

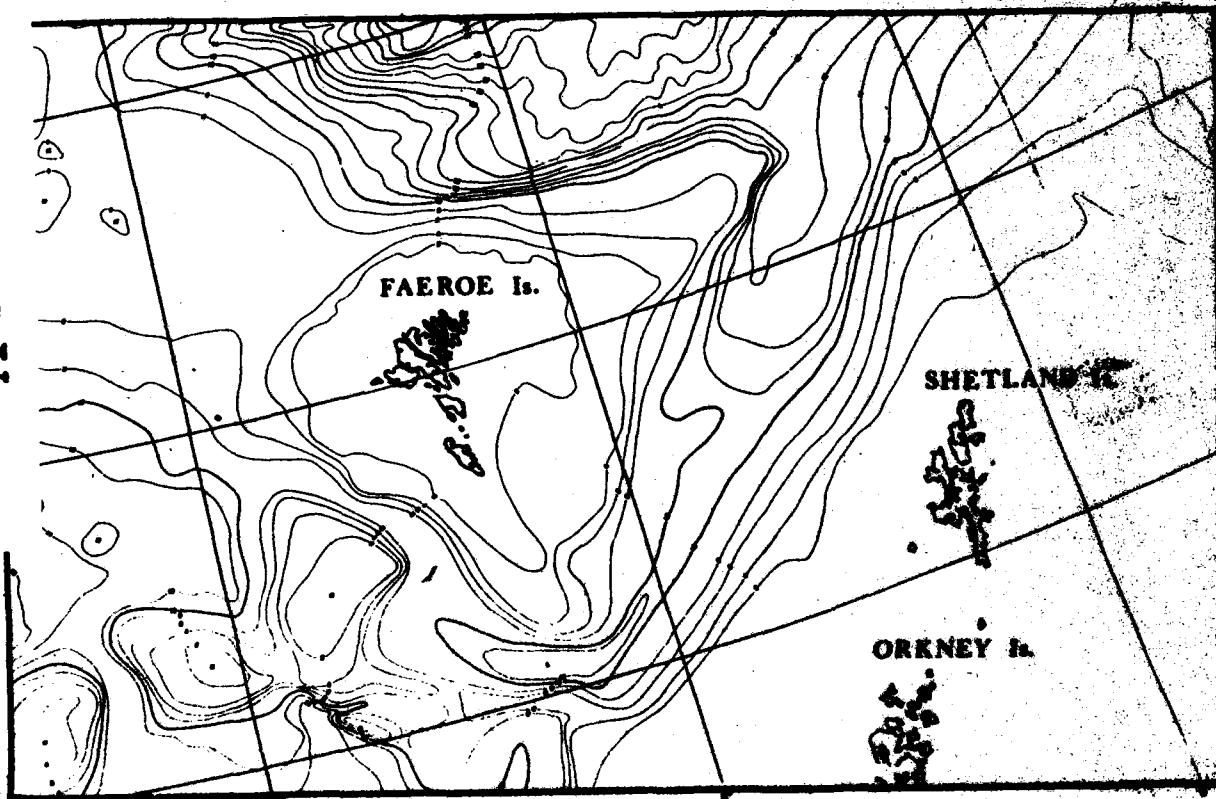
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Naval Ocean Research and
Development Activity
NSTL Station, Mississippi 39529



Data Summary - XCP Profiles in the Vicinity of the Faeroe Islands During October 1982

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April 1982

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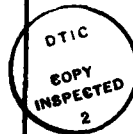
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ABSTRACT

In support of the Ocean Measurements Program in the Iceland-Faeroe (Subpolar) oceanic front region, Expendable Current Probes (XCP) were deployed at four time series stations and in four circulation regimes. Forty-six of seventy-three probes deployed transmitted usable data. We discuss data editing and matching of CTD and XCP casts. We present vertical profiles of XCP data and CTD data. We discuss the primary water types present and their relationship to the subpolar front. We discuss the determination and variation of bulk Richardson numbers.

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DATA SUMMARY:

XCP PROFILES IN THE VICINITY OF THE FAEROE ISLANDS DURING OCTOBER 1980

1. INTRODUCTION

During 14 October - 3 November 1980, oceanographic operations were conducted aboard the USNS KANE (Cruise 270980, Phase II) in support of the Ocean Measurements Program (OMP) in the Iceland-Faeroe (Subpolar) oceanic front region.

Phase II objectives were:

- (a) To assess a complex oceanographic environment in the vicinity of an oceanic front, and
- (b) To describe the temporal and spatial distribution of fine-scale structure, vertical stability, and mixed layer depth in a dynamic oceanic region.

Hallock (1981) has reported in summary detail on operations during all three phases, and Teague (1981a, 1981b) has compiled two volumes of CTD profile data taken during the cruise.

In support of the above objectives, Expendable Current Probes (XCP) were deployed at four time series stations that were occupied for an inertial (13 hours) period and in four circulation regimes:

- (a) South of the Iceland-Faeroe Ridge
- (b) Within the Subpolar front
- (c) North of the front
- (d) On the Norway side of the eastern extension of the front

It was hoped that XCP data would provide insight into:

- (a) Variability of shear due to inertial modulation
- (b) Bulk Richardson numbers might be derived from XCP and CTD data
- (c) Estimates of shear and Richardson number variability might be determined.
- (d) Effects of intense geomagnetic activity on probe performance

2. DATA COLLECTION AND PROCESSING

Vertical profiles of current velocity between about 25 m and 800 m were obtained with an XCP system (Sanford, 1980). The instrument is essentially an elongated XBT fitted with special electronics and sensors to detect the weak electric potential induced by the movement of sea water through the earth's magnetic field. The output is a velocity profile related to an unknown depth independent reference velocity. The probes also transmit a temperature profile that can be used to make depth comparisons with CTD casts (Table 1) when available. Performance trials indicated that the system has an rms uncertainty of about 1 cm/s (Sanford, 1980).

Conductivity, temperature and depth (CTD) measurements were taken with a Neil Brown Mark III CTD. Instrumentation details are described by Teague (1981a). RMS uncertainty in temperature and salinity are about 0.005°C and 0.005 g/kg, respectively.

Forty-six of seventy-three probes deployed transmitted usable data (Table 1). Four of these forty-six probes had defective temperature outputs, but the u and v current profiles appeared reasonable (Appendix A) in comparisons with others obtained in nearby profiles.

The Applied Physics Laboratory/University of Washington (APL/UAW) furnished a set of edited profiles with a vertical sample interval of about 2 to 3 meters. We interpolated these profiles, using a cubic spline, to 1 meter intervals, so they would be compatible with the 1 meter NAVOCEANO CTD data file.

3. HYDROGRAPHY

The hydrography in the vicinity of the Faeroe Islands is dominated by the Iceland/Faeroe Ridge and the Subpolar front (Fig. 1). Both features tend to separate the cold, less saline arctic and subarctic waters from the warm, saline Atlantic waters. The surface expression of the front is generally taken as the 35.0 g/kg isohaline, which represents the zone of maximum horizontal salinity gradients, while the vertical expression of the front is most easily visualized when displayed as the zone separating the several water types present. This technique has been discussed by Hermann (1967) and Hansen (1979).

The simplified representation shown in Figure 2 gives some idea of the areal extent of this front for a selected region. Its vertical scope is over several hundreds of meters, and its horizontal scale is over hundreds of kilometers. The shaded area around the solid line indicates that the front is rich in fine structure and many degrees of mixing intensities are possible. The solid line labeled 100 represents the approximate boundary below which the water masses contain no Atlantic type waters. The several water types used to determine this line were: Modified North Atlantic Water (MNA, T=8.5°C, S=35.24 g/kg), Norwegian Sea Deep Water (NS, T=-0.5°C, S=34.92 g/kg) and North Icelandic Winter Water/Arctic Intermediate Water (NI/AI, T=3.0°C, S=34.78 g/kg). Traditionally, NI/AI water has a salinity of 34.88 g/kg, but on the basis of observations we have used 34.78 g/kg. Meincke (1978) used this same salinity value attributing its decrease to a 20 year trend in this area.

This front region is a complex oceanographic area resulting from the mixing and interacting of several water types with significantly different characteristics. Modified North Atlantic Water dominates the surface flow. North Icelandic Winter Water and Arctic Intermediate Water are found at intermediate depths. Norwegian Sea Deep Water, which is formed by the surface cooling of North Atlantic Water, sinks along the polar front northwest of the Faeroe Islands and spreads throughout the area as a southward intermediate and deep flow, with the Iceland-Faeroe Ridge and polar front acting as an effective barrier in preventing the colder waters from "overflowing" into the northeastern Atlantic (Hansen, 1979). Vertical oscillations of several hundreds of meters with horizontal length scales of 60 km or less appear to occur.

Mysak (1977) used hydrographic data to show the presence of isopycnal oscillations with horizontal length scales of 30-60 km. Analysis of current meter data indicated energy peaks at almost all depths of 2-3 days. He attributed these

oscillations to baroclinic instability in the Norwegian Current. Figure 3 indicates that vertical and horizontal oscillations occur throughout the water column in the frontal zone.

Oscillations with periods between 8 to 11 days and from 2 to 5 days have been reported by Meincke and Kvinge (1978) from one year observations of current meter records between Iceland and Scotland at two locations.

Hansen (1979) presented evidence for the existence of eddies and meanders with horizontal scales on the order of 30 to 50 km and vertical scales on the order of 100 to 200 m, extending down to about 500 m. Figure 4 indicates the presence of a cyclonic eddy or meander at the 100 m level across the front. The barbed arrows in Figure 4 show the relative current along the 100 m depth. Shear probes 546, 547, and 548 show significantly different patterns in both speed and direction. Shear probe 548 shows a northeast current at about 45 cm/sec, probe 547 a northwest current at 20 cm/sec, and probe 546 a southeast shear at about 10 cm/sec. Figures 5 and 6 show the vertical u and v current variation for the three probes. Most of the variation appears in the u component, not only in amplitude but in phase as well, particularly when comparing probes 546 and 547 between 100 m and 300 m where a 180° phase shift is indicated. Both u and v components of probe 546 appear to indicate a significant change in speed at about 200 m and 400 m. That change could indicate where probe 546 entered and left the strongest part of the front (Fig. 2).

From visual inspection of Figures 2, 5, and 6 the following observations are made:

| <u>Shear Probe</u> | <u>Component</u> | <u>Comments</u> |
|--------------------|------------------|---------------------------------------|
| 546 | u,v | 150-250 m probe crosses through front |
| 547 | u | 150-250 m probe crosses through front |
| 548 | u,v | 400-450 m probe crosses through front |

The resulting complex water mass distribution appears to be a shallow phenomenon, with the deeper water below about 600 m being more uniform, occurring throughout the year. Countryman (1969) reported on similar conditions during July and August 1963, as did Meincke (1978) during June 1977 and Hansen (1979) during September 1973.

4. XCP AND CTD DEPTH AND TEMPERATURE COMPARISONS

Due to adverse weather throughout much of the cruise, synoptic drops of XCP and CTD were prohibited. Time differences of one-half hour and greater between XCP and CTD deployment were common (Table 1).

XCP depths are determined from a quadratic empirical equation that incorporates a nominal fall rate of about 4.5 m/sec. Varying deployment conditions may cause significant deviations between true depth and the values calculated by the formula, so some corrections of probe depth errors should be attempted.

An accepted method of checking shear probe depth data is to make a comparison between temperature-depth profiles derived from CTD (Appendix B) records and the temperature profiles from the XCP cast. Green and Saunders (1981) showed a

statistical method for making probe depth corrections. Their method is most applicable to cases in which CTD and XCP profiles are nearly simultaneous. Since this condition was rare during these operations a more direct simplified check was used. The few cases where direct CTD/XCP intercomparisons were made showed that depth and temperature corrections were small.

In most cases there was a thoroughly mixed surface layer overlying a sharp thermocline. The surface layer temperature was used as the reference for XCP temperature offset correction, and the depth of the mixed layer furnished a distinct reference depth for probe profiles. The near surface thermocline or depth of mixed layer was determined by the depth at which the thermal gradient exceeded $5.6 \times 10^{-3} \text{ }^\circ\text{C/m}$ (James, 1966).

Figures 7 and 8 are an example of the vertical temperature derivative ($^\circ\text{C/m}$) for shear probe 504. The dashed vertical lines are at plus and minus $5.6 \times 10^{-3} \text{ }^\circ\text{C/m}$, the temperature gradient boundaries used in defining the bottom of the mixed layer. Depth of the bottom of the mixed layer is indicated in both figures, but more clearly in Figure 7. Note that the two depths do not agree because the depth determined from the shear probed data was somewhat shallower due to the assumed fall rate of the probe. Note, also, however, that using this method can result in defining several deeper layer depths. These secondary layer depths can usually be distinguished from the near-surface layer depth. Since this method of determining layer depths is subjective, visual inspection of the smoothed profiles is mandatory and some "eyeballing" is unavoidable.

Smoothed temperature profiles of XCP and CTD casts are located in Appendix C. Aside from several instances of obvious horizontal temperature offsets the smoothed profiles track each other fairly consistently. Some of the profile differences are due to finestructure detail caused by temporal and spatial variations in the water column, while other variations occur as a result of the nonlinearity characteristics of the XCP temperature probe.

There appears to be generally good agreement between CTDs and XCPs on the depth of the mixed layer. Four of the drops indicated no depth difference, four indicated a deeper depth as determined by the shear probe, and six indicated a deeper depth as determined by the CTD. Maximum difference in depth was -34 meters (drop 525) where the shear probe recorded a deeper depth to the bottom of the mixed layer. These errors can be attributed to uncertainties in launch time start and probe dynamic at profile initiation (Green and Saunders, 1981), as well as rich finestructure variability in the data.

5. STRATIFICATION

The Richardson number (Ri) is an indicator of dynamical stability of a stratified shear flow:

$$Ri = \frac{N^2}{S^2}$$

where N = Brunt-Väisälä frequency and

S = current shear

In general, for $Ri > 0.25$, disturbances of the flow (such as internal gravity waves) do not grow due to the stabilizing effect of the static stability. When $Ri < 0.25$, flow disturbances grow rapidly and lead to turbulence or overturning of the stratification.

Calculating Richardson numbers over a fixed vertical interval (bulk Richardson number) may not be representative of the flow at some particular depth, since the largest values of vertical density and velocity gradients occur in thin layers of various thickness that will most likely be randomly located with respect to any feature (Federov, 1978). Averaging vertical gradients over large depth intervals may lead to an overestimate of the Richardson number since the density gradient may increase more rapidly than the vertical velocity gradient.

Smoothed one meter vertical profiles of Brunt-Väisälä frequency (N^2), shear (S^2), and bulk Richardson number (Ri) are presented in Appendix D, while scatter plots of bulk Richardson numbers are presented in Appendix E. The Ri profiles in Appendix D were made from values of N^2 and S^2 that had an estimated signal-to-noise ratio of at least one. These values fall in quadrant 1 of the log-log plots in Appendix E.

The depth of bulk maximum Richardson number (smoothed 1 m interval) varied from about 85 m to about 505 m (Table 2). Bulk Richardson number profiles indicated a wide range of variability. In homogeneous, well-mixed zones Ri approached or was equal to zero, particularly in the deeper Norwegian Sea water below about 500 m. Separating zones of low Ri values are interface layers with larger Ri values (up to about 47, XCP 534 at 72 m) just below the bottom of the mixed layer. Evans (1981) found similar inter-fingering of high (up to 100) and low (0) Ri numbers in tropical Atlantic waters that showed evidence of salt fingering or thermohaline staircase structure. Evans claims that these high values (higher than typical thermocline values of 1 to 3) indicate stable flow across the interfaces and that the salt-finger fields will be undisturbed. In these cases the microscale variability in temperature and salinity will be intense.

Estimated values of Ri when passing through the strongest part of the subpolar front were: $Ri = 5$ at 425 m for XCP 548; $Ri = 16$ at 374 m for XCP 547; $Ri = 19$ at 176 m for XCP 546. In the vicinity of the front, shear varied in both magnitude and direction (Figures 4, 5, 6).

There did not appear to be any obvious overall relationship between the depths of maximum N^2 and S^2 except that at several stations (504, 534, 547) a maximum in both N^2 and S^2 occurred just below the bottom of a well-defined mixed layer. The maximum was usually indicated by a distinct sharp signature in N^2 rather than in S^2 . This is consistent with the observation that the diffusion of momentum by the shear is greater than the diffusion of the density due to the vertical constraint of gravity.

Successful probe operation is dependent upon the magnitude and stability of the earth's geomagnetic field. During periods of intense magnetic activity or magnetotelluric disturbances, data contamination may occur. This is particularly true at higher geomagnetic latitudes where the earth's magnetic field is more active. Figure 9 is a plot of the daily indices of geomagnetic activity (A_k) for Anchorage, Alaska, and Leirvogur, Iceland. Although several major geomagnetic storms did occur at operational latitudes during the period 11 and 23 October, with diminished amplitude at Leirvogur compared to Anchorage, no discernible effect was noted on probe performance.

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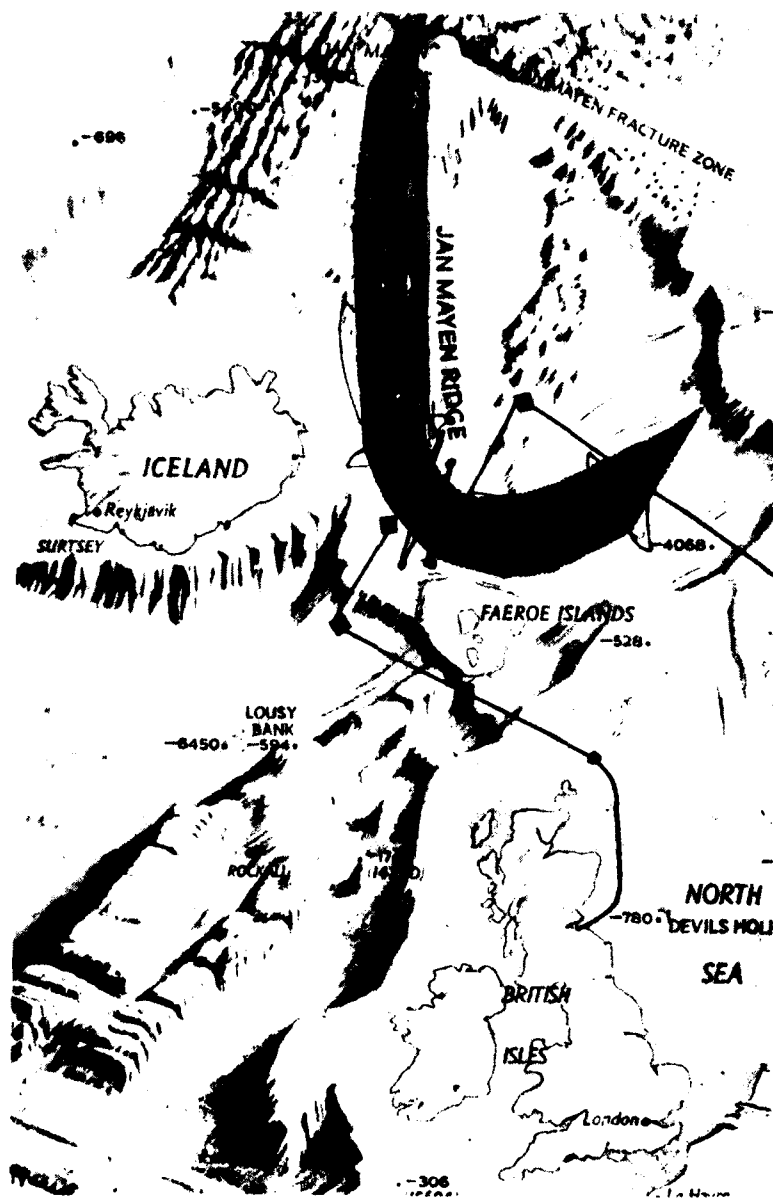


Figure 1. Schematic bathymetric relief of the Northeast Atlantic and the Subpolar Front. Cruise Track and primary (◆) type III stations.

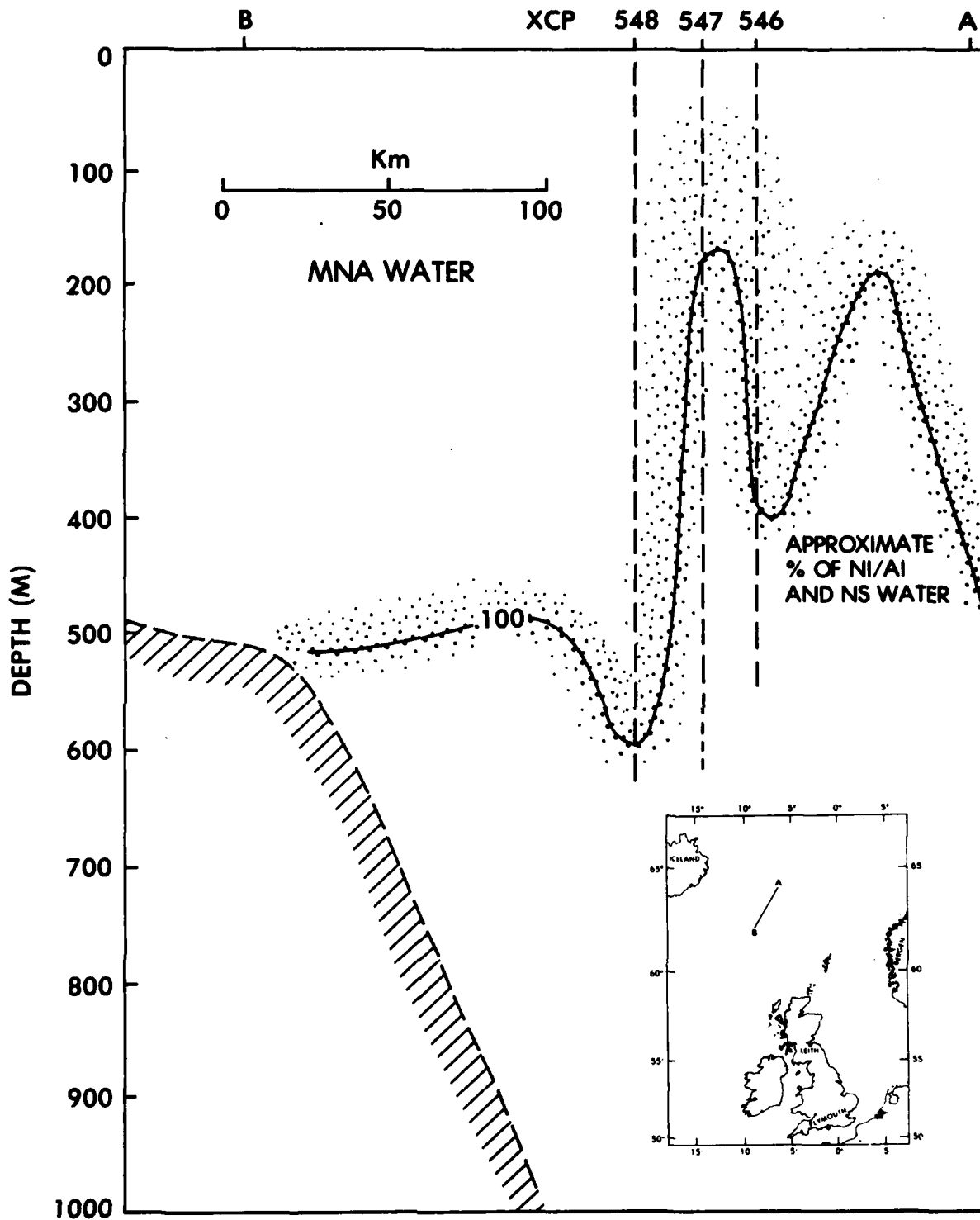


Figure 2. Vertical section along Line AB

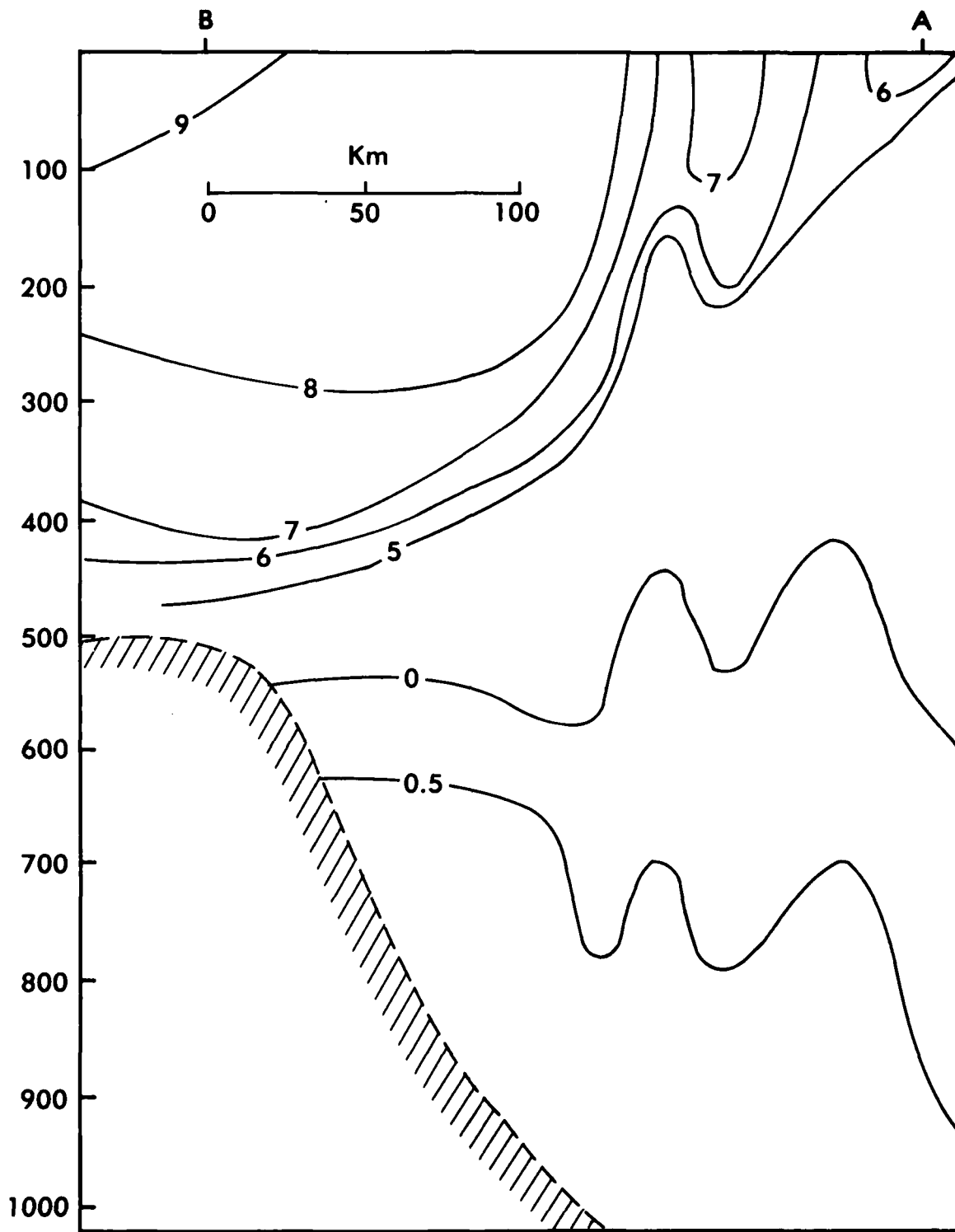


Figure 3. Temperature section along Line AB

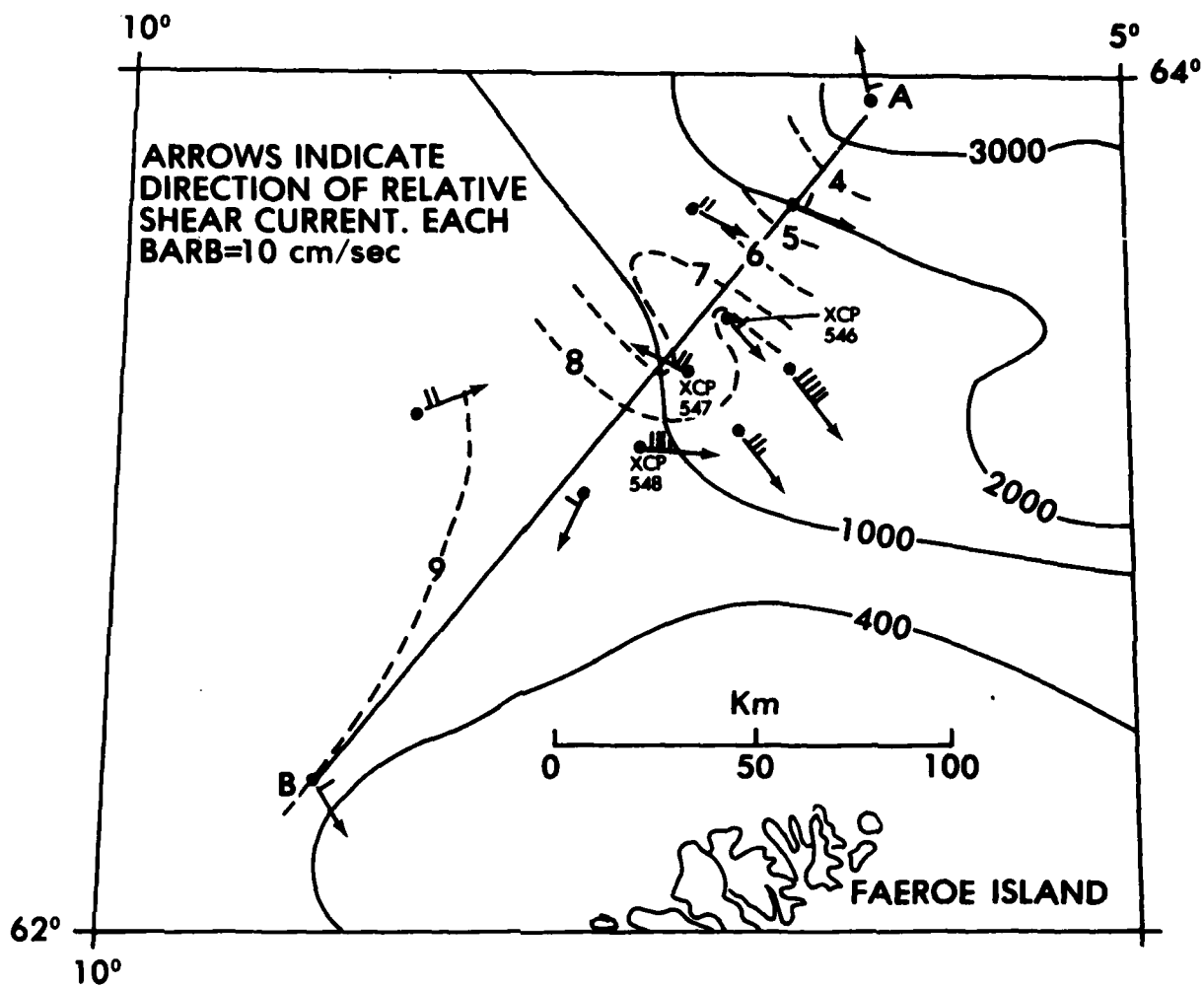


Figure 4. Temperature field at 100 m along Line AB

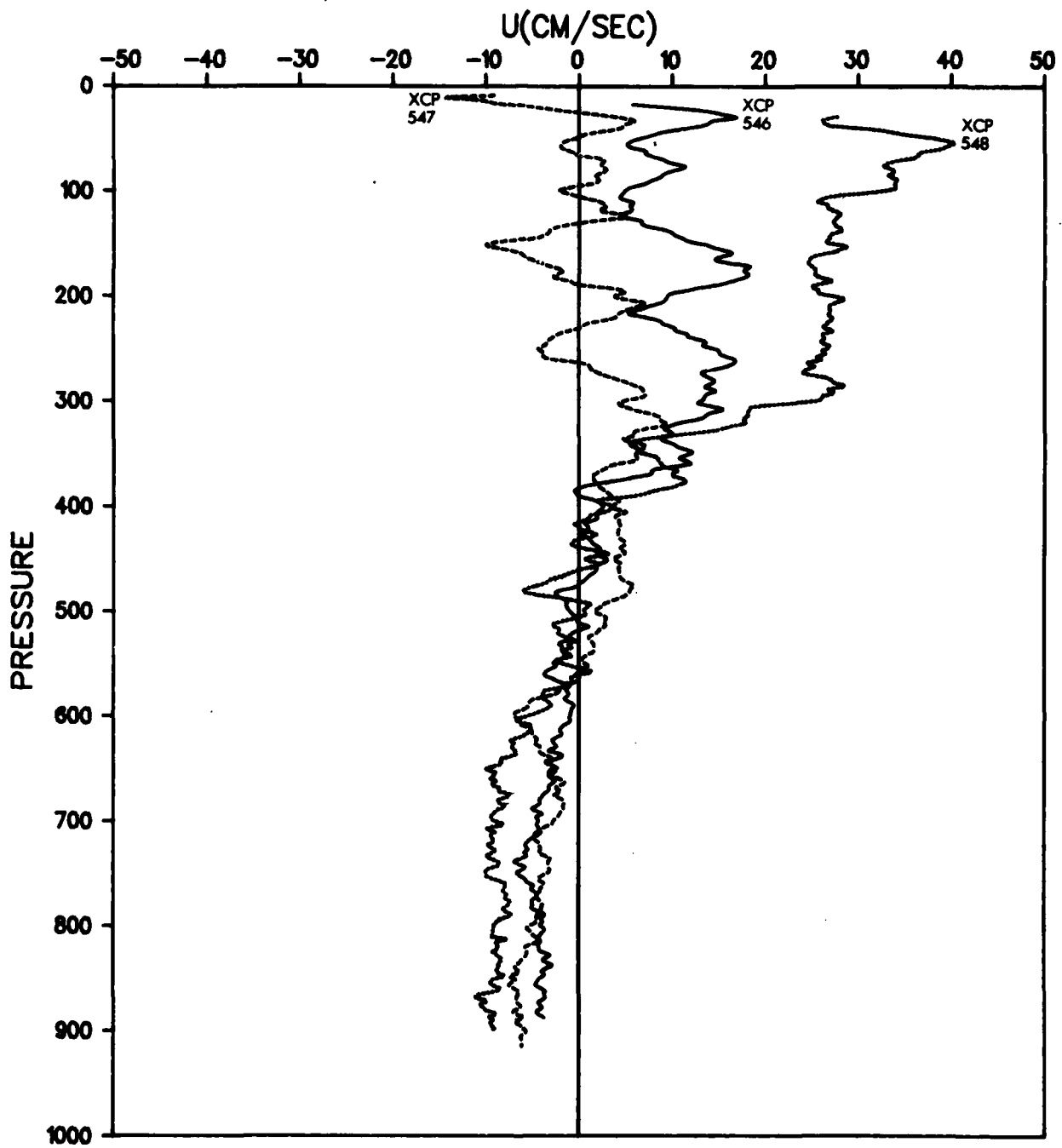


Figure 5. Crossing the front (U component of current)

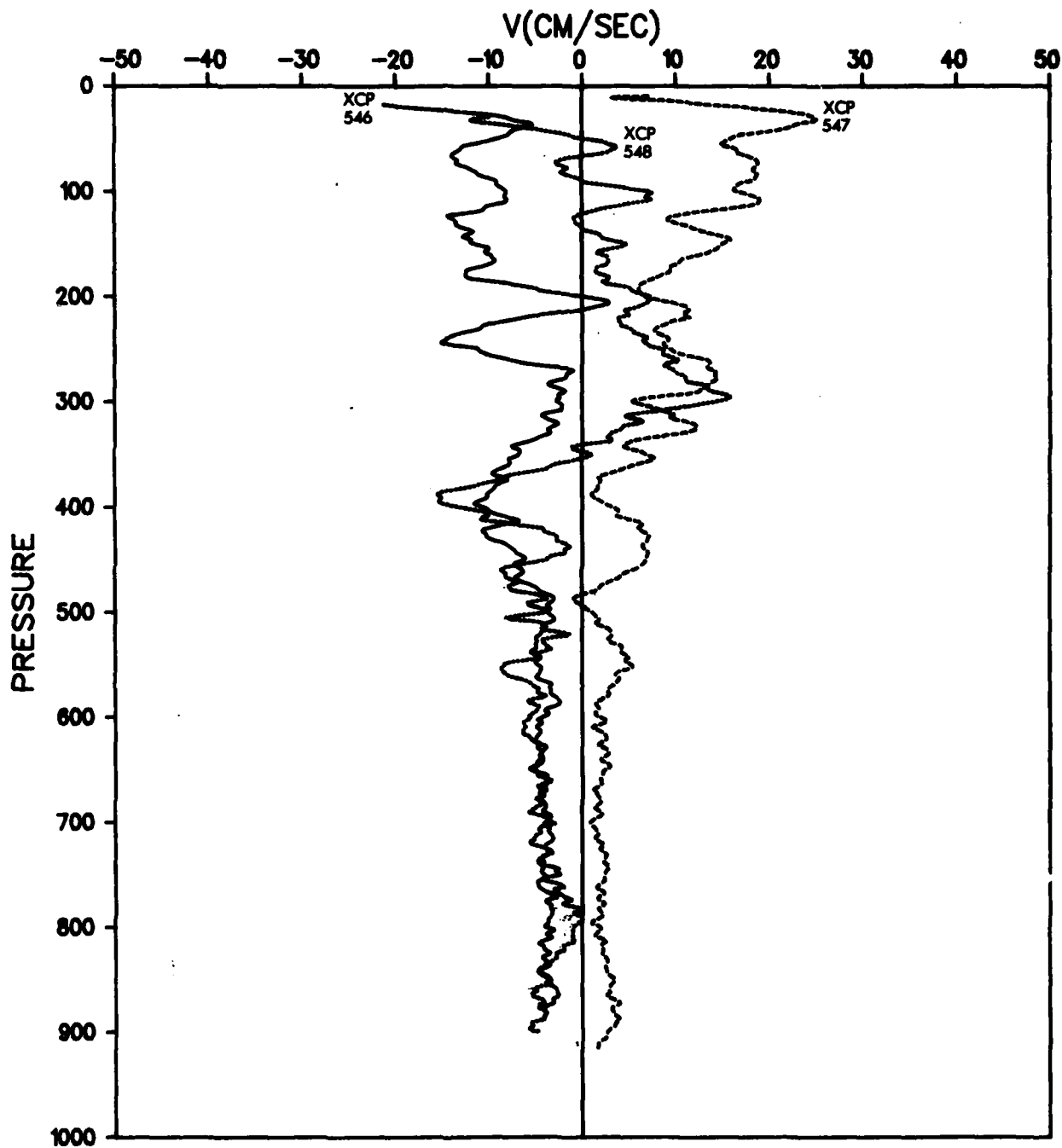


Figure 6. Crossing the front (V component of current)

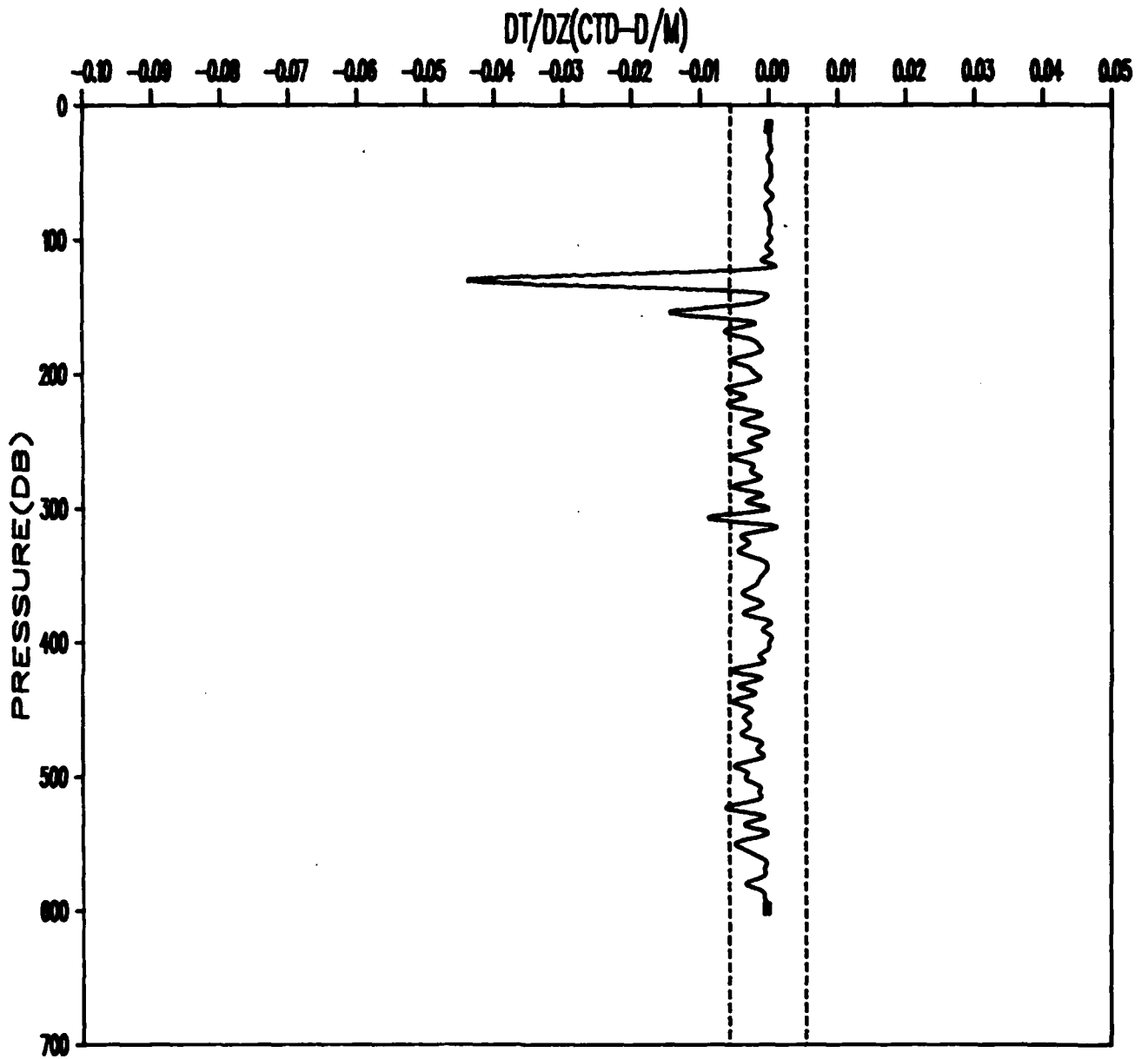


Figure 7. Derivative of CTD (Cast 109076) temperature with depth

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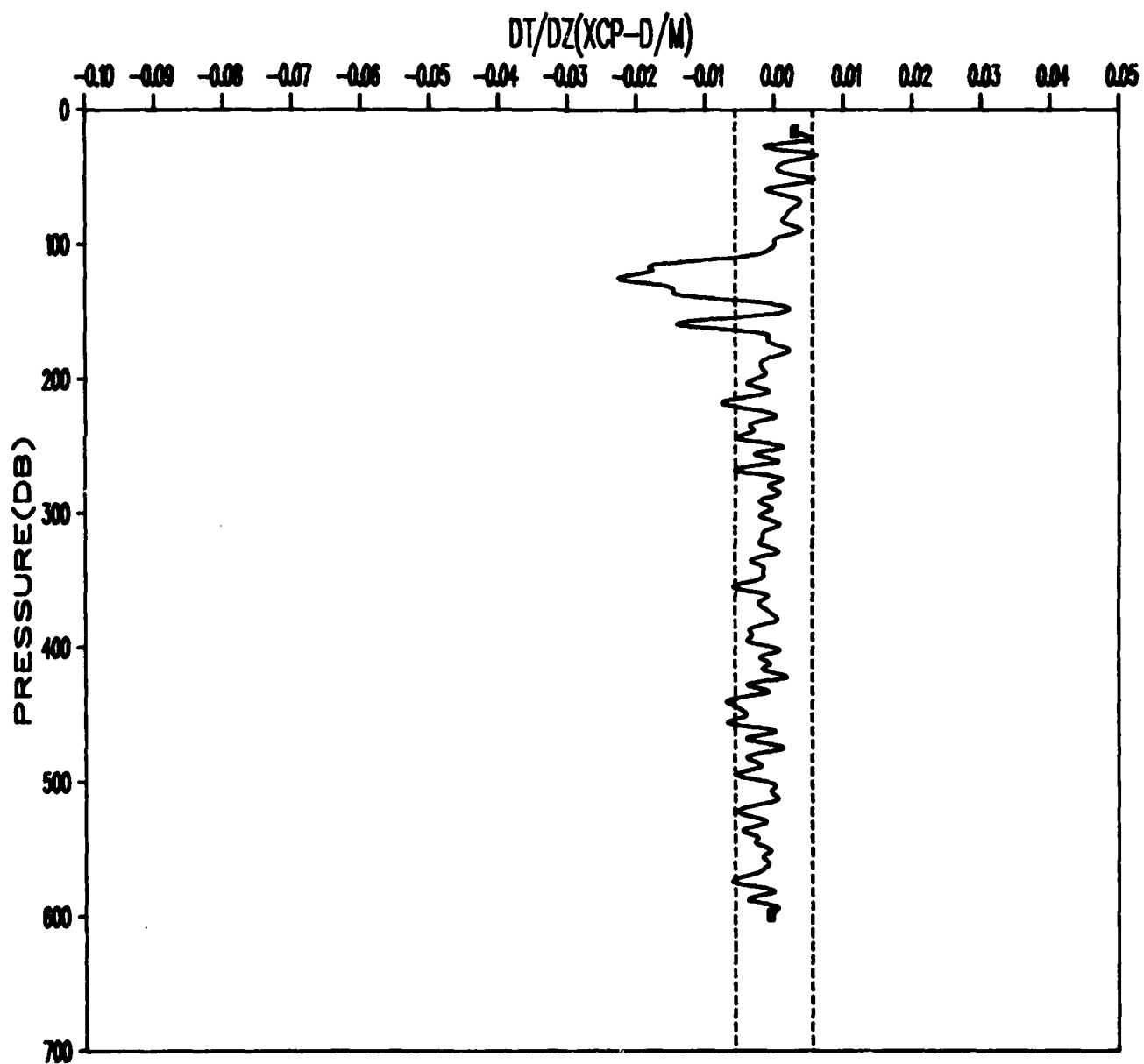


Figure 8. Derivative of XCP temperature with depth - XCP 504

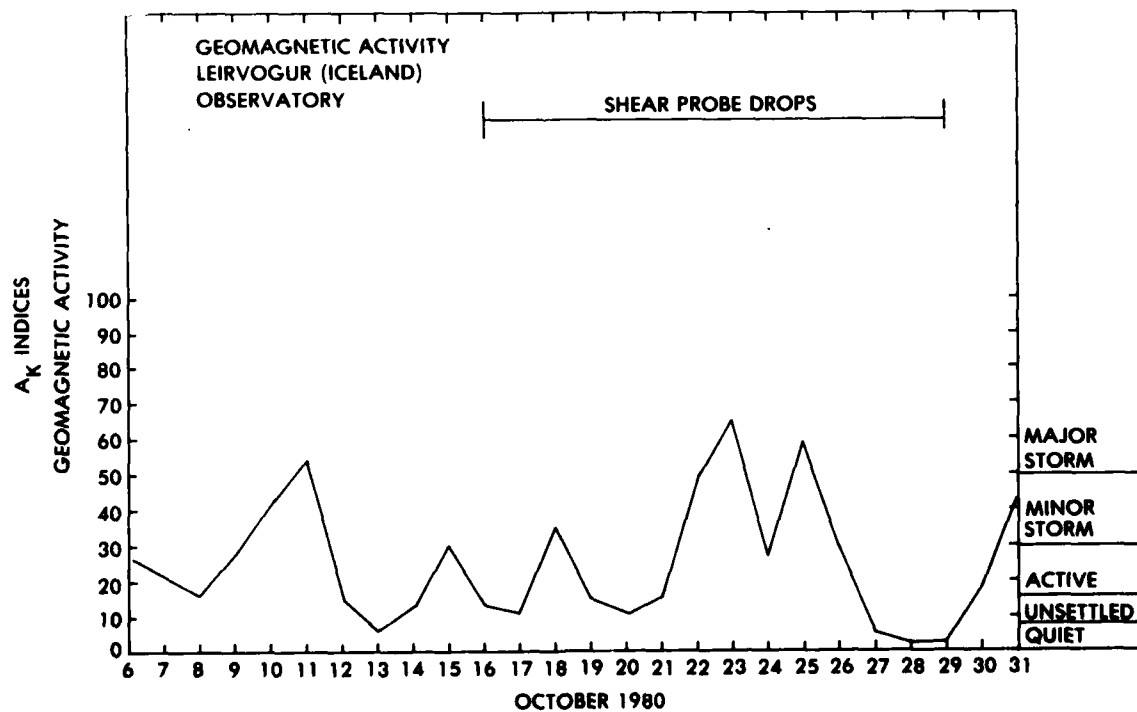
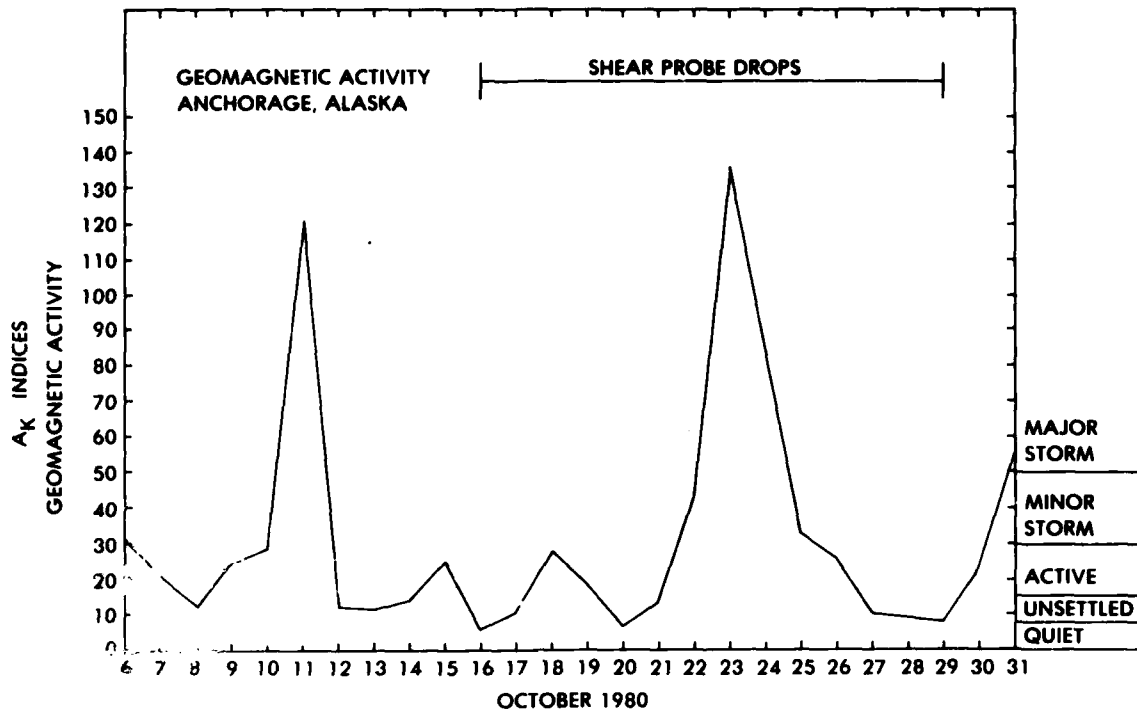


Figure 9. Geomagnetic activity during October 1980, for Leirvogur, ICELAND, and Anchorage, Alaska

Table 1. XCP Summary (Cruise 270980 - Phase II)

| XCP DROP | LATITUDE | LONGITUDE | JULIAN DAY/TIME (Z) | NEAREST CTD CAST | LATITUDE | LONGITUDE | JULIAN DAY/TIME (Z) | LONGITUDE | JULIAN DAY/START TIME (Z) | JULIAN DAY/END TIME (Z) | COMMENTS |
|----------|-----------|-----------|---------------------|------------------|-----------|-----------|---------------------|-----------|---------------------------|-------------------------|-------------------|
| 502 | 60°22.8'N | 07°02.8'W | 290/0637 | 105073 | 60°38.8'N | 07°21.4'W | 290/1659 | 07°21.4'W | 290/1659 | 290/1714 | Time Series No. 1 |
| 503 | 60°40.0'N | 07°18.3'W | /1813 | 109076 | 61°39.1'N | 10°13.9'W | 291/1156 | 291/1156 | 291/1211 | | |
| 504 | 61°37.7'N | 10°12.9'W | 291/1256 | 109078 | 61°37.7'N | 10°12.6'W | /1640 | /1640 | /1925 | | |
| 506 | 61°38.4'N | 10°14.3'W | /1548 | 109079 | 61°37.1'N | 10°13.0'W | /2004 | /2035 | /2325 | | |
| 507 | 61°37.1'N | 10°12.9'W | /2004 | 109079 | 61°37.1'N | 10°13.0'W | /2015 | /2035 | /2325 | | |
| 508 | 61°37.1'N | 10°12.9'W | /2015 | 109080 | 61°37.5'N | 10°13.5'W | 292/0010 | 292/0040 | 292/0336 | | |
| 510 | 61°38.1'N | 10°13.4'W | /2015 | 109081 | 61°36.8'N | 10°13.2'W | /0436 | /0505 | /0818 | | |
| 512 | 61°37.1'N | 10°12.8'W | /0436 | 109082 | 61°37.9'N | 10°12.9'W | /0856 | /0920 | /1203 | | |
| 514 | 61°38.0'N | 10°12.6'W | /1308 | 109083 | 61°38.6'N | 10°12.4'W | /1308 | /1349 | /1636 | | |
| 515 | 61°37.6'N | 10°13.2'W | /1730 | 109085 | 61°36.6'N | 10°12.4'W | /0856 | /1349 | /1636 | | |
| 517 | 61°58.7'N | 09°37.5'W | /2056 | 110084 | 61°59.2'N | 09°38.0'W | /2056 | /2118 | /2130 | | |
| 519 | 62°22.8'N | 09°04.8'W | 293/0121 | 111085 | 62°23.2'N | 09°05.0'W | 293/0121 | 293/0142 | 293/0154 | | |
| 520 | 62°45.2'N | 08°32.6'W | /0454 | 112086 | 62°48.1'N | 08°51.7'W | /0454 | /0530 | /0540 | | |
| 525 | 63°42.2'N | 07°12.7'W | /2342 | 117091 | 63°41.7'N | 07°12.8'W | /2342 | /2212 | /2237 | | |
| 527 | 63°42.3'N | 07°09.6'W | 294/0739 | 117093 | 63°42.7'N | 07°09.0'W | 294/0739 | 294/0415 | 294/0702 | | |
| 528 | 63°43.2'N | 07°06.5'W | /0750 | 117094 | 63°42.7'N | 07°09.6'W | /0750 | /0825 | /1120 | | |
| 530 | 63°43.5'N | 07°09.0'W | /1236 | 117095 | 63°43.7'N | 07°09.0'W | /1236 | /1254 | /1525 | | |
| 533 | 63°42.9'N | 07°09.9'W | /2002 | 117097 | 63°42.9'N | 07°09.1'W | /2002 | /2029 | /2321 | | |
| 534 | 64°08.0'N | 06°04.9'W | 295/1302 | 122103 | 64°08.0'N | 06°04.0'W | 295/1302 | 295/1320 | 295/1354 | | |
| 535 | 63°59.9'N | 06°15.5'W | /1509 | 123104 | 63°59.5'N | 06°15.4'W | /1509 | /1528 | /1545 | | |
| 538 | 63°44.7'N | 06°42.7'W | /2106 | 126106 | 63°43.5'N | 06°40.5'W | /2106 | /2006 | /2025 | | |
| 539 | 63°35.8'N | 06°53.1'W | 296/0032 | 128107 | 63°36.2'N | 06°51.6'W | 296/0032 | 296/0331 | 296/0351 | | |
| 542 | 63°34.4'N | 06°55.1'W | /0129 | 130108 | 63°27.7'N | 07°04.0'W | /0129 | /0331 | /0351 | | |
| 543 | 63°32.6'N | 06°58.4'W | /0156 | 130108 | 63°27.7'N | 07°04.0'W | /0156 | /0331 | /0351 | | |
| 544 | 63°50.8'N | 06°59.7'W | /0223 | 130108 | 63°27.7'N | 07°04.0'W | /0223 | /0331 | /0351 | | |
| 546 | 63°28.0'N | 07°02.5'W | /0312 | 130108 | 63°27.7'N | 07°04.0'W | /0312 | /0331 | /0351 | | |
| 547 | 63°20.5'N | 07°15.8'W | /0548 | 131109 | 63°20.4'N | 07°16.0'W | /0548 | /0609 | /0631 | | |
| 548 | 63°12.0'N | 07°26.6'W | /0842 | 132110 | 63°12.3'N | 07°25.9'W | /0842 | /0901 | /0924 | | |
| 549 | 63°03.7'N | 07°40.1'W | /1602 | 133111 | 63°04.3'N | 07°39.5'W | /1602 | /1643 | /1703 | | |
| 550 | 63°13.4'N | 06°55.6'W | 297/0350 | 136116 | 63°13.7'N | 06°54.9'W | 297/0350 | 297/0412 | 297/0431 | | |
| 551 | 63°21.2'N | 06°44.8'W | /0620 | 137117 | 63°20.7'N | 06°41.9'W | /0620 | /0719 | /0742 | | |
| 556 | 66°00.1'N | 02°00.3'W | 301/0025 | 171148 | 66°59.8'N | 02°00.2'W | 301/0025 | 301/0046 | 301/0333 | | |
| 558 | 65°57.6'N | 02°01.0'W | /0419 | 171148 | 66°59.8'N | 02°00.2'W | /0419 | /0046 | /0333 | | |
| 559 | 65°59.9'N | 02°01.1'W | /0455 | 171149 | 66°05.1'N | 02°01.4'W | /0455 | /0516 | /0803 | | |
| 560 | 66°00.1'N | 02°00.3'W | /0854 | 171150 | 66°00.0'N | 01°59.5'W | /0854 | /0856 | /1148 | | |
| 561 | 66°00.1'N | 02°00.0'W | 301/1235 | 171150 | 66°00.0'N | 01°59.5'W | 301/1235 | 301/0046 | 301/0333 | | |
| 562 | 66°00.5'N | 02°00.7'W | /1633 | 171151 | 66°00.0'N | 02°00.8'W | /1633 | /1307 | /1601 | | |
| 563 | 65°00.2'N | 00°59.2'W | 302/2325 | 175155 | 65°00.4'N | 01°01.4'W | 302/2325 | 302/2116 | 302/2208 | | |
| 564 | 65°00.1'N | 00°58.9'W | 303/0339 | 171157 | 65°00.3'N | 00°57.7'W | 303/0339 | 303/0414 | 303/0708 | | |
| 566 | 64°59.7'N | 01°00.3'W | /1131 | 171158 | 64°59.7'N | 00°59.6'W | /1131 | /0811 | /1056 | | |
| 567 | 65°00.0'N | 00°59.4'W | /1532 | 171159 | 64°59.7'N | 00°59.6'W | /1532 | /1153 | /1445 | | |
| 568 | 64°59.8'N | 01°00.0'W | /1912 | 175160 | 64°59.7'N | 01°00.2'W | /1912 | /1549 | /1837 | | |
| 569 | 65°00.3'N | 00°59.2'W | /2320 | 175161 | 65°00.4'N | 00°59.4'W | /2320 | /1939 | /2227 | | |
| 571 | 65°00.5'N | 00°56.5'W | /2552 | 175161 | 65°00.4'N | 00°59.4'W | /2552 | /1939 | /2227 | | |
| 573 | 65°00.0'N | 00°59.6'W | | 175161 | 65°00.4'N | 00°59.4'W | | /1939 | /2227 | | |

Table 2. Data Summary

| Probe Drop | Data Range (m) | Bottom of Mixed Layer (m) | Depth (m) Max S ₂ | Depth (m) Max N ₂ | MEDIAN VALUE OF | | MEAN VALUE OF | | RI |
|------------|----------------|---------------------------|---------------------------------|---------------------------------|--|--|--|--|------|
| | | | | | S ₂ x 10 ⁻⁴ x Sec ⁻² | N ₂ x 10 ⁻⁴ x Sec ⁻² | S ₂ x 10 ⁻⁴ x Sec ⁻² | N ₂ x 10 ⁻⁴ x Sec ⁻² | |
| 503 | 23-504 | 120 | 224 | 452 | .267 | .106 | .394 | .148 | .376 |
| 504 | 16-599 | 105 | 115 | 130 | .102 | .021 | .157 | .040 | .255 |
| 517 | 25-660 | 160 | 576 | 612 | .143 | .057 | .385 | .115 | .299 |
| 519 | 20-509 | 80 | 461 | 464 | .114 | .052 | .414 | .114 | .275 |
| 520 | 20-460 | 120 | 123 | 340 | .245 | .110 | .613 | .132 | .215 |
| 525 | 15-892 | 90 | 575 | 121 | .175 | .026 | .550 | .074 | .224 |
| 534 | 25-891 | 60 | 66 | 73 | .151 | .029 | .222 | .087 | .392 |
| 535 | 27-902 | 50 | 105 | 56 | .086 | .031 | .240 | .082 | .342 |
| 538 | 20-885 | 100 | 650 | 109 | .315 | .017 | .626 | .073 | .117 |
| 546 | 18-888 | 100 | 198 | 234 | .091 | .027 | .194 | .086 | .443 |
| 547 | 19-915 | 100 | 118 | 104 | .069 | .021 | .177 | .087 | .492 |
| 548 | 30-900 | 90 | 304 | 424 | .163 | .042 | .272 | .096 | .353 |
| 549 | 20-792 | 180 | 351 | 407 | .122 | .044 | .277 | .106 | .383 |
| 550 | 26-892 | 90 | 218 | 309 | .087 | .040 | .222 | .094 | .423 |
| 551 | 25-916 | 110 | 275 | 321 | .095 | .029 | .241 | .097 | .402 |
| 563 | 29-908 | 80 | 79 | 76 | .084 | .039 | .144 | .090 | .625 |

Appendix A:
Expendable Shear Current/Temperature
Probe (XCP) Profiles

COMMENTS:

1 m Smoothed and Interpolated Profiles
No Temperature Profile for:

XCP 507 Fig. A-5
XCP 535 Fig. A-21
XCP 549 Fig. A-30
XCP 571 Fig. A-45

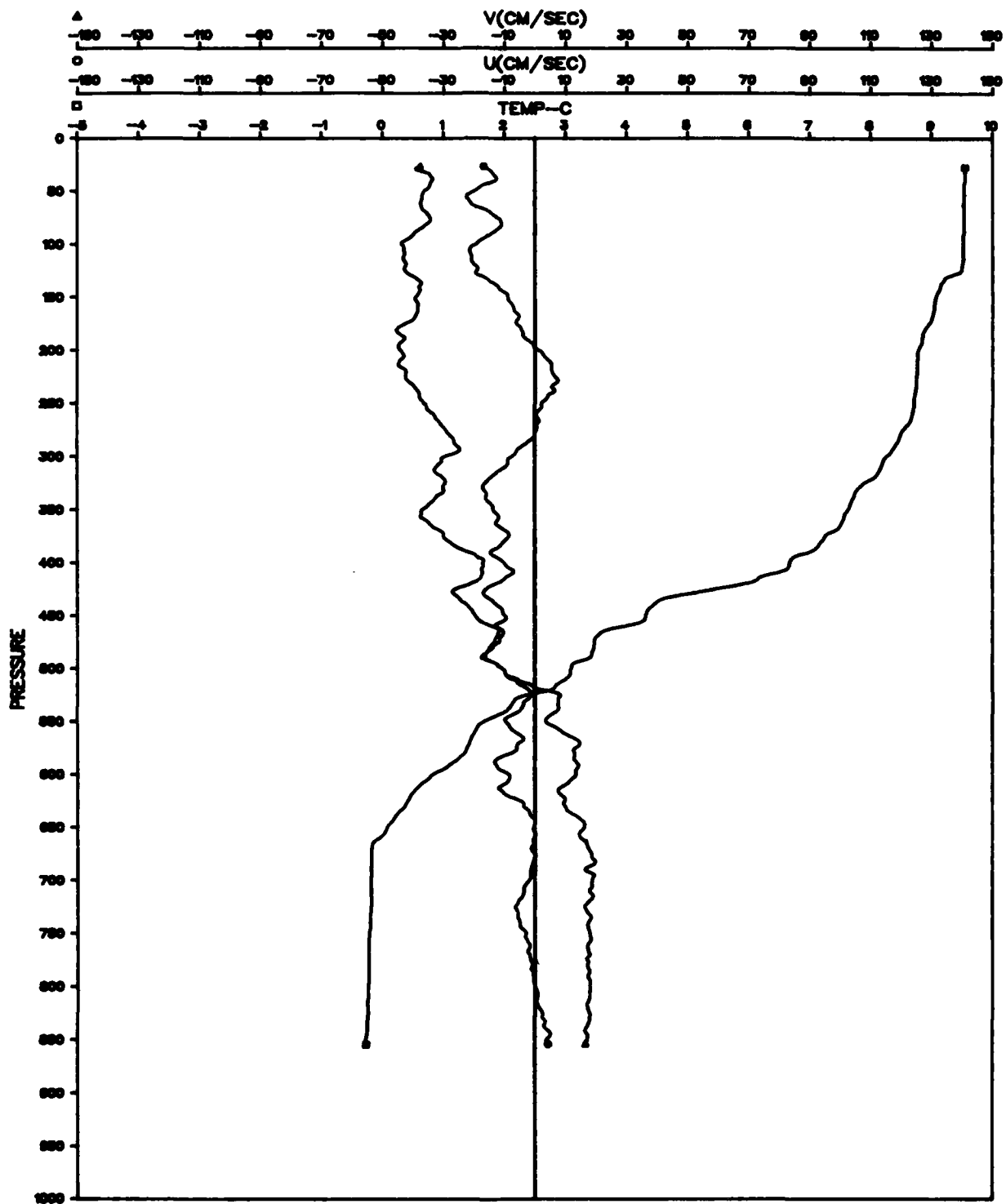


Figure A-1. File: KANE, Segment: C 502

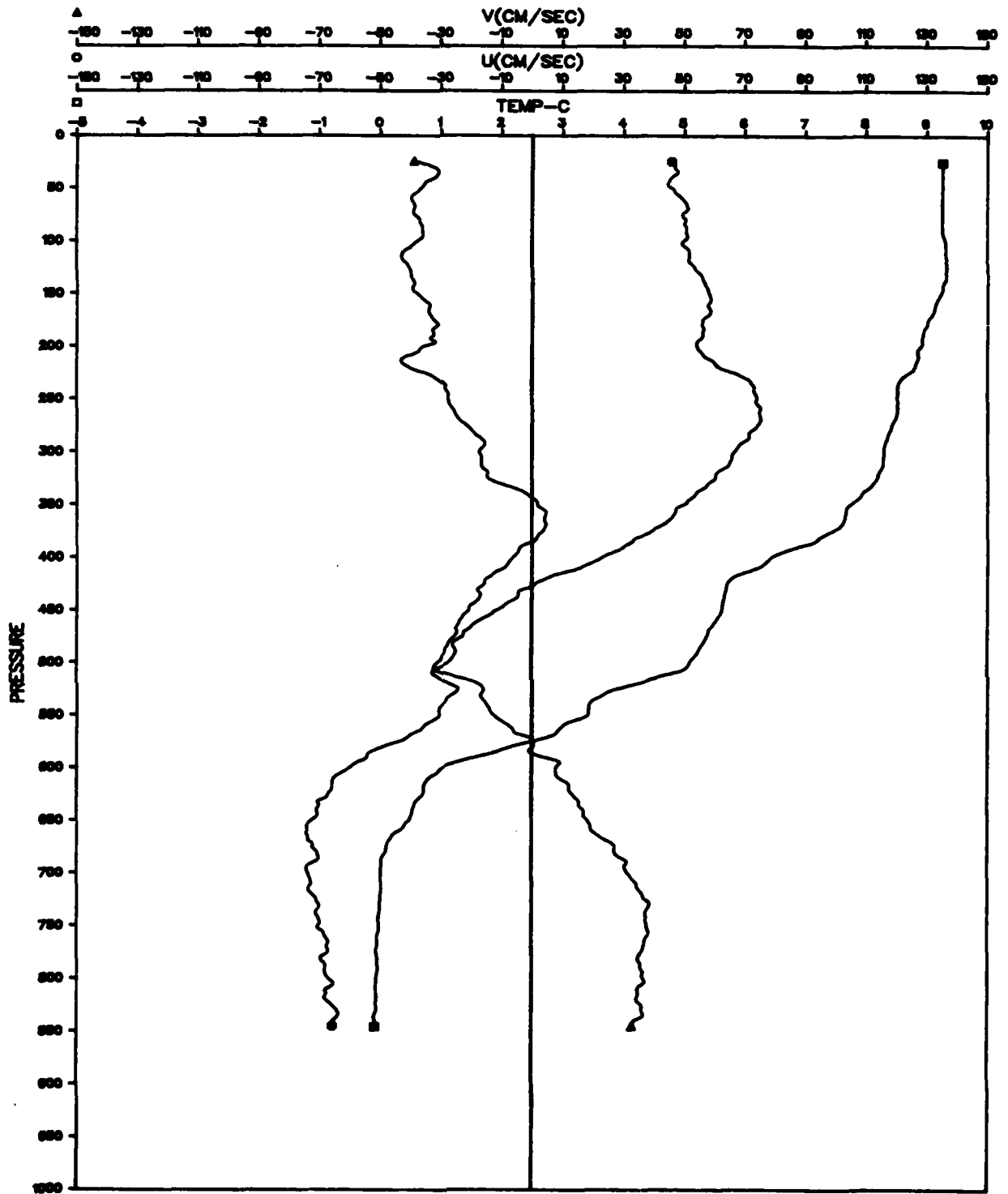


Figure A-2. File: KANE, Segment: C 503

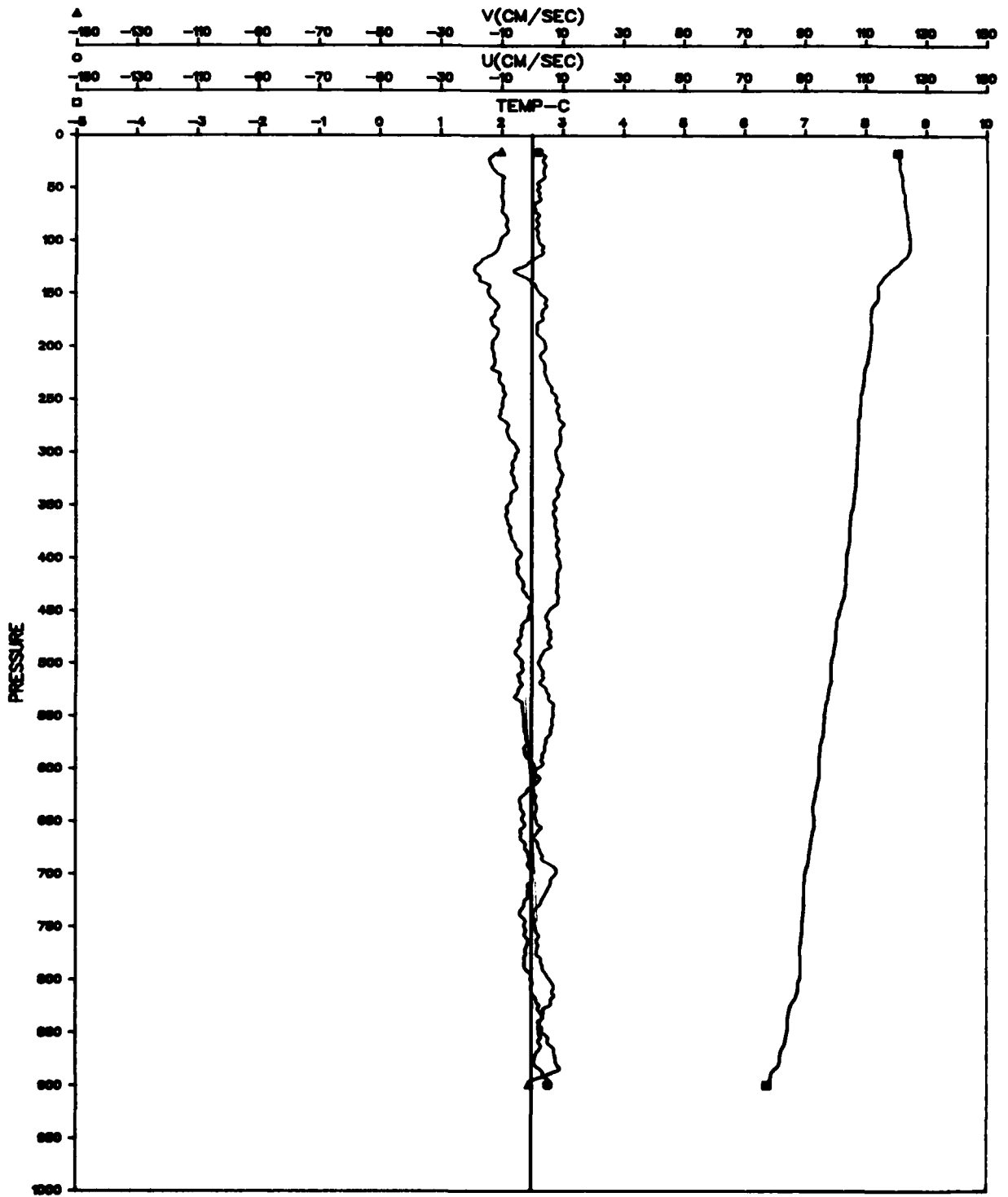


Figure A-3. File: KANE, Segment: C 504

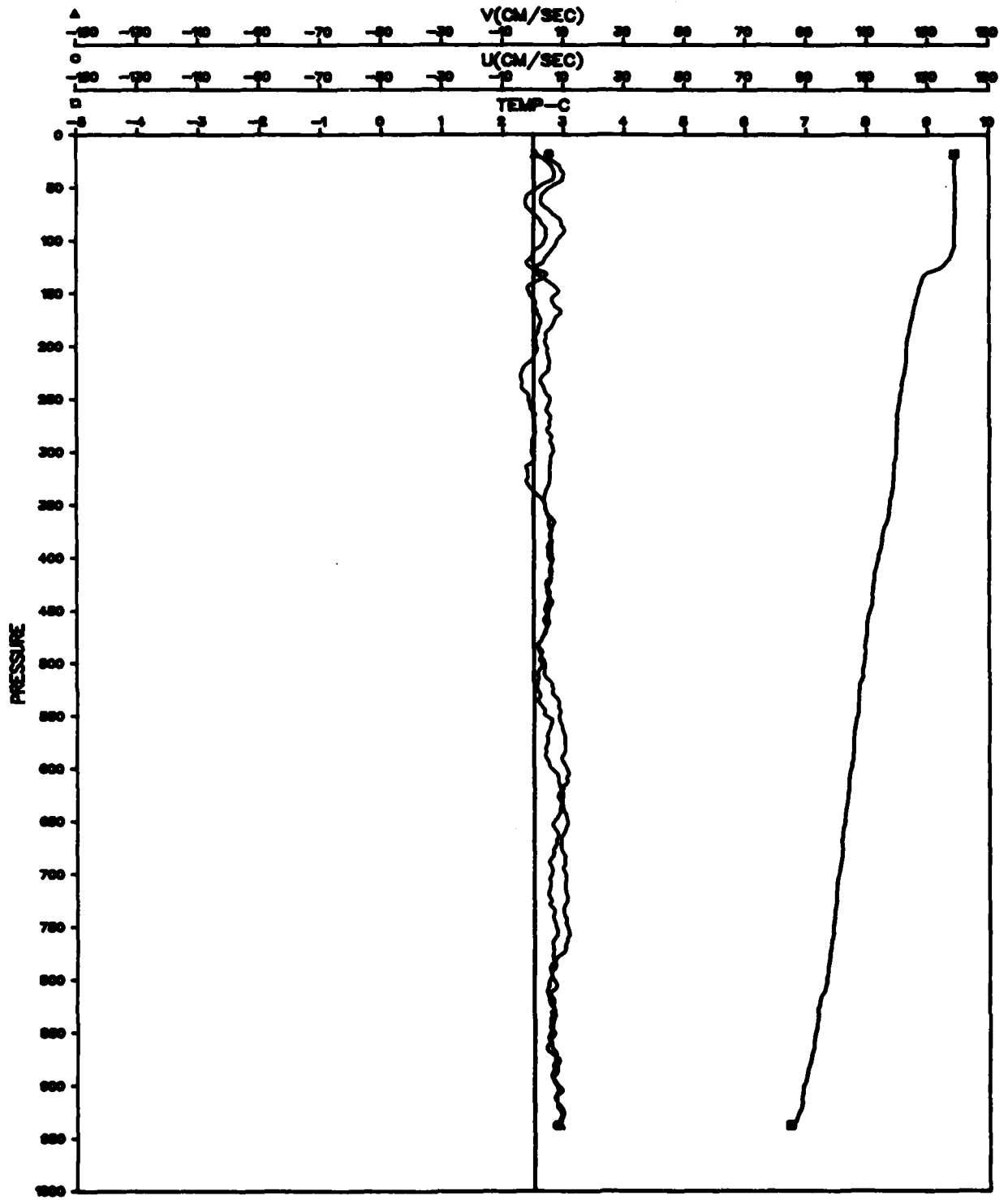


Figure A-4. File: KANE, Segment: C 506

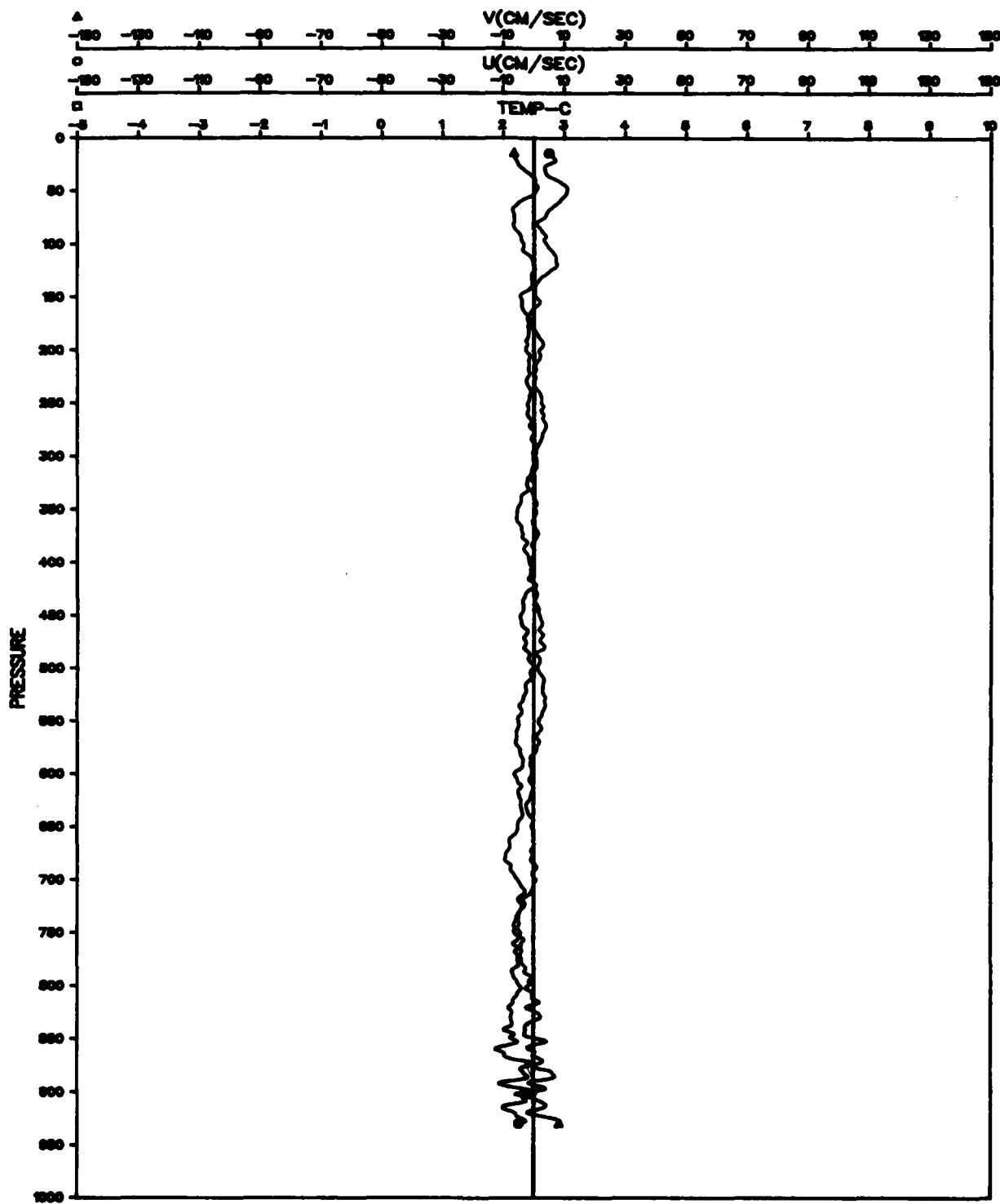


Figure A-5. File: KANE, Segment: C 507

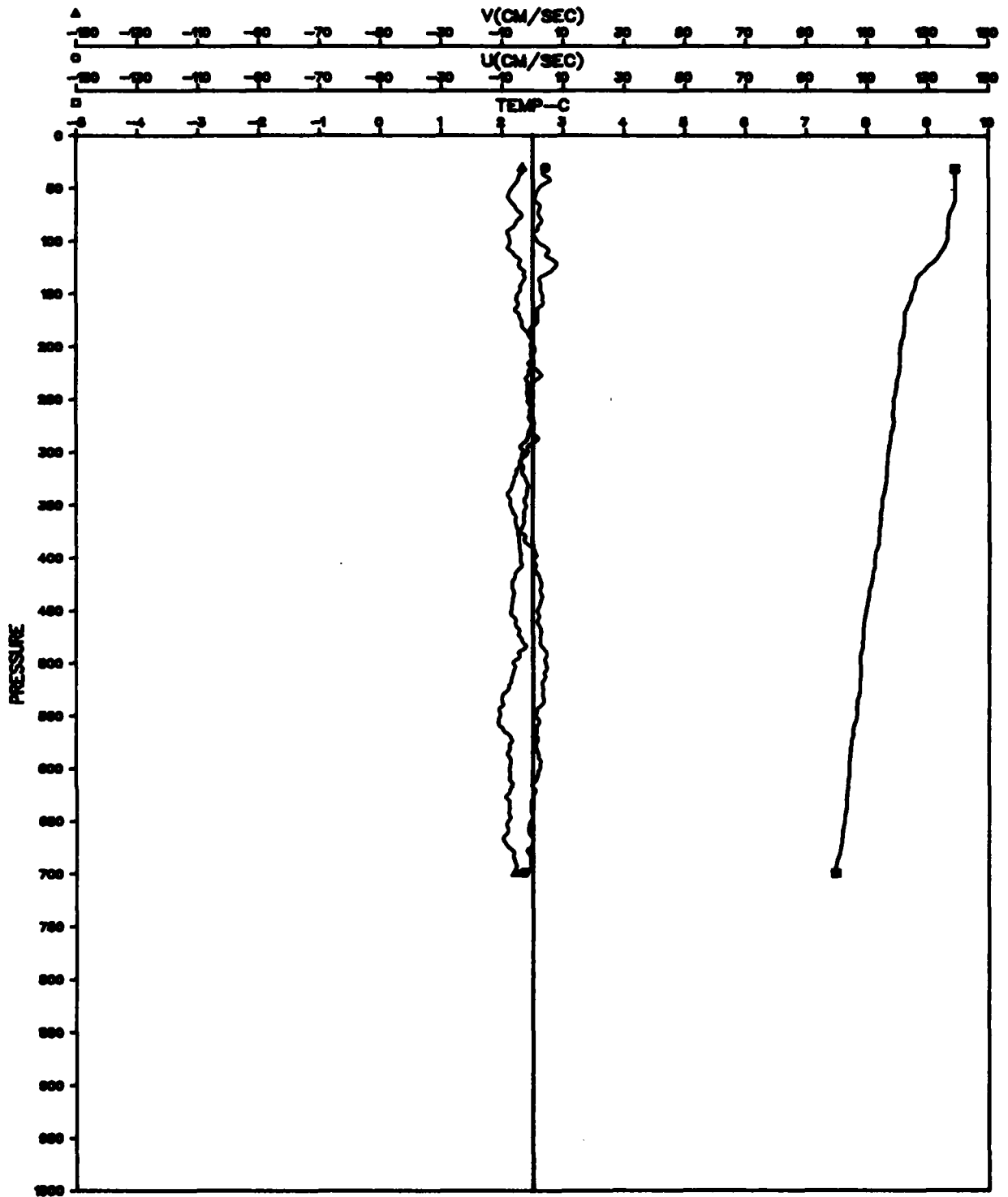


Figure A-6. File: KANE, Segment: C 508

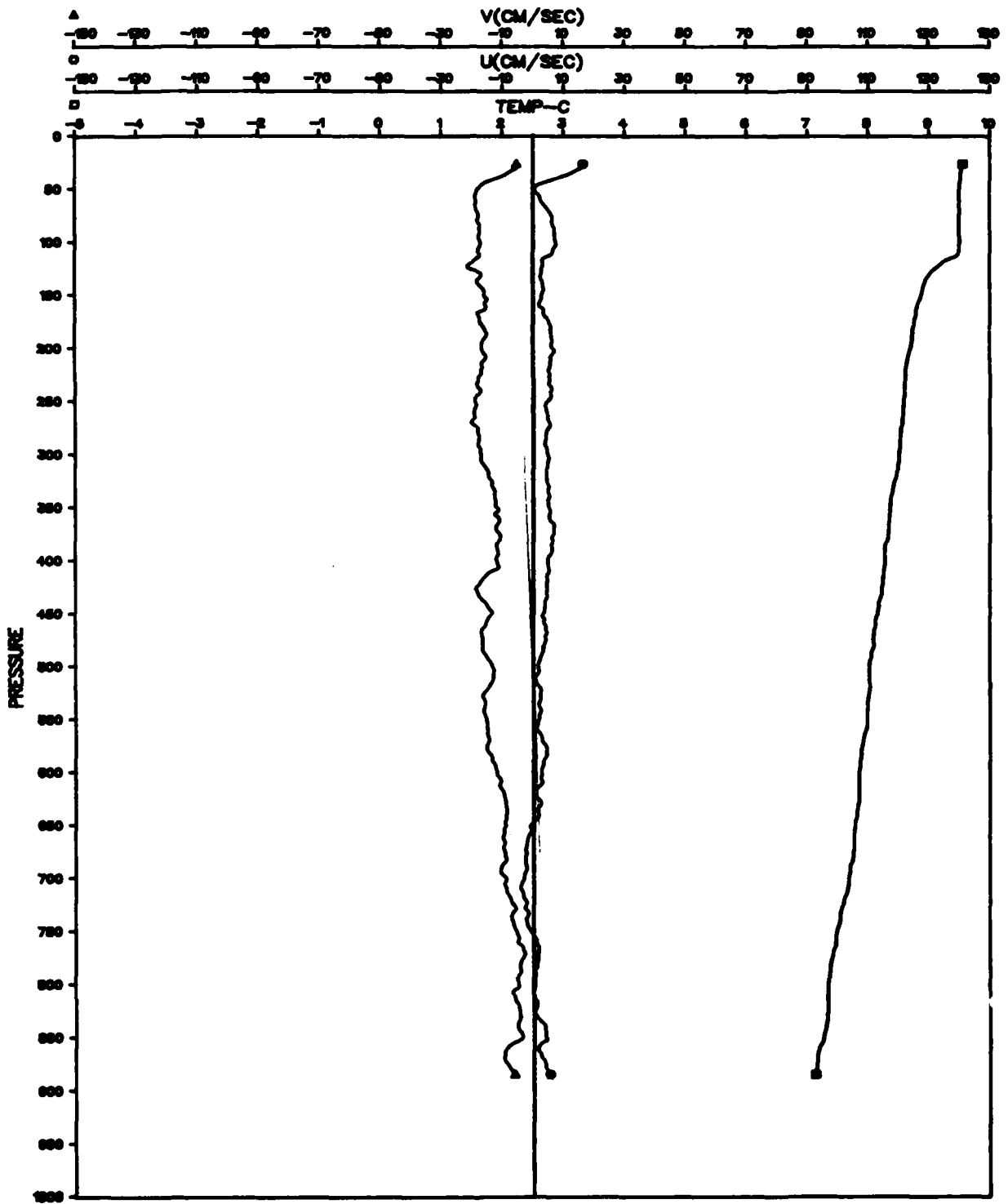


Figure A-7. File: KANE, Segment: C 510

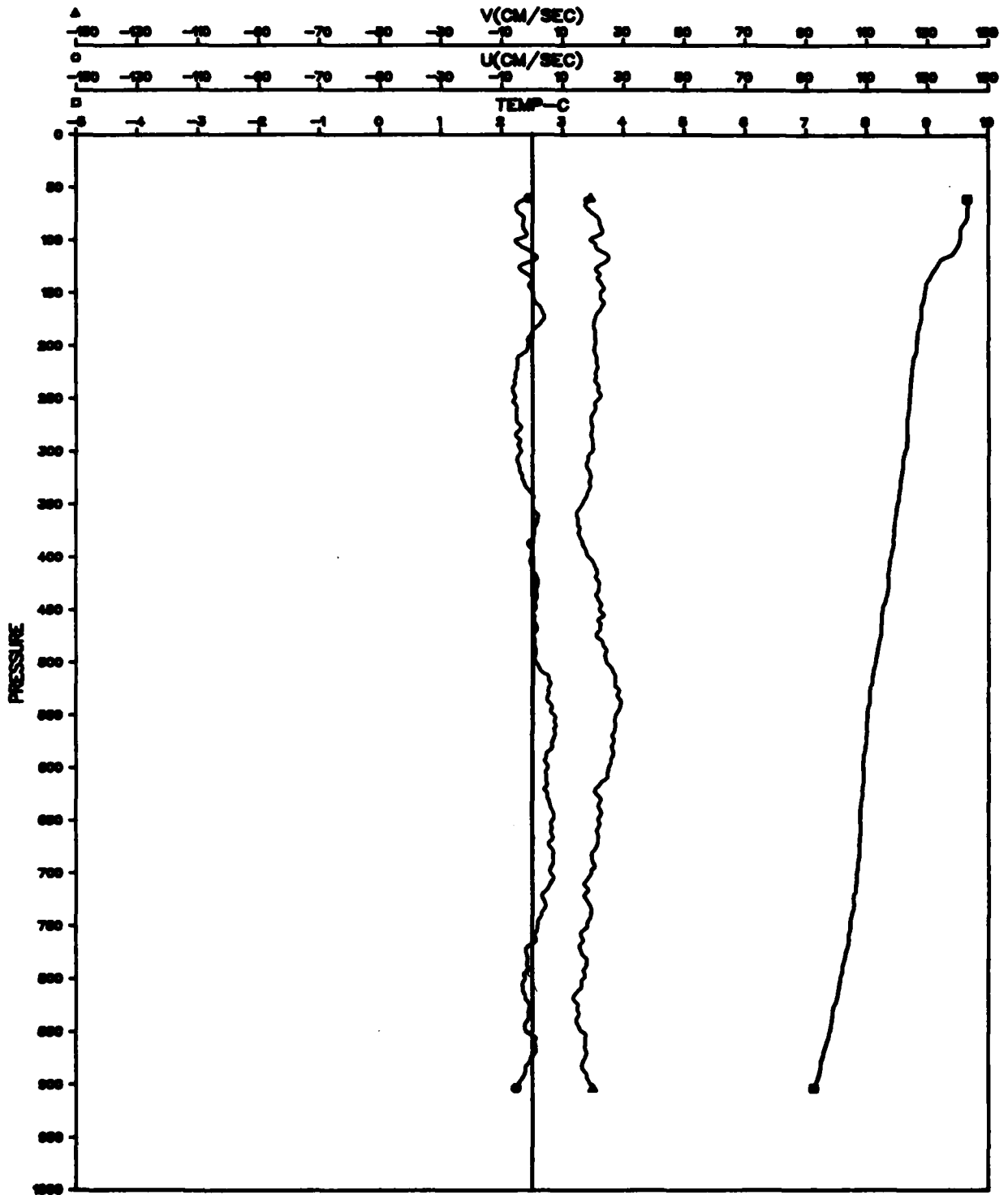


Figure A-8. File: KANE, Segment: C 512

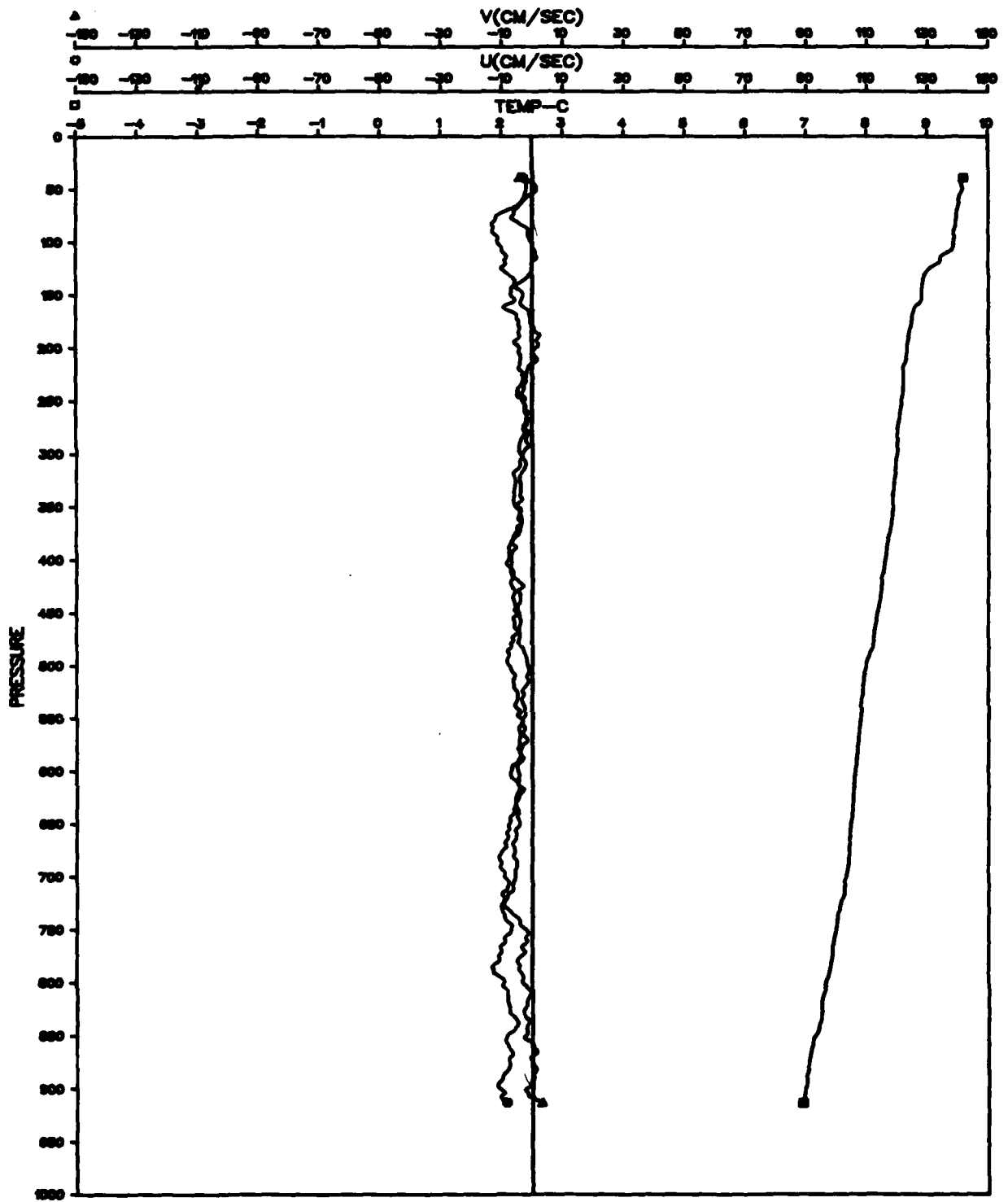


Figure A-9. File: KANE, Segment: C 513

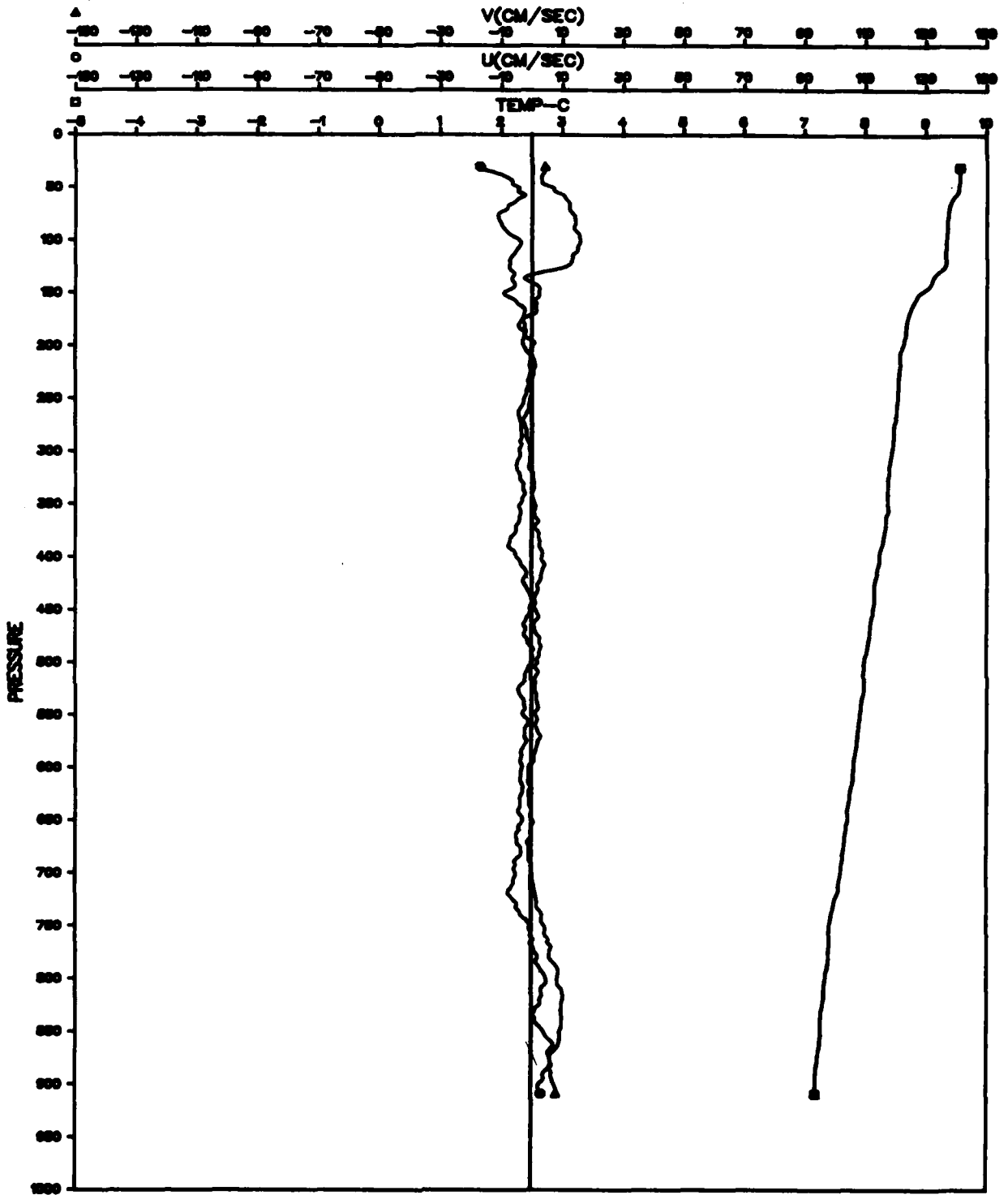


Figure A-10. File: KANE, Segment: C 514

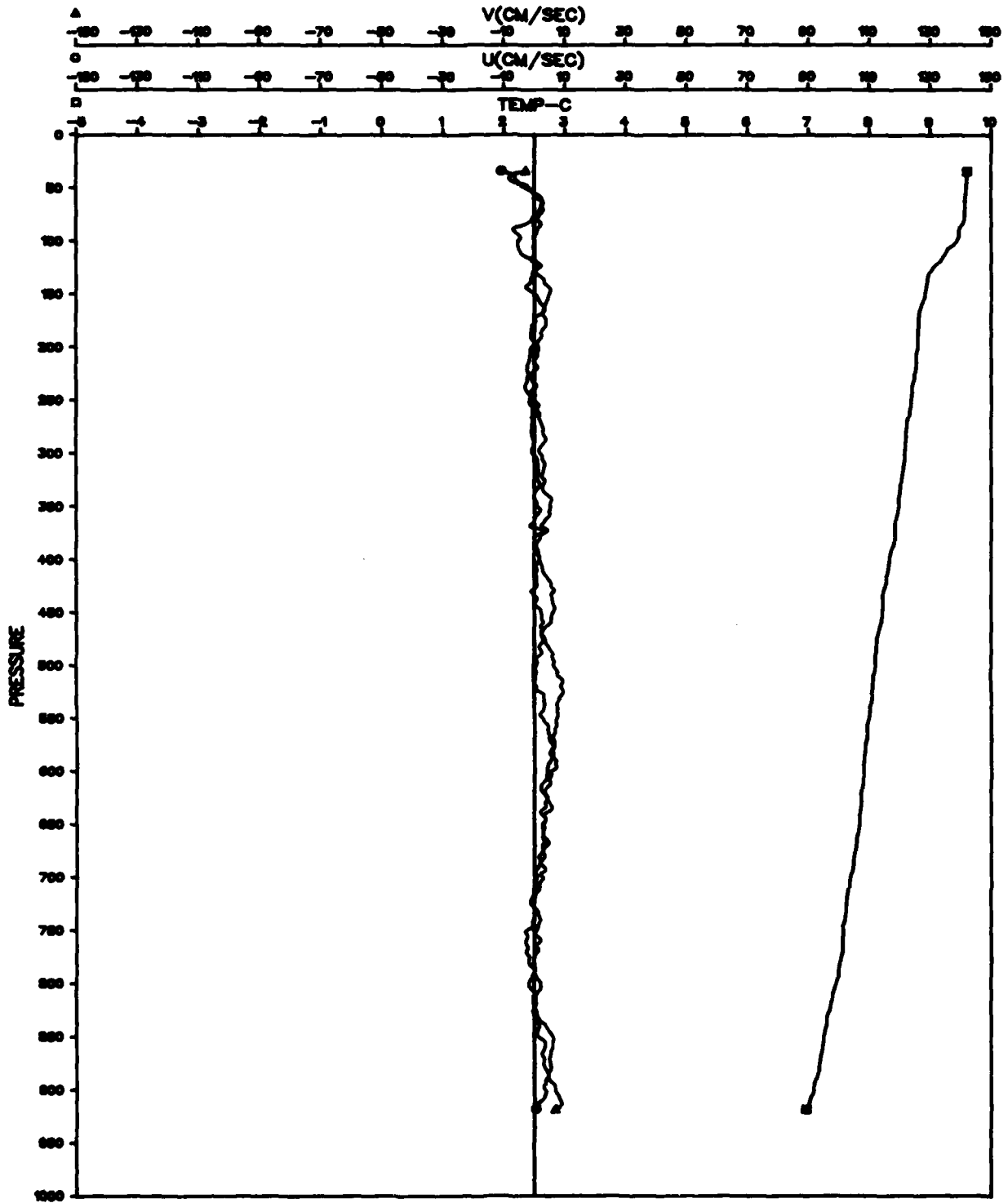


Figure A-11. File: KANE, Segment: C 515

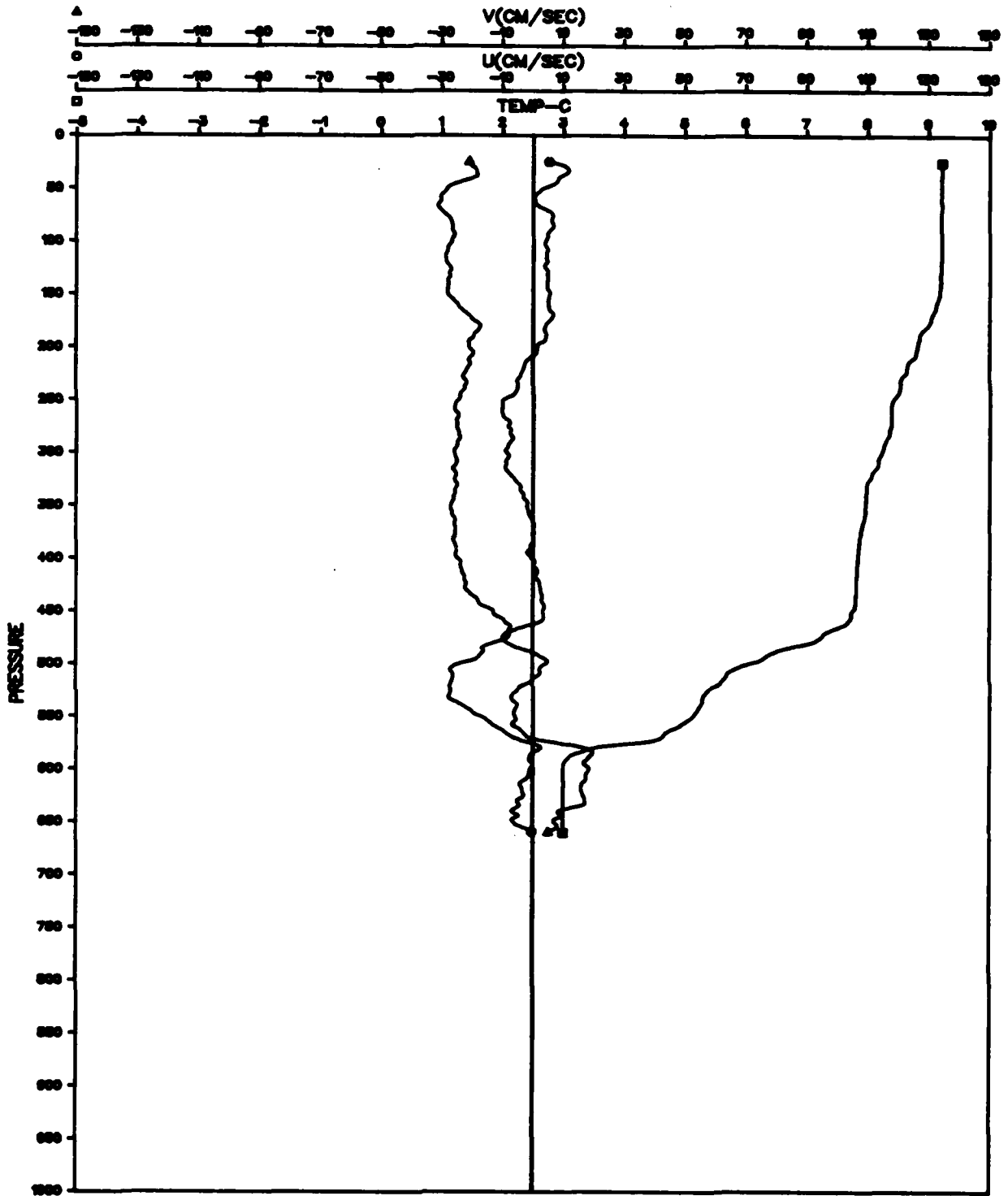


Figure A-12. File: KANE, Segment: C 517

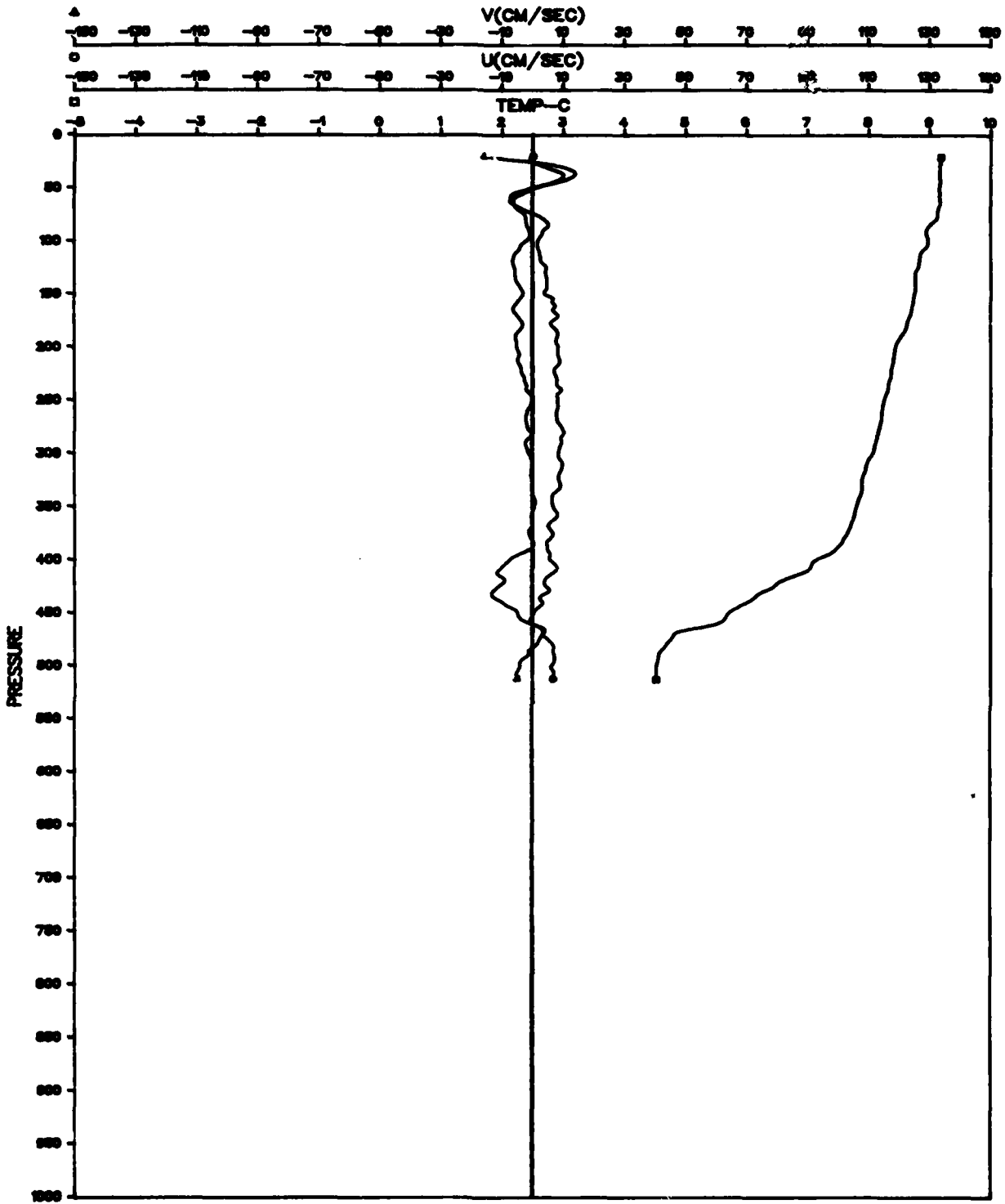


Figure A-13. File: KANE, Segment: C 519

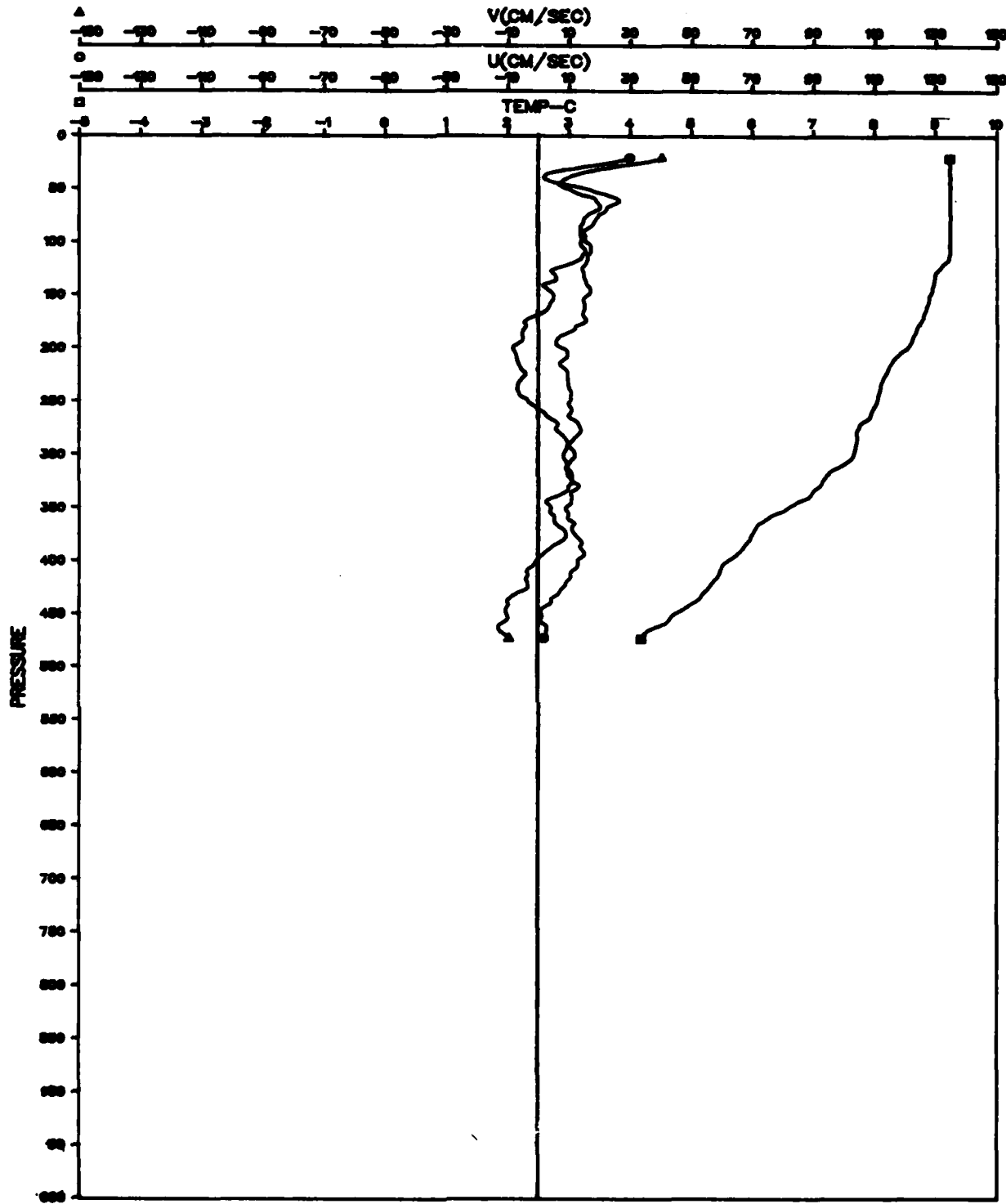


Figure A-14. File: KANE, Segment: C 520

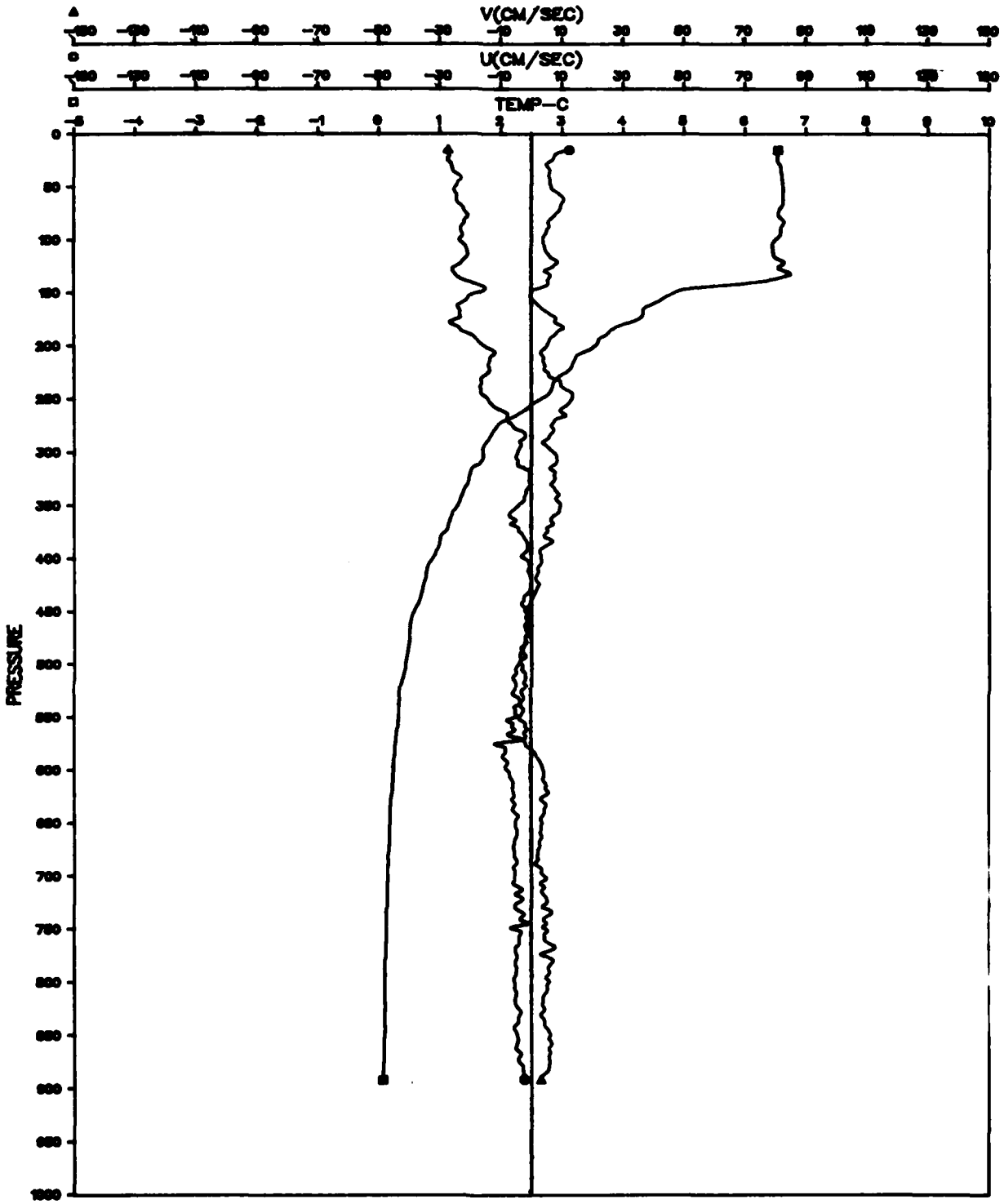


Figure A-15. File: KANE, Segment: C 525

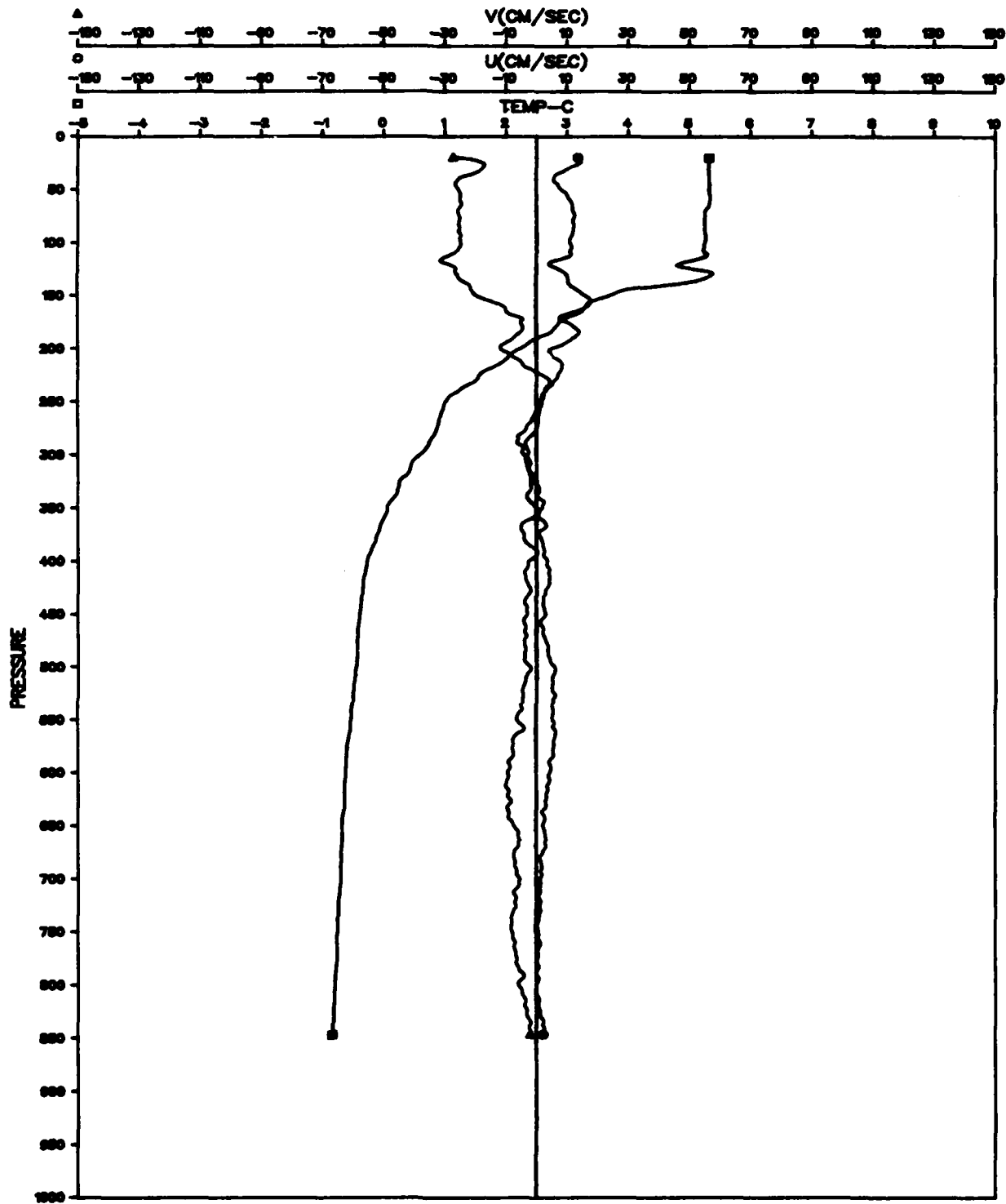


Figure A-16. File: KANE, Segment: C 527

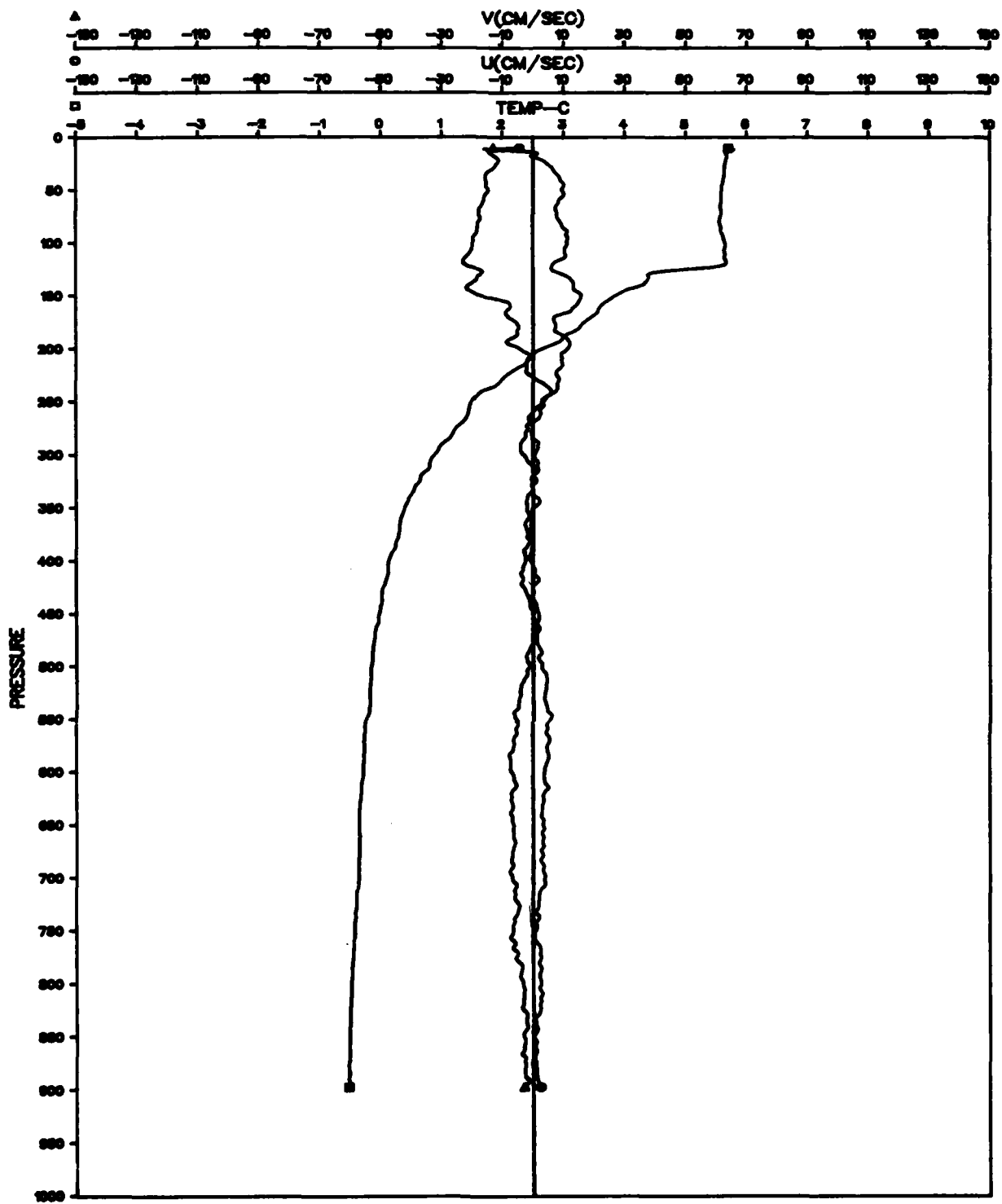


Figure A-17. File: KANE, Segment: C 528

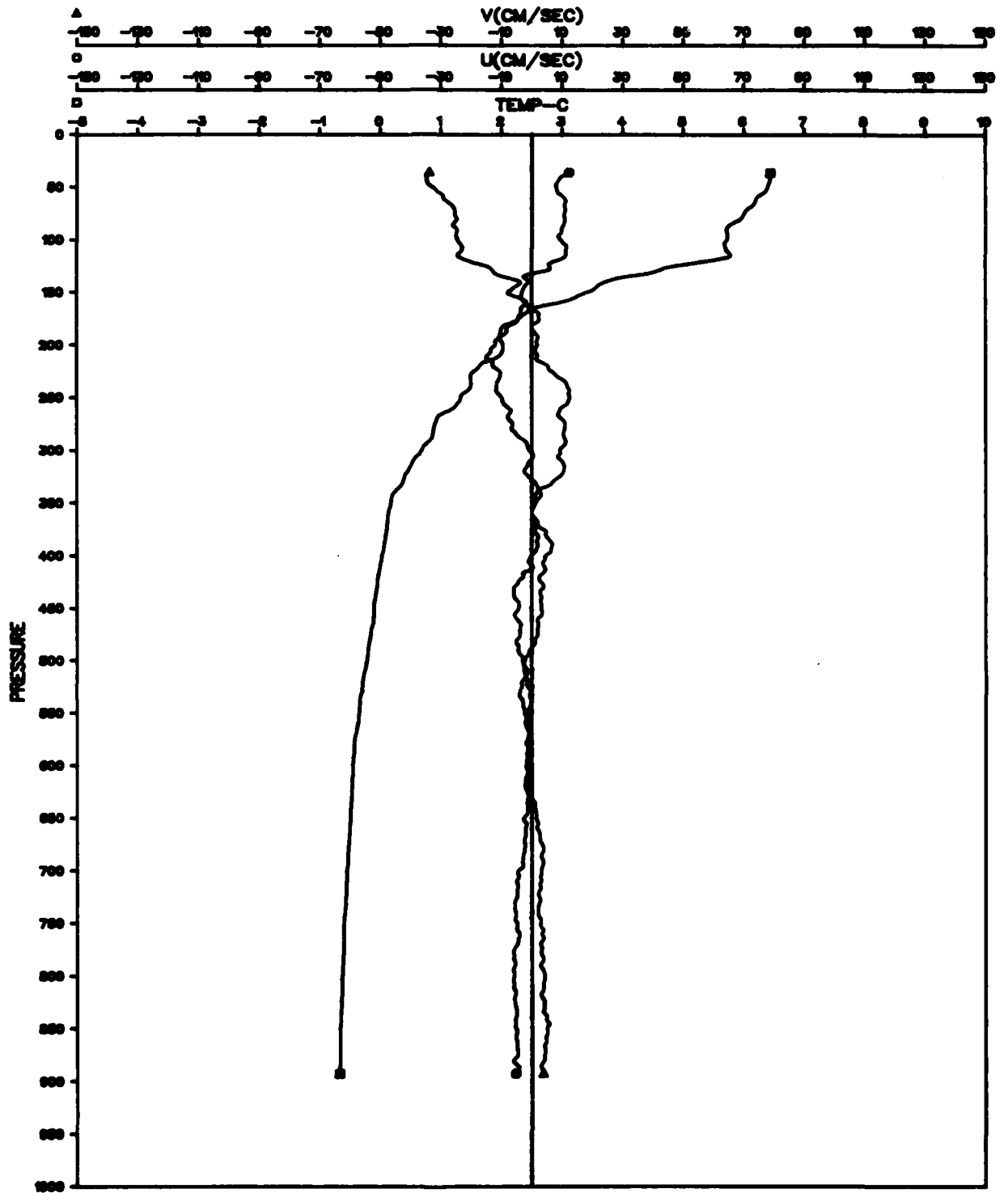


Figure A-18. File: KANE, Segment: C 530

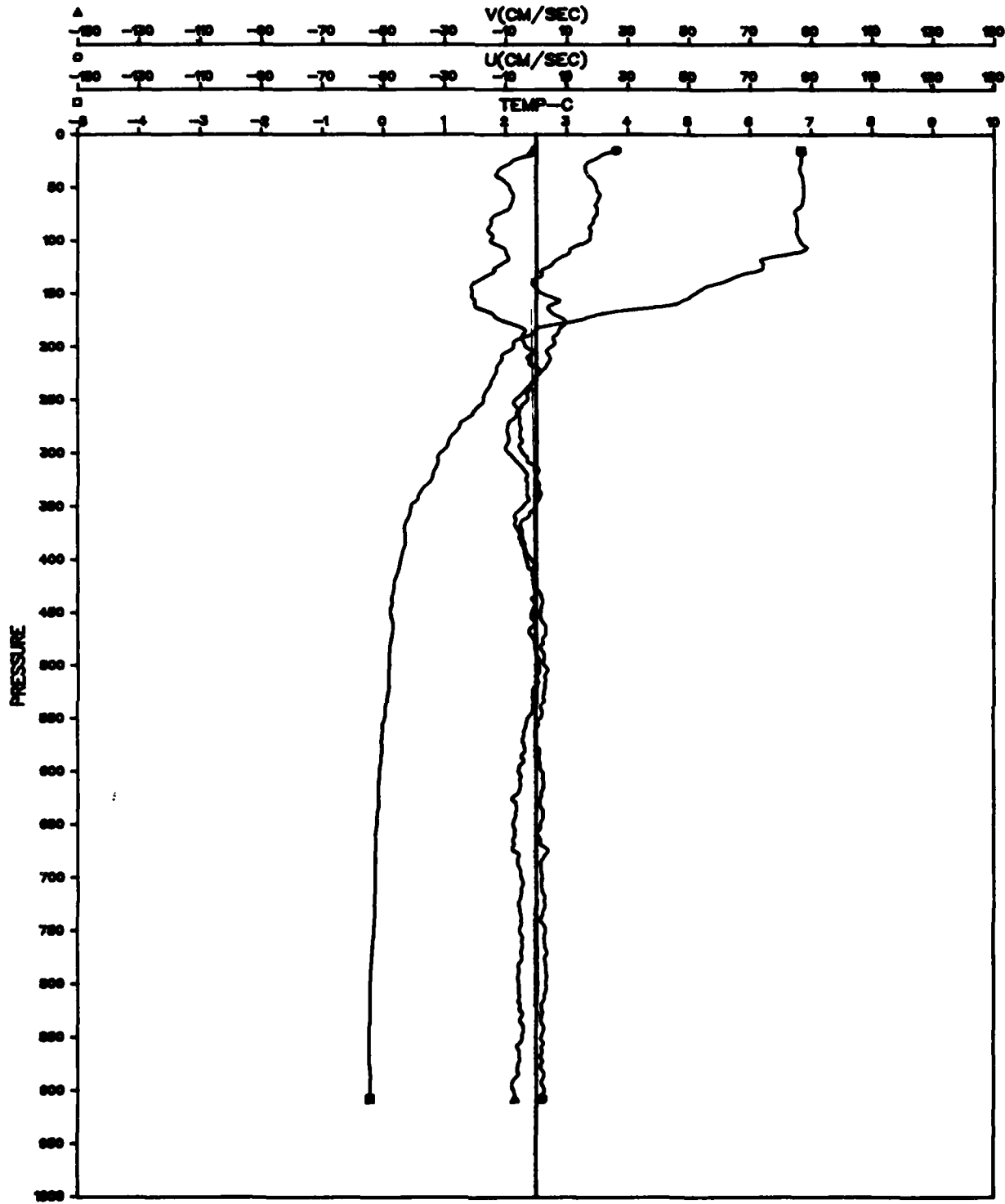


Figure A-19. File: KANE, Segment: C 533

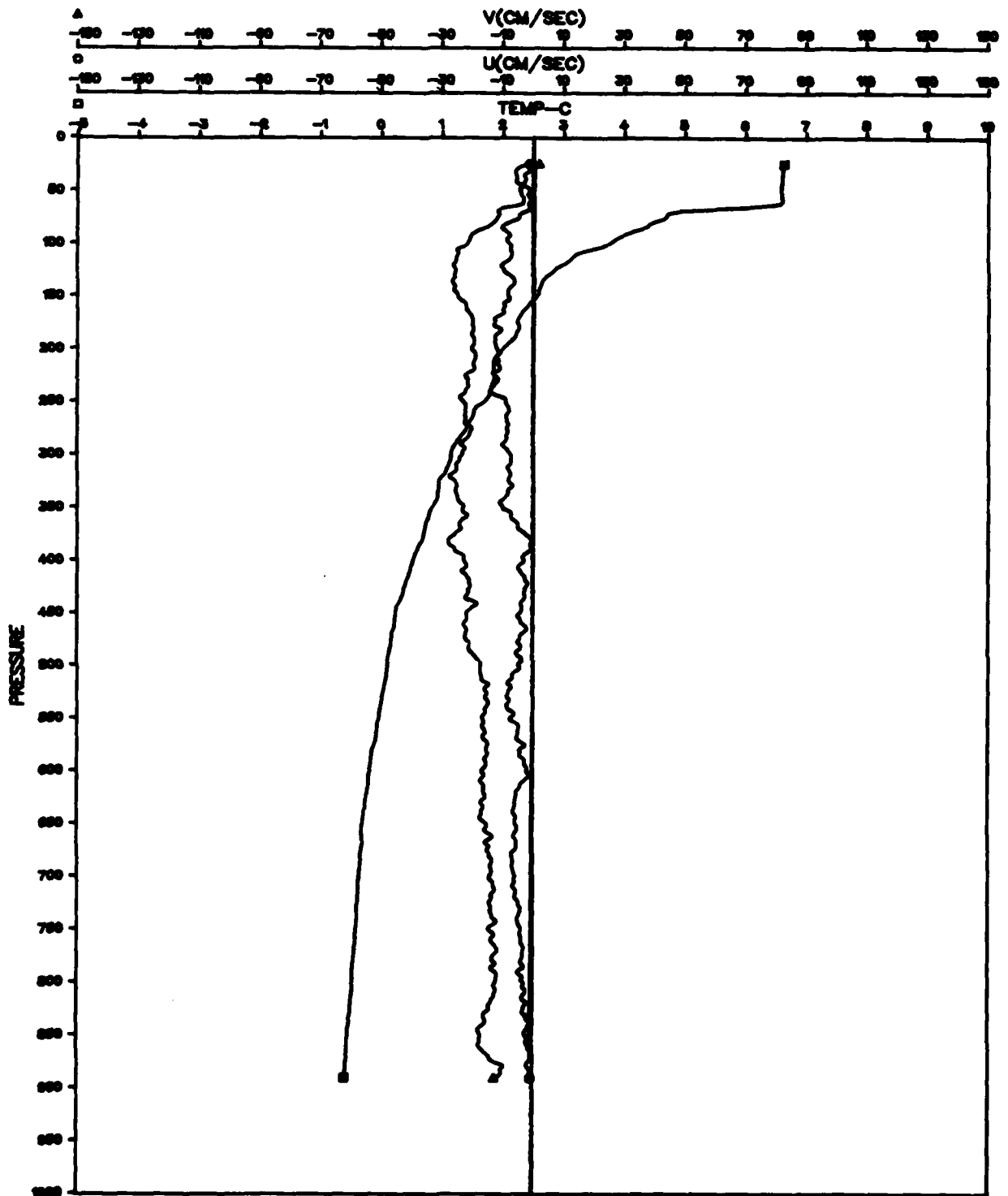


Figure A-20. File: KANE, Segment: C 534

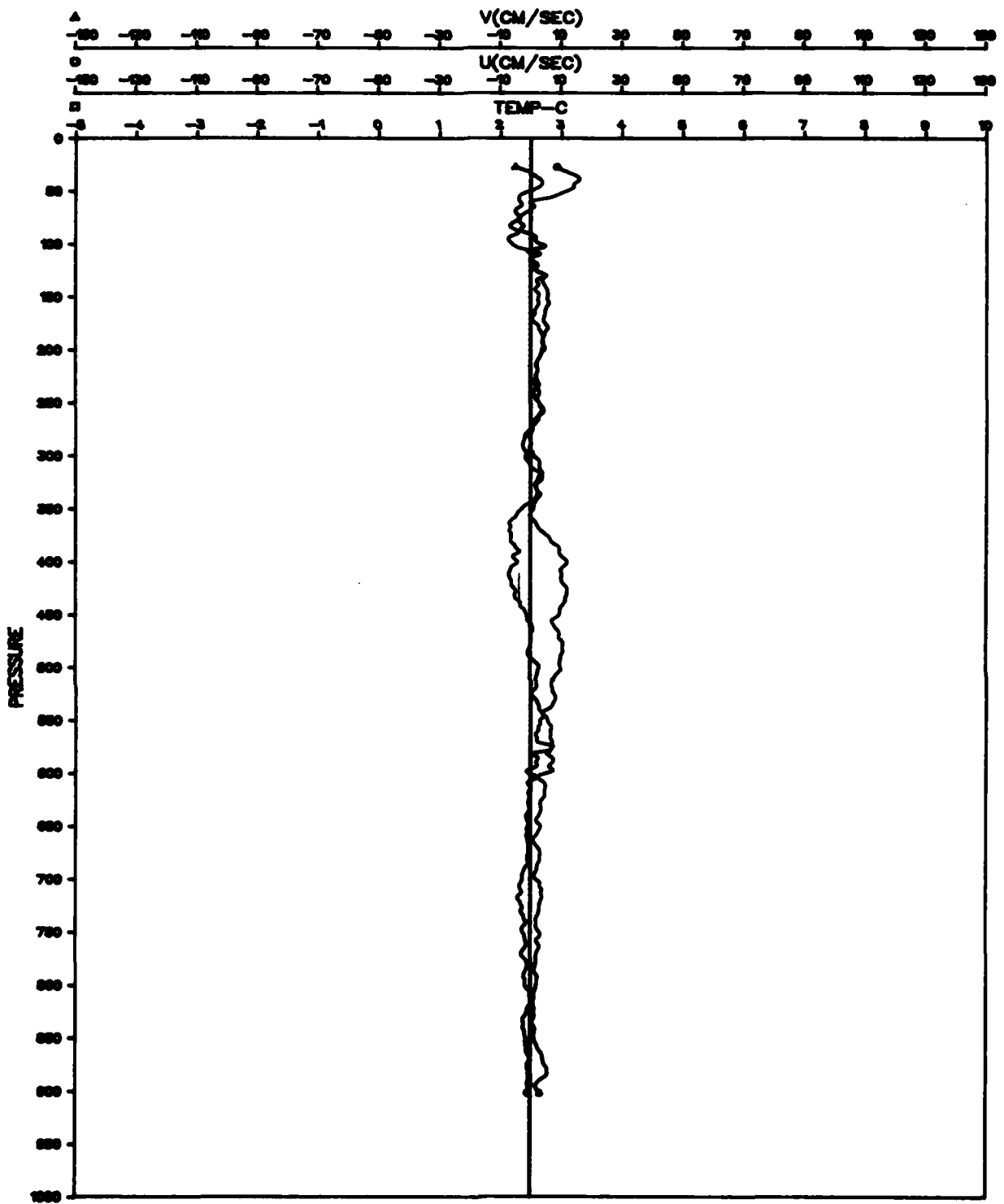


Figure A-21. File: KANE, Segment: C 535

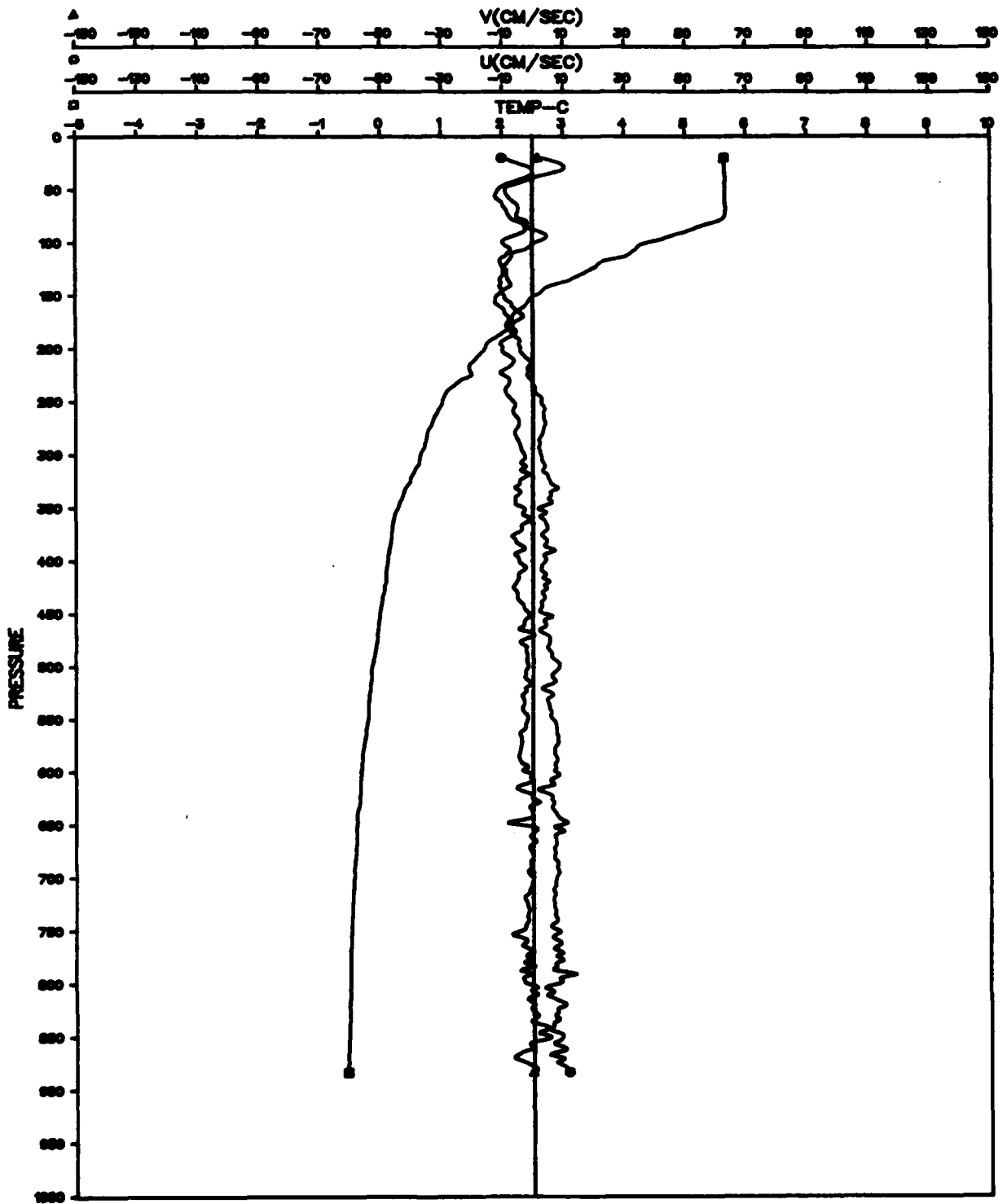


Figure A-22. File: KANE, Segment: C 538

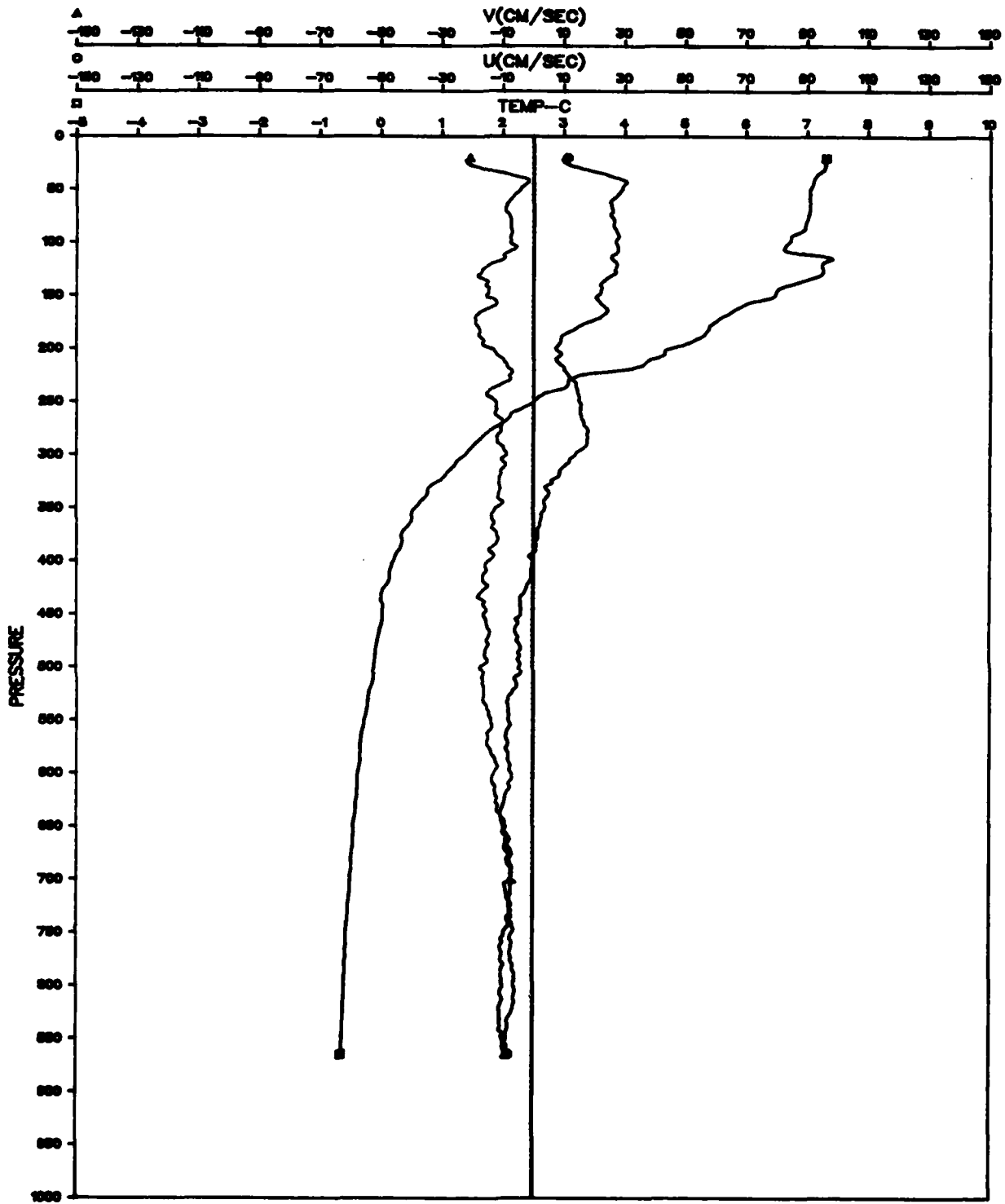


Figure A-23. File: KANE, Segment: C 539

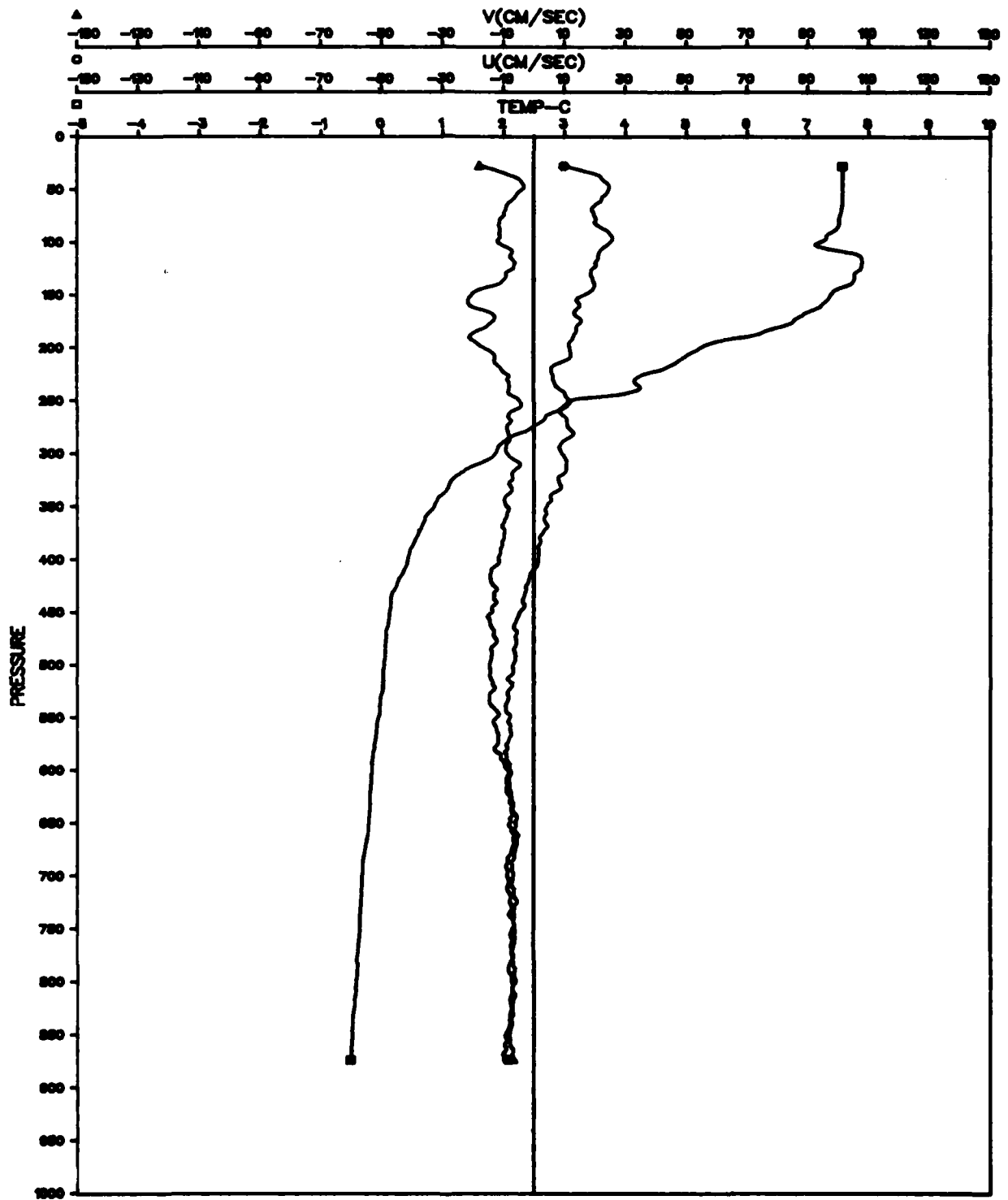


