10. NEAR-SURFACE VELOCITY AND TEMPERATURE STRUCTURE OF THE PERU CURRENT AT ODP SITES 685, 686, AND 688[1]

Dean L. Merrill[2]

INTRODUCTION

The Peru Current has been studied frequently as the classic example of an eastern boundary current (Sverdrup, 1930; Gunther, 1936; Wooster and Reid, 1963; Wyrtki, 1967). The coastal upwelling generated by this eastern boundary current regime and the various components of this current system are well documented (Schweigger, 1958; Wyrtki, 1963; O'Brien and Hurlburt, 1972; Idyll, 1973). The effect of El Niños and southern oscillation on the coastal current system off Peru are also well known (Barnett, 1977; Wyrtki, 1975; Smith, 1983). During ODP Leg 112, we were able to complement the data for oceanographic conditions between 9° and 14°S during drilling operations. A current-meter system aboard the *JOIDES Resolution* allowed us to record continuous near-surface current and temperature profiles to characterize the Peru Current and associated temperature regimes at several drill sites during Leg 112. Originally intended for observing surface currents as part of ice-management programs during high-latitude ODP cruises, the current-meter system deployed during Leg 112 was successfully tested and provided valuable data about the current regime and temperature structure of the upper water column of the Peru Current. These current-meter data were also useful for detecting anomalous surface and subsurface flows during drilling, which may affect the orientation of the drill string and hence drilling operations.

A Smart Acoustic Current Meter (SACM), manufactured by Neil Brown, was installed and tested during the first half of Leg 112 and used for near-surface profiling during the latter part of the cruise at Sites 685, 686, and 688 (Table 1 and Fig. 1). Both Sites 685 and 688 are deep-water sites (5070.8 and 3825.8 m, respectively), and only the uppermost part of the water column was profiled owing to the depth restriction of the current meter (500 m). Site 686 was a shallow-water site (446.8 m), which enabled us to profile to within 4.8 m of the seafloor (Fig. 2).

GENERAL SETTING

The Peru Current follows the west coast of South America from southern Chile to the equator, where it turns westward and merges with the South Equatorial Current. The Peru Current is an example of an eastern boundary current that is typically wide and flows slowly (Wooster and Reid, 1963). Current speeds in the Peru Current generally do not exceed 30 cm/s at the surface and decrease rapidly with depth, while directions are generally north to north-northwest (Gunther, 1936; Pickard and Emery, 1982). The Peru Current is approximately 800 km wide (Idyll, 1973).

There are two northward-flowing components of the Peru Current (Idyll, 1973): (1) the Coastal Current, which flows over the narrow shelf of South America from Valpariso, Chile, to north of Chimbote, Peru, and (2) the Oceanic Current, which is wider than the Coastal Current (up to 625 km wide) and extends as deep as 700 m.

Gunther (1936), Reid (1959), Wooster and Gilmartin (1961), Smith (1983), and others described southerly countercurrents that flow both at surface and at depth. The Peru Countercurrent, also known as the Gunther Current, underlies the surface currents moving toward the equator. Between the Coastal and Oceanic currents lies a surface countercurrent that rarely extends farther than several degrees south of the equator. For reasons that are not fully understood, the coastal current weakens sporadically. This allows the surface countercurrent to move farther south, which disrupts the coastal upwelling that normally occurs along the coast and creates a condition known as El Niño.

Surface winds are out of the southeast and have sustained wind speeds of 3-5 m/s year-round. In conjunction with the Coriolis Effect, these winds induce a westerly component to the Peru Current and move surface waters away from the land. Cold, nutrient-rich water replaces the surface water, combines with the warm equatorial atmosphere, and creates cloudy atmospheric conditions most of the year.

EQUIPMENT

The current meter used in this study is a two-axis SACM that is manufactured by Neil Brown and configured in a direct-reading mode. The SACM can be deployed to a water depth of 500 m and transmits data every 2 s through a conducting cable to an IBM PC/XT located in the Dynamic Positioning Room of the *JOIDES Resolution*. Temperature and meter tilt as well as the U (east-west) and V (north-south) components of horizontal velocity are displayed. The current meter corrects velocities internally for meter tilt before transmitting data to the IBM PC/XT.

Speeds are accurate to ± 1.0 cm/s or $\pm 5\%$, whichever is greater. Directions are accurate to within $\pm 5°$ and have been corrected for true north. The response time for speed and direction is 0.2 s. Temperature response time is 1 min and is accurate to within $\pm 0.05°C$.

METHODS

Profiling was performed in a continuous mode, and data were collected during both descent and ascent as separate records for comparison and averaging purposes. The SACM does not measure vertical motions, thus profiling at slow winch speeds produces accurate current-meter profiles.

Current-meter and temperature profiles were conducted at the site while the ship's dynamic positioning system was operating. In the calm weather conditions and sea states encountered during Leg 112, this positioning system kept the ship on location to within 1% of water depth, which enabled us to run accurate profiles from a horizontally stable platform.

When feasible, profiles were run daily at Sites 685 and 688 at approximately 0800 hr and again at approximately 1900 hr; each profile required about 3 hr to complete. Site 685 profiles include data from 24 through 30 November 1986. Only one profile was collected at Site 686 (on the evening of 1 December) because of

[1] Suess, E., von Huene, R., et al., 1988. *Proc. ODP, Init. Repts.*, 112: College Station, TX (Ocean Drilling Program).

[2] Ocean Drilling Program, Texas A&M University, College Station, TX 77843.

Table 1. Locations, water depths, and dates of deployment of the current meter at Sites 685. 686, and 688.

Hole	Location	Distance offshore (km)	Water depth (mbsf)	Dates of deployment (1986)
112-685A	9°06.78′S, 80°35.01′W	191	5070.8	24–30 November
112-686A	13°28.81′S, 76°53.49′W	61	446.8	1 December
112-688C, D	11°32.26′S, 78°56.57′W	152	3819.8	9–10 December
112-688E	11°32.28′S, 78°56.65′W	152	3825.8	11–13 December

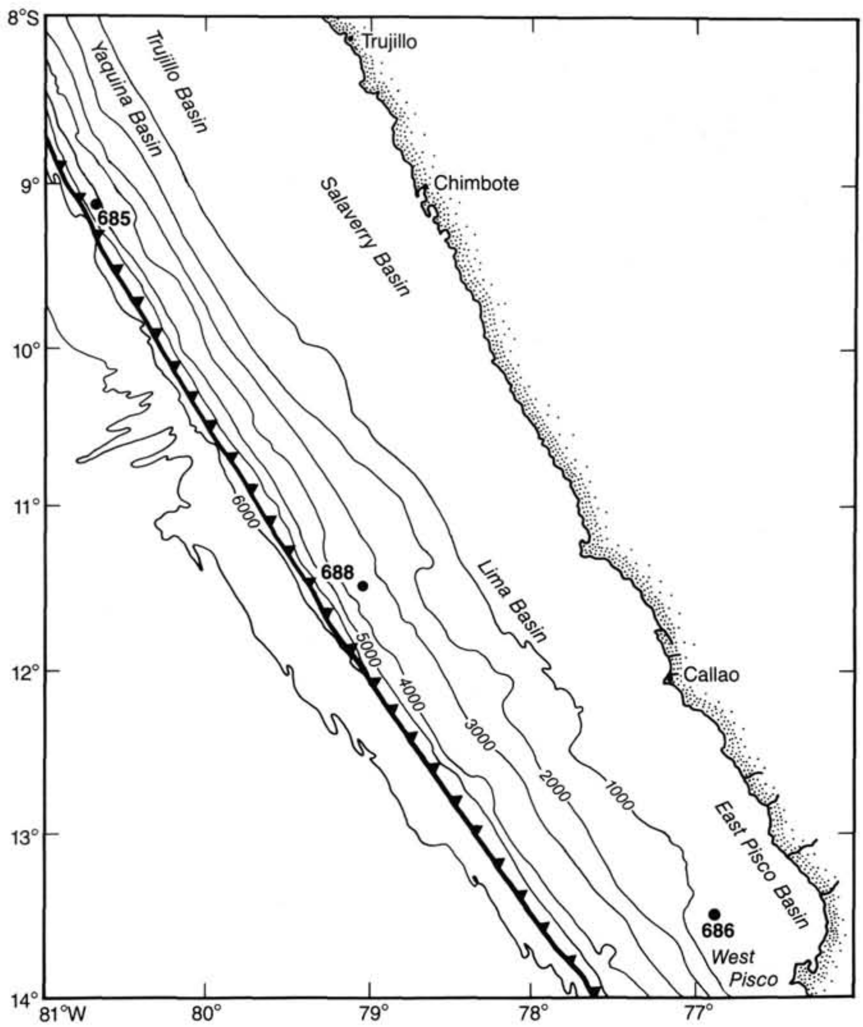

Figure 1. Locations of Sites 685, 686, and 688, where continuous current and temperature profiles were recorded during Leg 112.

difficulties with the vessel positioning system. Profiles from Site 688 were collected during 10 to 13 December.

