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Small-scale variability of chemical parameters in the Baltic

by

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The intension of our recent cruise with R.V. "Poseidon" to the Central Baltic was a. o. to start an investigation on the small and medium scale variability of physical and chemical parameters in different regions of the Baltic at different times of the year. Knowing the range of variability and if possible the processes creating the inhomogeneities in the distribution, one would get a better idea about the significance of data collected at isolated stations and at more or less randomly selected observation times. This is especially important for the international monitoring programme in the Baltic where obligatory sampling at the open sea stations is carried out four times a year, only.

From many previous observations in the Baltic at anchor stations with 3, 6, or 8 hour sampling intervalls (e. g. IBY, BOSEX '77) it is well known that the amplitudes of variability of physical and chemical parameters might exceed the seasonal fluctuations and nobody would expect a homogene distribution of plankton and detritus.

We believe that our chemical profiling system is a suitable tool to study problems and phenomena of patchiness and short term variability. A description of the system was presented in paper C:4 Hydr. Cttee. by Grasshoff and Hansen at the C.M. 1978.

In May/June 1980 a research cruise to a region 35 nautical miles south-east of Gotland (c. f. Figure 1) was carried out with R.V. "Poseidon". The night hours were used for towing our chemical profiler. Altogether more than 50,000 individual physical and chemical data were collected during about 80 hours of towing. The present paper is based on an evaluation of approximately 5,000 data. The parameters recorded were depth, temperature, salinity, pH, total CO_2, phosphate, silicate, ammonia, nitrite, nitrate, and dissolved oxygen. The data were stored on tape and simultaneously on floppy disks of the evaluation computer. Analogue records of all parameters were taken in parallel for immediate control and assistance of the evaluation of the digital data files.

In addition to the profiling, conventional hydrographic series were carried out close to the observation field.

The general hydrographic situation is characterized by a moderate warming of the surface layer from 0 - 20 m to about 5 °C and a small decrease in salinity of about 0.2 °/oo. Down to the permanent halocline in 65 - 90 m salinity is almost constant whereas temperature decreases to less than 2 °C. Below the halocline salinity increases to over 12 °/oo and temperature to over 6 °C. A more detailed temperature profile taken with the profiler uncovered a double layered structure of the "winter water". Obviously a thin layer of water formed during the relatively cold winter 1978/79 remained between the halocline and the water formed during the last winter. The significantly higher nutrient content in the older winter water supported this assumption.

The distribution of dissolved oxygen shows the usual picture with slight oversaturation (because of warming and plankton bloom) in the surface layer and a slight decrease down to the halocline. From there the oxygen decreases to zero in 130 m. Hydrogen sulphide was found from 130 m down to the bottom with maximum contents of over 30 m moles $\cdot$ m^{-3} (c. f. Figure 2).

The profiles of nutrients show nothing extraordinary: Very low contents of phosphate, nitrate, nitrite, ammonia, and silicate in the surface layer, significant increase in the winter water, and rather high concentration in the water below the halocline with maximum phosphate values of more than 5 m moles · m^{-3} near the bottom. Of course, nitrate decreases to zero at the oxygen zero level and ammonia increases to over 8 m moles · m^{-3} in the bottom water (c. f. Figure 3).

Before entering the discussion of our profiler data, we would like to mention a quite unusual phenomenon in the phosphate distribution at 1, 4 and 30 m level for which we do not have any reasonable explanation (c. f. Figure 4). These data are based on conventional sampling during the period from 15. to 29. May at our permanent station near the observation area.

The phosphate data showed quite "normal" concentration ranges from 15. - 22. May in all three levels. Starting on the 26. May, the phosphate content increased rather suddenly to maximum values of 3.5 ! m moles · m^{-3} in 1 m, 3.3 m moles · m^{-3} in 4 m, and 3.8 ! m moles · m^{-3} in 30 m with a slight plateau (26./27. May), and an intermediate decrease on the 28. May in 4 and 30 m. On the 29. May the phosphate values were back to "normal". If the high values would have been confined to the top metres, one would have suspected contamination from the ship's waste water discharge, but the increase in 30 m cannot be explained with this kind of contamination. Comparable phosphate levels were found only below 130 m (c. f. Figure 3) and are absolutely uncommon in surface layers of the open Baltic. In spite of the rather calm weather the amount of phosphate observed in the top 30 m during the 3 days is by far too large to be created by our own vessel. ("Poseidon" steamed at least 10 nautical miles away from the observation area for discharge of sewage tanks.) Assuming an uncertainty of reoccupying the same station position for conventional sampling of 300 m, a rough estimation of the accumulated phosphate content in the top 30 m yields more than 25 t of phosphorus as a minimum if we assume that we just managed to sample in the centre of the "spot" which is very unlikely. An upwelling of water from below the permanent halocline can be excluded as the water temperatures during the two days were rather low in these layers and other nutrients did not show other than expected variations. As already mentioned we have no reasonable explanation but recent uncontrolled dumping of phosphate wastes from a vessel.

The general concept of our profiling measurements was to uncover small scale spatial variabilities of chemical parameters together with basic physical parameters. For this purpose we selected a square of about 2.5 nautical miles side length and towed the "fish" with a speed of 4.5 knots at selected depth levels in order to get a high spatial resolution of the data points. The square was divided into 6 legs. The resolution of the digital data points is 280 m, but the parallel analogue record allows a "manual" interpretation between the data points, which is of importance if rather drastic changes occur in the range of a few hundred metres. During the night of 25. May we observed a "front" moving out of the observation square, depicted by an uplift of water from about 50 m to the 25 m level. This was of special interest as the nutrient enriched "old" winter water was now raised into the euphotic zone. During the following days we have concentrated our efforts on that "front".

The Figures 5 - 7 are examples of computer plots of the digital data from leg 1 - 6 in the 30 m horizon. Each leg comprises 18 individual data points. A marked decrease in temperature (Ø) from the "normal" temperature of almost 5 °C to less than 1.8 °C within a distance of 500 m is the striking feature of the records from leg 1 - 6 except of leg 2. This decrease is connected with a decrease of pH from over 8 to 7.6 or less, an increase in silicate and especially in nitrate from near zero to almost 4 m moles $\cdot$ m^{-3}.

From the data collected in the 30 m horizon (6 legs during the night 25./26. May) threedimensional quasisynoptic plots were made (Figure 8 - 11). The "front" seems to have a wave-like structure with an amplitude of more than 20 m. The rather large spatial variability is very obvious from these computer graphs.

On the following day the front had moved in north-eastern direction and could be observed in the north-eastern corner of the square.

Because of this interesting phenomenon, we decided to concentrate our efforts on 10 repeated profiles normal to the front just northeast of the square (legs 21 - 30, 27./28. May). Data were collected from 10 depth levels between 8 and 100 m. All these data of salinity, temperature, oxygen, nitrite and nitrate recorded within 7 hours are plotted versus depth in Figures 12 - 15.

The length of the profile was 2 nautical miles. For each parameter and each level 18 individual digital data points were taken. The spatial resolution is, therefore, 200 m. The figures demonstrate very clearly the striking variability. The solid curve in the plots represents the calculated mean. A detailed investigation shows a clear grouping of the data on either side of the curve in the levels between 50 and 20 m due to the sampling outside and in the "wave". Even below the halocline a significant variability of nutrient related parameters can be observed.

For some levels the short term variability is larger than the average seasonal fluctuations (nitrate, nitrite). The moving velocity of the "wave" appeared to be about nautical mile per day corresponding to 77 $m \cdot h^{-1}$ or 2 $cm \cdot s^{-1}$.

Wherever significant differences occur between the levels of dissolved constituents in the top layer, the recent winter water and the "old" winter water, the short term variability in space and time seems to be large, i. e. something more than ± 200 %. But even the scatter of the phosphate values is significant, i. e. over ± 100 %.

In order to elucidate the fine structure of the "Wave" a computer graph was produced from all 180 temperature data (Figure 16 a). Because of the complicated structure of the temperature distribution the computer was unable to make a full evaluation on the basis of the digital data. Using the analogue records the diagramme was completed (Figure 16 b). At the first glance the picture looks like a breaking wave, creating an intensive mixing and uplift of deeper water into shallower layers. However, the wave moves in opposite direction, i. e. from right to left in the figure. An explanation of the tailing of the wave crest might be shear. A reason for the large amplitude of the wave might be that we are below the warmer 10 m surface layer down to the halocline in water bodies which have a specific gravity close to the maximum. As can be extracted from the profile of specific gravity (Figure 17) the layering is stable but the gradient is very weak. Only a small amount of energy is needed to lift the water from 50 m to 30 m.

As the period of the year in which these conditions in the water above the halocline prevail is much longer than the period of convection in late fall and early winter, we tend to believe that this mechanism of uplift of nutrient enriched water into the photic zone may play an important role in the supply processes. This, of course, is based on the assumption that such a kind of perturbance is not an isolated event but a more or less regular feature.

In order to verify this hypothesis a longer profile was recorded along the assumed direction of propagation of the "wave". Figures 18 and 19 show some of the recorded data on an 80 nautical miles profile in south-westerly direction. Especially temperature, pH, nitrate and silicate seem to have some regularities. Even fine structures in the temperature profile (from 480 data points corresponding to 300 m spatial resolution) are repeated or mirrored by the chemical parameters. A statistical treatment of floating averaging over 10 data points was applied. The resulting curves are depicted in Figures 20 and 21. A further treatment of the temperature profile was made to resolve a possible regularity and to suppress any "noise" created by short term fluctuations (Figure 22). From this figure it appears that the perturbance observed in the "square" seems to be a regular one, having a wave-like structure, a wave length of 24 ± 5 km (over 5 peaks), a period of 13.3 ± 1.5 days, a propagation speed of 1.85 km $\cdot$ d^{-1} and an approximate amplitude of 25 ± 10 m.

Taking all 480 data points from the 80 mile profile at 30 m, there seem to be some (expected) correlation between temperature and the different chemical parameters as depicted in Figures 22 - 24. As temperature is a parameter which can be easily recorded continuously with a towed sensor, one might get an idea about the order of variability to be expected in the chemical parameters from temperature profiles.

Concluding from this first intensive study with our chemical profiler and the preliminary evaluation of only about 10 % of our collected data it seems to be quite obvious that patchiness and small and medium scale variability play an important role and cannot be disregarded when interpreting chemical data collected at isolated, widely spaced stations by conventional sampling procedures. The question is now how the situation might be at different times of the year in different regions. In fact, it seems to be rather dangerous to connect conventional station data with nice isolines, at least for some regions and some periods of the year. Without knowing the amplitudes, frequency and regional distribution of the variability, a reasonable assessment of e. g. the monitoring data from the open Baltic may be an impossible undertaking.

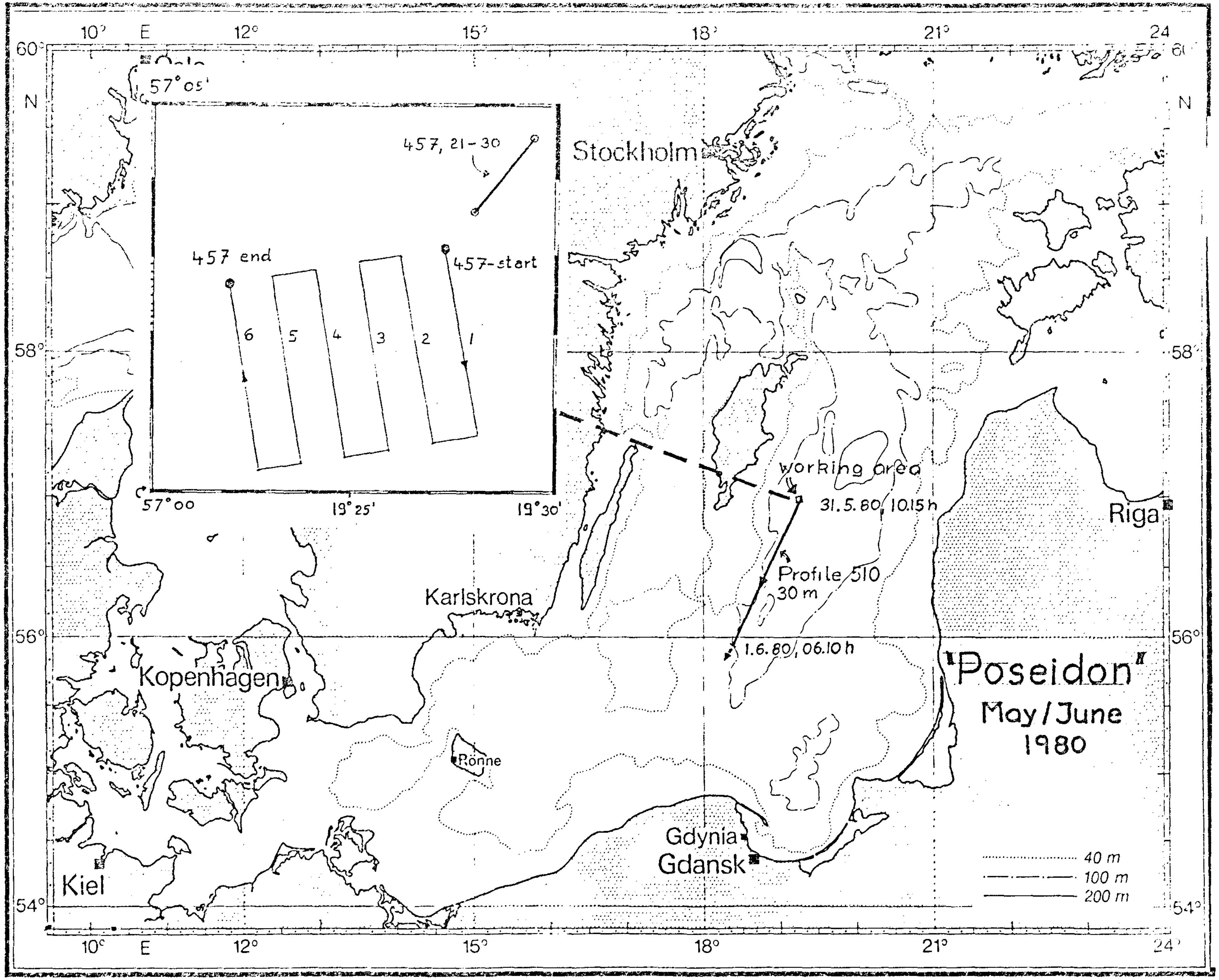


Figure 1 : Map of the working square and the 80 nautical mile profile.

