Reports

Transient Circulation Event near the Deep Ocean Floor

Abstract. *On 24 January 1968, a transient deep-circulation event was recorded by a triangular array of autonomous current recorders installed 3 meters above the bottom at two of the three positions and at intervals of 3 to 1000 meters above the bottom at the third position in a depth of 3950 meters above the relatively smooth floor of the eastern North Pacific. The event interrupted a 24-hour record of relatively steady but peculiar conditions, lasted for about 1½ hours, and was followed by current directions and speeds that greatly differed from those of the initial period. The event occurred over a volume of the sea of at least 2 kilometers in horizontal dimensions and 1 kilometer thick. Associated with the event were many small clockwise-rotating features extending from 3 to at least 1000 meters above the bottom and a rapidly increasing current velocity at 1000 meters. The event was probably local and may have involved convective motion, internal waves, and the passage of a front. Some of the changes in horizontal velocity may have resulted from the combined effects of upwelling and the earth's rotation.*

Although in atmospheric exchange processes transient events are thought to be extremely important and probably to dominate, investigators who have postulated models and have analyzed measurements of deep ocean circulation and vertical exchange in deep waters have tacitly assumed the existence and dominance of relatively steady-state processes (*1*).

The transient events occasionally observed in deep water are commonly thought not to produce net motion and hence not to affect the net steady-state processes. However, such events may affect mixing (and thus exchange) at depth. Also transient events that apparently affected net motion have been observed in the North Atlantic (*2*) and in the eastern North Pacific (*3*). We here report observations of a transient event that most probably affected net motion and vertical exchange in the deep sea.

Our measurements were made on 23 to 24 January 1968 with an array of six autonomous current meters near the sea floor, about 400 km off the northern coast of Baja California, Mexico. The center of the array was at 30°30′N, 119°50′W, where the ocean is about 3950 m deep. The topography of the sea floor in this area is gently undulating with about 100 m of relief. The closest known bold topographic feature is Showboat seamount, 24 km south of the site. Otherwise, as far as is known, the low relief extends for 150 km in all directions (Fig. 1).

The autonomous current meters (*4*) have now been used on more than 200 occasions. They are self-contained, freely descending current meters with a Savonius rotor used as a measuring device, a compass-oriented directional recording system, a ballast release timer, radio beacon, and other gear for recovery.

On the occasion reported here, two current meters, tethered to remain 3 m from the bottom, were dropped at the extremes of a 2-km east-west line. About 2 km north of the midpoint of this line a vertically interconnected array of four current meters was installed at 3, 30, 300, and 1000 m above the ocean floor. All current meters were tethered by a 6-mm braided nylon line, and those in the vertical array were tethered in series with about 40 kg of buoyancy above (*5*). The entire duration of the records of this array from arrival on the ocean floor to departure was about 36 hours. The directional recording of all six instruments functioned properly, but the speed recording of instruments 200B, 201, and 202 malfunctioned. For the initial hours the individual current speeds (2 to 4 cm/sec) were close in magnitude to speeds previously reported for this area (*4*). The current directions, however, showed totally unexpected differences between currents at all locations (Fig. 2). Particularly striking is the persistent opposition of directions of current flow at 3 m and 30 m off the bottom in the vertical array (*6*). Some 26 hours after the start of the record (that is, at ~ 10:50 G.M.T., 24 January 1968) all records showed sudden shifts in current direction. The initial phase of this change was synchronous within 24 minutes for all instruments. The transient phase of the event then persisted for from ½ hour at one of the single instruments to about 1½ hours at all instruments in the vertical array. At the two single instruments (201 and 202, Fig. 1), the event consisted of a simple sudden shift in current direction, whereas at the array (Fig. 3) it consisted of a series of 7 to 34 complete clockwise rotations. After this event the measured currents became relatively steady for the remaining 3½ hours on record, but in directions different from those existing for hours previous to the event. The current speeds did not change conspicuously during the event, generally increasing by only 15 to 25 percent at the three instruments that recorded speed. However, immediately after the event the speed at instrument 200A (3 m from the bottom) further increased about 10 percent, and the speed at 1000 m from the bottom in-