Because of the long response time of the temperature probe (1 min), temperatures measured in the profiling mode were either too warm or too cold, depending on the direction of profiling. Although we recognized that the temperature gradient caused the temperature offset and that this gradient was not linear, we were able to approximate closely the true temperature by profiling in both the descent and ascent modes at the same speed (7 m/min) so that the resulting profiles could be averaged and plotted. We performed several discrete profiles to check the feasibility of this procedure and had excellent results. Extraneous and erroneous data were deleted from the velocity data files, processed to remove variability created by the profiling process, and then plotted.

The draft of the vessel (7.5 m) and the extension of the thrusters and their cone of influence (an additional 7 m) caused the top 15 m of the water column to be directly within the influence of the ship. For these reasons, the top 15 meters of our current profiles may be in error. Even though the vessel was maintained in such a position so that it constantly headed into the prevailing surface current while on station, the ship undoubtedly diverted currents immediately surrounding the hull. Dynamic-positioning thruster action may also have produced anom-

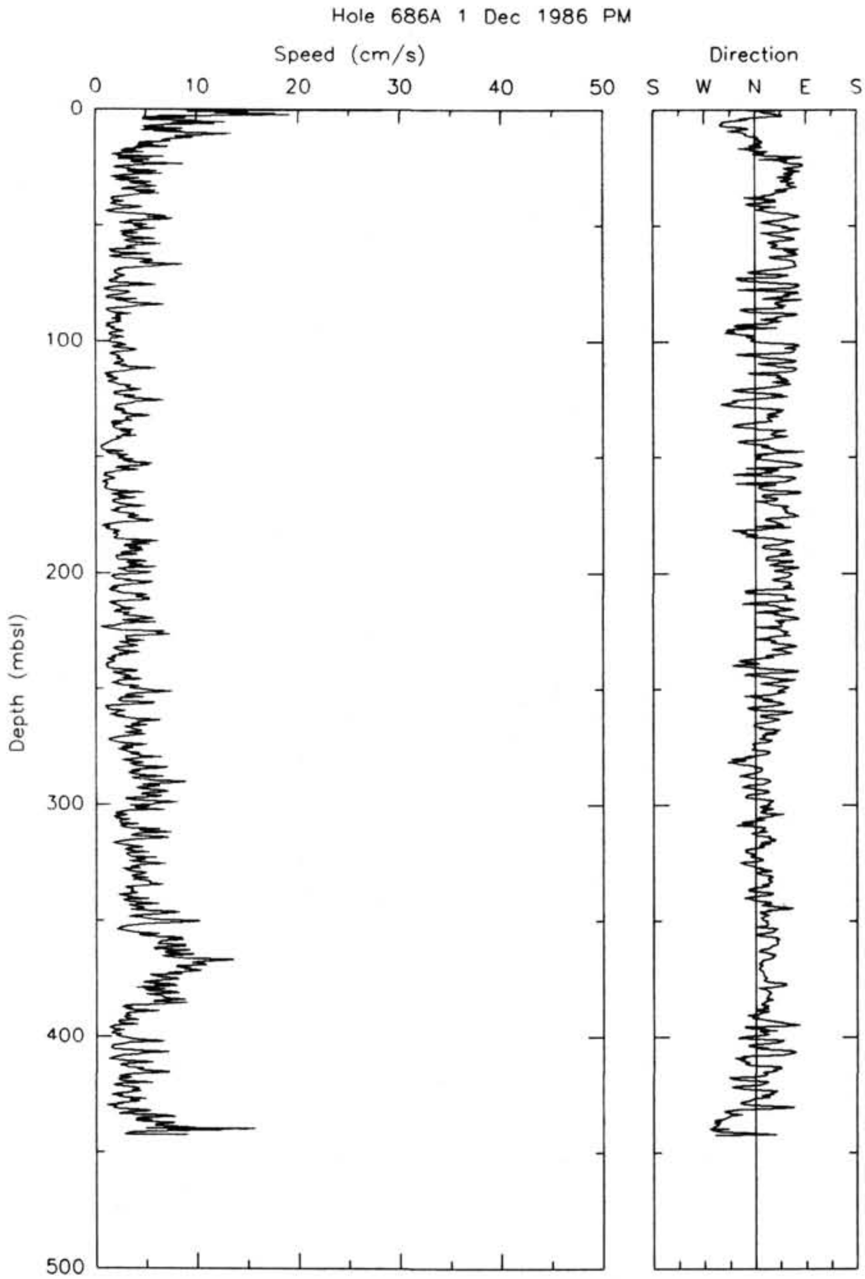

Figure 2. Current-meter profile conducted at Hole 686A on 1 December 1986.

alies. In addition to the induced currents, the internal compass may have been deflected by the influence of the steel hull. We interpreted the recorded surface currents with these factors in mind.

CURRENT-METER DATA

Site 685

Current speeds at Site 685 (Fig. 3) exhibited a high degree of variability over short time spans. Speeds near the surface (0 to 20 m depth) averaged 26.6 cm/s and varied by up to 22 cm/s over a 12-hr period. From the morning until the evening of 27 November, near-surface currents decreased from a high of 37 cm/s directed toward the northwest to a low of 15 cm/s directed toward the north-northwest.

Velocities below a depth of 20 m averaged 10.8 cm/s. Although velocities generally decreased with depth, a high degree of variability was observed with nearly the same rapidity of change as observed in the near-surface currents. Between the morning of 24 November and the morning of 25 November, current speeds increased from 8 to 23 cm/s, with a corresponding decrease over the next 24 hr. From the morning of 27 November until the morning of 29 November, current speeds at a depth of from 20 to 275 m built up gradually from an average of 11 to 23 cm/s. We also observed a change in current direction from north to northwest during the same period and at the same depths. From the morning of 29 November to the evening of 29 November, speeds within this zone slowed to 12 cm/s, but the corresponding directions remained oriented toward the northwest.

Site 686

Site 686 was the only shallow-water (446.8 m) site examined during Leg 112 (Fig. 2). The entire water column to within 4.8 m of the seafloor was profiled. The single profile at this site showed