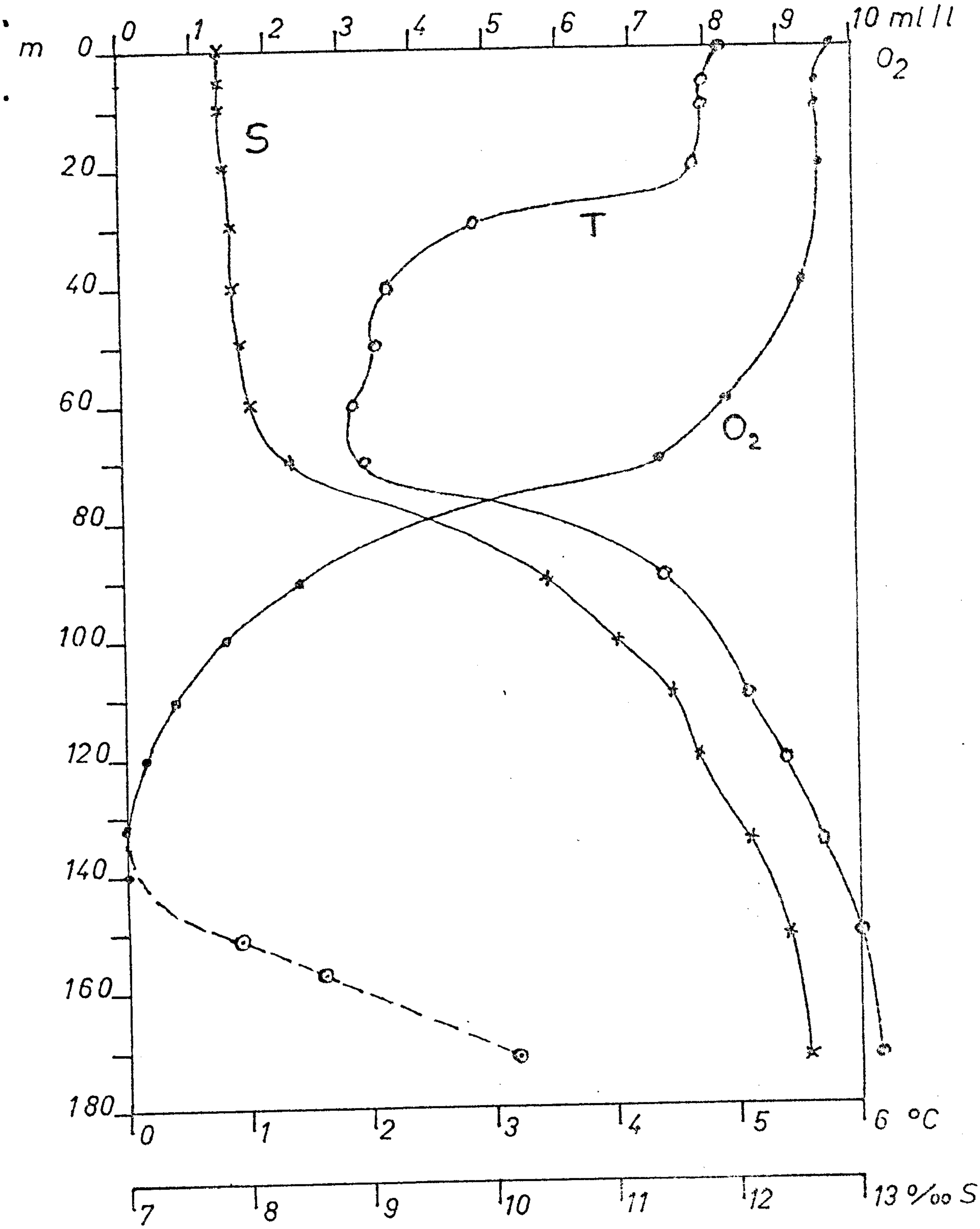


Figure 2 : Vertical distribution of S, T, O_2, H_2S near the working square (with conventional sampling).

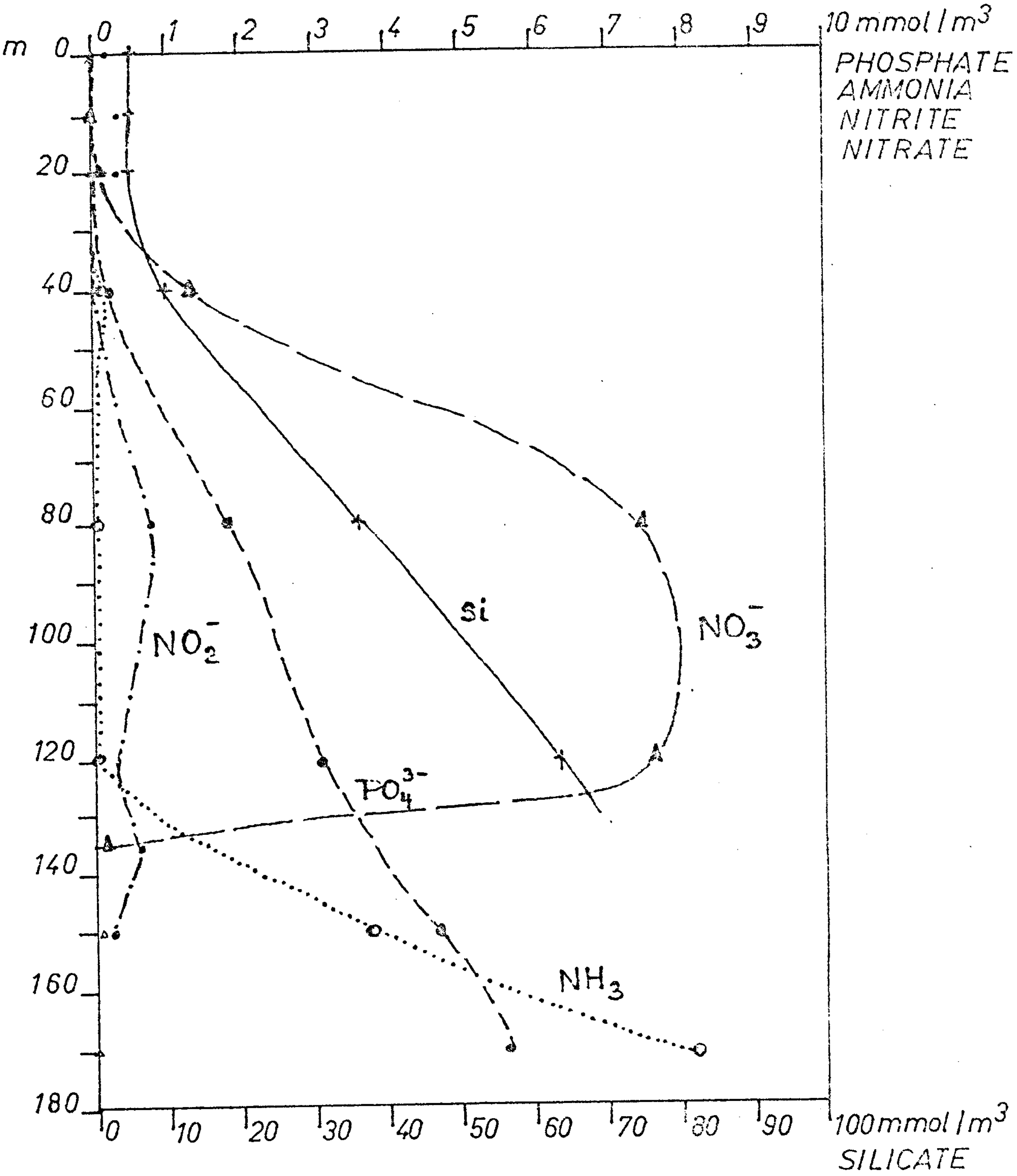


Figure 3 : Vertical distribution of nutrients near the working square (with conventional sampling).

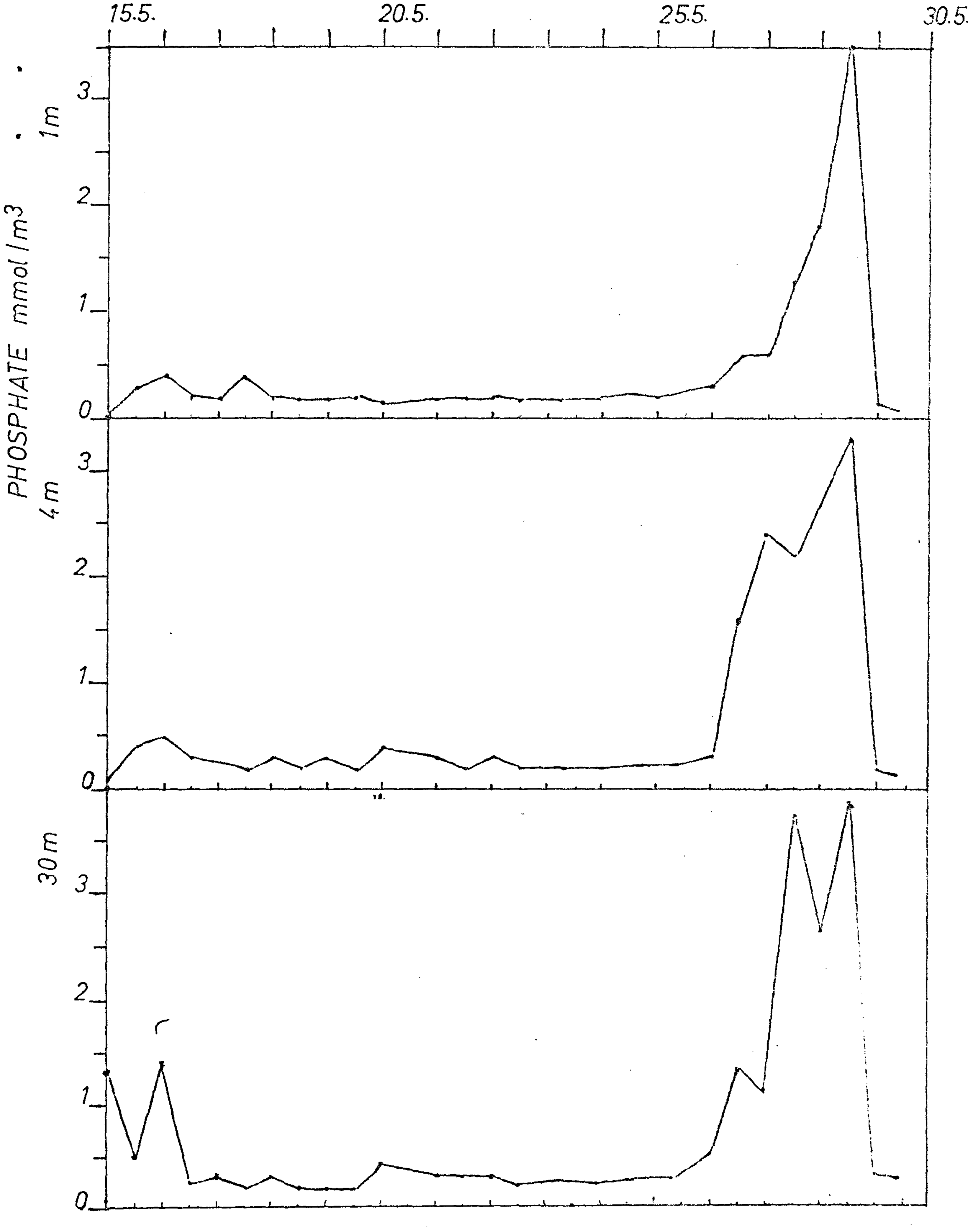


Figure 4 : The phosphate content from 15. - 30. May 1980 in 1, 4, 30 m at a station near the working square (with conventional sampling).

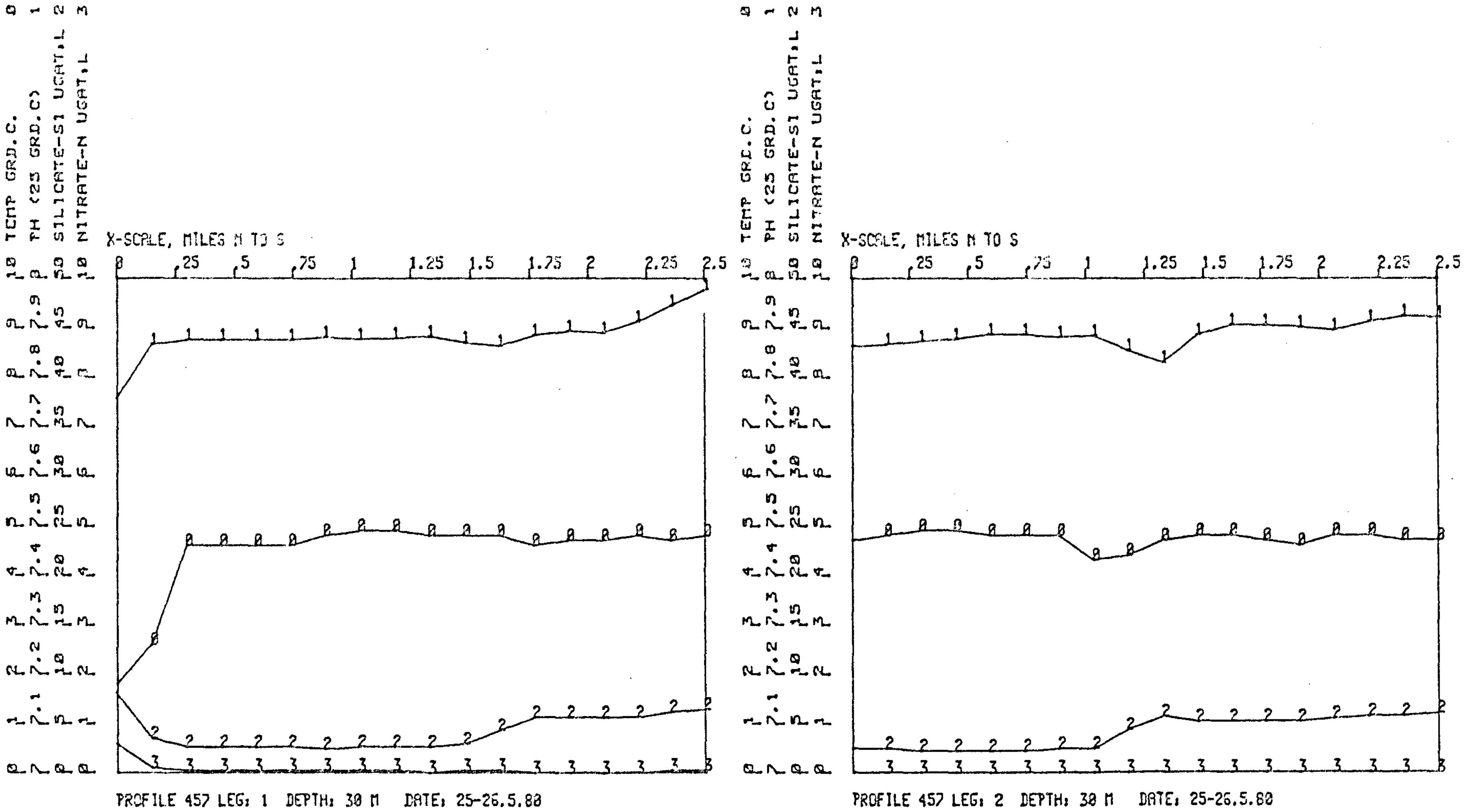
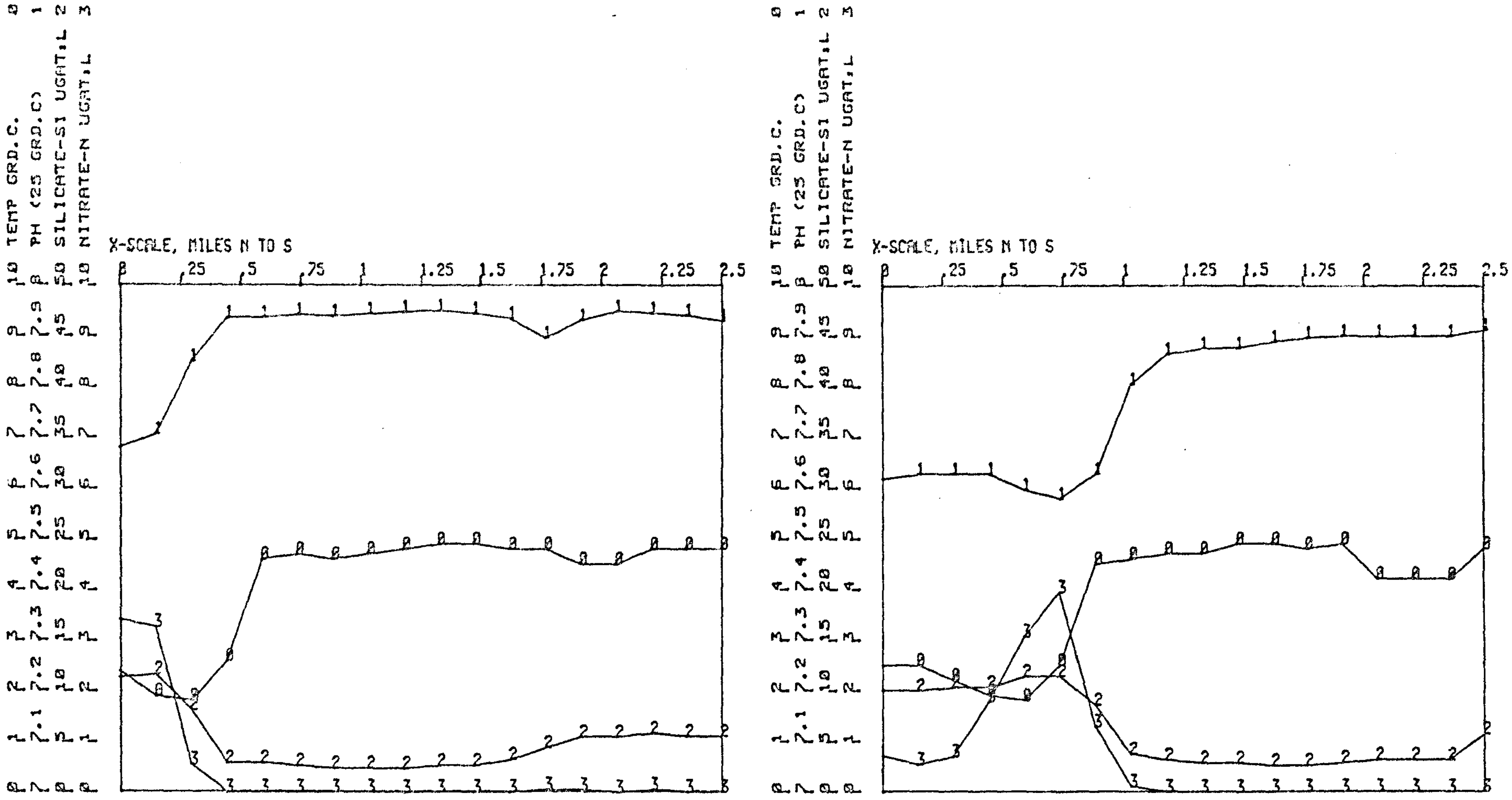