Figure A-24. File: KANE, Segment: C 542

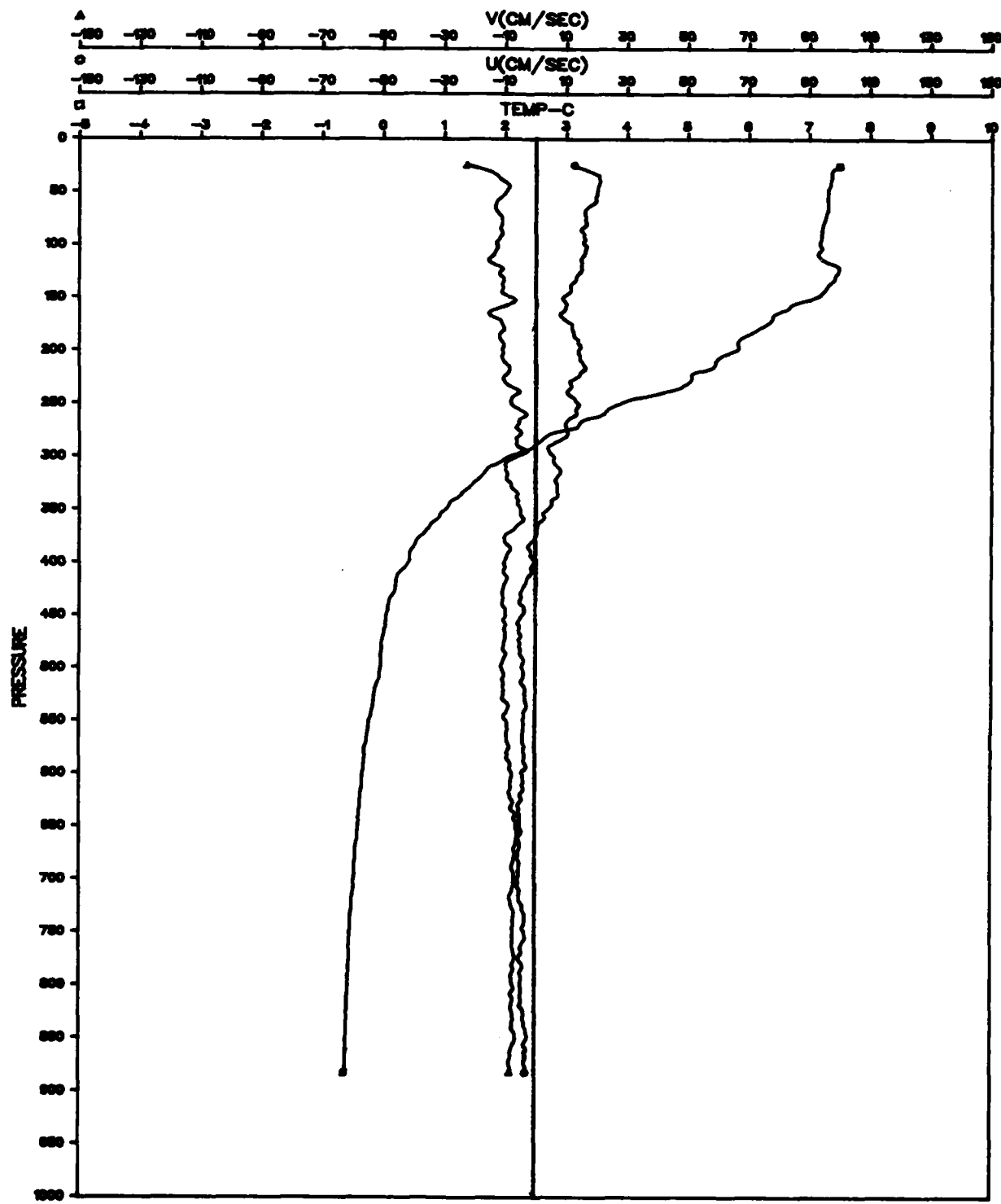


Figure A-25. File: KANE, Segment: C 543

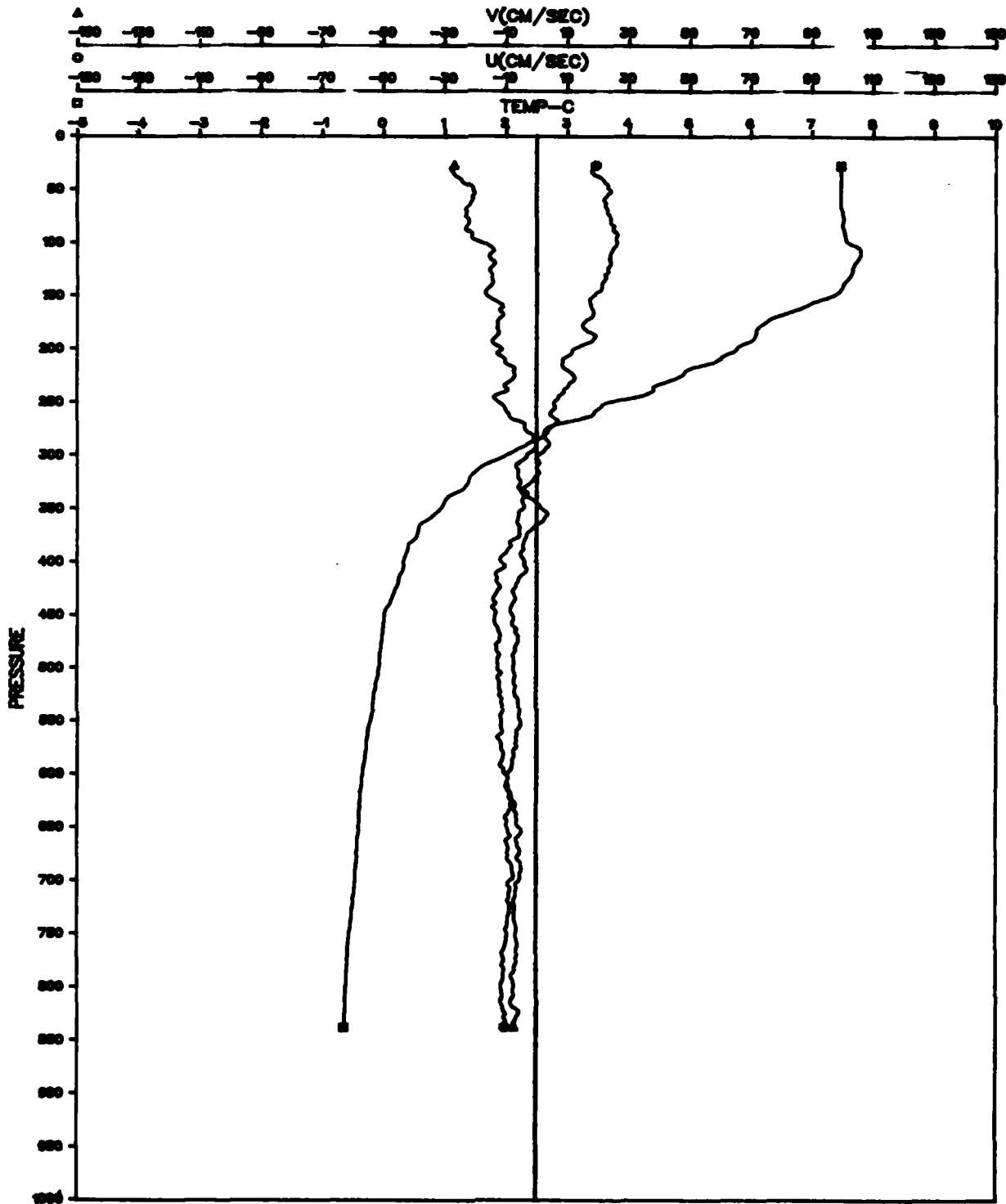


Figure A-26. File: KANE, Segment: C 544

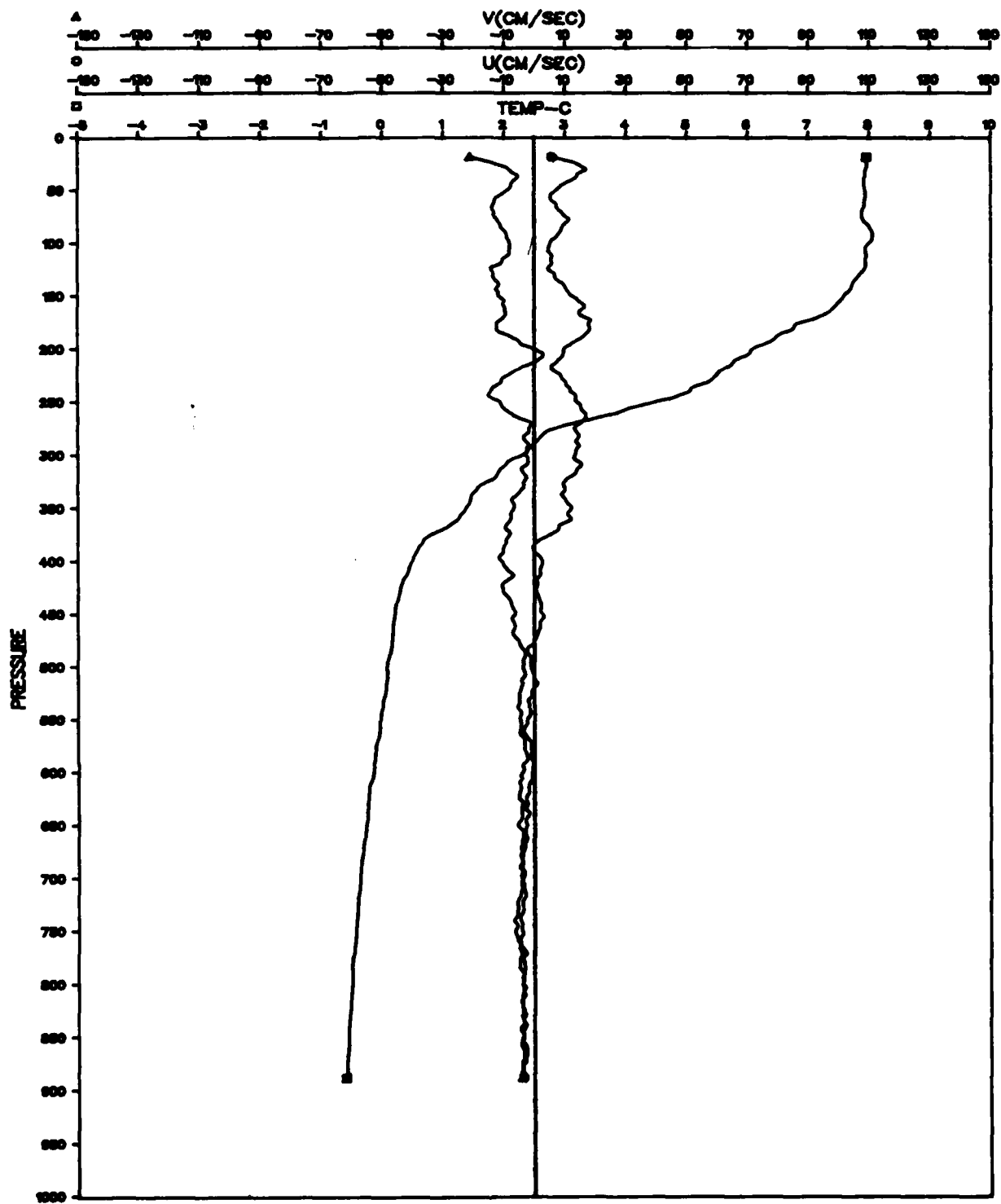


Figure A-27. File: KANE, Segment: C 546

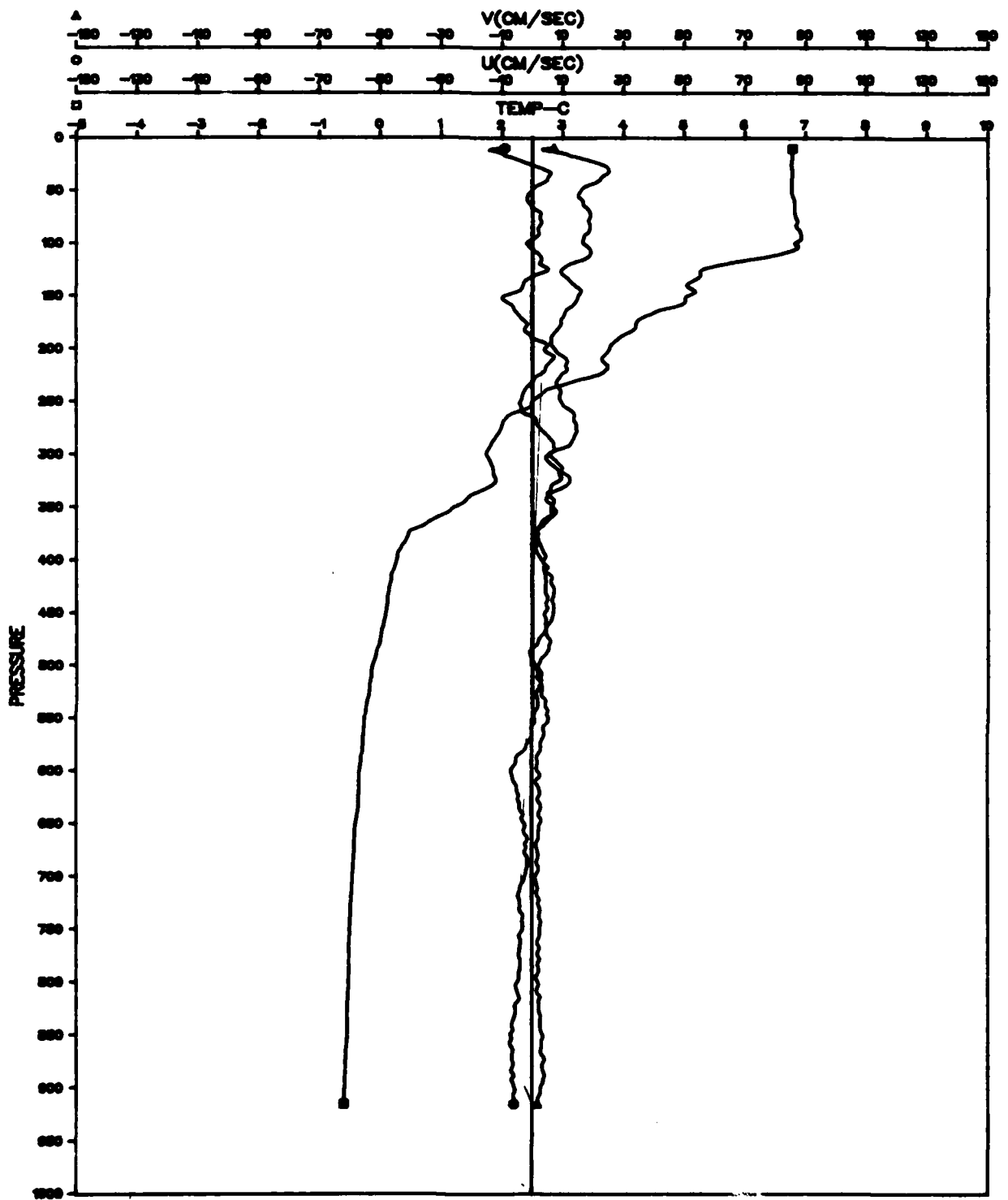


Figure A-28. File: KANE, Segment: C 547

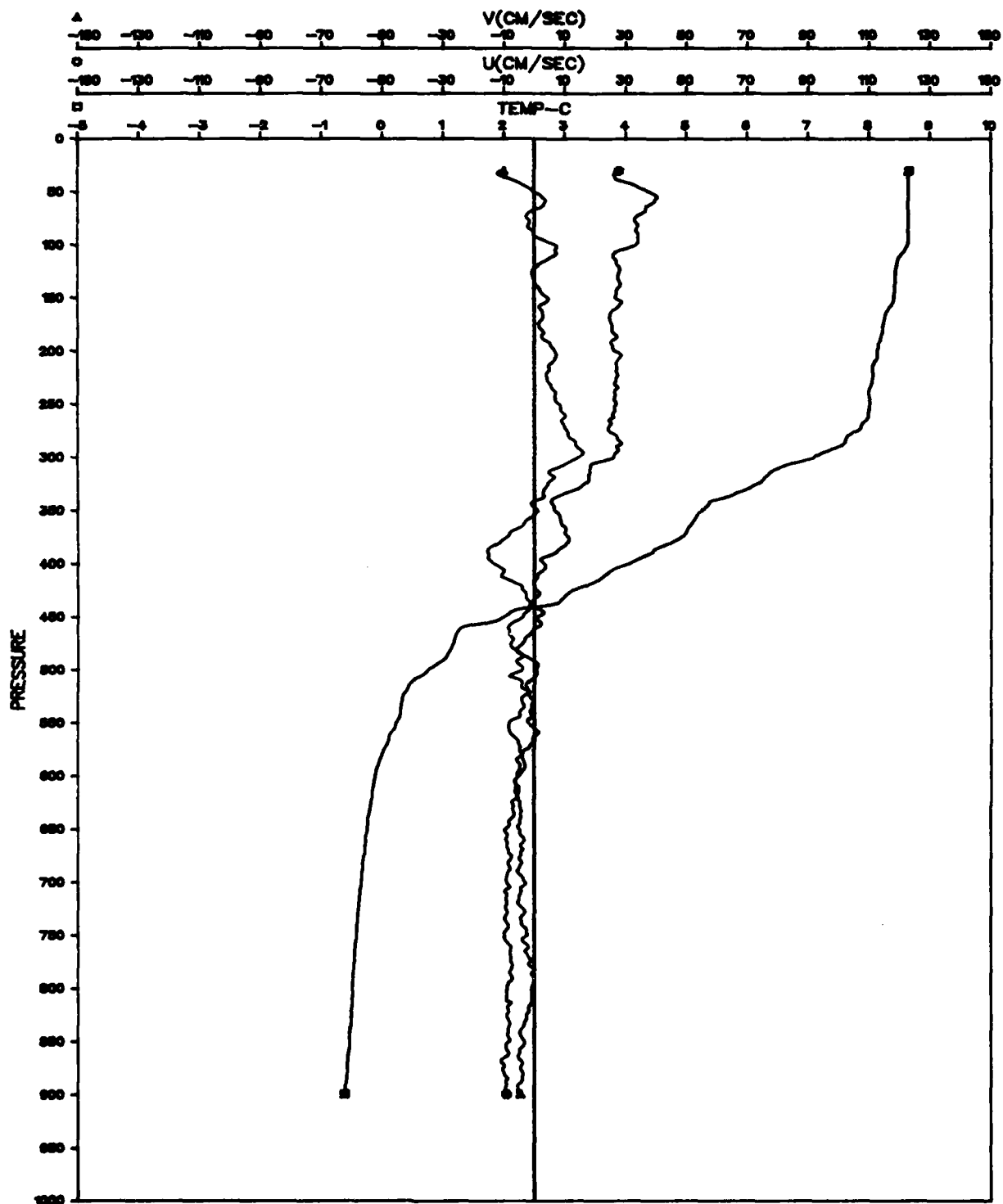


Figure A-29. File: KANE, Segment: C 548

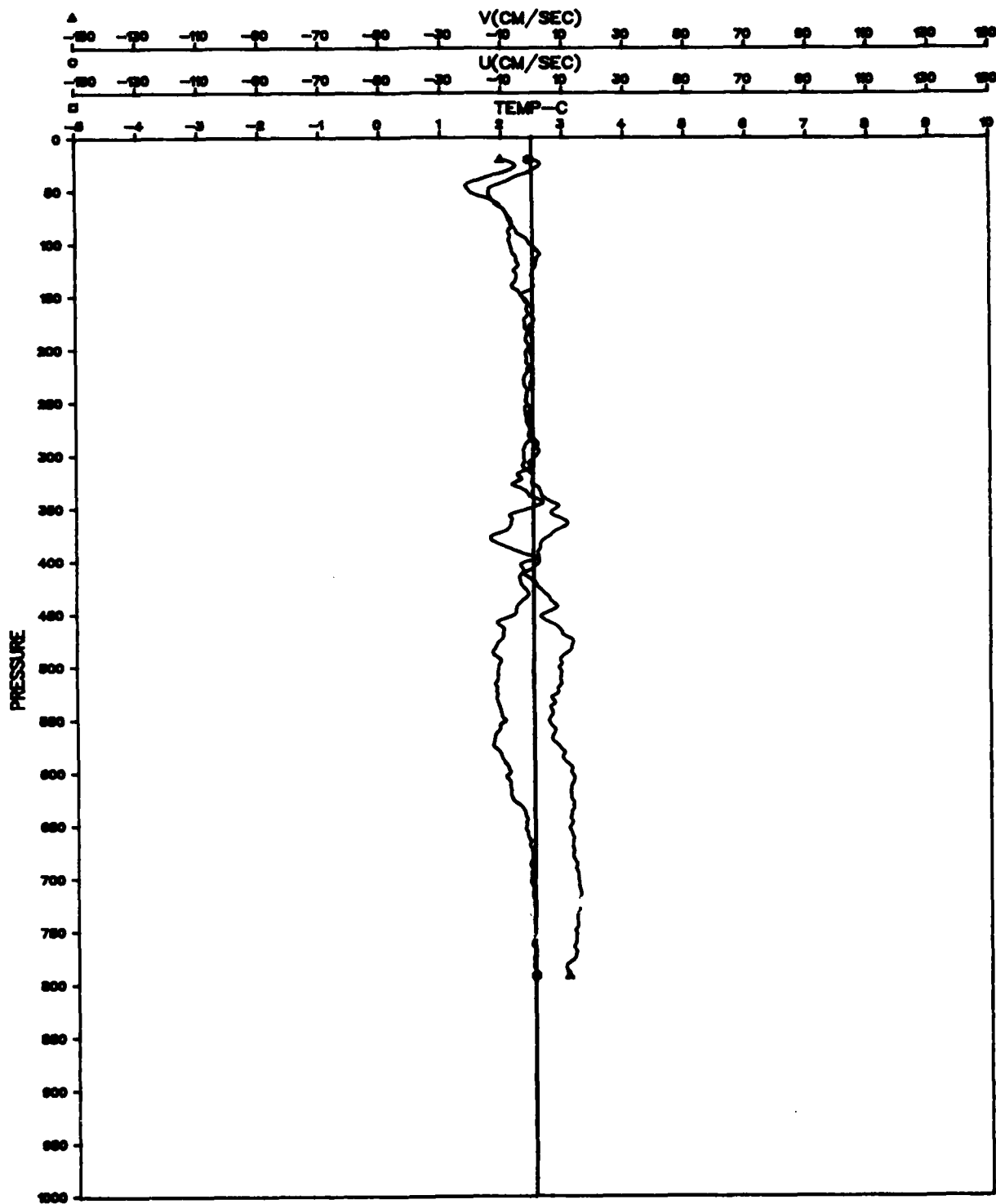


Figure A-30. File: KANE, Segment: C 549

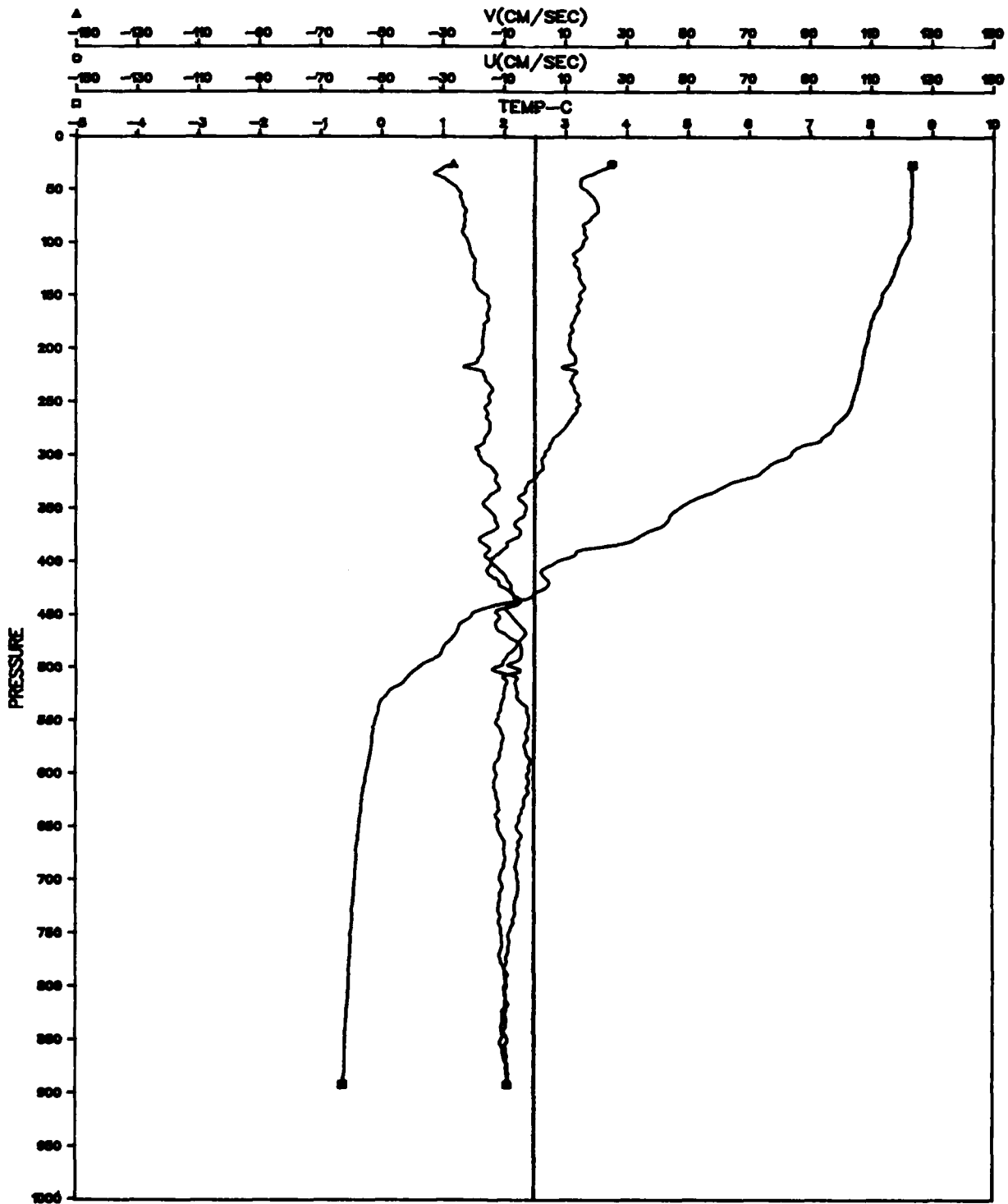


Figure A-31. File: KANE, Segment: C 550

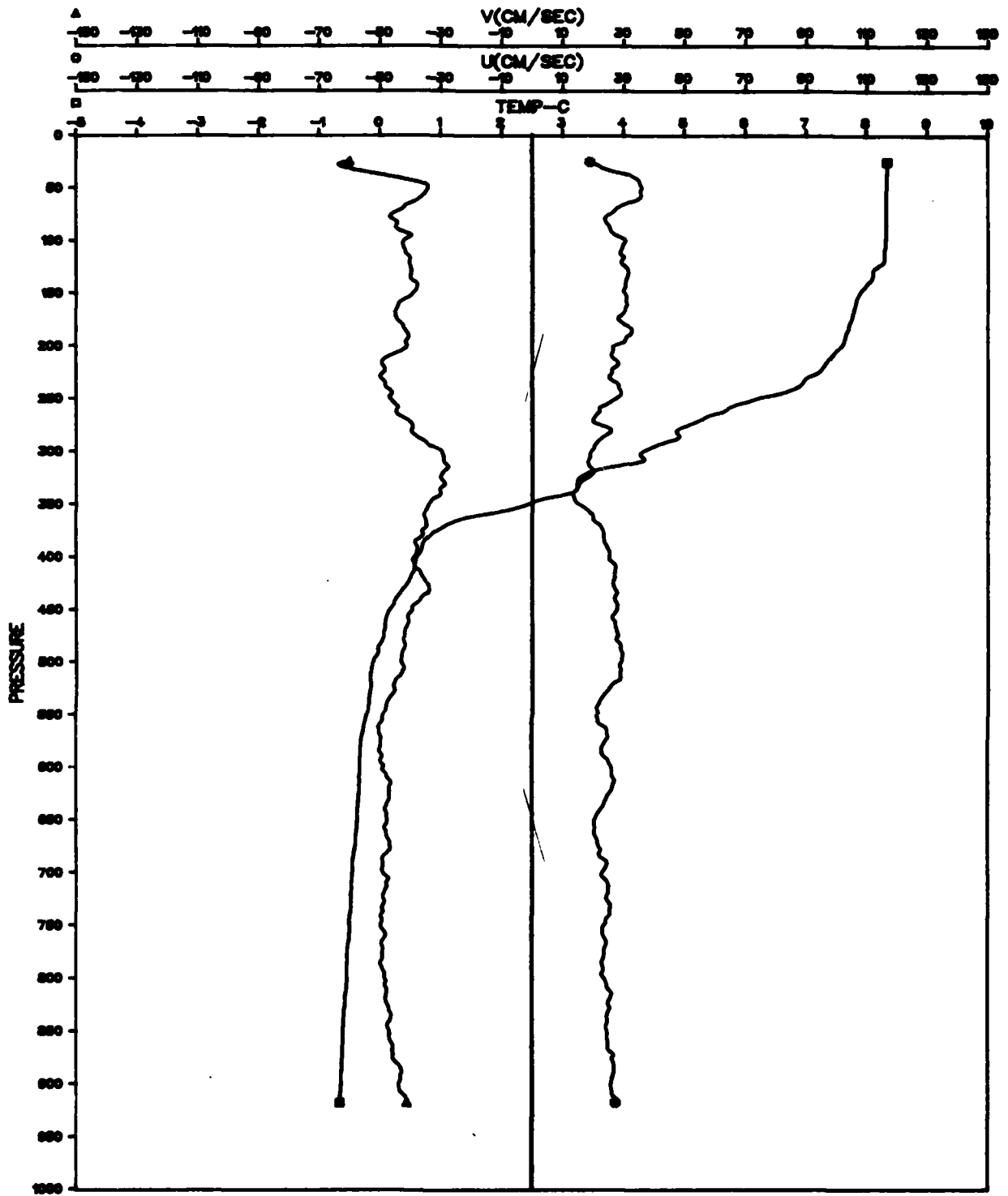


Figure A-32. File: KANE, Segment: C 551

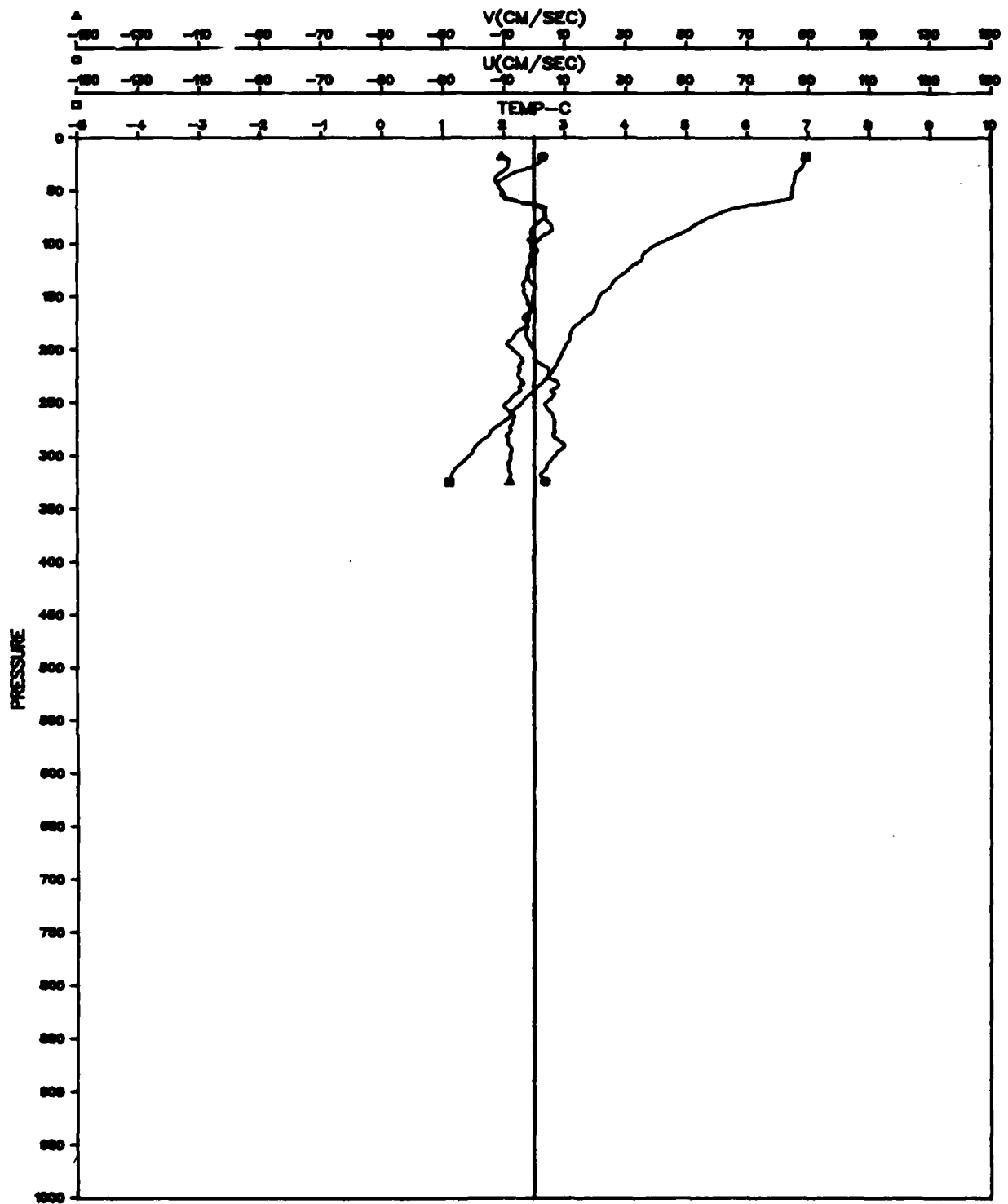


Figure A-33. File: KANE, Segment: C 556

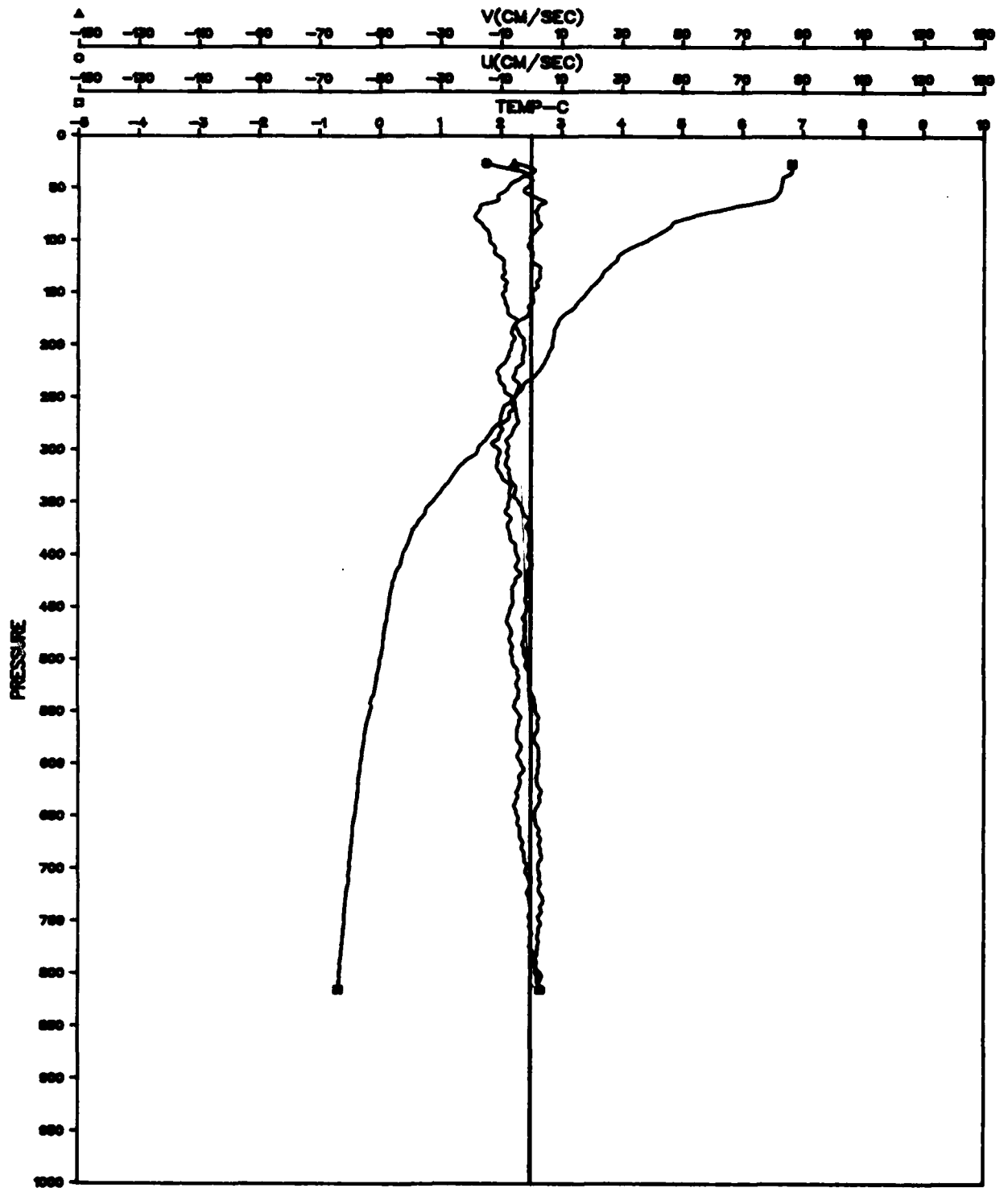


Figure A-34. File: KANE, Segment: C 558

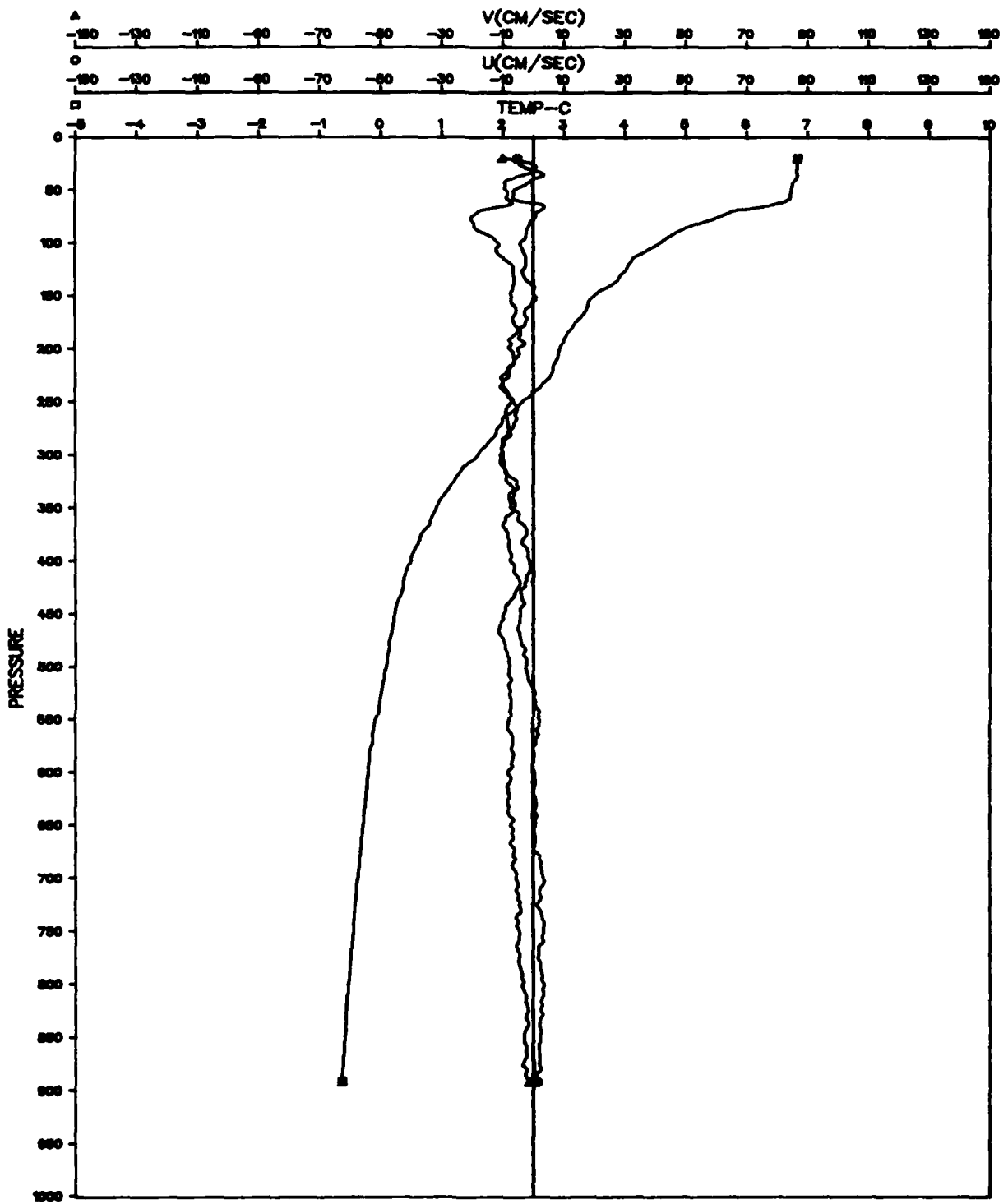


Figure A-35. File: KANE, Segment: C 559

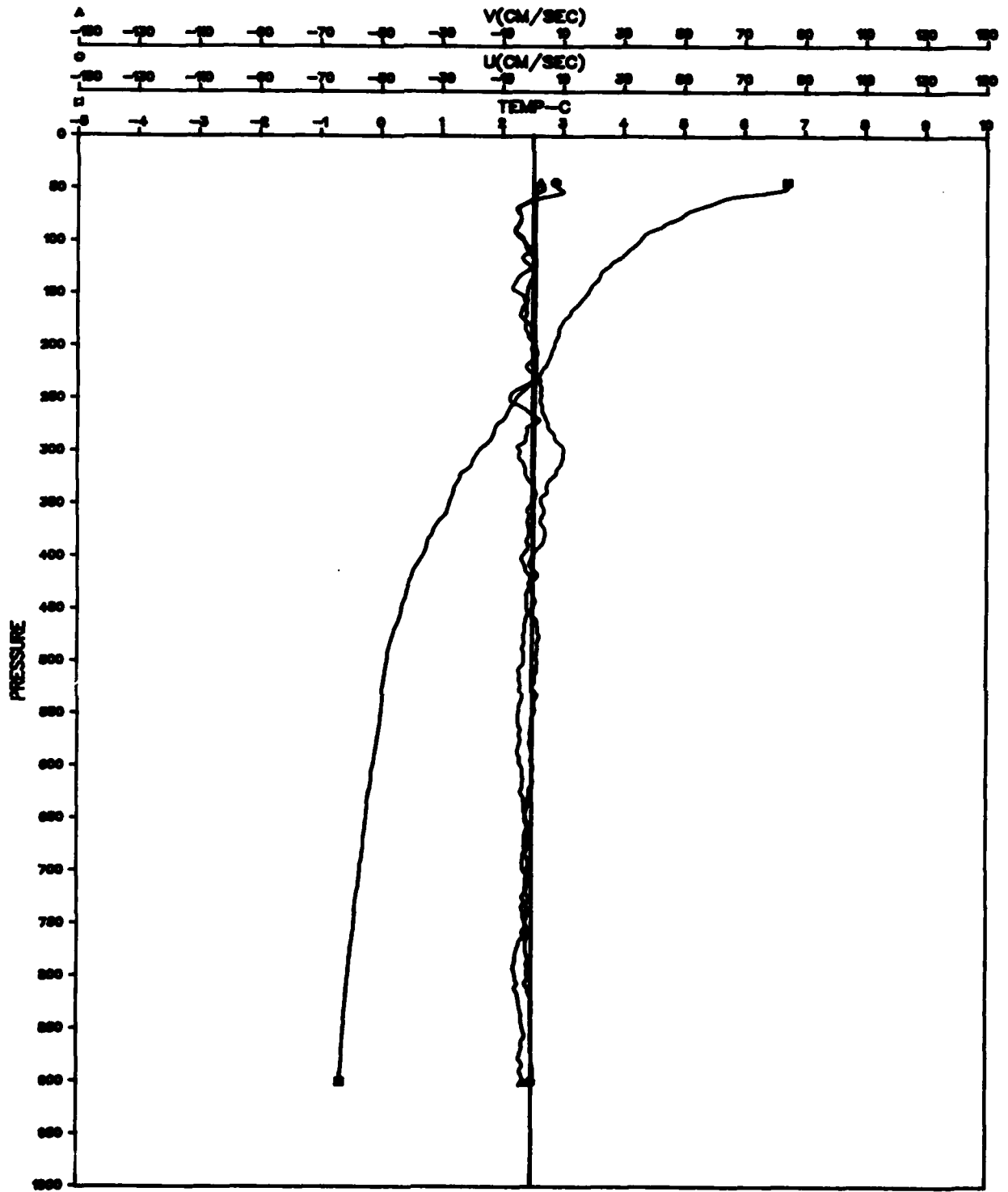


Figure A-36. File: KANE, Segment: C 560

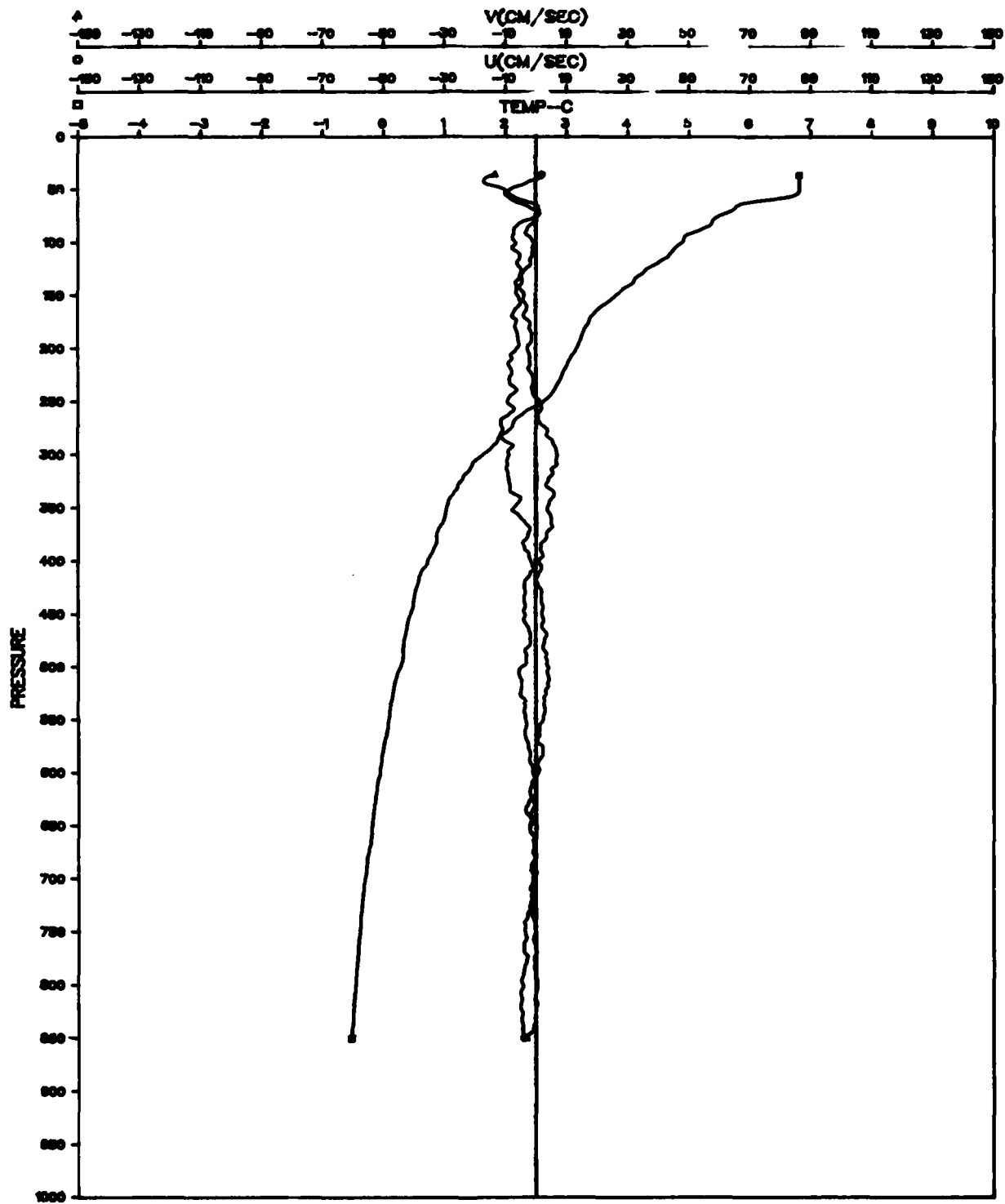


Figure A-37. File: KANE, Segment: C 561

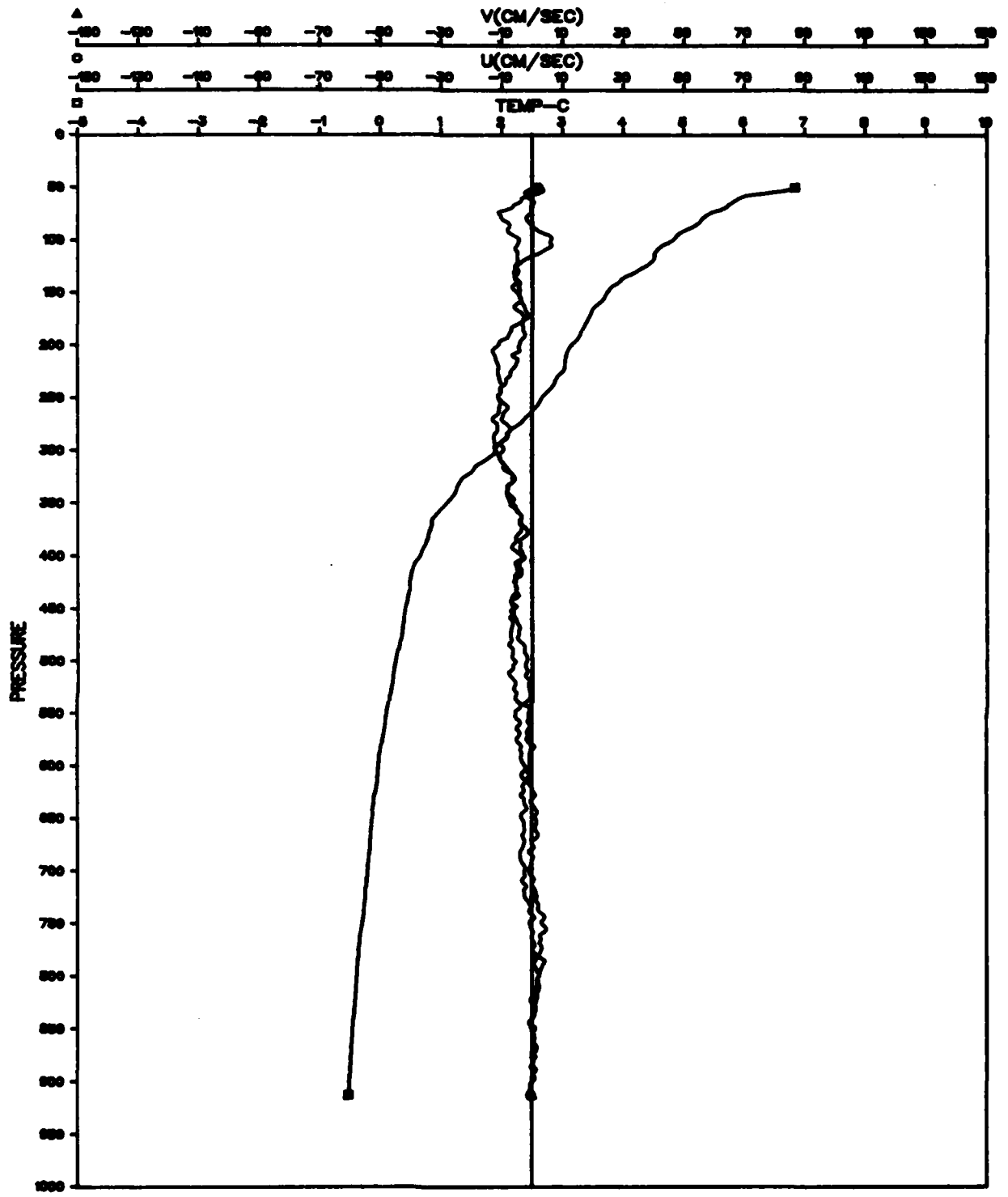


Figure A-38. File: KANE, Segment: C 562

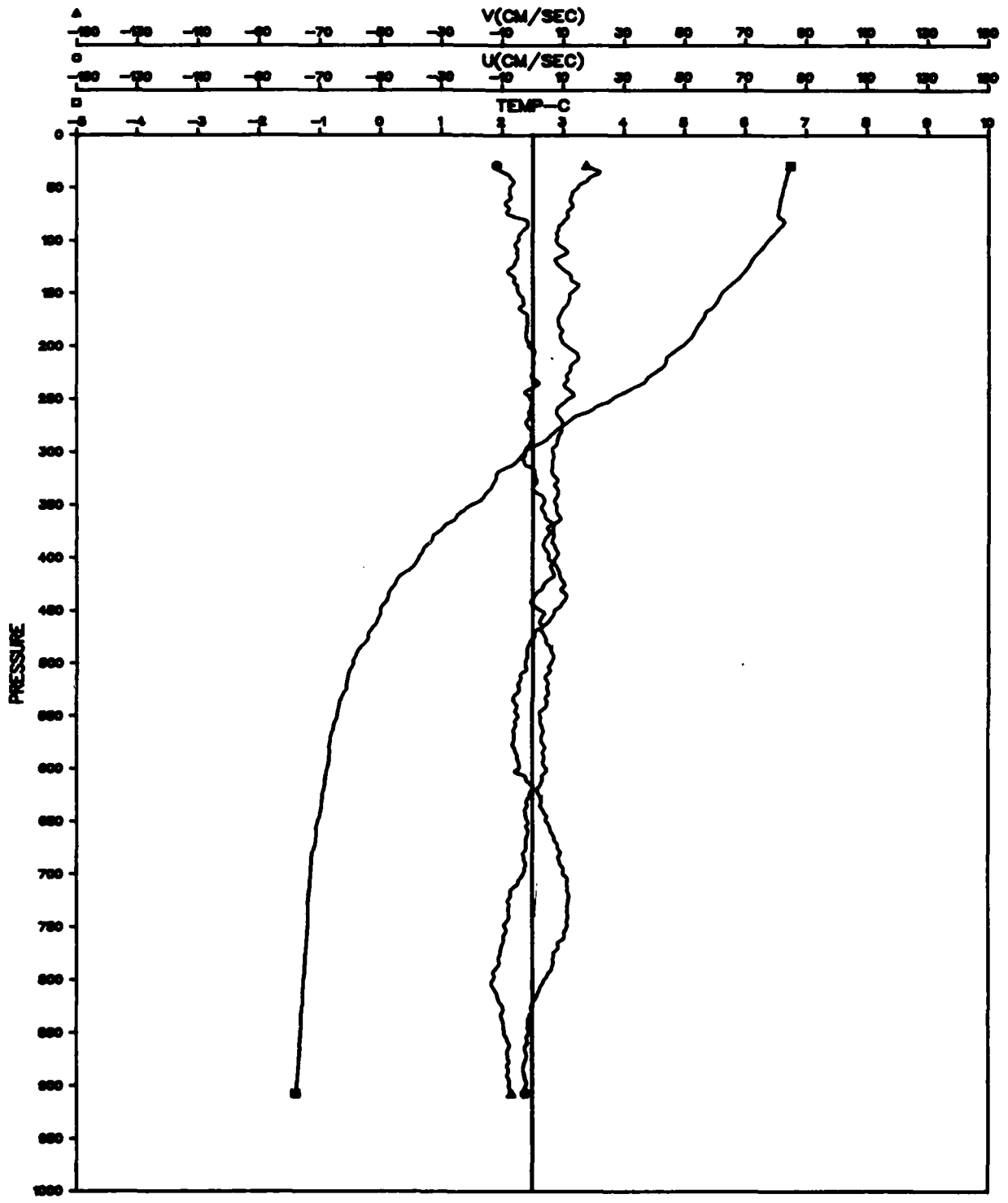


Figure A-39. File: KANE, Segment: C 563

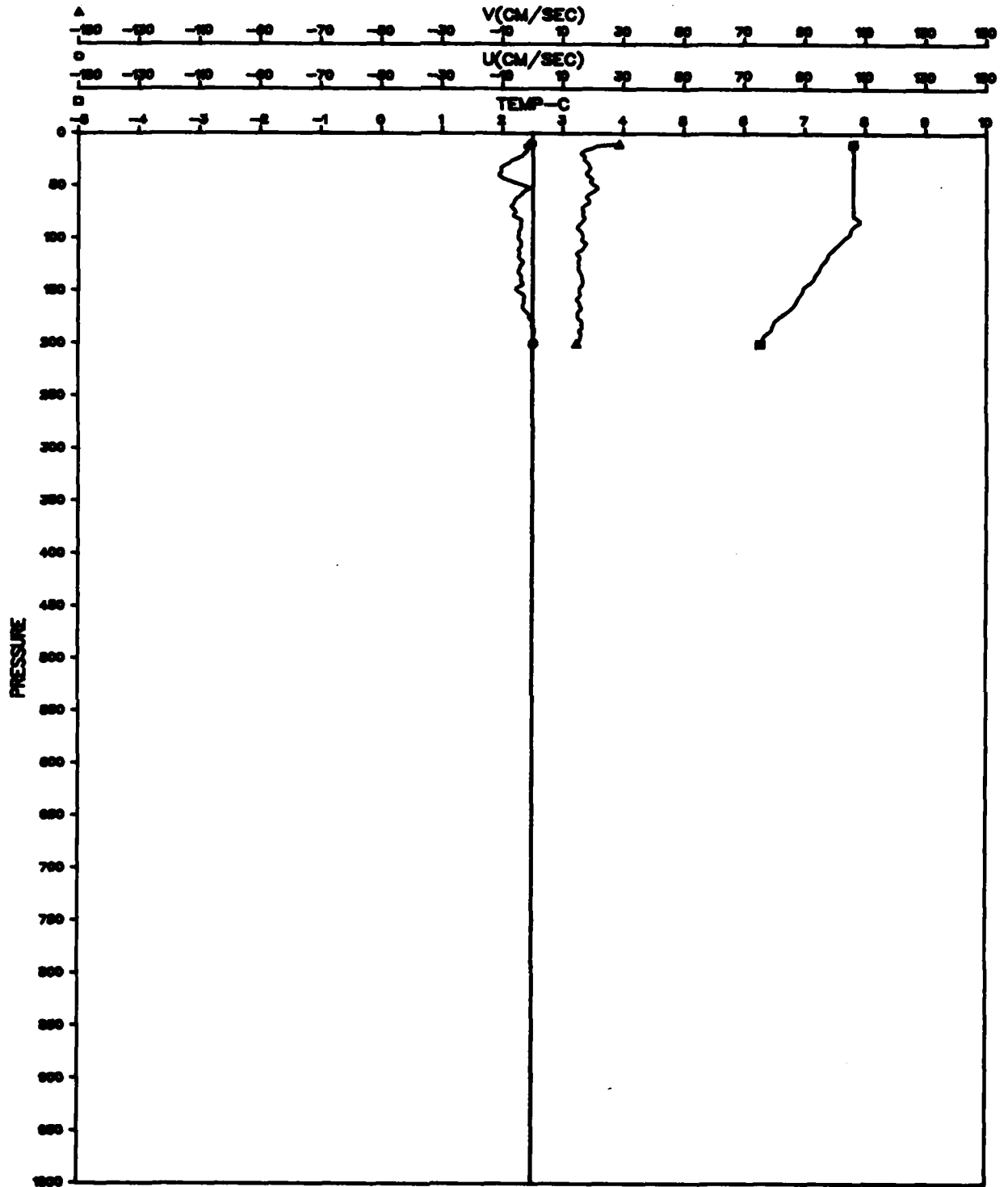


Figure A-40. File: KANE, Segment: C 564

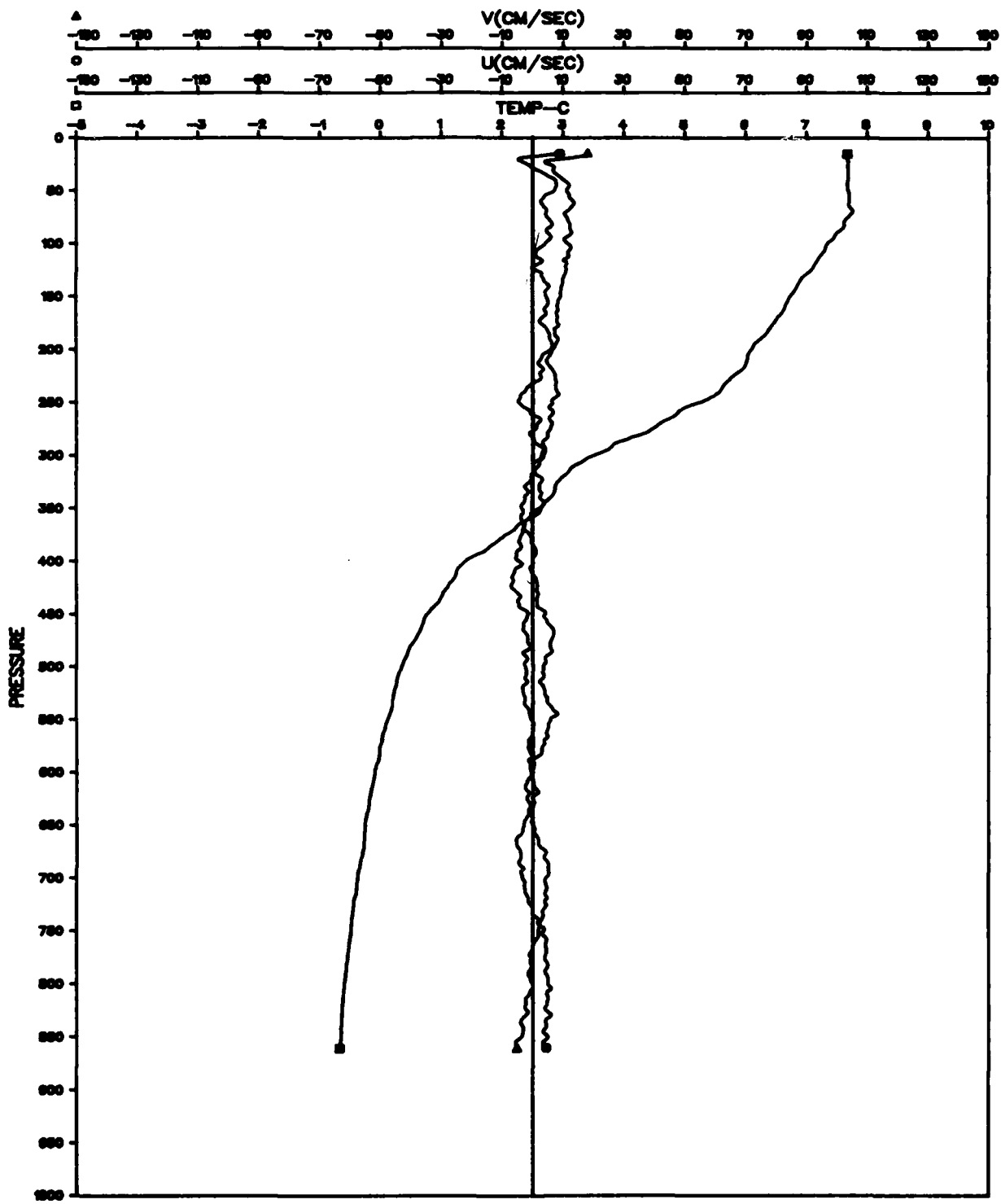


Figure A-41. File: KANE, Segment: C 566

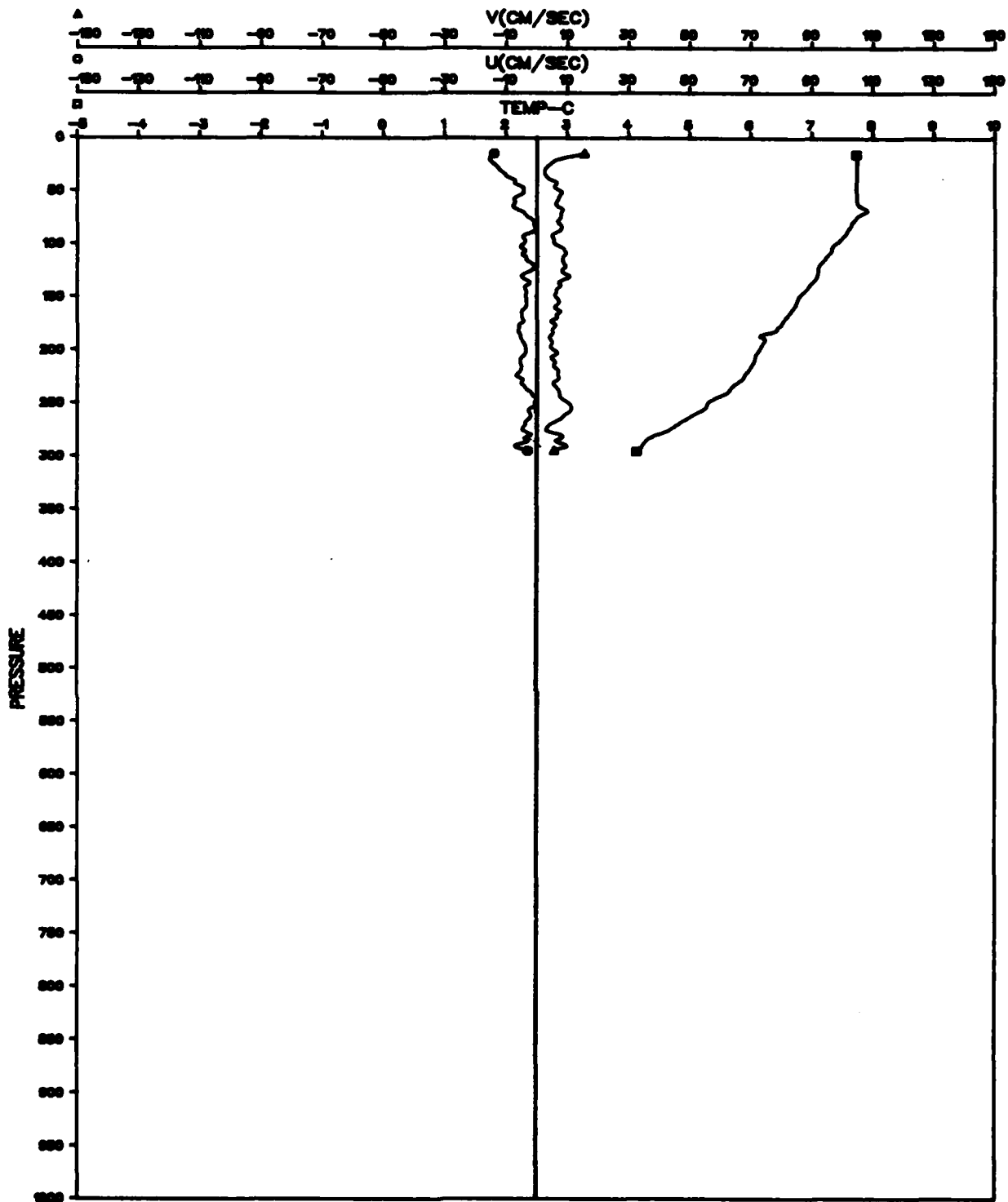


Figure A-42. File: KANE, Segment: C 567

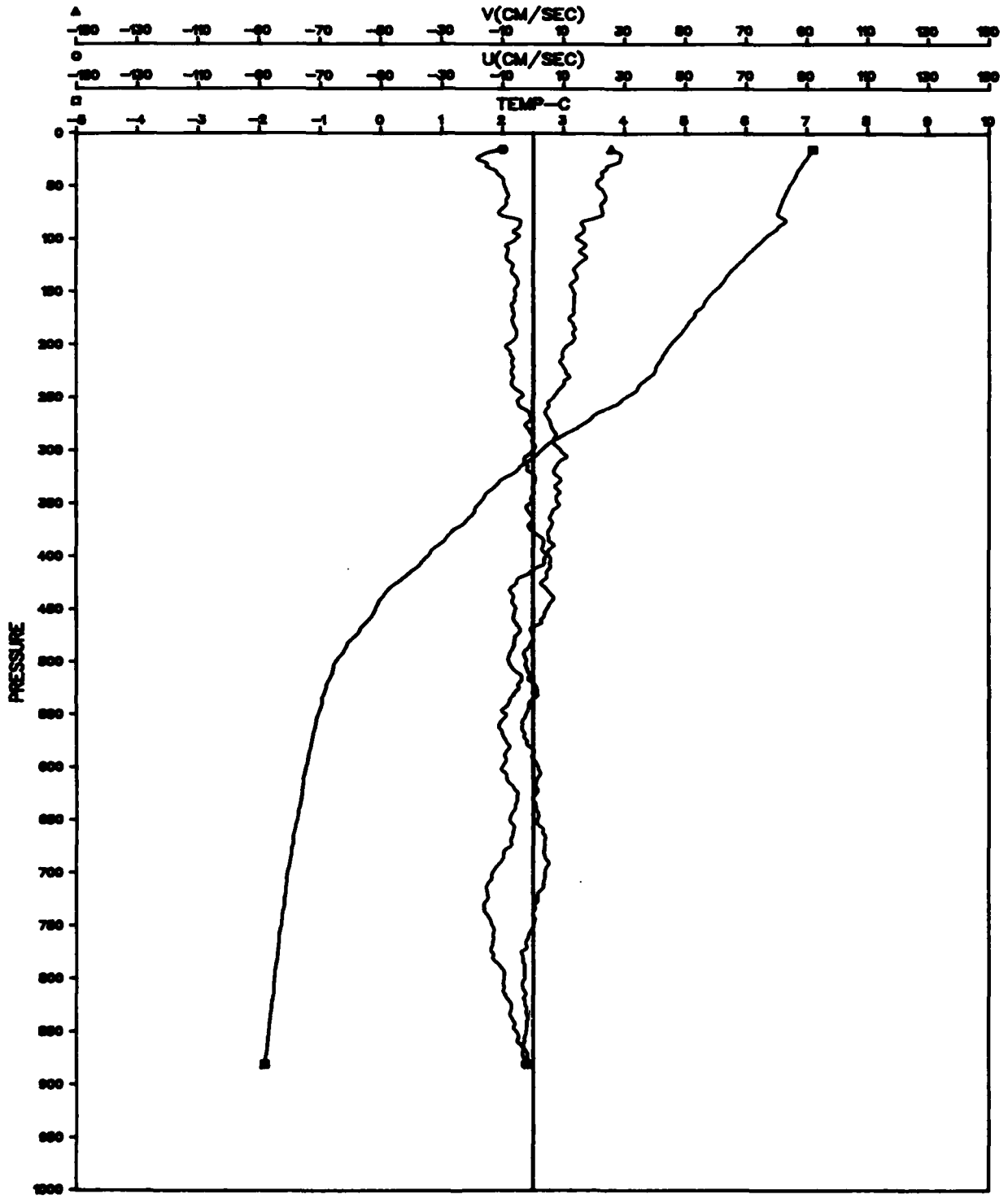


Figure A-43. File: KANE, Segment: C 568

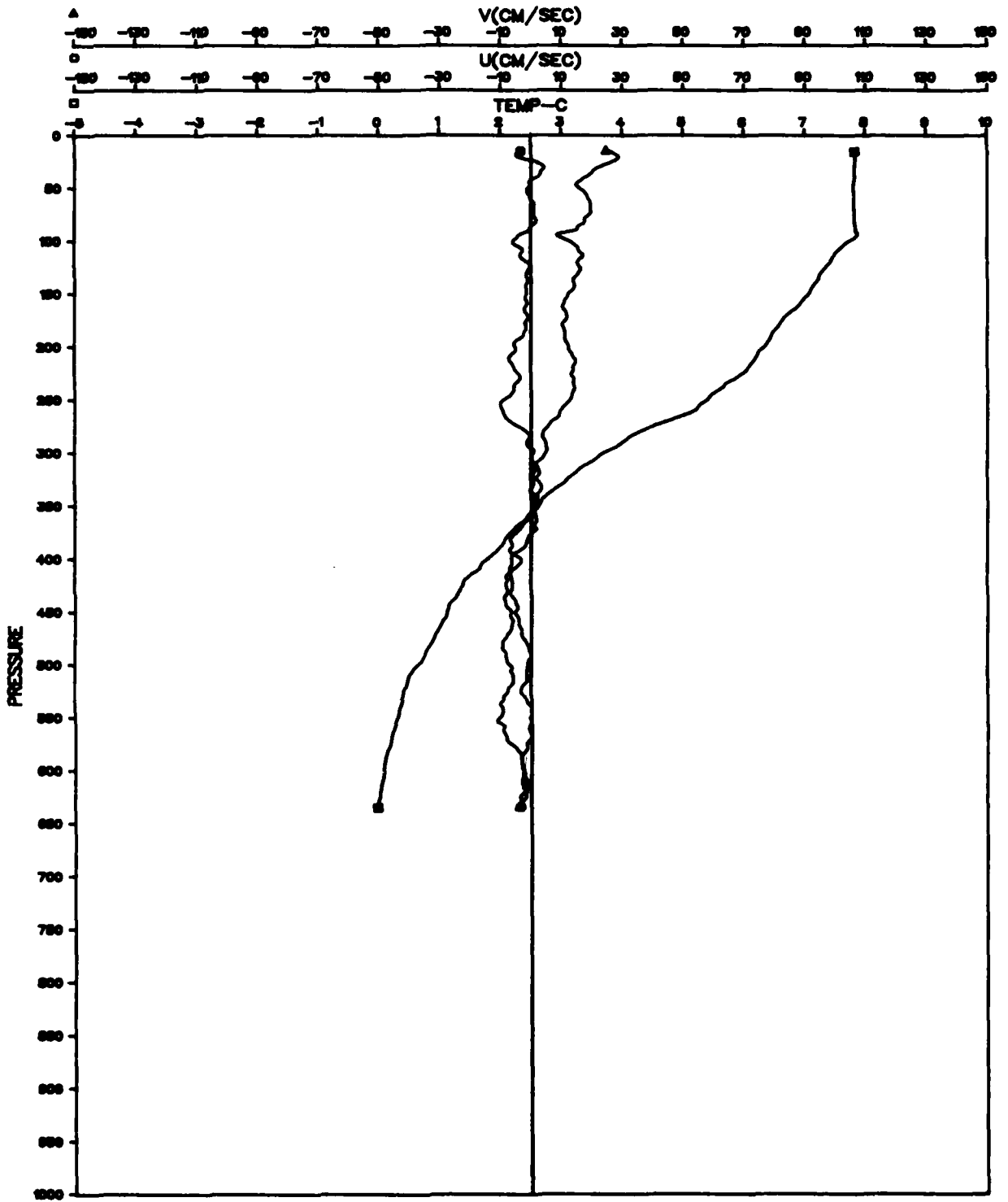


Figure A-44. File: KANE, Segment: C 569

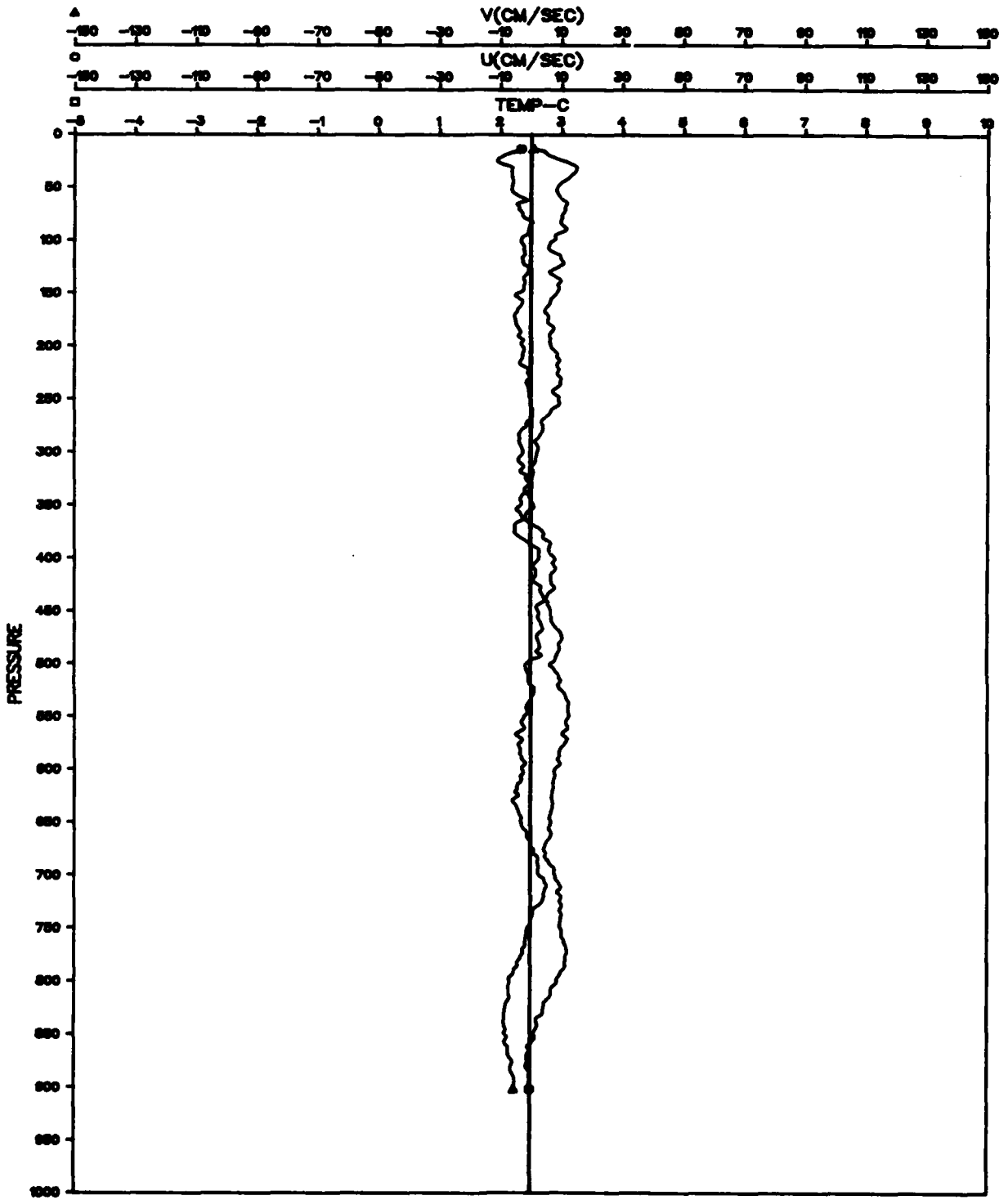


Figure A-45. File: KANE, Segment: C 571

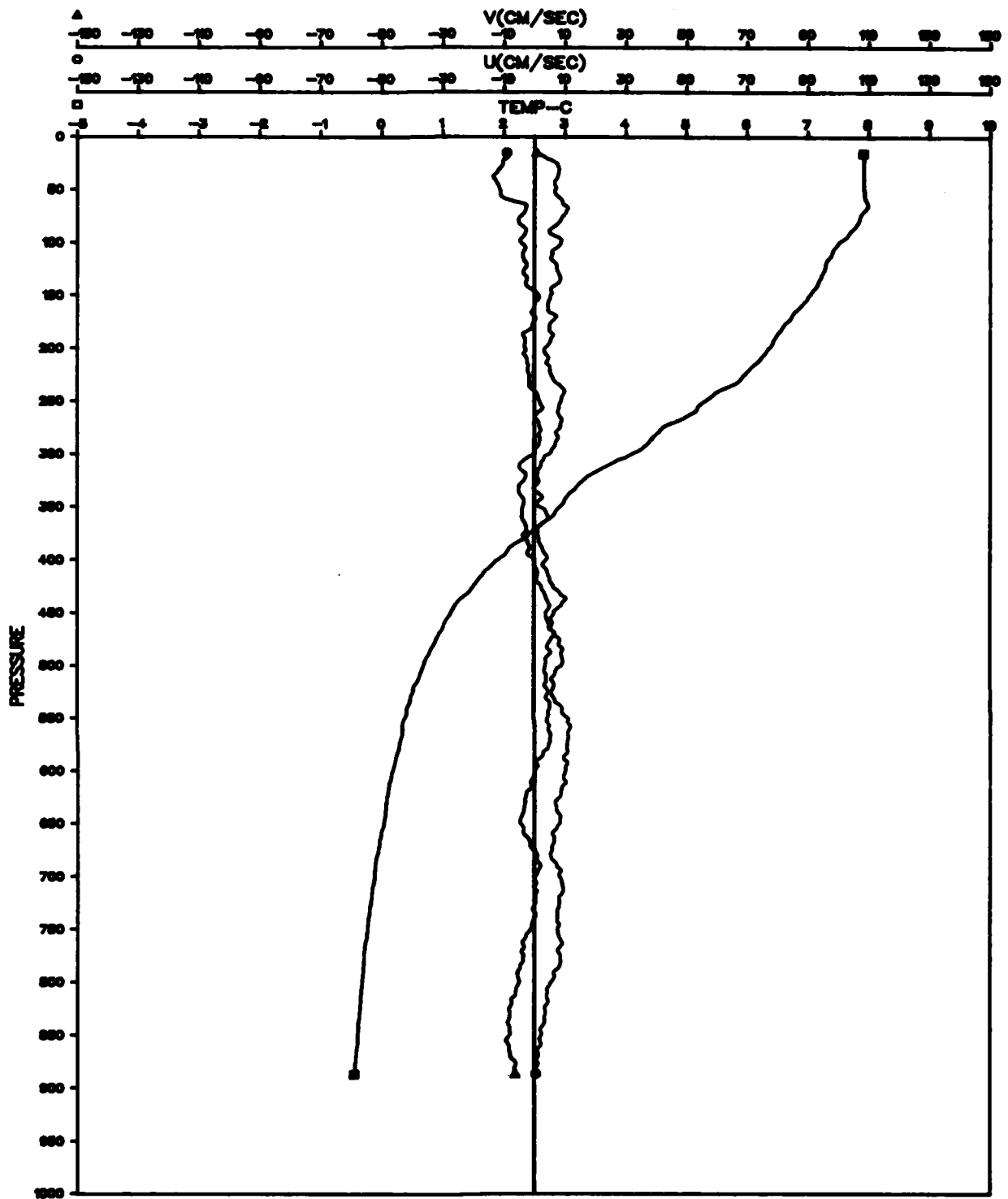


Figure A-46. File: KANE, Segment: C 573

**Appendix B:
Selected CTD Vertical Profiles
and T-S Diagrams**

COMMENTS:

Low Pass Filtered 1 m Resolution Subsampling Interval 1 m

Data Truncated Below 1000 m:

**Stations 117091
122103
123104
126106
130108
130109
132110
136116
137117
175155**

For Complete Profile See Teague, 1981

PRECEDING PAGE BLANK-NOT FILLED

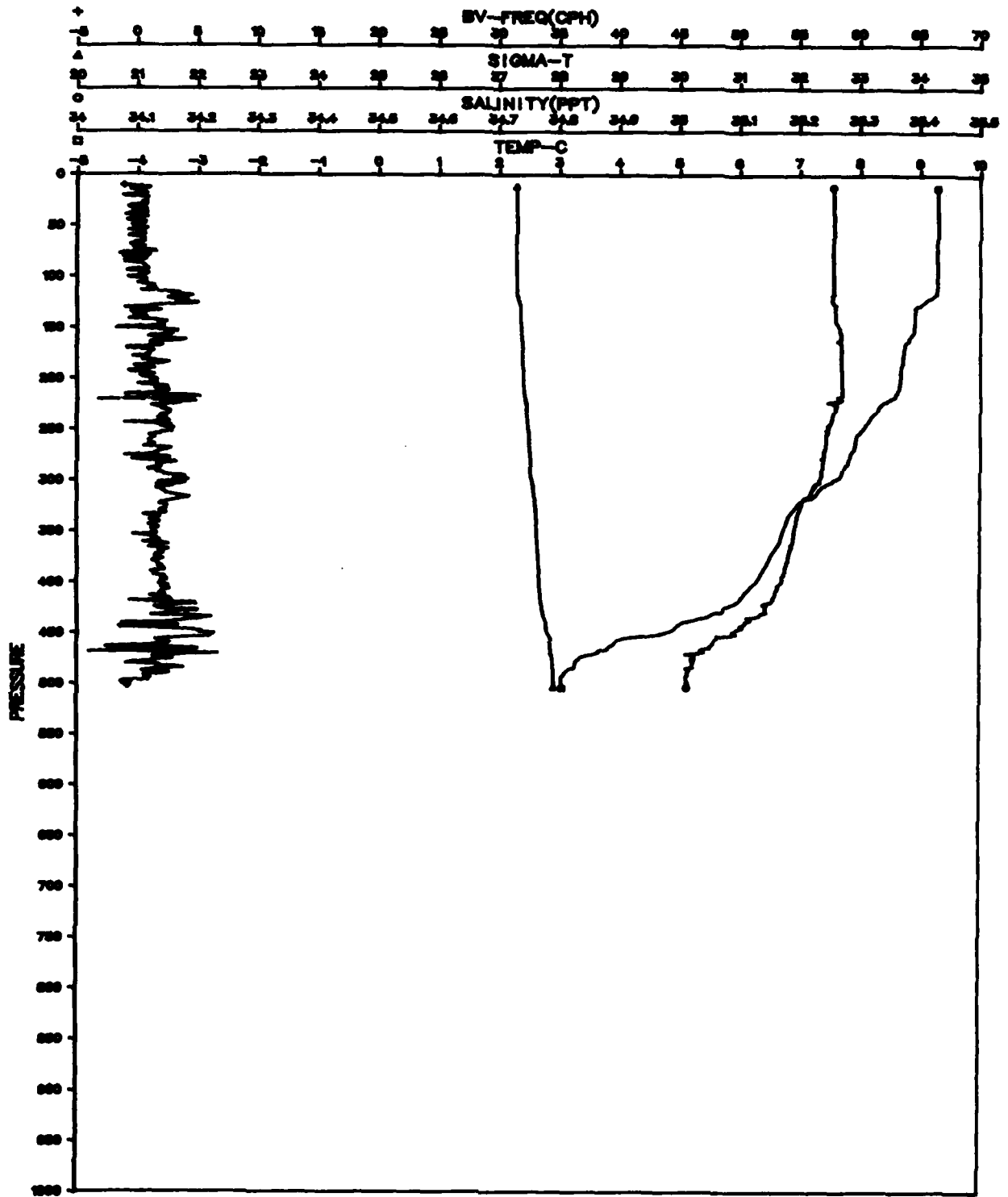


Figure B-1. File: 270980, Segment: 105073

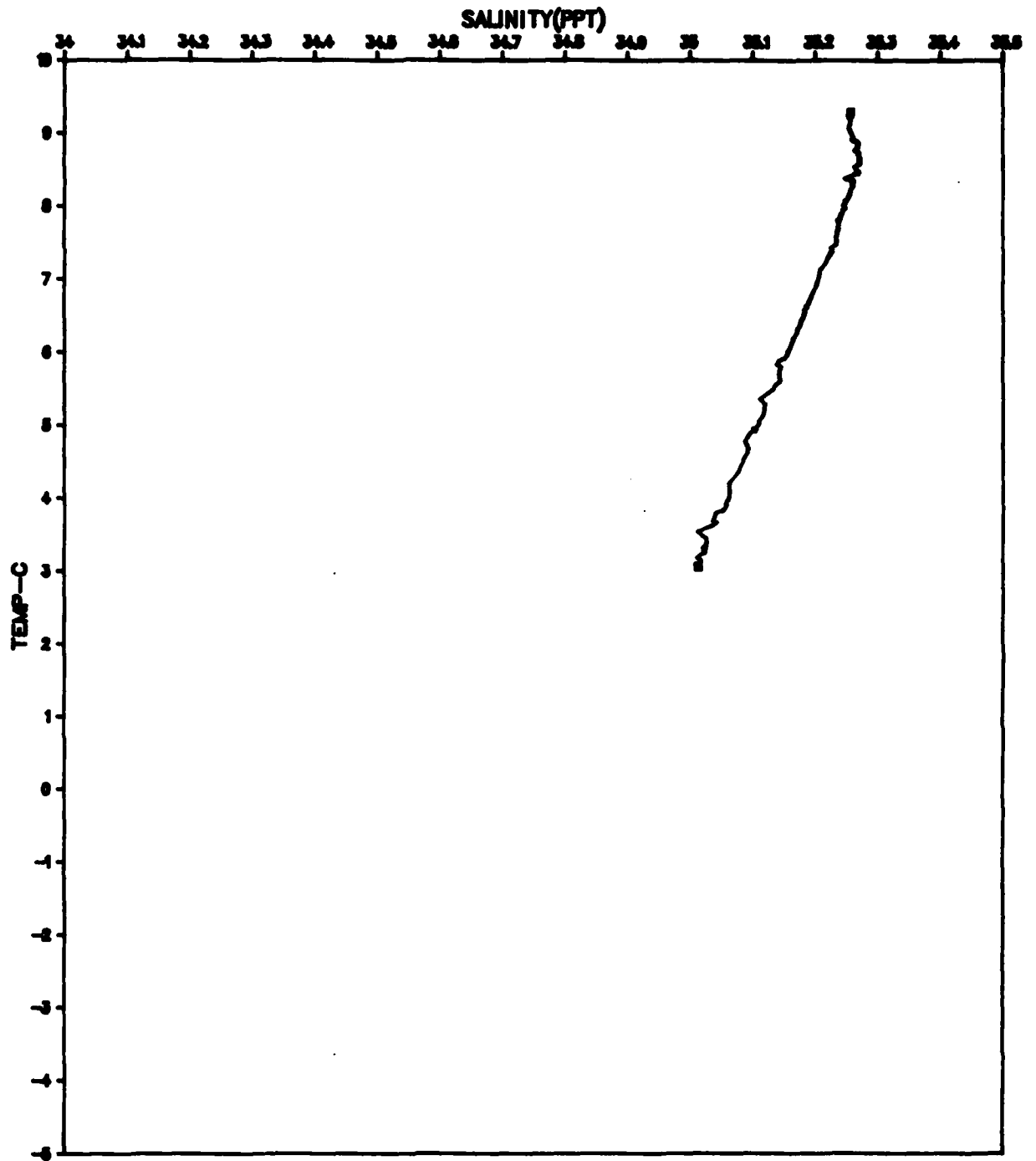


Figure B-2. File: 270980, Segment: 105073

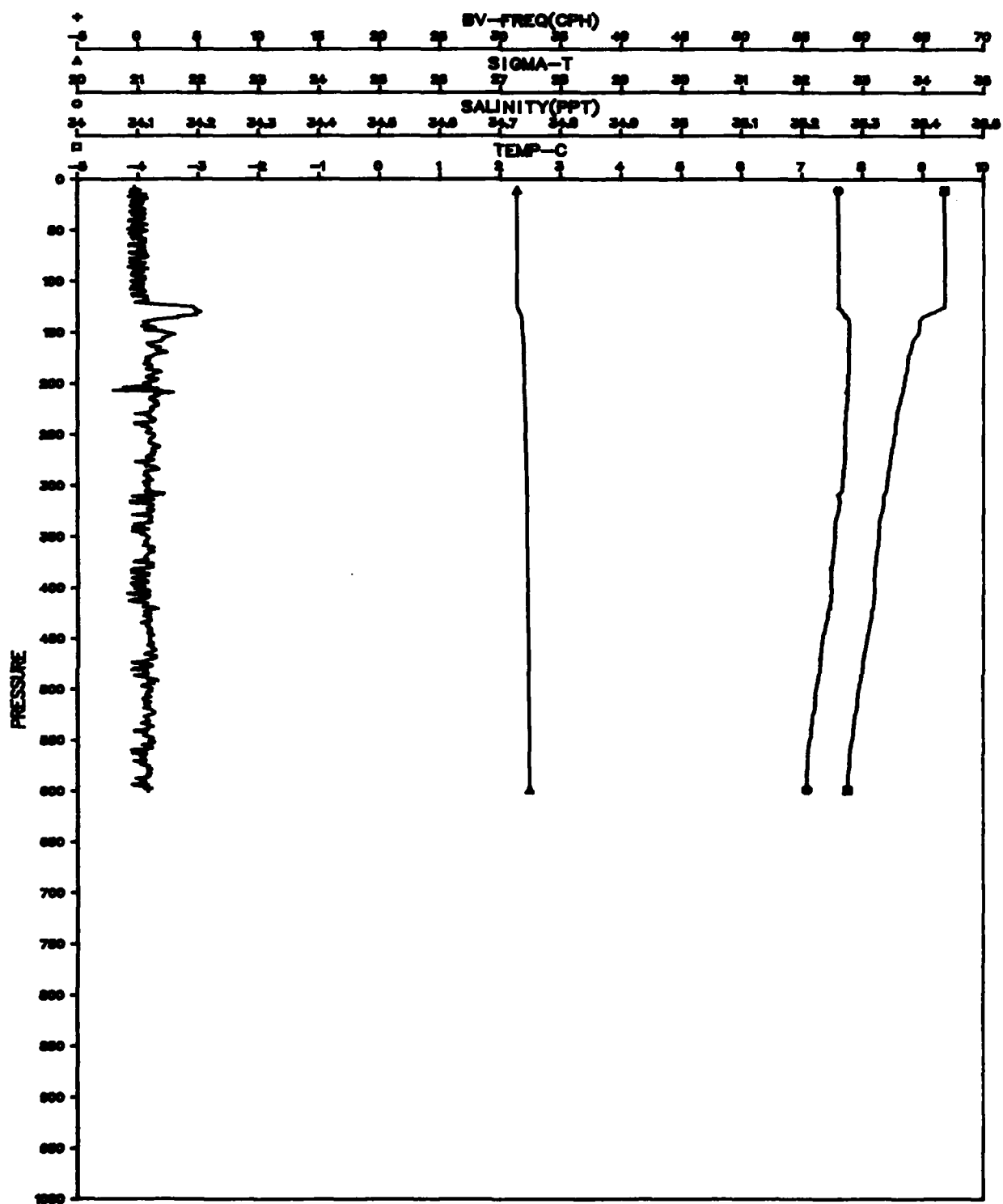


Figure B-3. File: 270980, Segment: 109076

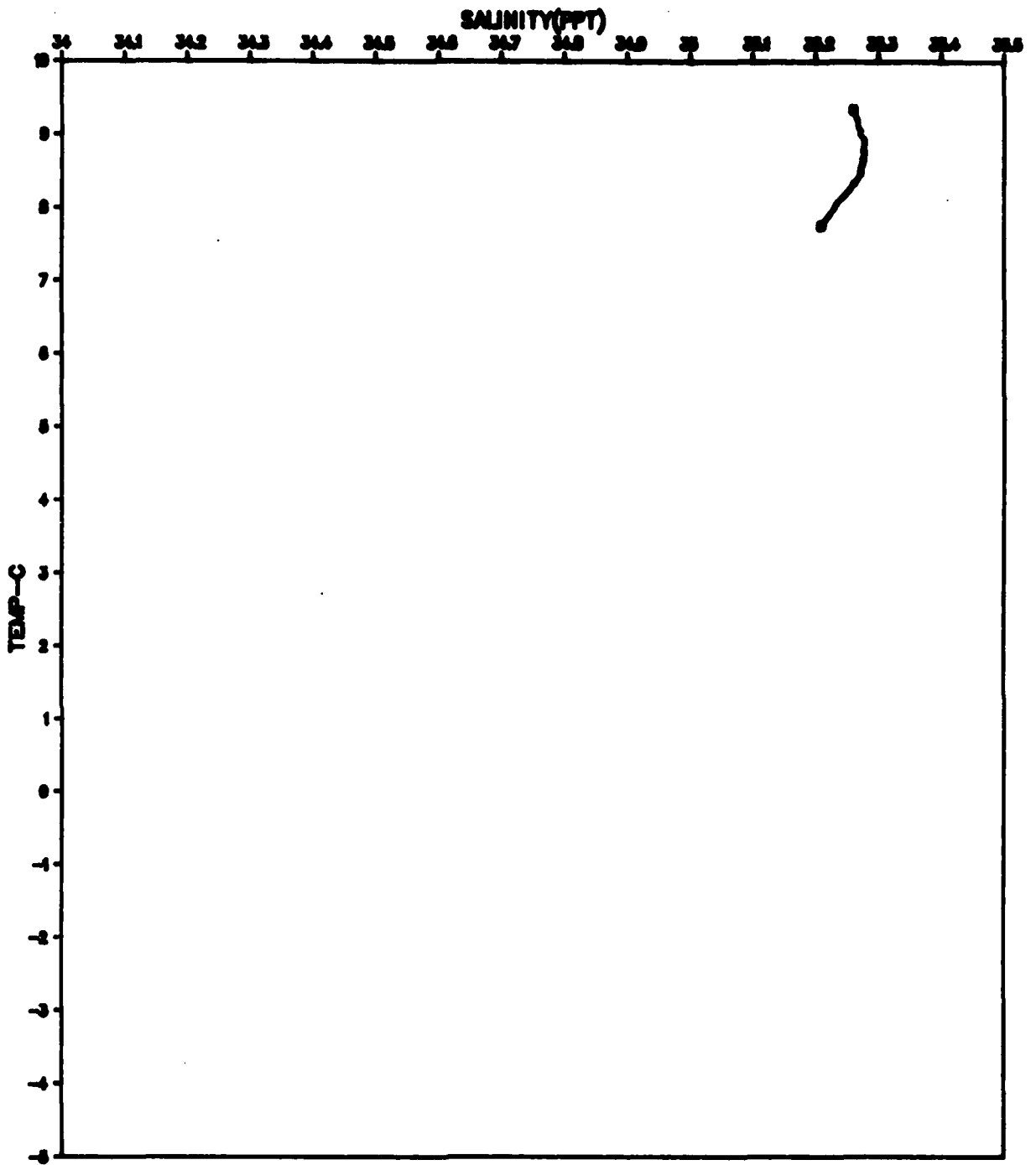


Figure B-4. File: 270980, Segment: 109076

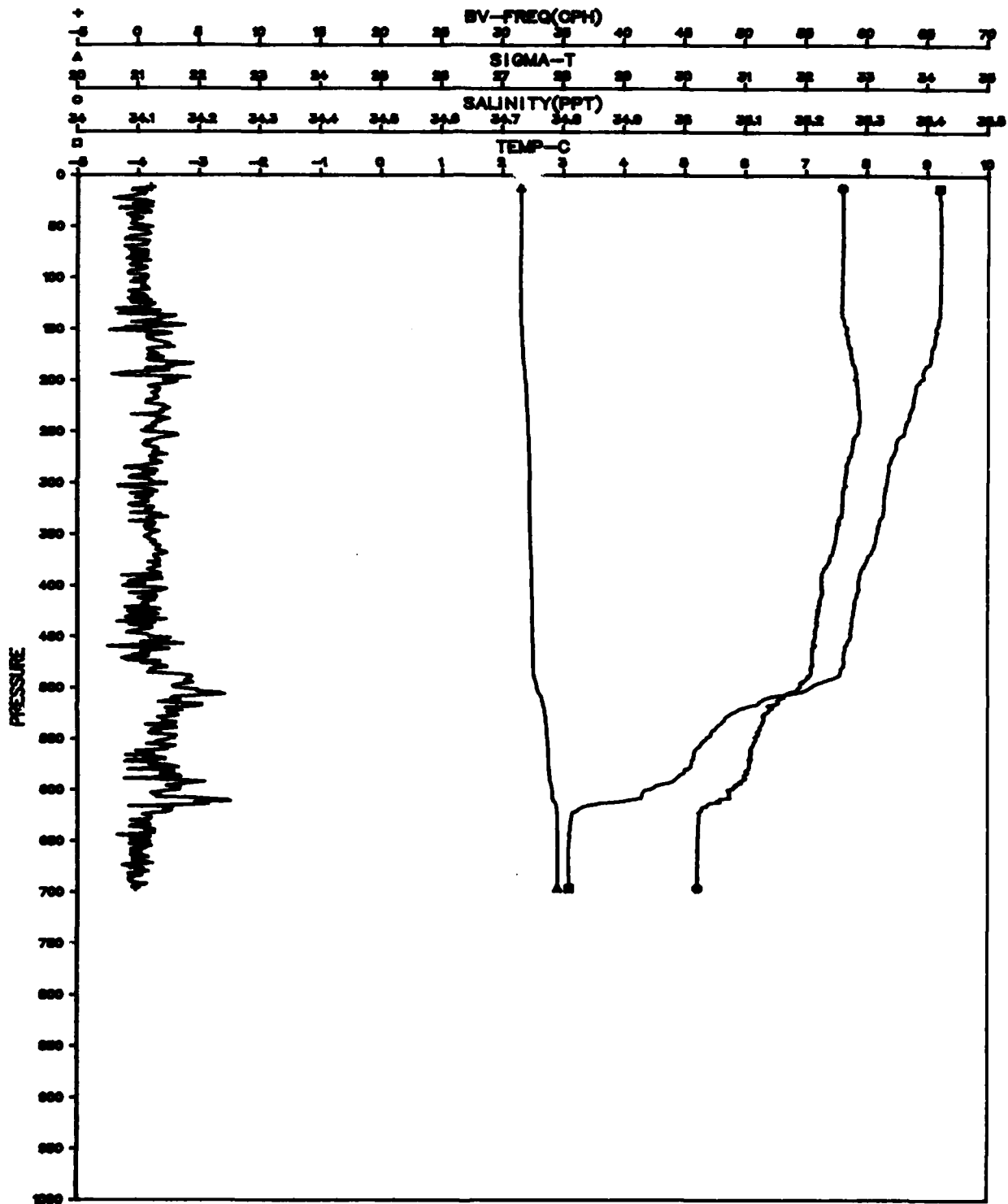


Figure B-5. File: 270980, Segment: 110084

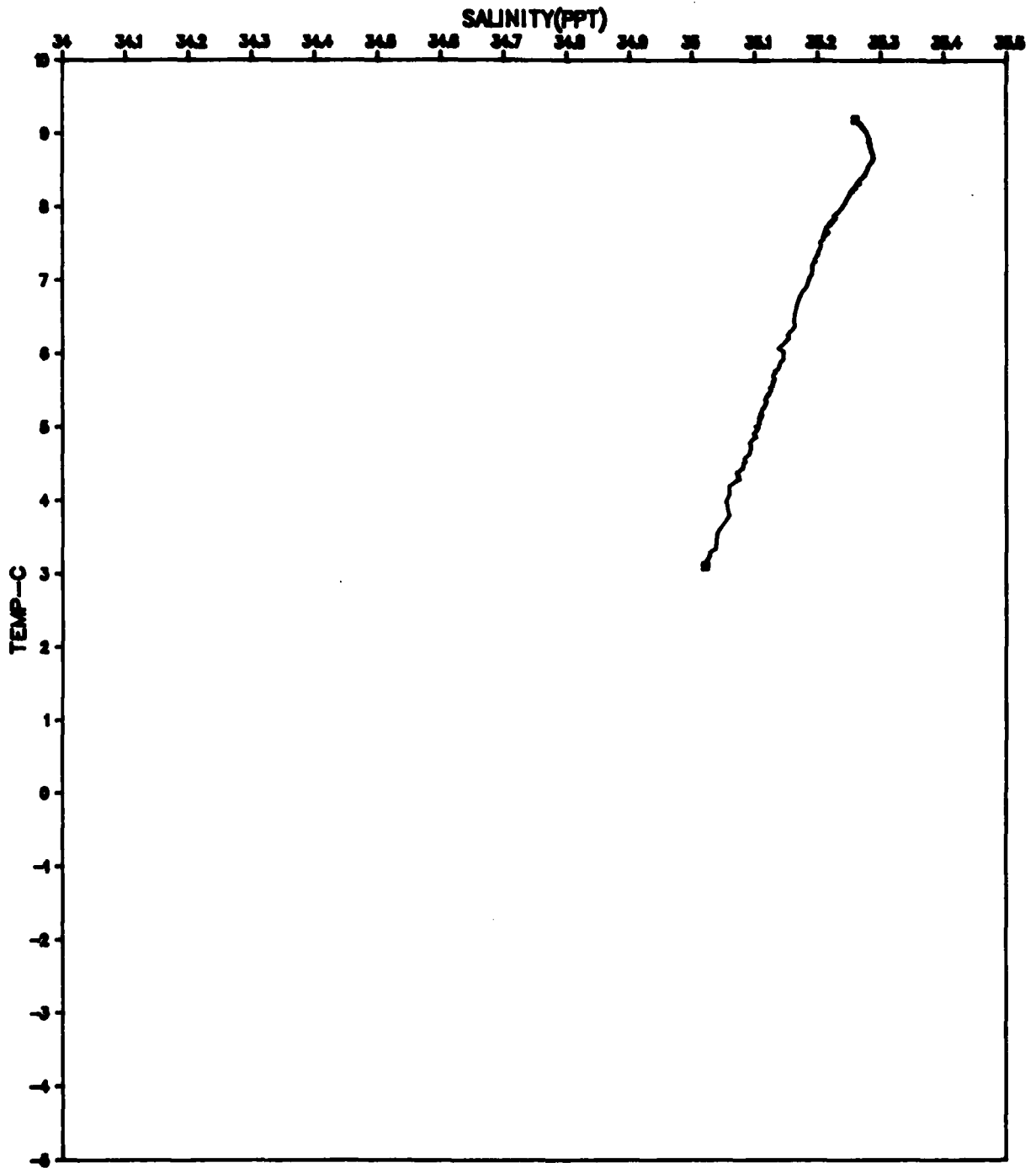


Figure B-6. File: 270980, Segment: 110084

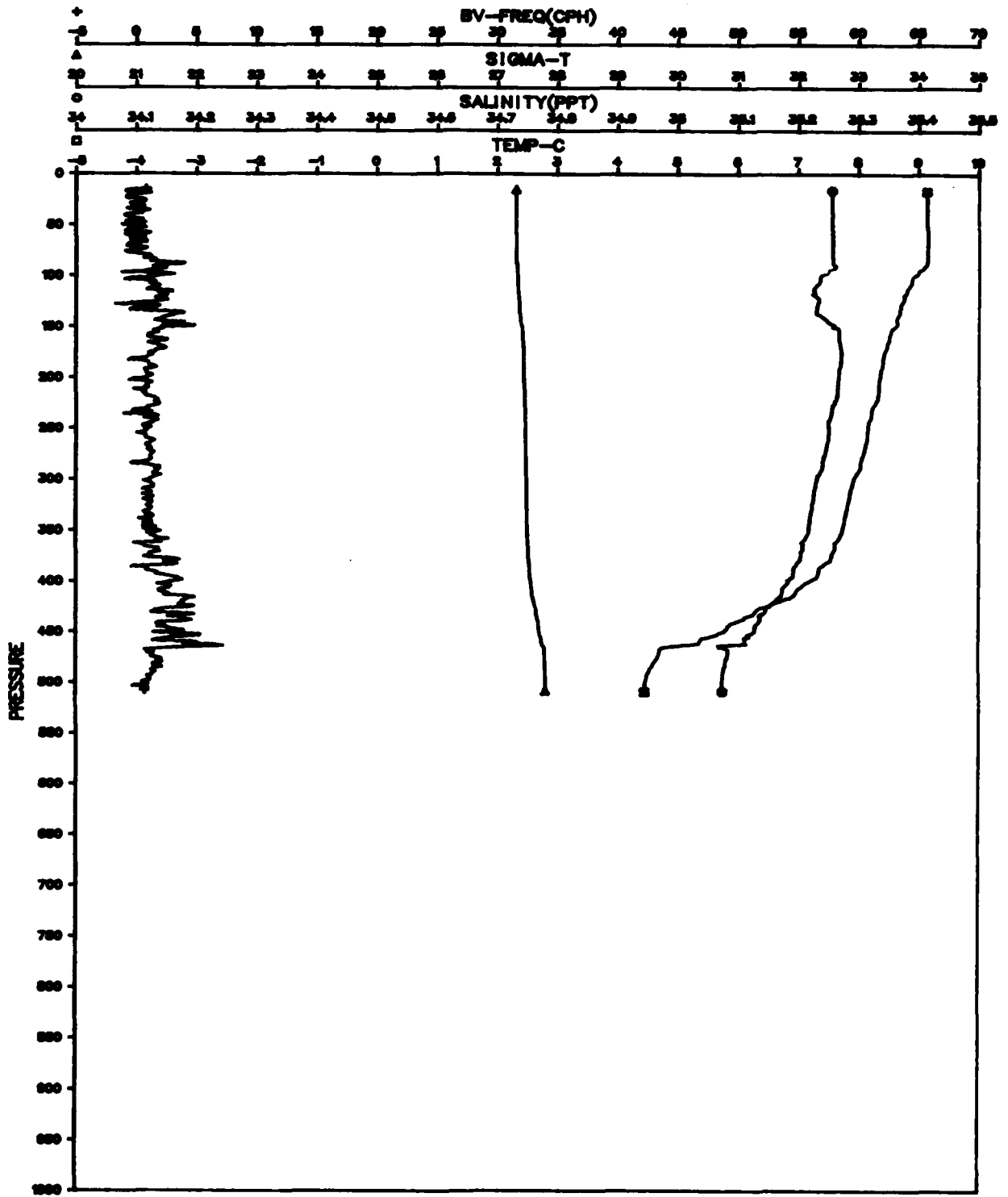


Figure B-7. File: 270980, Segment: 111085

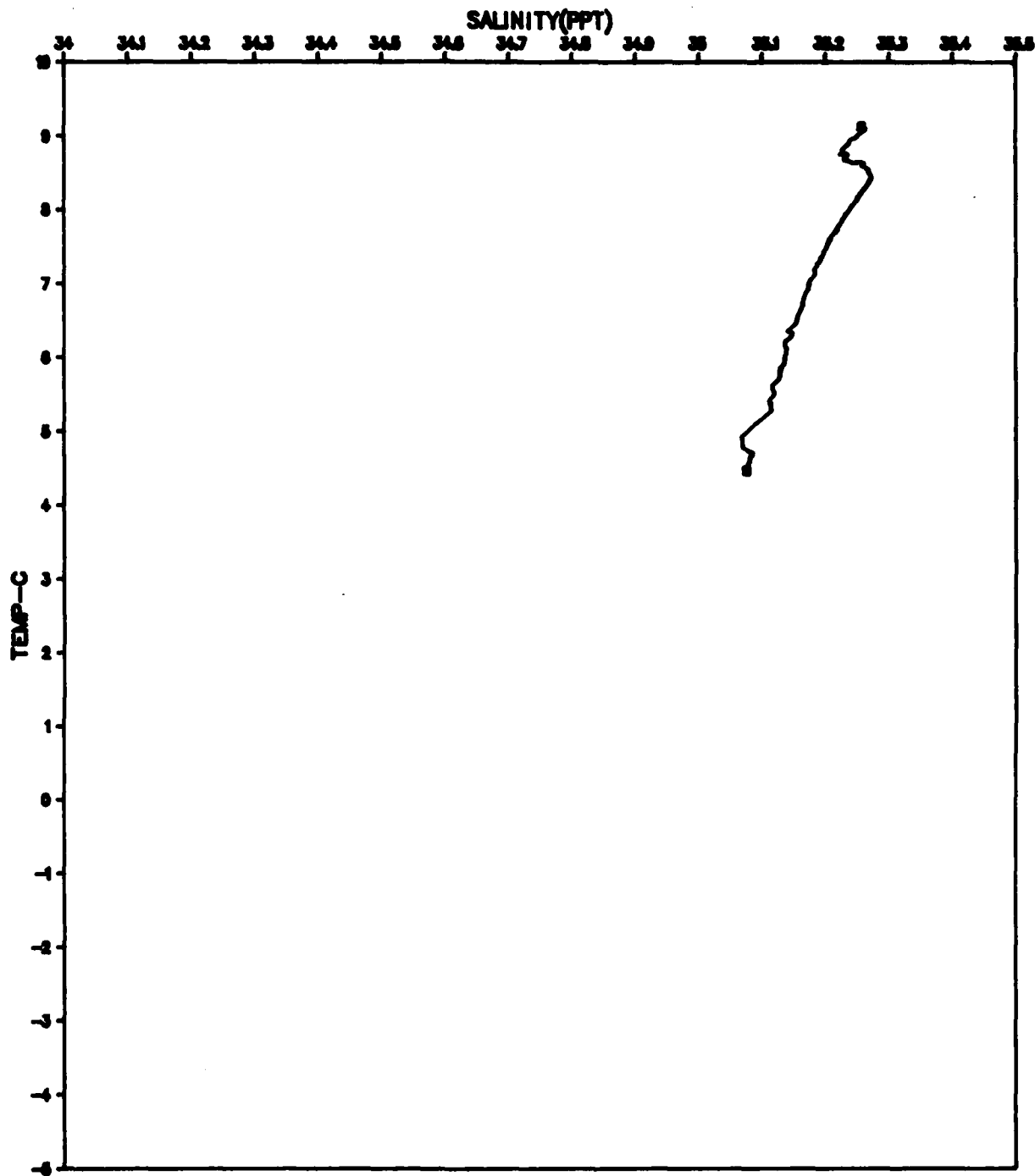


Figure B-8. File: 270980, Segment: 111085

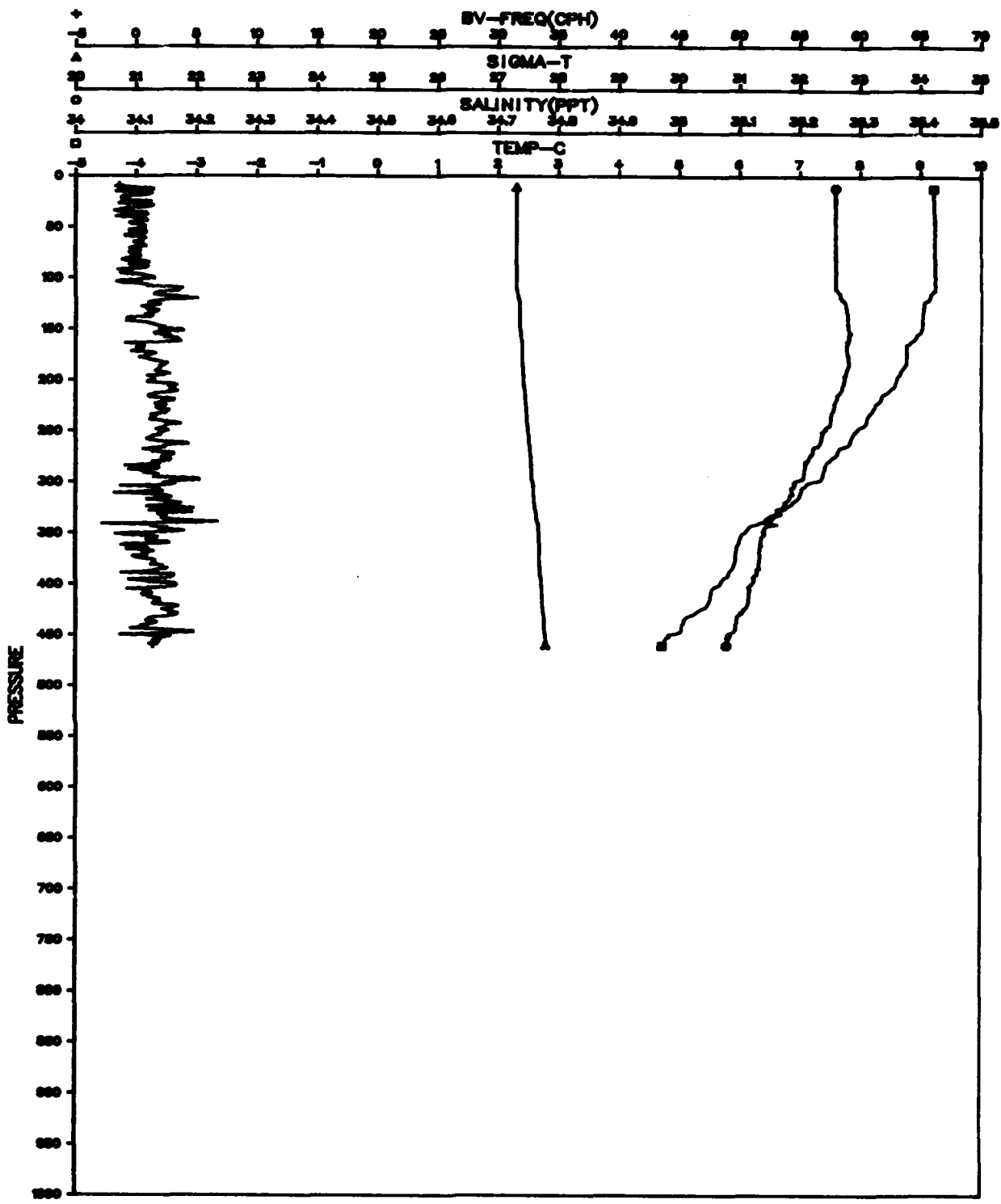


Figure B-9. File: 270980, Segment: 112086

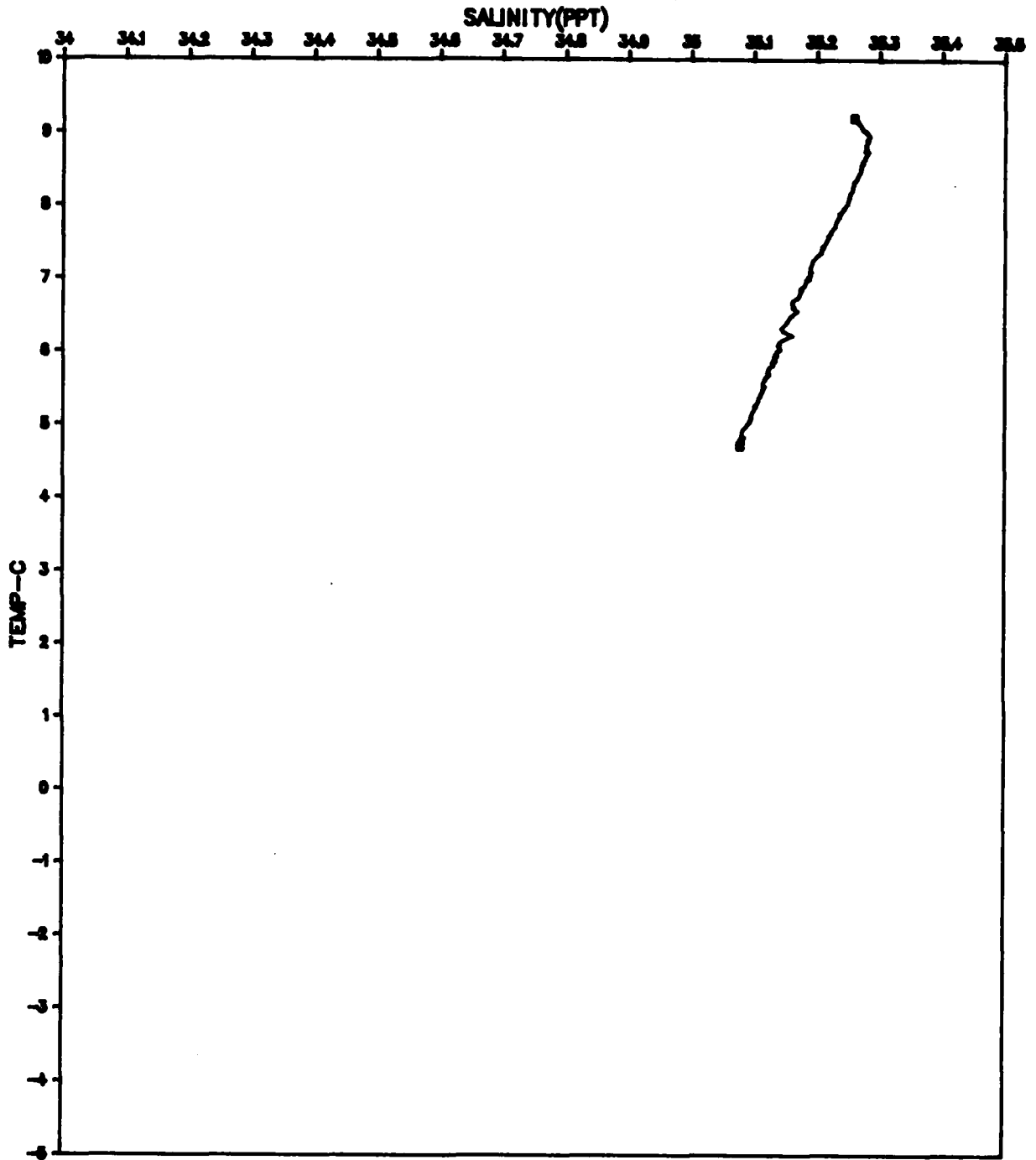


Figure B-10. File: 270980, Segment: 112086

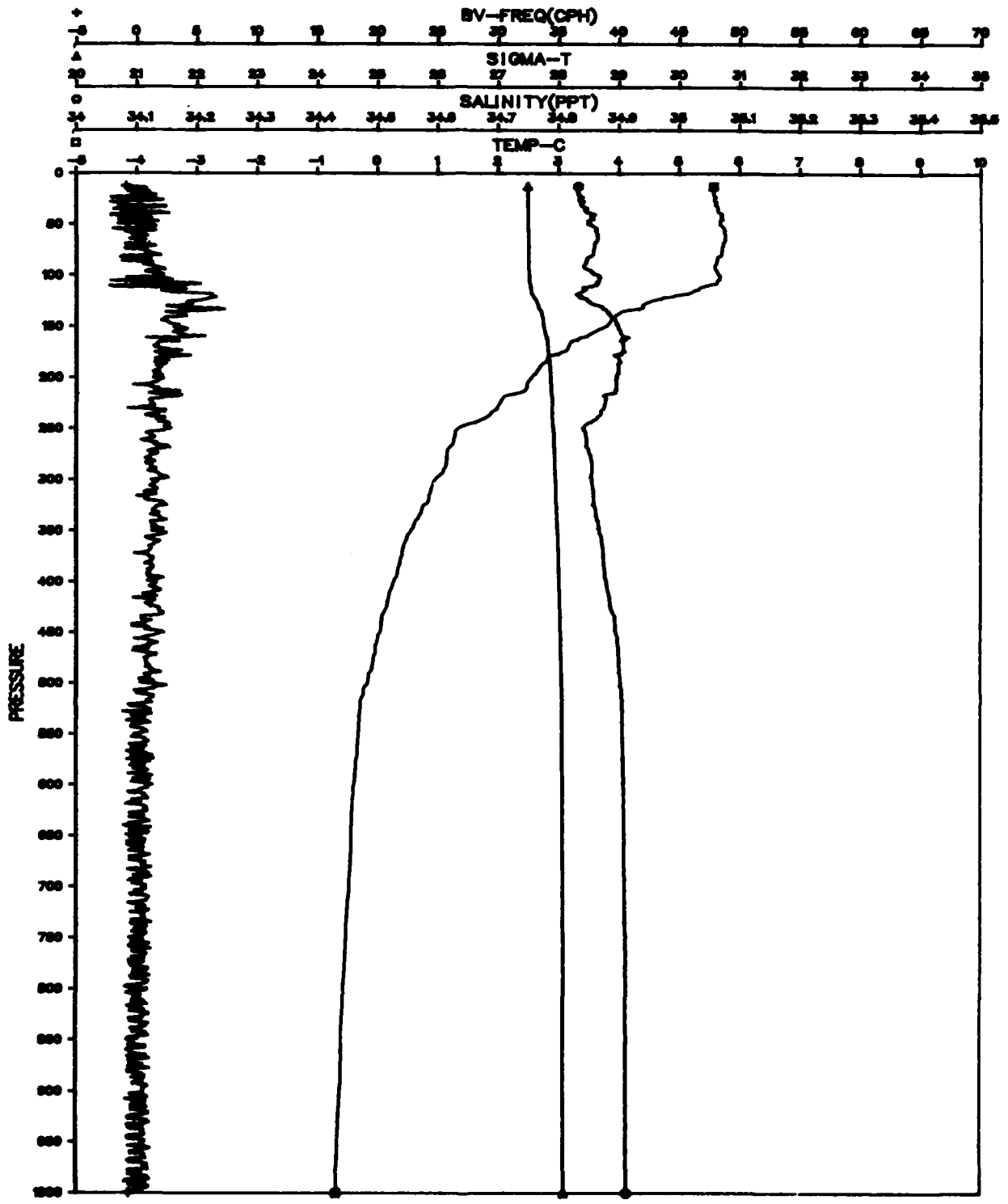


Figure B-11. File: 270980, Segment: 117091

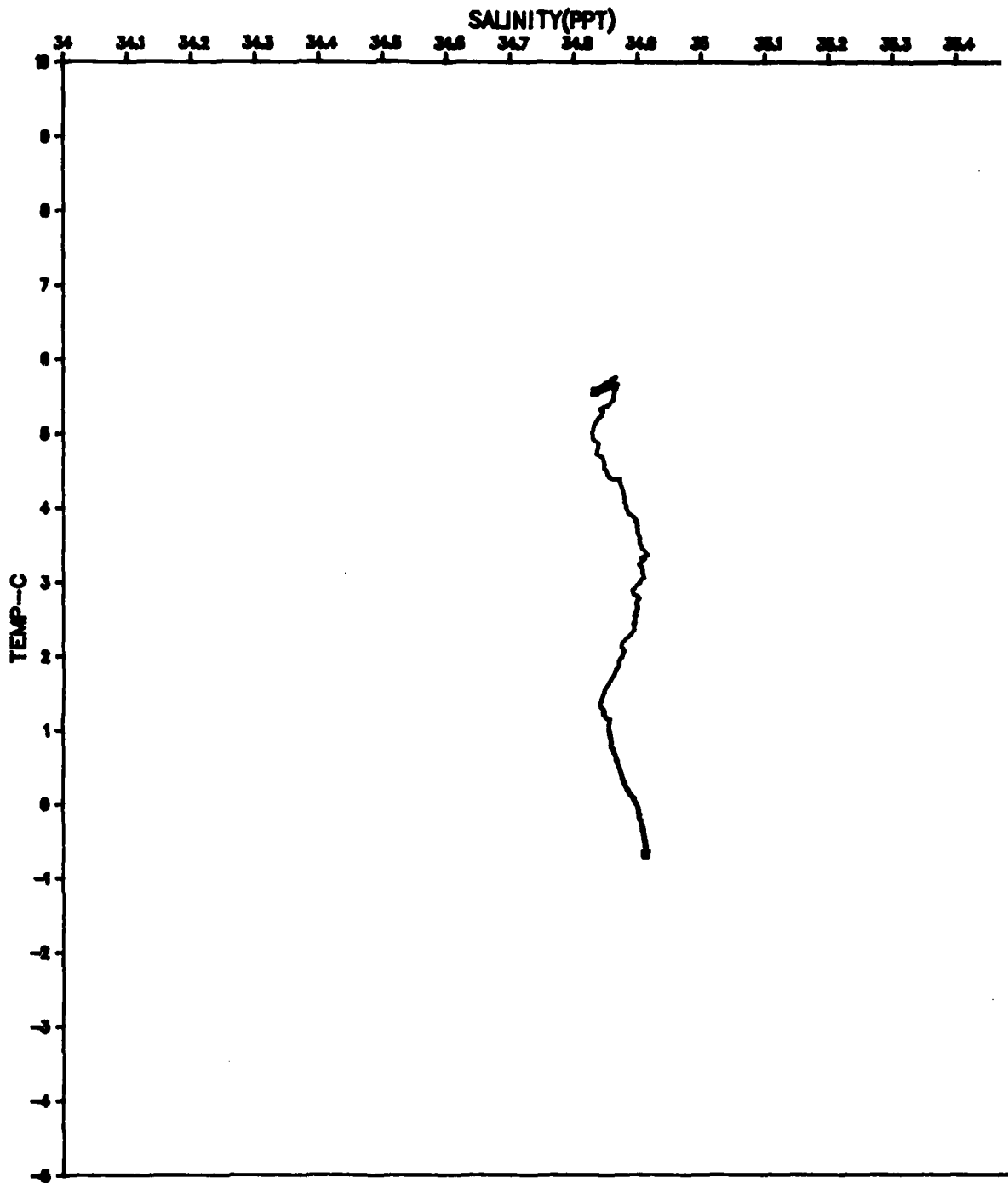


Figure B-12. File: 270980, Segment: 117091

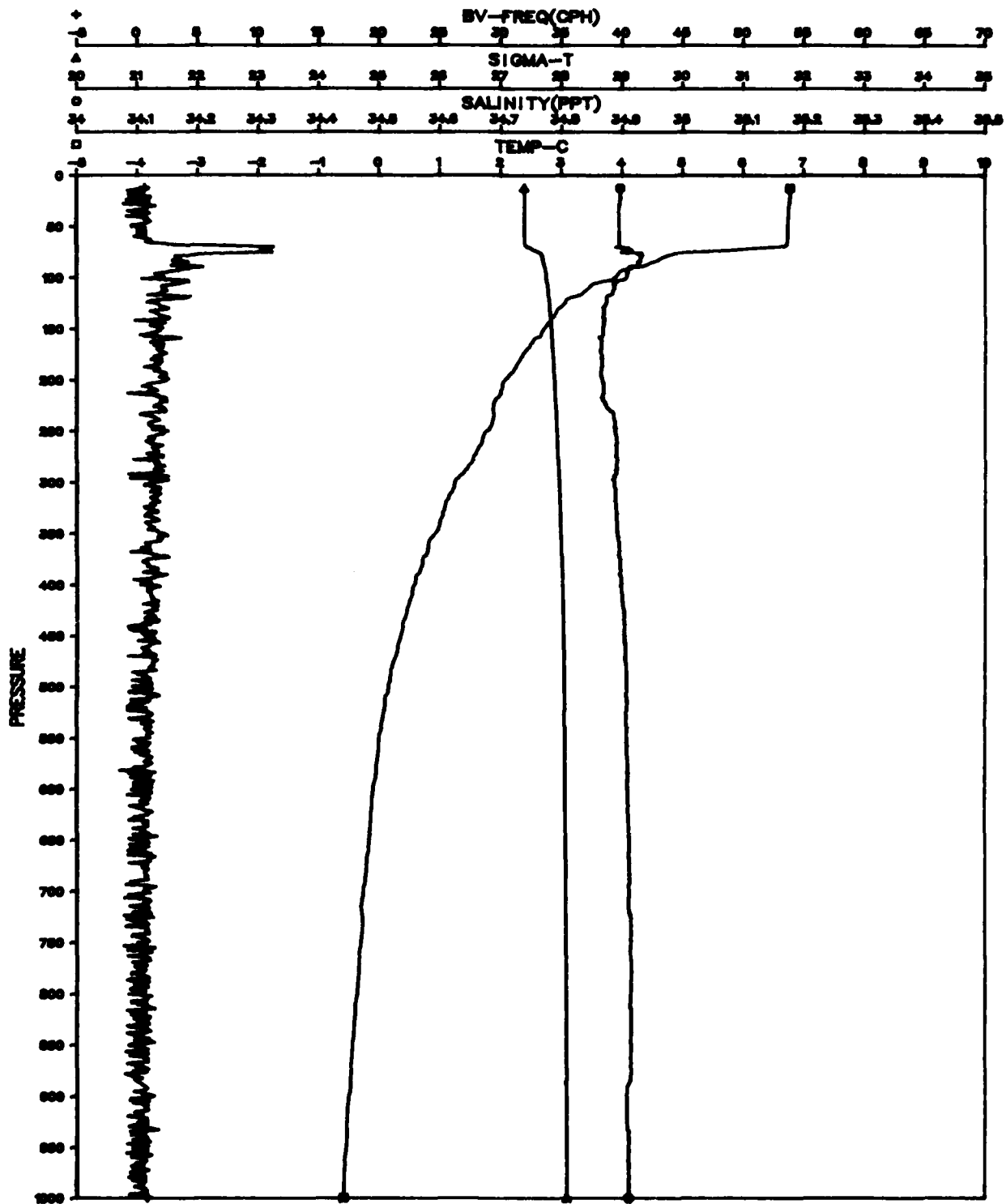


Figure B-13. File: 270980, Segment: 122103

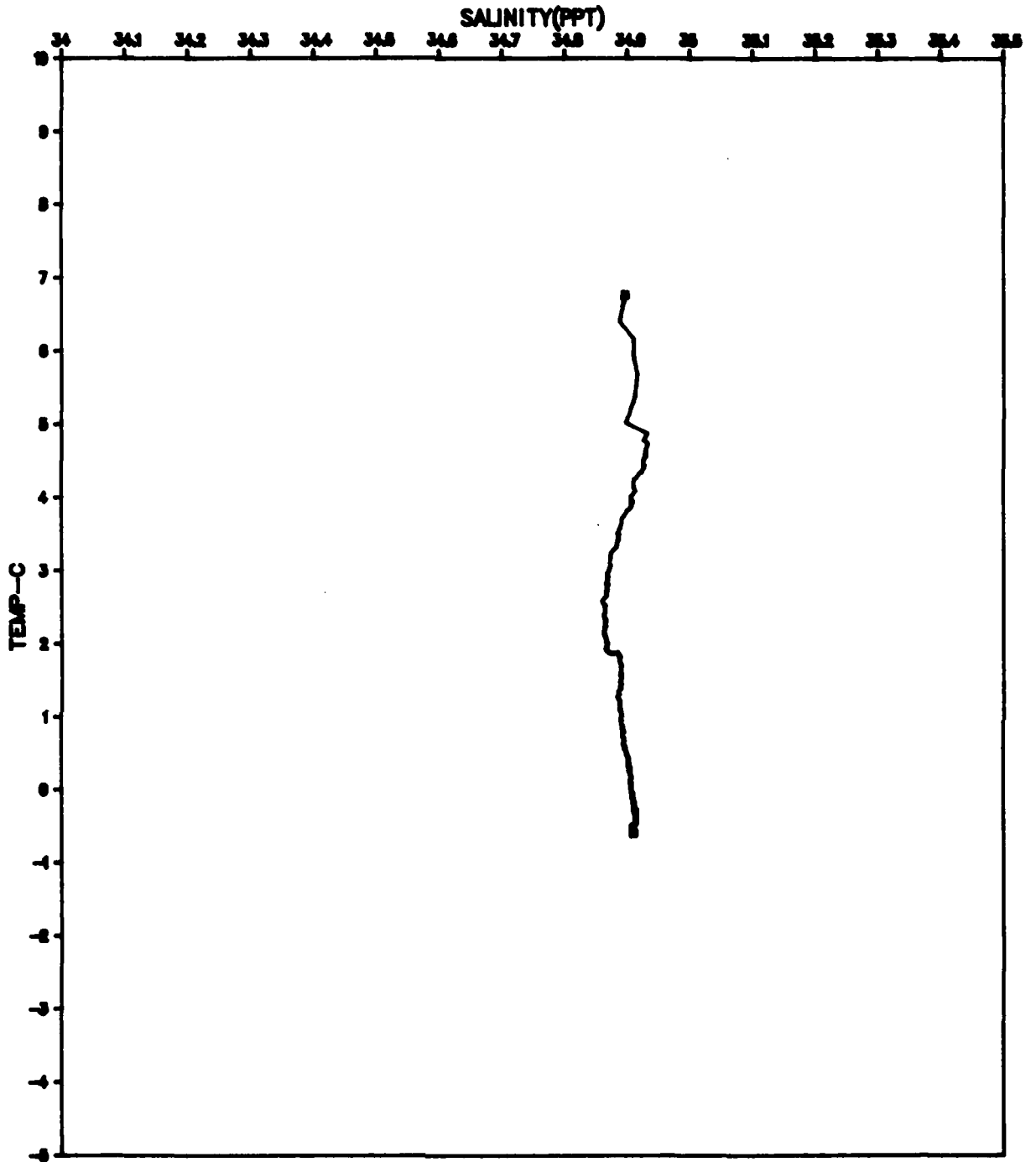


Figure B-14. File: 270980, Segment: 122103

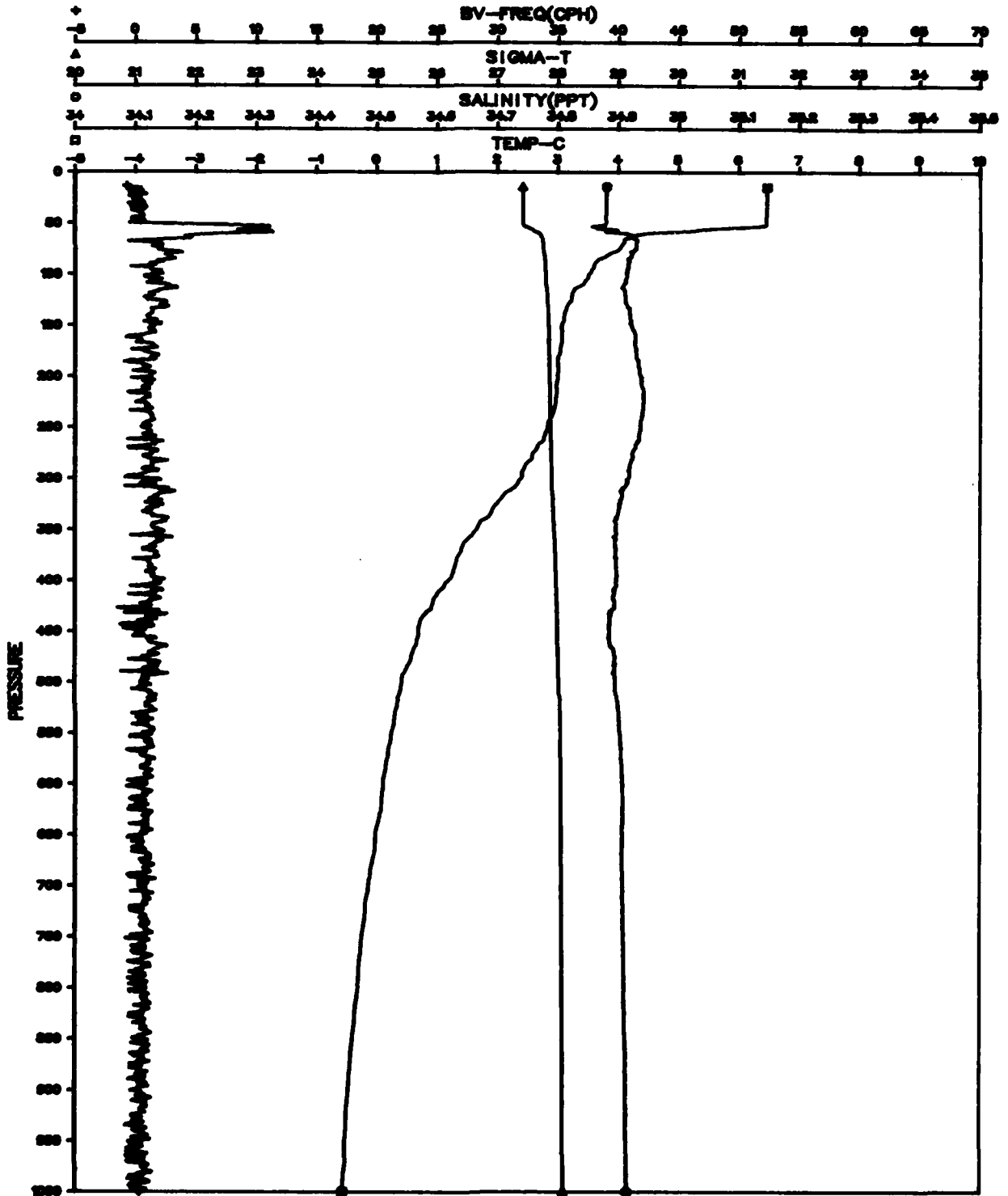


Figure B-15. File: 270980, Segment: 123104

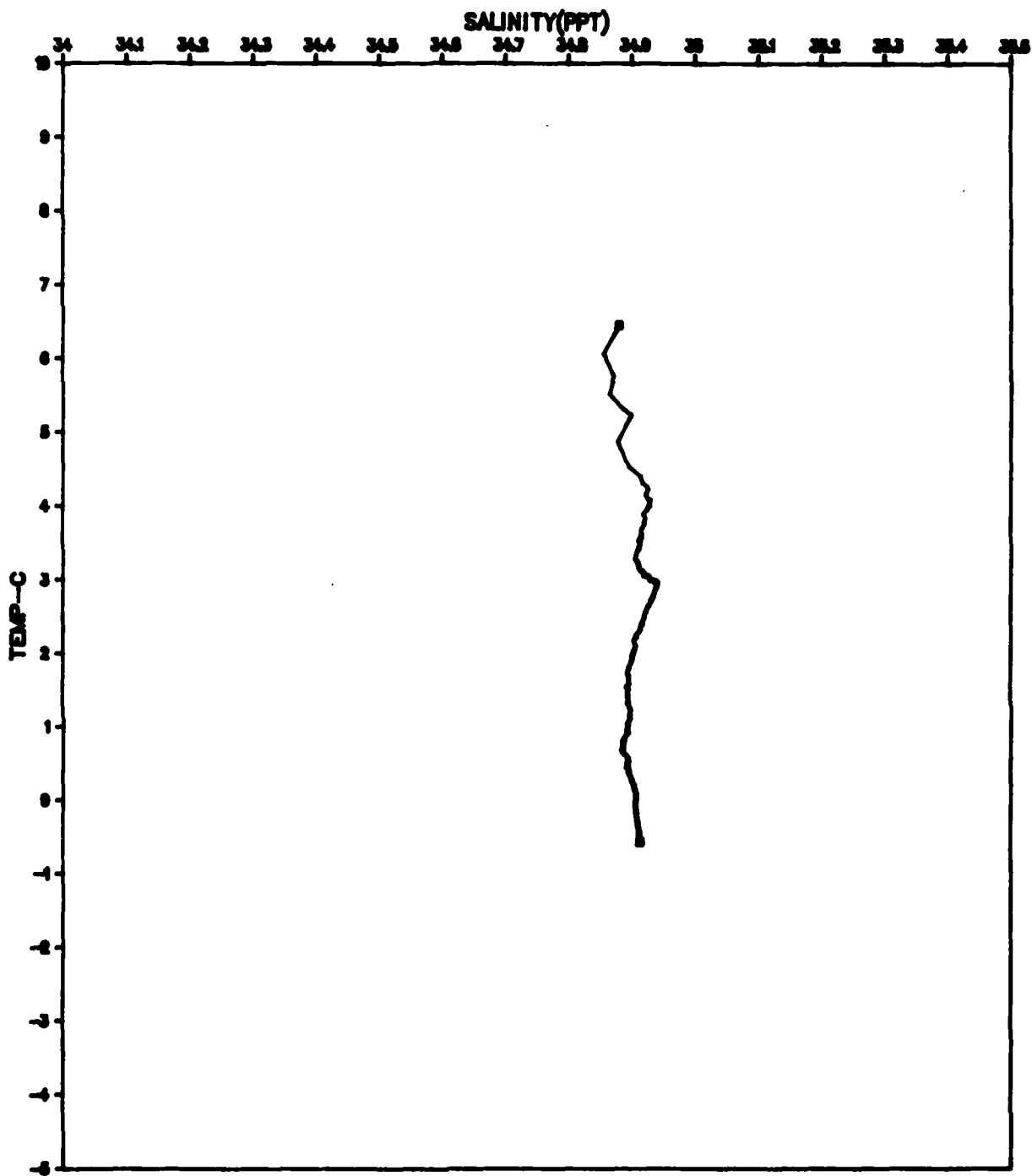


Figure B-16. File: 270980, Segment: 123104

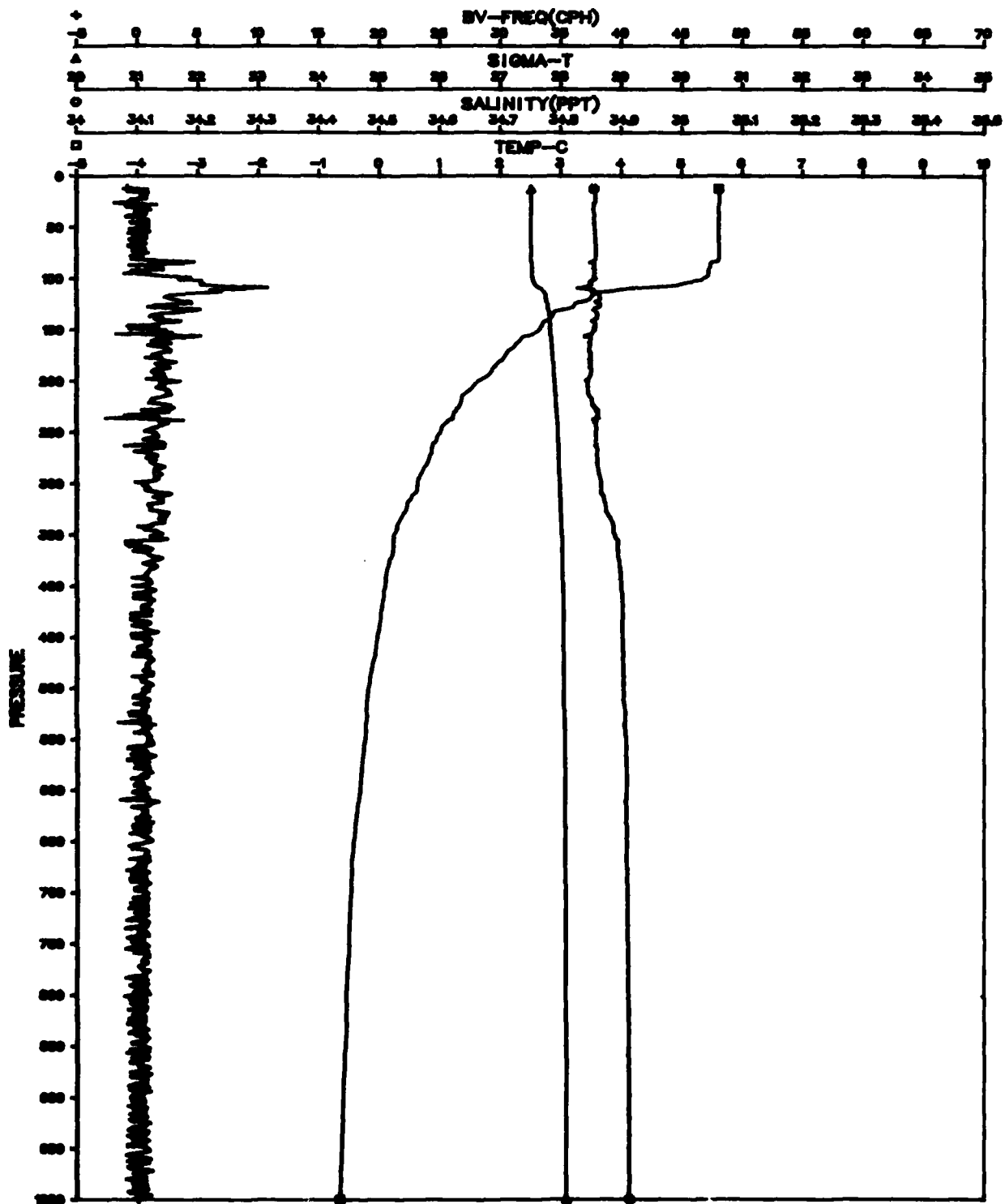


Figure B-17. File: 270980, Segment: 126106

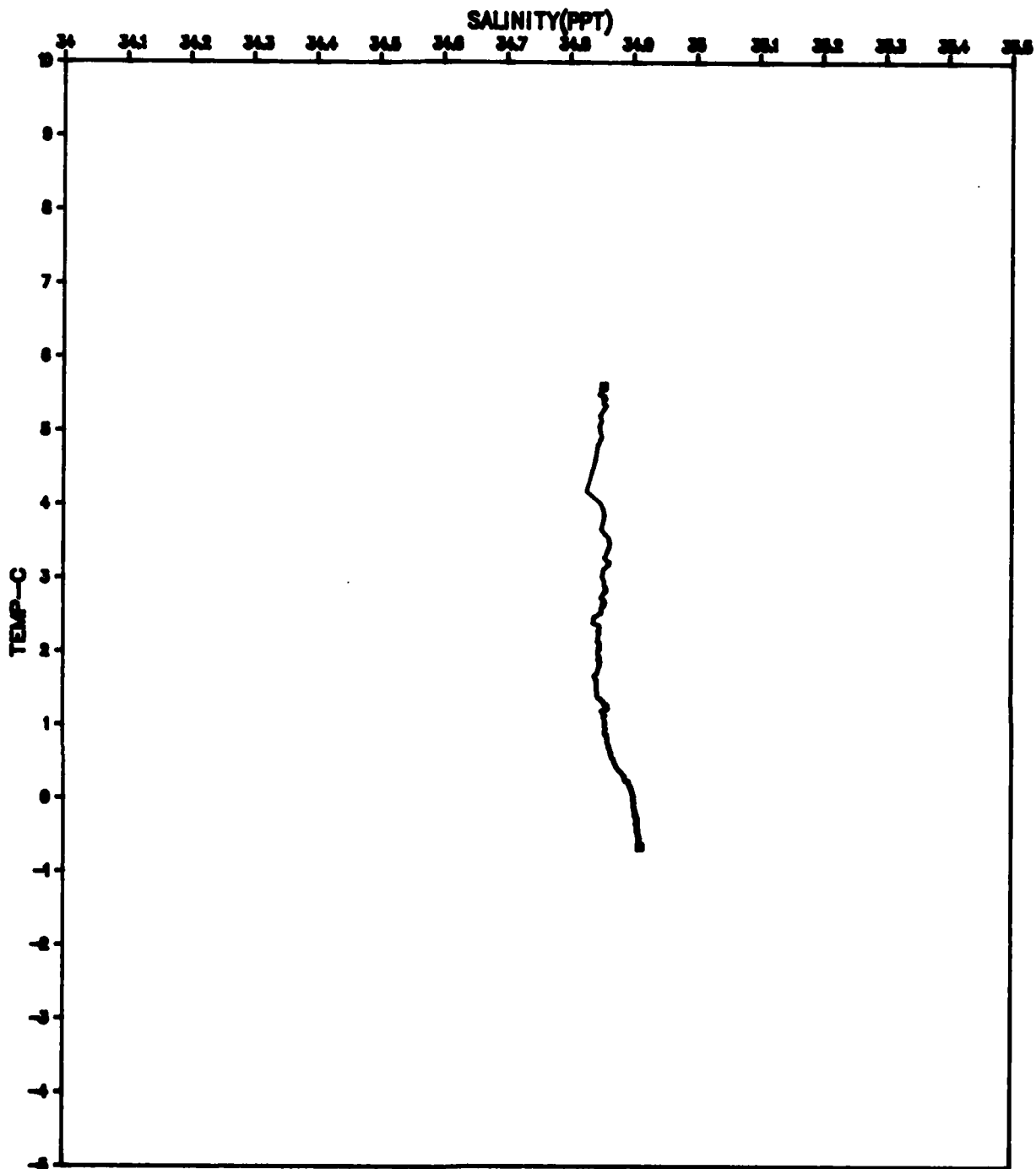


Figure B-18. File: 270980, Segment: 126106

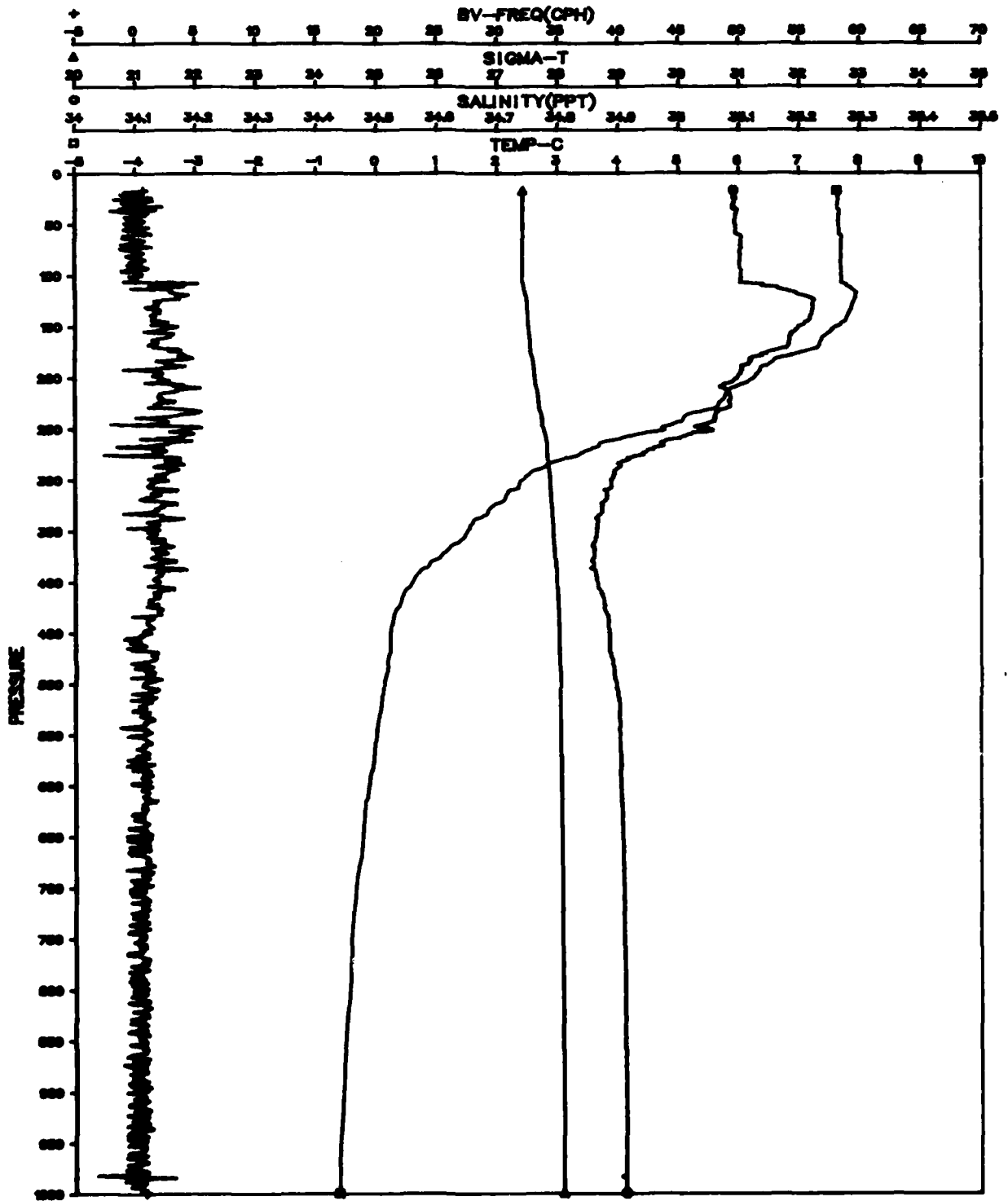


Figure B-19. File: 270980, Segment: 130108

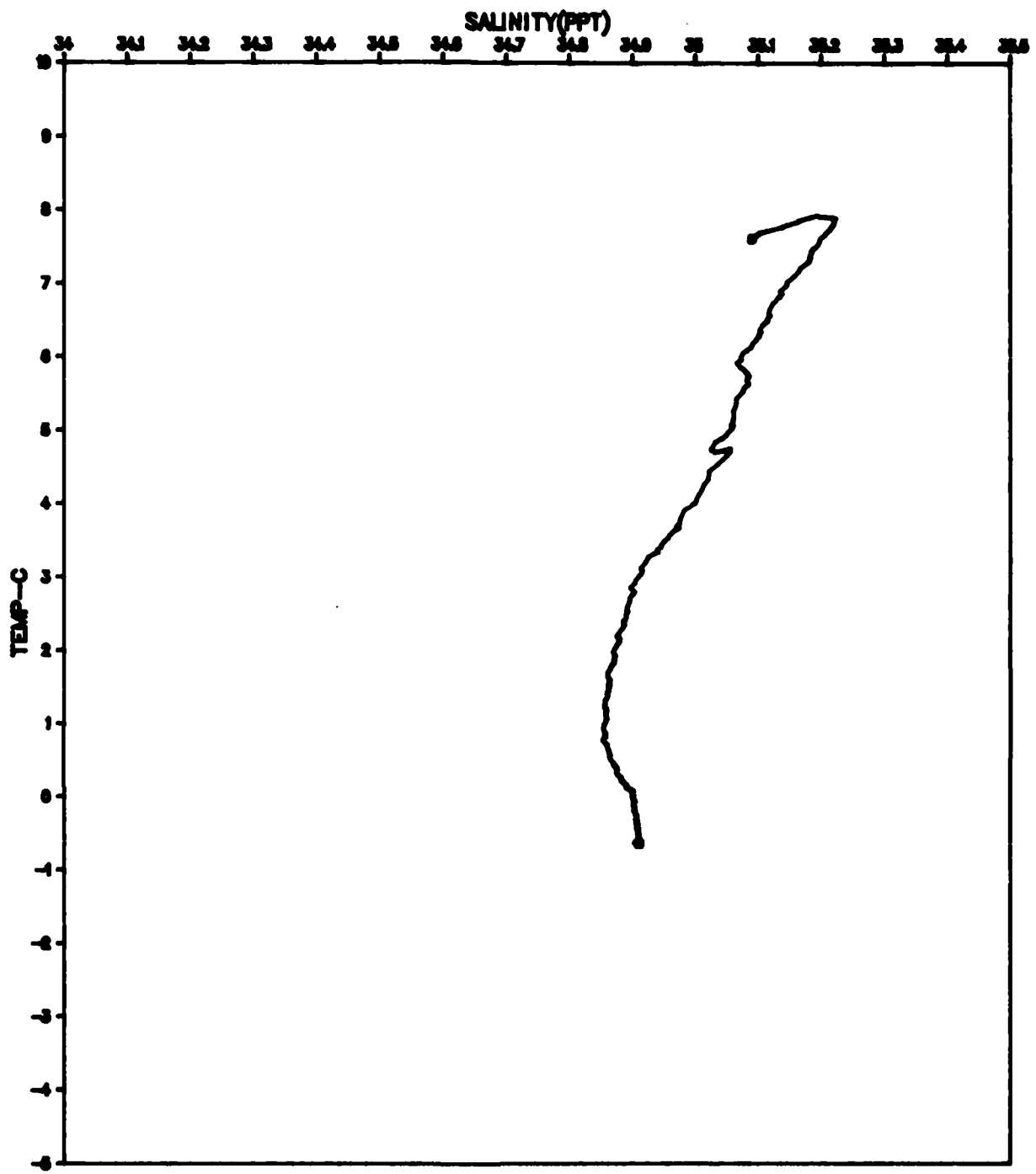


Figure B-20. File: 270980, Segment: 130108

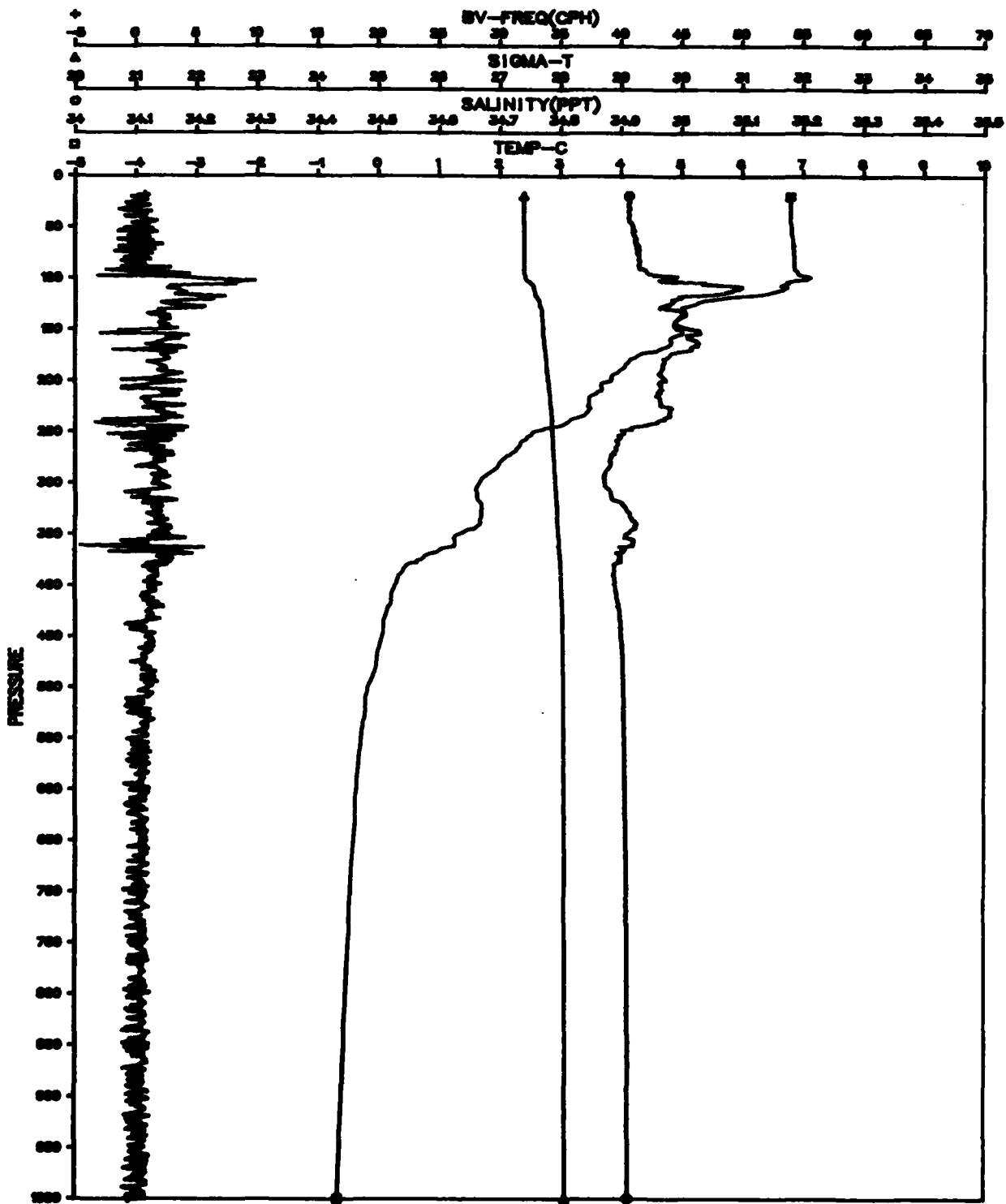


Figure B-21. File: 270980, Segment: 131109

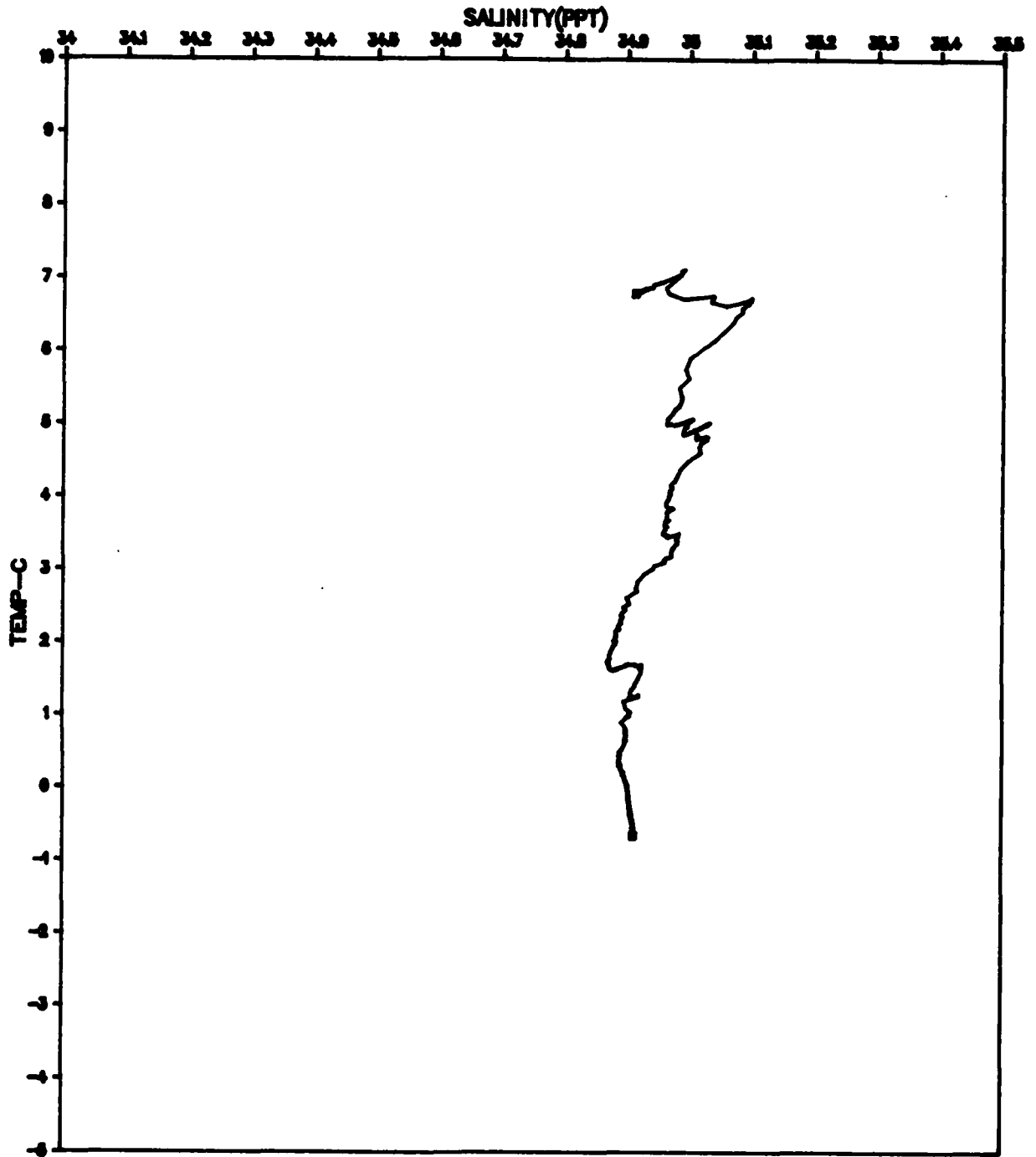


Figure B-22. File: 270980, Segment: 131109

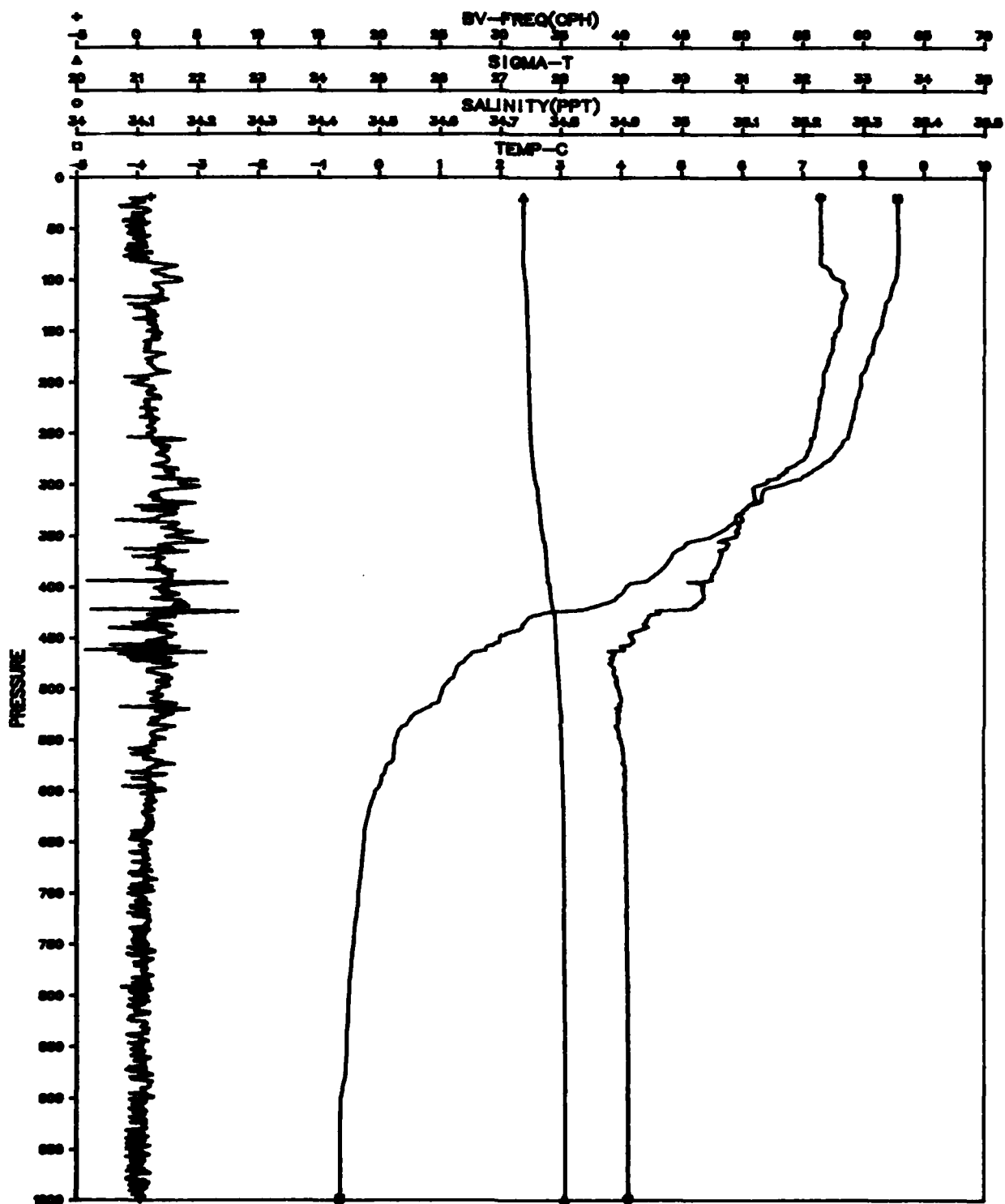


Figure B-23. File: 270980, Segment: 132110

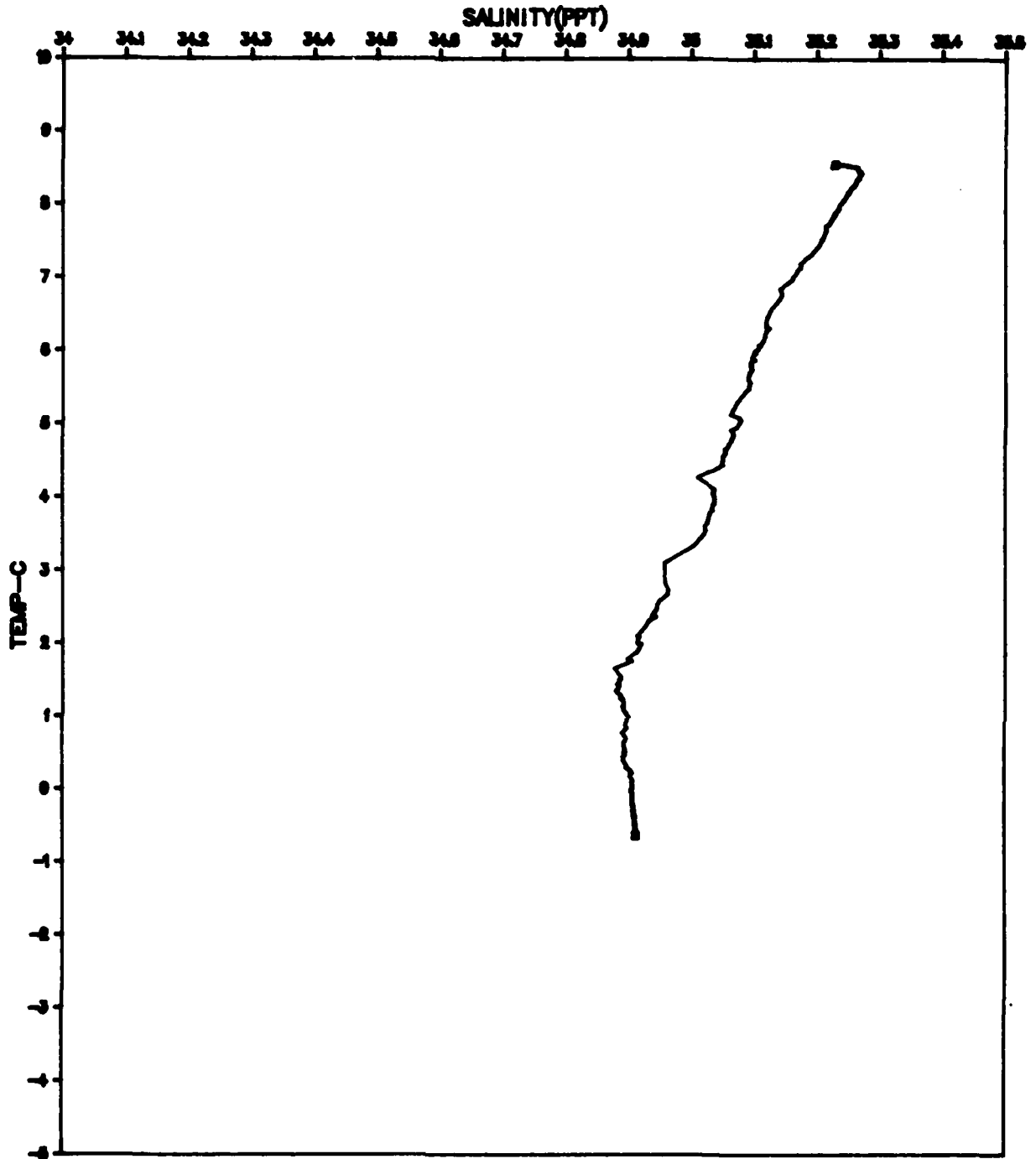


Figure B-24. File: 270980, Segment: 132110

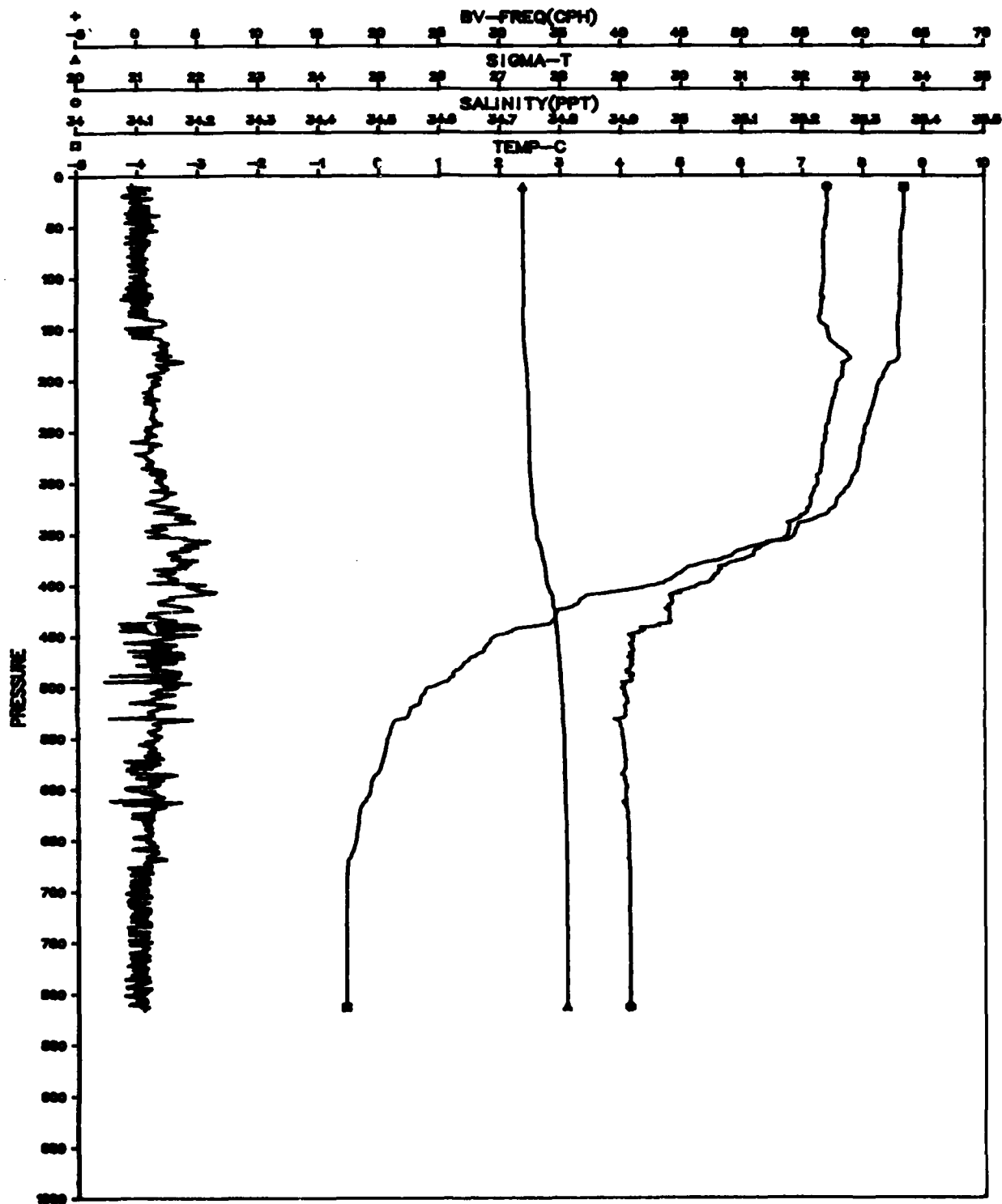
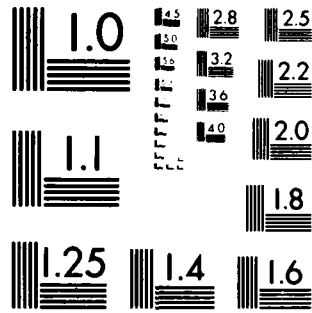


