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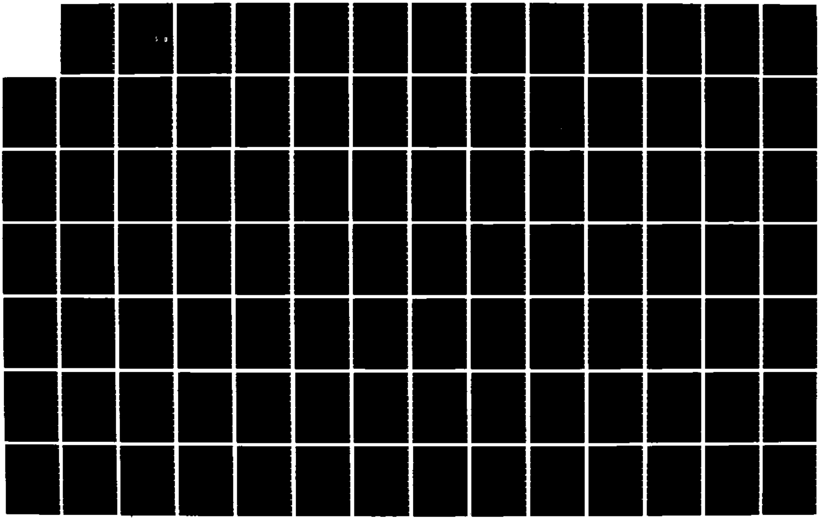

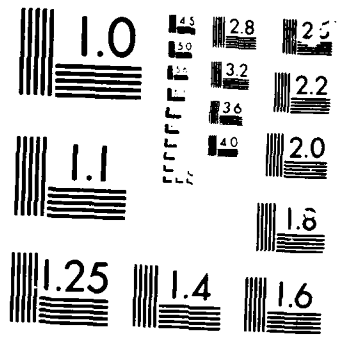

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AXBT Measurements off the Northeast Coast of South America, Spring 1985

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Executive summary

In March and May 1985, 219 air-deployed expendable bathythermograph (AXBT) profiles were taken off the northeast coast of South America in a region of large scale thermohaline steps. Presented in this report are a map of the location of the staircase field during this time, contours of the depths of the 6–22°C isotherms, and individual profile plots. The main body of the steps was found to lie on either side of a line from 8°N 50'W to 16°N 61'W, with weaker and more poorly defined steps occurring outside the main field. The mesoscale flow patterns inferred from the isotherm plots indicated that during this time period the North Equatorial Current entered the region over a broad area north of 10°N. Much of the flow proceeded westward toward the lesser Antilles, but the upper several hundred meters of the southern part of the flow (between about 10–14°N) turned southward between 50°–54°W and flowed back to the east, forming a tight loop. The eddy field on the southern edge of the survey, between 3–10°N, 40–50°W, appeared to be either poorly developed or shifted to the south and east outside most of the survey range.

Acknowledgments

The authors wish to acknowledge the very able assistance of Robert A. Brown of the Naval Ocean Research and Development Activity (NORDA) in the installation and use of the EPDAS data collection system, and of Ronald T. Miles, also of NORDA, for special modifications to the system. LCDR Robert C. Willems of the Office of Naval Research provided the deep AXBTs, and the Naval Research Laboratory provided the aircraft and technical and flight crews. We particularly thank CDR James Kirkendall of the Naval Research Laboratory's Operations Services Branch for making the aircraft again available in May for completion of the operations. Jeffrey Smart of the Johns Hopkins Applied Physics Laboratory greatly facilitated the data processing by making his editing program available to us, and Peter Flynn of PSI, Inc., did much of the computer processing. Kim Saunders helped solve computer interface problems, and Joyce Ford provided secretarial services. This work was supported under the Naval Ocean Research and Development Activity Fine Scale Variability Program, U.S. Navy Program Element 61153N.

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1. Introduction

Between 20–31 March and 6–13 May 1985, the U.S. Naval Research Laboratory P-3A aircraft 150607 flew a series of oceanographic survey flights off the northeast coast of South America. The flights were part of a multi-institutional program to investigate the large scale thermohaline steps (staircases) found in the main thermocline. Such staircases have been reported in the area for at least the past 15 years (Delnore and McHugh, 1972; Mazeika, 1974; Perkins and Saunders, 1982; Bruce et al., 1984; Boyd and Perkins, 1986). They are similar to those observed in the Tyrrhenian Sea and under the Mediterranean Outflow (e.g., Johannessen and Lee, 1974; Elliott et al., 1974), and occur under the same conditions of a relatively warm, salty water mass overlying a cooler, fresher one. Double diffusion of the salt fingering type is presumed to be the causative process. In the case of the region off the northeast coast of South America, the two water masses are the warmer, saltier Subtropical Underwater (SUW) (Defant, 1981; terminology from Wüst, 1964) lying between about 100 and 200 m (Wüst, 1978) and the cooler, fresher Antarctic Intermediate Water (AAIW) centered in this area between 700–800 m (Wüst, 1978; terminology from Pickard and Emery, 1982).

The airborne operations had three objectives: to aid concurrent shipboard operations, to map the horizontal and vertical extent and characteristics of the thermal field, and to determine the mesoscale flow. This report presents a map of staircase locations, contours of the 6–22°C isotherms, and plots of individual edited and filtered station temperature profiles.

2. Operations Description

The aircraft staged from Grantley Adams International Airport, Barbados, West Indies. A total of seven flights took place, four in March and three in May. The survey had to be executed during two time periods because an aircraft mechanical problem during the first period necessitated premature termination of operations. The first four flights occurred 22–29 March 1985. The remaining three flights were then completed 8–13 May 1985. The drop positions for the two partial surveys are given in Figure 1 and Table 1. Locations where AXBTs were dropped in both March and May are circled.

During the flights, the aircraft dropped both shallow (nominally 305 m) and deep (nominally 760 m) air-deployed expendable bathythermographs (AXBTs) approximately every 111 km to provide a grid of subsurface temperature data to a maximum depth of nearly 800 m. Normally the aircraft flew between 12,000–14,000 feet at between 280–300 knots. A combination of a Litton 72 inertial navigation system and a Litton 211 VLF/OMEGA navigation system was used for navigation, giving an accuracy of 1 to 2 nmi. Because of the potential but unknown effects of wind upon the falling probe, the drop positions are considered accurate to about 1.5 times the navigational accuracy, or to about 3 nmi or 5.5 km. Weather was generally good, with scattered cumulus clouds between 2,000–7,000 feet, and occasional haze. More haze and clouds, including some cumulonimbus, were encountered during the May operations. The maximum sea state, as observed from the aircraft, appeared to be 2 or 3 (scattered to numerous whitecaps).

During the fourth flight a rendezvous took place between the aircraft and the research vessel involved in the project, the R/V ENDEAVOR from the University of Rhode Island, with Dr. Ray Schmitt of the Woods Hole Oceanographic Institution as chief scientist. Three deep AXBTs were dropped within a few hundred yards of the ship during a time when the ship was making a CTD (conductivity temperature depth) cast, and this data was used to develop improved equations for calculating AXBT depth and temperature.

The 8 May flight passed within the Exclusive Economic Zone of a number of countries, including Guyana, which requested that two observers be allowed to participate. Their names are given in Section 3.

3. Scientific Party

a. 20–31 March 1985

Janice D. Boyd, Chief Scientist	(NORDA)
Henry T. Perkins, Scientist	(NORDA)
Robert A. Brown, Electronics Technician	(NORDA)

b. 6–13 May 1985

Henry T. Perkins, Chief Scientist	(NORDA)
Robert A. Brown, Electronics Technician	(NORDA)

8 May 1985

Mr. Theo A. Earle, Observer	(Guyana)
Maj. E. W. Adams, Observer	(Guyana)

4. Data Collection and Processing

The AXBT data was collected using a version of the NORDA-designed EPDAS ("Expendable Probe Data Acquisition System") data collection system. The system consisted of a data interface unit, two Hewlett Packard 9825T microcomputers and a Hewlett Packard 7245 printer/plotter. The variable frequency analog signals from the three aircraft sonobuoy receiver channels were received, amplified and filtered, and converted to digital form at a sampling rate of 8 samples per second (corresponding to about every 20 cm in depth). The data was stored on data cassettes for later analysis and was plotted in near real-time. Total time required for data acquisition and storage was about 6 minutes for shallow probes and 12 minutes for deep.

A few clearly bad or irretrievably noisy profiles were discarded. Further editing of the raw data was performed at the Johns Hopkins Applied Physics Laboratory using an interactive editor. Any bad data at the beginning and end of each profile was deleted, and a linear interpolation was applied across any regions of bad data within a profile. If a linear interpolation was not reasonable (for example, if the depth range was too great) then the bad data and any points below were discarded. A total of 184 deep and 35 shallow AXBT temperature profiles were obtained from the operations.

After editing, improved equations for calculating temperature and depth were applied. All AXBTs were manufactured by Sippican Ocean Systems, Inc., of Marion, Massachussetts, to Navy specifications for frequency to temperature and elapsed fall time to depth conversions. The specified conversion equation for temperature is

$$T = -40.0 + 0.02778F ,$$

where F is frequency in hertz and T is temperature in °C. The Navy standard requires the temperature accuracy to be about ±0.56°C within the range −2° to 35°C, but the probe is known to be much more accurate than this (e.g., Bane and Sessions, 1984). The specified depth equation is

$$z = 1.52t$$

where z is depth in meters and t is elapsed time after probe release in seconds. Sippican, however, publishes the slightly modified formula (still within the Navy specification)

$$z = 1.5926t - 0.00018t^2 .$$

The same equations are assumed to apply to both shallow and deep AXBTs.

For many research purposes more accurate conversion equations are desirable. To devise better equations for this study, three deep AXBTs were dropped near the R/V ENDEAVOR during one of the ship's CTD casts and the CTD data was used to calculate improved equations. Three AXBT profiles and one CTD profile are admittedly a small number, but no more were available. The resulting corrected AXBT profiles are clearly so much closer to the CTD profile that we think the modified temperature and depth equations developed from this data set, while not the last word on the topic, nevertheless represent genuine improvements over the above formulas.

The difference $\Delta z = z_{CTD} - z_{AXBT}$ was plotted versus t for a number of features identifiable on both the CTD and AXBT profiles. The curve was well fit (R^2 = 0.91) by the quadratic

$$\Delta z = 0.0559t - 0.00006t^2$$

Combining this with the Sippican formula gives the corrected equation

$$z = 1.6485t - 0.00024t^2$$

When this formula was used, features on the CTD and AXBT profiles differed in depth by at most 6 m and usually by much less.

A similar technique was used to develop an improved temperature equation. A plot of $\Delta T = T_{CTD} - T_{AXBT}$ versus T_{CTD} was well described by either a linear fit (R^2 = 0.88) or by a cubic (R^2 = 0.92). The difference between the two fits was so small that the linear relationship was selected. This fit was

$$\Delta T = 0.5753 - 0.0317 T_{CTD}$$

Assuming T_{CTD} to be the "best guess" for the true temperature T, this gives

$$1.0317T = 0.5753 + T_{AXBT} .$$

Using the Sippican formula for T_{AXBT} yields the improved equation

$$T = -38.2133 + 0.0269F .$$

Using this equation, the ENDEAVOR CTD and our AXBT profiles differed by at most 0.15°C and usually by much less.

After the improved temperature and depth equations were applied to the data, the profiles were filtered and resampled at a 2 m interval. The filtering was a compromise between that suitable for the low noise profiles or portions of profiles and that required for the high noise portions. Spectral analysis of several of the particularly low-noise profiles indicated a noise level beginning at a wavenumber of about 0.6 cycles m^{-1}, corresponding to a wavelength of 1.67 m. However, a large proportion of the profiles had elevated noise levels below 600 m. This was later found to be due to sonobuoy receiver problems and probably aggravated by local atmospheric temperature inversions which reduced the signal strength beyond a certain distance. To remove this noise a considerably shorter wavenumber cutoff was needed. It would have been possible to filter the shallower portion of the profiles with one filter and the deeper with another and then to patch the two parts together. However, some experimentation showed this to be unnecessary. A Bartlett filter with a half power point at 0.2 cycles m^{-1} was found to reduce the noise in the deeper portions of the profiles satisfactorily while still preserving the characteristics of the shallower portions. All profiles were so filtered and then subsampled at 2 m intervals.

After the AXBT hits the water, about 30 seconds elapse before the probe is released. During this time a carrier frequency is transmitted. To prevent interference or other noise from starting the data collection system early, the EPDAS system requires the operator hit a key on the computer keyboard when it is certain that a good carrier is being received. Occasionally noise or a late start by the operator still resulted in an erroneous start. When this happened the depths were offset by an unknown (but usually estimatable) amount. The drops which had such false starts are noted in Table 1 and on the individual profile plots.

5. Discussion

A primary goal of the survey was to delineate the region of large scale thermohaline steps. This finding is shown in Figure 2. The main body of the step field extends northwestward from 7°N 49°W to at least 16°N 60.5°W, the westward limit of the survey. By and large the well-developed steps fell within a very well-defined area, and no "holes" were observed within this area with the aircraft data, although data from the concurrent ship operations showed occasional small "holes." Weak but identifiable steps occurred outside portions of the boundary of the well-defined steps. However, the transition from no thermal steps to well-defined steps was very abrupt at the central northern and southeastern boundaries. More details may be seen in the individual profile plots in Figures 13-231, which also include plots of the temperature gradients as estimated using centered differences.

Another goal of the survey was to determine the mesoscale flow field and to relate it to the occurrence of the staircases. Figures 3-12 present depths of the 22-6°C isotherms. If density is primarily determined by temperature, these contours approximate streamlines. Kawase and Sarmiento (1985) have shown that a strong salinity front exists in this region, so this assumption may not be completely true. However, the magnitude of the dominant thermal features of Figures 3-12 makes it unlikely that conclusions drawn solely from the temperature contours would be made invalid by salinity variations.

The figures suggest that from the 12° isotherm and up in the water column, the flow field north of 14°N is characterized by a broad entry of water into the area from the northeast. The flow between 10-14°N and east of 54°W is dominated by flow from the east-southeast (presumably the North Equatorial Current, NEC) which turns southward between 50-54°W and turns back to the east, forming a tight loop. The loop penetrates to a maximum of about 250 m, but clearly begins to weaken below 150 m. Although becoming weaker, the feature is still visible in the plots of the 14° and 12° isotherms, but has disappeared in the plot of the depth of the 10° isotherm.

Bruce and Kerling (1984) have discussed the results of two AXBT surveys in March and September 1983 that overlapped the southern and eastern part of our region. In March they observed a much weaker loop only a few degrees east and south of our loop, but they also found a large northern anticyclonic eddy at 7-10°N of which we see no evidence. The lack of evidence for the Northern Eddy is of particular interest, since Bruce (1984) found this eddy repeatedly in his ships of opportunity XBT temperature sections through this area.

The well-developed loop is also of interest because its location corresponds nicely to the origin of the North Equatorial Countercurrent (NECC) during summer and fall of most years. Richardson and McKee (1984) reported that the NECC begins earlier and continues later on the western side of the Atlantic compared to the central or eastern parts, but they found that between 35–45°W it typically originates in May and near 2–3°N, rather to the south of our loop. Our loop must have originated earlier than this, in March at the latest, because it was spanned by both partial surveys and the northern half was clearly well developed by the end of March. Furthermore, the origin of the NECC usually appears to be South Atlantic water from the North Brazil Coastal Current which turns back to the east in this area (Richardson and McKee, 1984). Instead, our data suggest a considerable transport into an early NECC which originates from the North Atlantic. The absence of Bruce's Northern Eddy and the presence of the early loop certainly suggest anomalous meteorological conditions during winter and spring 1985.

In Figure 10, the depth of the 8° isotherm, a change in the flow becomes apparent. The flow entering from the east appears to separate at about 14°N into a northerly component which enters from the north-northeast and a southerly component from the east-southeast. The two flows become parallel after 50°W. This impression is intensified in Figures 11 and 12, with the southerly component coming more and more from the south. The southern flow corresponds nicely to what Wüst (1978) has called the "Subantarctic Intermediate Current" lying between 500 and 1000 m. This water mass contains the Antarctic Intermediate Water, with its core between about 700–800 m.

We feel this interpretation of the flow field strongly supports the contention that the staircases are related to mixing between the warm, salty subtropical underwater (SUW) coming into the area from the northeast and the cool, fresh Antarctic Intermediate Water (AAIW) coming up from the southeast. The 18° or 20° isotherms can be taken as indicative of the SUW. The 6–8° isotherms indicate the AAIW, with the 6° isotherm lying within 100 m or less of the actual low salinity core. If we superimpose the flow fields inferred from Figures 5 (or 4) and 12 upon Figure 2, the locations of the thermal steps, we see that the steps in spring 1985 occurred in the region where water parcels following the presumed streamlines of the SUW and AAIW first encountered one another. Much of the field lies below 14°N which, at the depth of the water mass associated with the AAIW, seems to be the boundary between water derived from the north and water derived from the south.

Because the two partial surveys took place 5 weeks apart, a question exists as to how synoptic the combined observations are. In one sense the question is a moot one: the survey had to be completed in two parts and the combined observations are the best we have. However, examining the 24 locations at which drops were made in both March and May (see Fig. 1) gives a qualitative sense of how important the delay was. Minimum variation between paired profiles is seen in those east of 54°W; i. e., in those lying in the region of the current loop. Somewhat greater variability occurs west of 54°. Two extreme examples are drops 154 and 241 and drops 85, 88, and 248. Nevertheless, two nearby locations show minimal change over the 5 or so weeks: compare drops 155 and 243 and drops 125 and 249. Examination of the BOMEX time series in Delnore and McHugh (1972) shows that the thermal step region commonly exhibits variability over time scales of only a few hours to a few days that compares in magnitude to the variability observed at our 24 paired positions. Thus, we think it is quite legitimate to treat our two partial surveys as one reasonably synoptic single survey.

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Table 1. AXBT drop positions, March and May 1985

AXBT	Station	Date (Julian Day)	Latitude (N)	Longitude (W)	Flight	Comments*
5	93	81.534	15.007	−60.527	1	
8	76	81.543	16.000	−60.528	1	
11	59	81.553	17.002	−60.527	1	
13	42	81.565	18.313	−60.420	1	
14	19	81.618	18.513	−55.000	1	
15	8	81.629	19.178	−54.000	1	
16	9	81.639	18.858	−53.000	1	
17	10	81.648	18.517	−52.000	1	
18	11	81.657	18.178	−51.000	1	
19	12	81.667	17.833	−50.000	1	
20	24	81.676	16.821	−49.985	1	
21	23	81.686	17.107	−51.032	1	
22	22	81.694	17.510	−52.000	1	
24	20	81.712	18.178	−54.000	1	
25	7	81.726	19.500	−55.000	1	
26	18	81.736	18.817	−56.000	1	
29	17	81.758	19.115	−56.997	1	
30	5	81.766	20.120	−57.032	1	
31	16	81.776	19.415	−58.000	1	
32	4	81.786	20.430	−58.012	1	
33	15	81.796	19.733	−59.013	1	
34	3	81.806	20.802	−59.055	1	
35	2	81.815	20.992	−60.000	1	S
36	1	81.819	20.995	−60.500	1	
38	14	81.832	20.012	−59.998	1	
39	25	81.840	18.990	−60.525	1	S
41	26	81.852	19.000	−60.015	1	
42	43	81.861	18.002	−60.022	1	
43	60	81.870	16.985	−59.983	1	
44	77	81.878	15.985	−59.970	1	
45	94	81.887	14.998	−60.005	1	
47	112	84.495	13.698	−59.015	2	S
48	95	84.503	14.700	−59.008	2	
49	78	84.512	15.702	−59.015	2	
50	61	84.521	16.705	−59.015	2	
51	44	84.530	17.712	−59.003	2	
52	27	84.539	18.710	−58.997	2	
53	28	84.548	18.420	−58.000	2	
54	29	84.557	18.108	−57.002	2	
55	30	84.566	17.805	−56.000	2	
56	31	84.575	17.500	−54.990	2	
58	33	84.592	16.822	−53.002	2	
59	34	84.601	16.478	−52.000	2	
60	35	84.610	16.150	−51.000	2	
61	36	84.619	15.820	−50.000	2	
62	37	84.628	15.478	−49.002	2	
63	38	84.637	15.108	−48.000	2	
65	40	84.654	14.385	−46.000	2	
67	58	84.671	13.000	−45.022	2	Very noisy
68	57	84.680	13.362	−46.000	2	F
69	56	84.689	13.745	−47.002	2	S
70	55	84.697	14.085	−48.010	2	
71	54	84.706	14.455	−49.002	2	S
72	53	84.714	14.792	−50.000	2	
73	52	84.723	15.147	−51.000	2	S
74	51	84.731	15.508	−52.008	2	

*S = Shallow AXBT. F = False Start. Depth Incorrect.

Table 1. (Cont'd).

AXBT	Station	Date (Julian Day)	Latitude (N)	Longitude (W)	Flight	Comments*
75	50	84.740	15.823	−53.002	2	S
77	48	84.756	16.497	−55.030	2	S
78	47	84.765	16.803	−56.000	2	
79	46	84.773	17.118	−57.000	2	
81	45	84.789	17.408	−58.005	2	
82	62	84.799	16.403	−58.002	2	
83	79	84.807	15.402	−57.988	2	
85	112	84.818	14.395	−57.985	2	
86	112	84.827	13.708	−59.000	2	
87	112	86.496	13.685	−59.003	3	S
88	96	86.507	14.410	−57.993	3	
89	80	86.518	15.100	−56.998	3	
90	63	86.526	16.100	−57.003	3	
91	64	86.534	15.828	−56.000	3	
92	65	86.543	15.503	−55.000	3	
93	66	86.551	15.155	−54.000	3	
94	67	86.560	14.807	−53.000	3	
95	68	86.568	14.495	−51.997	3	
96	69	86.577	14.167	−51.000	3	
97	70	86.585	13.731	−50.000	3	F
98	71	86.593	13.438	−48.996	3	
99	72	86.602	13.093	−47.983	3	
100	73	86.610	12.745	−47.002	3	
101	74	86.619	12.367	−46.000	3	
102	75	86.628	11.983	−44.987	3	
103	92	86.636	11.000	−44.997	3	
104	109	86.644	10.000	−45.005	3	
105	126	86.652	9.001	−45.013	3	
106	125	86.662	9.378	−46.010	3	
107	124	86.671	9.730	−46.996	3	S
108	123	86.680	10.095	−47.998	3	
109	106	86.688	11.080	−48.023	3	
110	107	86.697	10.756	−47.001	3	
112	108	86.708	10.342	−46.000	3	
113	91	86.716	11.365	−45.990	3	
114	90	86.725	11.720	−47.002	3	S
115	89	86.734	12.100	−48.002	3	
116	88	86.743	12.455	−49.000	3	
117	71	86.751	13.438	−59.997	3	S
118	87	86.763	12.775	−49.993	3	
119	86	86.772	13.137	−51.000	3	
120	85	86.781	13.488	−52.000	3	
121	84	86.789	13.802	−52.998	3	
123	82	86.807	14.460	−55.003	3	
124	81	86.815	14.765	−56.007	3	
125	97	86.825	14.082	−56.998	3	
126	113	88.556	13.397	−58.002	4	
127	98	88.573	13.785	−56.000	4	
128	99	88.582	13.435	−54.967	4	F
129	100	88.591	13.102	−53.970	4	
130	101	88.598	12.795	−52.997	4	
131	102	88.607	12.475	−52.000	4	
132	103	88.615	12.132	−51.002	4	
134	104	88.624	11.790	−50.002	4	
135	105	88.633	11.446	−49.000	4	

*S = Shallow AXBT F = False Start Depth Incorrect

Table 1. (Cont'd).

AXBT	Station	Date (Julian Day)	Latitude (N)	Longitude (W)	Flight	Comments*
136	122	88.642	10.425	−48.990	4	
137	139	88.650	9.443	−49.000	4	
138	140	88.660	9.071	−48.001	4	
140	142	88.678	8.366	−46.000	4	
141	143	88.687	8.010	−45.001	4	
144	159	88.706	7.313	−46.000	4	
145	158	88.715	7.713	−47.000	4	
146	157	88.724	8.072	−48.000	4	
147	156	88.733	8.415	−49.015	4	
148	155	88.742	8.765	−50.000	4	F
149	138	88.751	9.761	−50.014	4	
150	121	88.759	10.770	−50.000	4	
151	120	88.768	11.115	−51.015	4	
152	119	88.776	11.463	−52.000	4	
153	118	88.785	11.785	−53.000	4	
154	117	88.795	12.122	−54.000	4	
155	116	88.804	12.458	−55.005	4	
156	991	88.816	11.333	−55.005	4	
157	992	88.823	11.330	−55.005	4	
158	993	88.832	11.333	−55.005	4	F
159	115	88.849	12.762	−55.995	4	
160	114	88.858	13.088	−57.000	4	
161	113	88.867	13.387	−57.998	4	
163	147	128.524	11.380	−58.000	5	
164	148	128.532	11.082	−56.998	5	
165	165	128.541	10.067	−57.018	5	
166	166	128.550	9.753	−56.007	5	
167	167	128.559	9.408	−55.000	5	
168	168	128.567	9.067	−53.998	5	
169	169	128.576	8.750	−53.007	5	
170	170	128.585	8.435	−52.000	5	
171	187	128.594	7.430	−52.015	5	
172	201	128.600	6.747	−52.028	5	
173	202	128.609	6.355	−51.025	5	
174	203	128.618	6.075	−50.000	5	
175	204	128.628	5.733	−49.000	5	
176	205	128.637	5.372	−48.000	5	
177	206	128.647	5.030	−47.000	5	S
178	207	128.656	4.697	−46.000	5	S
179	193	128.662	5.352	−46.012	5	S
180	194	128.672	5.008	−45.000	5	S
181	208	128.678	4.337	−44.990	5	S
182	222	128.683	3.667	−45.005	5	
183	221	128.692	3.912	−46.002	5	S
184	220	128.700	4.320	−47.002	5	S
186	219	128.711	4.740	−48.000	5	
187	218	128.717	5.092	−49.010	5	S
188	217	128.725	5.385	−49.998	5	
190	215	128.741	6.053	−52.000	5	S. Very little data
191	214	128.749	6.390	−53.000	5	S. Very little data
192	200	128.755	7.117	−53.000	5	S
193	186	128.760	7.733	−53.032	5	
194	182	128.793	9.058	−57.003	5	
195	196	128.802	8.408	−57.010	5	
200	195	128.824	8.738	−58.025	5	
202	164	128.837	10.372	−57.977	5	

*S = Shallow AXBT. F = False Start. Depth Incorrect

Table 1. (Cont'd).

AXBT	Station	Date (Julian Day)	Latitude (N)	Longitude (W)	Flight	Comments*
204	146	128.854	11.690	−58.943	5	
205	129	130.506	12.695	−59.000	6	F
206	130	130.514	12.370	−58.000	6	
208	132	130.532	11.767	−55.998	6	
209	149	130.540	10.760	−56.000	6	
210	150	130.549	10.430	−55.000	6	
211	151	130.558	10.053	−53.855	6	
212	152	130.565	9.772	−53.002	6	
213	153	130.574	9.435	−52.002	6	
214	154	130.582	9.115	−51.000	6	
215	171	130.591	8.083	−50.988	6	
216	188	130.600	7.075	−50.997	6	
217	189	130.608	6.733	−49.000	6	
218	190	130.617	6.380	−49.000	6	
219	191	130.625	6.047	−48.000	6	
220	192	130.634	5.698	−47.000	6	S
221	176	130.645	6.347	−46.000	6	S
222	177	130.654	6.000	−45.000	6	S
223	160	130.663	7.000	−45.003	6	
224	143	130.672	8.000	−44.987	6	S
225	159	130.683	7.365	−46.000	6	S
226	175	130.693	6.708	−47.000	6	S
227	174	130.702	6.993	−48.005	6	
228	173	130.711	7.402	−48.997	6	
229	172	130.721	7.780	−48.997	6	
230	155	130.730	8.750	−50.000	6	
231	138	130.739	9.750	−49.990	6	
232	121	130.748	10.767	−49.983	6	
233	137	130.759	10.093	−50.997	6	
234	120	130.769	11.100	−51.000	6	
235	136	130.780	10.437	−51.978	6	
236	119	130.790	11.450	−51.997	6	
237	135	130.801	10.708	−52.860	6	
238	118	130.811	11.817	−52.993	6	
241	117	130.831	12.103	−54.057	6	
242	133	130.842	11.478	−55.003	6	
243	116	130.851	12.437	−55.027	6	
244	115	130.860	12.755	−55.977	6	
245	114	130.869	13.073	−57.003	6	
246	113	130.878	13.390	−58.002	6	
247	112	133.545	13.543	−59.005	7	
248	96	133.557	14.423	−58.000	7	S
249	97	133.565	14.122	−56.983	7	
251	98	133.574	13.770	−56.005	7	S
252	99	133.582	13.458	−55.005	7	
253	100	133.591	13.140	−54.000	7	S
254	101	133.599	12.785	−53.000	7	
255	102	133.608	12.457	−52.000	7	S
256	84	133.622	13.812	−52.998	7	
257	83	133.631	14.130	−54.007	7	S
258	82	133.639	14.440	−54.967	7	
259	81	133.649	14.845	−56.000	7	S

*S = Shallow AXBT. F = False Start. Depth Incorrect

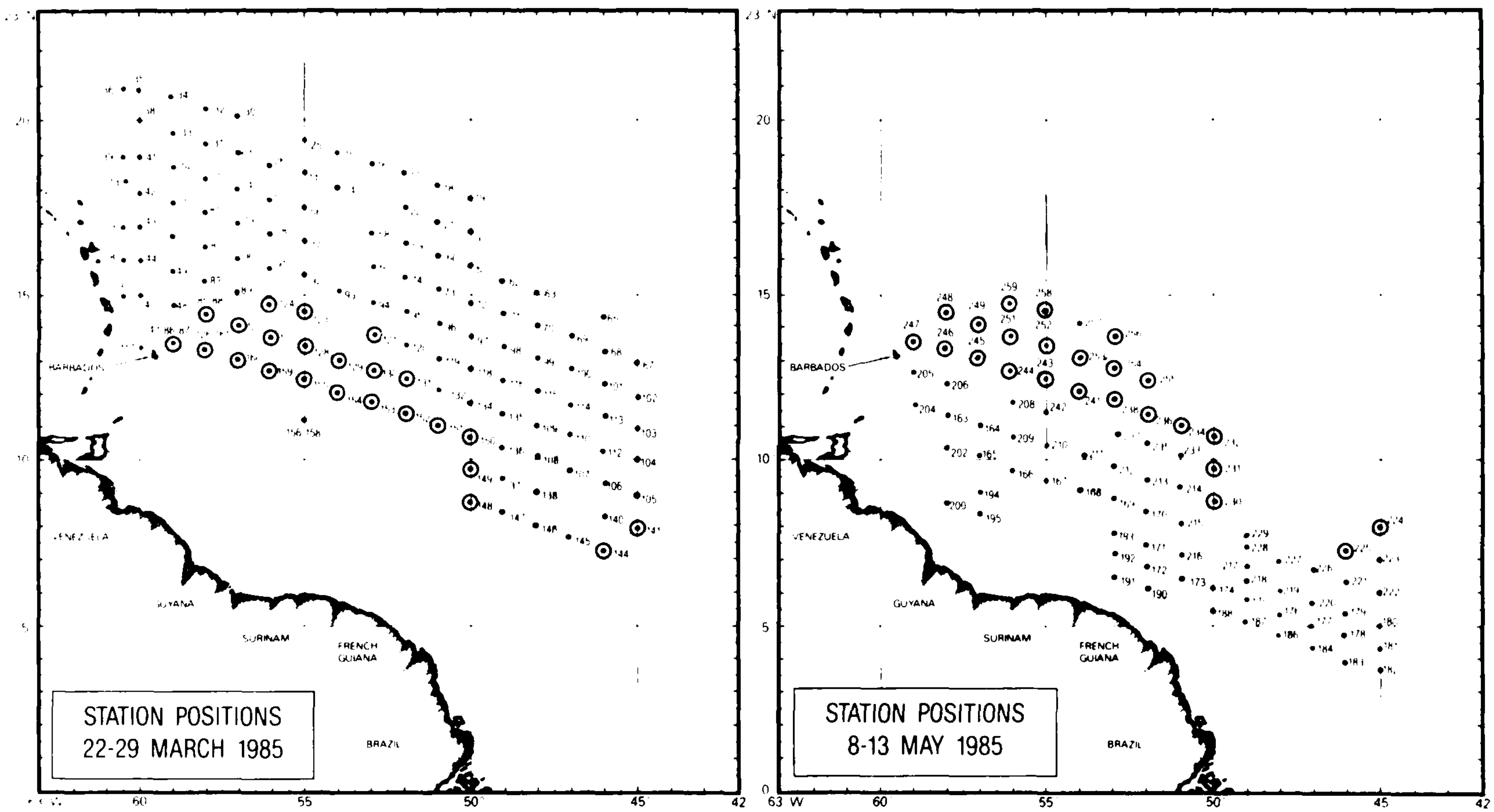


Figure 1. AXBT drop positions, March and May 1985. AXBTs were dropped during both months at the positions circled

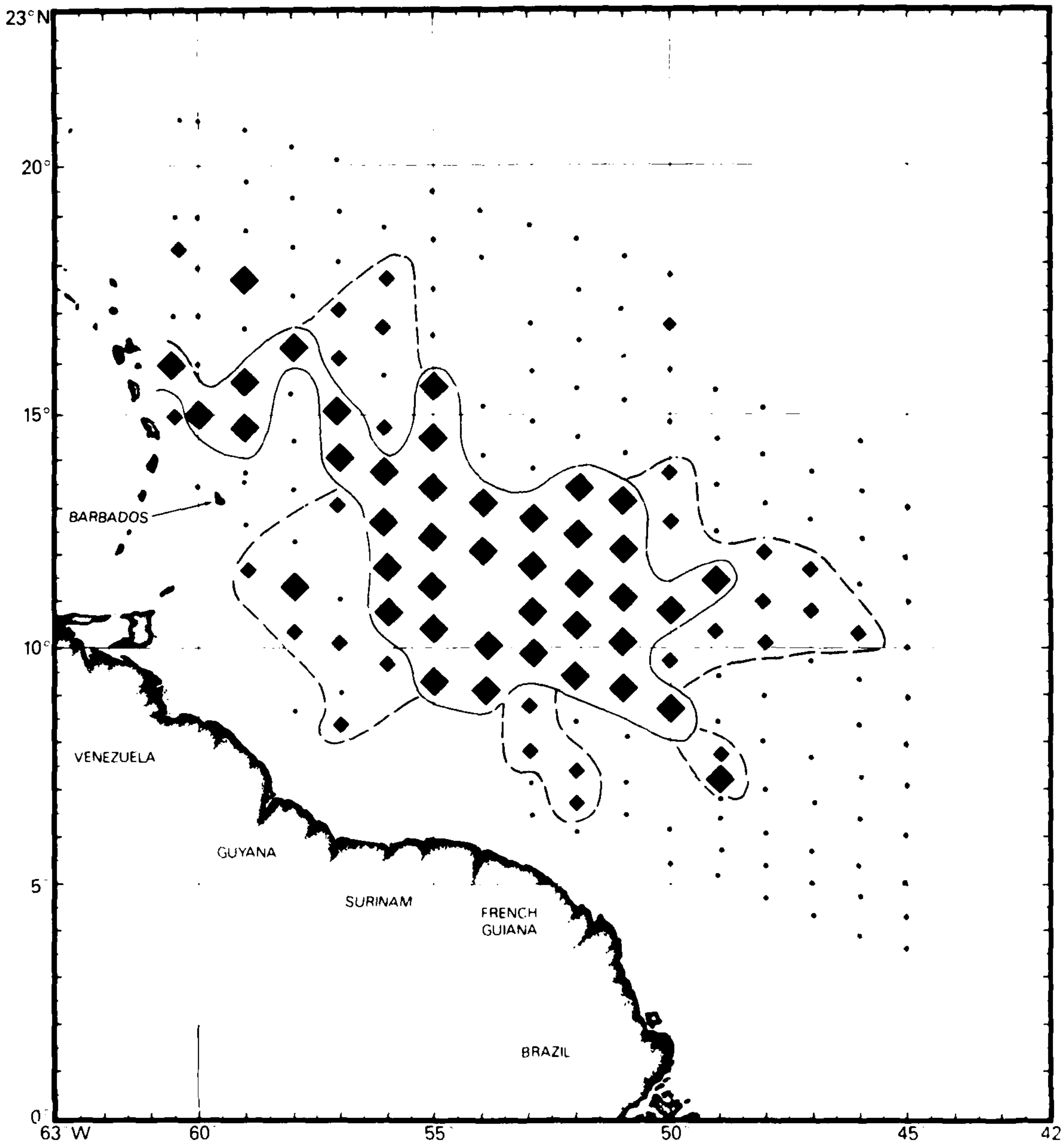


Figure 2. Location of large scale thermohaline steps, spring 1985. Large diamonds indicate strong steps; small diamonds weaker but identifiable steps.

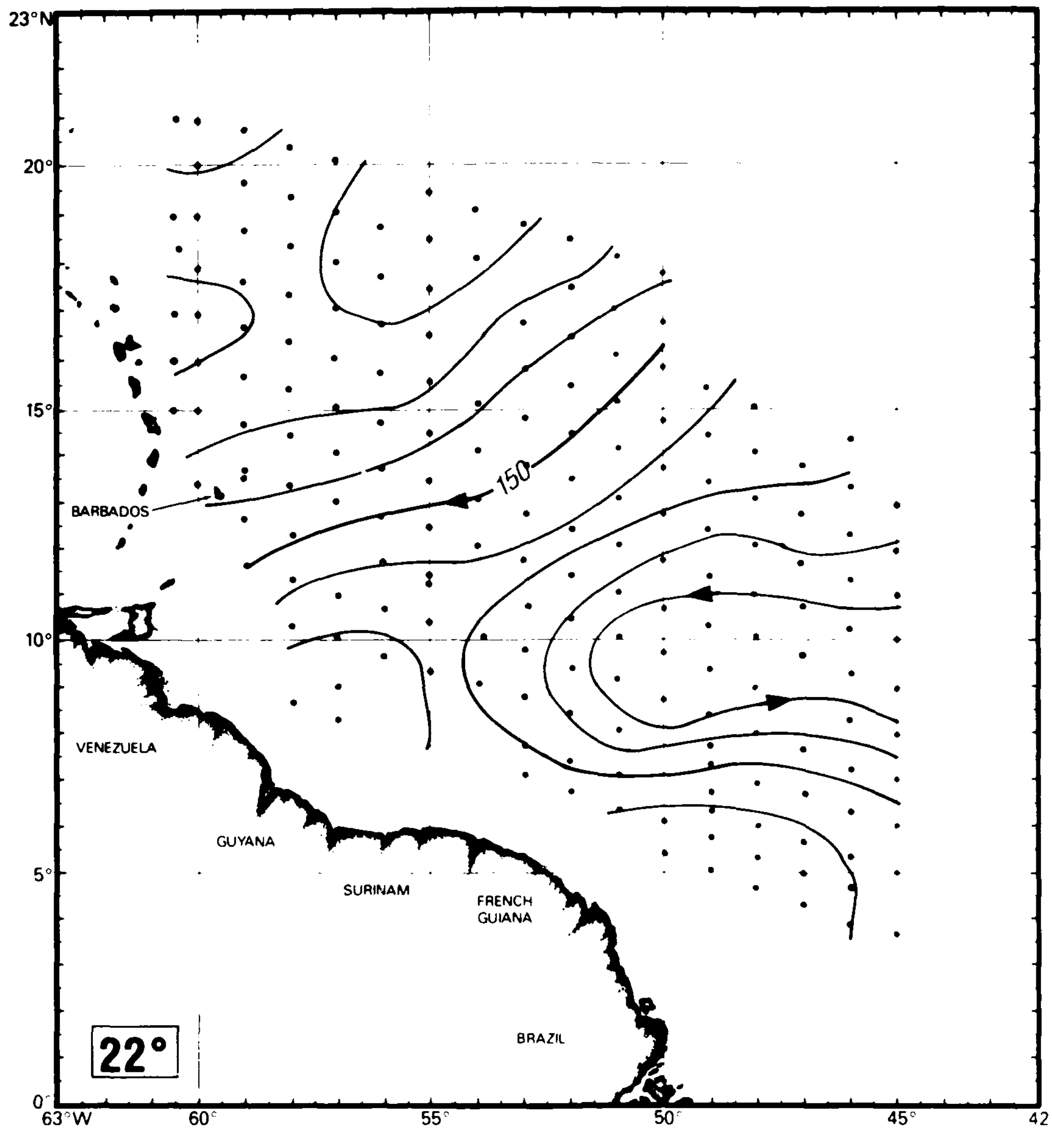


Figure 3. Depth in meters of the 22°C isotherm. Arrows indicate flow direction assuming the contours approximate streamlines.

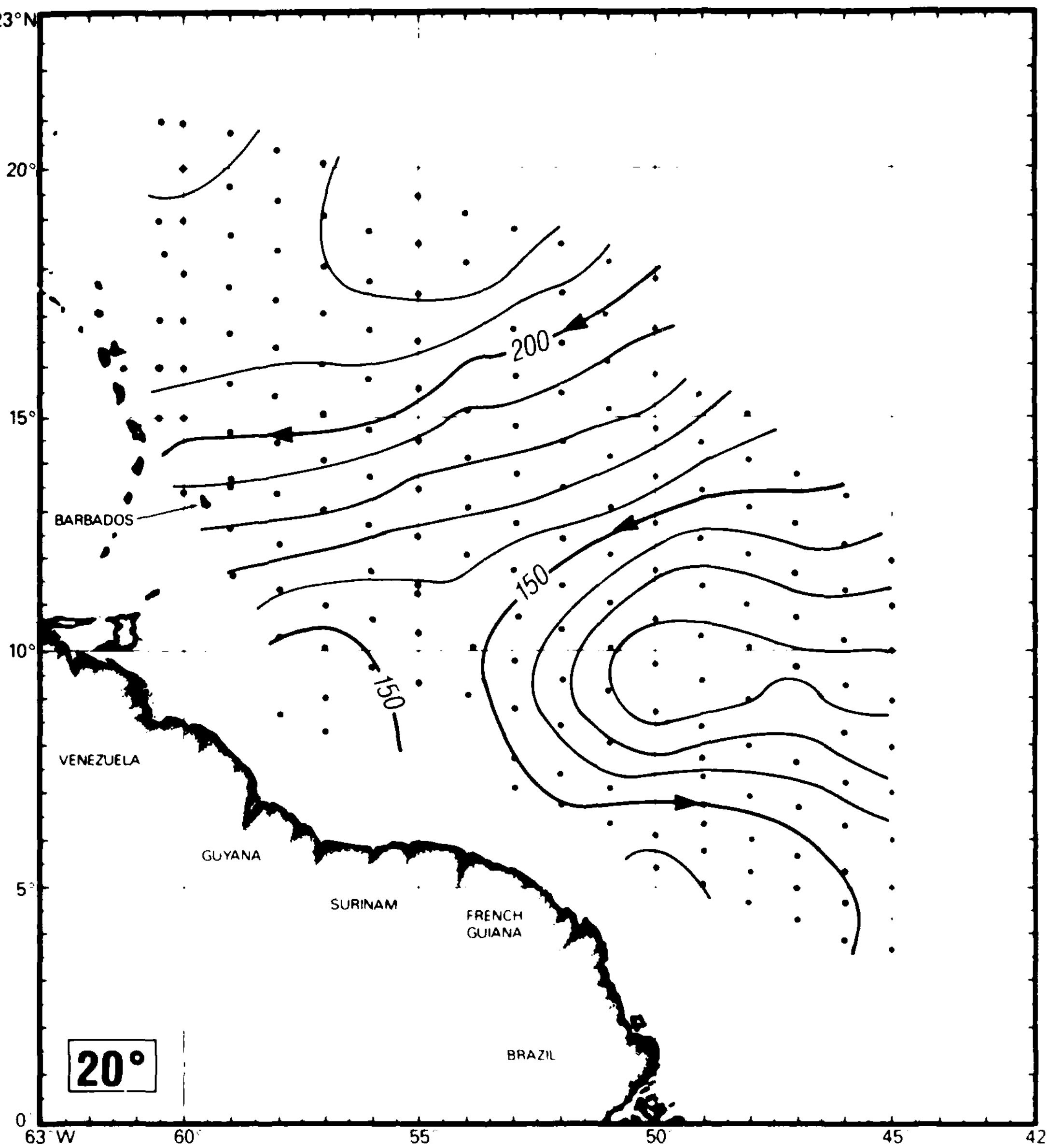


Figure 4. Depth in meters of the 20°C isotherm. Arrows indicate flow direction assuming the contours approximate streamlines.

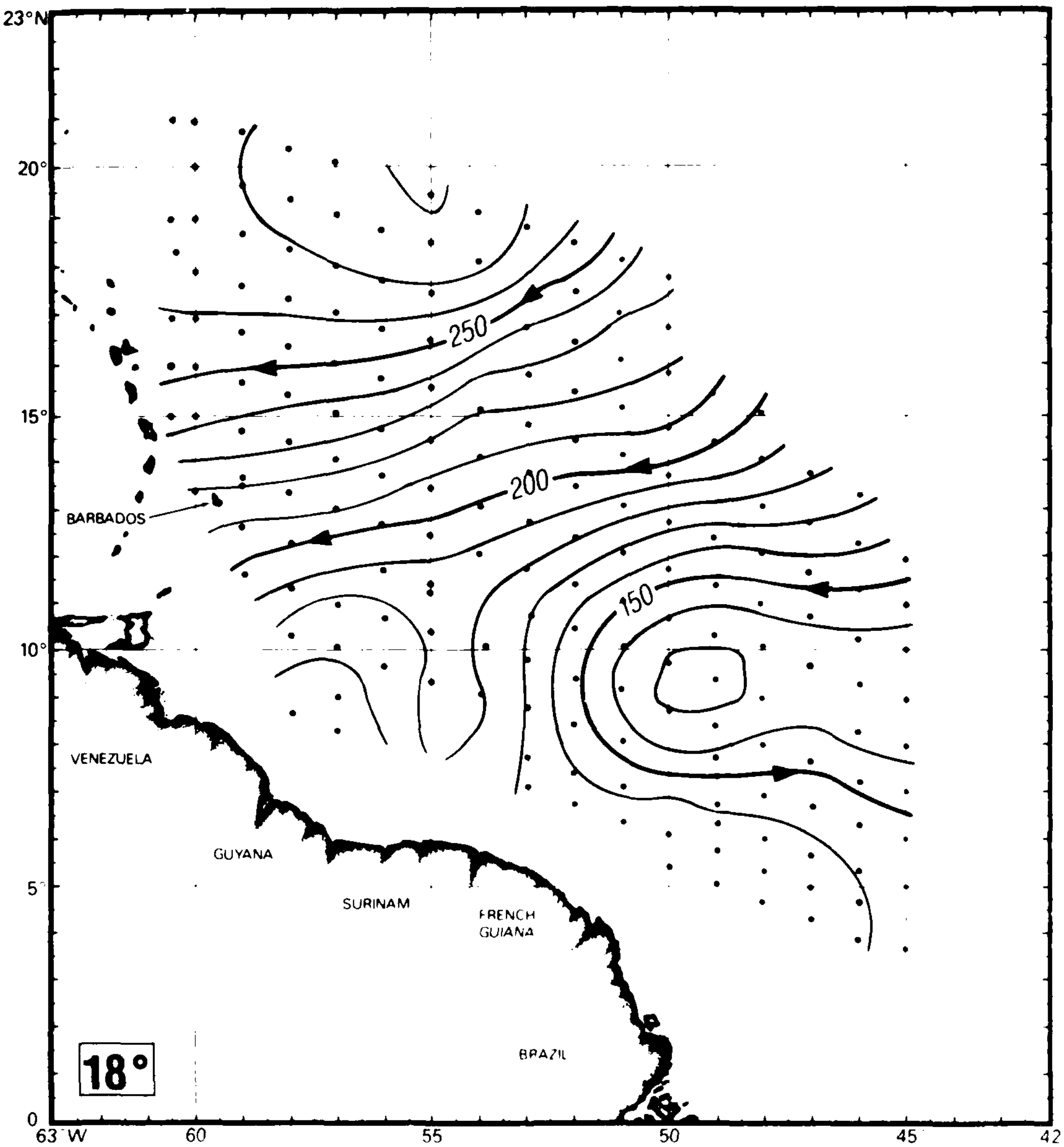


Figure 5. Depth in meters of the 18°C isotherm. Arrows indicate flow direction assuming the contours approximate streamlines.

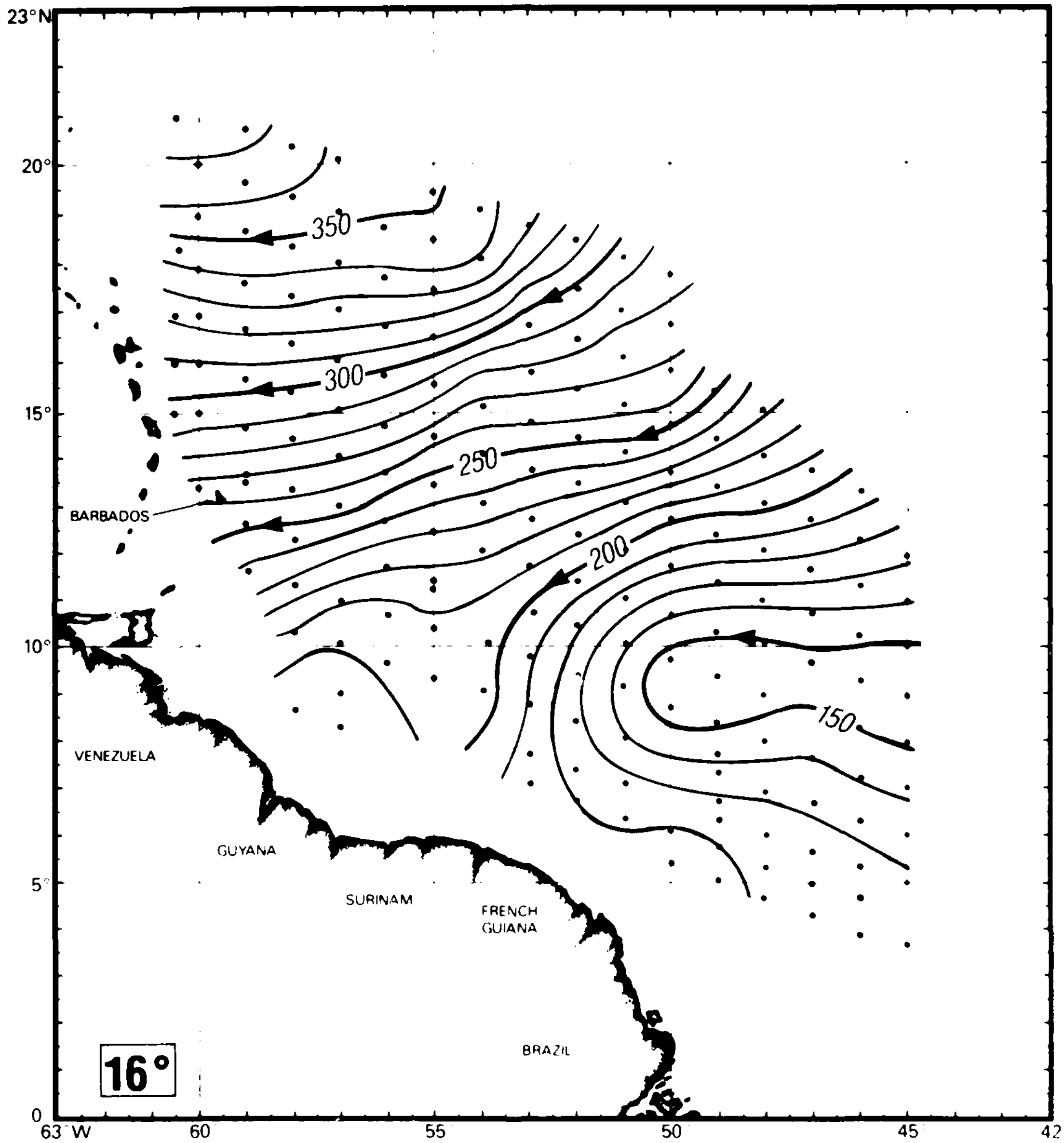


Figure 6. Depth in meters of the 16°C isotherm. Arrows indicate flow direction assuming the contours approximate streamlines.

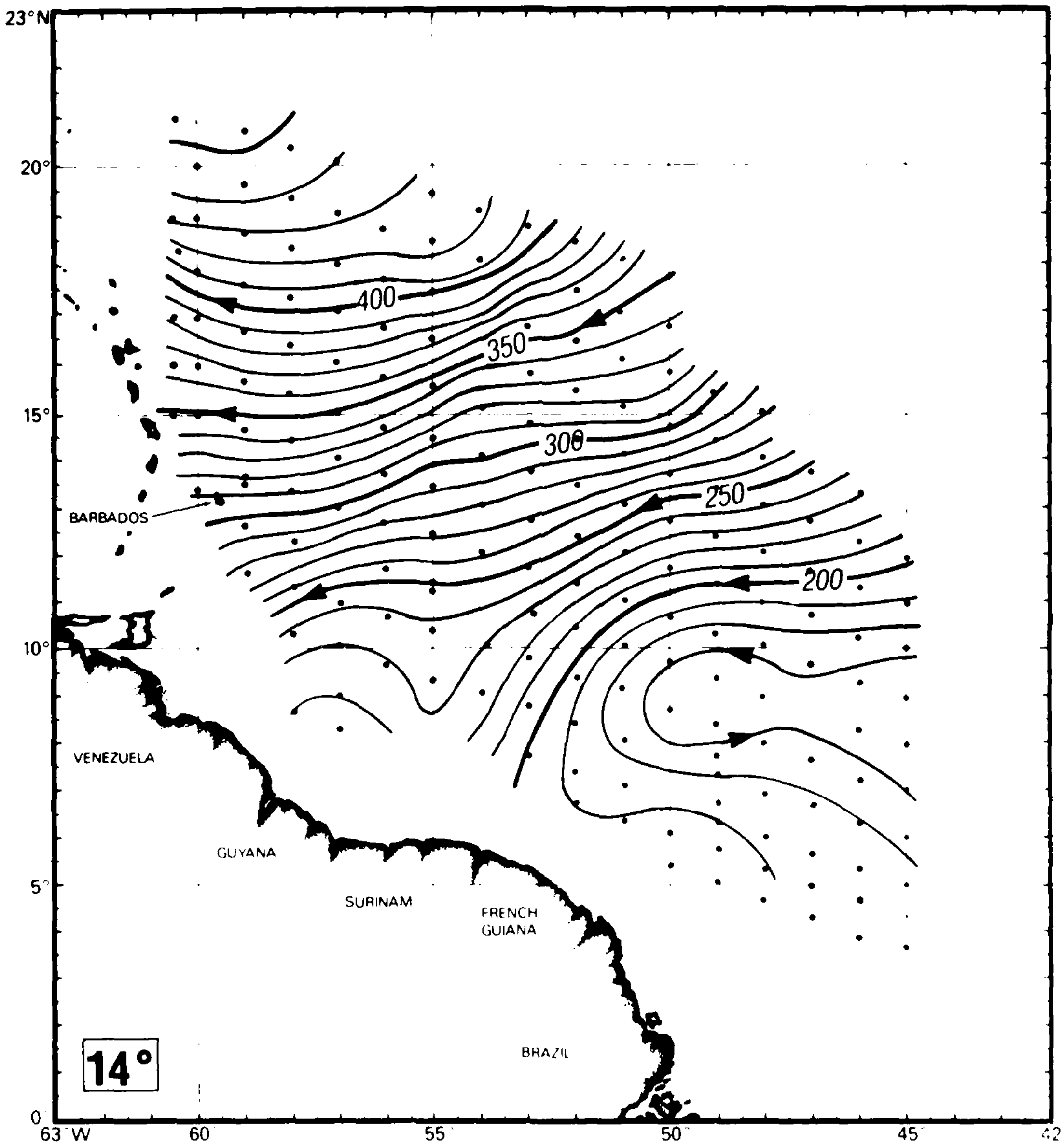


Figure 7. Depth in meters of the 14°C isotherm. Arrows indicate flow direction assuming the contours approximate streamlines

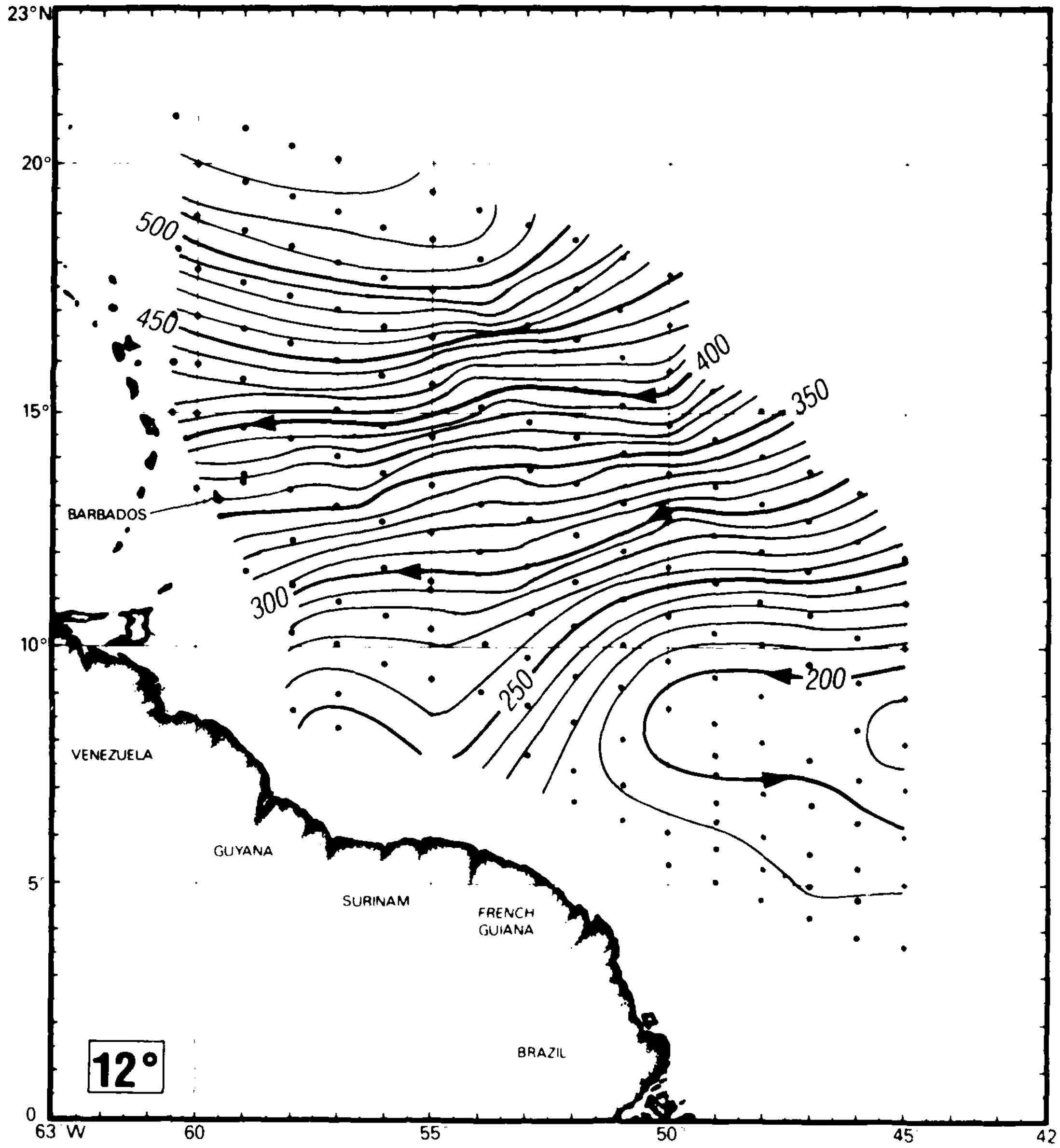


Figure 8. Depth in meters of the 12°C isotherm. Arrows indicate flow direction assuming the contours approximate streamlines.

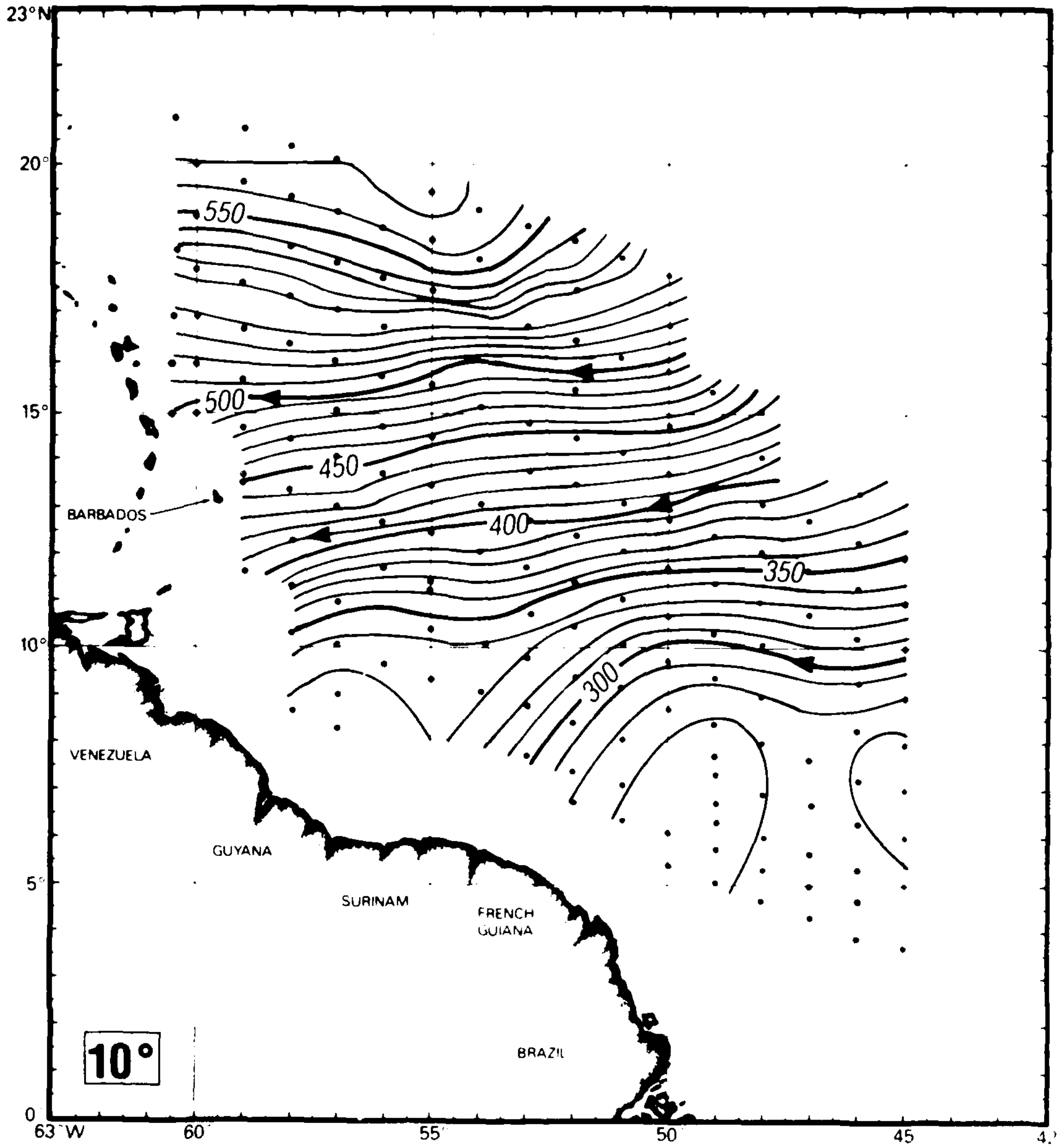


Figure 9. Depth in meters of the 10°C isotherm. Arrows indicate flow direction assuming the contours approximate streamlines.

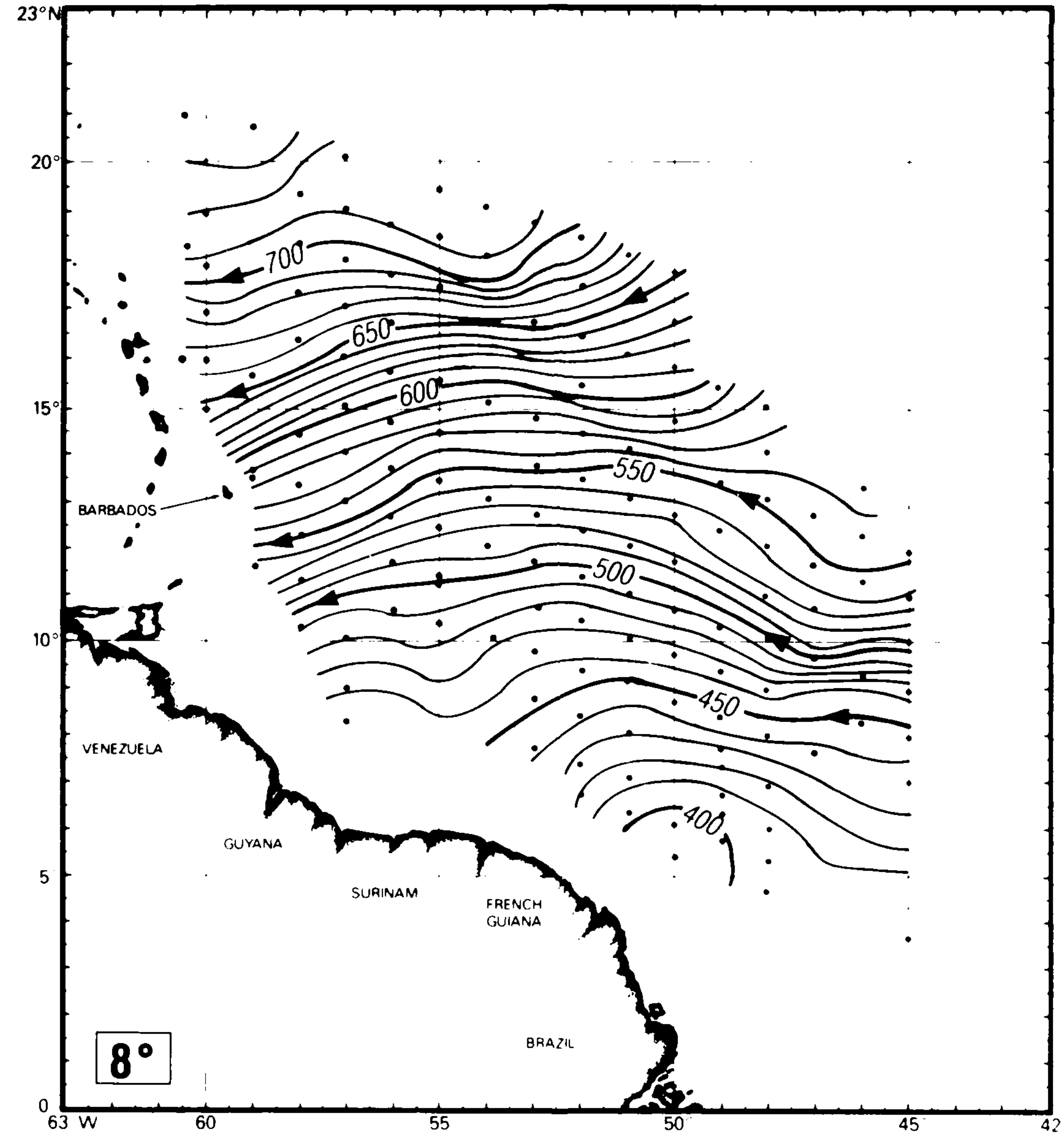


Figure 10. Depth in meters of the 8° C isotherm. Arrows indicate flow direction assuming the contours approximate streamlines.

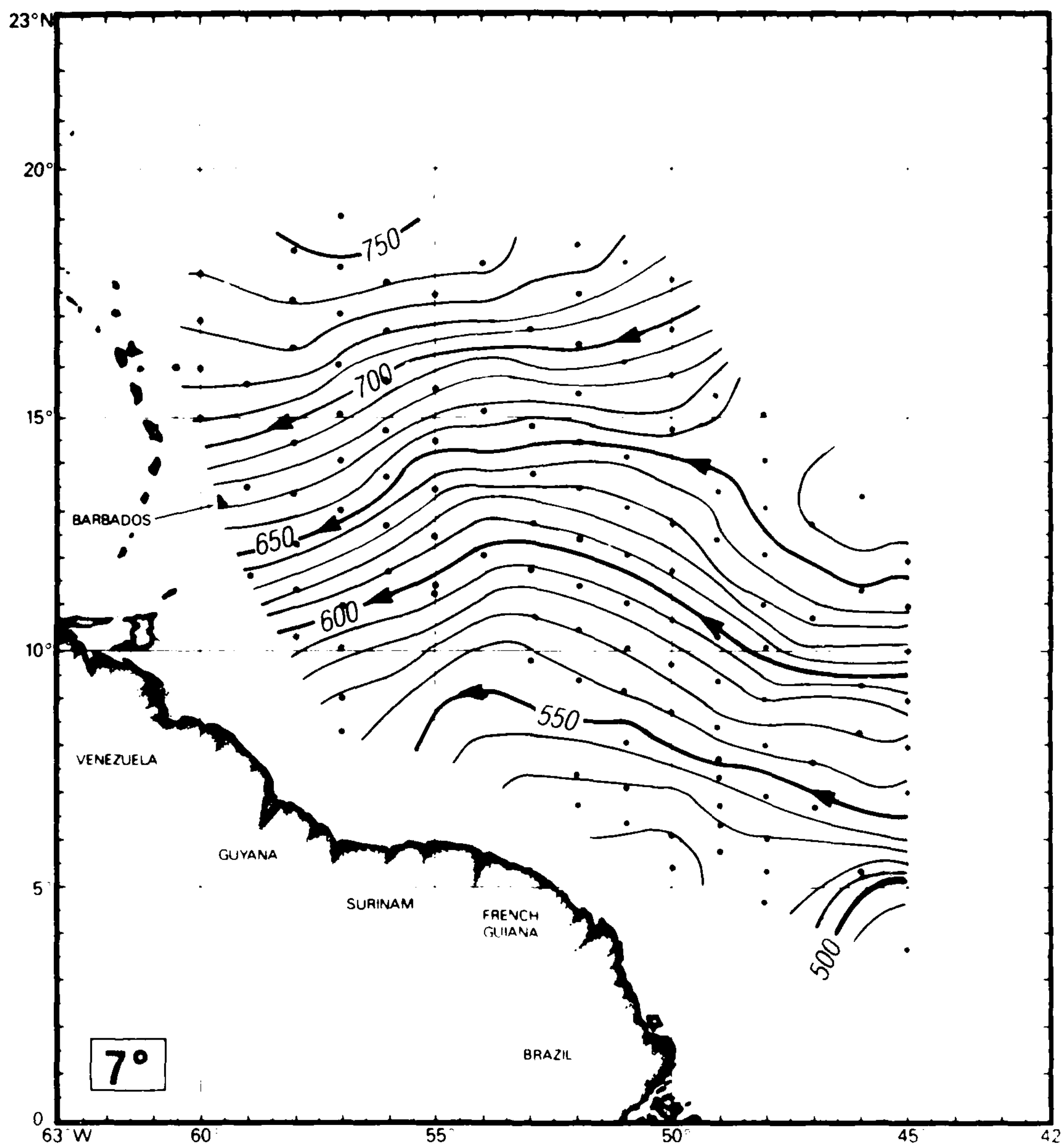


Figure 11. Depth in meters of the 7° C isotherm. Arrows indicate flow direction assuming the contours approximate streamlines.

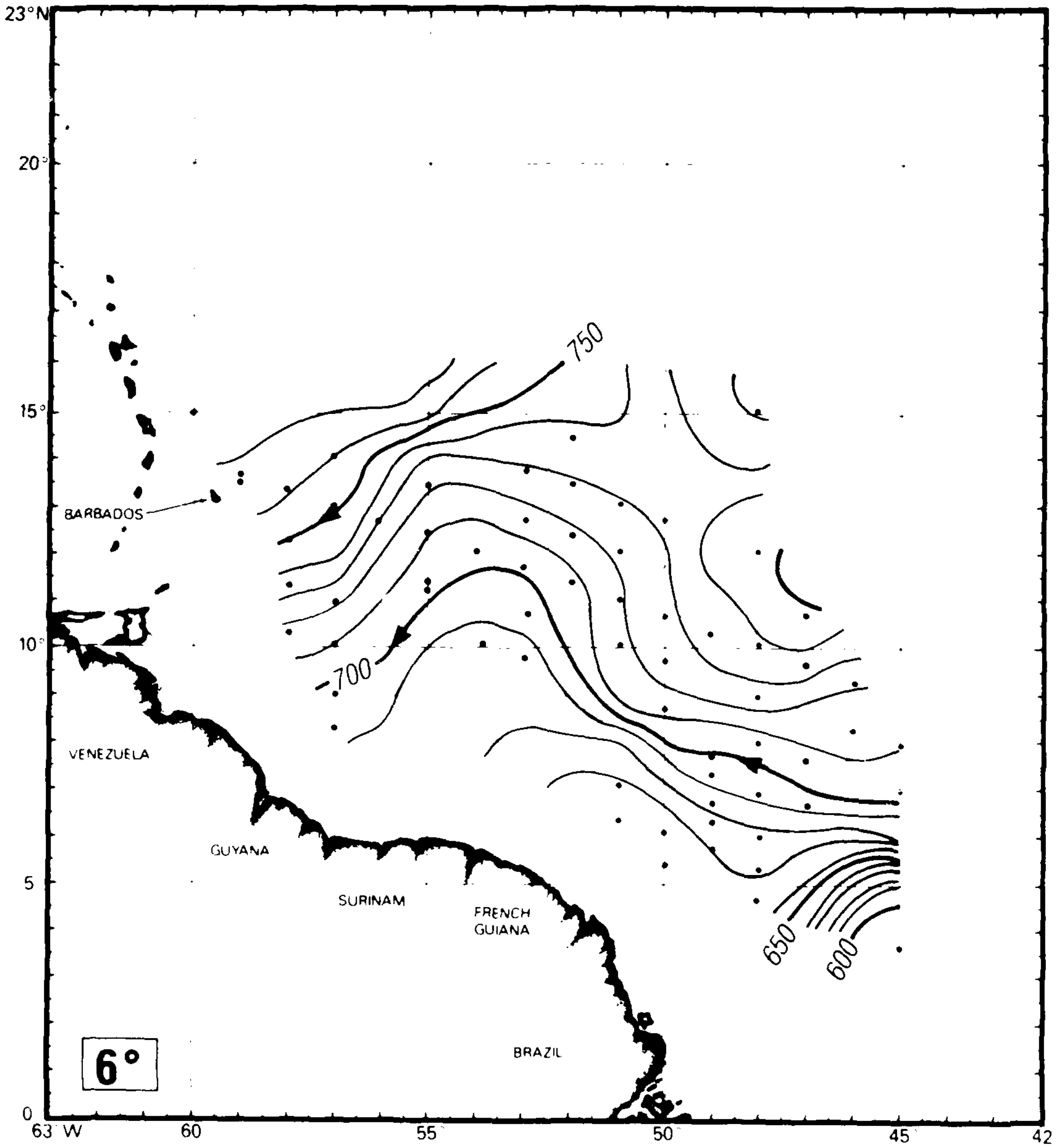
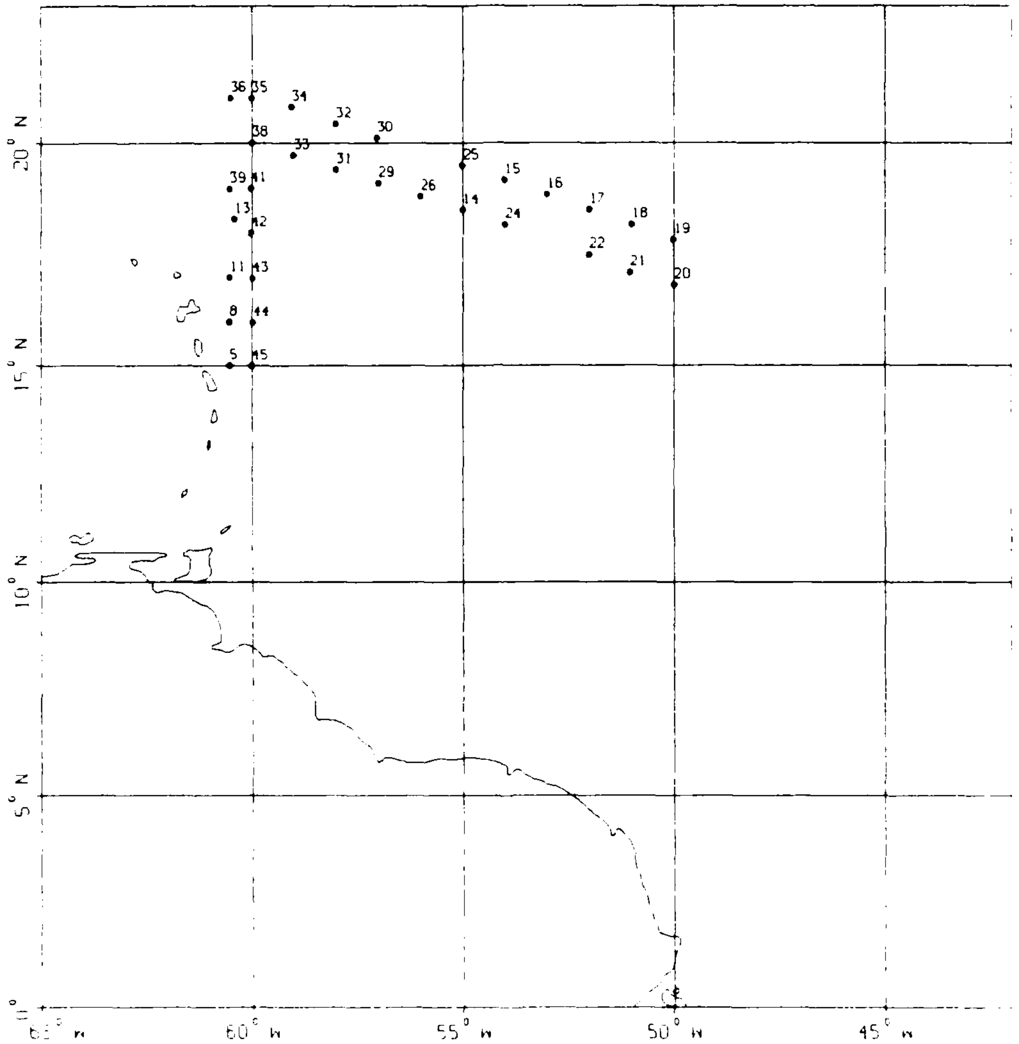
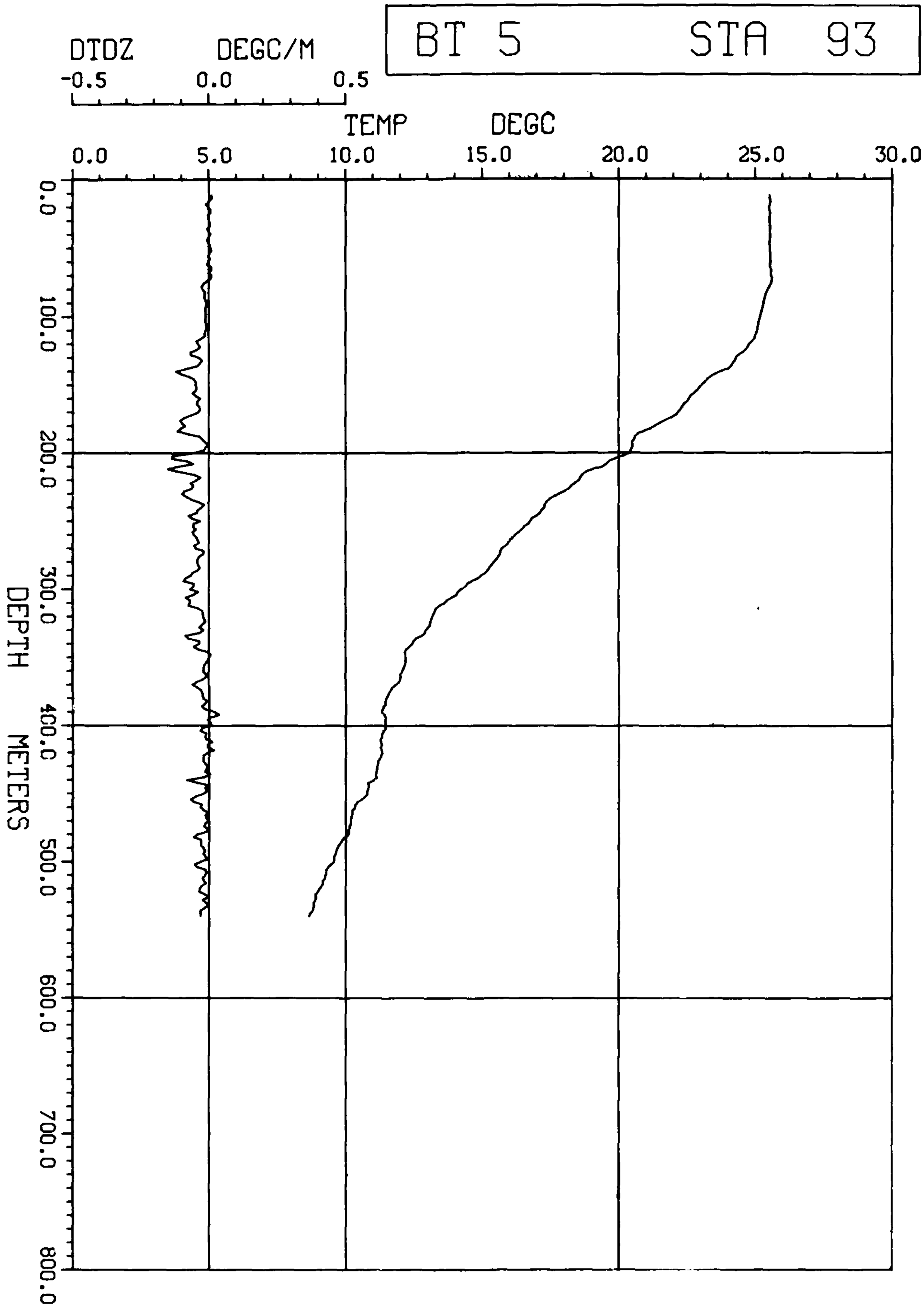


Figure 12. Depth in meters of the 6°C isotherm. Arrows indicate flow direction assuming the contours approximate streamlines.

Figures 13-231. Temperature versus depth and temperature gradient versus depth profiles, AXBT drops 5-259.