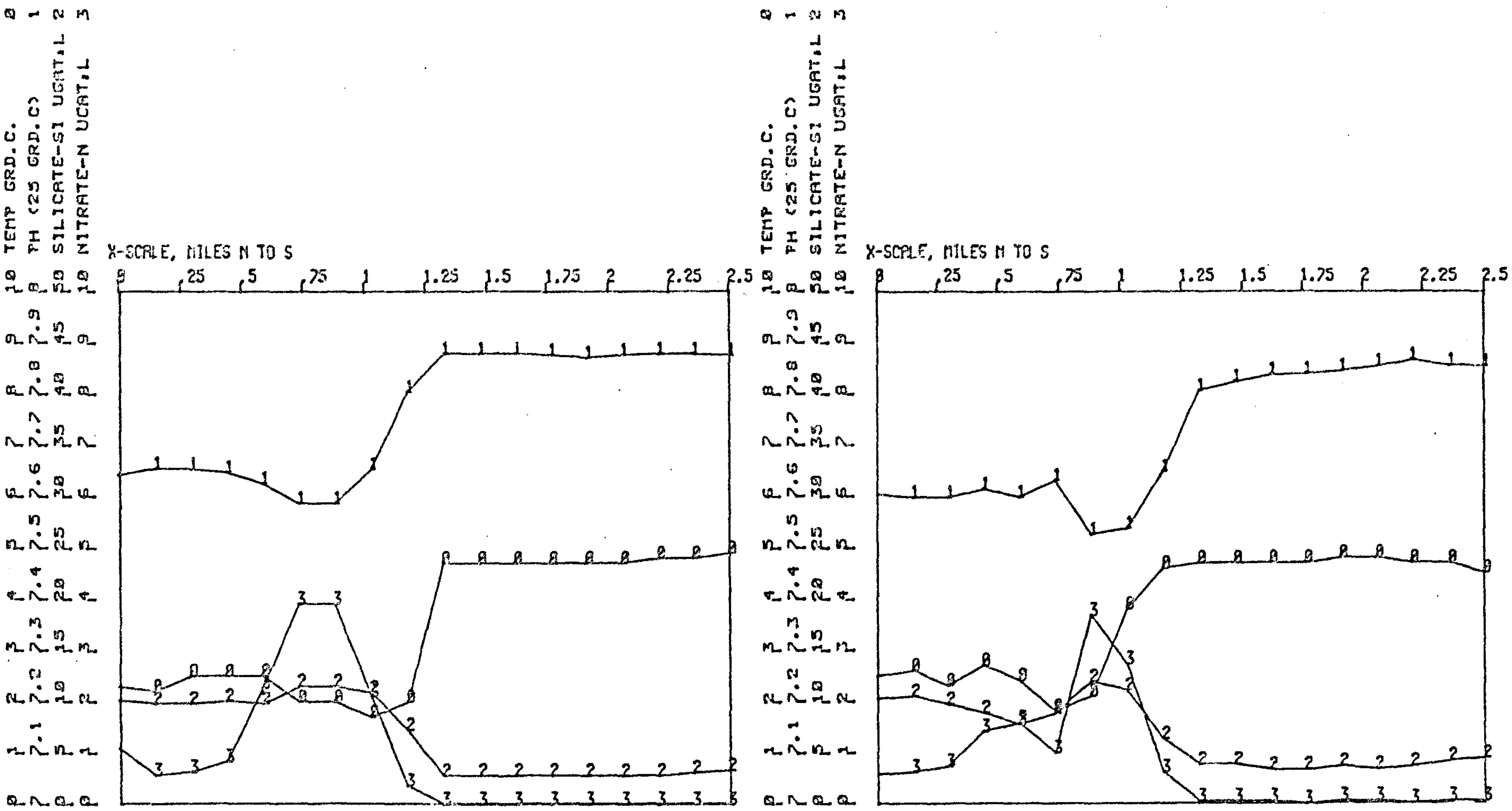
Figure 5 - 7 : 6 recorded legs in the 30 m level showing the distribution of temperature (0), pH (1), silicate (2), and nitrate (3) (c. f. map Fig. 1).



PROFILE 457 LEG: 3 DEPTH: 30 M DATE: 25-26.5.80

PROFILE 457 LEG: 4 DEPTH: 30 M DATE: 25-26.5.80

<u>Figure 6</u>



PROFILE 457 LEG; 5 DEPTH; 30 M DATE; 25-26.5.80

PROFILE 457 LEG; 6 DEPTH; 30 M DATE; 25-26.5.80

Figure 7

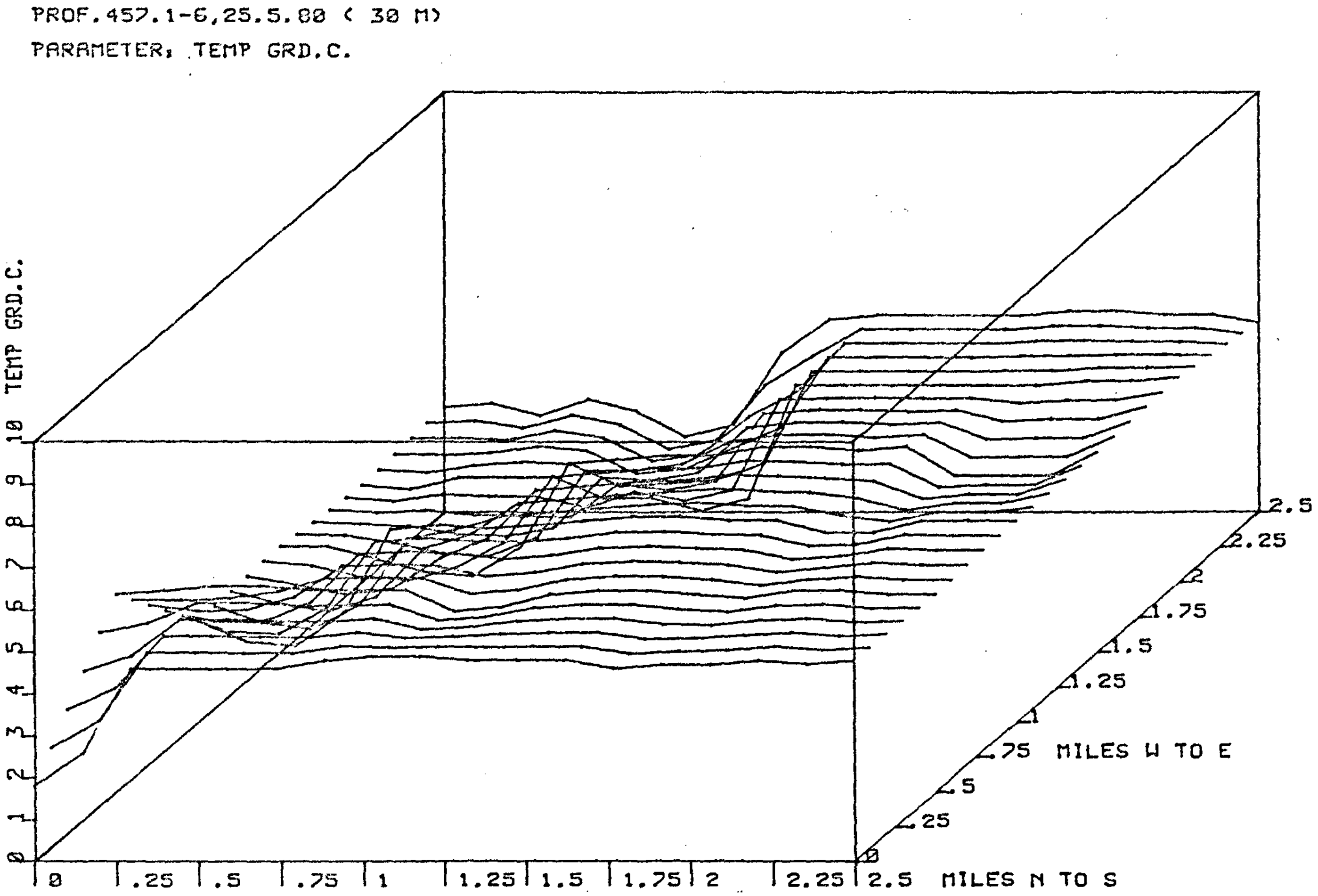


Figure 8 - 11 : Threedimensional plots of the quasisynoptic distribution of four selected parameters in the 30 m level (area c. f. map Fig. 1).

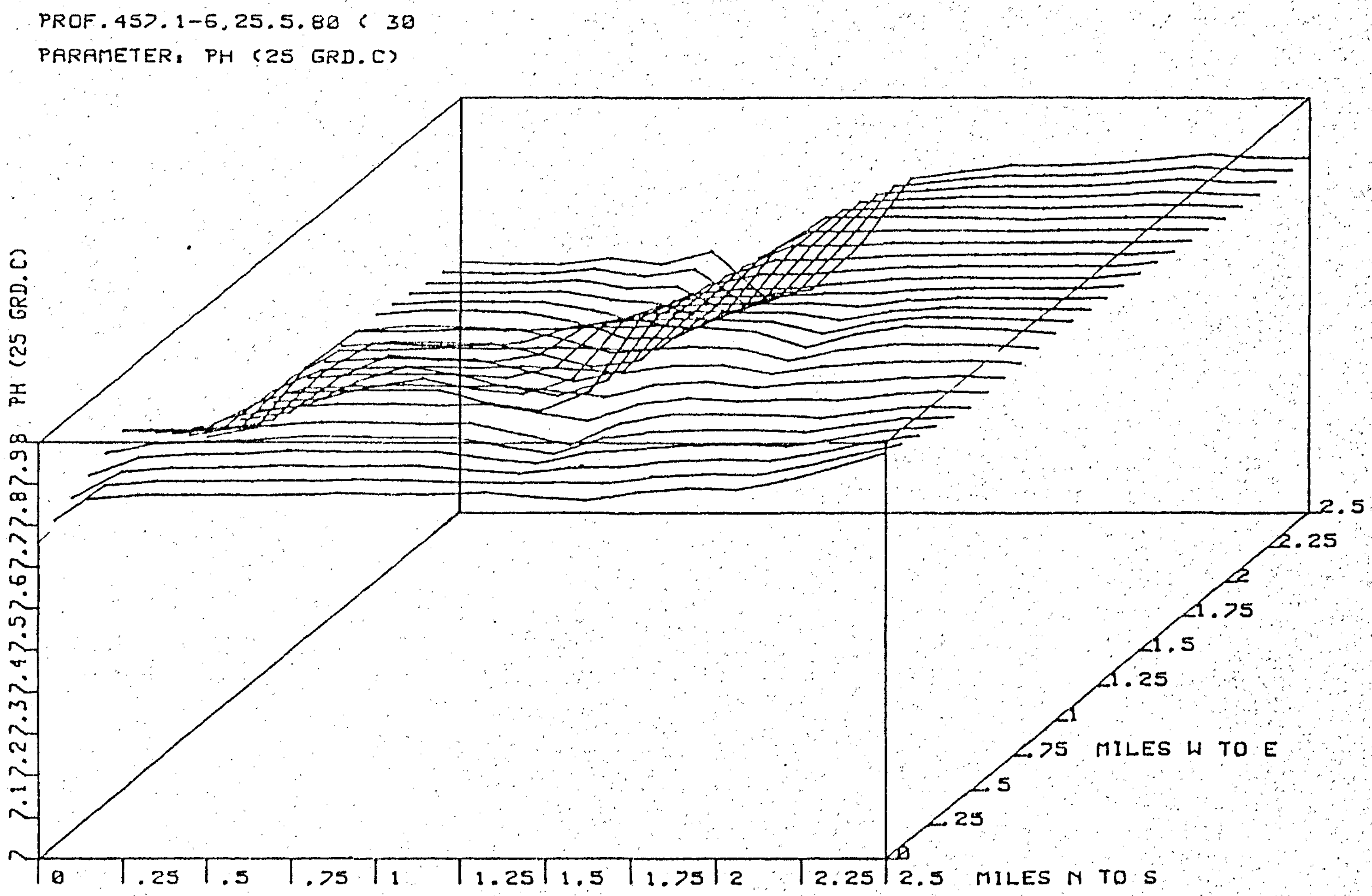

PROF.457.1-6,25.5.80 < 30
PARAMETER: PH (25 GRD.C)
PH (25 GRD.C)
7
7.1
7.2
7.3
7.4
7.5
7.6
7.7
7.8
7.9
8
0
.25
.5
.75
1
1.25
1.5
1.75
2
2.25
2.5
MILES N TO S
0
.25
.5
.75
1
1.25
1.5
1.75
2
2.25
2.5
MILES W TO E