Figure B-25. File: 270980, Segment: 133111



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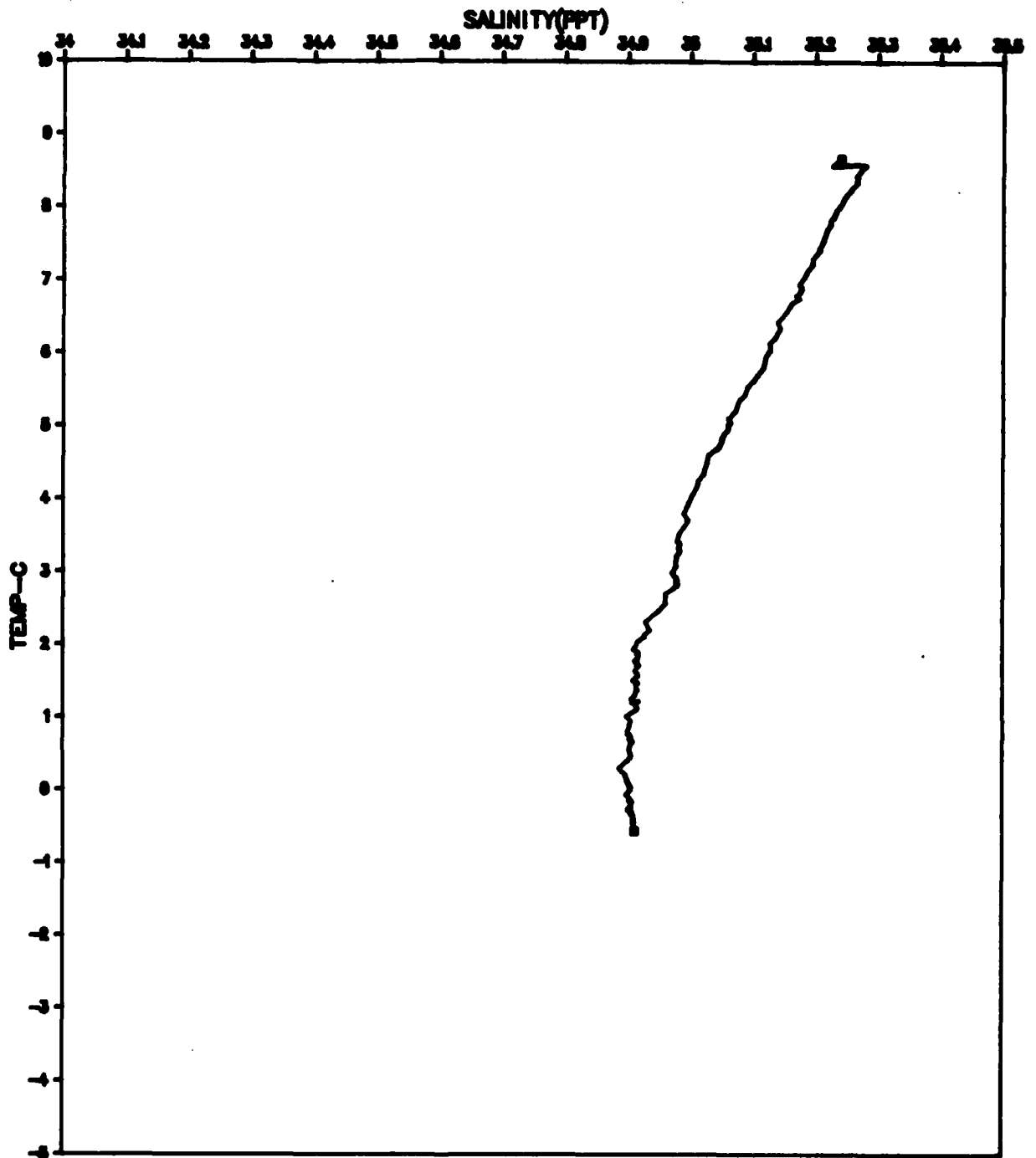


Figure B-26. File: 270980, Segment: 133111

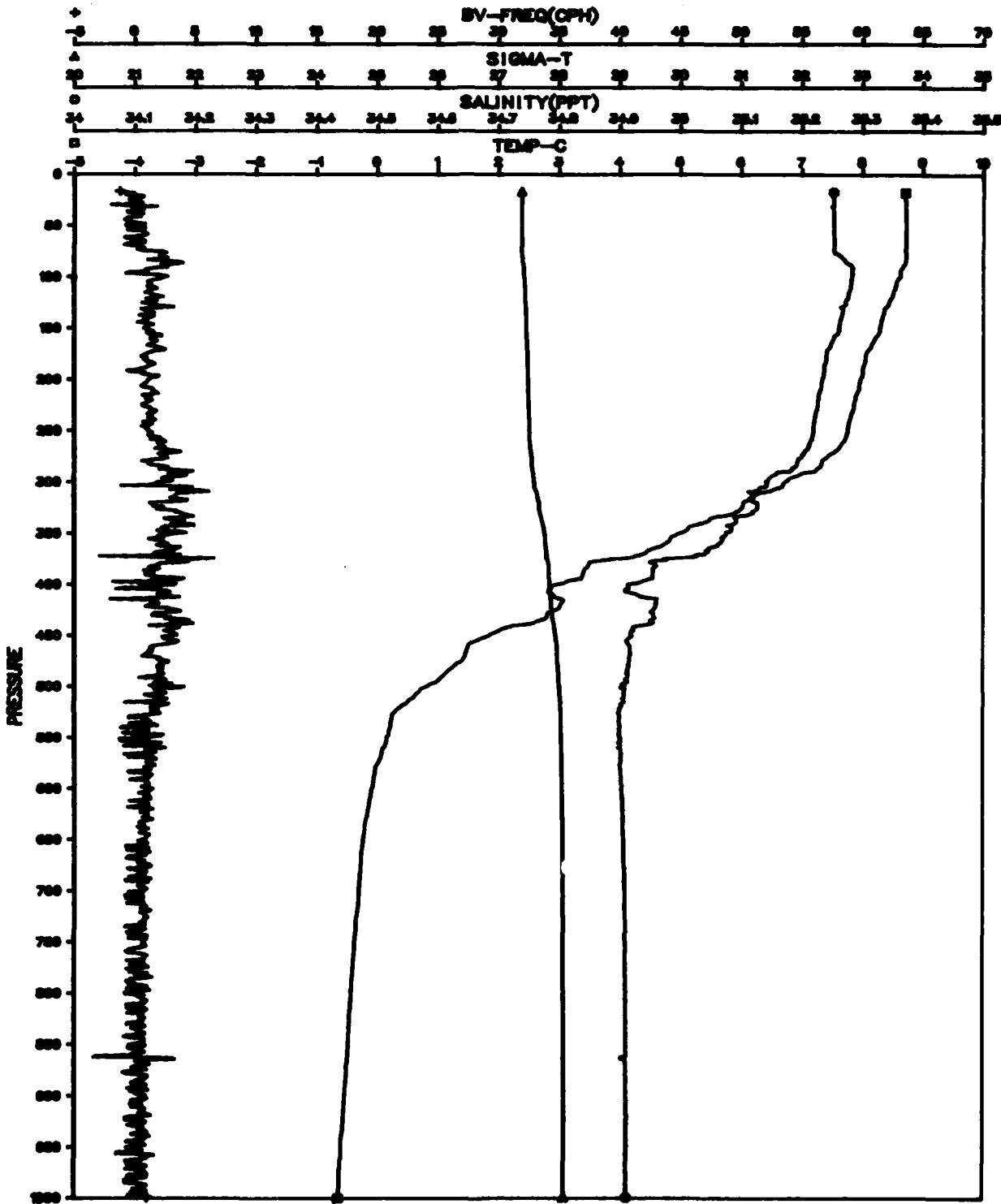


Figure B-27. File: 270980, Segment: 136116

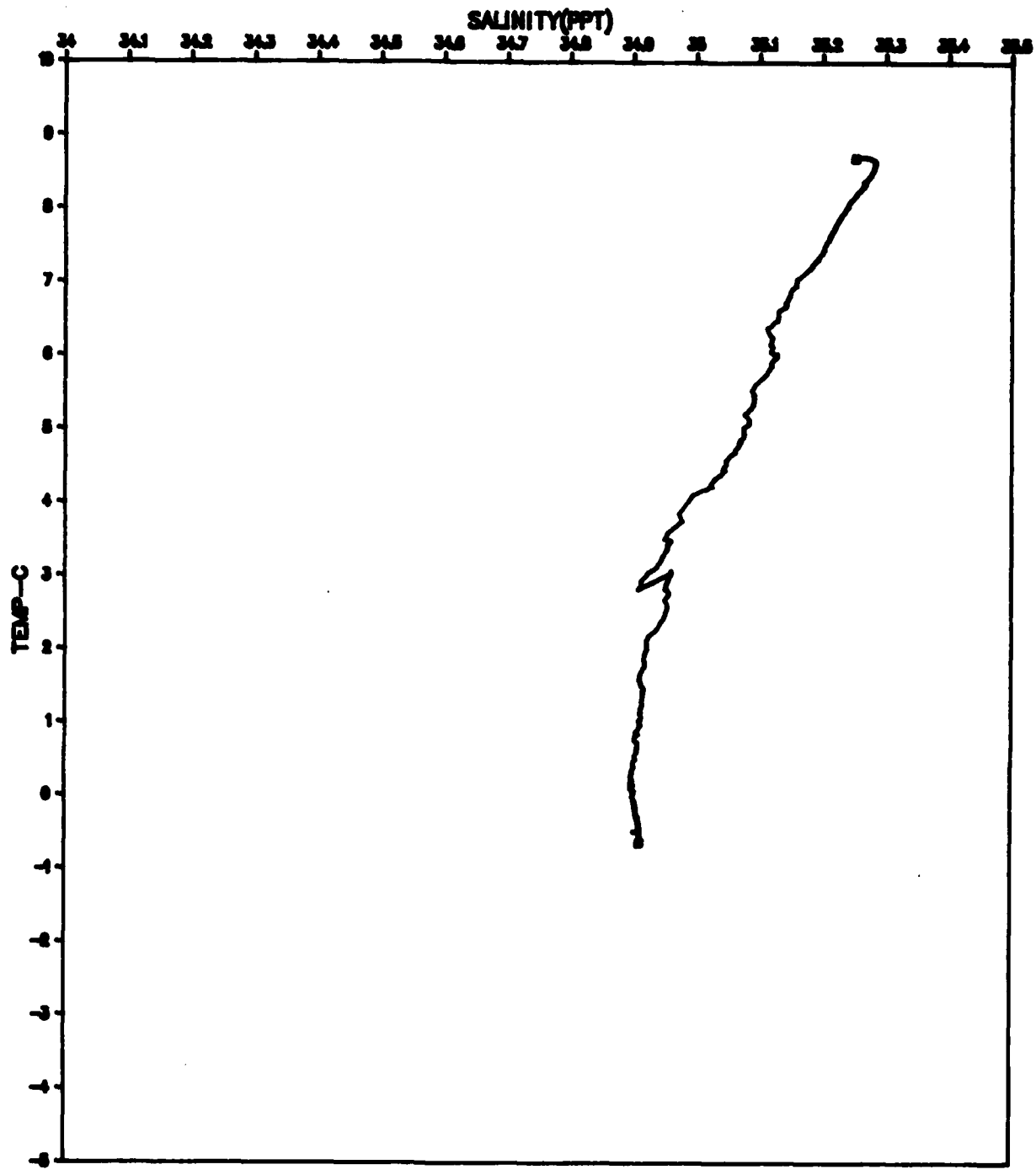


Figure B-28. File: 270980, Segment: 136116

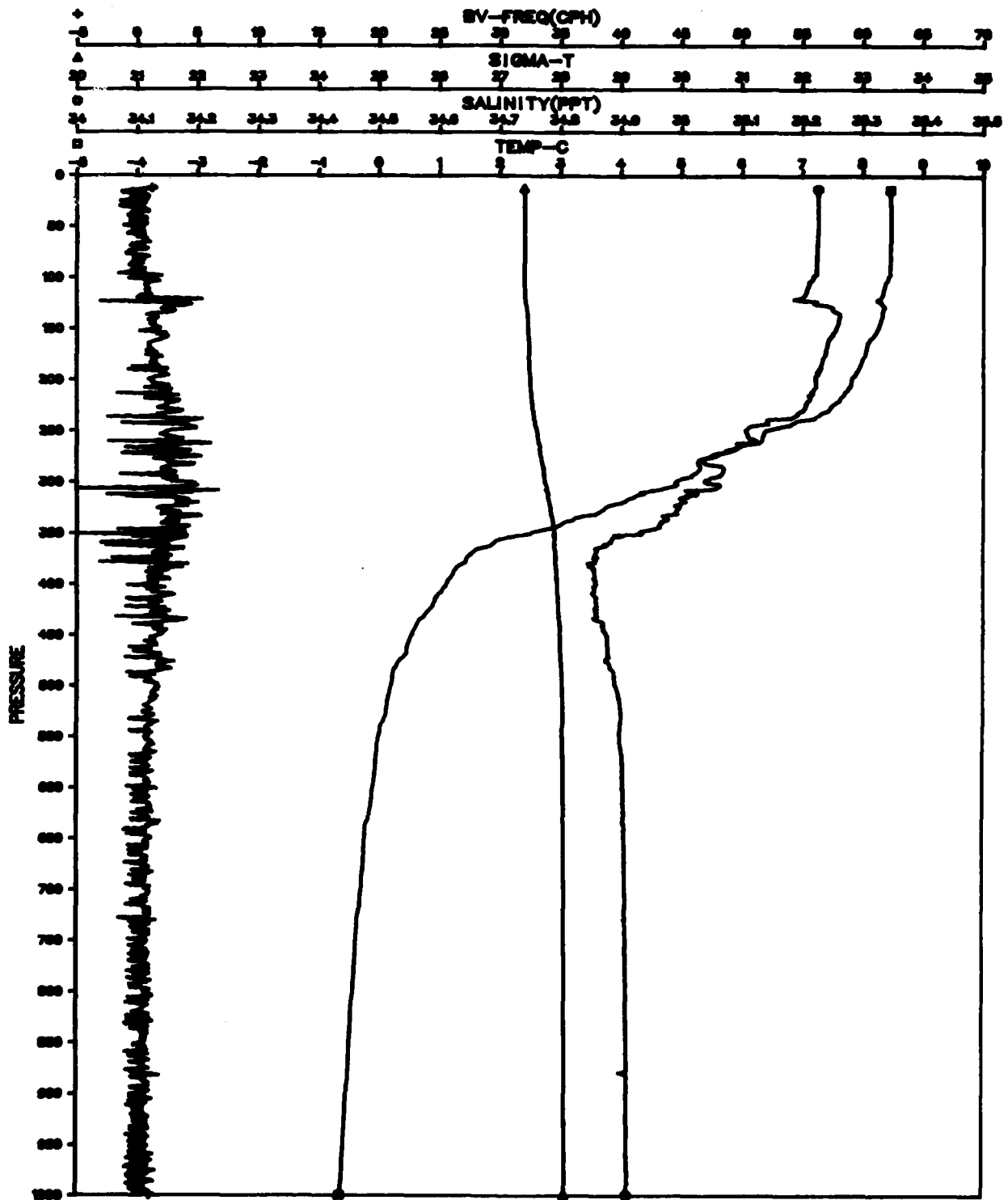


Figure B-29. File: 270980, Segment: 137117

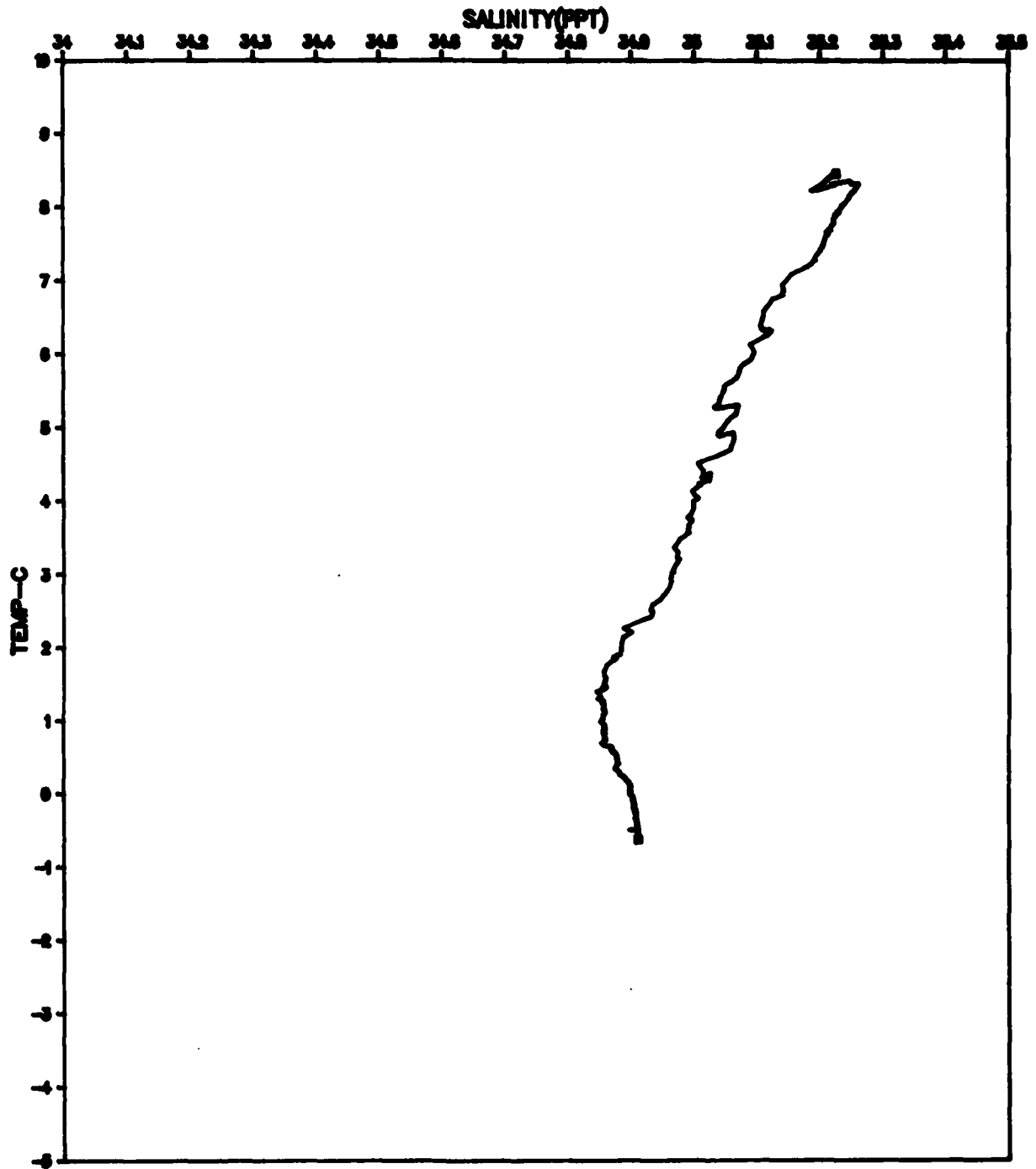


Figure B-30. File: 270980, Segment: 137117

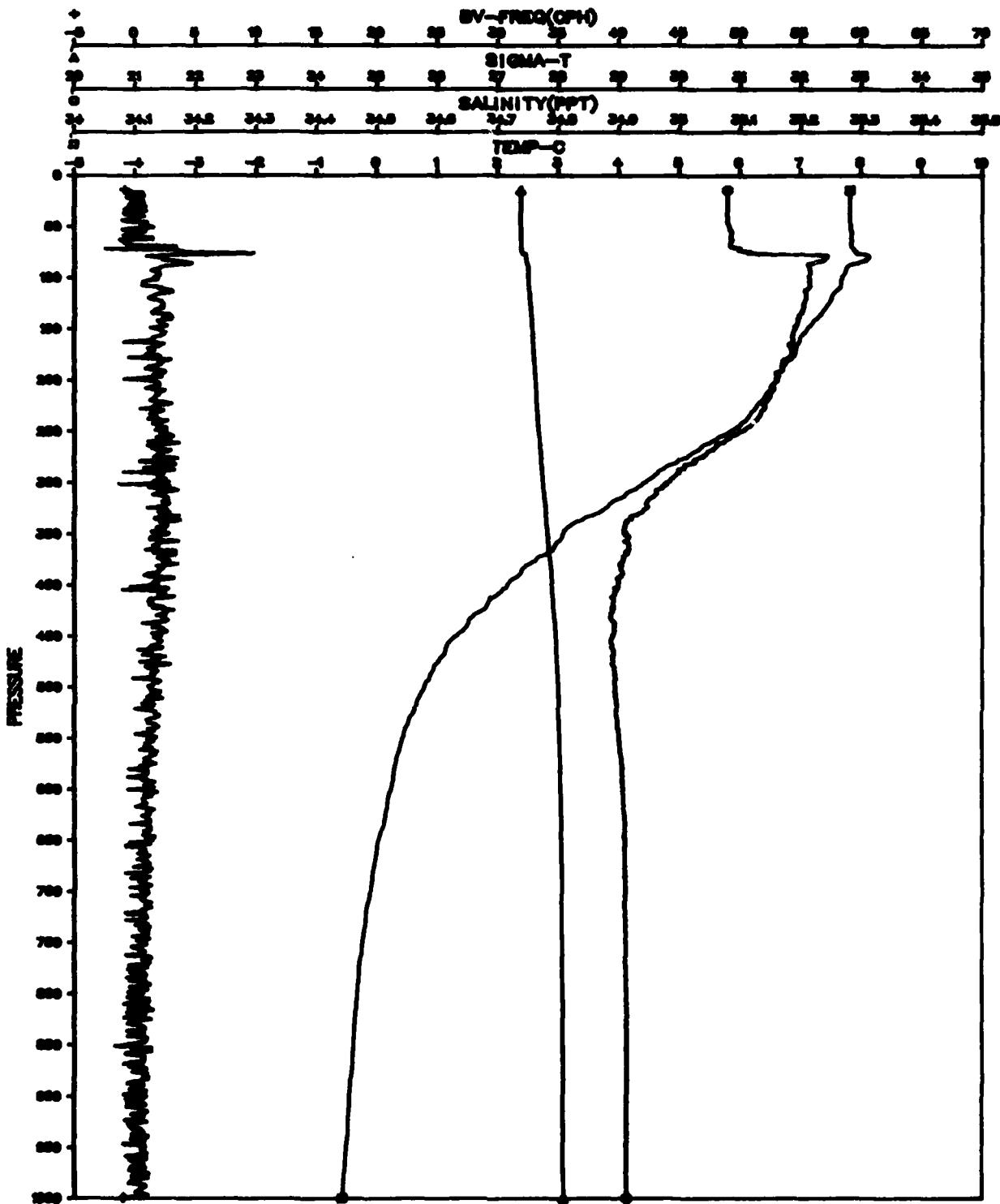


Figure B-31. File: 270980, Segment: 175155

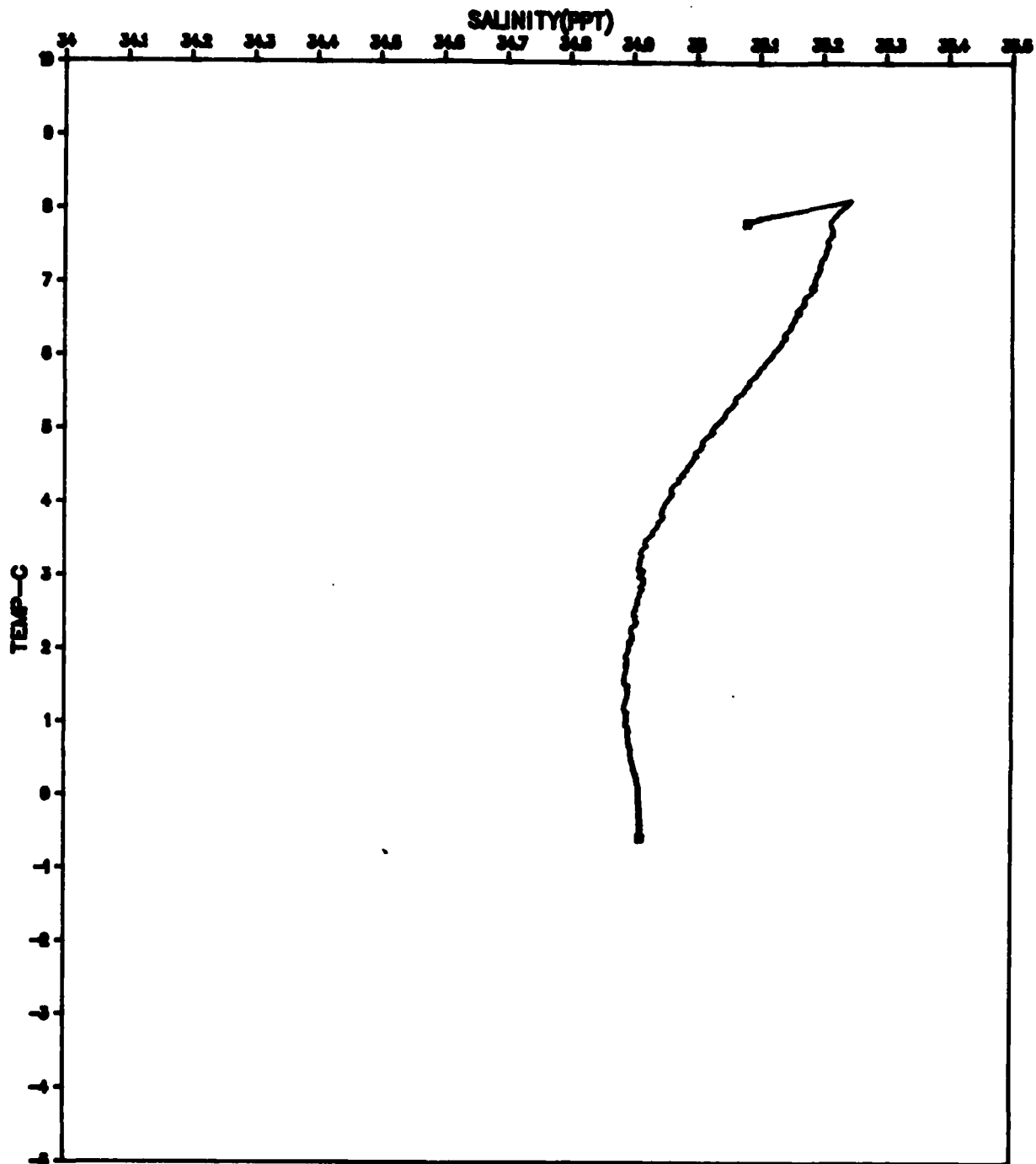


Figure B-32. File: 270980, Segment:175155

**Appendix C:
Selected XCP and CTD
Temperature Profiles**

**COMMENTS:
Low Pass Filtered 10 m Resolution Subsampling Interval 1 m**

FIGURE PAGE BLANK-NOT FILMED

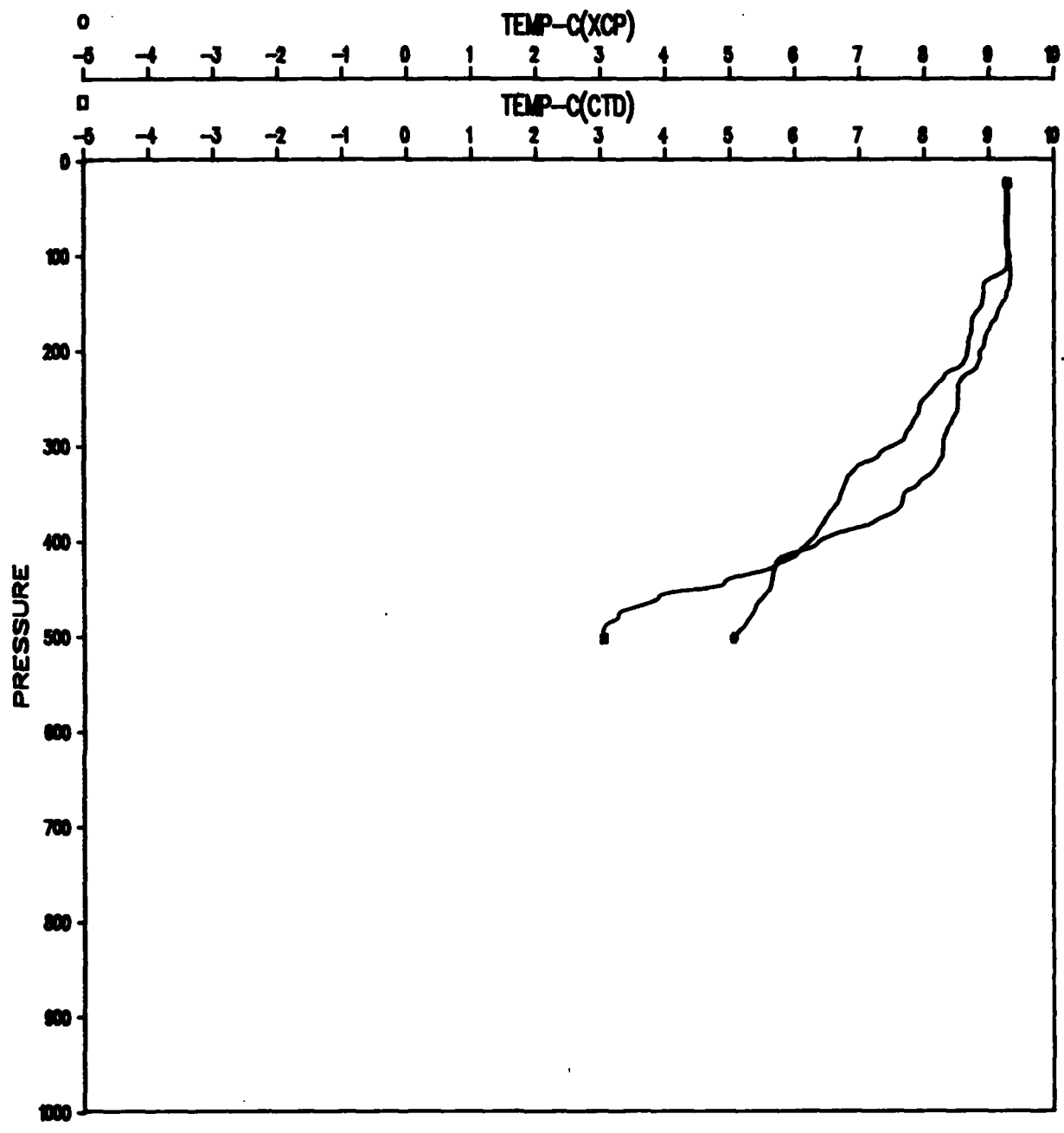


Figure C-1. File: KANE, Segment: C 503

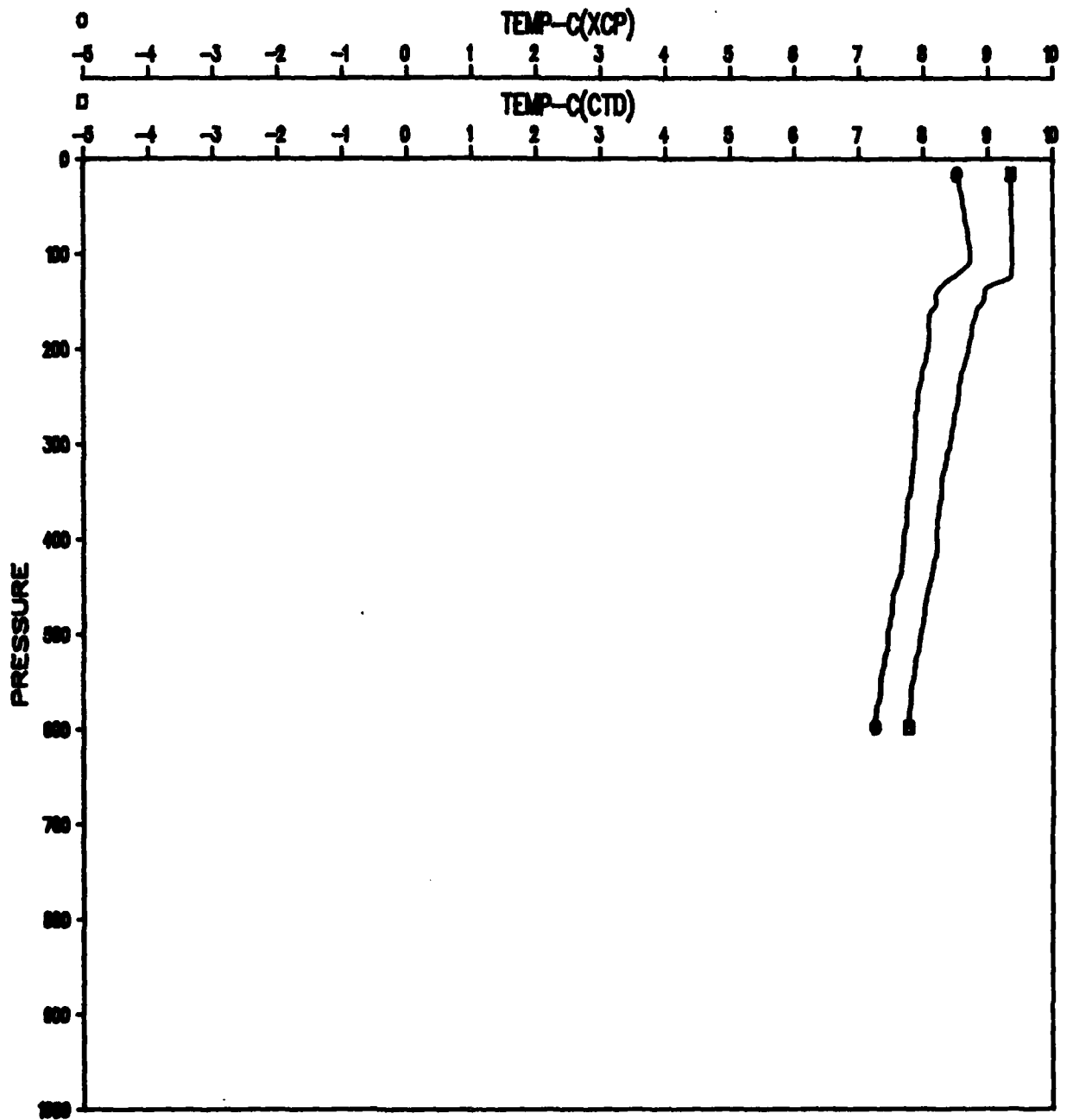


Figure C-2. File: KANE, Segment: C 504

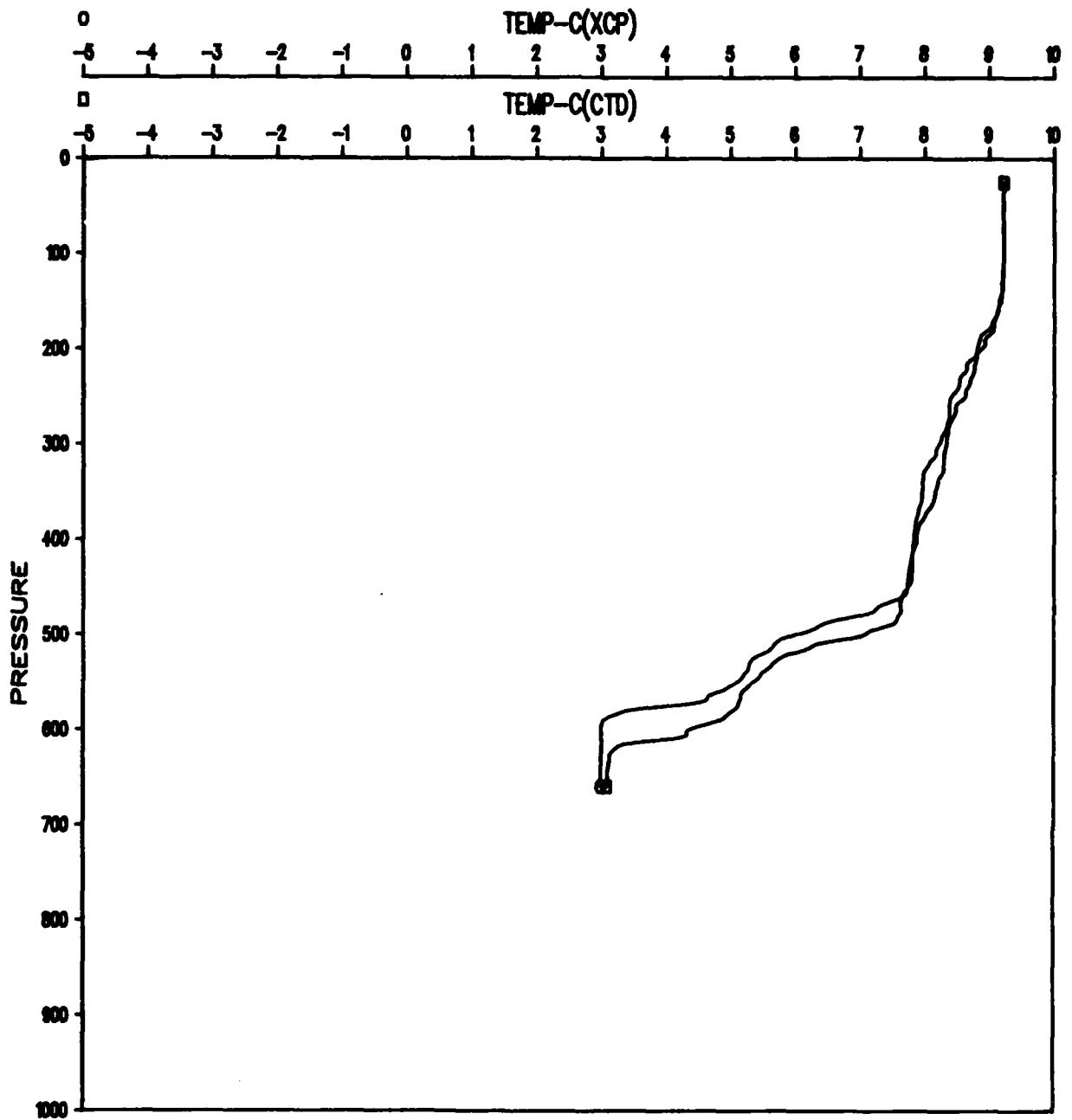


Figure C-3. File: KANE, Segment: C 517

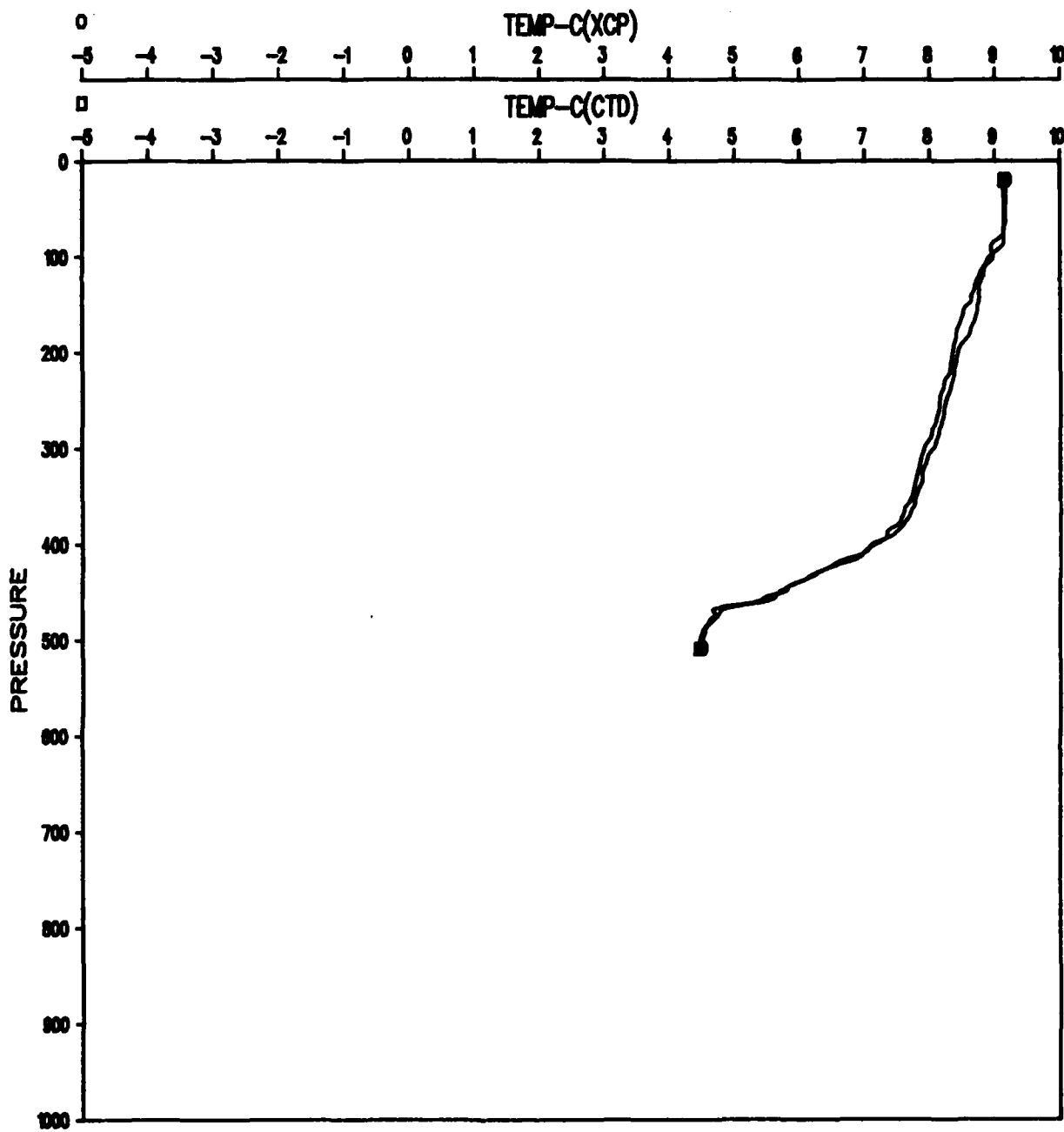


Figure C-4. File: KANE, Segment: C 519

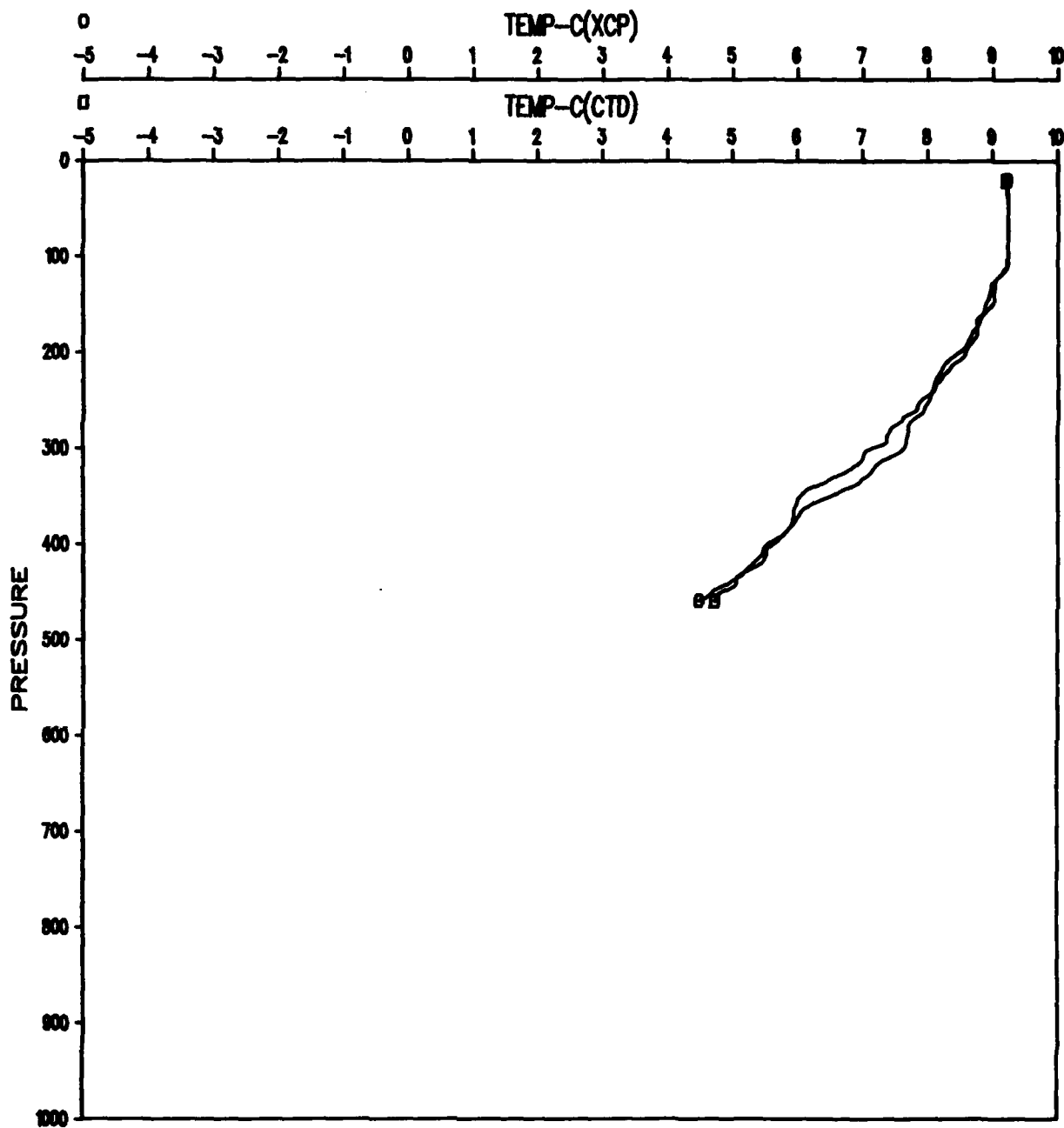


Figure C-5. File: KANE, Segment: C 520

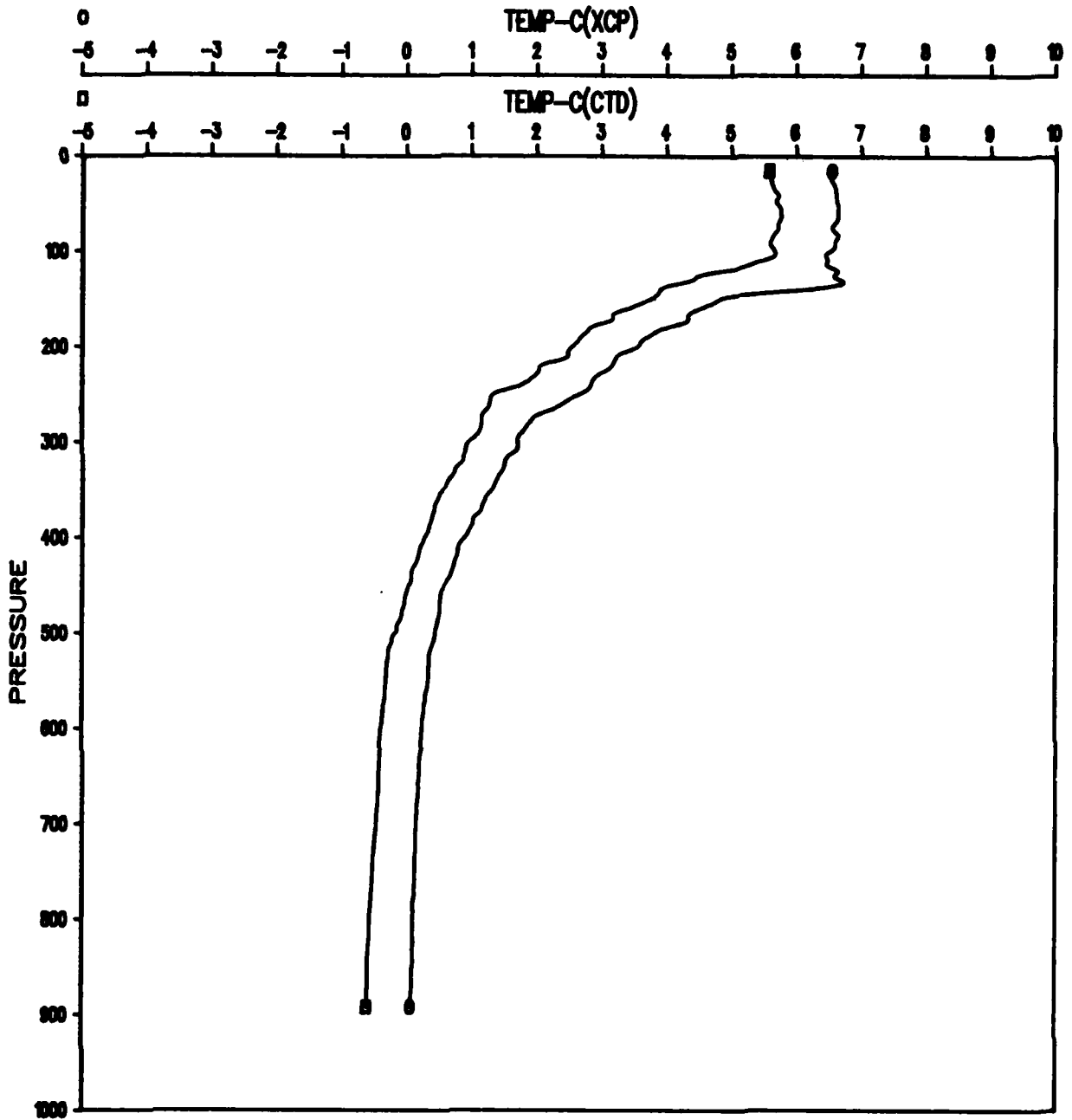


Figure C-6. File: KANE, Segment: C 525

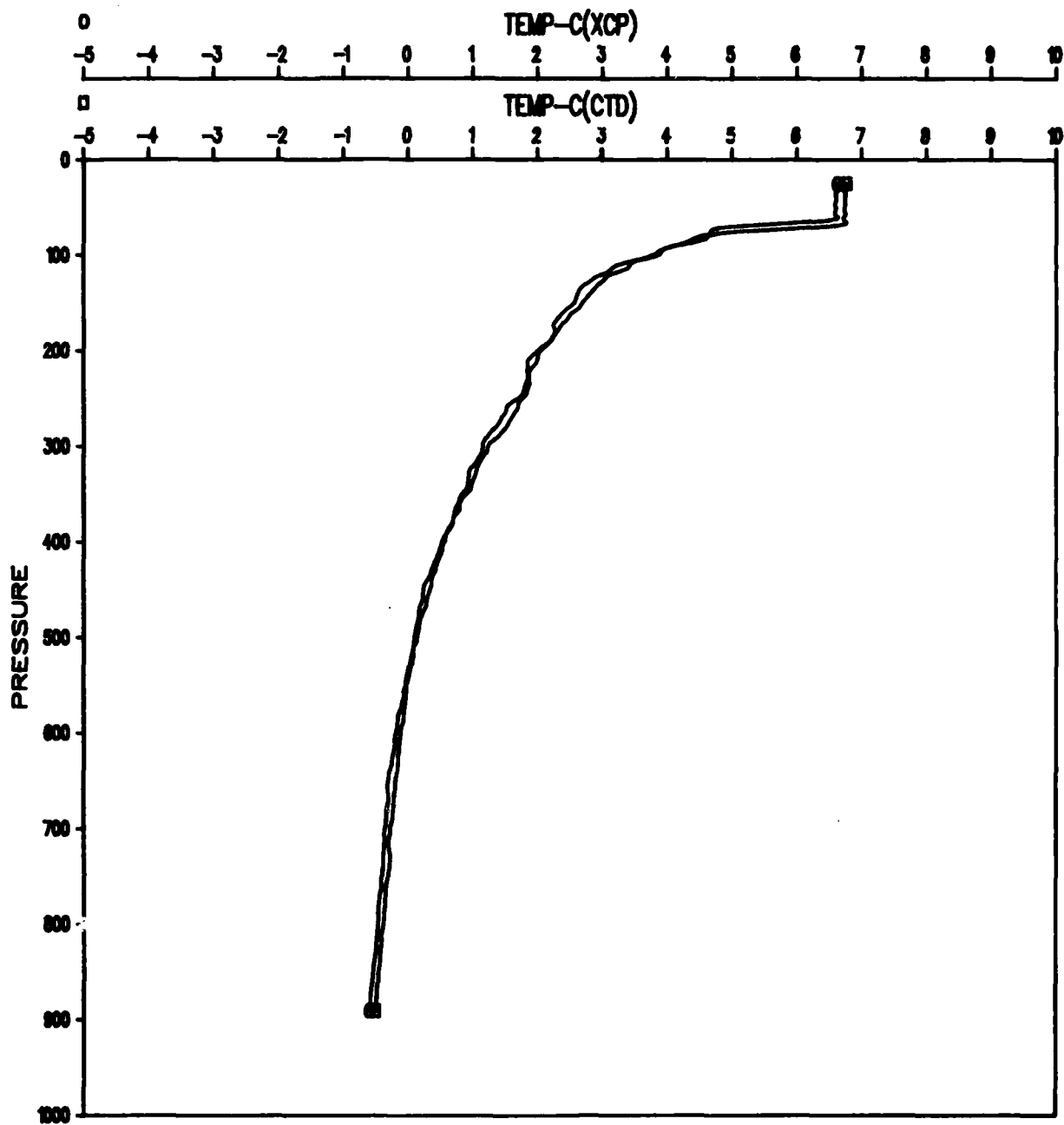


Figure C-7. File: KANE, Segment: C 534

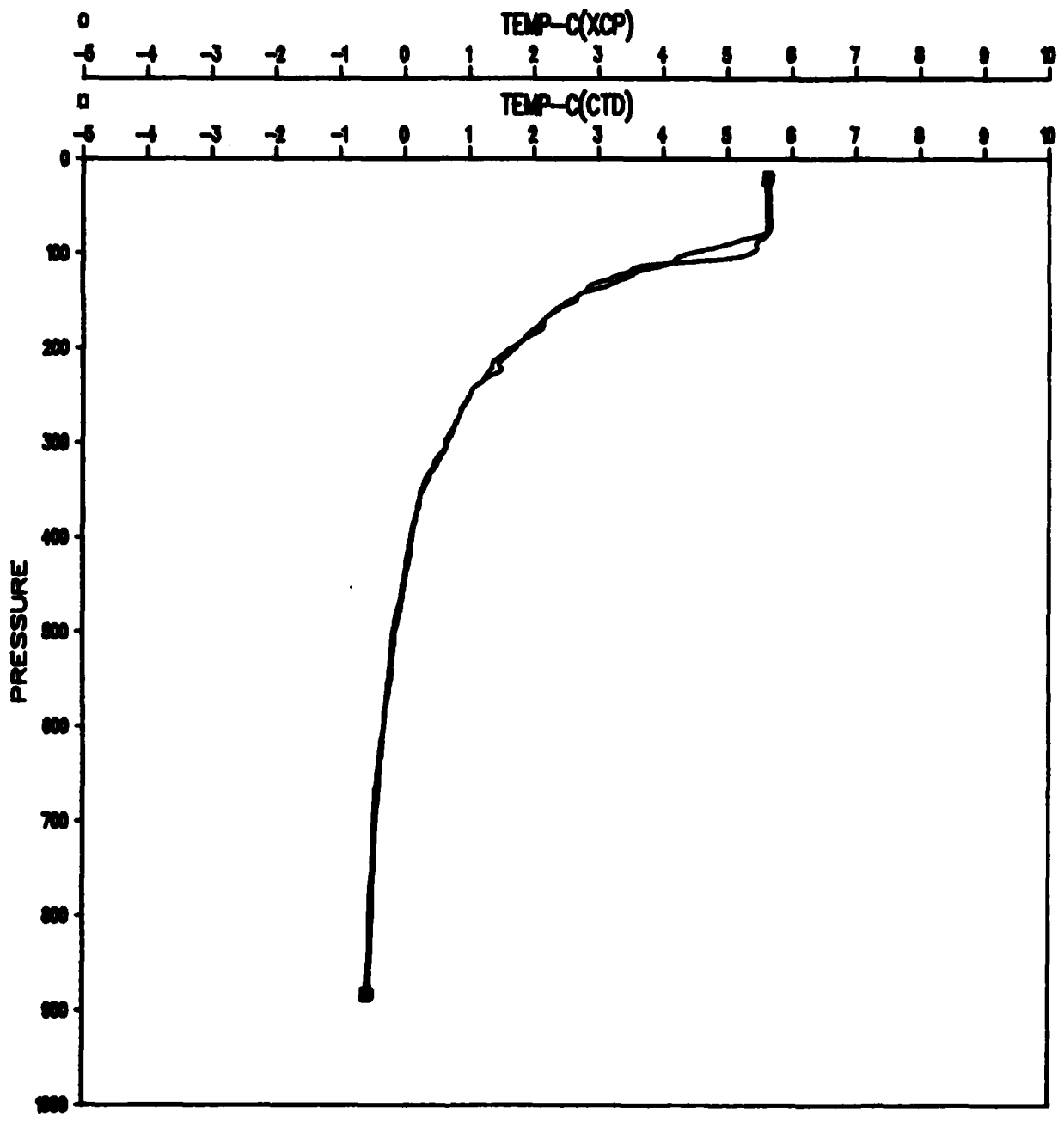


Figure C-8. File: KANE, Segment: C 538

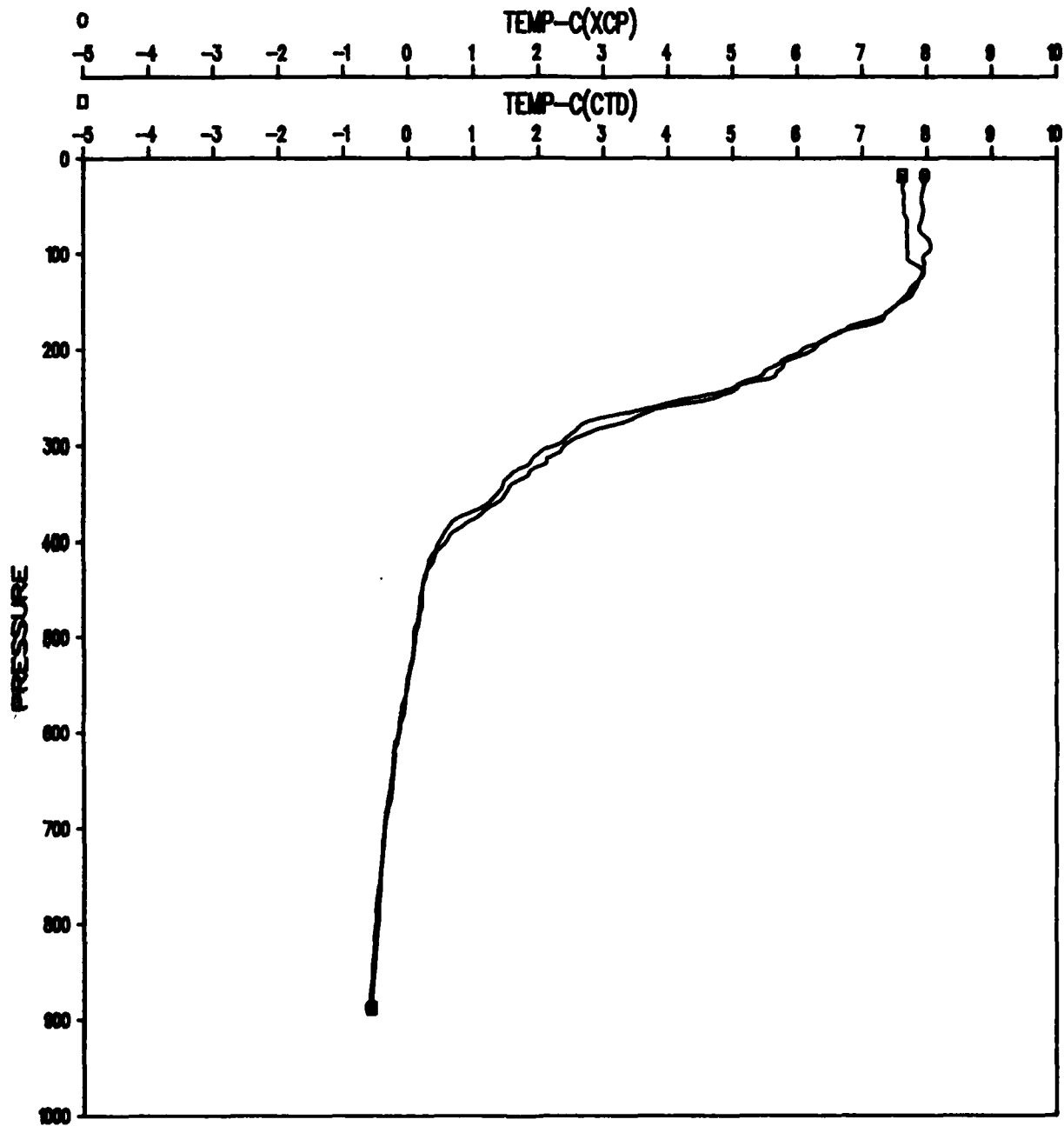


Figure C-9. File: KANE, Segment: C 546

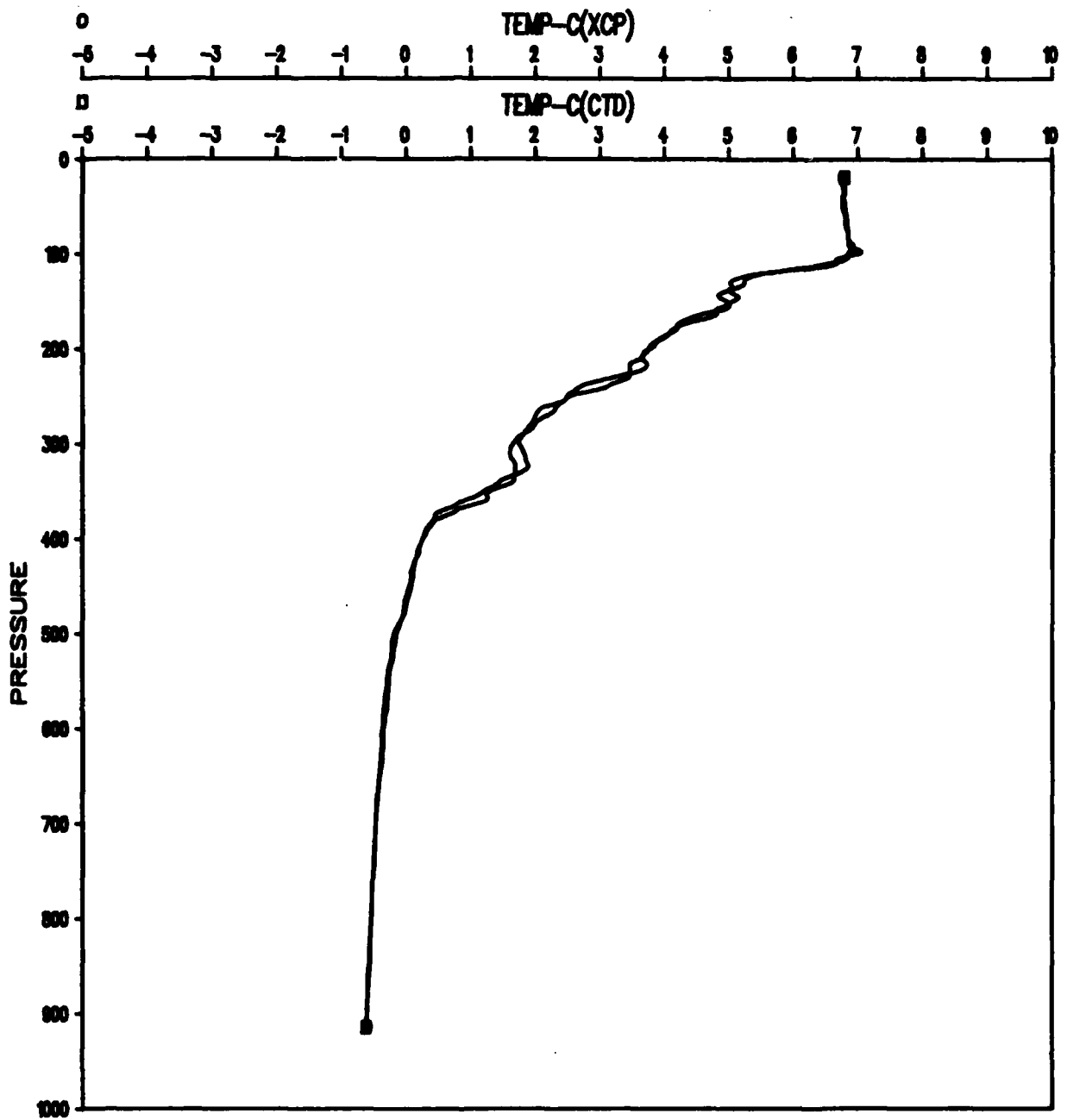


Figure C-10. File: KANE, Segment: C 547

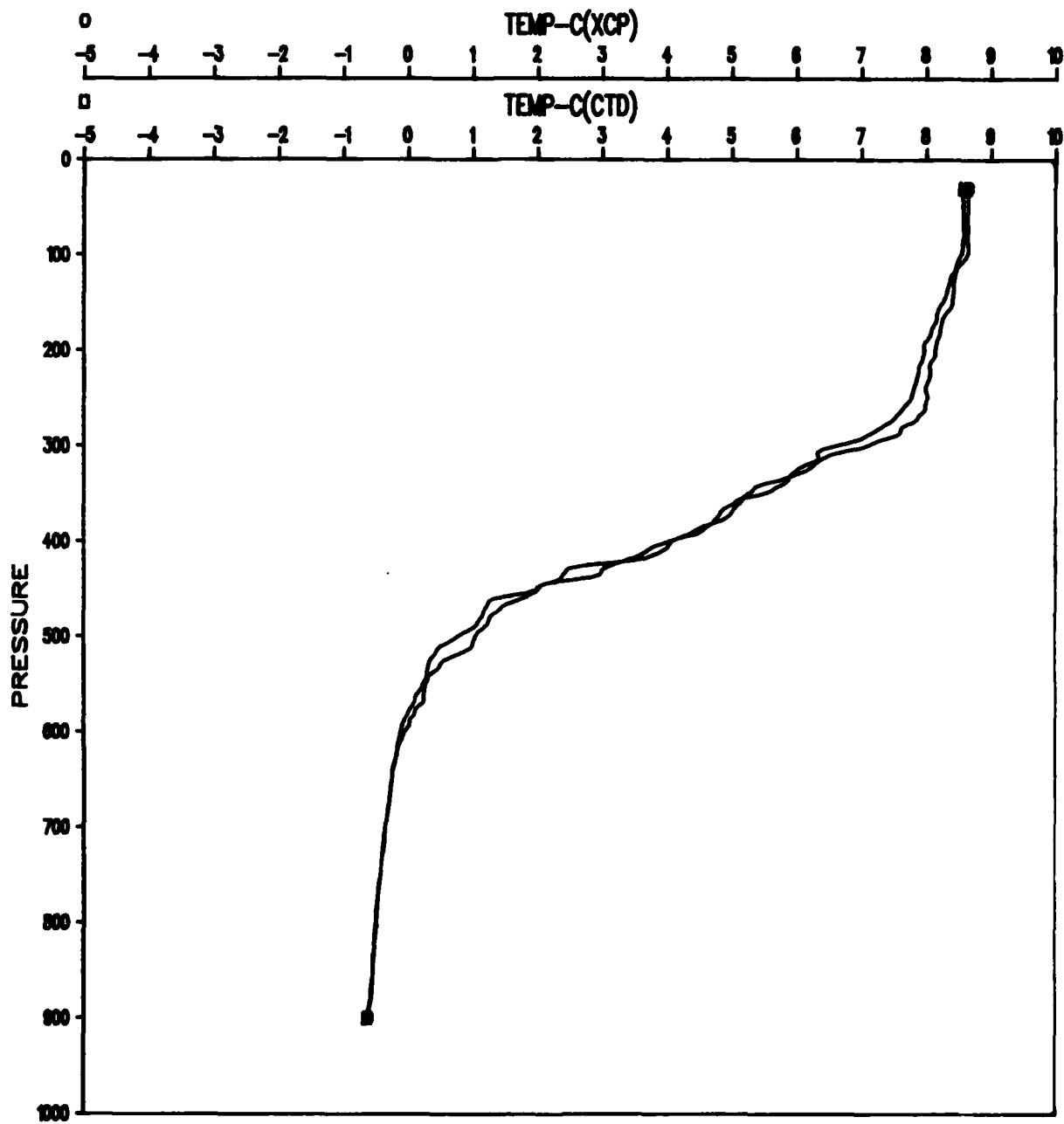


Figure C-11. File: KANE, Segment: C 548

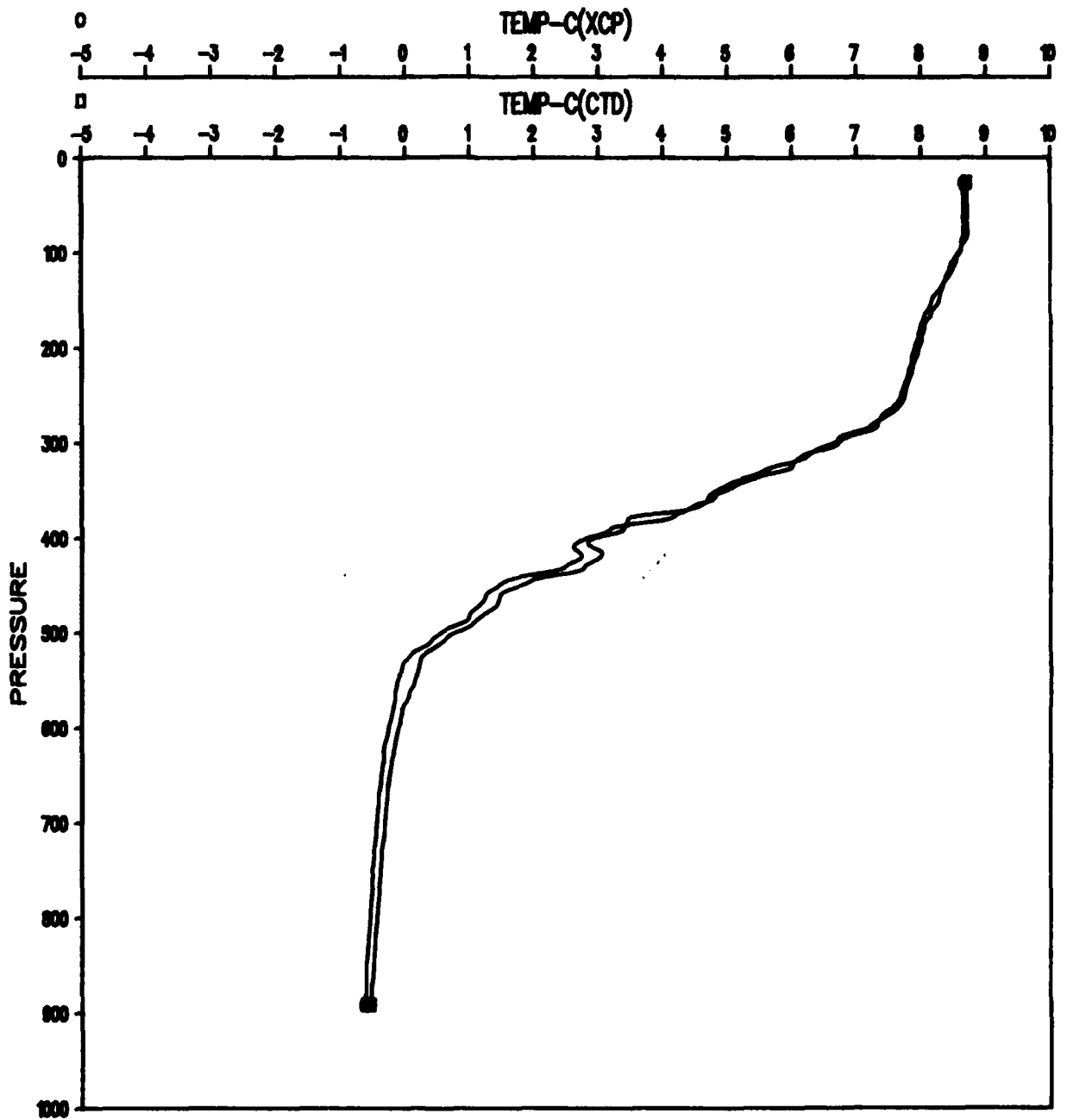


Figure C-12. File: KANE, Segment: C 550

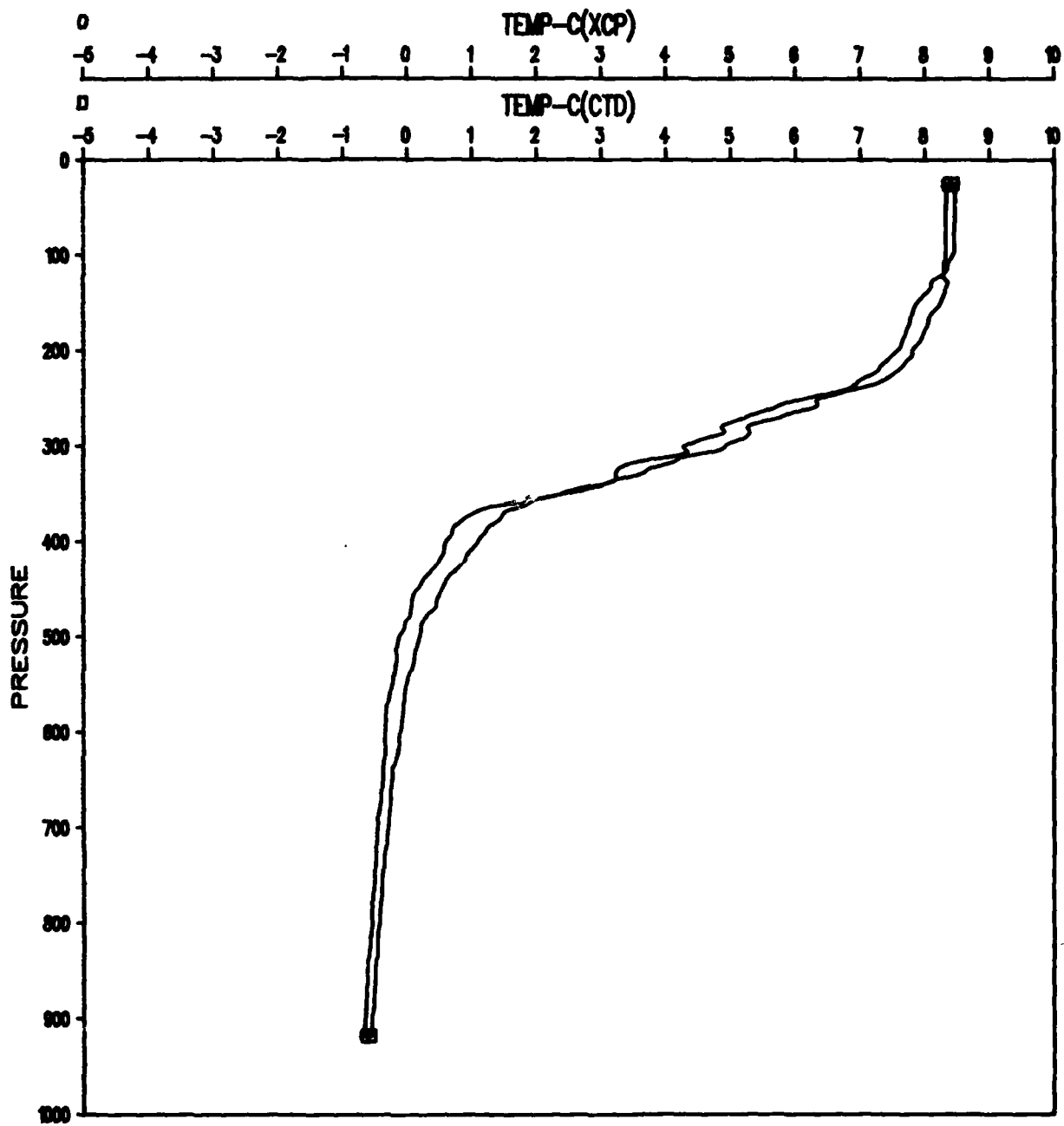


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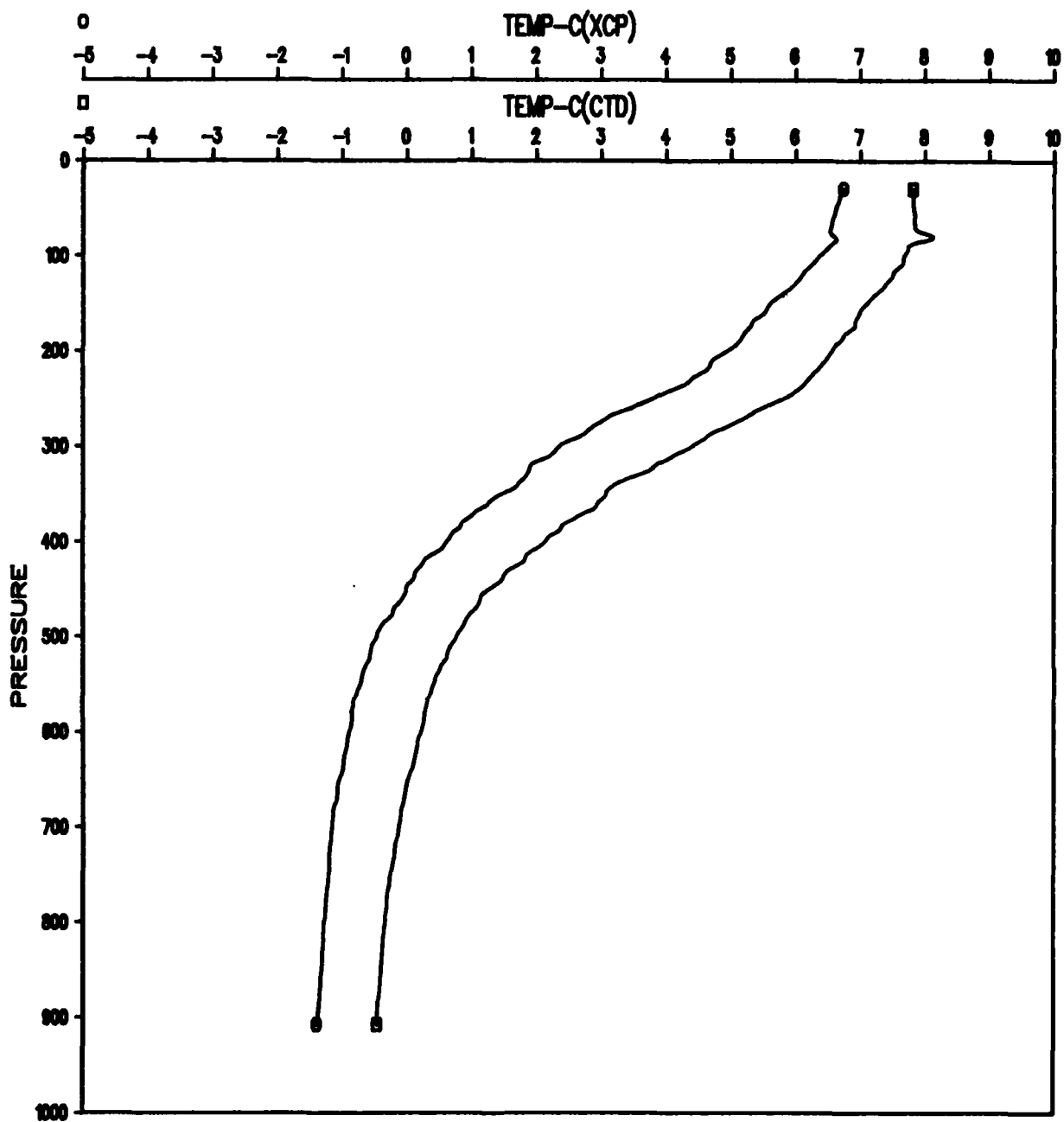