Station Positions Flight 1
22 March 1985

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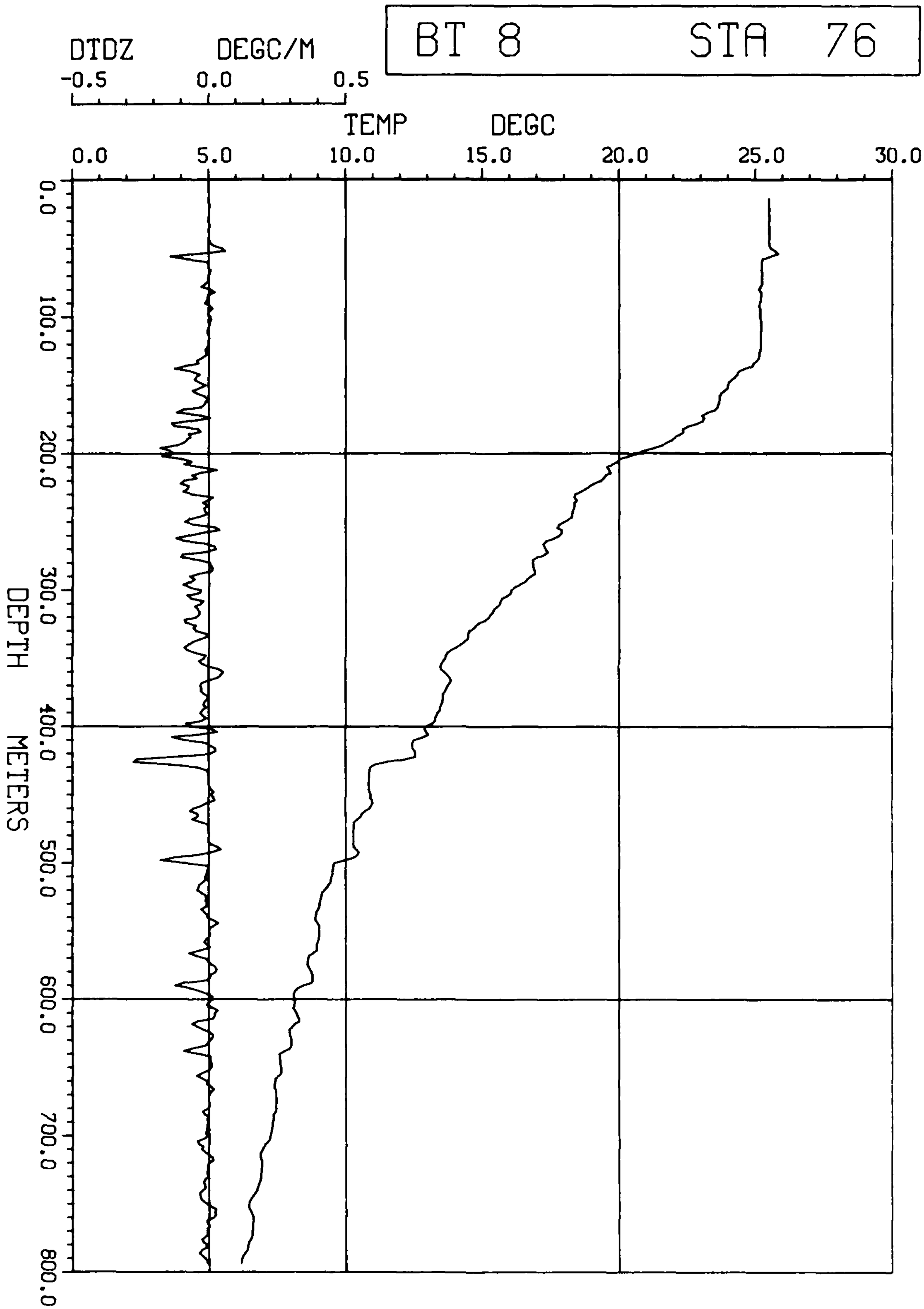
DEPTH METERS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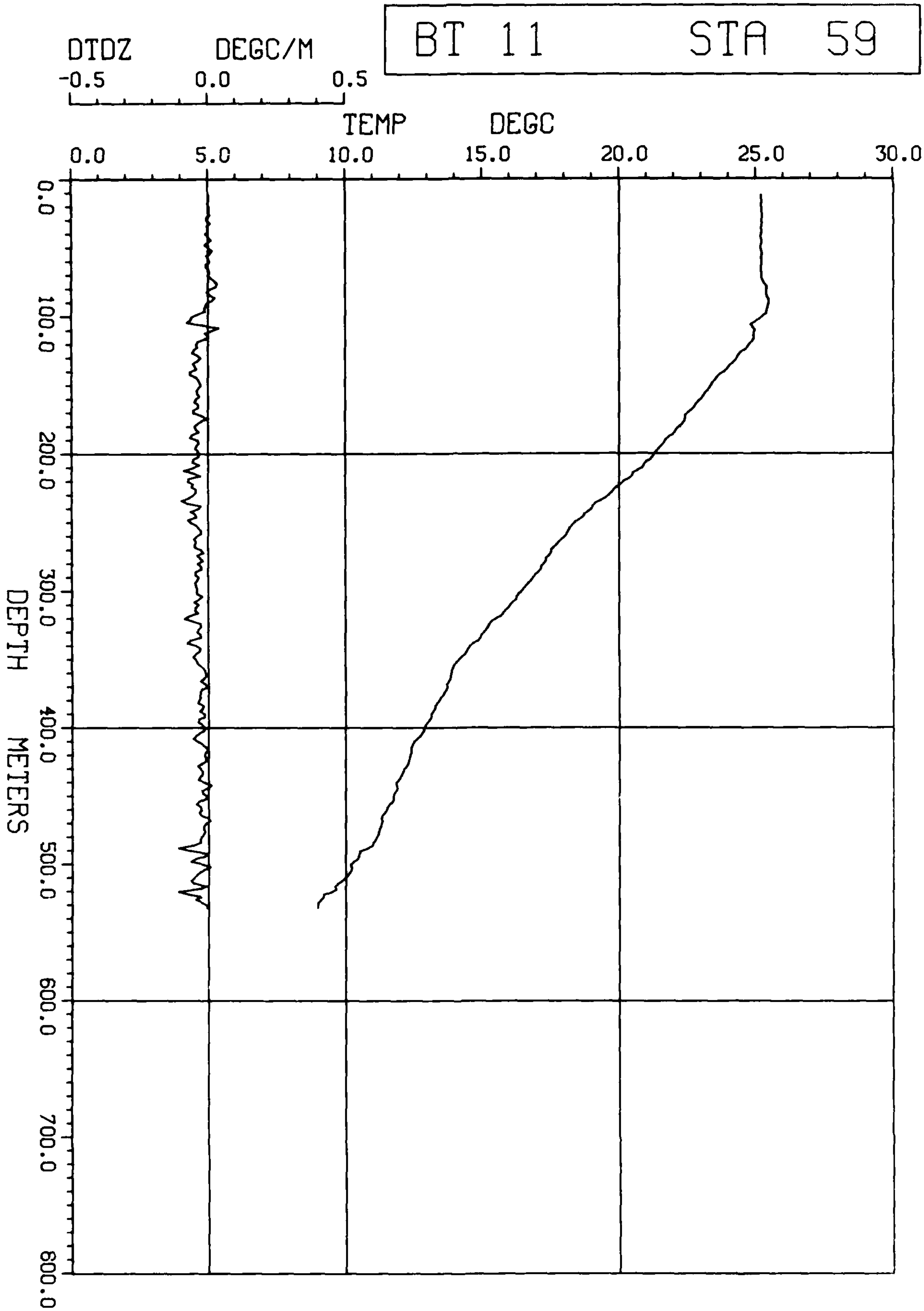
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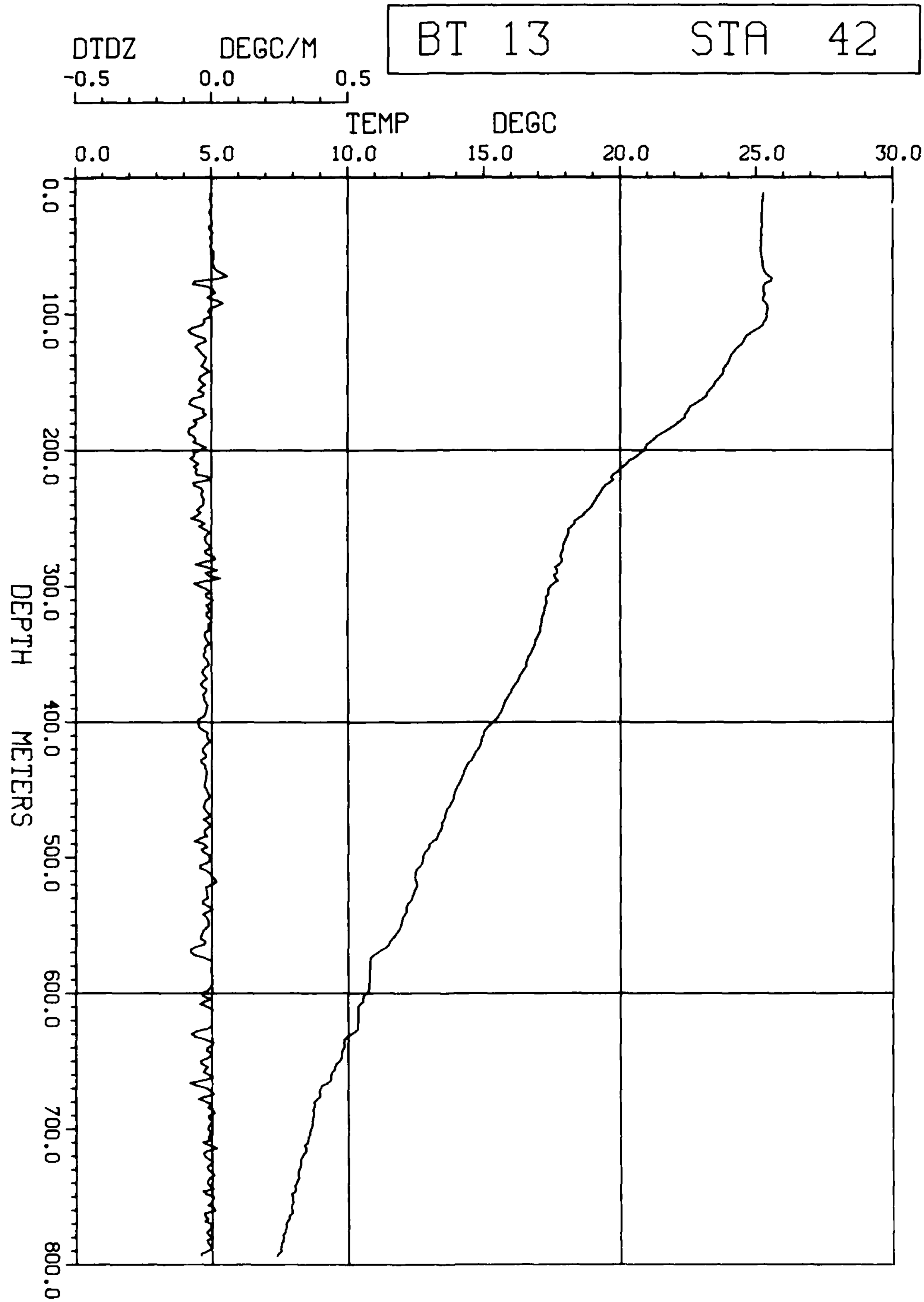
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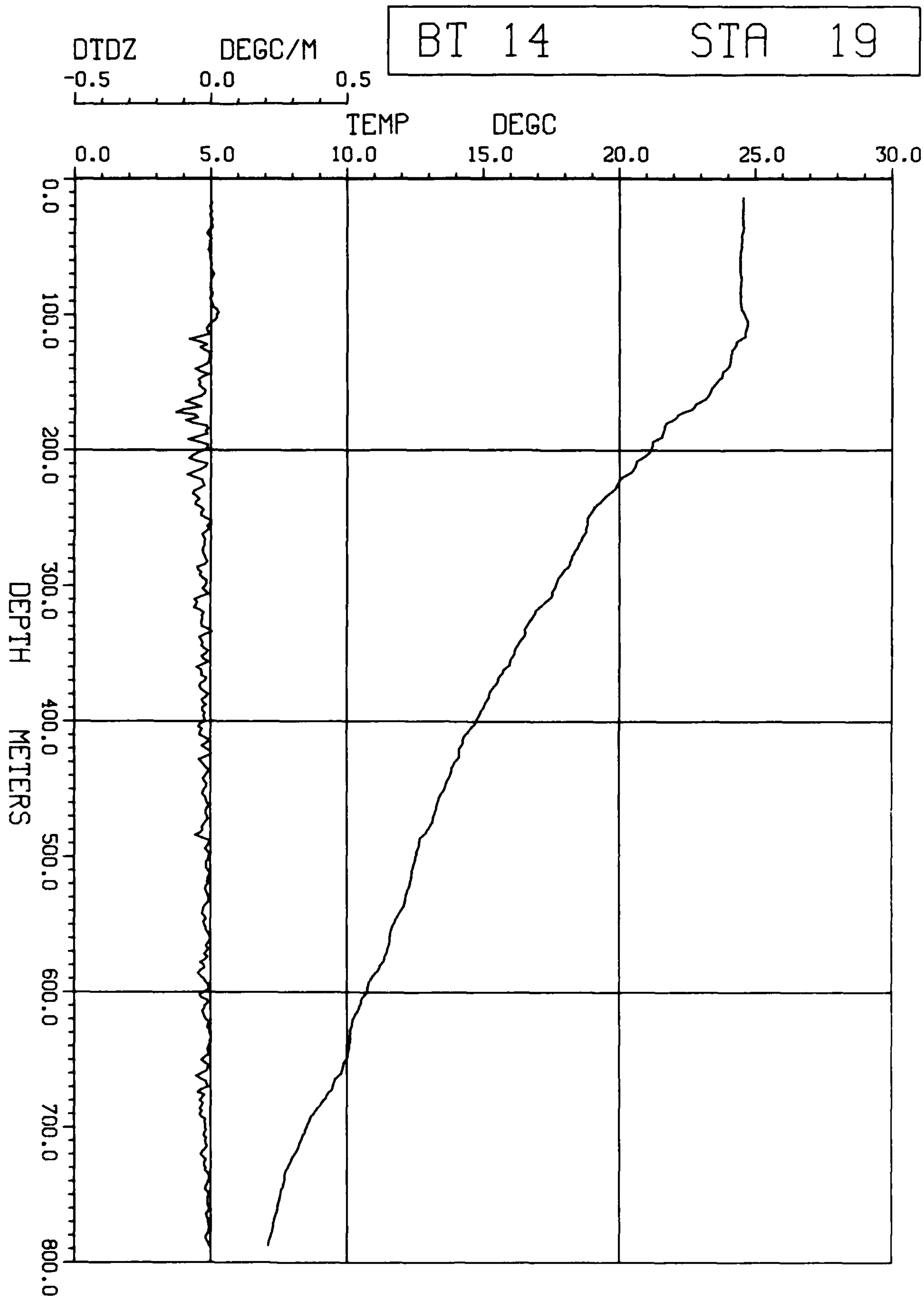
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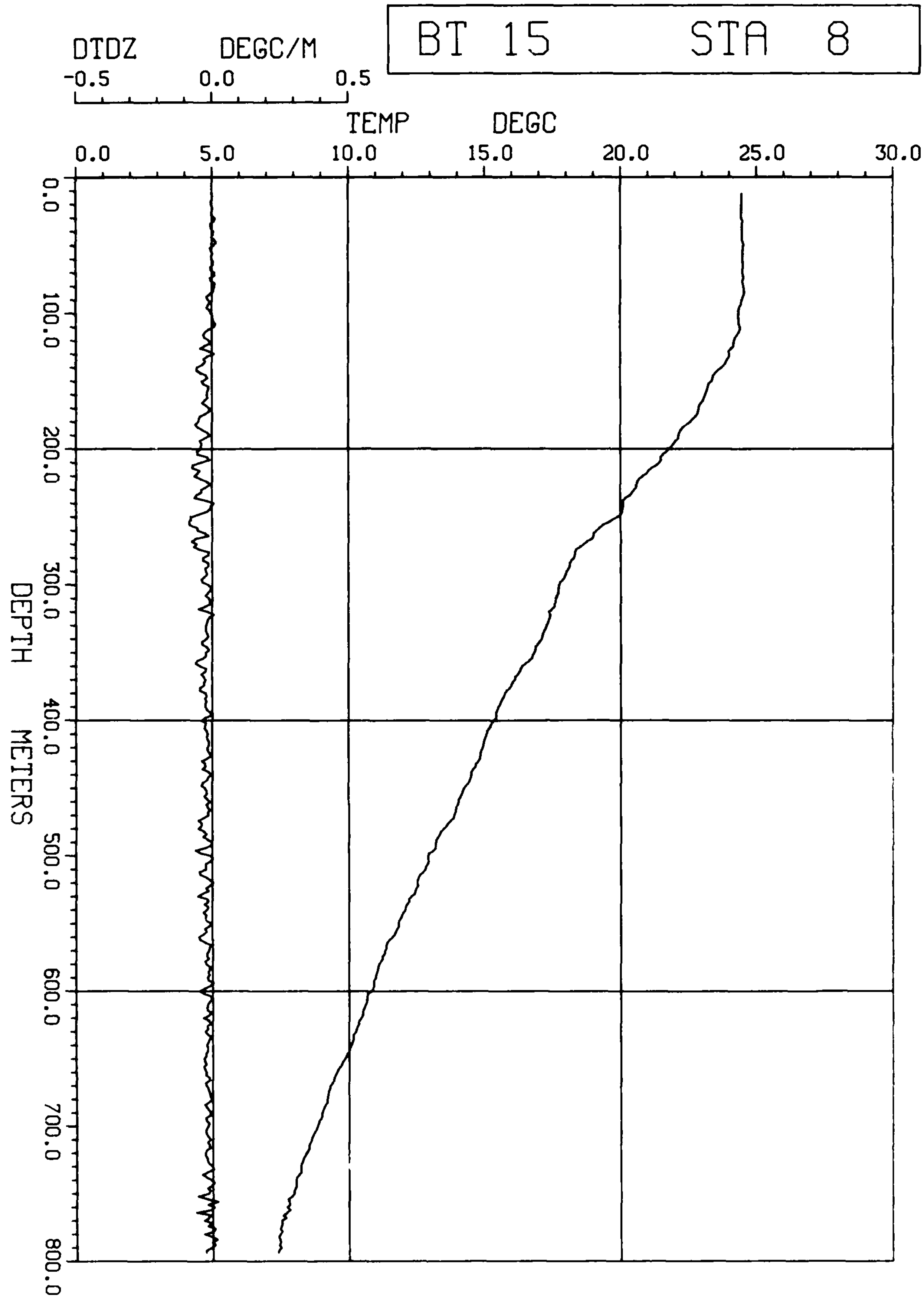

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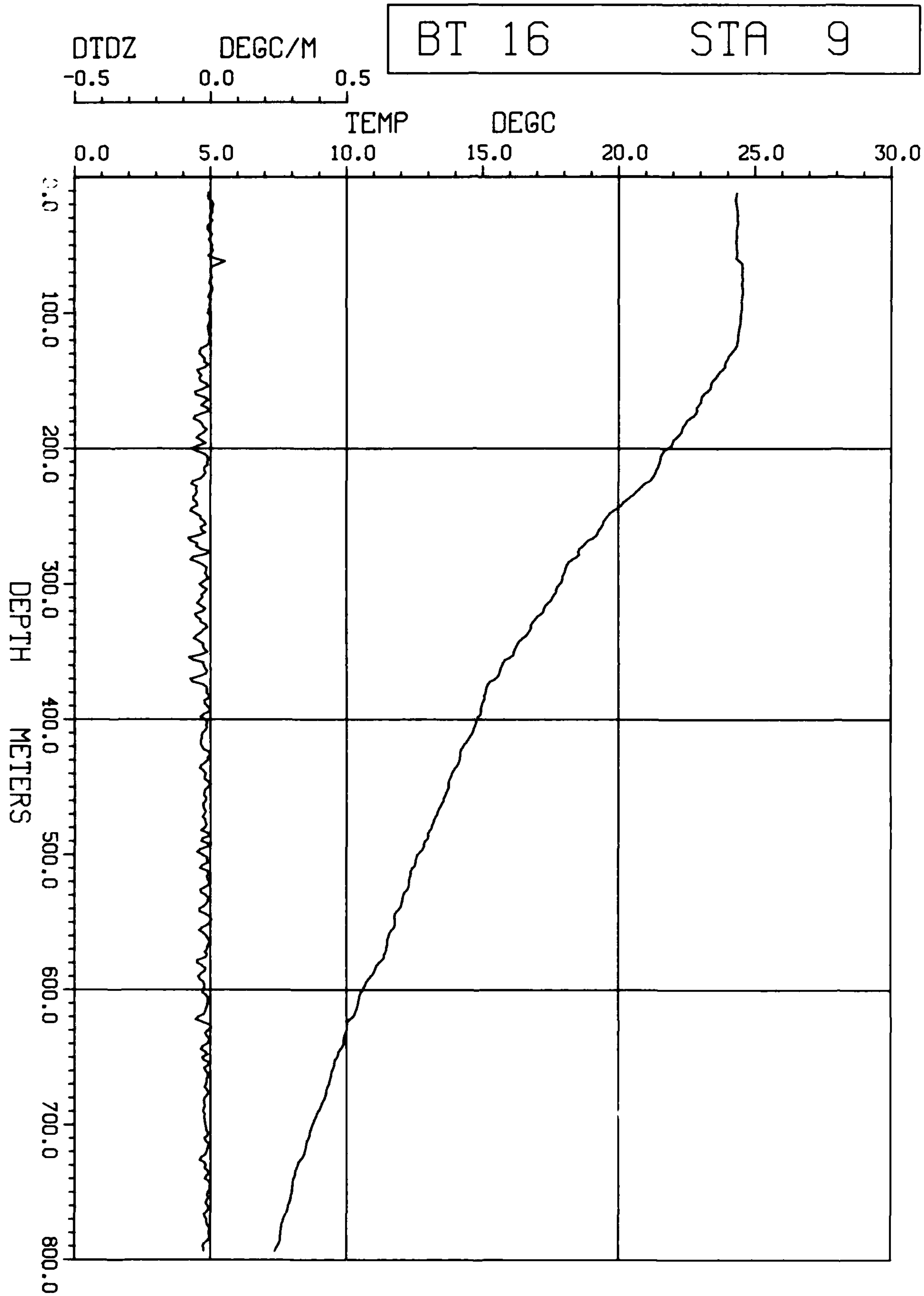
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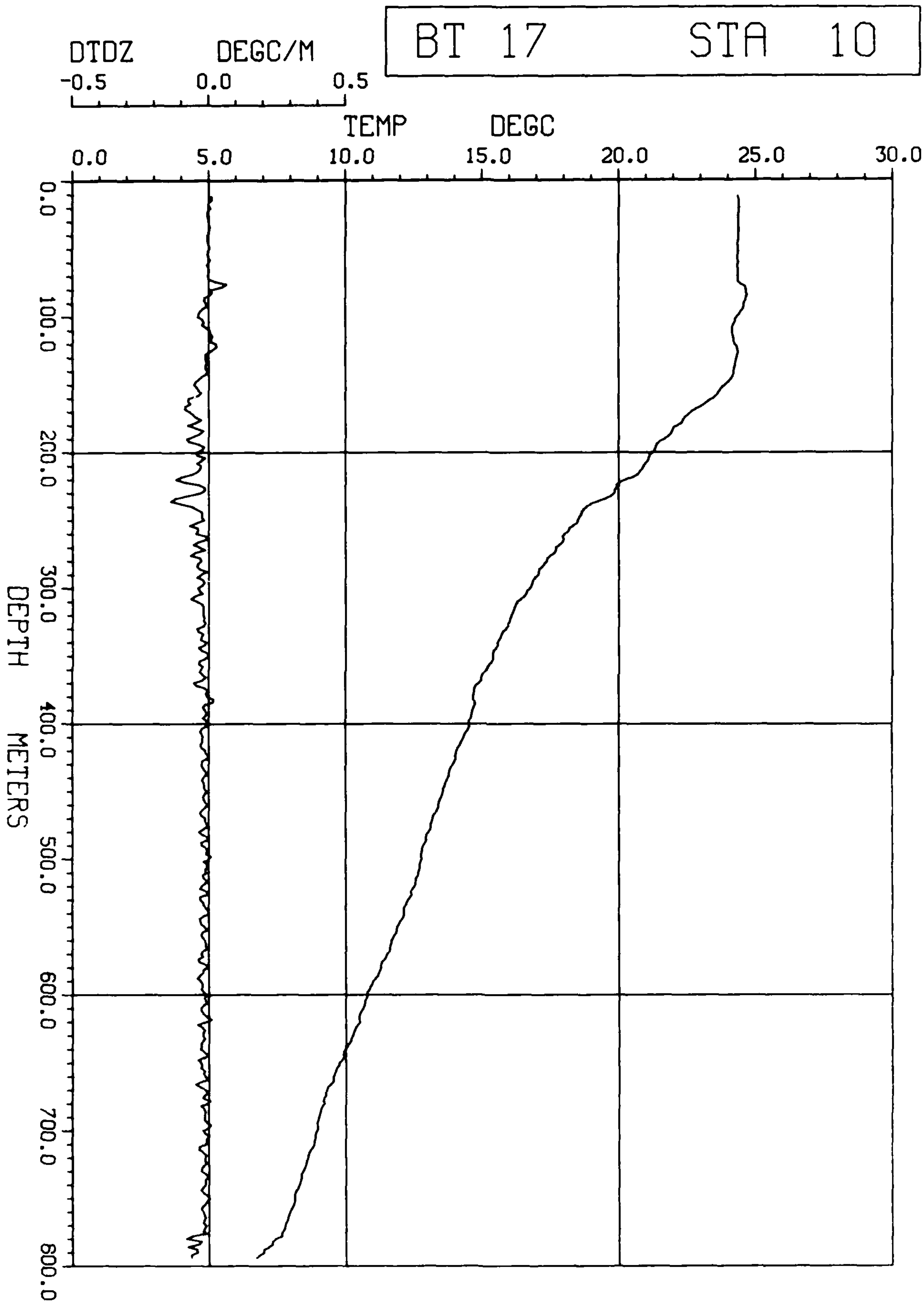

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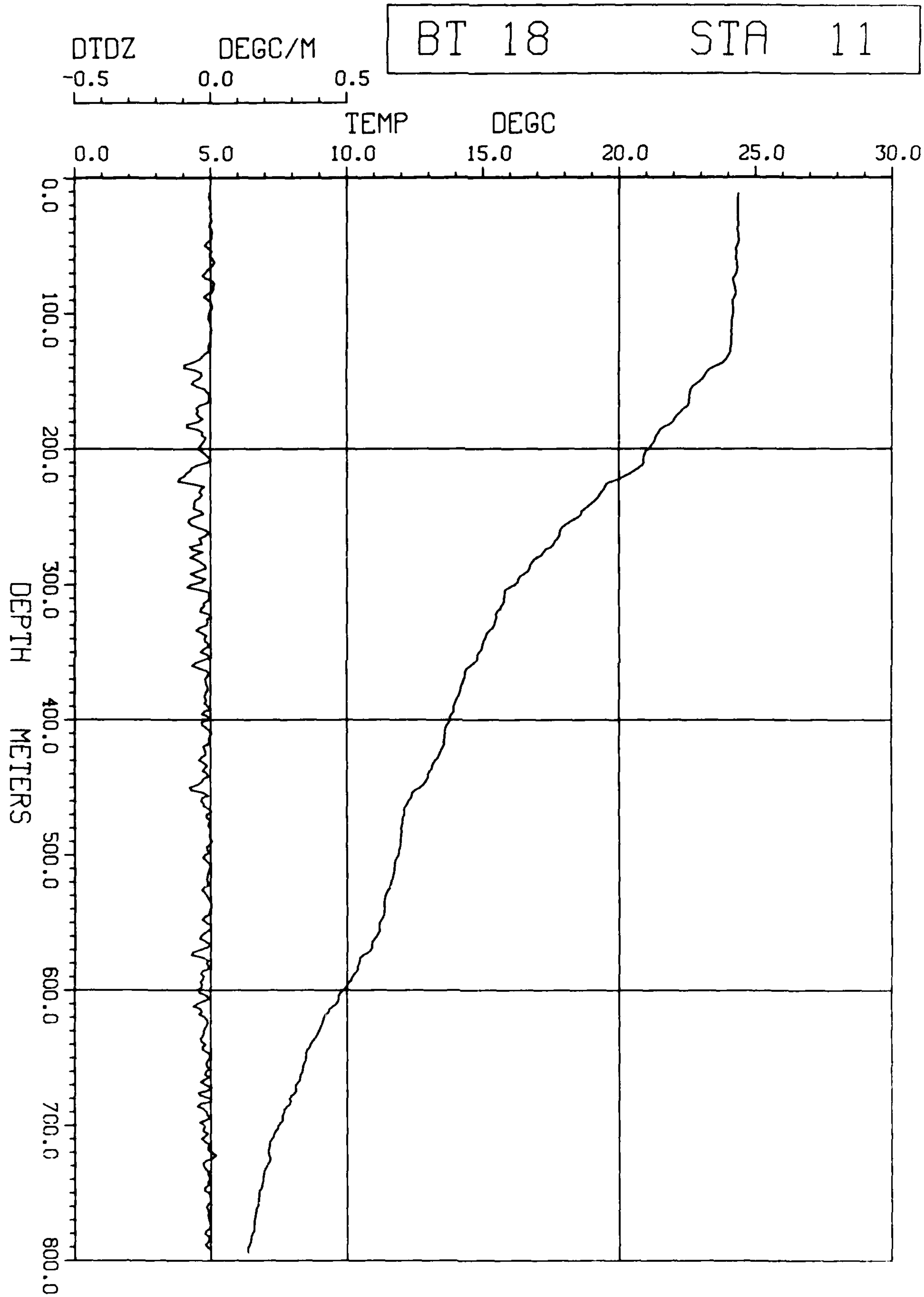
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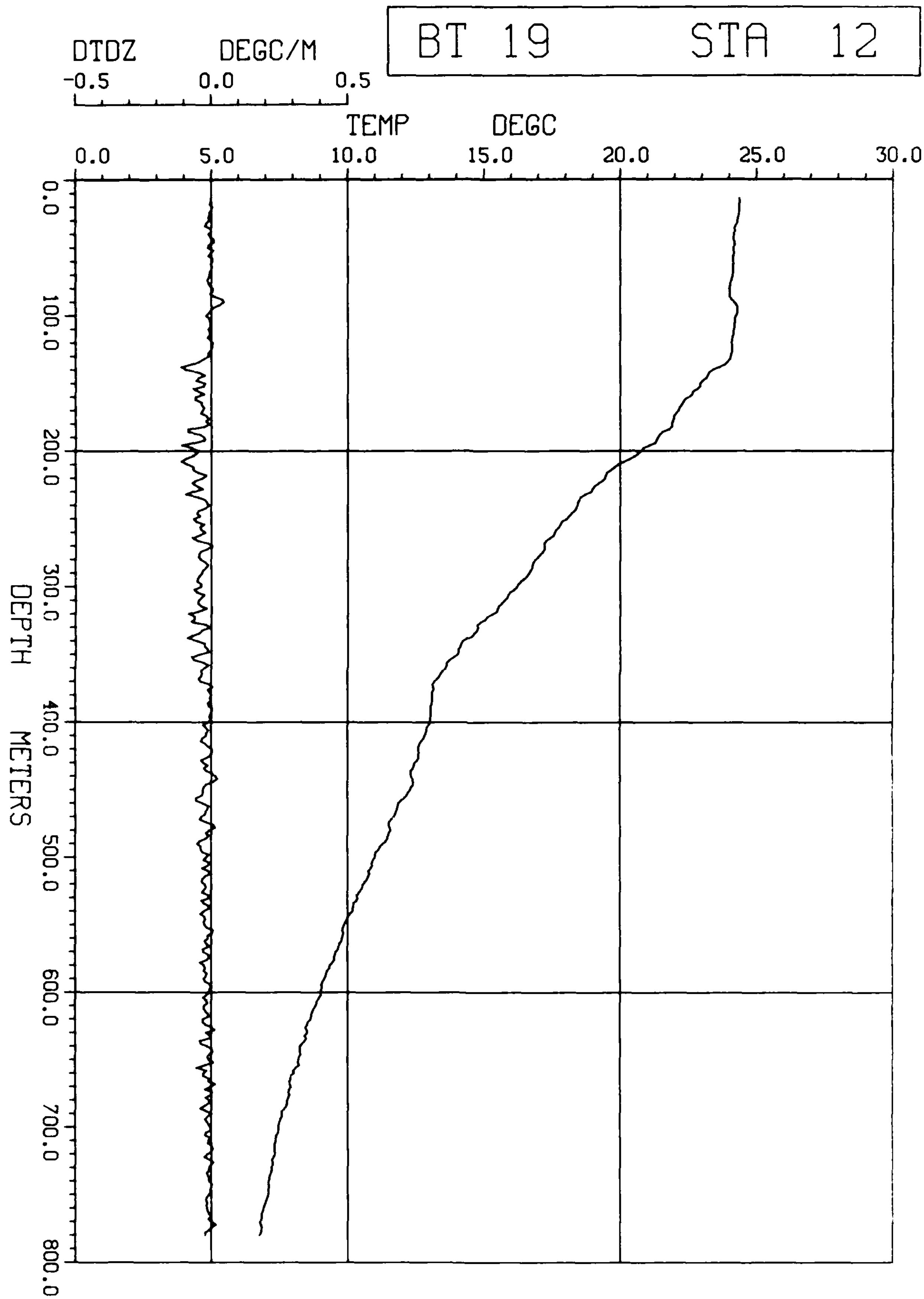
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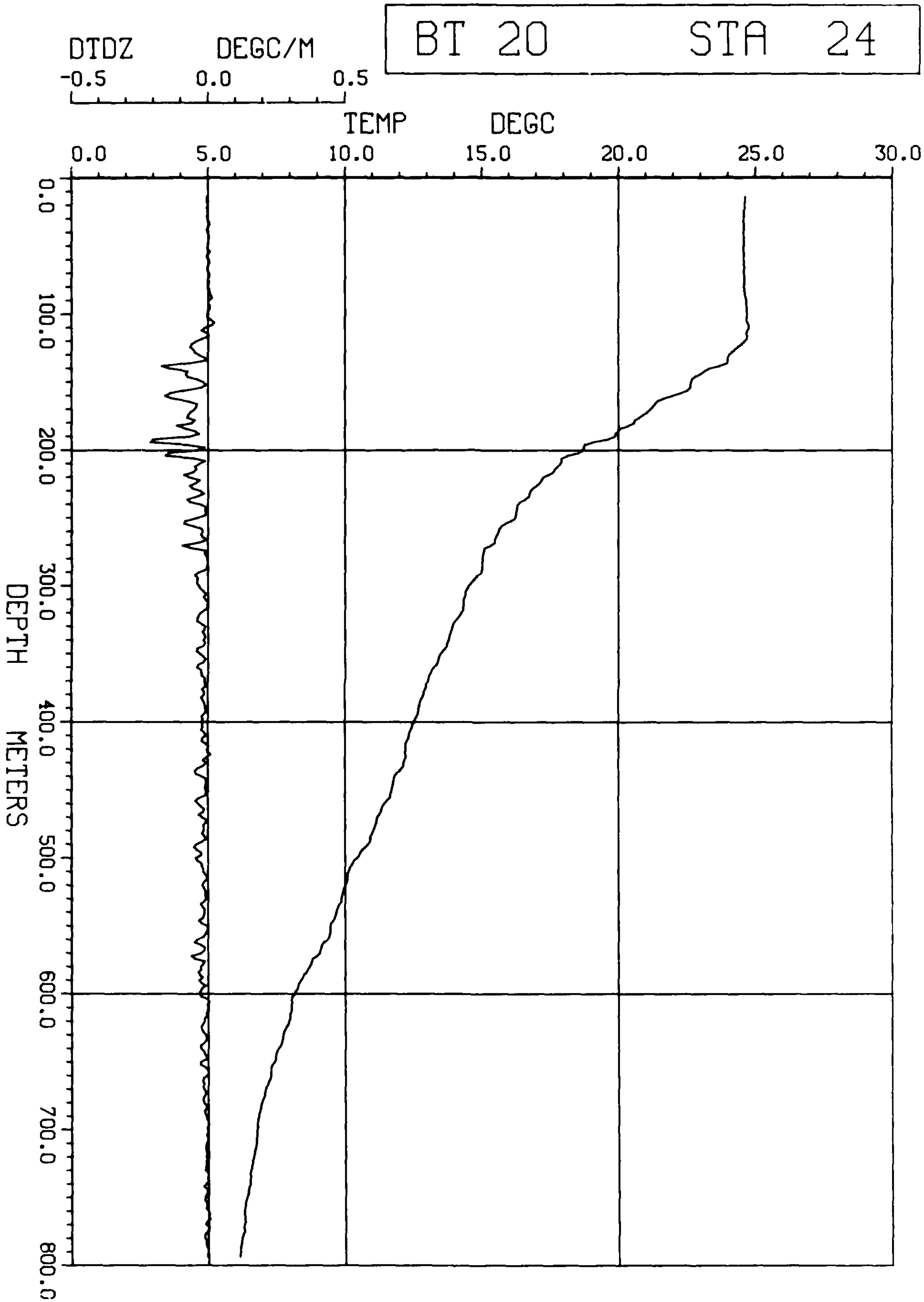
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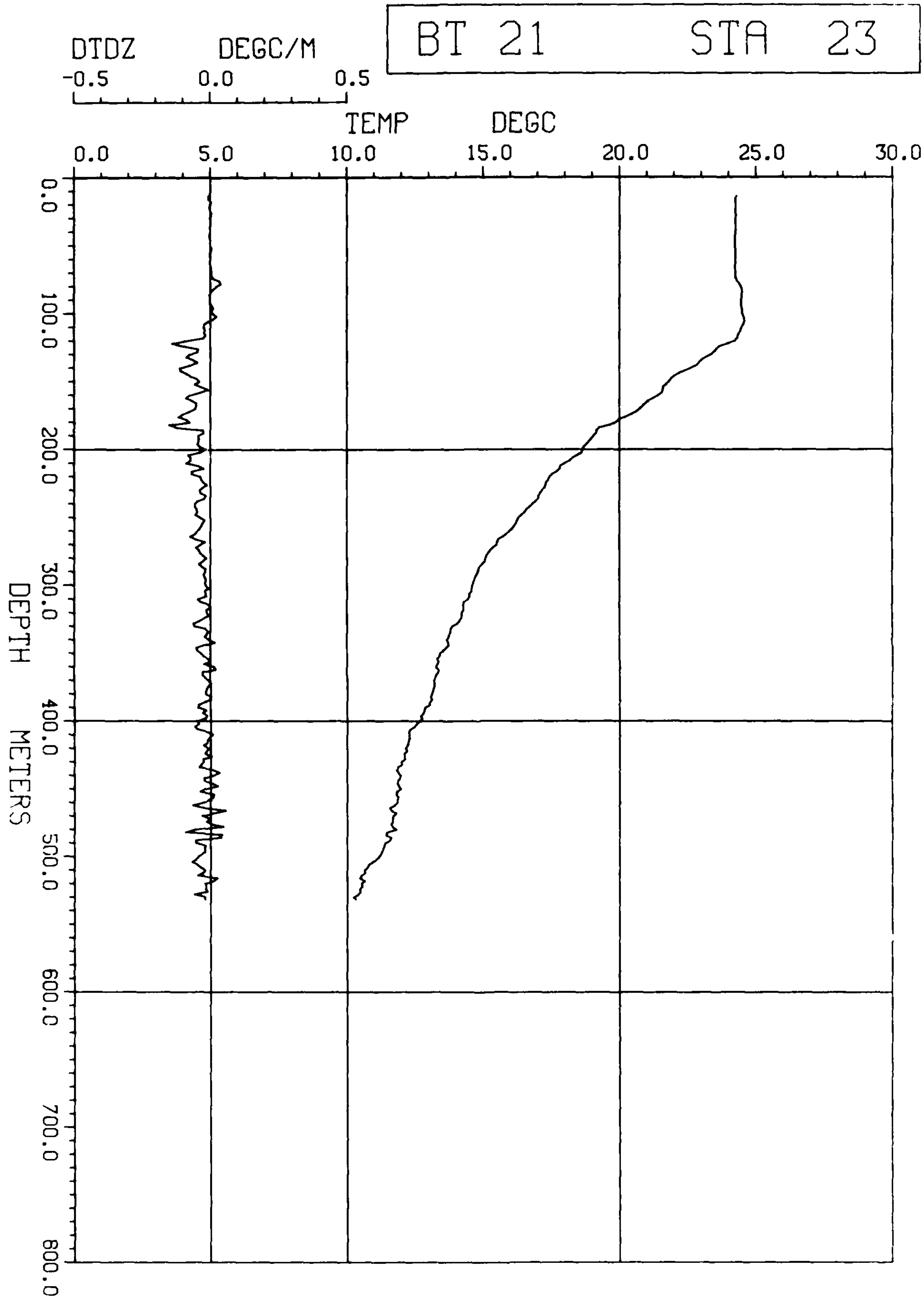
DEPTH METERS



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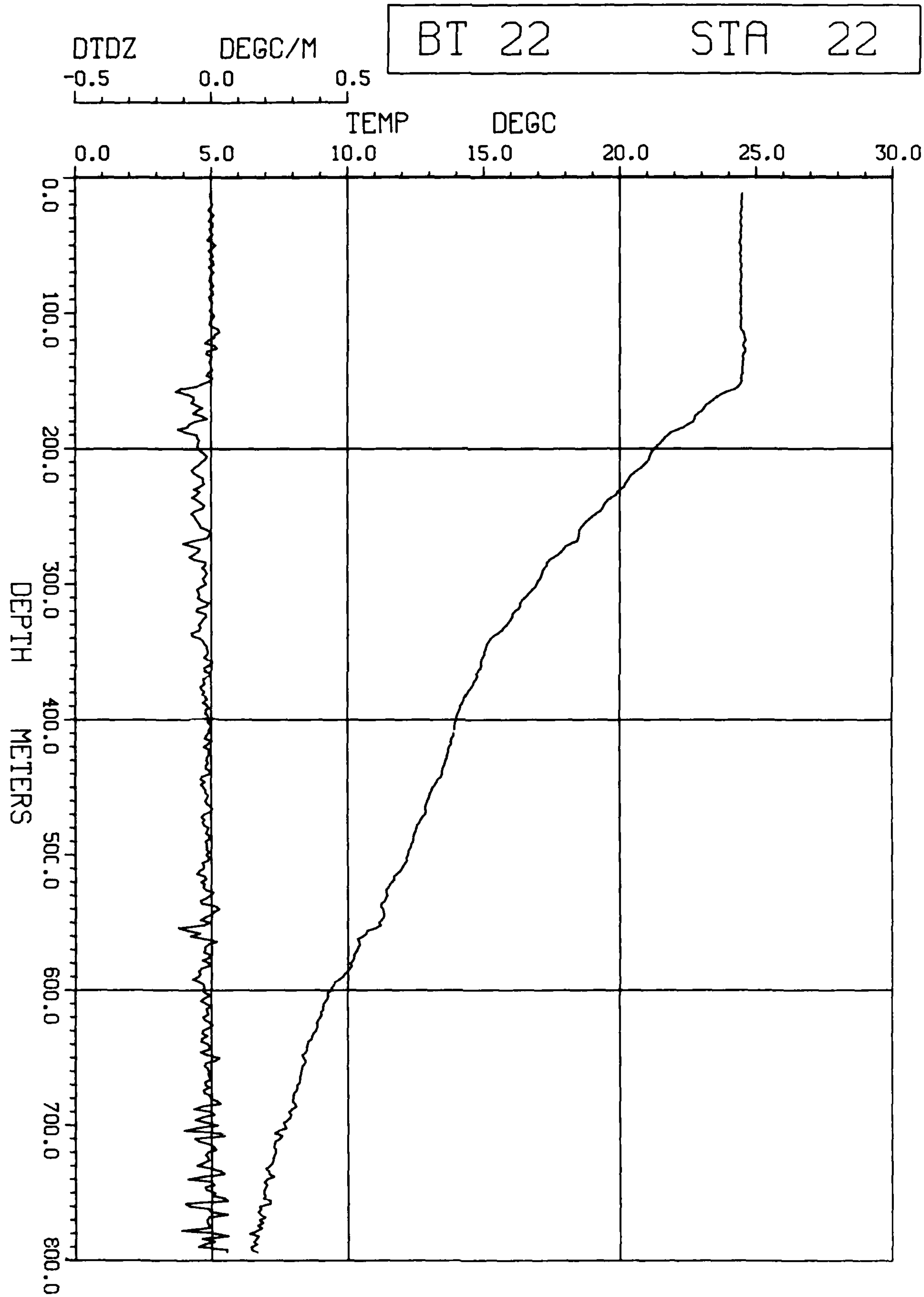
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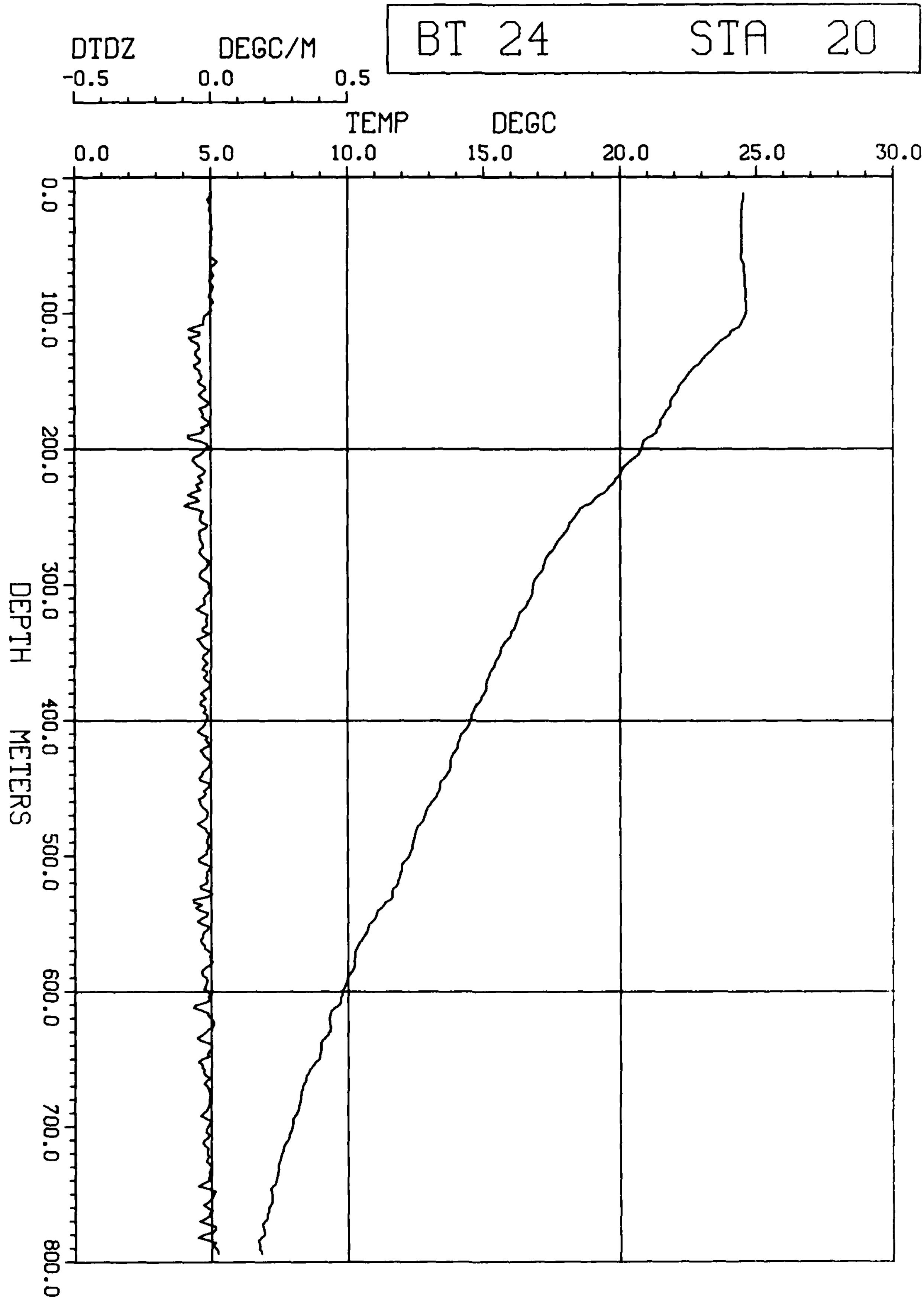
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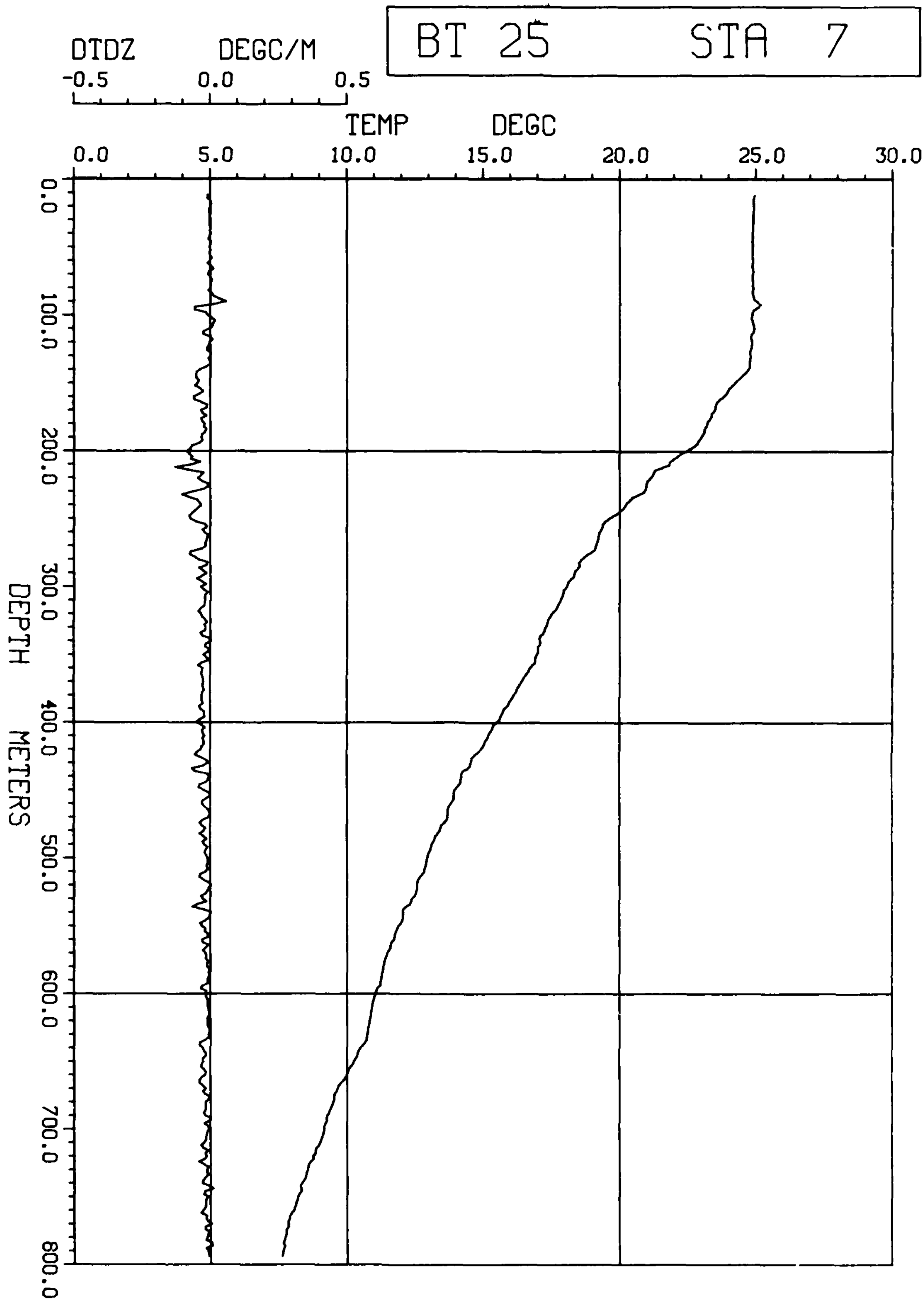
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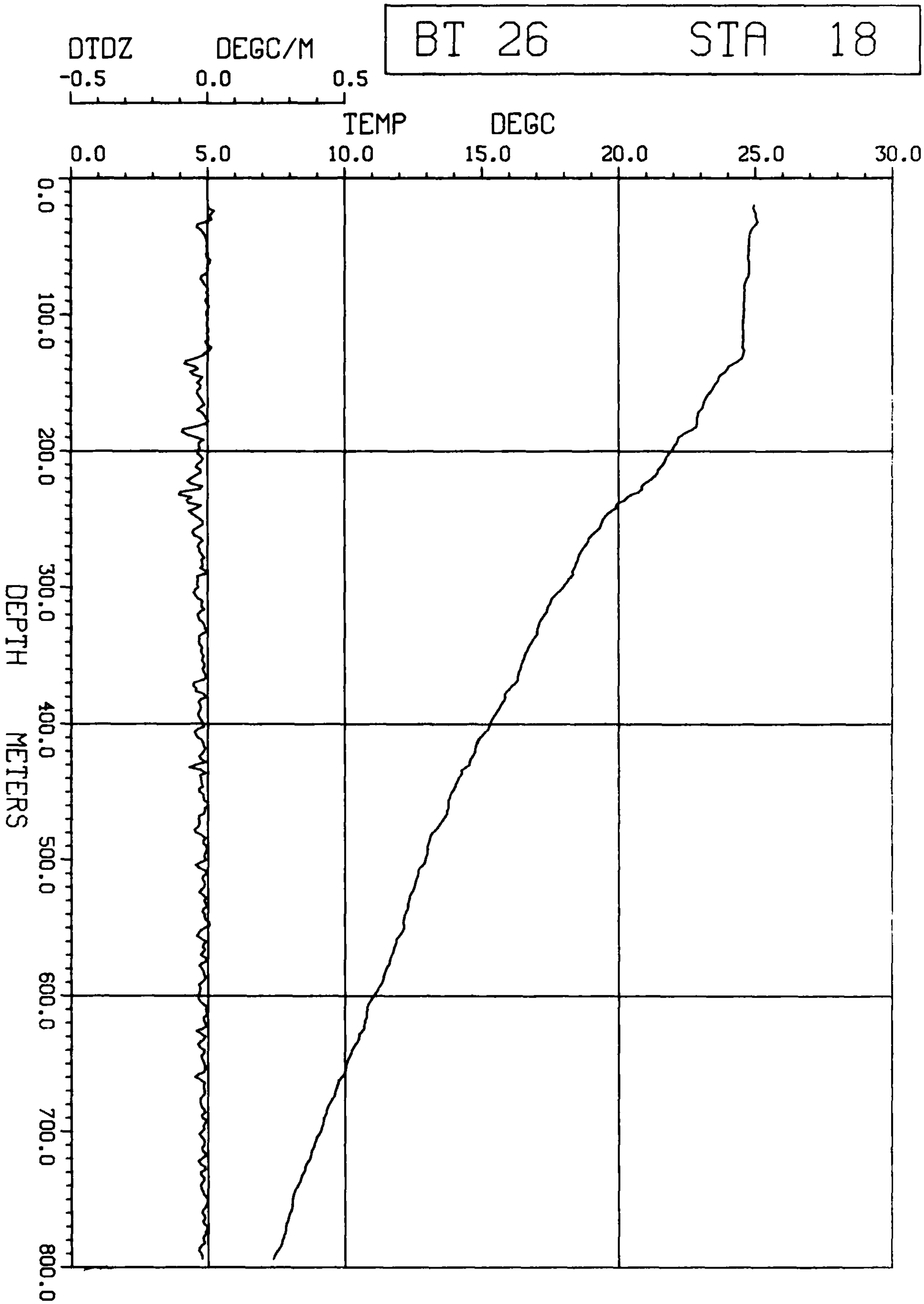

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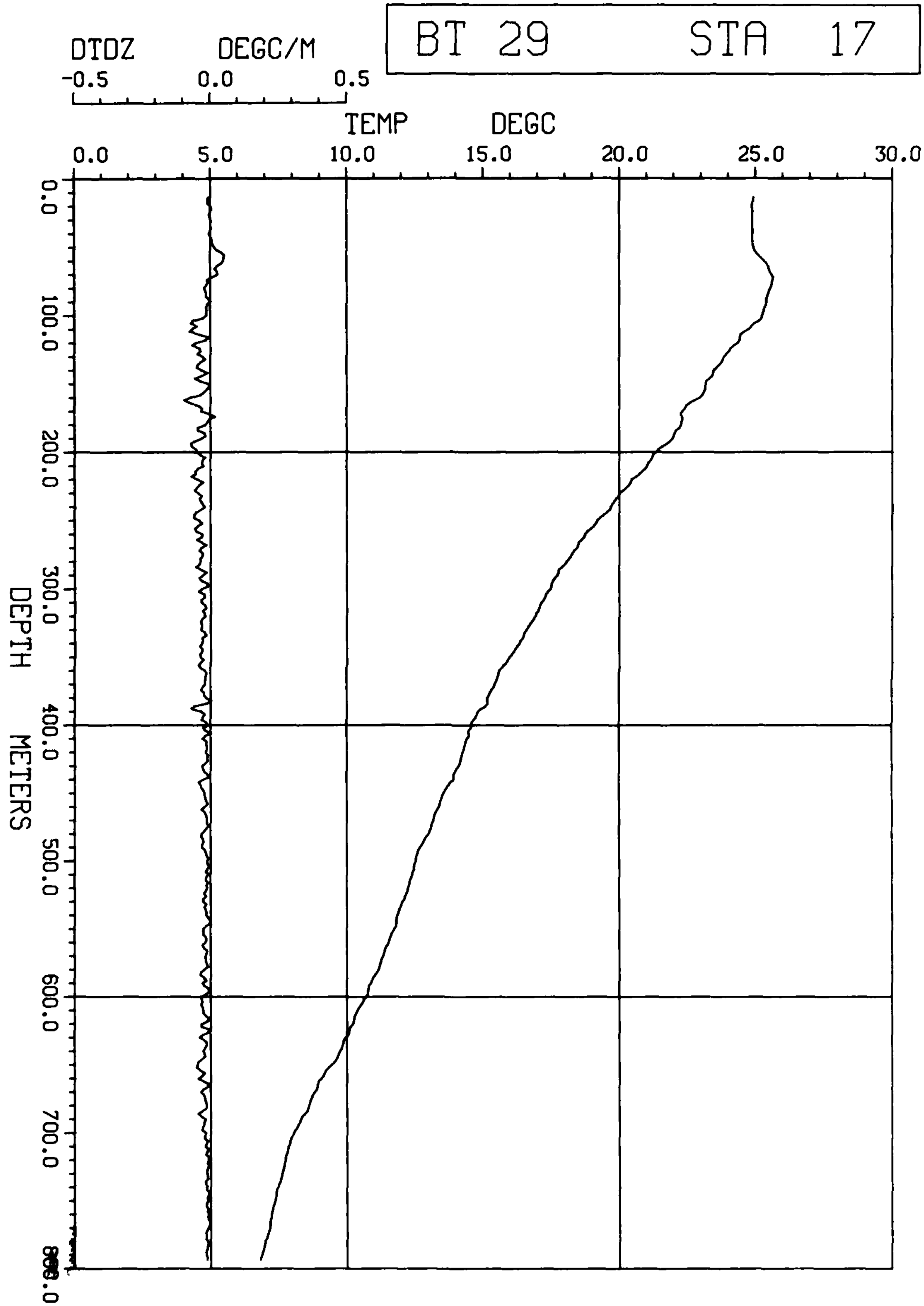
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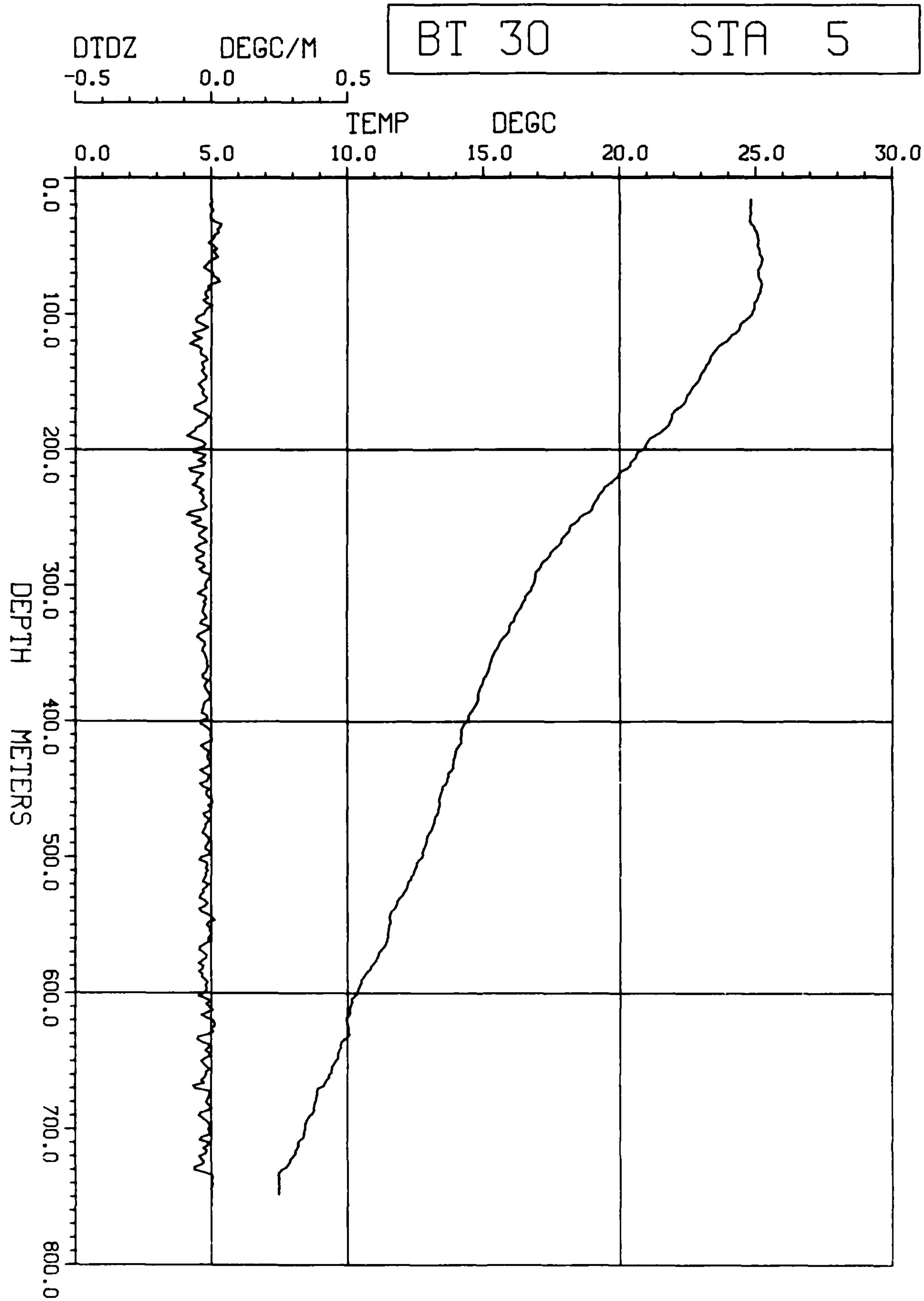
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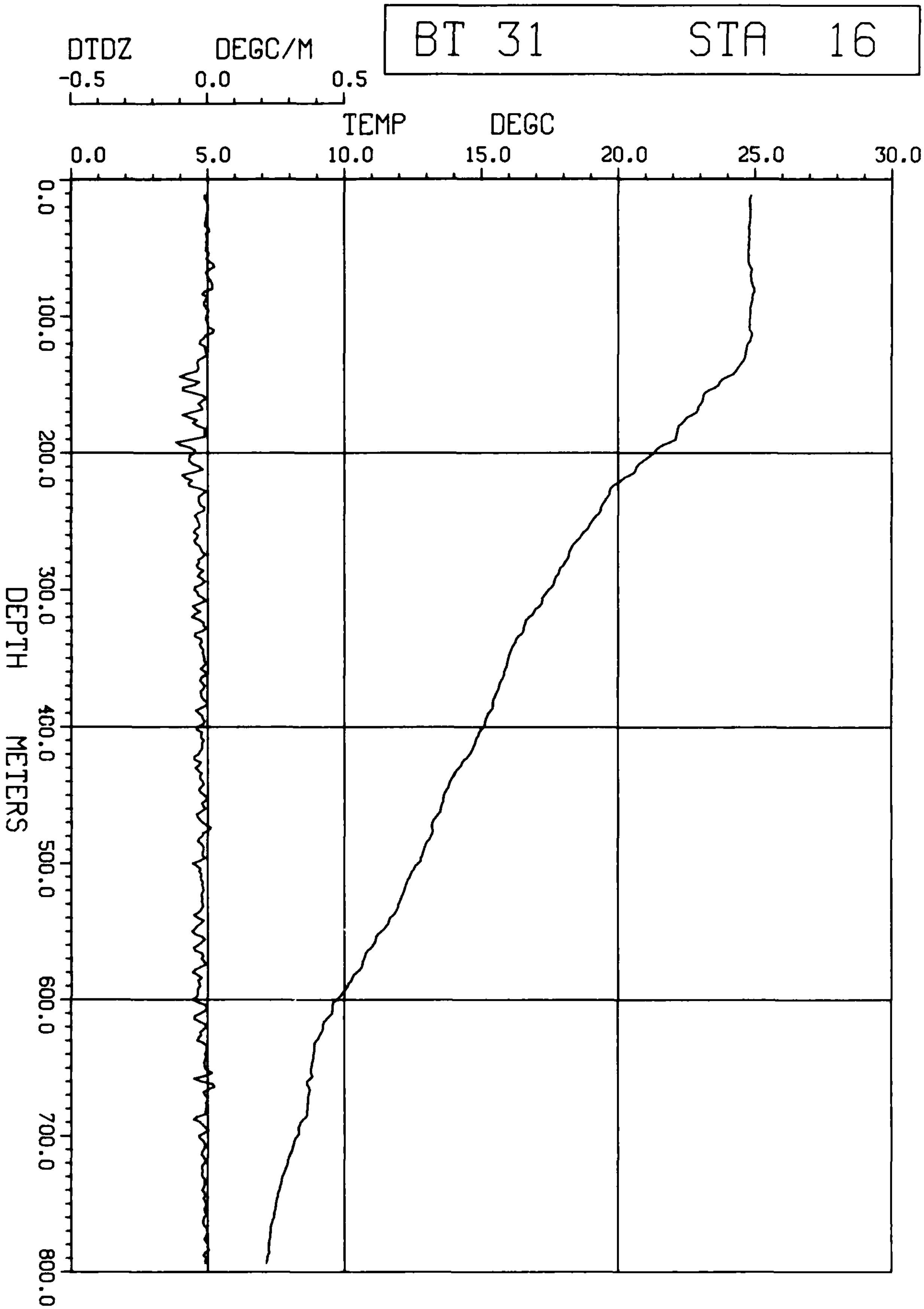
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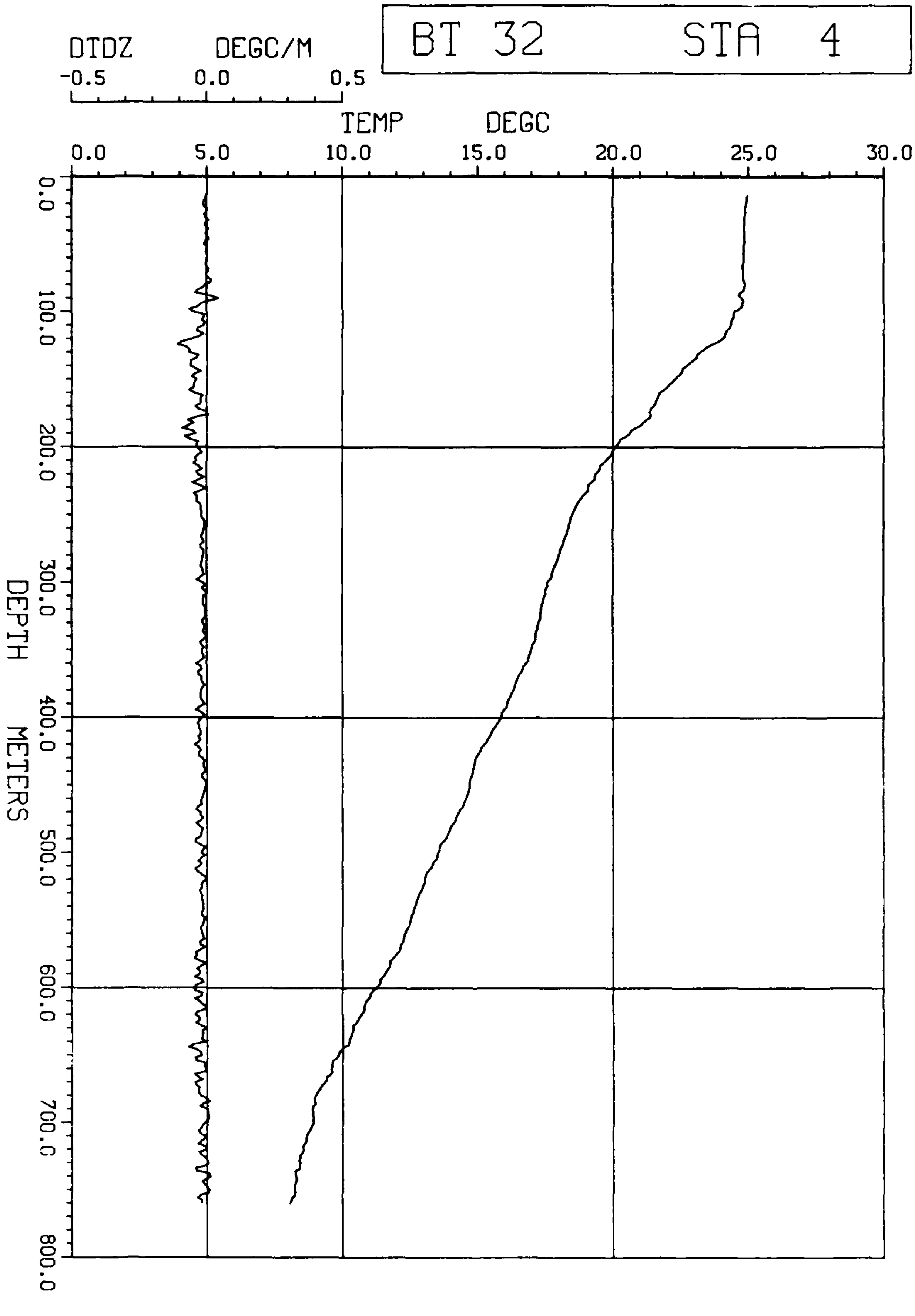
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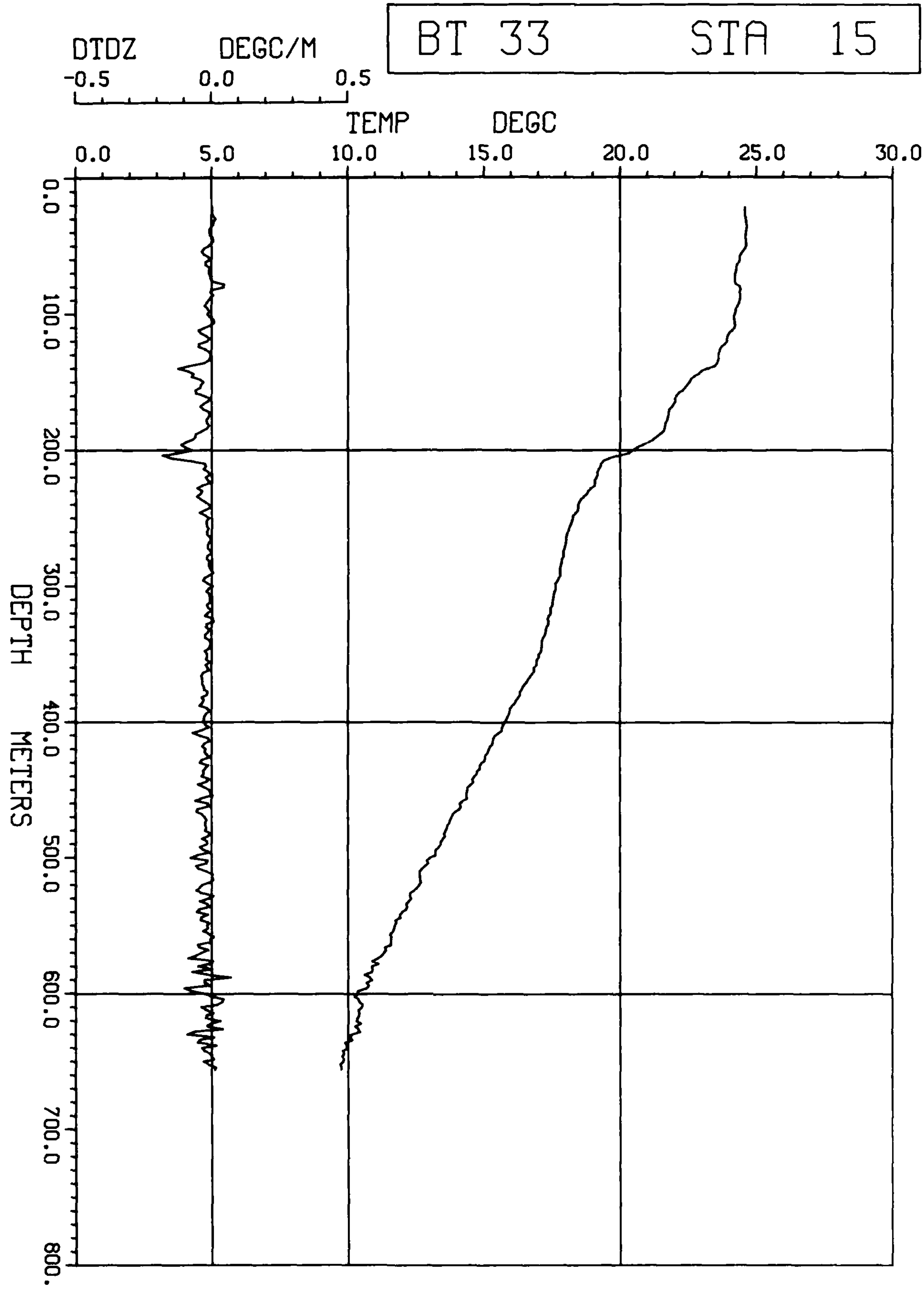
300.0
400.0
500.0
600.0
700.0
800.0
DEPTH METERS



BT 33 STA 15
DTDZ DEGC/M
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TEMP DEGC
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15.0
20.0
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DEPTH METERS
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200.0
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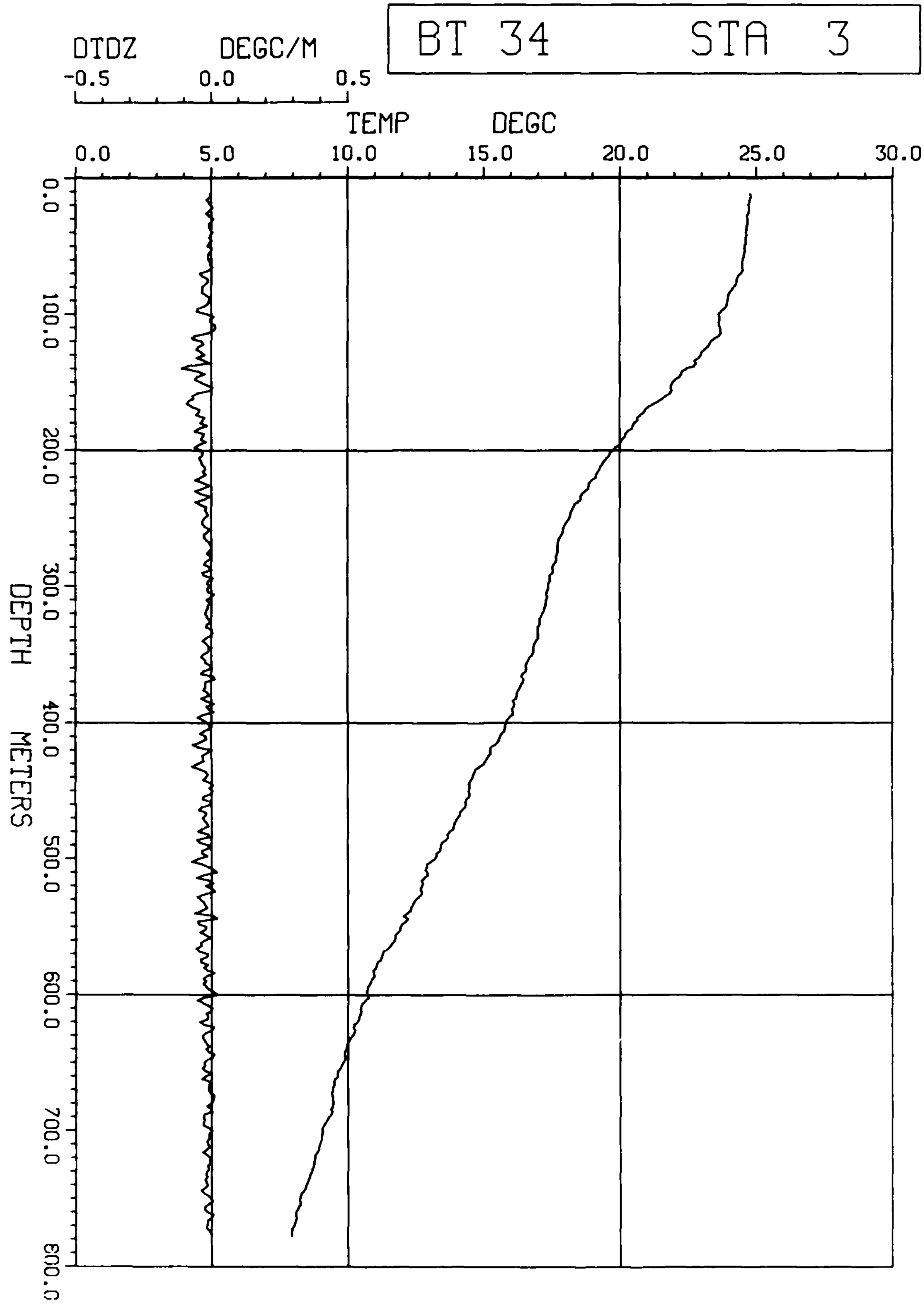
800.0


BT 34 STA 3
DTDZ DEGC/M
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TEMP DEGC
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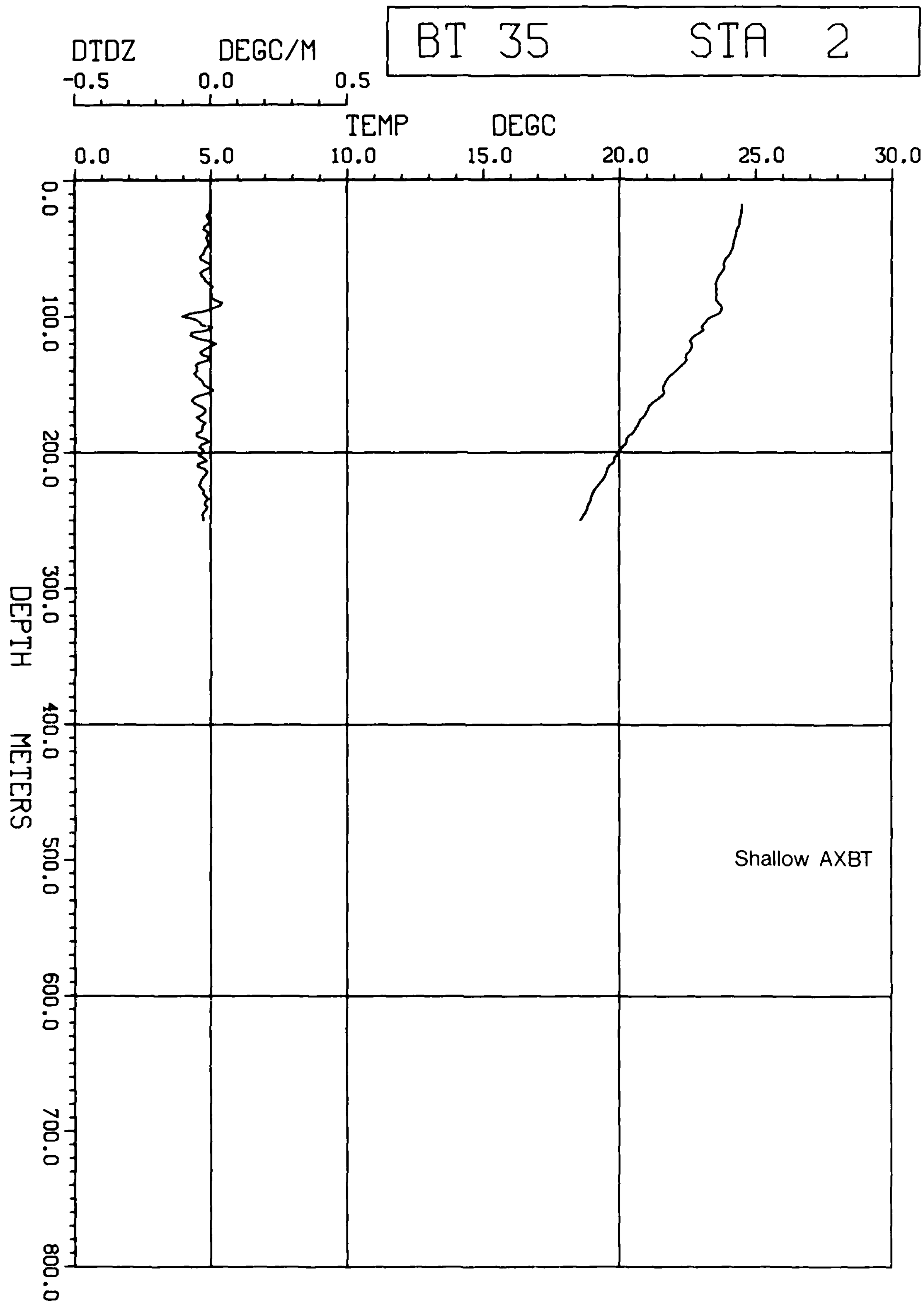
DEPTH METERS
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0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DTDZ DEGC/M
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TEMP DEGC
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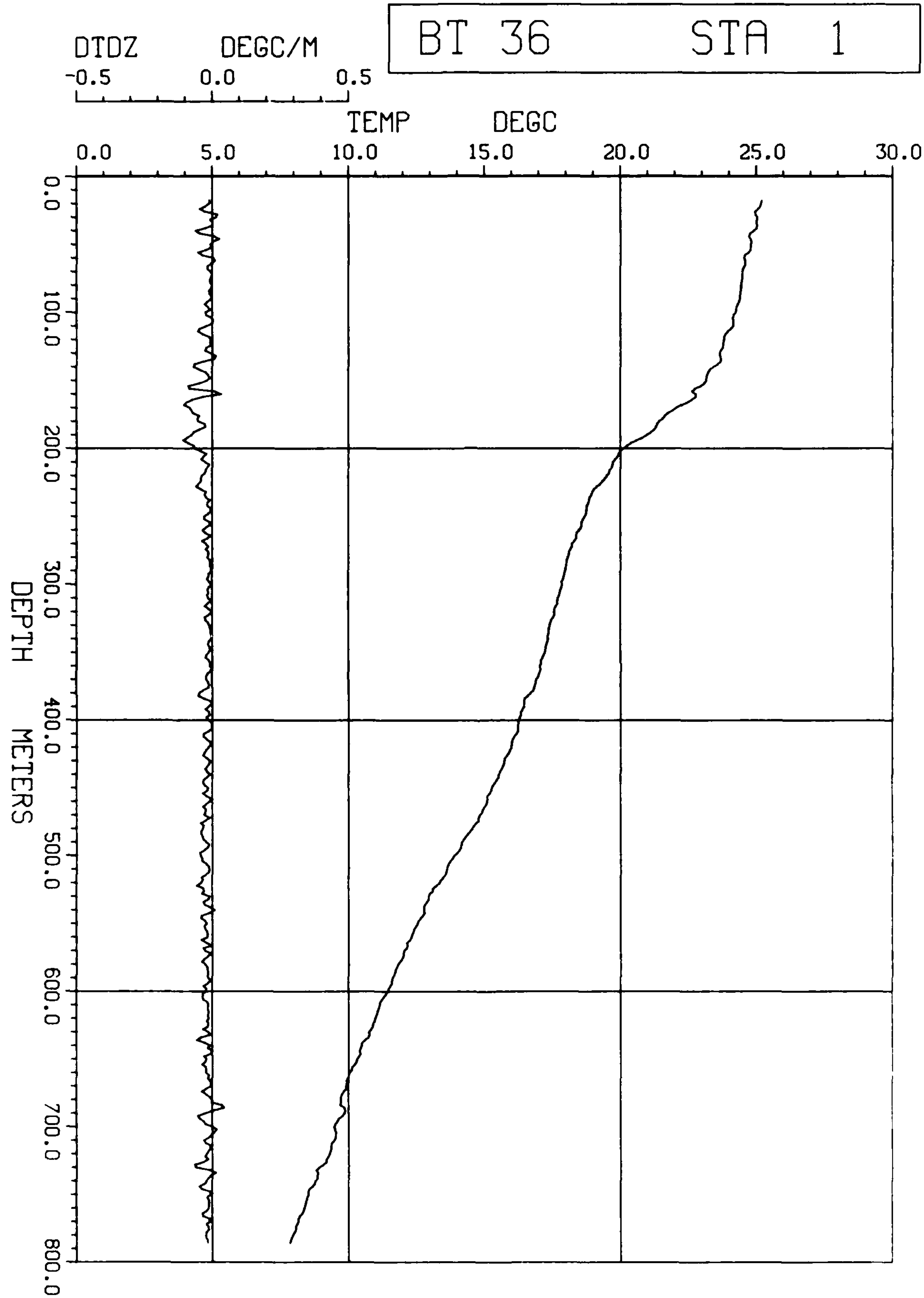
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0
DEPTH METERS
Shallow AXBT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DTDZ DEGC/M
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TEMP DEGC
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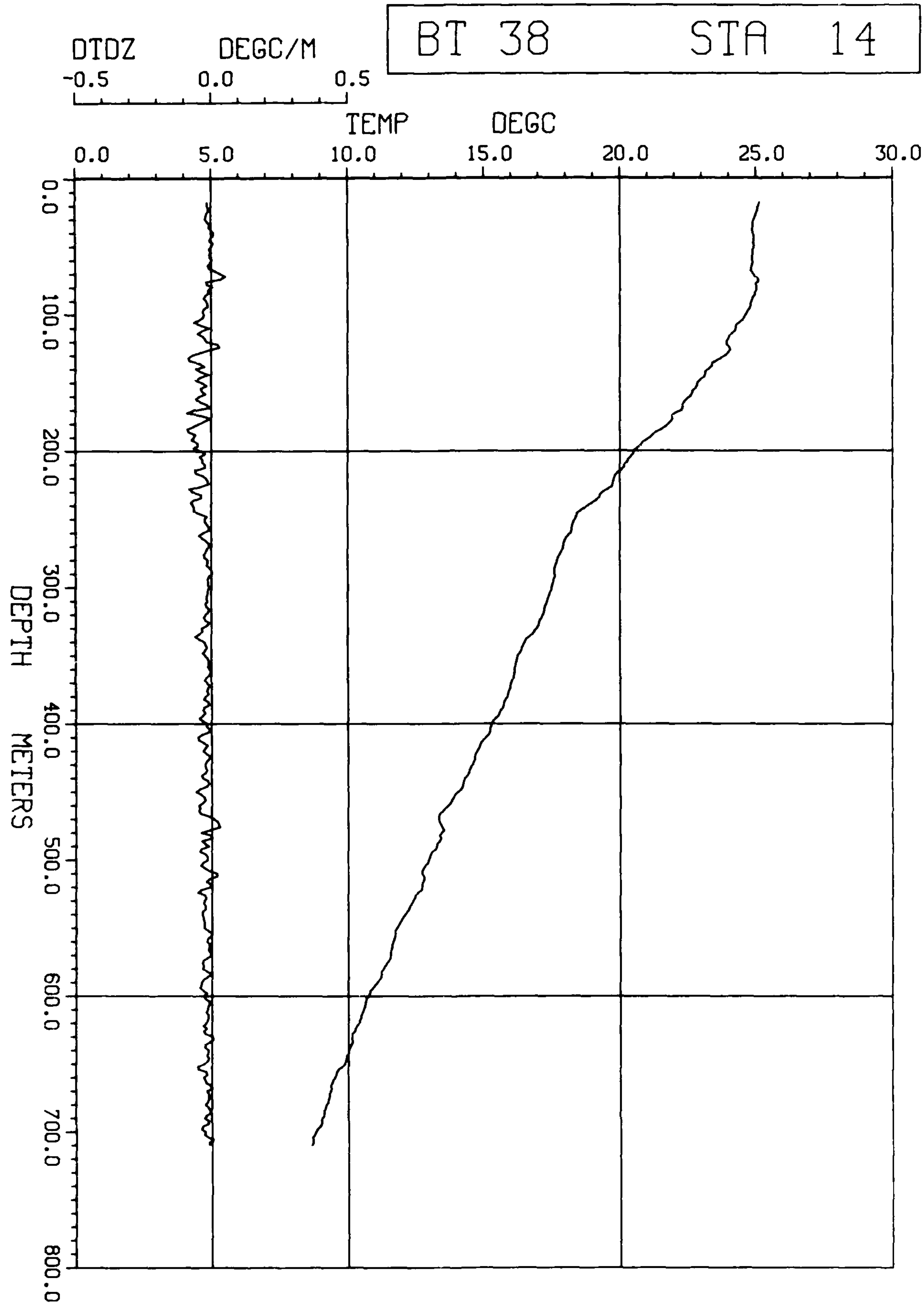
200.0
300.0
400.0
500.0
600.0
700.0
800.0
DEPTH METERS



BT 38 STA 14
DTDZ DEGC/M
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TEMP DEGC
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DEPTH METERS
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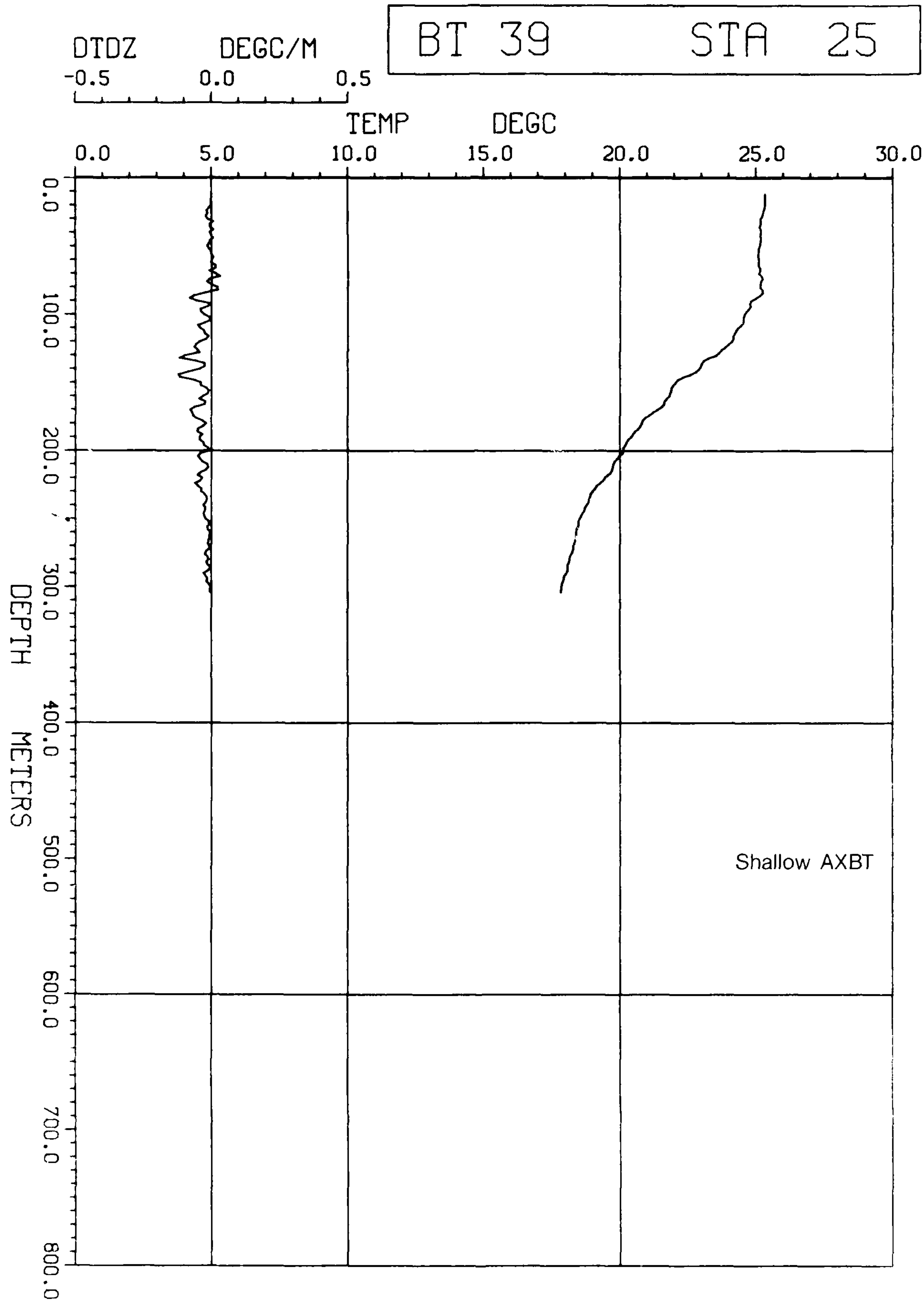