Figure 9

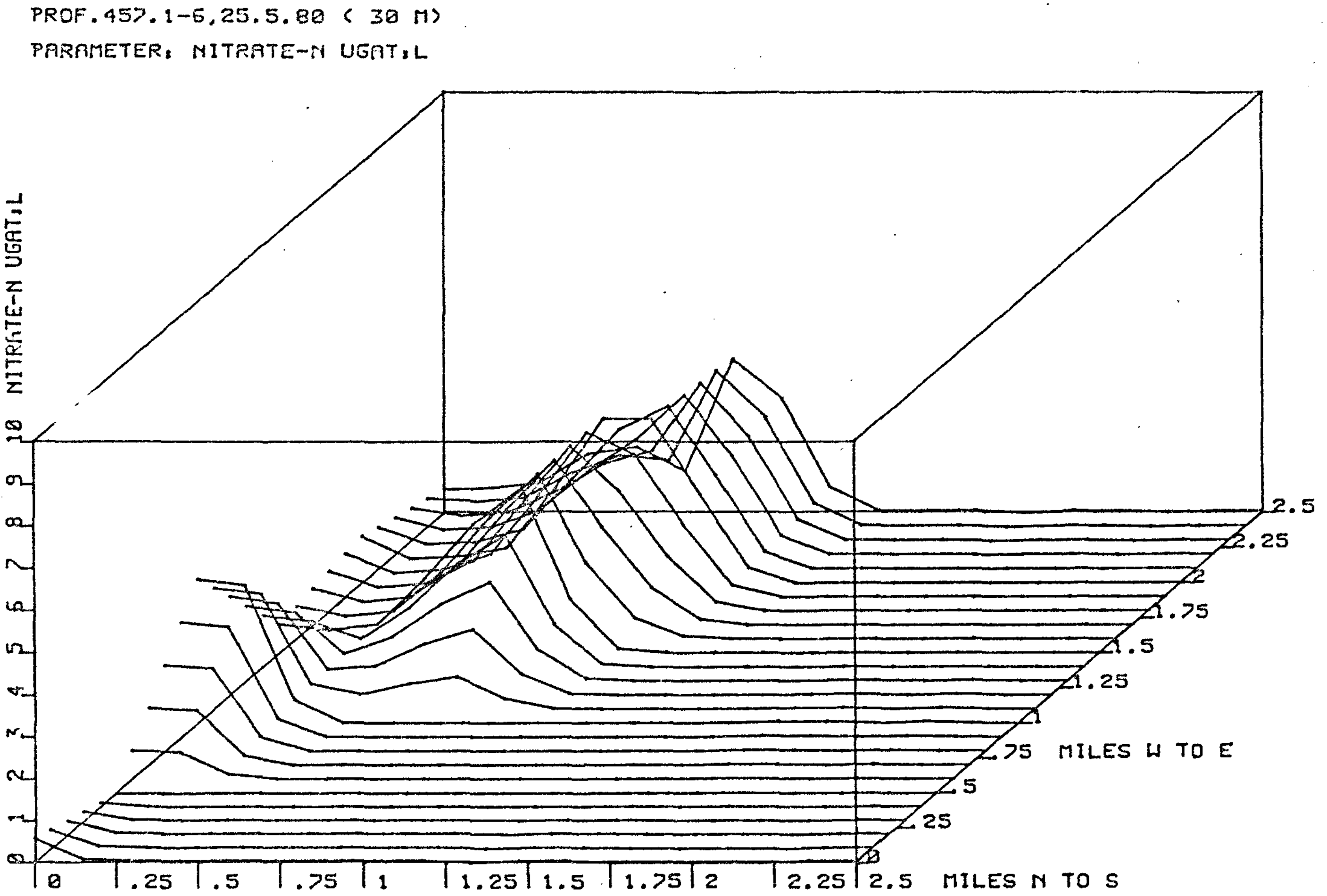

PROF.457.1-6,25.5.80 (30 M)
PARAMETER: NITRATE-N UGAT:L
NITRATE-N UGAT:L
0
1
2
3
4
5
6
7
8
9
10
0
.25
.5
.75
1
1.25
1.5
1.75
2
2.25
2.5
MILES N TO S
0
.25
.5
.75
MILES W TO E
1
1.25
1.5
1.75
2
2.25
2.5

Figure 10

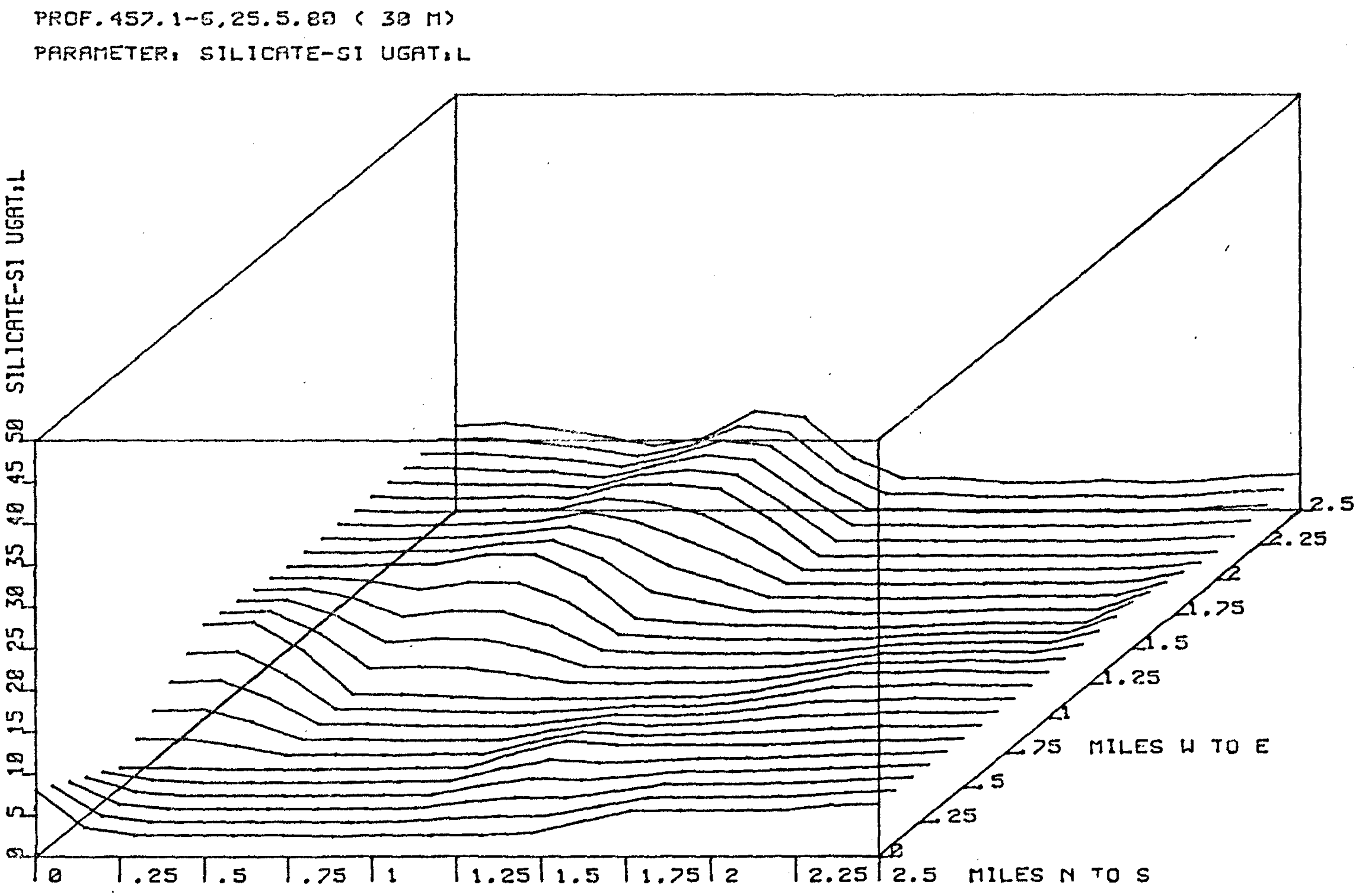

PROF.457.1-6,25.5.80 (30 M)
PARAMETER: SILICATE-SI UGAT:L
SILICATE-SI UGAT:L
0
5
10
15
20
25
30
35
40
45
50
0
.25
.5
.75
1
1.25
1.5
1.75
2
2.25
2.5
MILES N TO S
0
.25
.5
.75
1
1.25
1.5
1.75
2
2.25
2.5
MILES W TO E

Figure 11

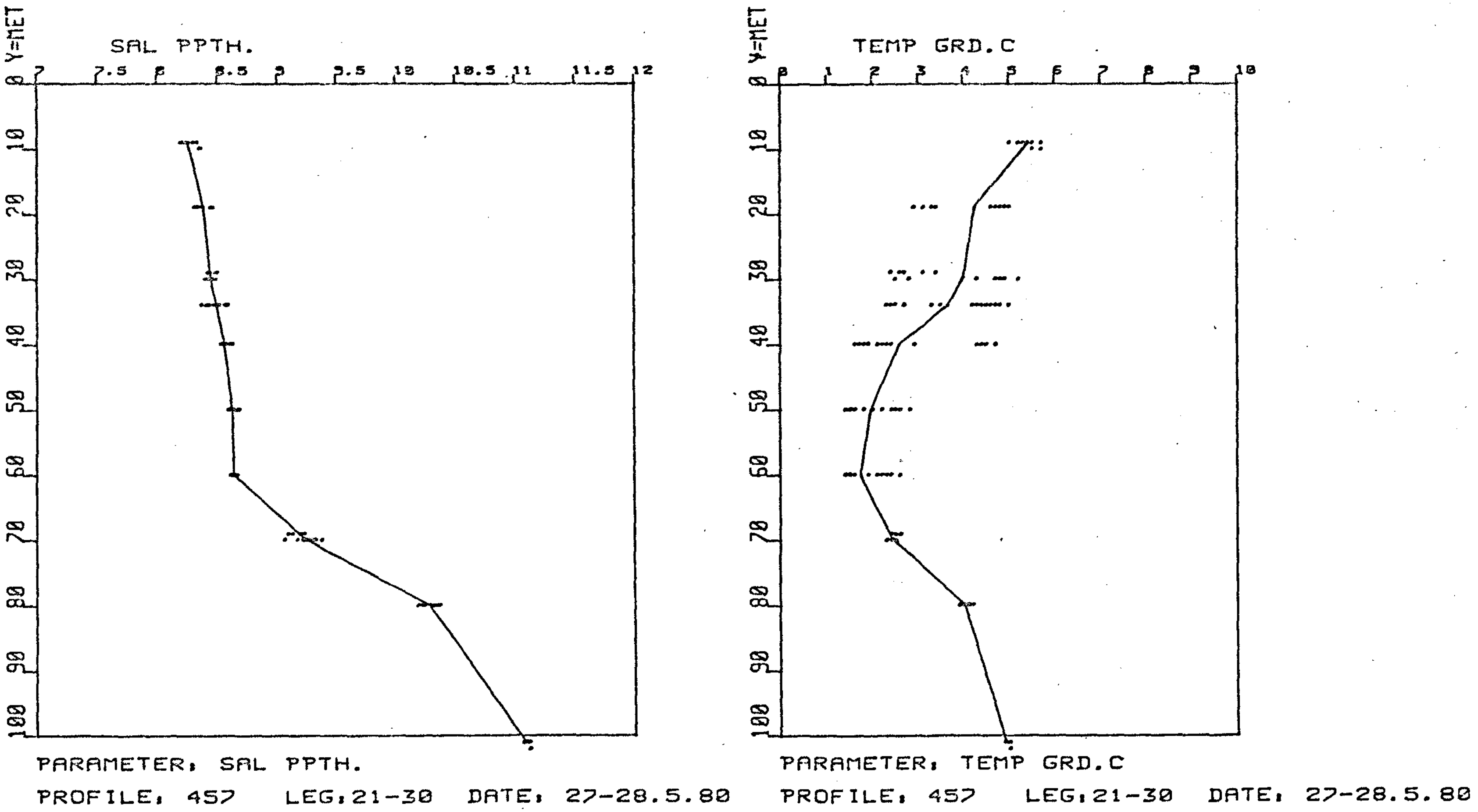
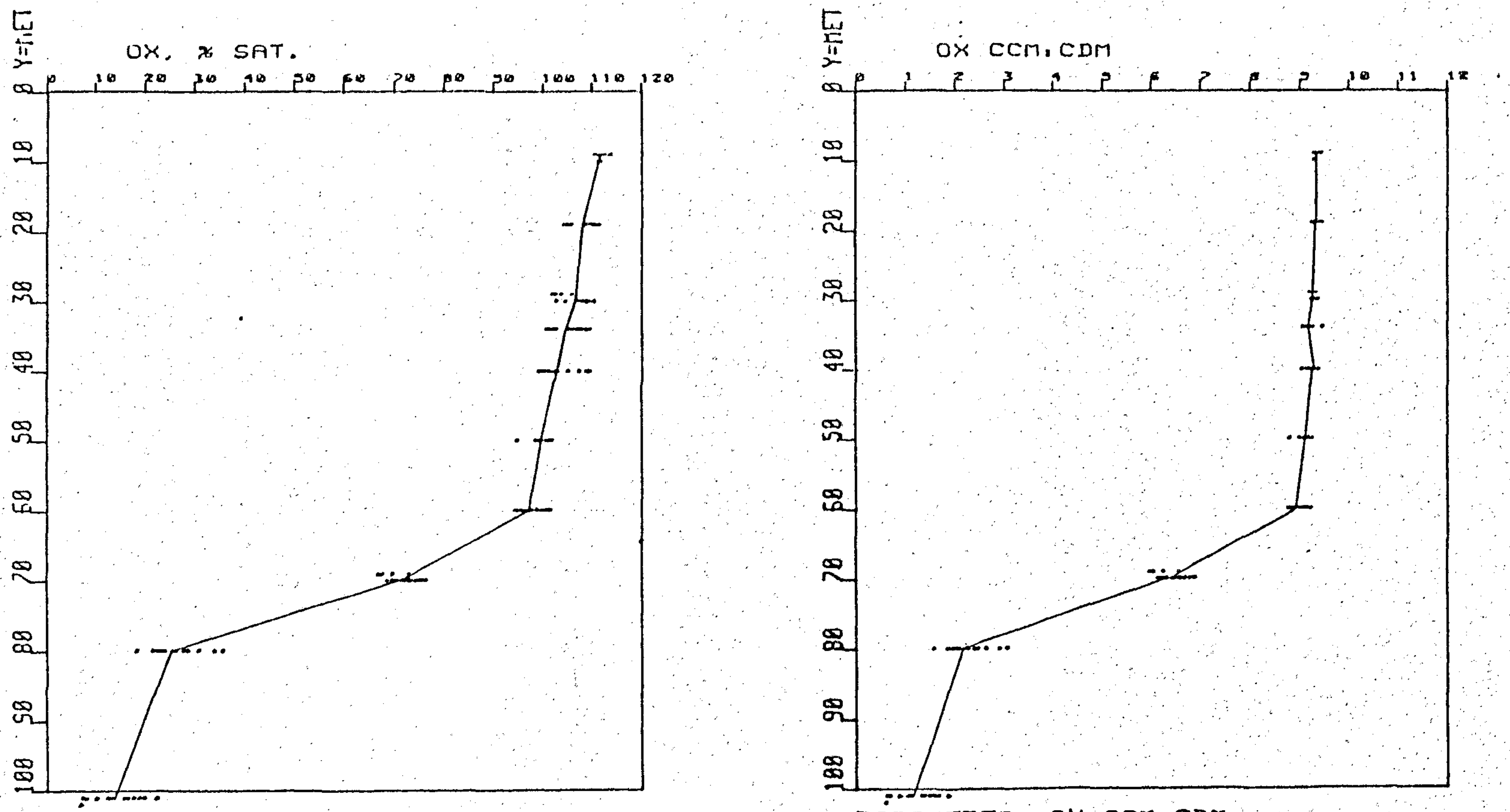


Figure 12 - 16 : Variability of selected physical and chemical parameters along a 2 nautical mile section in 10 depth levels. (Recorded within 7 hours; each depth 18 digital sampling points.)



