Annual Report

Contract No: 03-5-022-67 T.O. 3

Research Unit No: 91

Reporting Period: 1 April 1976-31 March 1977

Number of Pages: 56

Current Measurements in Possible Dispersal Regions of the Beaufort Sea

Knut Aagaard

Department of Oceanography

Dean Haugen

Applied Physics Laboratory

University of Washington

Seattle, Washington 98195

29 March 1977

I. Summary

At least in late winter the currents on the inner shelf appear to be slow, generally less than 5 cm see-l. Long-term mean currents are extremely small, representing net displacements over a week of only 1-2 km. The two measurements made north of Narwhal Island showed these small displacements to have been west-southwest. Tidal currents are probably not much above 1 cm see-l in winter.

On the outer shelf an entirely different situation prevails. Measurements made at 100 m under the ice from May-September showed the flow to reach over 55 cm sec^{-1}, and even over a 3-month period the mean flow was 13 cm see-l toward the east. Pollutants reaching the outer shelf at sub-surface depths could thus be transported 1000 km eastward in three months. The most remarkable feature observed was the dominance of the motion by low-frequency variations with a typical time scale of 10 days. These oscillations represent bursts of speed as high as 50 cm see-l or more; they are directed eastward and are aligned approximately with the shelf edge. Between the bursts there were shorter periods of westward motion, the maximum observed speed toward the west being 26 cm sec^{-1}. The cause of these motions is for the present unknown. Tidal currents are in the neighborhood of 5 cm see-l, and a diurnal inequality probably prevails at times of high lunar declination.

The implication of these measurements with respect to the transport and dispersal of pollutants on the Beaufort shelf is that the ice-covered inner and outer shelf represent very different advective regimes. Over the former, currents are weak and net displacements are small. However, over the outer shelf there are strong currents and pollutants can be transported very long distances.

II. Introduction

The objective of this work is to obtain long-term Eulerian time series of currents at selected locations on the shelf and slope of the Beaufort Sea. Such measurements are necessary to describe and understand the circulation on the shelf and the exchange between the shelf and the deep Arctic Ocean. This circulation and exchange are in turn the physical mechanisms which transport and dispense pollutants and substances of biological and geological importance. The water motion also influences the ice distribution and drift. The current time series must be long enough to define the important temporal scales of motion.

III. Current state of knowledge

Prior to the previous work, there had been only one time series current measurement of significant length on the Beaufort shelf. This was from a single instrument moored in water 54 m deep about 70 km east-northeast of Barrow during 15 days of August 1972. Other current measurements are also from summer and have been made in water shallower than 20 m; the records are of very short duration. During the spring and summer of 1973 we obtained two four-month long current records from the inner part of Barrow Canyon, whence waters enter onto the Beaufort shelf. By piecing together these observations, along with indirect evidence such as that provided by summer hydrographic measurements, one can arrive at some general ideas about the circulation on the Beaufort Sea shelf, primarily during summer.

Water originating in the Bering Sea and modified by its passage through the Chukchi flows northeast through Barrow Canyon at speeds as high as 100 cm see-l. Subsequently the majority of this flow probably turns eastward and enters the Beaufort Sea. On the shelf some 70 km east-northeast of Barrow, the eastward motion has been observed to average 60 cm sec^{-1} during a six-day interval. The eastward flow, concentrated on the outer shelf, can be traced through hydrographic evidence at least as far as Barter Island at 143°W. Measurements have shown that changes in the meridional atmospheric pressure gradient can temporarily reverse the flow in Barrow Canyon, and apparently also on the western Beaufort shelf.

Summer observations have also indicated the likelihood of an intermittent upwelling regime on the eastern part of the shelf. It is hypothesized that the upwelling is a response to locally strong easterly winds, and that the water upwelled onto the shelf moves westward.

While tidal effects are probably small, storm surges and related effects may be important in promoting significant changes of short time scales.

Earlier studies have contributed essentially nothing to knowledge of the advective exchange between the shelf and the deep basin.

IV. Study area

The area of interest extends eastward from Pt. Barrow along the entire northern Alaska coast, *i.e.* , from about 156°30'W to 141°W, a lateral distance of 600 km. The shelf is narrow, with the shelf break typically 80-90 km offshore. The total runoff is relatively small, highly seasonal, and concentrated in a very few rivers of any consequence, the largest of which is the Colville. Tidal amplitudes are small, with a probable mean spring range of about 15 cm; the tides are mixed, predominantly semi-diurnal. The entire area is covered by sea ice, both first and multi-year, through all but 2-3 months. Even during the height of summer, ice is usually found well onto the shelf.

v. Data collection

It is obviously impossible to attempt intensive time series coverage of the entire region. One is in practice limited to measurements at a few points, hopefully key ones. The first year of the present work we picked three sites. The first was in Barrow Canyon, at a point down-canyon from our earlier measurements, where the Bering Sea source waters for the Beaufort shelf presumably have begun turning eastward. We also selected two sites more nearly midway along the shelf, at about 150°W. One of these was on the outer shelf and one part-way down the slope, the idea being to get not only a representation of the shelf and adjacent slope flow regimes, but also to examine the possible exchanges between these regimes. These moorings were installed in April 1976 and were designed to measure until fall. At that time a new set of current meters was deployed north of Lonely, in coordination with the CTD work being performed there (see this year's annual report, Research Unit No. 151). All moorings carried two current meters each.

All of these sites can in general be expected to be covered by ice. Since anchored current meters record internally, so that data retrieval is dependent upon instrument recovery (a fairly formidable task in ice-covered waters), we decided on an alternative set of approaches that provide redundancy in data recovery. The first approach was to transmit the data acoustically. This involves storing the data in such a way that they can be recalled at very high rates upon command, the recall being done from the ice on an opportunity basis. This method has two side benefits, *viz.* that the current meters can be left in place as long as they continue to function, and that data recovery can be made as often as desired, *i.e.*, more nearly in real-time. The second approach to data recovery was to have the instruments record internally as usual, equip them with acoustic releases, and provide the arrays with an acoustic ranging and bearing system to enable pinpointing their position under the ice after having been released and risen to the under-ice surface. A hole can then be cut in the ice and divers used to attach recovery lines; the mooring is dragged laterally to the hole and brought up.

Each instrumentation system was thus to be comprised of an anchor, an acoustic anchor release, a lower current meter, a data buoy, an upper current meter, and appropriately distributed flotation. The current meters provide current speed, direction, and temperature in binary code. The data buoy is linked acoustically to the current meters. The buoy houses power supply, digital tape recorder, timing and control electronics, and acoustic telecommunication subsystems.

In addition we used the opportunity provided by the radar ice tracking program conducted from Narwhal Island in the spring of 1976 to obtain two shorter current records. In that case one internally recording current meter was simply hung through a hole cut in the ice adjacent to each of two radar targets. The ice tracking provided a description of the ice movement, so that vectorial summation of the ice and relative water motion gave a representation of true currents.

VI. Results

There have been very substantial difficulties and delays with the acoustically telemetering data buoy system. In consultation with the project office we therefore had to modify our original plans. The first modification occurred in spring 1976 when none of the data buoys were ready for deployment. Some of the reasons for this were discussed in the annual report of 26 March 1976. Rather than delay instrument deployment, we chose to put the moorings out with the intent to recover them the next fall through the ice. At that time two new moorings were to be deployed offshore from Lonely, complete with telemetry system. During 24-29 April the three moorings were installed as planned. Details have been provided in the quarterly report of 30 June 1976.

Meanwhile the two current meters offshore from Narwhal Island had also been deployed and recovered. These current records cover the three-and-a-half weeks 28 March-22 April.

In early fall it became apparent that there would be further delays in completing the data buoys. Again we decided to deploy with only the internal recording capability. This then required picking up the moorings the following March and re-deploying new moorings at that time, complete with acoustic telemetry.

The Barrow Canyon mooring was duly recovered on 6 October 1976 and the inshore Oliktok mooring, at 149°53'W, on 25 October. The third mooring released successfully, but was lost in a storm on 27-28 October before it could be brought up through the ice. Due to what- we believe to have been faulty magnetic tapes only partial current meter records were obtained from these moorings, one of about five days duration in Barrow Canyon and another with at least 95 days of clear records from north of Oliktok. On 15 October the inshore mooring north of Lonely was deployed, but an attempt to put in the deeper mooring on 17 October failed because of an echo sounder malfunction that required factory repairs. These activities have all been discussed in the quarterly report of 31 December 1976.

We have just now, on 23 March, recovered the Lonely mooring installed last spring. Both current meters had leaked through the external electrical terminal, so that the tape recorders had run only part of the time. These leaks occurred despite our having pressure tested the assemblies before deployment. They were probably due to thermal stressing as the moorings were put out. To prevent recurrence on the next deployments, we are removing the electrical connectors and inserting pressure hull plugs. The two new Lonely moorings will be deployed within the next few days. Only the deeper one of the two will carry a telemetering data buoy, however, as the second unit could not be completed on time. Present plans are to recover both of these moorings through the ice in October 1977. Meanwhile we'll attempt to interrogate the outer mooring on several occasions later this season.

VII. Discussion

We begin with what we shall call the Narwhal Island records. Current meter no. 433 was situated adjacent to radar target R3, and meter no. 437 adjacent to target R5. Both meters were suspended 10 m below the ice. Target R5 was in water less than 30 m deep and did not move more than 20 m the entire time. Target R3 was in water 35-40 m deep; it moved an appreciable distance only during the last 6 days of recording. Meter 433 recorded from 2340 GMT on 28 March to 1040 on 19 April, and meter 437 from 0107 on 28 March to 0027 on 22 April.

Figures 1-6 show the east (U) and north (V) components of velocity at meter 433 before correcting for ice drift (Fig. 7), and Figures 8-11 show the components of true current, *i.e.*, the vectorial sum of the relative current and the ice drift. The currents are generally small, less than 5 cm see-l, except during a few periods in the latter part of the record when they reached close to 10 cm -sec^1. These periods of higher speed coincided with the movement of the ice itself, which first achieved an appreciable velocity on 14 April. Comparison of Figures 12 and 13, which respectively are the progressive vector diagrams for the ice drift and the true current, show that during the last five days of record both the ice and the water moved in a similar manner: east or east-northeast during 14-15 April and then west-southwest during 16-19 April (the time ticks are 12 hours apart). This can also be seen by comparing Figure 7 with Figures 10 and 11.

Parts of the record suggest small oscillations of tidal frequency, with an amplitude of perhaps 1-2 cm see-l.

The mean motion over the entire period of measurement was nearly negligible. The mean relative water velocity was 0.2 cm see-l toward 243*T; the mean ice drift was 0.1 cm see-l toward 69*T; and the mean true water velocity was 0.1 cm see-l toward 240"T.