BT 39 STA 25
DTDZ DEGC/M
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TEMP DEGC
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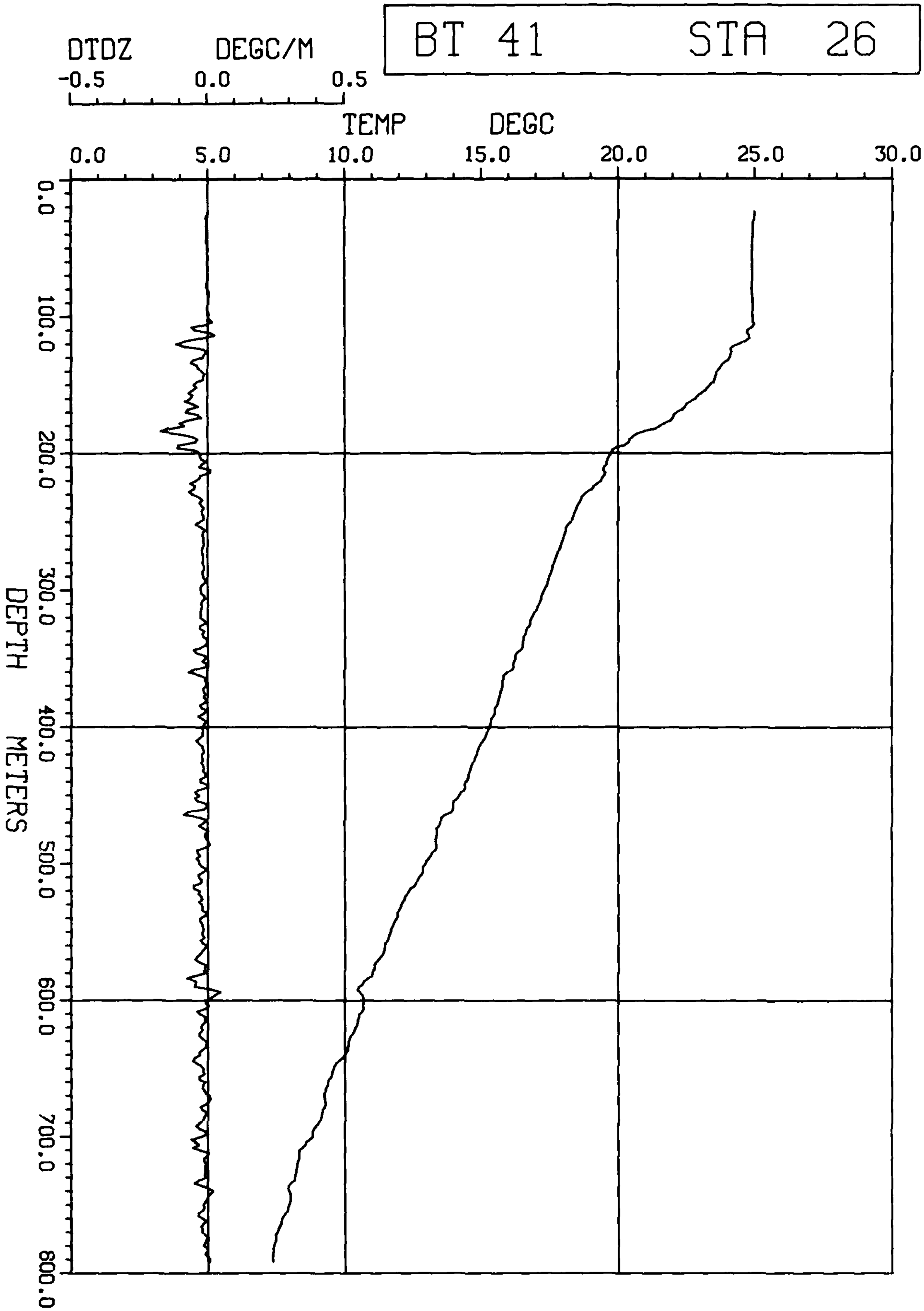
DEPTH METERS
Shallow AXBT



BT 41 STA 26
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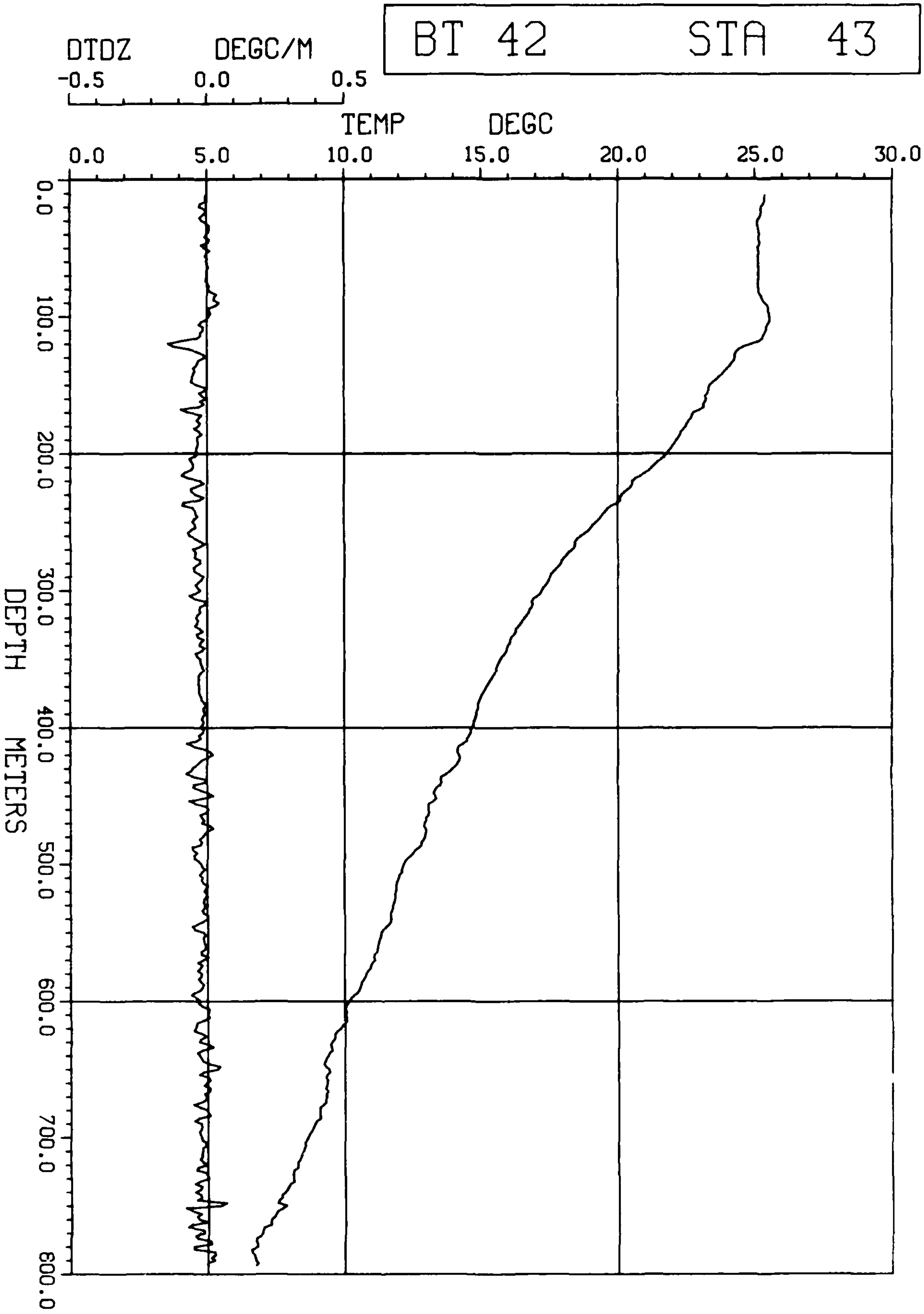
BT 42 STA 43
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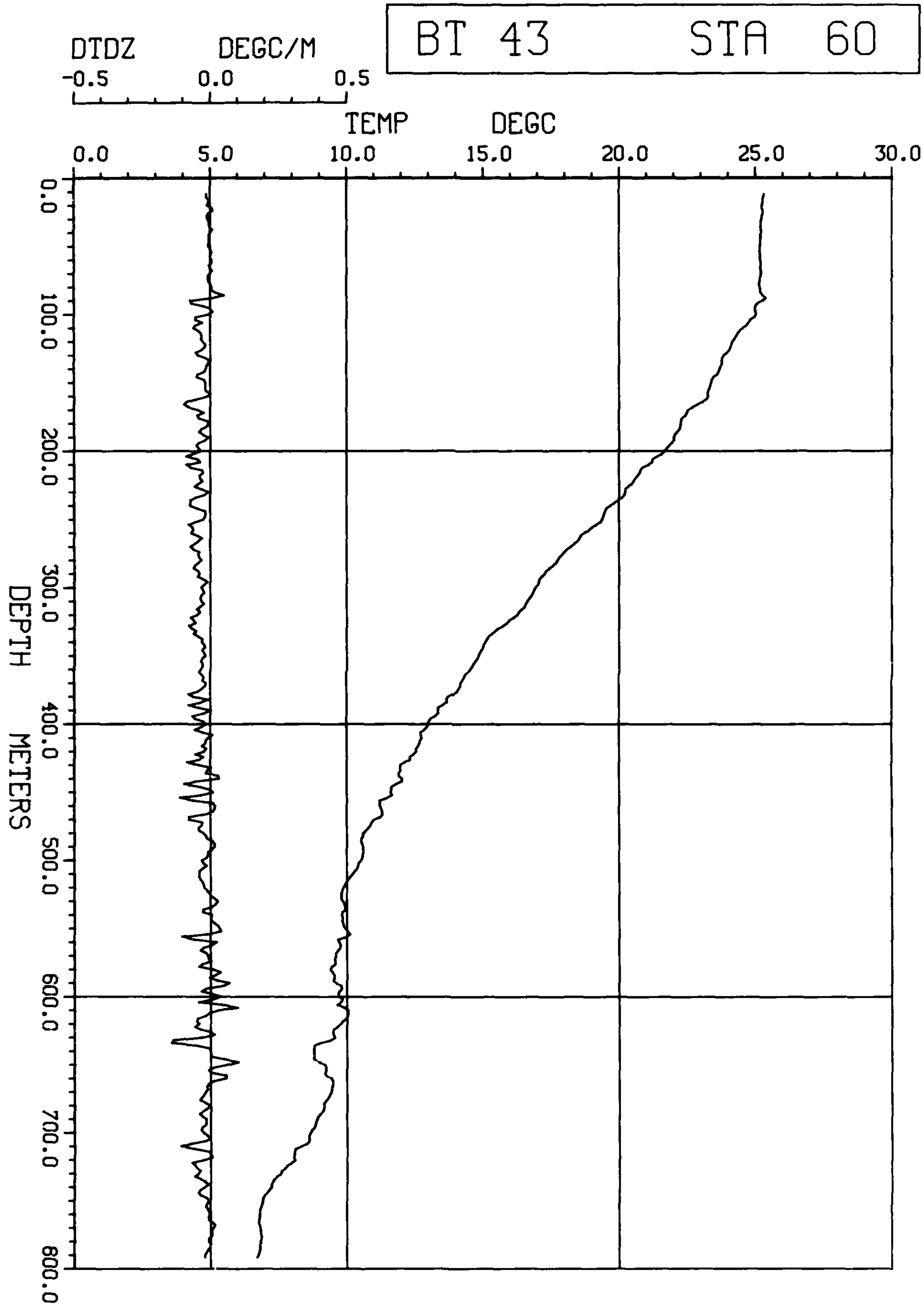
800.0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TEMP DEGC
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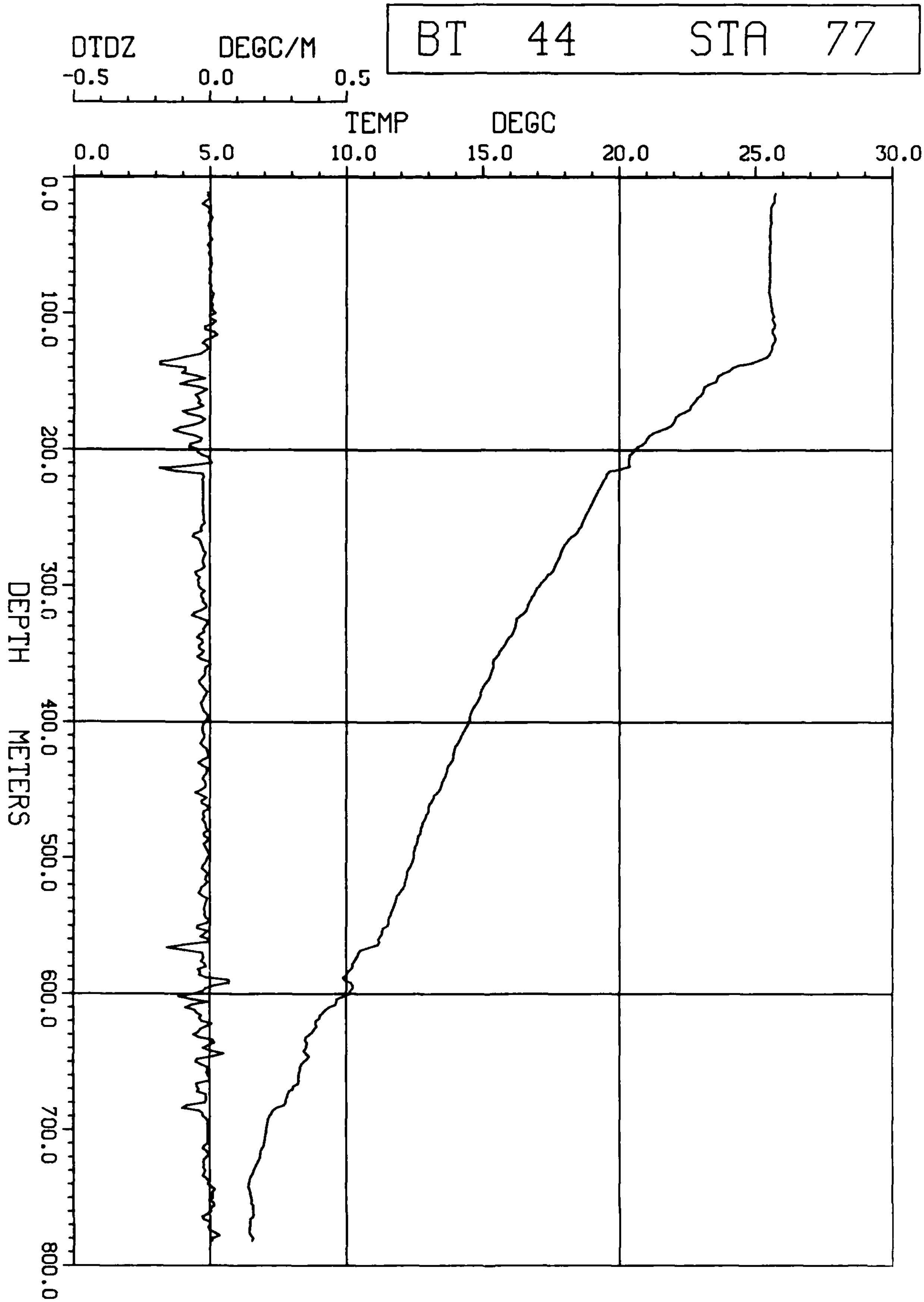

BT 44 STA 77
DTDZ DEGC/M
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TEMP DEGC
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DEPTH METERS
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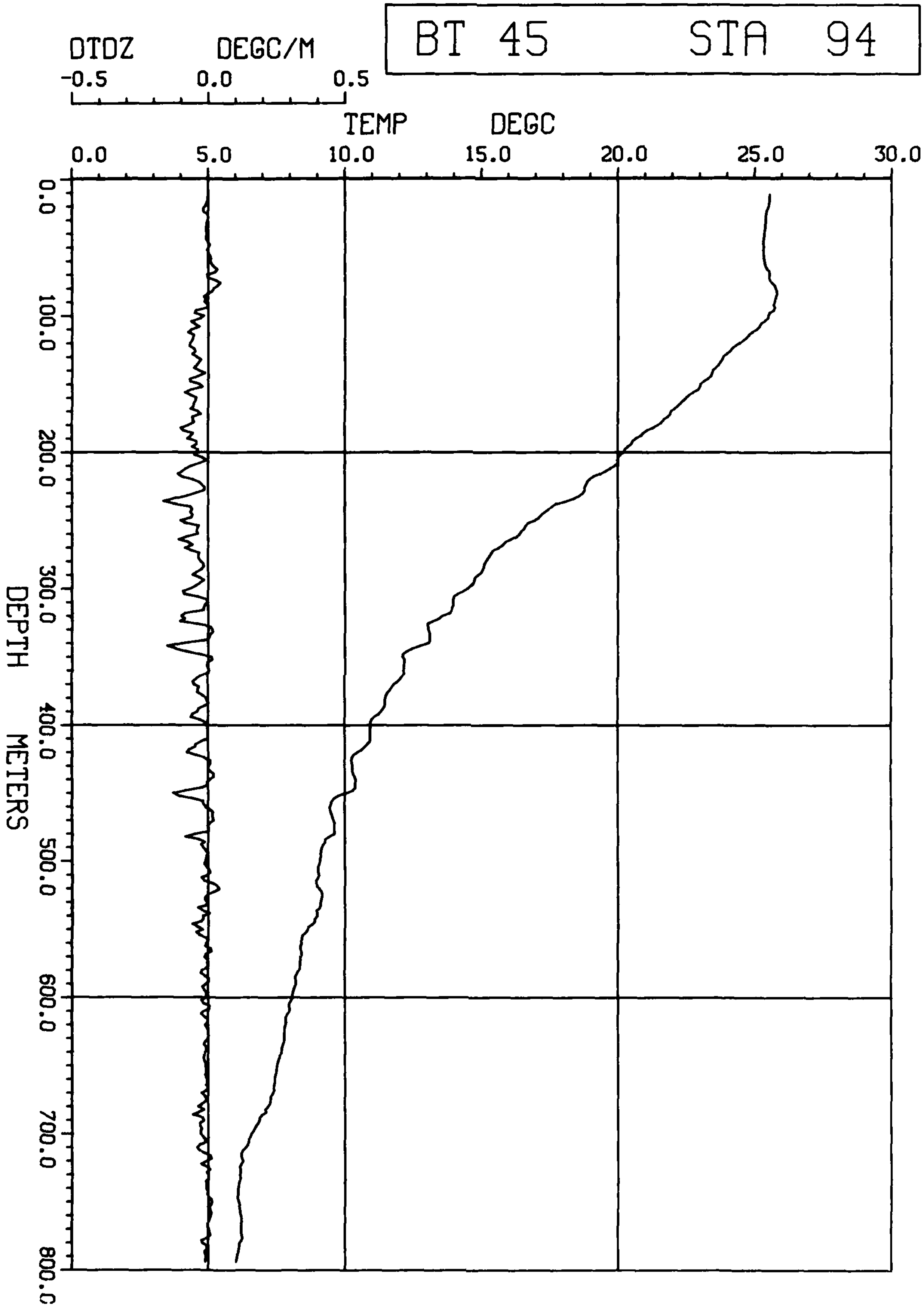
BT 45 STA 94
DTDZ DEGC/M
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TEMP DEGC
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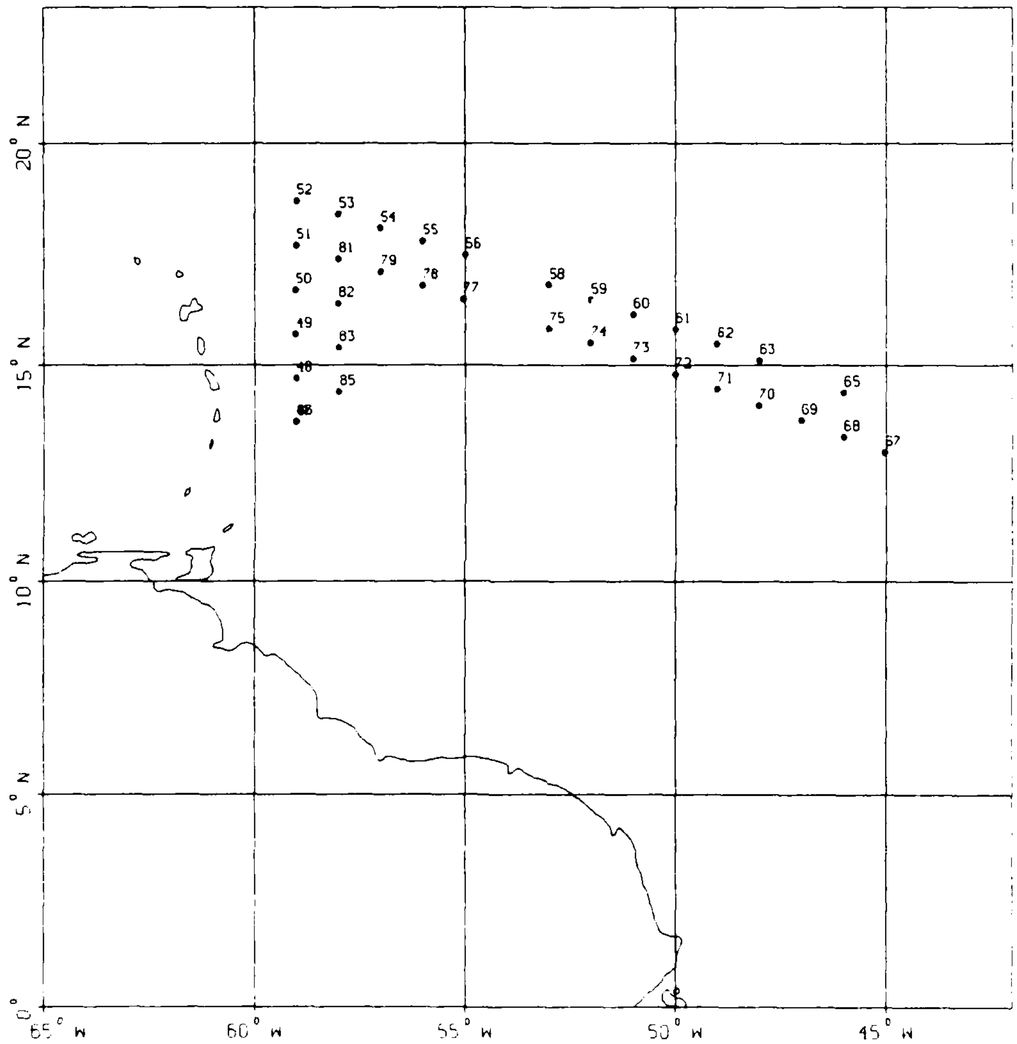
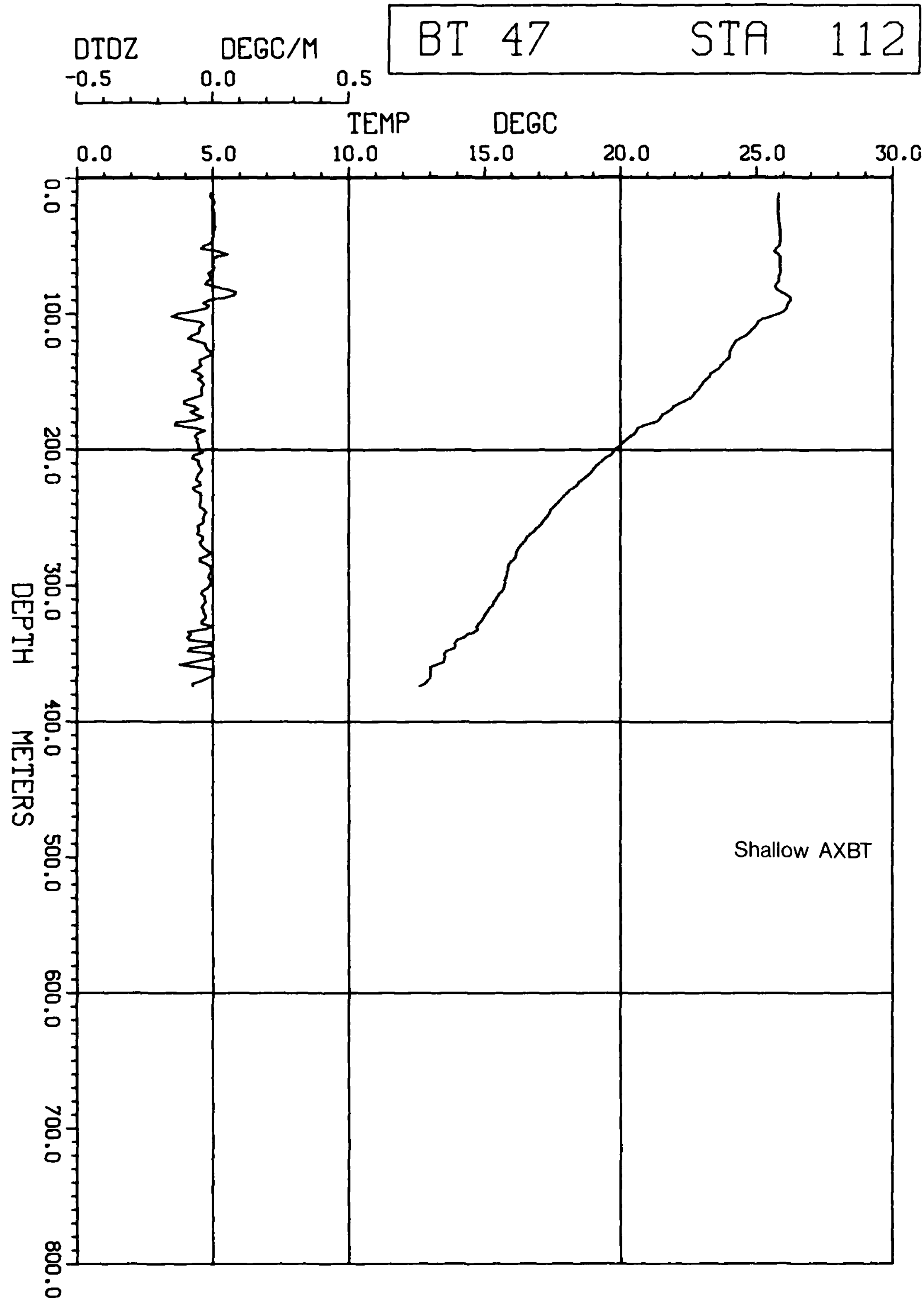
DEPTH METERS
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0

Station Positions Flight 2
25 March 1985





BT 47 STA 112
DTDZ DEGC/M
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TEMP DEGC
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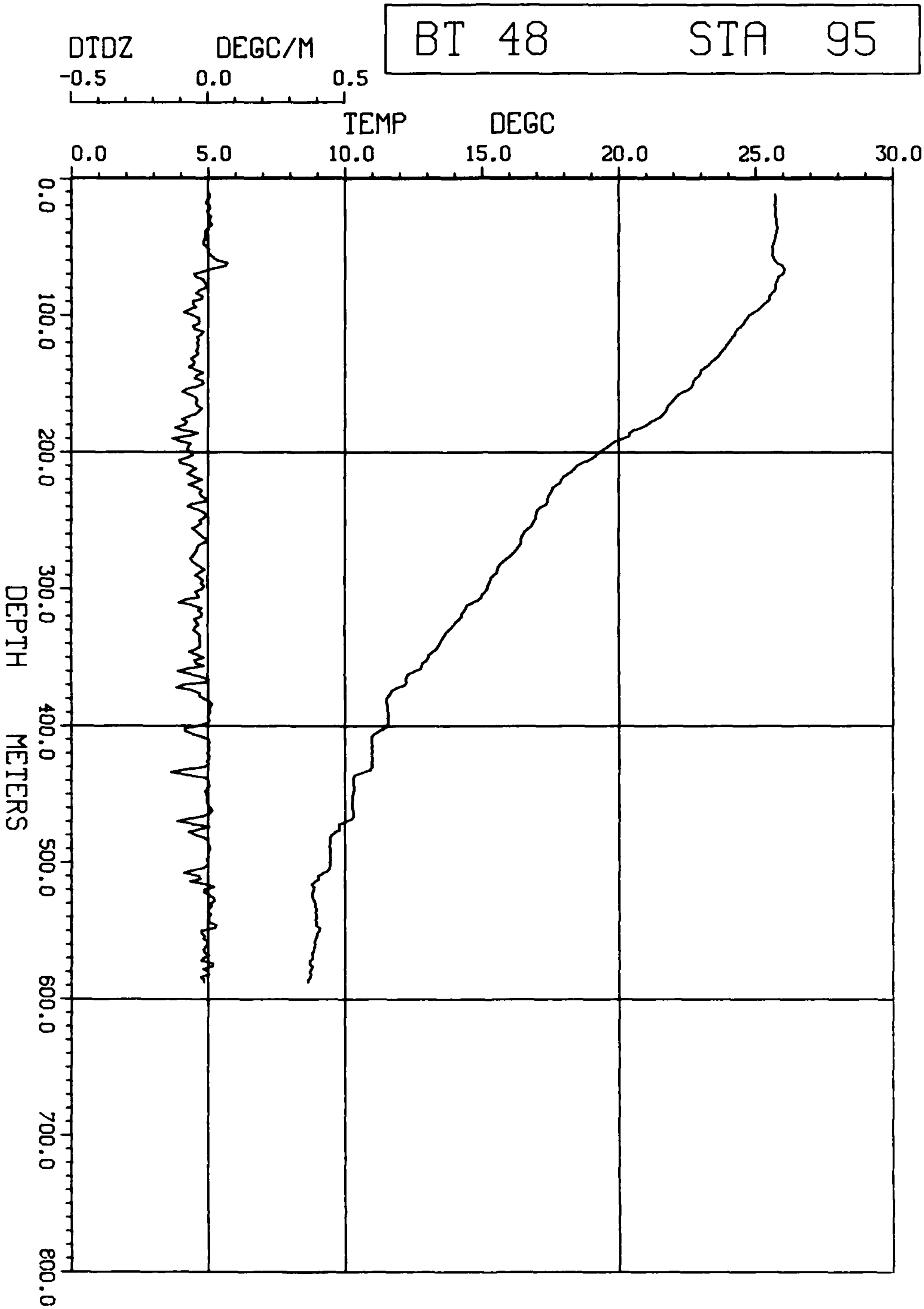
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0
DEPTH METERS
Shallow AXBT


BT 48 STA 95
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TEMP DEGC
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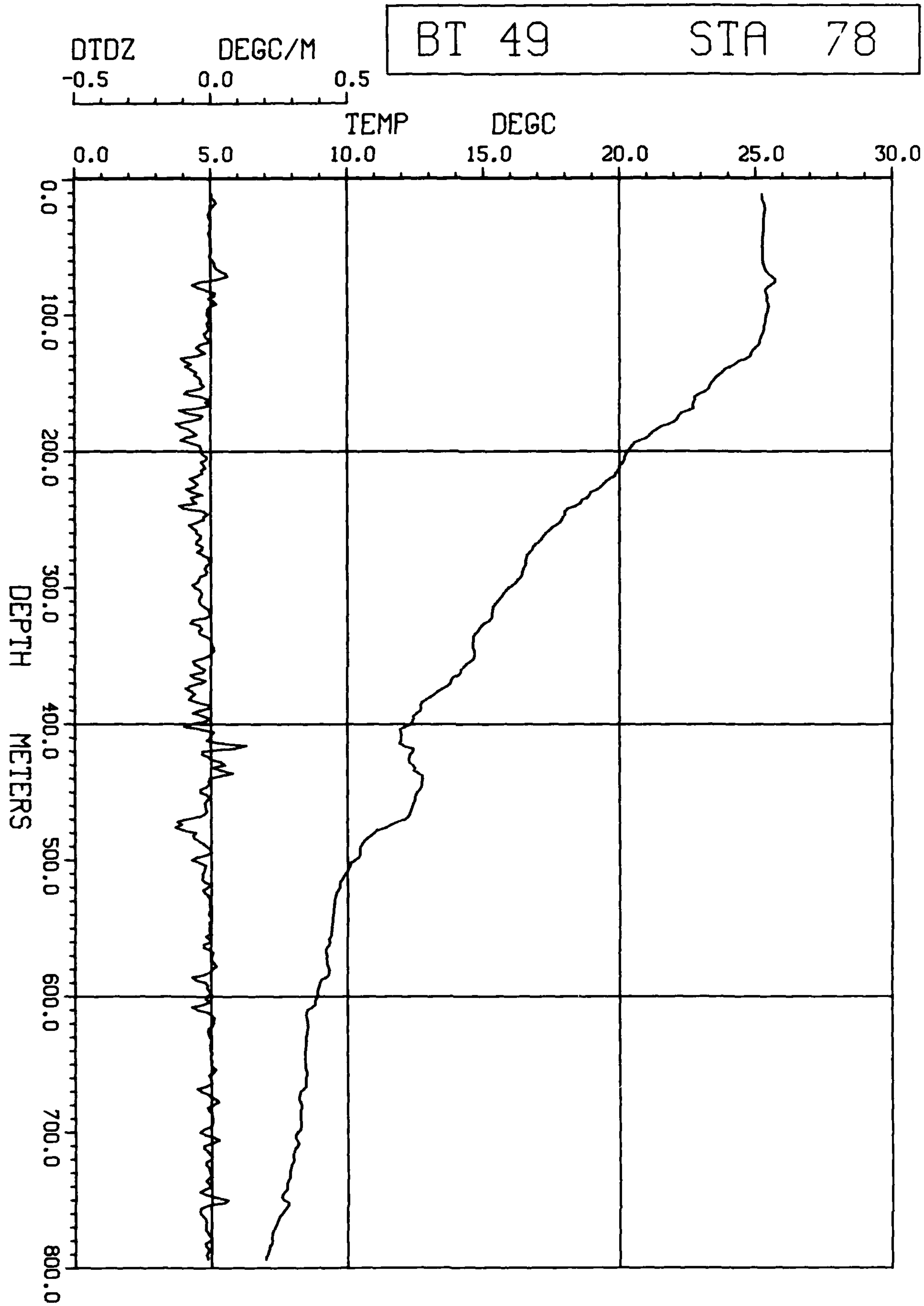
DEPTH METERS


BT 49 STA 78
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300.0
400.0
500.0
600.0
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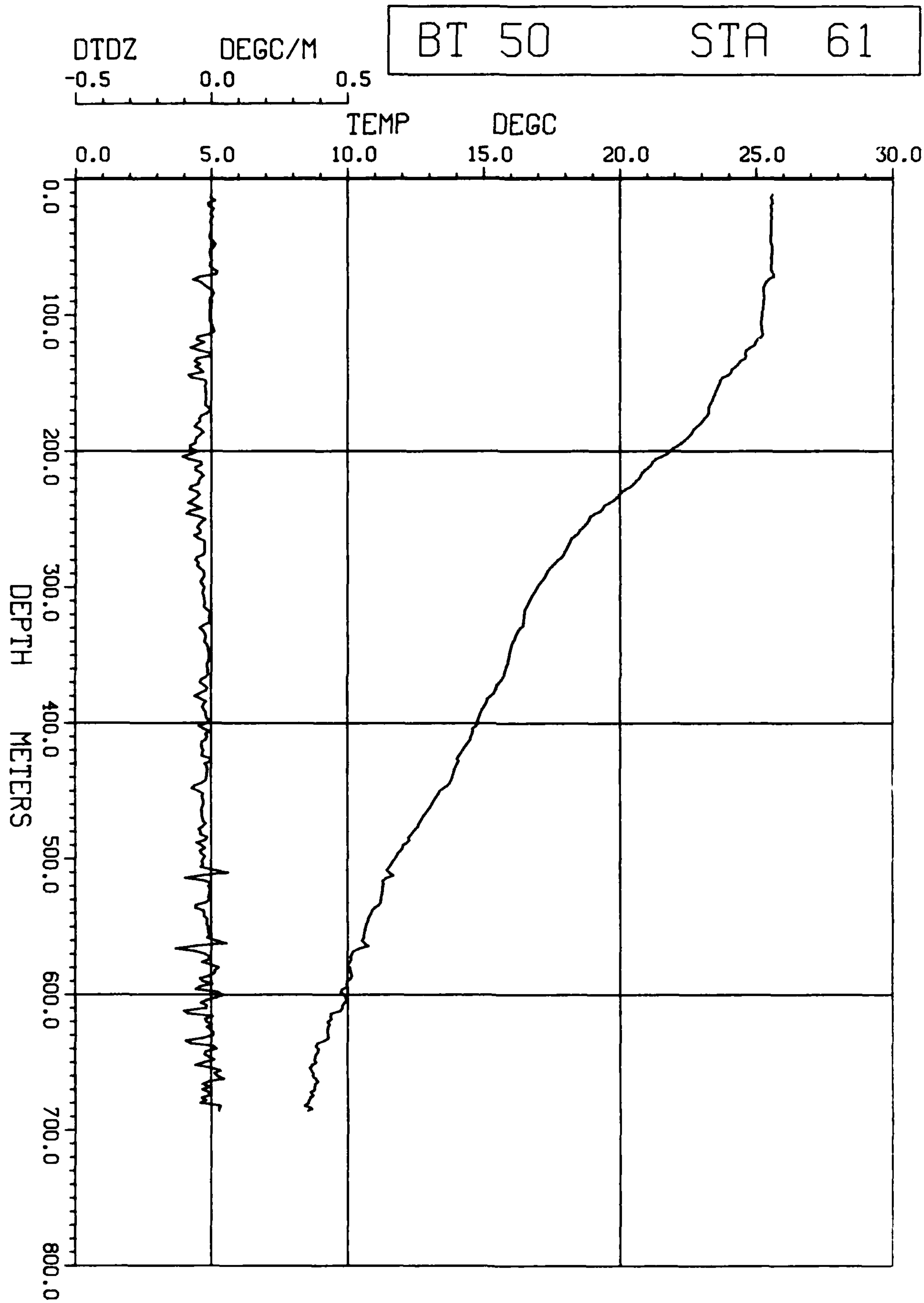
800.0
DEPTH METERS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DTDZ DEGC/M
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TEMP DEGC
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DEPTH METERS
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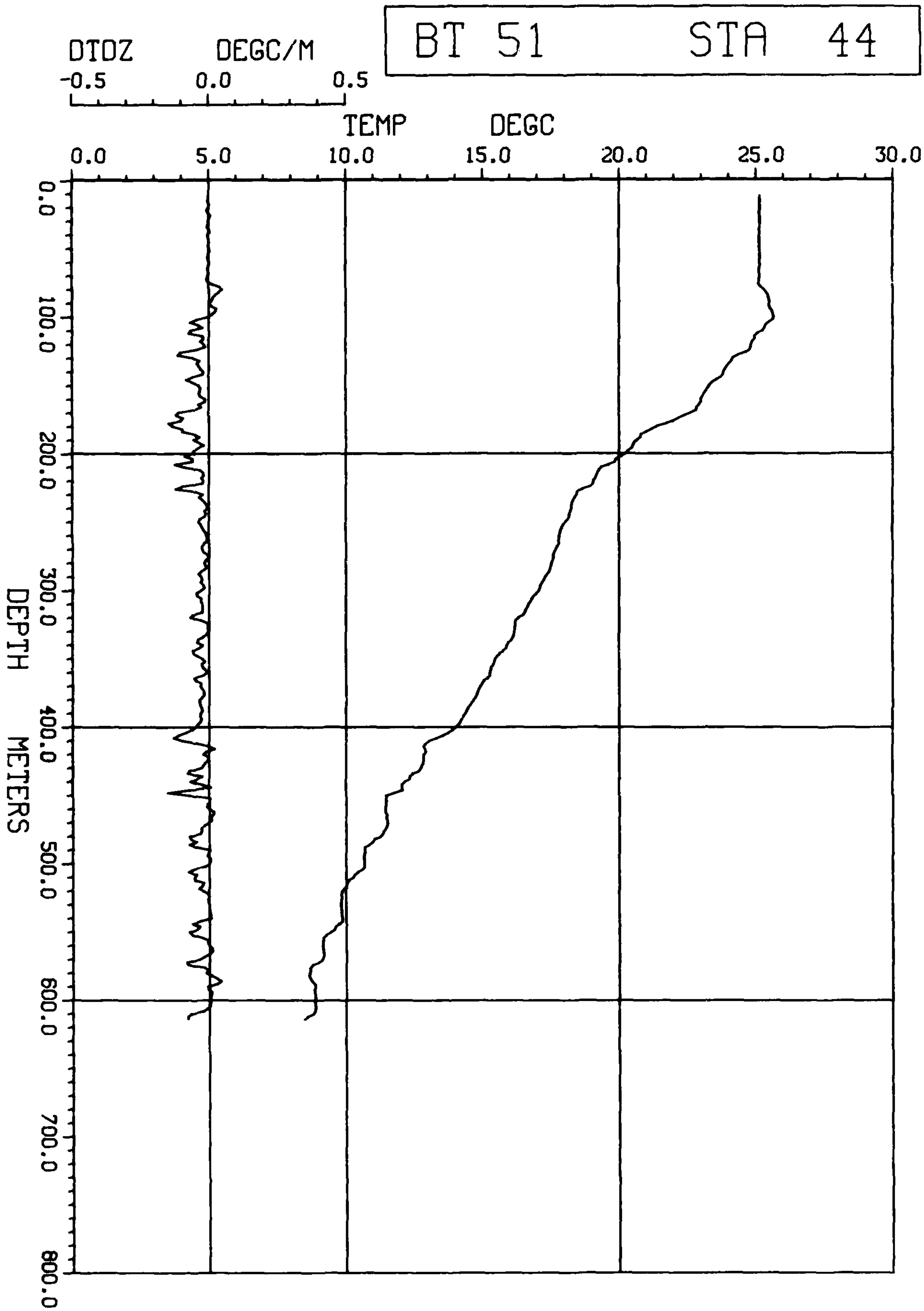
BT 51 STA 44
DTDZ DEGC/M
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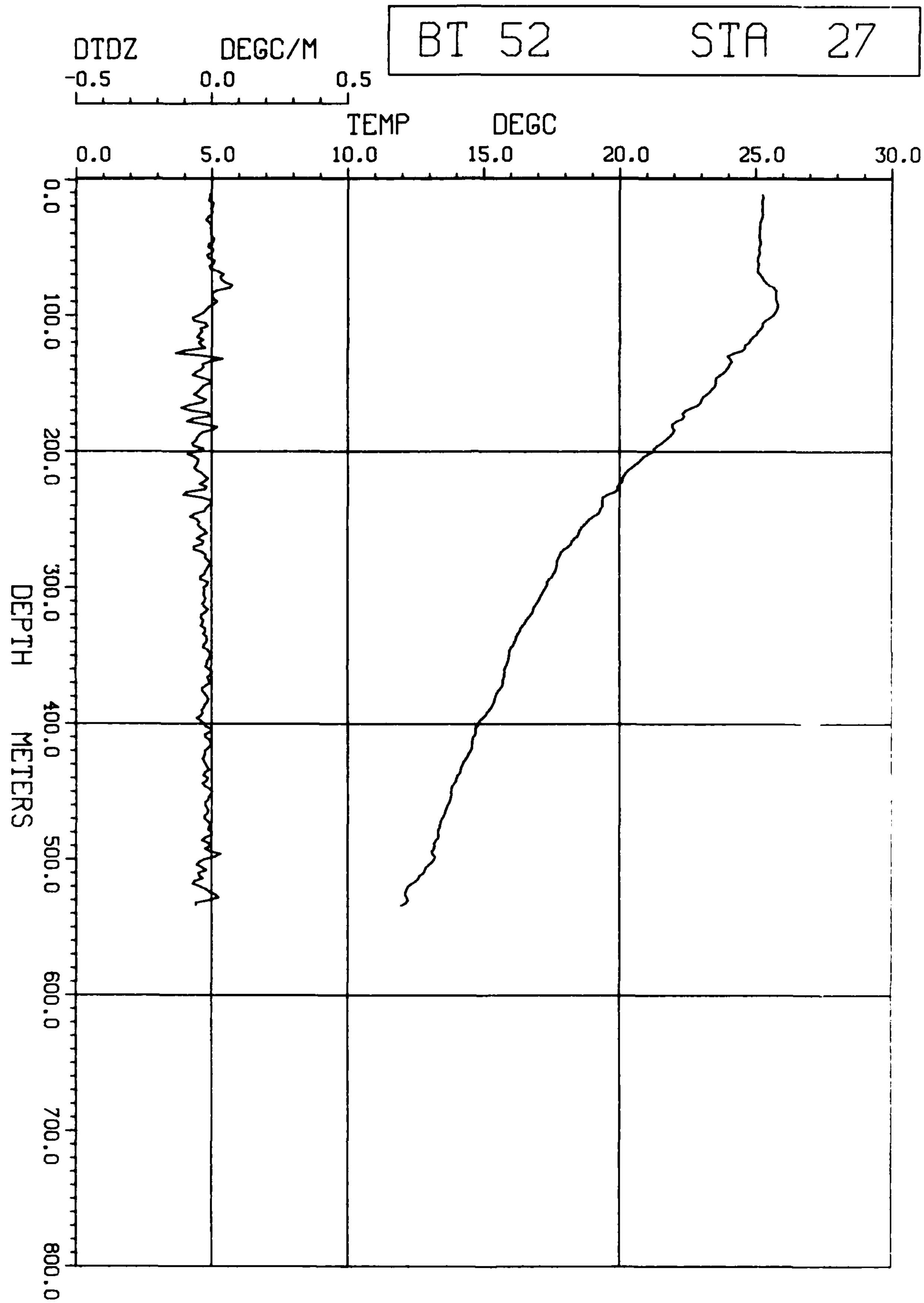
DEPTH METERS


BT 52 STA 27
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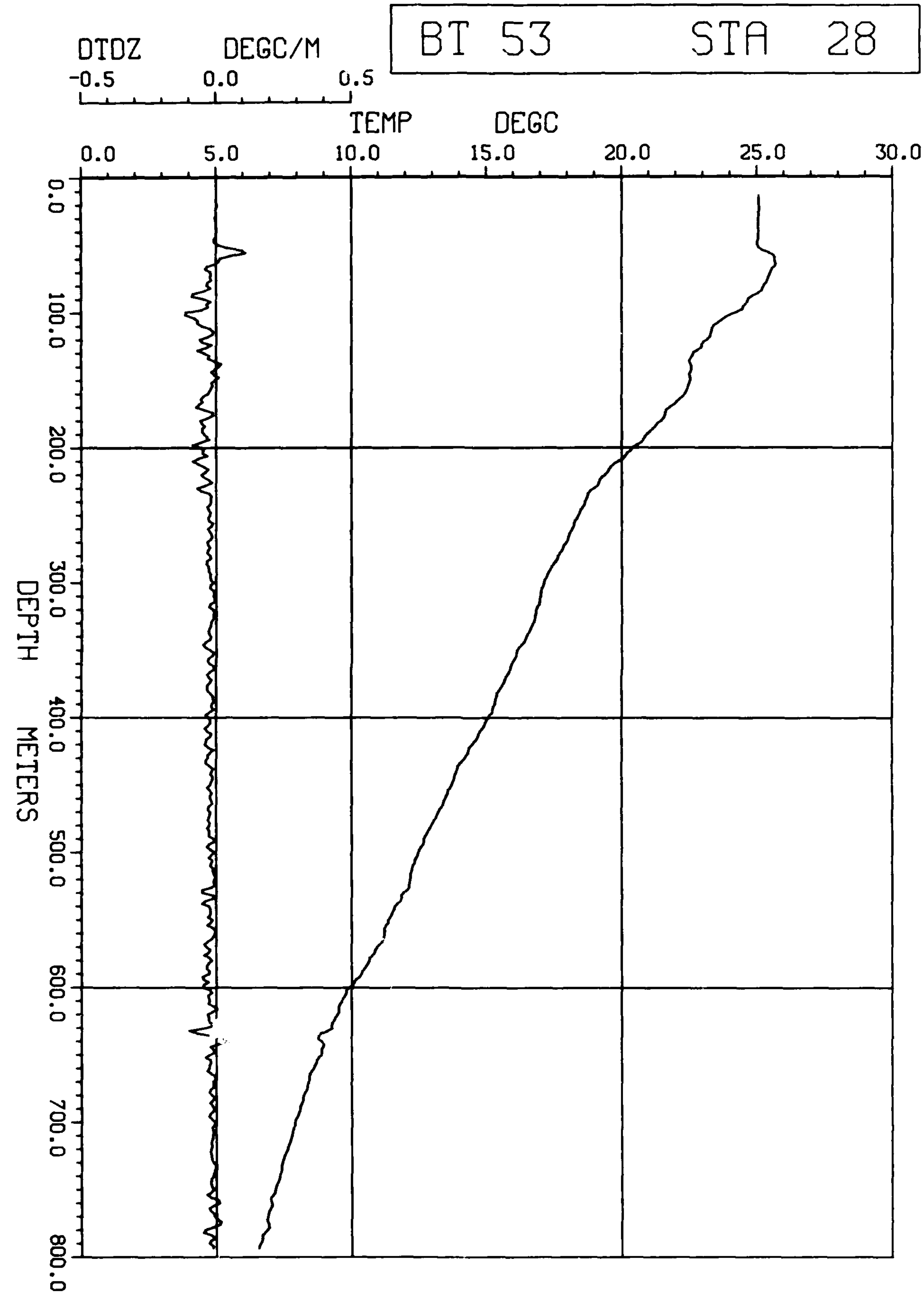
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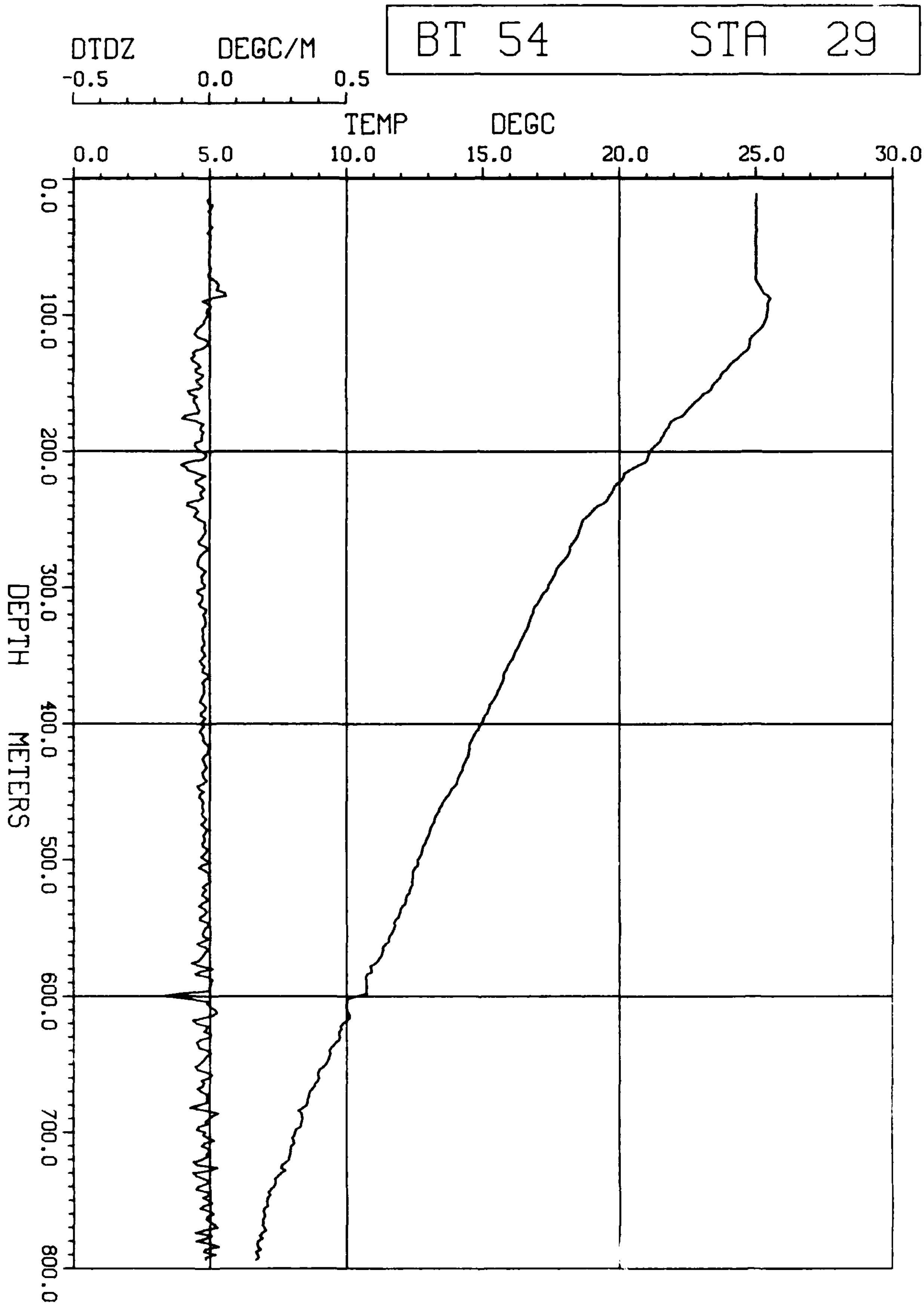
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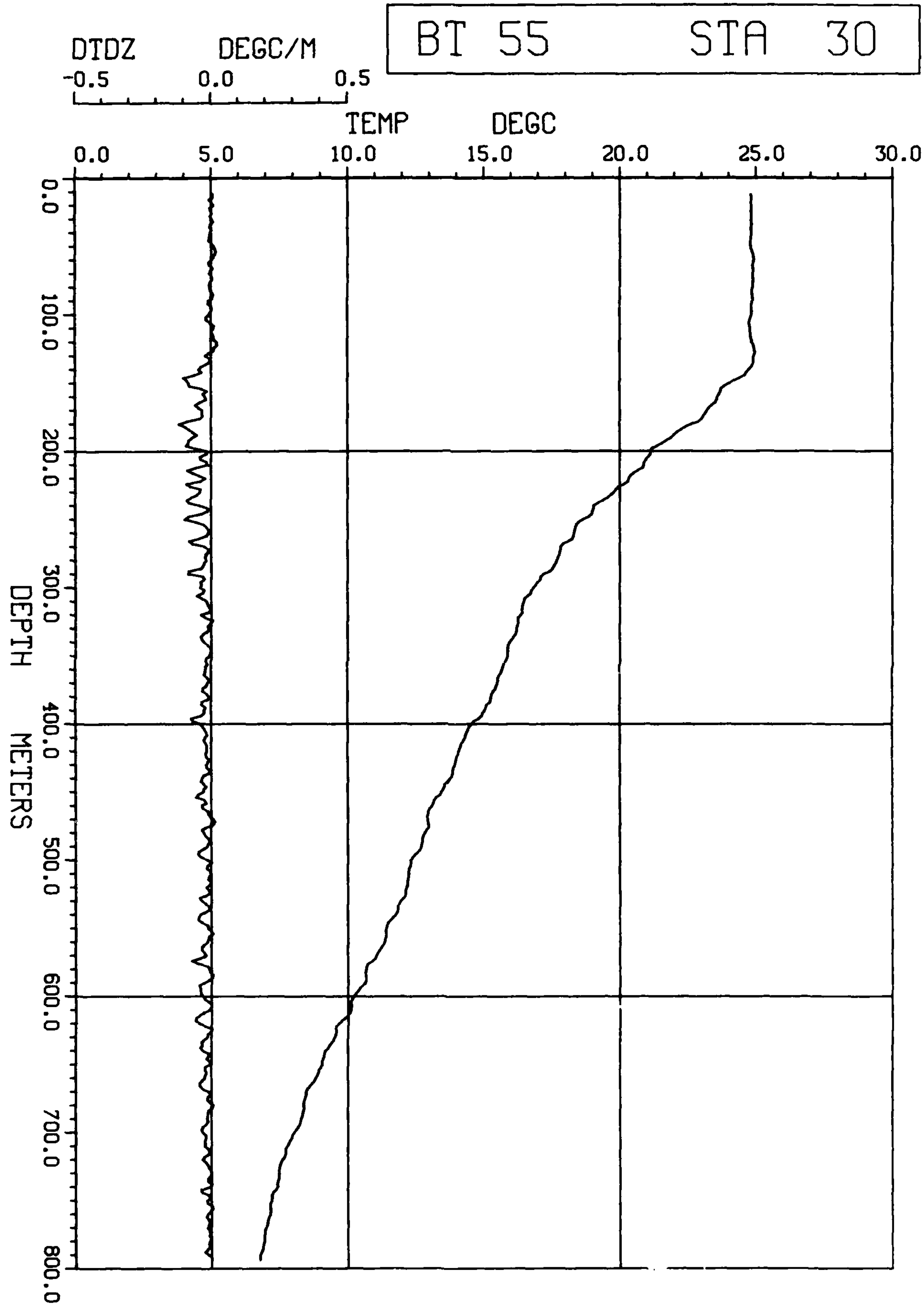
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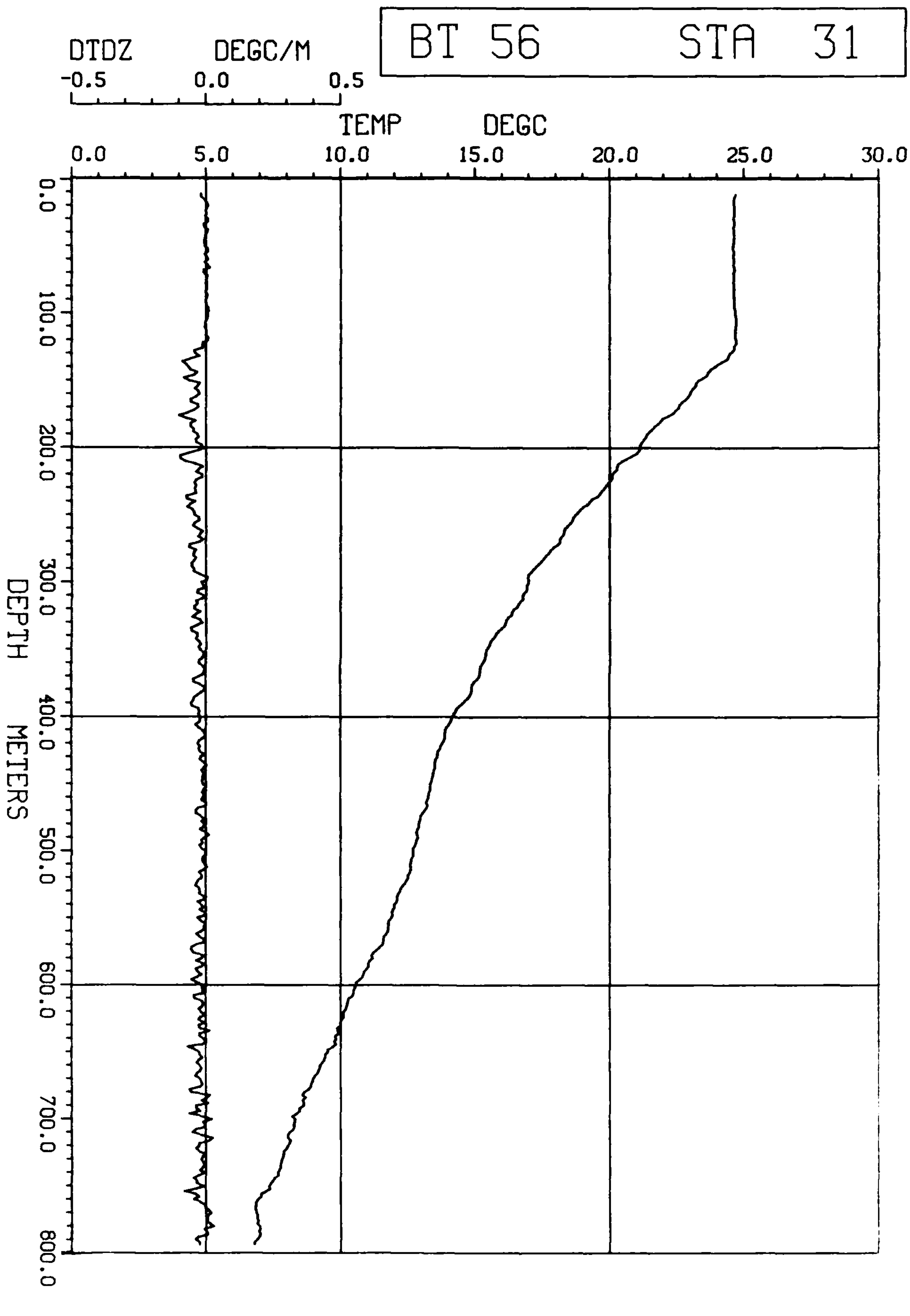
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TEMP DEGC
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DEPTH METERS
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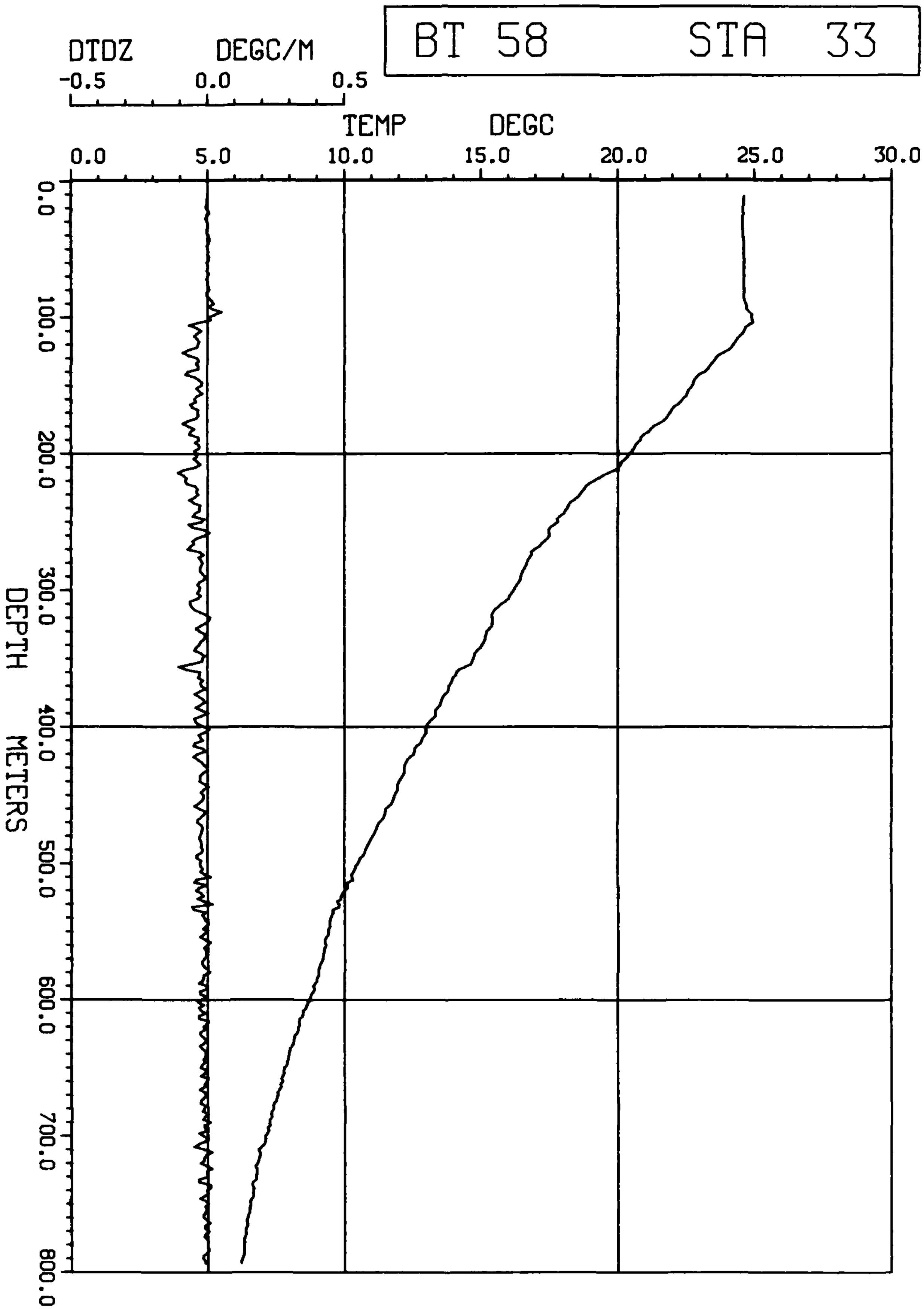
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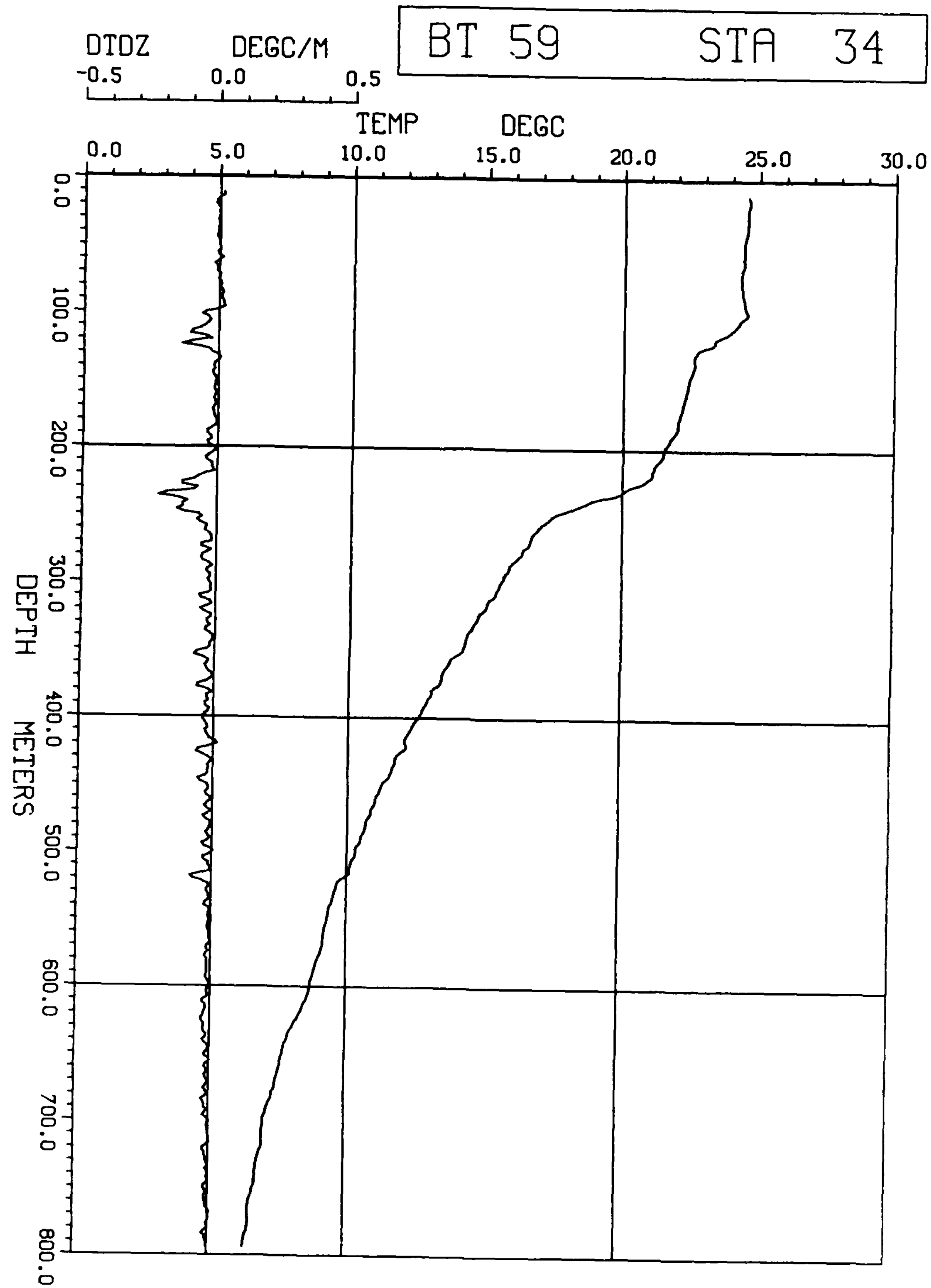
DEPTH METERS


BT 59 STA 34
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TEMP DEGC
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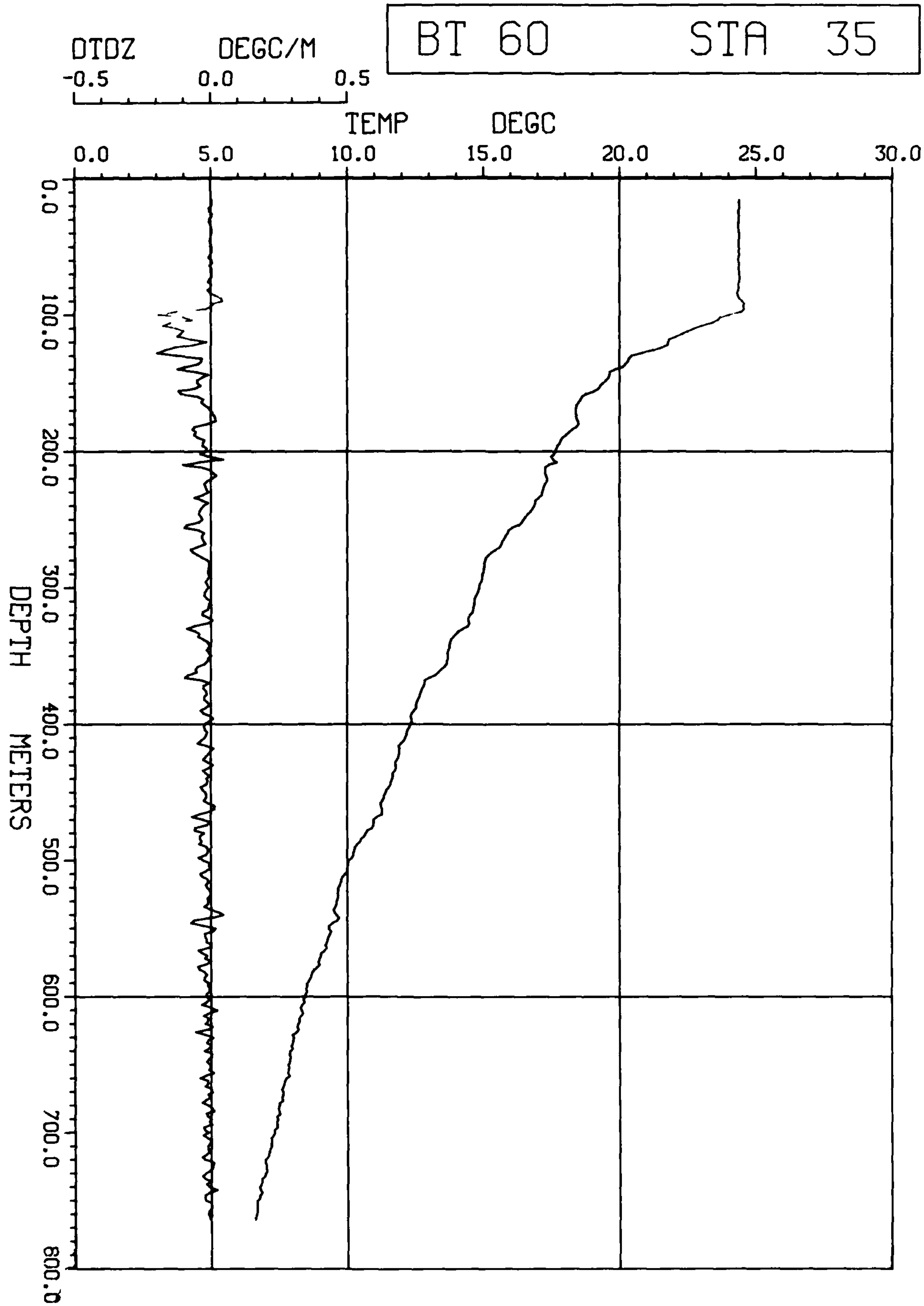
800.0
DEPTH METERS



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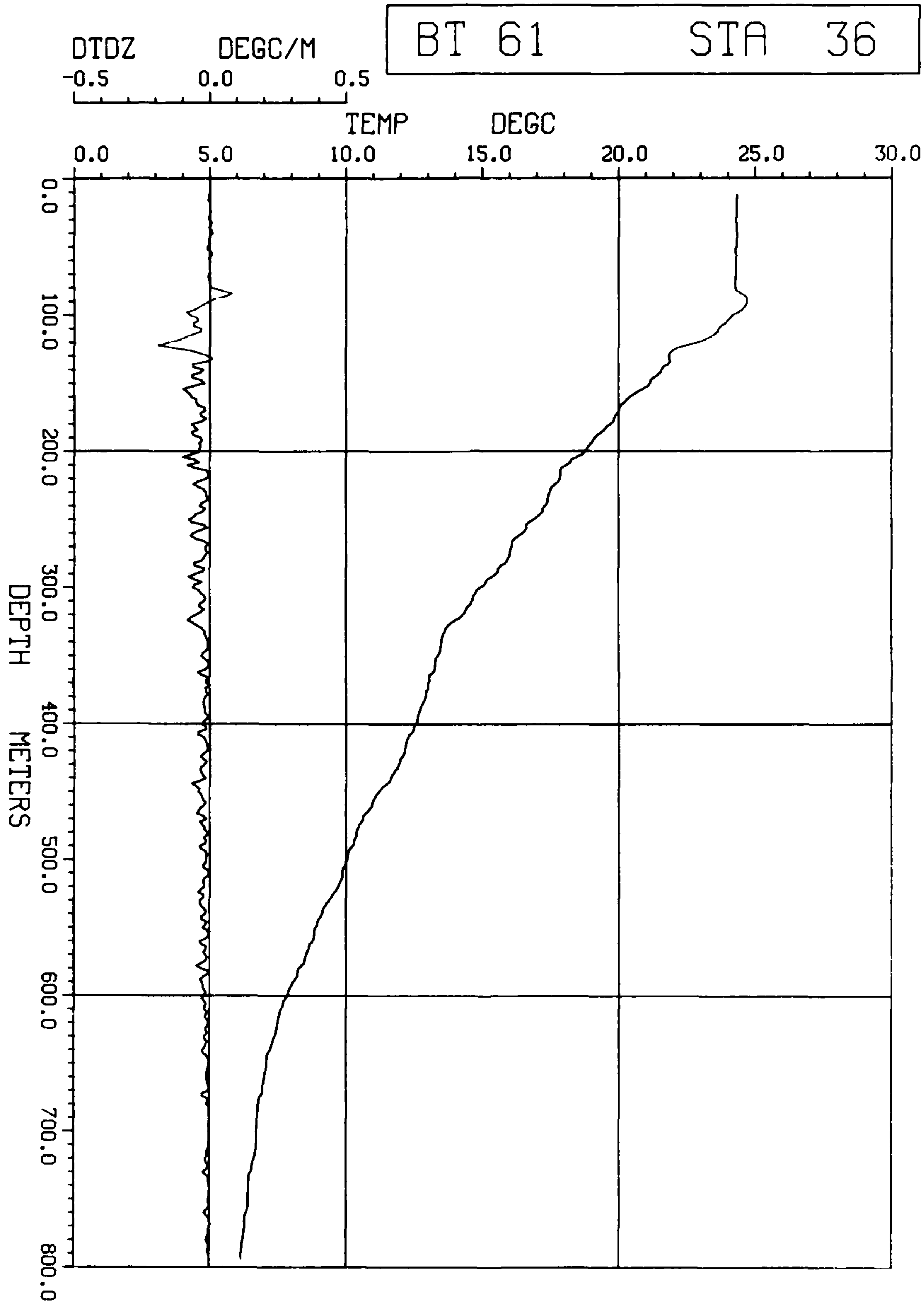
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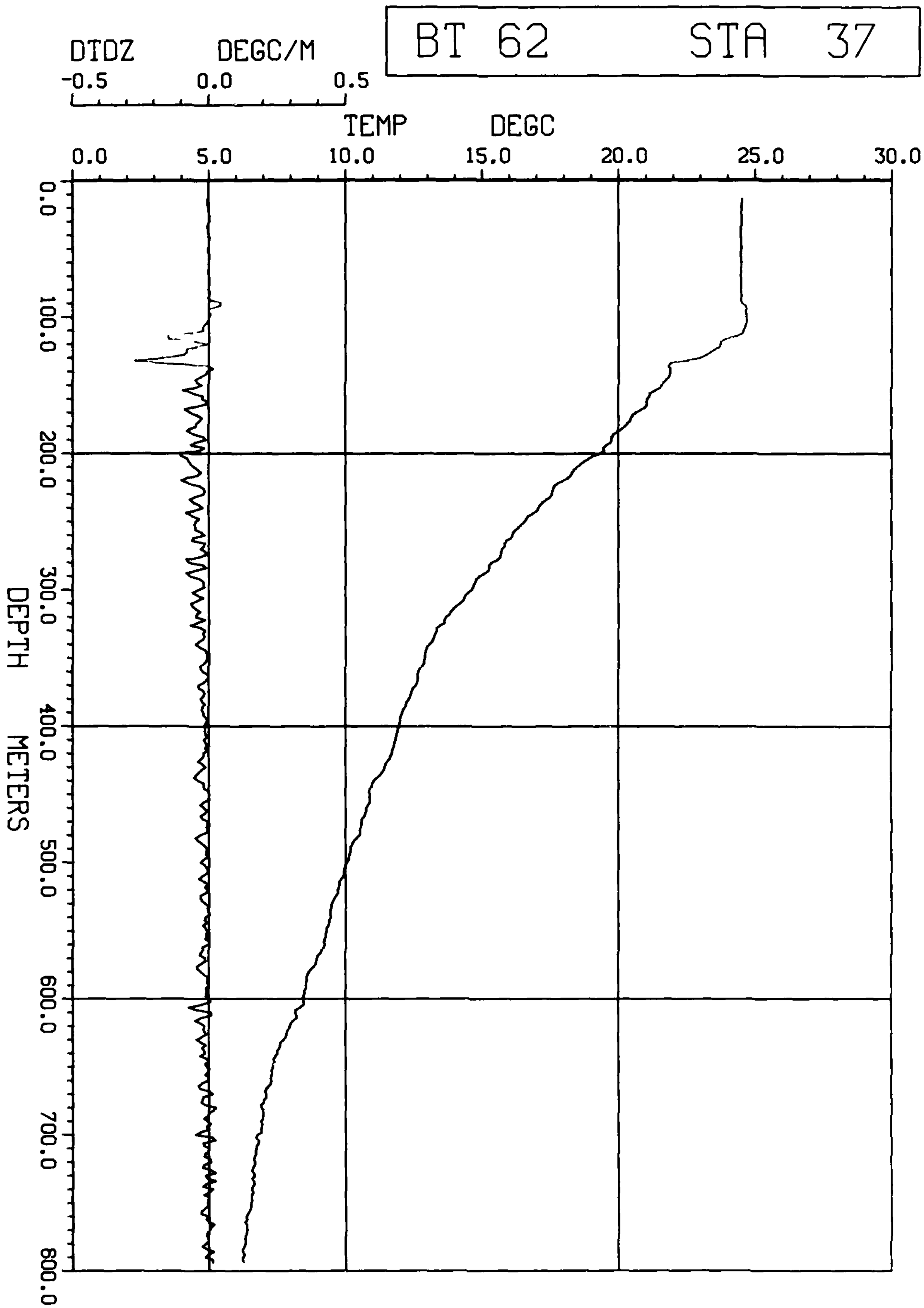

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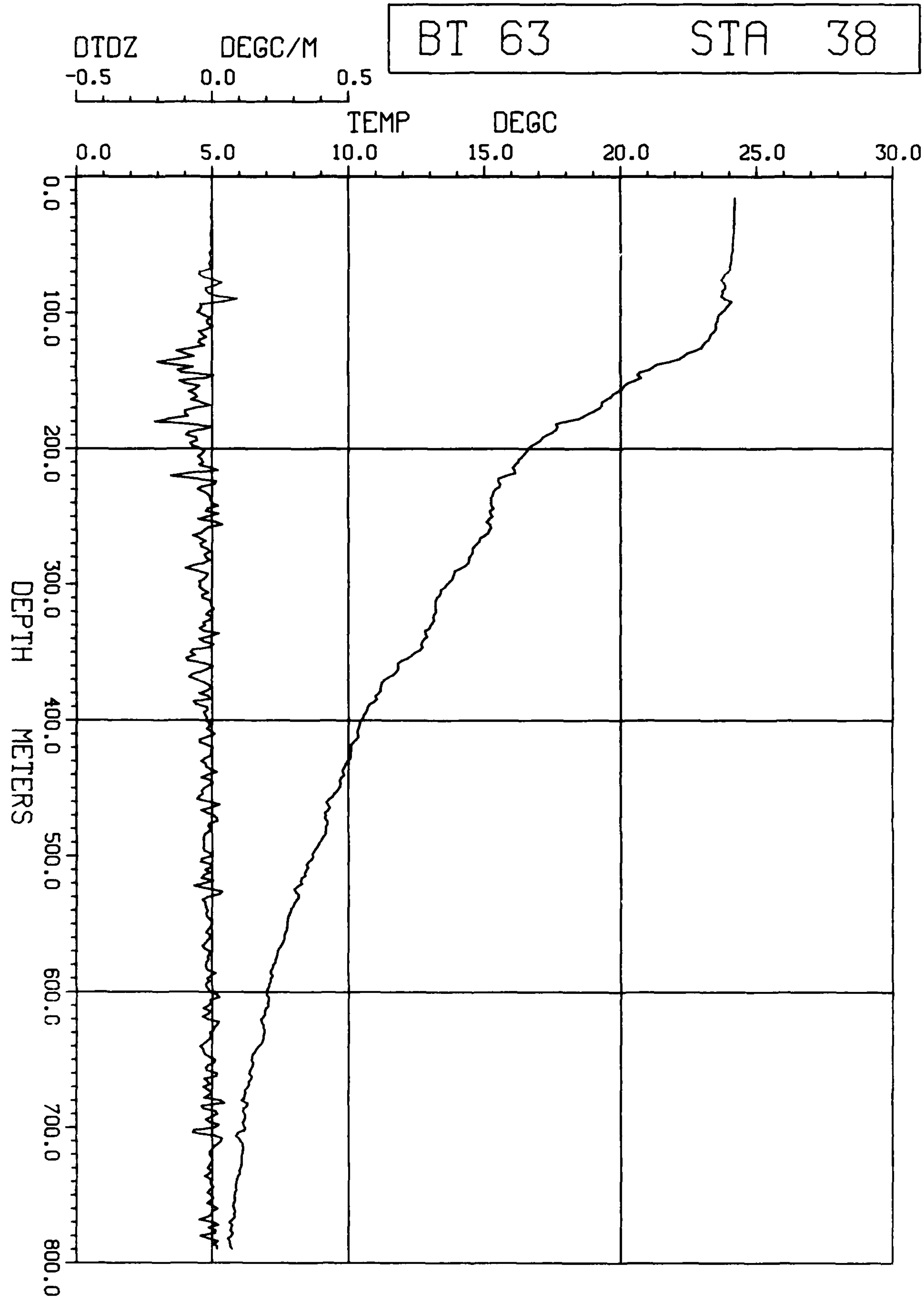
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0
DEPTH METERS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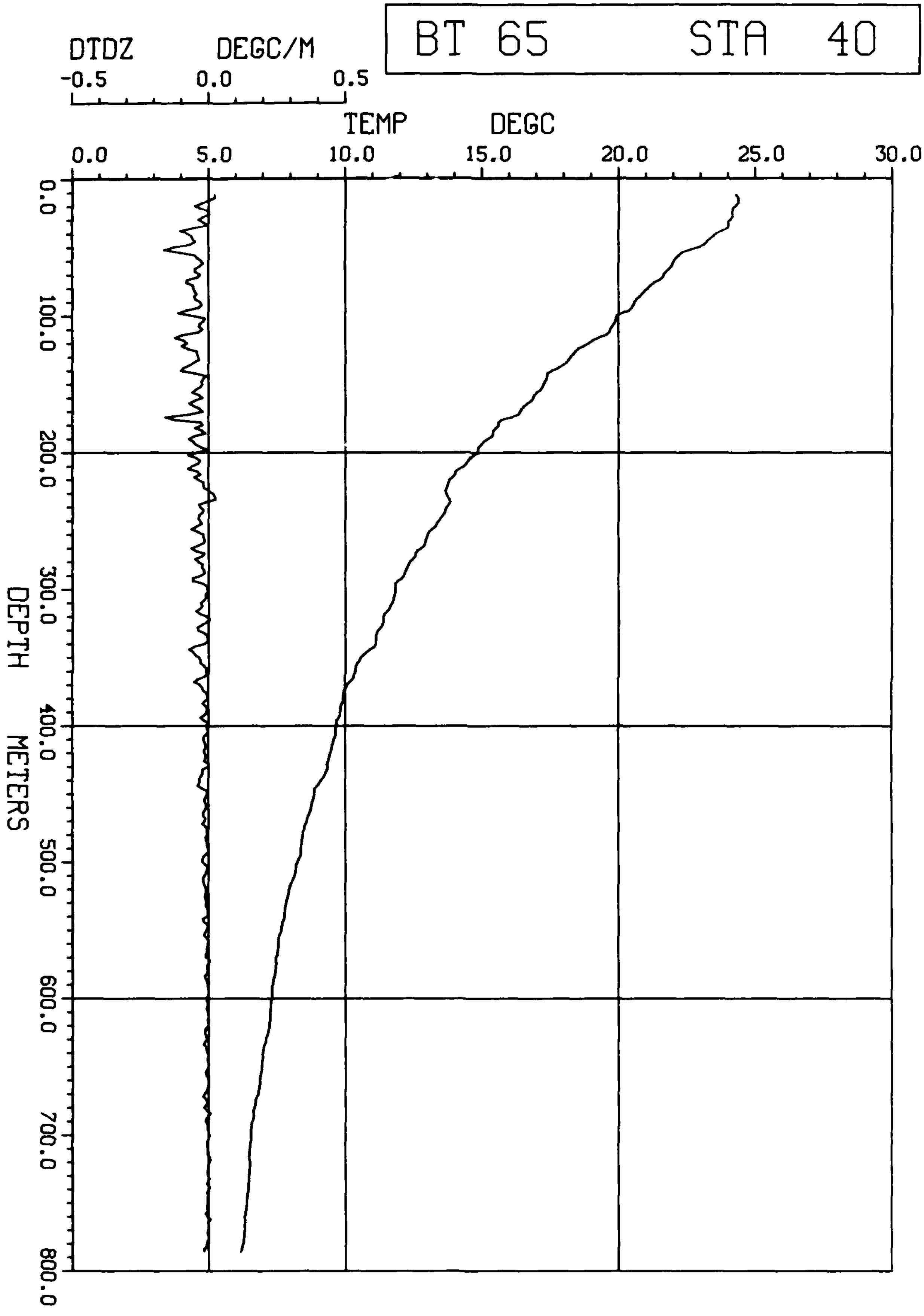
DEPTH METERS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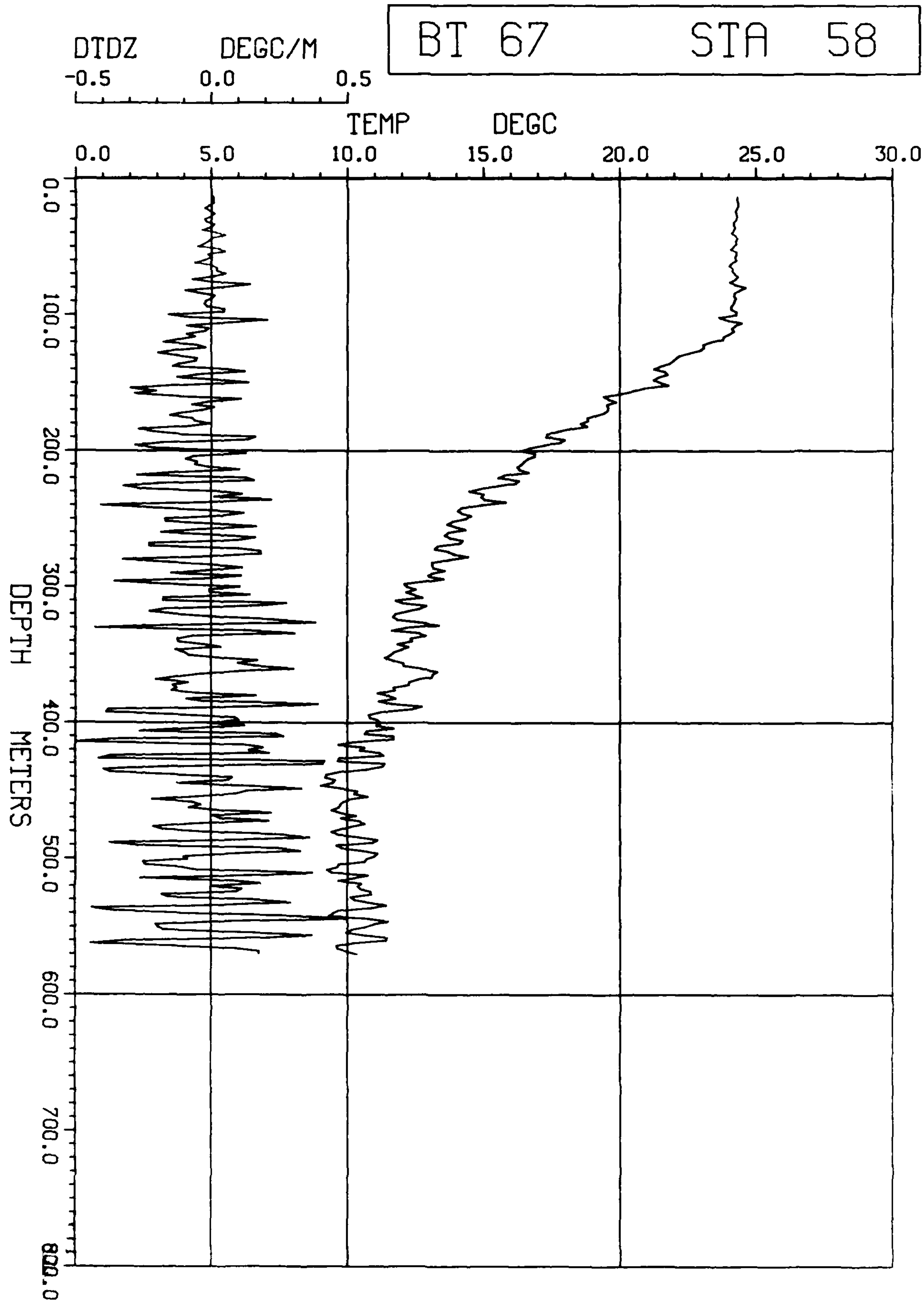
DEPTH METERS