PARAMETER: OX, % SAT.
PROFILE: 457 LEG:21-30 DATE: 27-28.5.80

PARAMETER: OX CCM:CDM
PROFILE: 457 LEG:21-30 DATE: 27-28.5.80

Figure 13

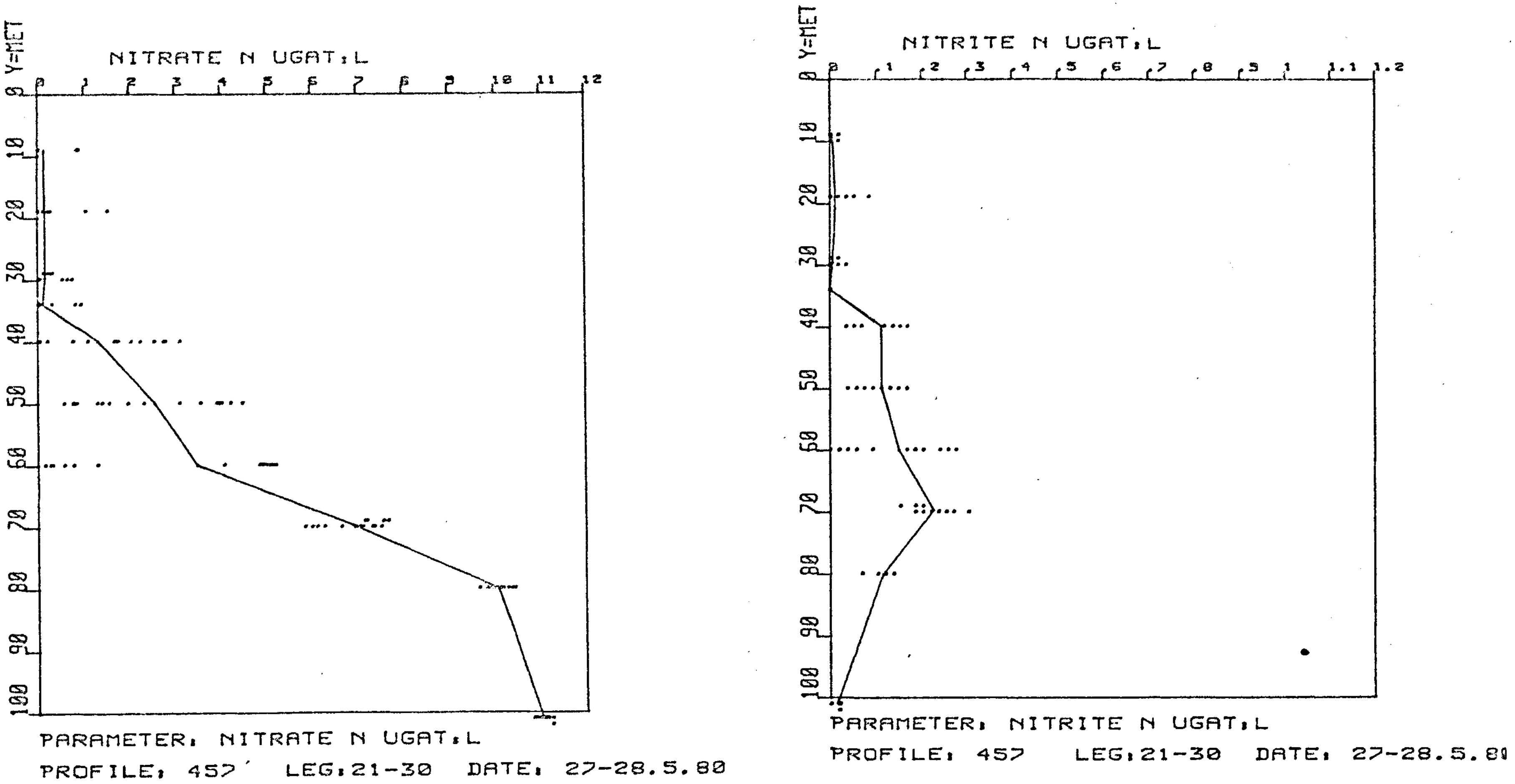

Y=MET
NITRATE N UGAT:L
0 1 2 3 4 5 6 7 8 9 10 11 12
0 10 20 30 40 50 60 70 80 90 100
PARAMETER: NITRATE N UGAT:L
PROFILE: 457 LEG:21-30 DATE: 27-28.5.80
Y=MET
NITRITE N UGAT:L
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1 1.1 1.2
0 10 20 30 40 50 60 70 80 90 100
PARAMETER: NITRITE N UGAT:L
PROFILE: 457 LEG:21-30 DATE: 27-28.5.80

Figure 14

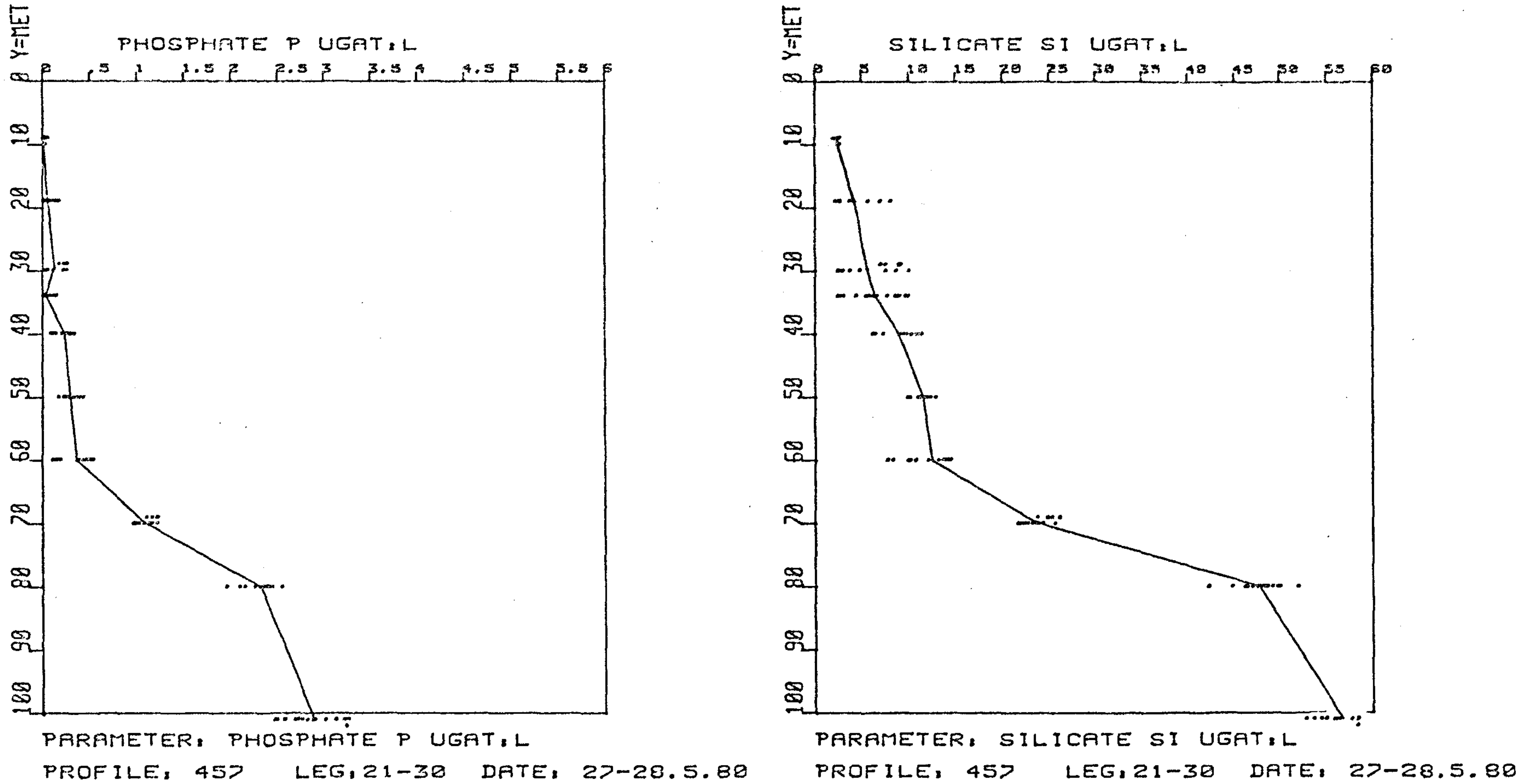
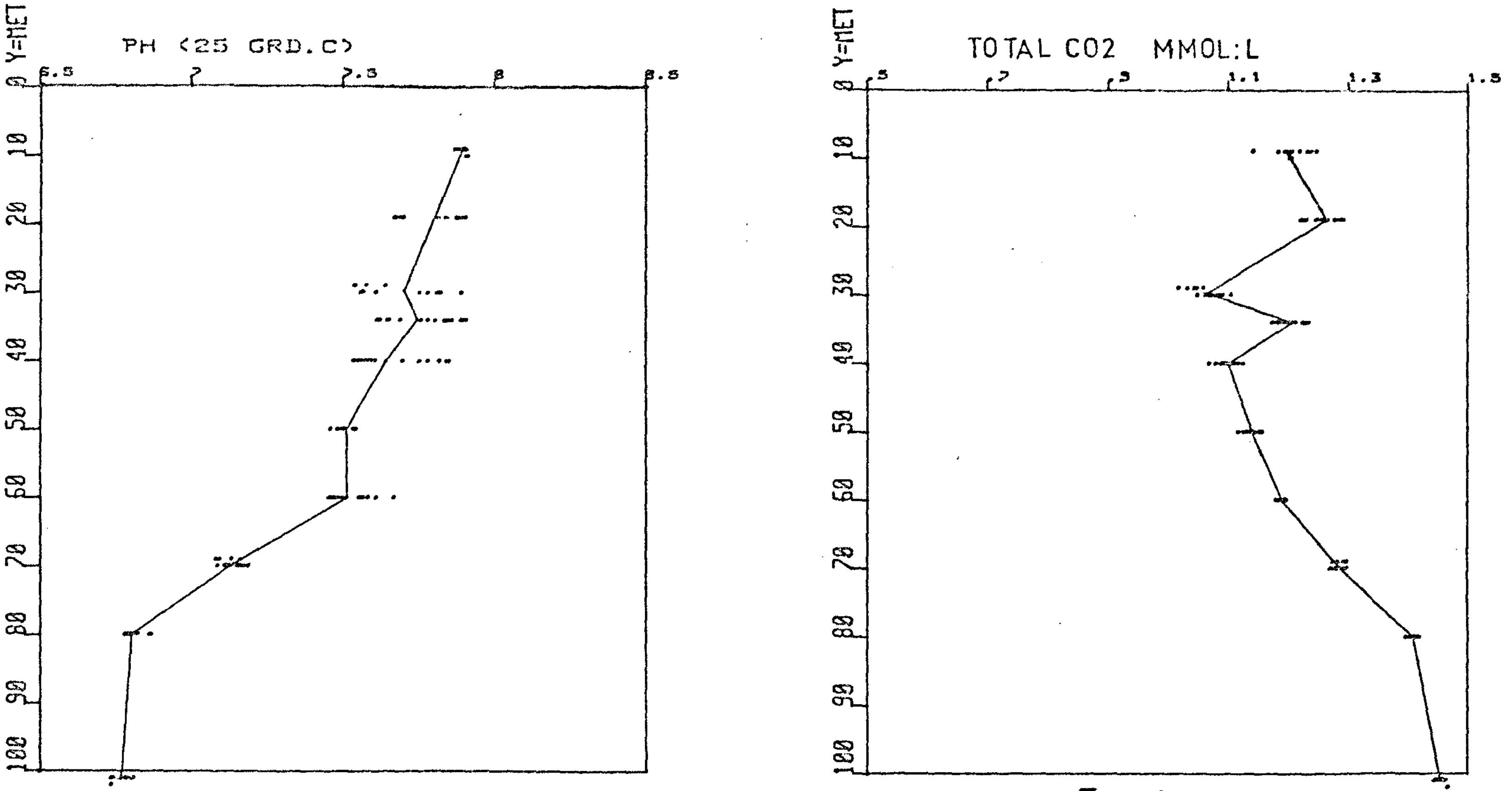

Y=MET
PHOSPHATE P UGAT:L
0 .5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6
0 10 20 30 40 50 60 70 80 90 100
PARAMETER: PHOSPHATE P UGAT:L
PROFILE: 457 LEG:21-30 DATE: 27-28.5.80
Y=MET
SILICATE SI UGAT:L
0 5 10 15 20 25 30 35 40 45 50 55 60
0 10 20 30 40 50 60 70 80 90 100
PARAMETER: SILICATE SI UGAT:L
PROFILE: 457 LEG:21-30 DATE: 27-28.5.80

Figure 15



PARAMETER: PH (25 GRD.C)
PROFILE: 457 LEG:21-30 DATE: 27-28.5.80

PARAMETER: Σ CO2
PROFILE: 457 LEG:21-30 DATE: 27-28.5.80

Figure 16

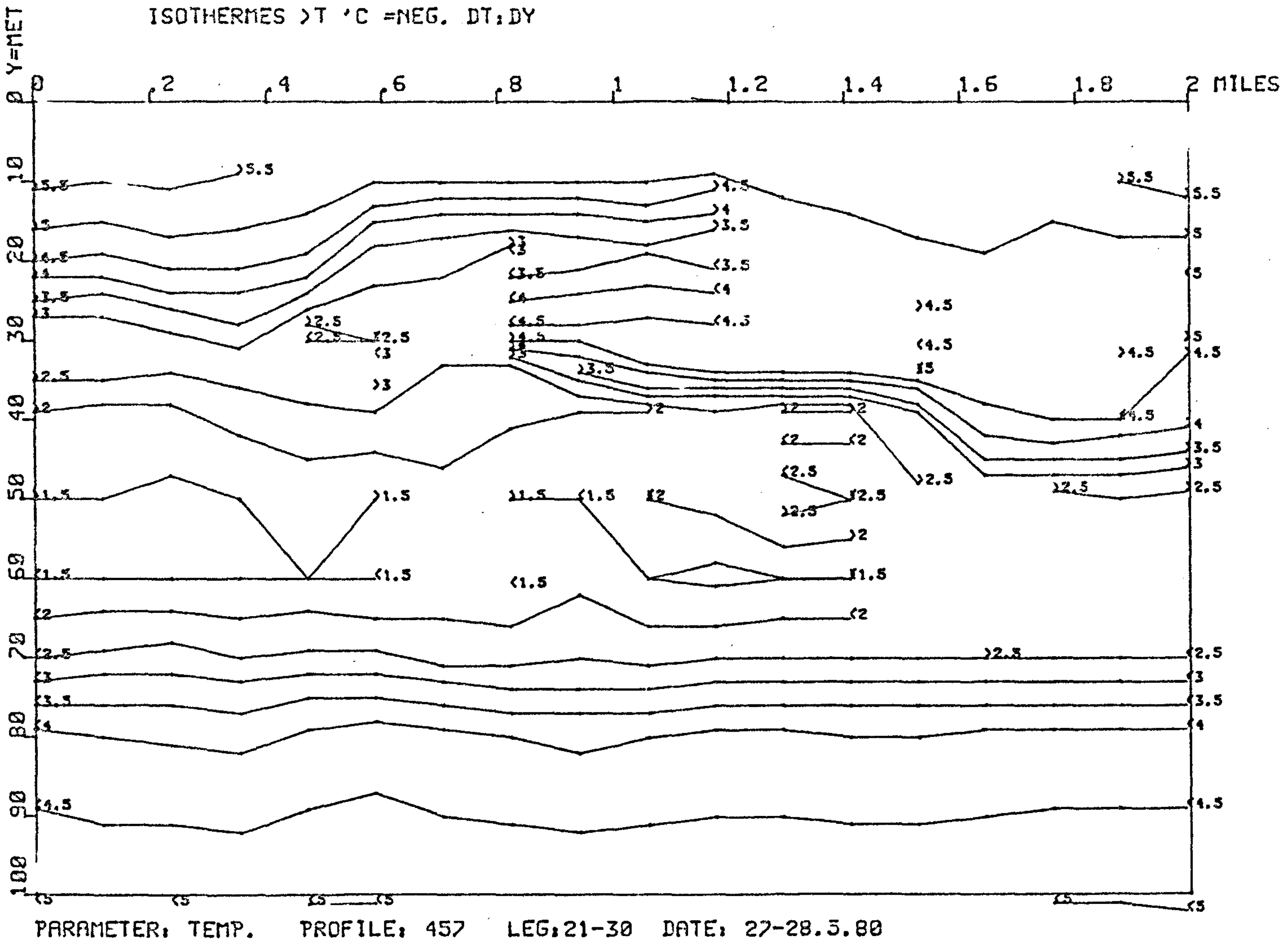


Figure 17 a : Isotherms on a 2 nautical mile section; computerplot, not interpreted. Recorded within 7 hours (location c. f. map Fig. 1).