Figure C-14. File: KANE, Segment: C 563

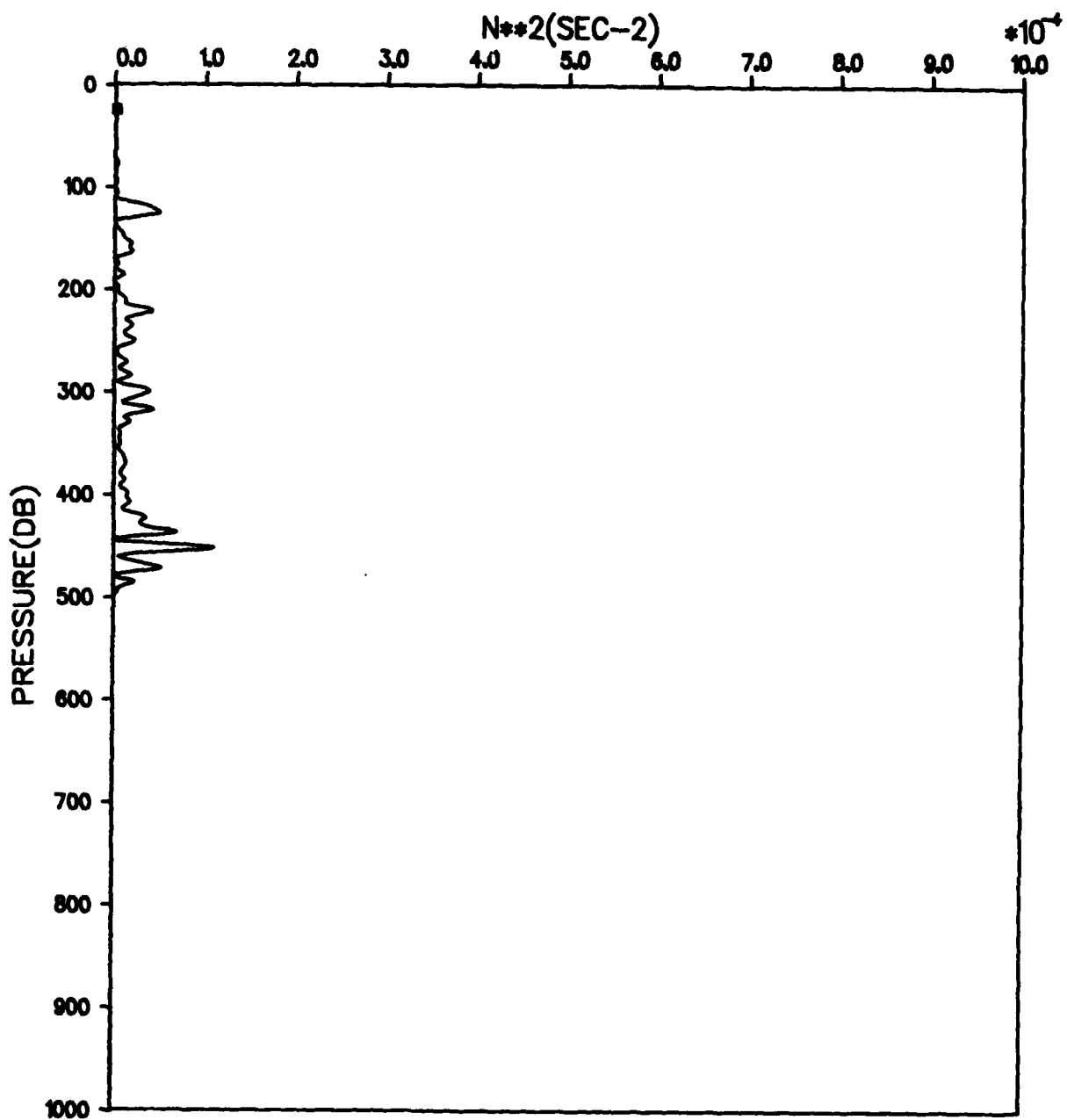


Figure D-1. File: KANE, Segment: C 503

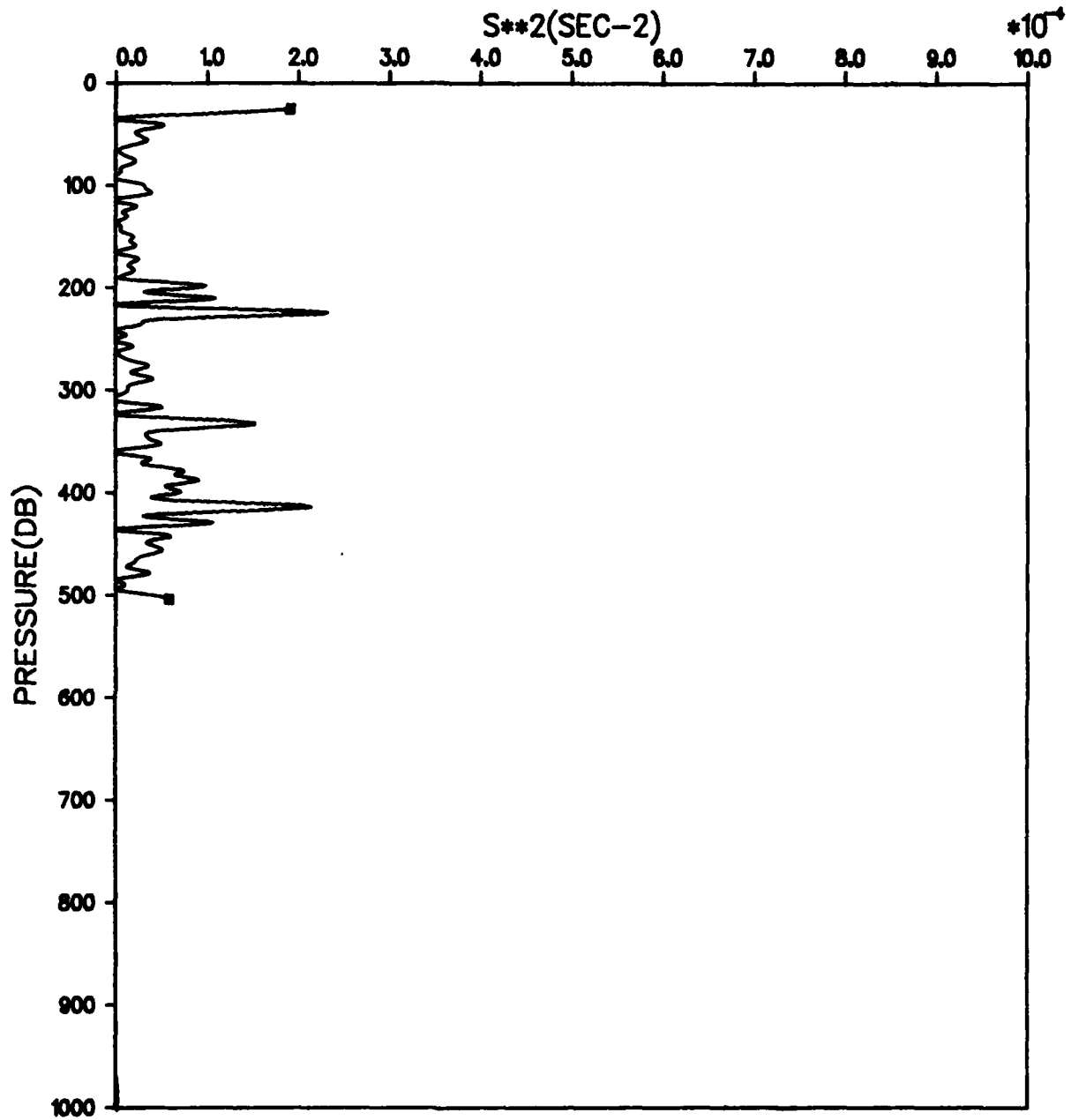


Figure D-2. File: KANE, Segment: C 503

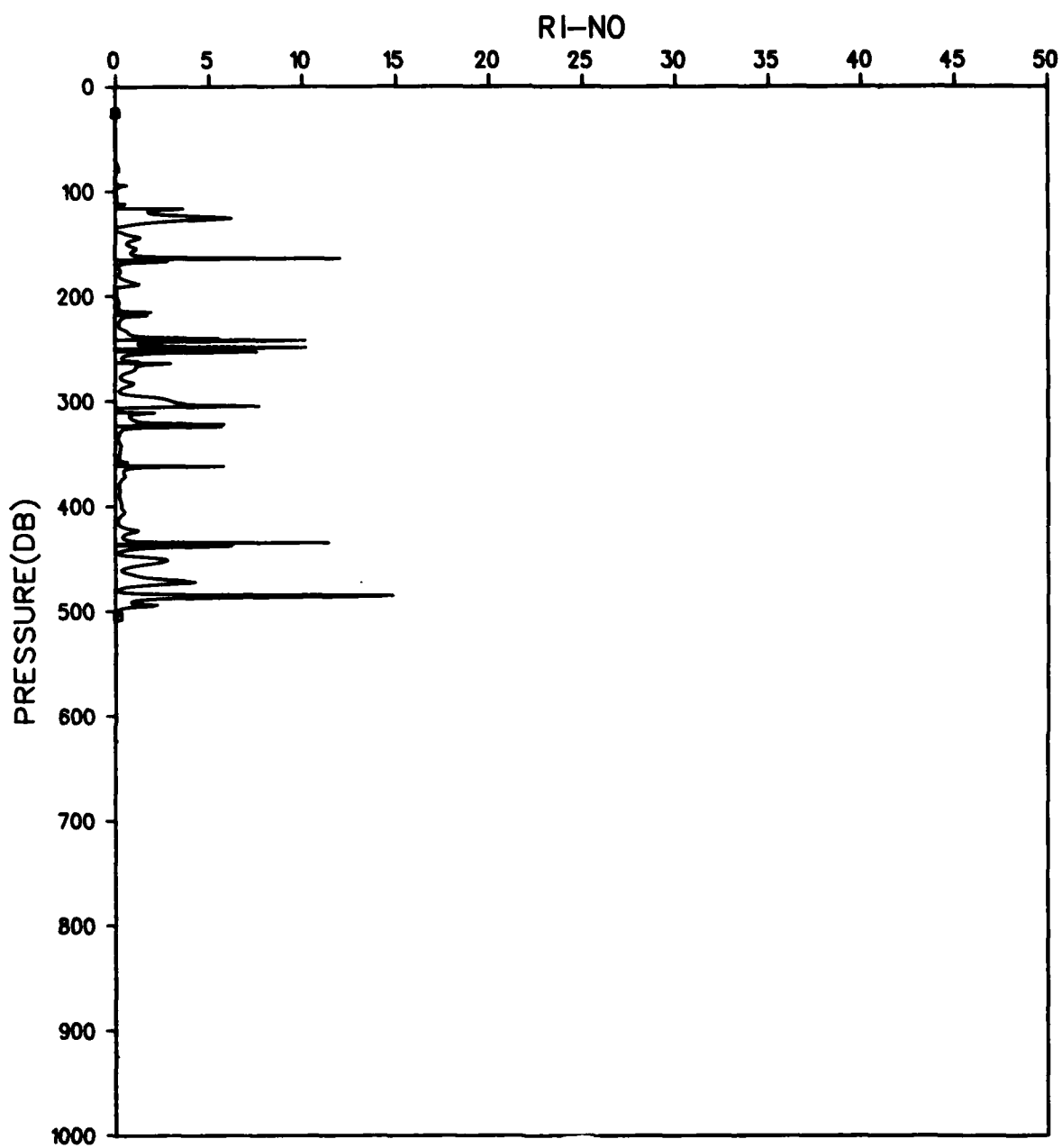


Figure D-3. File: KANE, Segment: C 503

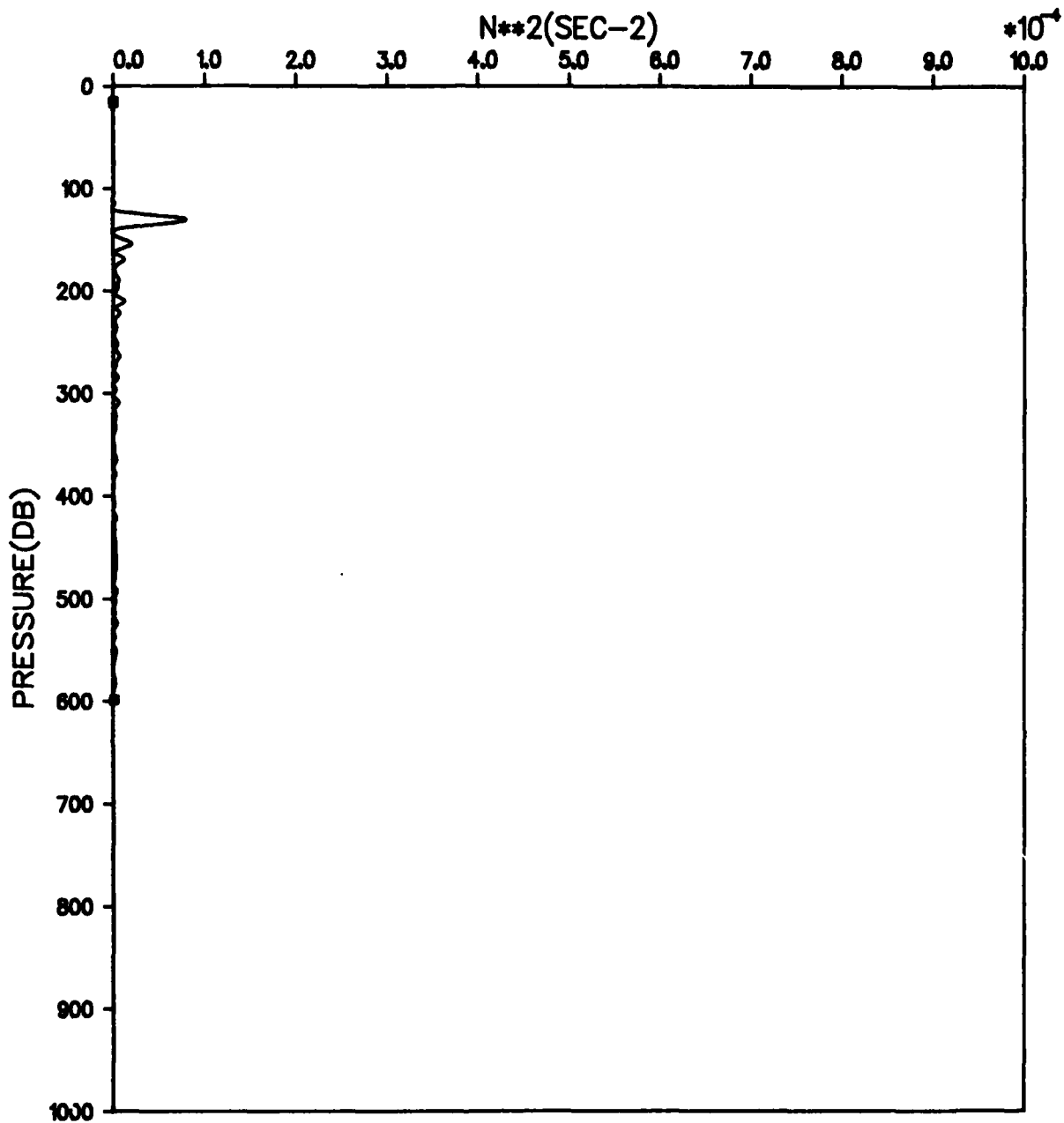


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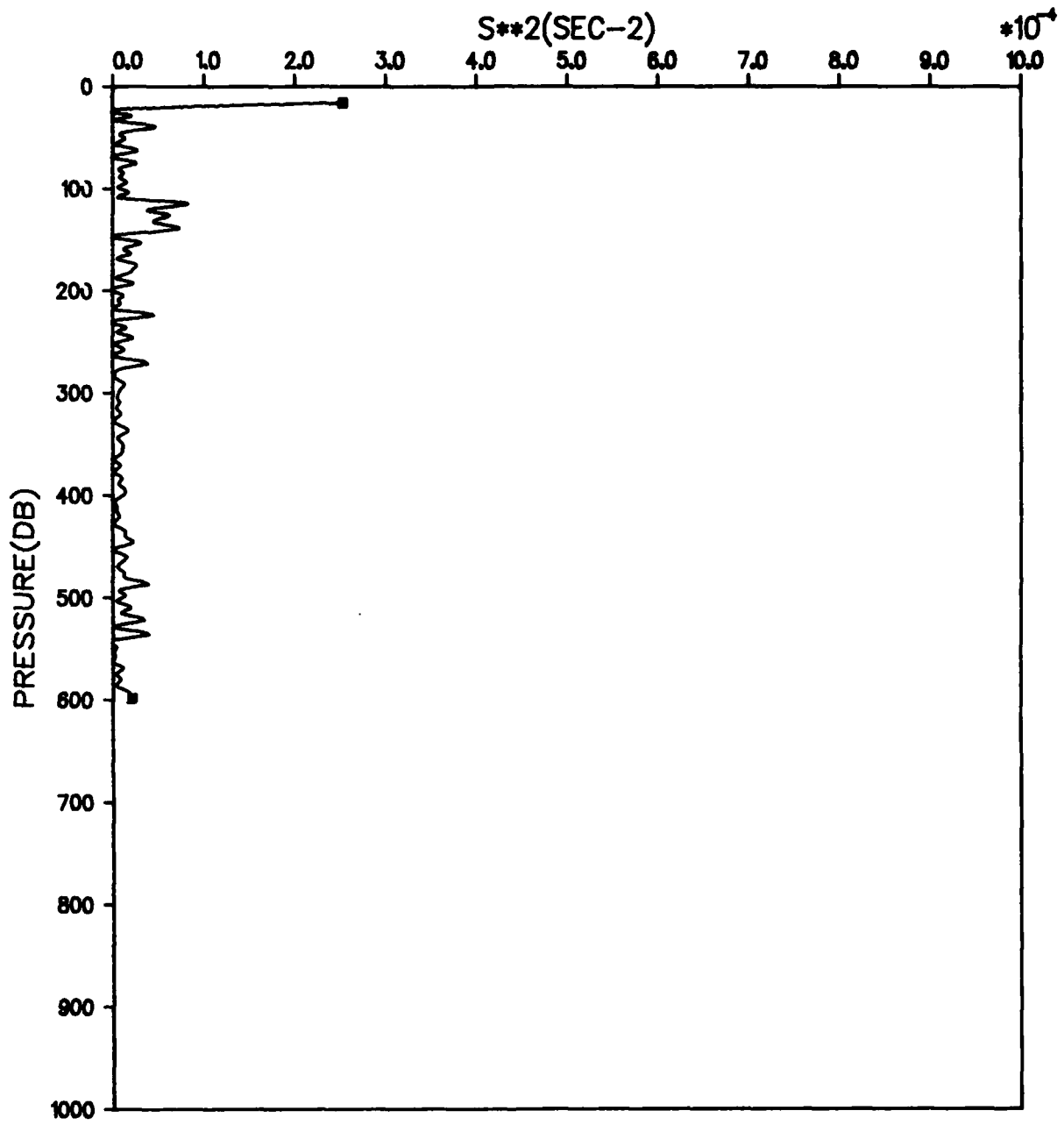


Figure D-5. File: KANE, Segment: C 504

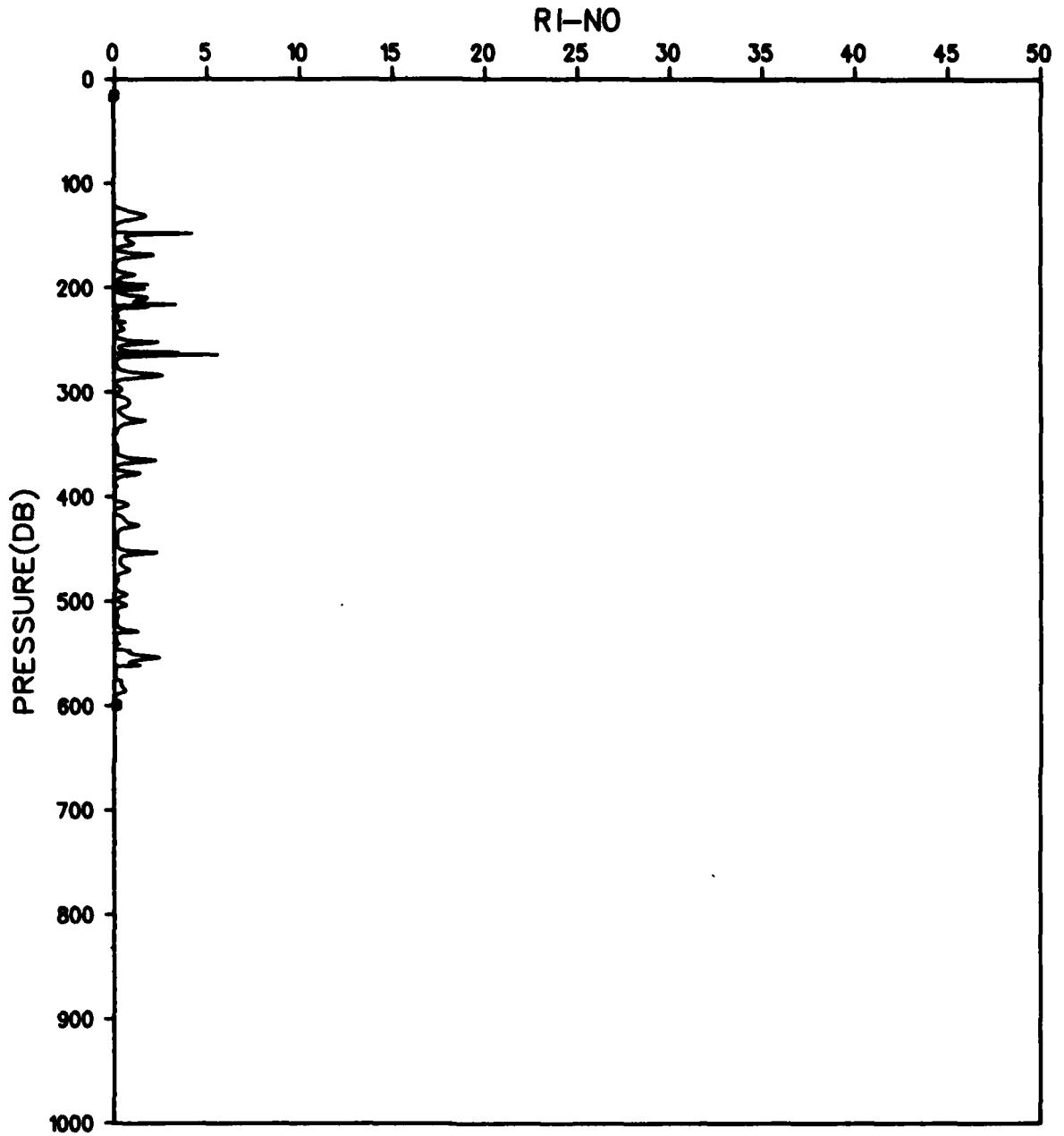


Figure D-6. File: KANE, Segment: C 504

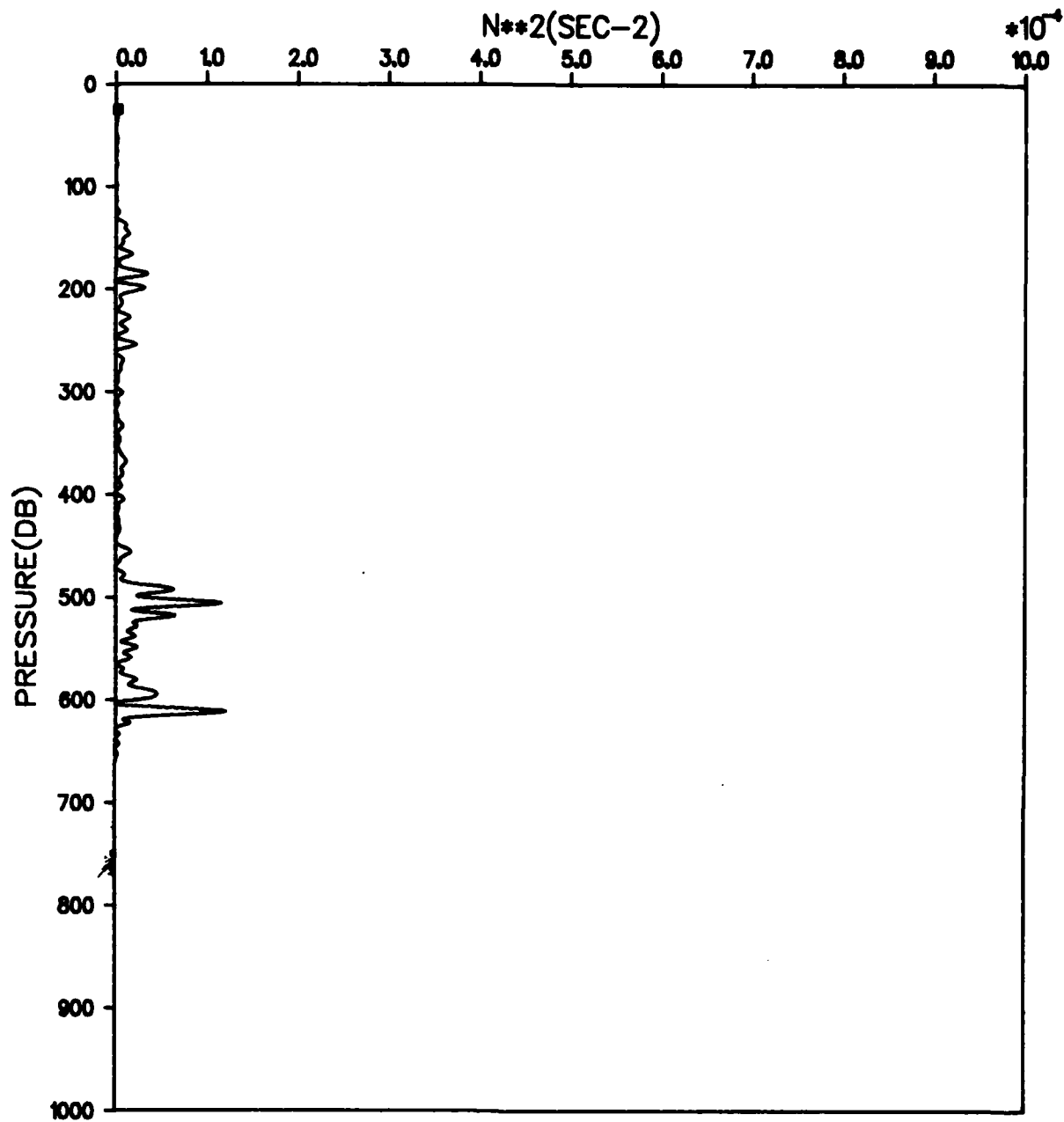


Figure D-7. File: KANE, Segment: C 517

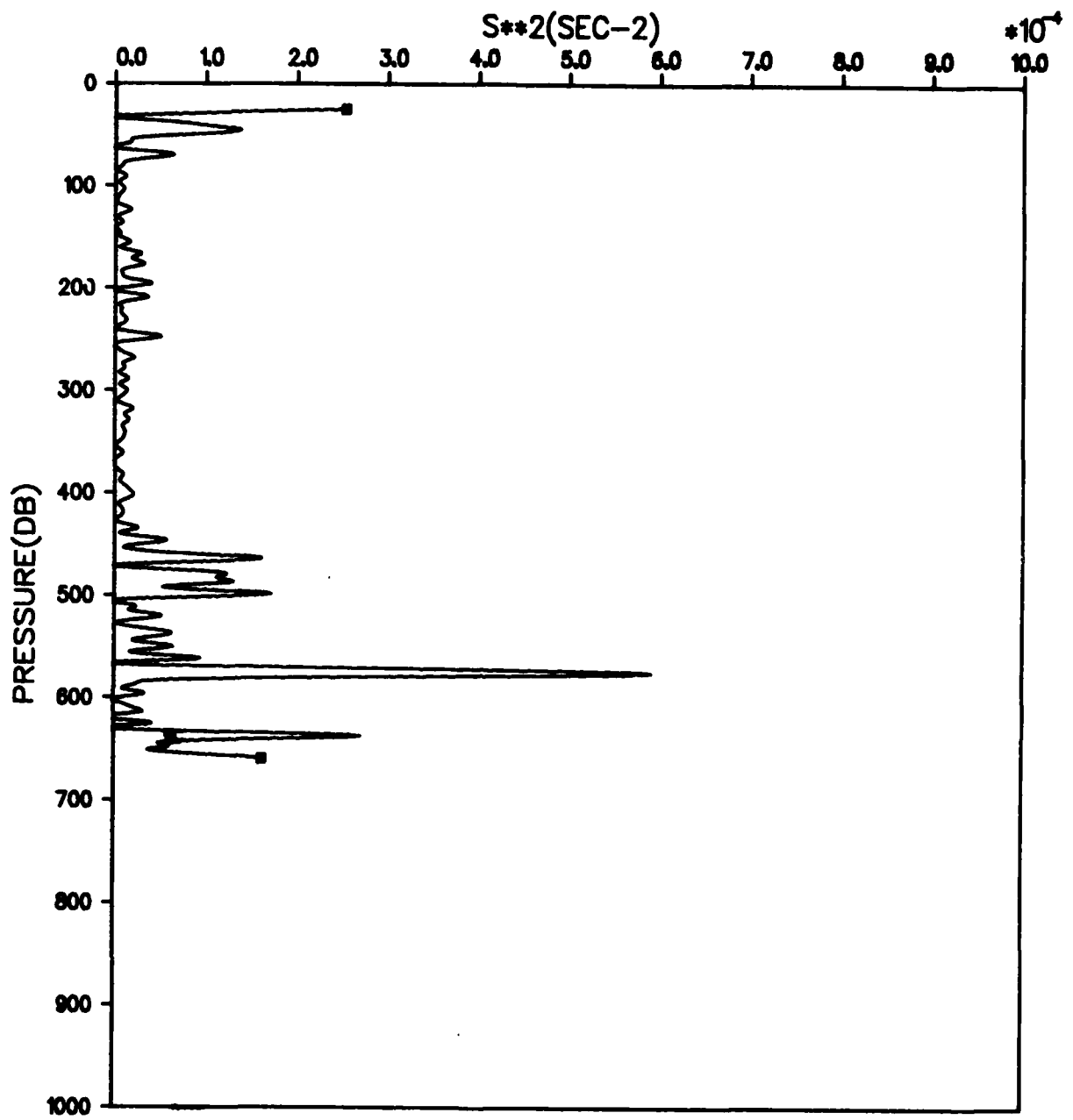


Figure D-8. File: KANE, Segment: C 517

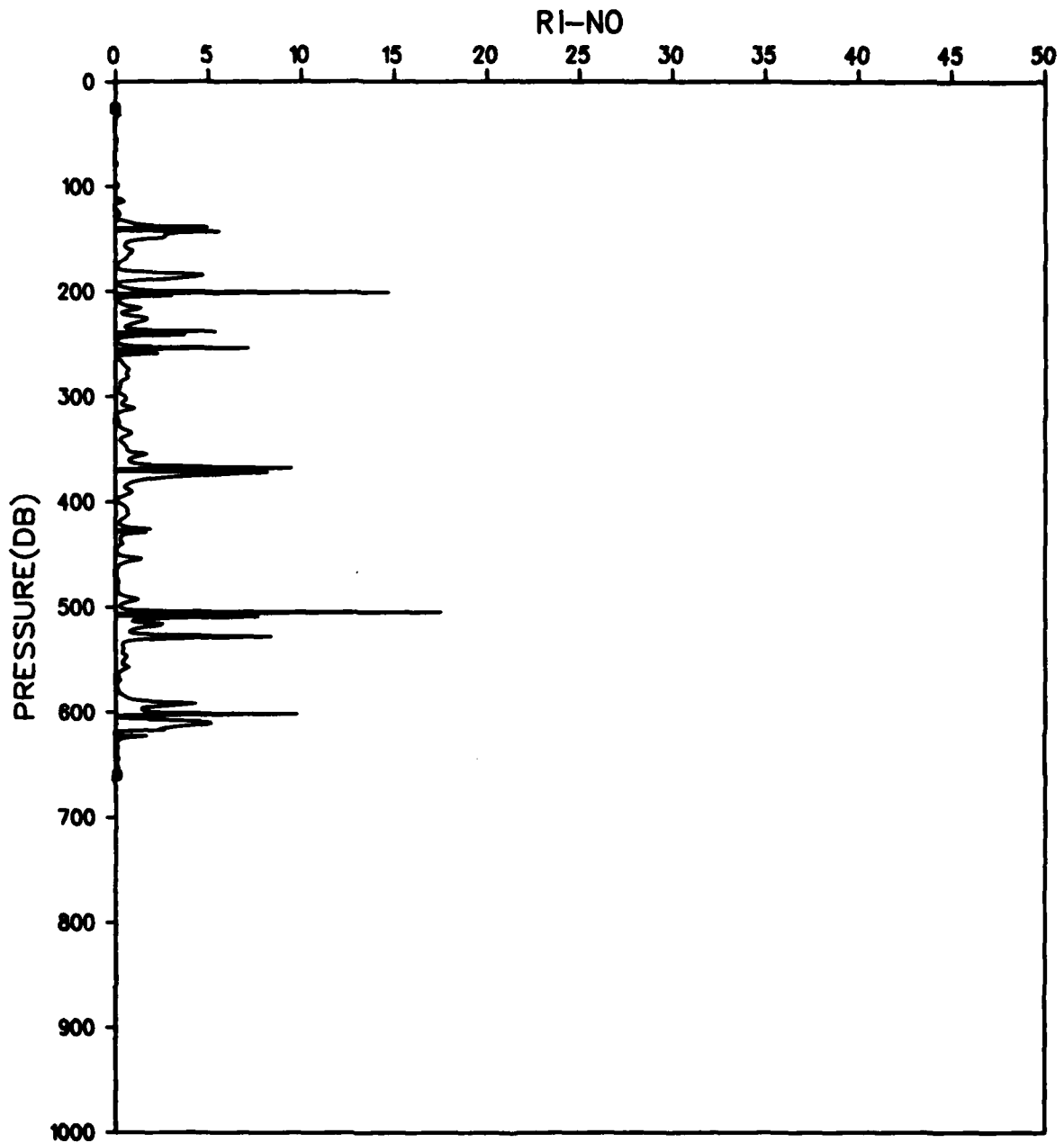


Figure D-9. File: KANE, Segment: C 517

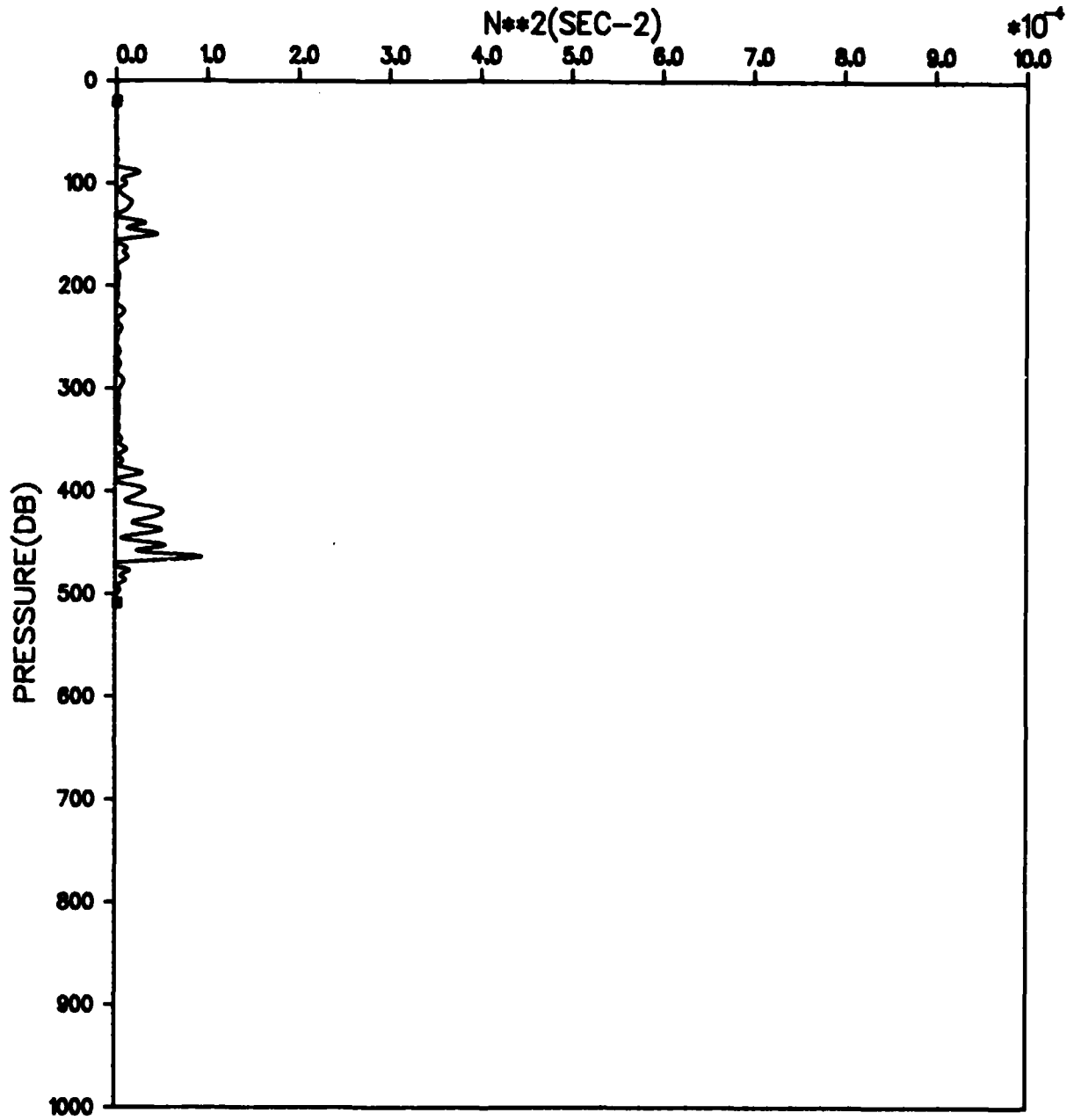


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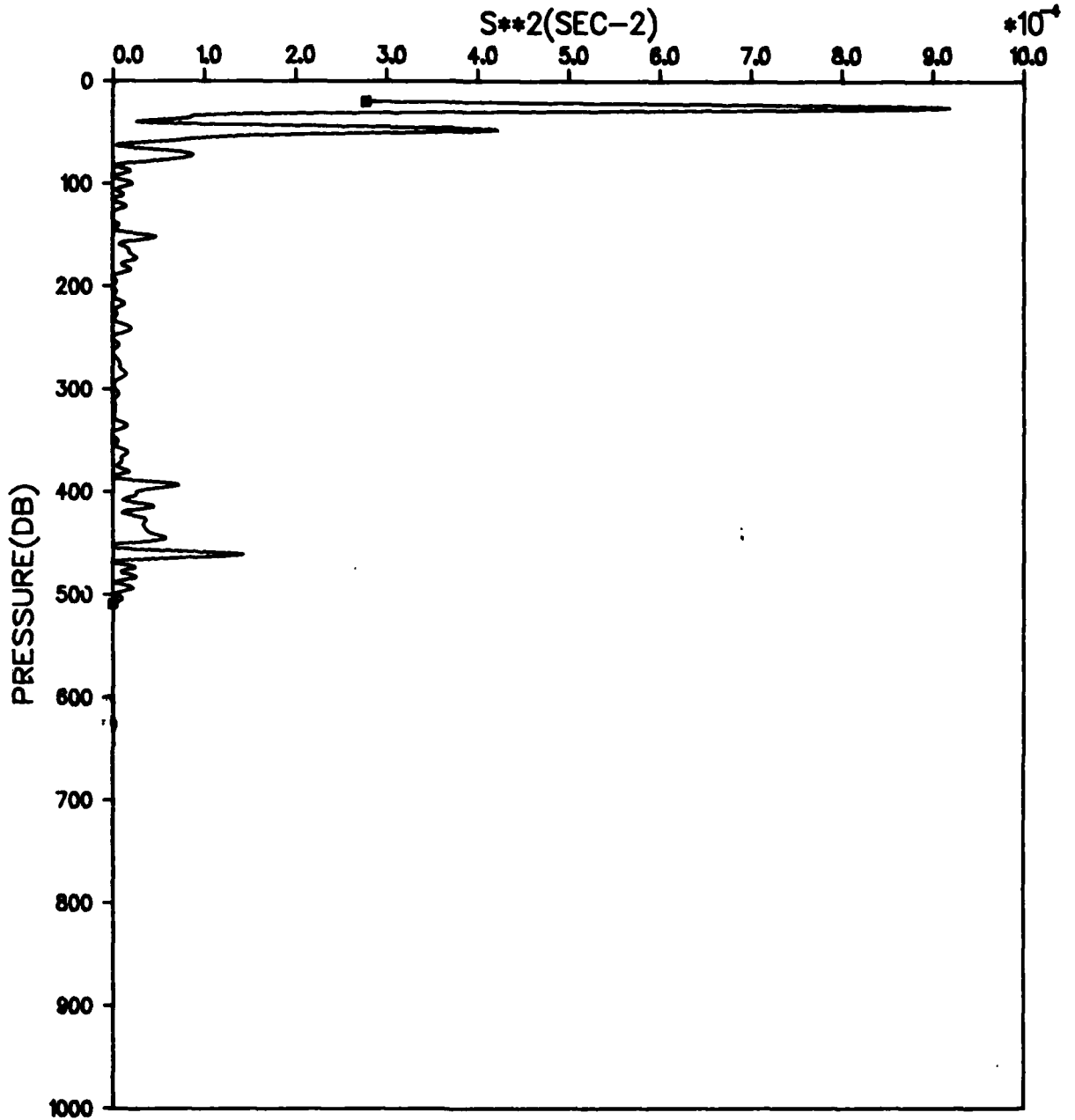


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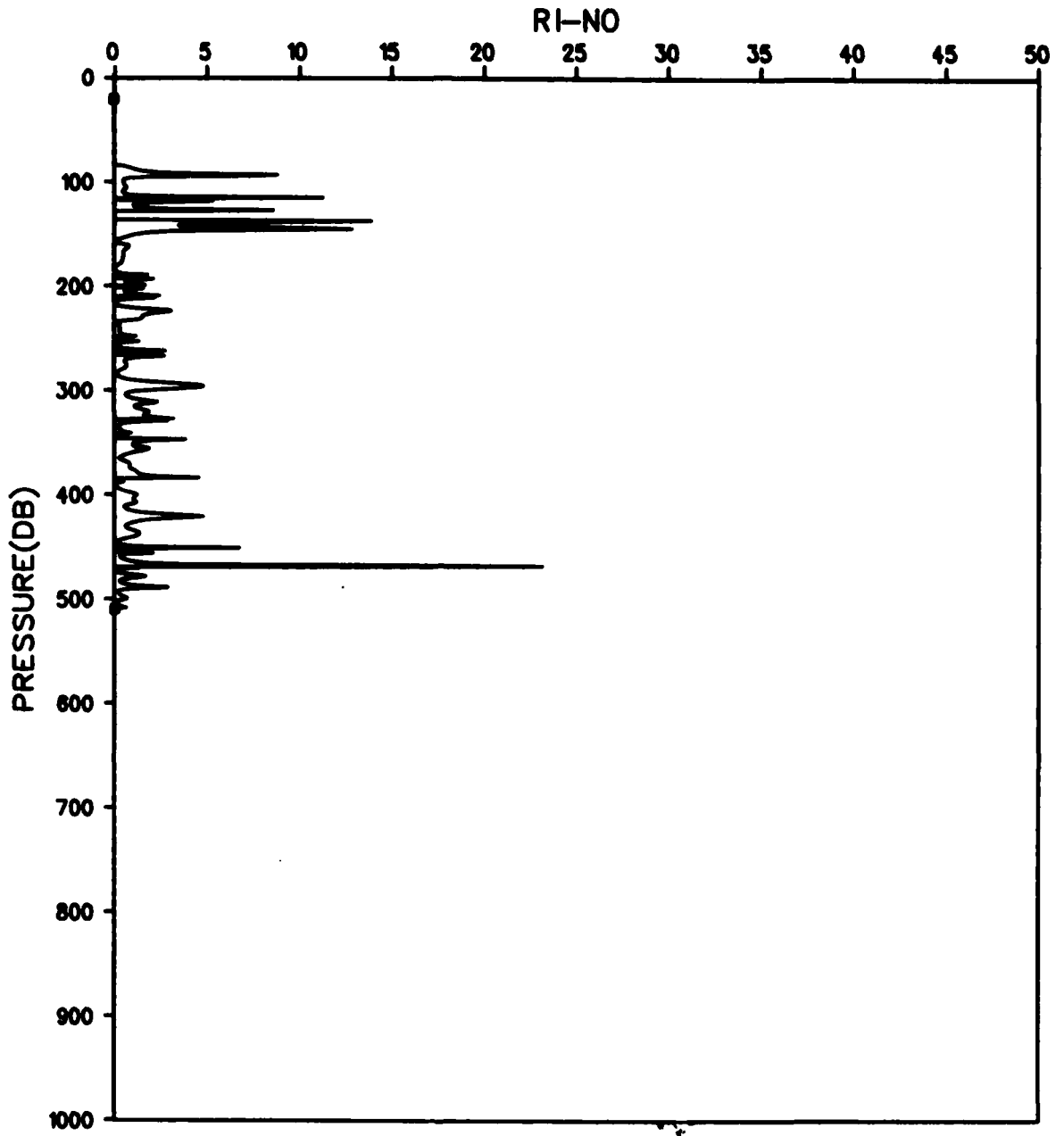


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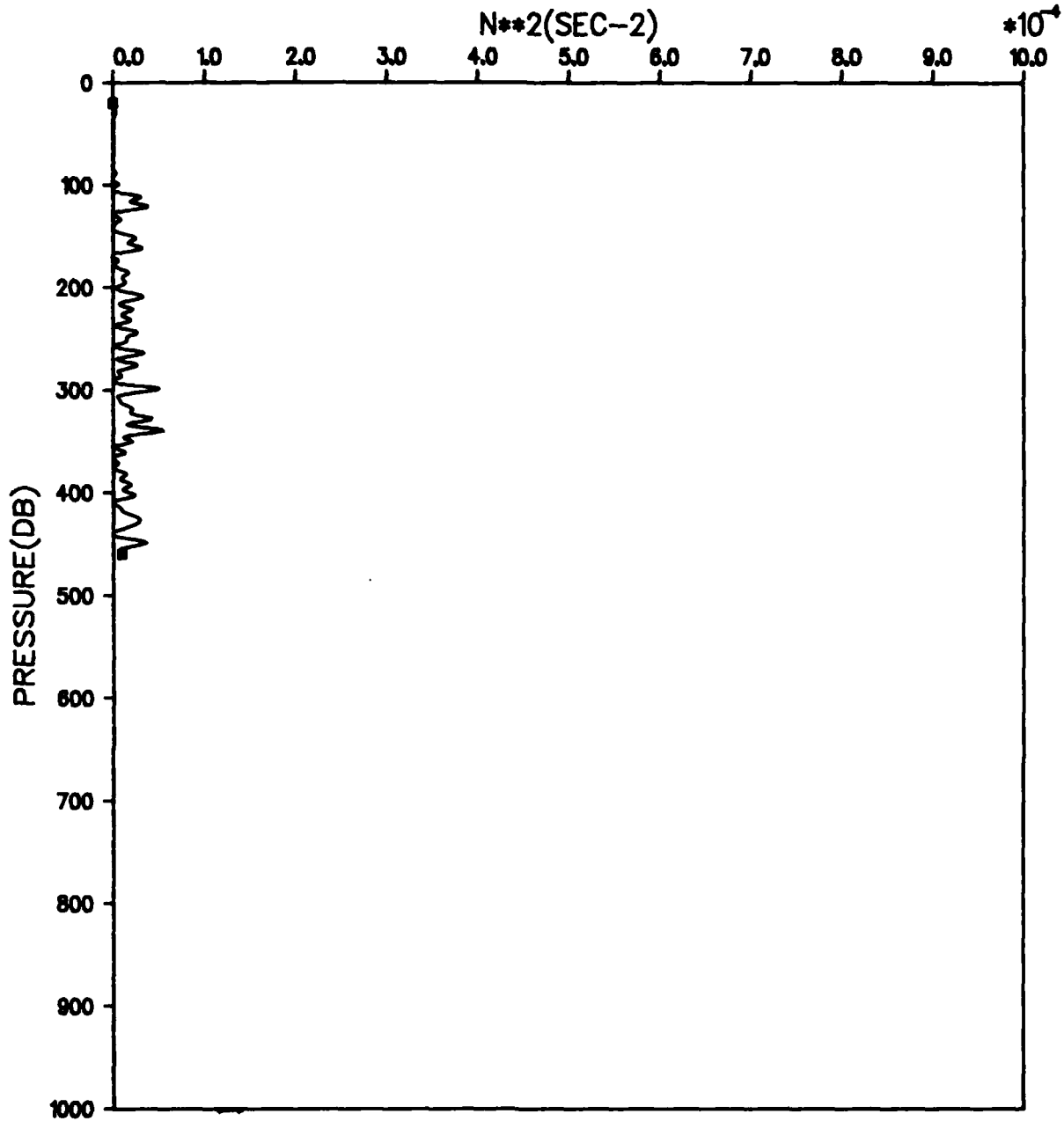


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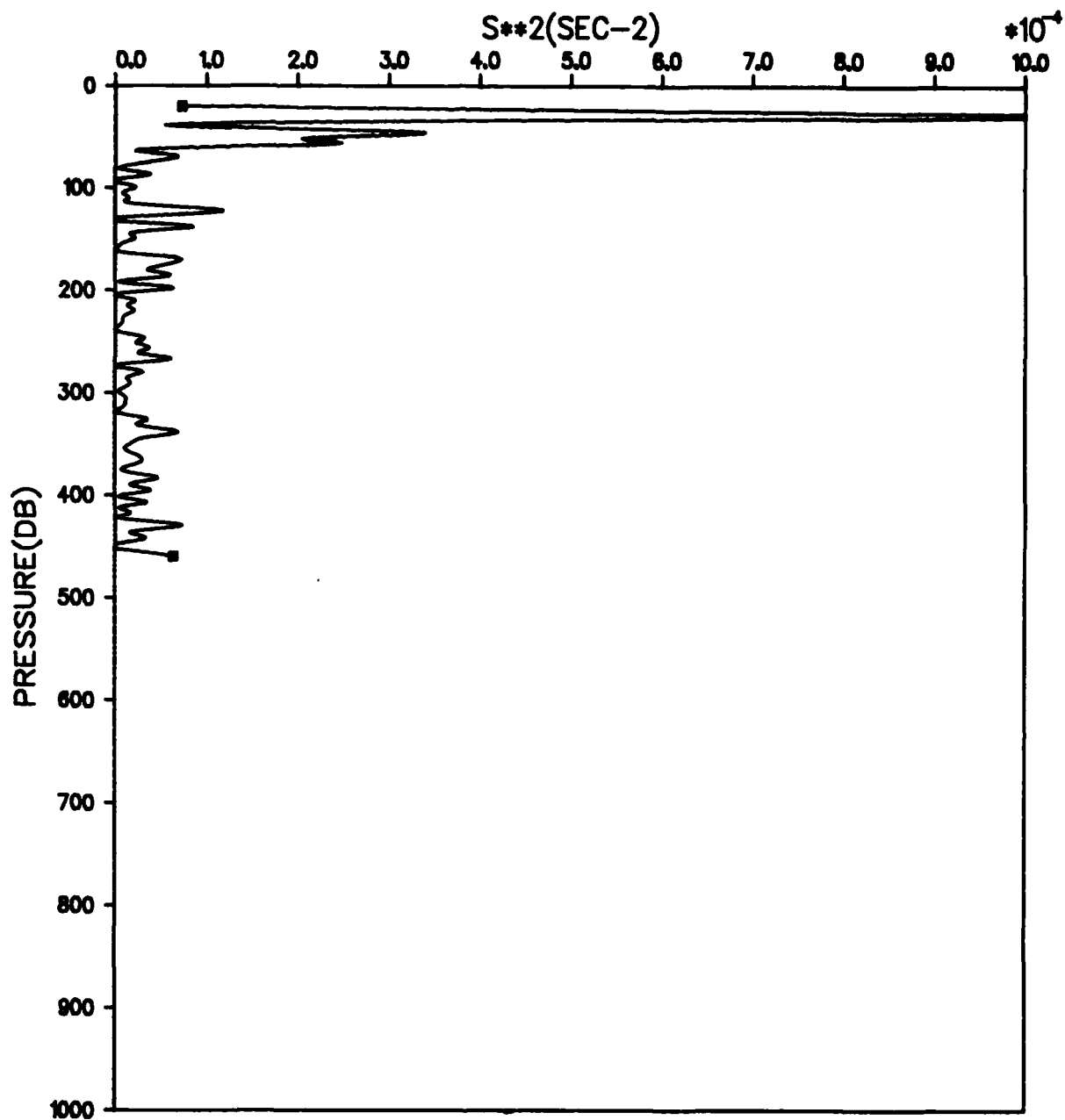


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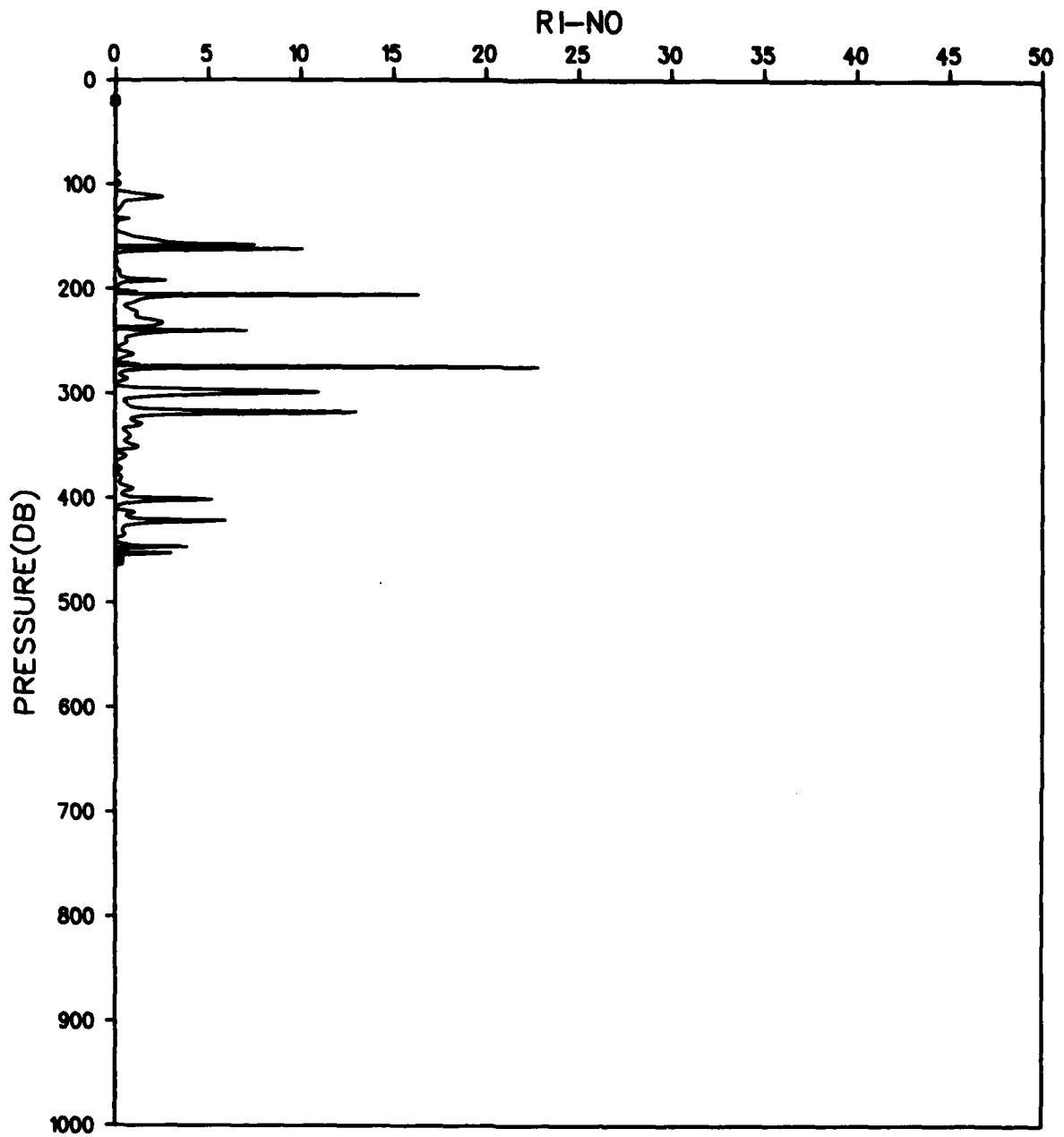


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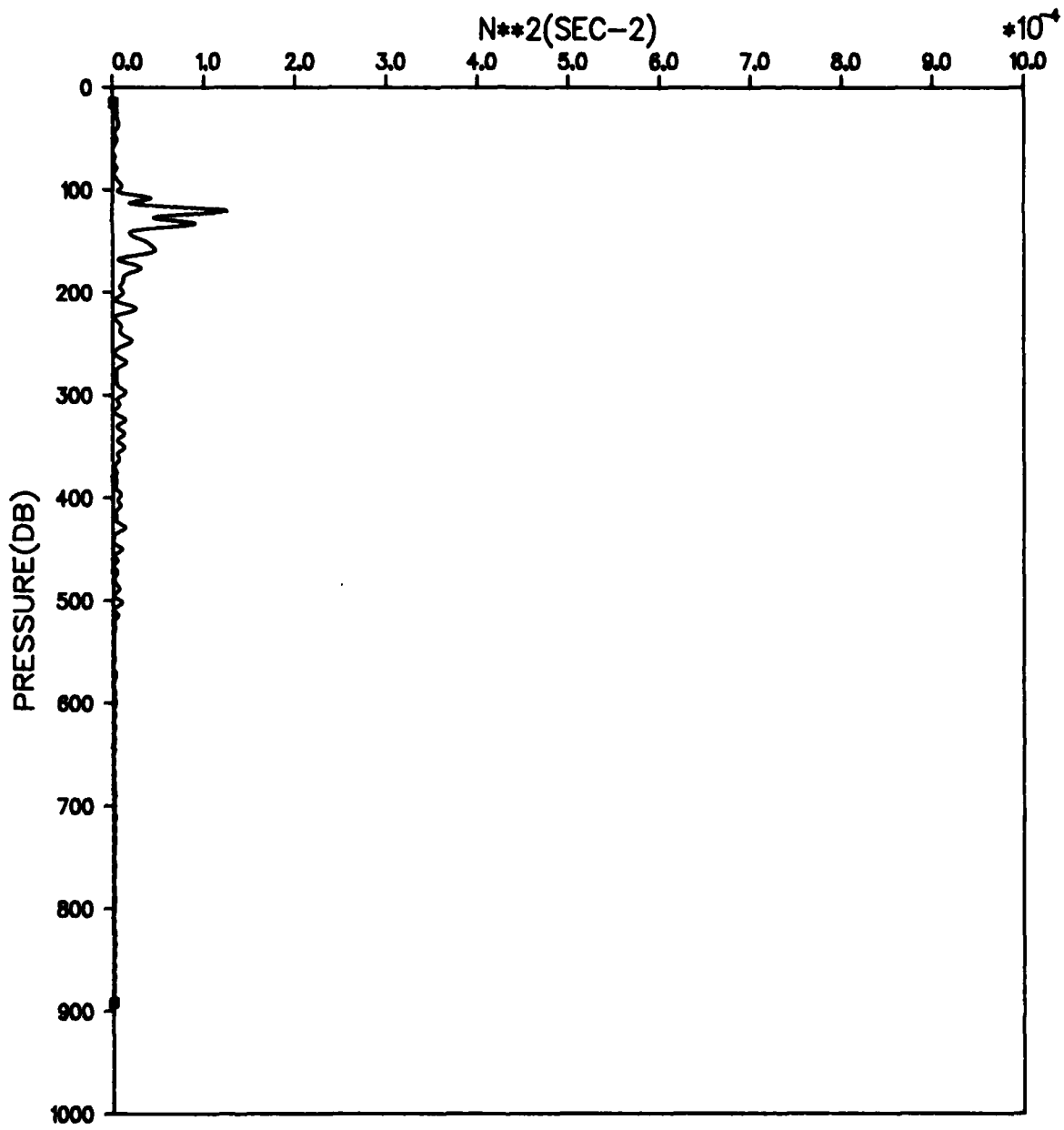


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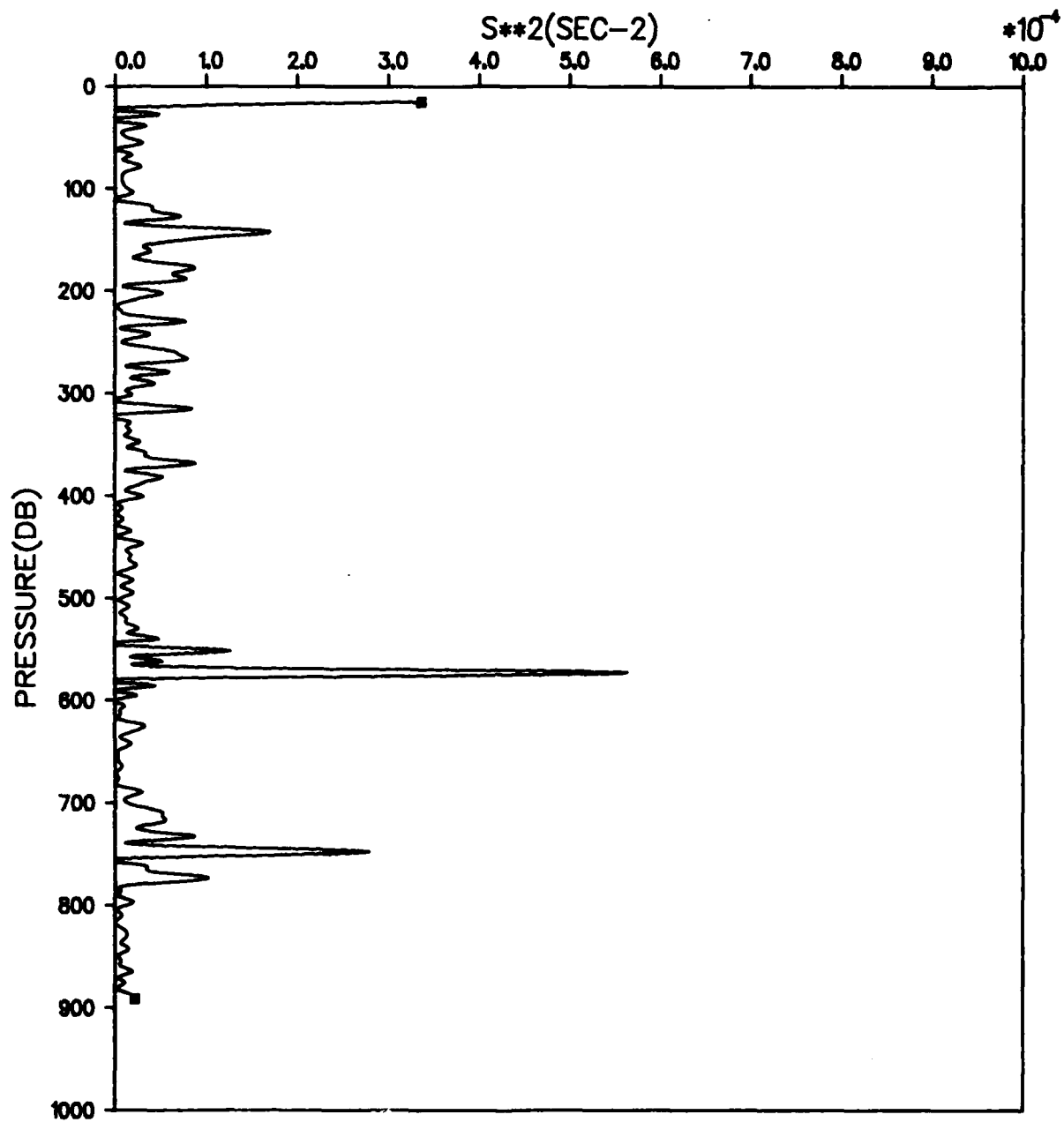


Figure D-17. File: KANE, Segment: C 525

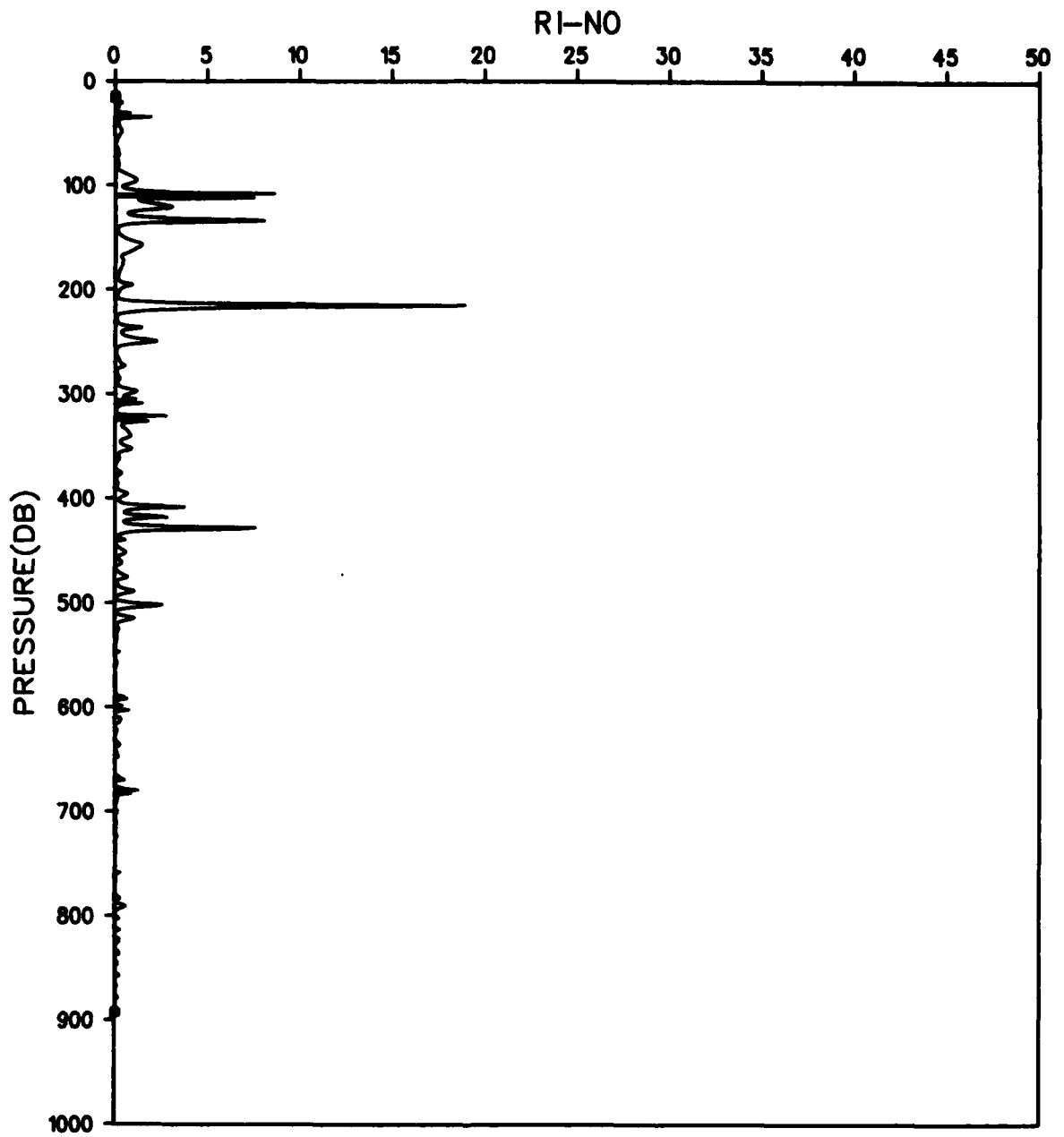


Figure D-18. File: KANE, Segment: C 525

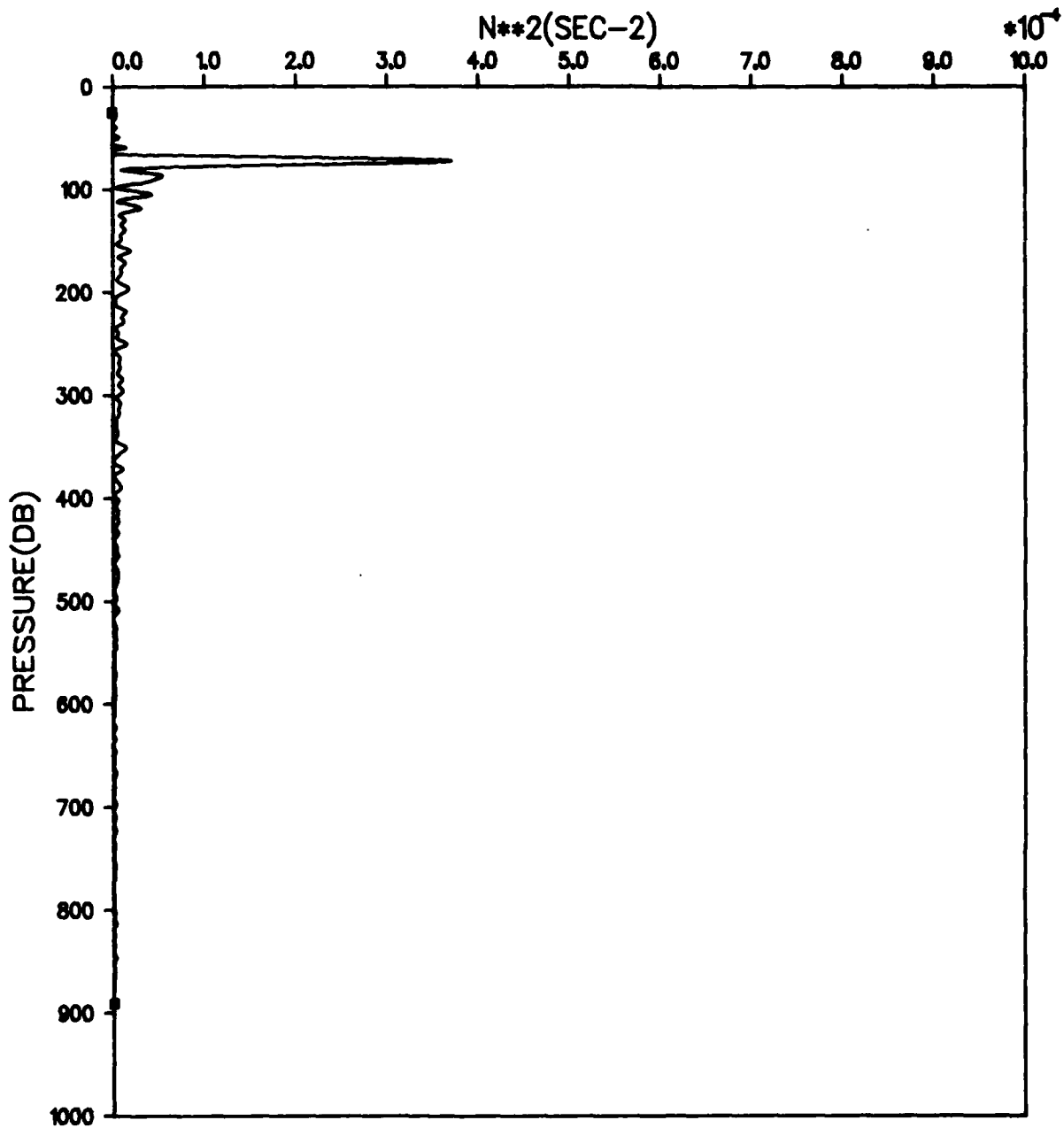


Figure D-19. File: KANE, Segment: C 534

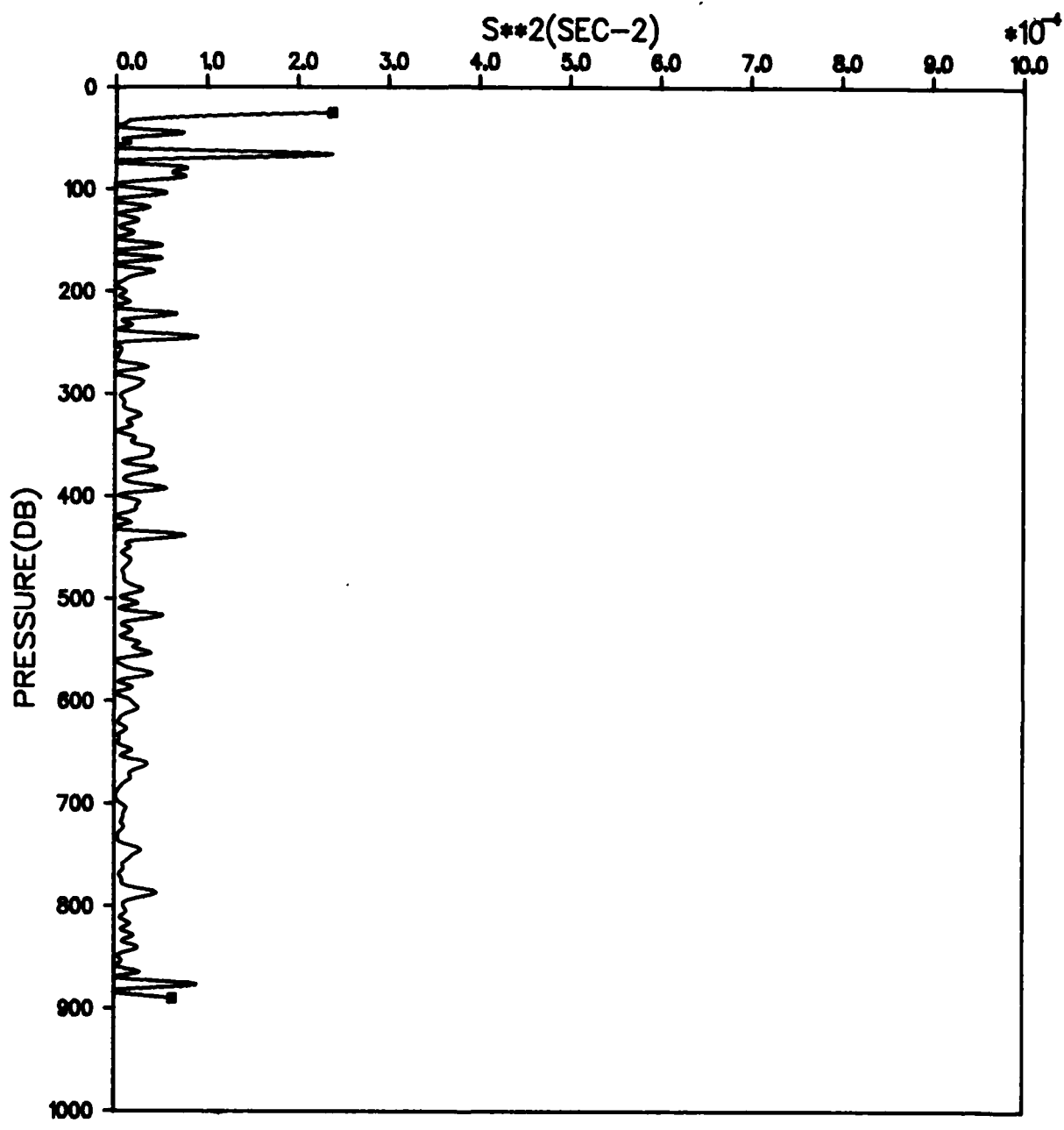


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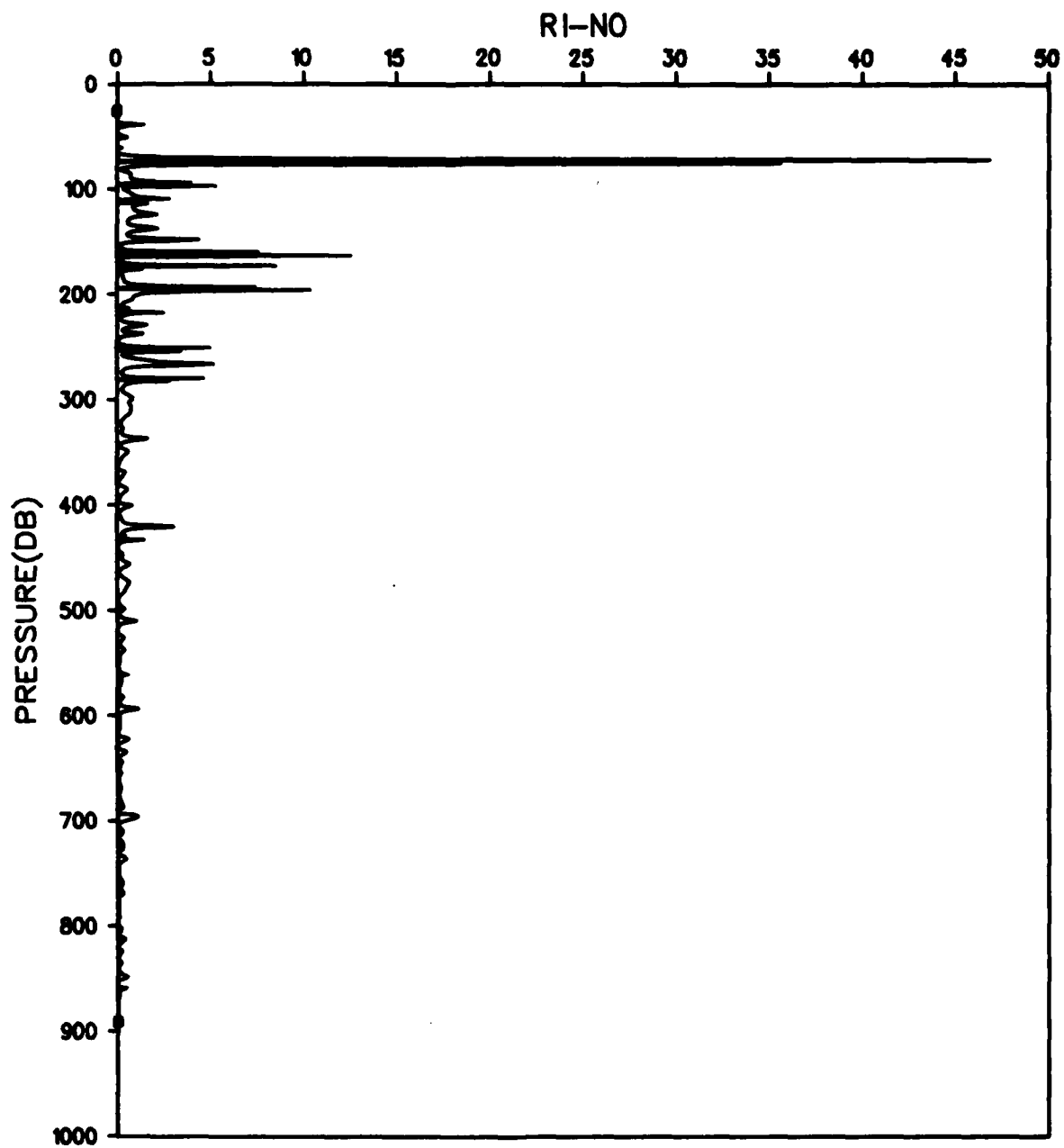


Figure D-21. File: KANE, Segment: C 534

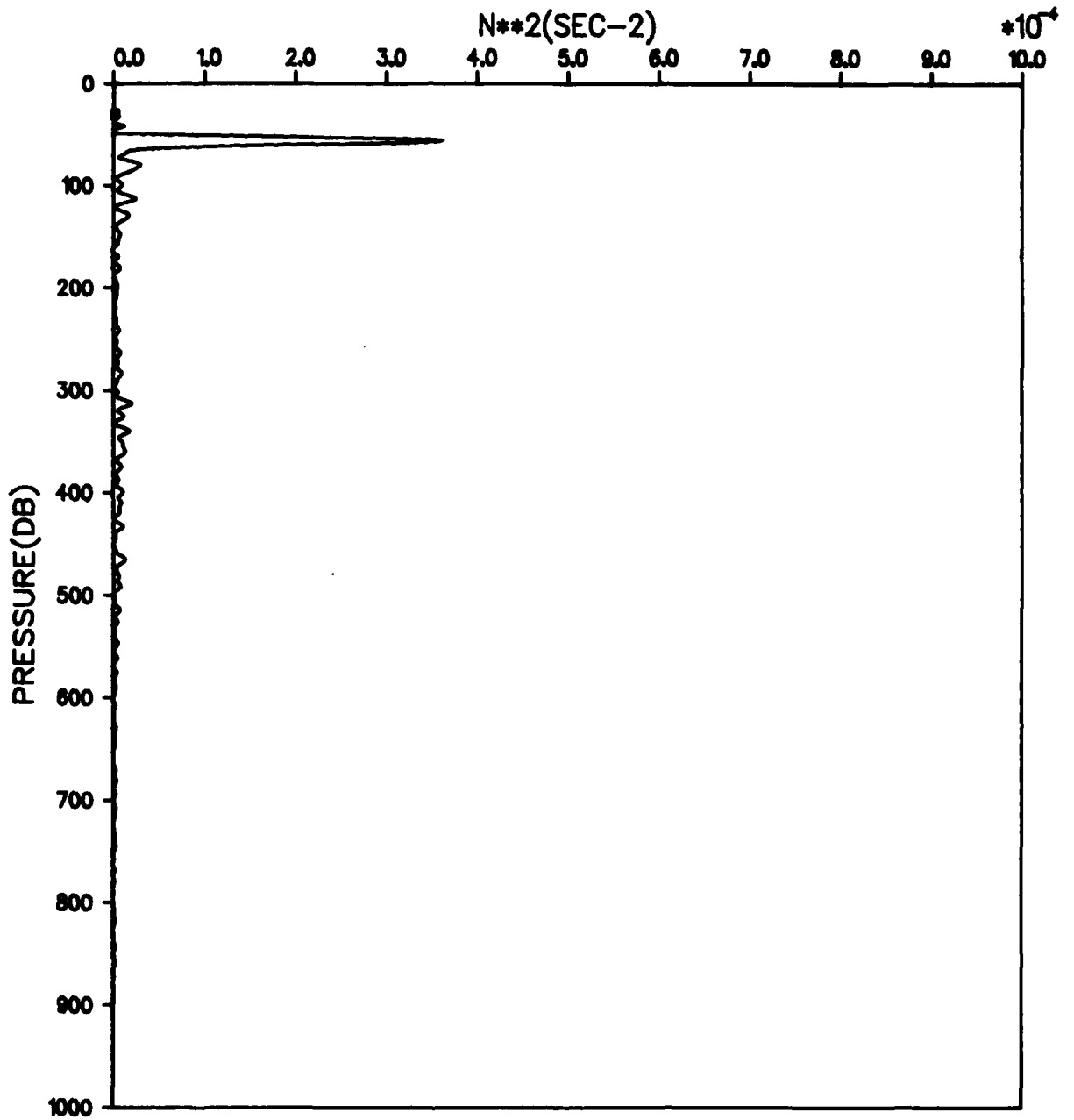


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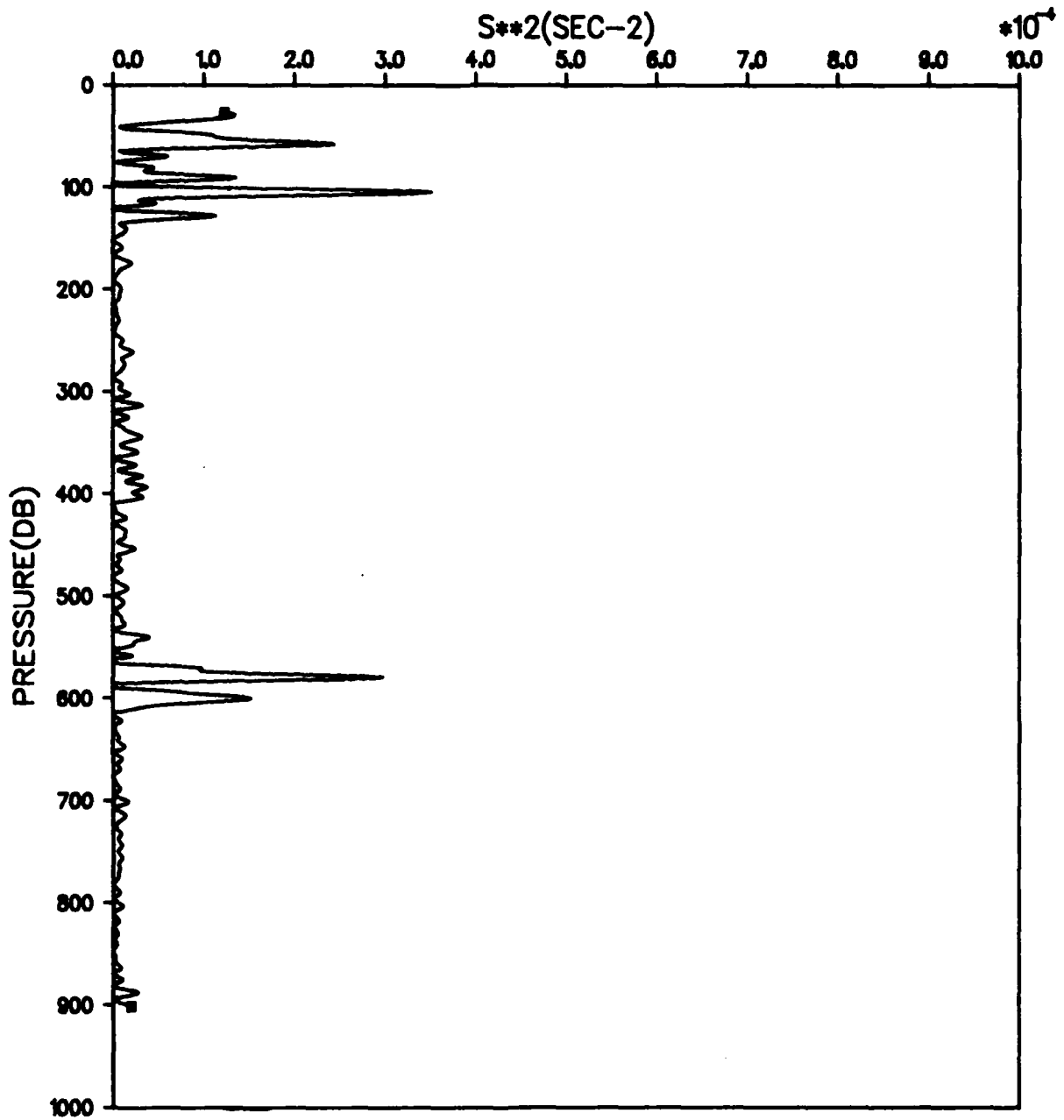