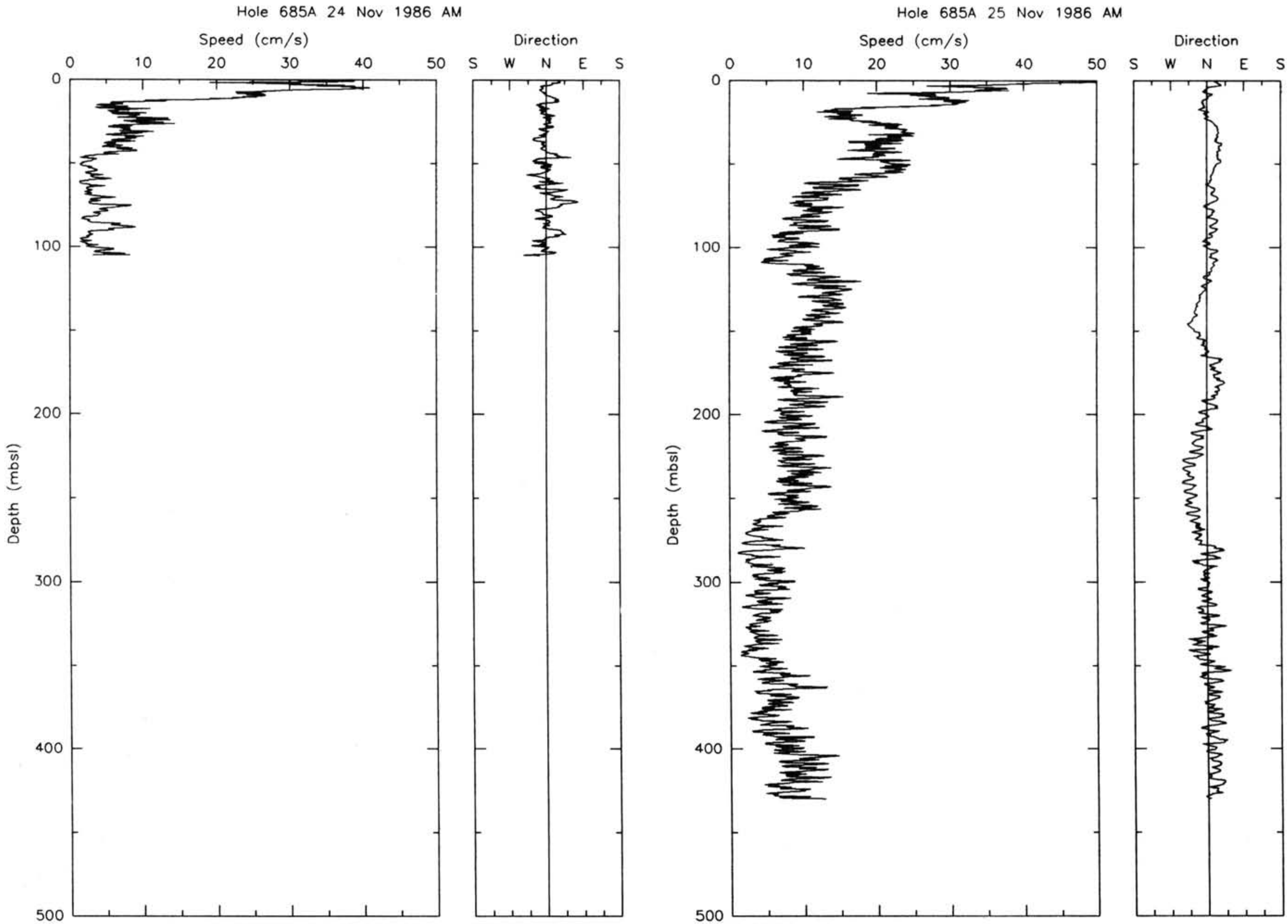

Figure 3. Current-meter profiles conducted at Hole 685A during 24–30 November 1986.

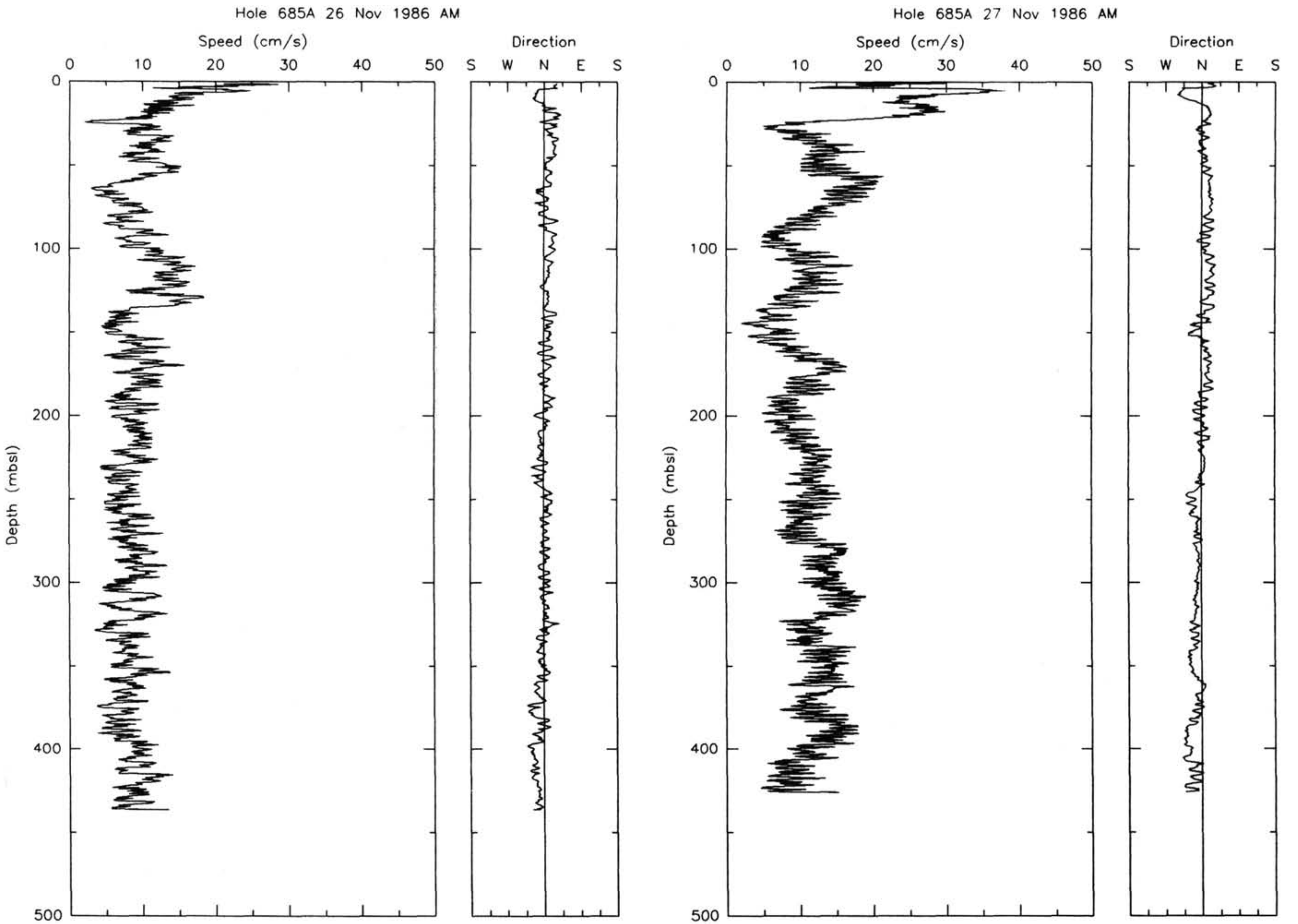

Figure 3 (continued).

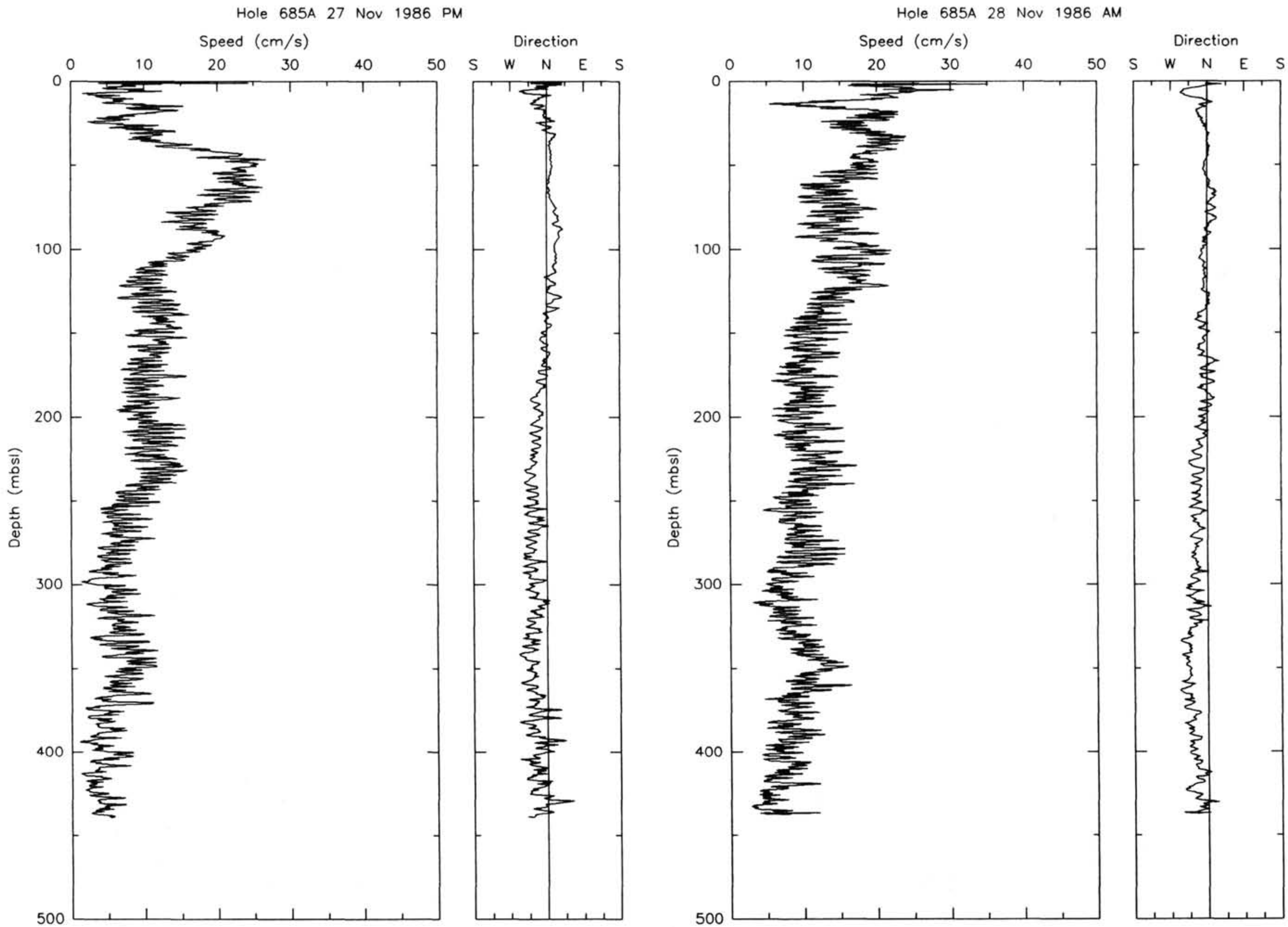

Figure 3 (continued).