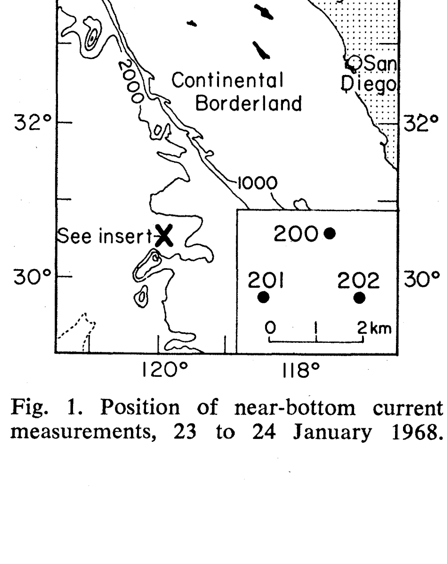
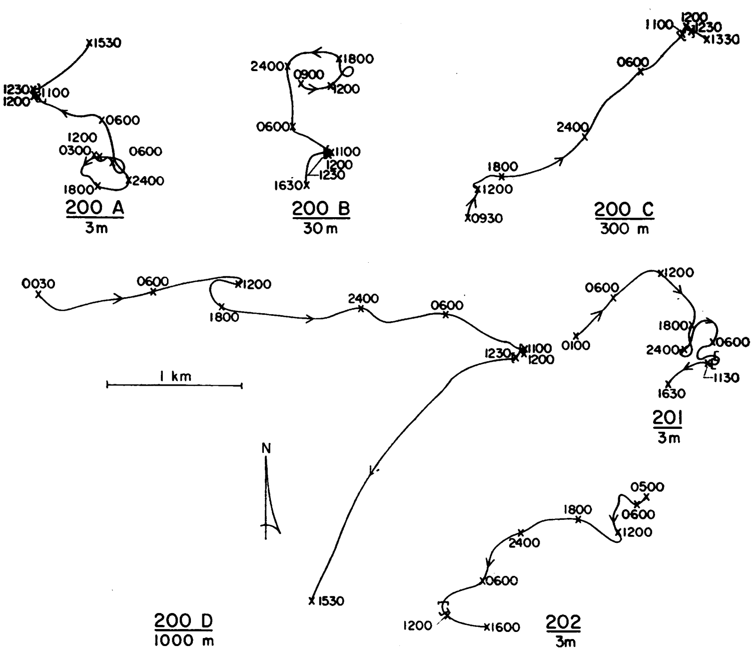


Fig. 1. Position of near-bottom current measurements, 23 to 24 January 1968.



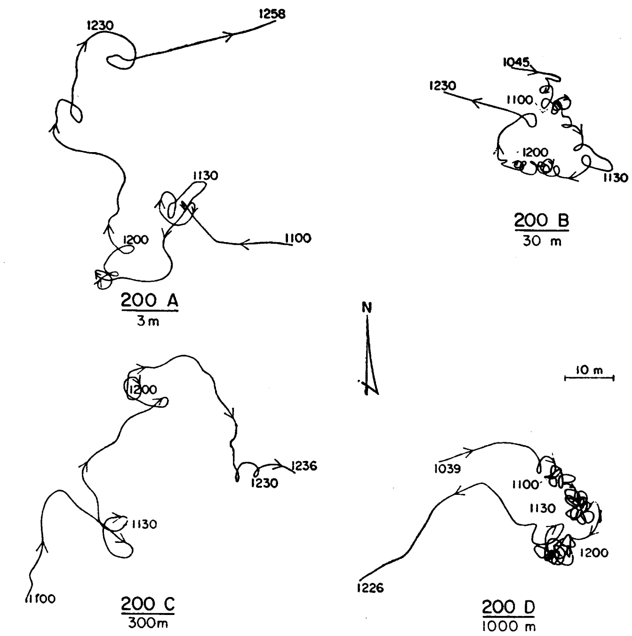


Fig. 2 (left). Vector-addition diagrams for entire record of current measurements. The "event" period is bracketed. Fig. 3 (right). Vector-addition diagrams during the period of the "event."

creased by 450 percent to 18 cm/sec, a rate that is most unusual at such depths. The current directions at the three instruments 3 m from the bottom showed divergence for the entire record after the event (Fig. 3).

For the three records where the speed recorder malfunctioned, a nominal constant speed has been used in the diagrams. The records are visible in the portions of the photograph that cover the event (Fig. 4).

From the records obtained it is not possible to describe the overall nature of the event. Clearly, however, it was a transient circulation feature with dimensions of the order of at least kilometers in horizontal and vertical extent.