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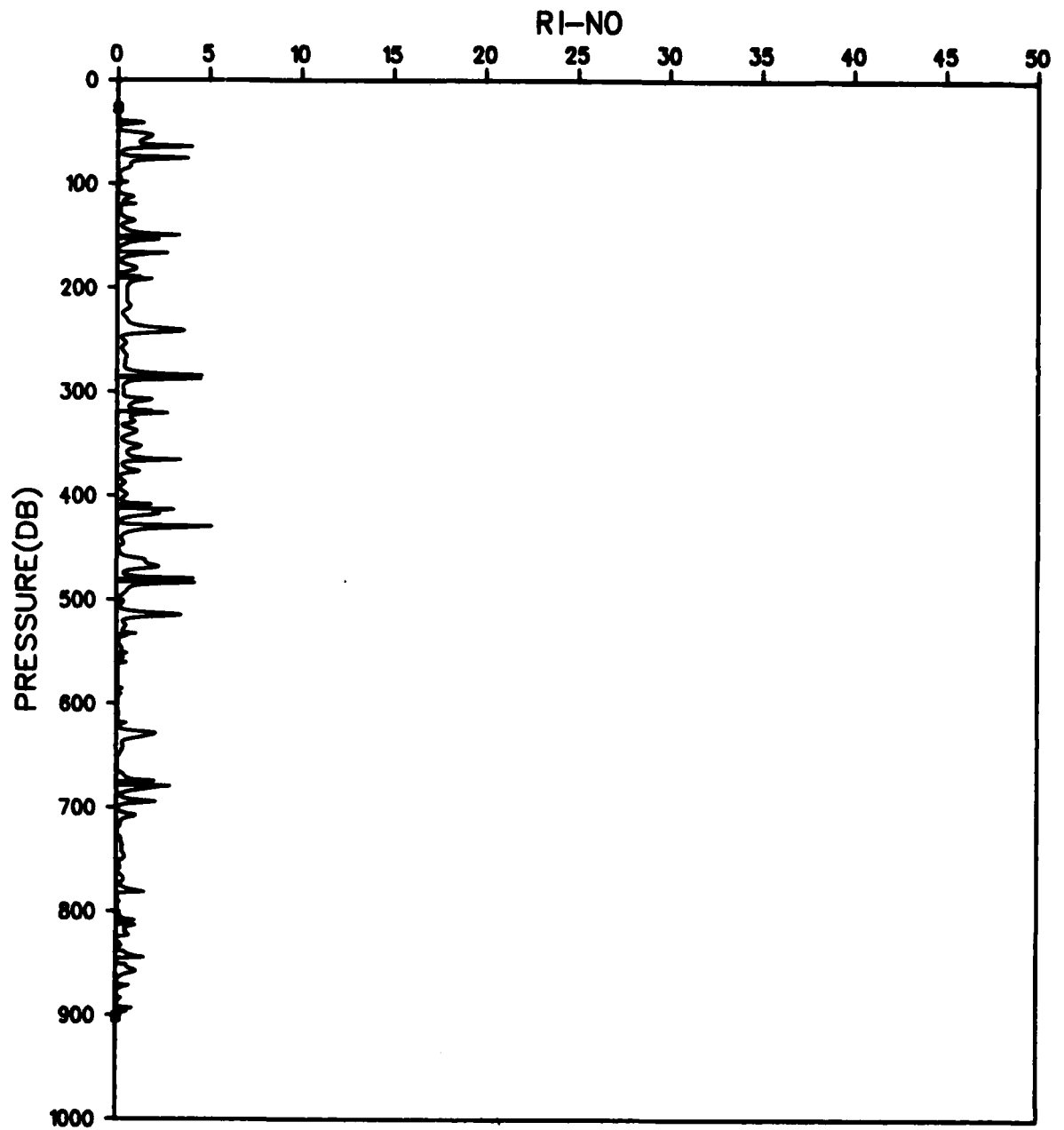


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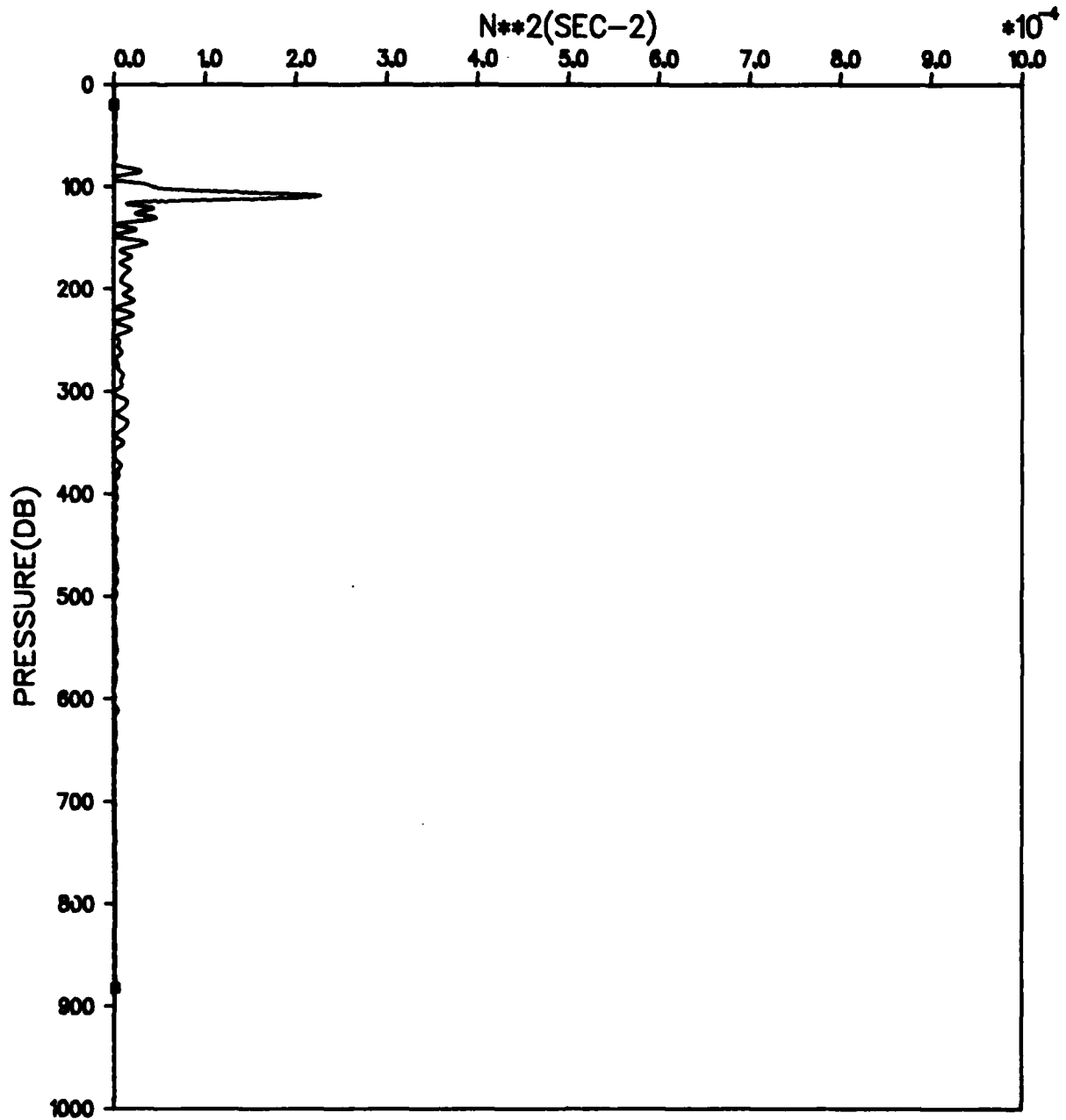


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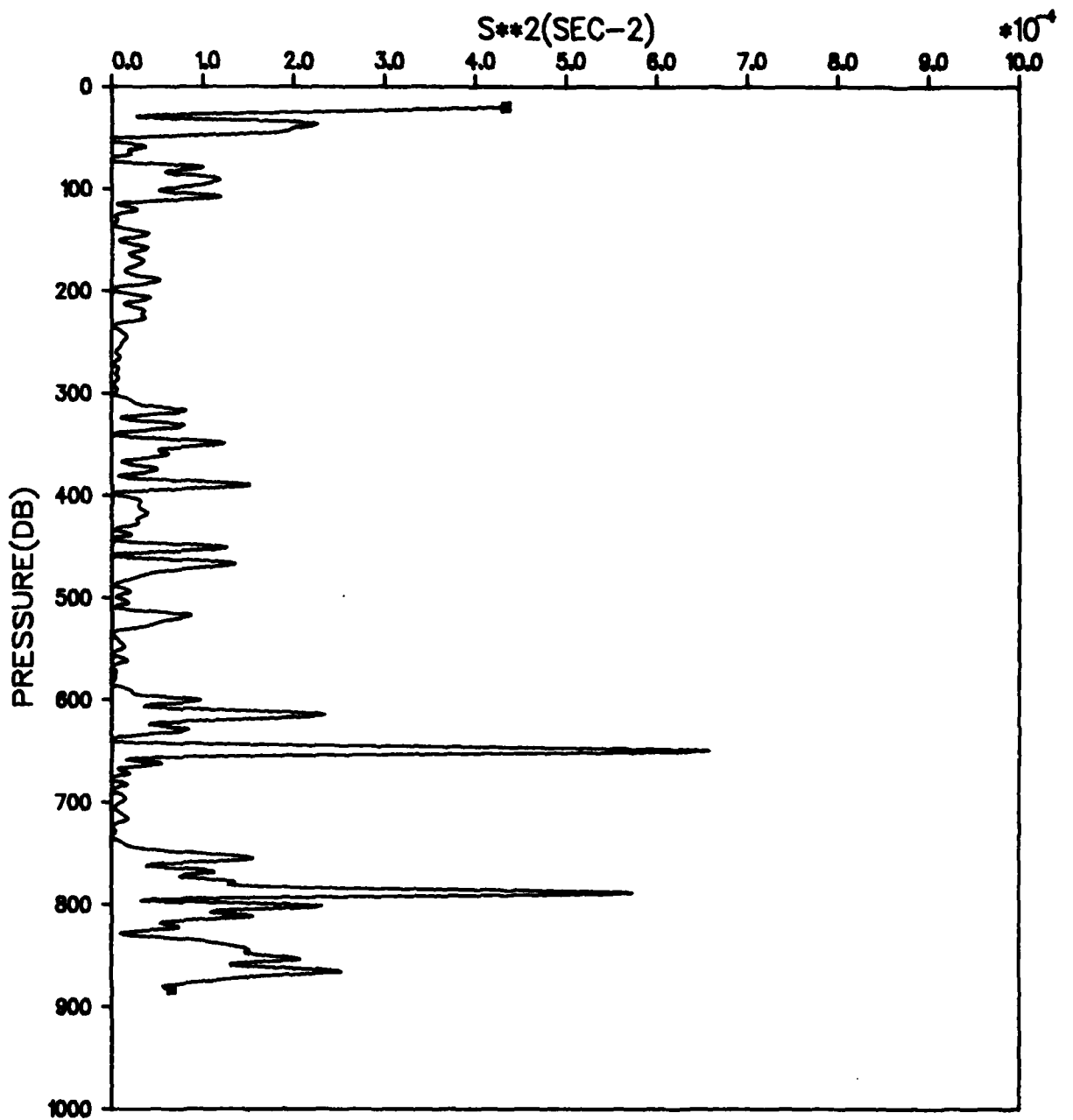


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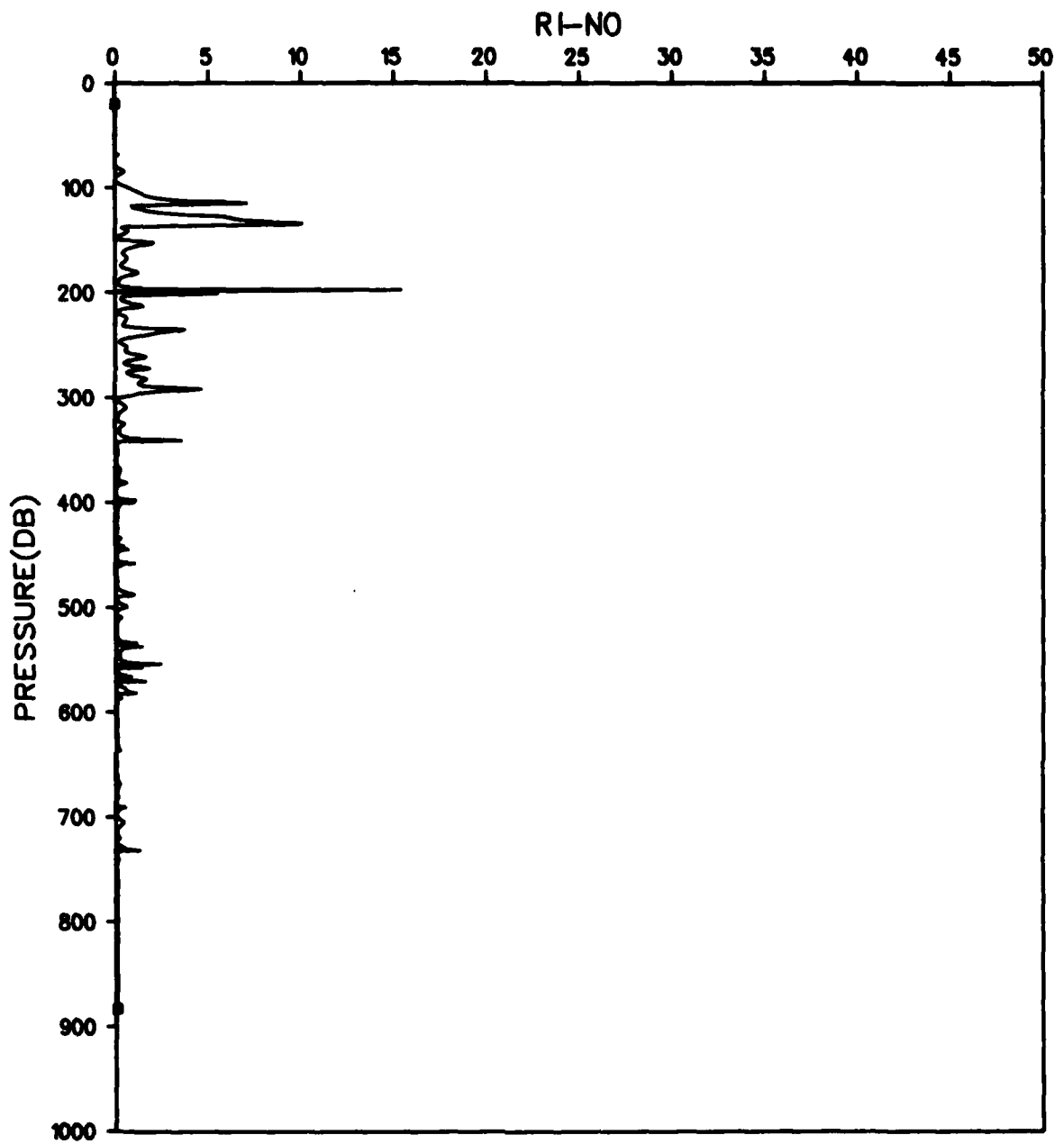


Figure D-27. File: KANE, Segment: C 538

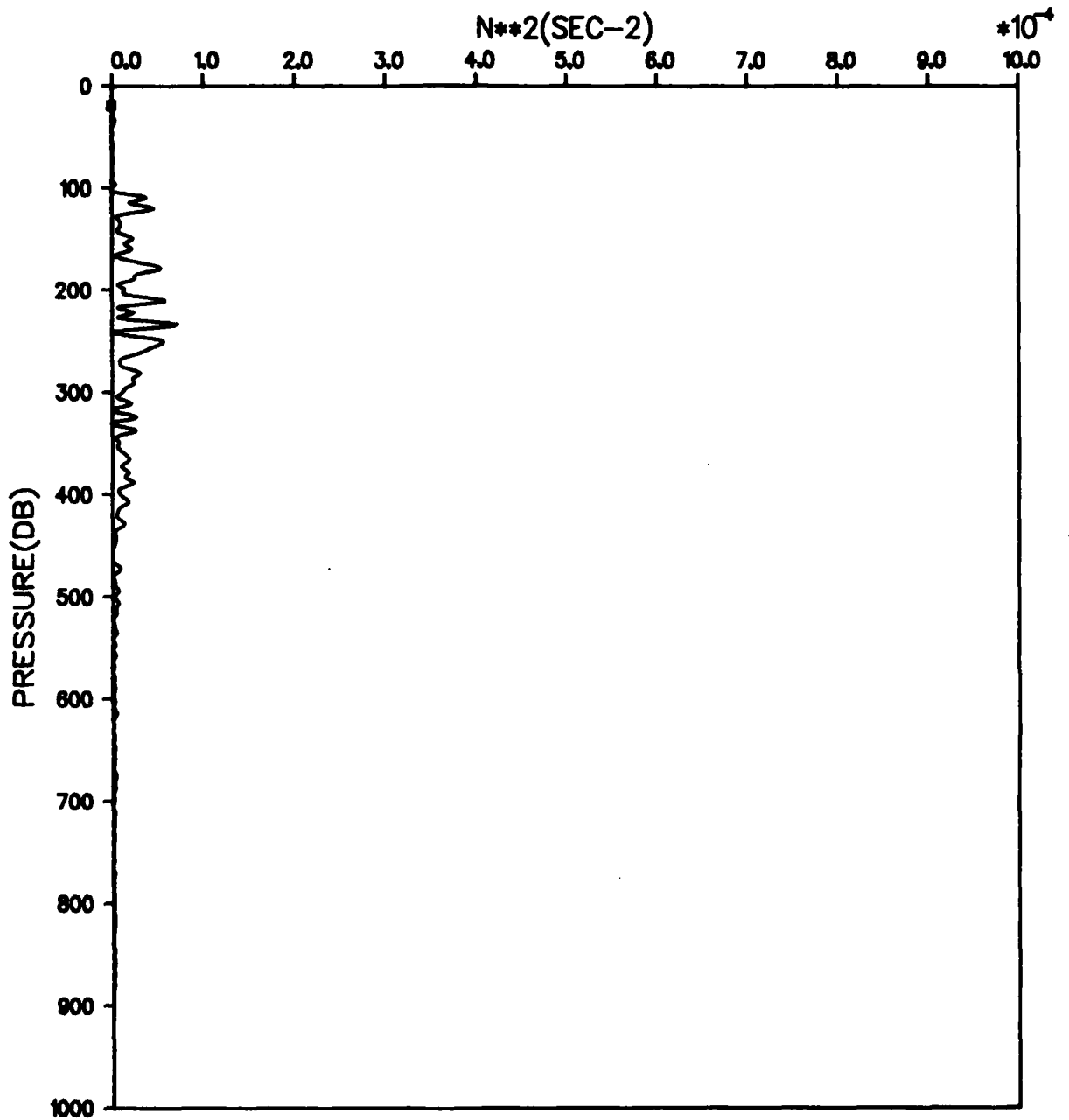


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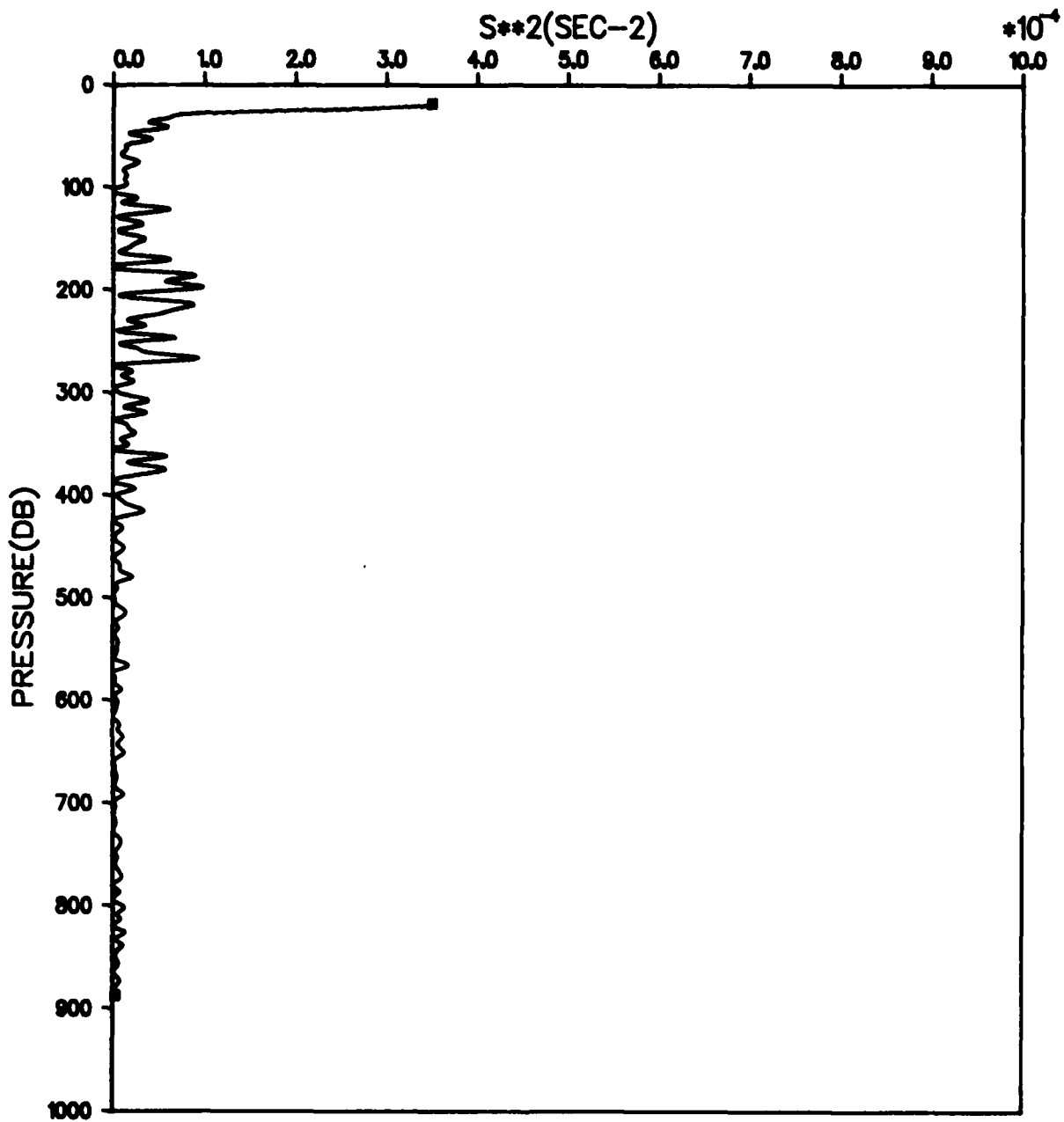


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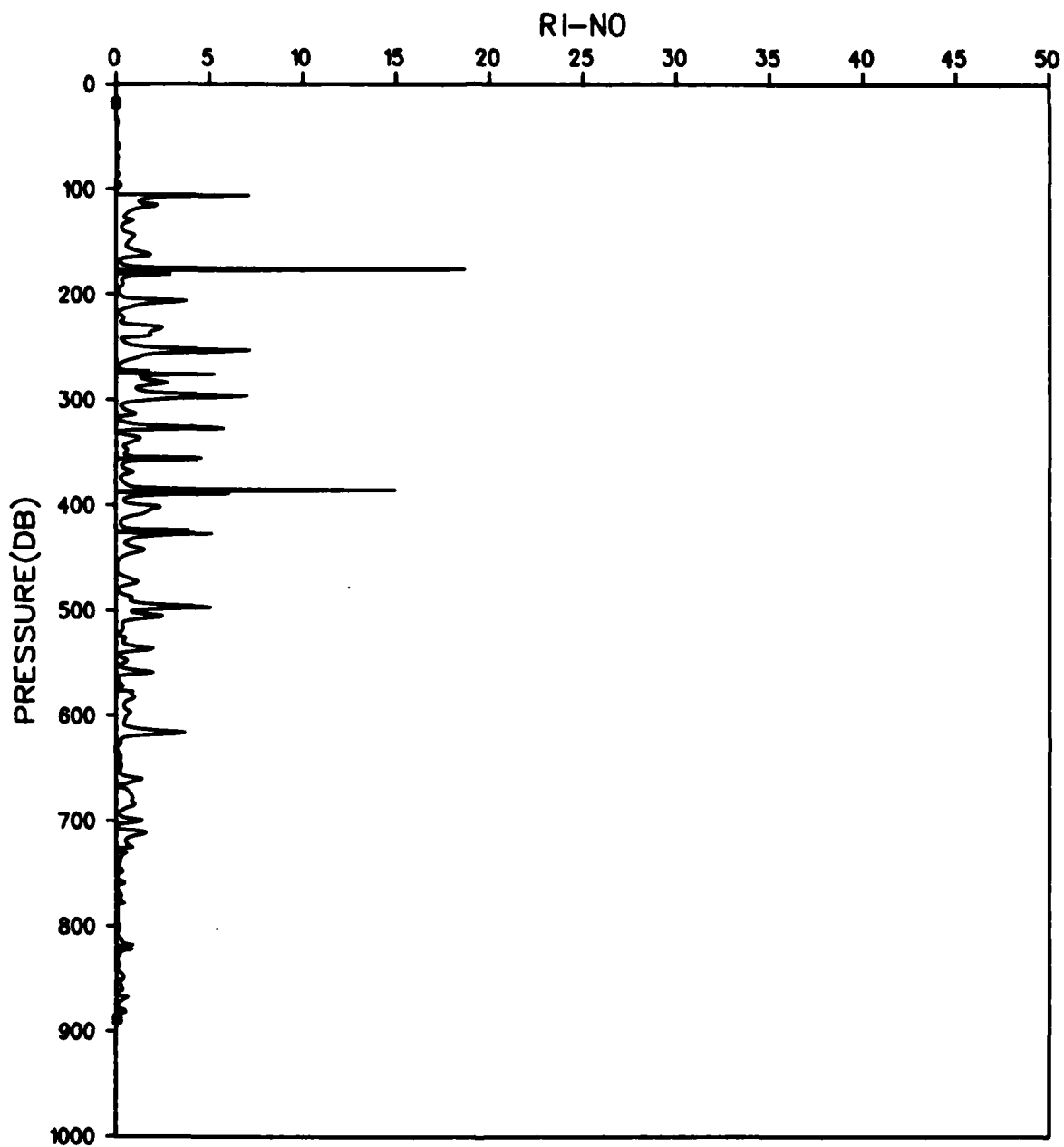


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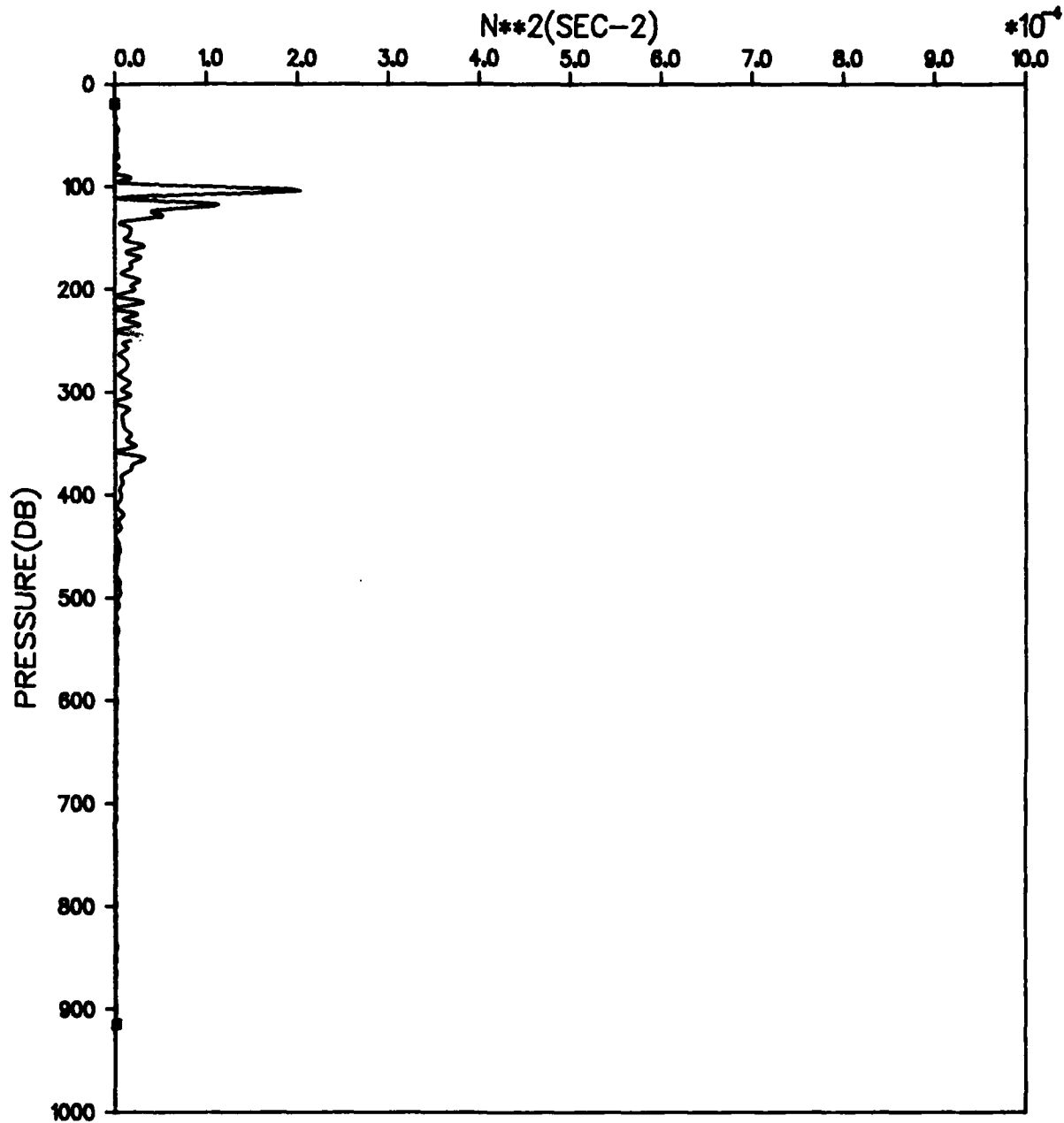


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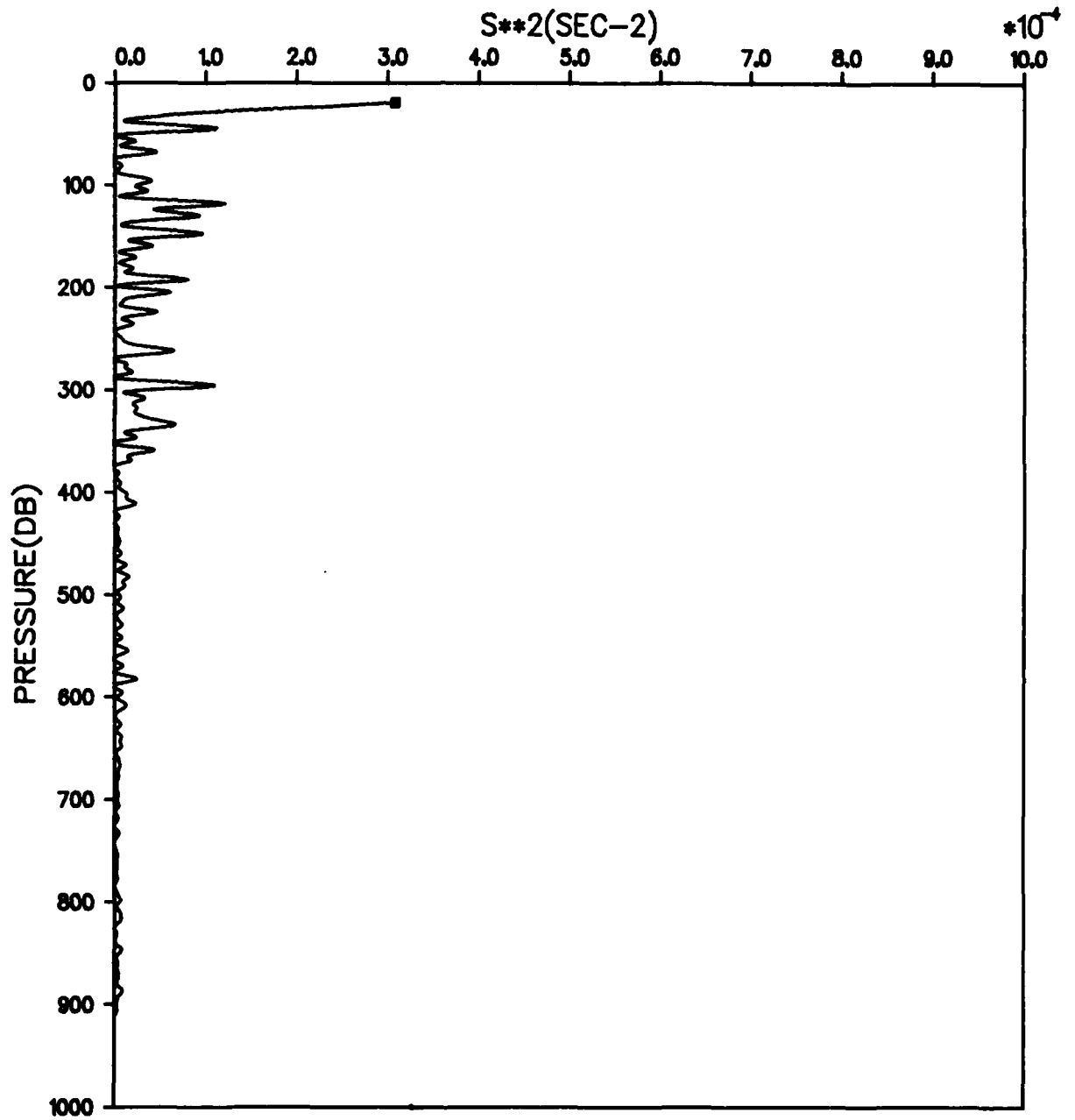


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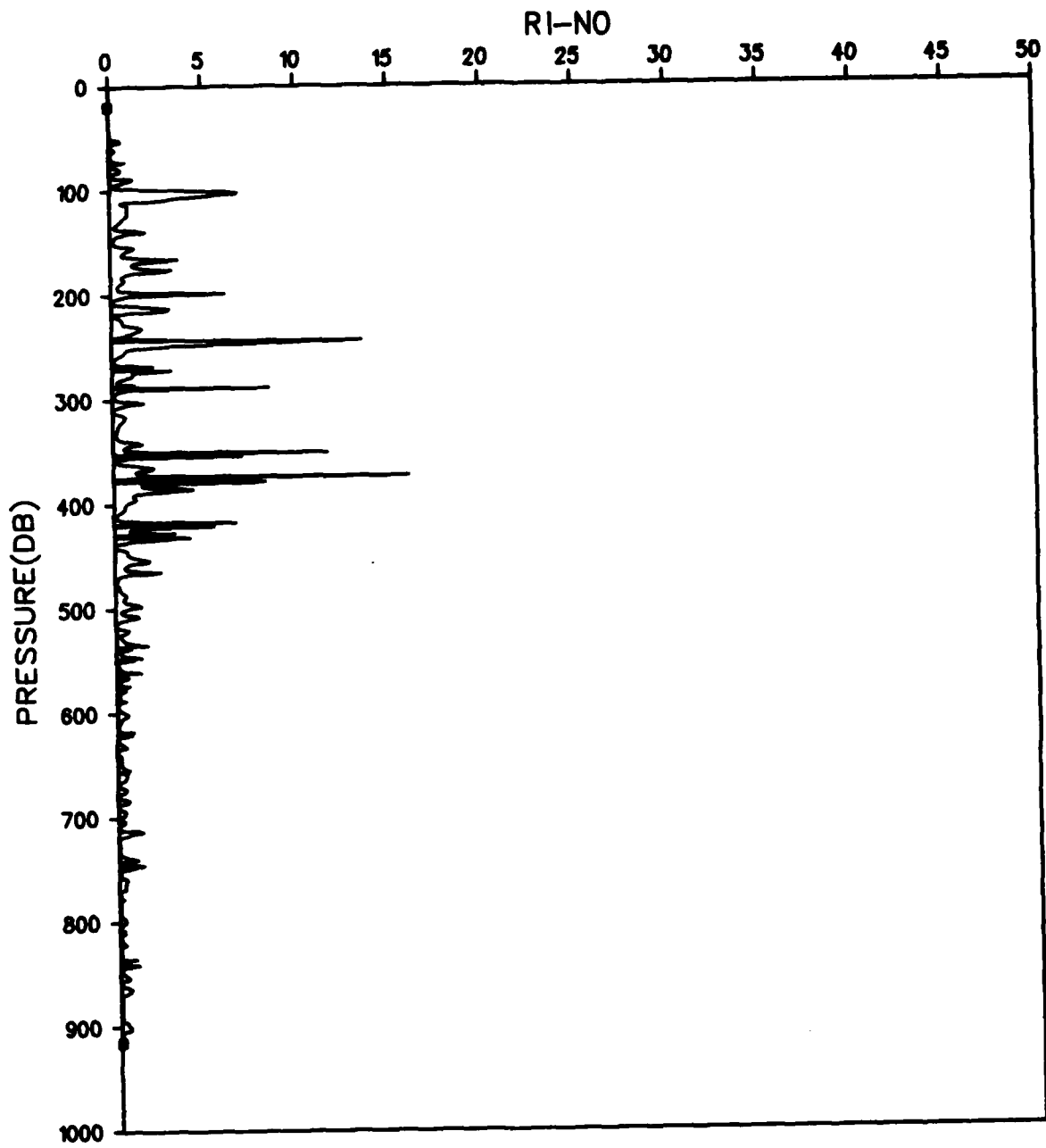


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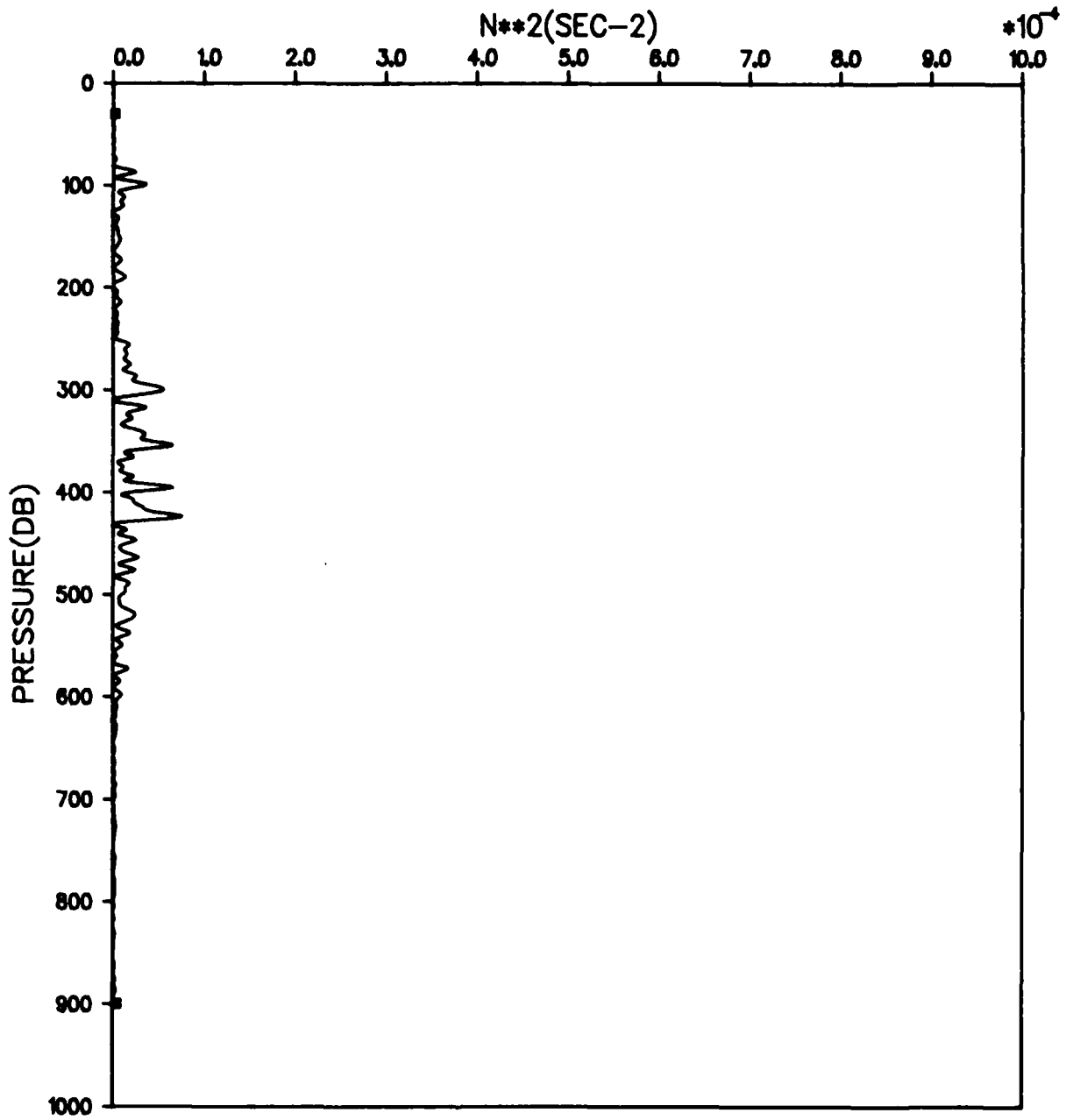


Figure D-34. File: KANE, Segment: C 548

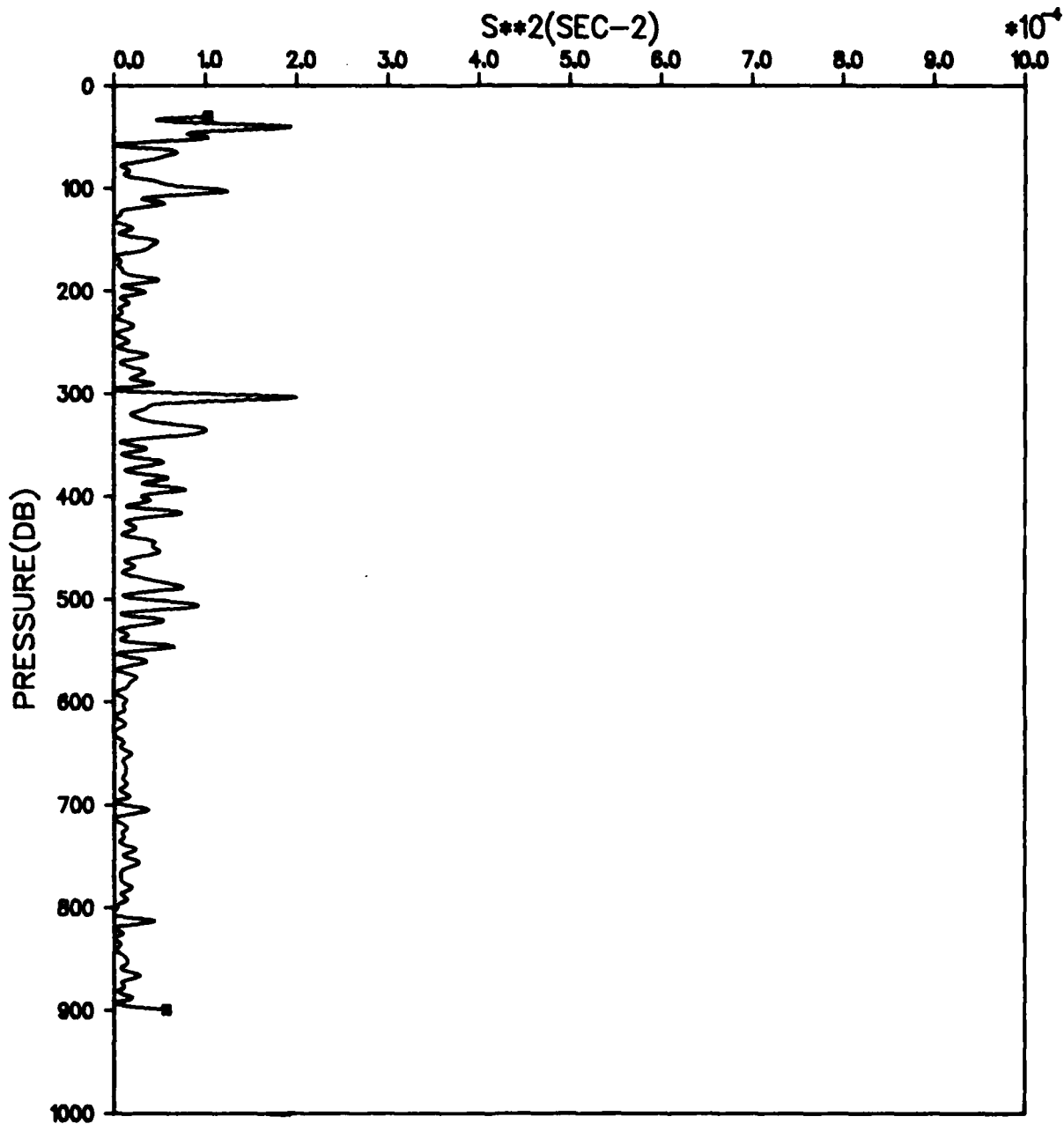


Figure D-35. File: KANE, Segment: C 548

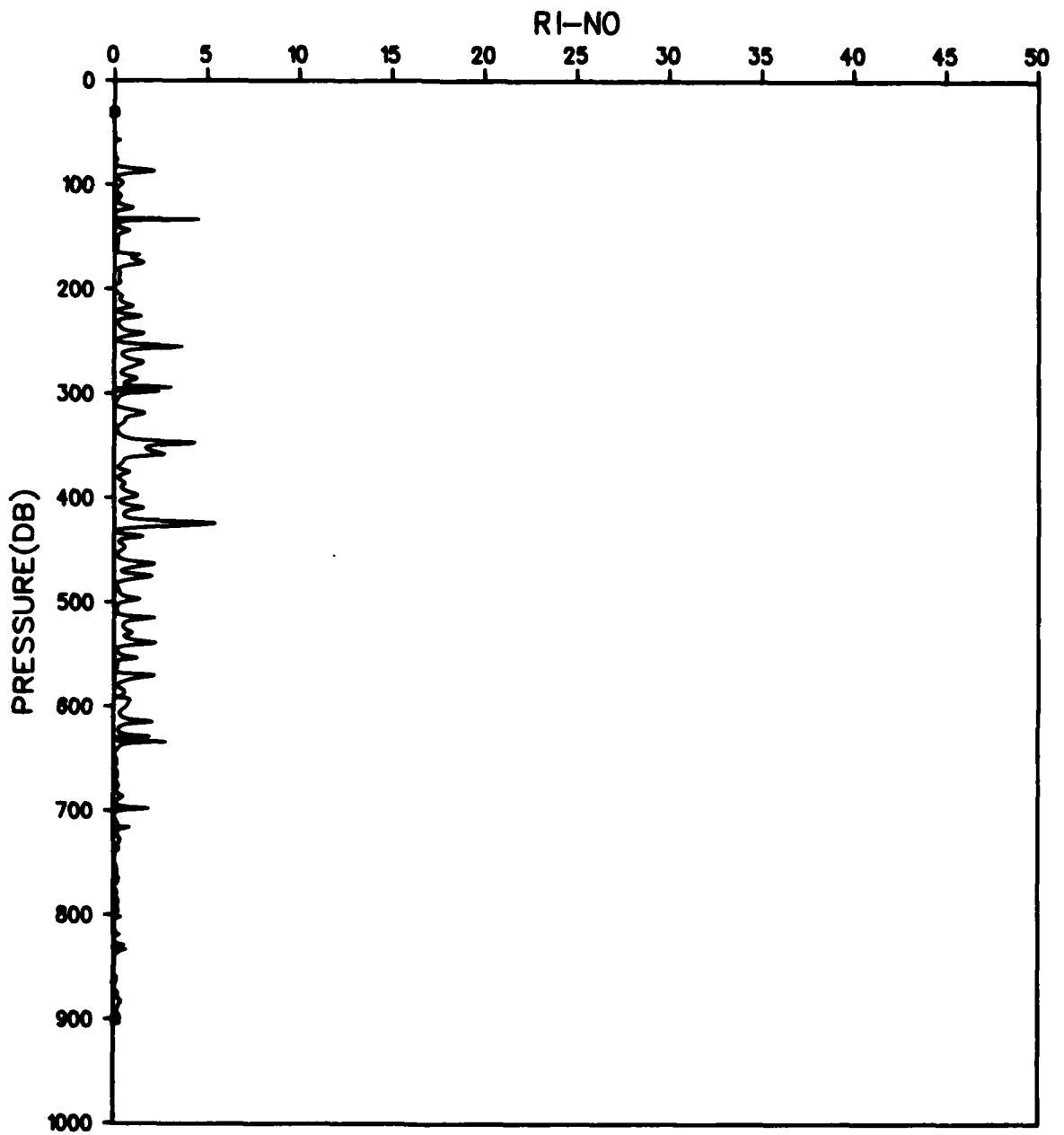


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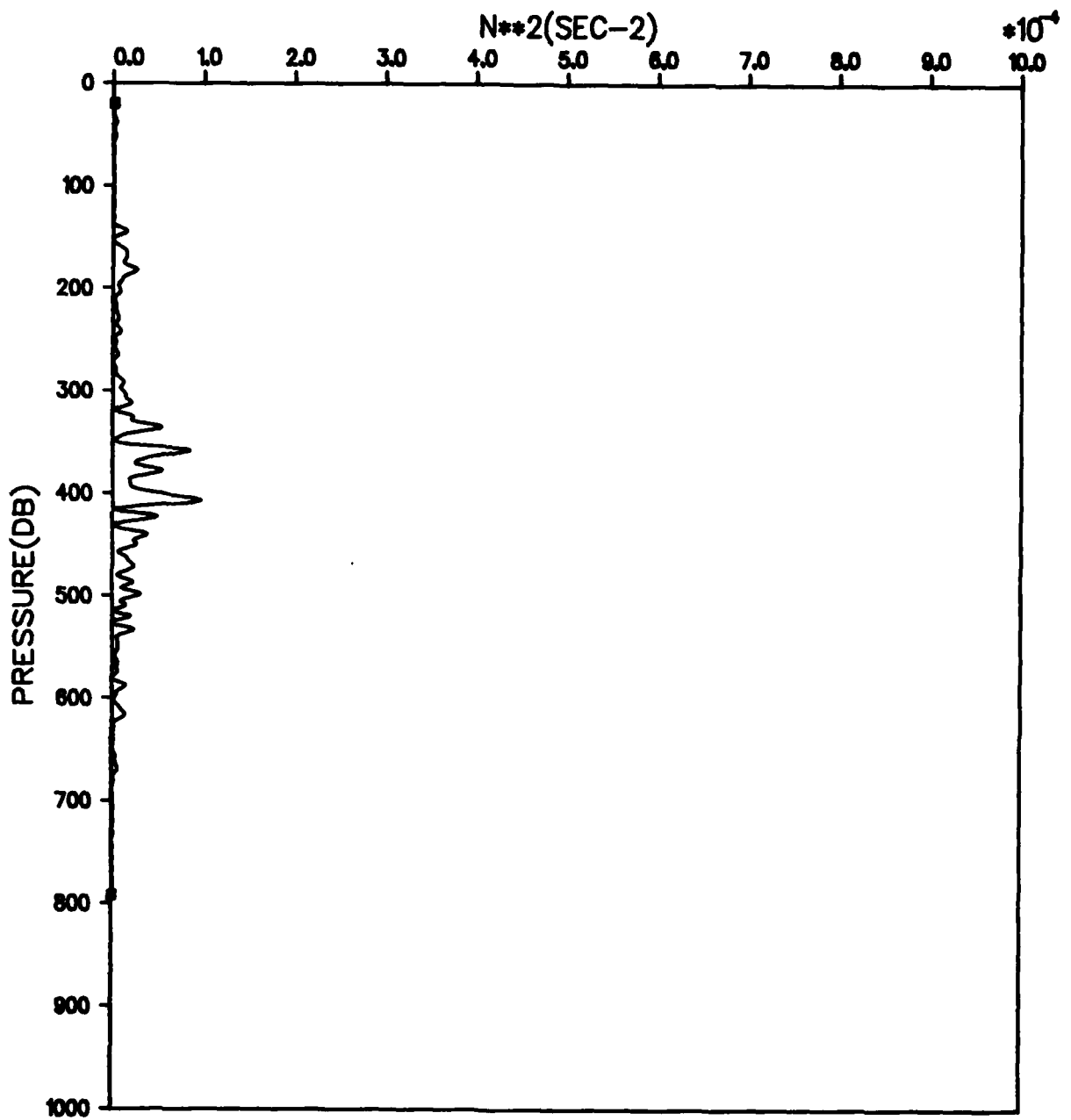


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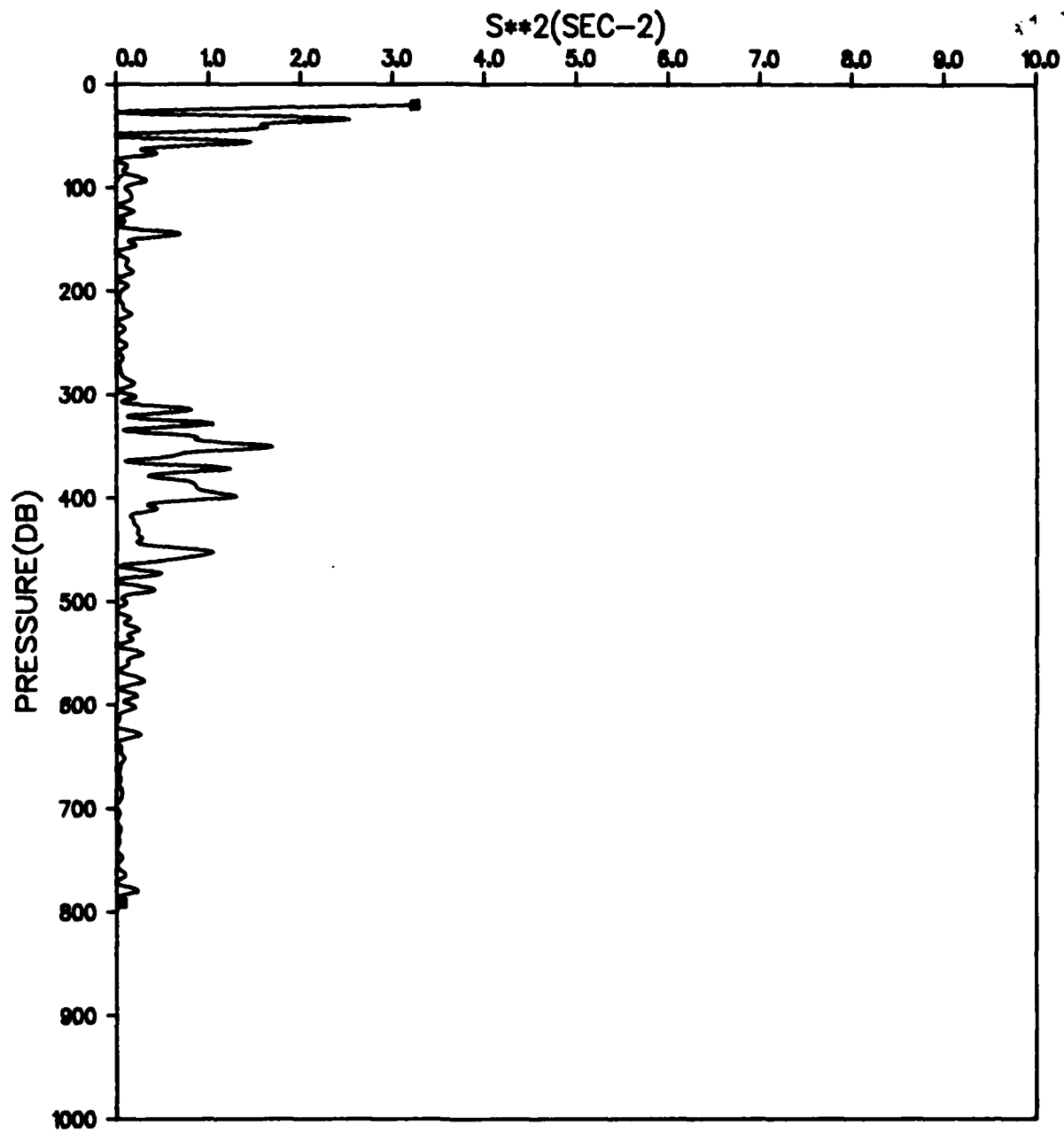


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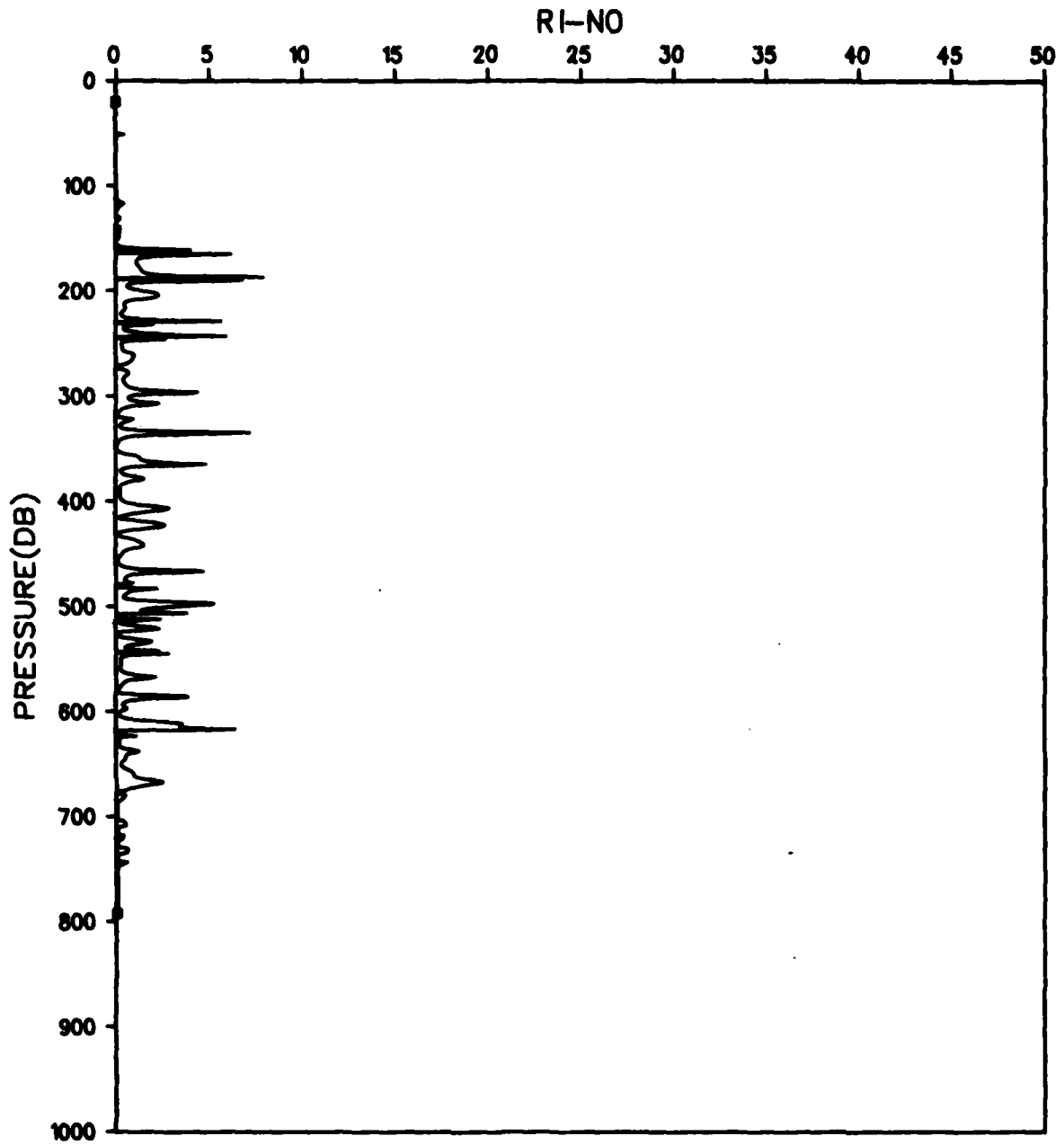


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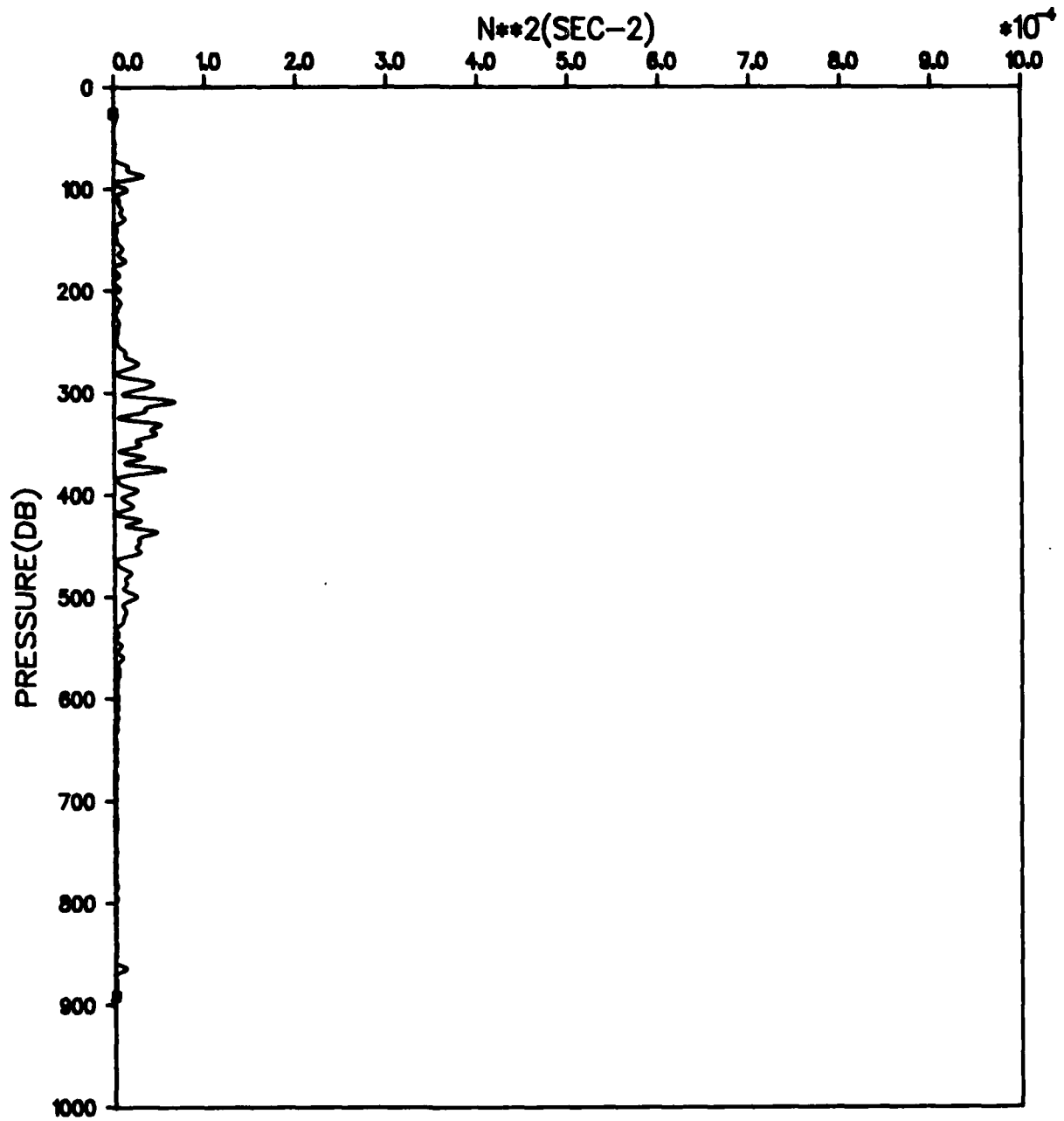


Figure D-40. File: KANE, Segment: C 550

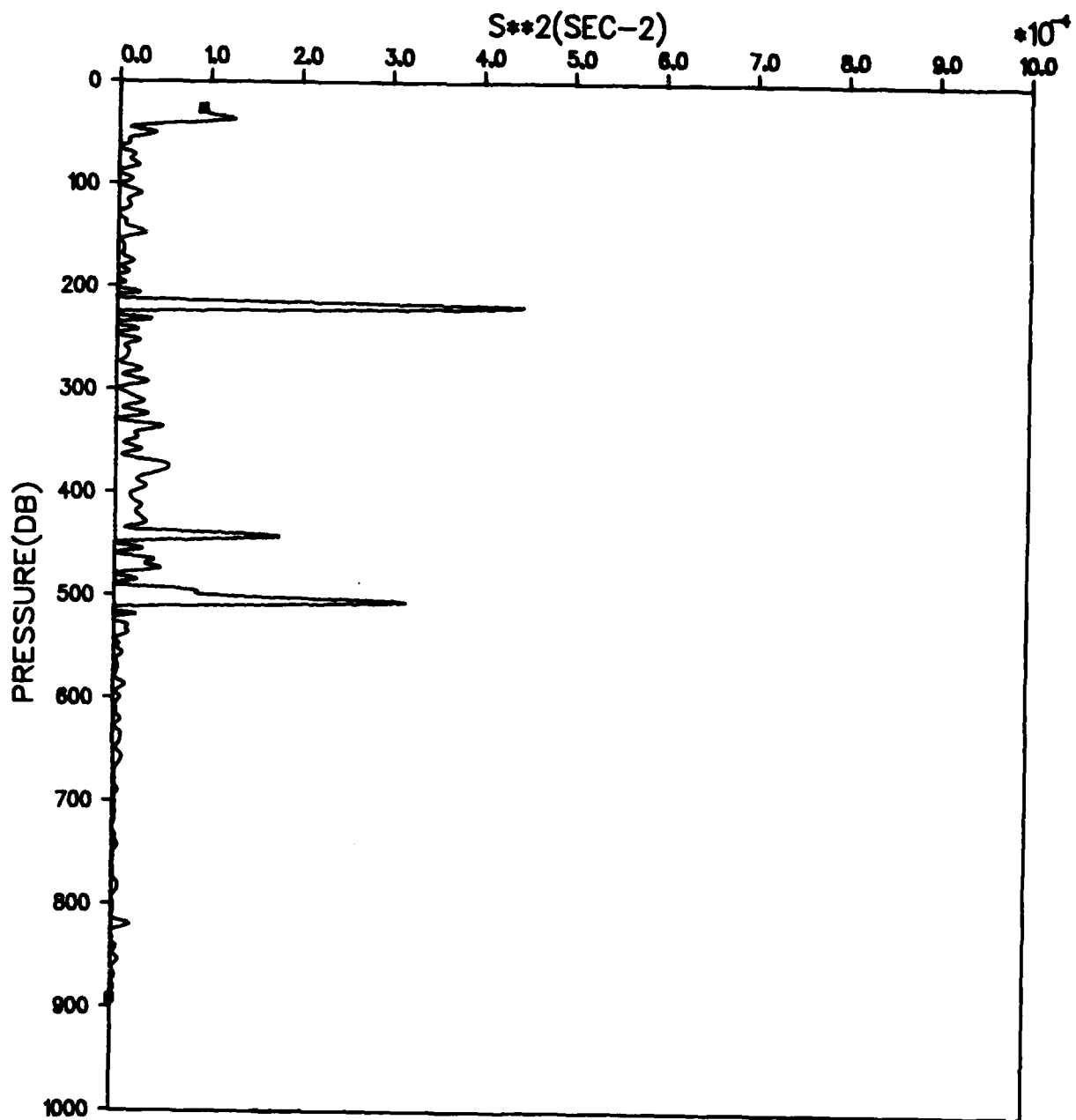


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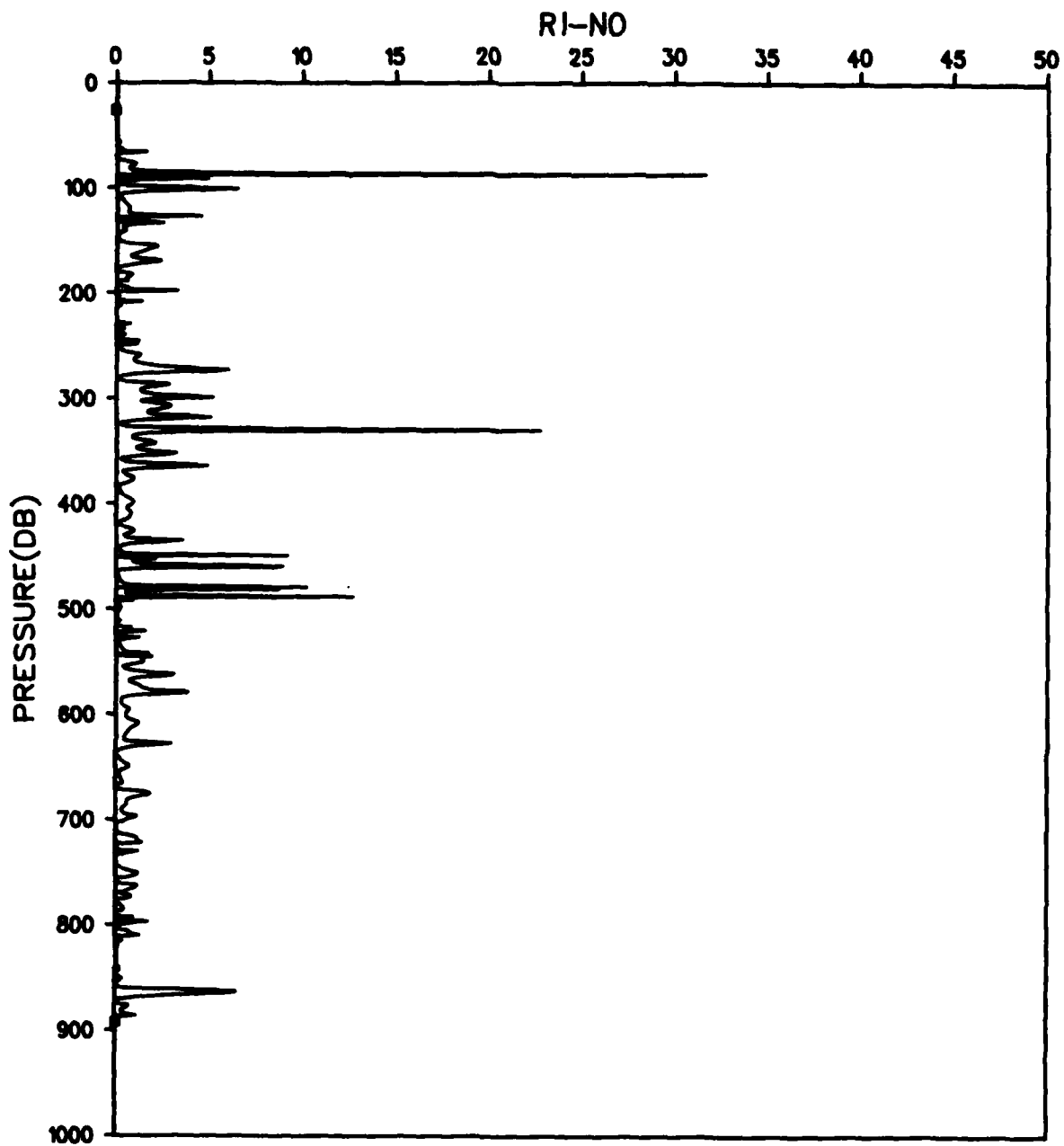


