. At Stations P1 and R3, in 397 m of water, the speeds were approximately 1 cm/sec lower than at the shallower stations. The median speeds at the 397-m stations were about 5.0-5.5 cm/sec; at the shallower stations, about 6.4 cm/sec. The highest 10 percentile speeds ranged from 9.6-11.7 cm/sec in 397 m of water to 14.1-16.2 cm/sec at the shallower stations. Speeds in excess of 20 cm/sec were rare.

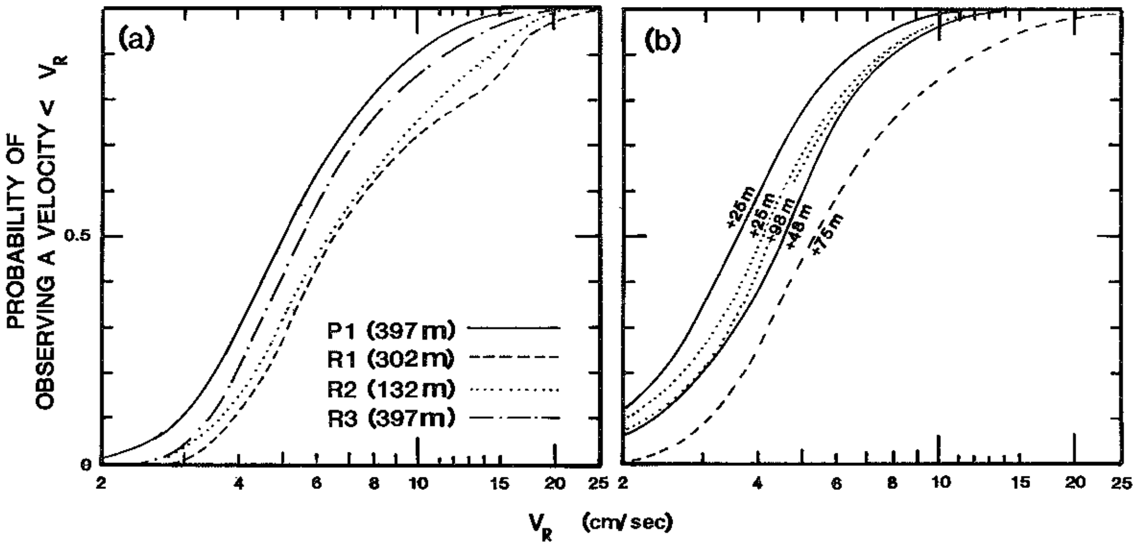

Figure 3. Distribution of current speeds. (a) Near-bottom (2-m elev) speeds. Currents at depths shallower than 397 m are stronger than the currents at that depth. At the deeper location, sediments with TVS concentrations greater than 20% (threshold resuspension speed = 5.6 cm/sec) will be resuspended more than half the time. Sediments with TVS concentrations of 13% will be resuspended about 10% of the time. (b) Midcanyon (25- to 75-m elev) speeds. The midwater currents are weaker than the near-bottom flows. The currents at an elevation of 25 m are generally weaker than those at elevations of 48-75 m.

The weakest currents generally were observed at an elevation of 25 m above the bottom, with median speeds of 3.5-4.1 cm/sec. The median speeds near the canyon-slope interface ranged from 4.3 to 5.3 cm/sec (Figure 3b). As was the case for the near-bottom currents, the highest speeds were observed at Station R1.

At an elevation of 25 m above the bottom at Station P1, the highest observed current speed in the 3500 observations made prior to December 9, 1983, was 20 cm/sec (more specifically, there was one occurrence each of speeds of 17, 19, and 20 cm/sec). On that date, a speed of 28 cm/sec was observed, followed 15 min later by an observation that exceeded the calibration speed of the instrument (45 cm/sec). The duration of the period of faster-than-expected flows was about 1 hour, and the direction of flow was cross-canyon. No other episodic, high-speed "events" were observed in any of the other meter records.

We can estimate the probability of resuspending organically enriched sediments deposited in the canyon using the results of our 1976 in situ measurements of the threshold speeds required to resuspend sediments (e.g. Hendricks 1983). At the 397-m depth, sediments with TVS concentrations in excess of about 20% would be resuspended more than 50% of the time and concentrations in excess of about 13% would be resuspended about 10% of the time.

Net Flow and Variability

The currents within the canyon are highly variable in time, particularly near the bottom of the canyon. Table 1 lists the speeds and directions of the net flows for all the depths and elevations analyzed up to the present time. The net flows were quite weak, ranging from 0.3 cm/sec up to about 2.7 cm/sec. The strongest net flows occurred near the bottom.

The arrows in Figure 2 indicate the direction of the net near-bottom flows at each of the stations. Separate arrows are used for each of the two observation periods at Station R1 because of the substantial differences between the two observation periods.