BT 67 STA 58
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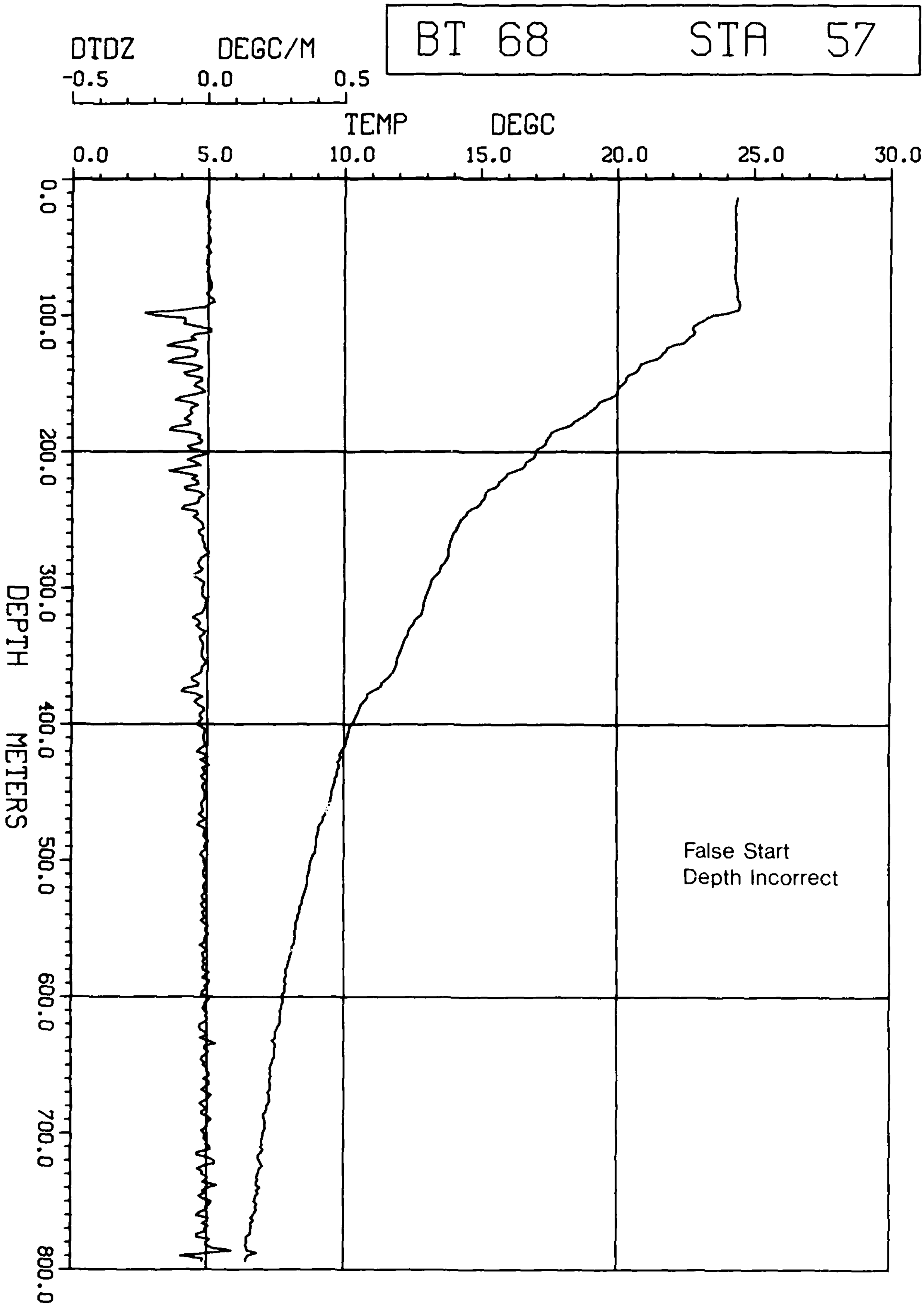
DEPTH METERS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DEPTH METERS
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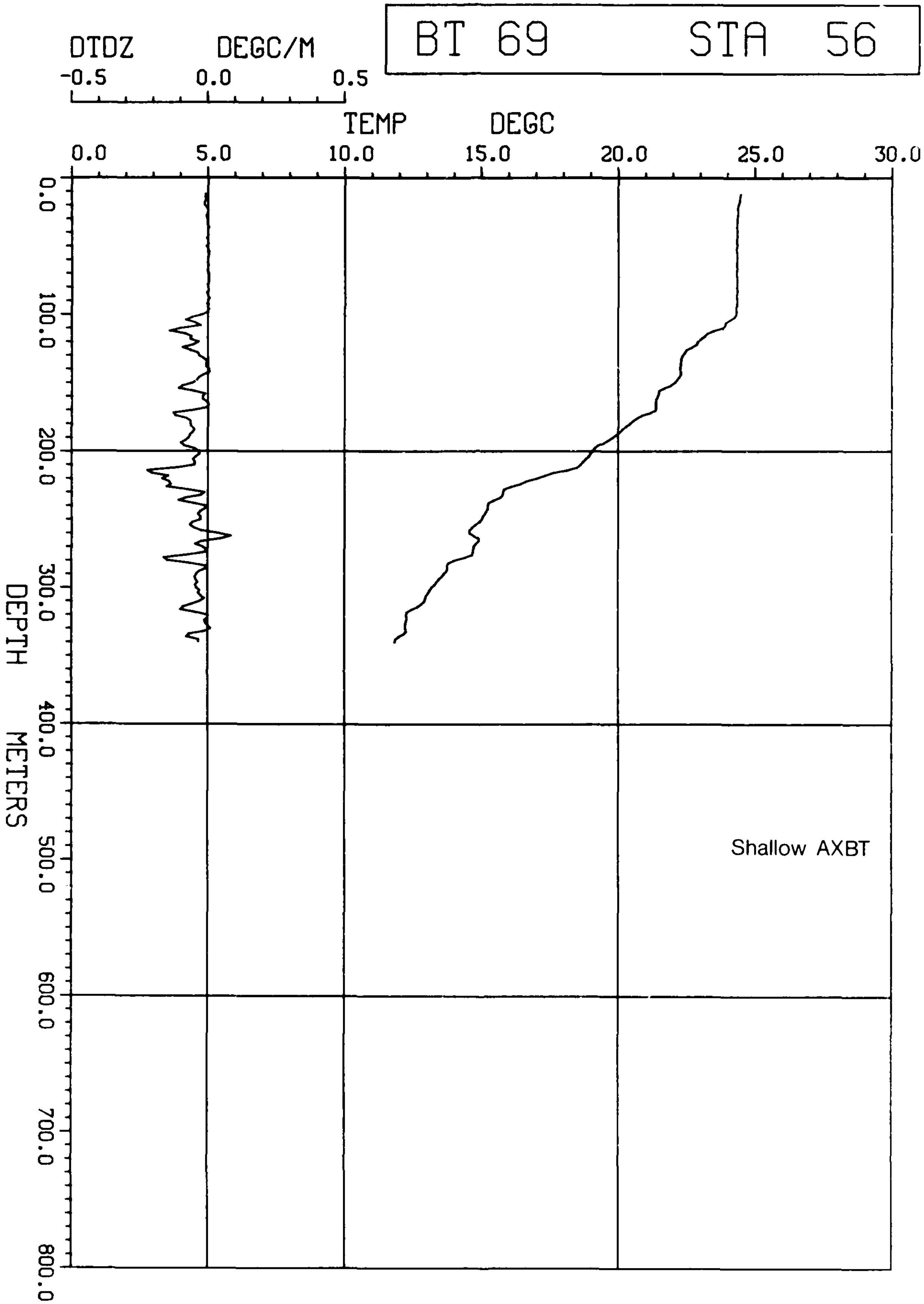
False Start
Depth Incorrect


BT 69 STA 56
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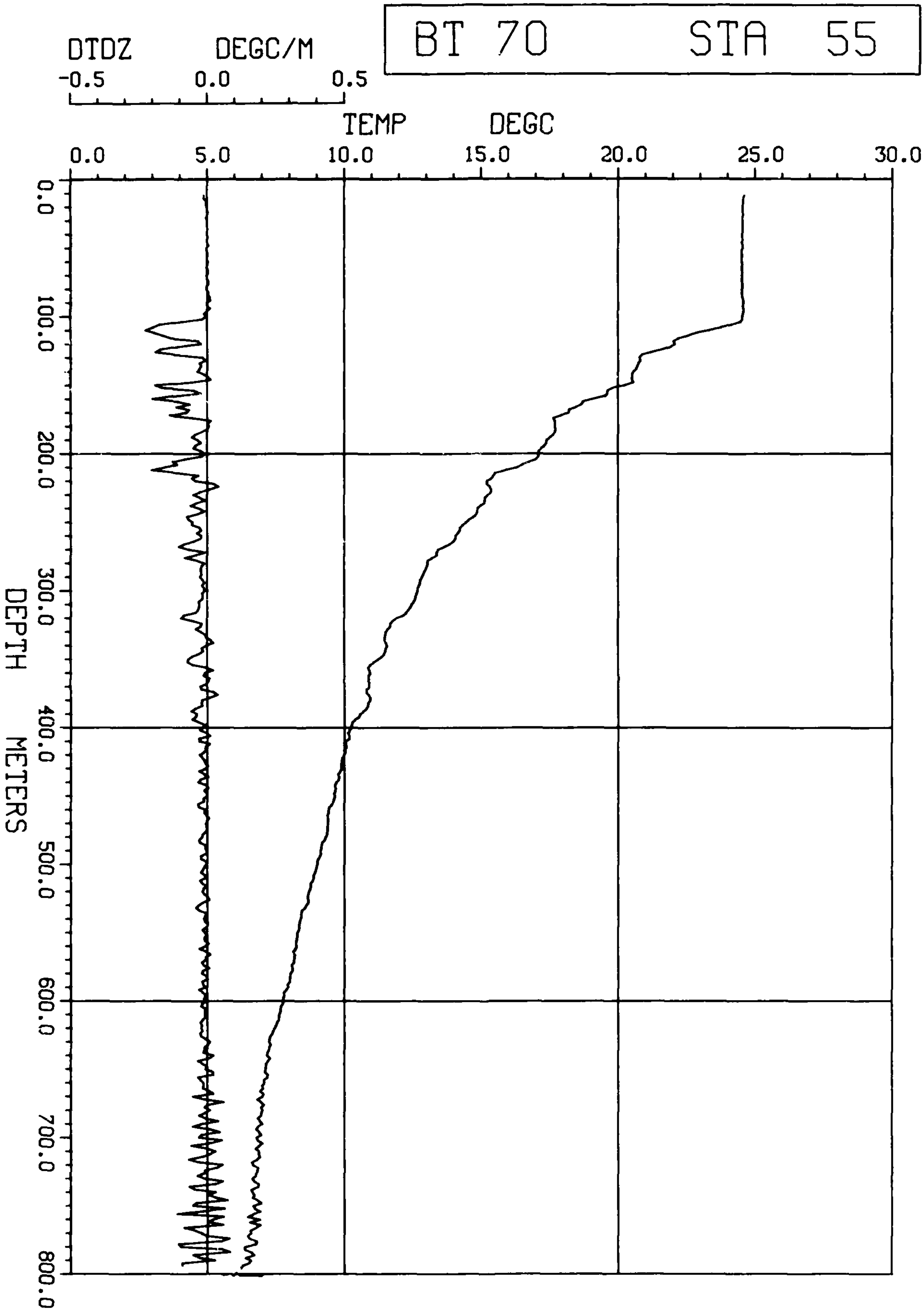
DEPTH METERS
Shallow AXBT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TEMP DEGC
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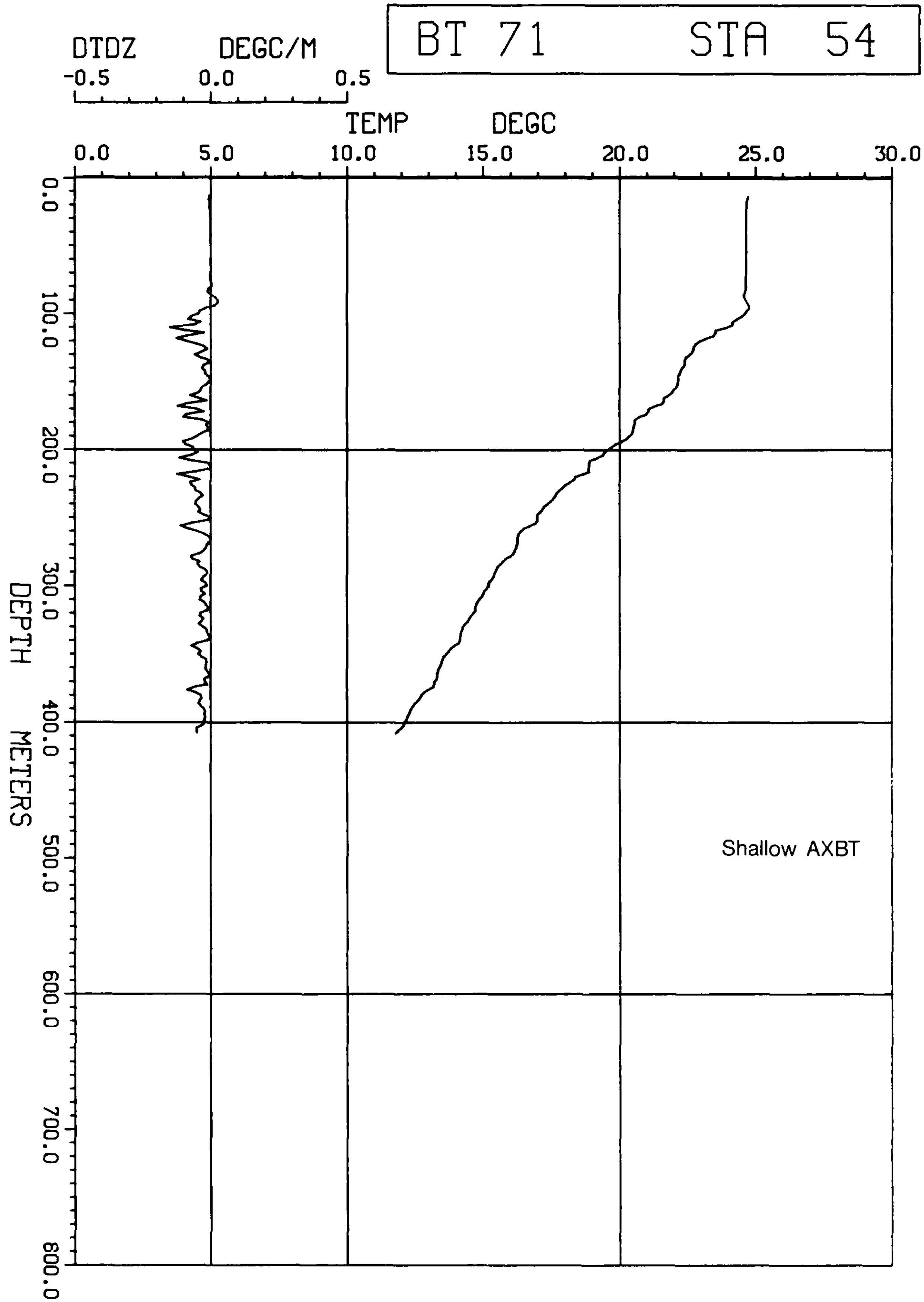
DEPTH METERS



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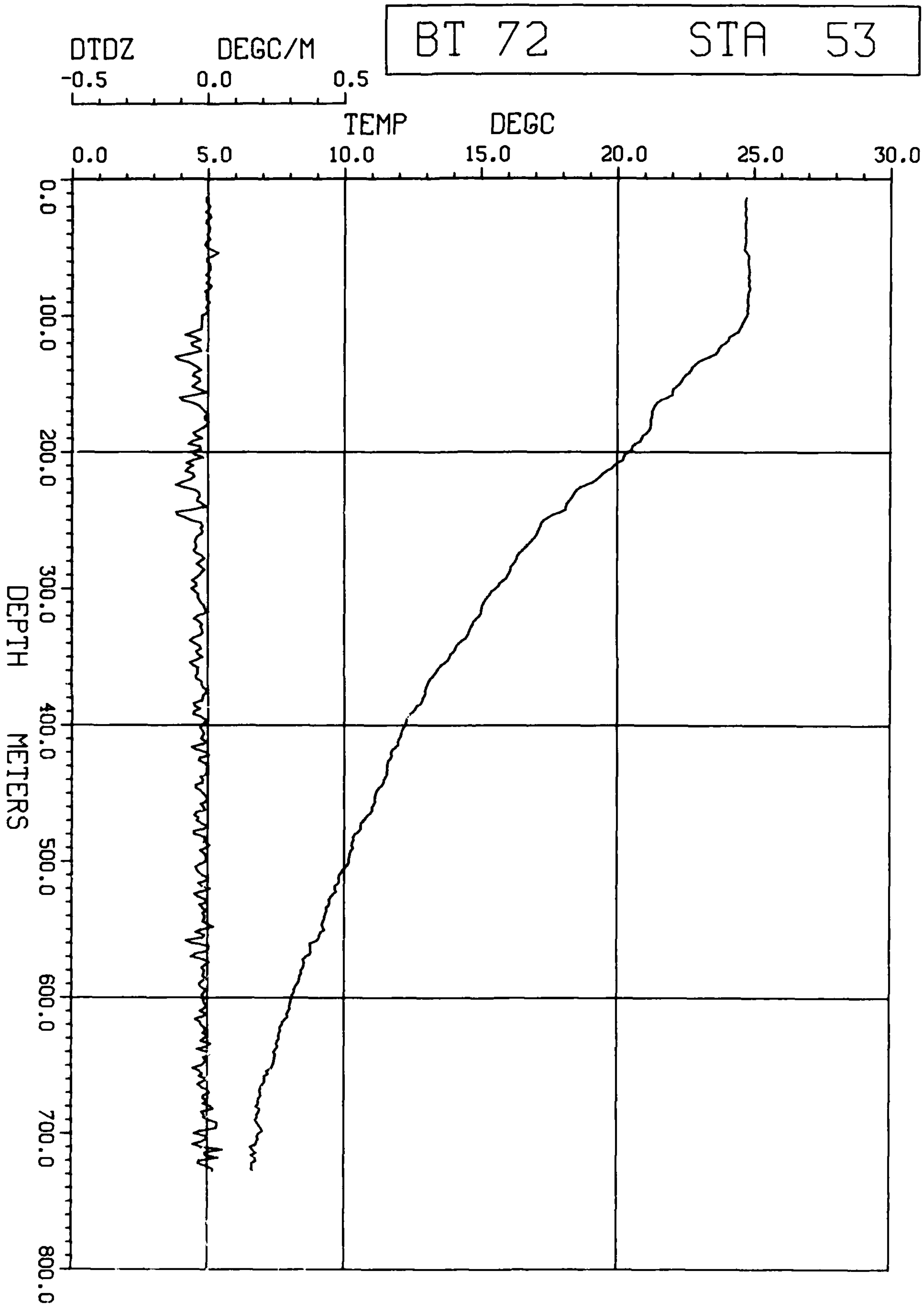
DEPTH METERS
Shallow AXBT


BT 72 STA 53
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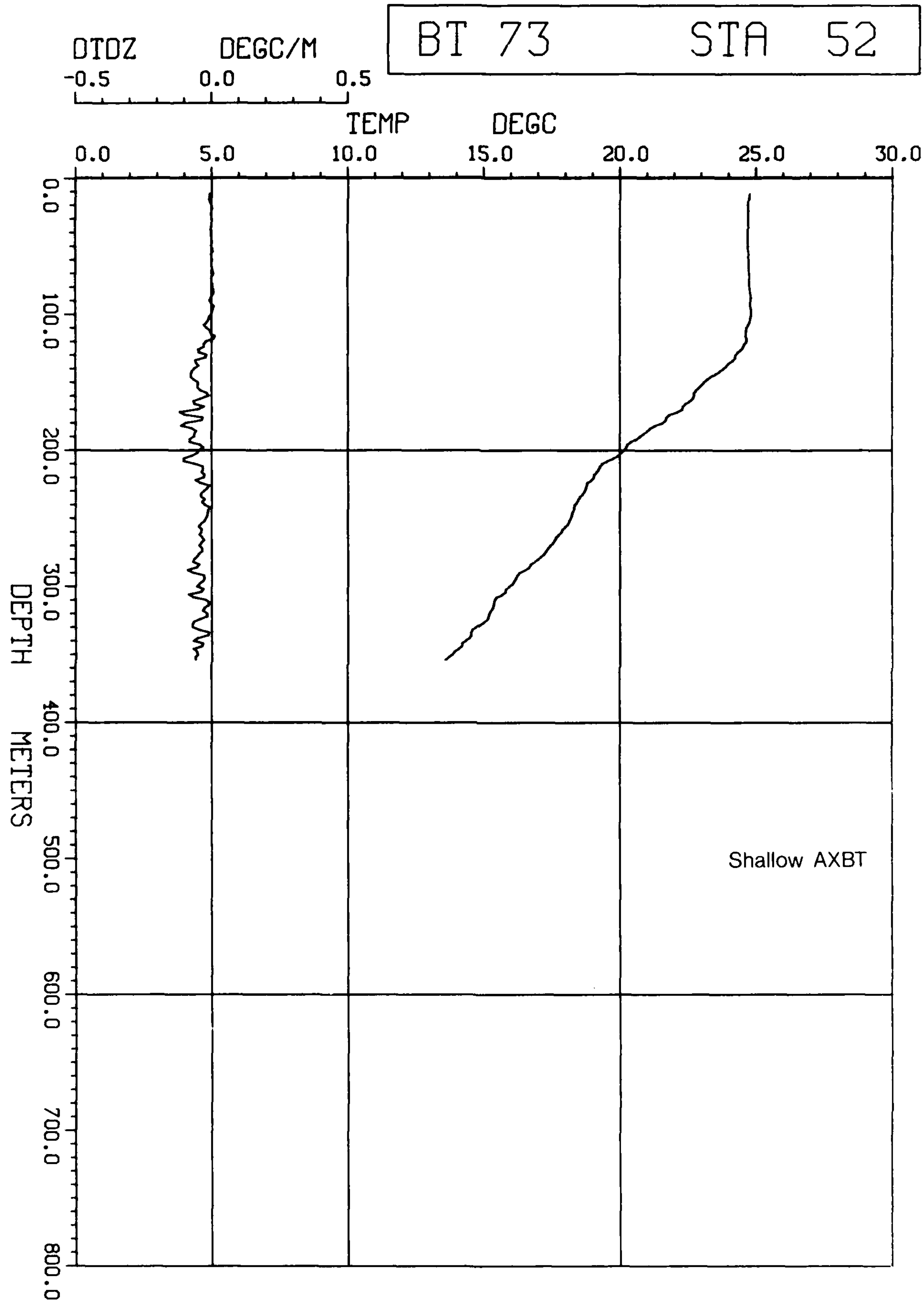
DEPTH METERS



BT 73 STA 52
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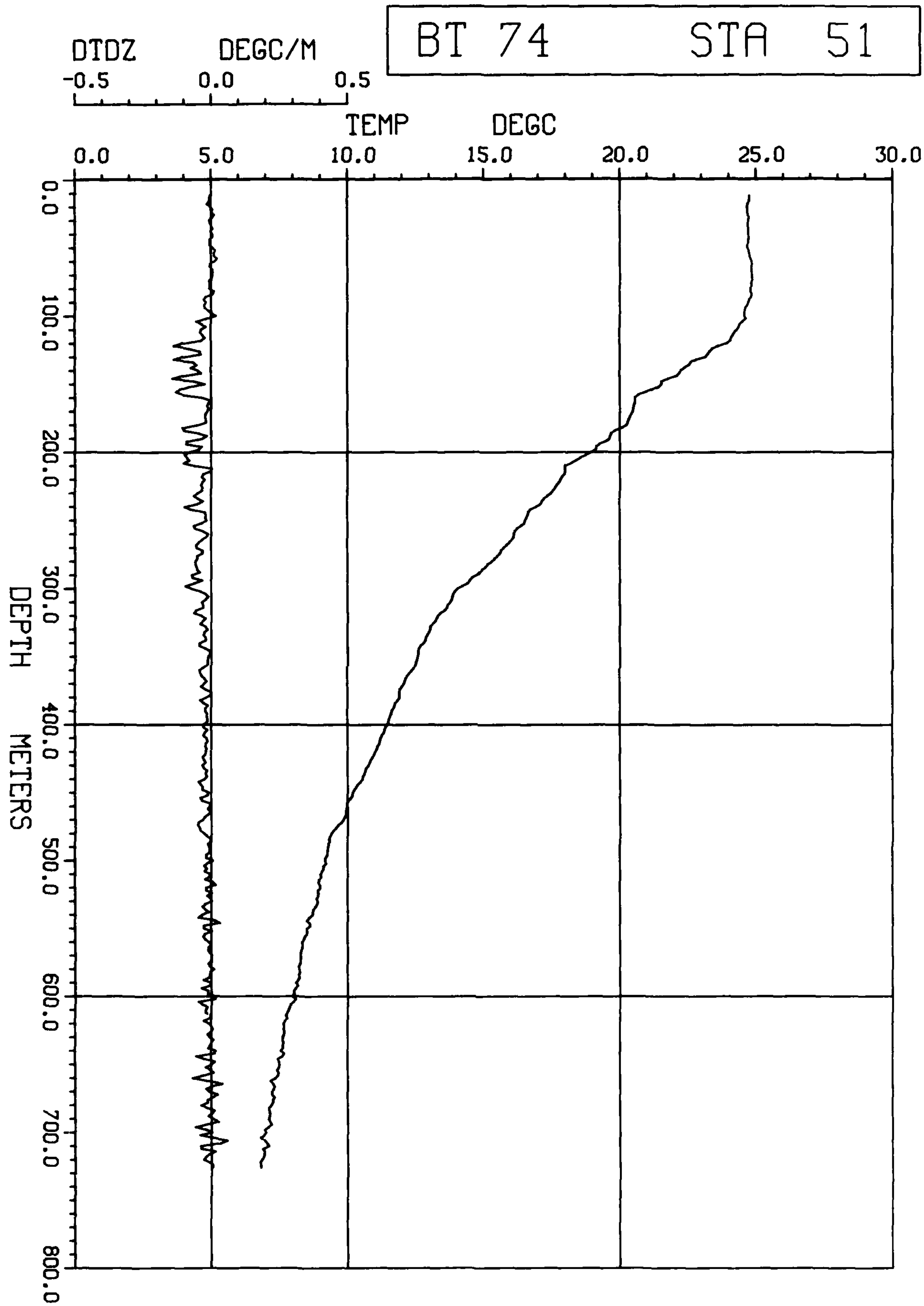
DEPTH METERS
Shallow AXBT


BT 74 STA 51
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TEMP DEGC
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400.0
500.0
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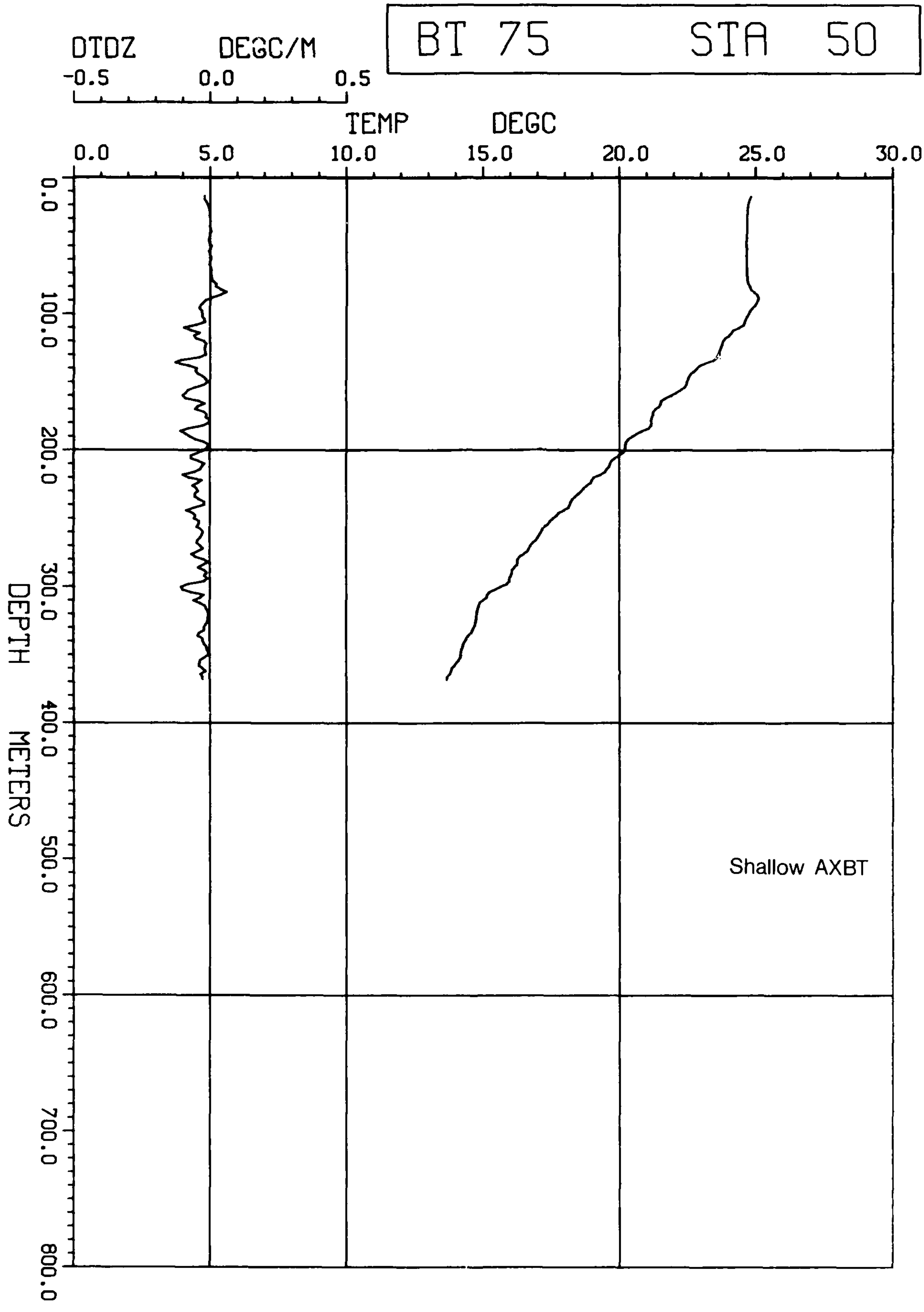
700.0
800.0
DEPTH METERS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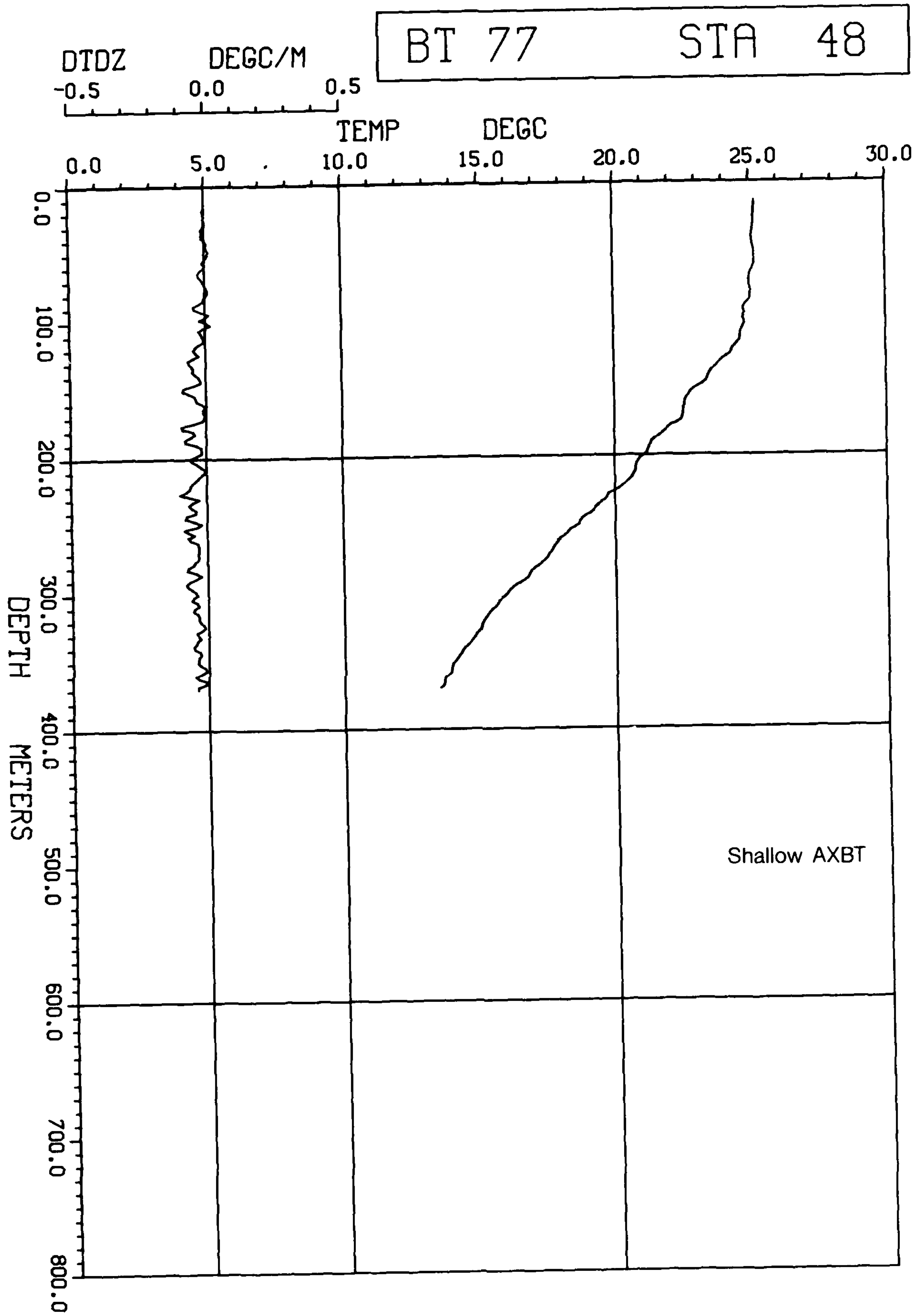
400.0
500.0
600.0
700.0
800.0
DEPTH METERS
Shallow AXBT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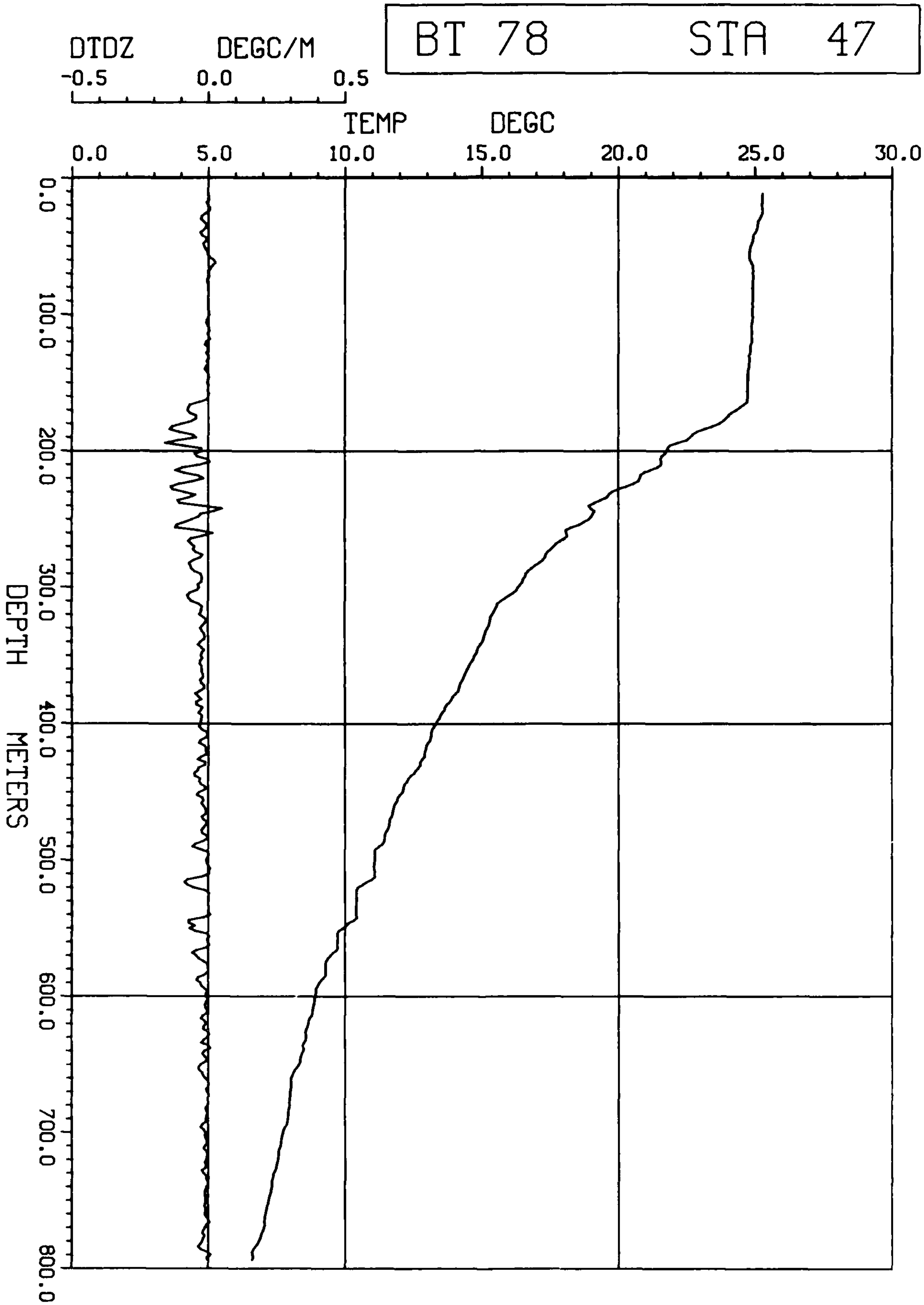
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0
DEPTH METERS
Shallow AXBT



BT 78 STA 47
DTDZ DEGC/M
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TEMP DEGC
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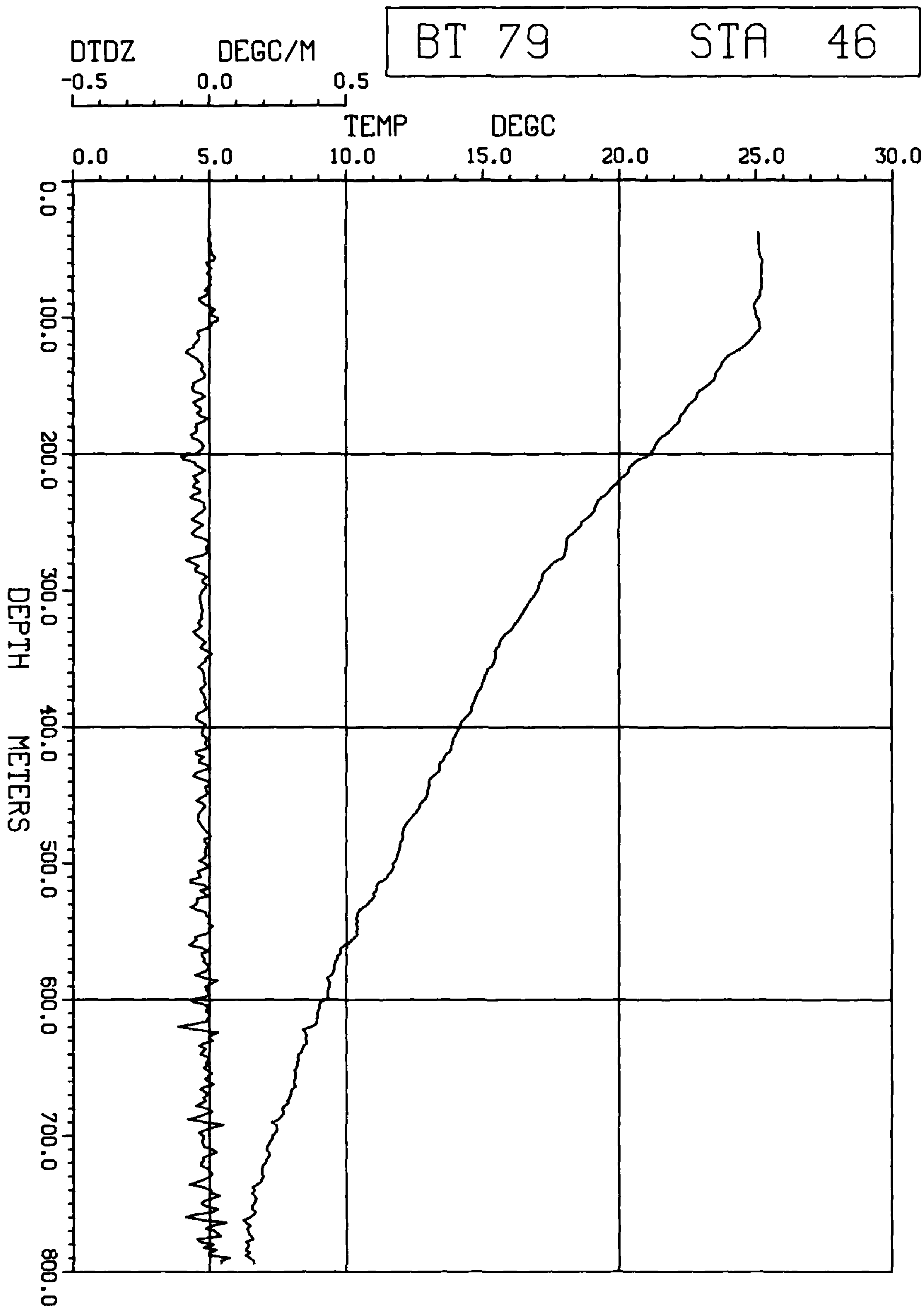
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0
DEPTH METERS


BT 79 STA 46
DTDZ DEGC/M
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TEMP DEGC
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DEPTH METERS
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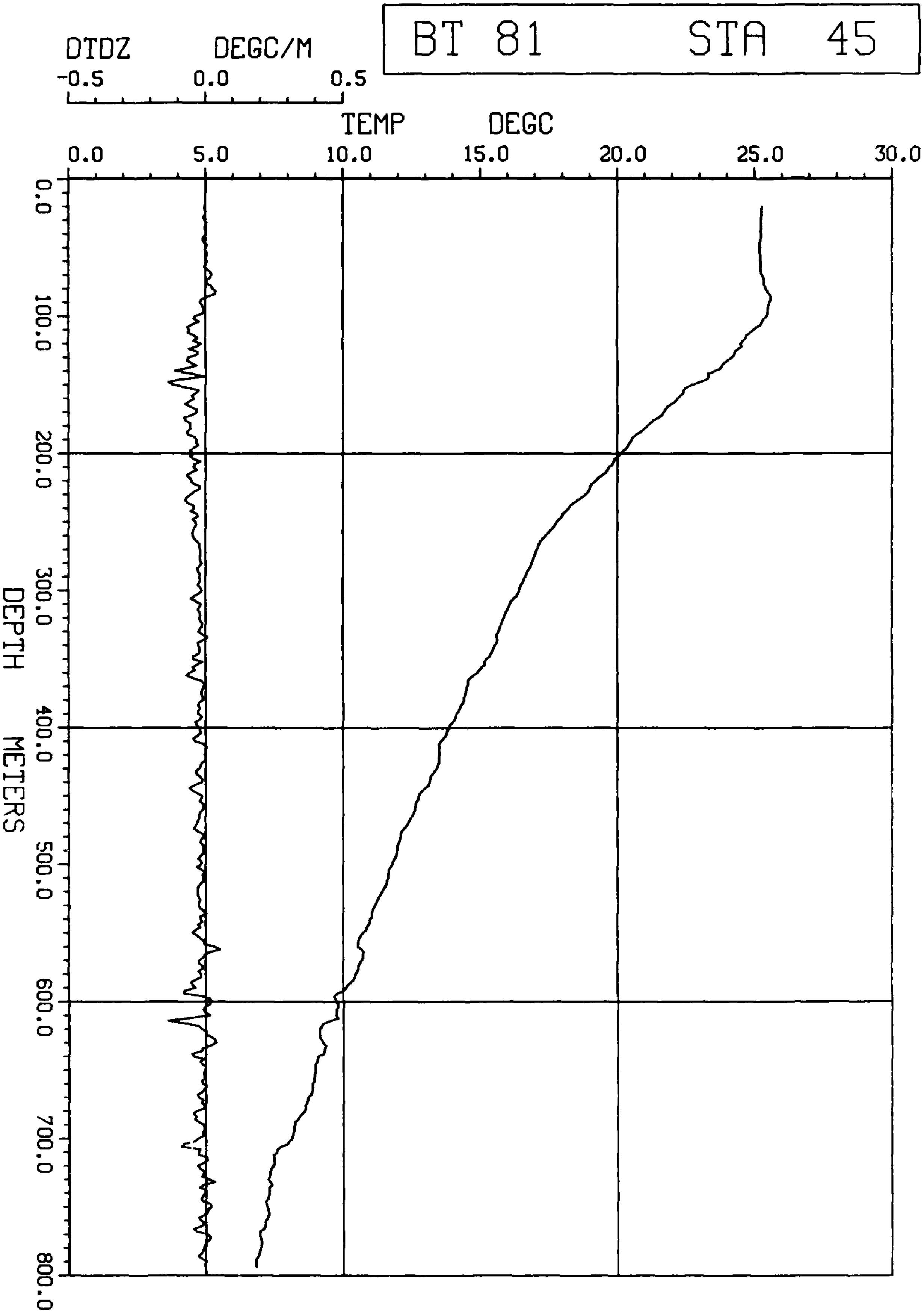
BT 81 STA 45
DTDZ DEGC/M
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TEMP DEGC
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400.0
500.0
600.0
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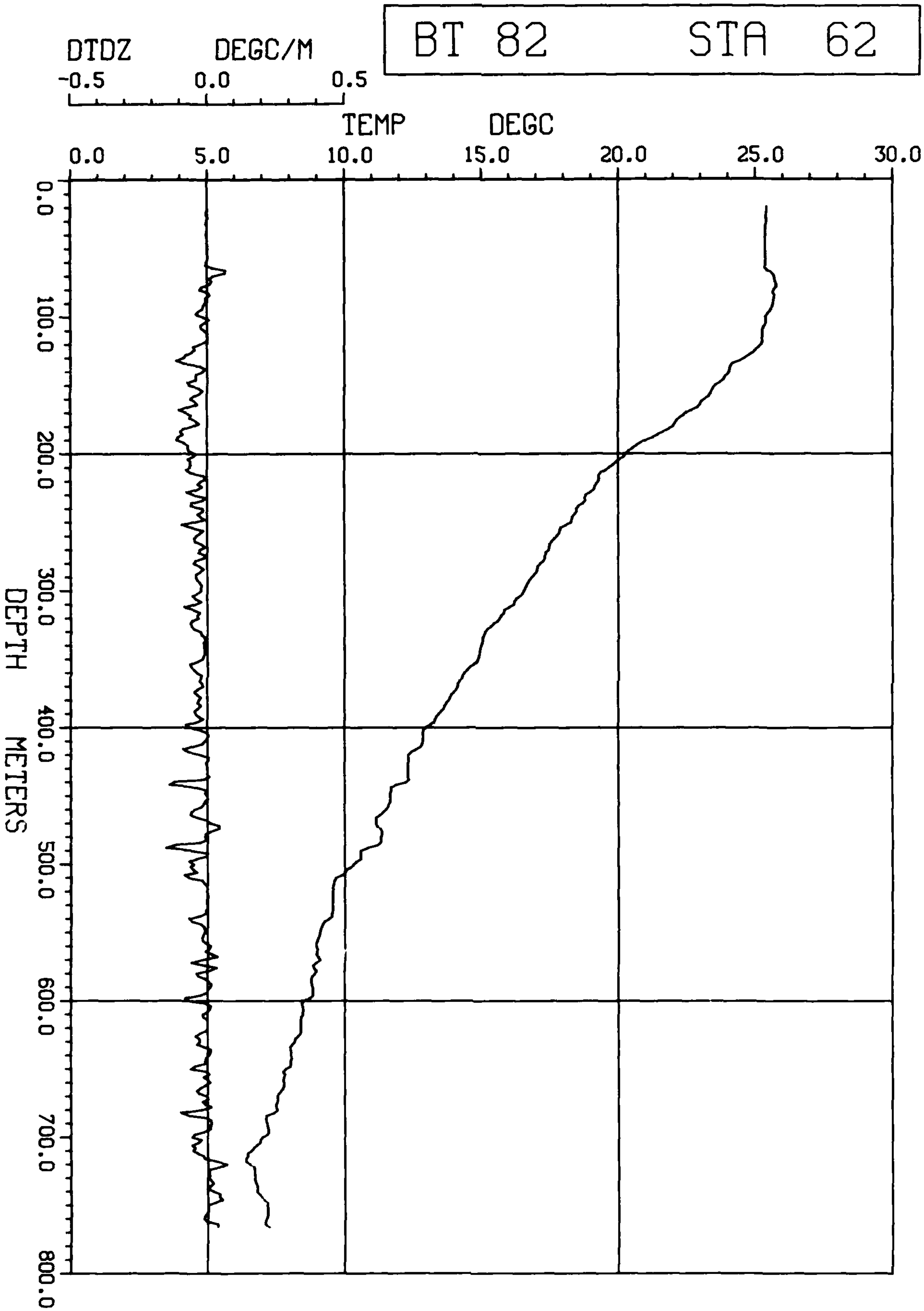
800.0



BT 82
STA 62
DTDZ
DEGC/M
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TEMP
DEGC
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5.0
10.0
15.0
20.0
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30.0
DEPTH
METERS
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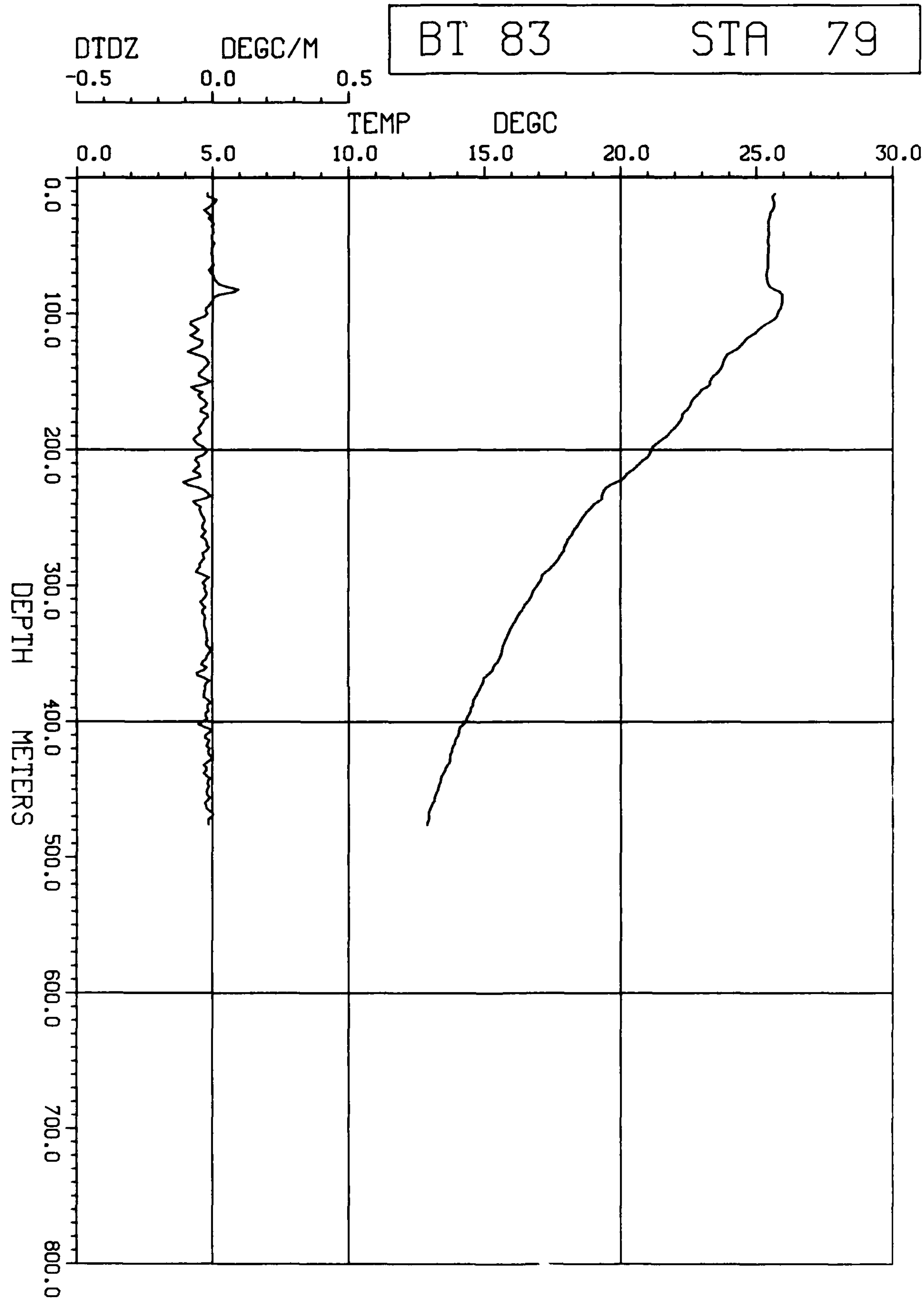
800.0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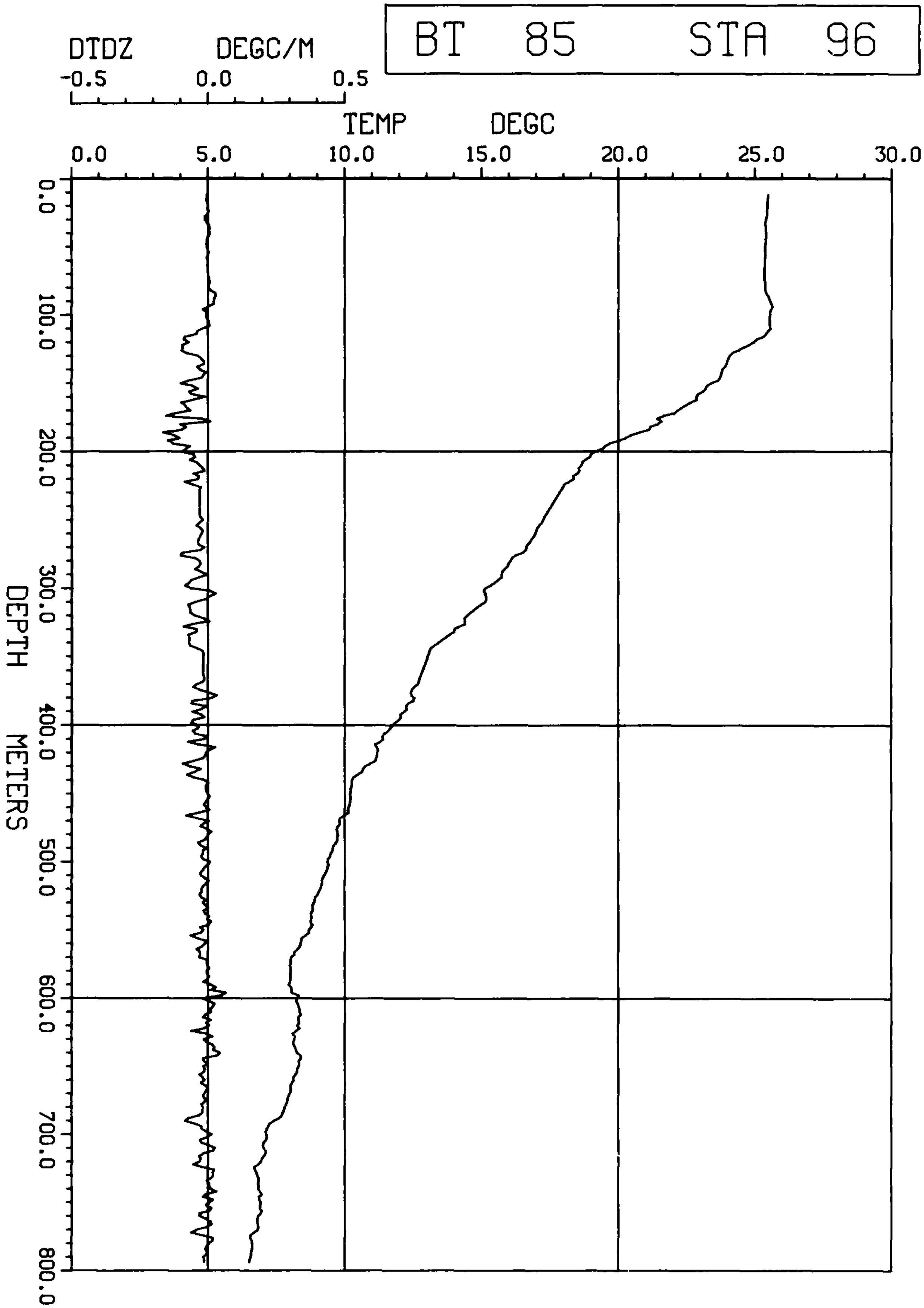

BT 85 STA 96
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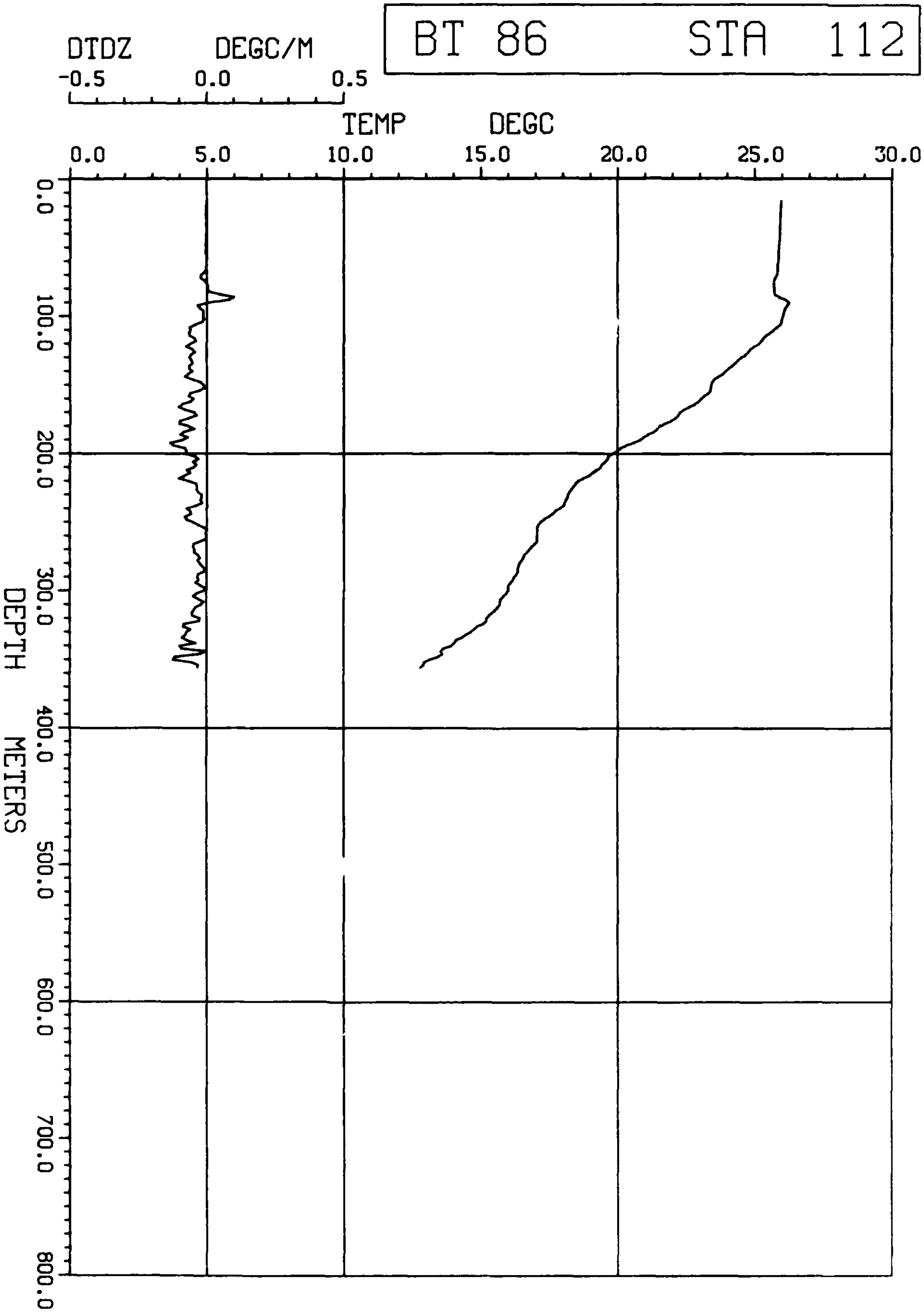
BT 86 STA 112
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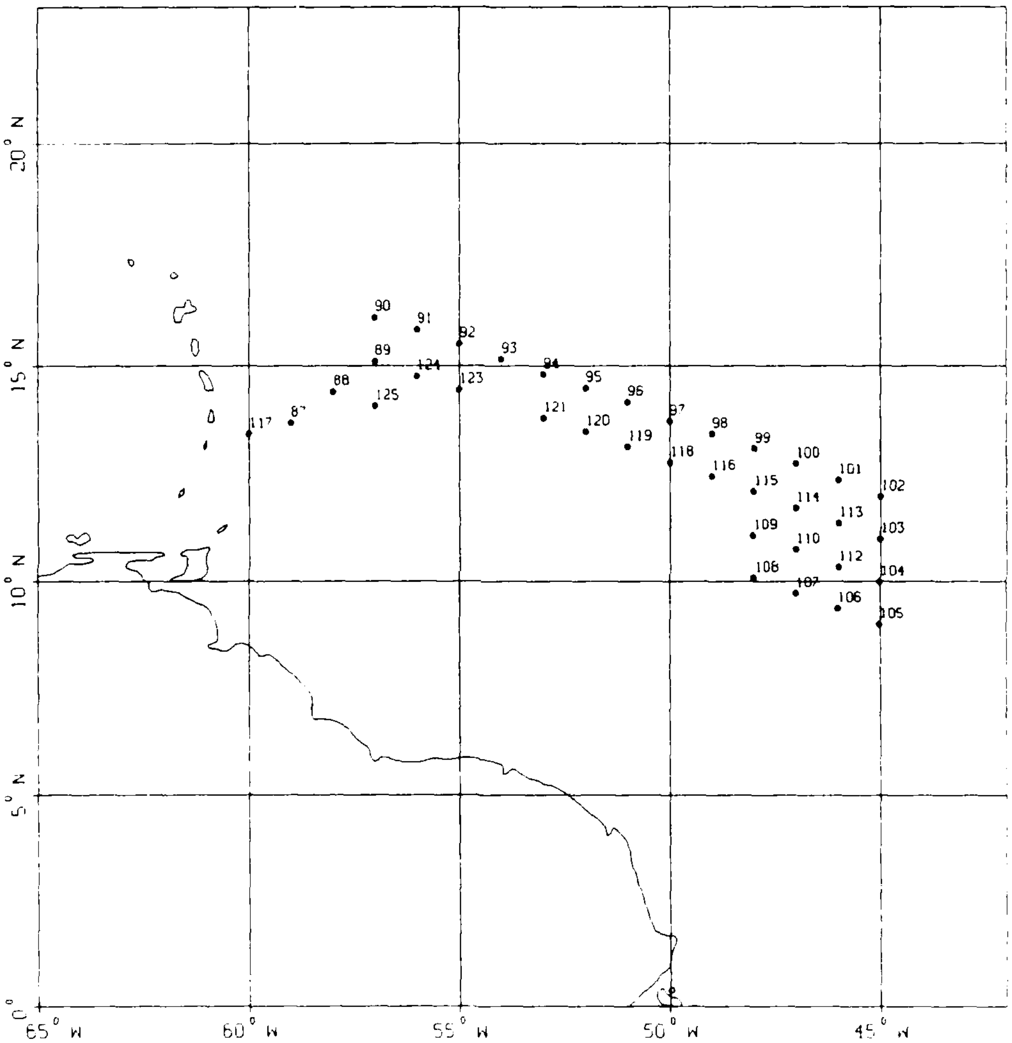
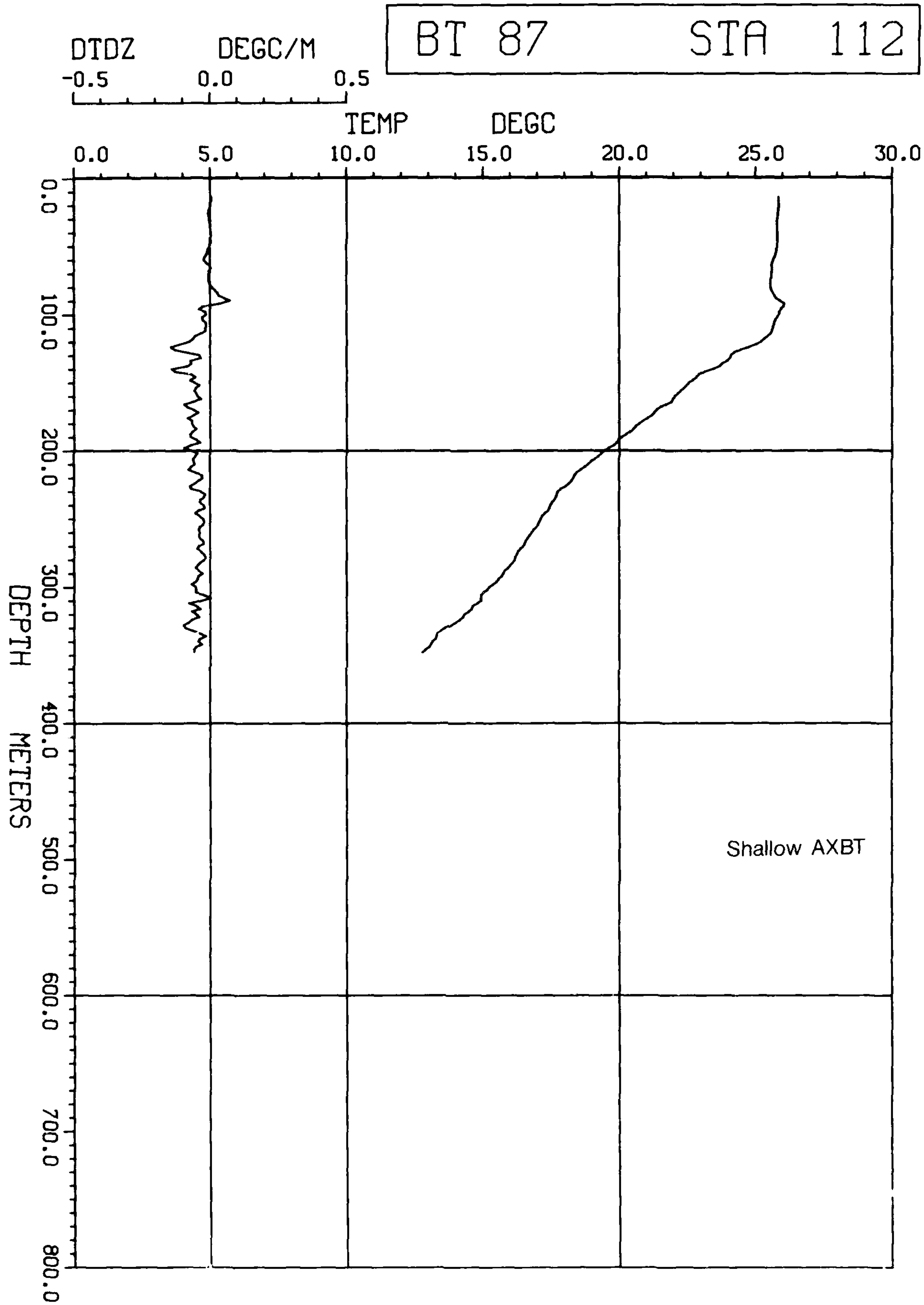
300.0
400.0
500.0
600.0
700.0
800.0
DEPTH METERS

Station Positions Flight 3
27 March 1985

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TEMP DEGC
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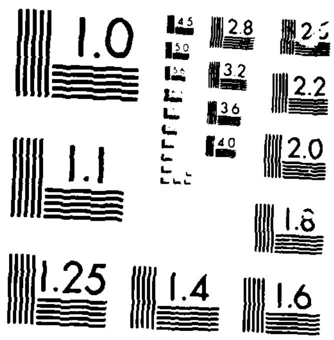
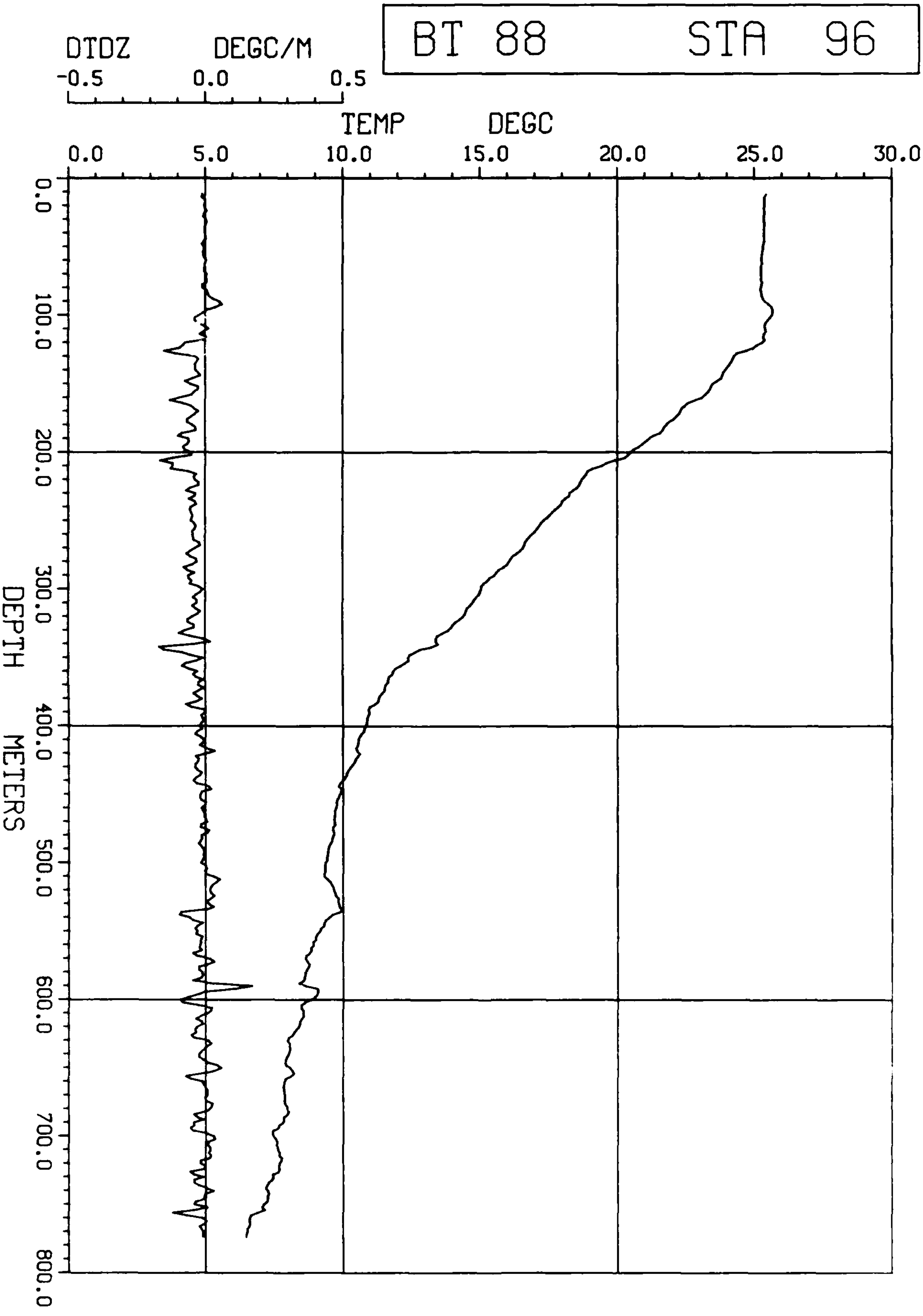
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
DEPTH METERS
Shallow AXBT

AD-A169 441 AXBT (AIR-DEPLOYED EXPENDABLE BATHYTHERMOGRAPH) MEASUREMENTS OFF THE NORT..(U) NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY NSTL STATION MS.. J D BOYD ET AL. JAN 86 NORDA-112

UNCLASSIFIED F/G 8/3 NL



MICROCOPY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TEMP DEGC
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10.0
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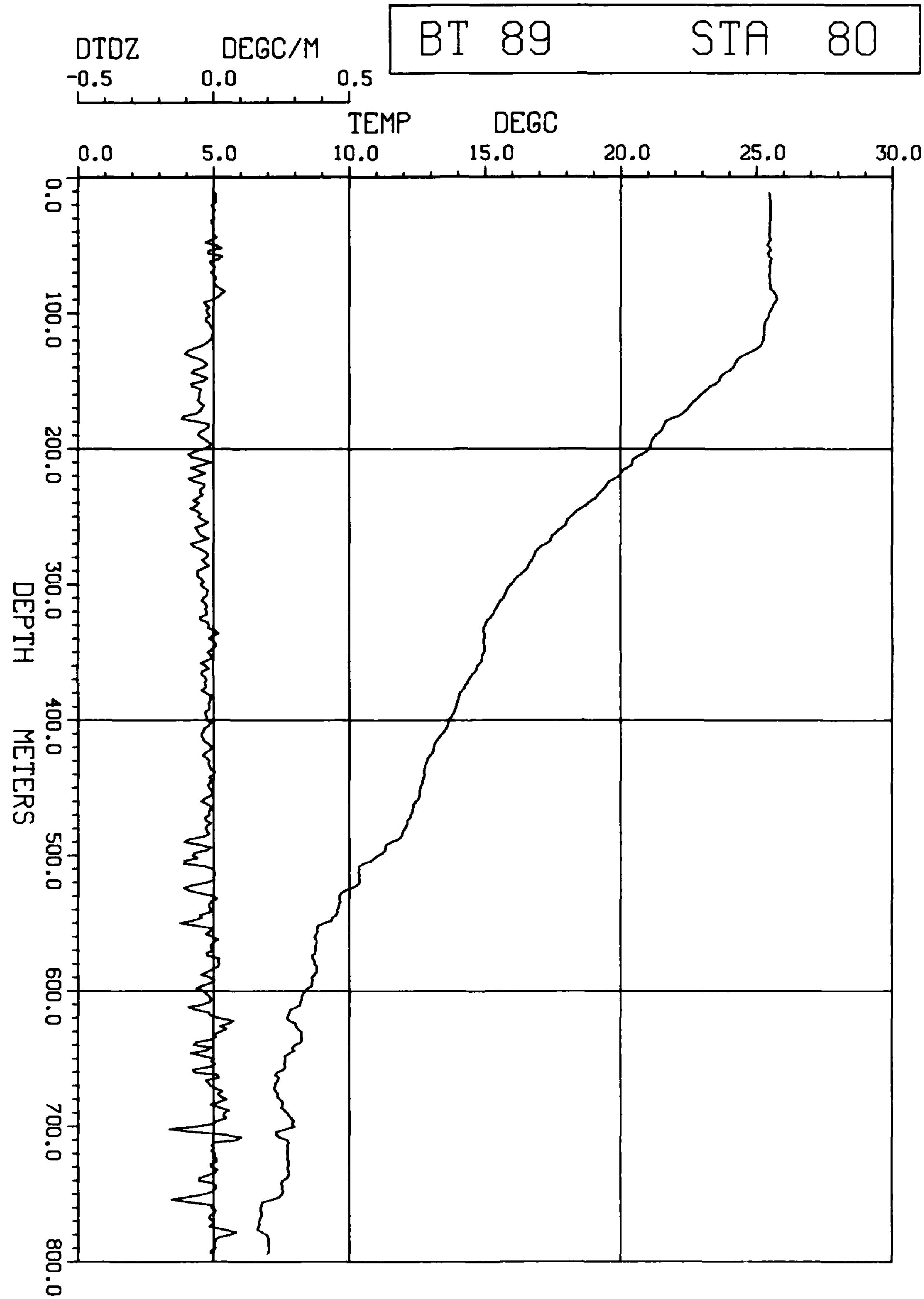
DEPTH METERS



BT 89 STA 80
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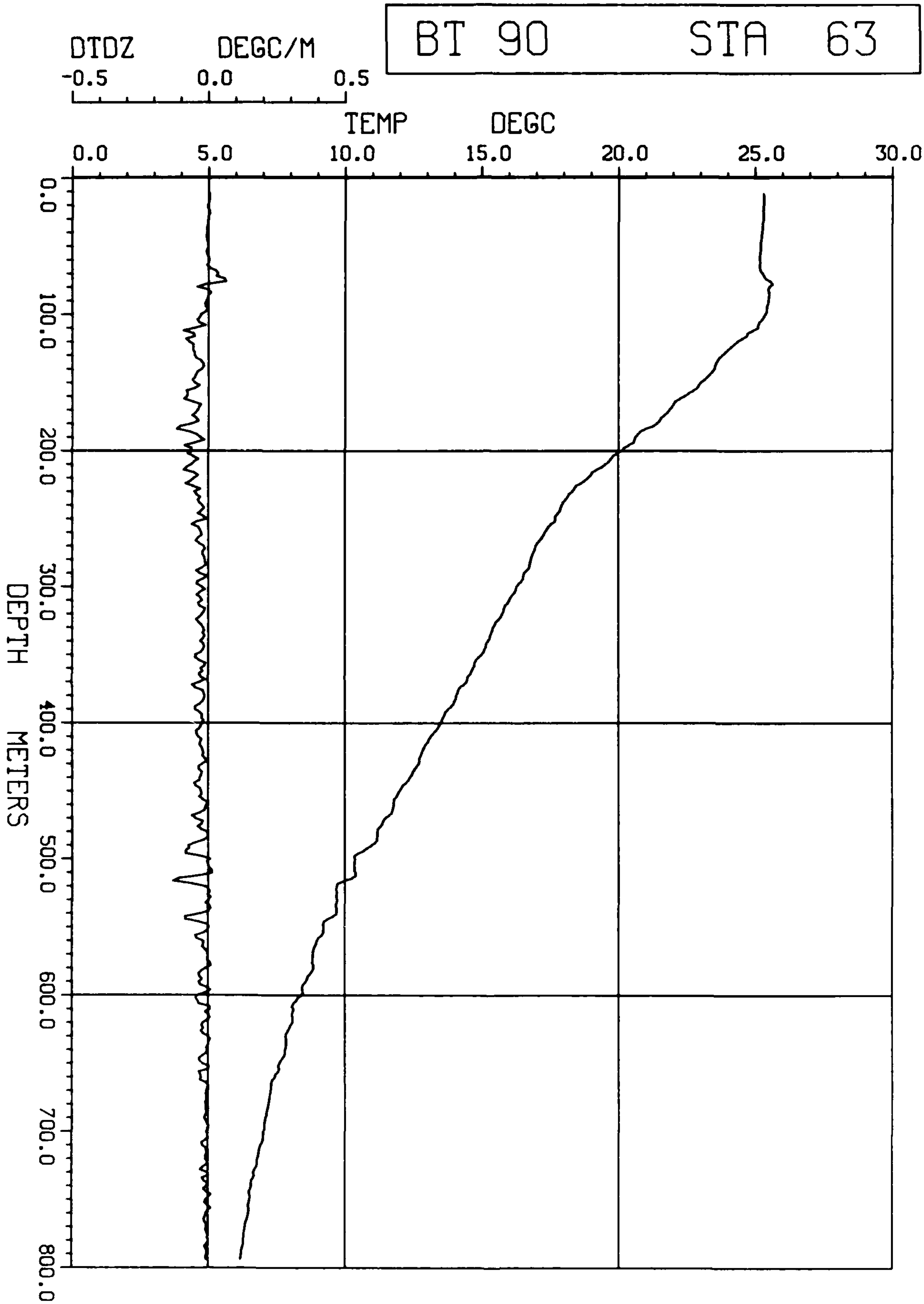
700.0
800.0
DEPTH METERS



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STA 63
DTDZ
DEGC/M
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0.5
TEMP
DEGC
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5.0
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15.0
20.0
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30.0
DEPTH
METERS
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400.0
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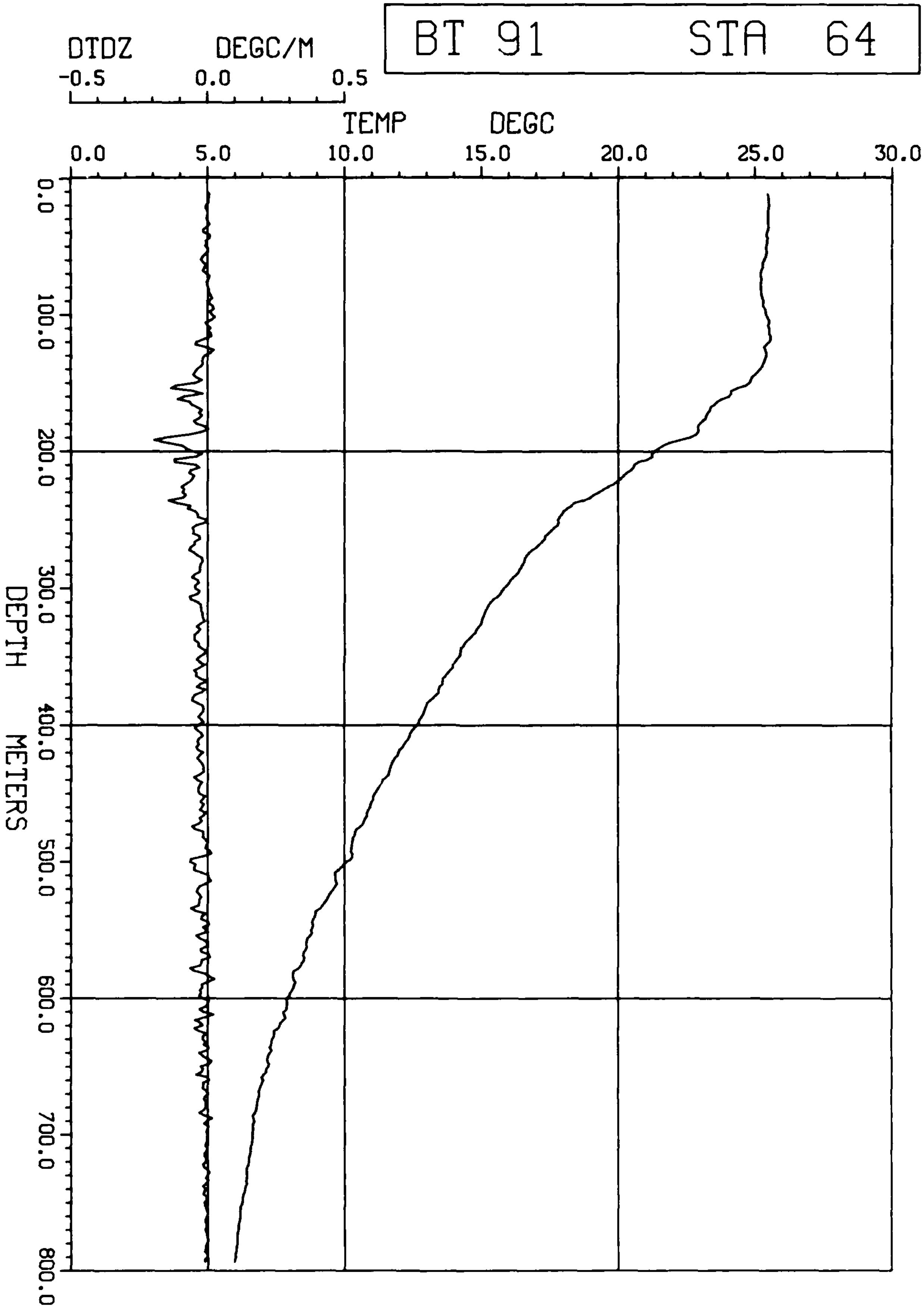
800.0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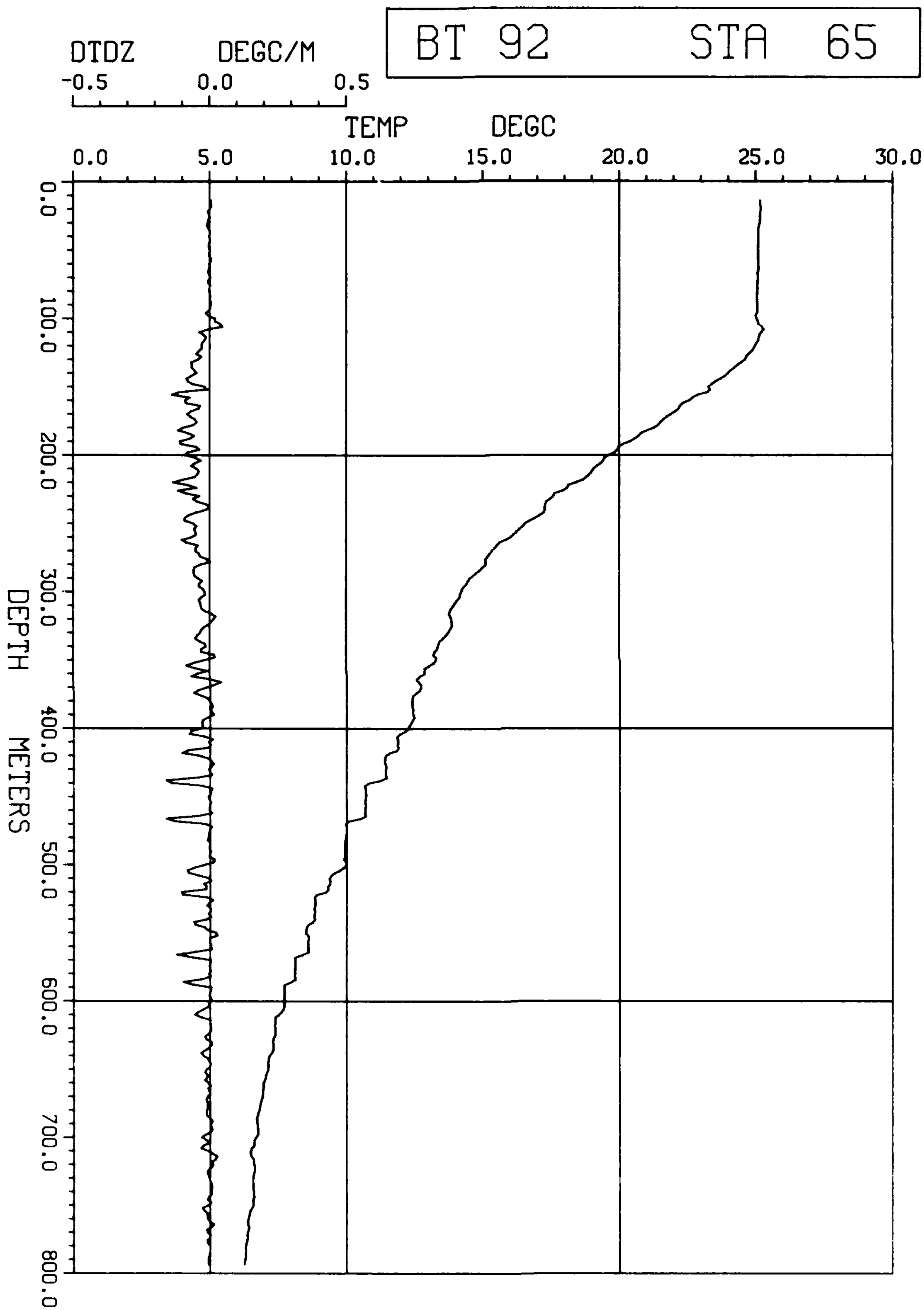