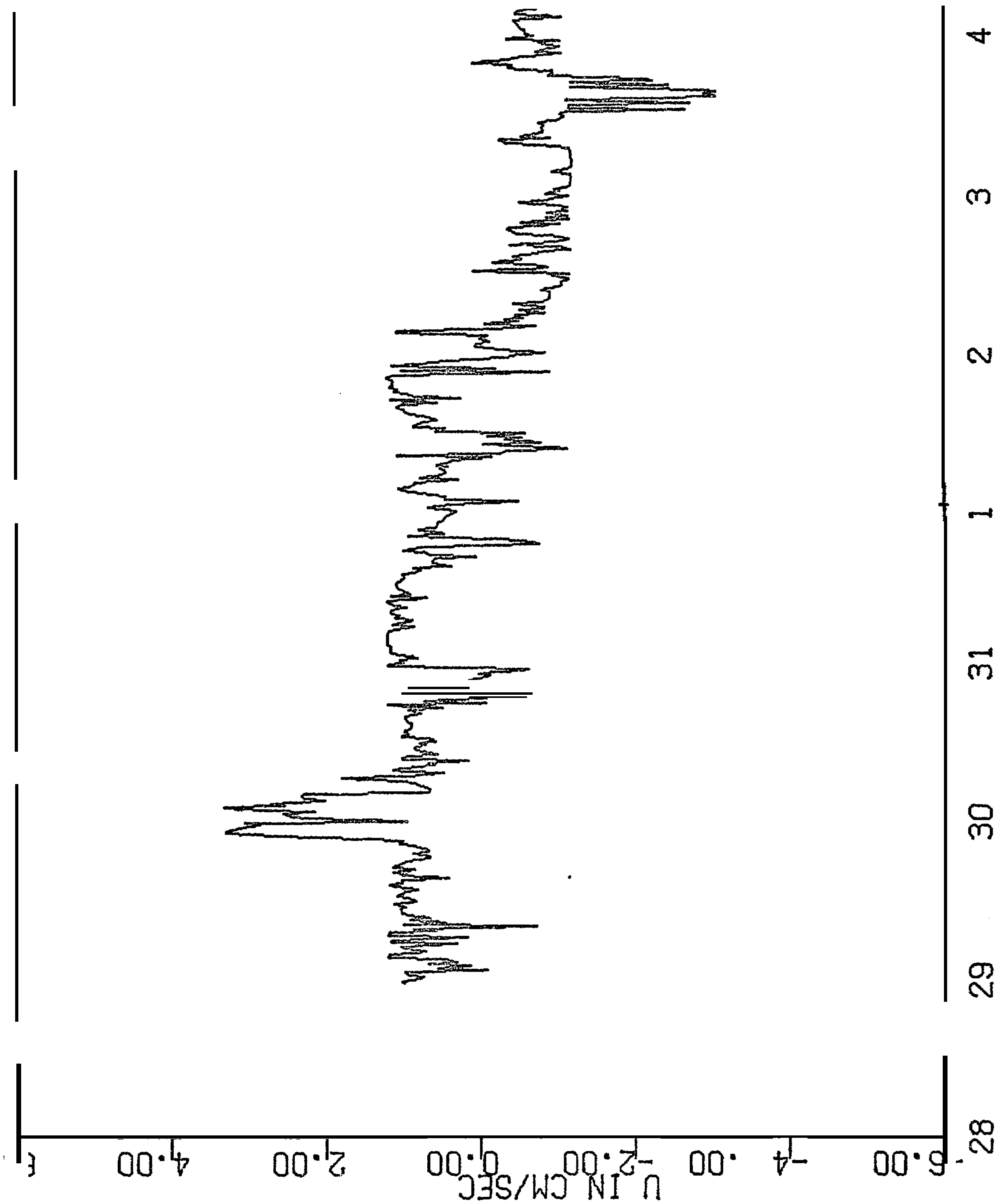


Figure 1

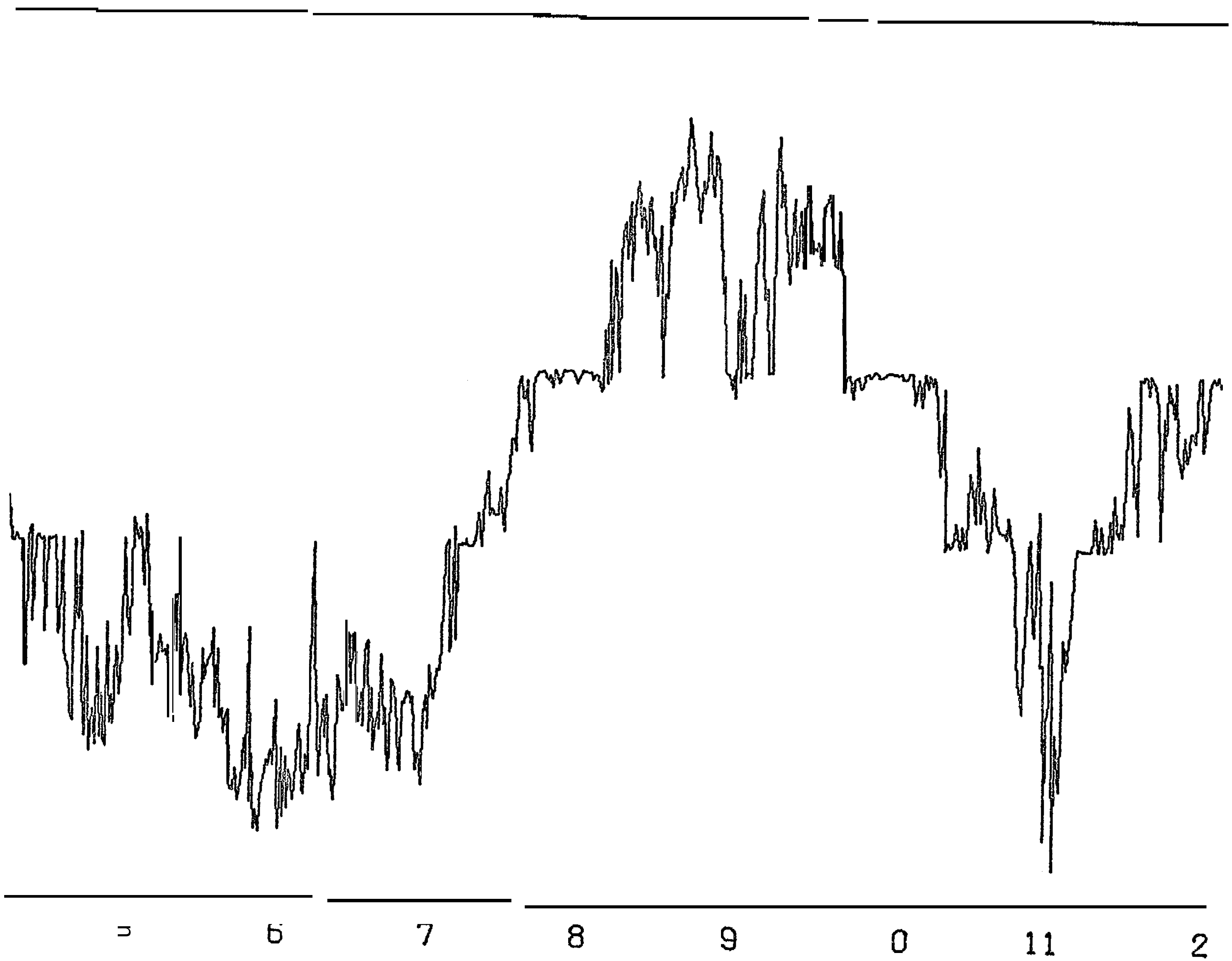


Figure 2

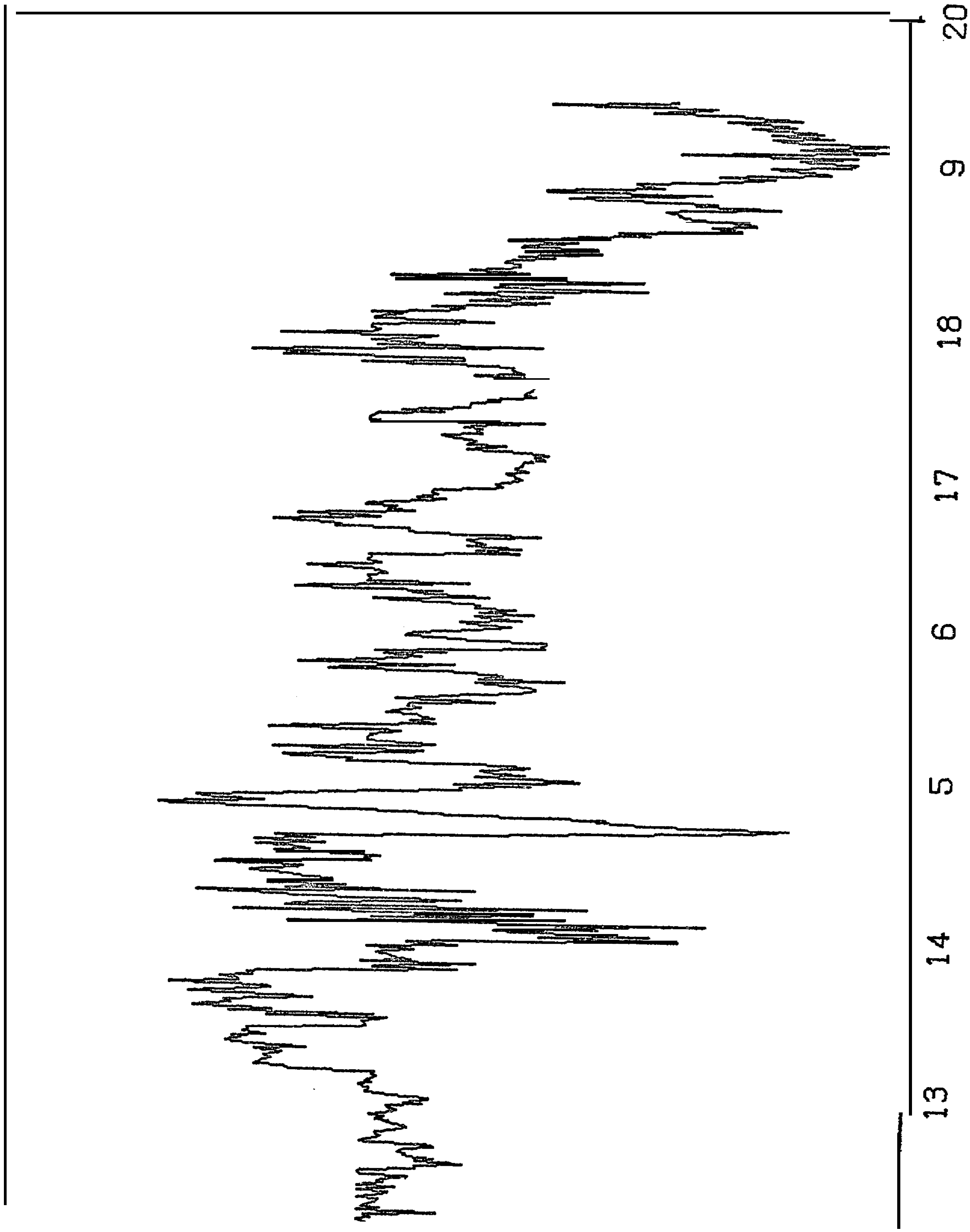


Figure 3

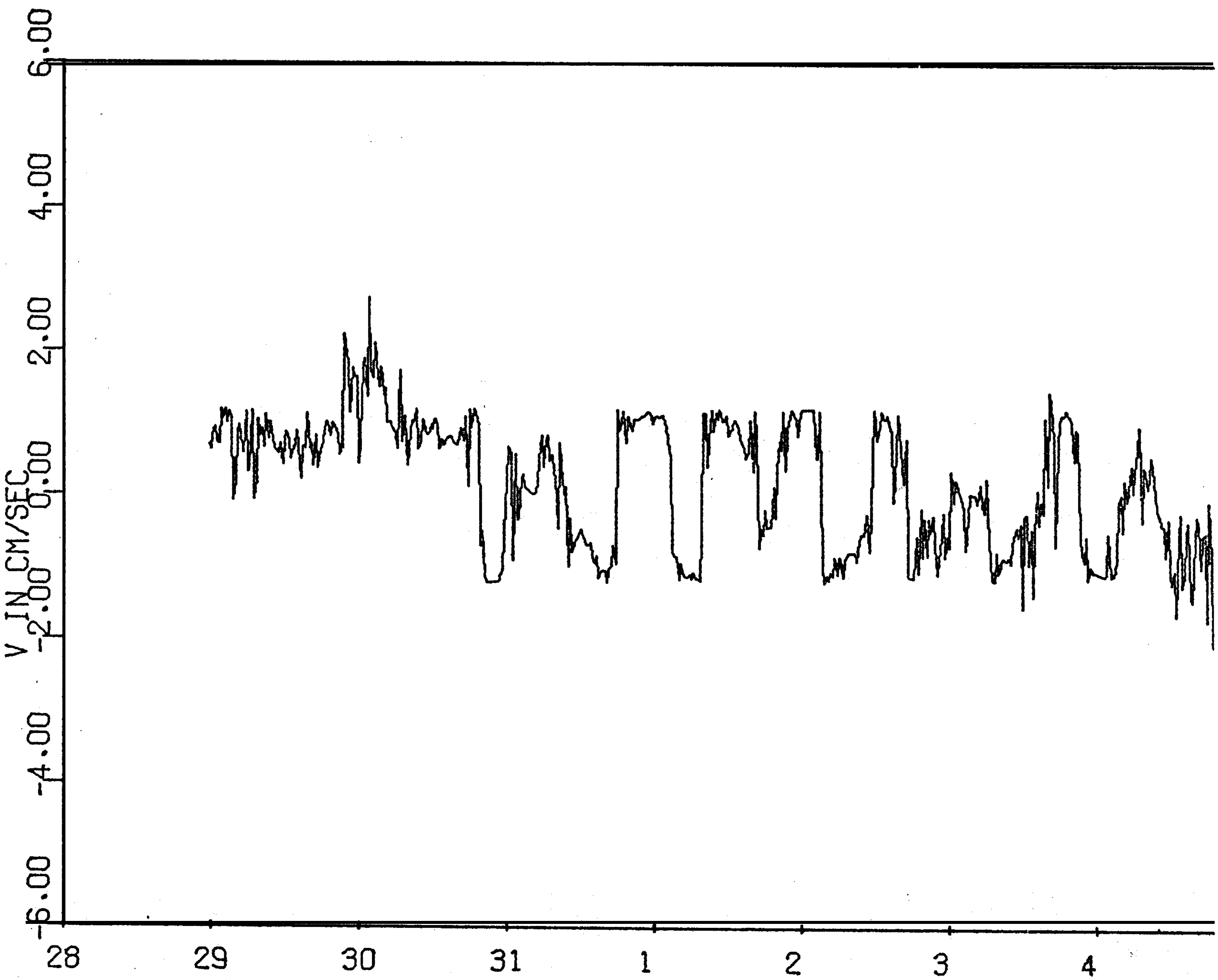


Figure 4

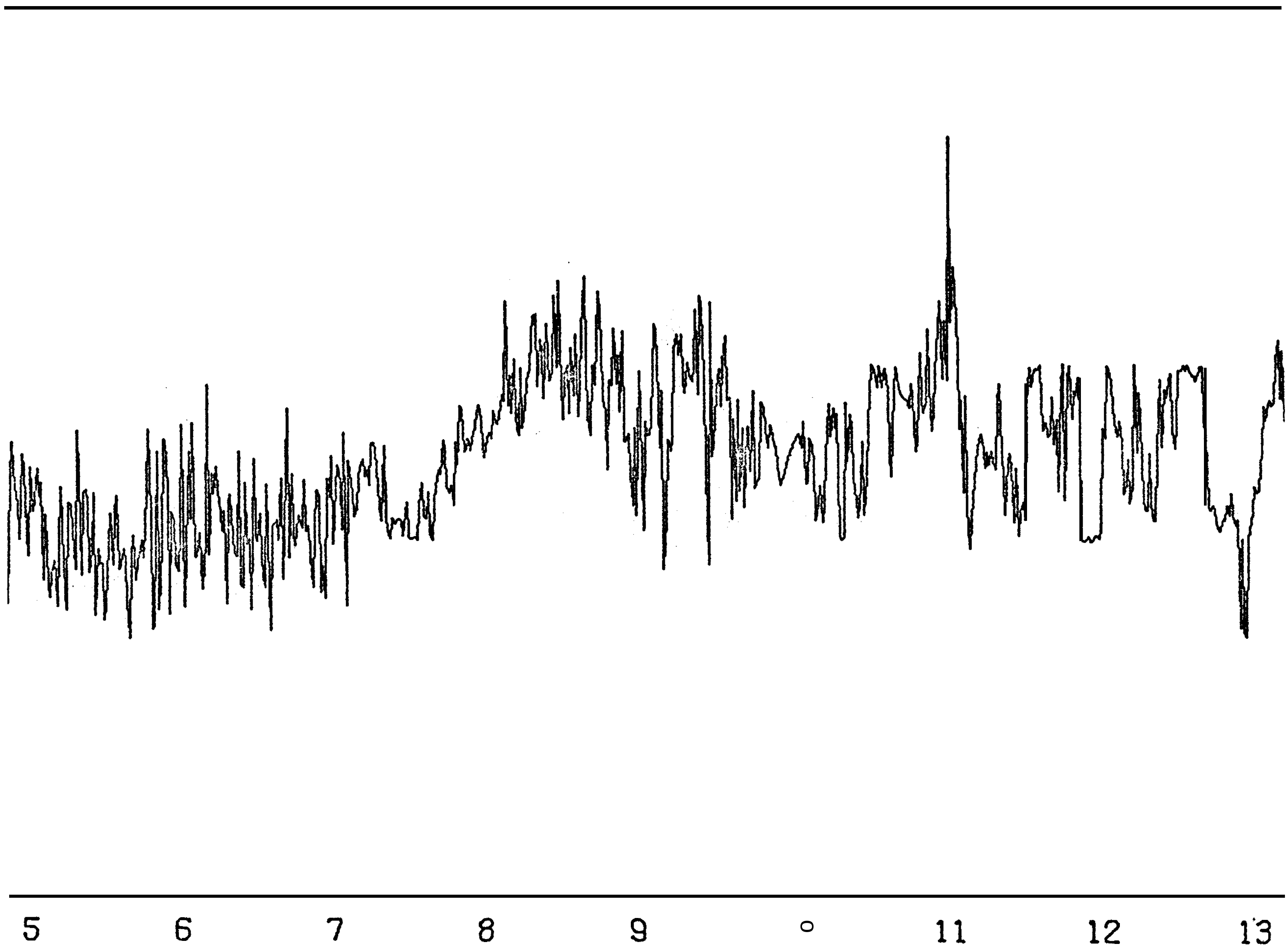


Figure 5

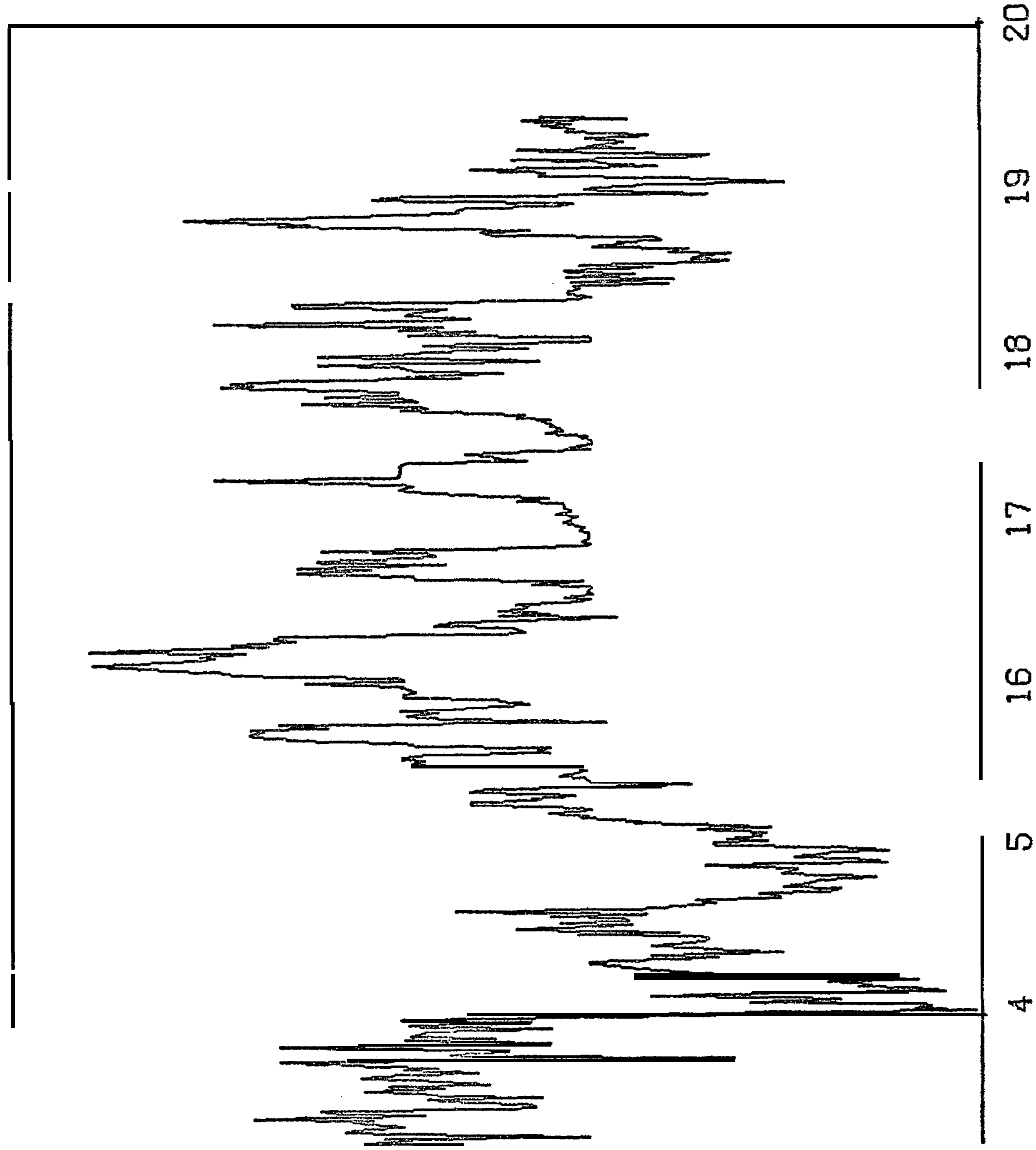


Figure 6

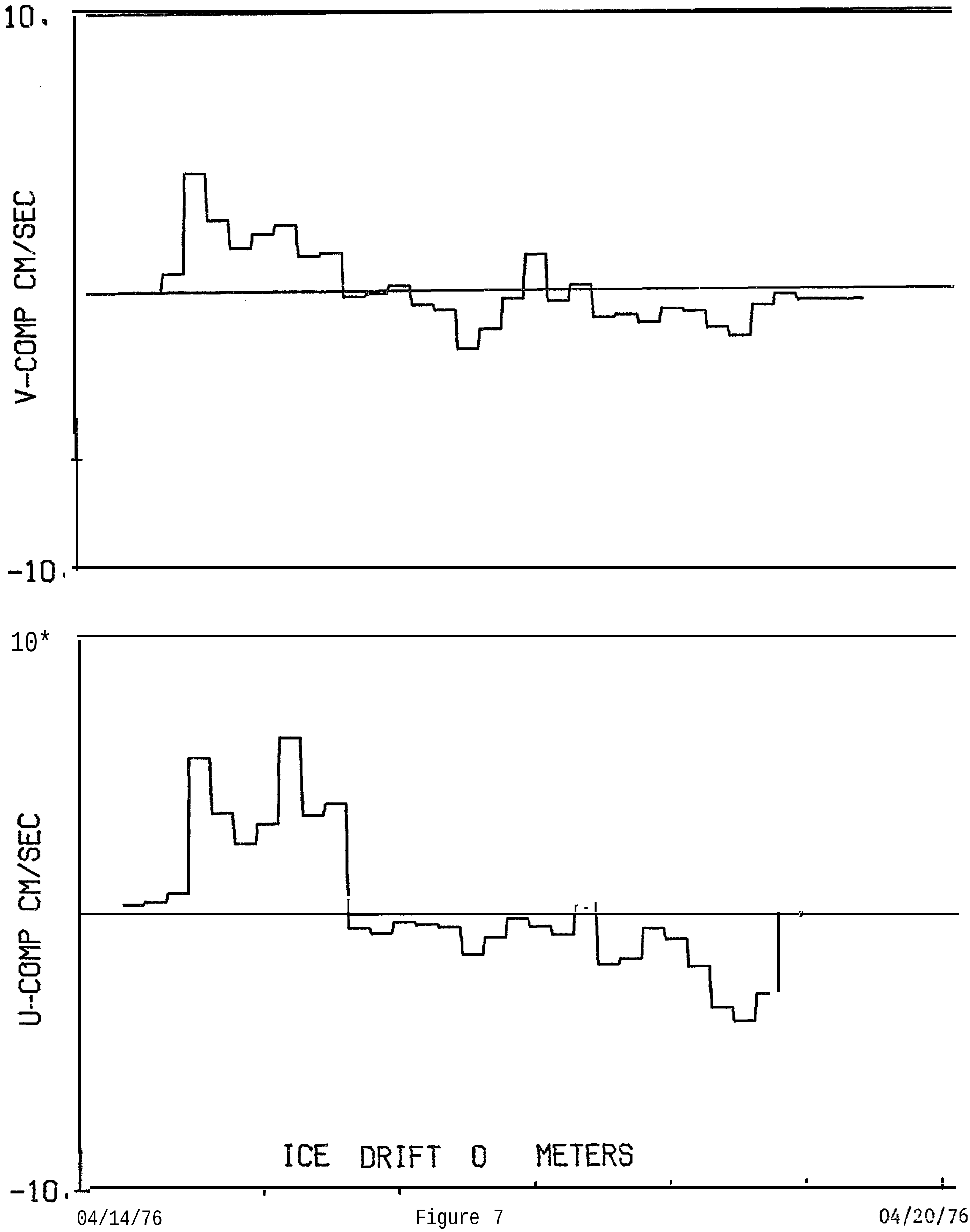

10.
V-COMP CM/SEC
-10.
10*
U-COMP CM/SEC
ICE DRIFT 0 METERS
-10.
04/14/76
04/20/76

Figure 7

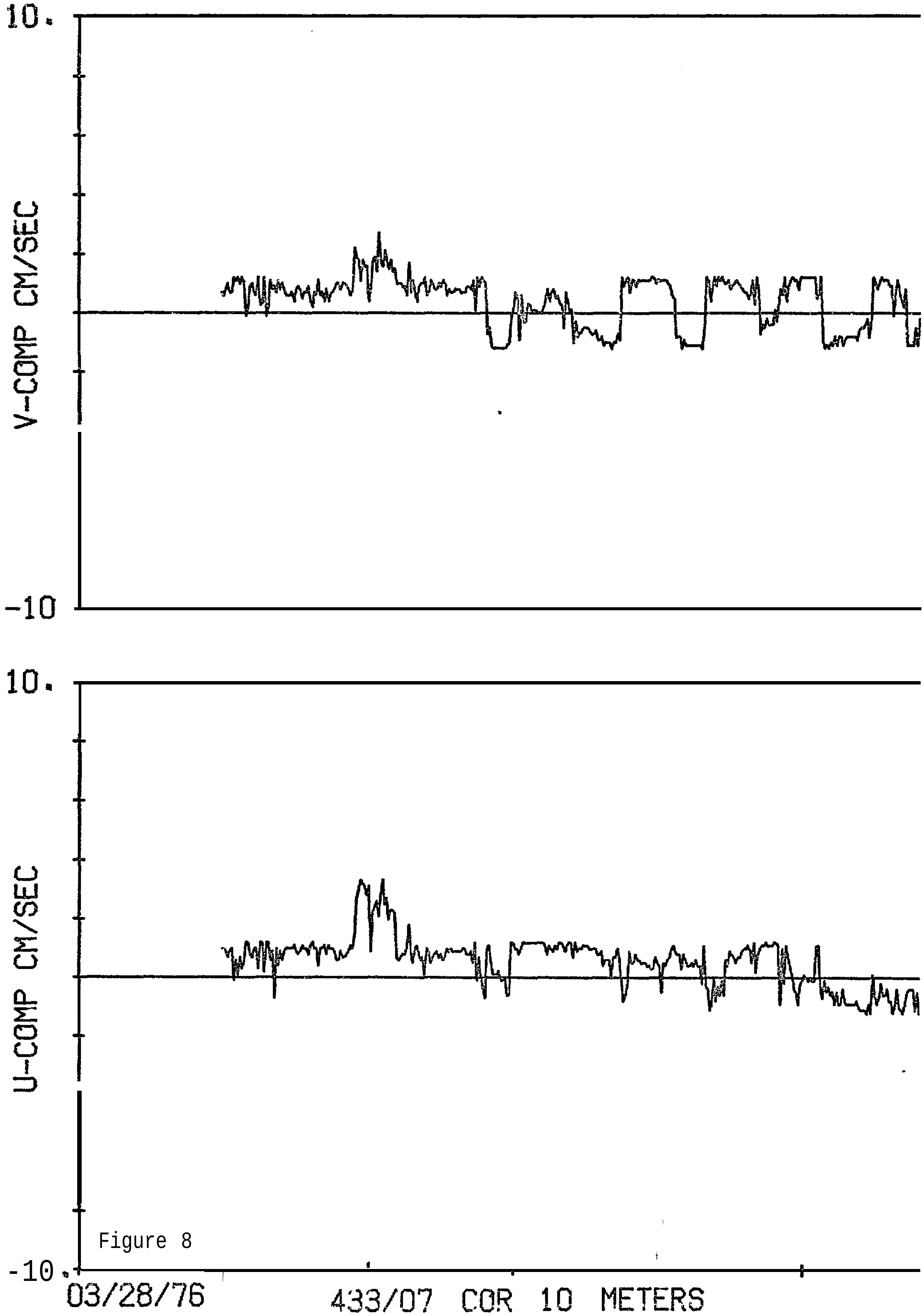

10.
V-COMP CM/SEC
-10
10.
U-COMP CM/SEC
-10.
03/28/76
433/07 COR 10 METERS

Figure 8

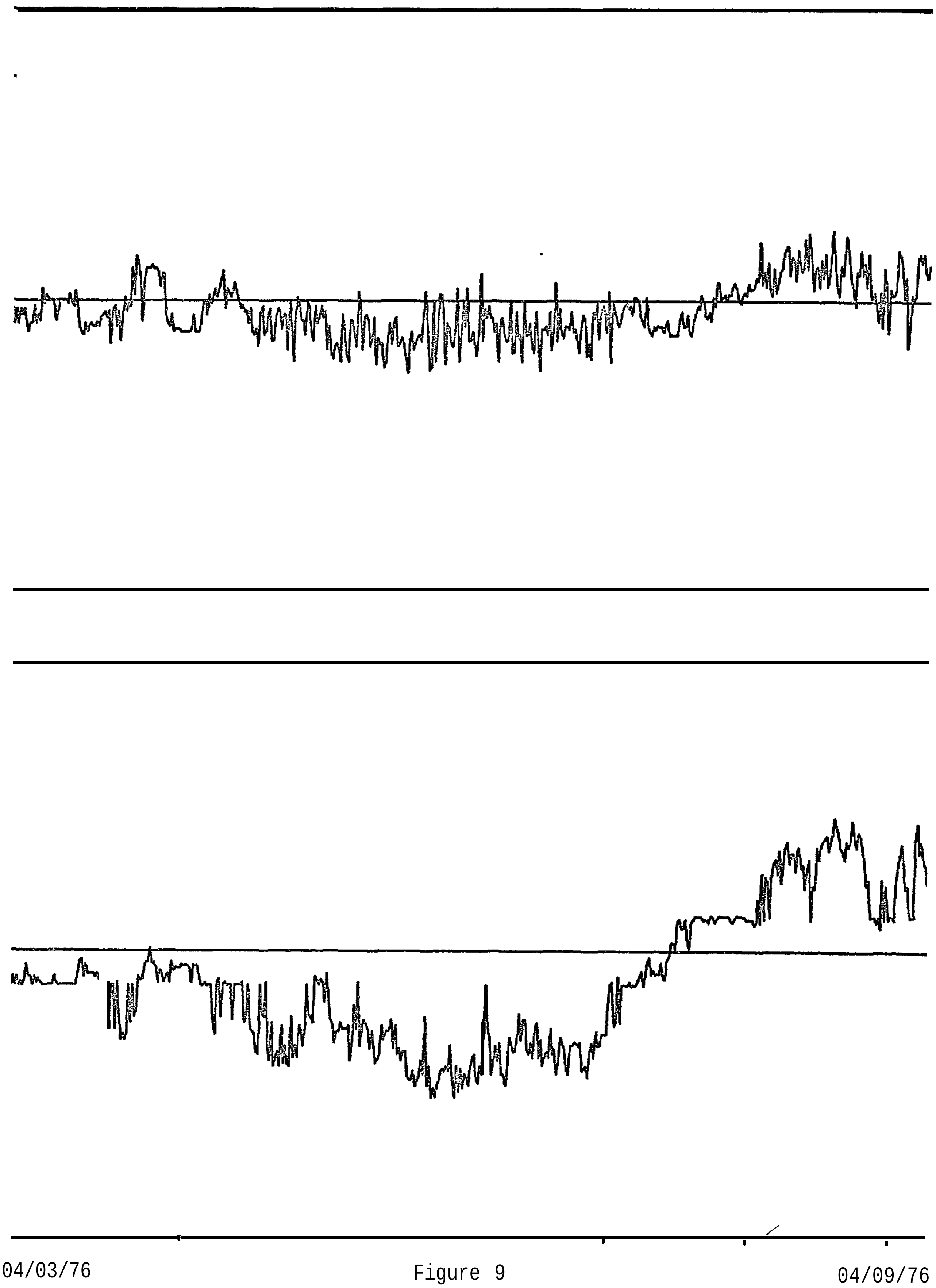


Figure 9

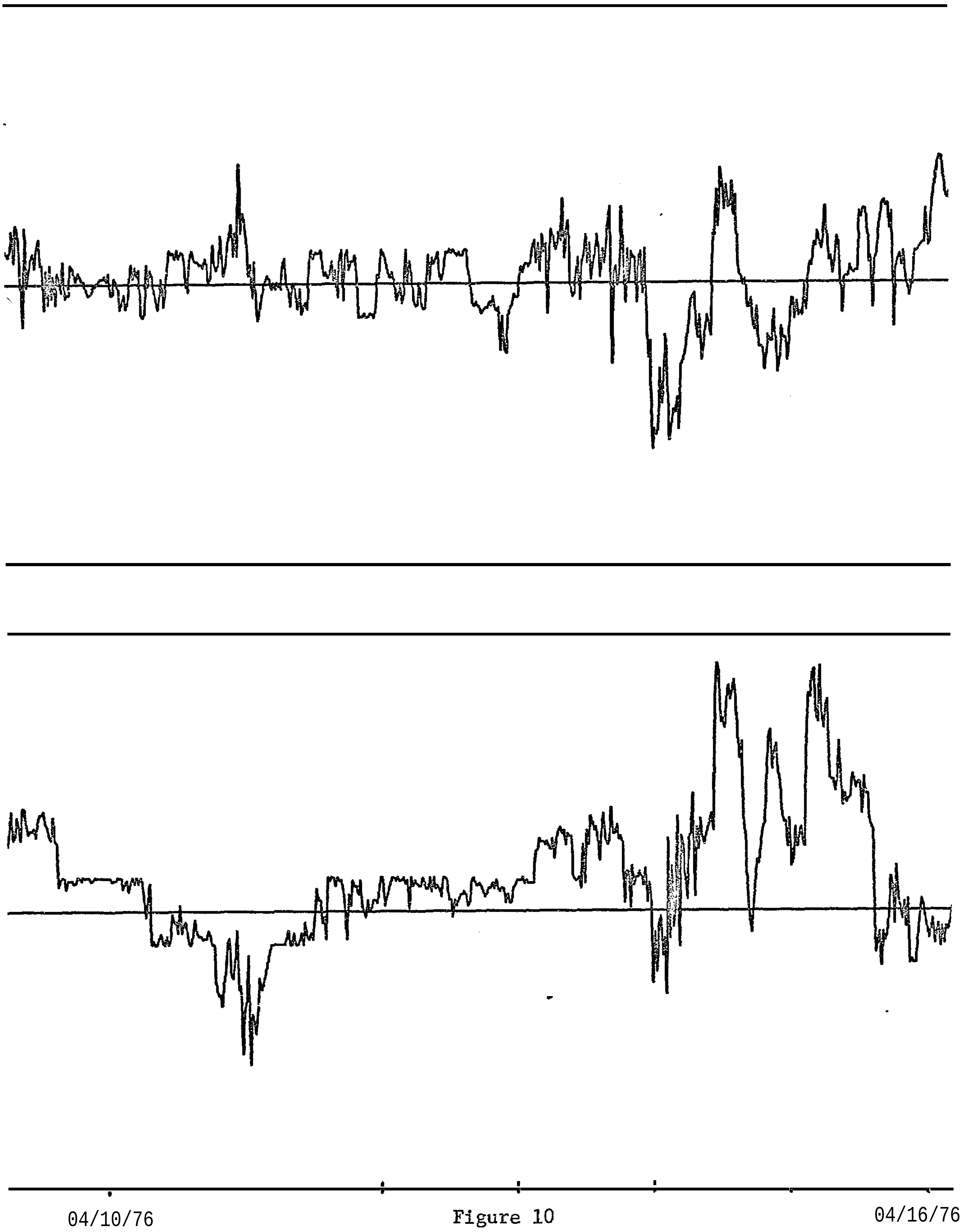


Figure 10

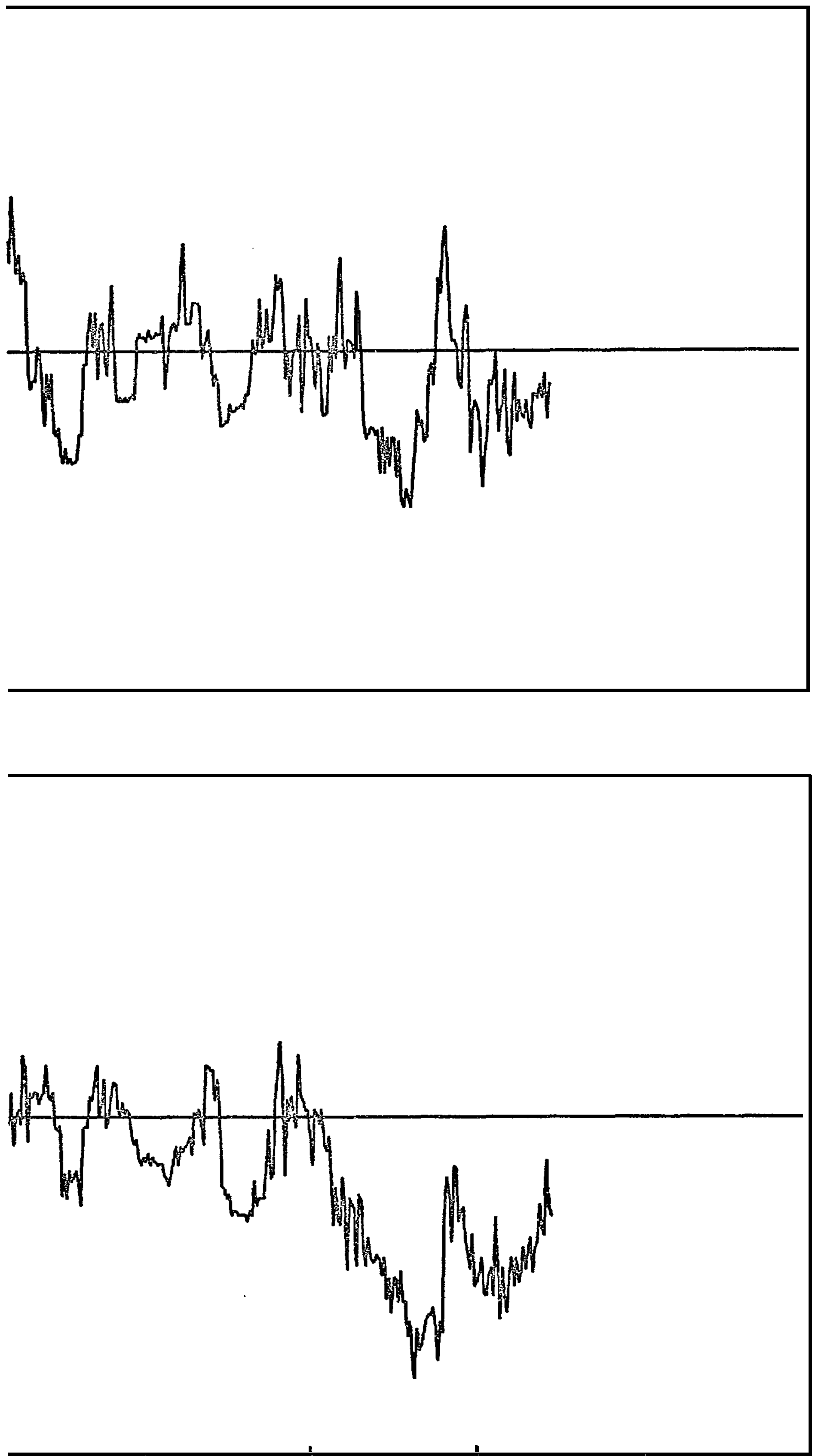


Figure 11

04/'2 ./76

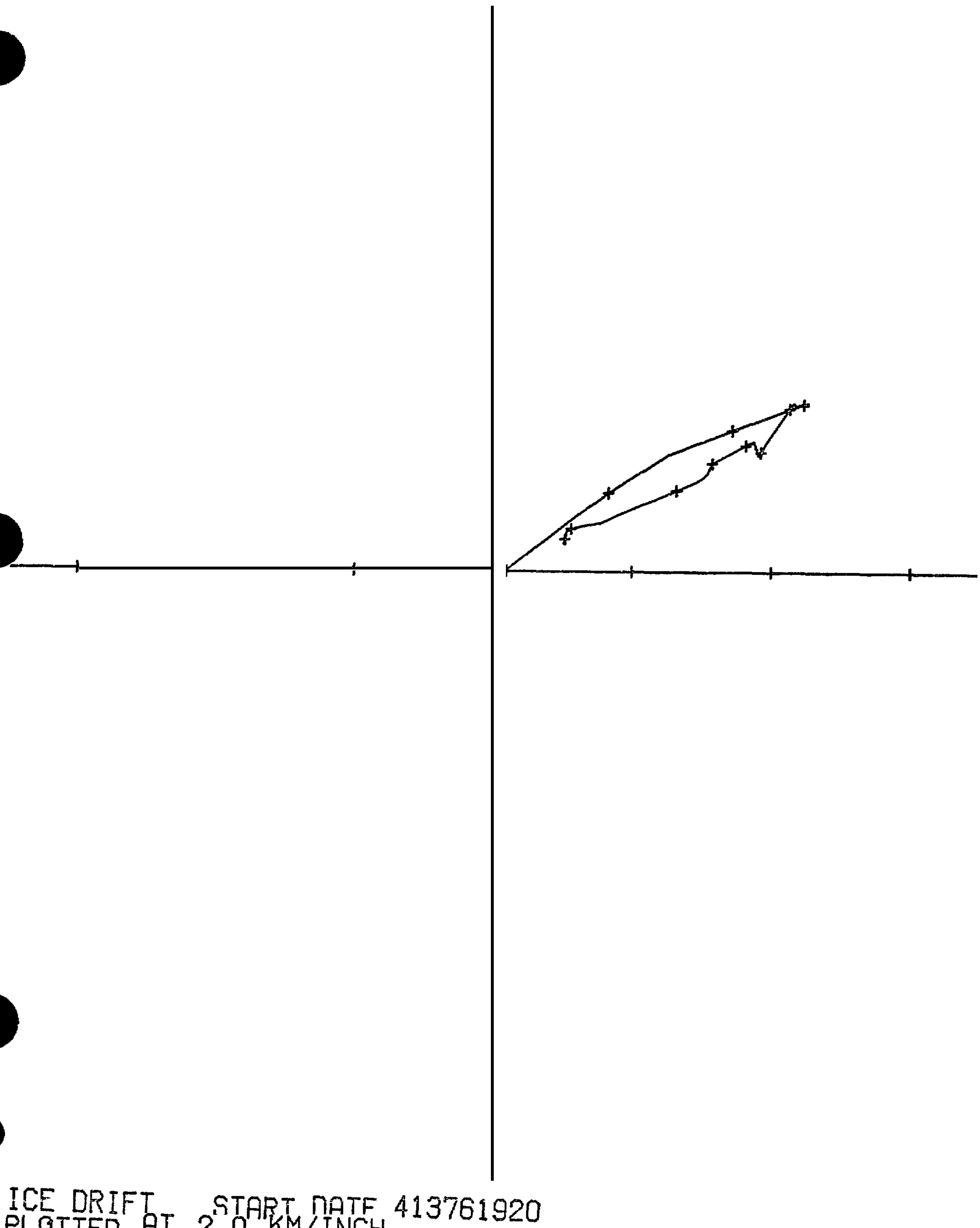


Figure 12

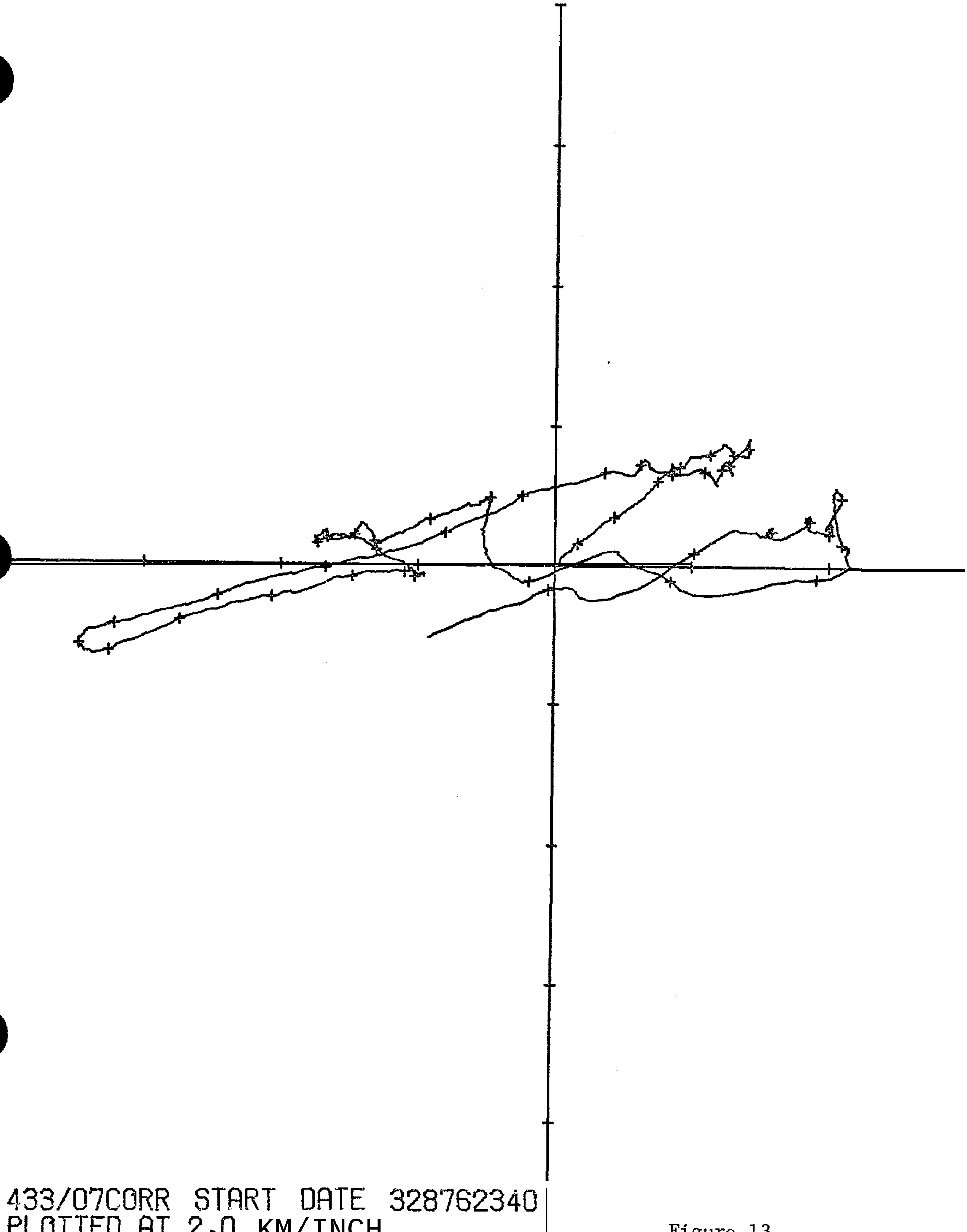


Figure 13

Figures 14-19 show the components of motion at meter 437. The speeds were even lower than at meter 433, never exceeding 6 cm sec^{-1}. With the possible exception of the events during 4-6 April, when there was a burst of motion toward the southwest, there is no apparent correlation between water motion at the two meters. Figure 20 is the progressive vector diagram for meter 437; it can be compared with Figure 13.

Again the record suggests small oscillations of tidal frequency with amplitude in the range 1-2 cm sec^{-1}, and with no clear phase difference between components.

The mean motion was comparable to that at meter 433, being 0.3 cm see-l toward 248°T.

The spectra for the two records are shown in Figure 21-26. The energy levels are of course very low, and only for the east component at meter 433 is there a low-frequency maximum. Relatively strong signals appear in both the diurnal and semi-diurnal tidal bands, corresponding to an amplitude of about 1 cm sec^{-1}, or a bit more. The spectral estimates indicate the presence of the K_1 component at both meters, but can distinguish M2 only at meter 437. The K_1 signals in the east and north components are coherent at each meter and in phase, but the M2 signals are incoherent.