Figure D-42. File: KANE, Segment: C 550

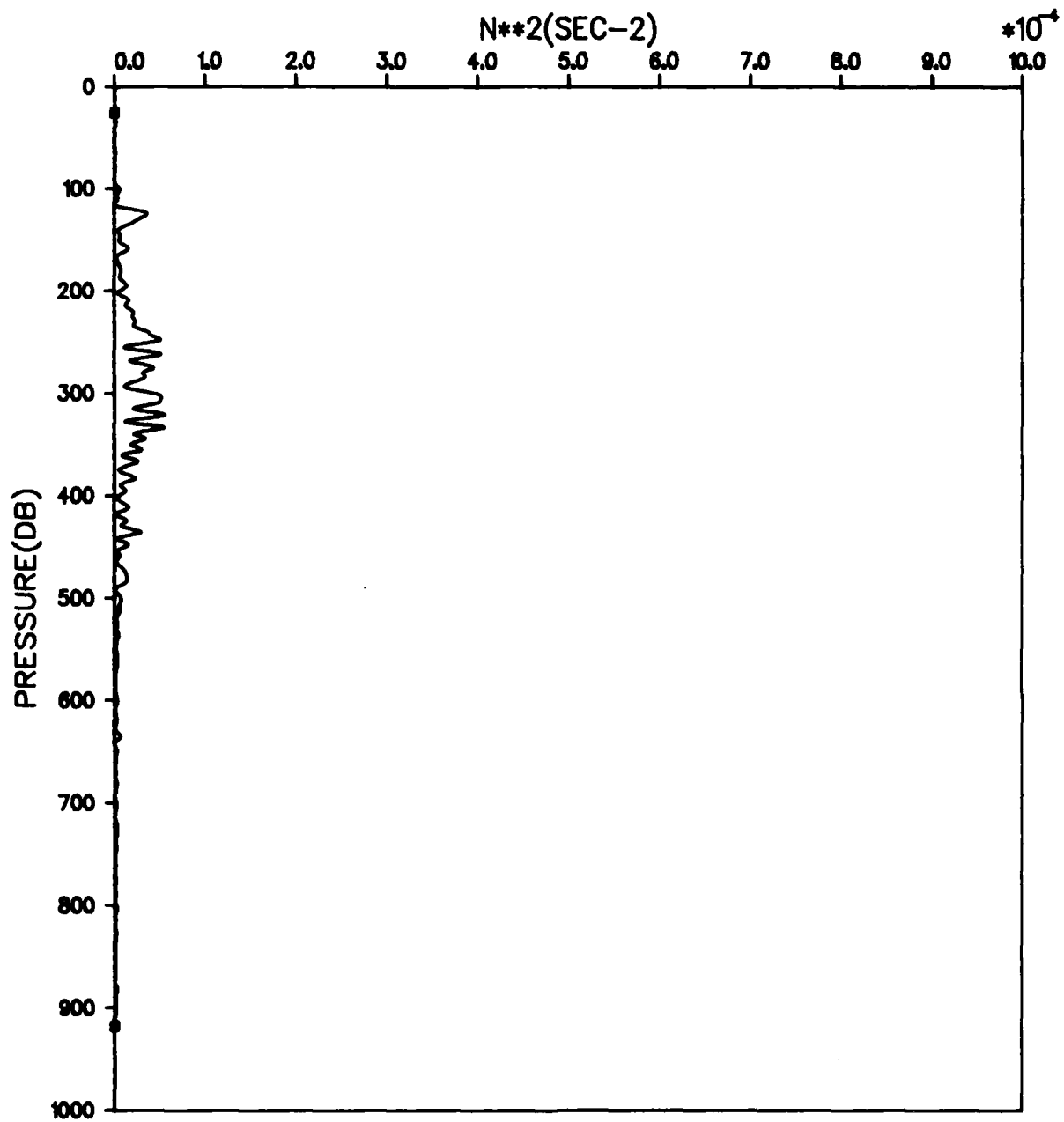


Figure D-43. File: KANE, Segment: C 551

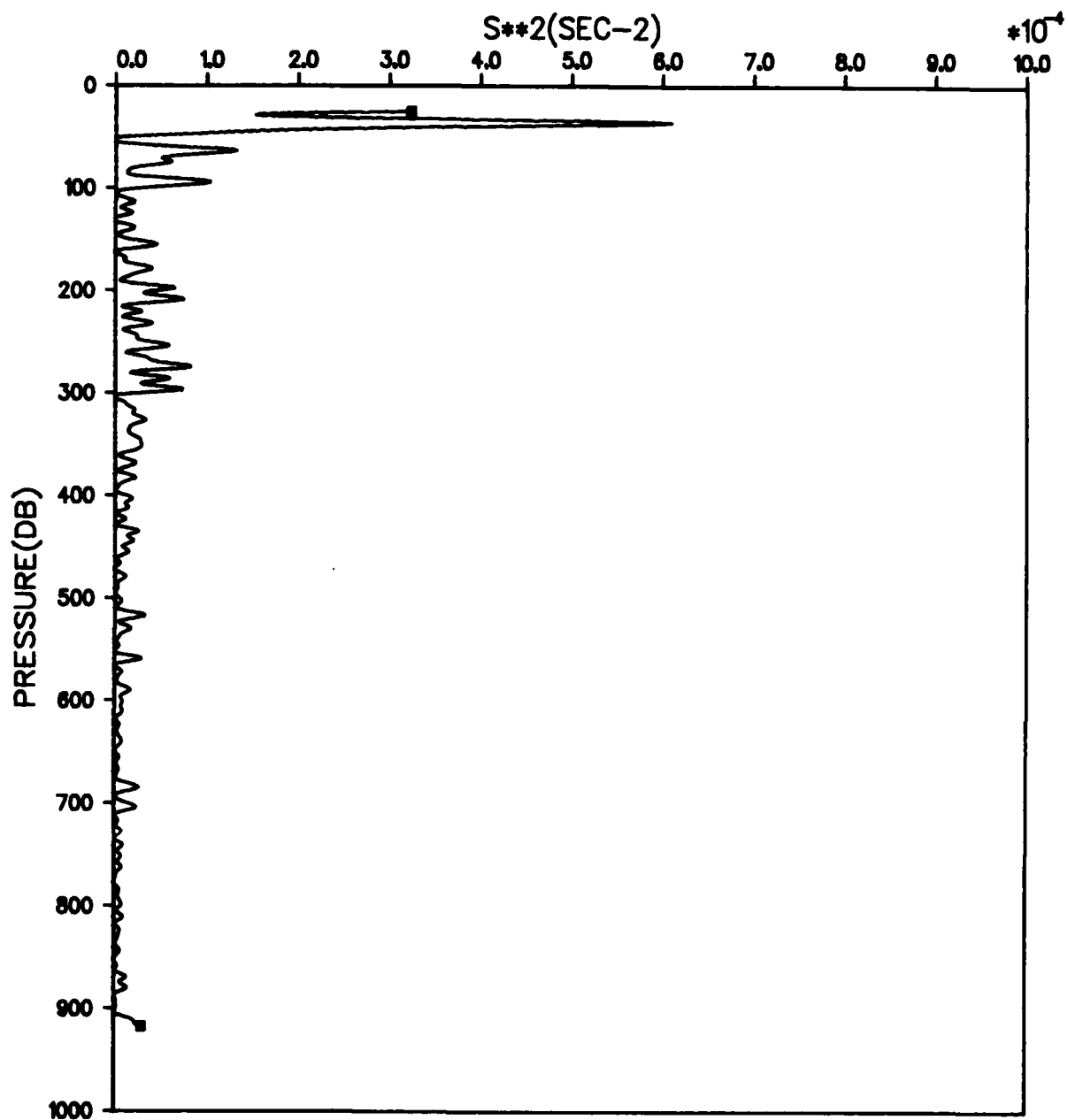


Figure D-44. File: KANE, Segment: C 551

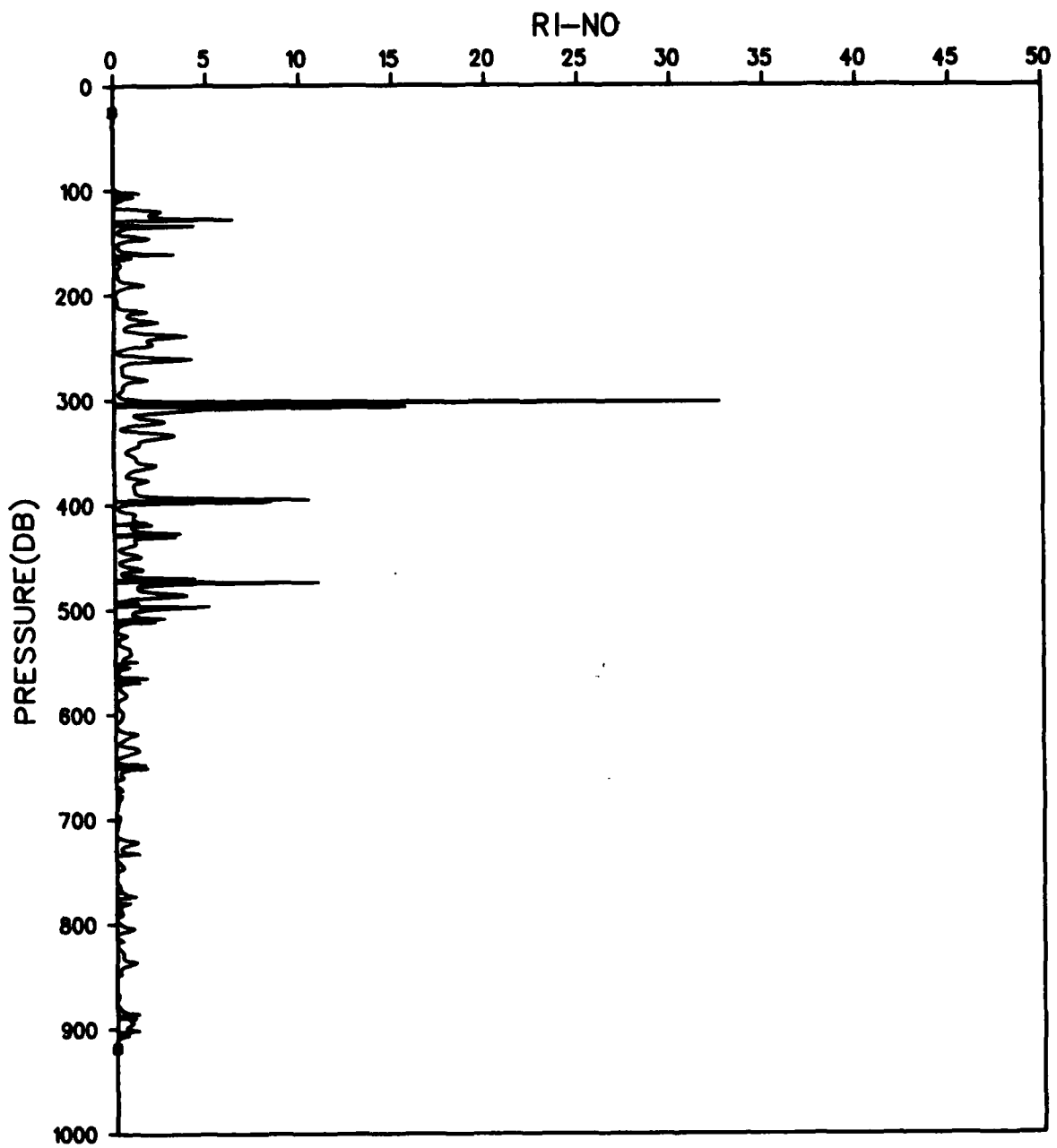


Figure D-45. File: KANE, Segment: C 551

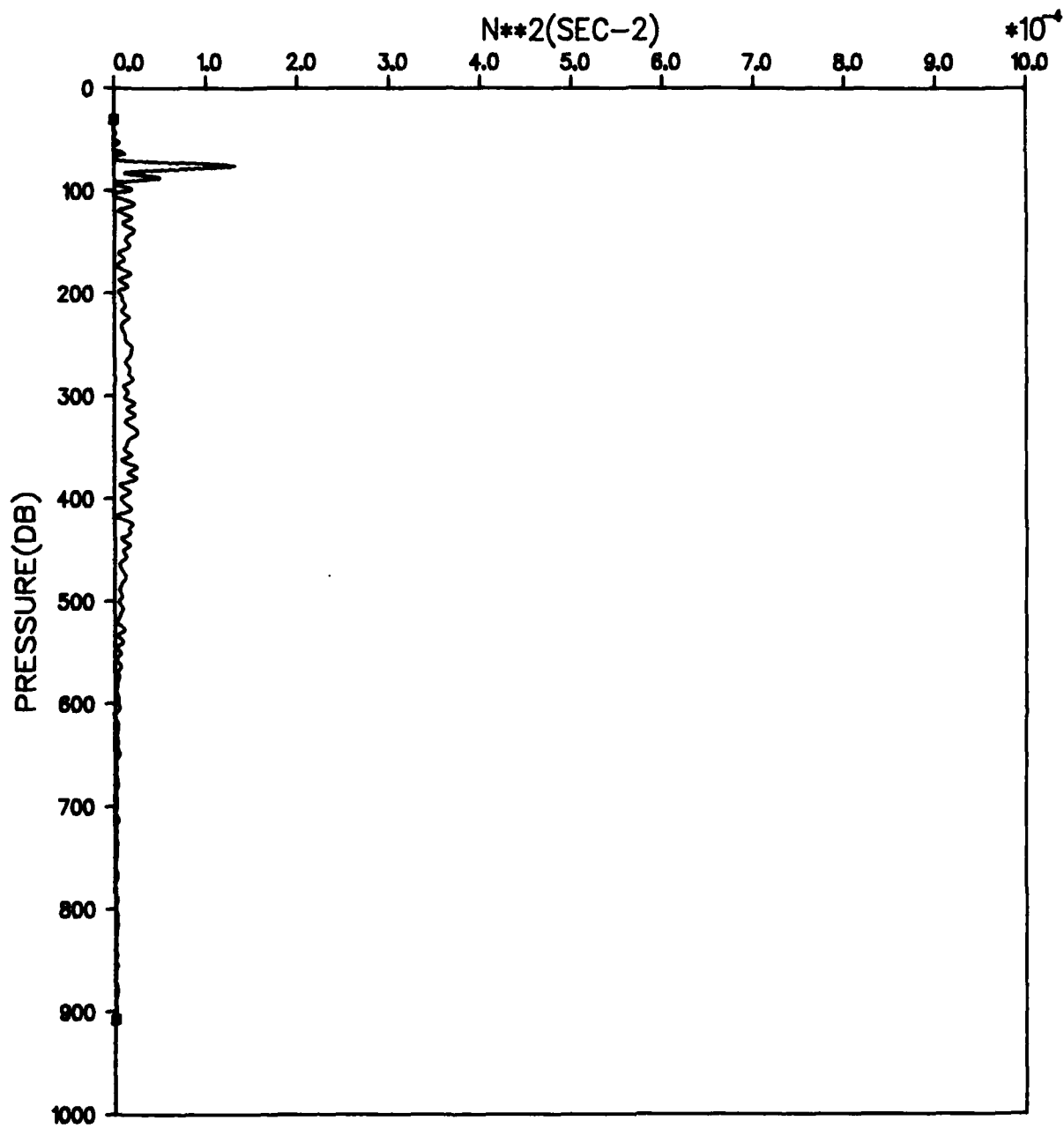


Figure D-46. File: KANE, Segment: C 563

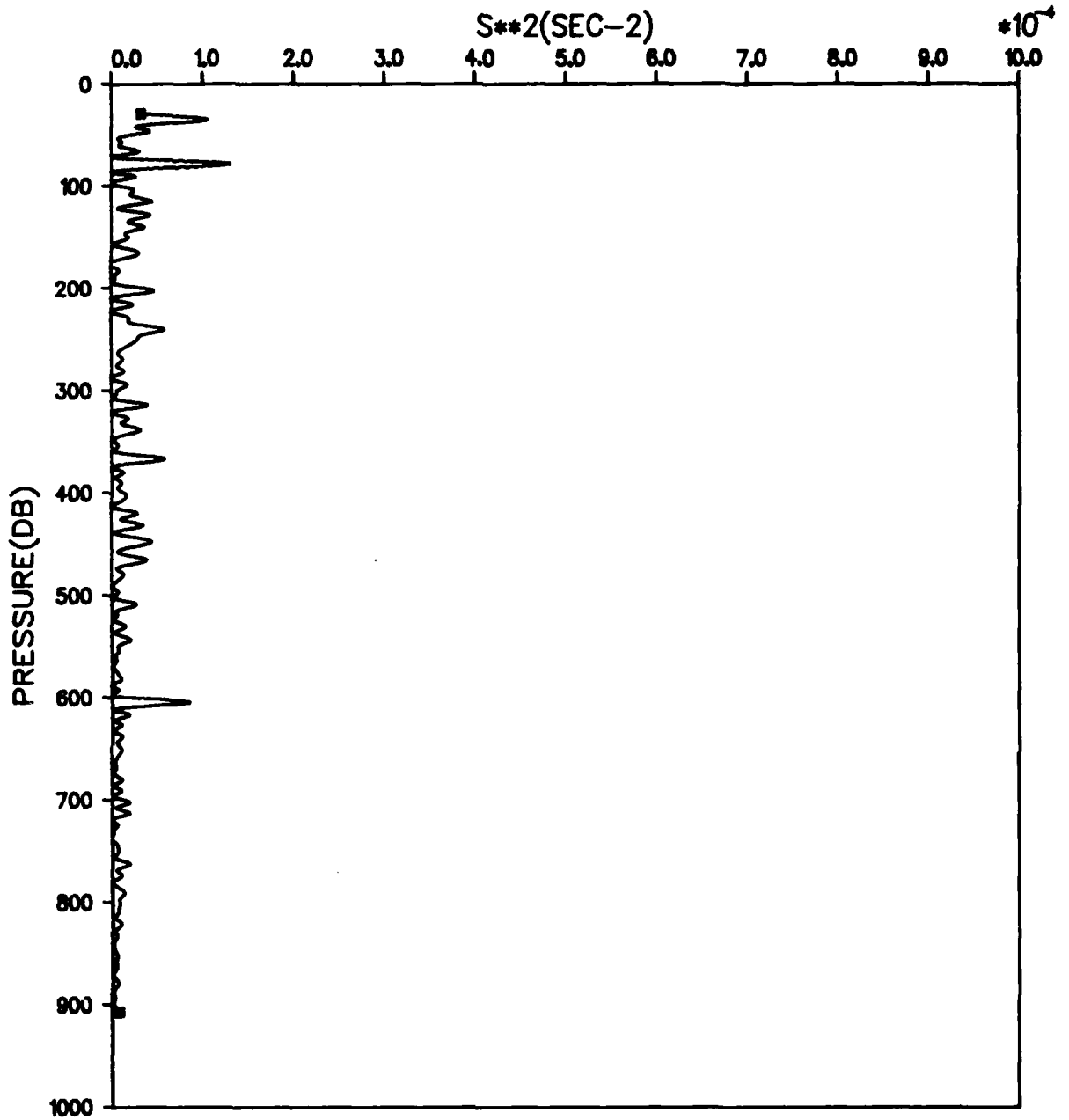


Figure D-47. File: KANE, Segment: C 563

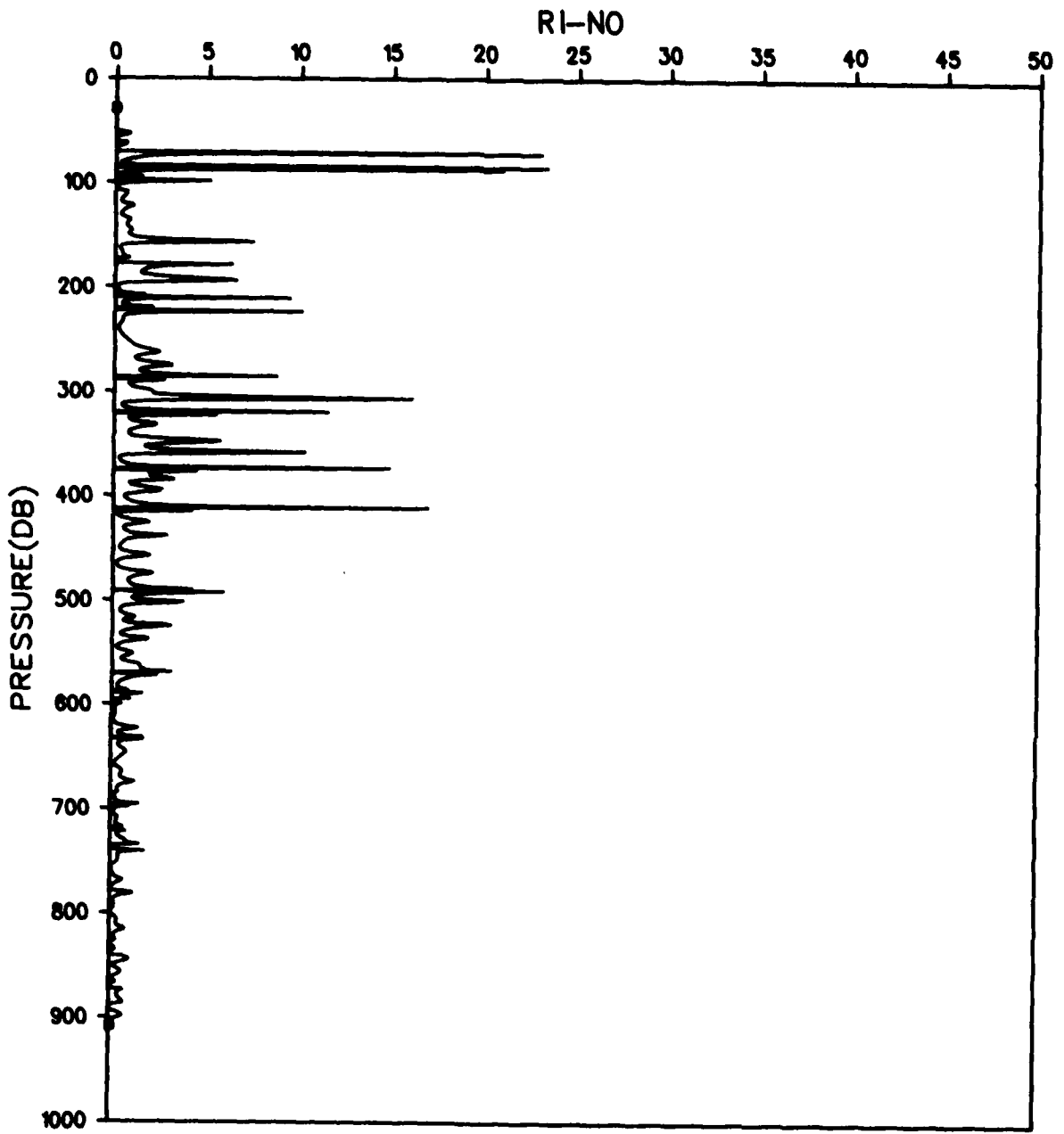


Figure D-48. File: KANE, Segment: C 563

Appendix E:
Log S² vs Log N²
(Bulk Richardson Numbers)

COMMENTS:
Low Pass Filtered 10 m Resolution Subsampling Interval 1 m

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The vertical (horizontal) line drawn parallel to the $\log N^2(\log S^2)$ axis represents the value of $\log S^2(\log N^2)$ for which the estimated signal-to-noise ratio is 1. Points plotted to the left (below) of the vertical (horizontal) line have an estimated signal-to-noise ratio of less than 1. Points in quadrant 1 have a signal-to-noise ratio of at least 1.

Negative values of N did occur in several of the profiles. These negative values were set to zero and not plotted. All non-zero values of S^2 were plotted.

The slanted lines represent Richardson numbers in the range $RI=0.0001$ to $RI=100$.

The original XCP data sets as received from APL/UAW had a vertical sample interval of about 2 to 3 m. We interpolated these profiles to 1 m intervals and then low passed the data with a half-power wave length of 10 m. Although the cutoff wave-length was set to 10 m, scales down to about 7 m still contributed to the record variance after filtering. Profiles were then subsampled at a vertical interval of 1 m.

Newman (1981) argues that this smoothing technique is statistically equivalent to "boxcar averaging." In the smoothed data, points at 7 m intervals represent an average of 7 samples of 1 m spacing in the unsmoothed profiles. Smoothing over an effective scale of 7 m reduces noise contributions by a factor of $1/\sqrt{7}$.

The XCP can resolve changes in velocity (rms) of about 1 cm/sec (Sanford, 1980). Smoothing the data over an effective 7 m scale length reduces this rms error by about $1/\sqrt{7}$, or $\sigma u = 3.780 \times 10^{-1}$ cm sec.

A minimum uncertainty (σS^2) based only on velocity resolution (assuming equal error from both u and v components) may be estimated as follows (Newman, 1981, personal communication):

$$\sigma S^2 = \frac{4S}{\Delta Z} \cdot \sigma u = (\text{Sec}^{-2})$$

where S is the vertical shear and ΔZ is the effective sample interval.

For a signal to noise ratio of unity $\sigma S^2 = S^2$ and

$$S^2 = \frac{4S}{\Delta Z} \cdot \sigma u$$

$$S = \frac{4}{\Delta Z} \cdot \sigma u$$

$$\begin{aligned} \Delta Z &= 700 \text{ cm} \\ \sigma u &= 3.78 \times 10^{-1} \text{ cm sec}^{-1} \\ S &= 2.16 \times 10^{-3} \text{ sec}^{-1} \\ S^2 &= 4.6656 \times 10^{-6} \text{ sec}^{-2} \\ \log S^2 &= -5.33 \end{aligned}$$

The Neil Brown CTD sensor can resolve changes in temperature and salinity with a precision (rms) of about 0.005°C and 0.005 ‰ .

Using representative values of the coefficients of thermal expansion and haline contraction (Evans et al., 1979; Newman, 1981) an estimate of noise associated with the Brunt-Väisälä frequency (N) may be given approximately by

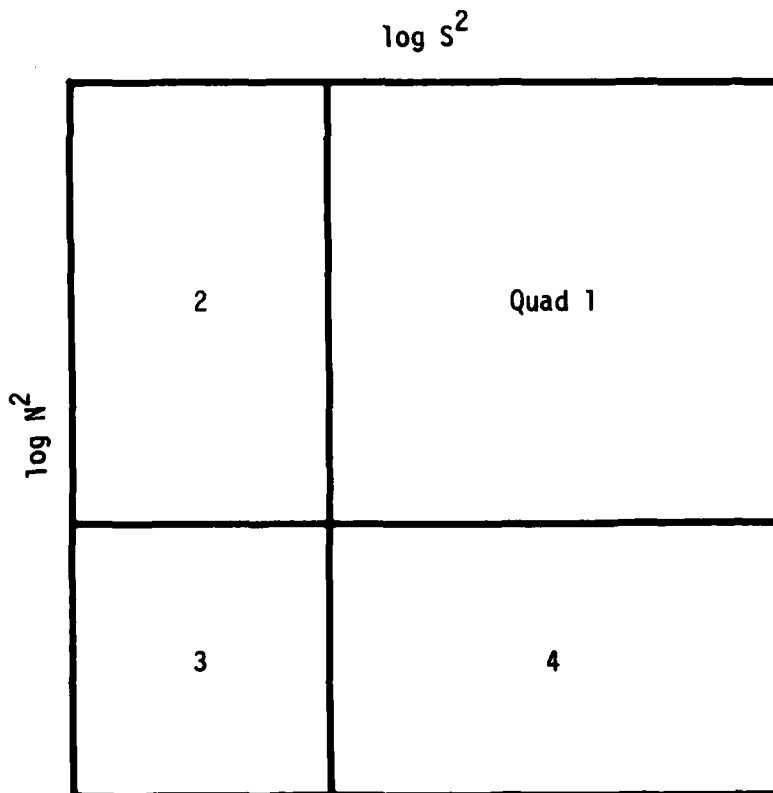
$$\rho_0 \Delta N^2 = \frac{g(\alpha \Delta T \pm \beta S)}{\rho_0 \Delta Z}$$

$$\begin{aligned} g &= 980 \text{ cm sec}^{-2} \\ \alpha &= 3 \times 10^{-4} \text{ g cm}^{-3} (\text{°C})^{-1} \\ \beta &= 8 \times 10^{-4} \text{ g cm}^{-3} (\text{‰})^{-1} \\ \rho_0 &= 1.0 \text{ g cm}^{-3} \\ \Delta Z &= 700 \text{ cm} \\ \Delta S &= 0.005 \text{ ‰} / \sqrt{T} = 1.8898 \times 10^{-3} \text{ ‰} \\ \Delta T &= 0.005 \text{ °C} / \sqrt{T} = 1.8898 \times 10^{-3} \text{ °C} \end{aligned}$$

Smoothing of the data reduces the noise level in ΔS and ΔT by a factor of $1/\sqrt{T}$.

$$\begin{aligned} \Delta N^2 &= 2.9103 \times 10^{-6} \text{ (sec}^{-2}\text{)} \\ \log \Delta N^2 &= 5.54 \end{aligned}$$

We selected $\log N^2 = \log S^2 = -6$ ($S = N = 1.0 \times 10^{-6} \text{ sec}^{-1}$) as being a reasonable cutoff level for a signal-to-noise ratio of 1.



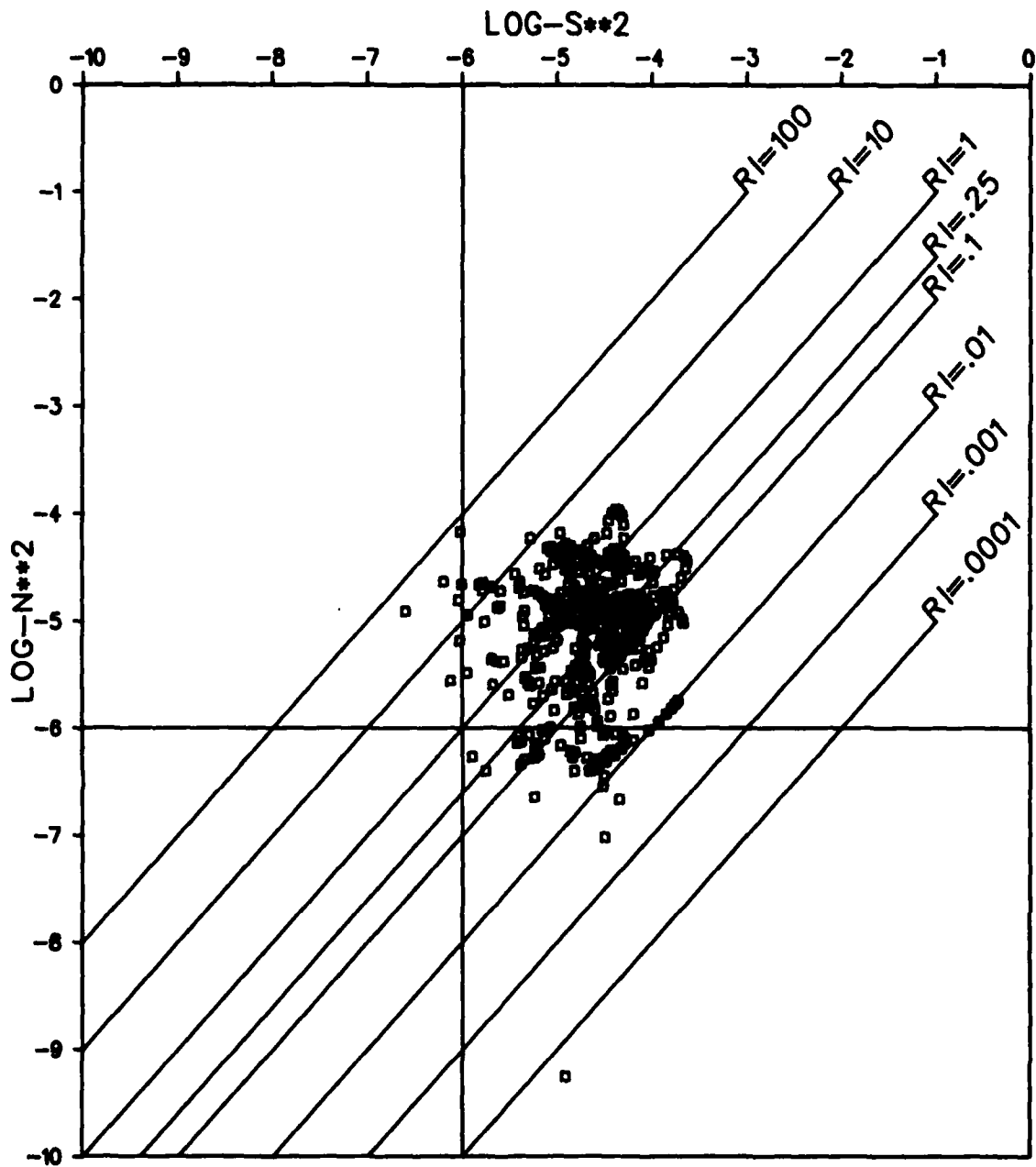


Figure E-1. File: KANE, Segment: C 503

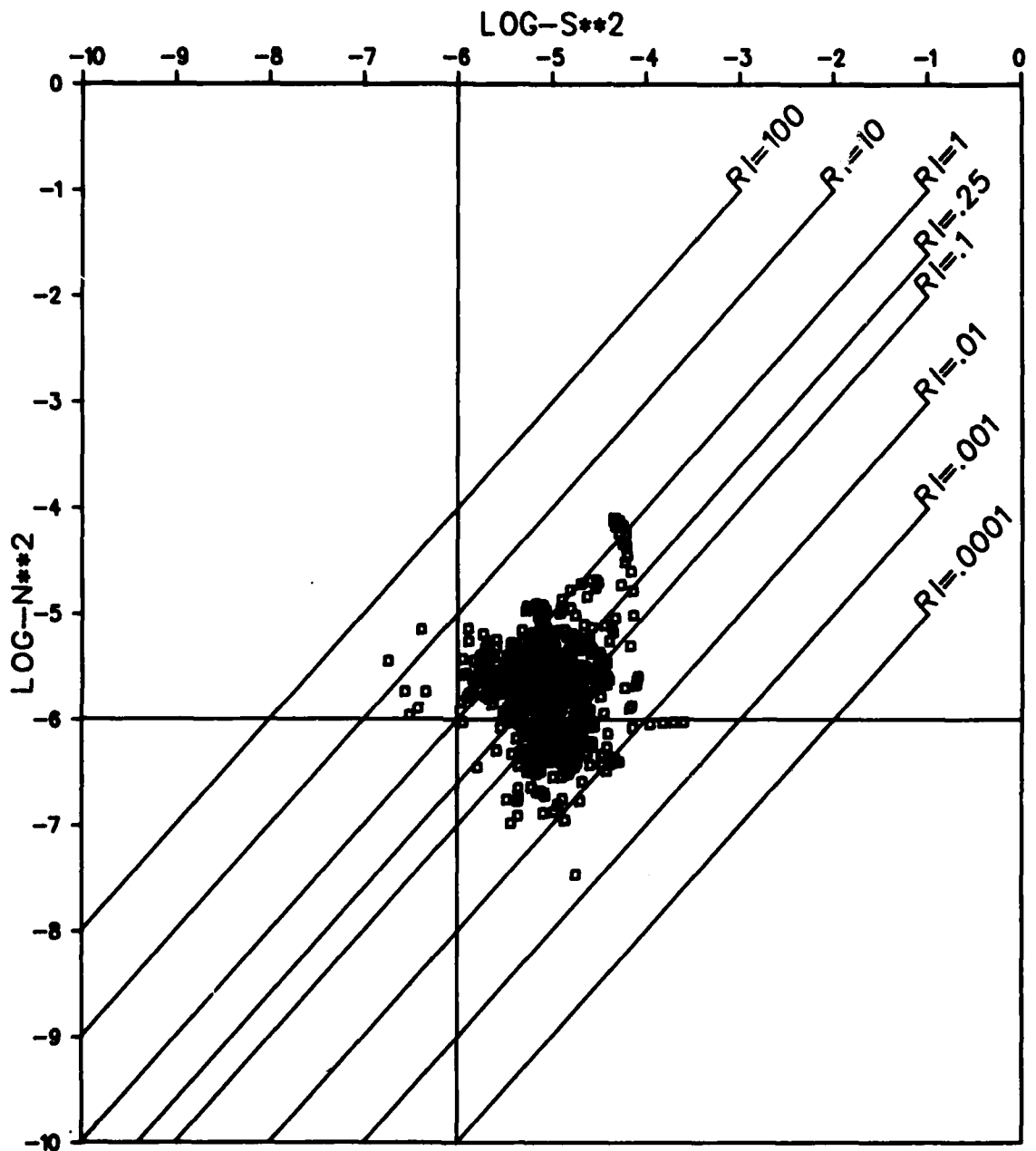


Figure E-2. File: KANE, Segment: C 504

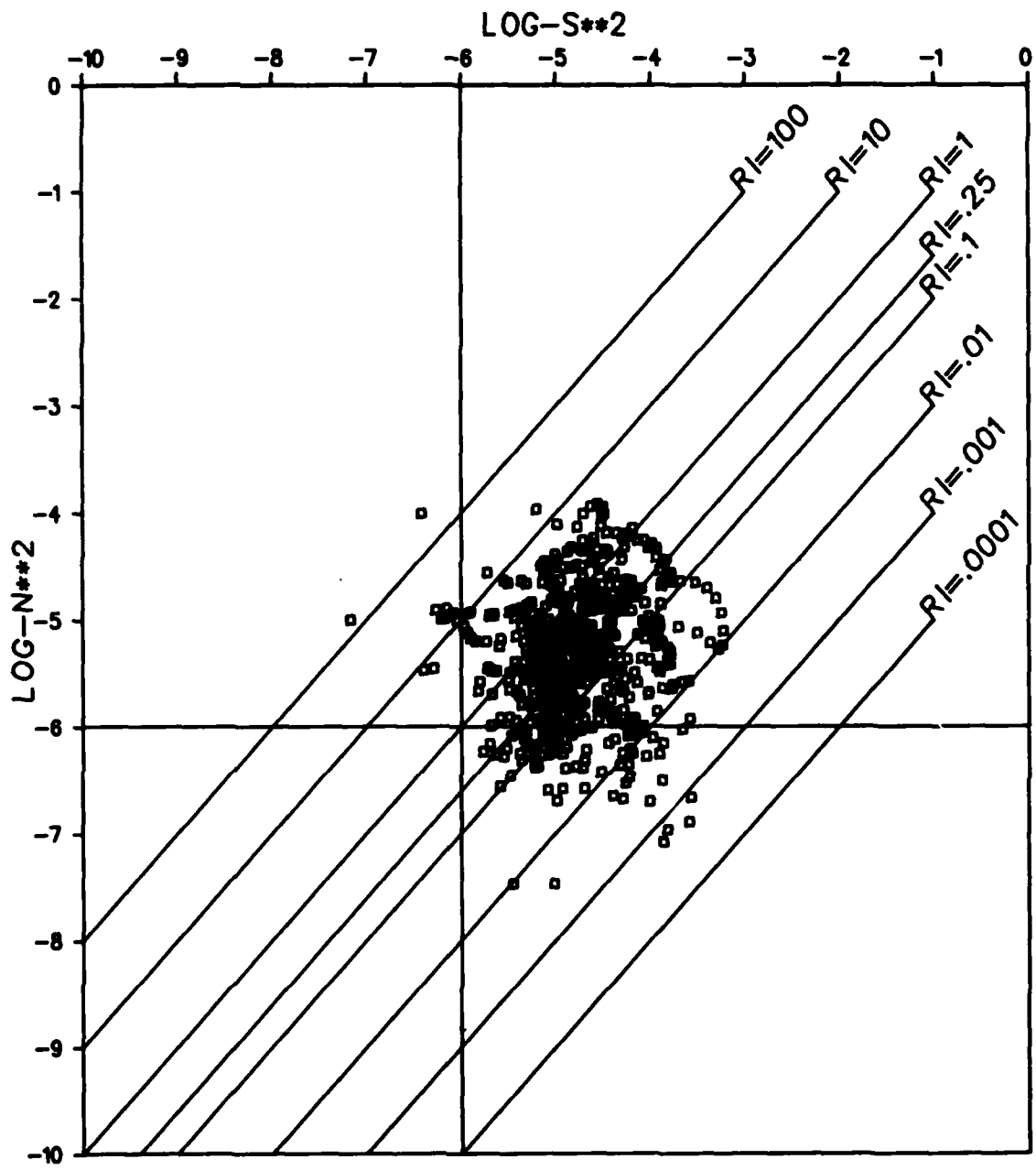


Figure E-3. File: KANE, Segment: C 517

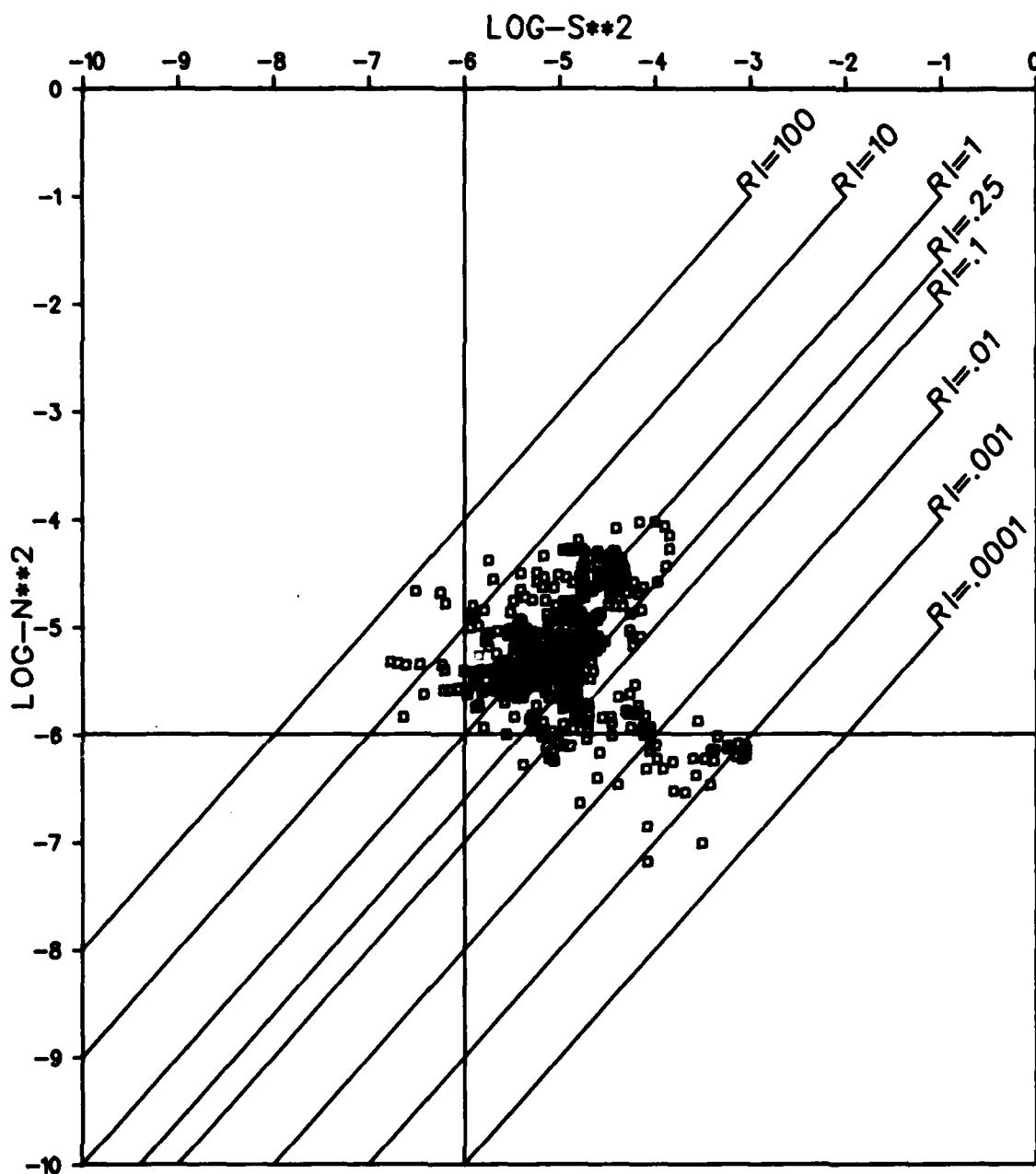


Figure E-4. File: KANE, Segment: C 519

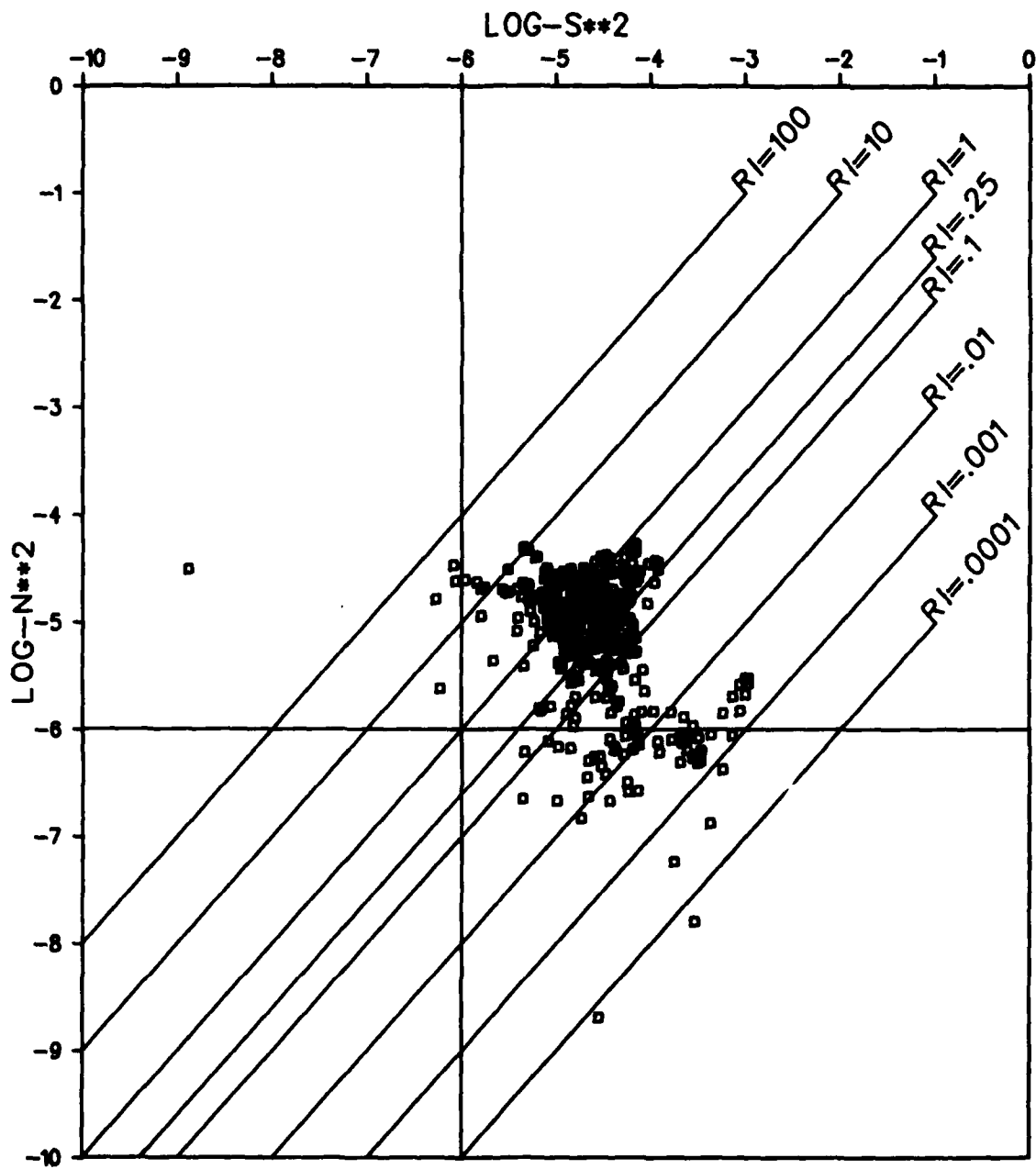


Figure E-5. File: KANE, Segment: C 520

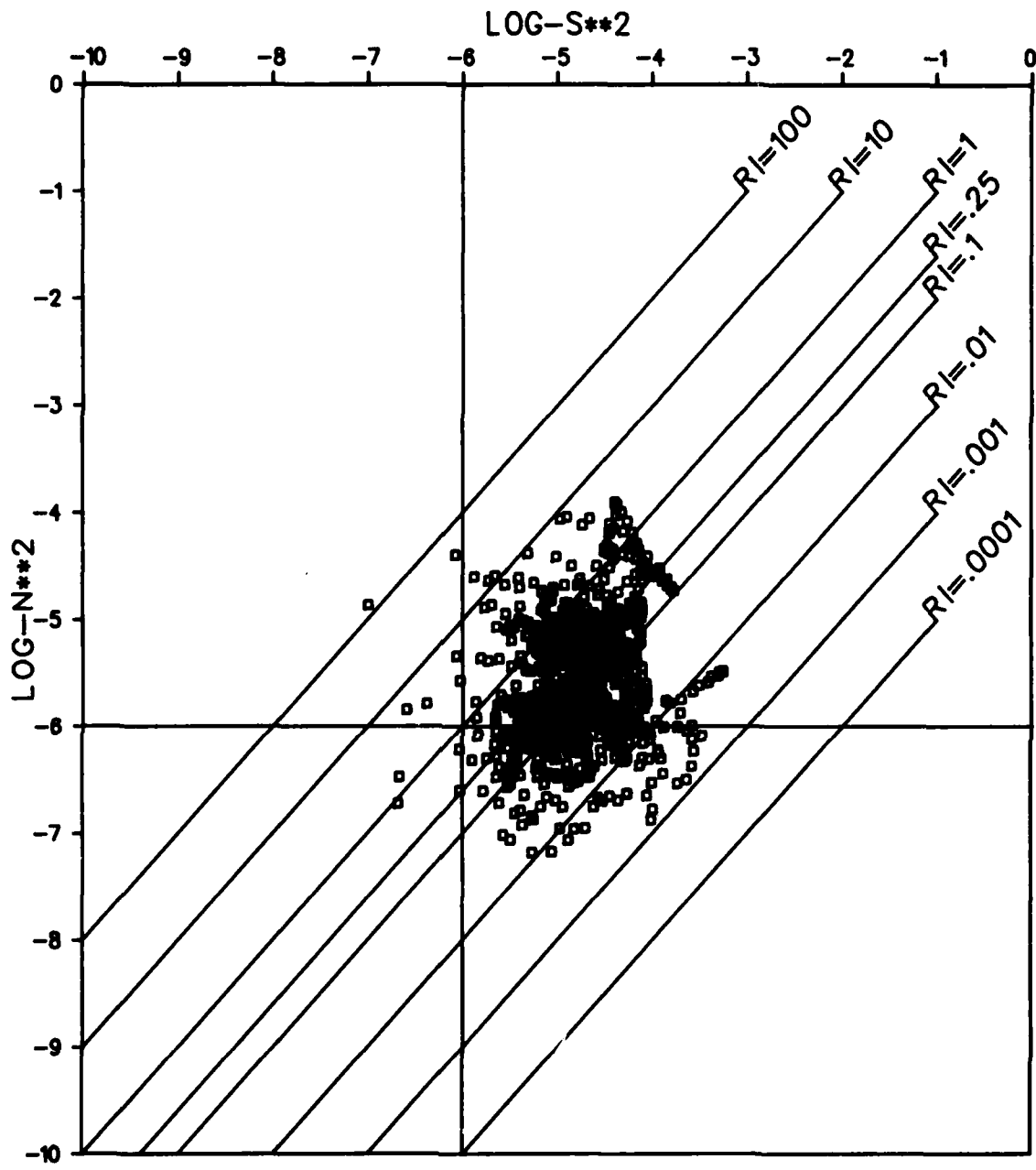


Figure E-6. File: KANE, Segment: C 525

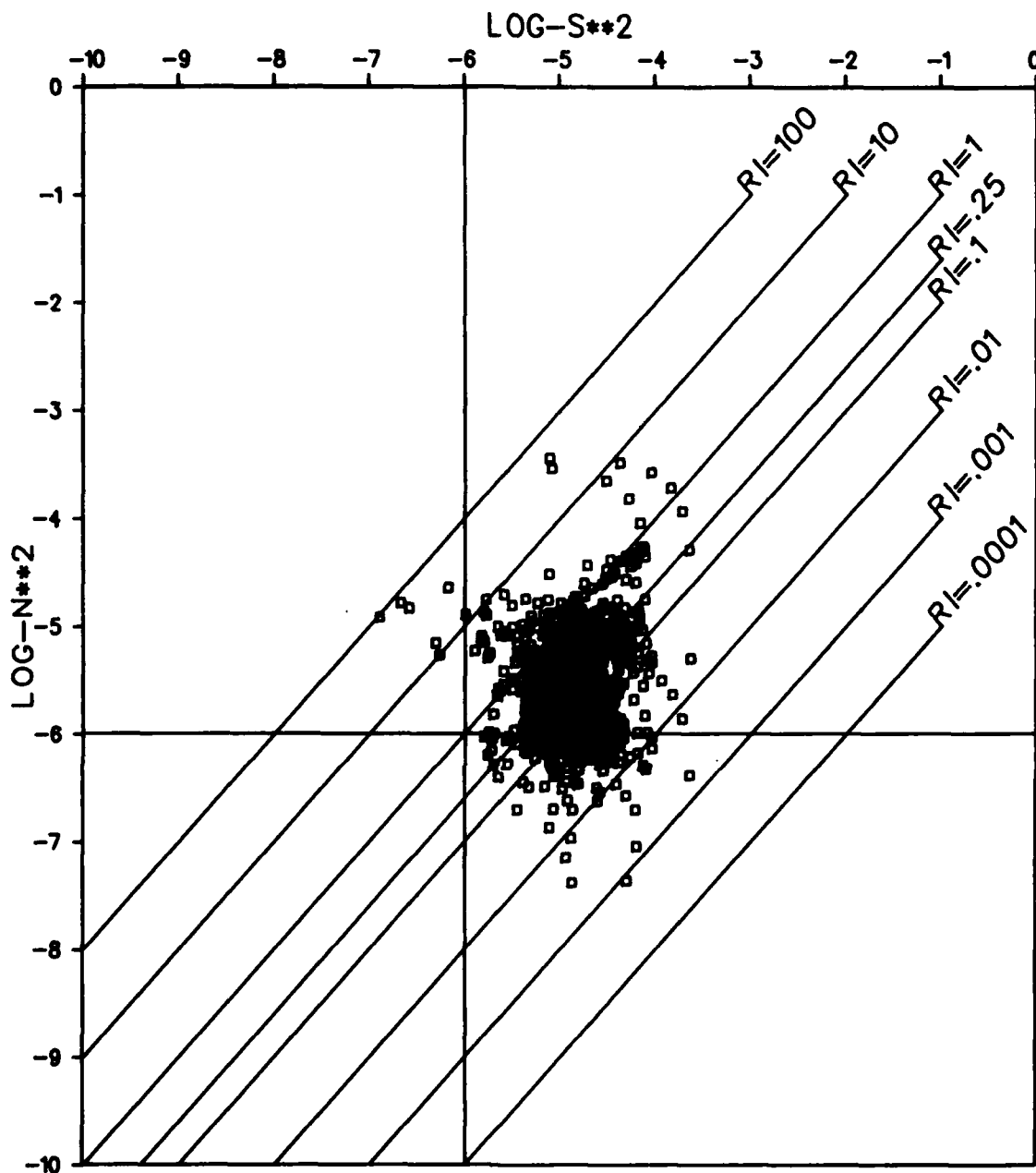


Figure E-7. File: KANE, Segment: C 534

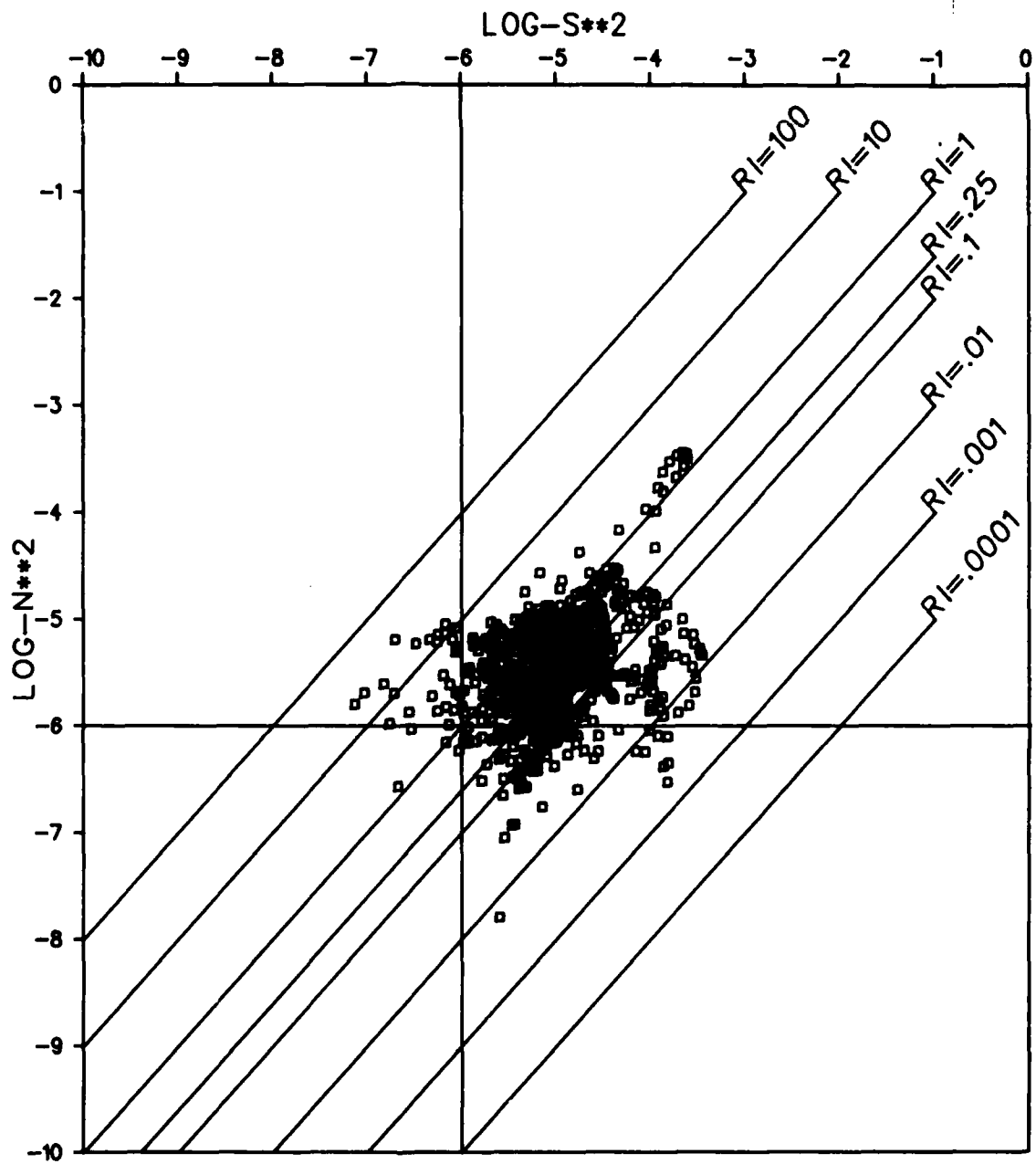


Figure E-8. File: KANE, Segment: C 535

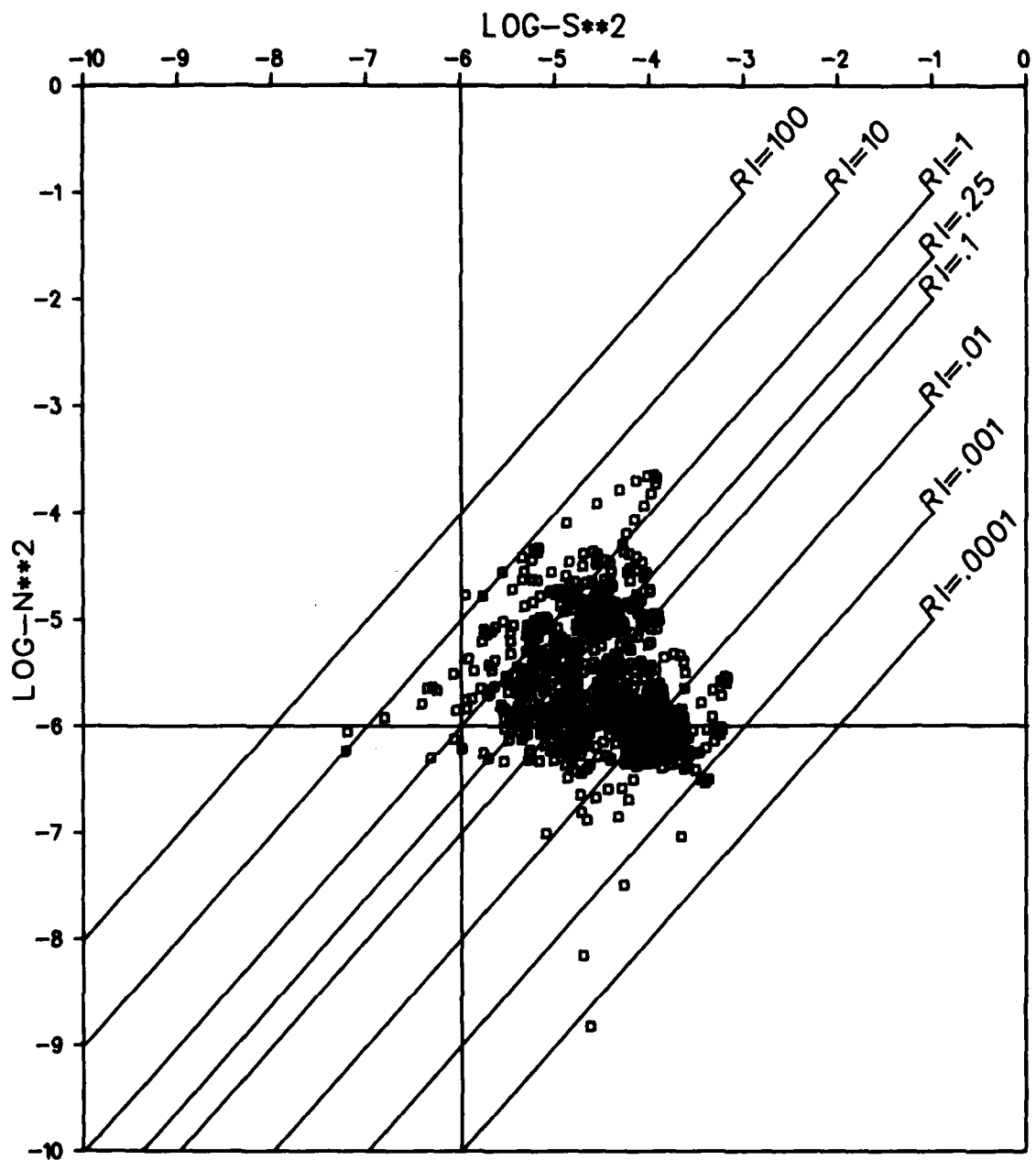


Figure E-9. File: KANE, Segment: C 538

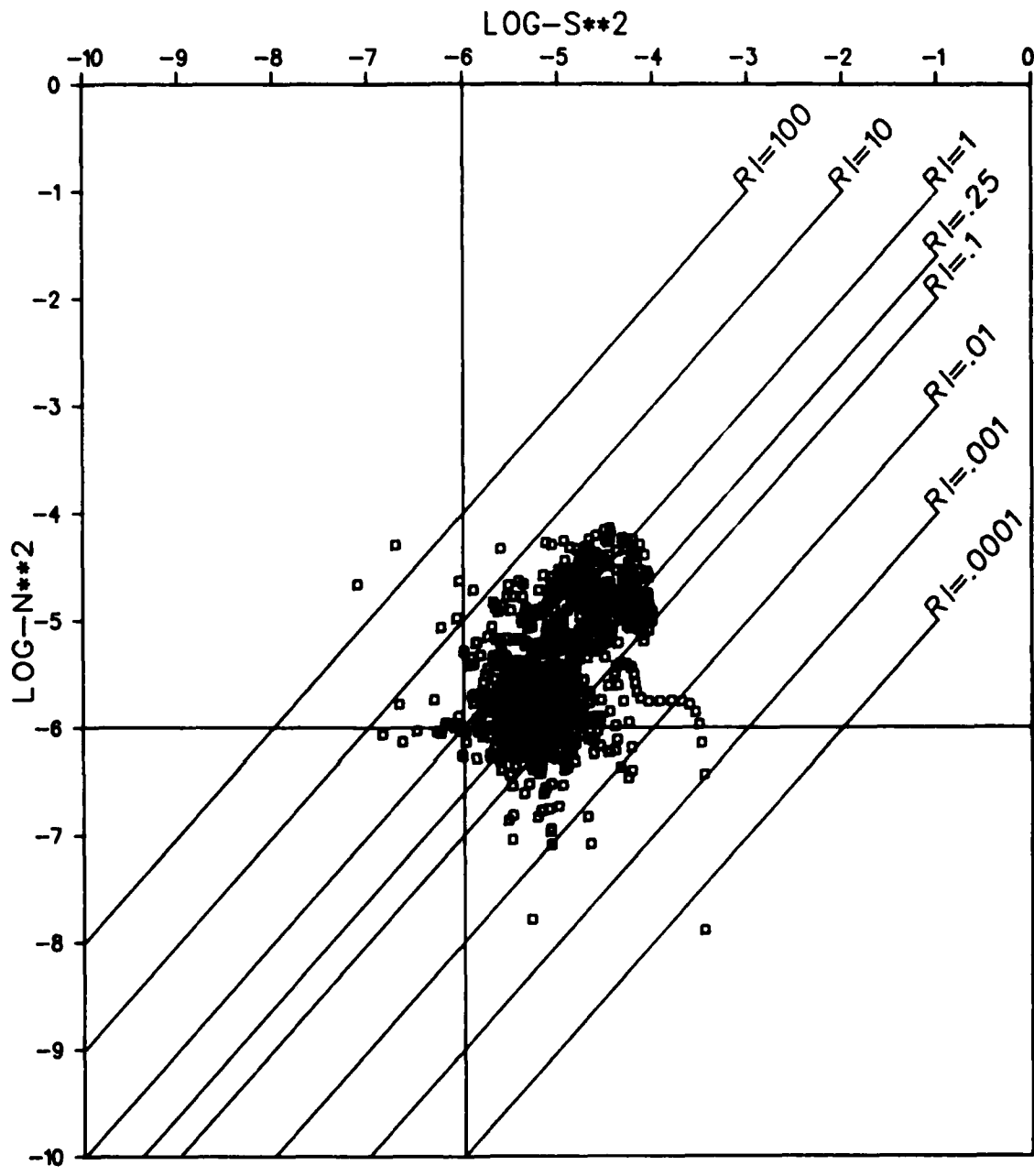


Figure E-10. File: KANE, Segment: C 546

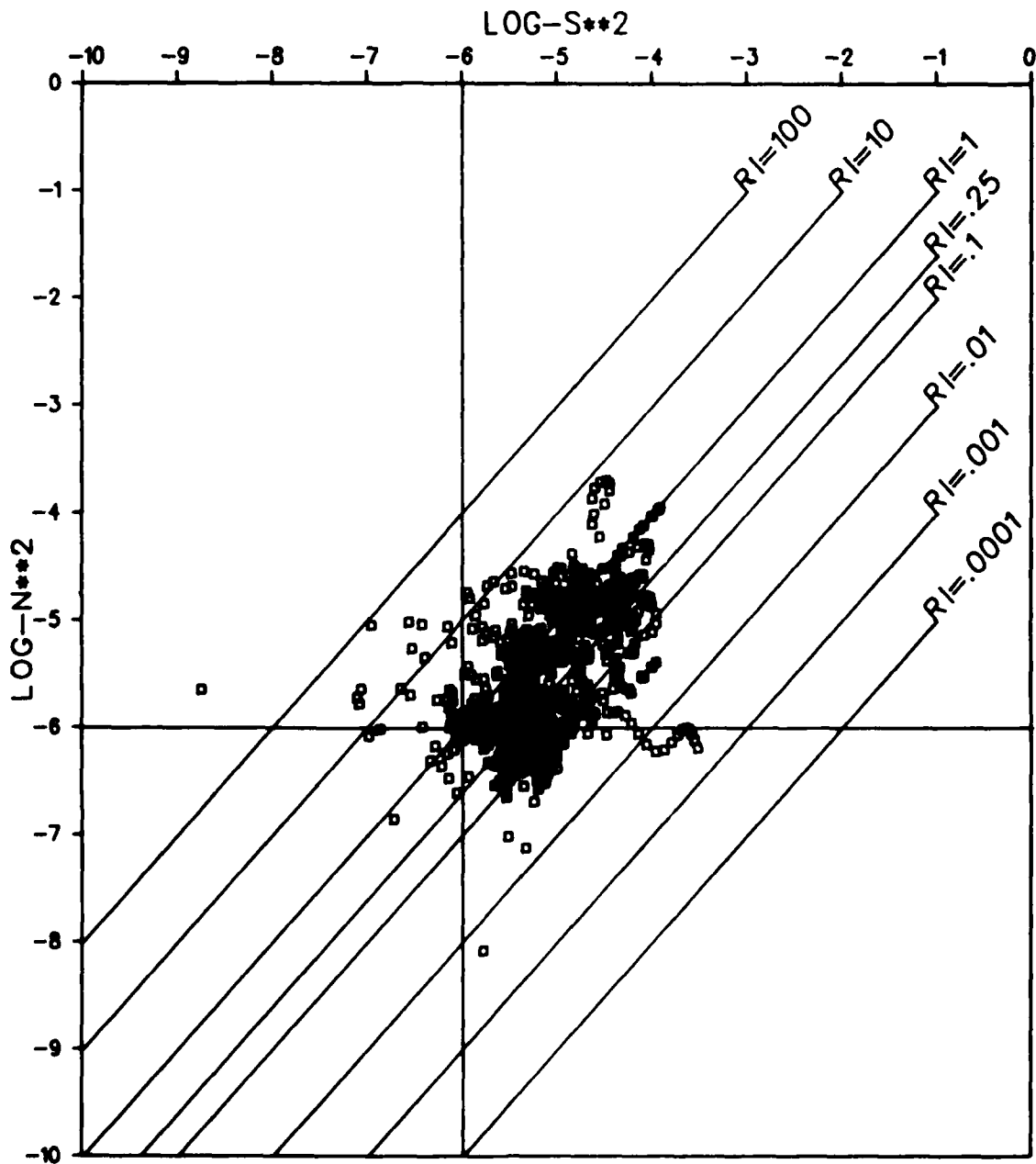


Figure E-11. File: KANE, Segment: C 547

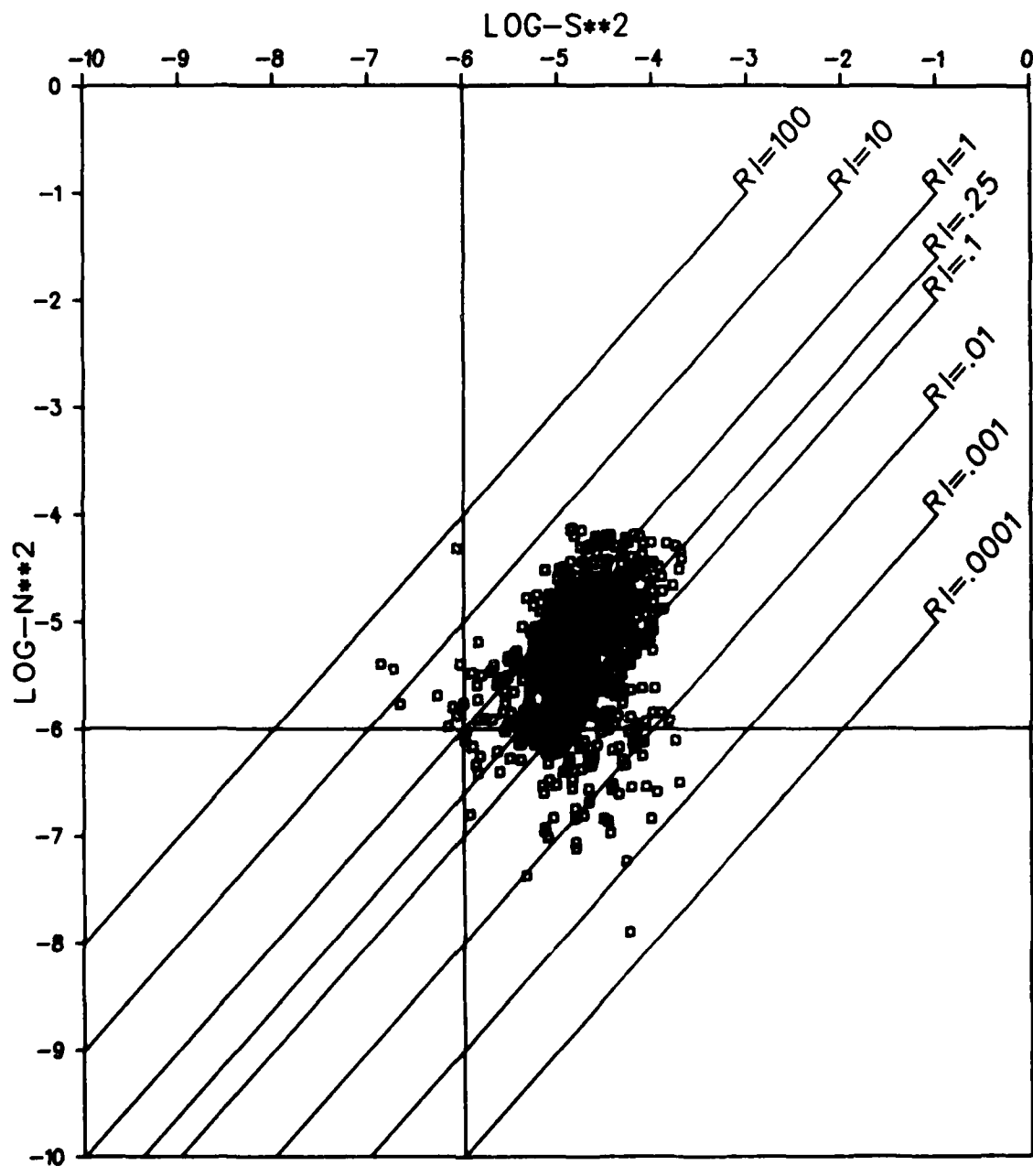


Figure E-12. File: KANE, Segment: C 548

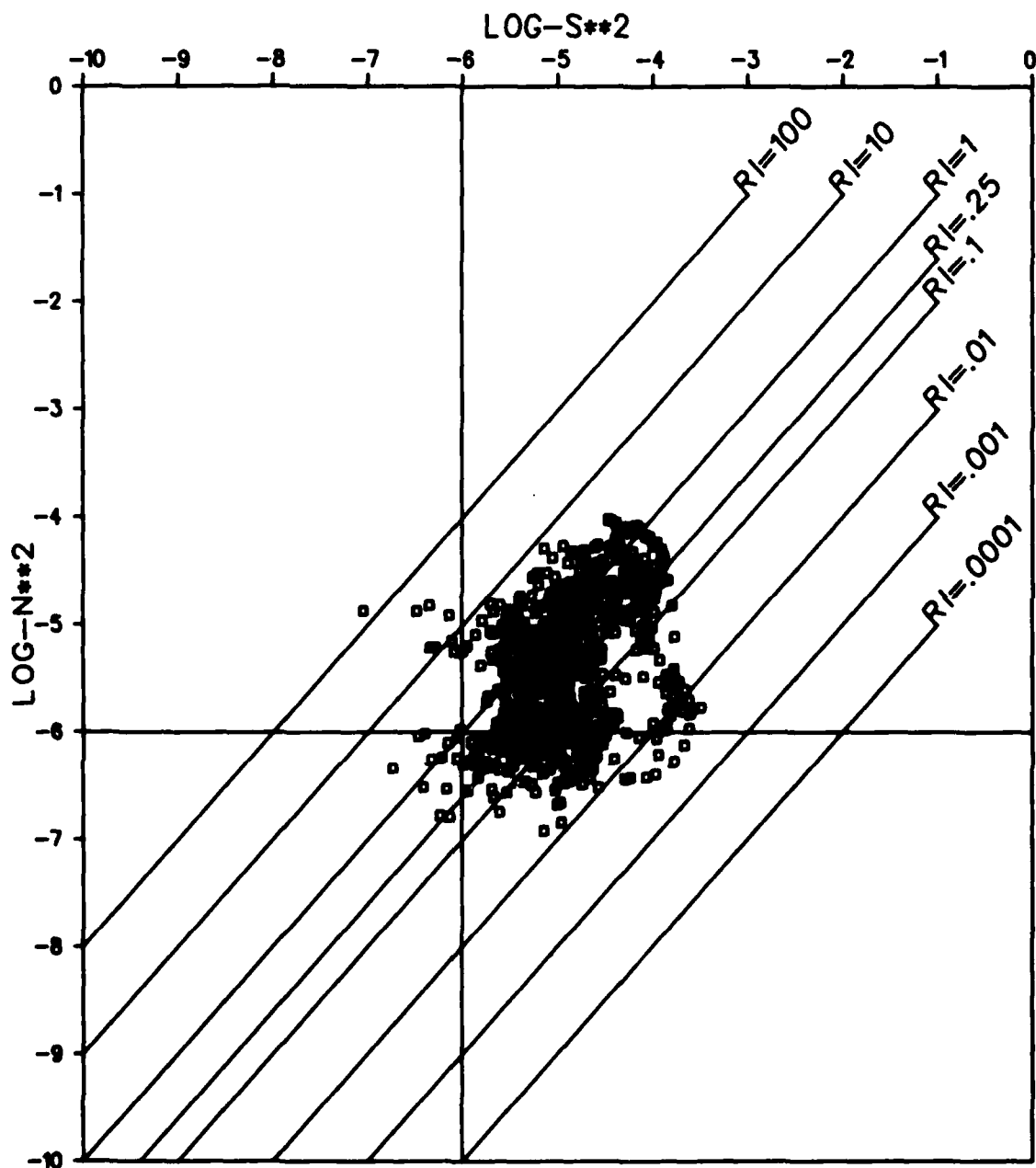


Figure E-13. File: KANE, Segment: C 549

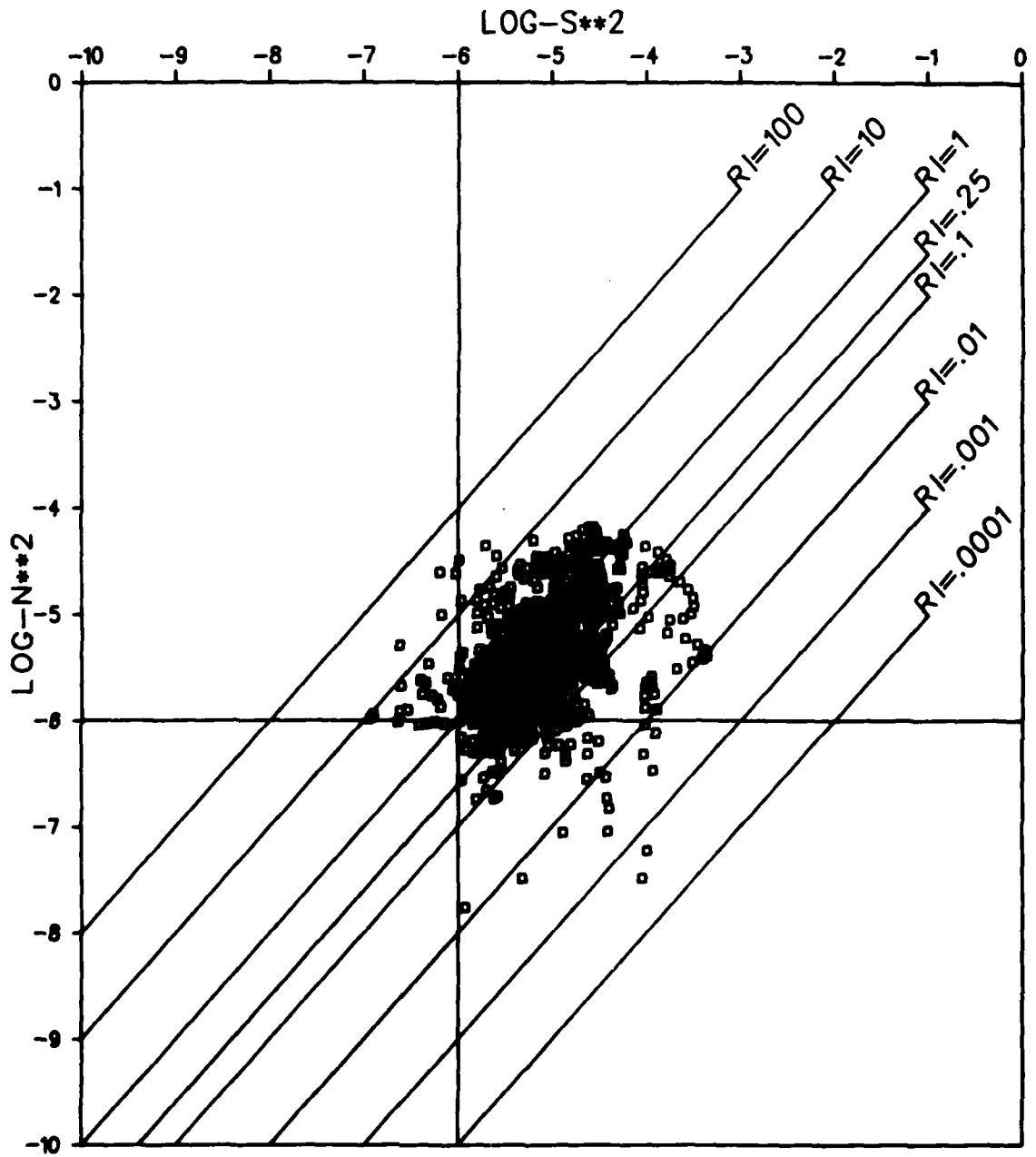


Figure E-14. File: KANE, Segment: C 550

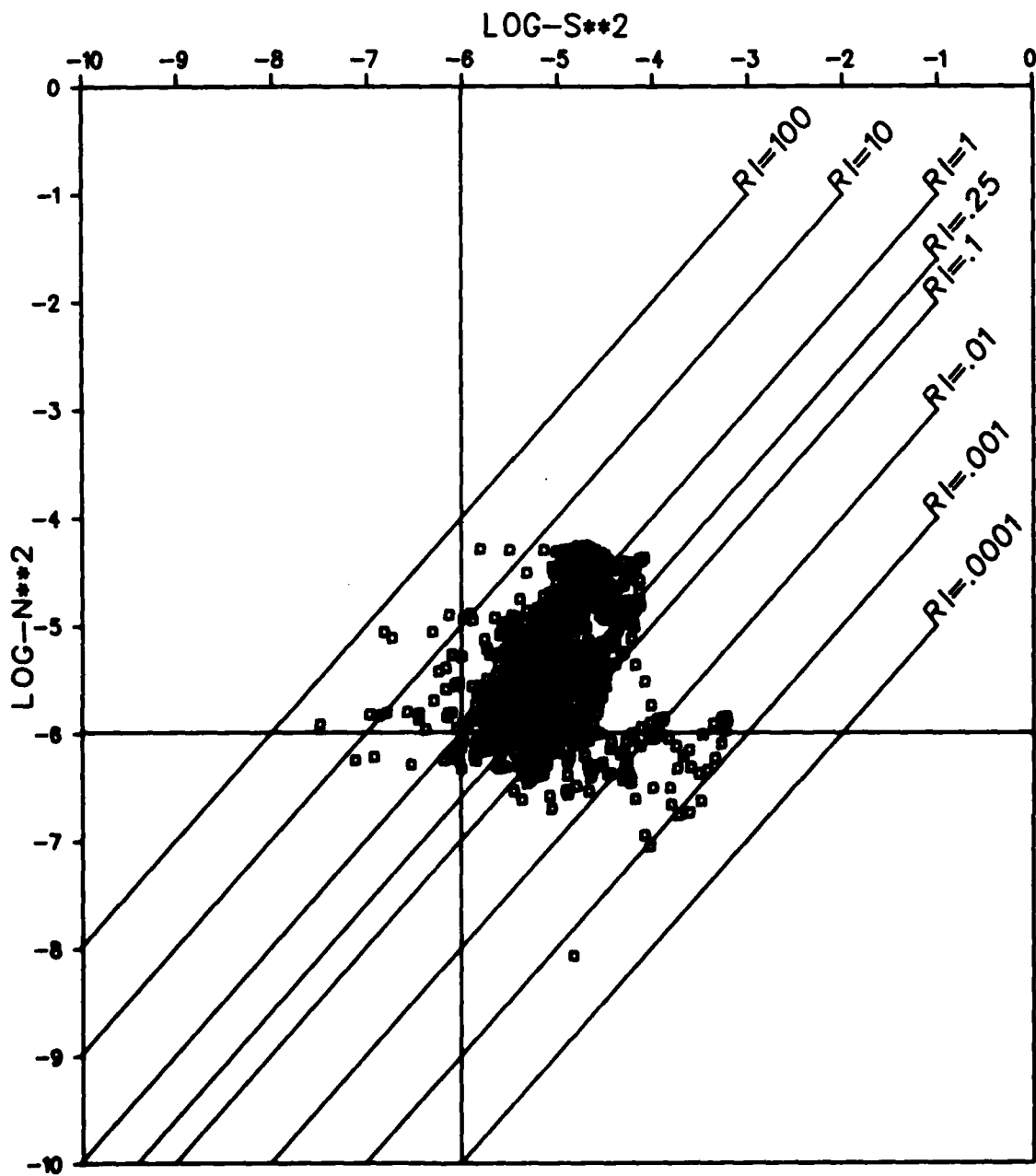


Figure E-15. File: KANE, Segment: C 551

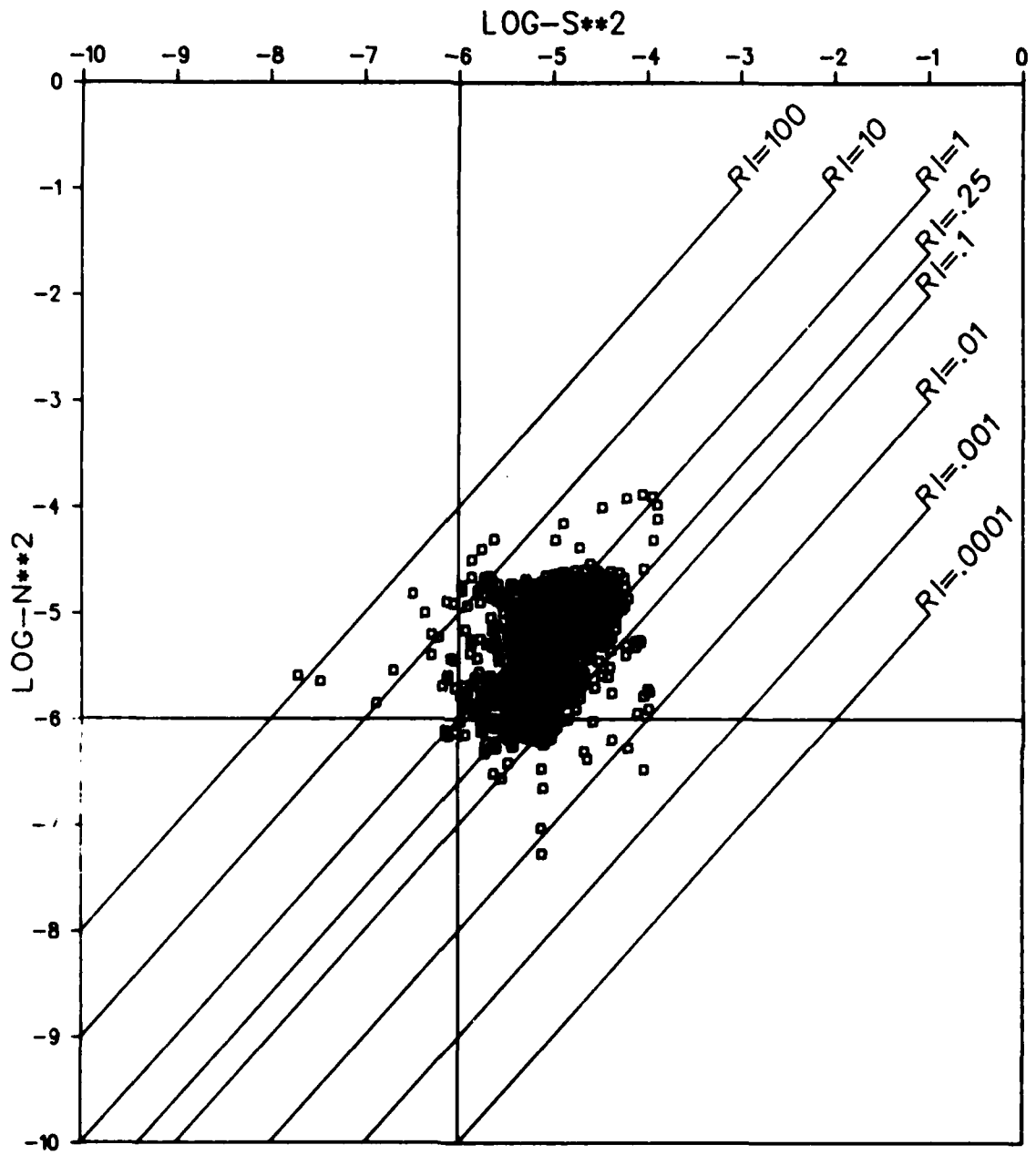


Figure E-16. File: KANE, Segment: C 563

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