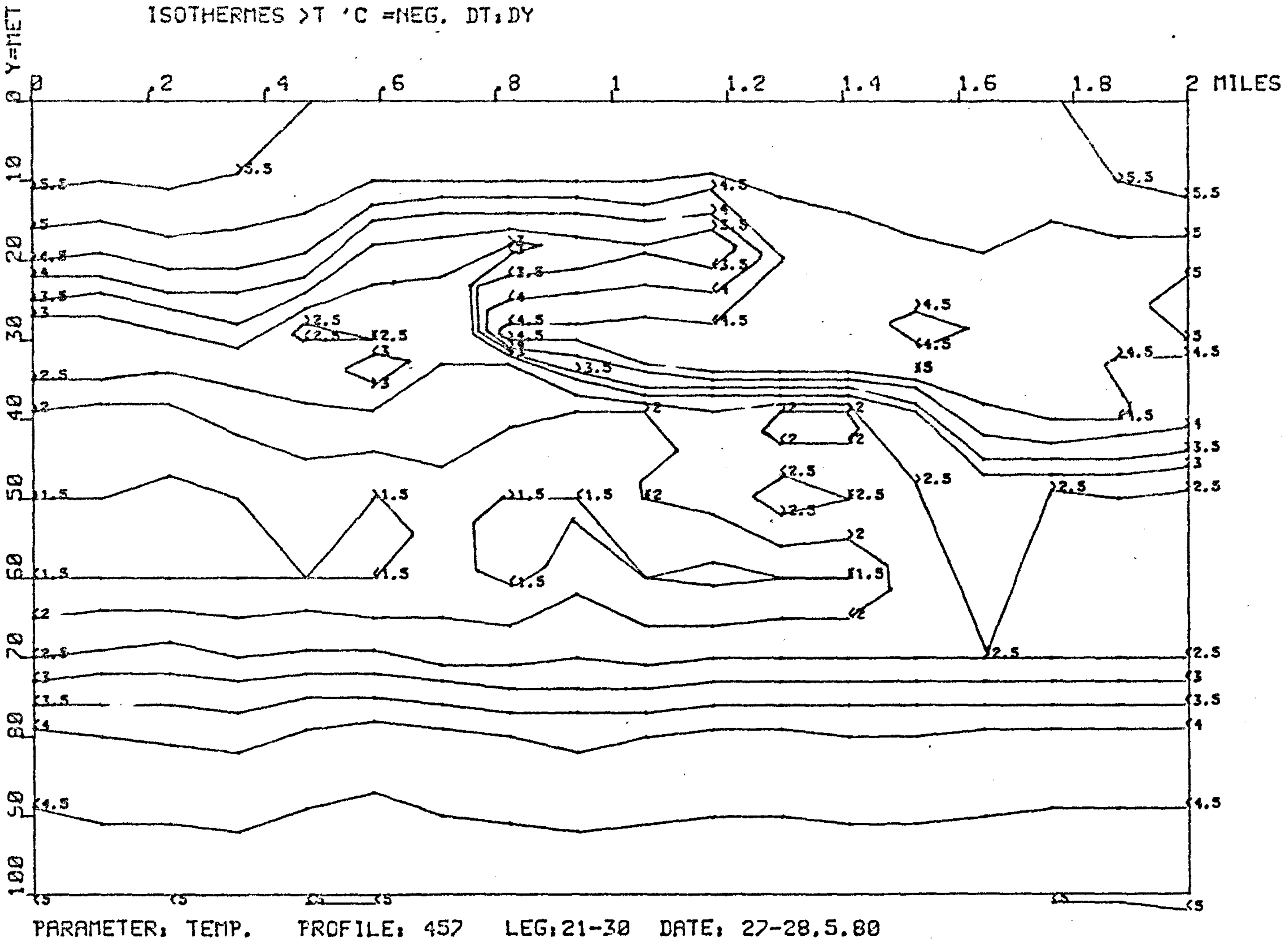


Figure 17 b : The same as Fig. 17 a, but completed and interpreted on the basis of continuous analogue records.

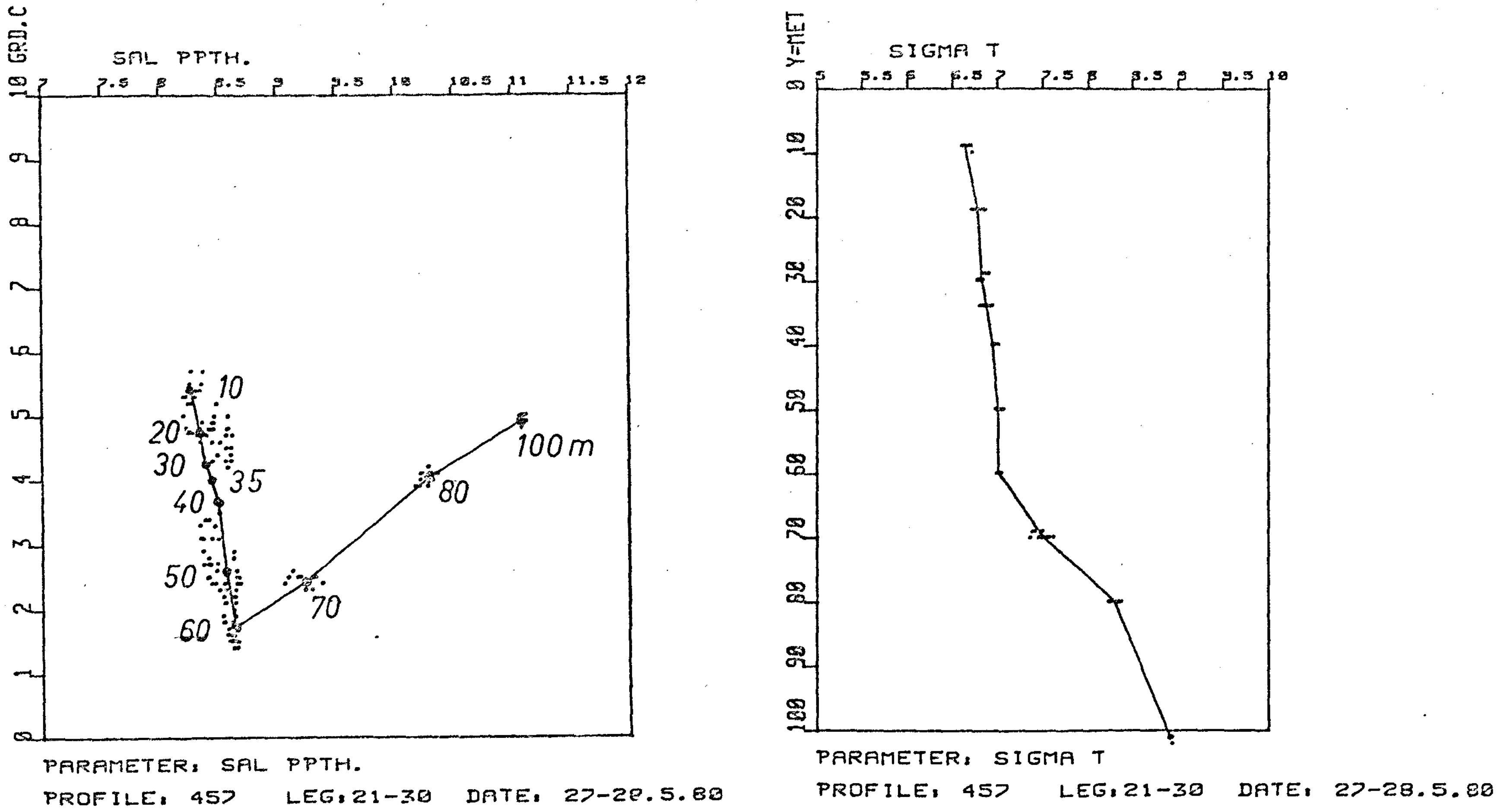
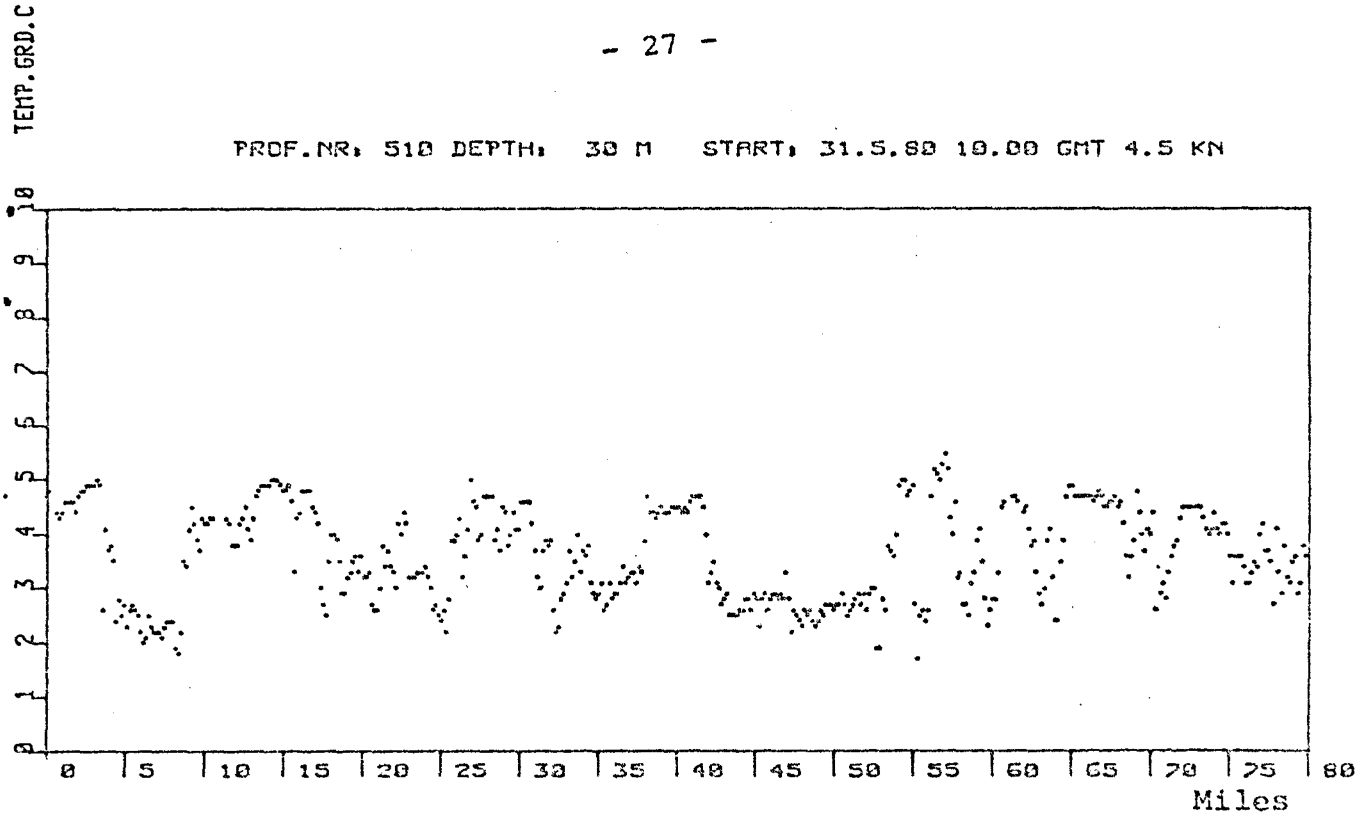


Figure 18 : T-S diagram of all data from the 2 nautical mile section and vertical distribution of density.



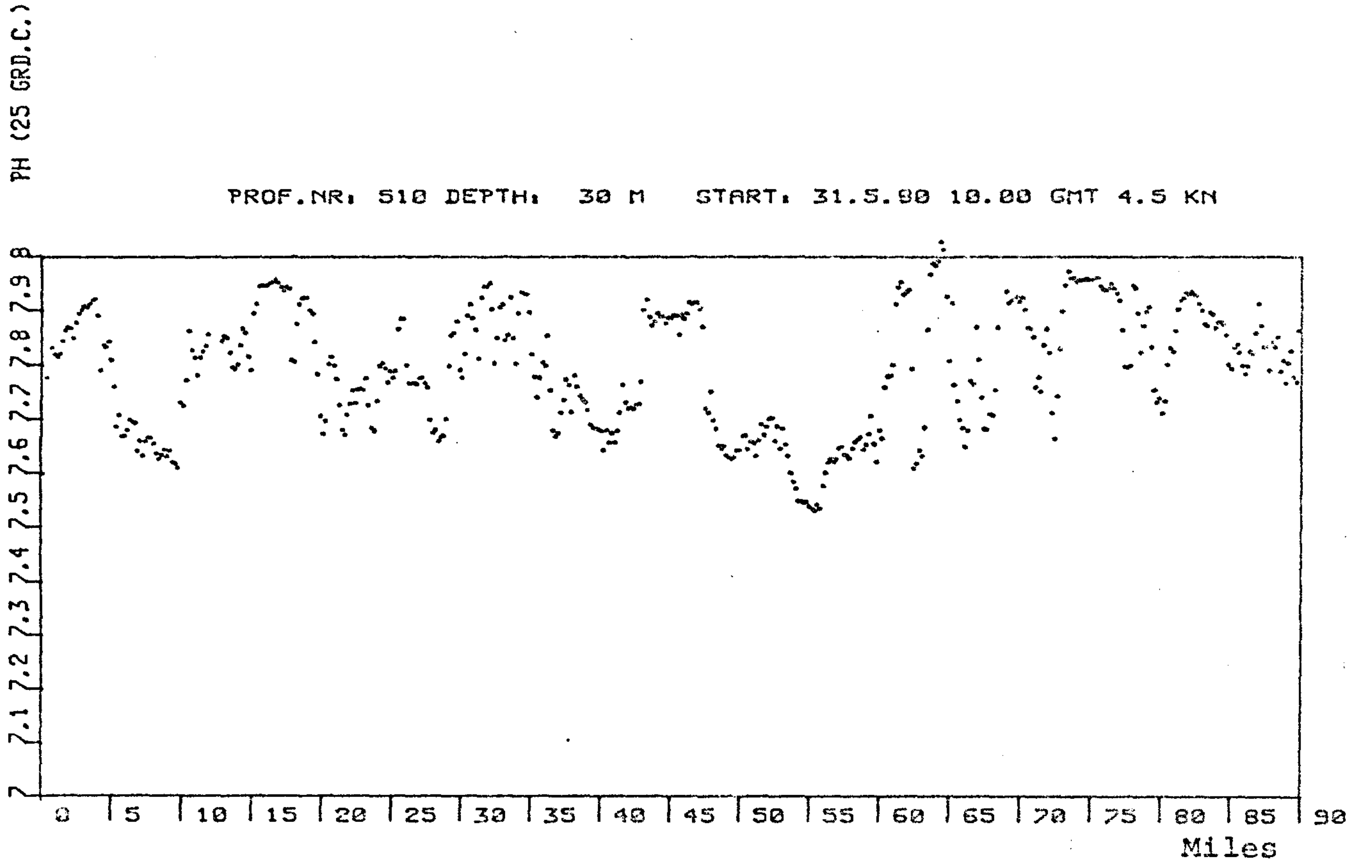


Figure 19 and 20 : Distribution of selected parameters in the 30 m level along a 80 nautical mile profile. 480 digital sampling points; corresponding spatial resulution 300 m, recording time 18 h. (Location of the profile c. f. map Fig. 1).