We expected that the net flow would be along the axis of the canyon; however, Figure 3 shows that the calculated net flows frequently did not confirm this expectation. At least two mechanisms could have led to these anomolous results: 1) the net flows were not accurately calculated as a result of the strong variations in the observed flows and/or 2) the meandering of the canyon induced secondary flows which led to erroneous estimates of net flow and direction. We have not determined the contributions of these processes to our calculated net flows. It is worth noting, however, that the net near-bottom flows nearly always have a down-canyon component, suggesting that this will be the predominant direction of transport.

Table 1 also lists the root-mean-square (rms) speeds along the major and minor axes of variation. Again, the near-bottom currents show the highest speeds. The major axes of variation for the near-bottom currents at each of the stations are indicated by the solid line in Figure 2; the major axes of variation for the uppermost meters (canyon-slope interface) are indicated by the dashed line. At Stations P1 and R2 these axes were roughly parallel to the axis of the canyon (estimated from bathymetric charts); at Station R1, the axes for the upper and lower meters were approximately parallel to the canyon axis for one of the observation periods, but not for the other. Since the charts indicate that the canyon makes a substantial change in direction near this station, the differences between the two observations could reflect differences in the precise location of the mooring.

The major axis of variation for the near-bottom currents in the western

Table 1. Net flows and rms[a] speeds of fluctuations.

		Net Flows		rms Flows		
Station/ Elevation (m)	Water Depth (m)	Net Speed (cm/sec)	Direction (deg mag N)	rms Speed (cm/sec) Major Axis	rms Speed (cm/sec) Minor Axis	Direction (deg mag N)
Interface						
R2/44	132	1.3	330	4.4	3.8	160-340
R1/75	302(1)[b]	1.7	287	5.8	3.9	158-338
R1/75	302(2)[b]	1.3	268	7.5	5.2	101-281
P1/49	397	0.3	086	4.9	2.9	158-338
R3/49	397	1.3	303	4.6	4.0	142-322
Intermediate						
R2/25	132	0.4	002	4.9	2.9	179-359
P1/25	397	0.7	305	4.4	2.4	177-357
Near-Bottom						
R2/2	132	2.7	246	7.9	3.8	016-196
R1/2	302(1)[b]	2.0	195	10.2	5.3	037-217
R1/2	302(2)[b]	2.8	287	6.4	4.6	139-319
P1/2	397	1.4	093	5.9	3.1	164-344
R3/2	397	1.2	099	6.3	4.8	081-261

[a]Root-mean-square.

[b]There were two observation periods at Station R1.

branch of the canyon was found to be approximately parallel to the estimated axis of that subcanyon; the variations at the canyon slope interface depth, however, were not. The properties of the currents at this elevation are sensitive to small changes in the elevation of the meter, relative to the depth of the surrounding slope area. If the meter is located above the interface depth, it will exhibit some of the properties of the near-bottom slope currents mixed with the characteristics of the canyon currents. This sensitivity has been observed in the temporal properties of the variations of the uppermost meters in some of the records and may also account for the differences between the major axis of variation and the axis of the canyon measured at Stations R3 and R1.

Figure 4a shows "typical" fluctuations in the near-bottom currents at various water depths for the along-canyon components of the flows. In general, the frequency of the near-bottom fluctuations increases as the water depth decreases. This dependence is consistent with the observations of Shepard et al. (1979) in other canyons. Spectral analysis of the "along-canyon" component of the flow indicates the presence of fluctuations with semidiurnal tidal periodicity and some hint of diurnal and/or inertial period fluctuations at a depth of 397 m. At a depth of 302 m, the semidiurnal fluctuation was still present, but accompanied by the suggestion of a harmonic of the semidiurnal tidal period and possible interference between diurnal and semidiurnal fluctuations. At the shallowest mooring (132 m), the tidal periods have been replaced by a broad spectral enhancement with periods corresponding to several multiples of the semidiurnal frequency. Figure 4b shows "typical" fluctuations for the "midwater" canyon currents at intermediate and interface elevations. In general, the dominant variations were associated with the tidal periods, with increasingly rapid fluctuations as water depth decreases at the intermediate elevation.

Correlations Between Pairs of Stations

An examination of the "long-period" (i.e., greater-than-tidal-period) fluctuations gives no evidence for correlations in the currents between pairs of moorings at different depths or in different branches of the canyons. The same conclusion appears to hold for the tidal and shorter period fluctuations. Thus, except for the net down-canyon near-bottom flows, the currents at various locations along the canyon are relatively independent.

In general, the greatest correlation was observed among the meters at a single (deep) mooring. Even then, there were substantial changes in phases of oscillation, suggesting the importance of internal tides, internal waves, and other baroclinic processes for canyon flows.