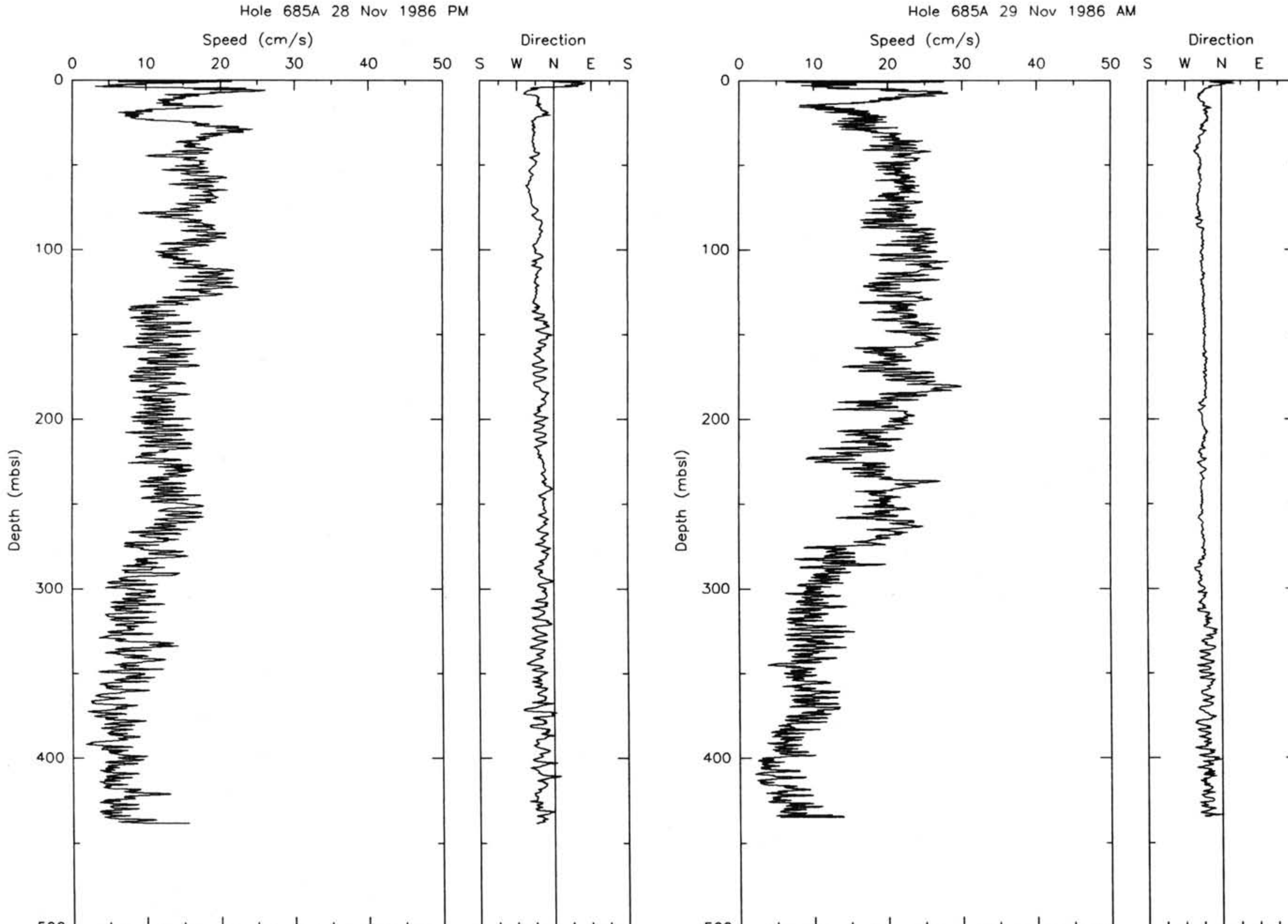

Figure 3 (continued).

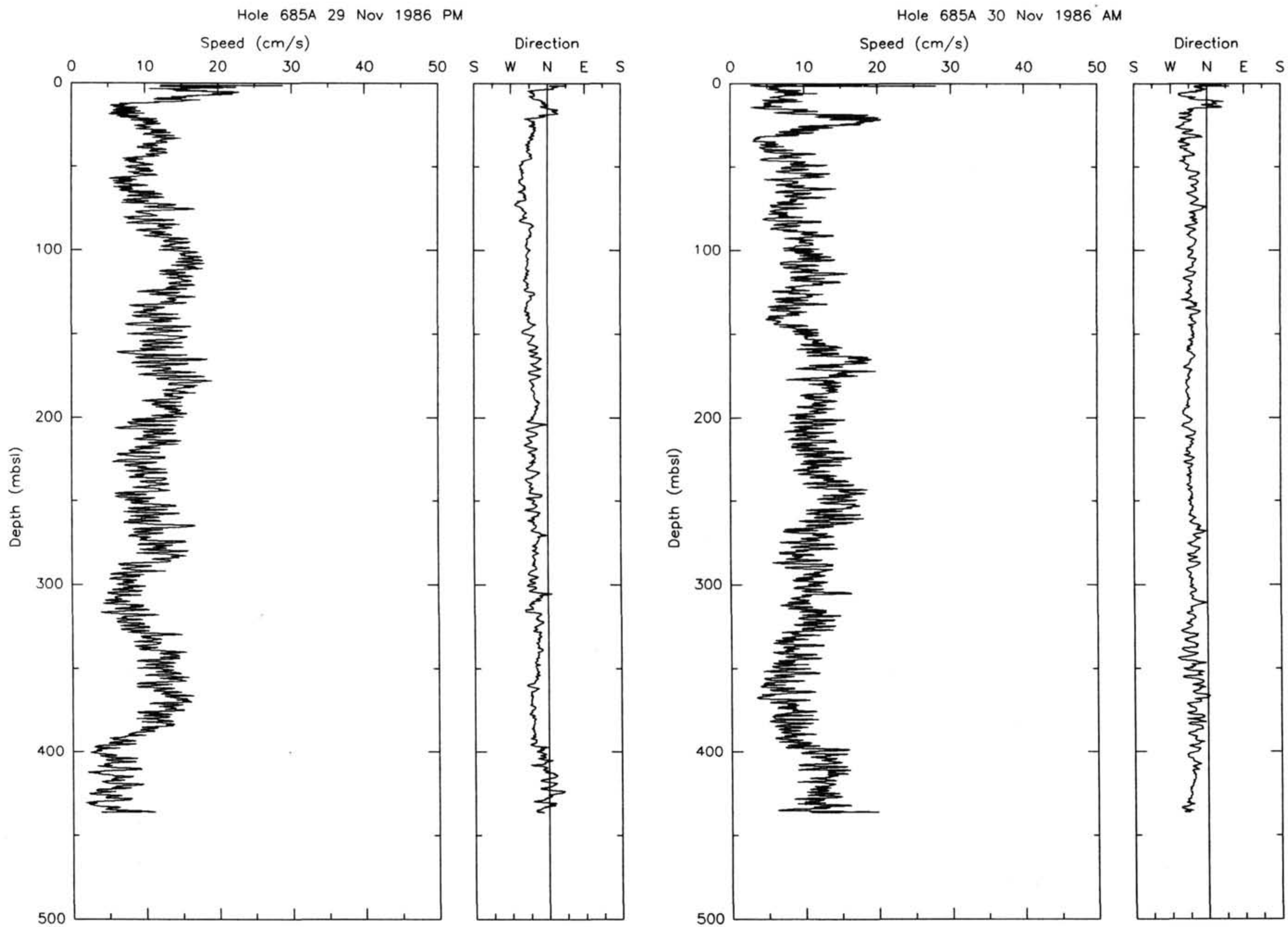

Figure 3 (continued).

a northward-flowing, 20-m-deep, near-surface current, with an average speed of 8 cm/s and a maximum speed of 28 cm/s. This surface current overlies a very slow moving (3 cm/s) current that (1) varied in direction from west-northwest to east-northeast, (2) had maximum speeds of 8 cm/s, and (3) extended to 354 meters below sea level (mbsl). We noted a >90° variation in direction over small vertical distances that most likely results from the instability of the current velocity field at the low observed speeds (1-3 cm/s).