Although the event conceivably could represent local motion directly associated with some large-scale regional phenomenon, several features of the records and other observations suggest otherwise. For example, as seen in the vector-addition diagrams, the total displacements during the entire history of the transient event are of the order of only a few hundred meters (Figs. 2 and 3). However, the instruments, almost 2 km apart, display almost simultaneous onset. Were this onset the direct result of large-scale motions, we would expect the nature of the shifts in directions to be similar at all stations, rather than different. Indeed, the long-persistent divergence, exhibited by the three bottom instruments after the event, seems al-

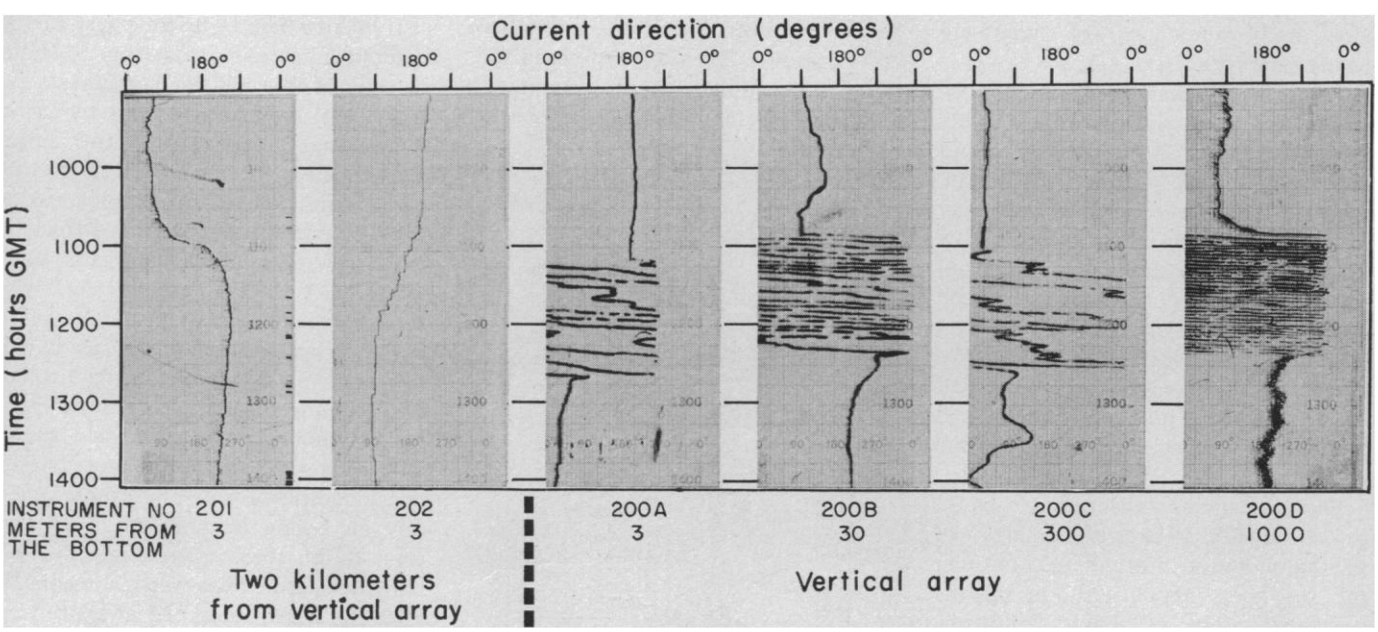


Fig. 4. Records of current measurements just prior to, during, and immediately after the period of the event. The transient event occurred 24 January 1968 at 30°30'N, 119°50'W; depth sea floor, 3950 m (2160 fathoms). (The records for the vertical array were traced on a clear overlay since the original records were too light to photograph.)

most irreconcilable with a direct effect of large-scale motion of transient water, although it might be a residual local effect of a relatively large-scale secondary feature of such a motion process, such as the passage of a front. A low probability of occurrence of large-scale differential shifts in deep water is also suggested from the indirect evidence that no deep-water records similar to any one of these have been obtained in any of the more than 200 drops of these instruments. In fact, instruments installed close together have ordinarily recorded almost congruent vector-addition diagrams (*4*). For these reasons, we are inclined to believe that these records represent the effects of a relatively local event and that we have recorded some substantial features of its development or onset, its decay or passage, and its terminal or residual effects.

The numerous rotations recorded during the event by the instruments of the vertical array undoubtedly are the result of small-scale eddies. The instruments respond negligibly to vertical water motion. Thus the fact that the paths of the eddies are essentially all closed clockwise curves suggests that the axes of rotation of the eddies are strongly inclined to the vertical or, if the axes are oriented near to the horizontal, that the eddies are moving vertically on consistently inclined paths. Since the instruments higher in the vertical string do not achieve equilibrium in a rapidly fluctuating current, no detail can be legitimately attributed to the records of these small rotations at the upper levels. However, their occurrence, rotating nature, and sense is, in our opinion, unequivocally shown (*7*).

These clockwise (anticyclonic) rotations cannot be attributed to general planetary vorticity in a converging system, and hence there must be local vorticity, perhaps associated with the passage of a feature resembling a front.