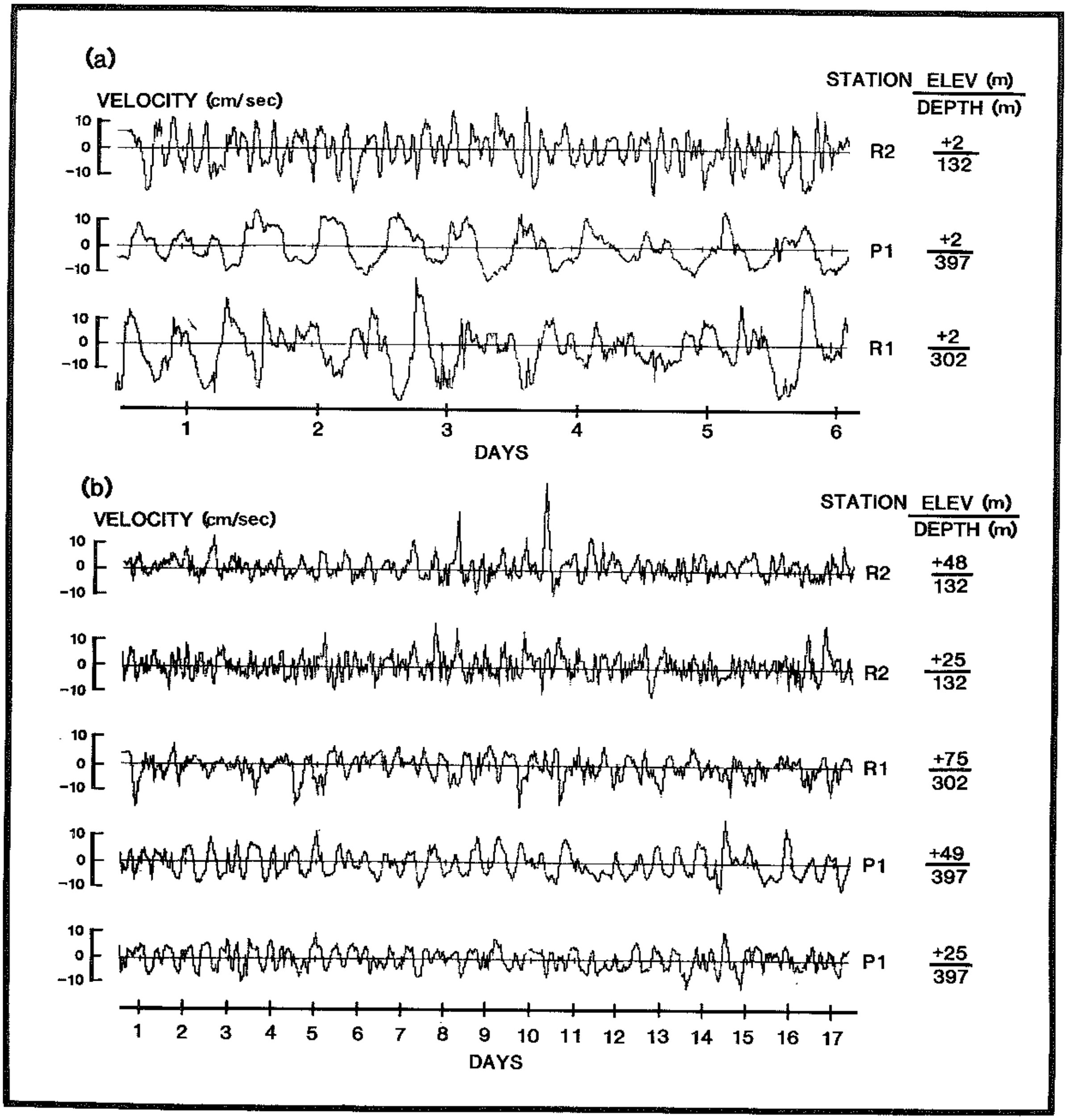

Figure 4. "Typical" along-canyon velocities. Velocities of +10 (up-canyon), 0, and -10 (down-canyon) cm/sec are indicated by the left-hand brackets. (a) Near-bottom velocities. Semidiurnal currents (2 cycles/day) dominated at Station P1 (397 m), but much more rapid changes were simultaneously recorded at Station R2 (132 m). The flows at the intermediate Station R1 (302 m) during a different time show a mix of these characteristics. (b) Intermediate and interface velocities. The upper two records were simultaneously collected at Station R2; the lower three were simultaneously collected at Stations R1 (302 m) and P1 (397 m). The records at an intermediate elevation (25 m) generally show more contribution by high-frequency fluctuations than do the interface flows (48- to 75-m elev).

Transport of Resuspended Sediments

Little similarity was found between the near-bottom current fluctuations at pairs of canyon stations. This suggests that, except for the (apparent) weak net down-canyon flow at all the near-bottom stations, there is little "organized" transport of near-bottom water along the canyon axis. Thus, resuspended particulates can be expected to be transported down-canyon by relatively weak currents. Up-canyon transport by advective processes is unlikely, but a diffusion-like up-canyon (as well as down-canyon) transport of resuspended particulates could be generated by fluctuations and secondary flows. The strength of this "diffusive" transport was not estimable with the existing data, but it is likely to be substantially lower than the strength of advective transport associated with net flows.

The net currents at an elevation of 25 m were generally found to have a net up-canyon component to their movement; thus, particulates settling from the water column into the canyon could, for a while, be carried up-canyon by these currents. We could not estimate the strength of this 25-m-elevation transport from the data collected to date, but for a variety of reasons, including weaker currents and greater variability in the direction of net flow, it is likely to be weaker than the strength of near-bottom transport.

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