BT 92 STA 65
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0.5
TEMP DEGC
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DEPTH METERS
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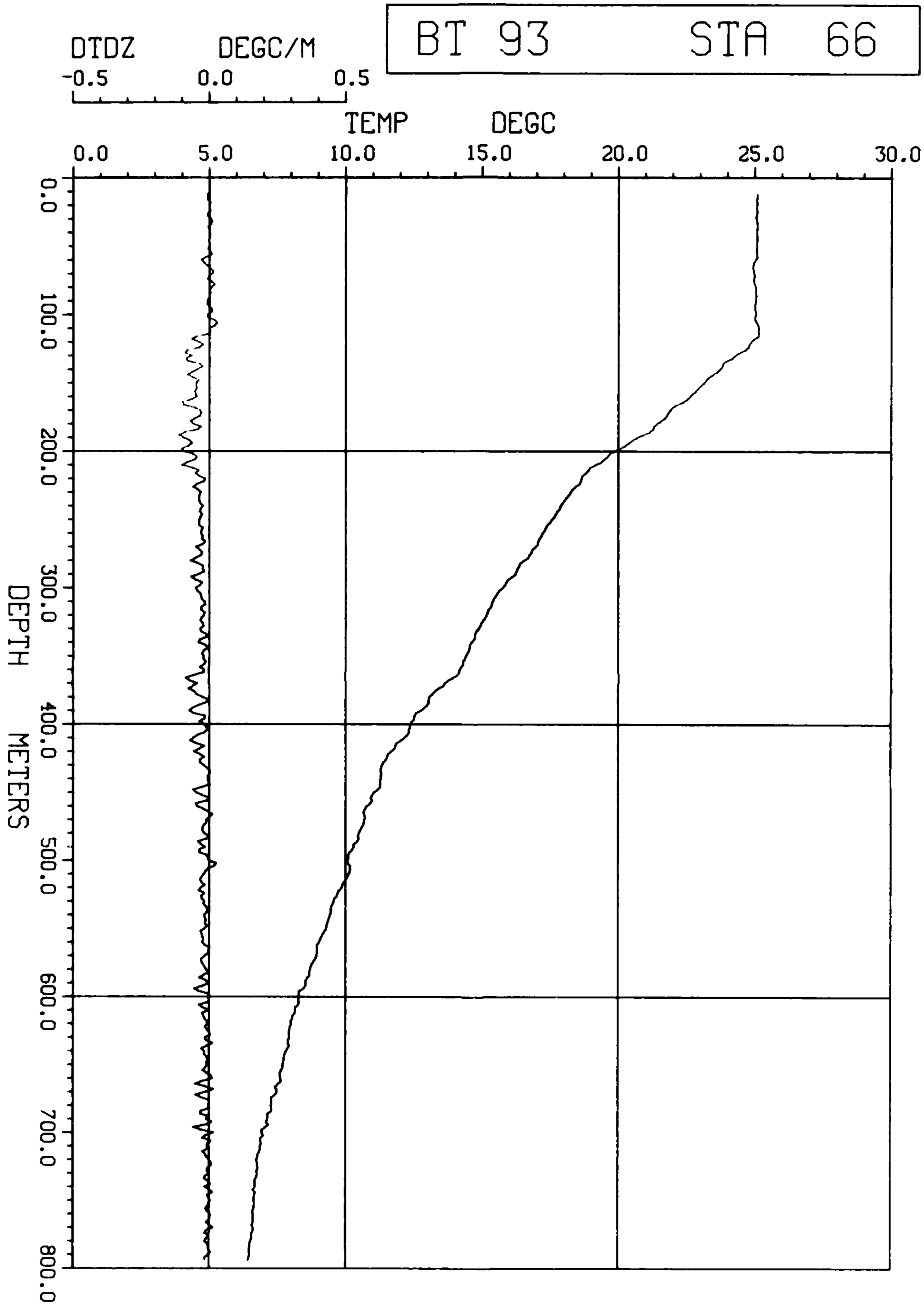
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DTDZ DEGC/M
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TEMP DEGC
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DEPTH METERS
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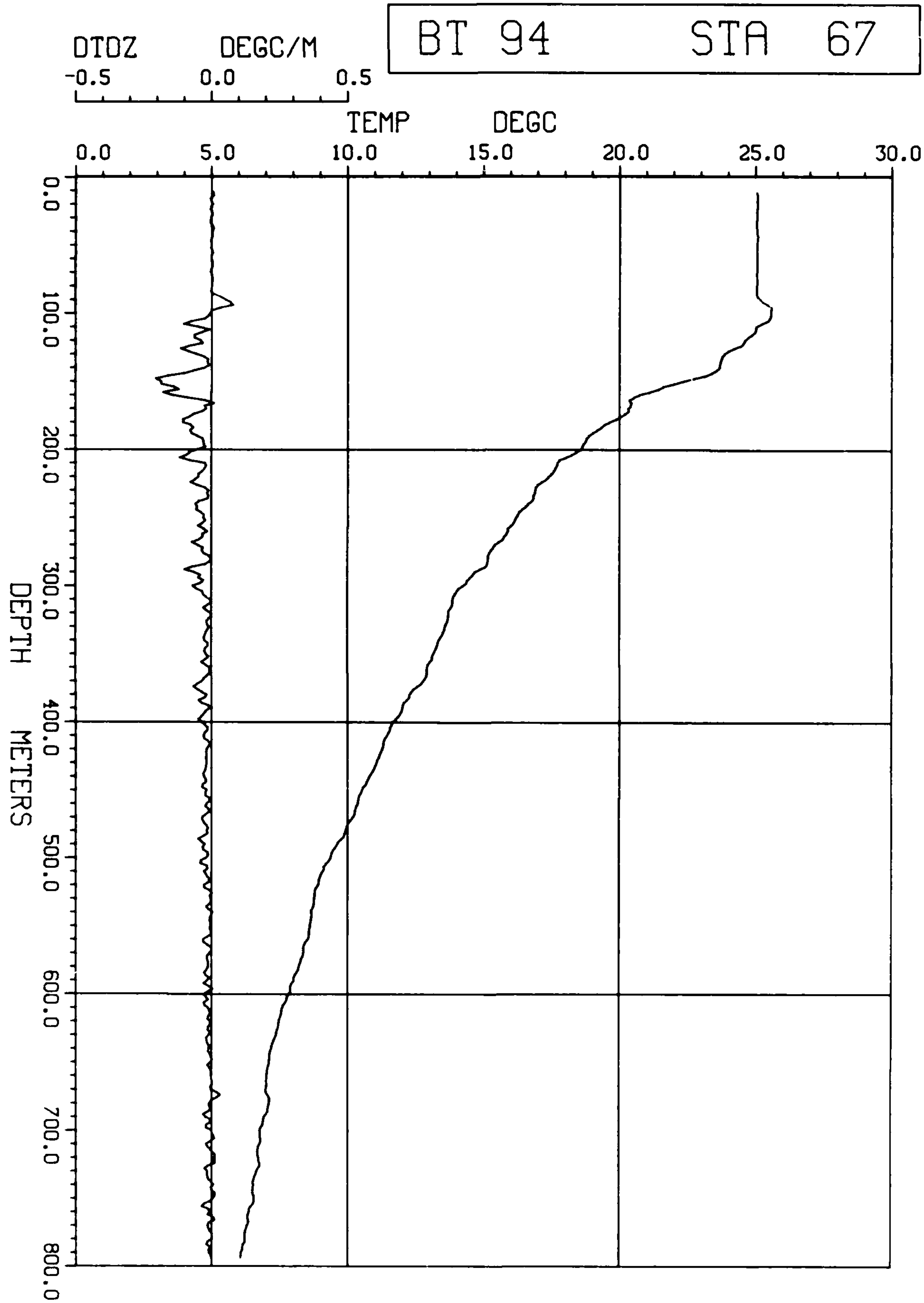
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DTDZ DEGC/M
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TEMP DEGC
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DEPTH METERS
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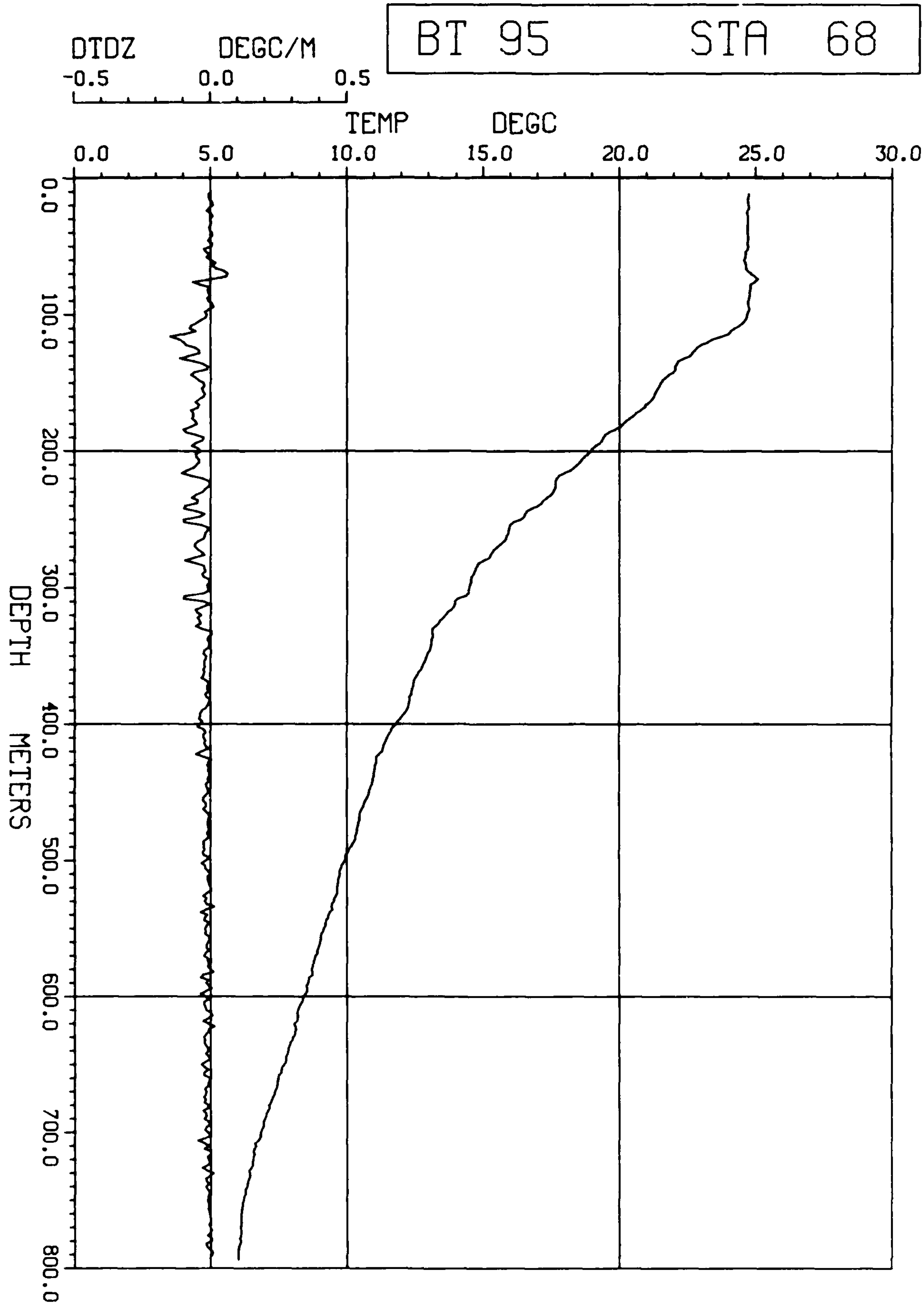

BT 95 STA 68
DTDZ DEGC/M
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TEMP DEGC
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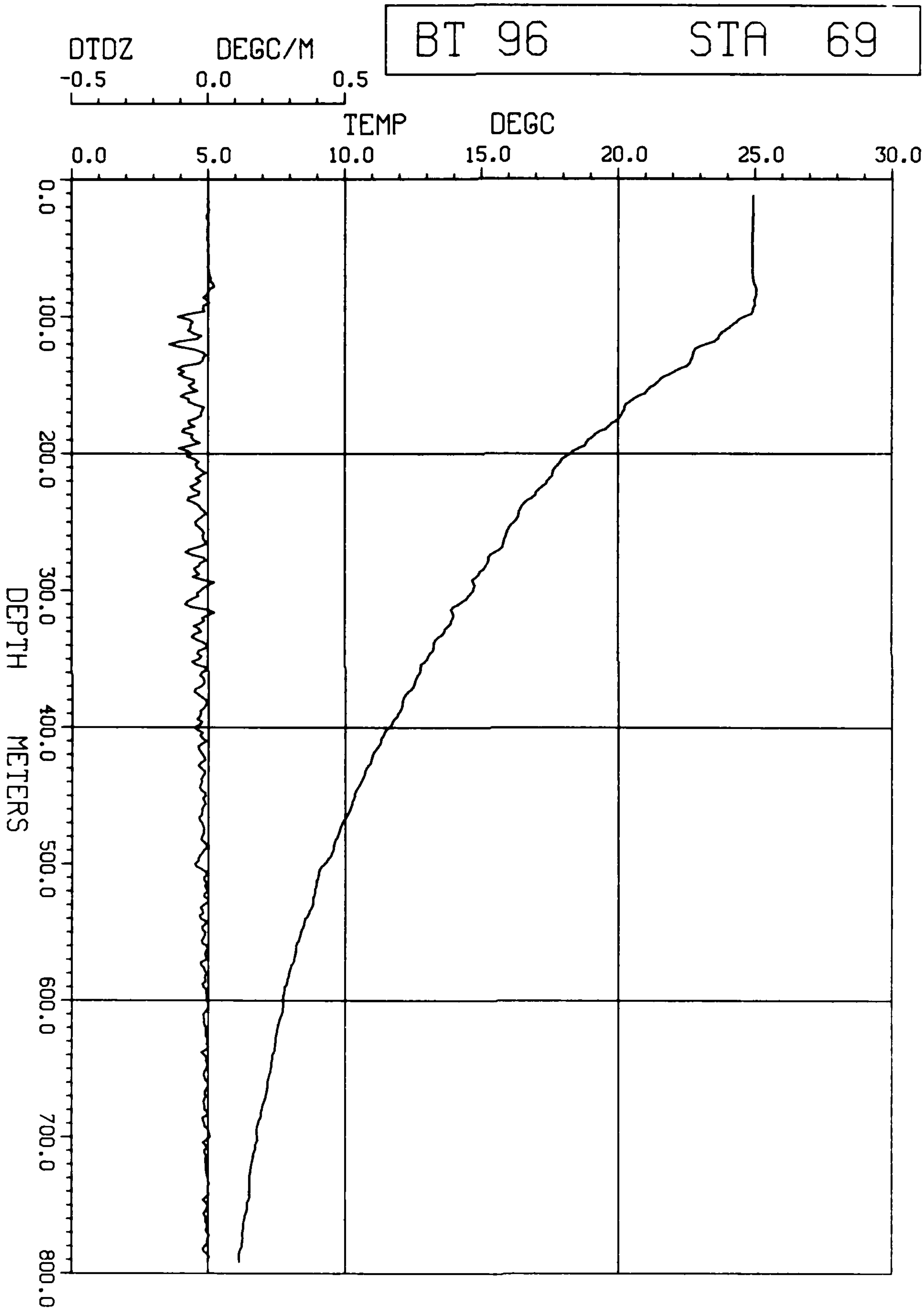
DEPTH METERS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DTDZ DEGC/M
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0.5
TEMP DEGC
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10.0
15.0
20.0
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DEPTH METERS
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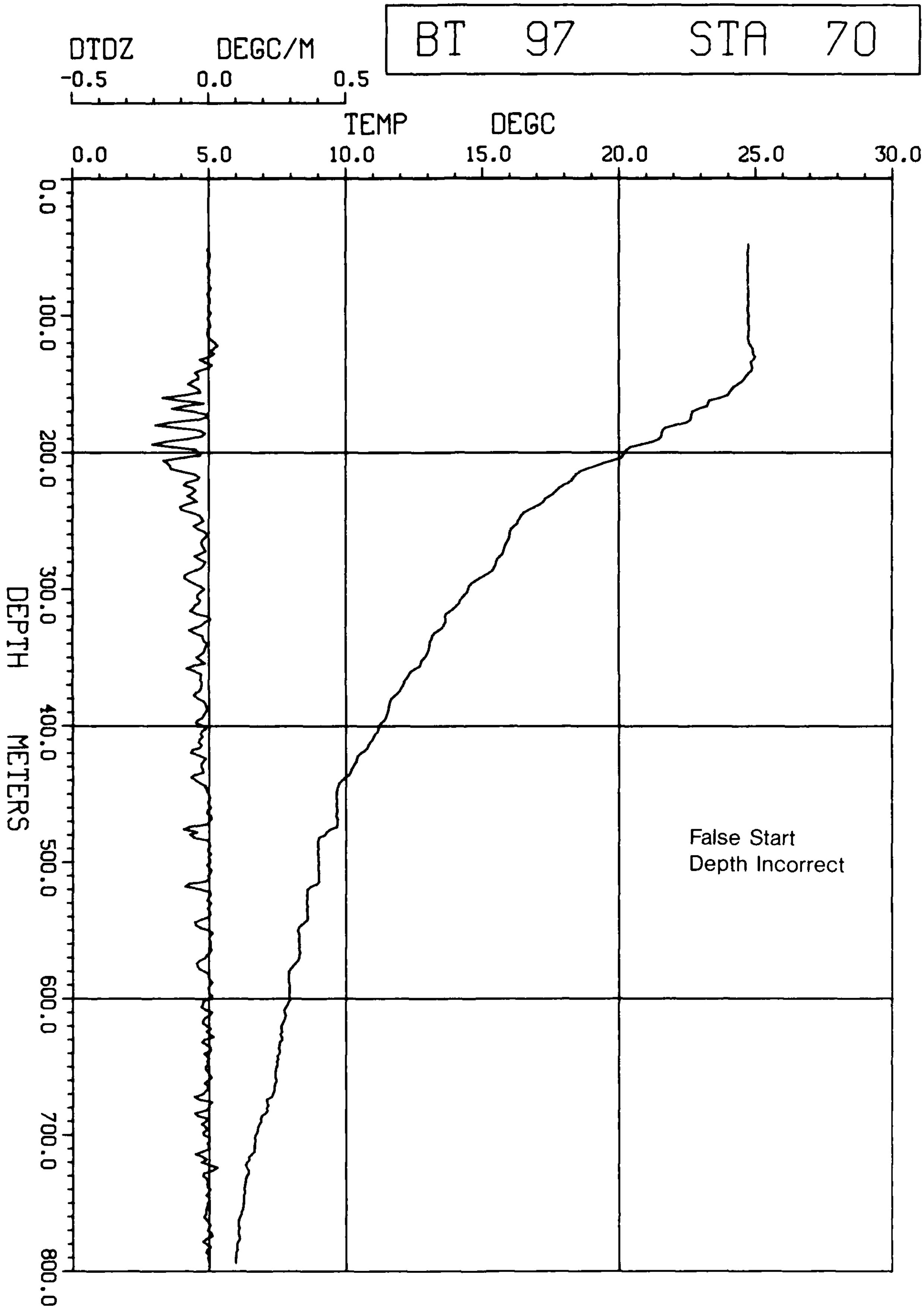
800.0


BT 97 STA 70
DTDZ DEGC/M
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DEPTH METERS
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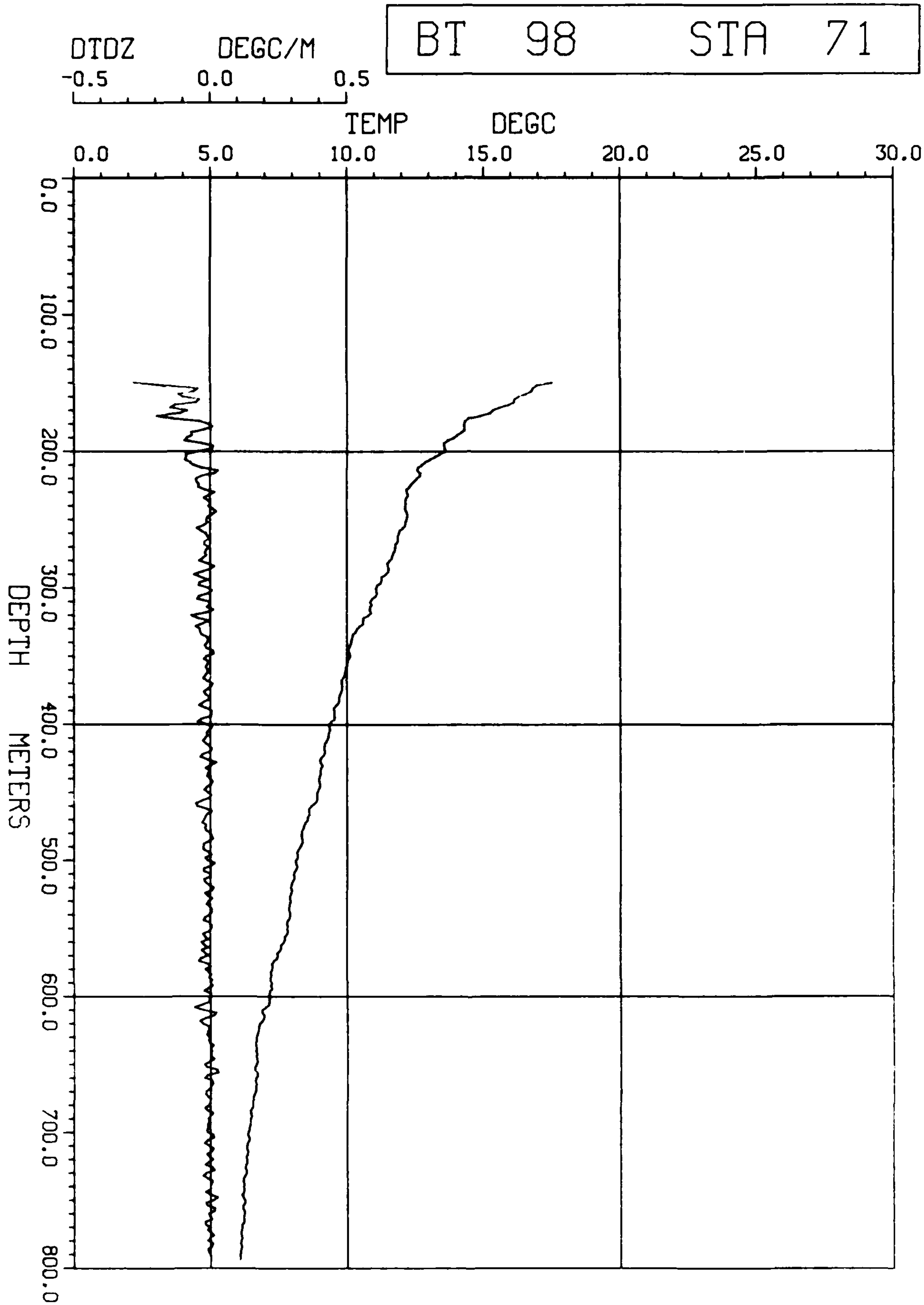
False Start
Depth Incorrect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TEMP DEGC
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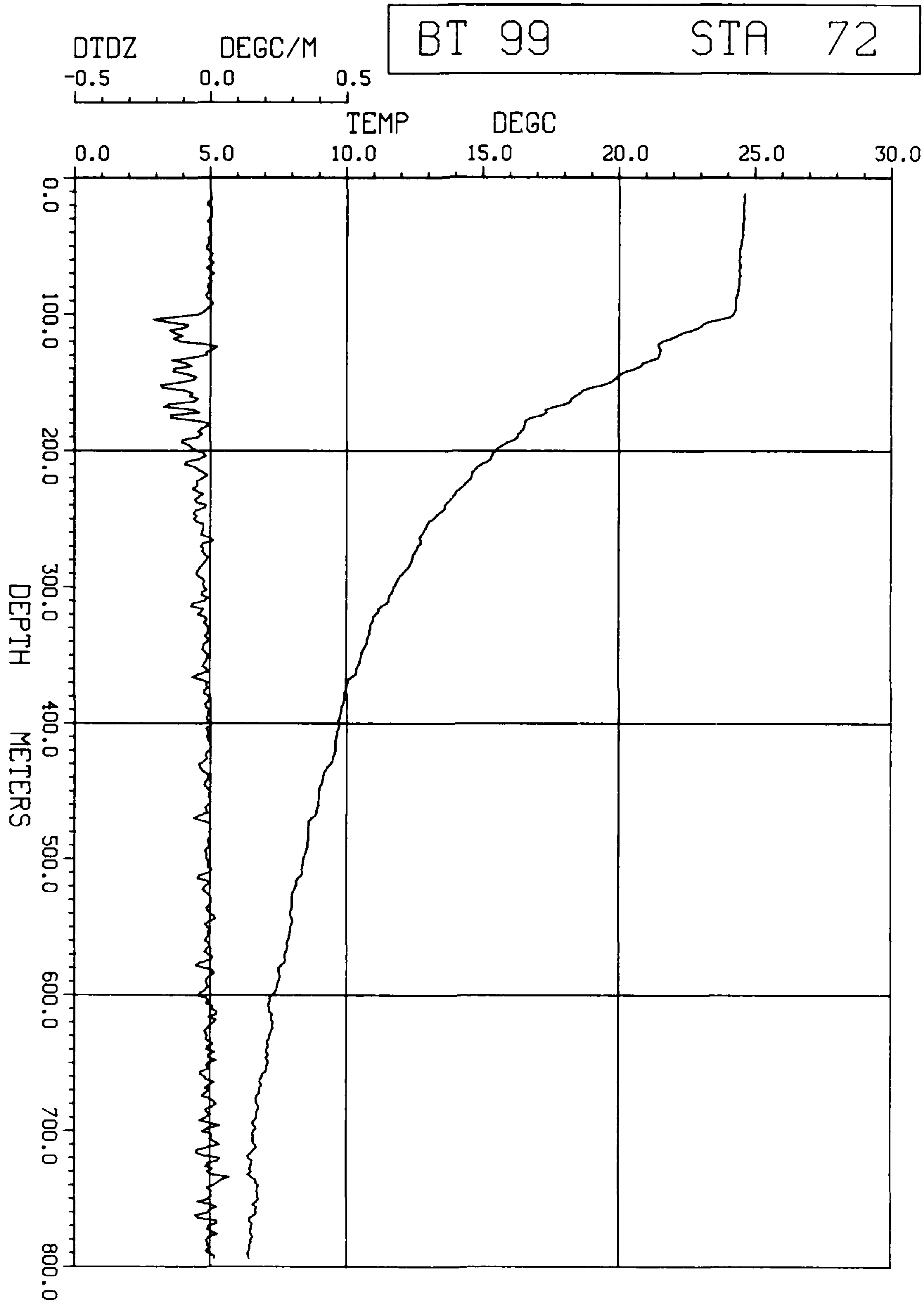
800.0
DEPTH METERS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TEMP DEGC
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DEPTH METERS
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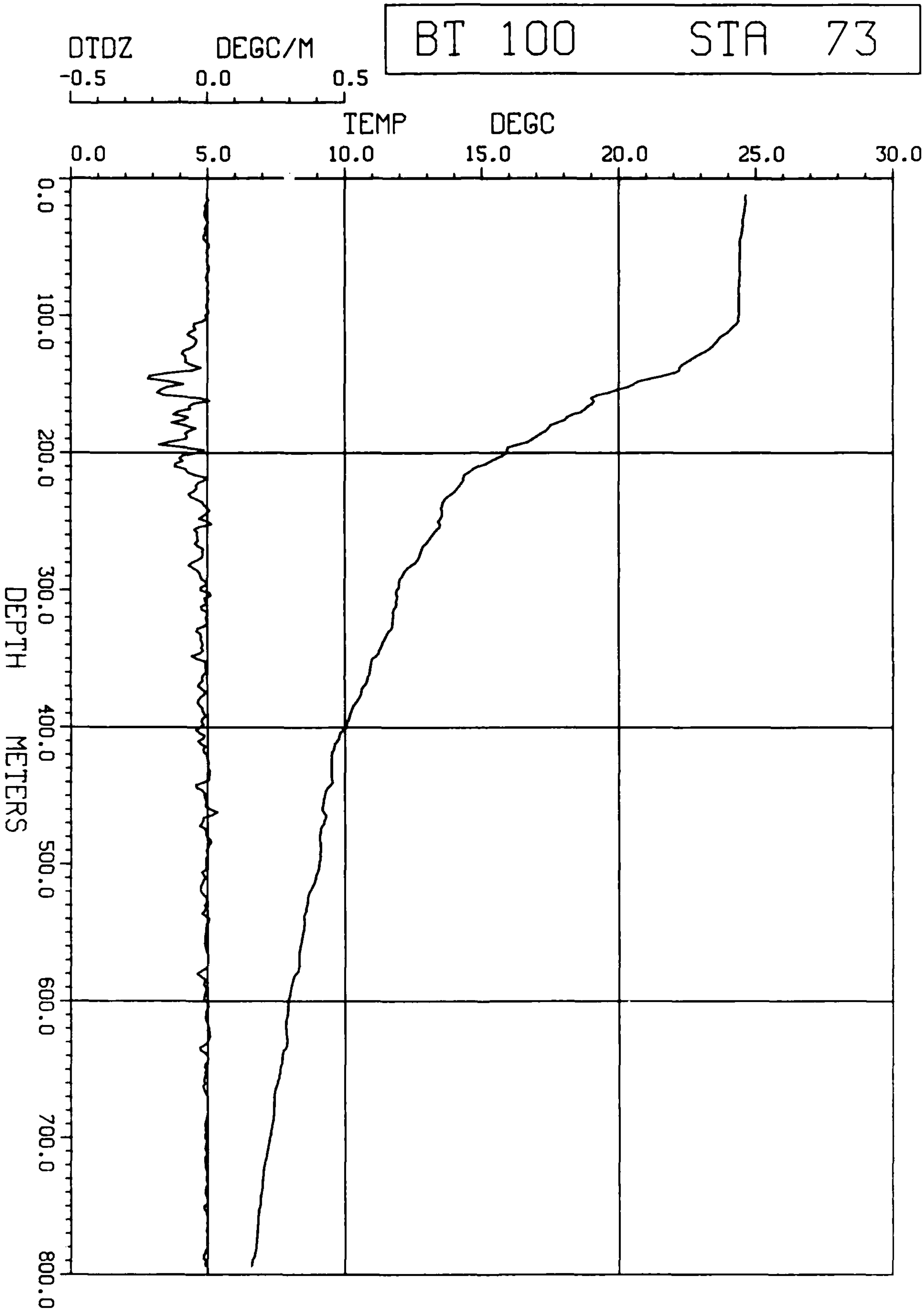

BT 100 STA 73
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TEMP DEGC
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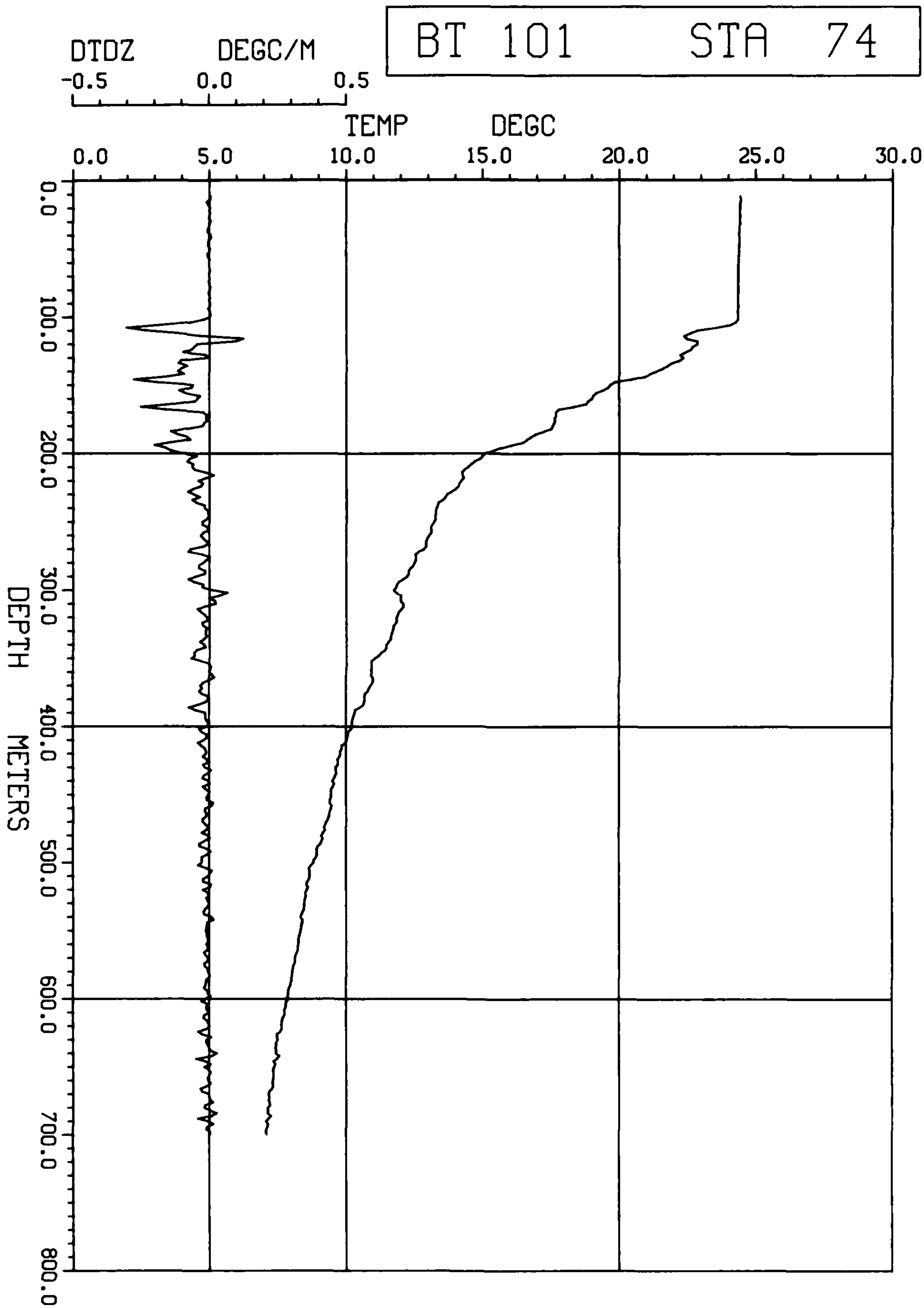
DEPTH METERS



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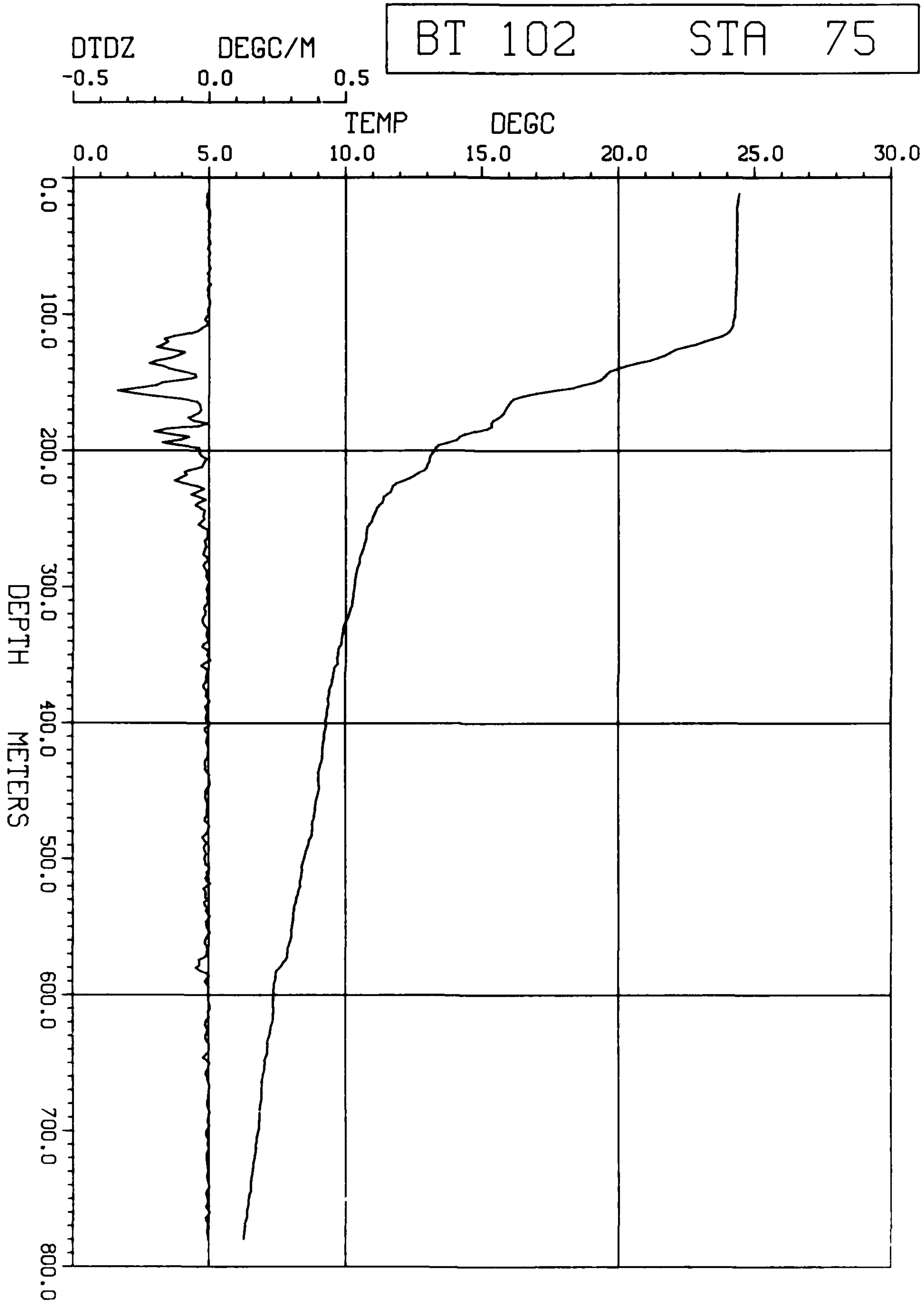

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DEPTH METERS
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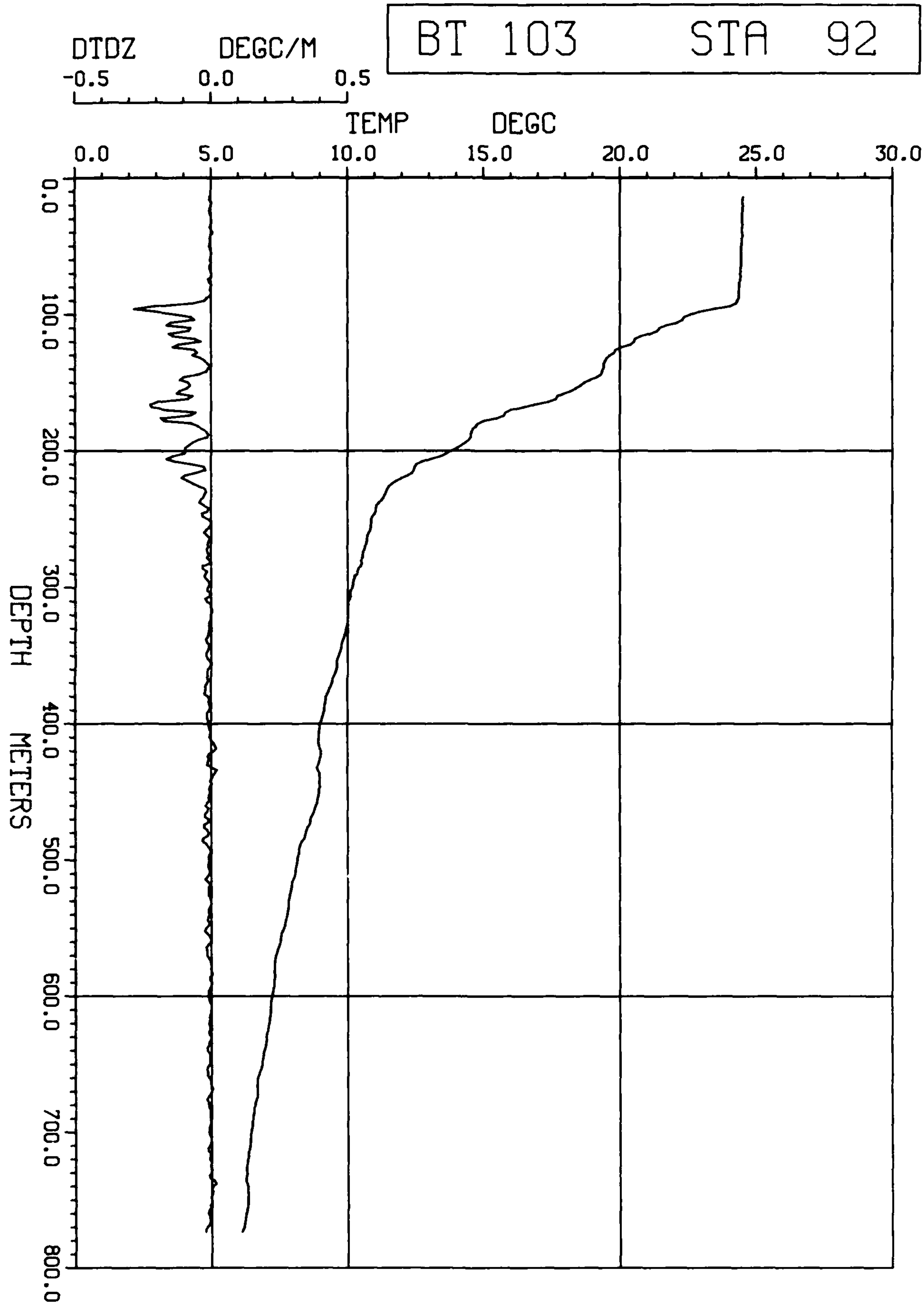
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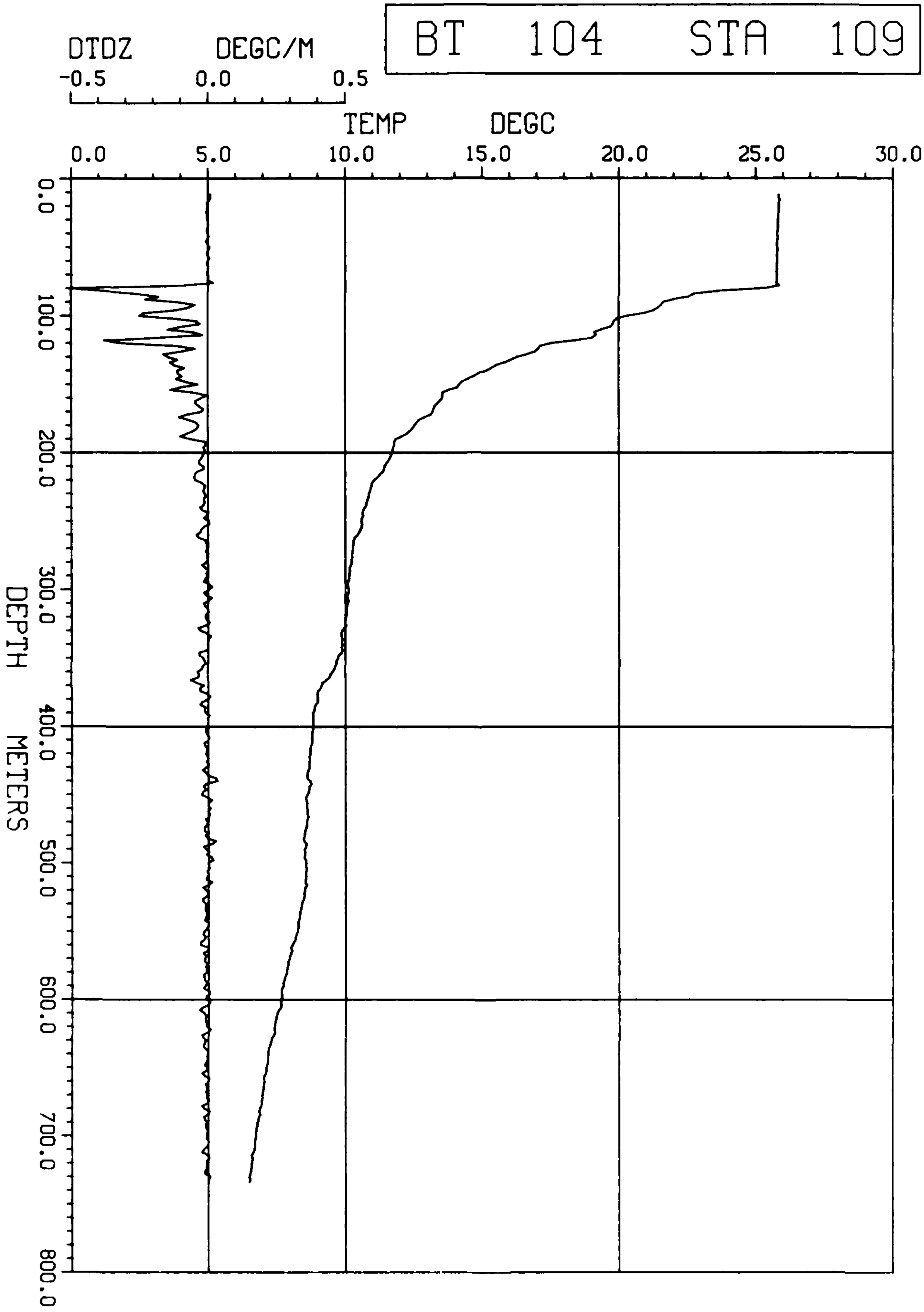

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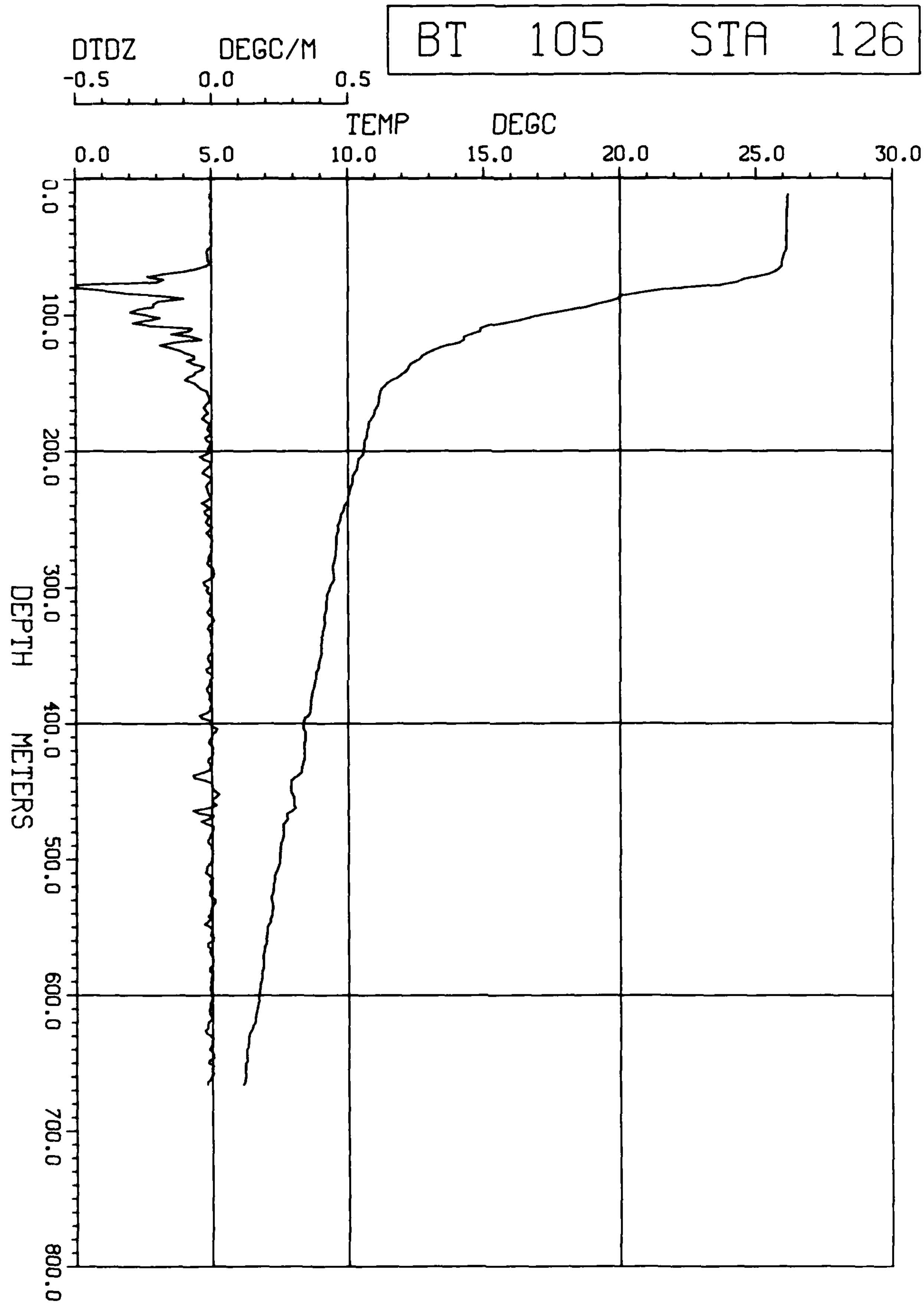
DEPTH METERS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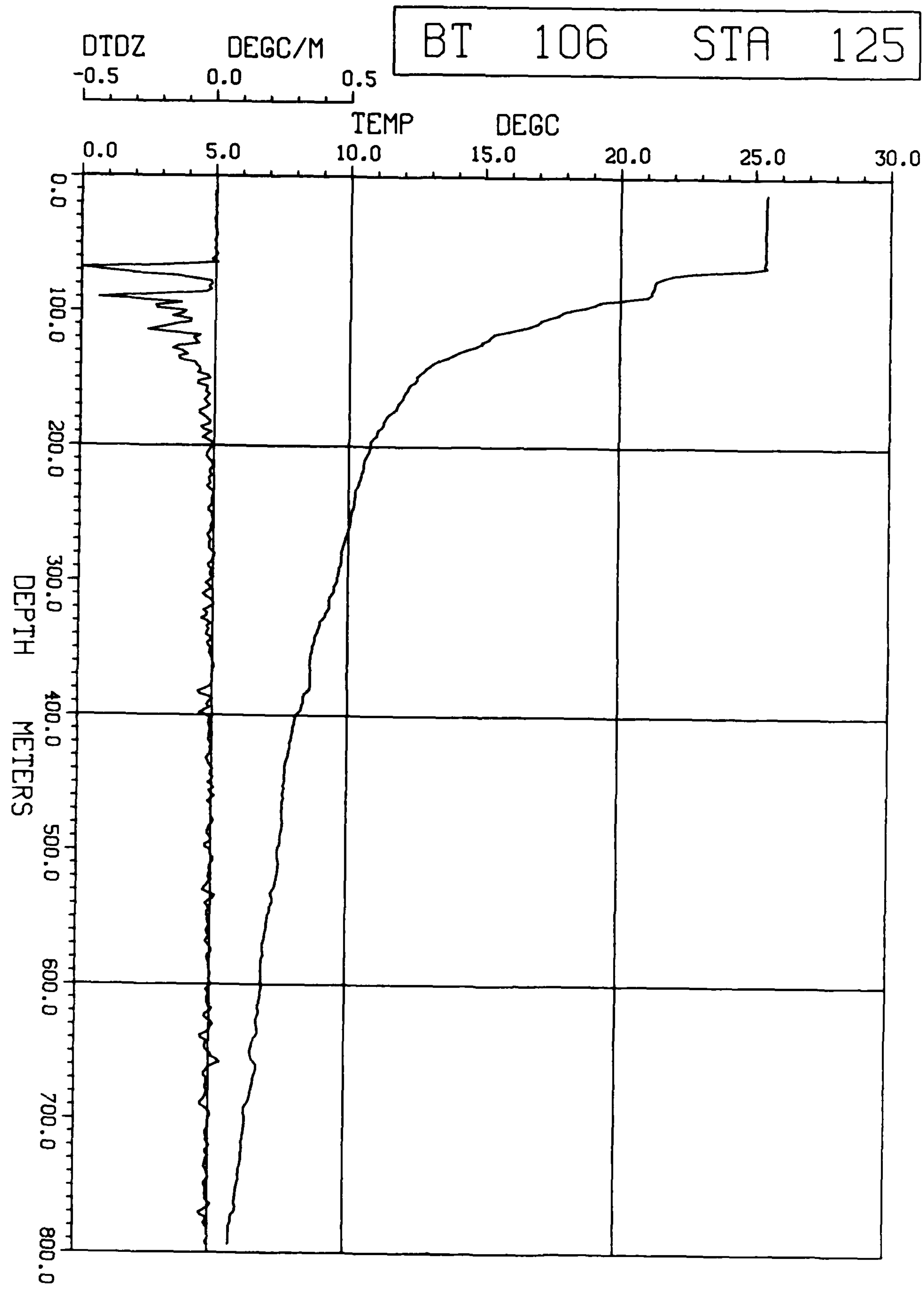
DEPTH METERS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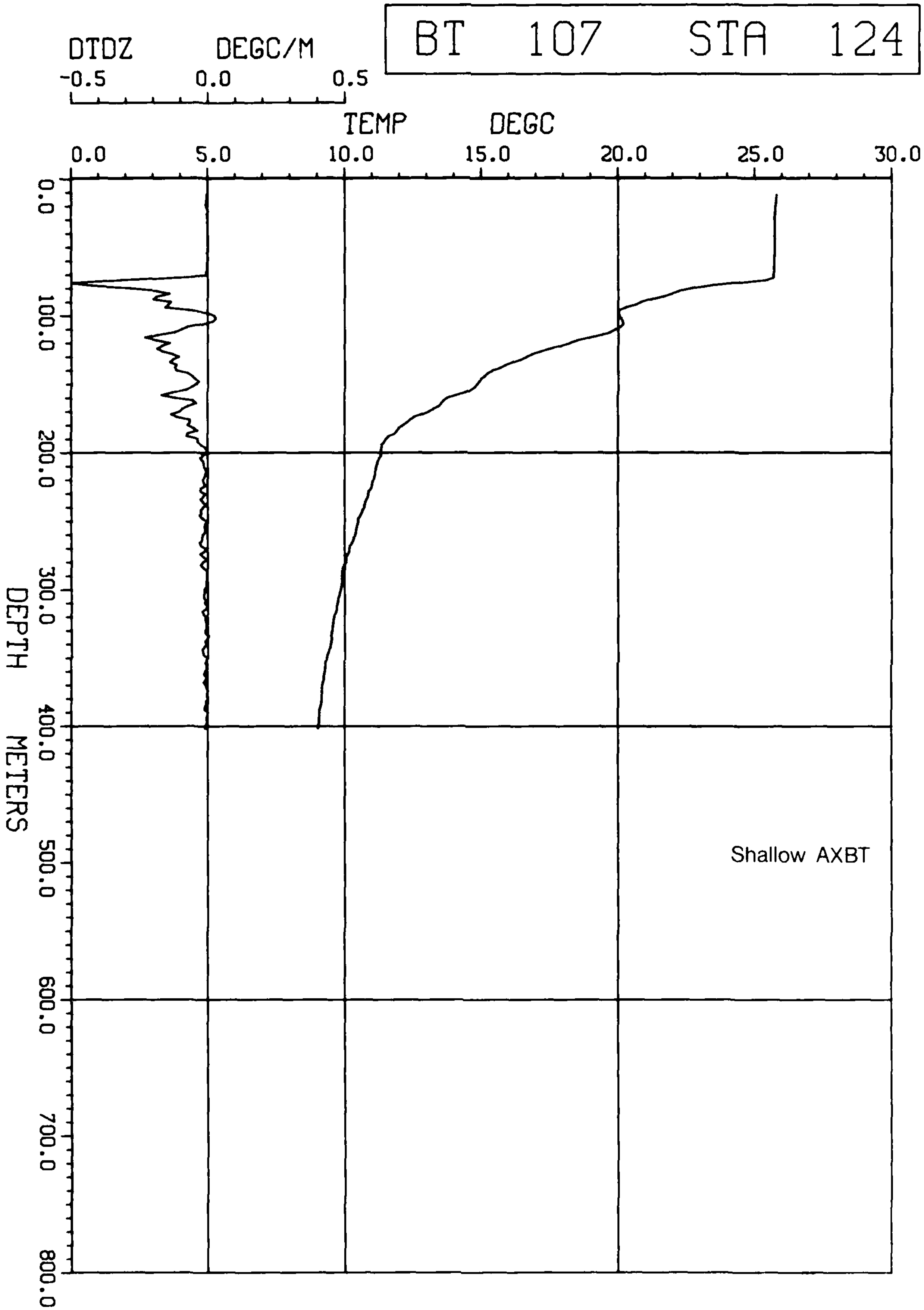

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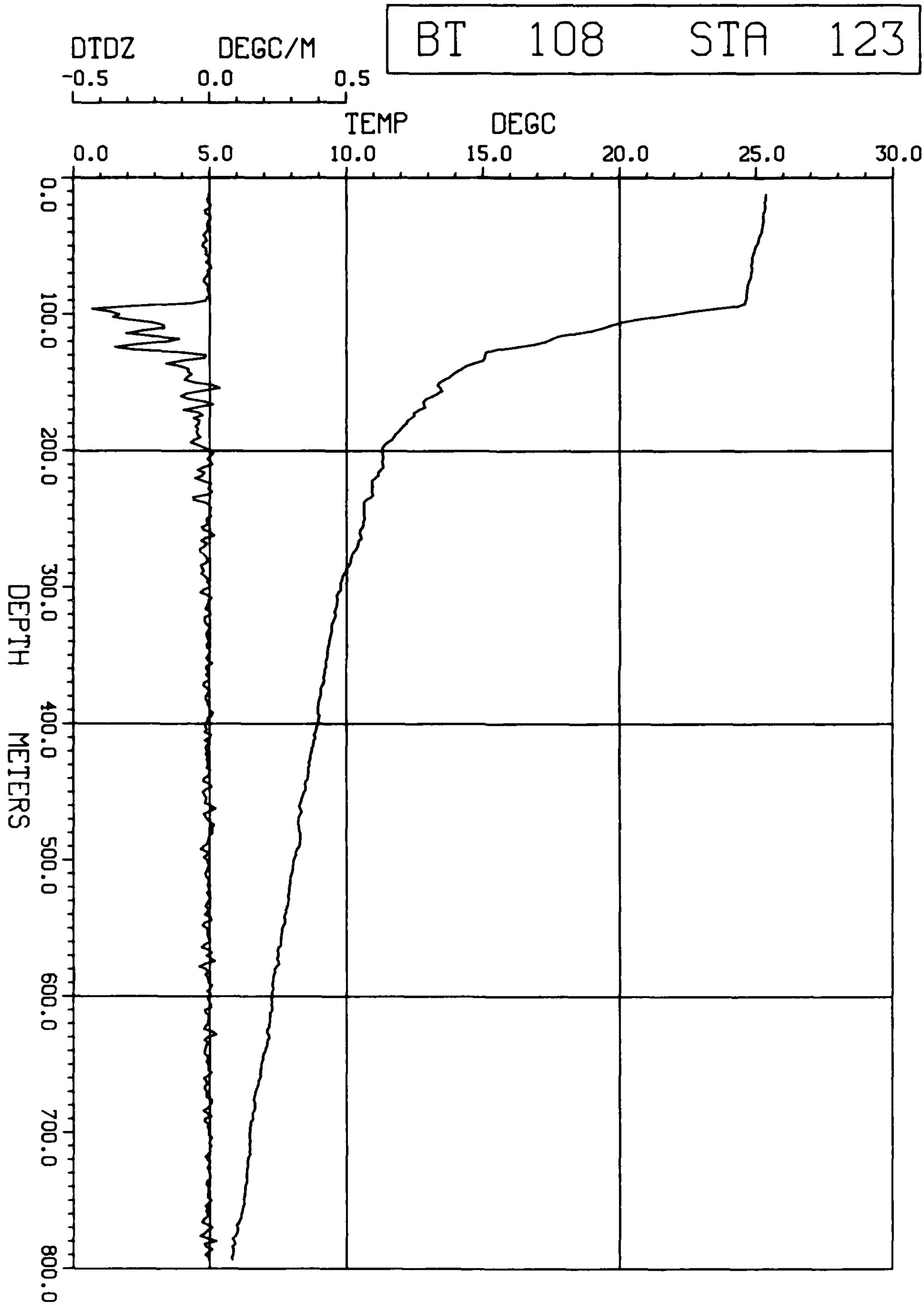
Shallow AXBT



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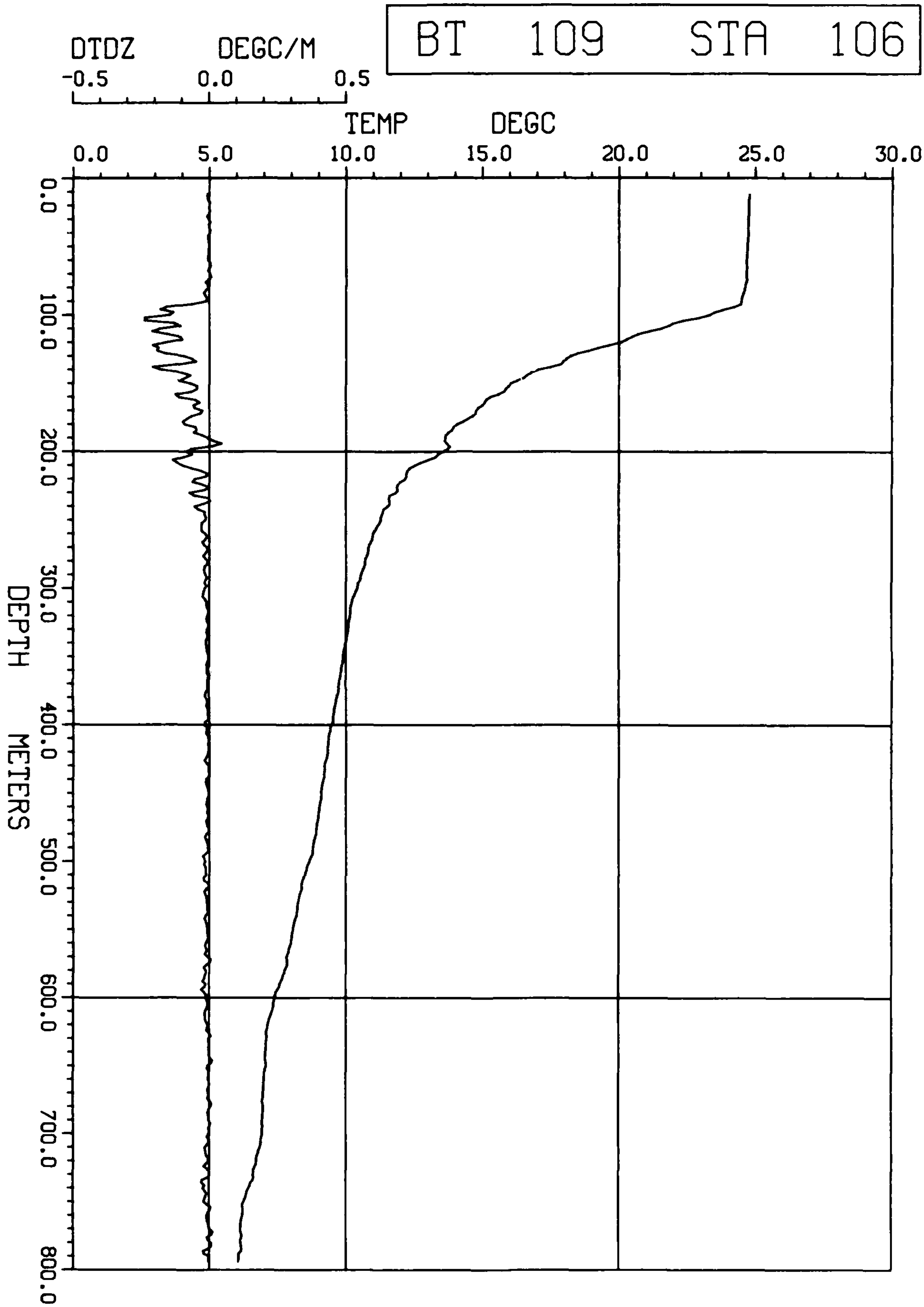
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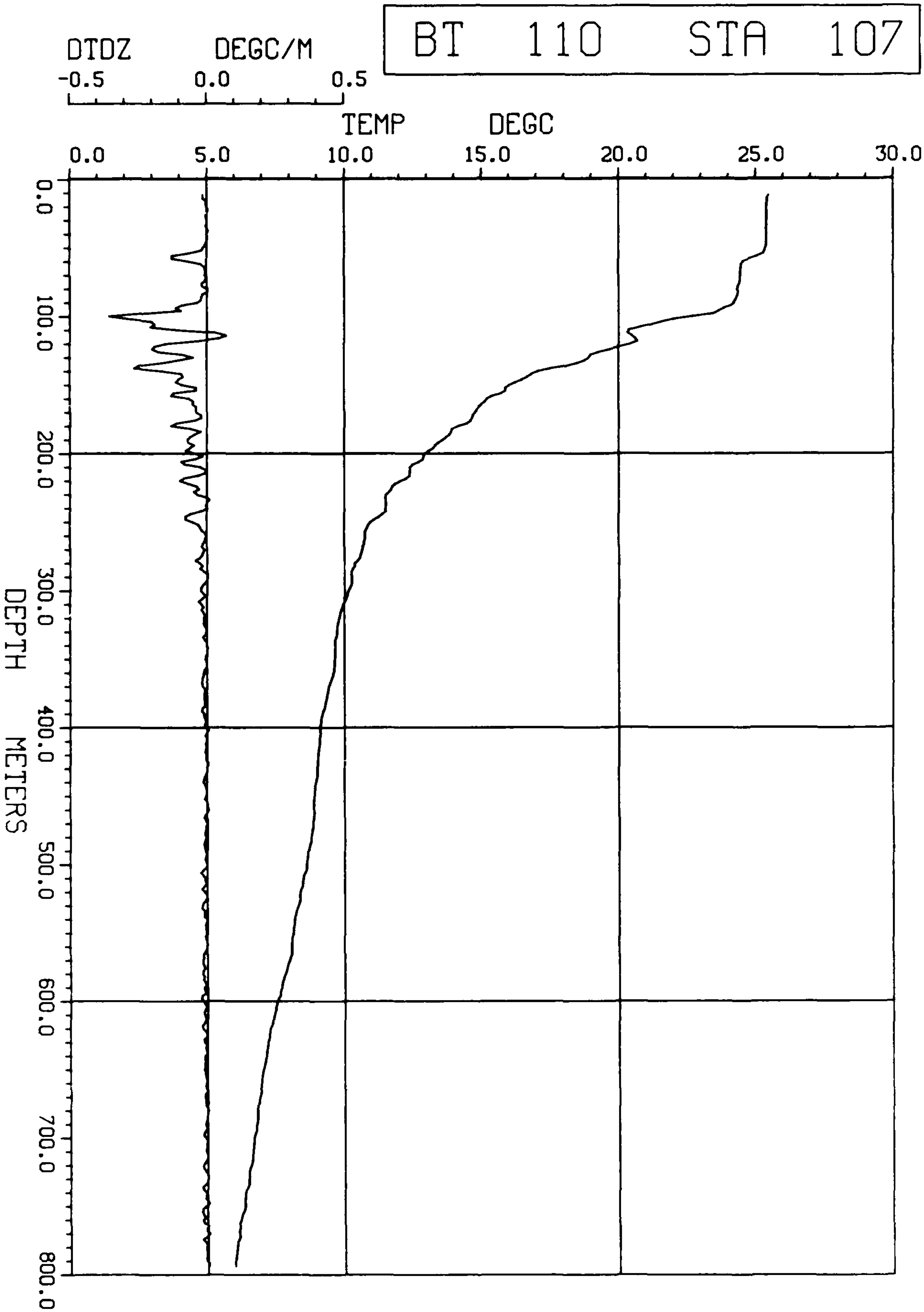
DEPTH METERS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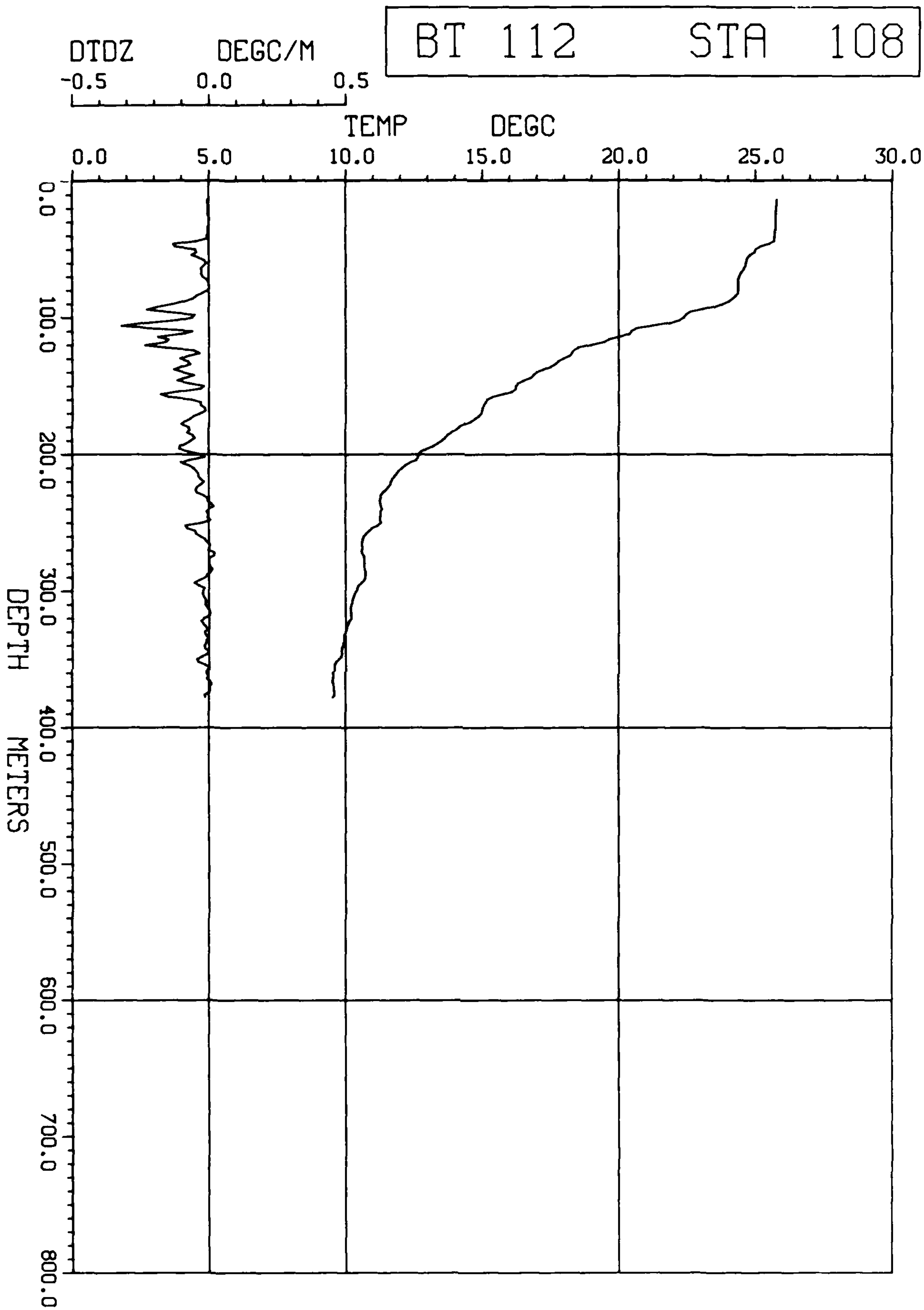
DEPTH METERS


BT 112 STA 108
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TEMP DEGC
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DEPTH METERS
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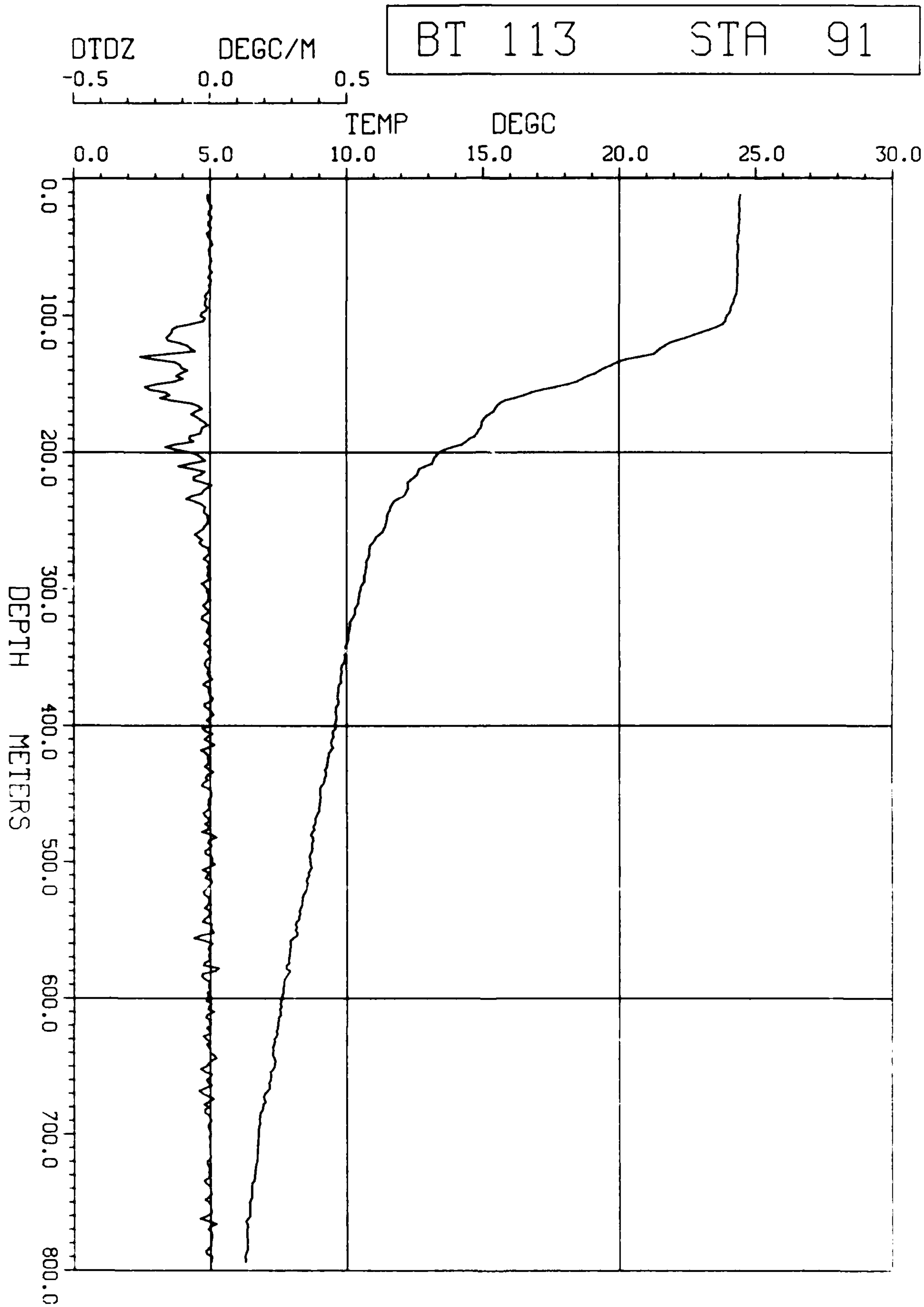

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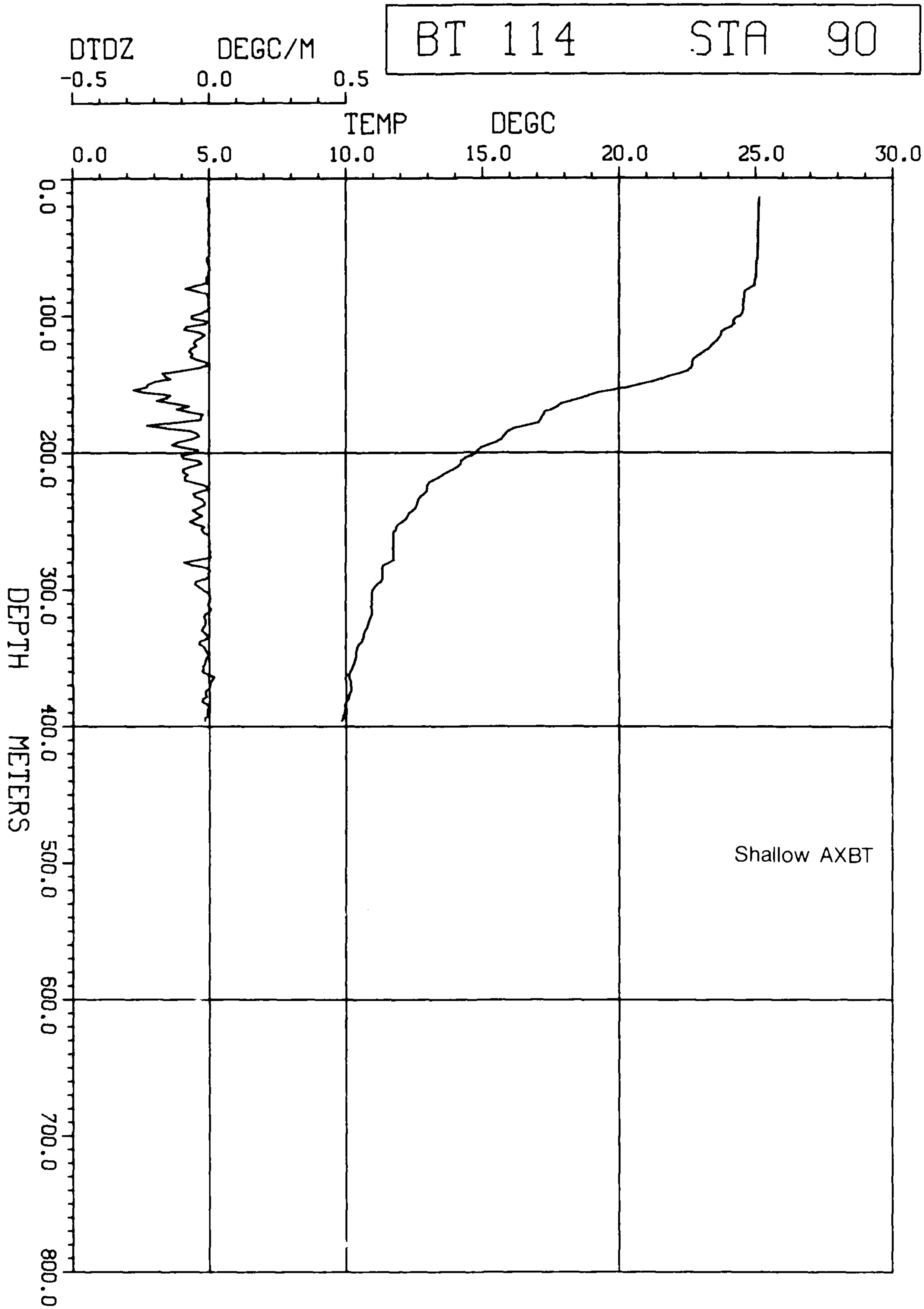
500.0
600.0
700.0
800.0
DEPTH METERS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DTDZ DEGC/M
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TEMP DEGC
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DEPTH METERS
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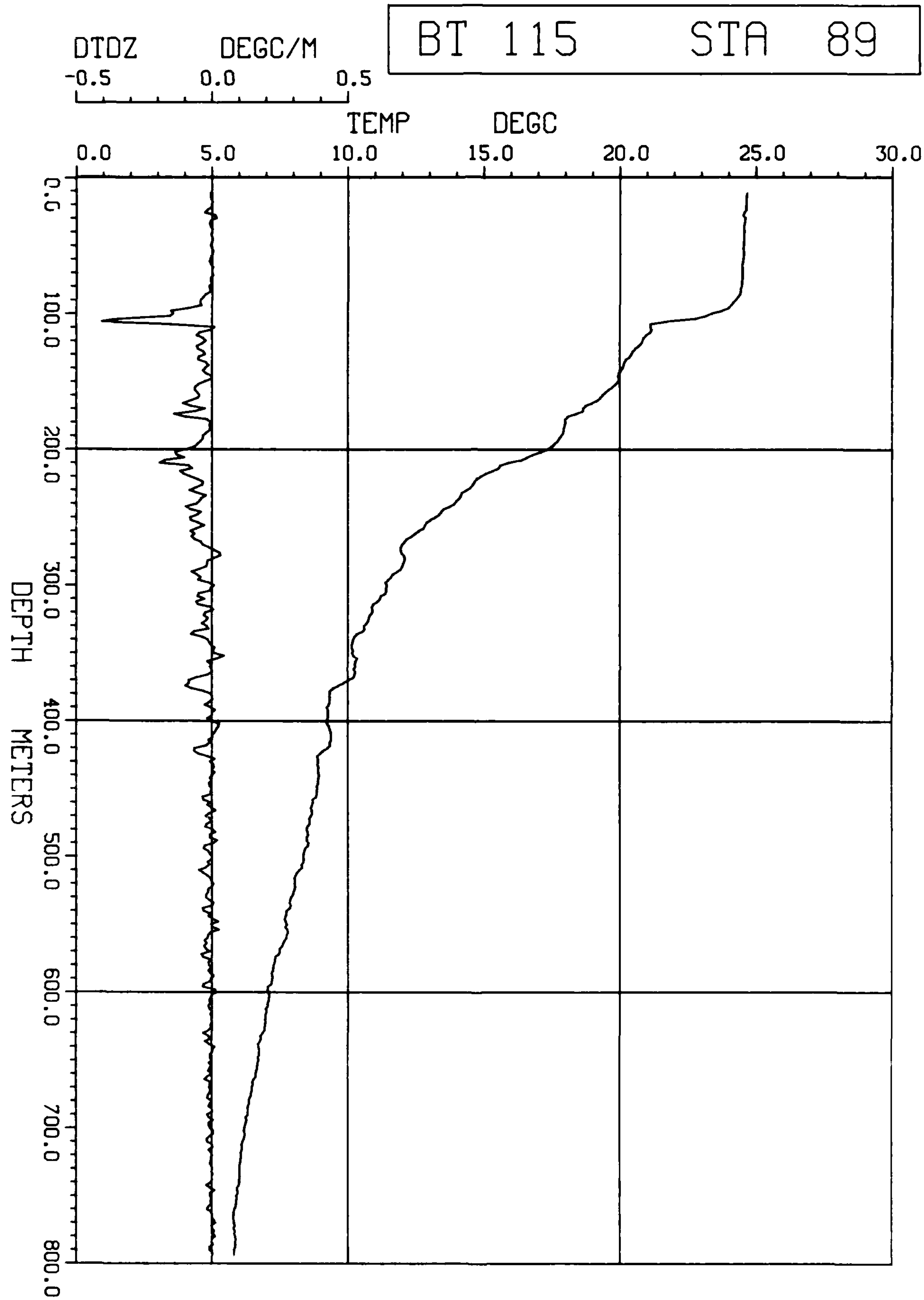
Shallow AXBT