The high velocity that commences at 1000 m immediately after the rotating phase is one of the most striking features of the event. The velocities at this level suddenly rise at the termination of rotation from about 4 cm/sec to 18 cm/sec and persist at this high level to the termination of the record (approximately 3½ hours). This change of velocity is intriguing. We are inclined to attribute it, in part, to the differential angular momentum from the earth's rotation imparted to water masses moving in a vertical direction at low latitudes. Differential velocities due to this effect are, of course, negligible in atmospheric and oceanic circulation in general. At the abyssal depths, however, where velocities are normally very low, this effect may not be negligible. For example, if the phenomenon that we have encountered involves the vertical rise of water from rest, the horizontal velocity of that water 1000 m above will now be about 7 cm/sec toward the west (*8*). Should this water have been derived from a near-bottom layer already moving toward the west, such as the layer at 3 m, at the velocity that we encounter there (about 4 cm/sec) the upwelling process would then give rise to water at 1000 m moving westerly at a velocity of 10 or more centimeters per second. The velocities are of the order of the westward component of the current at the 1000-m level after the event. Downwelling, however, is indicated by the persistent terminal divergence near the bottom. Thus any upwelling must have originated above the bottom, perhaps just above the level of high shear.

We cite the above points only to indicate that the horizontal velocities resulting from vertical motion are not trivial in the deep regions of the sea and that they may be involved in the high velocities subsequent to the event at 1000 m.

Two other possible explanations for the origin and nature of this event are that this event was the wake effect of a large topographic feature or that it was the result of a turbidity current originating on such a feature. We are not inclined to accept either of these possibilities as the true cause of the actual occurrence, although we cannot rule them out. The only known large nearby topographic feature is Showboat seamount. All prior measurements of deep current direction in this area place this seamount downstream from the measurement site. In the reported instance the current records are so complex that we cannot assert that the site is not in the wake of this feature. However, in past records the currents much closer to and even on the flanks of the seamount have been quite steady (*4*).

A turbidity current originating on the flanks of this seamount could conceivably have given rise to the reported event. Indeed, a turbidity current is attractive in explaining the high velocities 1000 m from the bottom, for a turbid mass of water might reach density equilibrium at such a depth, spread rapidly into the surrounding region, and give rise to complex transient currents at many levels. A turbidity current extending over the surrounding region for 24 km and 1 km in depth, and producing the reported changes in velocity over this volume, would require the movement of great quantities of sediment. However, available information on the nature of the material of Showboat seamount (*9*) indicates that its surface is pillow lava, and that it is virtually devoid of fine sediment. Hence, there is no known source for a powerful turbidity current originating from this topographic feature. We cannot, of course, rule out the possibility that the event resulted from a turbidity current from the continent.

RICHARD A. SCHWARTZLOSE
JOHN D. ISAACS

Scripps Institution of Oceanography, University of California at San Diego, La Jolla 92037

References and Notes

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4. J. D. Isaacs, J. L. Reid, Jr., G. B. Schick, R. A. Schwartzlose, *ibid.* **71**, 4297 (1966).
5. This buoyancy restricted the vertical displacement (dip) of the instruments to less than 1 percent of the depth, under the effects of the currents reported here.
6. From inspection of the vector-addition diagrams of these two instruments, one is tempted to attribute this record of persistent shear in a varying current to an instrumental error with one compass misoriented 180° in assembly. Although not absolutely impossible, this inadvertency has been almost certainly ruled out by review of the assembly procedure and of the calibration records.
7. These autonomous instruments sometimes show rotations due to torque resulting from twist in their tethers. When observed, these rotations are of much longer period than those reported here, are of a special character, and occur only at miniscule current speeds (approximately 0.1 cm/sec, that is, only in the presence of current-generated orienting moments a thousandth part of those that persisted in the reported records). Strong vertical motion alone could cause random rotation in these instruments. This appears to be an unlikely cause in this case since all instruments show the same sense of rotation and because of the rotation of the instrument at 3 m, which cannot be involved in persistent vertical motion.
8. For low latitudes this velocity (ΔV) is approximated by
$$\Delta V = \Delta Z \cos \phi\omega$$
where ΔZ is the vertical displacement, ϕ is the latitude, and ω is the angular velocity of the earth (that is, $\sim 7.3 \times 10^{-5}$ rad sec^{-1}). Such an effect was noted with waters upwelling by an atomic explosion [T. R. Folsom and J. D. Isaacs, *Armed Forces Spec. Weapons Proj. Interim Tech. Rep. 1064* (1955) (available from the Defense Atomic Support Agency Washington, D.C.)].
9. Unpublished photographs were taken 9 September 1965 at 30°14′N, 120°05′W.
10. We thank M. Sessions and F. Dacy for operating the current meters. Supported by the U.S. AEC under contract AT(11-1)-34, project 127, and the State of California through the University of California's Marine Life Research Program at Scripps Institution of Oceanography.

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