These two records thus show motion on the inner shelf to have been small, generally with a 20-minute mean of 5 cm see-l or less, and only on a few occasions approaching 10 cm sec^{-1} (and then only at the outer meter). The mean motion over more than three weeks was very small, one-fourth kilometer per day or less, and directed west-southwest. Tidal currents were of order 1 cm see-l, with comparable energy in both the diurnal and semi-diurnal bands. However, only the K_1 component was clearly identifiable in both records.

We turn now to the mooring on the outer shelf north of Oliktok. Current meter no. 660 was suspended at a nominal depth of 100 m, in water 225 m deep. Figures 27-42 show the east (U) and north (V) components of velocity at this meter from 1215 GMT on 27 May 1976 to 1200 GMT on 14 July, and from 1215 GMT on 16 July to 0830 GMT on 1 September. The two-day gap in the middle of the record, along with the truncated end and beginning are due to noise and other data reduction problems which have not yet been satisfactorily resolved. The portions of the records shown here were relatively clean.

The difference between these currents and those observed on the inner shelf is remarkable. The speeds are a full order of magnitude greater than those observed on the inner shelf. The velocity varied between 56 cm see-l easterly and 26 cm see-l westerly. The entire 95-day record is dominated by large low-frequency oscillations which have a typical peak-to-peak amplitude exceeding 50 cm see-l and a time scale of order 10 days. The oscillations are not centered about the line of zero velocity, but rather are offset in the direction of positive U-component. In effect, therefore, the oscillations represent long bursts of high easterly velocity separated by shorter periods of lesser flow toward the west. Between the easterly bursts there were frequently smaller oscillations with amplitude and time scale of order 10 cm see-l and 2 days, respectively.

The flow did not alternate strictly between east and west, for there were also appreciable north-south motions. Rather there was a tendency for the water