BT 115 STA 89
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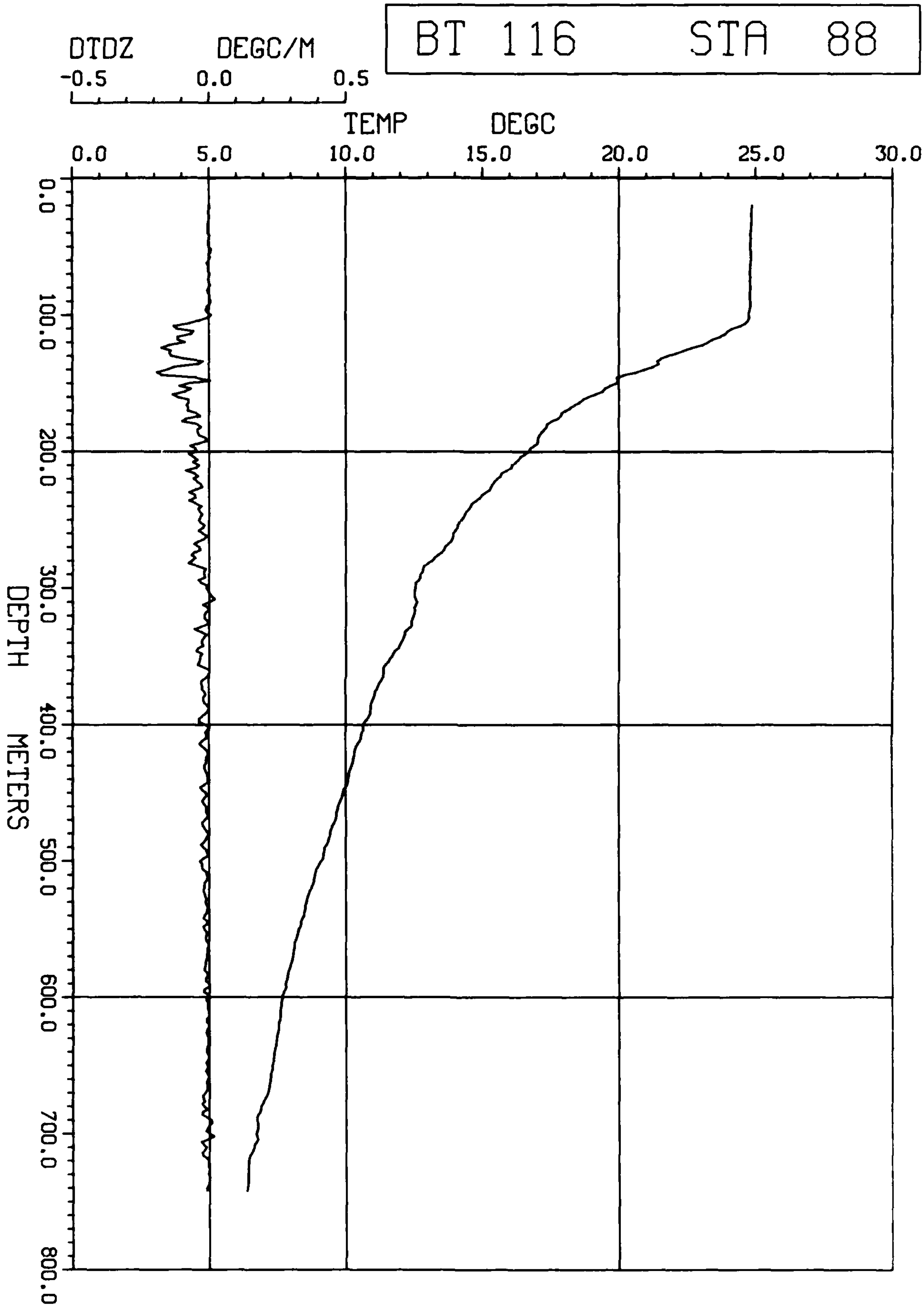
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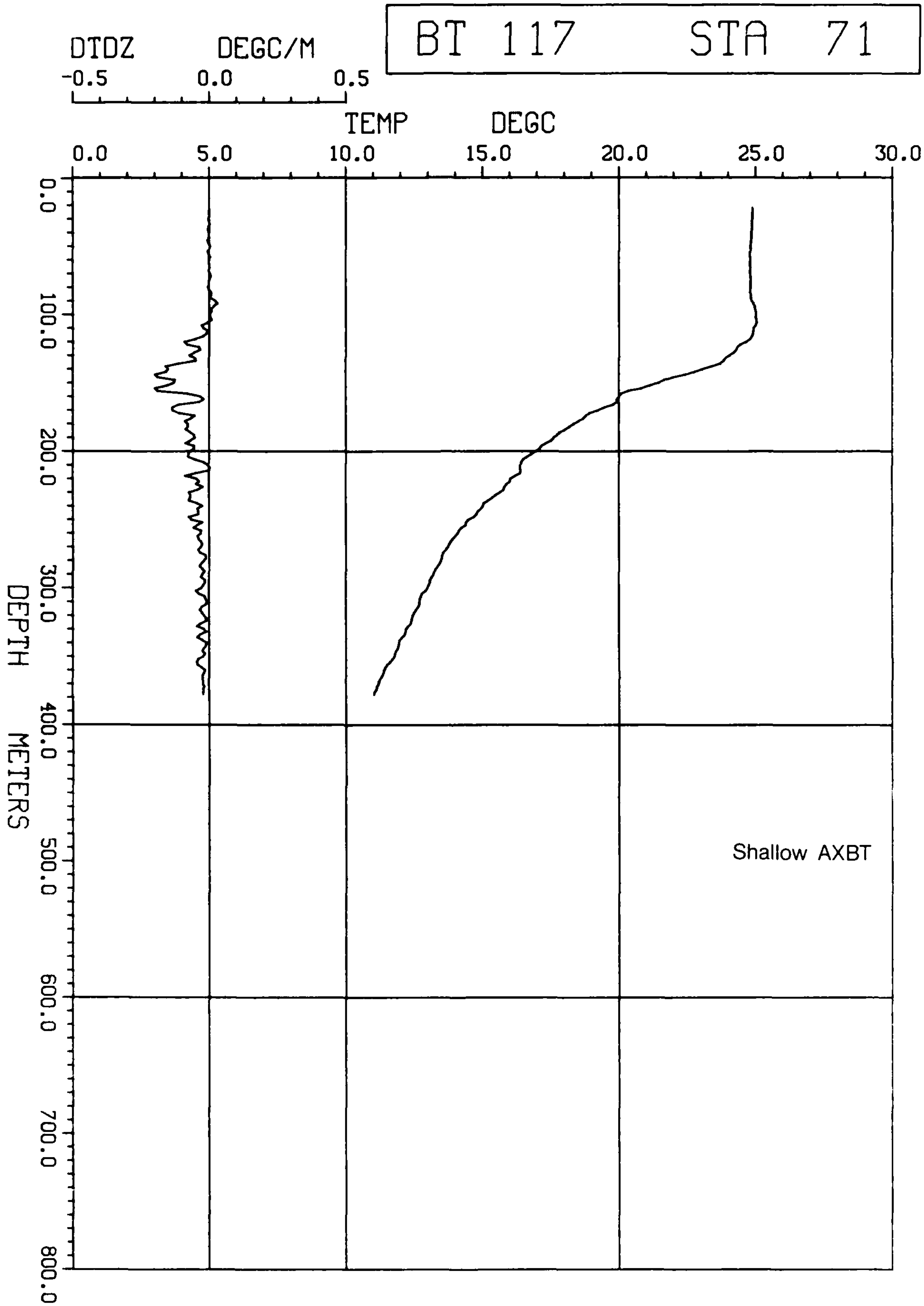
BT 117 STA 71
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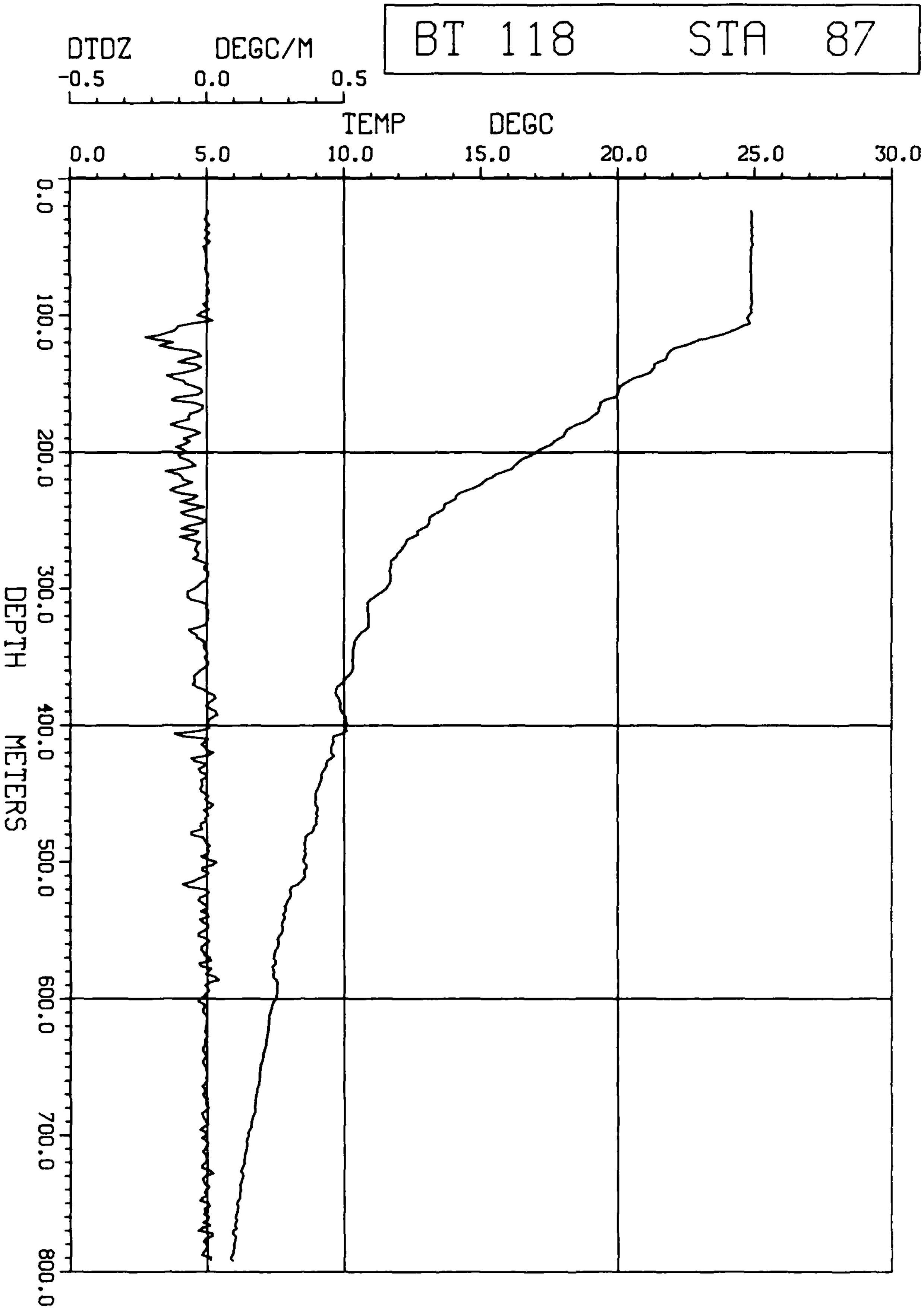
0.0 5.0 10.0 15.0 20.0 25.0 30.0
DEPTH METERS
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0
Shallow AXBT



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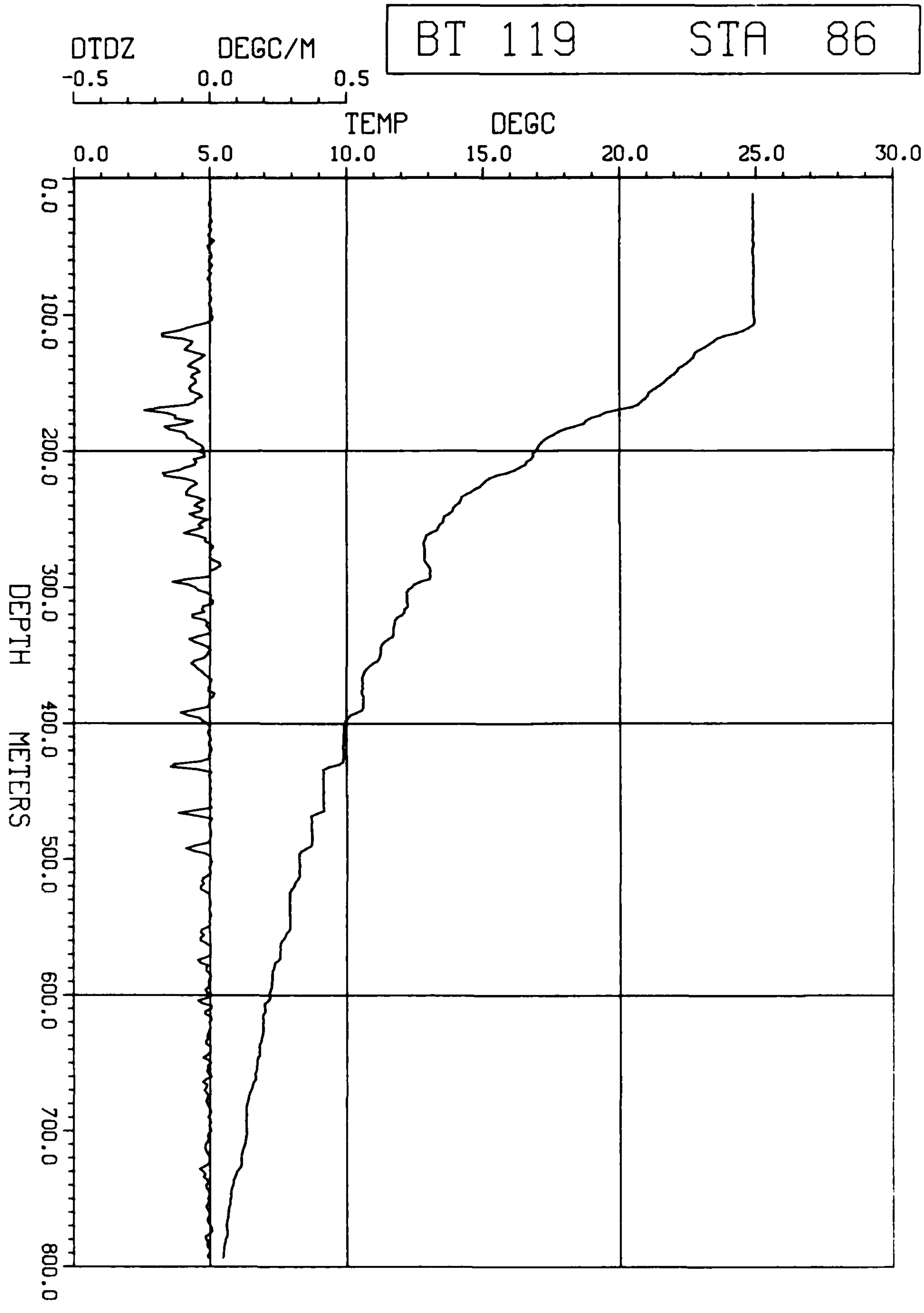
DEPTH METERS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TEMP DEGC
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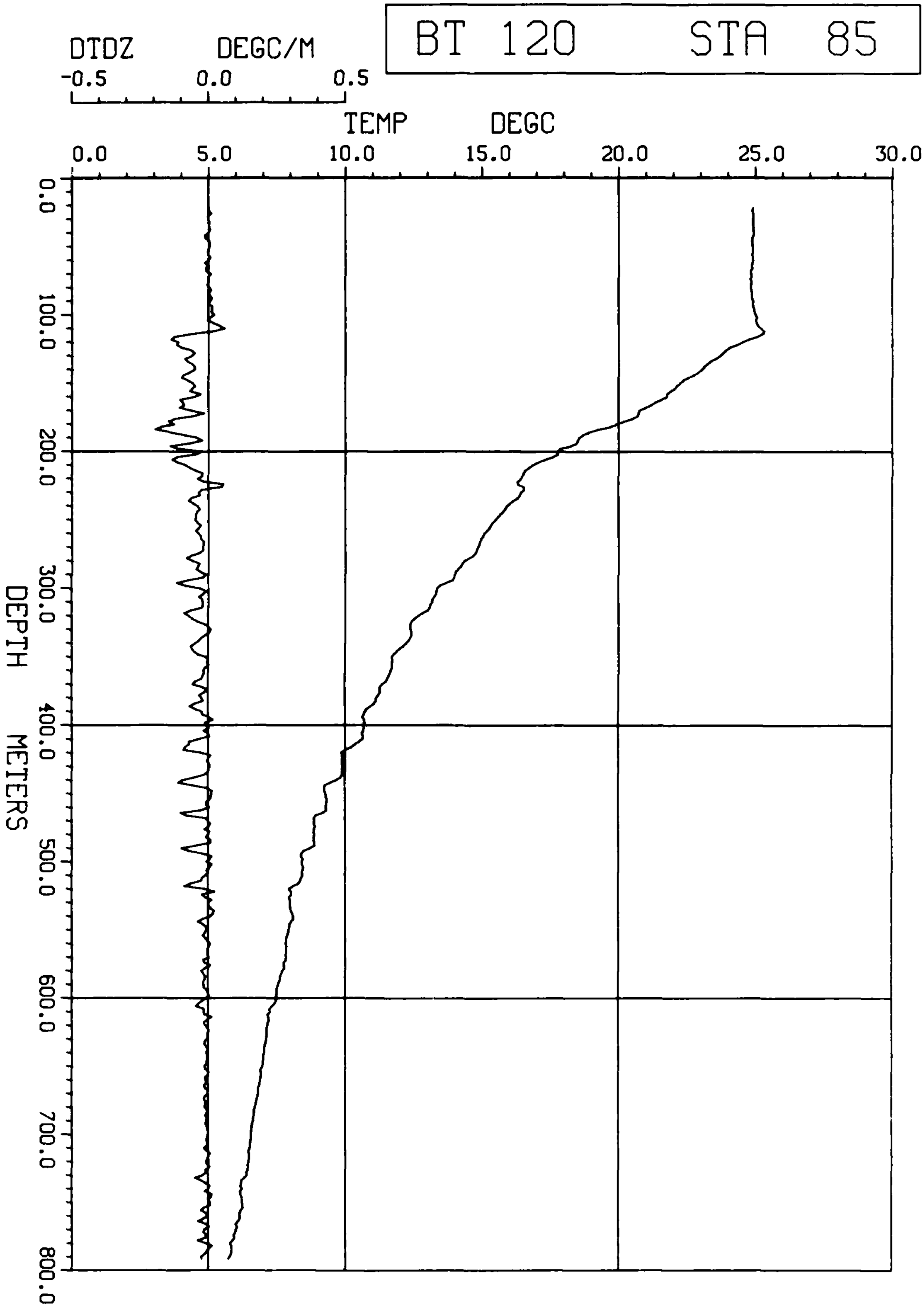
DEPTH METERS



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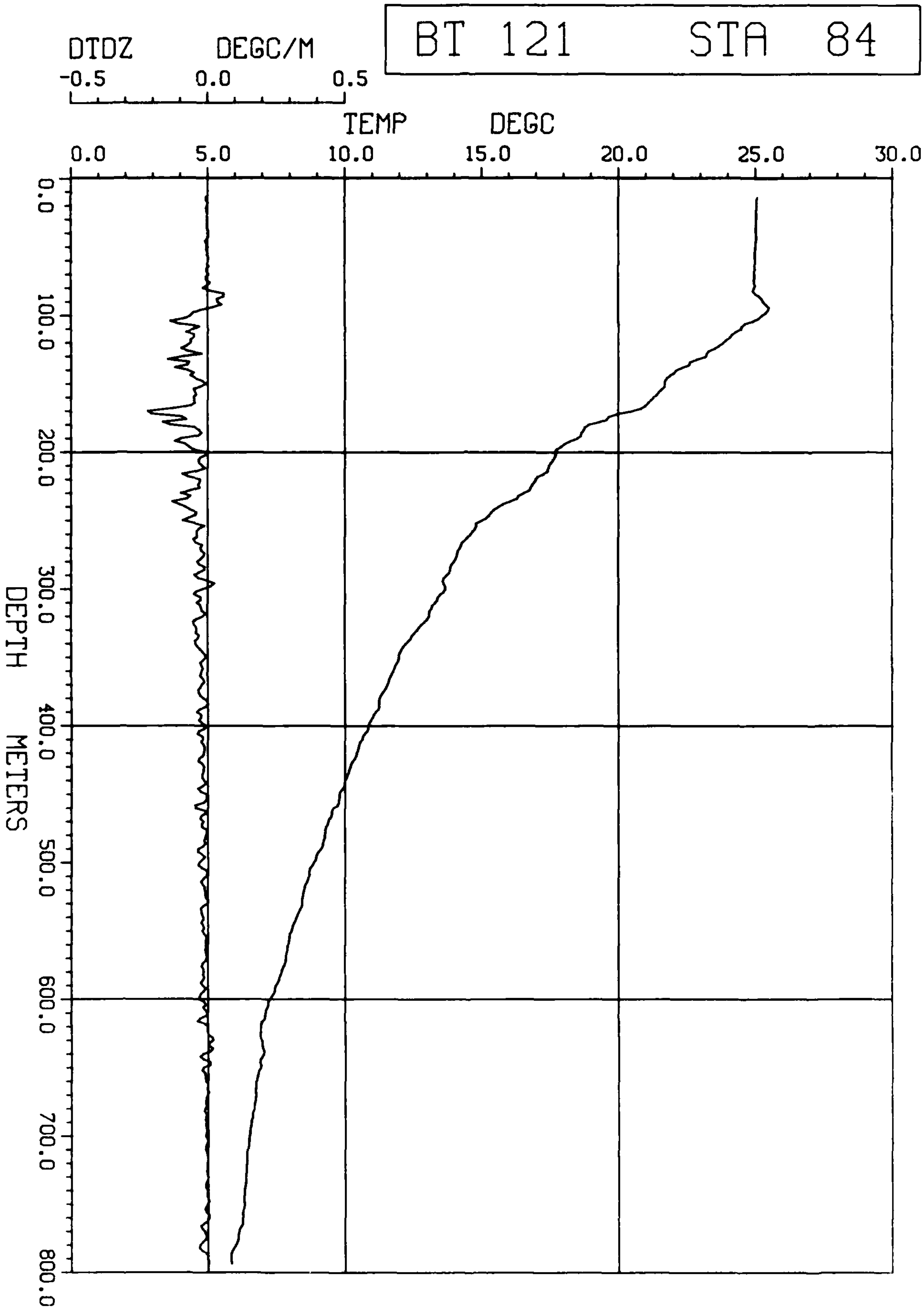
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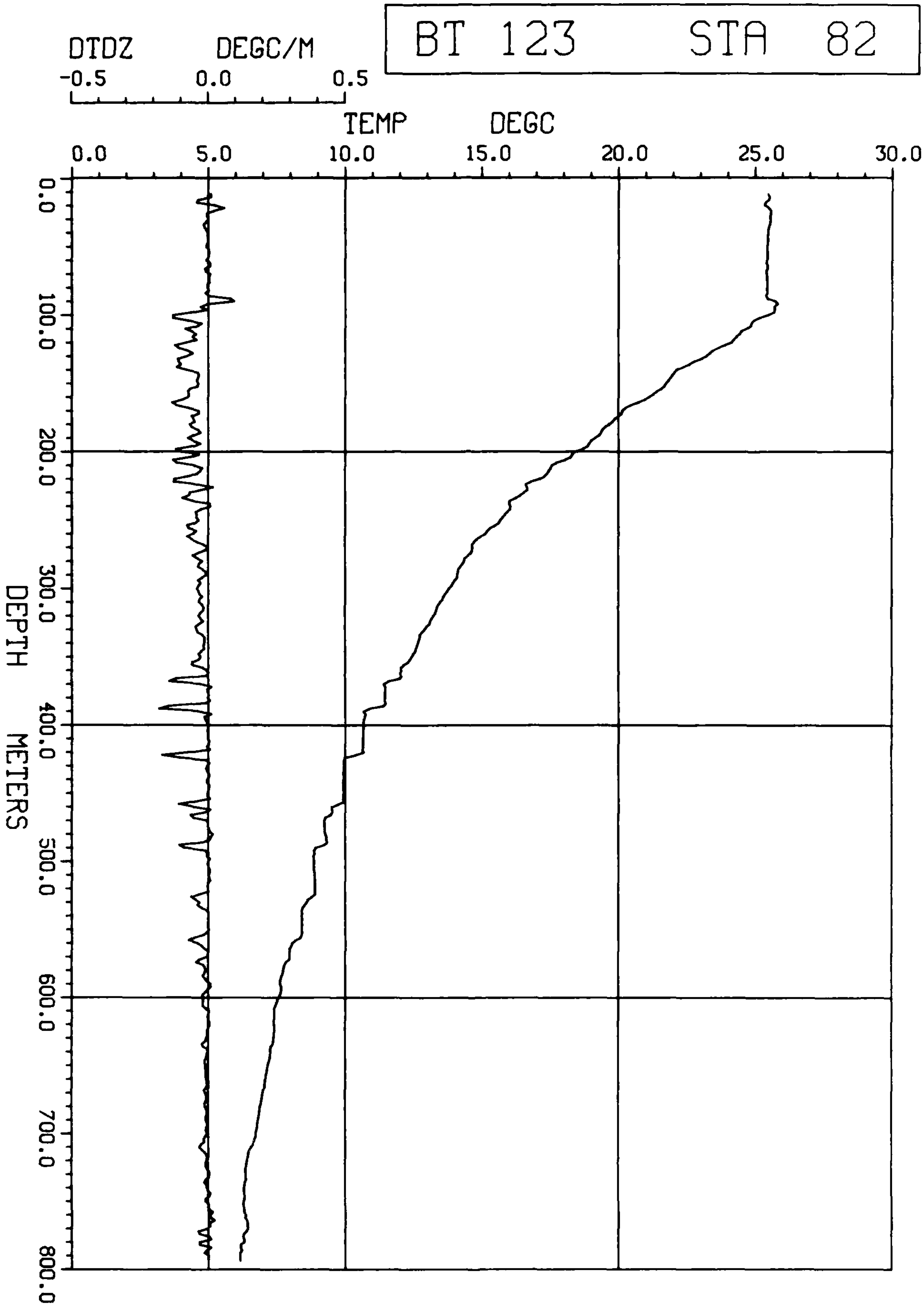
DEPTH METERS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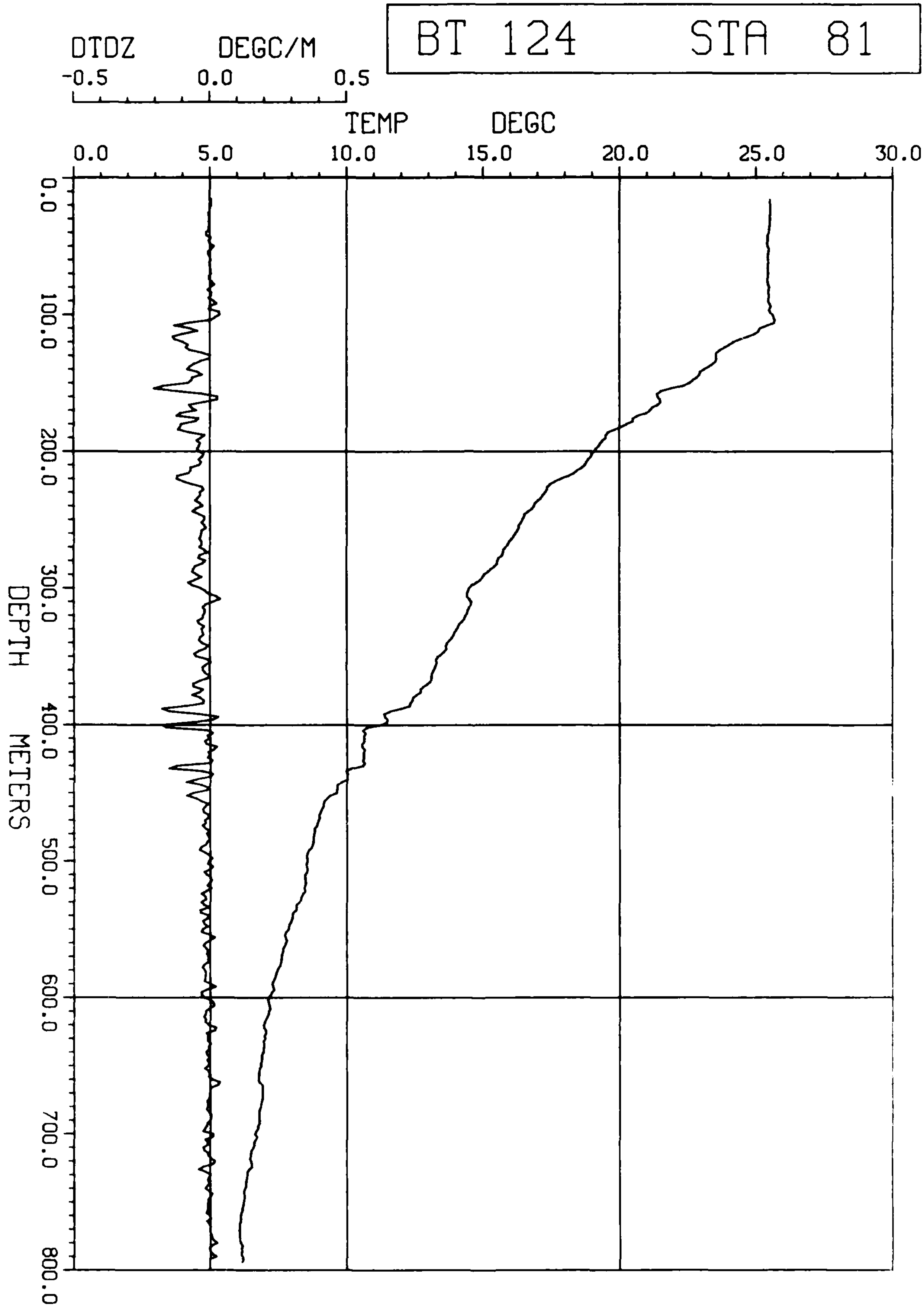

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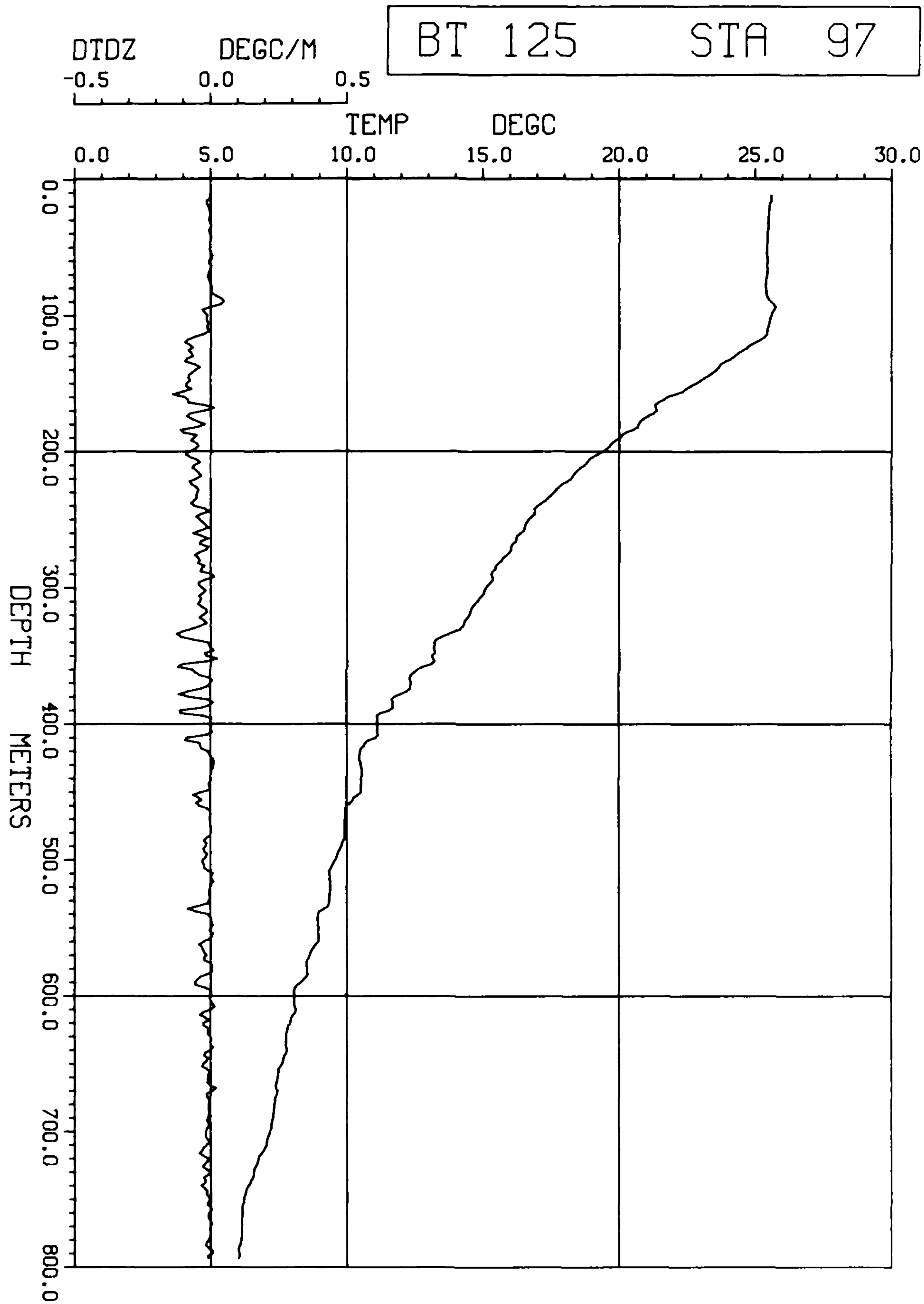
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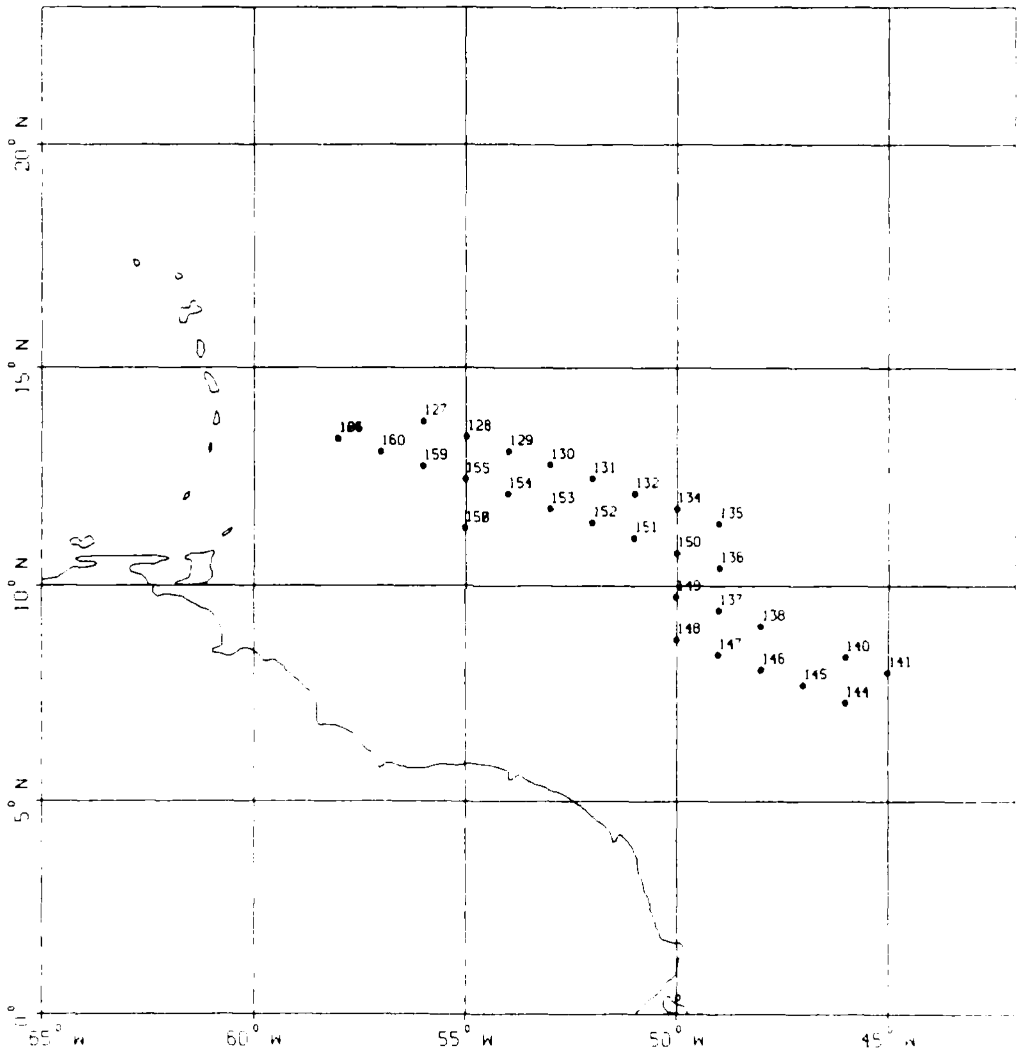
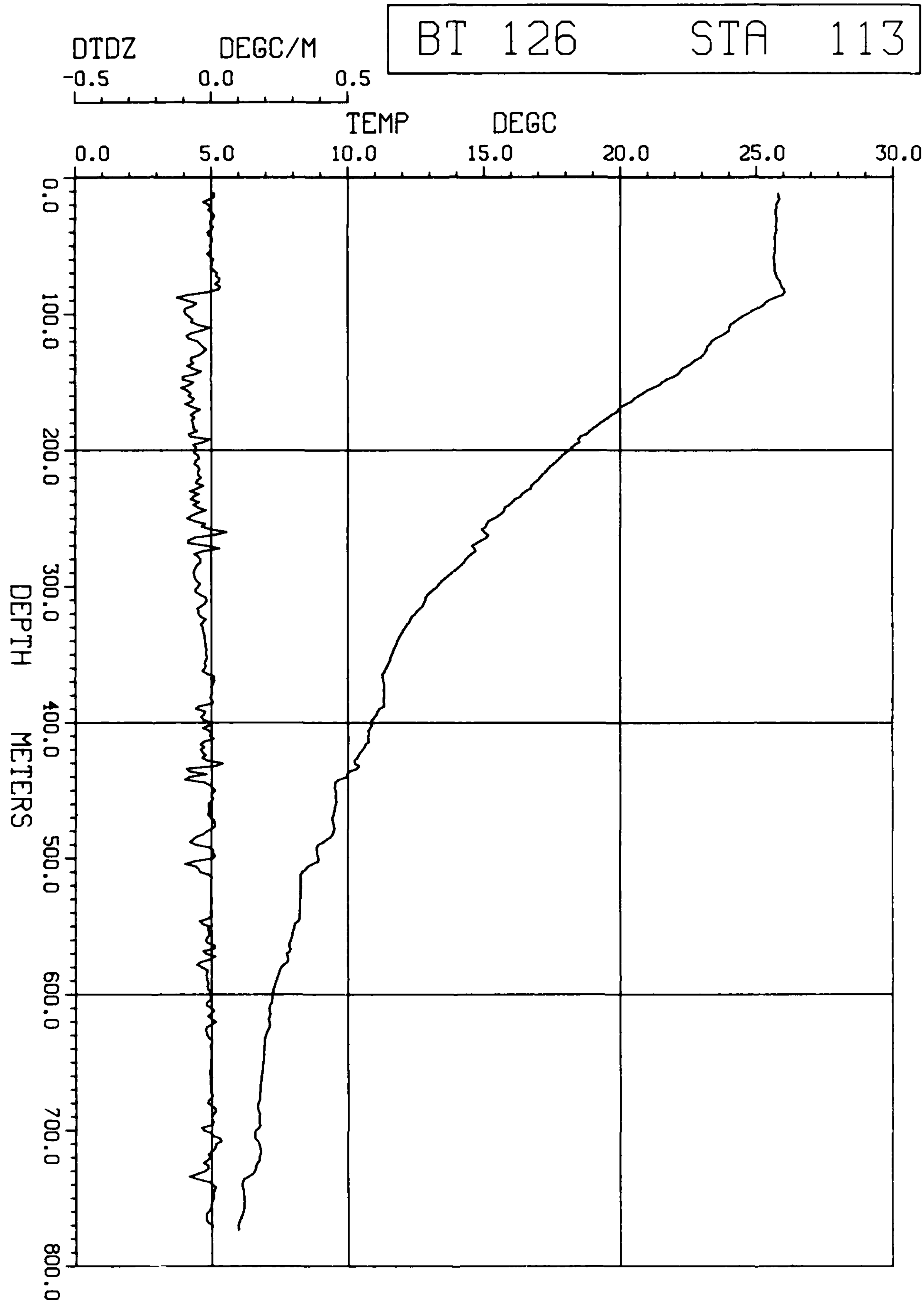
Station Positions Flight 4
29 March 1985





BT 126 STA 113
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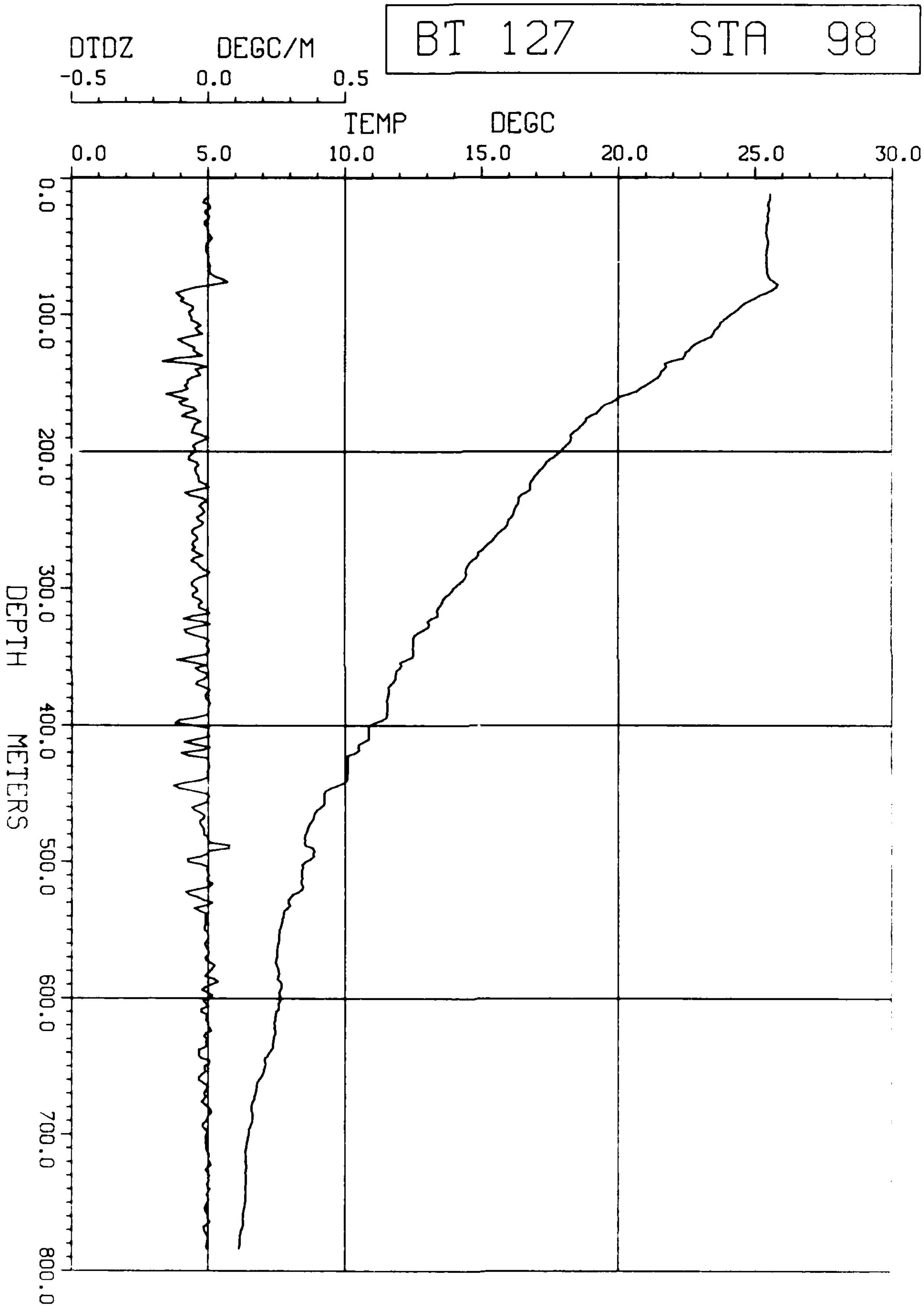
DEPTH METERS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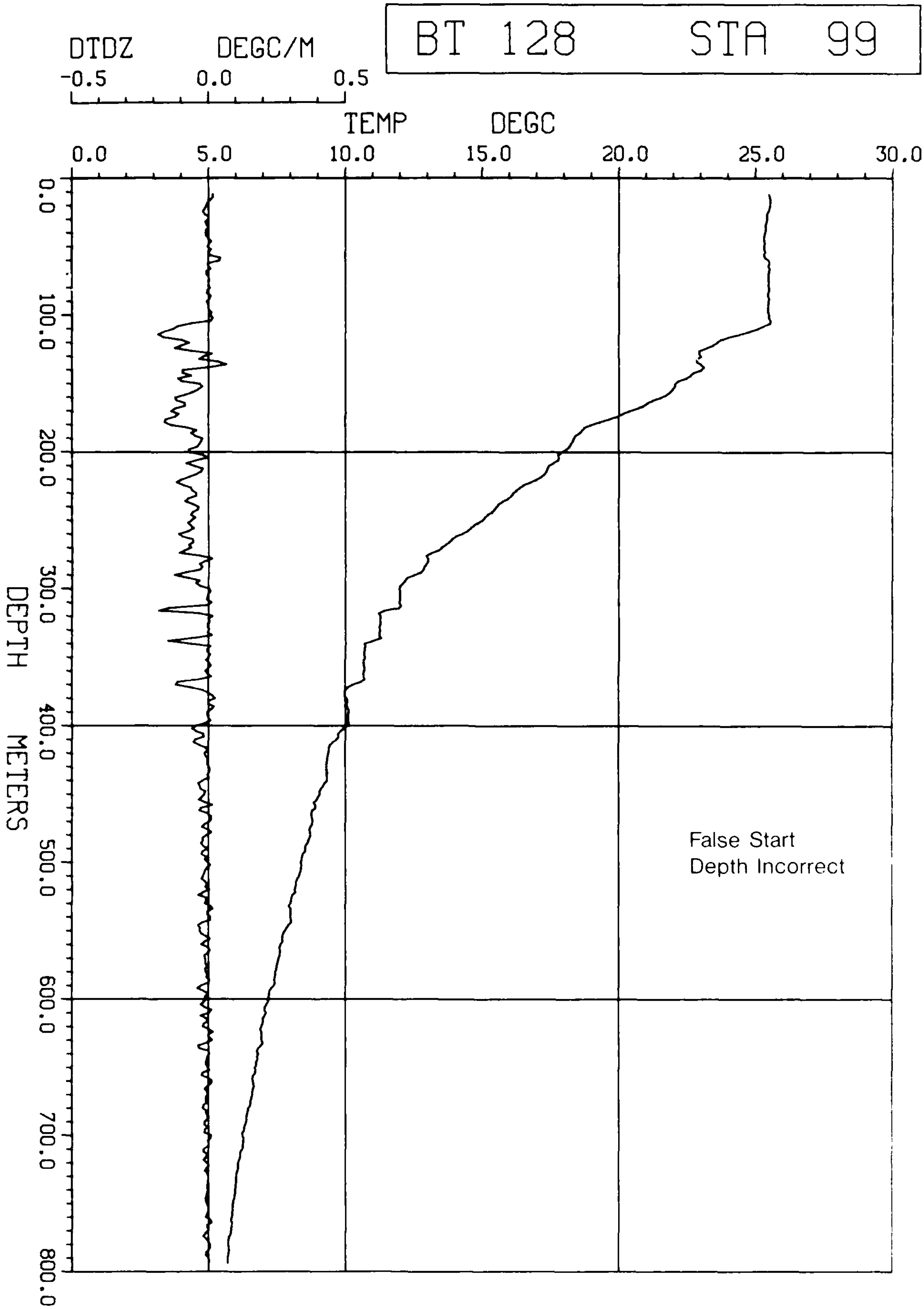
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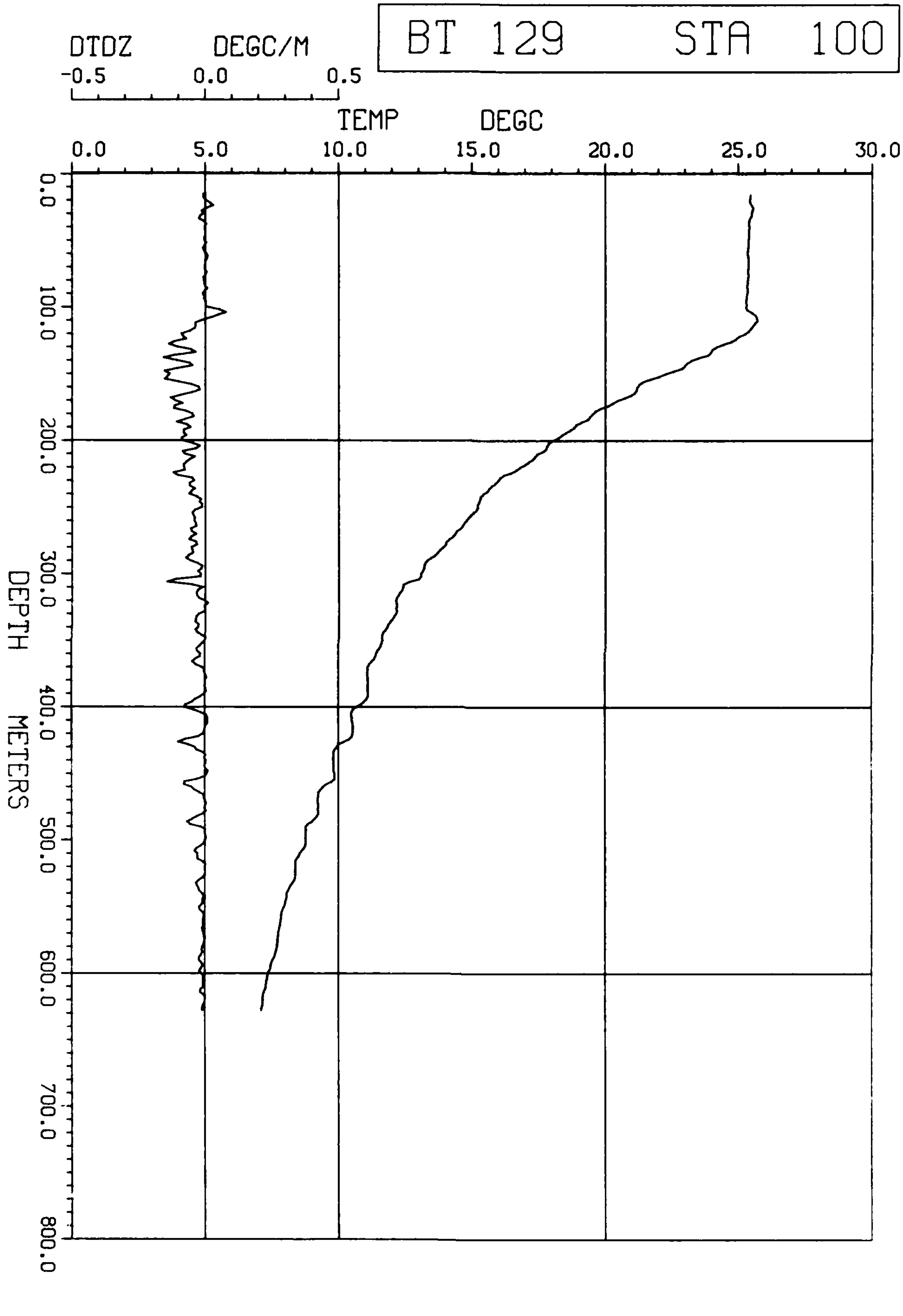
Depth Incorrect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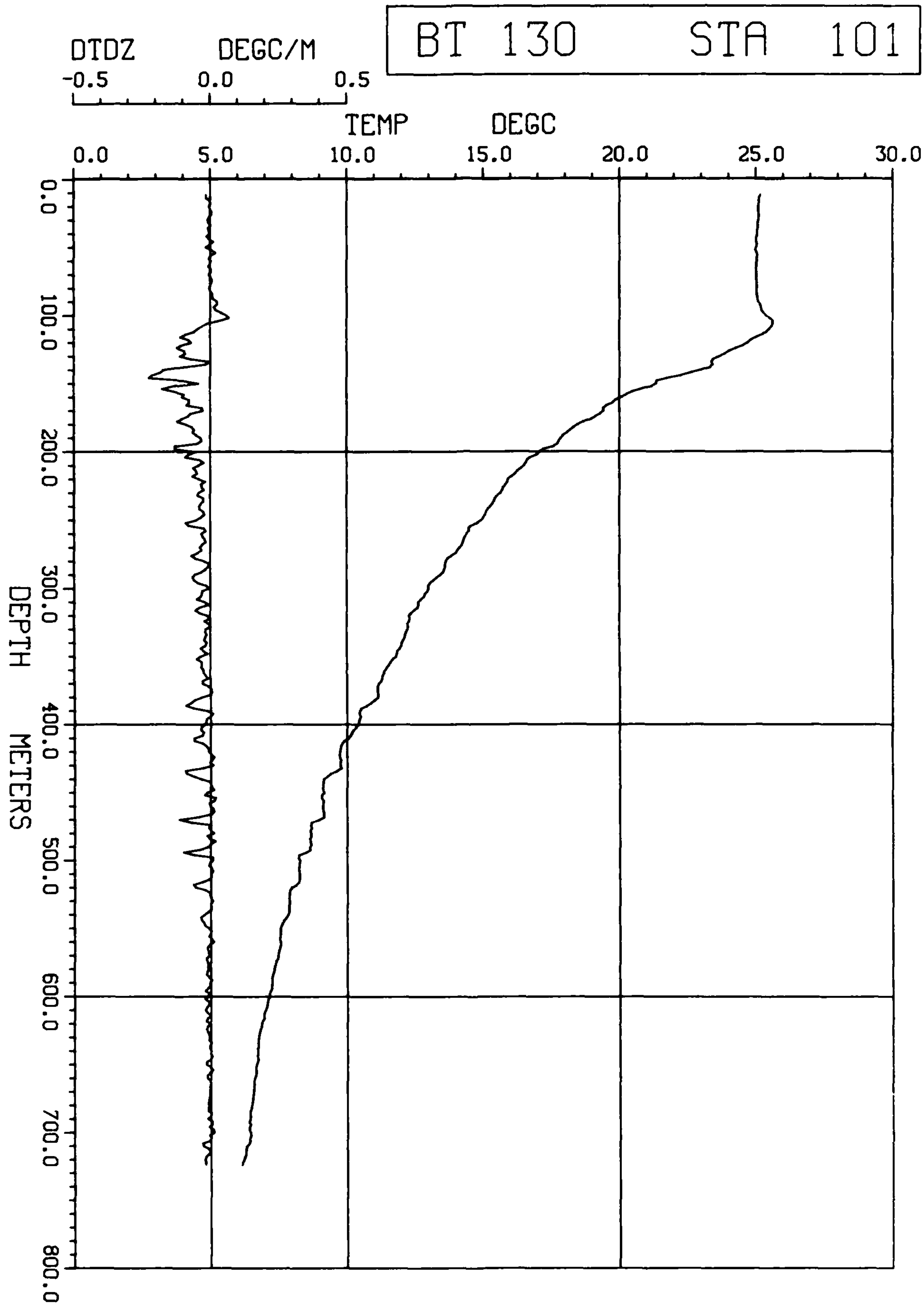
DEPTH METERS



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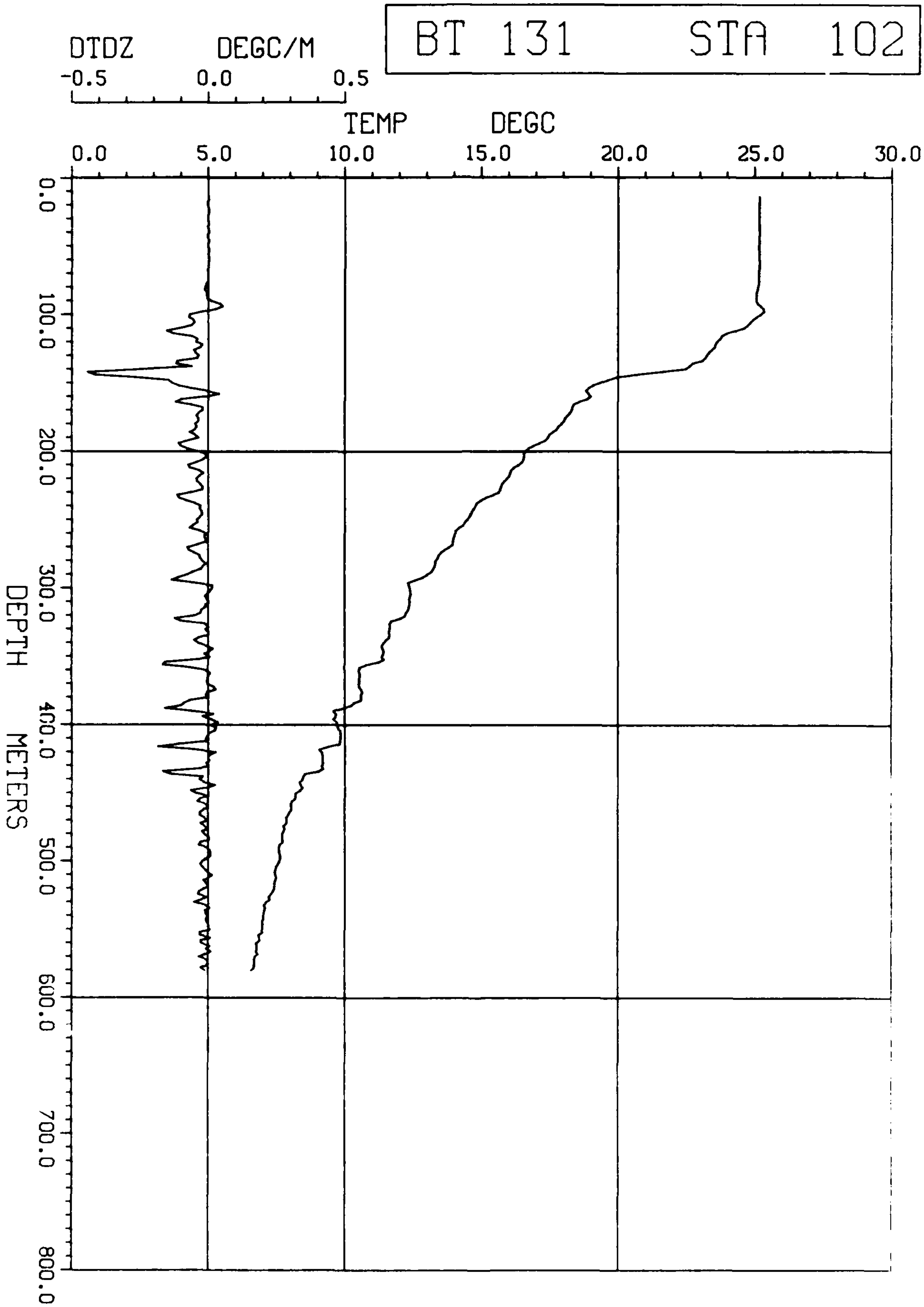
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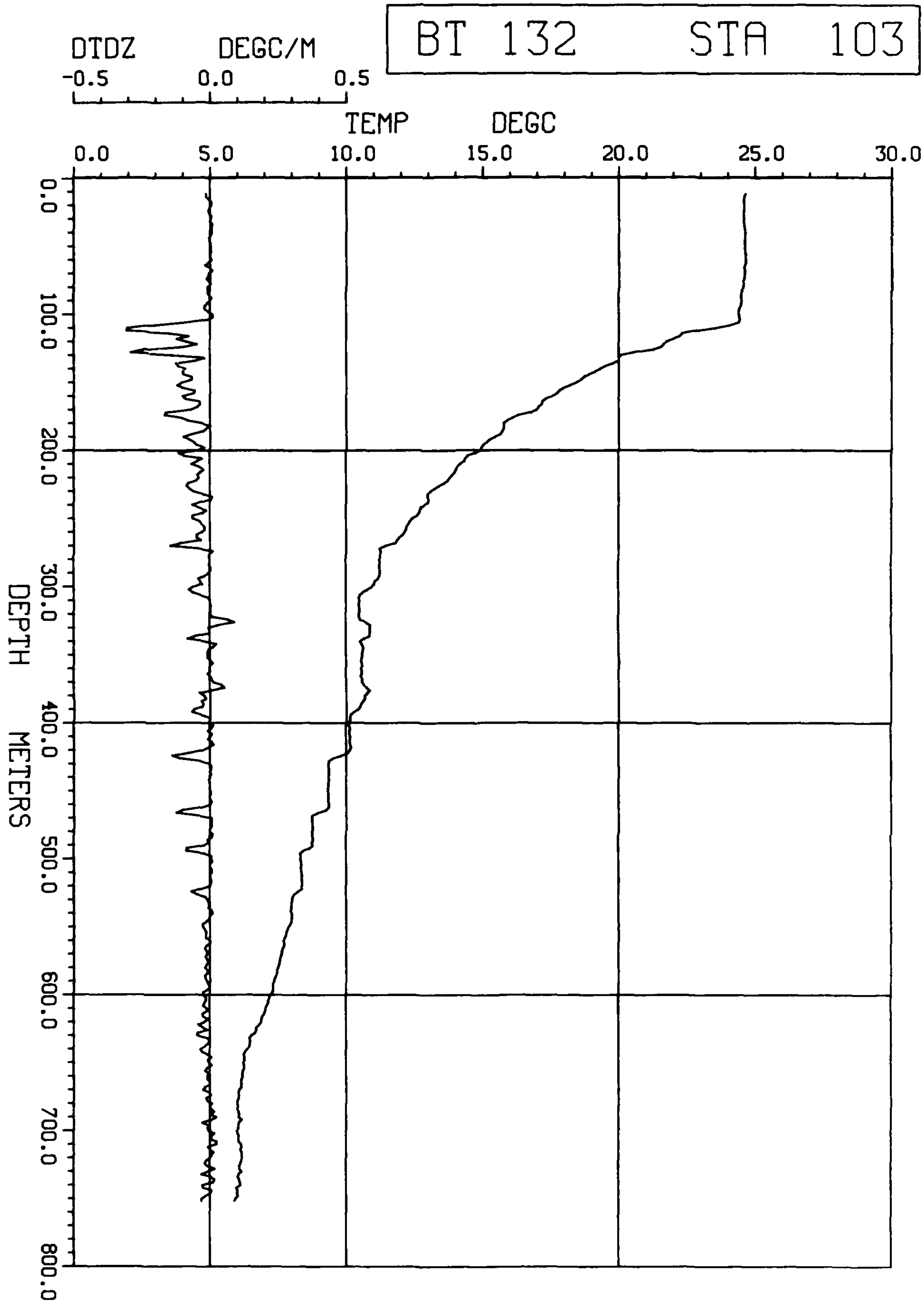

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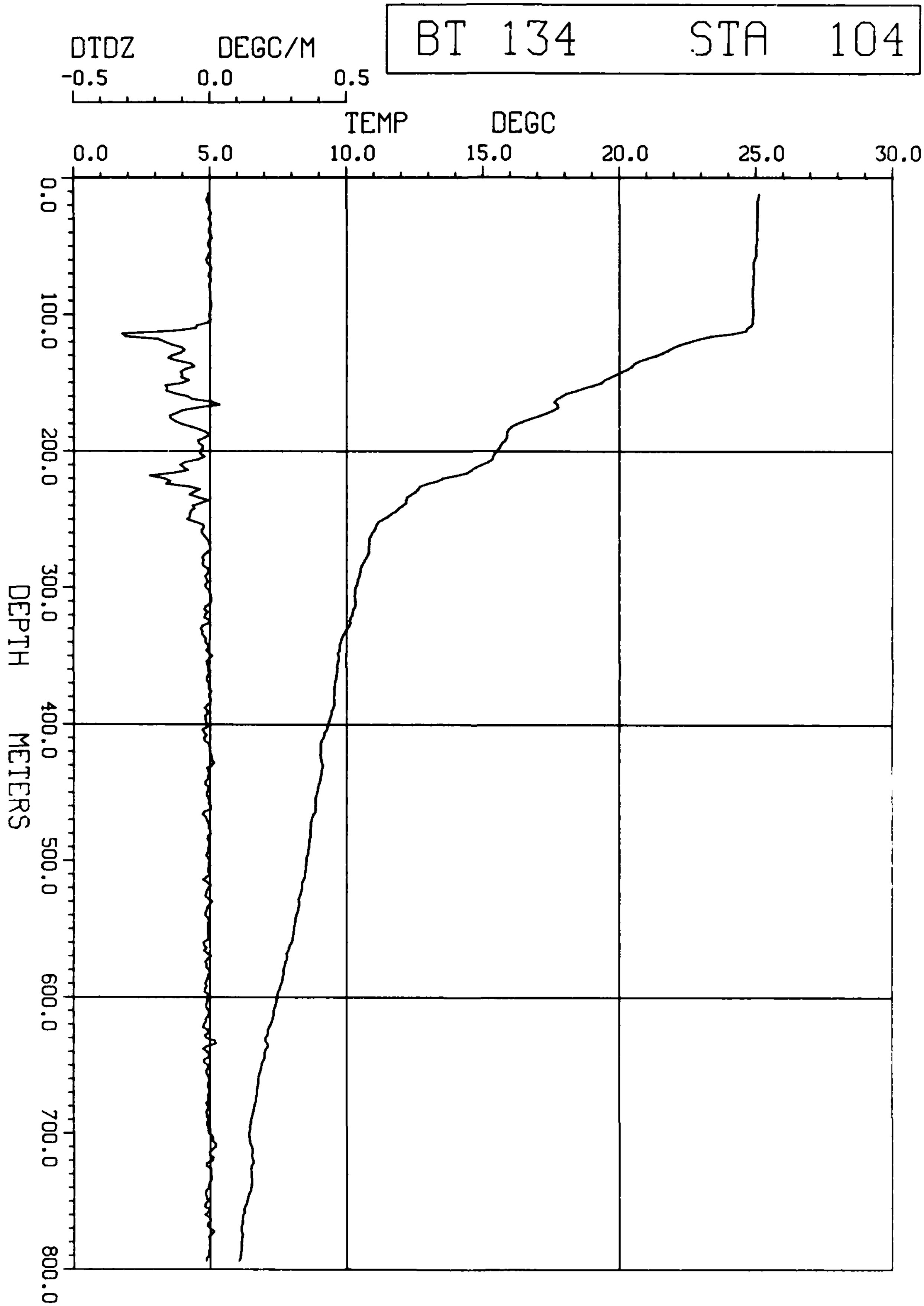
800.0
DEPTH METERS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DTDZ DEGC/M
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TEMP DEGC
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DEPTH METERS
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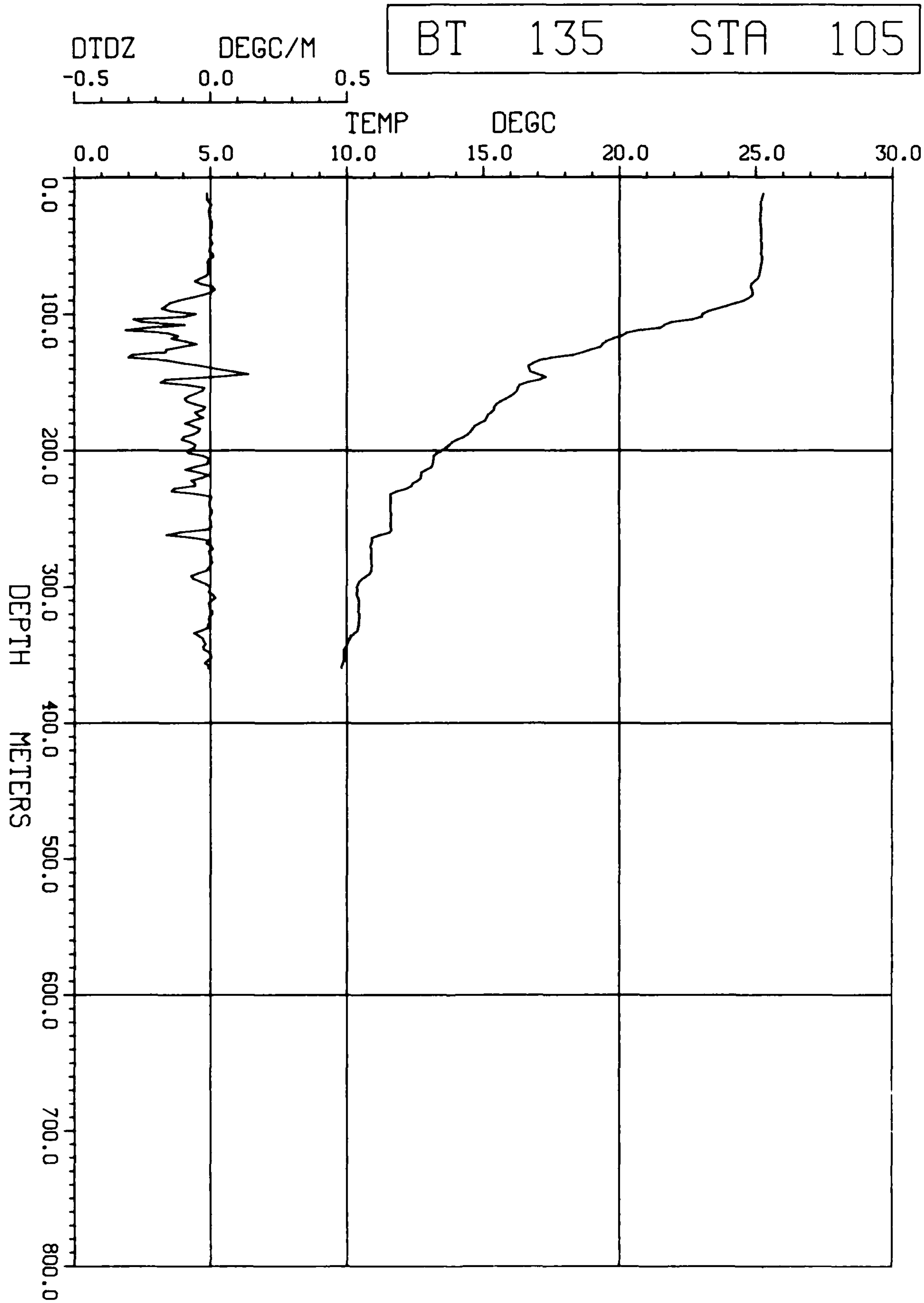

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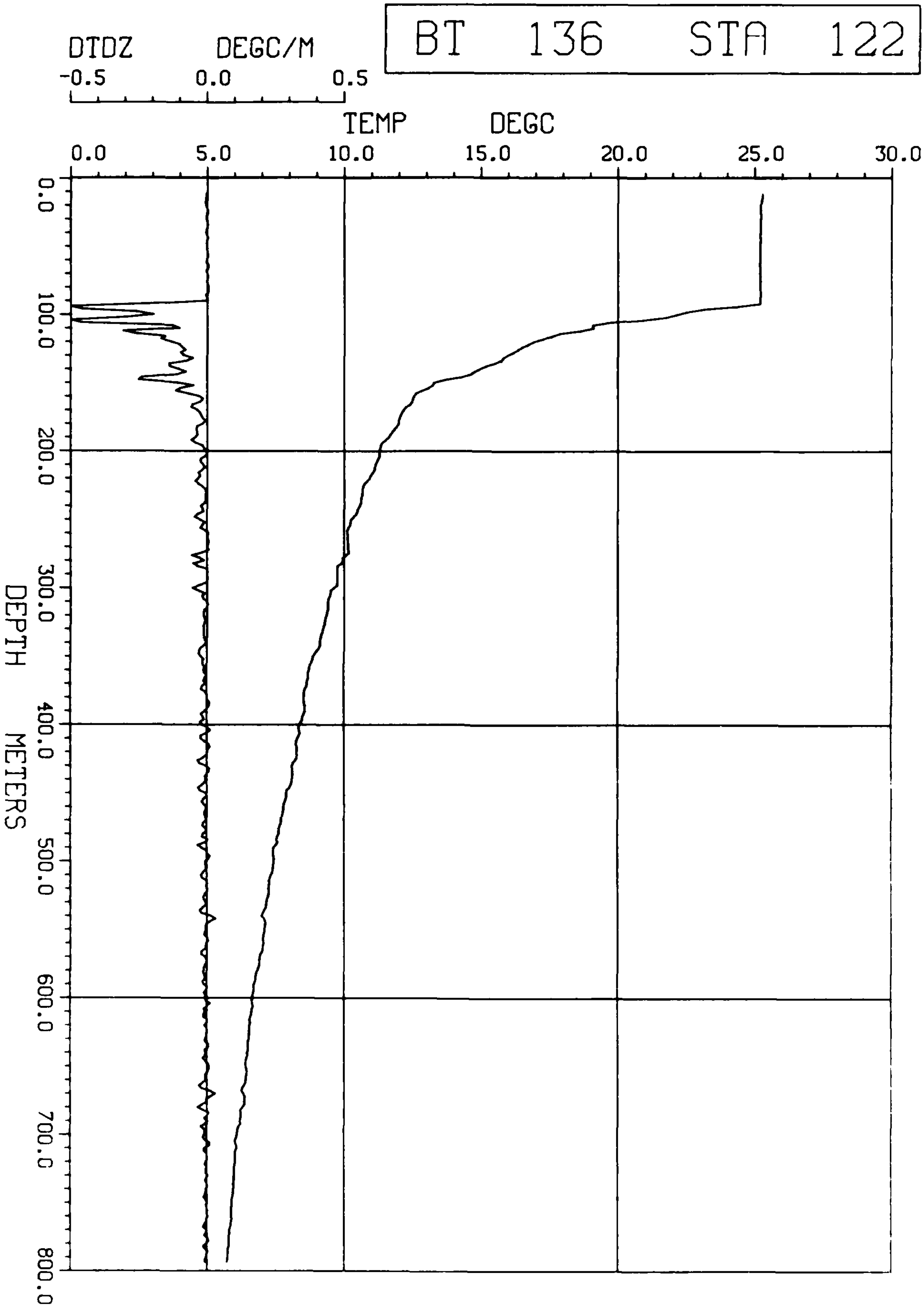
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TEMP DEGC
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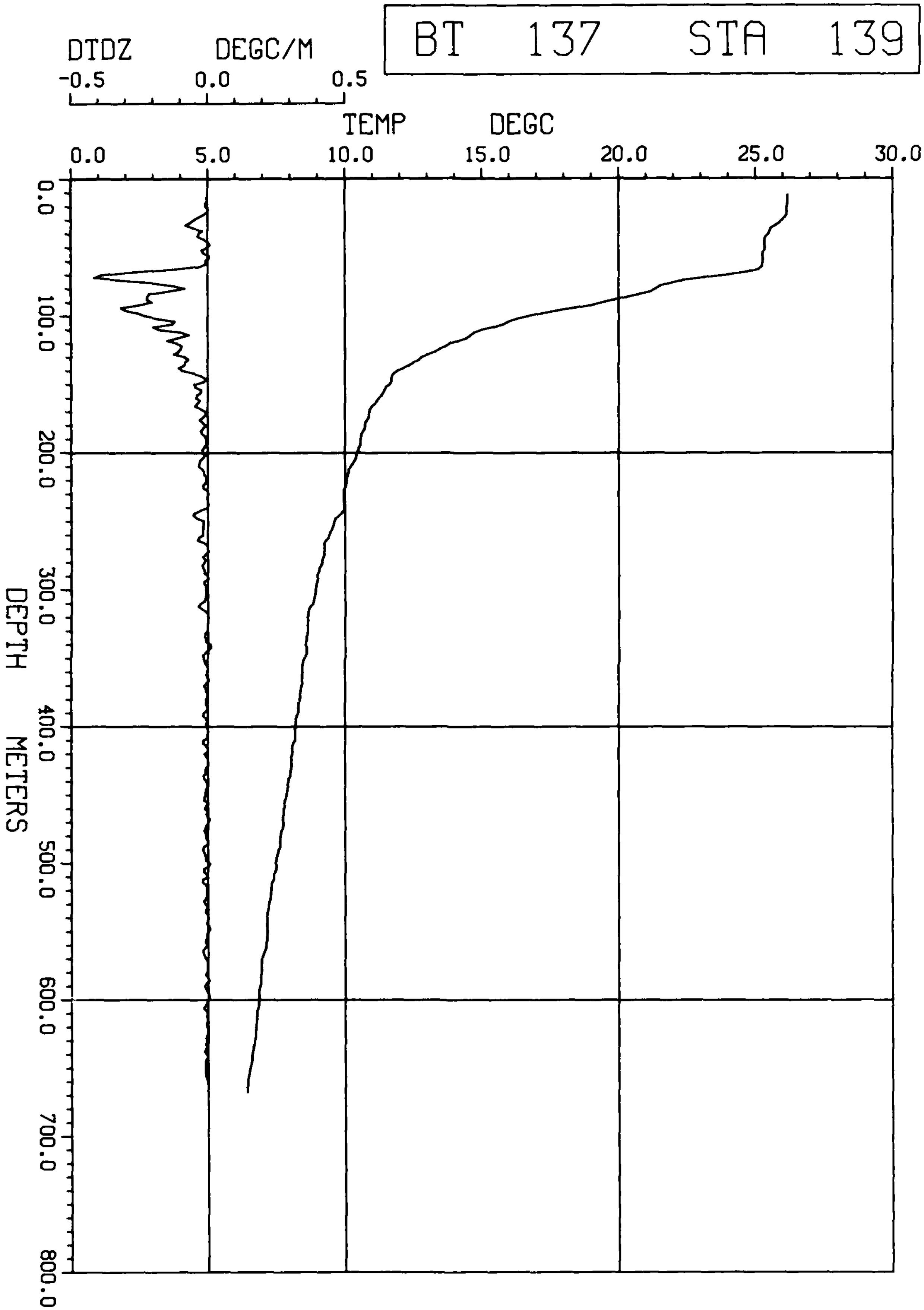
DEPTH METERS



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DEPTH METERS
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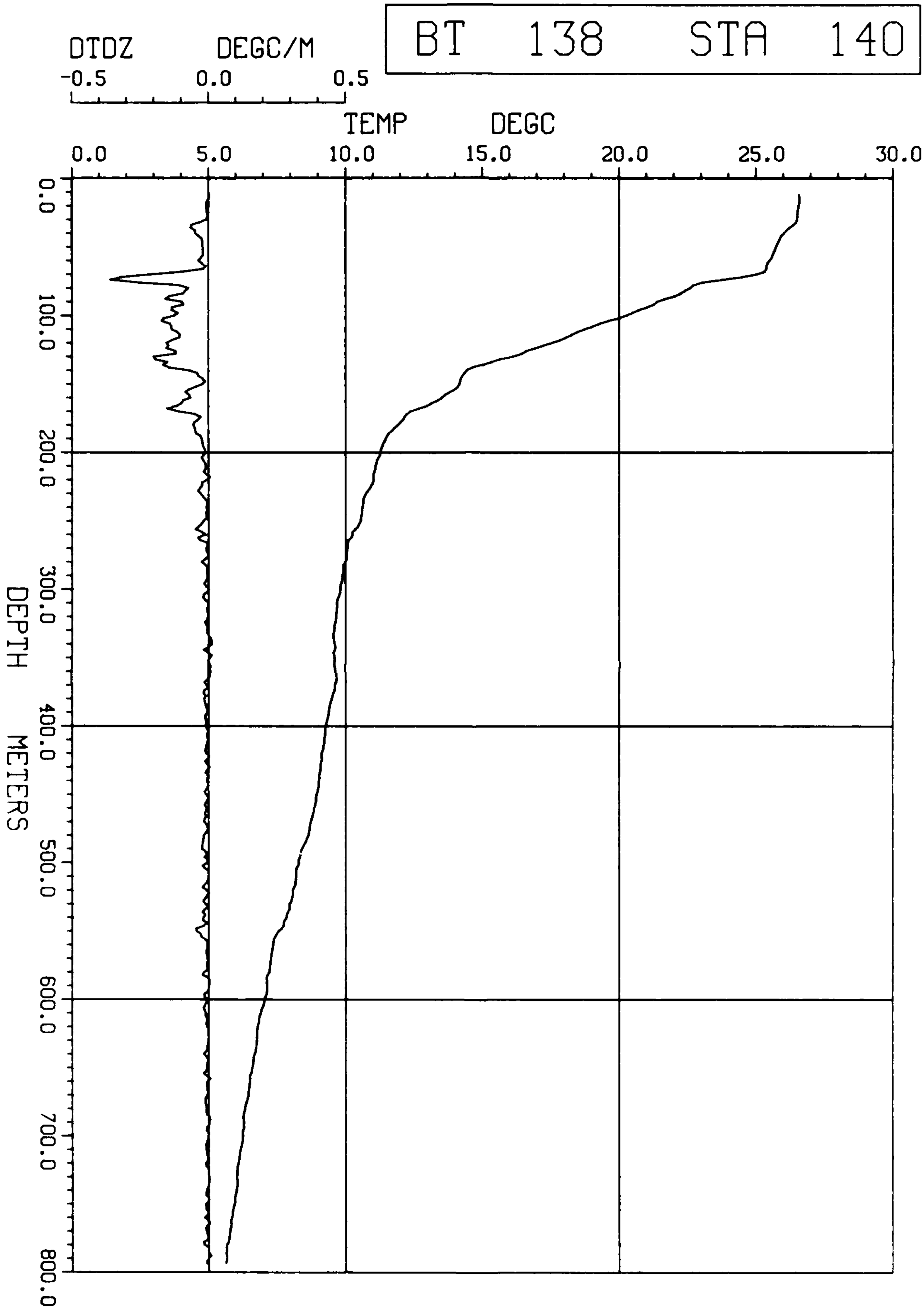
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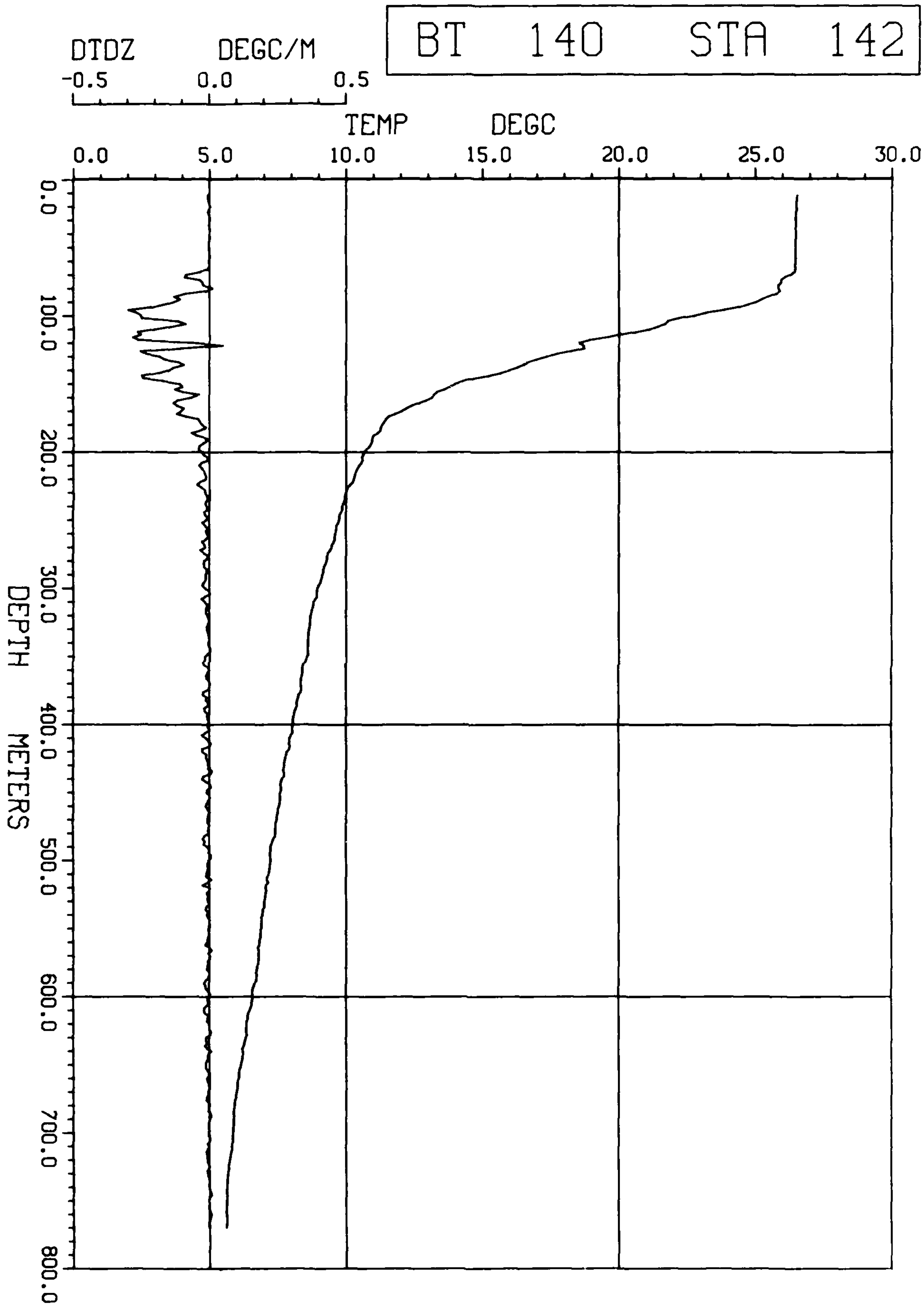
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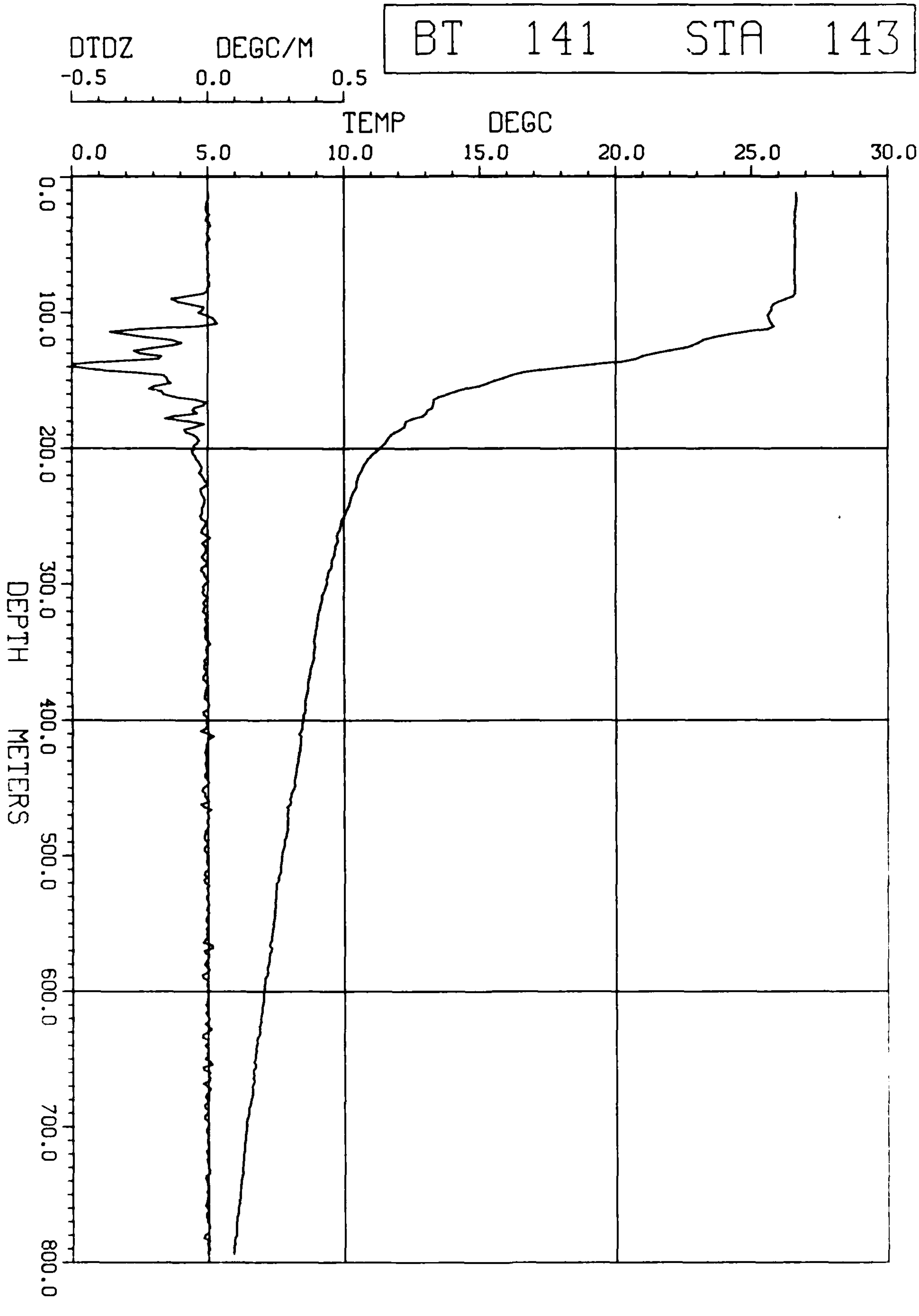
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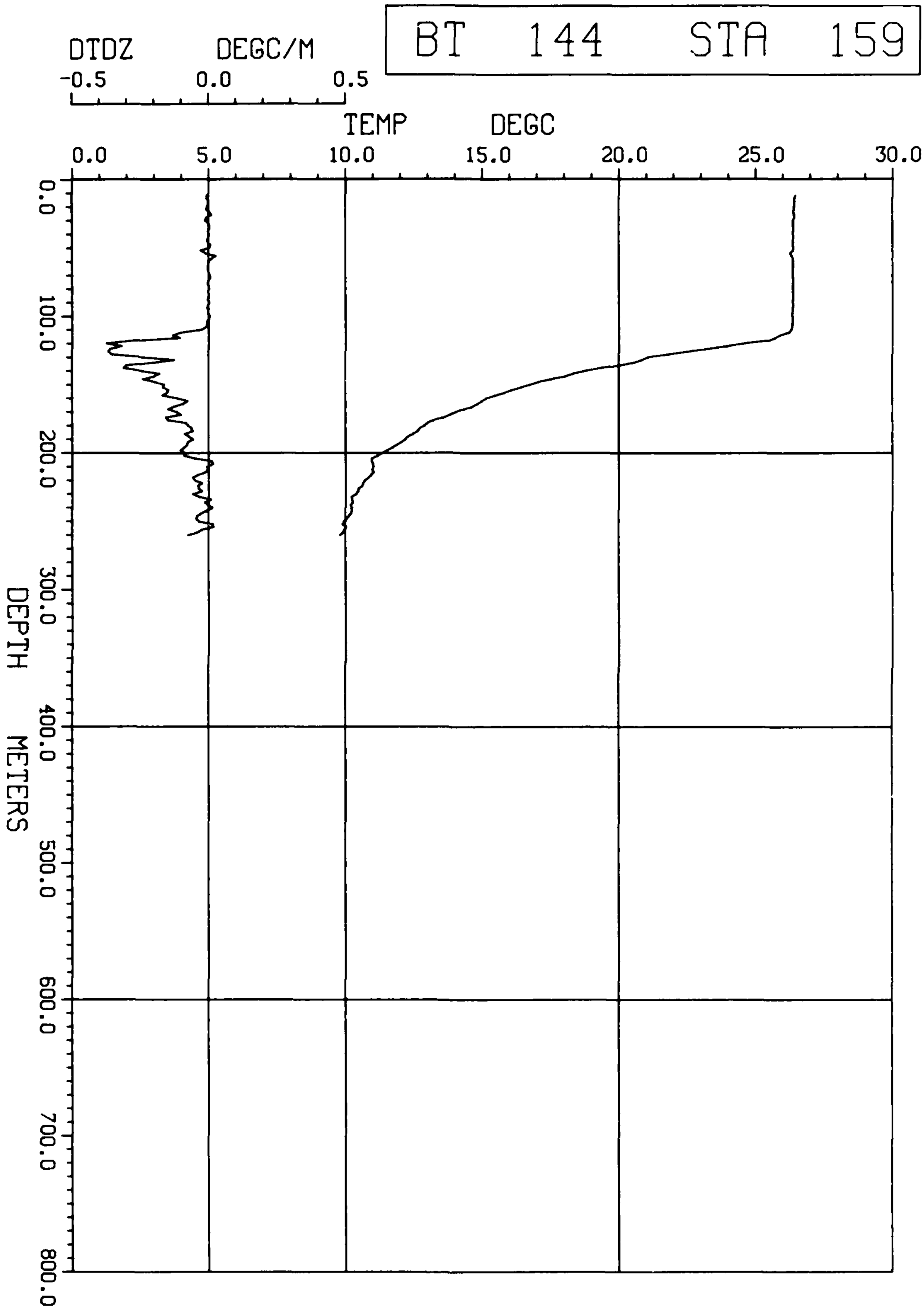
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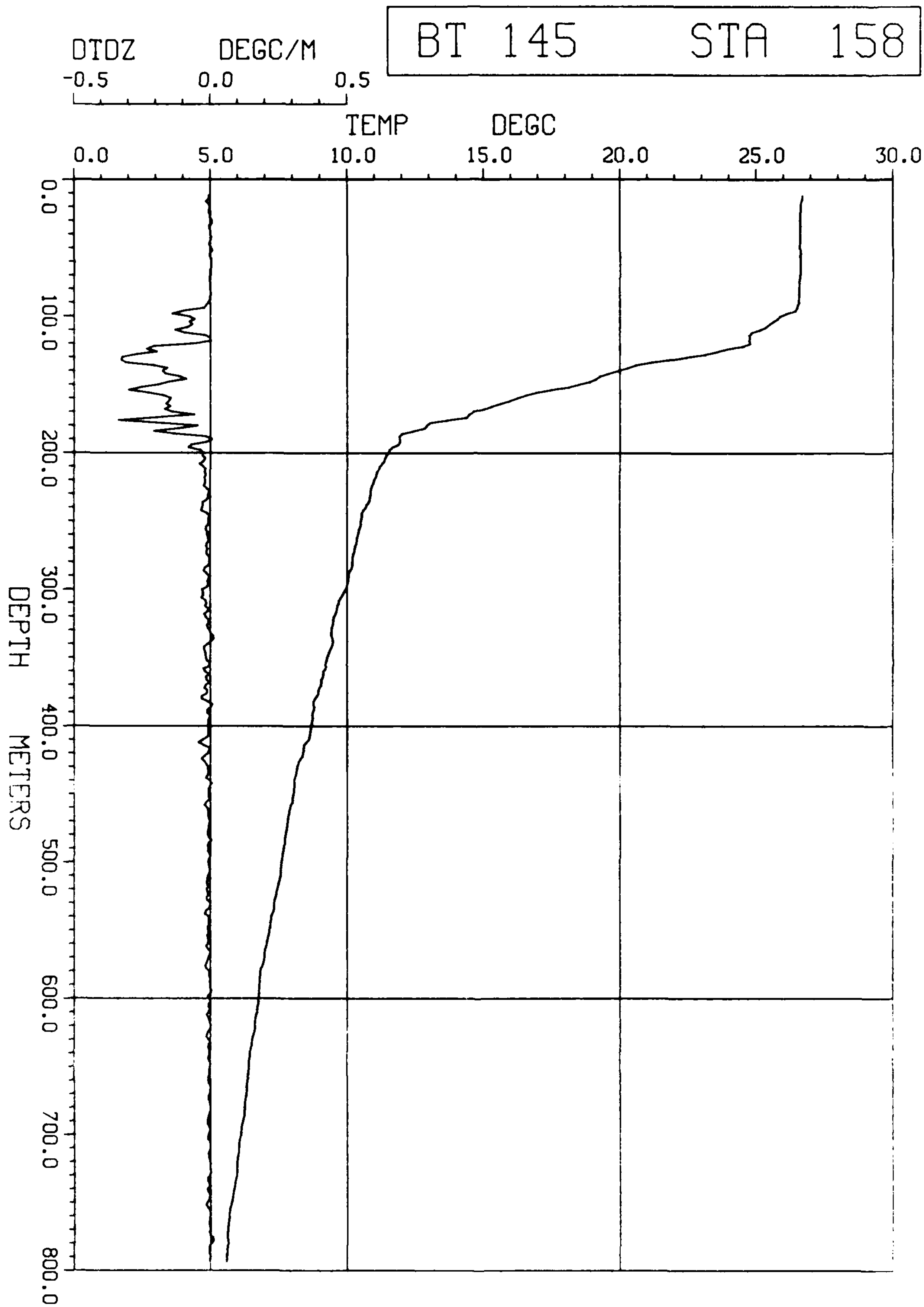
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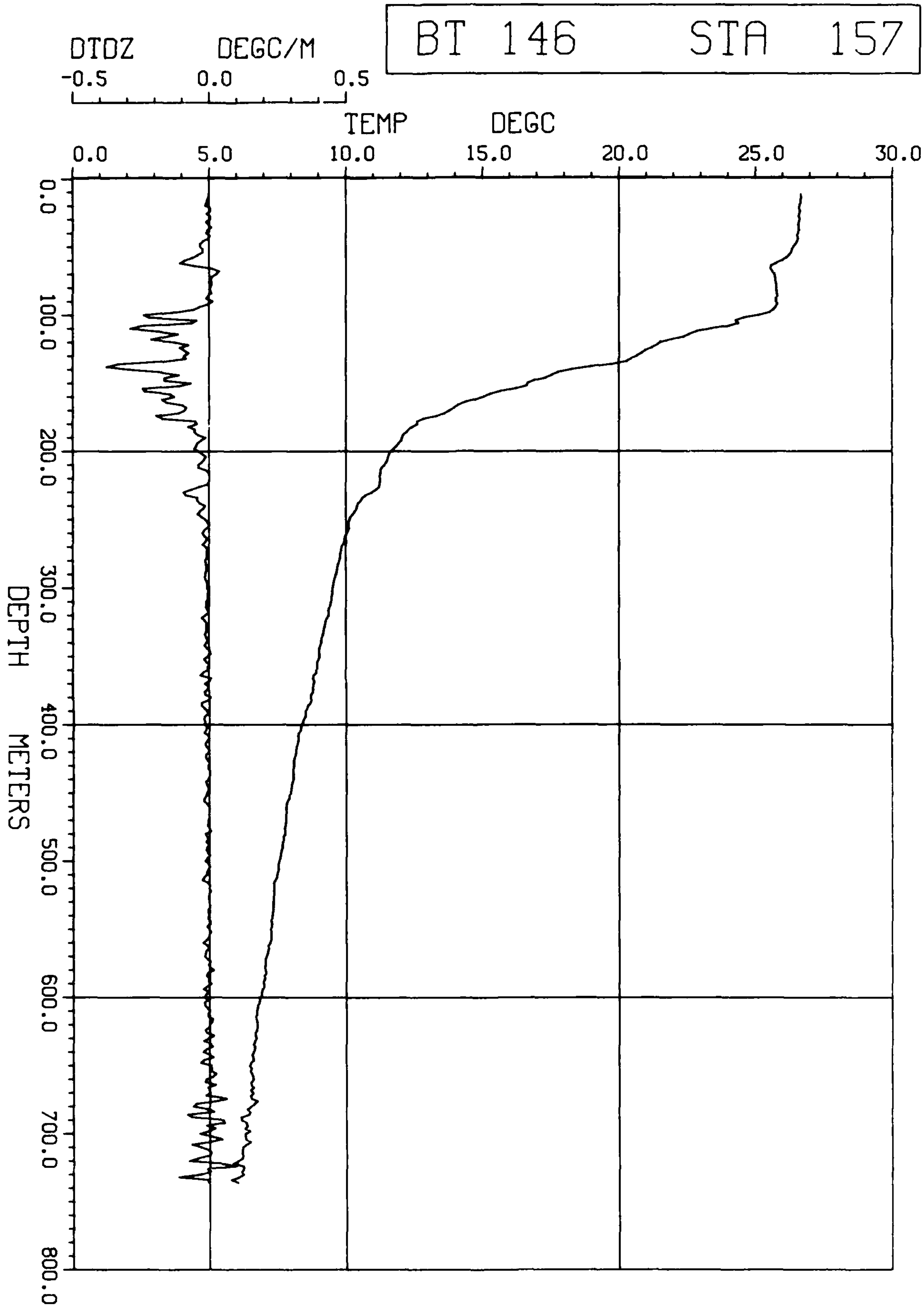
DEPTH METERS