Current directions shifted from a north-northeast direction at 354 m to a westerly, offshelf, direction just above the seafloor. The average current speed increased by 3 to 6 cm/s in this layer, with maximum speeds of 16 cm/s observed near the seafloor.

Site 688

A two-layer current regime, with surface currents that extend to approximately 43 mbsf, was observed at Site 688 (Fig. 4). Surface-layer speeds averaged 11.7 cm/s, with maximum speeds of 73 cm/s. Directions in this layer varied from the east-northeast to the northwest, but generally showed a movement from west to east with depth.

Currents below 43 m at this site were much slower and less variable than the surface currents and had average speeds of 4.8 cm/s, with a maximum of 16 cm/s; these were directed north to north-northwest. Current directions in this zone varied greatly because of the instability of the velocity field.

TEMPERATURE DATA

Site 685

Temperature data from Site 685 indicate an average surface-water temperature of 20.0°C and a shallow-surface mixed layer that extends to 5 m (Fig. 5). The temperature gradient below the thermocline is -1.393×10^{-2} °C/m Measured water temperatures average 9.9°C at 433 m.

Site 686

The average surface temperature at Site 686 was 17.5°C (Fig. 6). No surface mixed layer was evident at this site. A temperature gradient of -1.098×10^{-2} °C/m occurred from the base of the thermocline to 376 m. Colder waters were observed from 376 m to the seafloor, as indicated by a change in thermal gradient to -4.076×10^{-2} °C/m. The temperature at the bottom of the profile (422 m) was 8.02°C.

Site 688

Average surface-water temperature at Site 688 was 21.1°C (Fig. 7). The bottom of the mixed layer here was the deepest of the three sites and had an average depth of 16.4 m. Below the thermocline, the temperature gradient of -1.393×10^{-2} °C/m was identical to that at Site 685. The temperature at 430 m averaged 8.8°C.

CONCLUSIONS

At Sites 685 and 688, north to northwesterly directed surface currents of 11.7 to 17.5 cm/s (average) and north to northwesterly directed subsurface currents of less than 10 cm/s (average) indicate the presence of the oceanic part of the Peru Current. Identical temperature gradients below the thermocline at each site support this conclusion. No evidence of a subsurface countercurrent was observed at either Site 685 or Site 688 down to the maximum depth of profiling.

Of particular interest are the temperature and current profiles at Site 686, where evidence of a very sluggish coastal current moving toward the equator was found. No countercurrent was observed at any depth in the profile. At the base of the colder bottom water at Site 686, velocities increase slightly and shift to the west, in an offshelf direction. This change in direction may be a real shift in direction for a large part of the shelf waters or may result from local topographic steering. Without detailed knowledge of the local topography and without a number of current-meter transects, including the profile at Site 686, we were unable to determine the direction of the regional bottom-water currents.

REFERENCES

Barnett, T. P., 1977. An attempt to verify some theories of El Niño. *J. Phys. Ocean.*, 7:633-647.

Gunther, E. R., 1936. A report on oceanographical investigations in the Peru Coastal Current. *Discovery Rep.*, 13:107-276.

Idyll, C. P., 1973. The anchovy crisis. *Sci. Am.* 228(6):22-29.

O'Brien, J. J., and Hurlburt, H. E., 1972. A numerical model of coastal upwelling. *J. Phys. Ocean.*, 2:14-26.

Pickard, G. L., and Emery, W. J., 1982. *Descriptive Physical Oceanography; An Introduction*: New York (Pergamon Press).

Reid, J. L., 1959. Evidence of a South Equatorial Countercurrent in the Pacific Ocean. *Nature*, 184:209-210.

Schweigger, E. H., 1958. Upwelling along the coast of Peru. *J. Oceanogr. Soc. Japan*, 14(3):87-91.

Smith, R. L. 1983. Peru Coastal Currents during El Niño: 1976 and 1982. *Science*, 221:1397-1399.

Sverdrup, H. U., 1930. Some oceanographic results of the *Carnegie*'s work in the Pacific: the Peruvian Current. *Trans. Geophys. Un., 10th and 11th Annu. Meet.*, 257-264.

Wooster, W. S., and Gilmartin, M., 1961. The Peru-Chile undercurrent. *J. Mar. Res.*, 19(3):97-122.

Wooster, W. S., and Reid, J. L., 1963. Eastern boundary currents. *In* Hill, M. N. (Ed.), *The Sea: Ideas and Observations*: New York (Wiley-Interscience), 11:253-280.

Wyrtki, K., 1963. The horizontal and vertical field of motion in the Peru Current. *Bull. Scripps Inst. Oceanogr.*, 8(4):313-346.

———, 1967. Circulation and water masses in the eastern Equatorial Pacific Ocean. *Int. J. Oceanol. Limnol.*, 1(2):117-147.

———, 1975. El Niño—the dynamic response of the Pacific Ocean to atmospheric forcing. *J. Phys. Ocean.*, 5:572-584.

Ms 112A-122

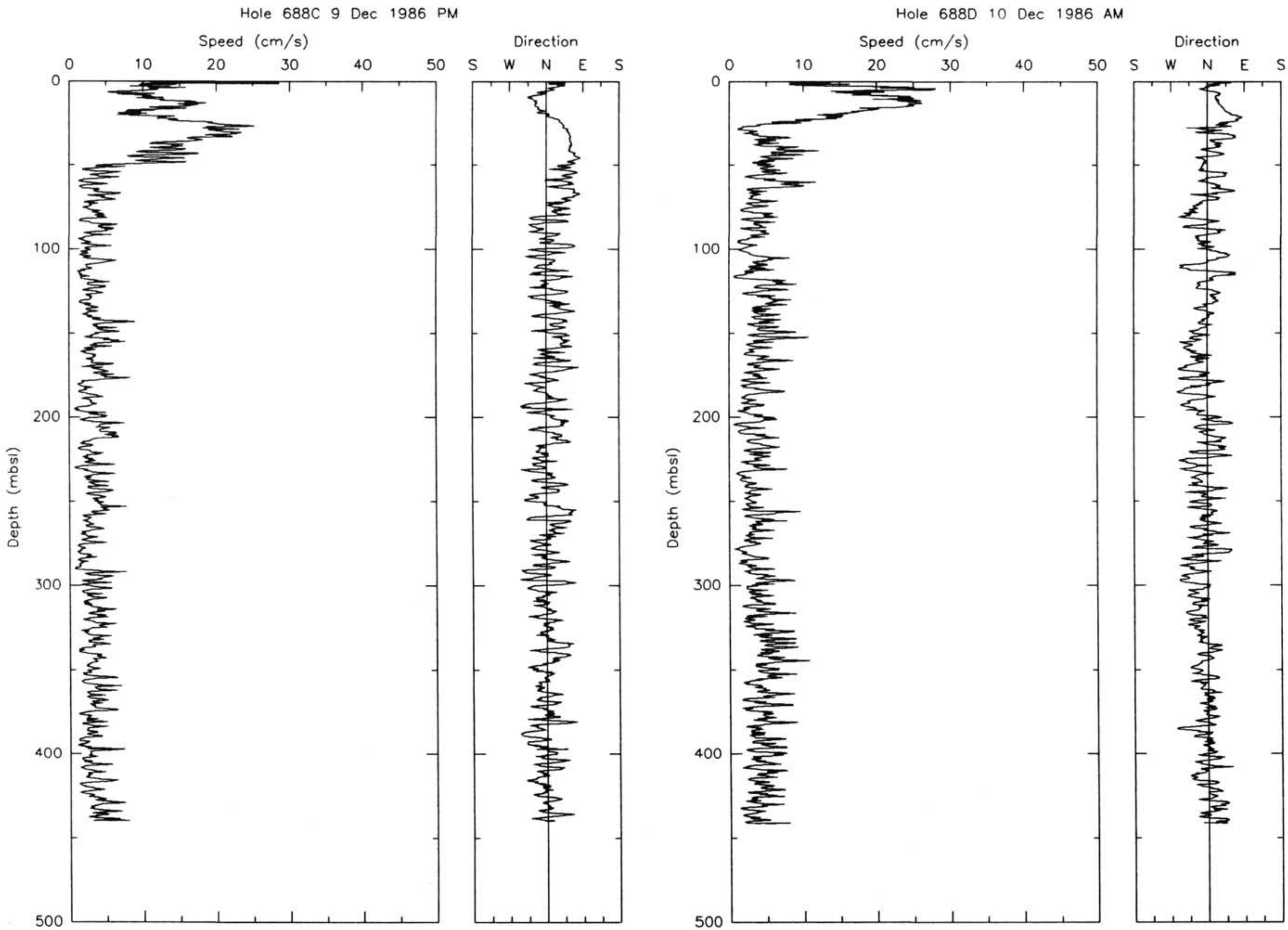

Figure 4. Current-meter profiles conducted at Holes 688C, 688D, and 688E during 9–13 December 1986.