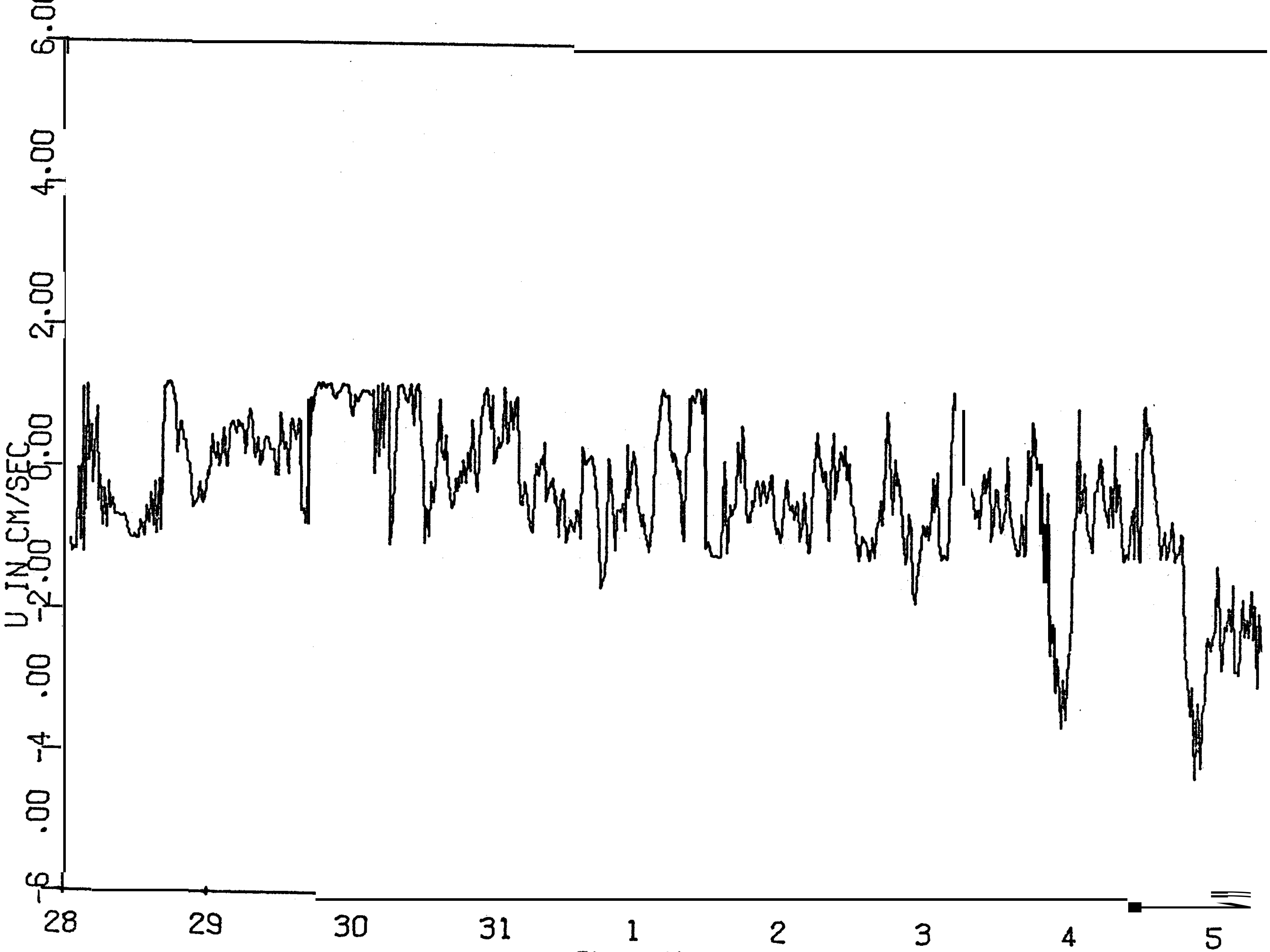


Figure 14

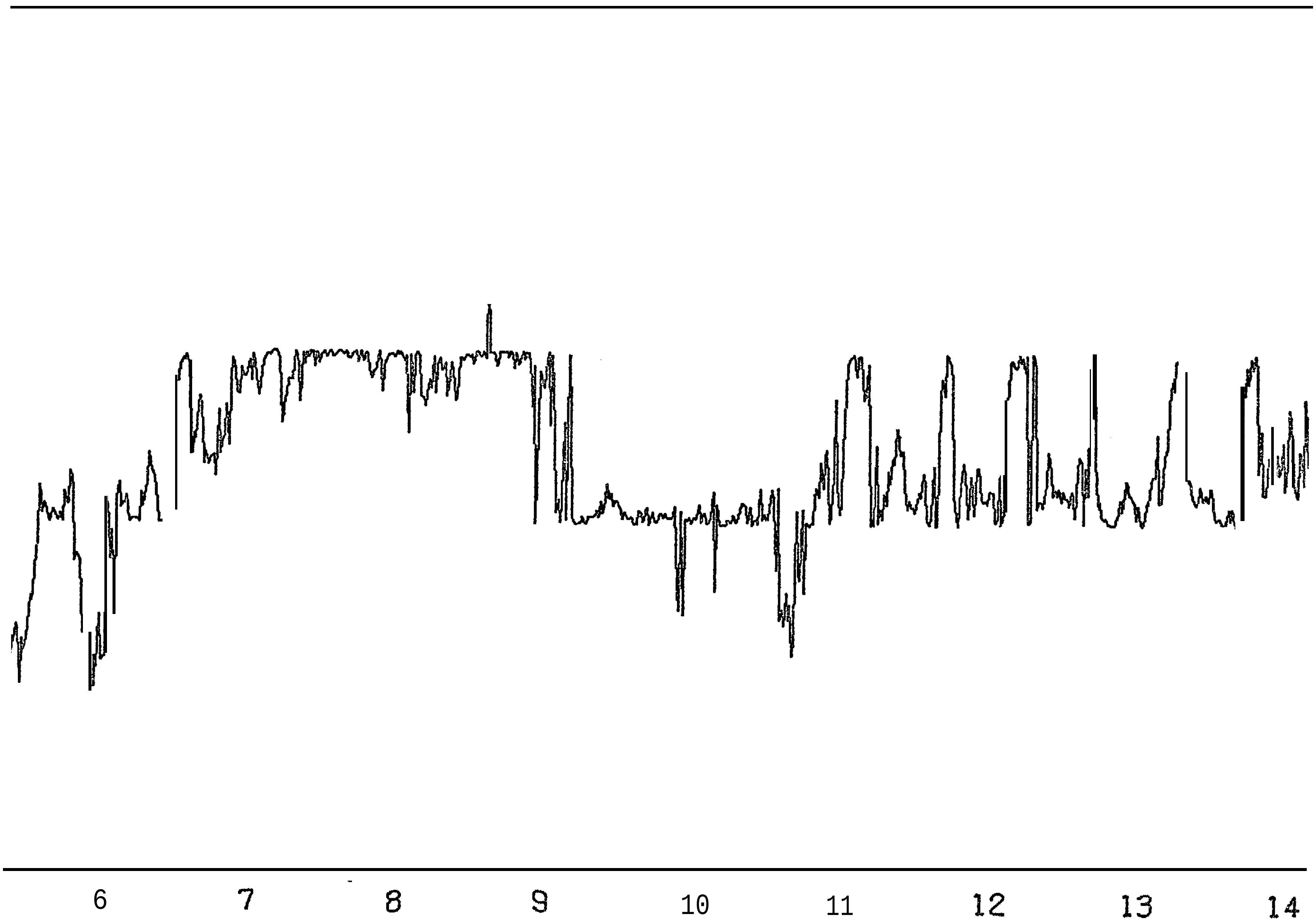


Figure 15

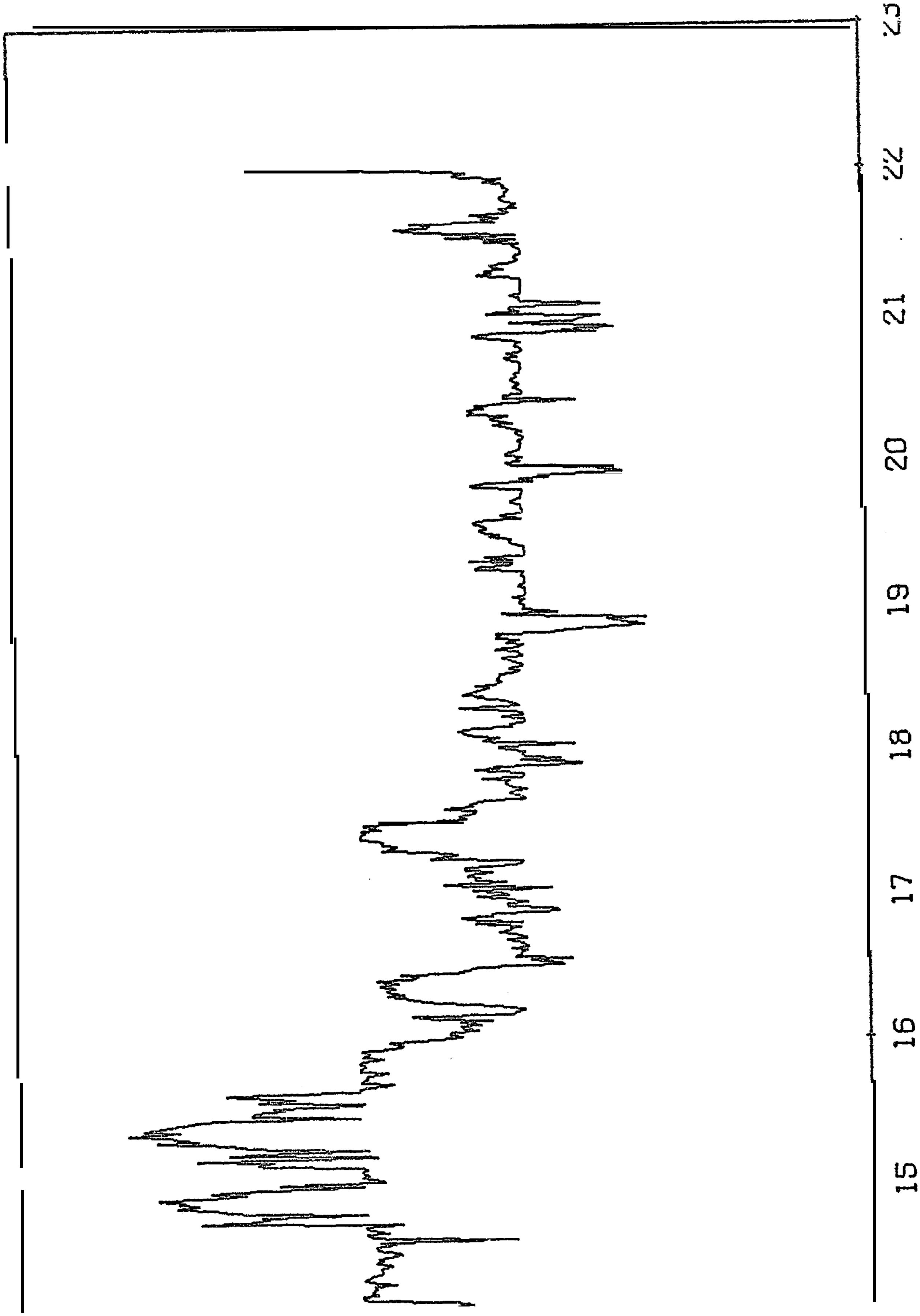


Figure 16

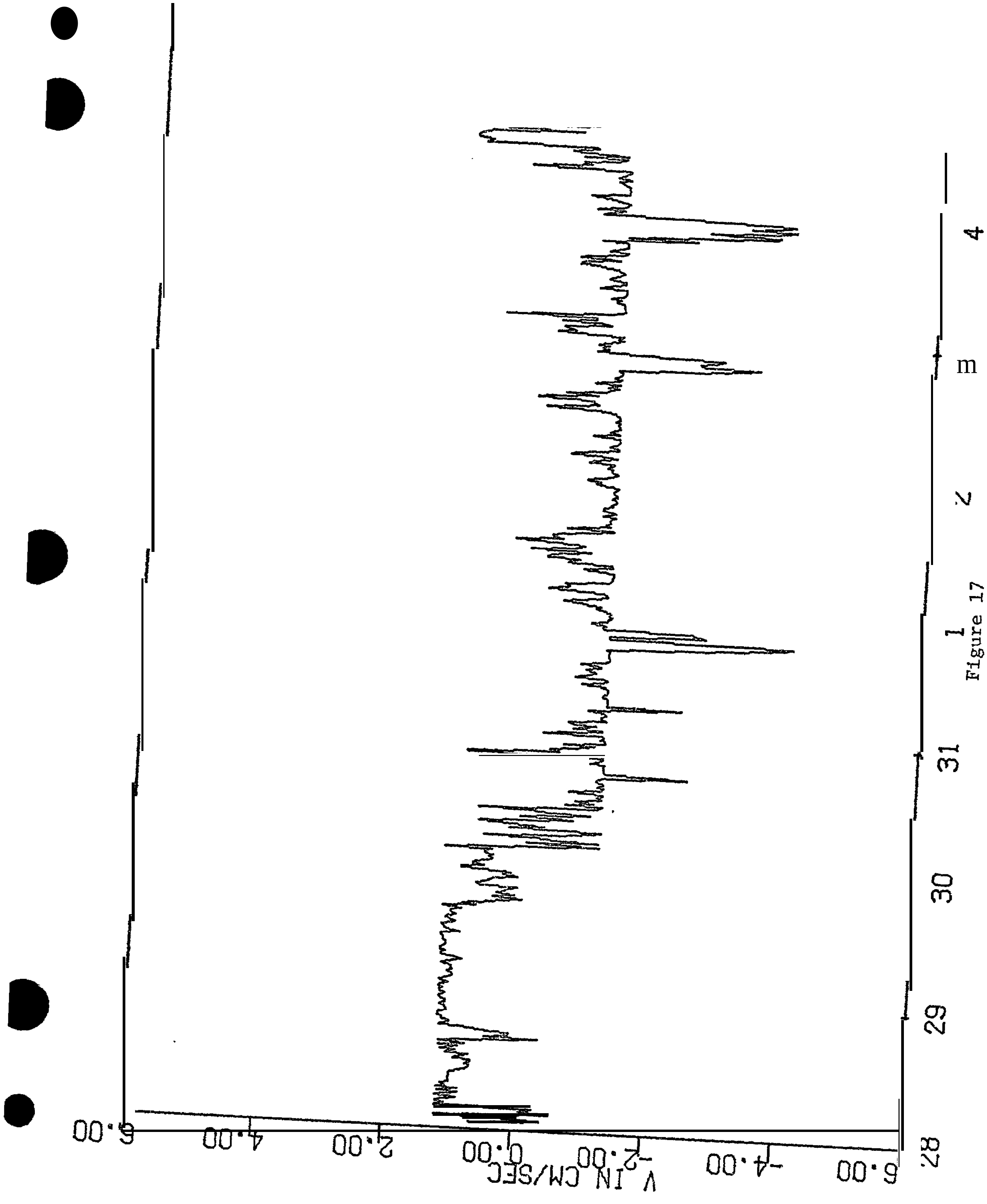


Figure 17

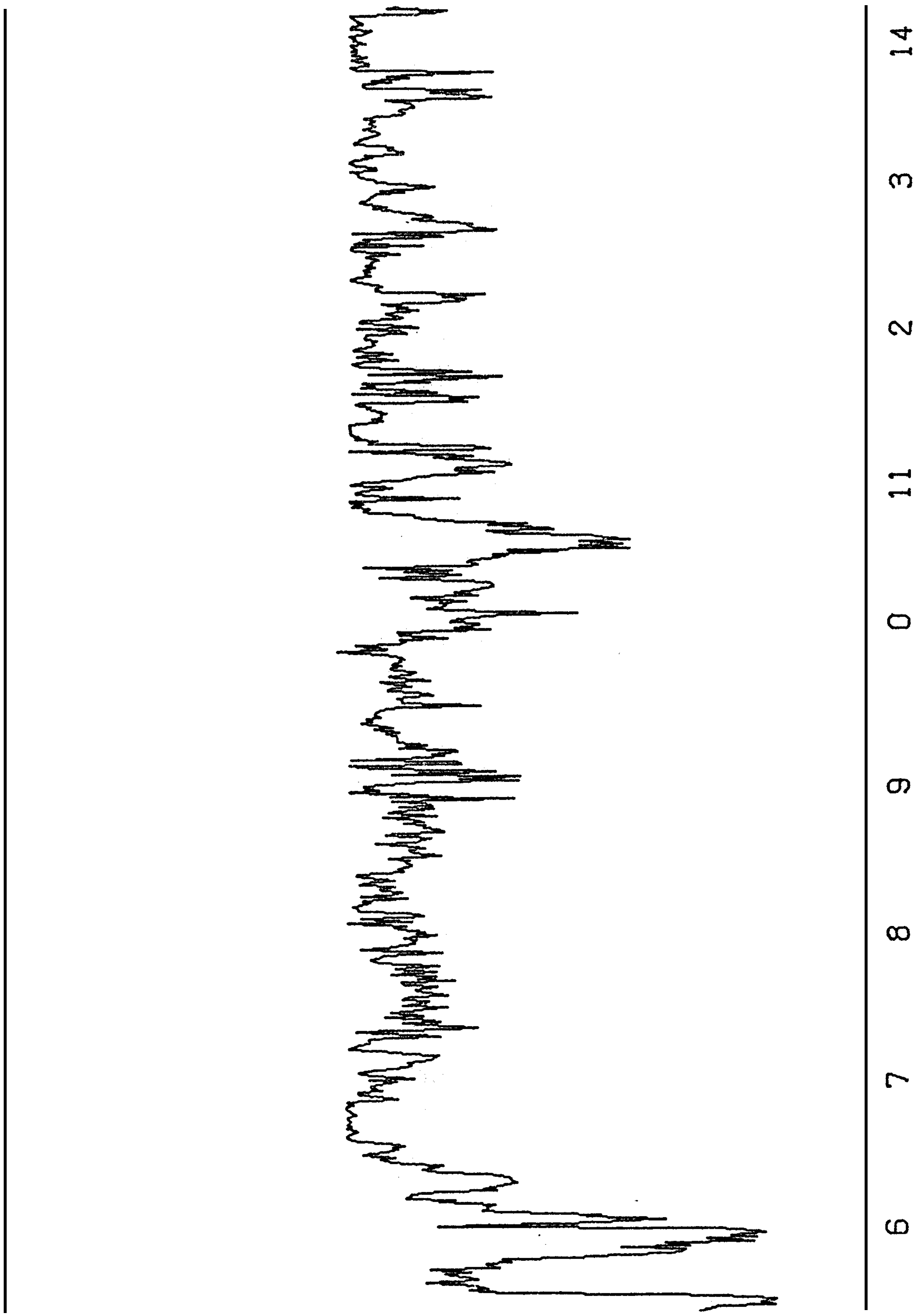


Figure 18

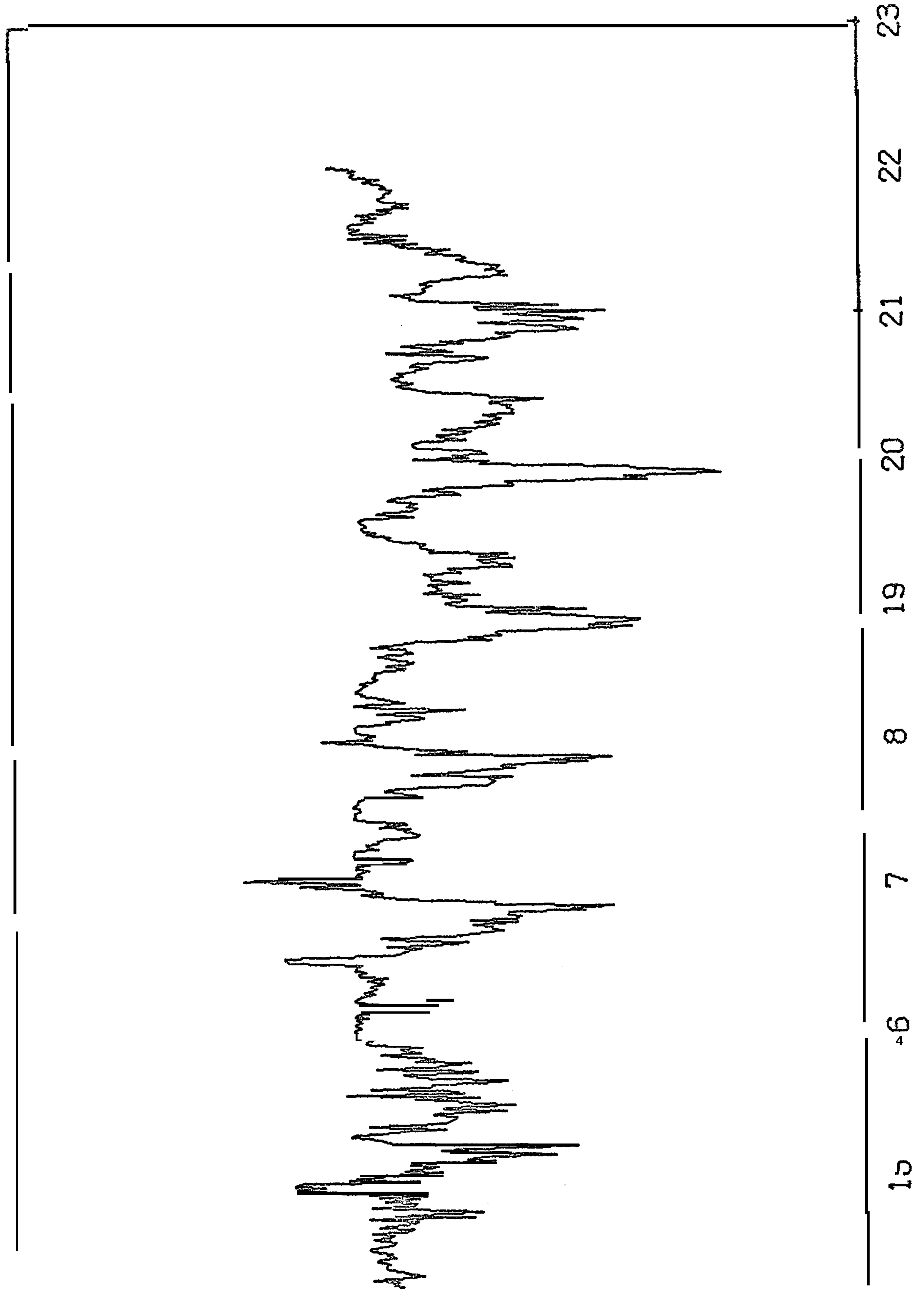


Figure 19

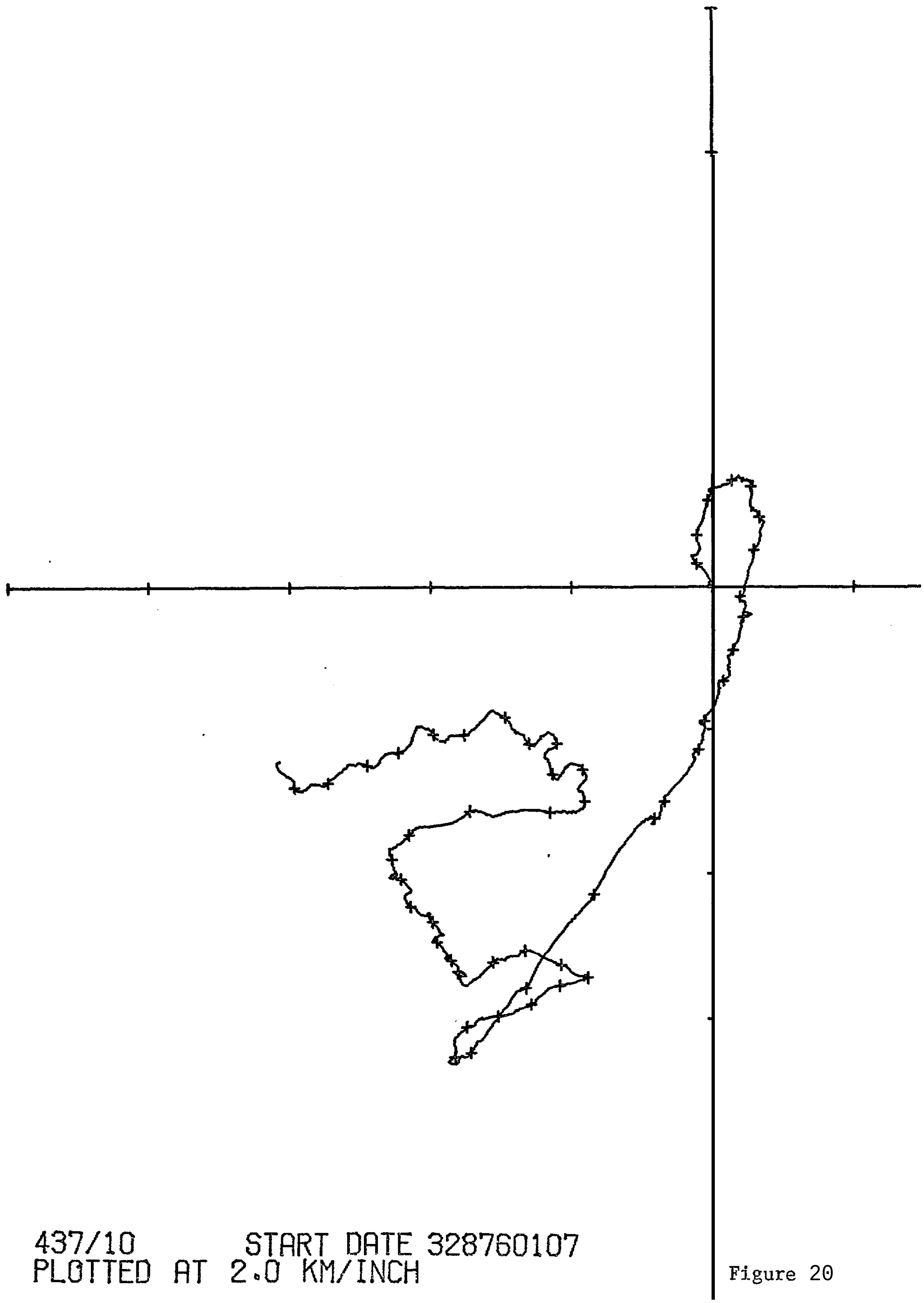


Figure 20

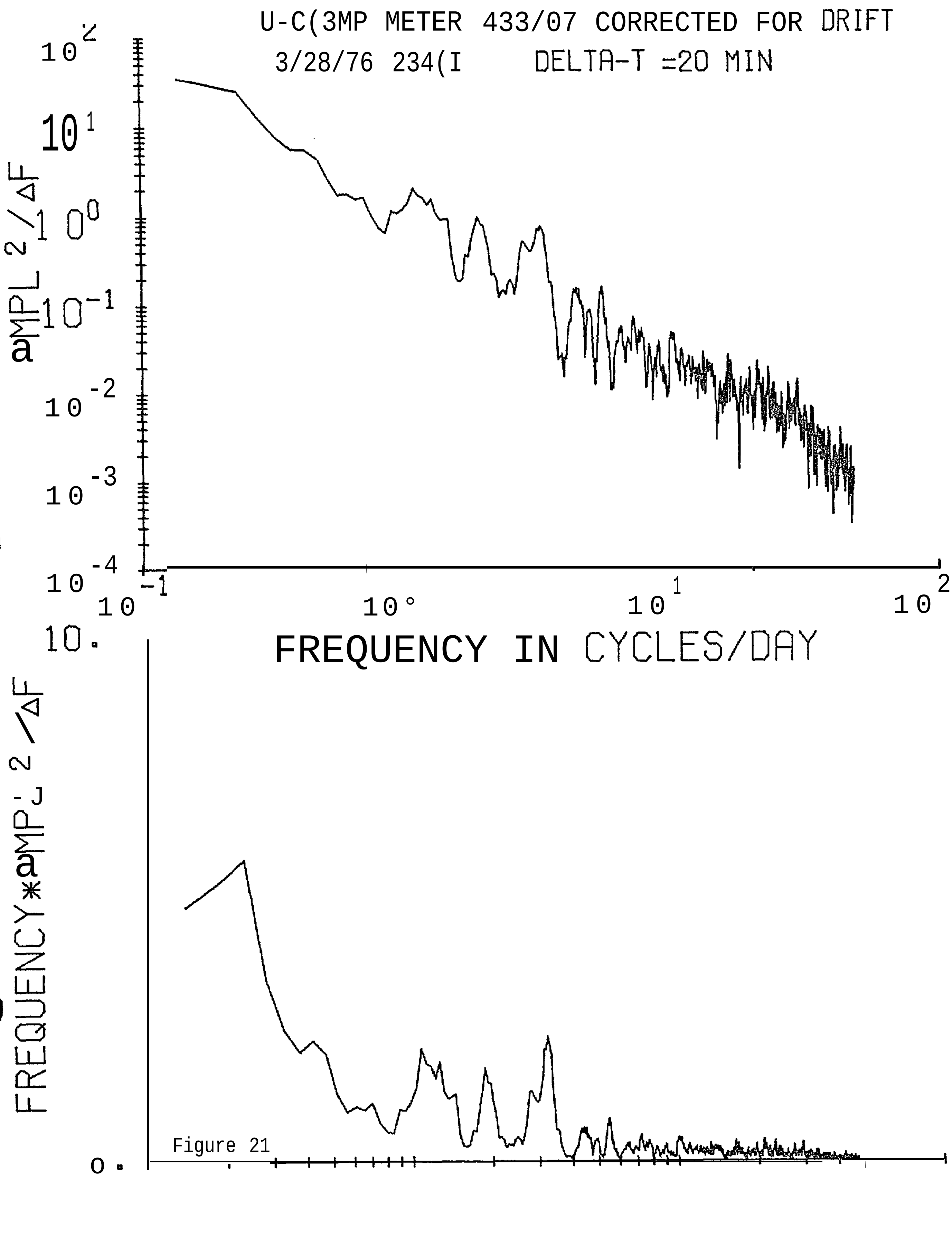

U-C(3MP METER 433/07 CORRECTED FOR DRIFT
3/28/76 234(I DELTA-T =20 MIN
aMPL 2/ΔF
FREQUENCY IN CYCLES/DAY
FREQUENCY*aMP'J 2 /ΔF

Figure 21

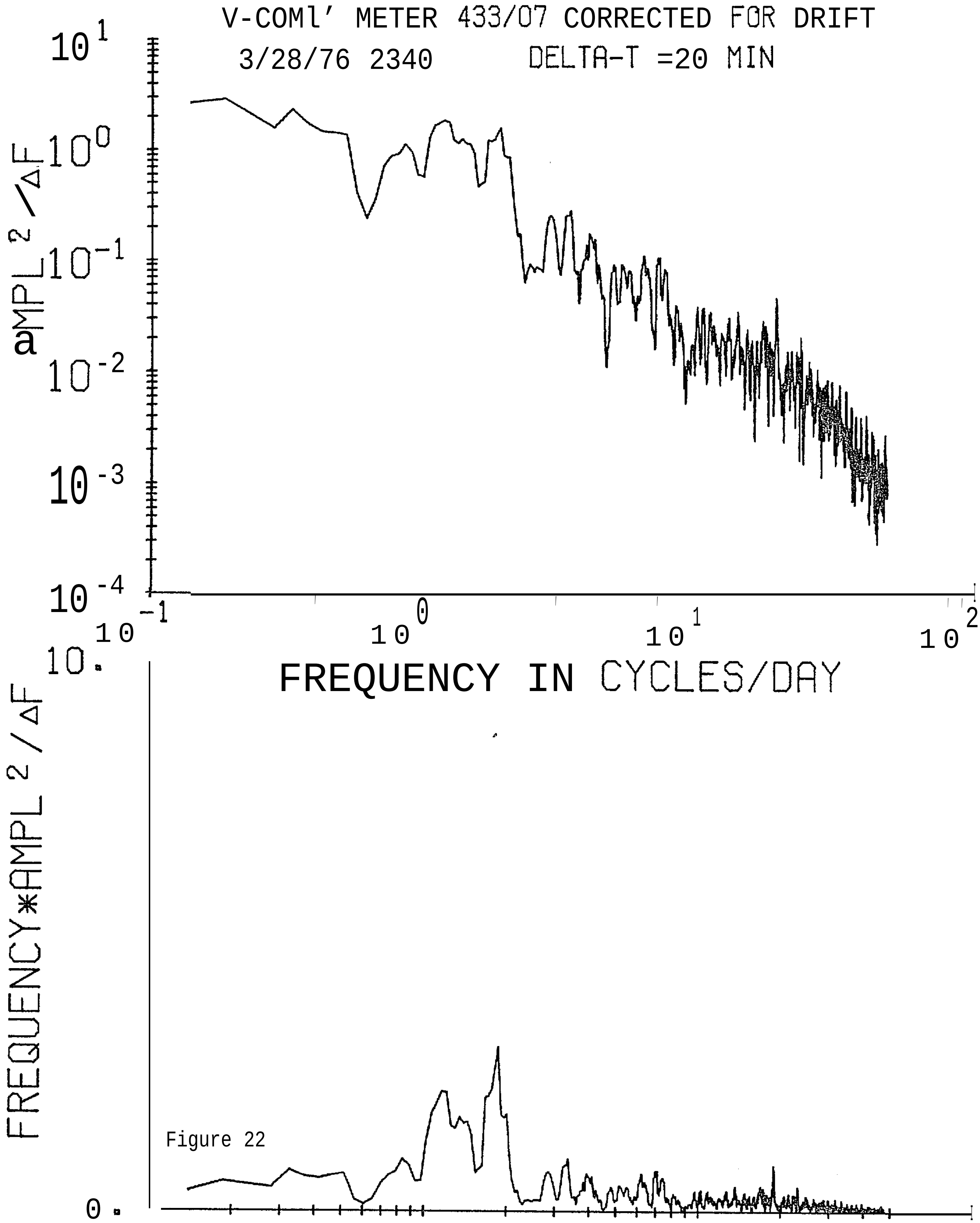

V-COMl' METER 433/07 CORRECTED FOR DRIFT
3/28/76 2340
DELTA-T =20 MIN
AMPL 2 /ΔF
10 1
10 0
10 -1
10 -2
10 -3
10 -4
10 -1
10 0
10 1
10 2
FREQUENCY IN CYCLES/DAY
FREQUENCY*AMPL 2 /ΔF
10.
0.