BT 146 STA 157
DTDZ DEGC/M
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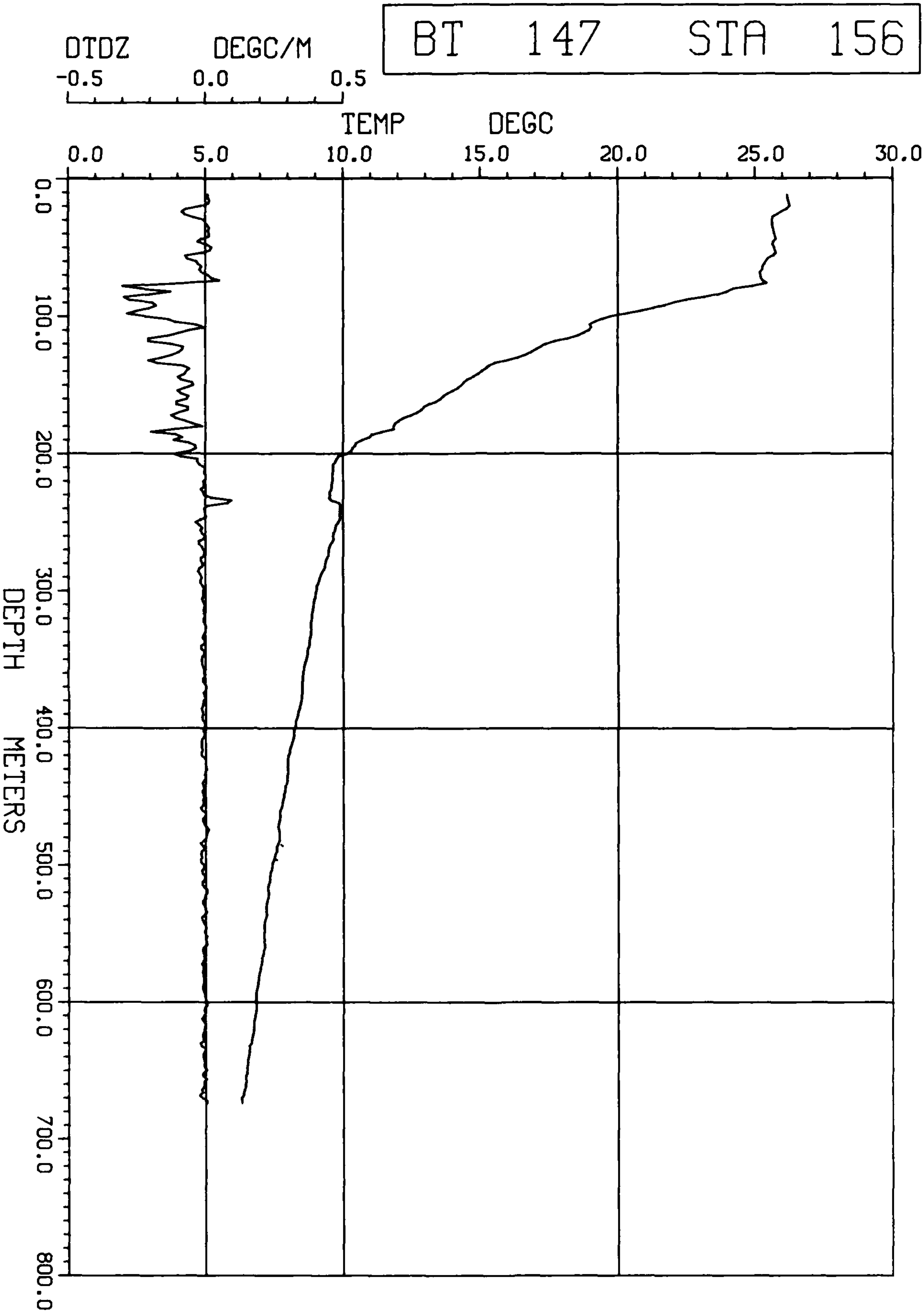
BT 147 STA 156
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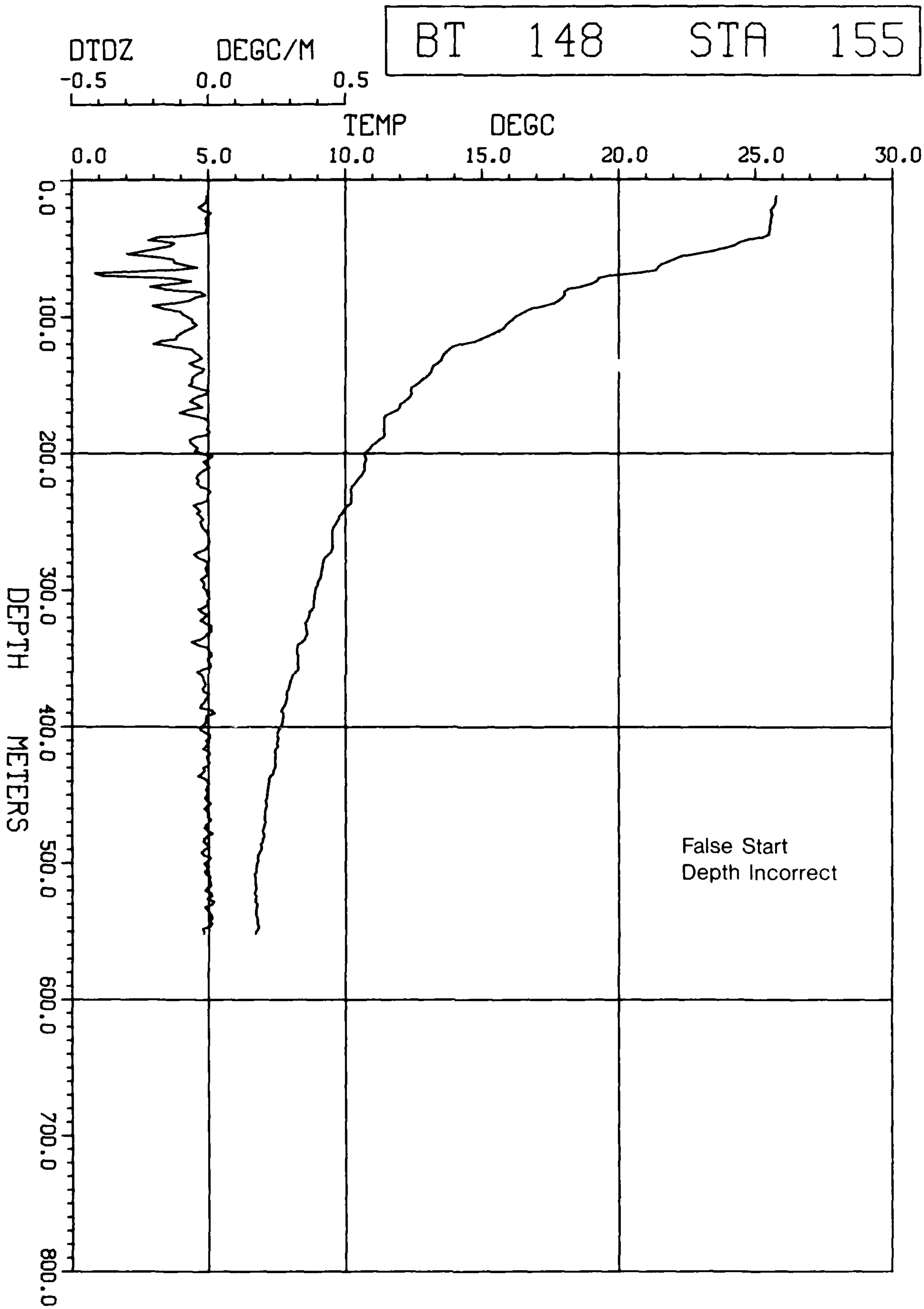
DEPTH METERS


BT 148 STA 155
DTDZ DEGC/M
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DEPTH METERS
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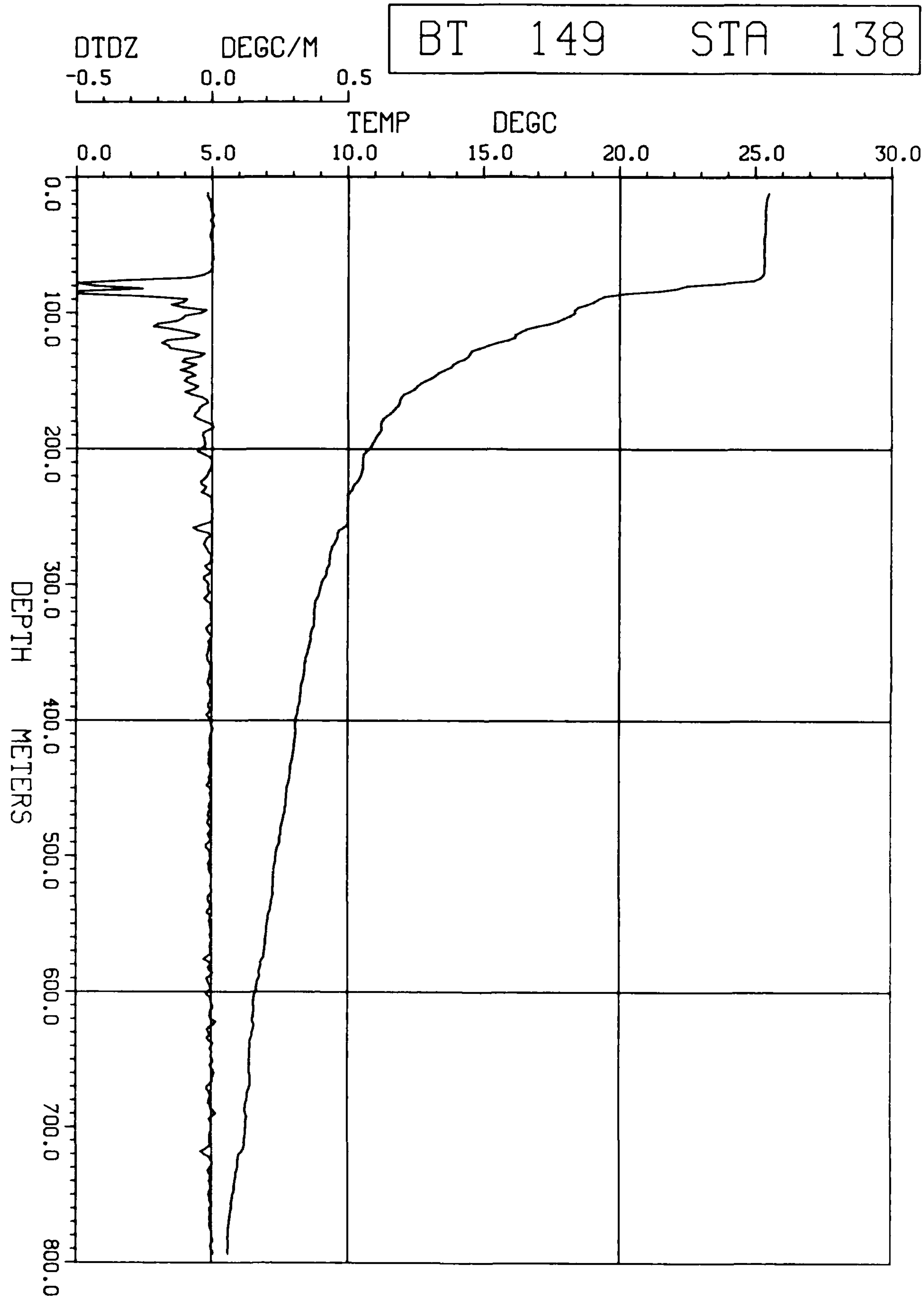
Depth Incorrect



BT 149 STA 138
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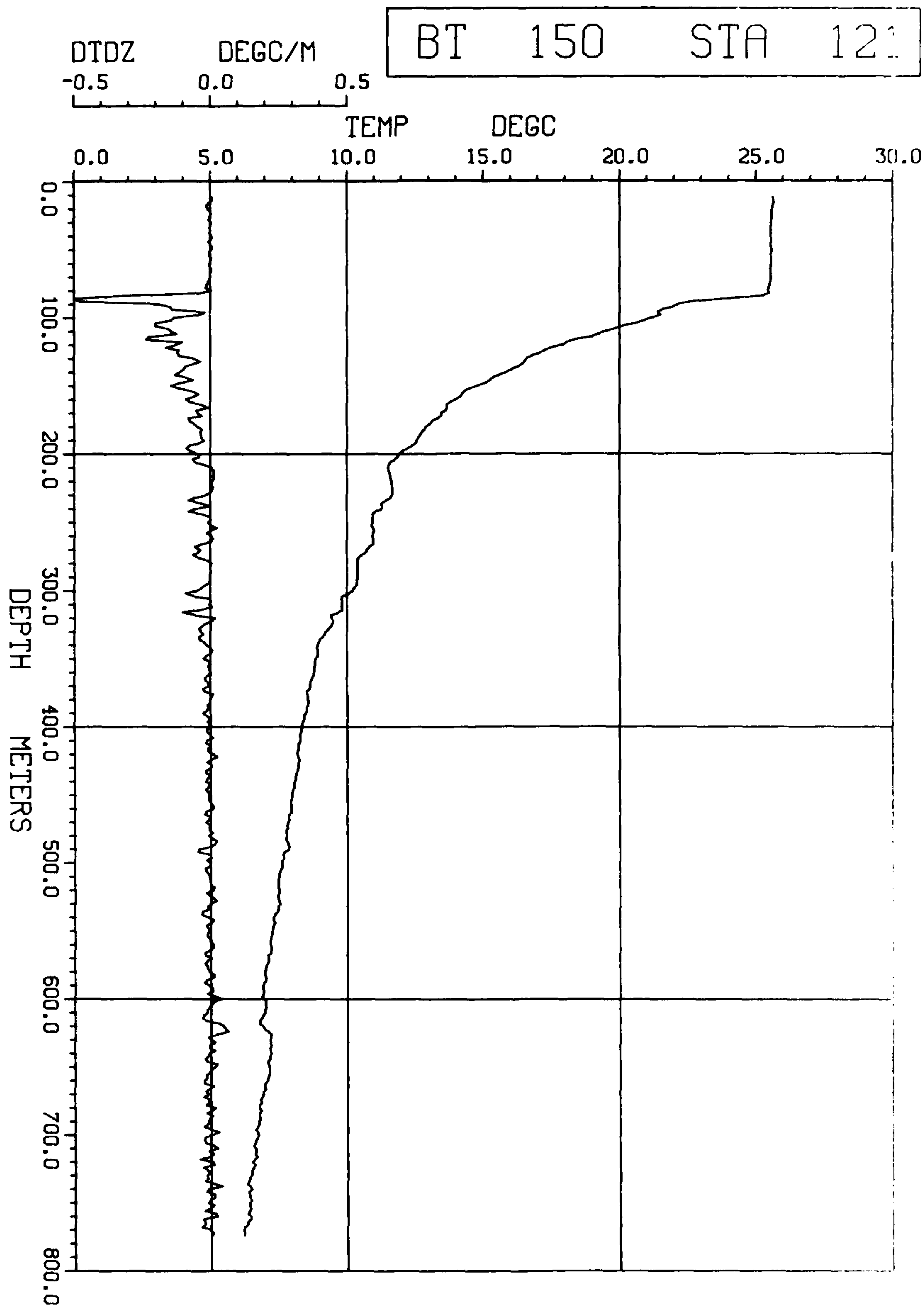
DEPTH METERS


BT 150 STA 121
DTDZ DEGC/M
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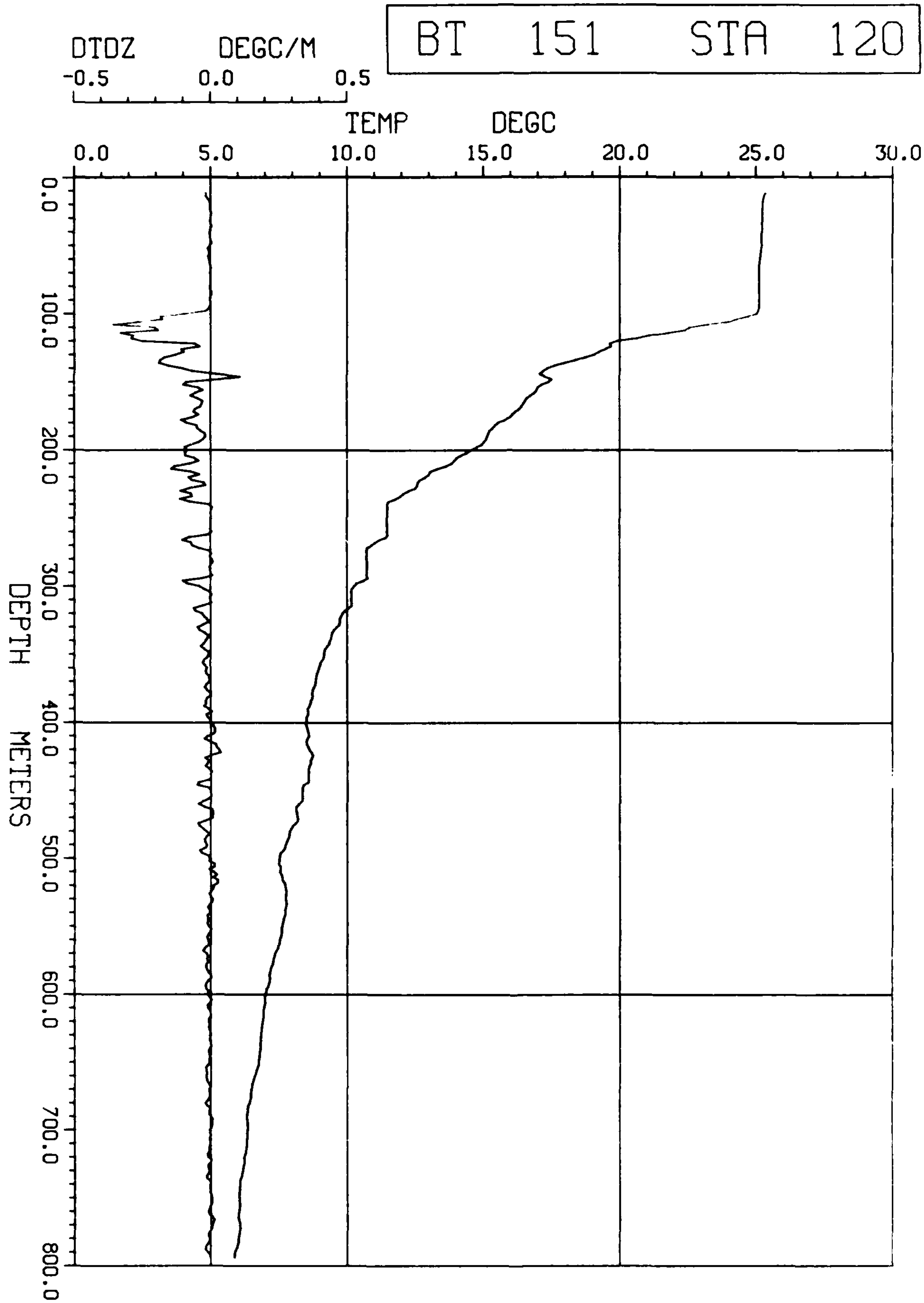

BT 151 STA 120
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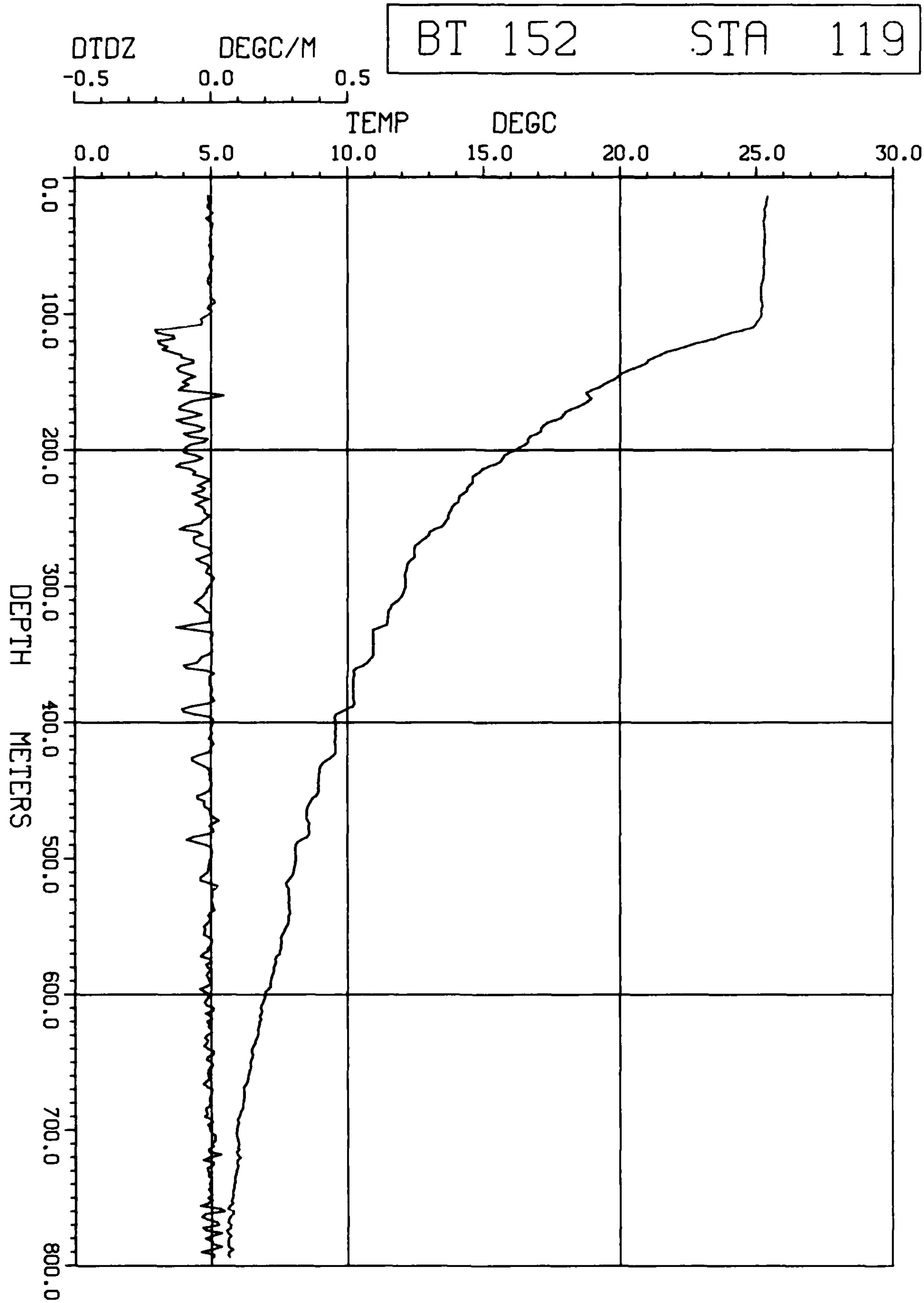
DEPTH METERS



BT 152 STA 119
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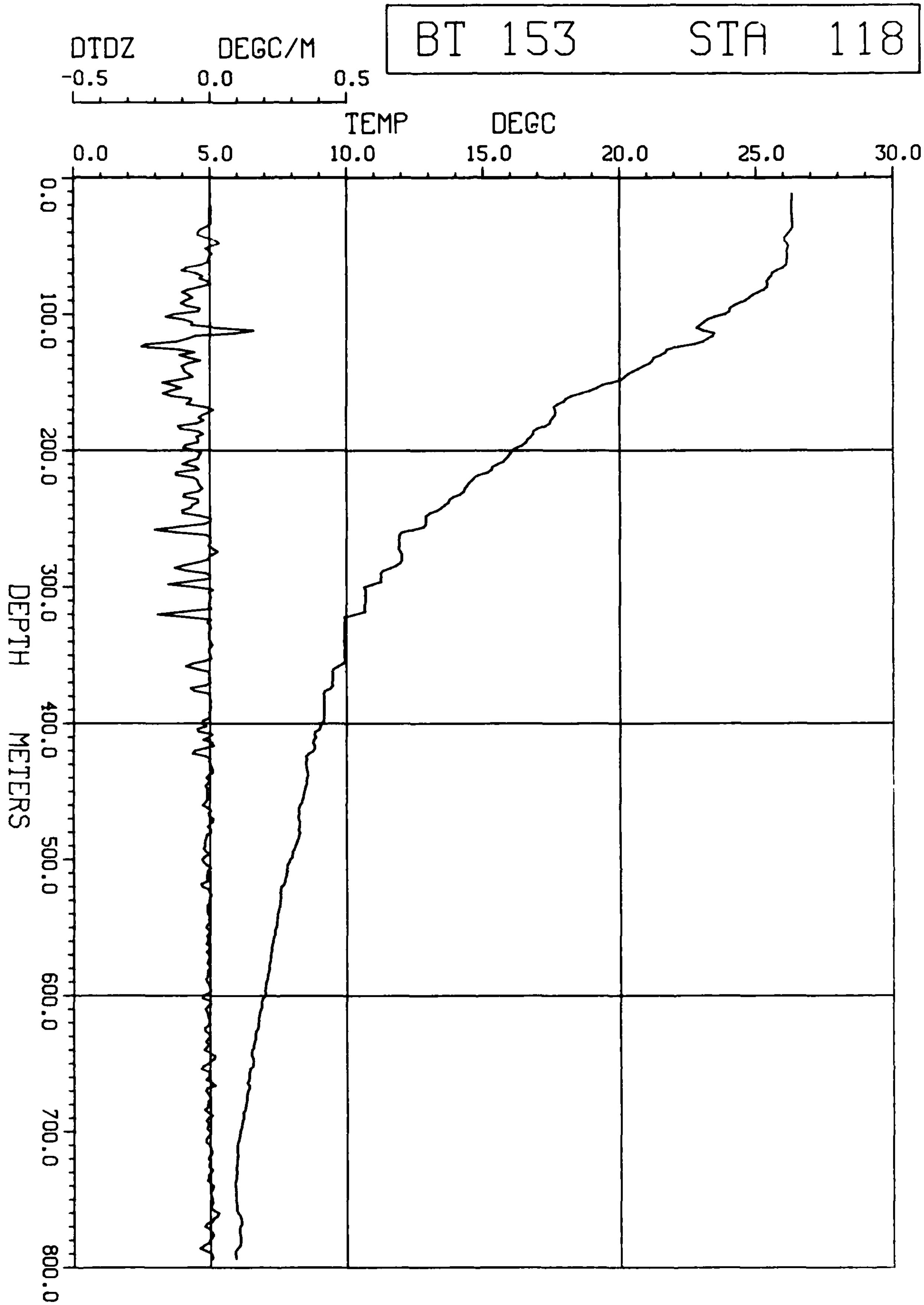

BT 153 STA 118
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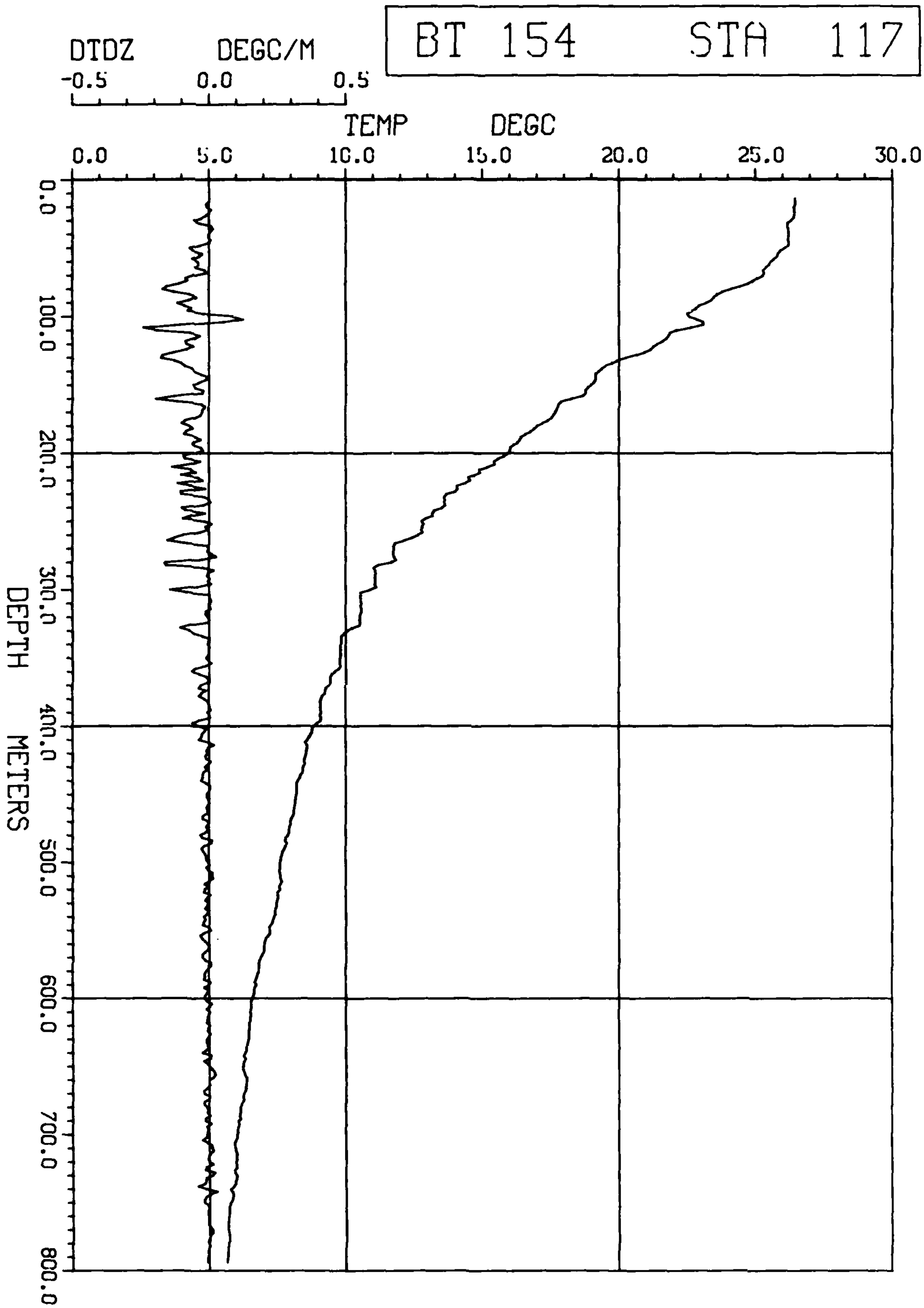
DEPTH METERS



BT 154 STA 117
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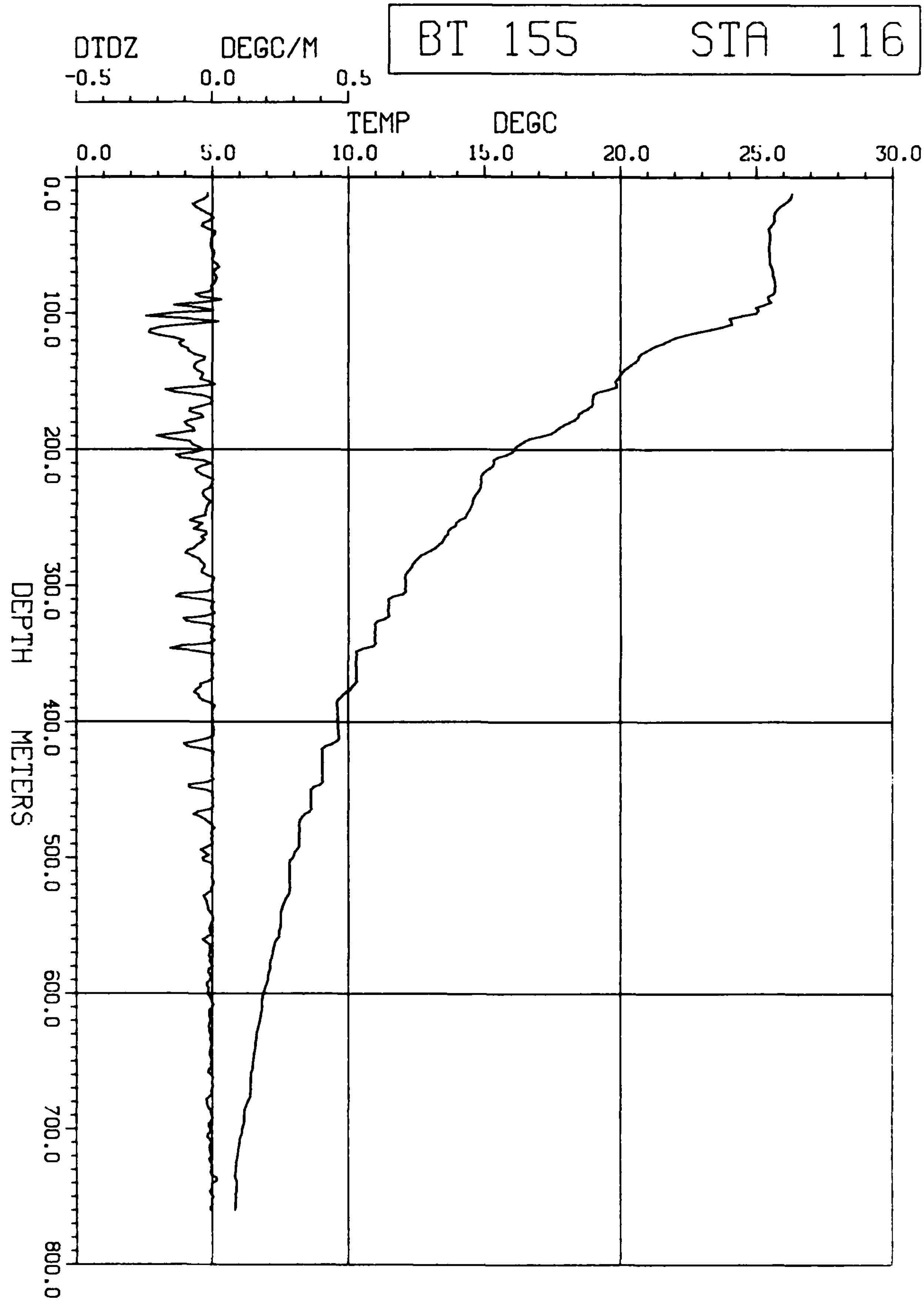
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TEMP DEGC
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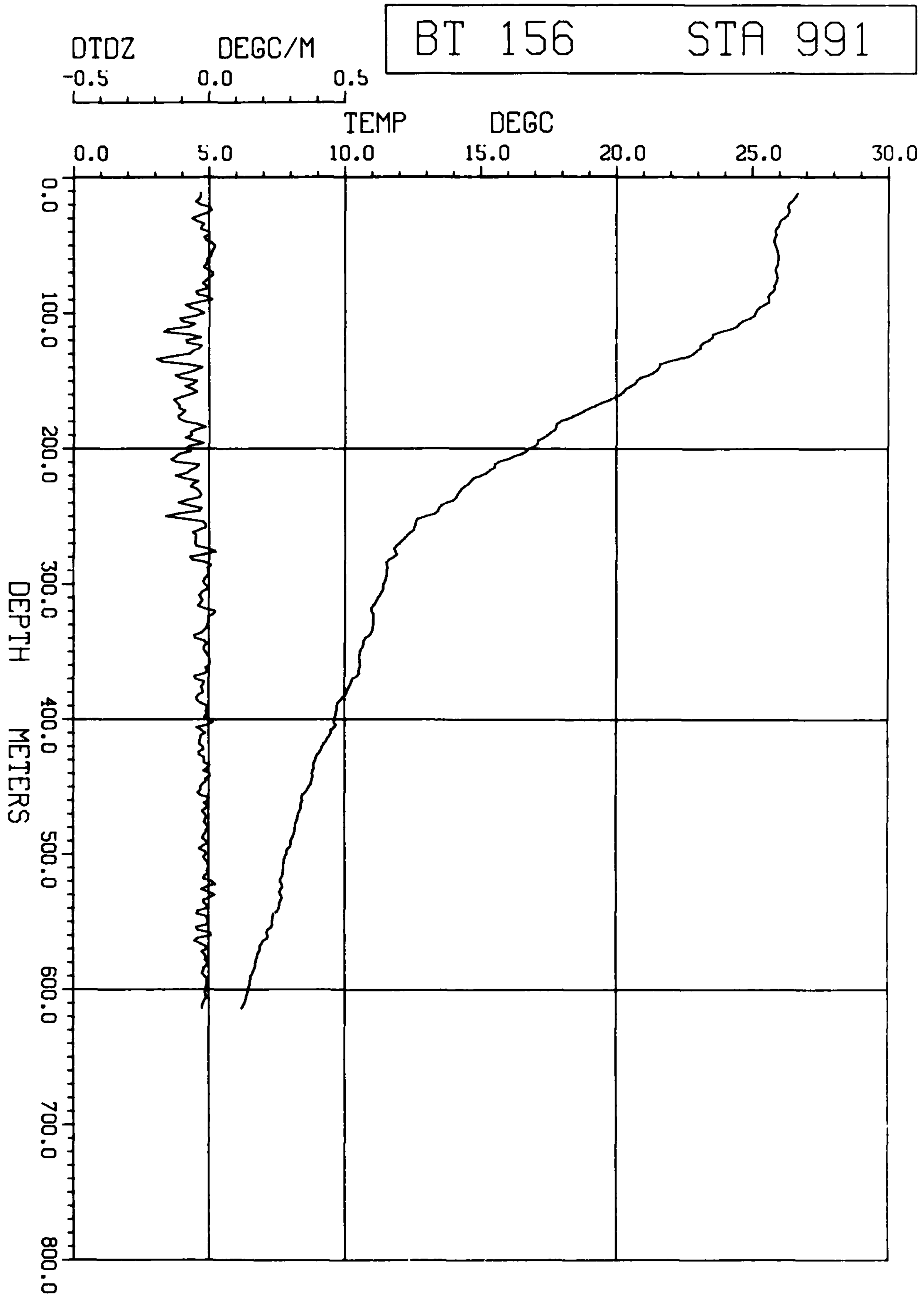
DEPTH METERS



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TEMP DEGC
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DEPTH METERS
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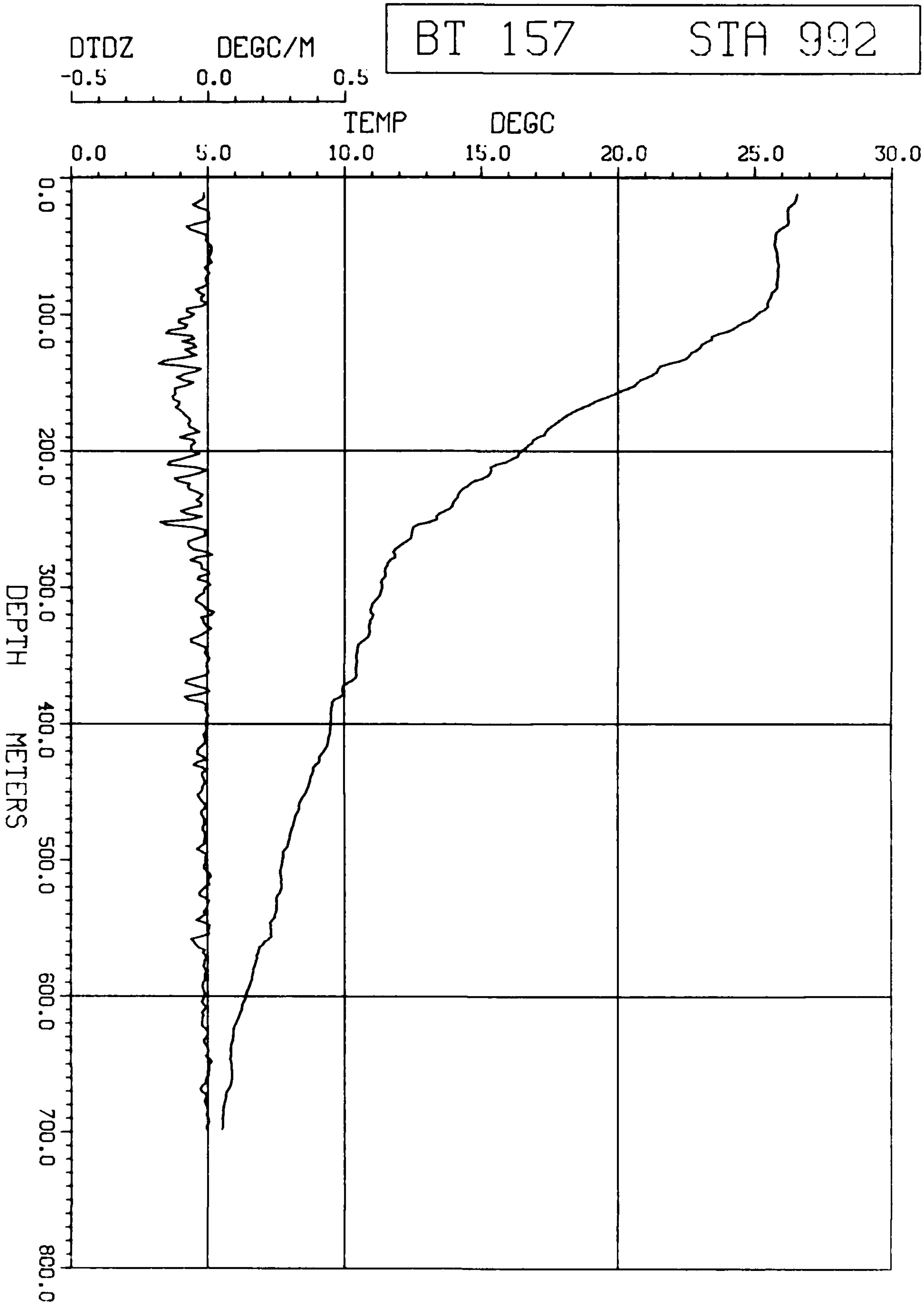

BT 157 STA 992
DTDZ DEGC/M
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TEMP DEGC
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DEPTH METERS
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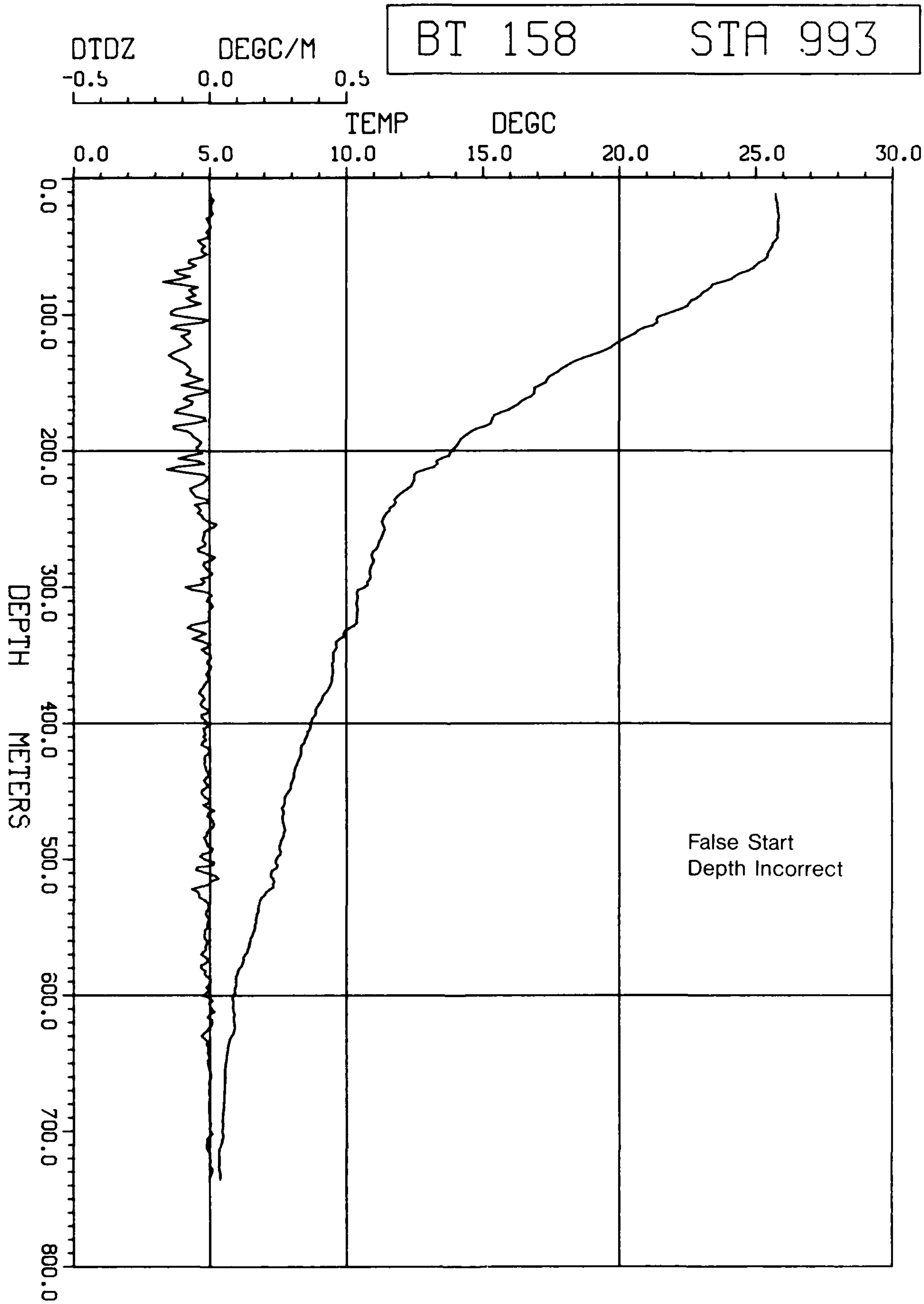

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TEMP DEGC
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DEPTH METERS
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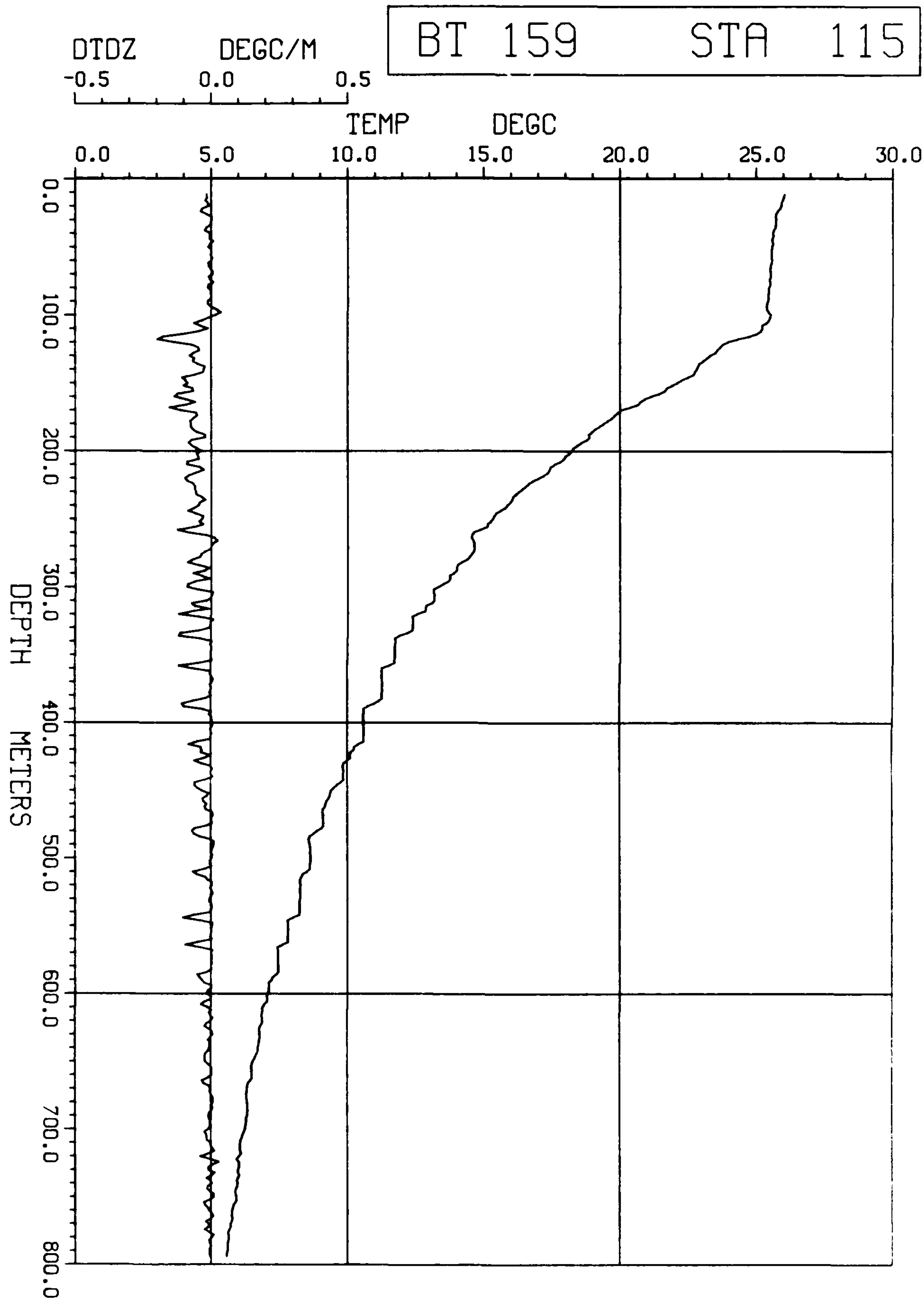
False Start
Depth Incorrect


BT 159 STA 115
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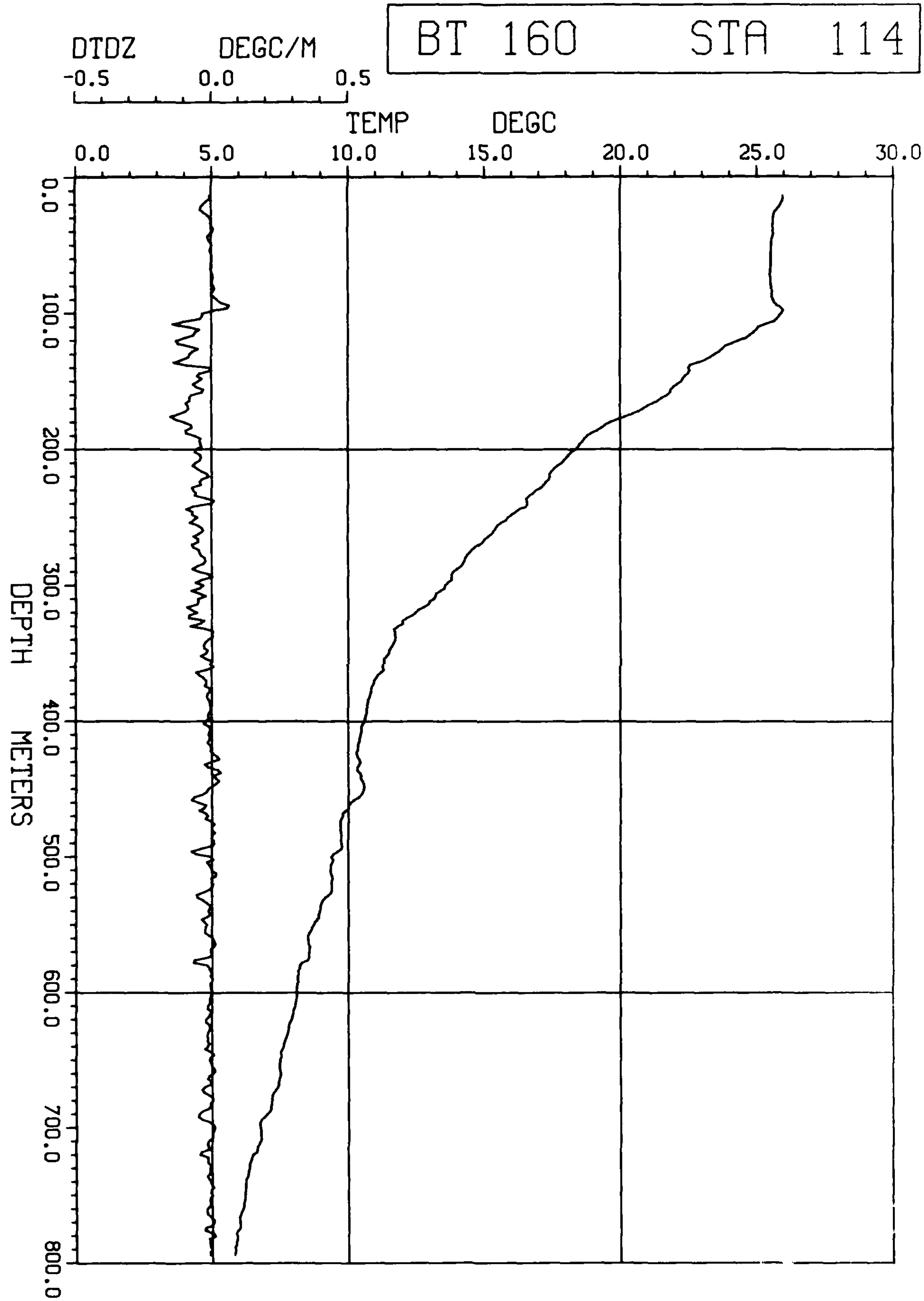
DEPTH METERS


BT 160 STA 114
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30.0
DEPTH METERS
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200.0
300.0
400.0
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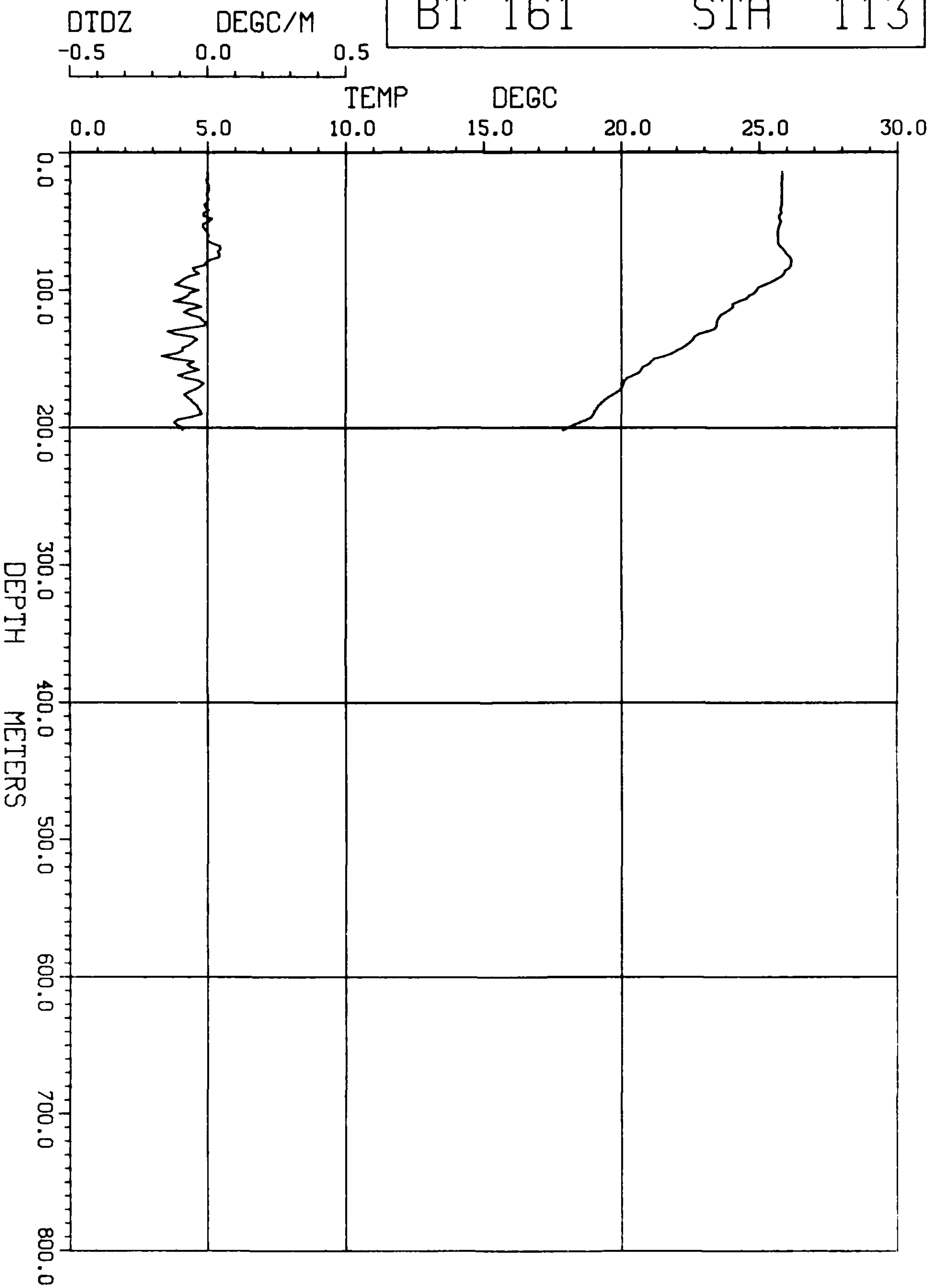
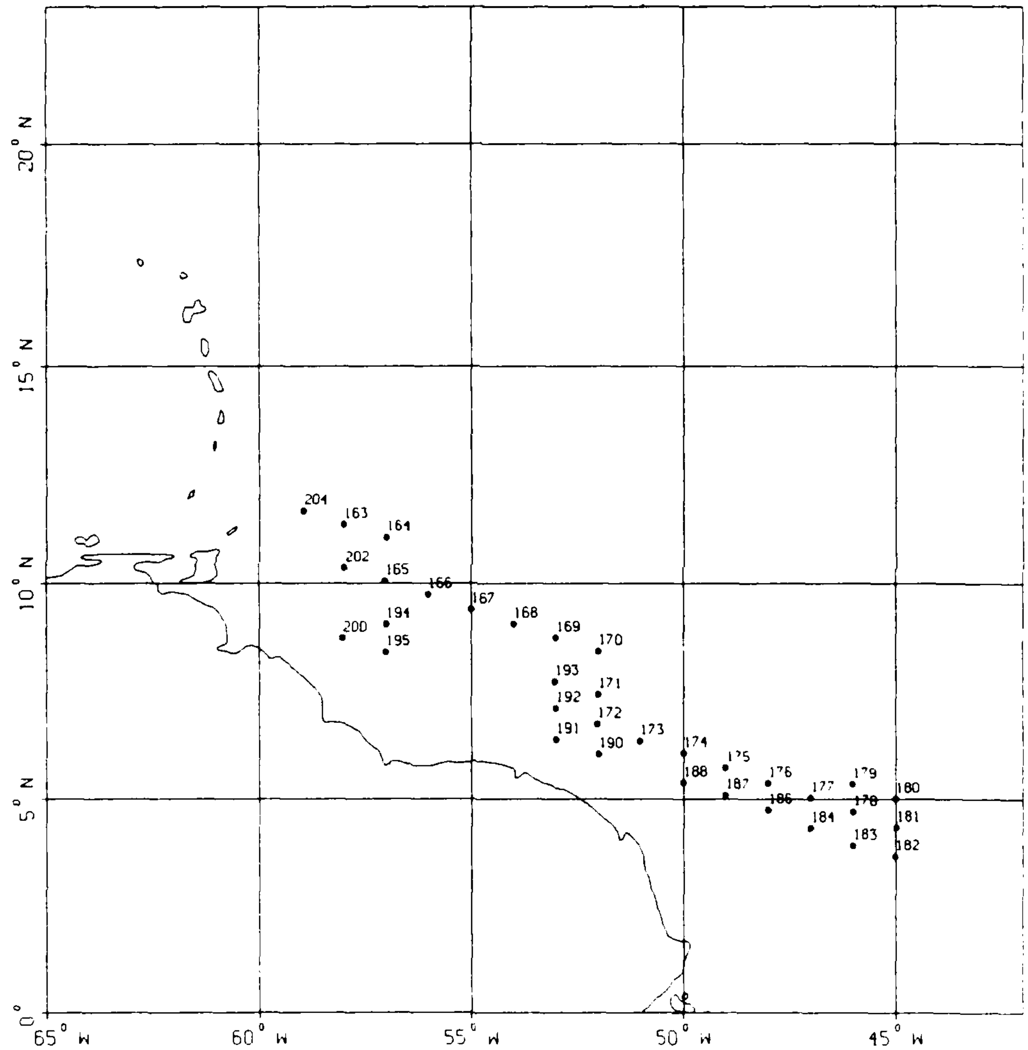
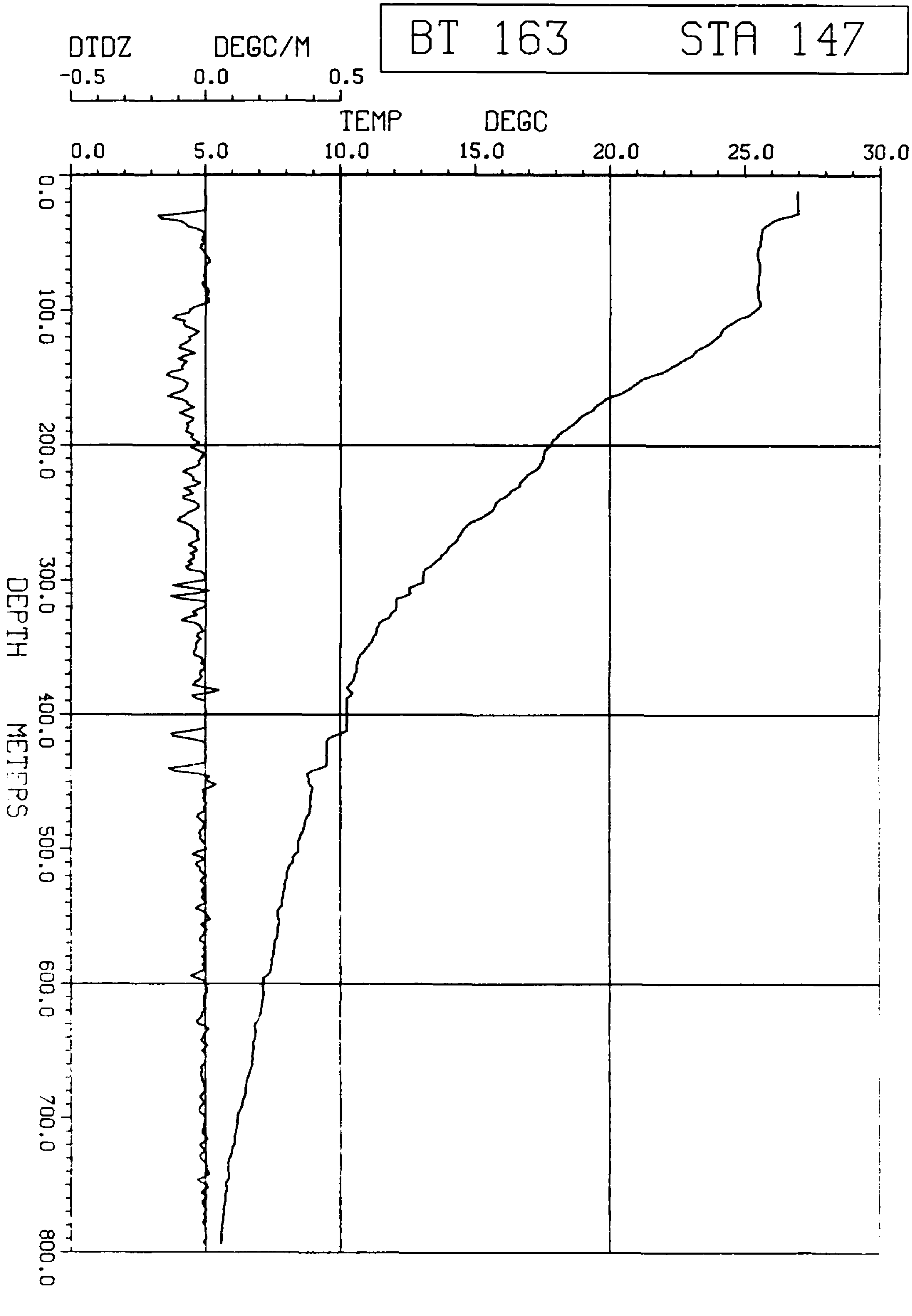
600.0
700.0
800.0

BT 161 STA 113



Station Positions Flight 5
8 May 1985

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TEMP DEGC
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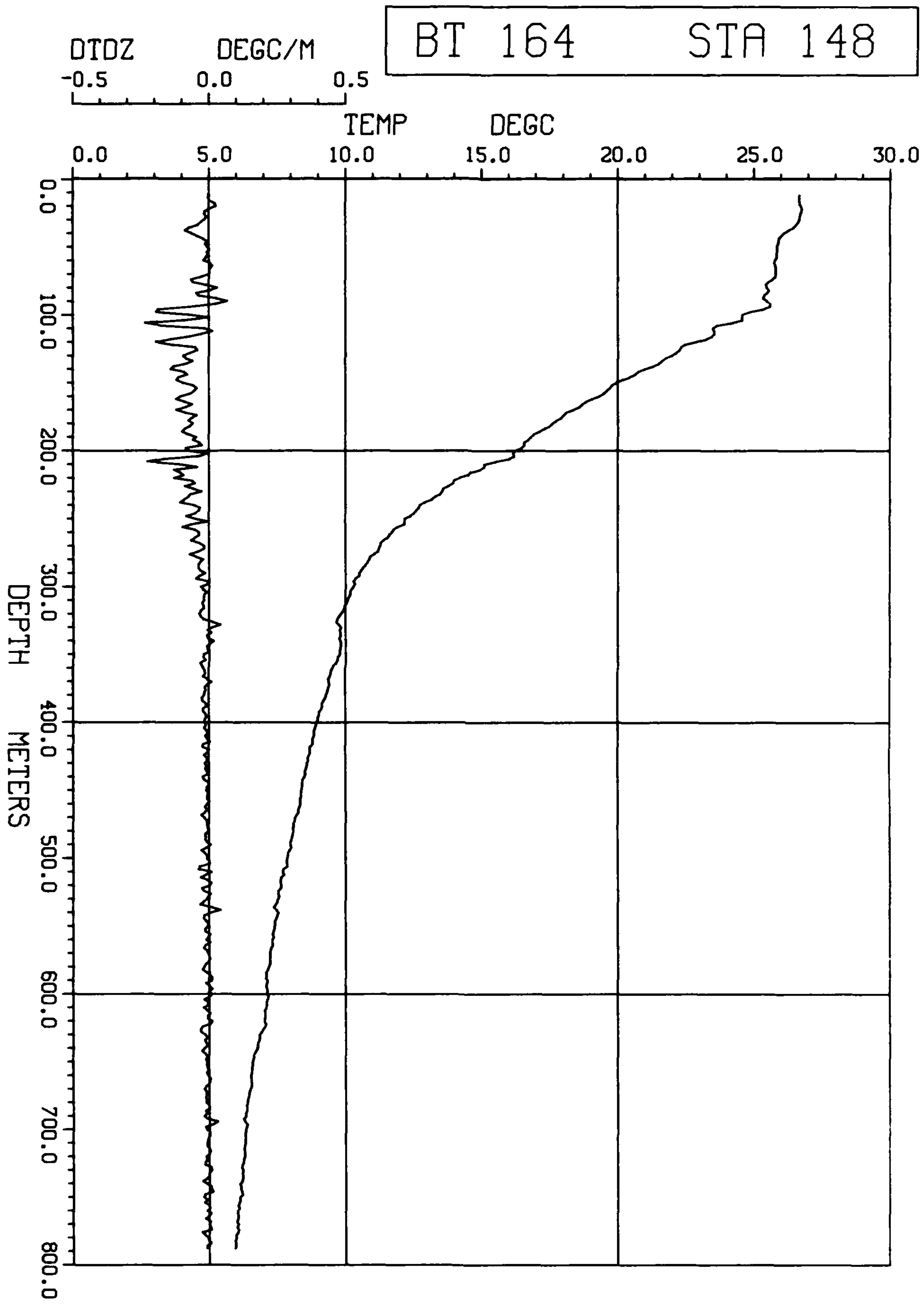
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0
DEPTH METERS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DTDZ DEGC/M
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TEMP DEGC
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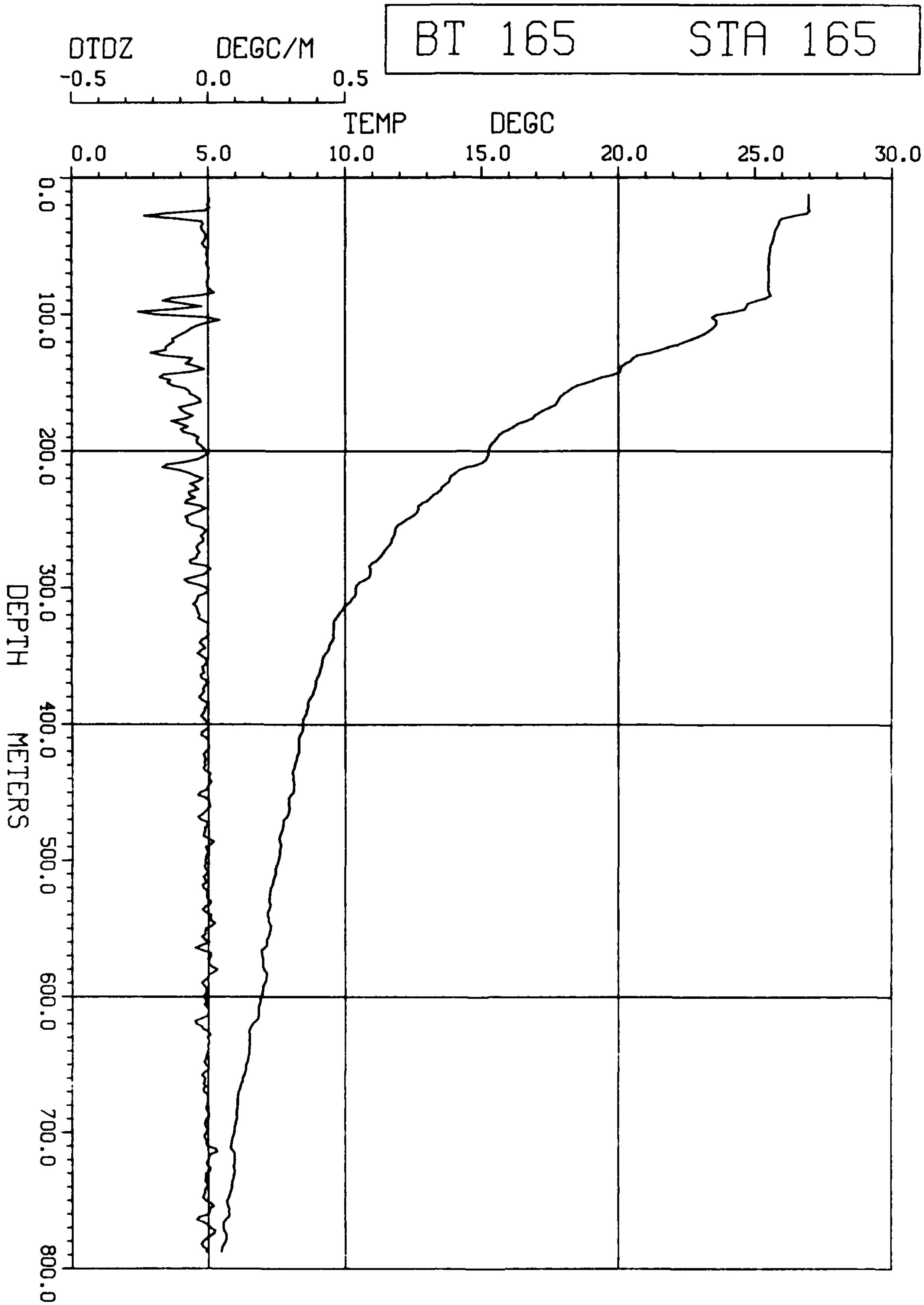
800.0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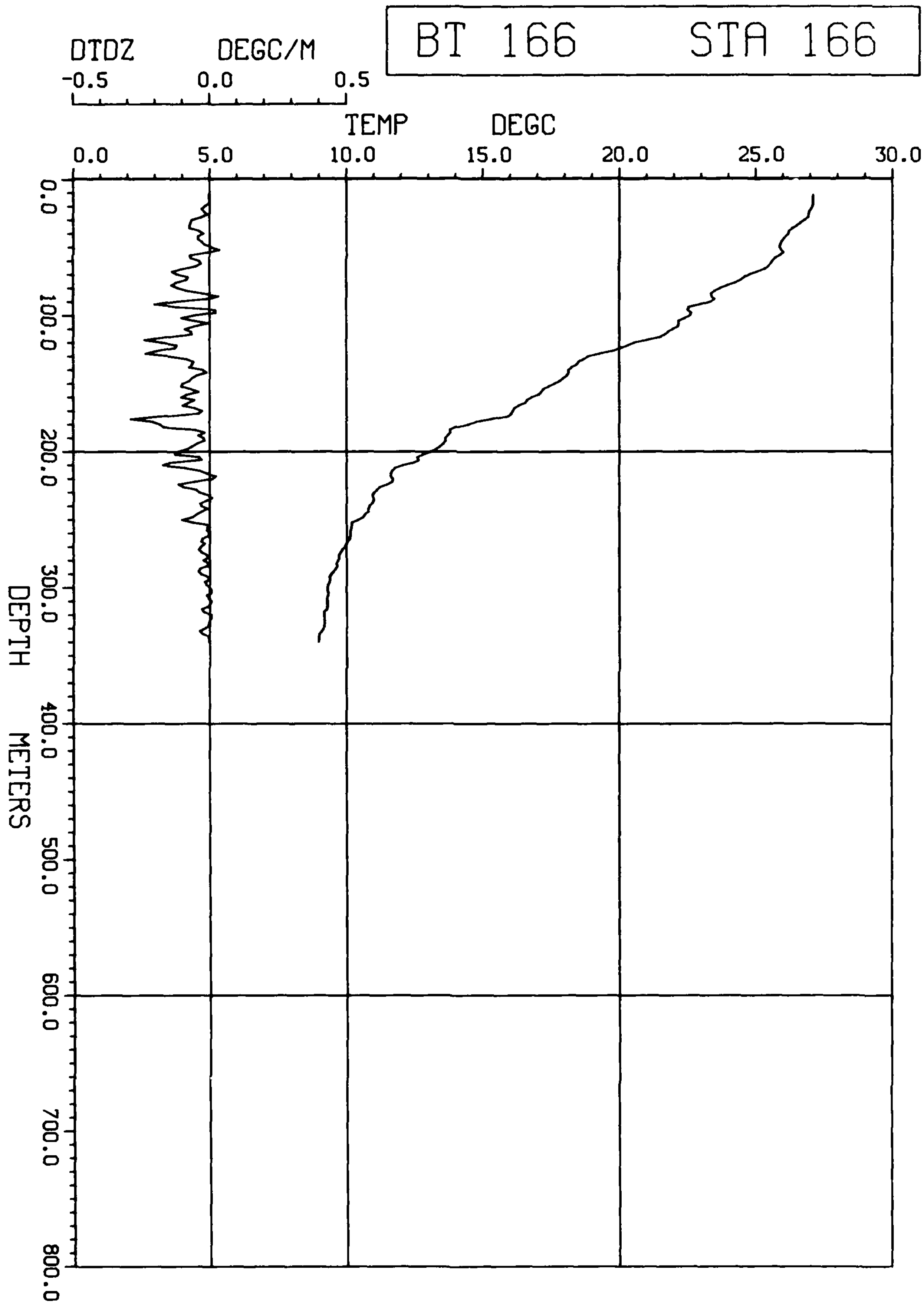
DEPTH METERS