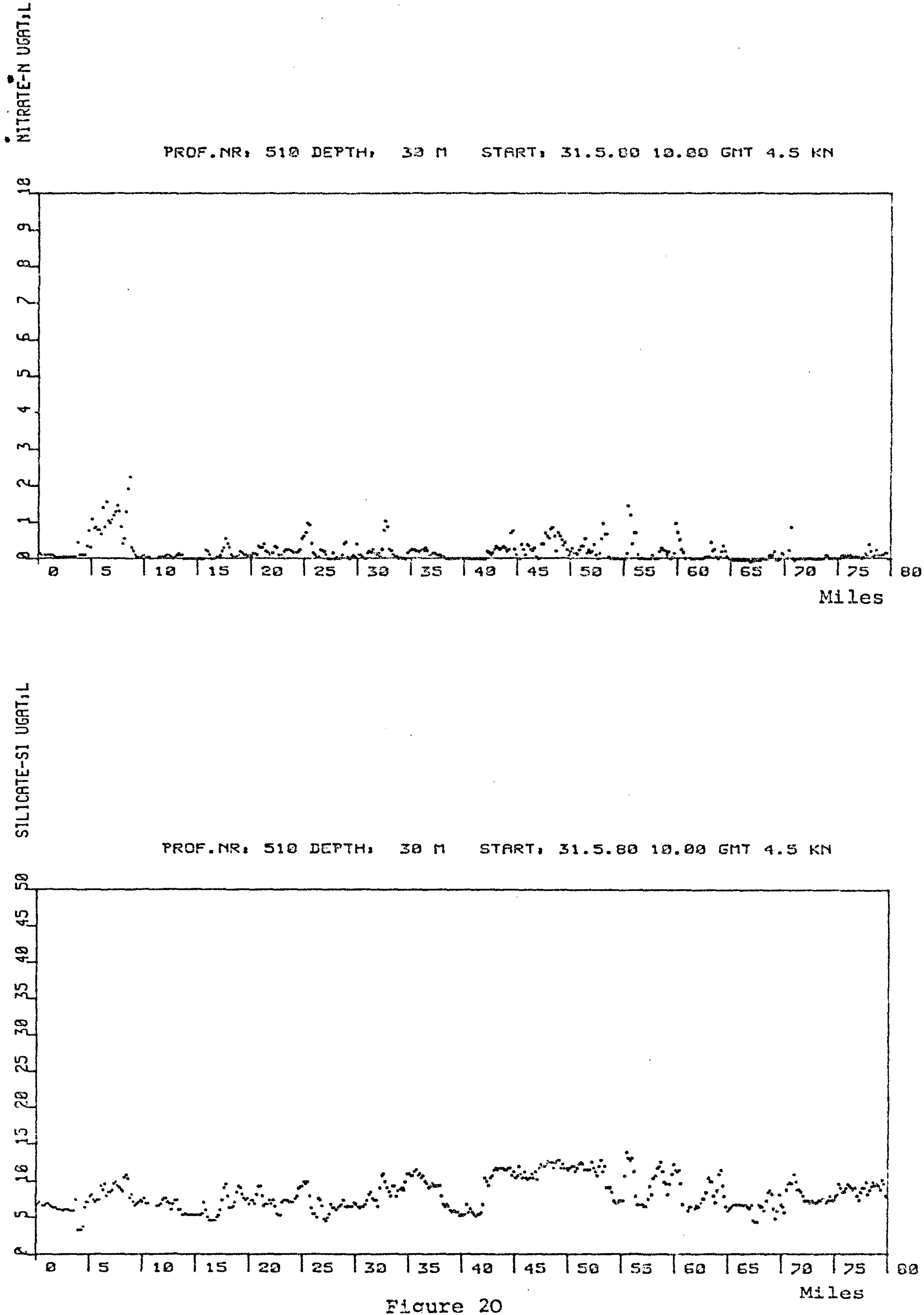

NITRATE-N UGAT;L
PROF.NR: 510 DEPTH: 30 M START: 31.5.80 10.00 GMT 4.5 KN
0 1 2 3 4 5 6 7 8 9 10
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Miles
SILICATE-SI UGAT;L
PROF.NR: 510 DEPTH: 30 M START: 31.5.80 10.00 GMT 4.5 KN
0 5 10 15 20 25 30 35 40 45 50
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Miles

Figure 20

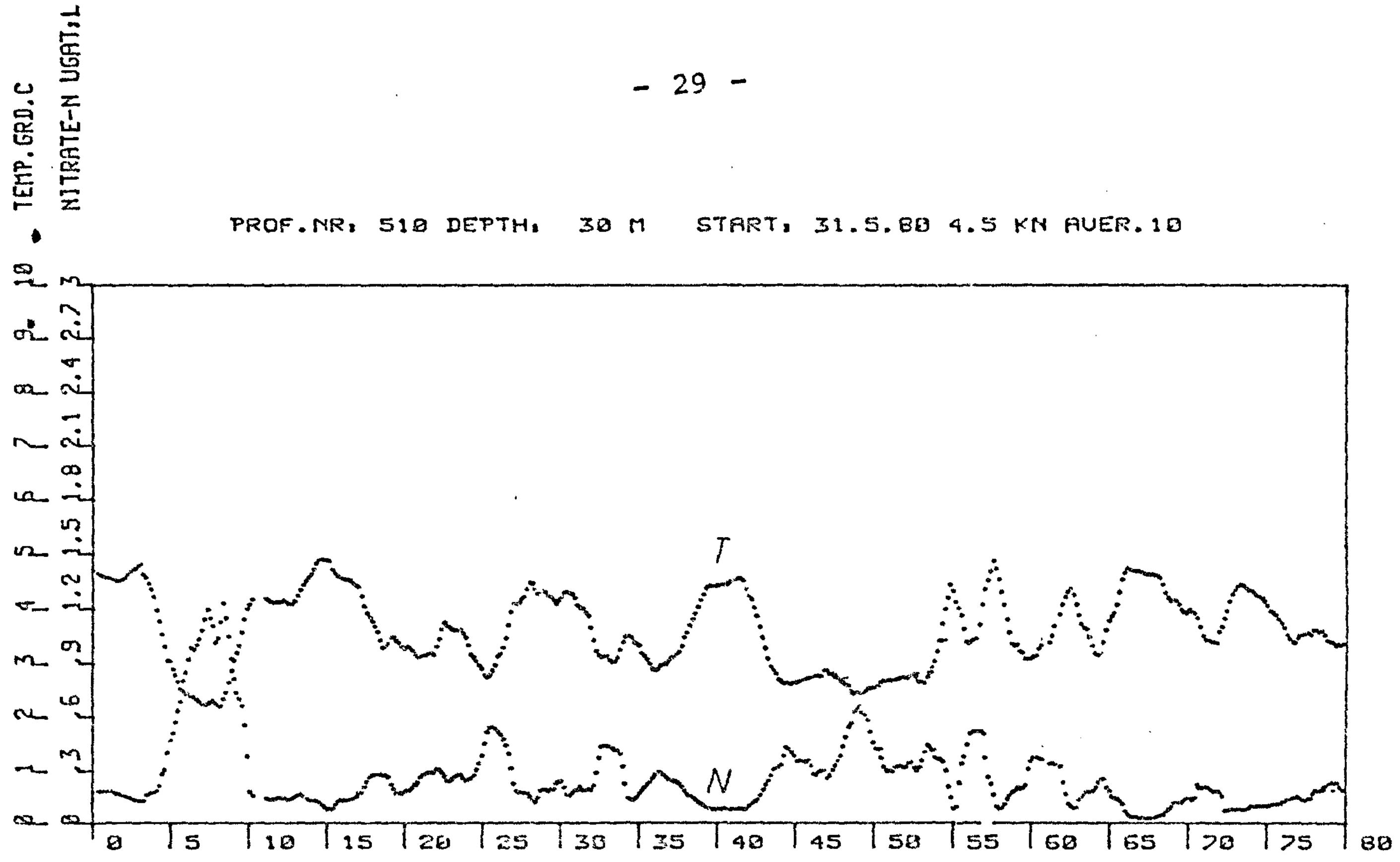


Figure 21 - 23 : Distribution of selected parameters along the same profile as Fig. 19/20. Floating averages over 10 sampling points.