Figure 22

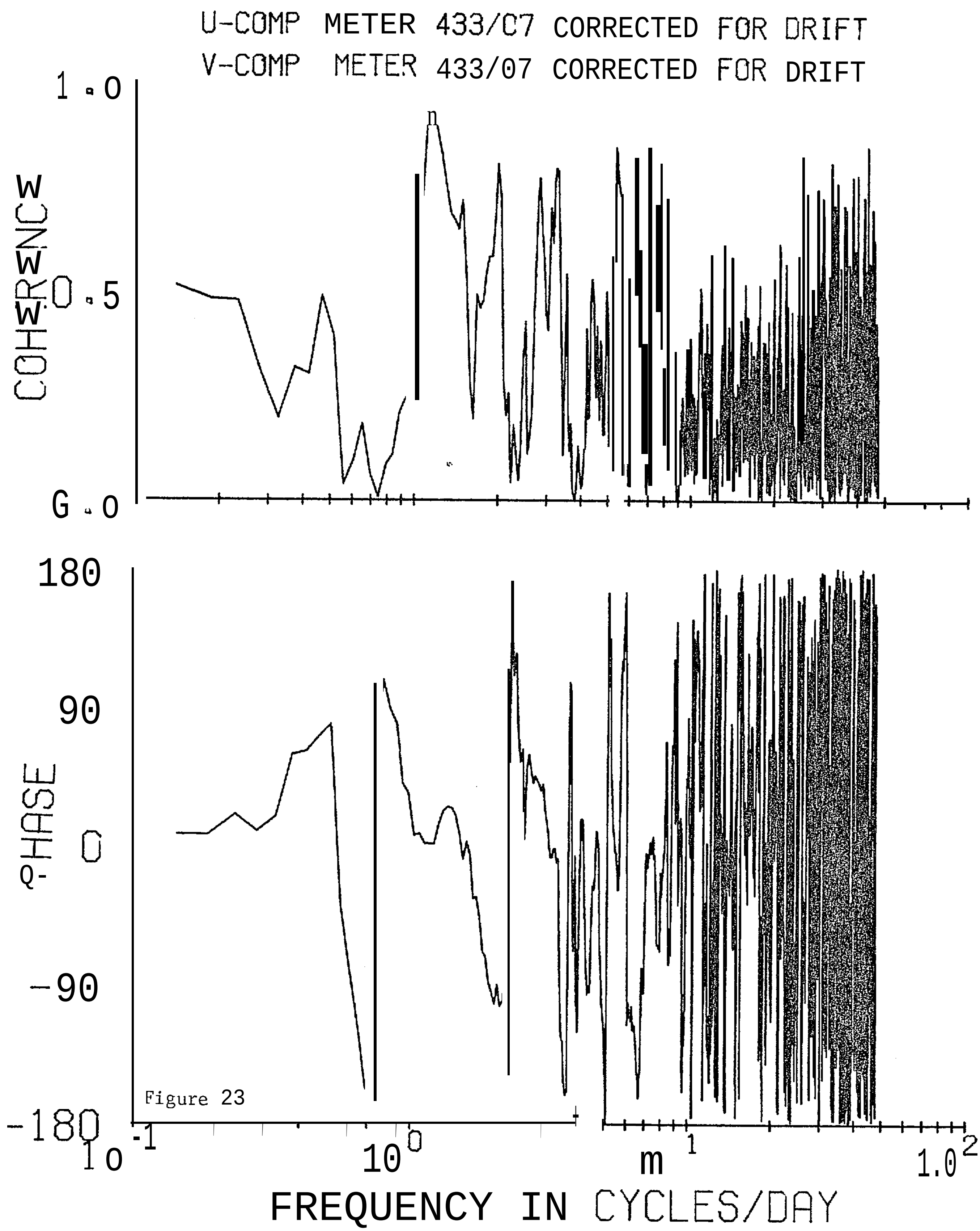

U-COMP METER 433/C7 CORRECTED FOR DRIFT
V-COMP METER 433/07 CORRECTED FOR DRIFT
1.0
0.5
G.0
180
90
0
-90
-180
FREQUENCY IN CYCLES/DAY

Figure 23

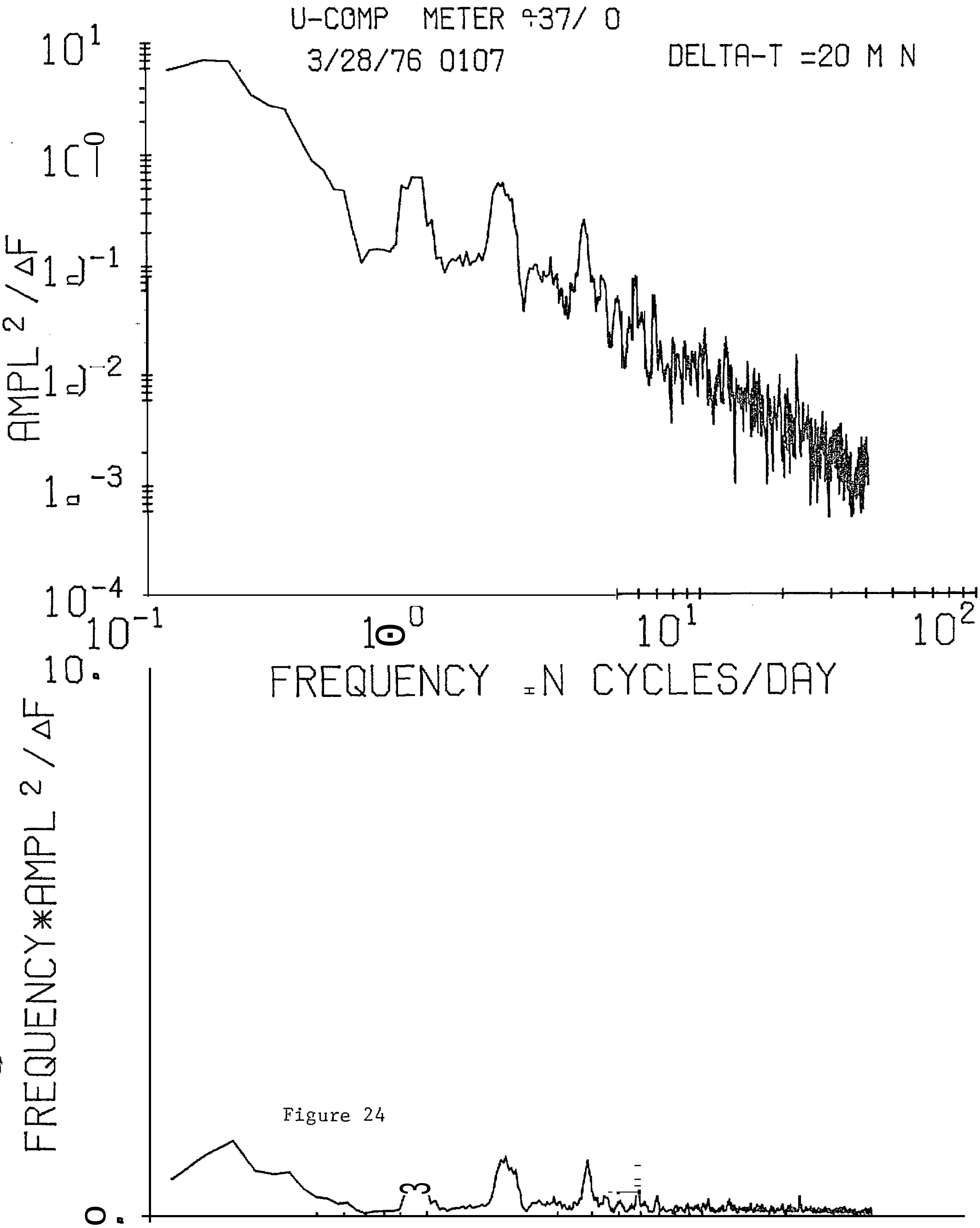

U-COMP METER ÷37/ 0
3/28/76 0107
DELTA-T =20 M N
AMPL 2 / ΔF
FREQUENCY N CYCLES/DAY
FREQUENCY*AMPL 2 / ΔF

Figure 24

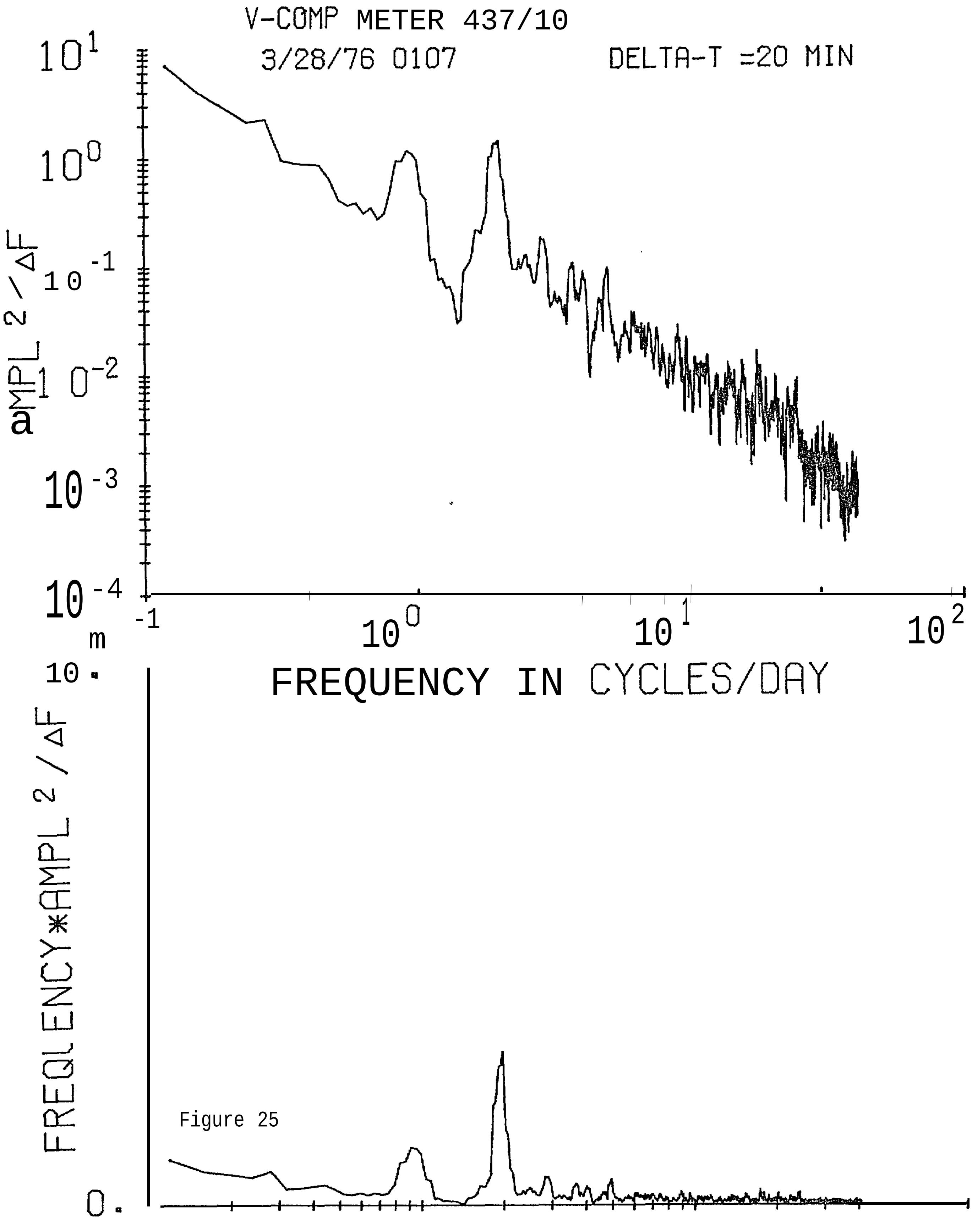

V-COMP METER 437/10
3/28/76 0107
DELTA-T =20 MIN
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
AMPL 2 /ΔF
-1
10^0
10^1
10^2
FREQUENCY IN CYCLES/DAY
10
0
FREQUENCY*AMPL 2 /ΔF

Figure 25

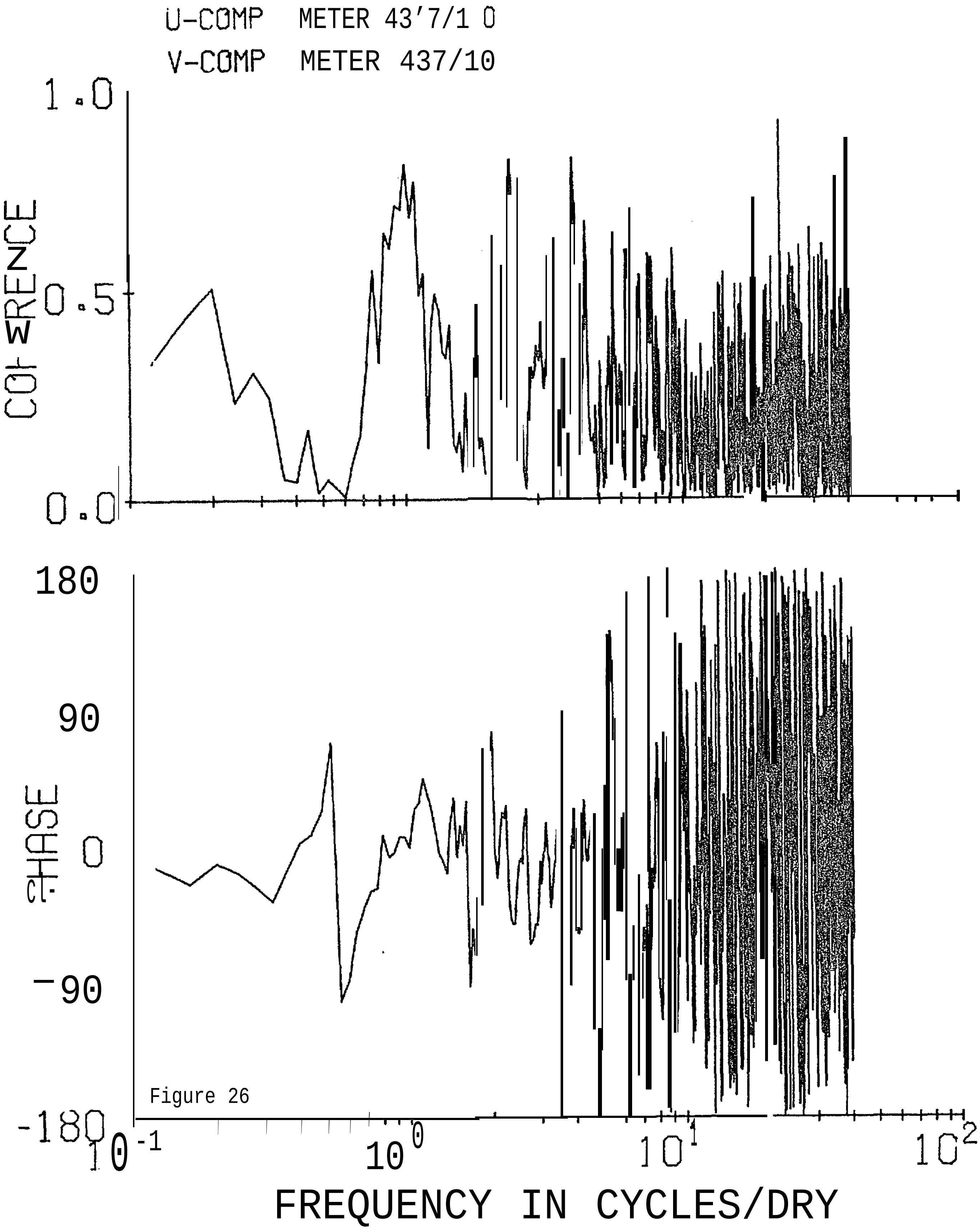

U-COMP METER 43'7/1 0
V-COMP METER 437/10
1.0
0.5
0.0
COHERENCE
180
90
0
-90
-180
PHASE
10-1
100
101
102
FREQUENCY IN CYCLES/DRY

Figure 26

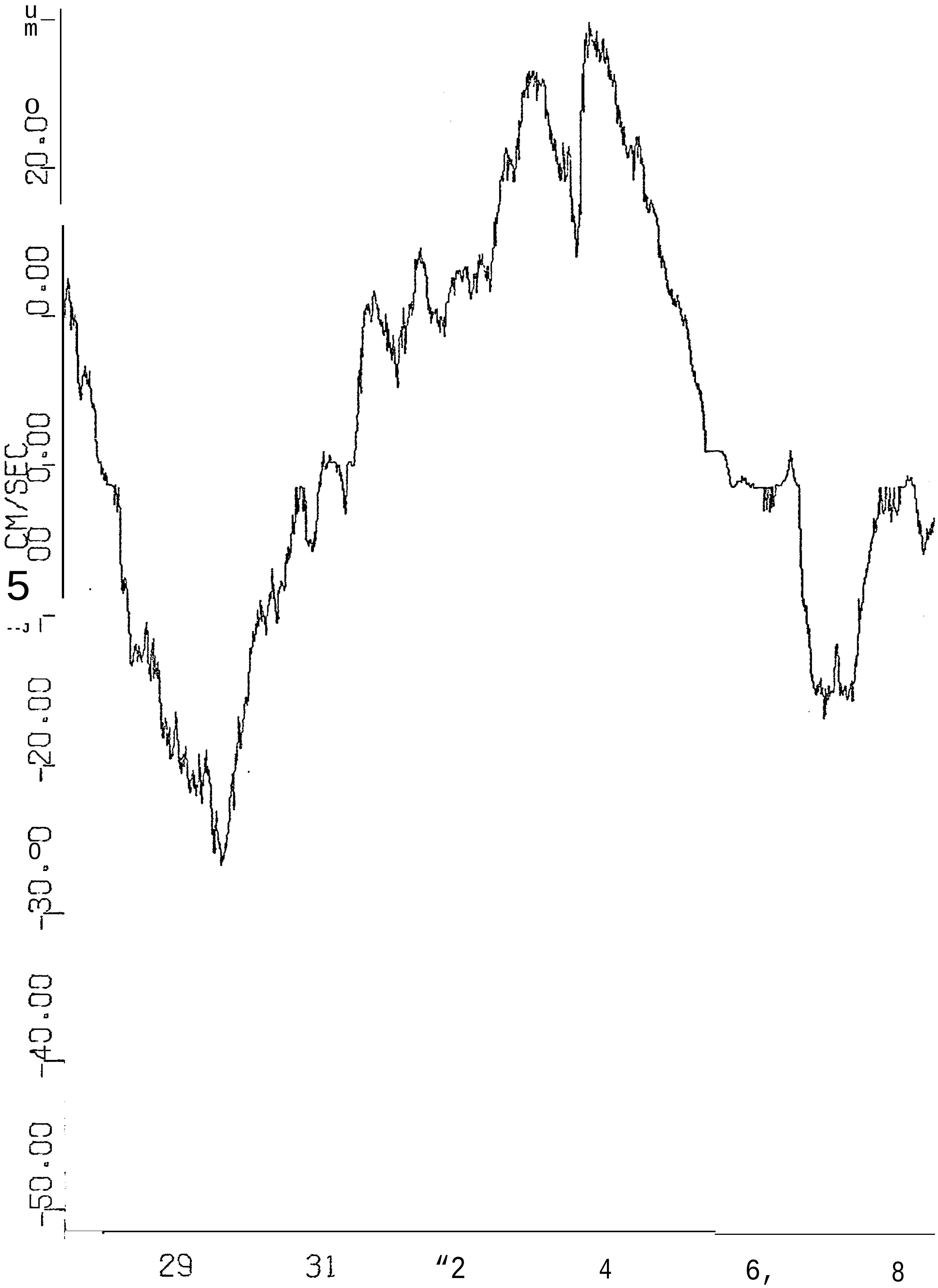
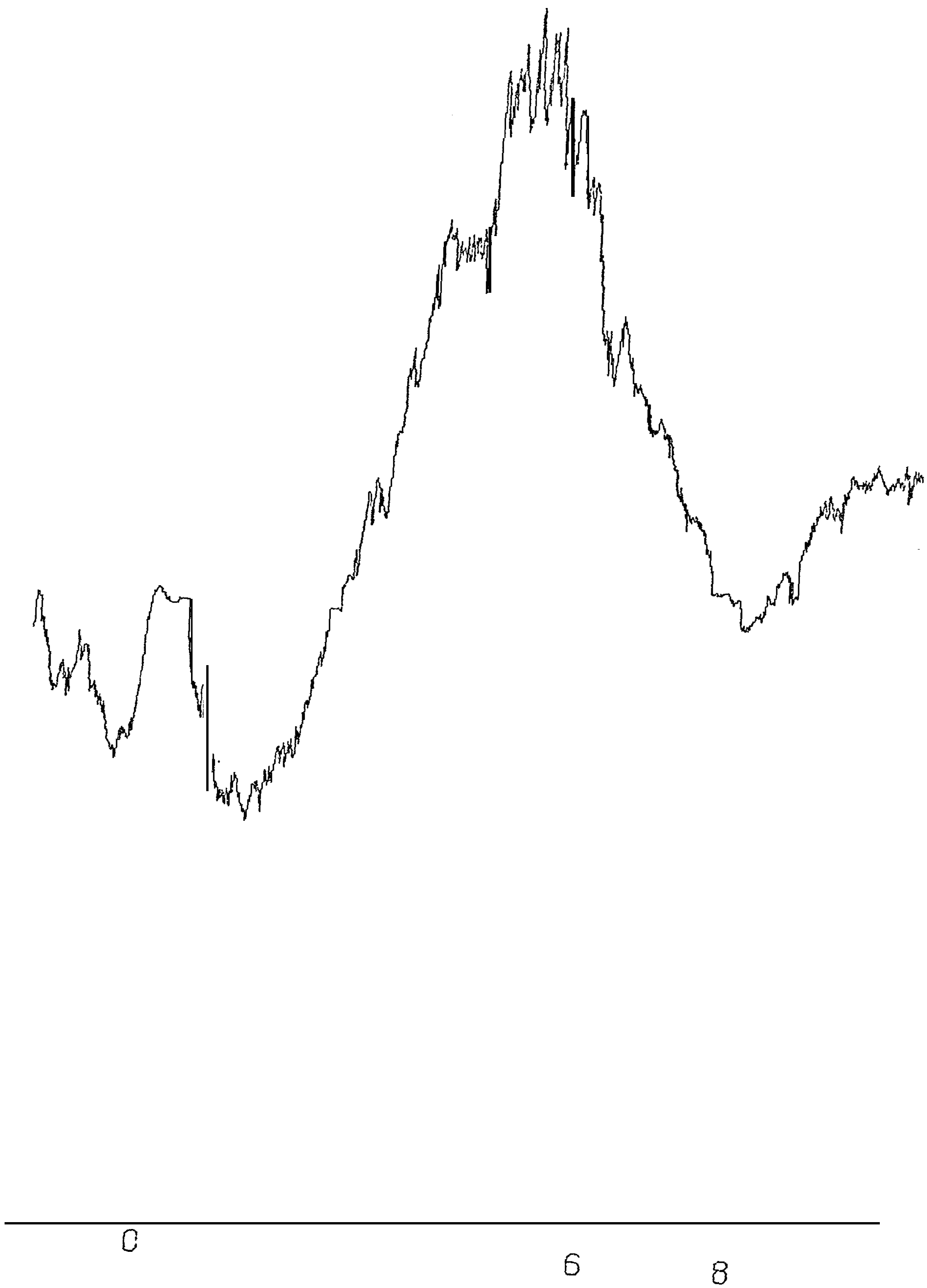