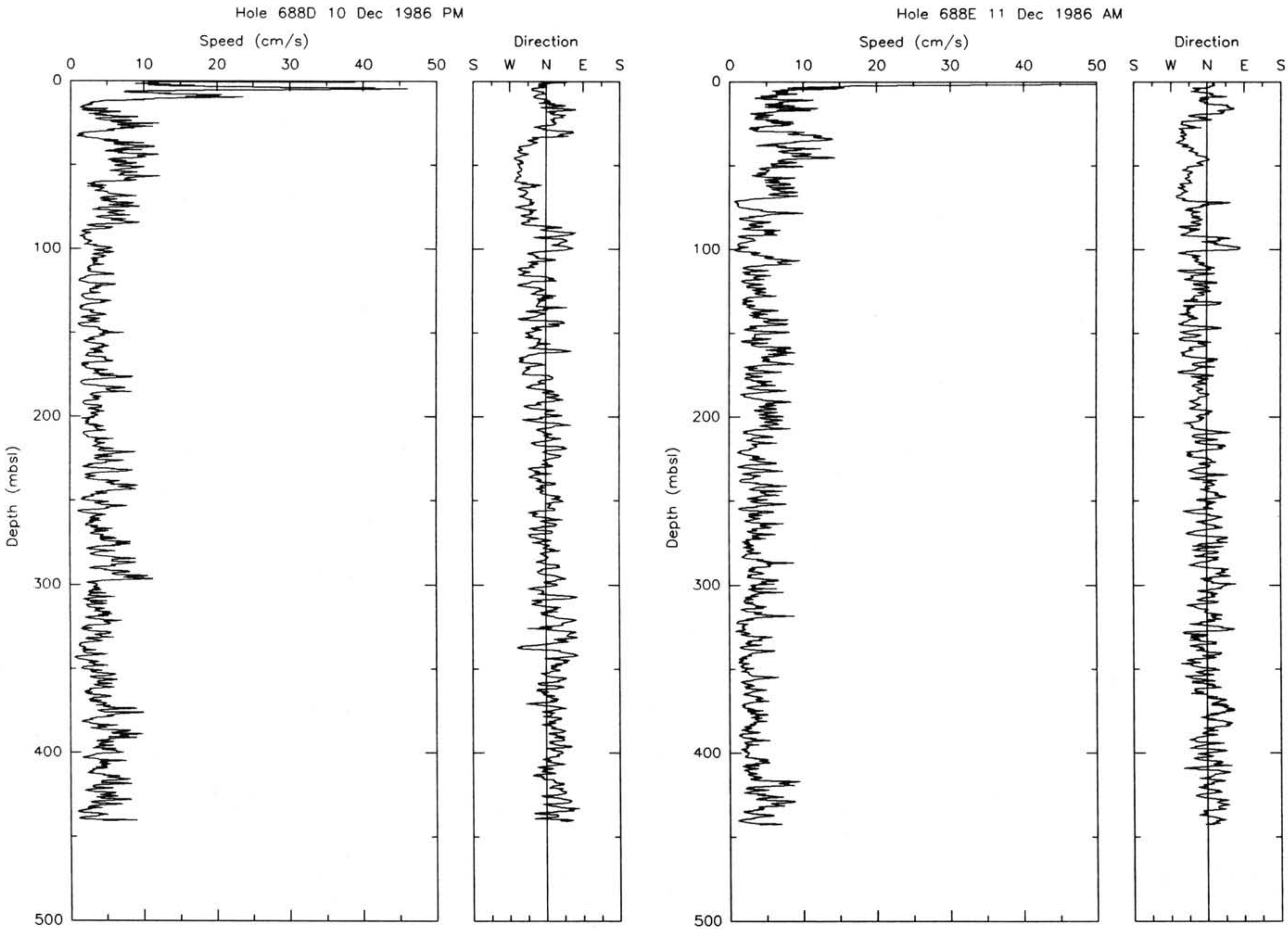

Figure 4 (continued).

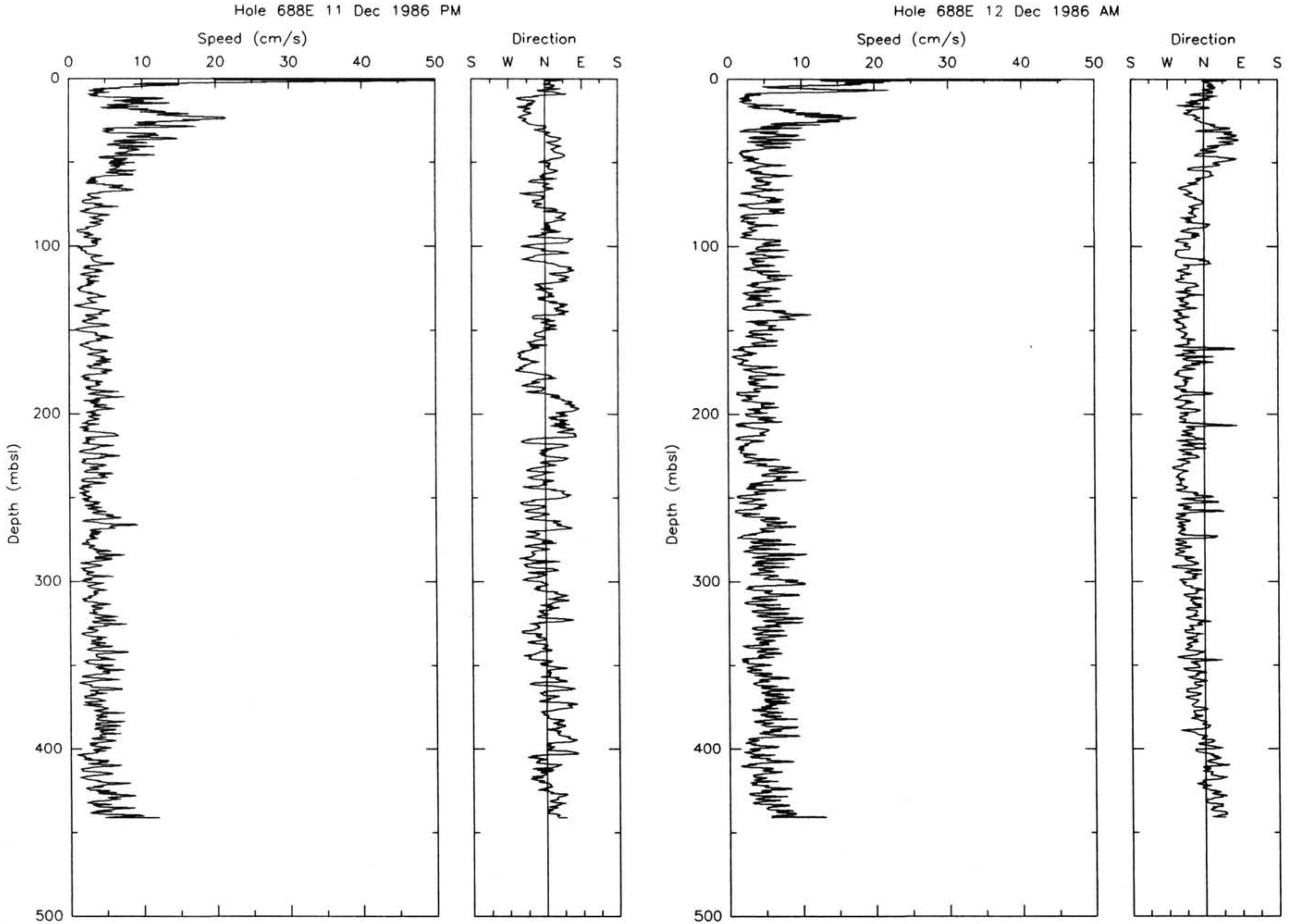

Figure 4 (continued).