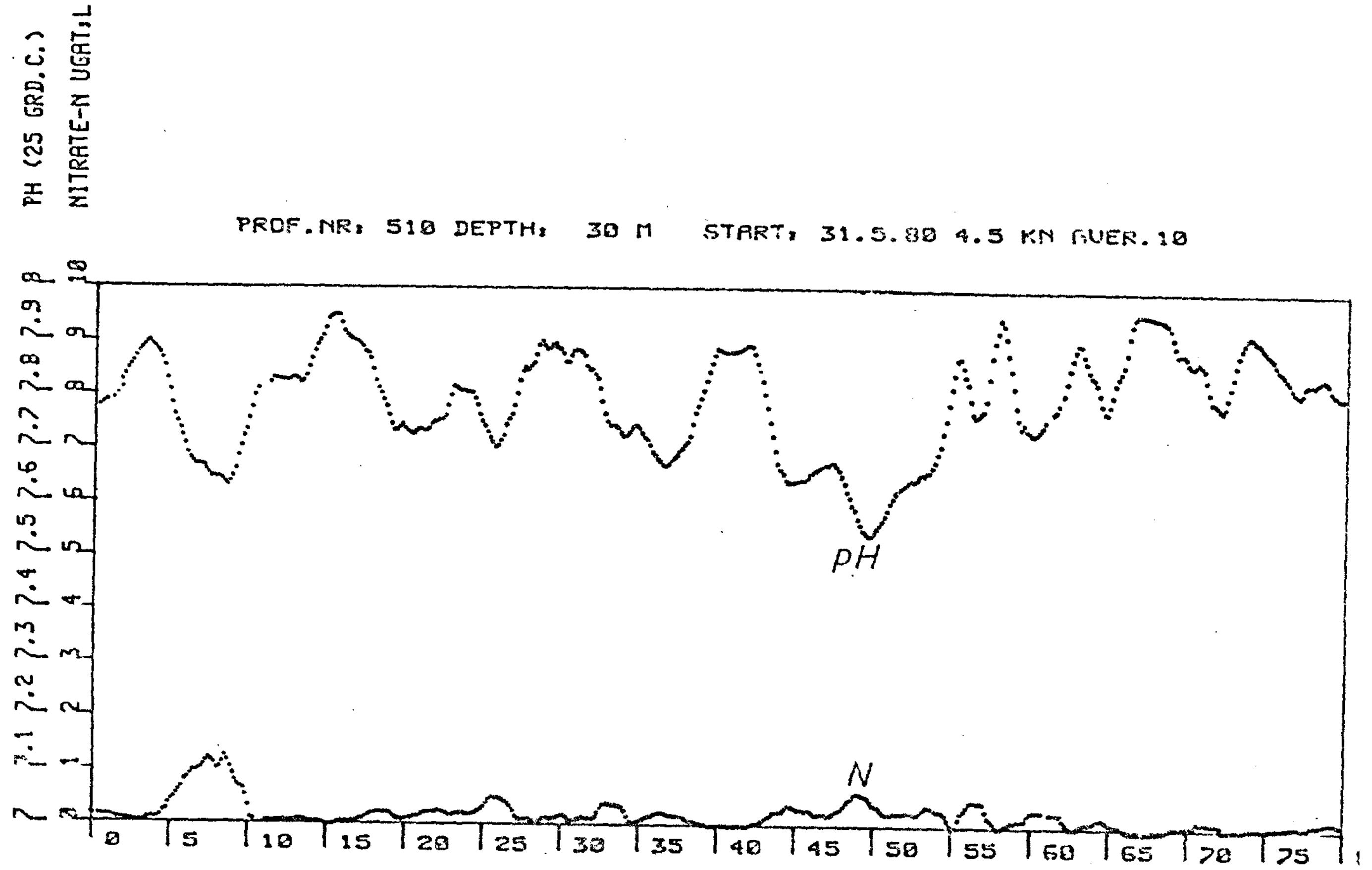


Figure 22

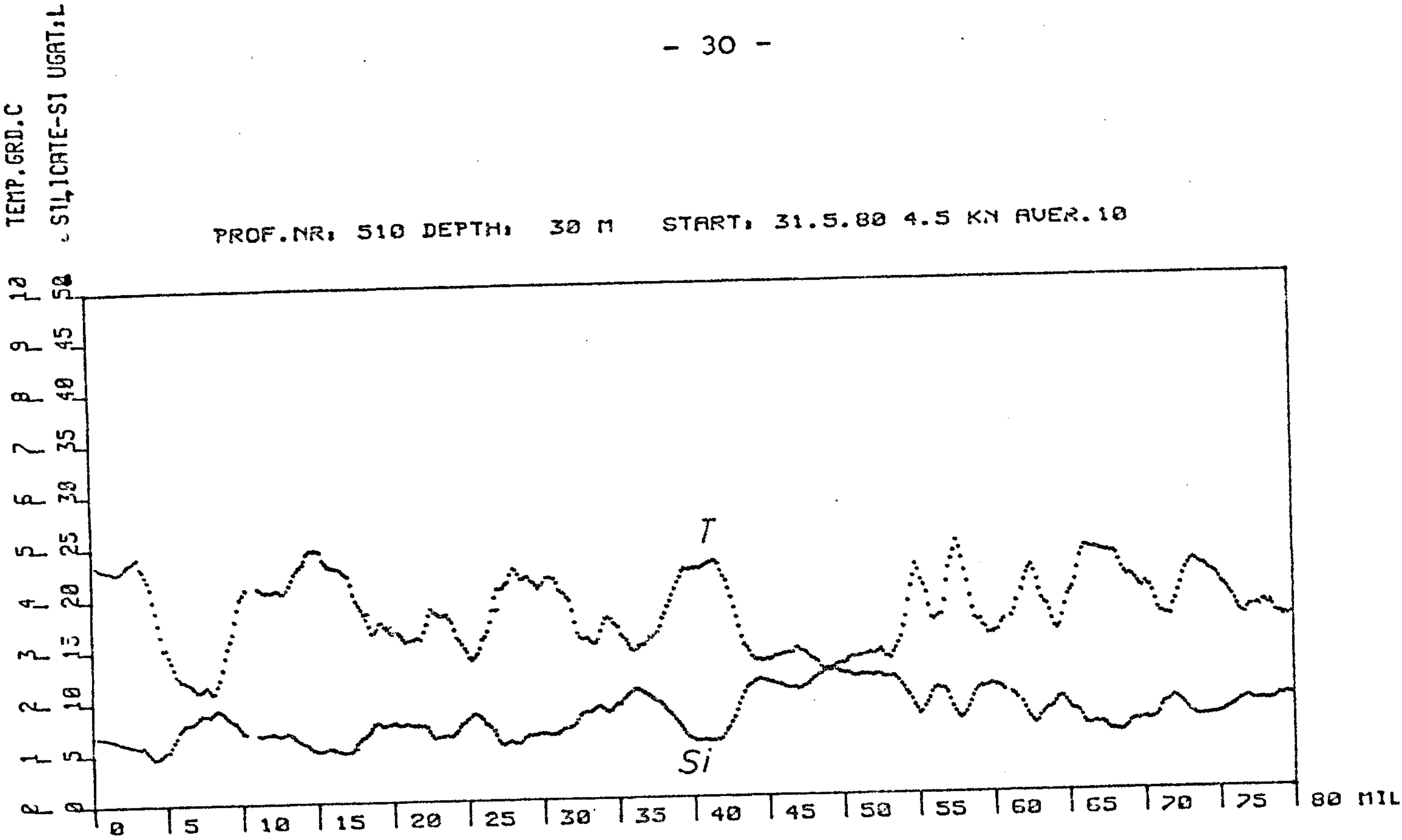


Figure 23

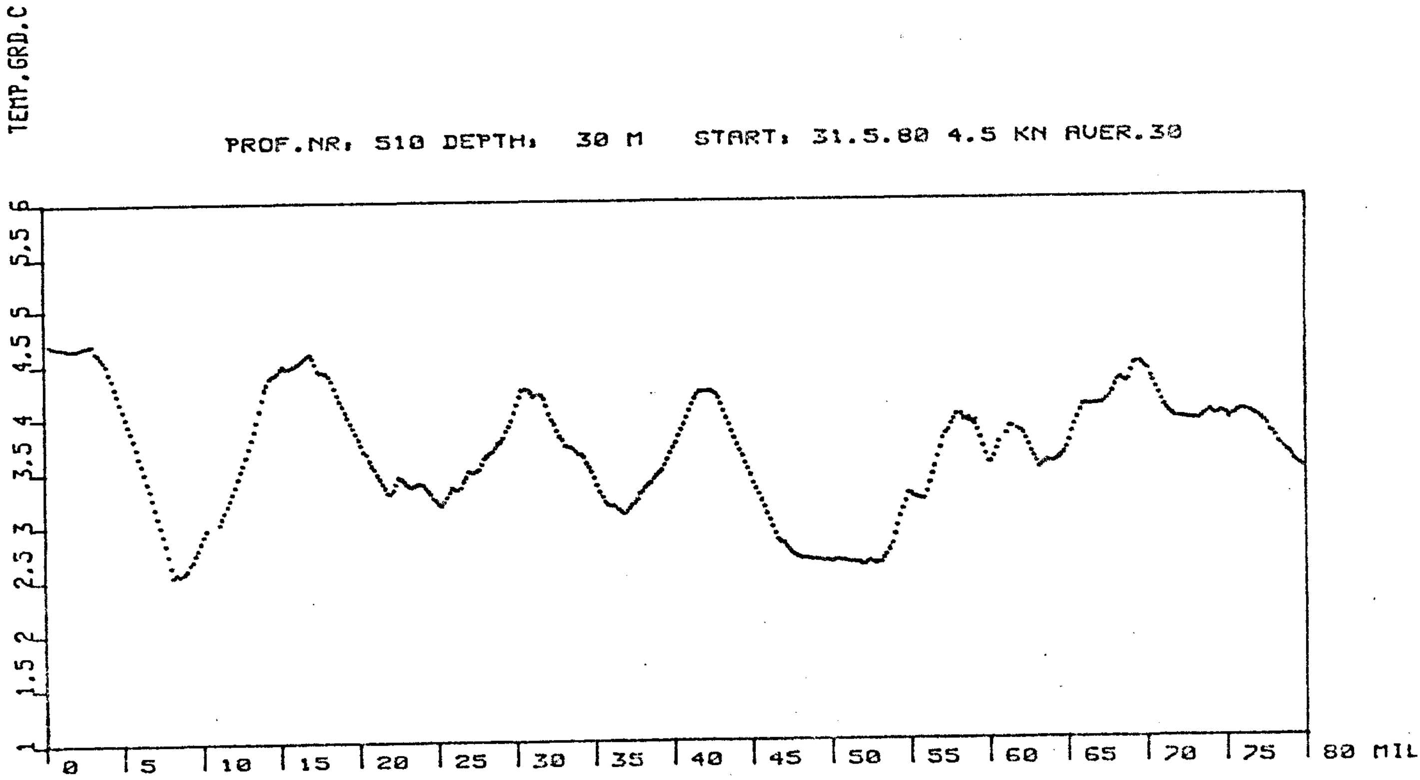


Figure 24 : Temperature along the same track as above but floating average over 30 sampling points, i. e. suppression of small scale variabilities.

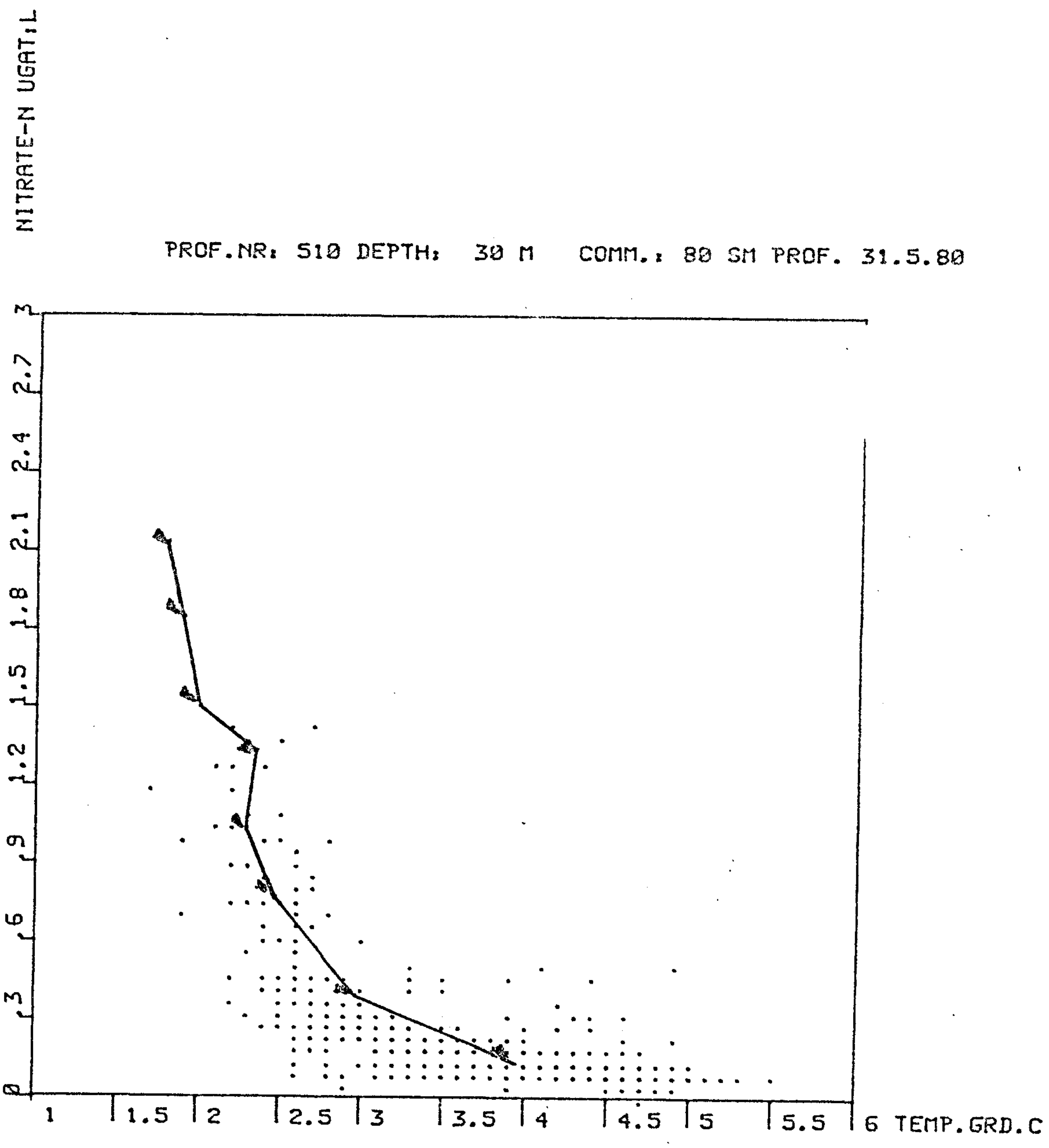


Figure 25 - 27 : Relationship between temperature and nitrate, silicate and pH (all 480 data points from the 80 nautical mile profile).

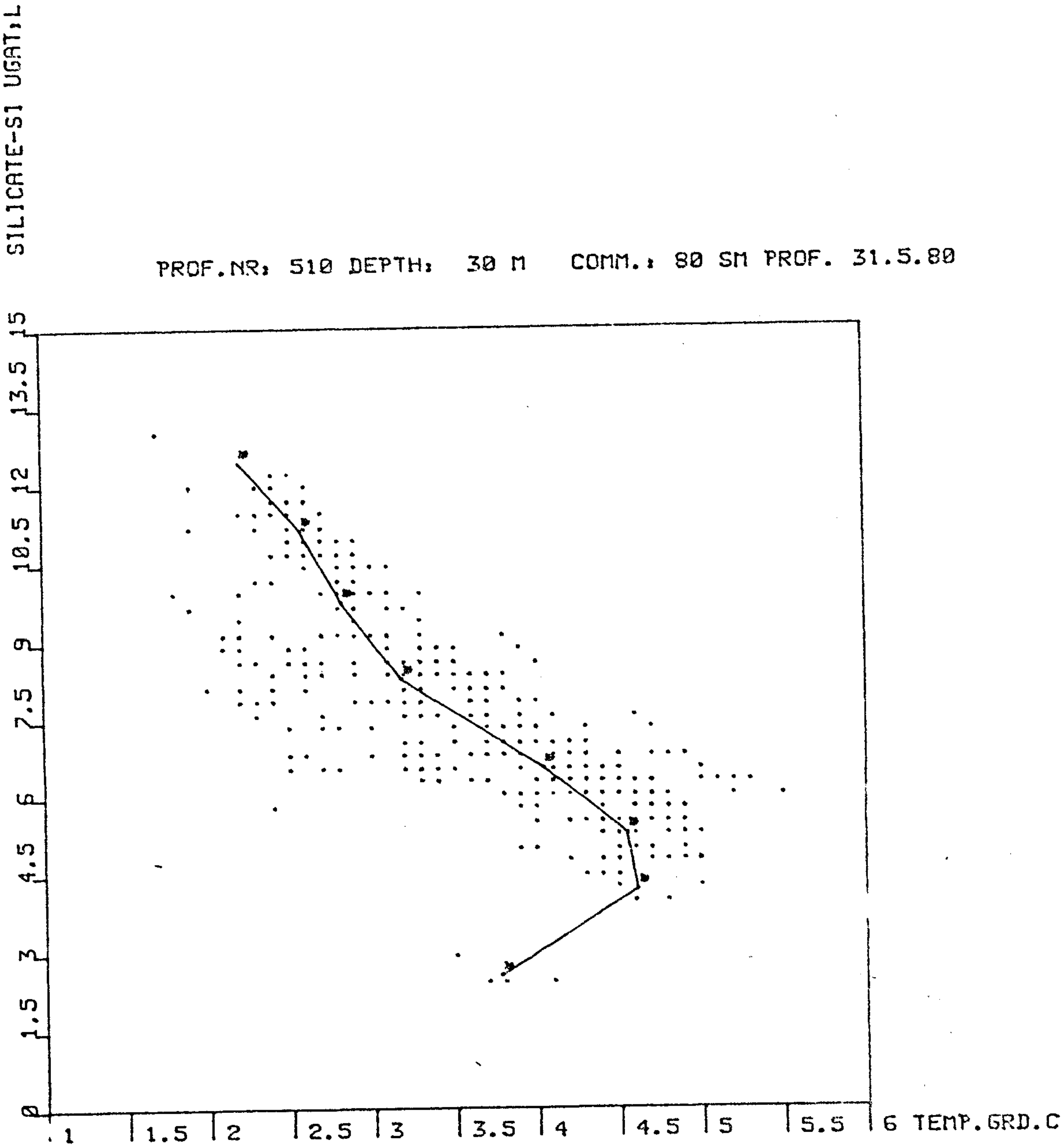

SILICATE-SI UGAT;L
PROF.NR: 510 DEPTH: 30 M COMM.: 80 SM PROF. 31.5.80
15
13.5
12
10.5
9
7.5
6
4.5
3
1.5
0
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6 TEMP.GRD.C

Figure 26

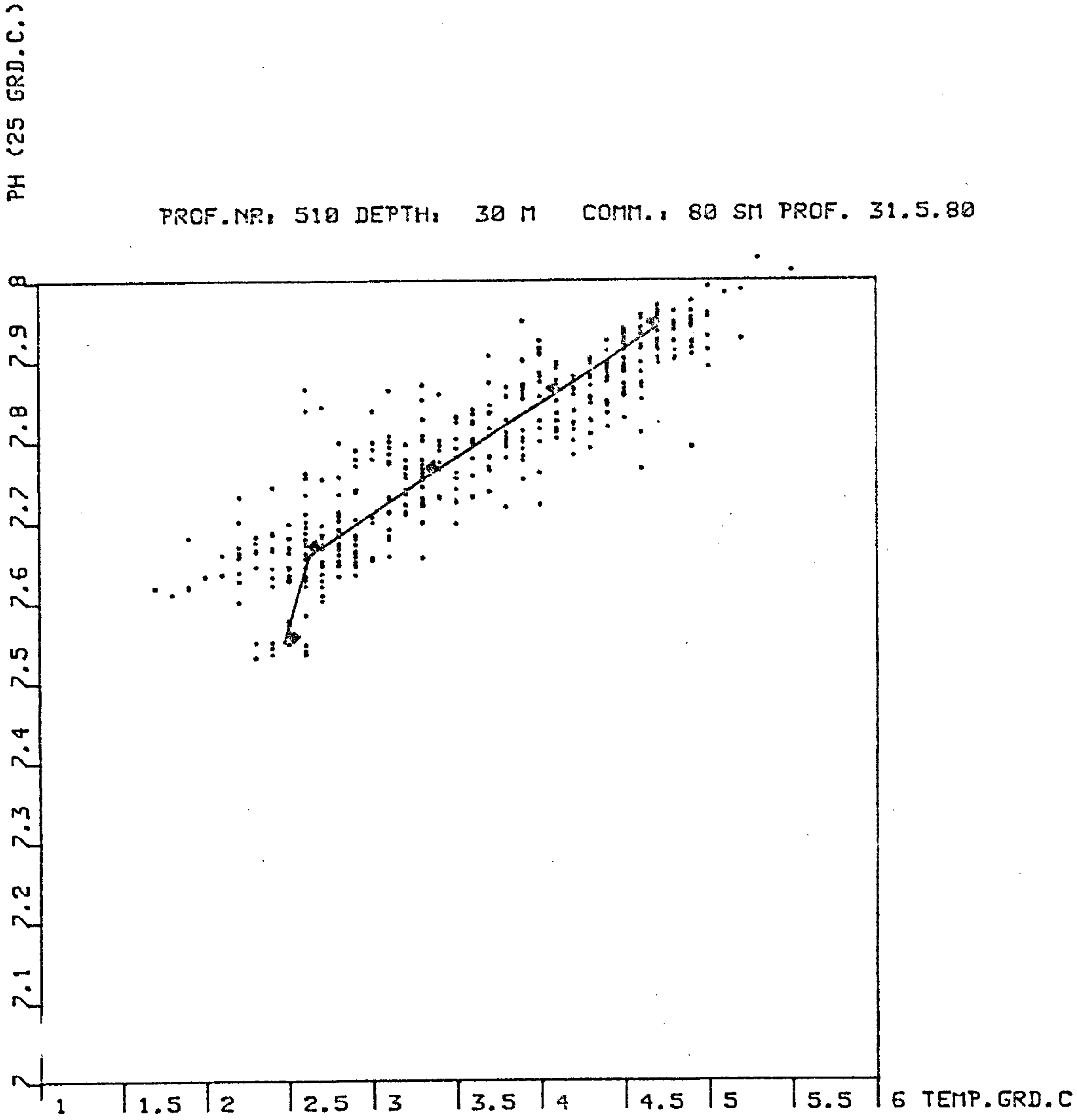

PH (25 GRD.C.)
PROF.NR: 510 DEPTH: 30 M COMM.: 80 SM PROF. 31.5.80
8
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6 TEMP.GRD.C

Figure 27