Figure 27


0
6
8

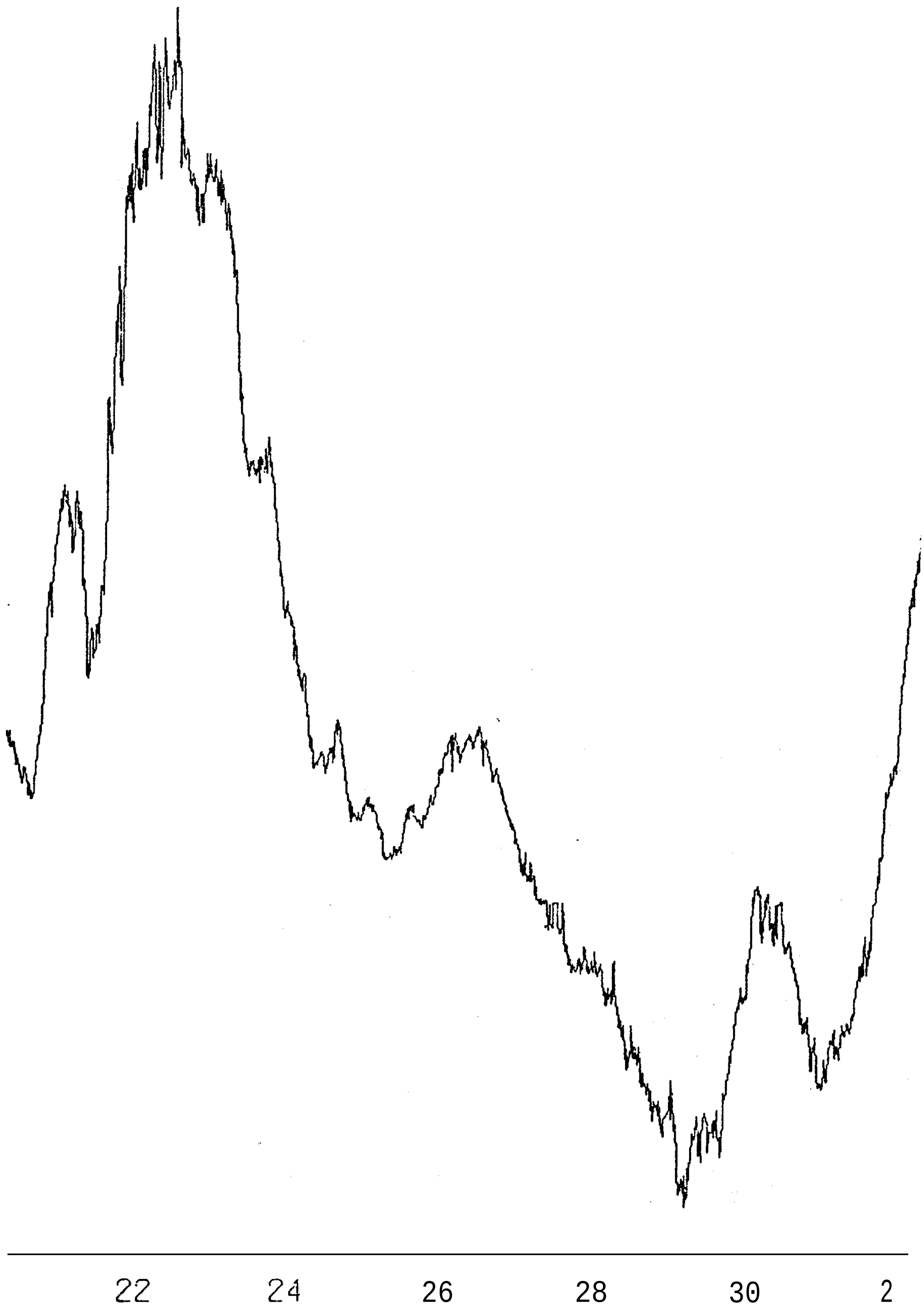


Figure 29

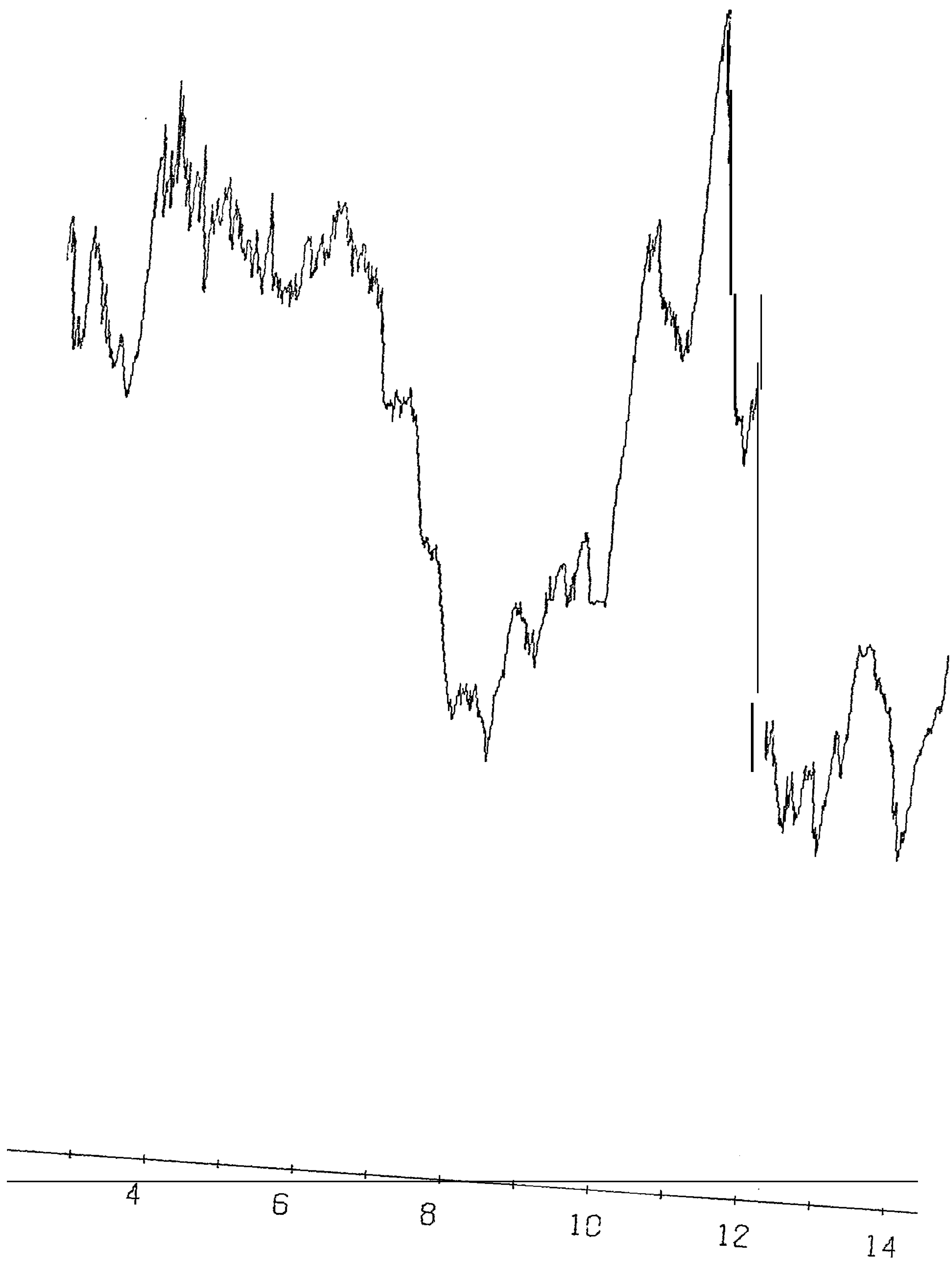


Figure 30

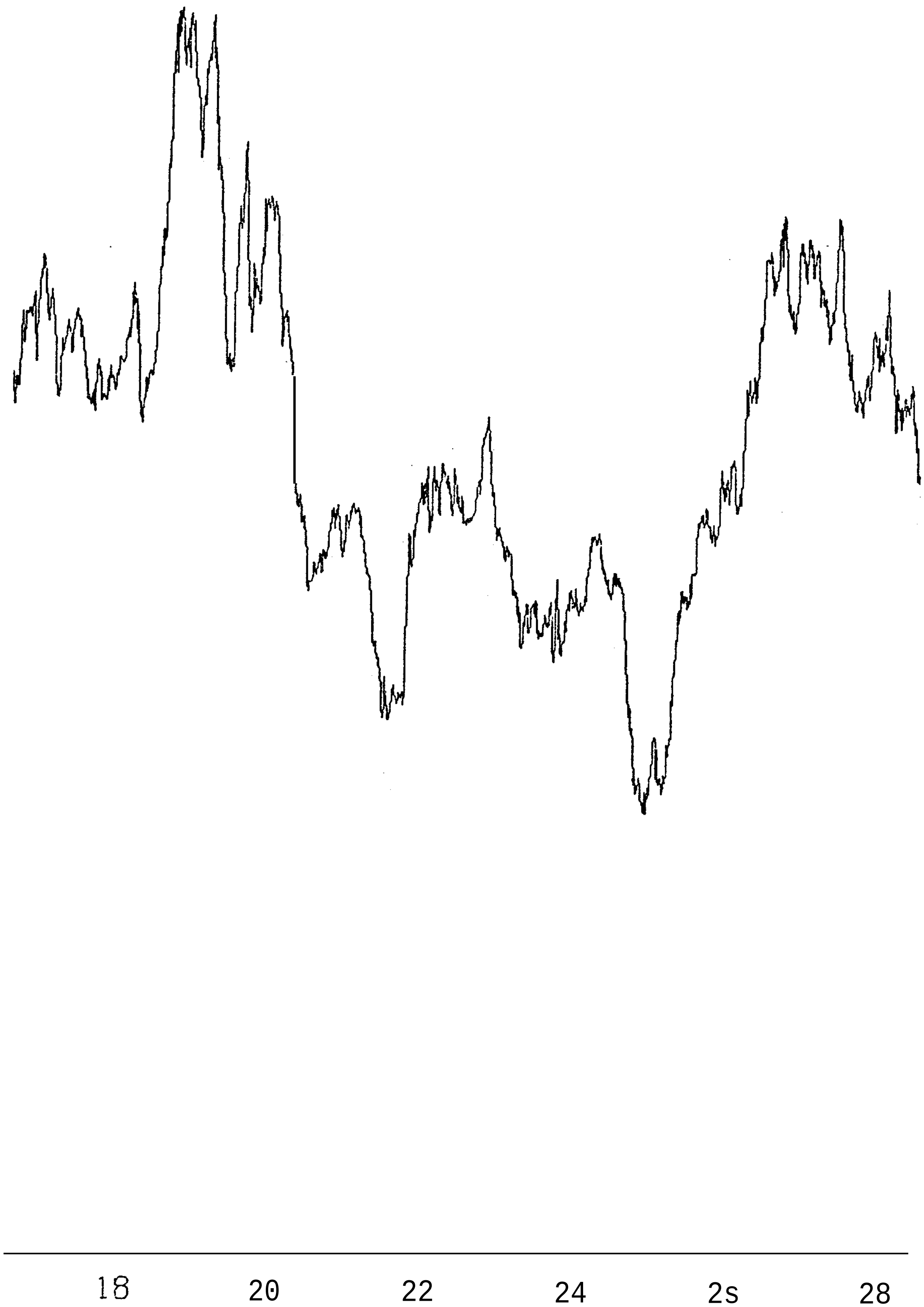


Figure 31

Figure 32

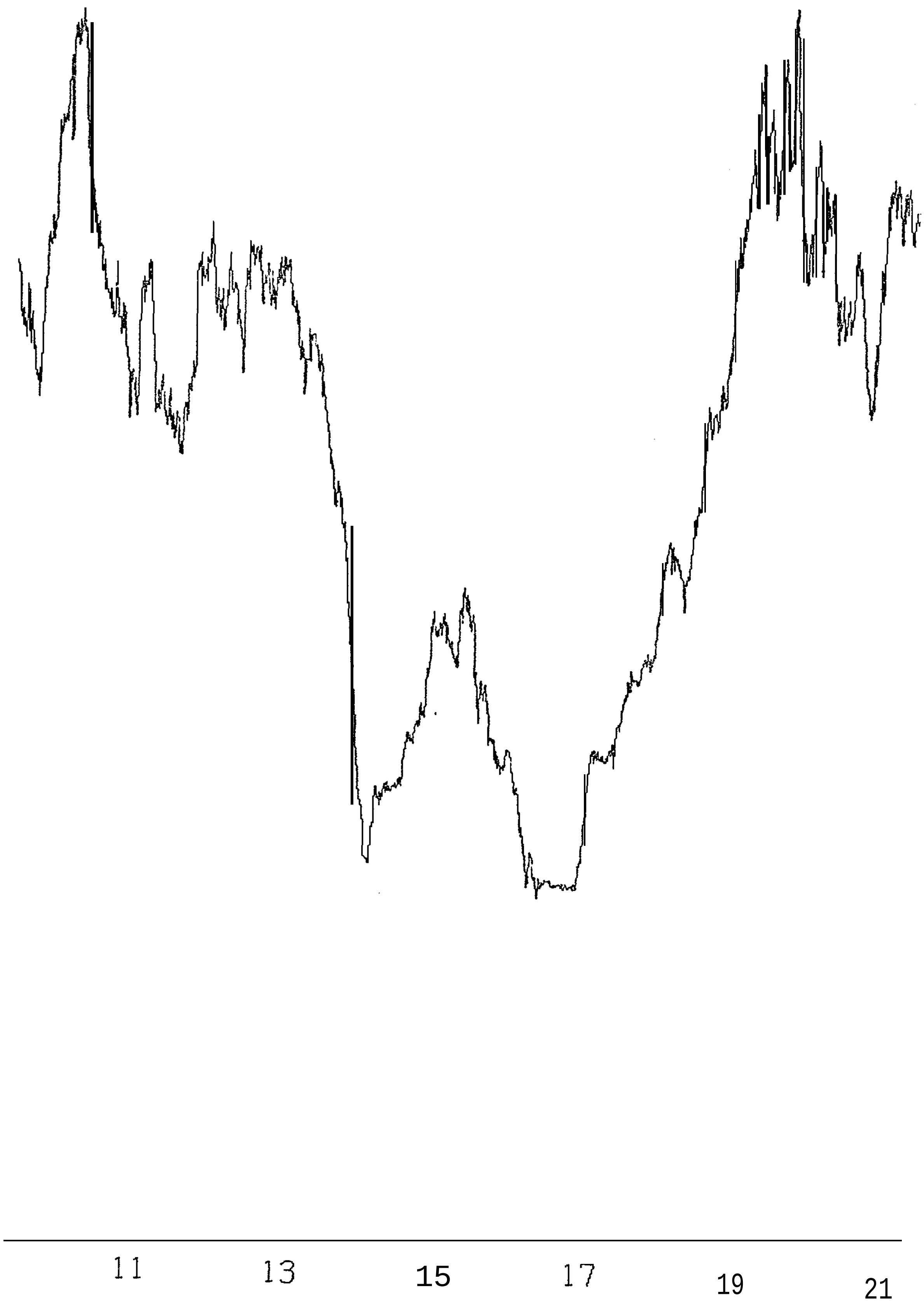


Figure 33

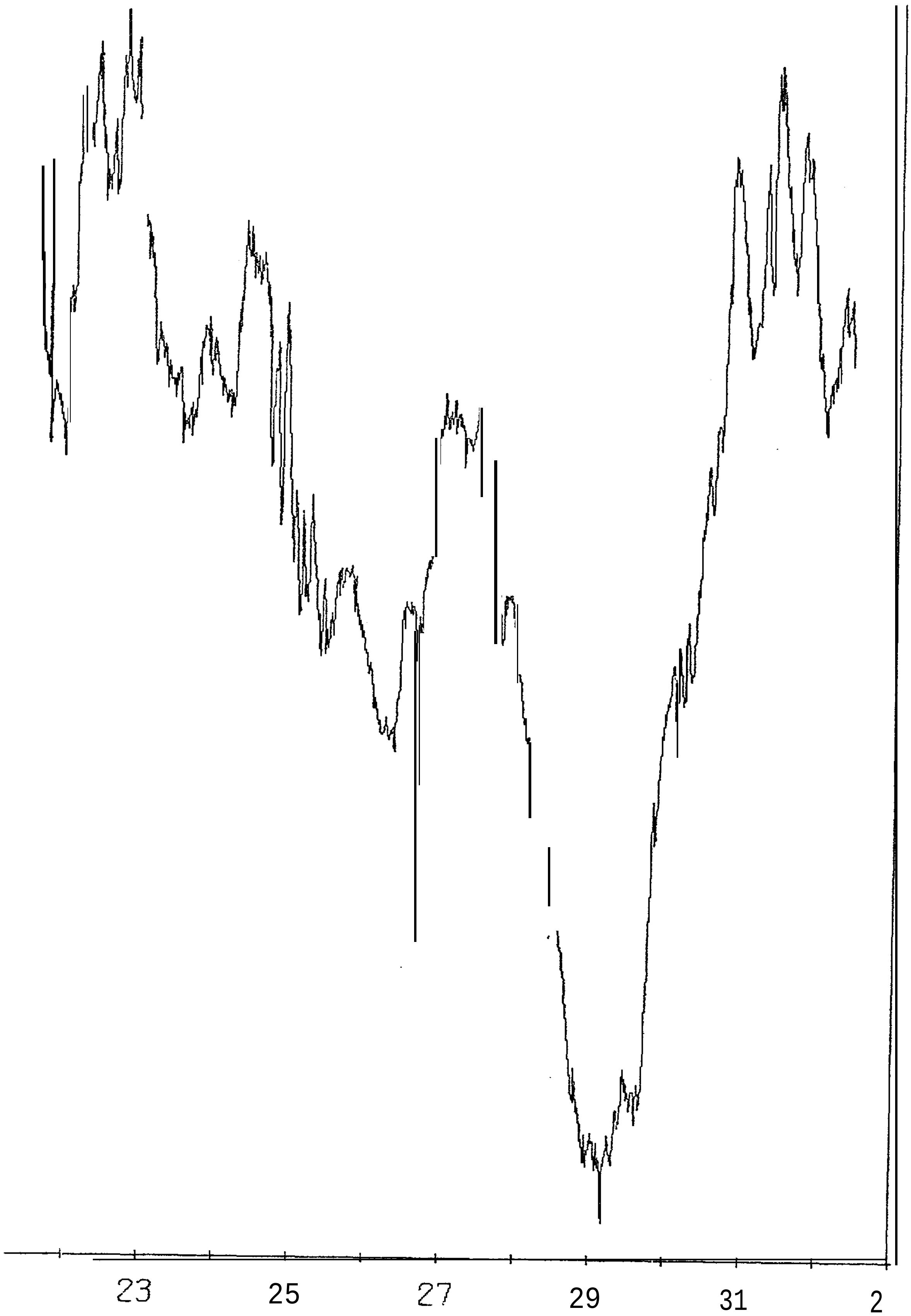


Figure 34

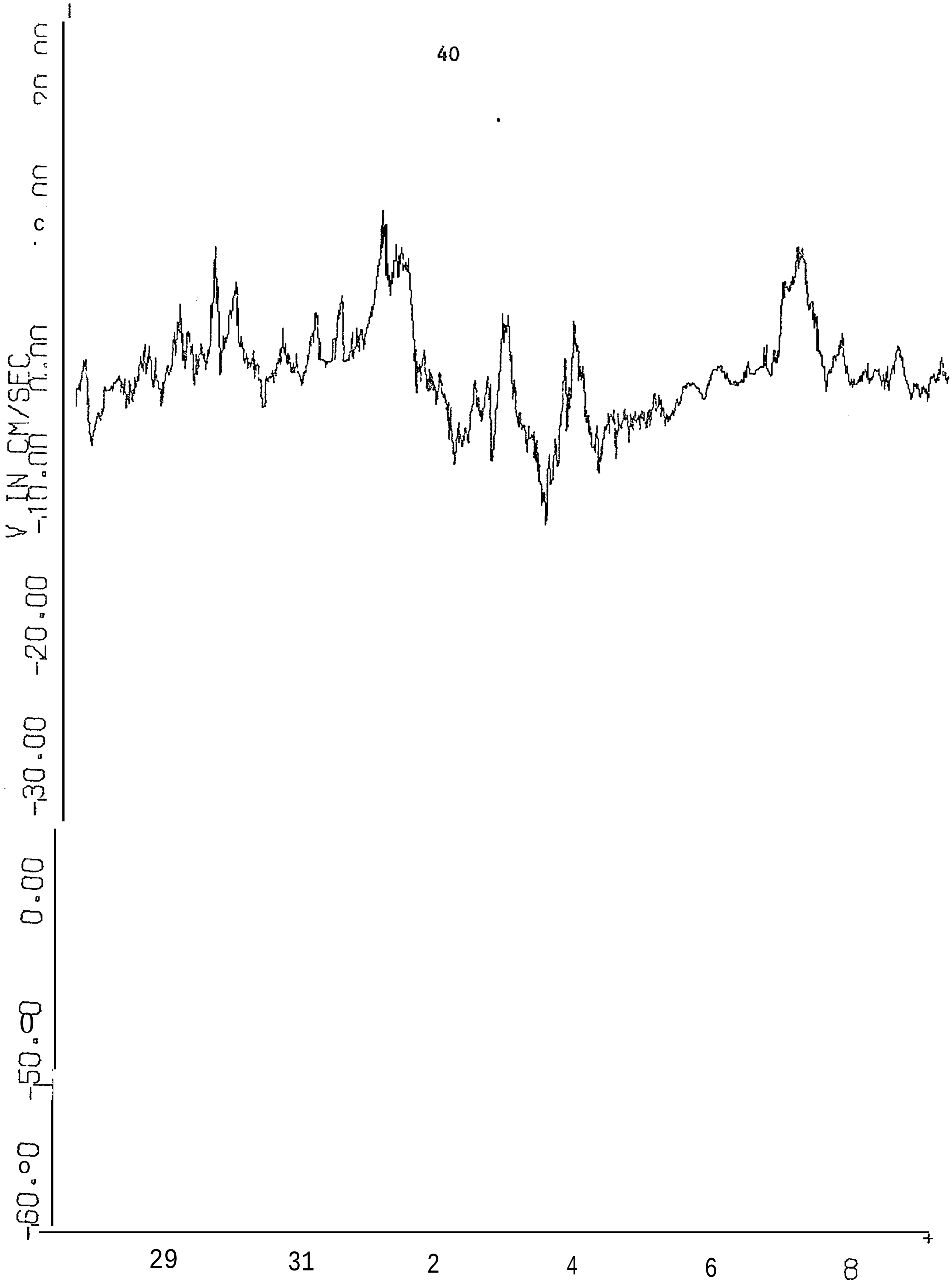

V IN CM/SEC
20.00
10.00
0.00
-10.00
-20.00
-30.00
0.00
-50.00
-60.00
29
31
2
4
6
8

Figure 35

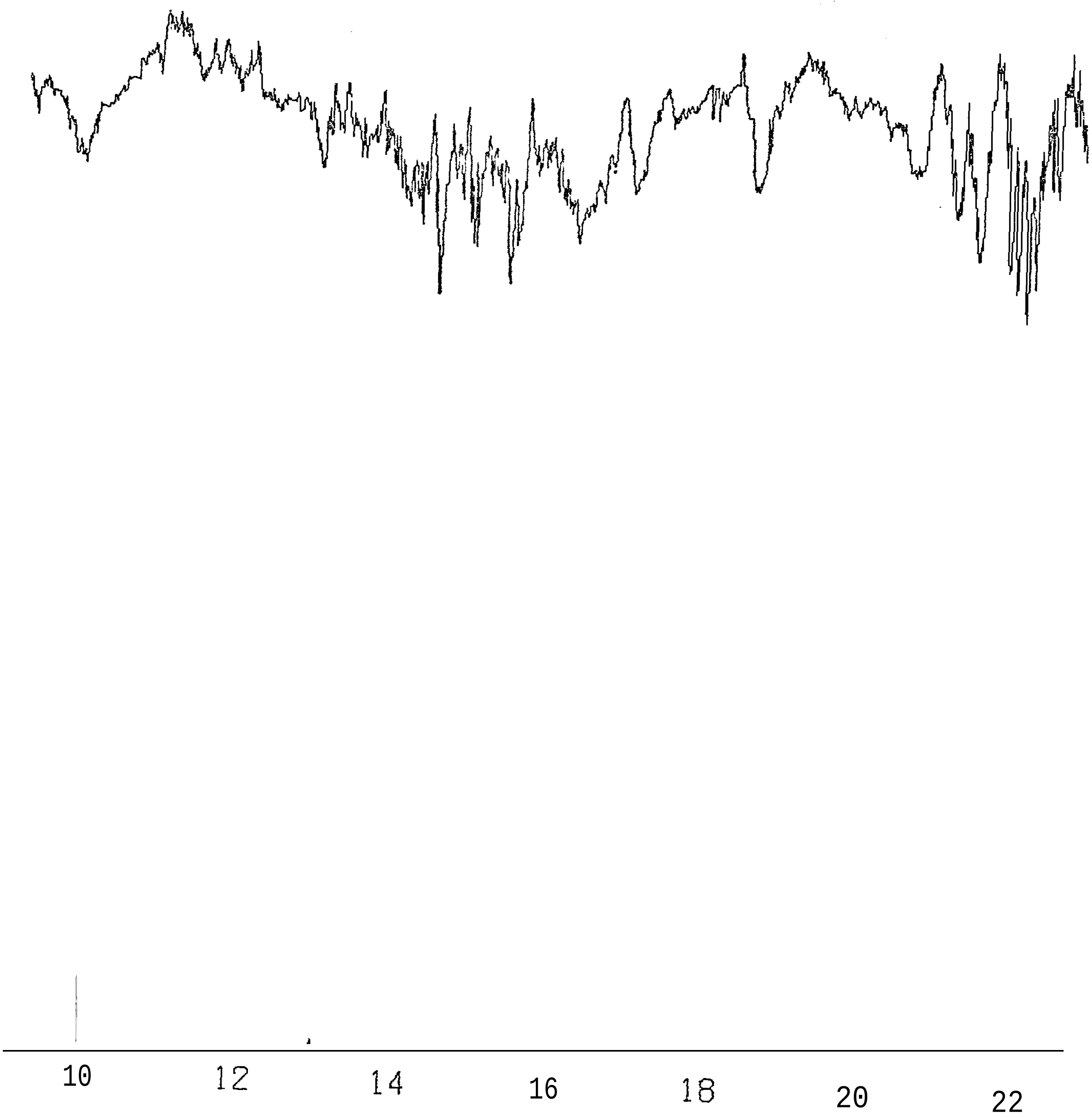


Figure 36

Figure 37

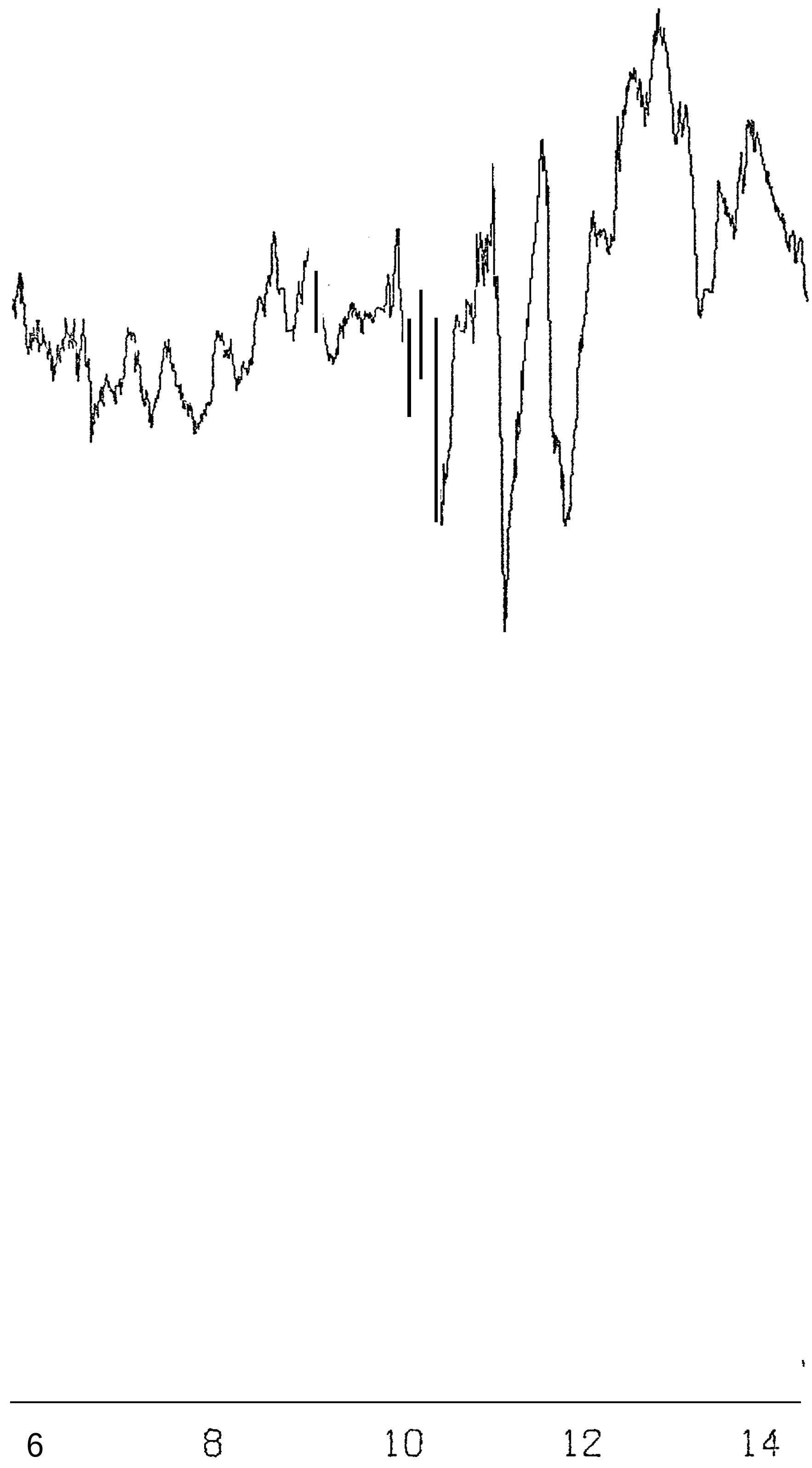


Figure 38

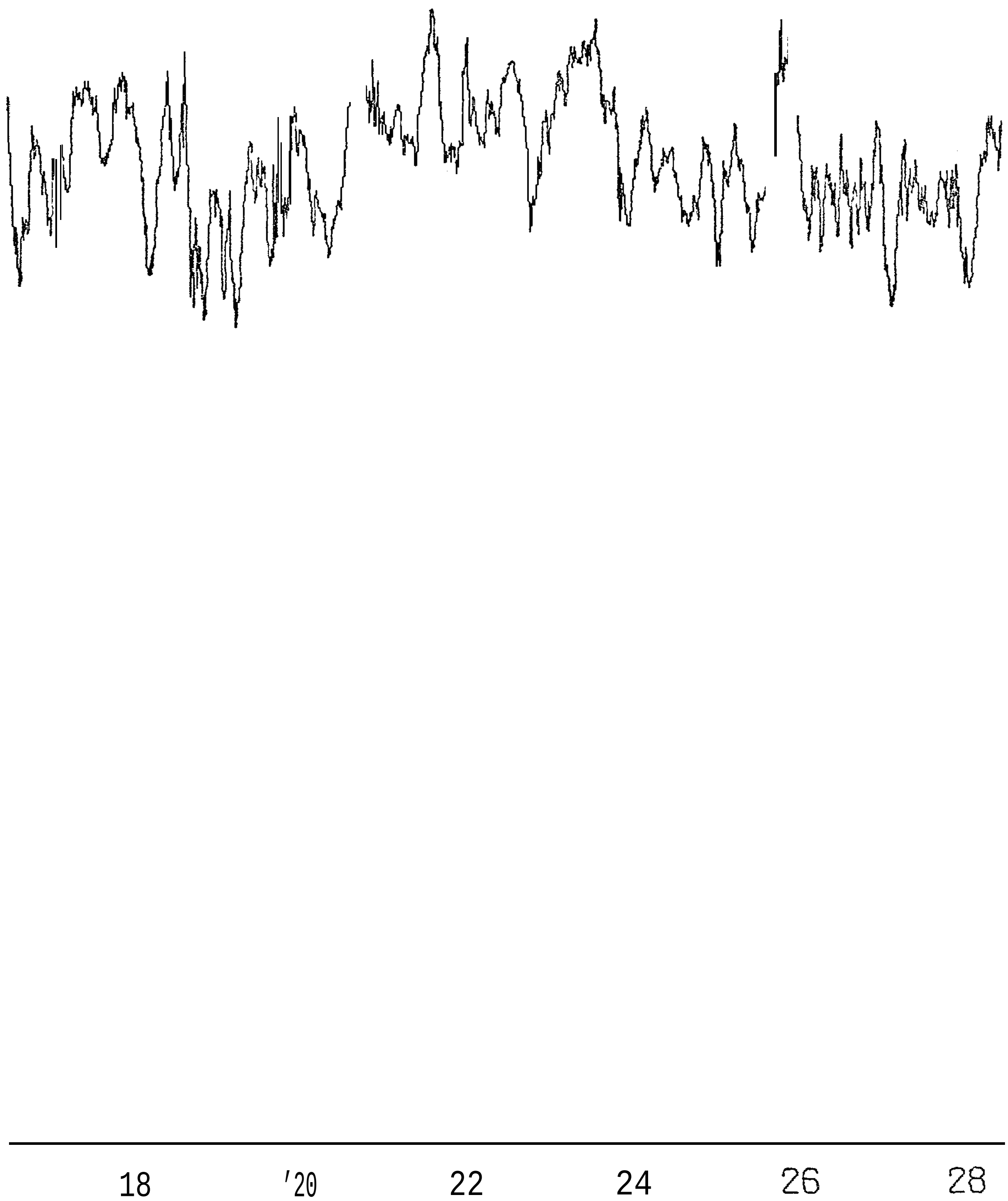


Figure 39

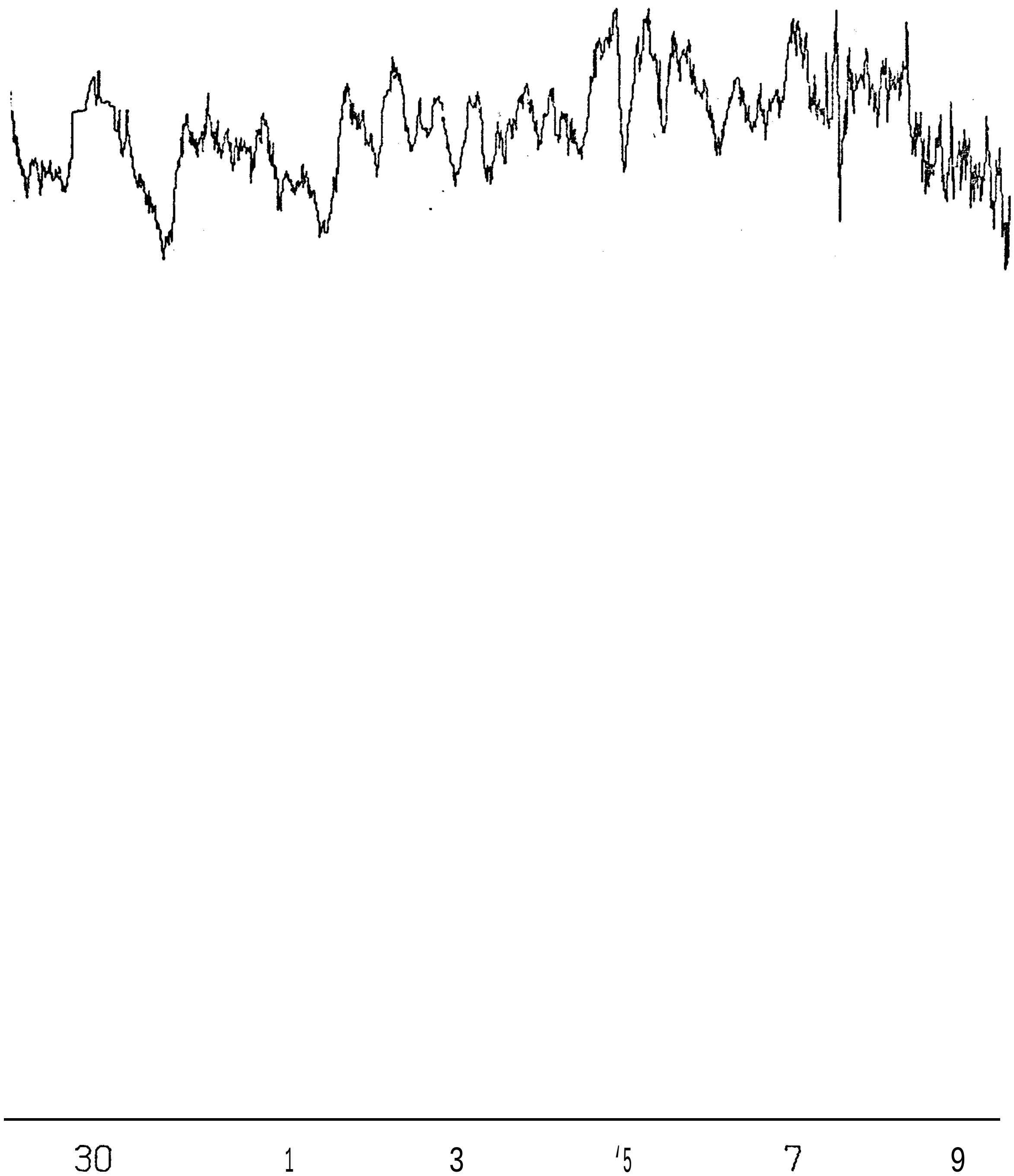


Figure 40

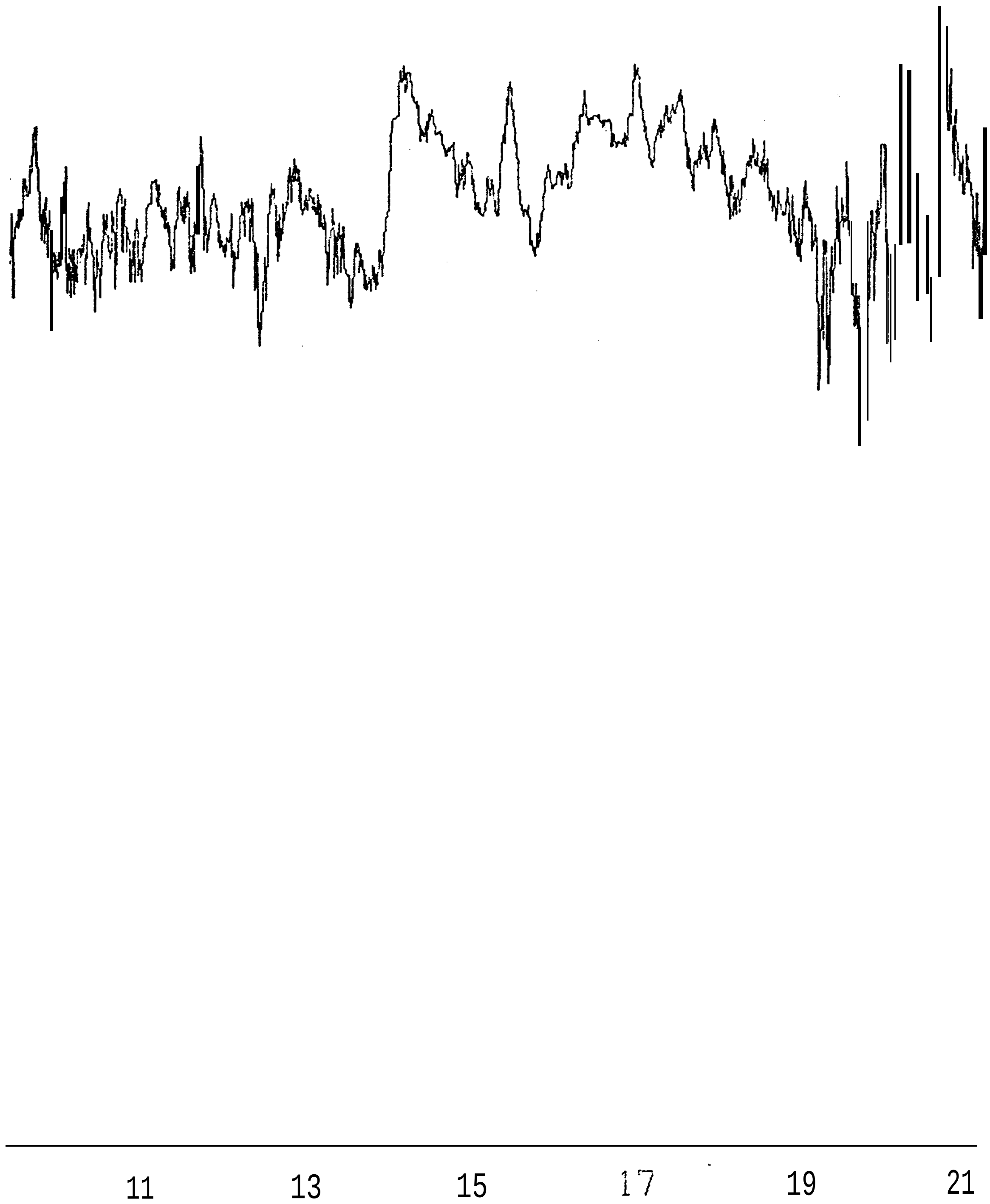


Figure 41

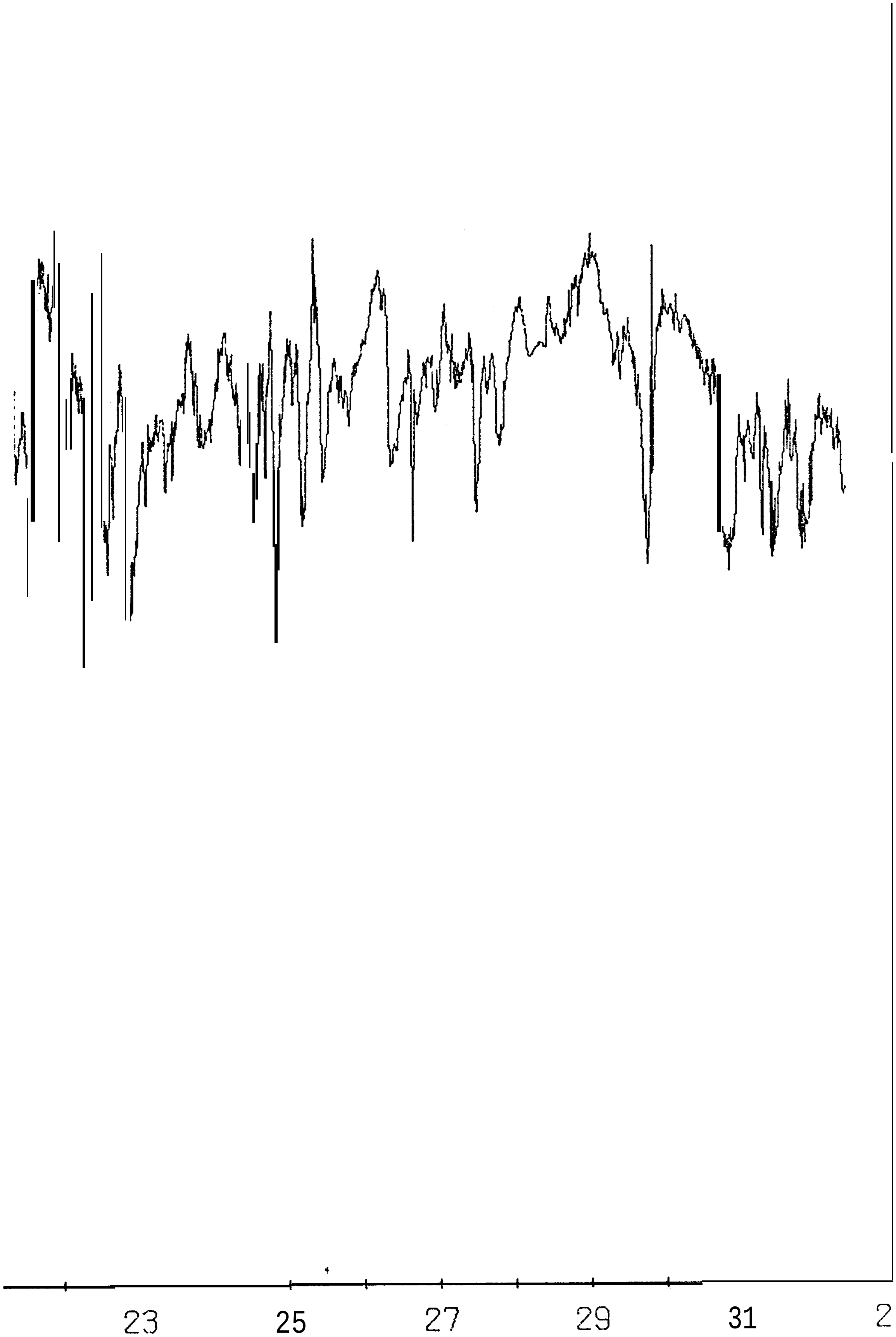


Figure 42

to have a southerly component of motion when moving east, and northerly when moving west. An example can be seen in the records between 19-27 June, when the easterly burst was accompanied by a smaller southerly component, and vice versa during the ensuing period 27 June-2 July. Since the trend of the isobaths is about 100°-280°T, the oscillations nearly represent alternating motion along the shelf edge.

The mean motion also appears to be steered by the bathymetry. During 27 May-14 July the mean set was 7.0 cm see-l toward 100"T and during 16 July-1 September 18.5 cm see-l toward 98°T, coincident with the estimated trend of the isobaths in the region.

Figures 27-42 also indicate rather clear tidal signals, again considerably larger than those inshore. The tidal amplitude is in the neighborhood of 5 cm see-l, and appears to have a diurnal inequality. For example, an inequality is indicated in the record of north velocity component during the period centered about 21 August. In this connection I note that the maximum lunar declination was on 20 August.