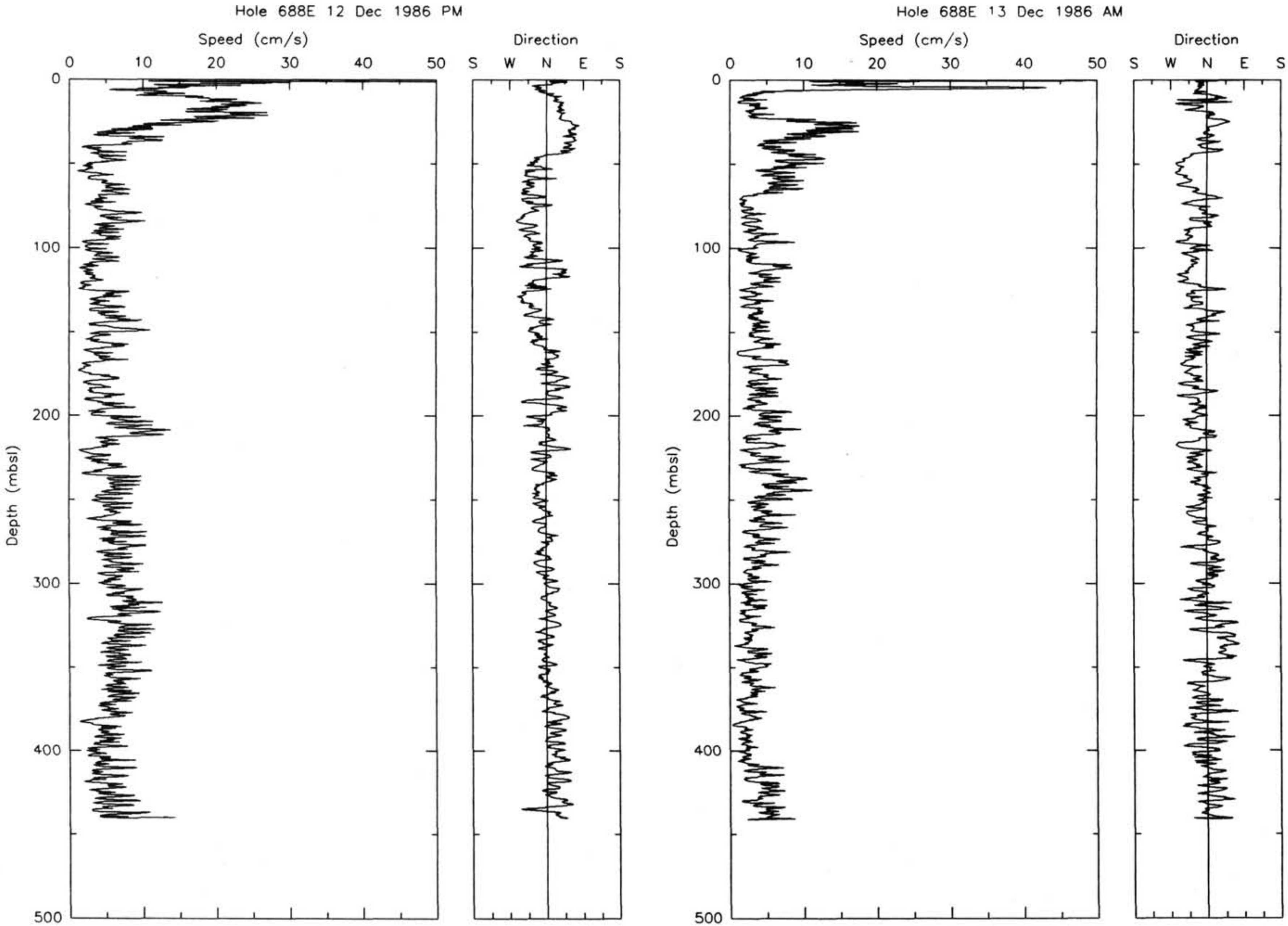

Figure 4 (continued).

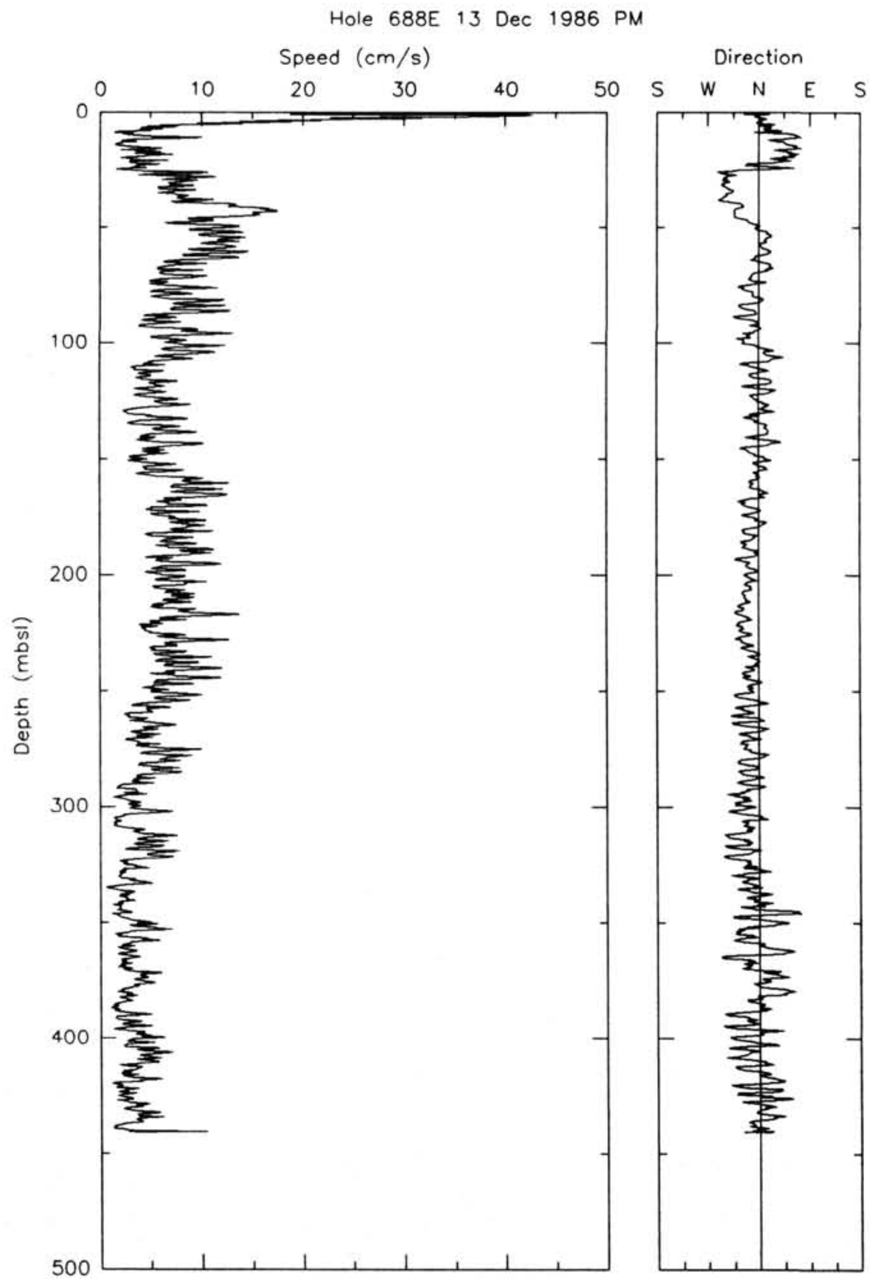

Figure 4 (continued).