The spectra are shown in Figure 43-48. They are of course dominated by the low-frequency bands, the energy scaling of which obscures the higher spectral estimates. While the low-frequency bands are somewhat noisy, the coherence and phase spectra show that at the low-frequency coherence peaks, the east and south components tend to be approximately out of phase. This corresponds to the current alternating between either shelf-edge direction. Examination of the spectral estimates in the tidal band shows typical amplitudes of 2-4 cm sec^{-1} for the M_2, S_2, K_1 and O_1 constituents, although in any given series (e.g., U-component, part 2) all may not be clearly identifiable. Except at the M_2 and S_2 frequencies in the first half of the record, the coherence between velocity components is very low at the four tidal frequencies indicated. For the M2 and S_2 constituents in the first half of the record, the north component leads the east component by 90°, so that the tidal ellipse rotates anti-cyclonically.

On the outer shelf, then, we have observed a very active field of motion. The mean flow was aligned with the shelf edge and in the eastward direction. The mean speed over the 95-day record was nearly 13 cm see-l, representing an eastward displacement of more than 1000 km during the 95 days. There was a very large low-frequency oscillation, approximately along the shelf edge, representing long bursts of speed as high as 56 cm sec^{-1} toward the east. These bursts alternated with shorter periods of slower westward motion. The relationship between these low-frequency motions and the on-shelf flooding by dense water reported in the STD work (see this year's annual report, Research Unit No. 151) is not clear. The directly observed maximum speeds at 100 m were comparable to those calculated from the CTD work for the sub-surface core at about the same depth, but directed oppositely. Conceivably the calculated current represents the between-bursts westward flow observed north of Oliktok. However, the latter did not clearly involve an onshore component, as did the flow calculated from the CTD work north of Lonely. Nor did the temperature recorder on the current meter show any water warmer than about -1.4°C. For the present, the issue remains unresolved. Tidal currents were of order 5 cm see-l, and at least the semi-diurnal tide rotates clockwise.

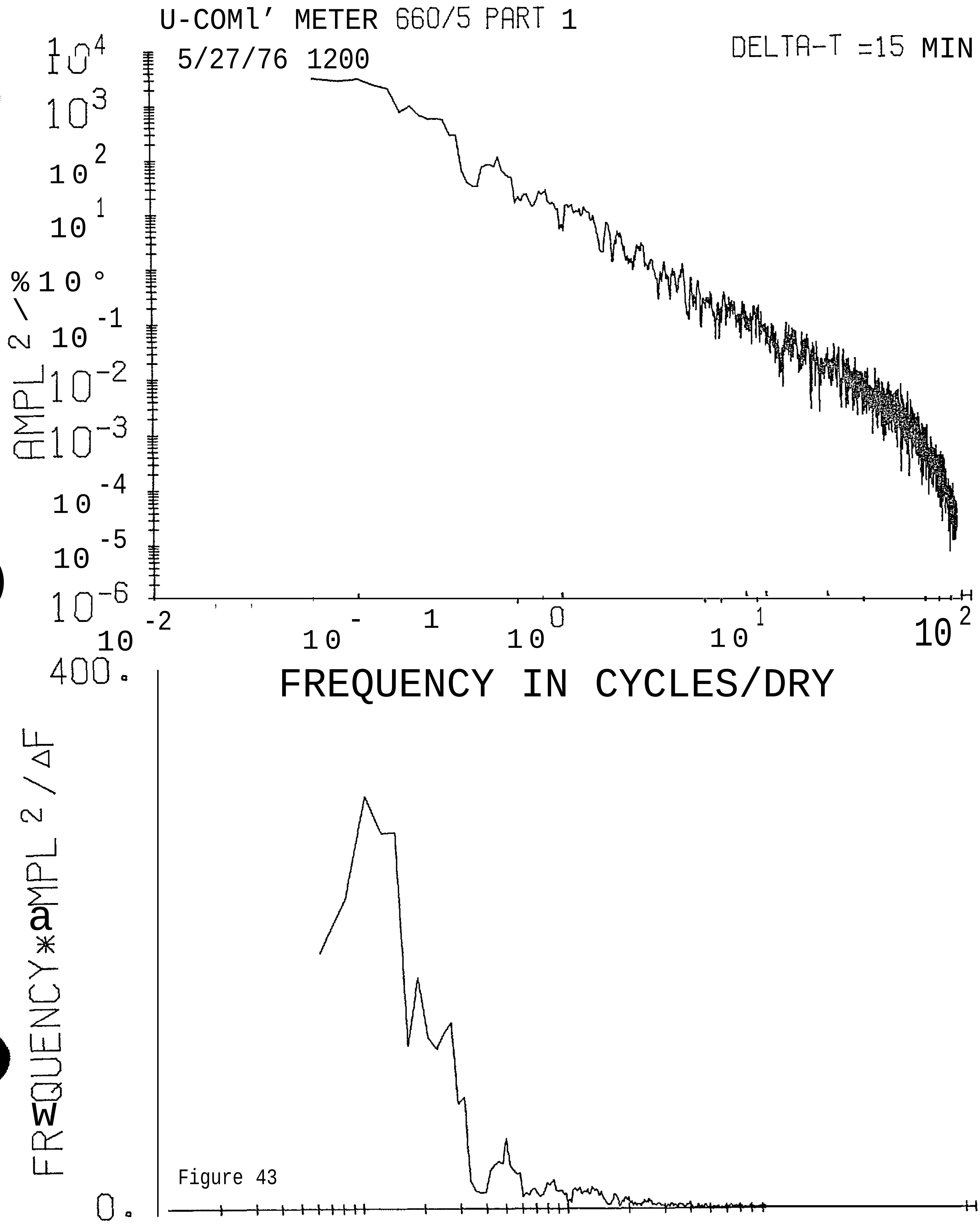

U-COMl' METER 660/5 PART 1
5/27/76 1200
DELTA-T =15 MIN
AMPL 2 /%
FREQUENCY IN CYCLES/DRY
400.
0.
FREQUENCY*AMPL 2 /ΔF

Figure 43

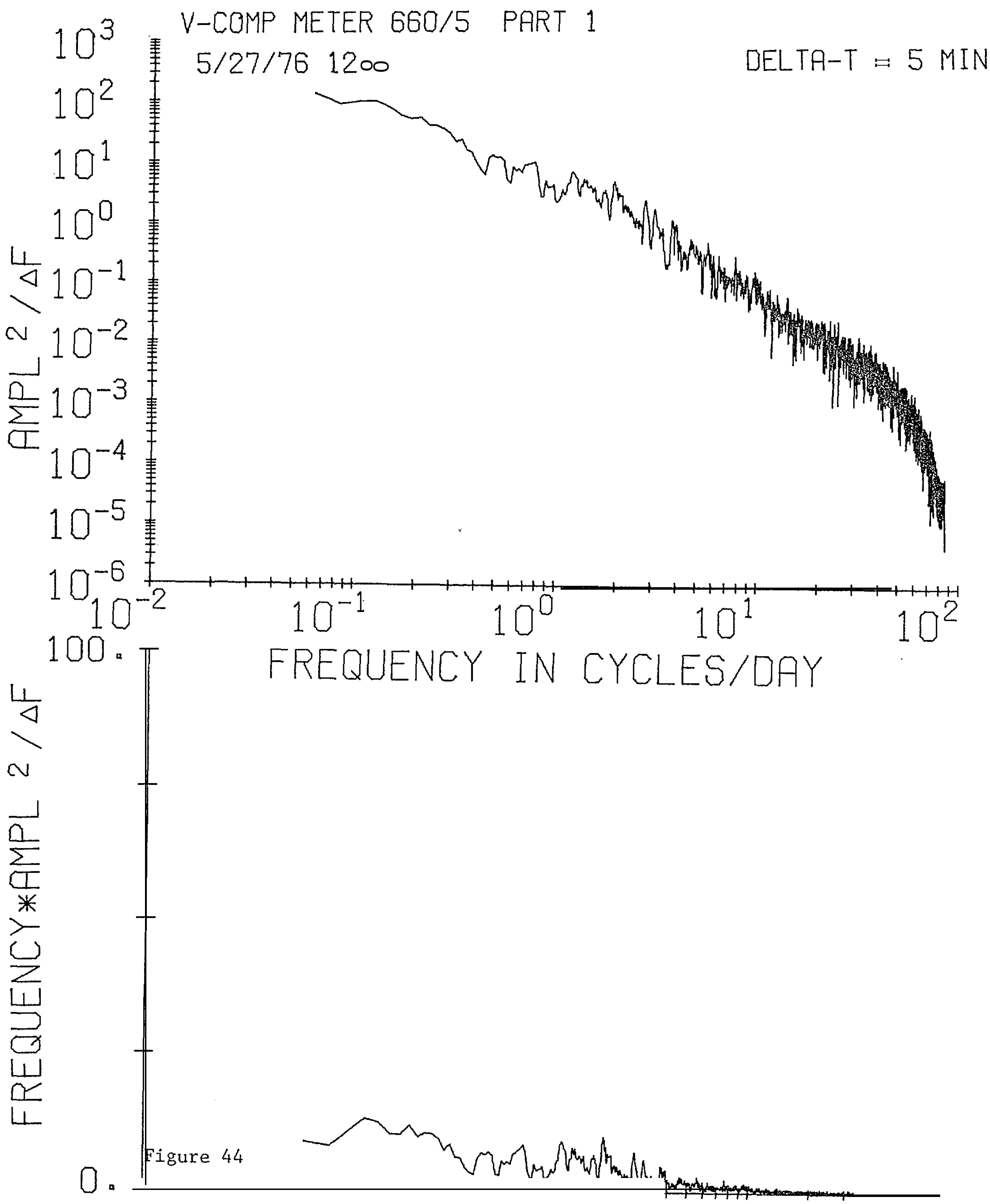

V-COMP METER 660/5 PART 1
5/27/76 12oo
DELTA-T = 5 MIN
AMPL 2 / ΔF
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-2
10^-1
10^0
10^1
10^2
FREQUENCY IN CYCLES/DAY
FREQUENCY*AMPL 2 / ΔF
100.
0.

Figure 44

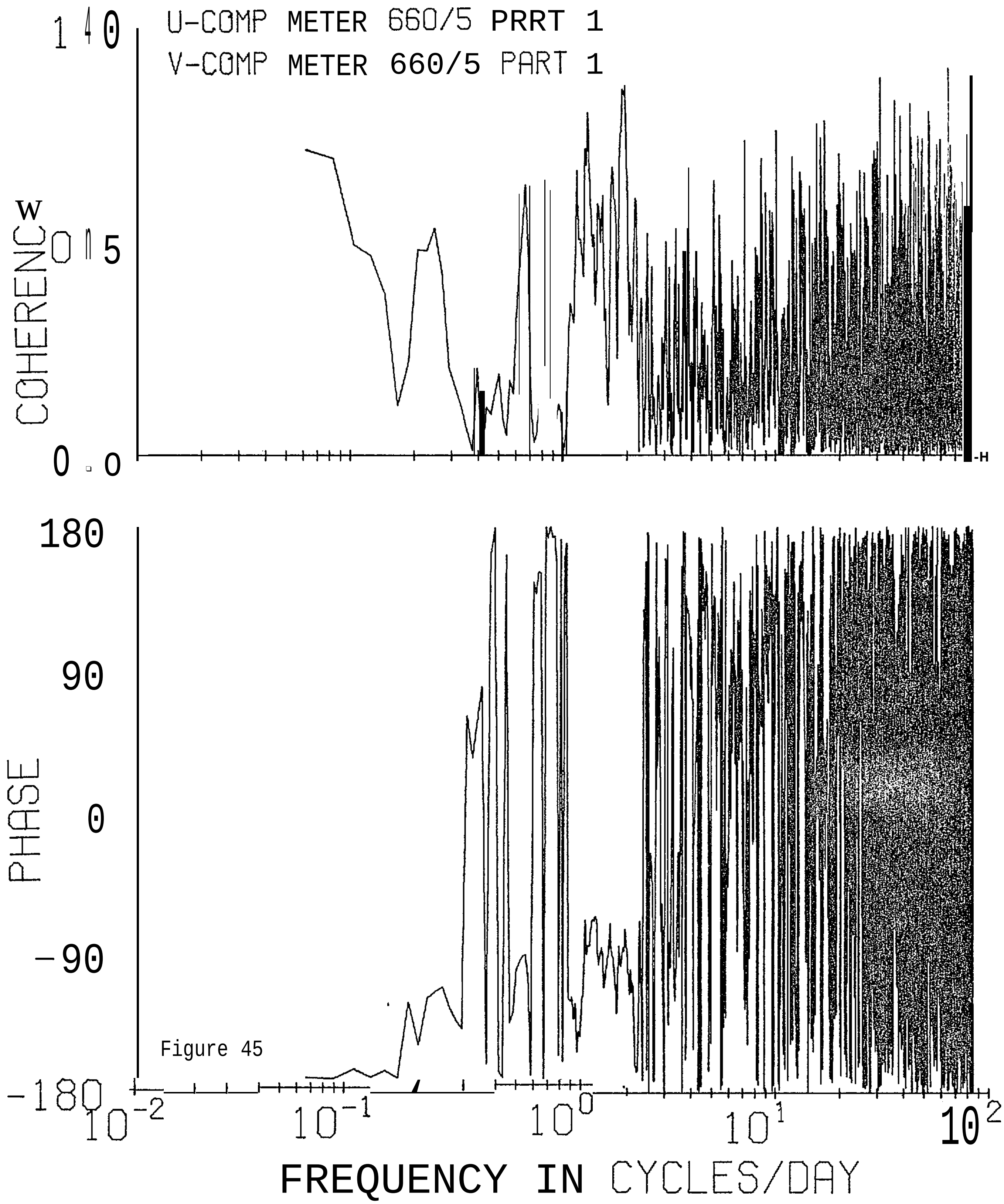

U-COMP METER 660/5 PRRT 1
V-COMP METER 660/5 PART 1
COHERENCY
1.0
0.5
0.0
PHASE
180
90
0
-90
-180
10^-2
10^-1
10^0
10^1
10^2
FREQUENCY IN CYCLES/DAY

Figure 45

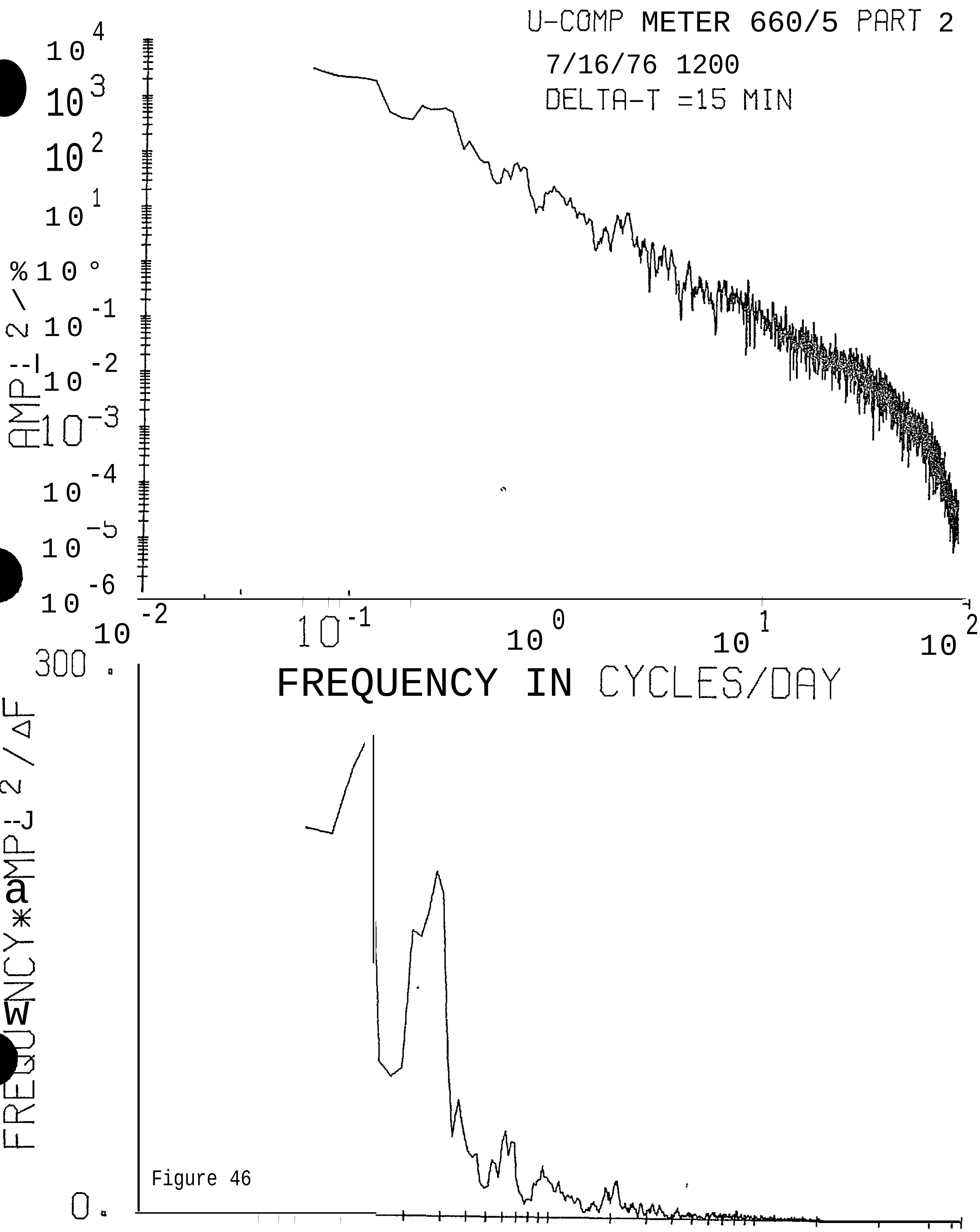

U-COMP METER 660/5 PART 2
7/16/76 1200
DELTA-T =15 MIN
FREQUENCY IN CYCLES/DAY
300
0

Figure 46

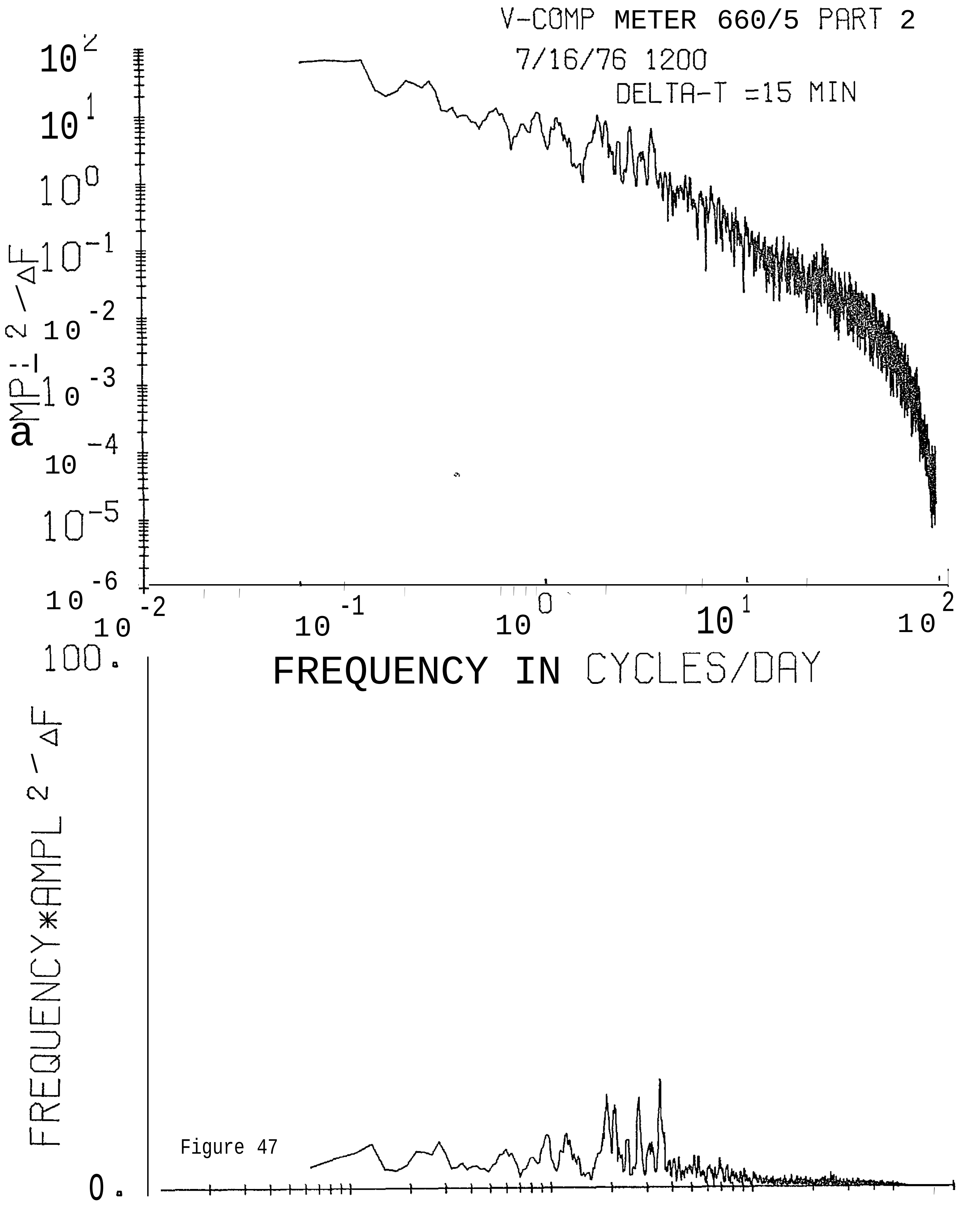

V-COMP METER 660/5 PART 2
7/16/76 1200
DELTA-T =15 MIN
AMPL 2 / ΔF
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-2
10^-1
10^0
10^1
10^2
FREQUENCY IN CYCLES/DAY
100.
FREQUENCY*AMPL 2 / ΔF
0.

Figure 47

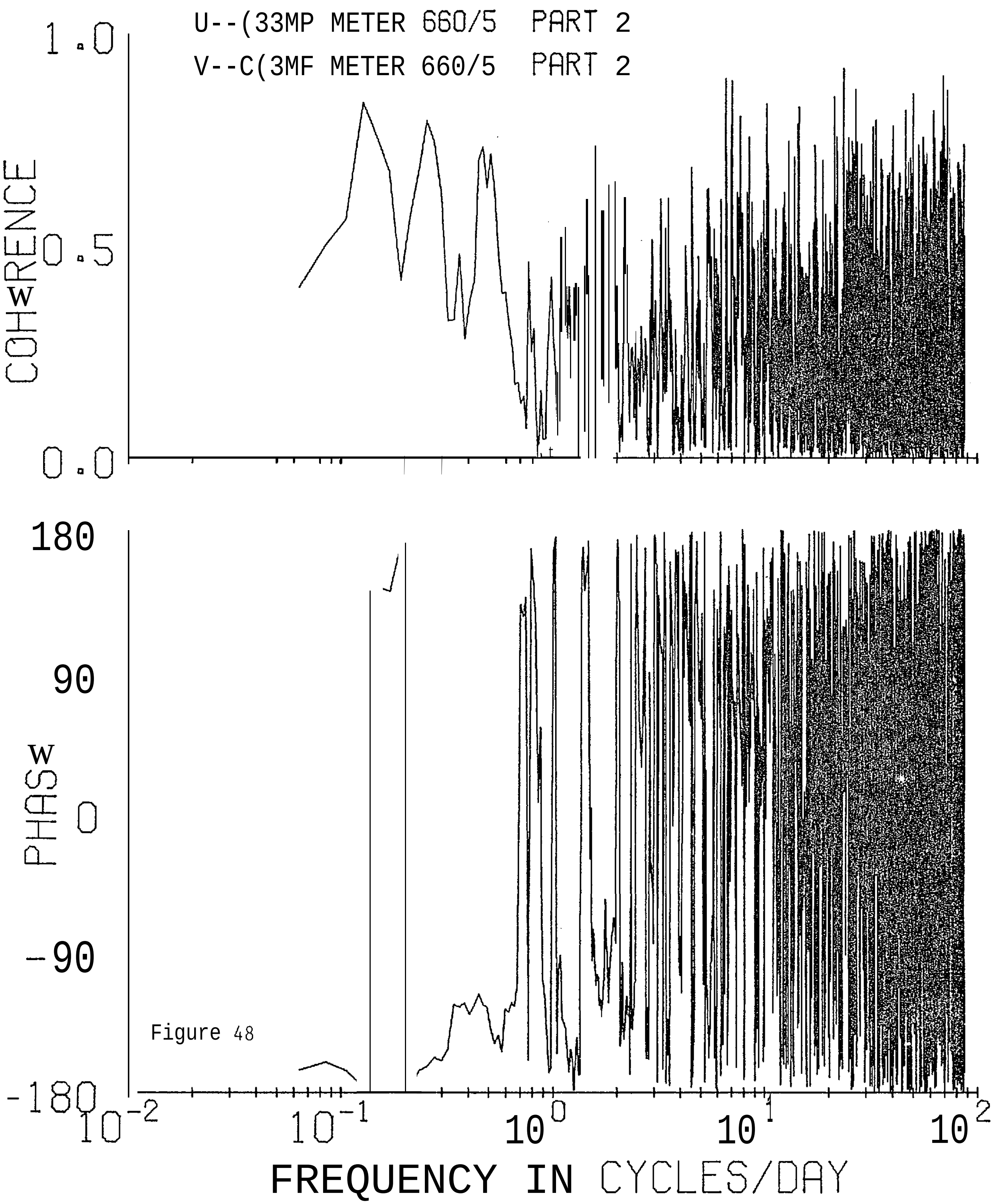

U--(33MP METER 660/5 PART 2
V--C(3MF METER 660/5 PART 2
COHERENCE
1.0
0.5
0.0
PHASE
180
90
0
-90
-180
10-2
10-1
10 0
10 1
10 2
FREQUENCY IN CYCLES/DAY

Figure 48

VIII. Conclusions

At least in late winter the currents on the inner shelf appear to be slow, generally less than 5 cm see-l. Long-term mean currents are extremely small, representing net displacements over a week of only 1-2 km. The two measurements made north of Narwhal Island showed these small displacements to have been west-southwest. Tidal currents are probably not much above 1 cm sec^{-1} in winter.

On the outer shelf an entirely different situation prevails. Measurements made at 100 m under the ice from May-September showed the flow to reach over 55 cm sec^{-1}, and even over a 3-month period the mean flow was 13 cm see-l toward the east. Pollutants reaching the outer shelf at sub-surface depths could thus be transported 1000 km eastward in three months. The most remarkable feature observed was the dominance of the motion by low-frequency variations with a typical time scale of 10 days. These oscillations represent bursts of speed as high as 50 cm see-l or more; they are directed eastward and are aligned approximately with the shelf edge. Between the bursts there were shorter periods of westward motion, the maximum observed speed toward the west being 26 cm see-l. The cause of these motions is for the present unknown. Tidal currents are in the neighborhood of 5 cm see-l, and a diurnal inequality probably prevails at times of high lunar declination.

IX. Needs for further study

The outer shelf is an extremely active area, and it would appear worthwhile to attempt a further year of time series between the 100- and 200-m isobaths. This could best be done by deploying two more moorings north of Lonely when the present moorings are picked up in October. The new ones would remain out til late May following.

X. Summary of 4th quarter operations

A. Field operations

Field work is presently in progress. .

B. Estimate of funds expended by Department of Oceanography, University of Washington to 28 February 1977.

Total allocation (5/16/75-9/30/77)			$188,542
A. Salaries, faculty and staff		$17,611	
B. Benefits		2,087	
C. Expendable supplies & equipment		21,202	
APL direction homing unit	$957		
Flotation	.$2,700		
D. Permanent equipment		47,680	
Acoustic releases	$12,739		
E. Travel		4,352	
F. Computer		439	
G. Other Direct Costs		6,349	
Freight	$4,734	4,734	

H. Indirect costs 7,714

Total expenditures	112,168
Remaining balance	76,374

B

C. Estimate of funds expended by Applied Physics Laboratory, University of Washington to

Total allocation (5/16/75-9/30/77)	$150,418

(Breakdown information not available at time of report preparation.)