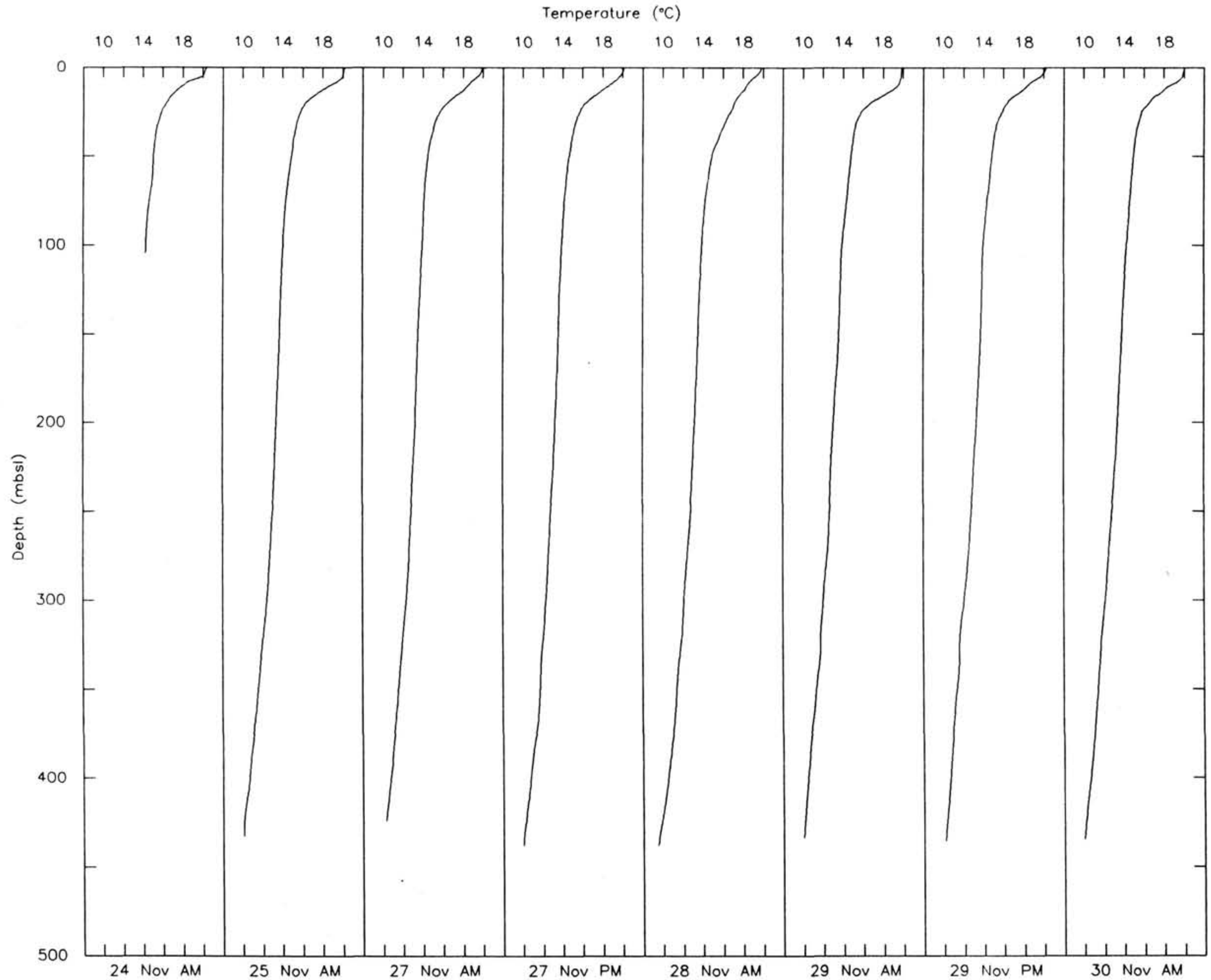

Figure 5. Temperature profiles conducted at Site 685 during 24–30 November 1986.

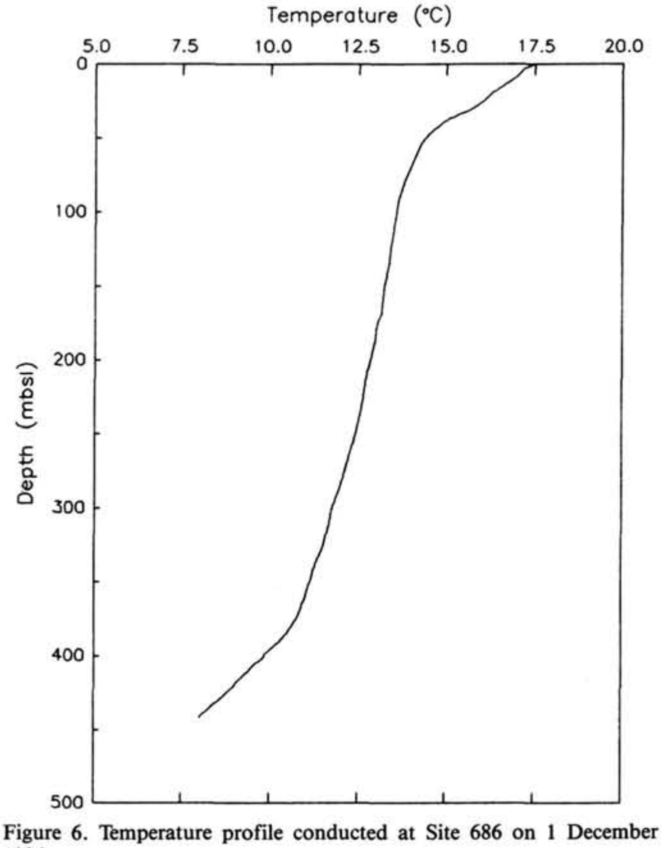

Figure 6. Temperature profile conducted at Site 686 on 1 December 1986.

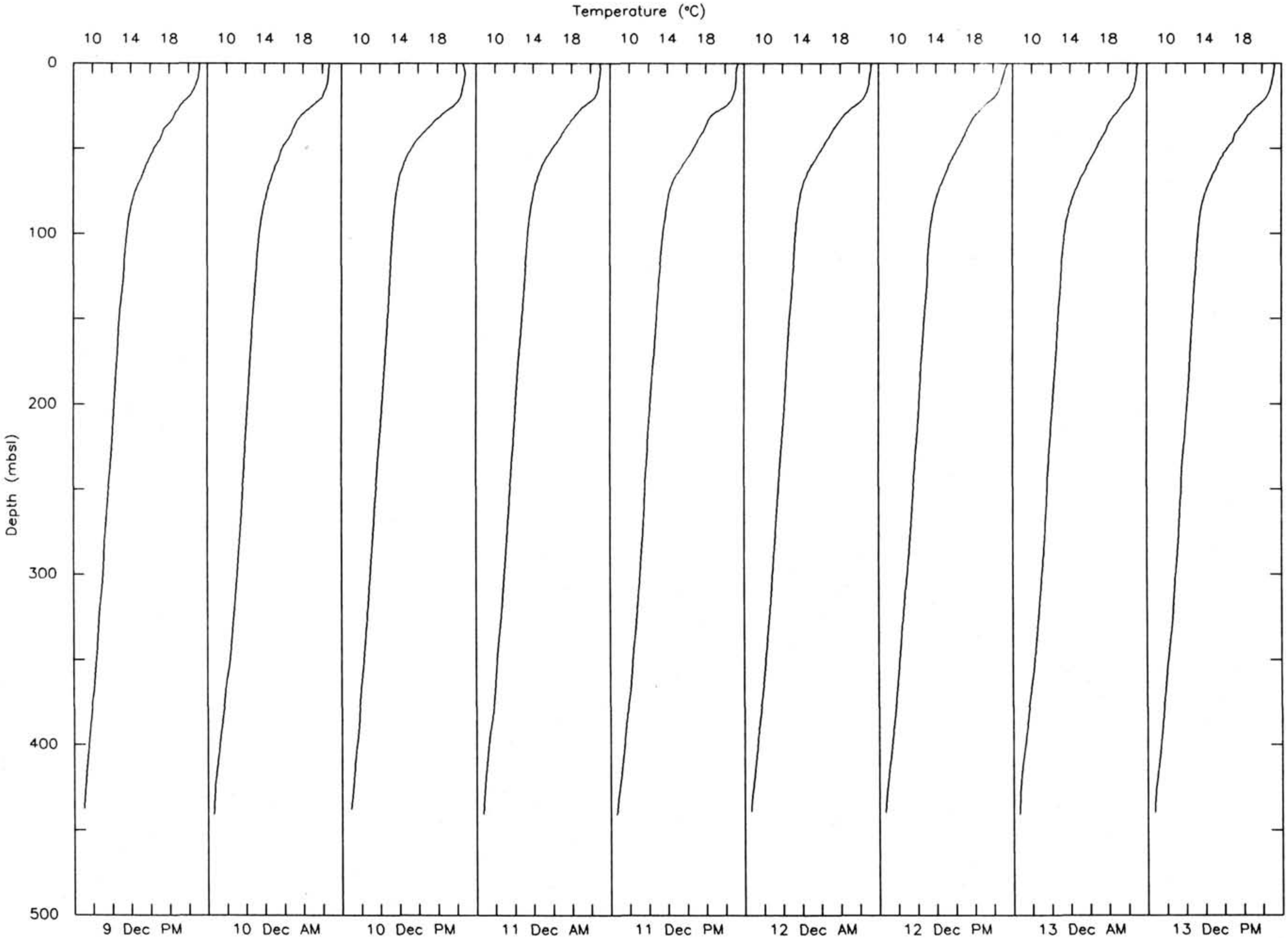

Figure 7. Temperature profiles conducted at Site 688 during 9–13 December 1986.