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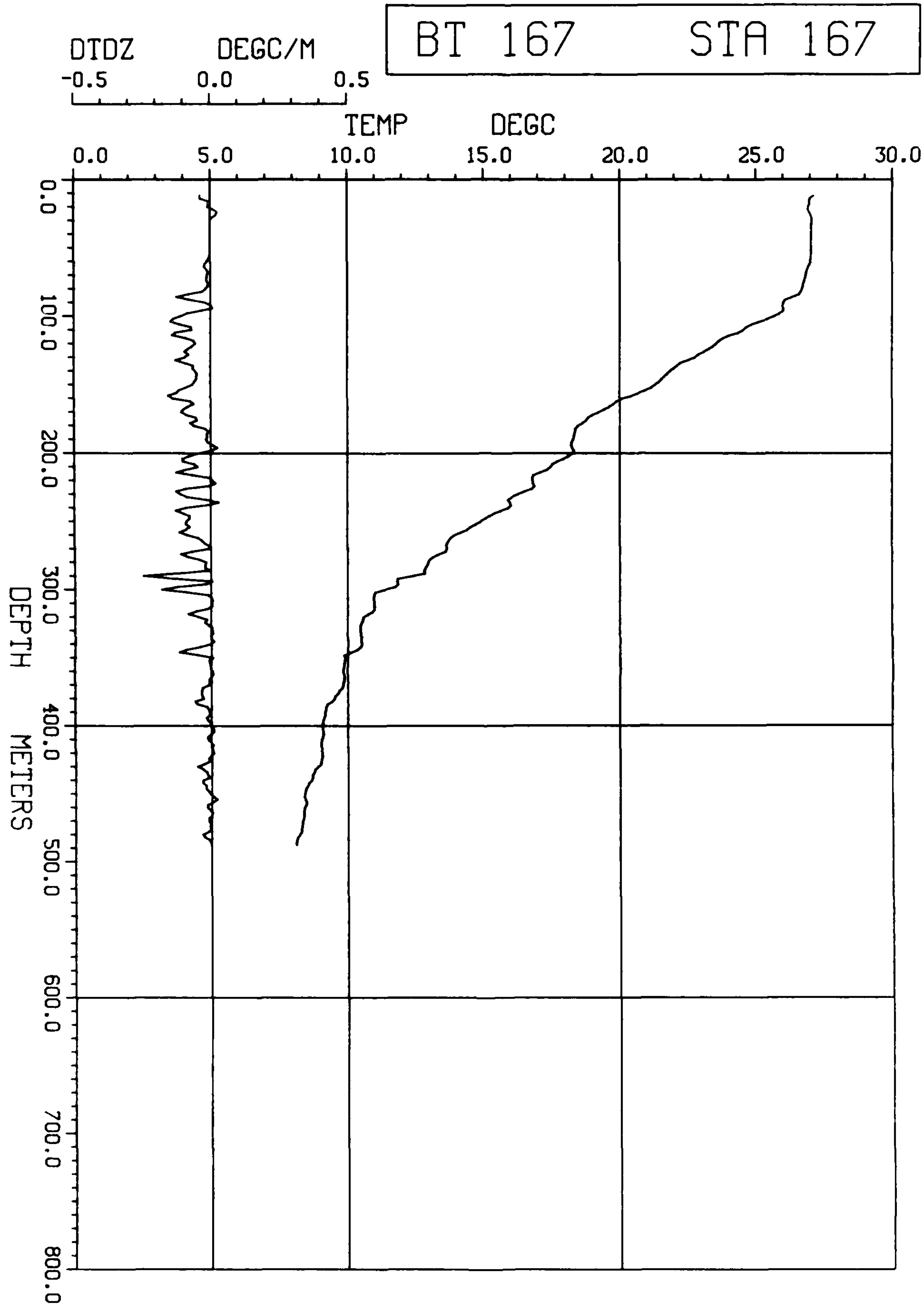
DEPTH METERS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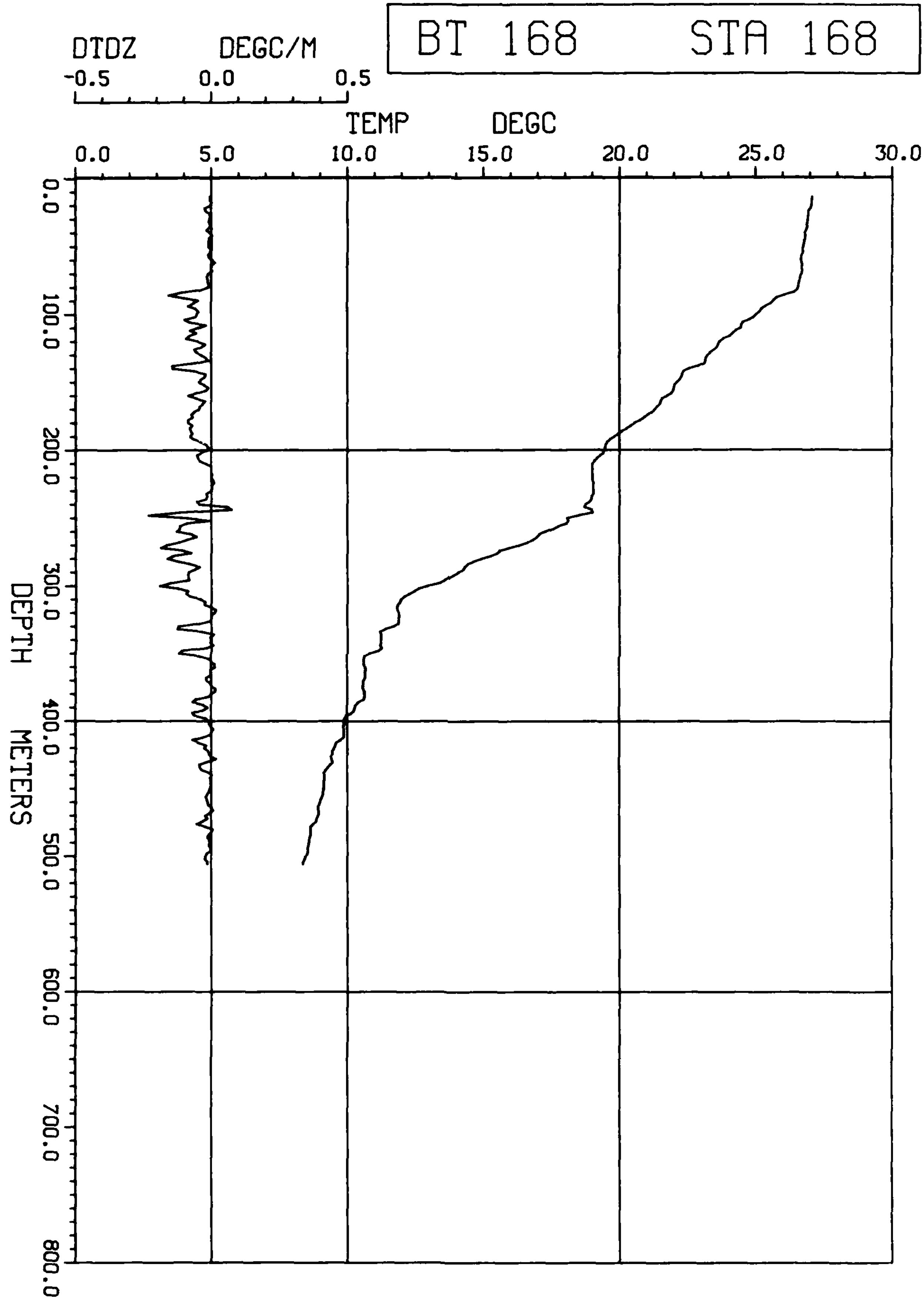
DEPTH METERS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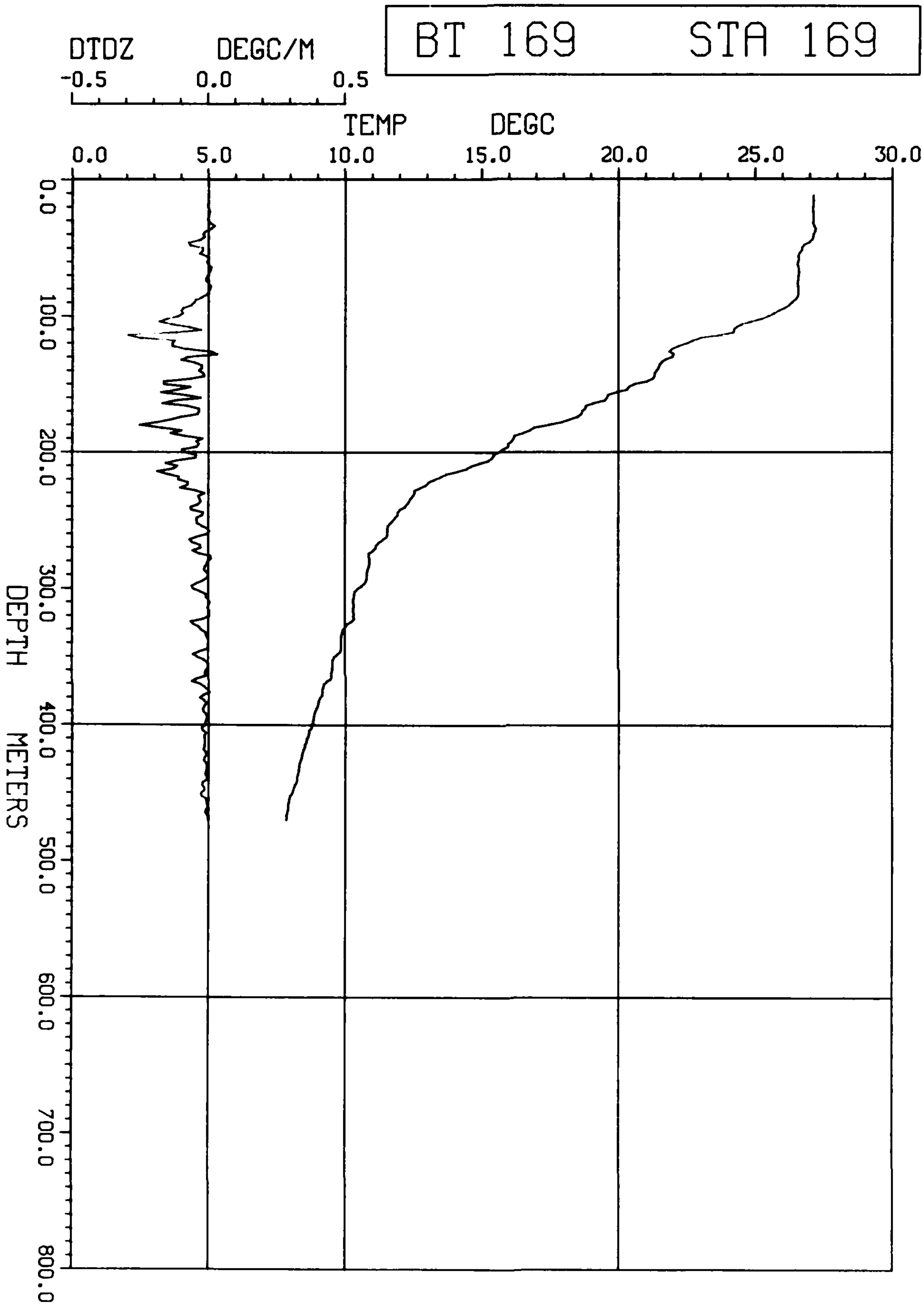
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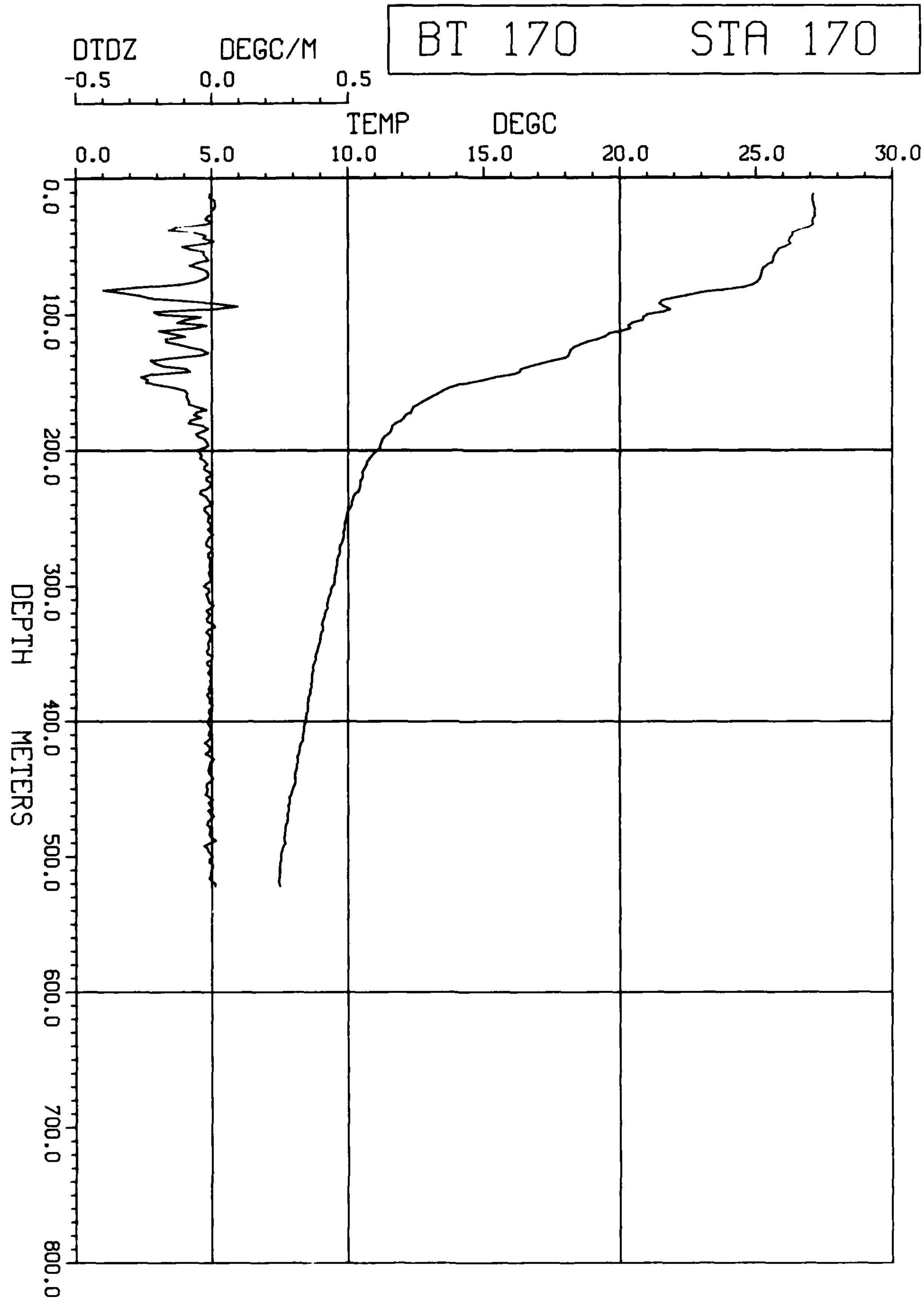
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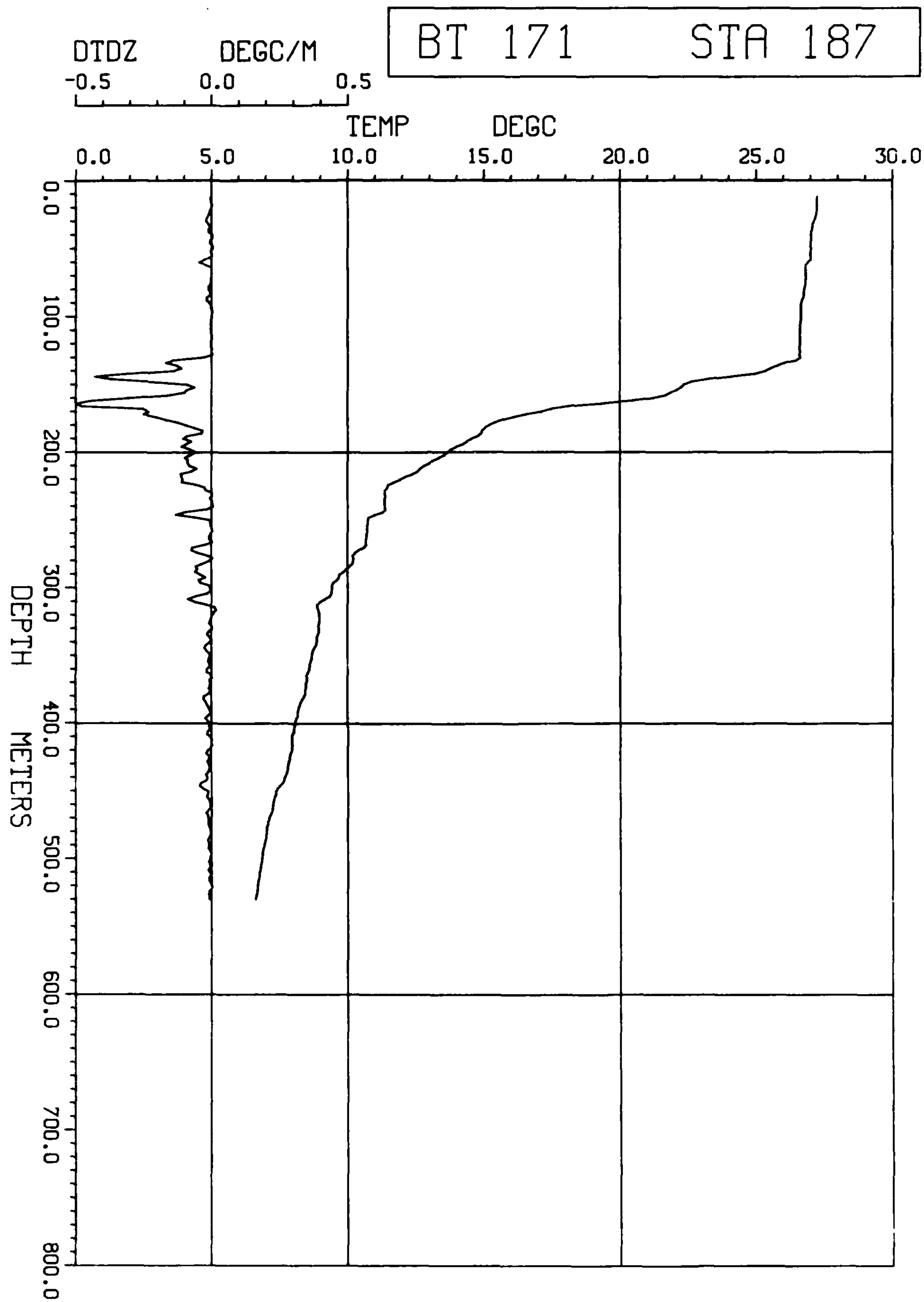
DEPTH METERS



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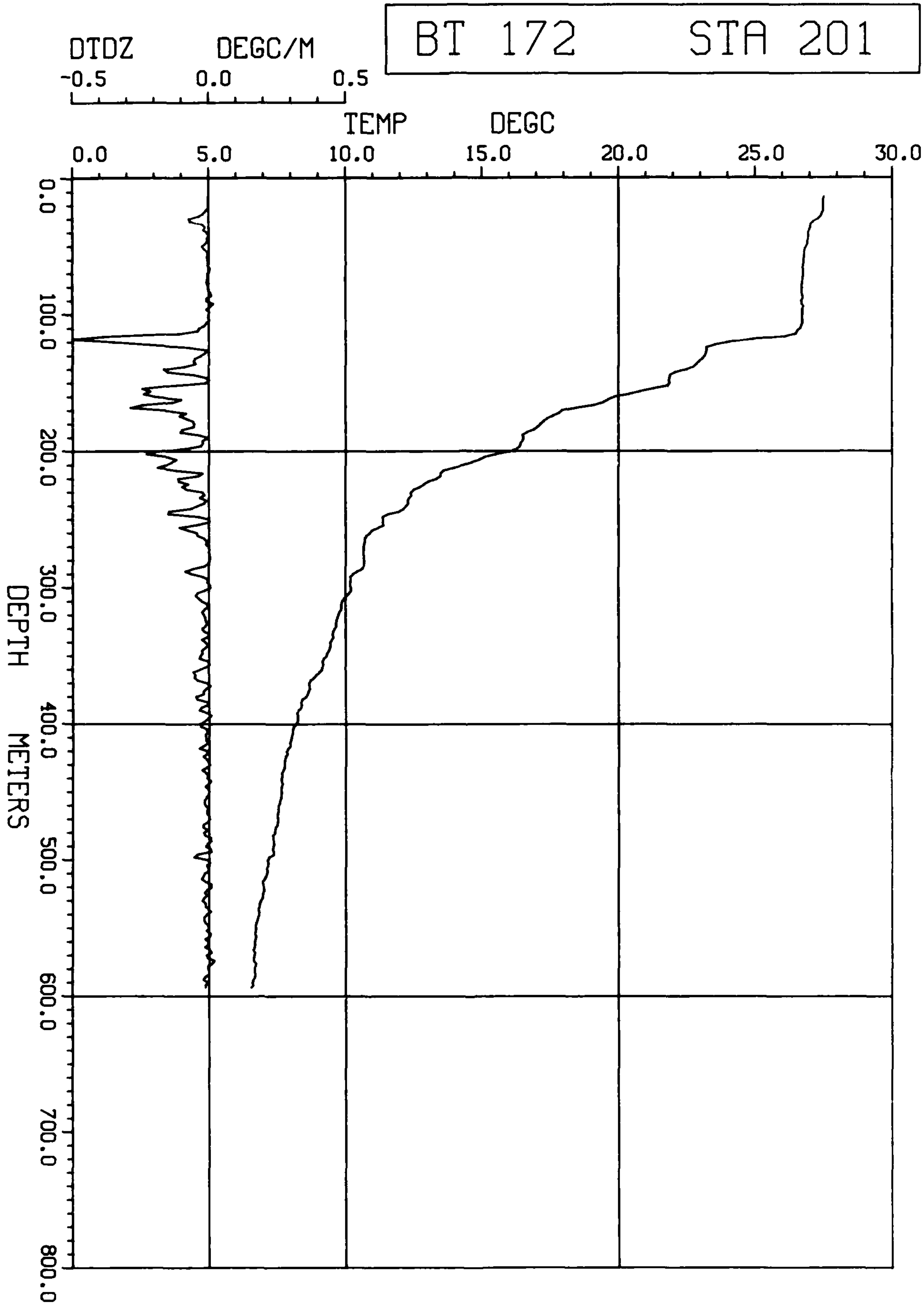
800.0
DEPTH METERS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0.5
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15.0
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DEPTH METERS
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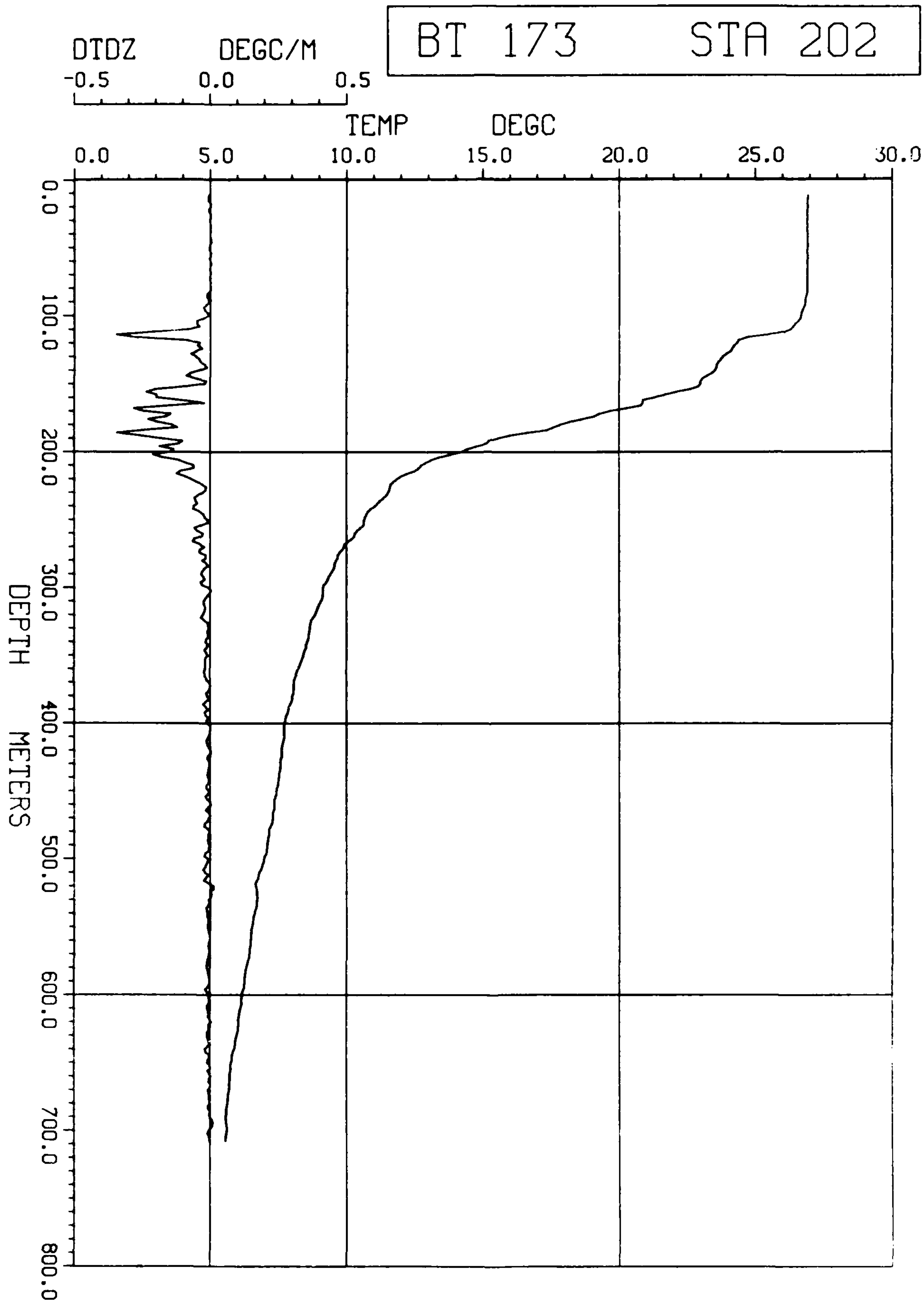
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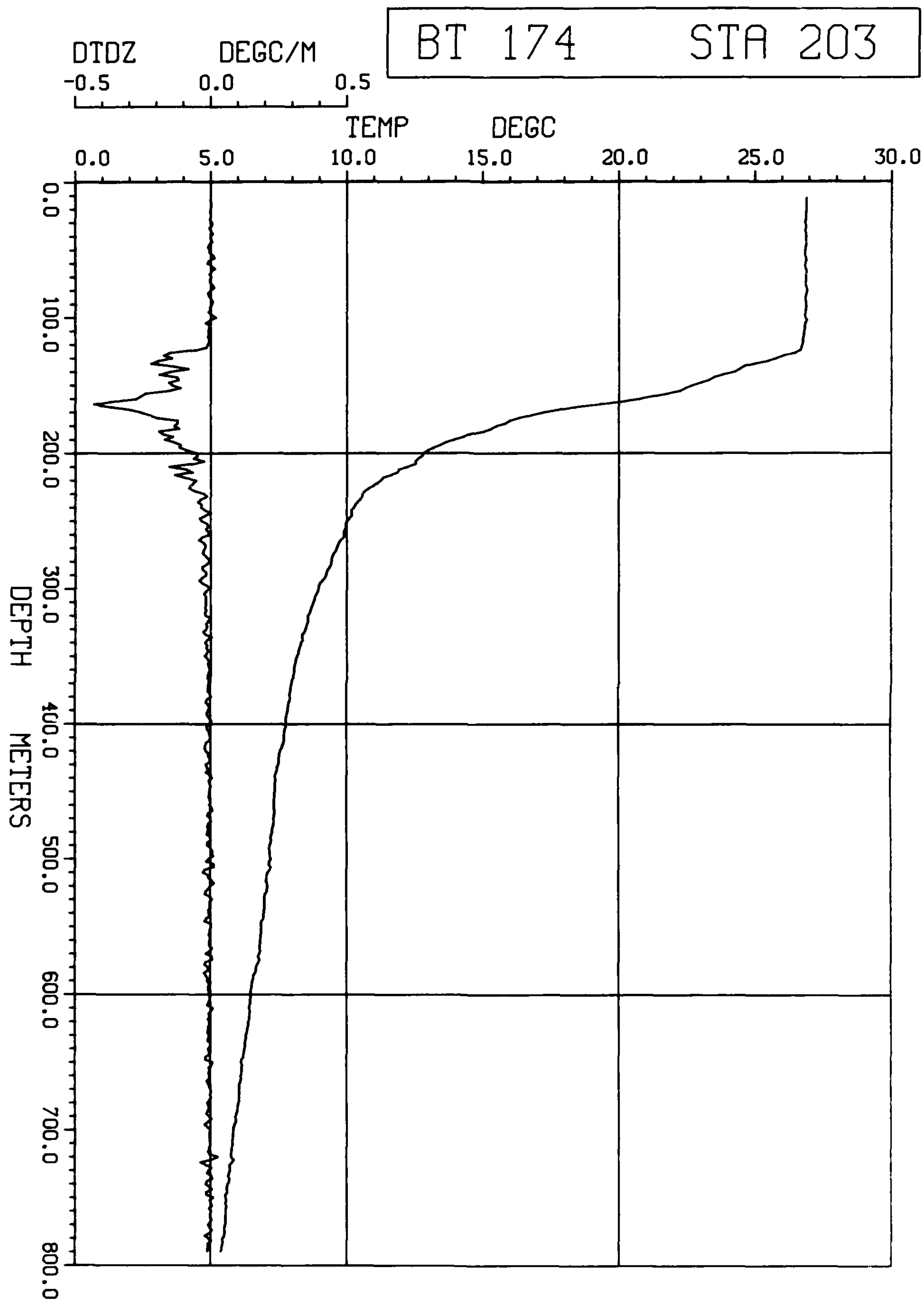
DEPTH METERS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TEMP DEGC
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DEPTH METERS
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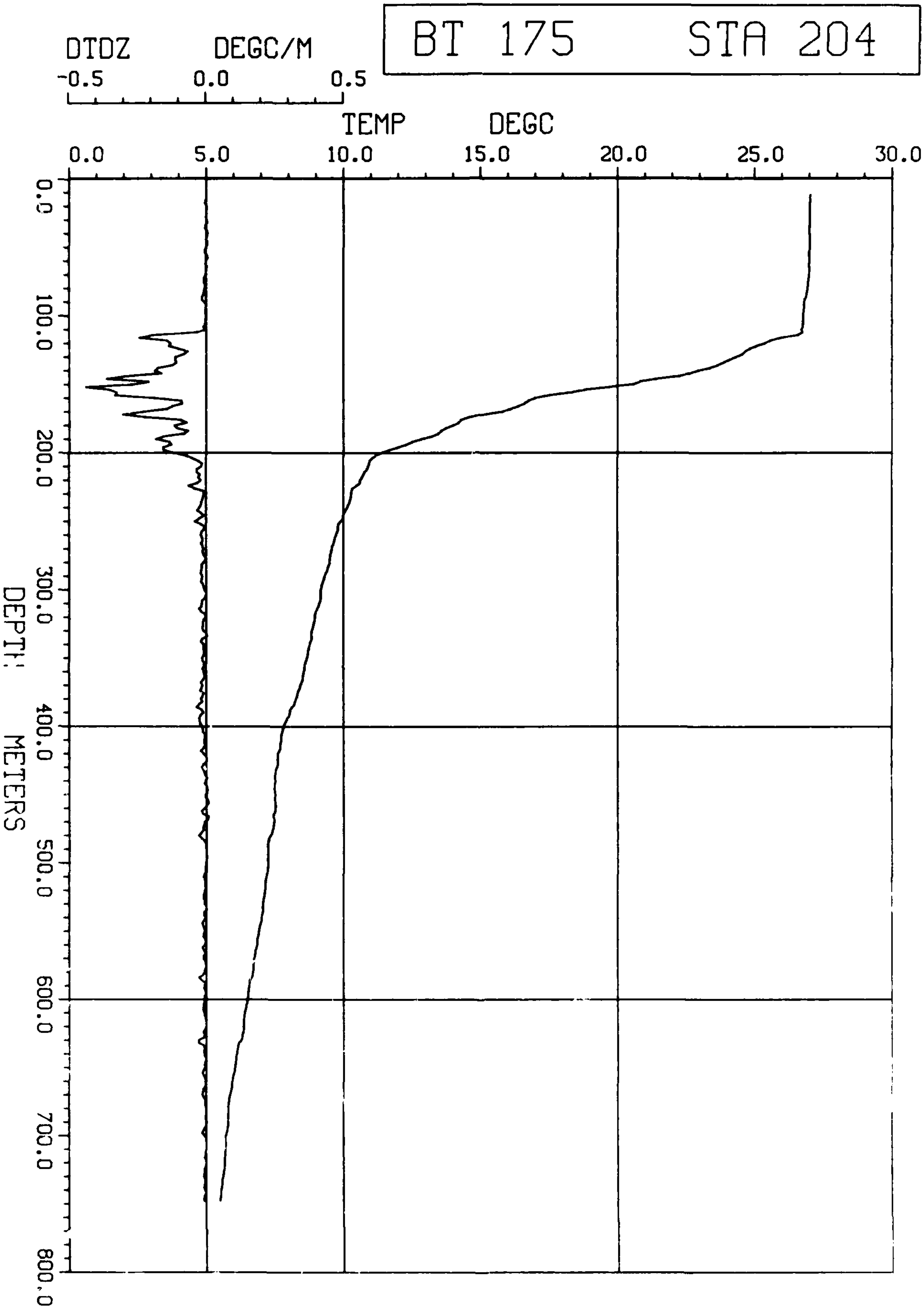

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TEMP DEGC
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DEPTH METERS
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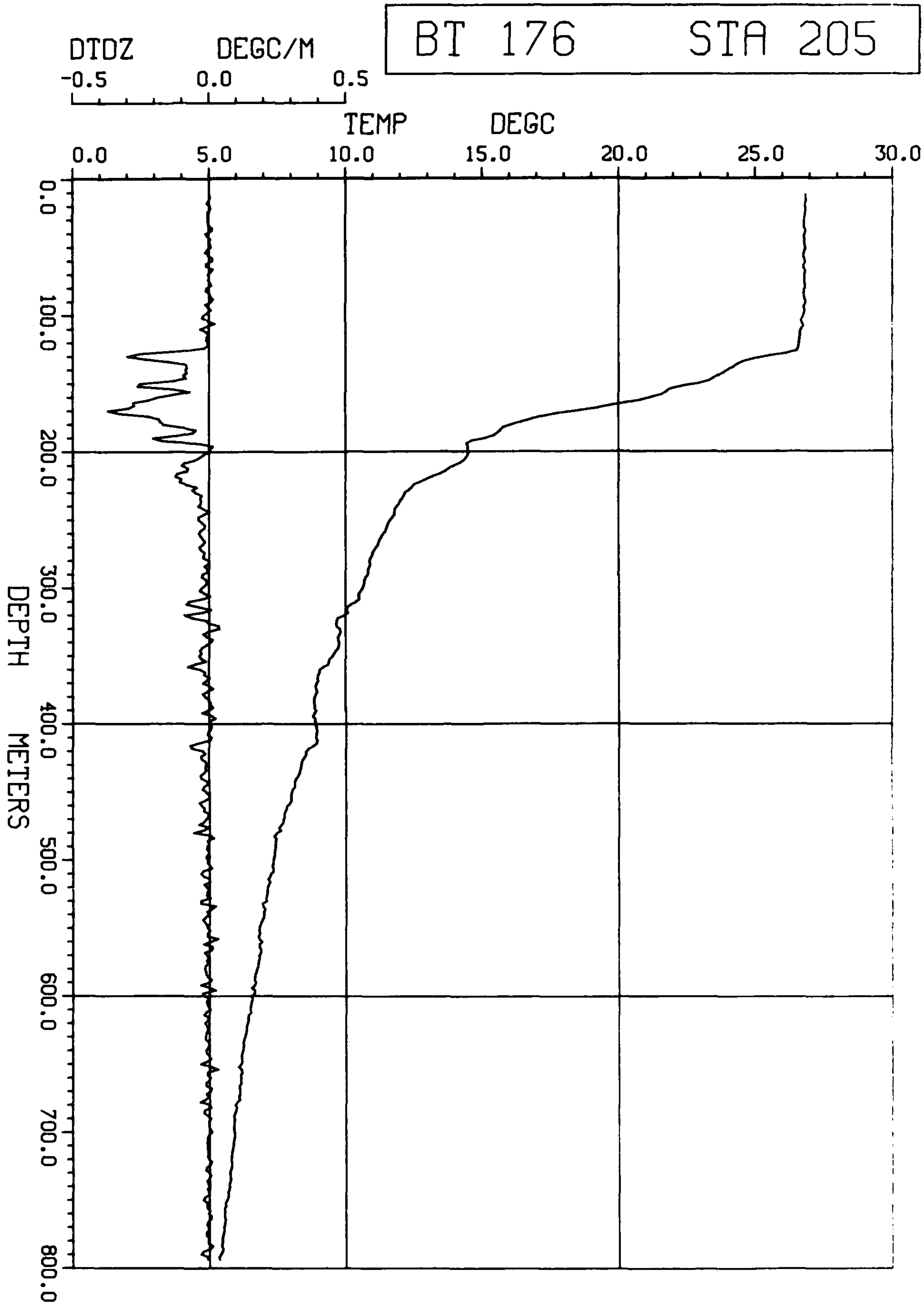

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TEMP DEGC
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400.0
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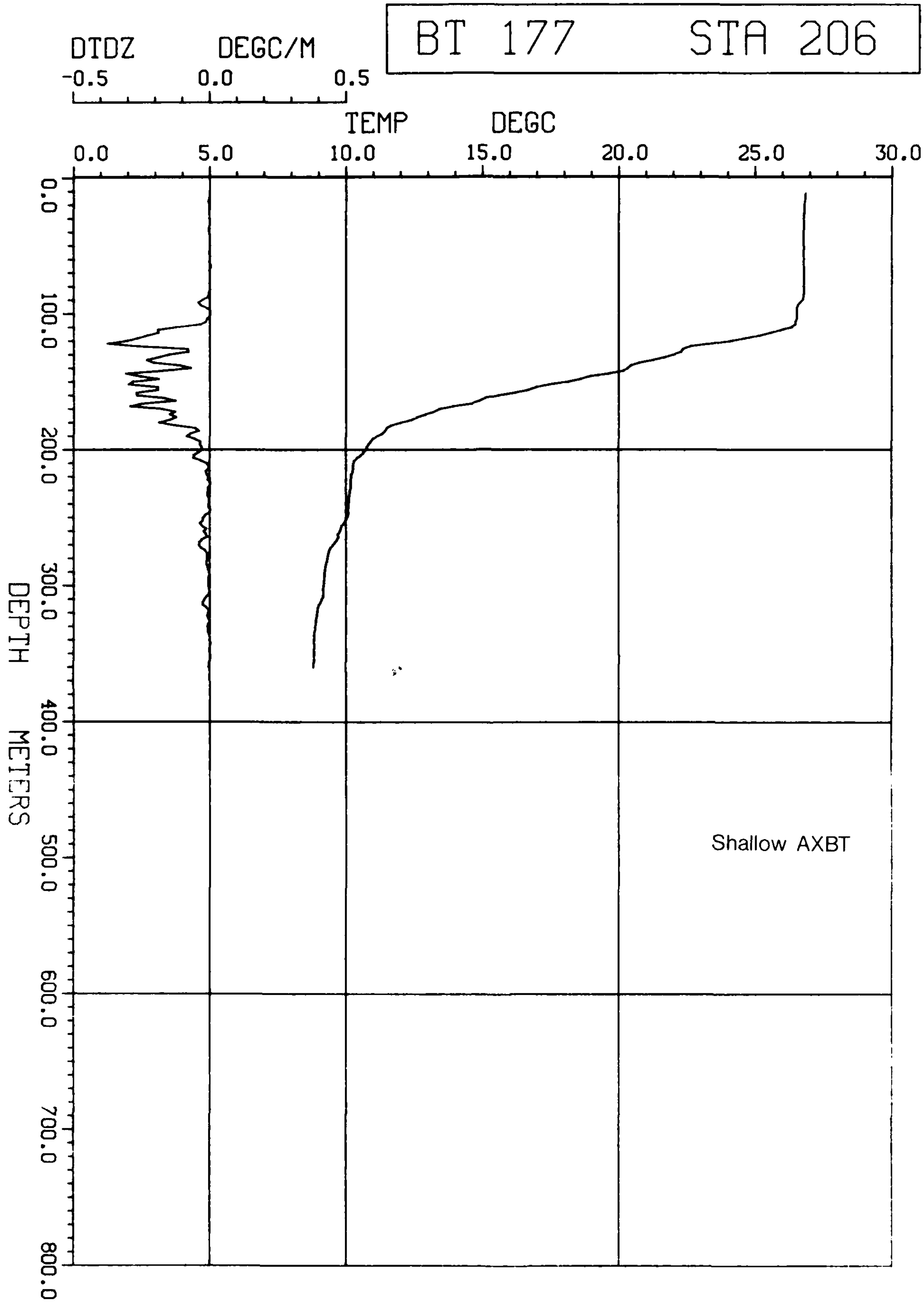
800.0


BT 177 STA 206
DTDZ DEGC/M
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TEMP DEGC
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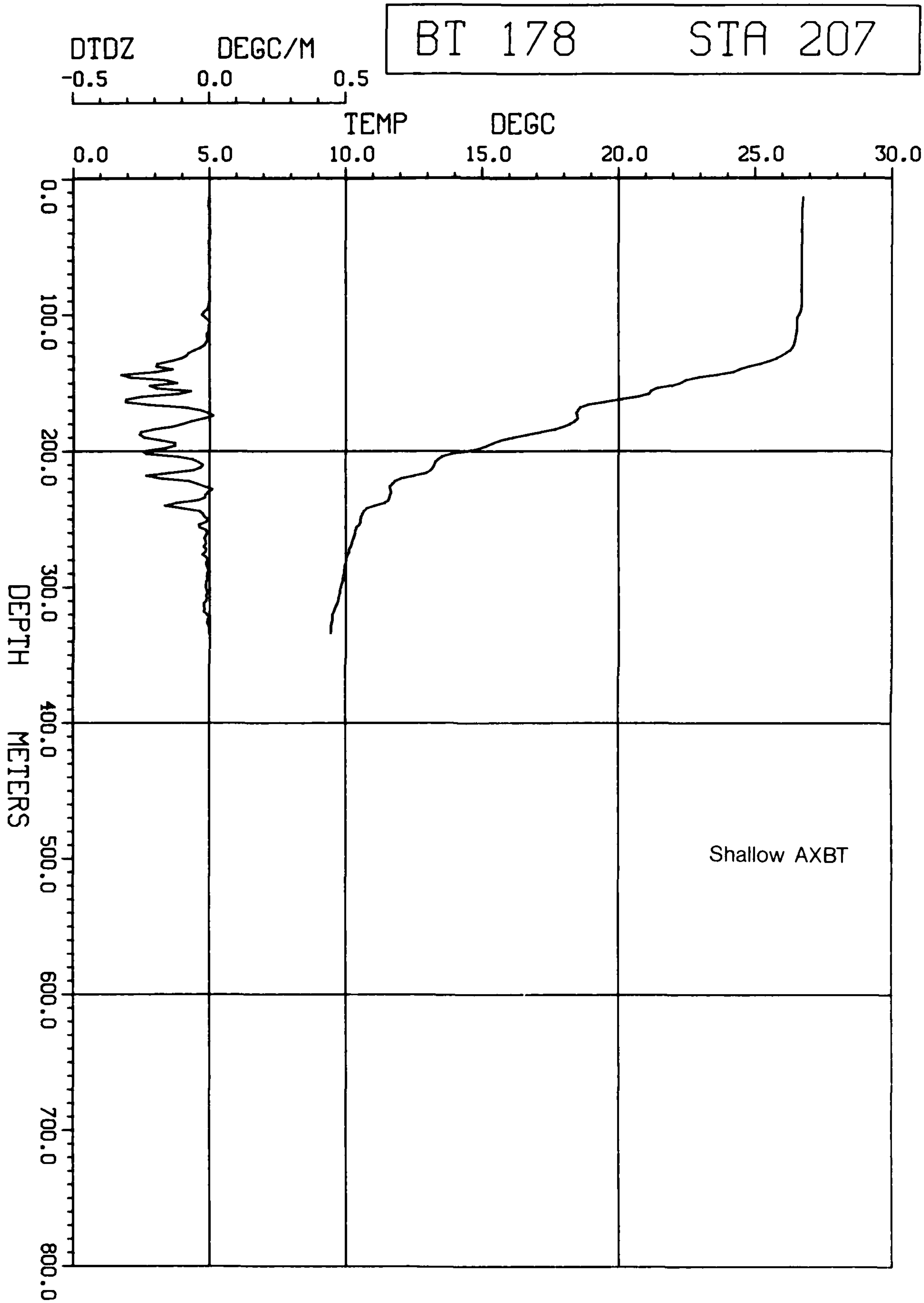
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0
DEPTH METERS
Shallow AXBT



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TEMP DEGC
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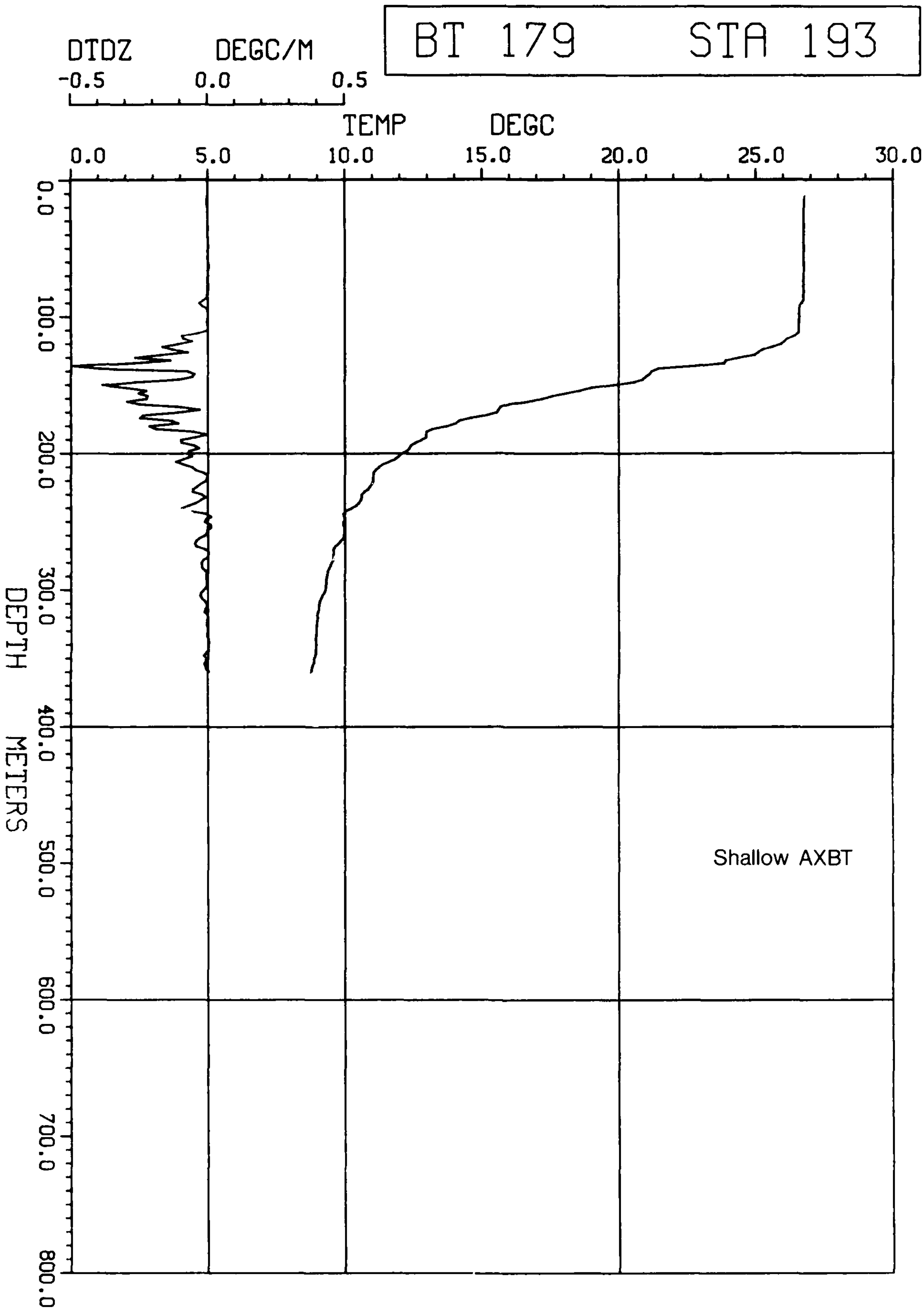
DEPTH METERS
Shallow AXBT



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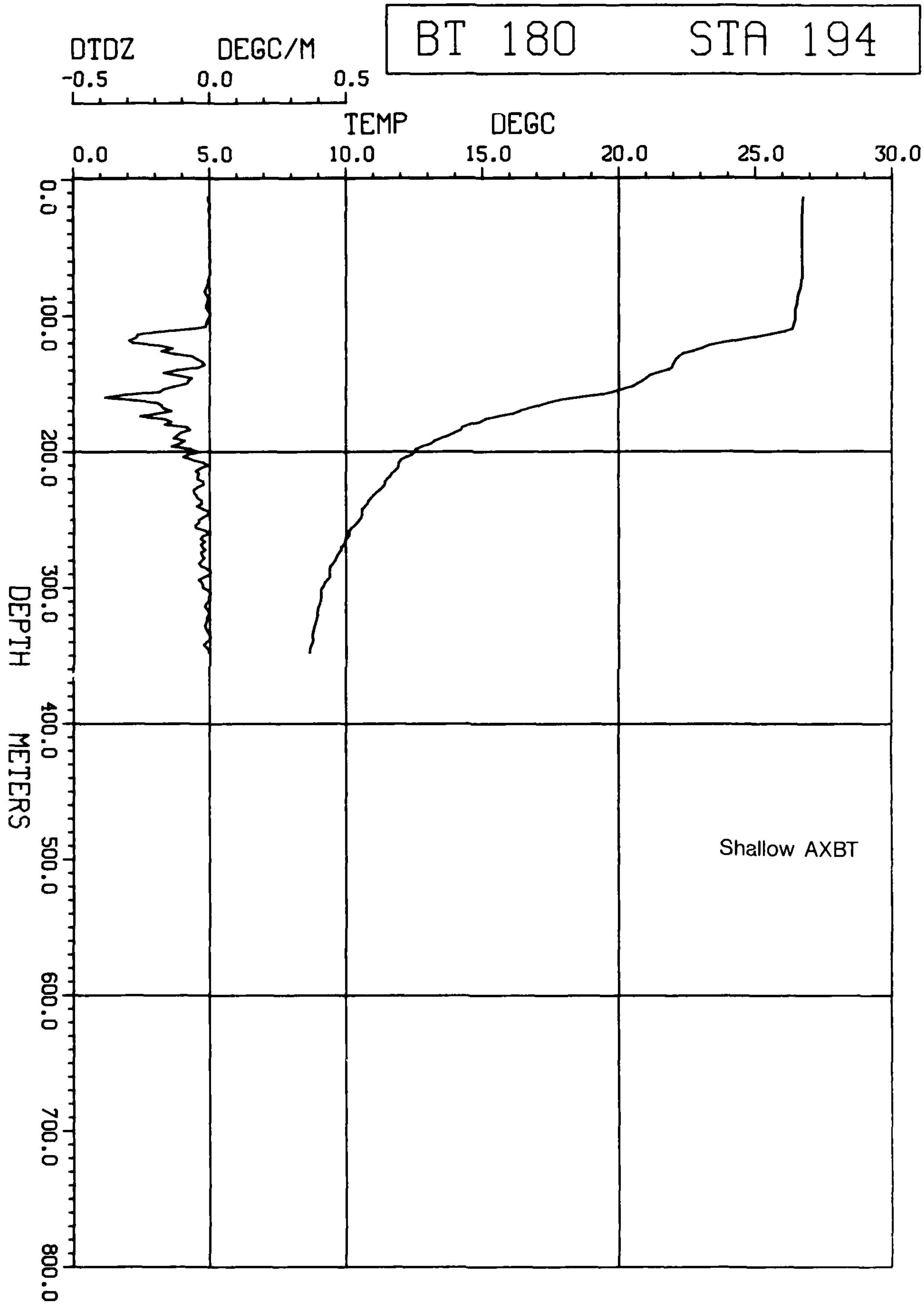
DEPTH METERS
Shallow AXBT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TEMP DEGC
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DEPTH METERS
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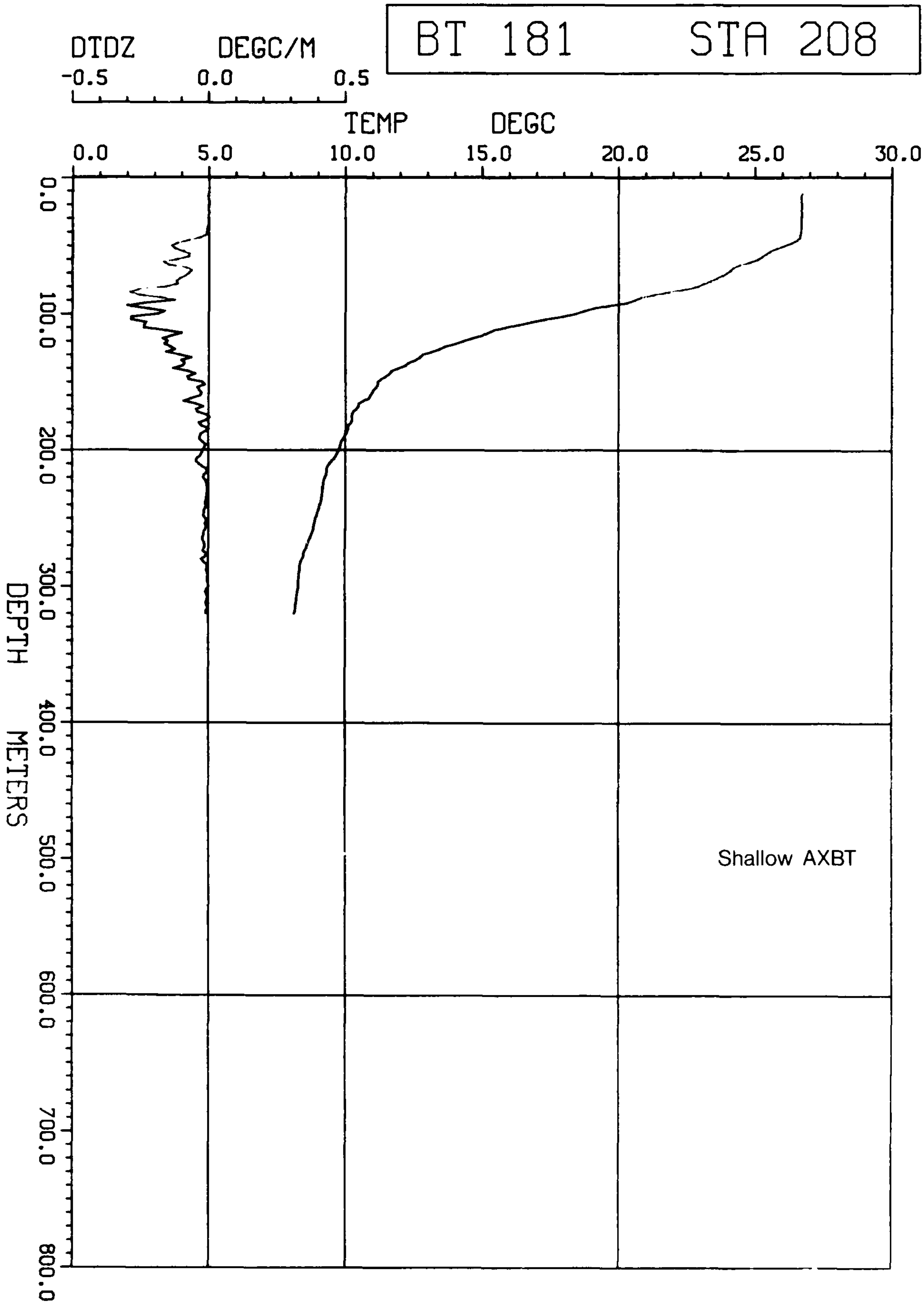
Shallow AXBT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TEMP DEGC
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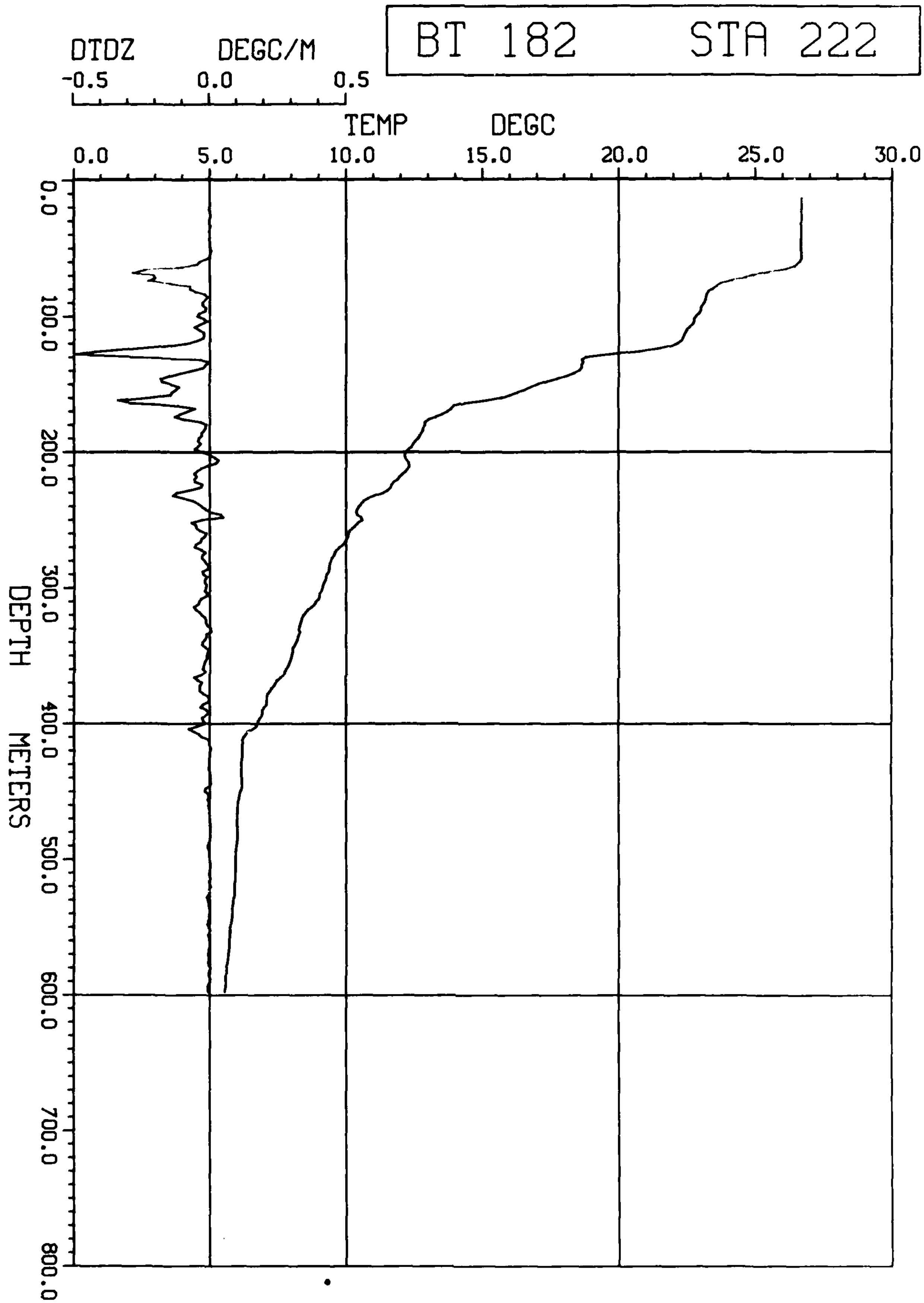
Shallow AXBT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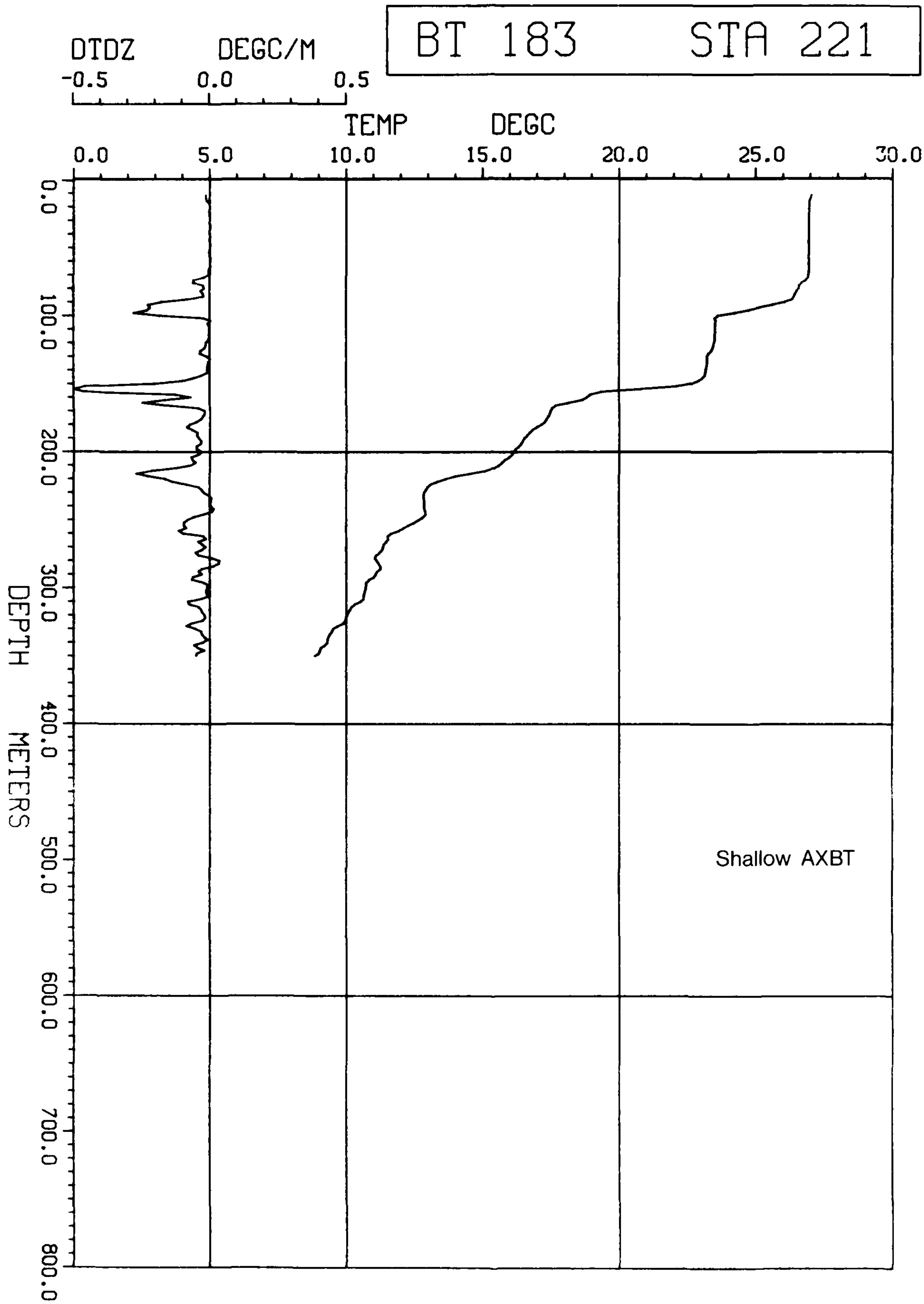
DEPTH METERS



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DEPTH METERS
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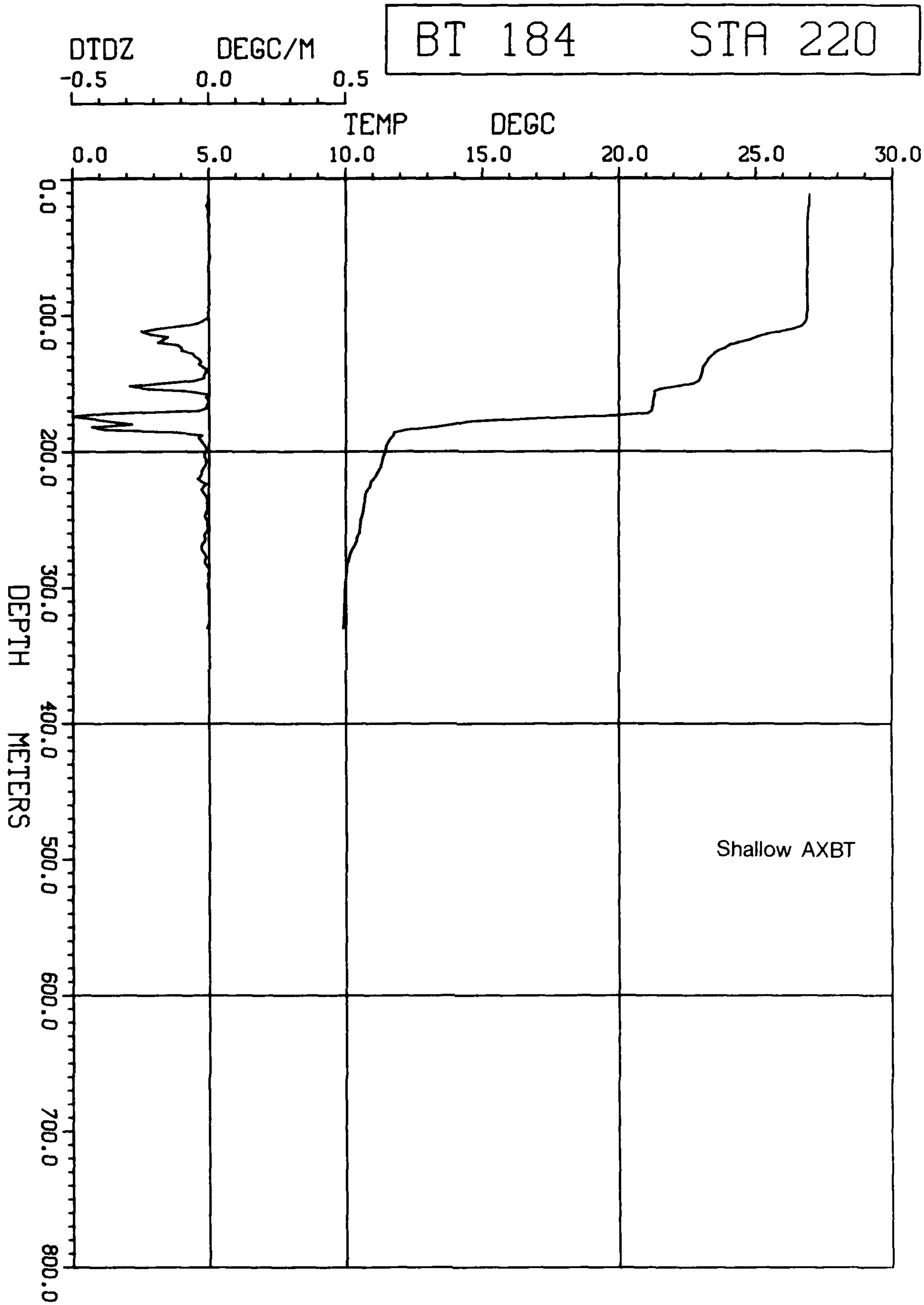
Shallow AXBT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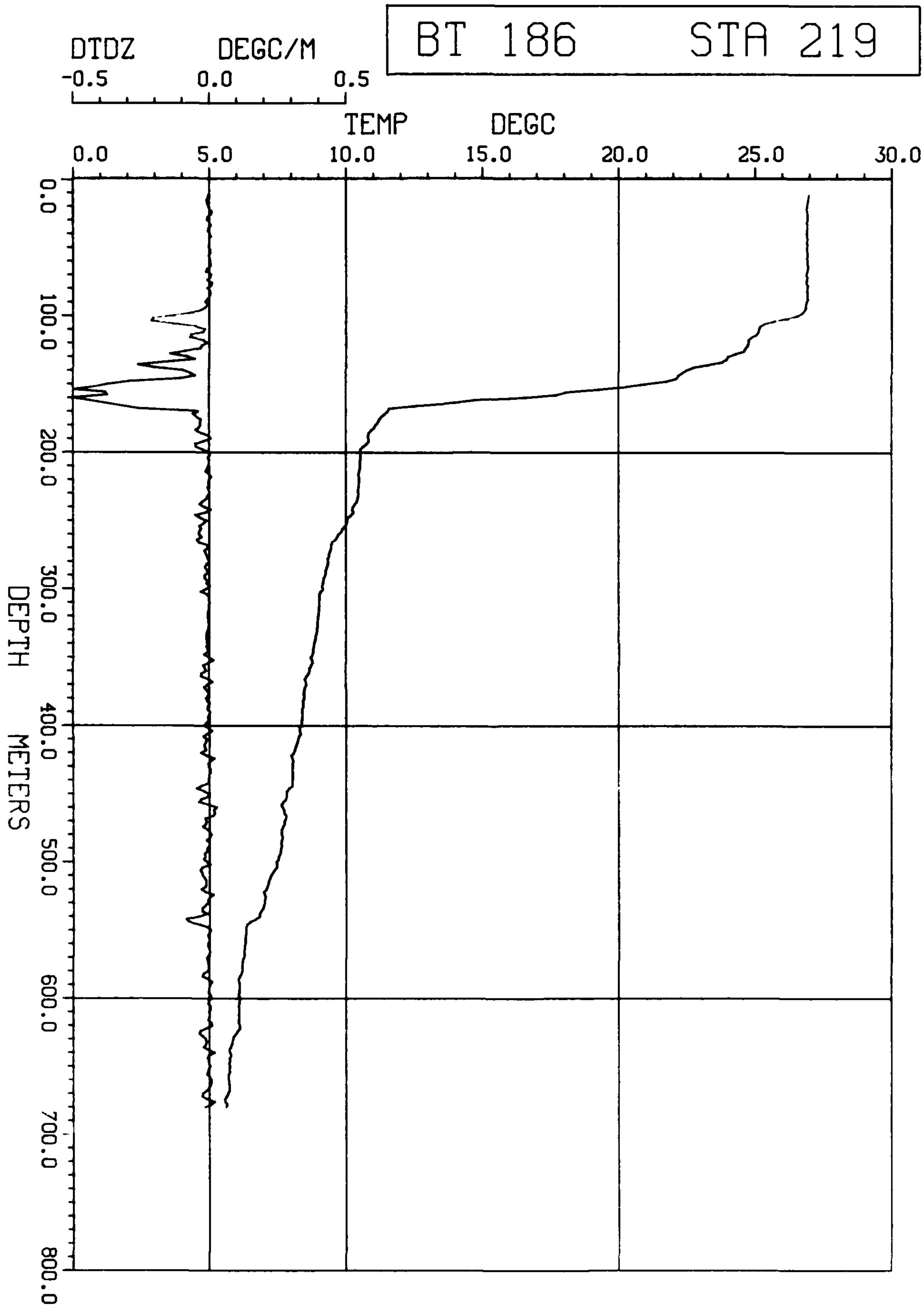
Shallow AXBT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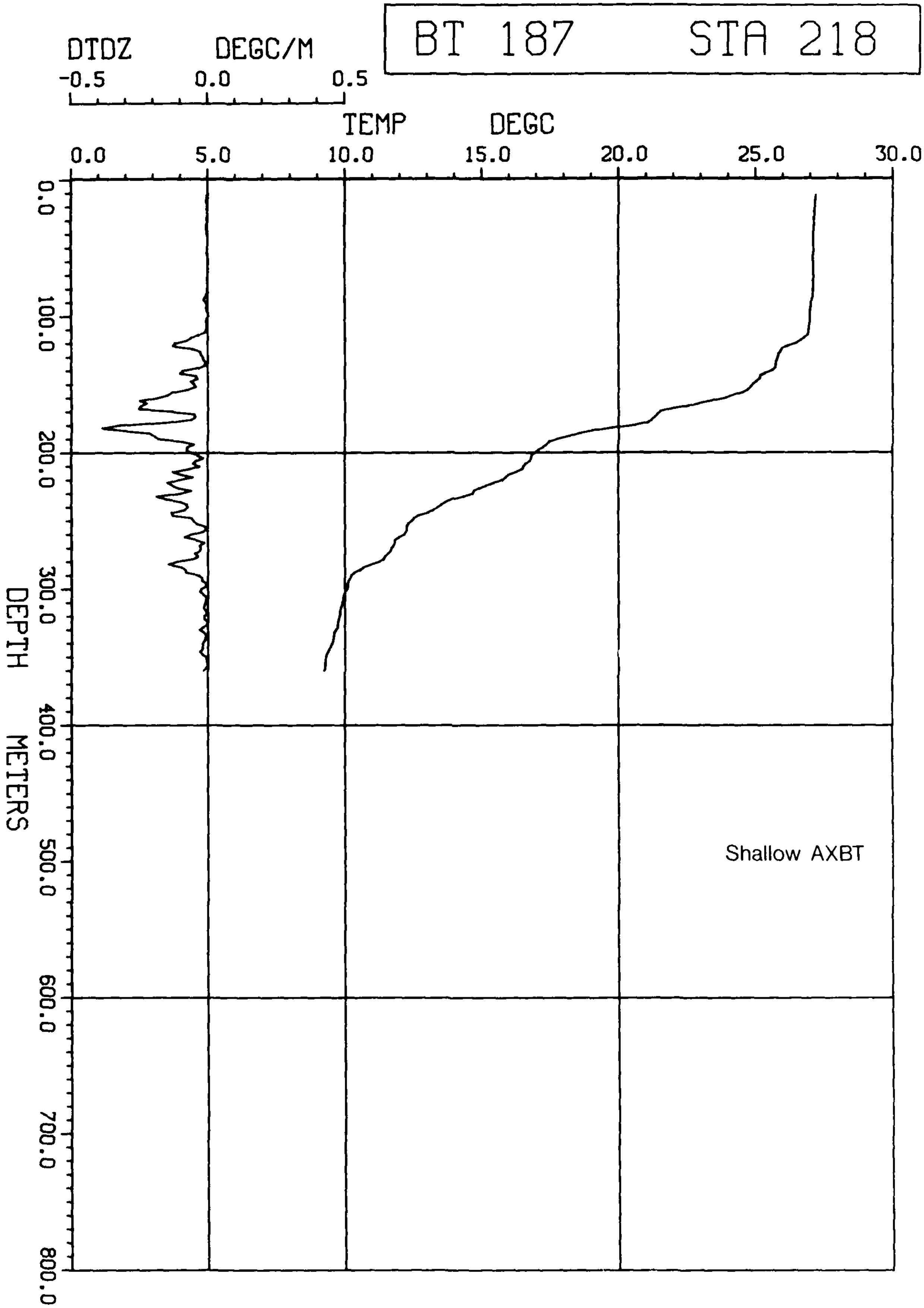
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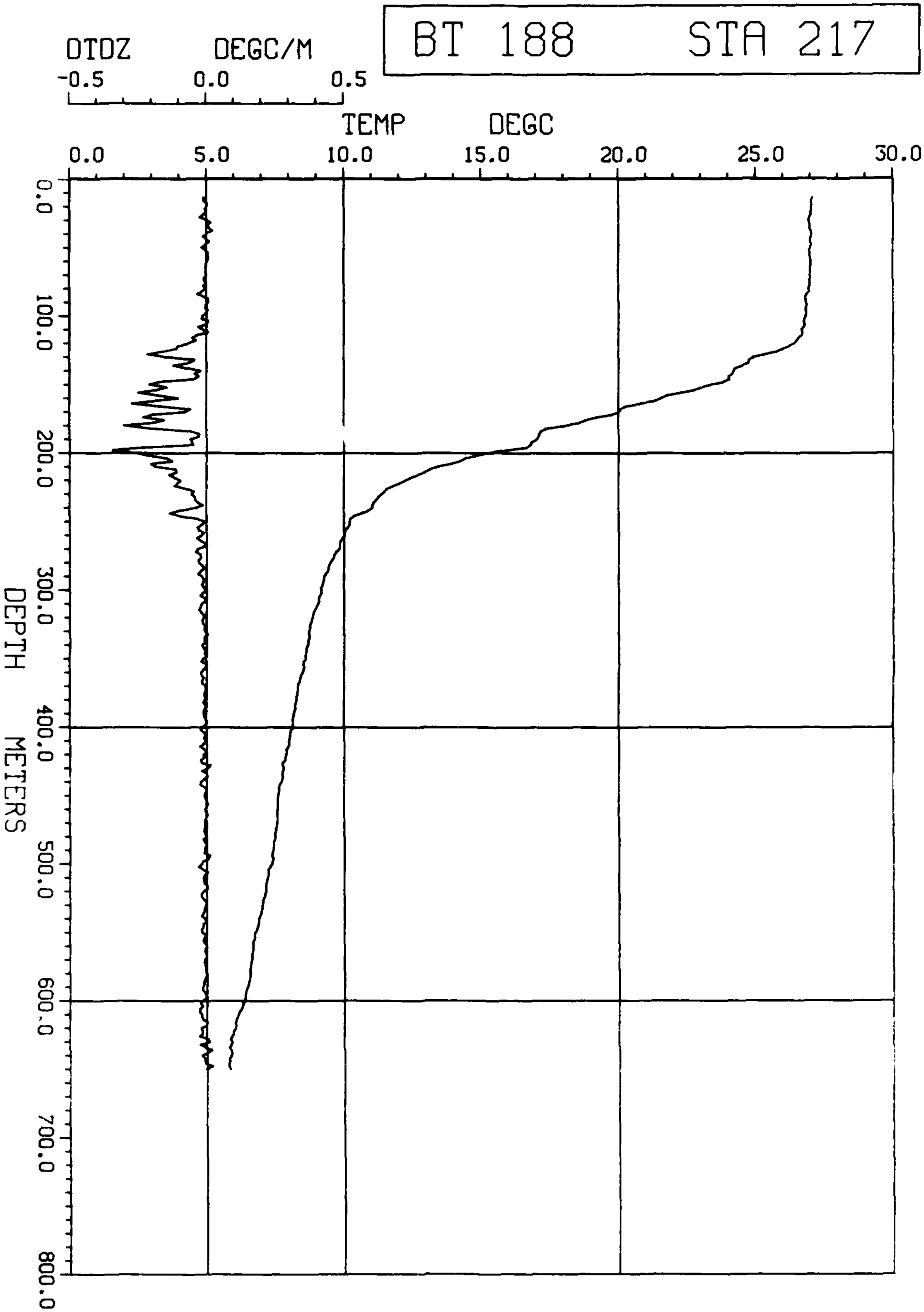
DEPTH METERS
Shallow AXBT



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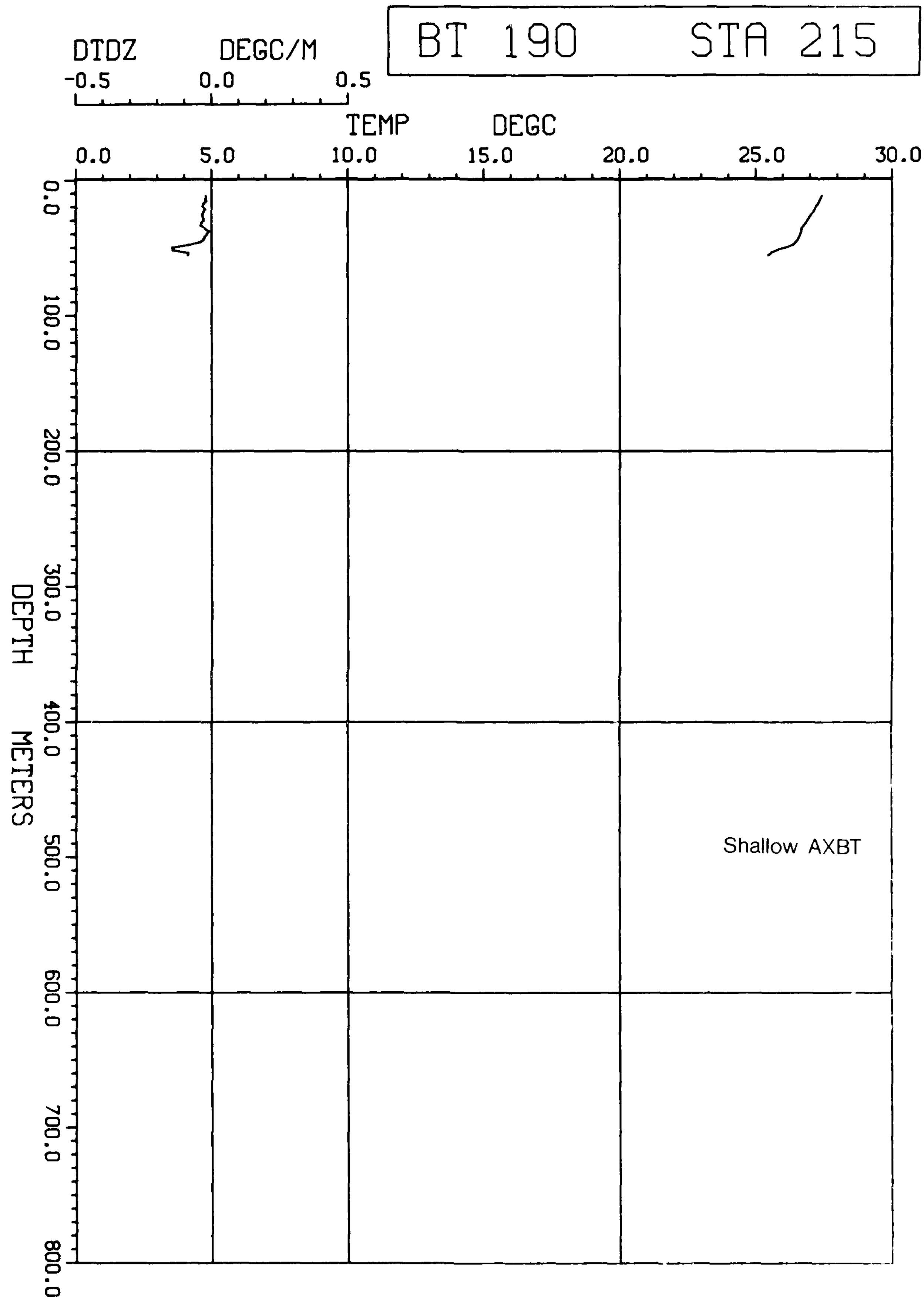
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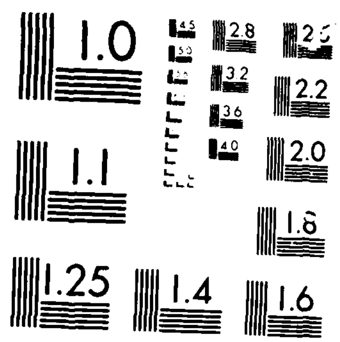
Shallow AXBT

AD-A169 441 AXBT (AIR-DEPLOYED EXPENDABLE BATHYTHERMOGRAPH) 3/3
MEASUREMENTS OFF THE NORT..(U) NAVAL OCEAN RESEARCH AND
DEVELOPMENT ACTIVITY NSTL STATION MS.. J D BOYD ET AL.
UNCLASSIFIED JAN 86 NORDA-112 F/G 8/3 NL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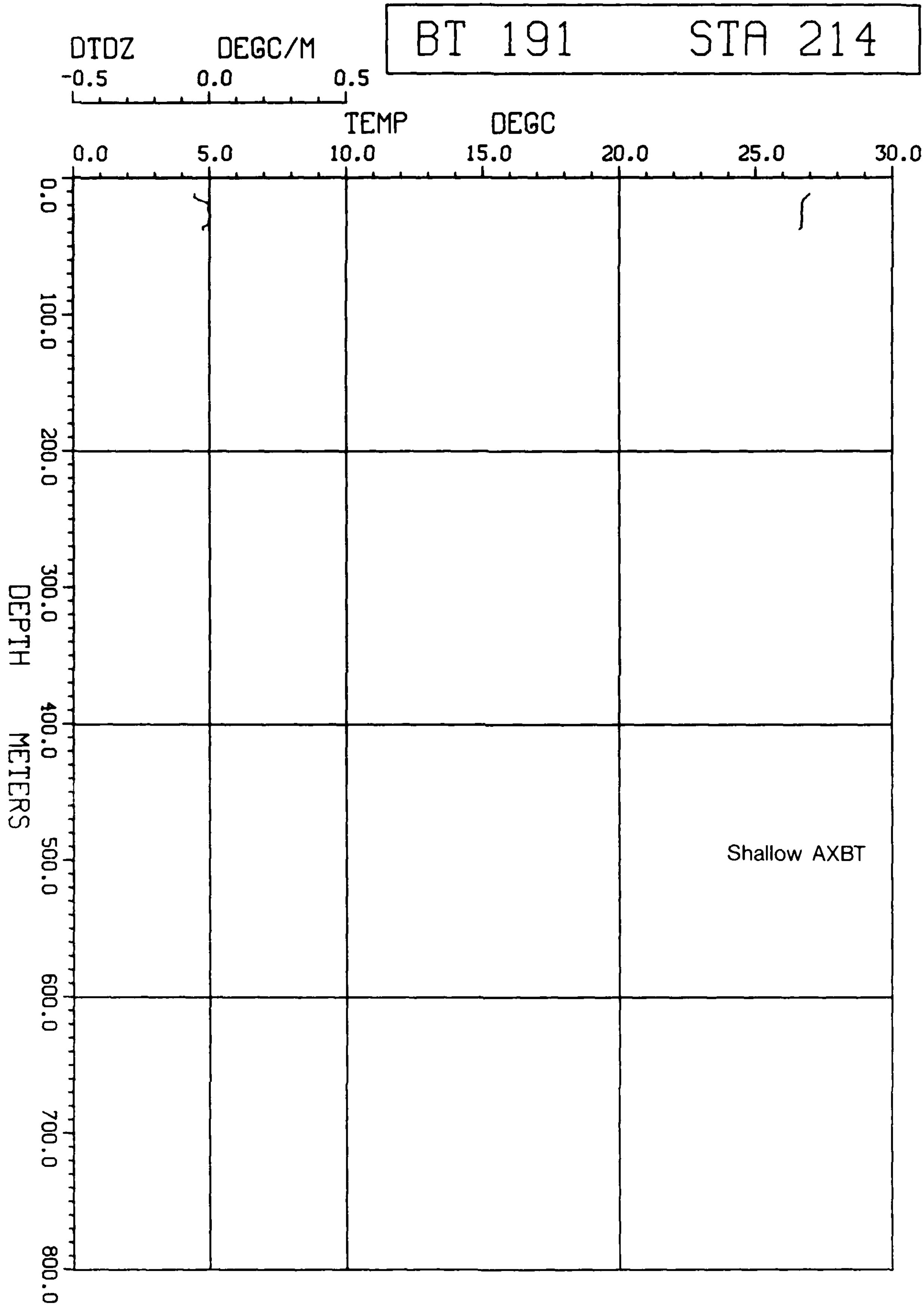
1.4
1.6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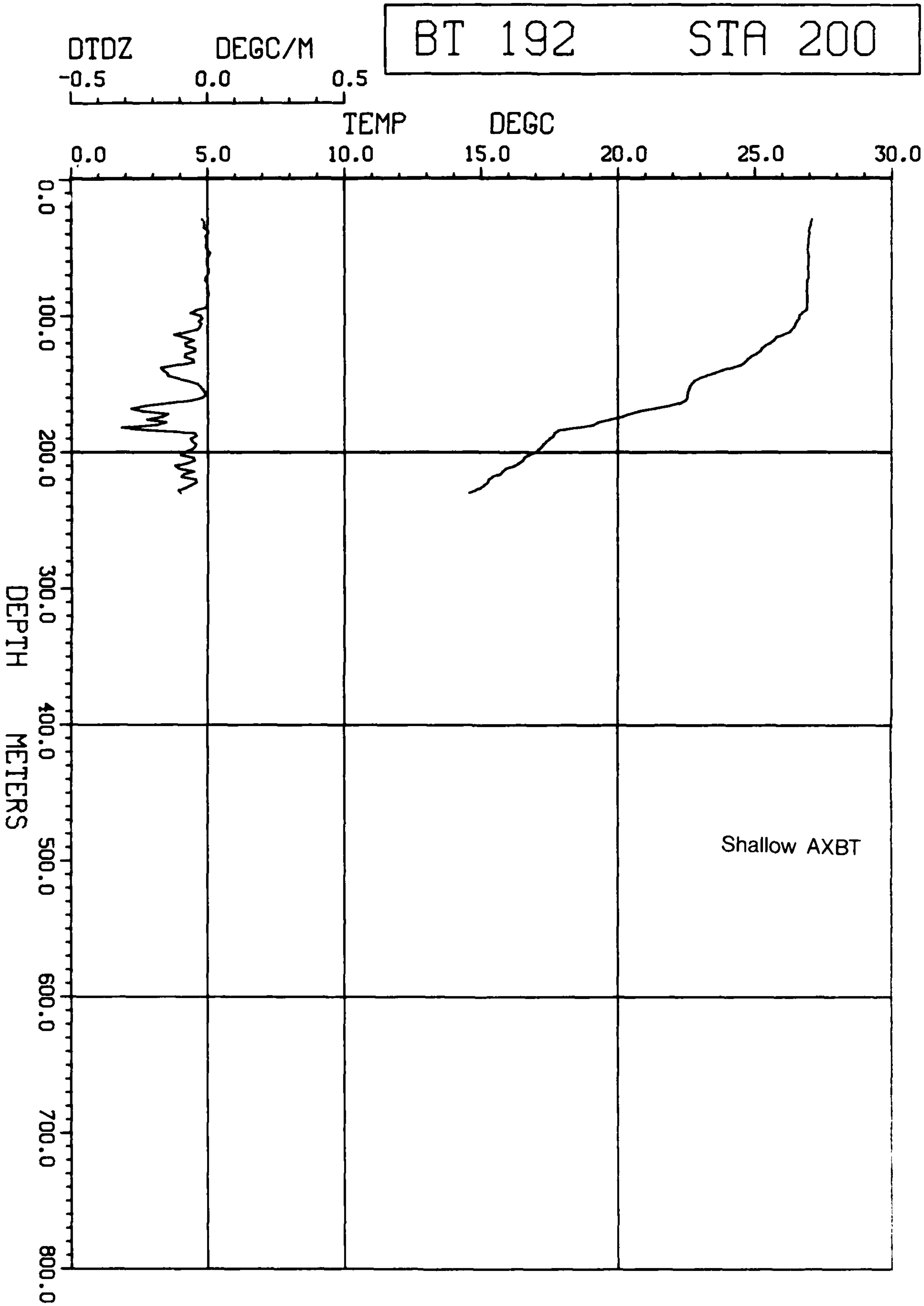
Shallow AXBT



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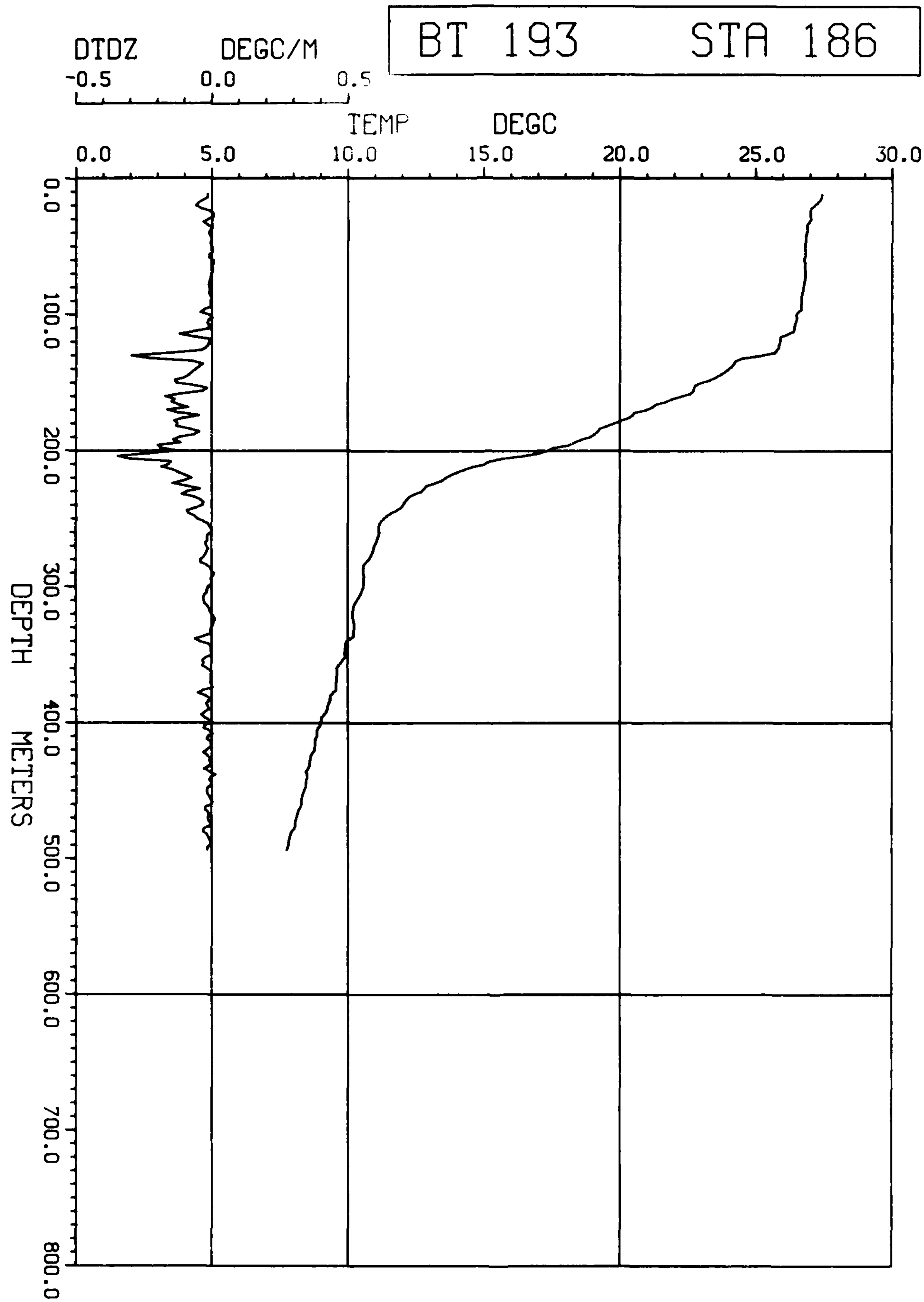
800.0
DEPTH METERS
Shallow AXBT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20.0
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DEPTH METERS
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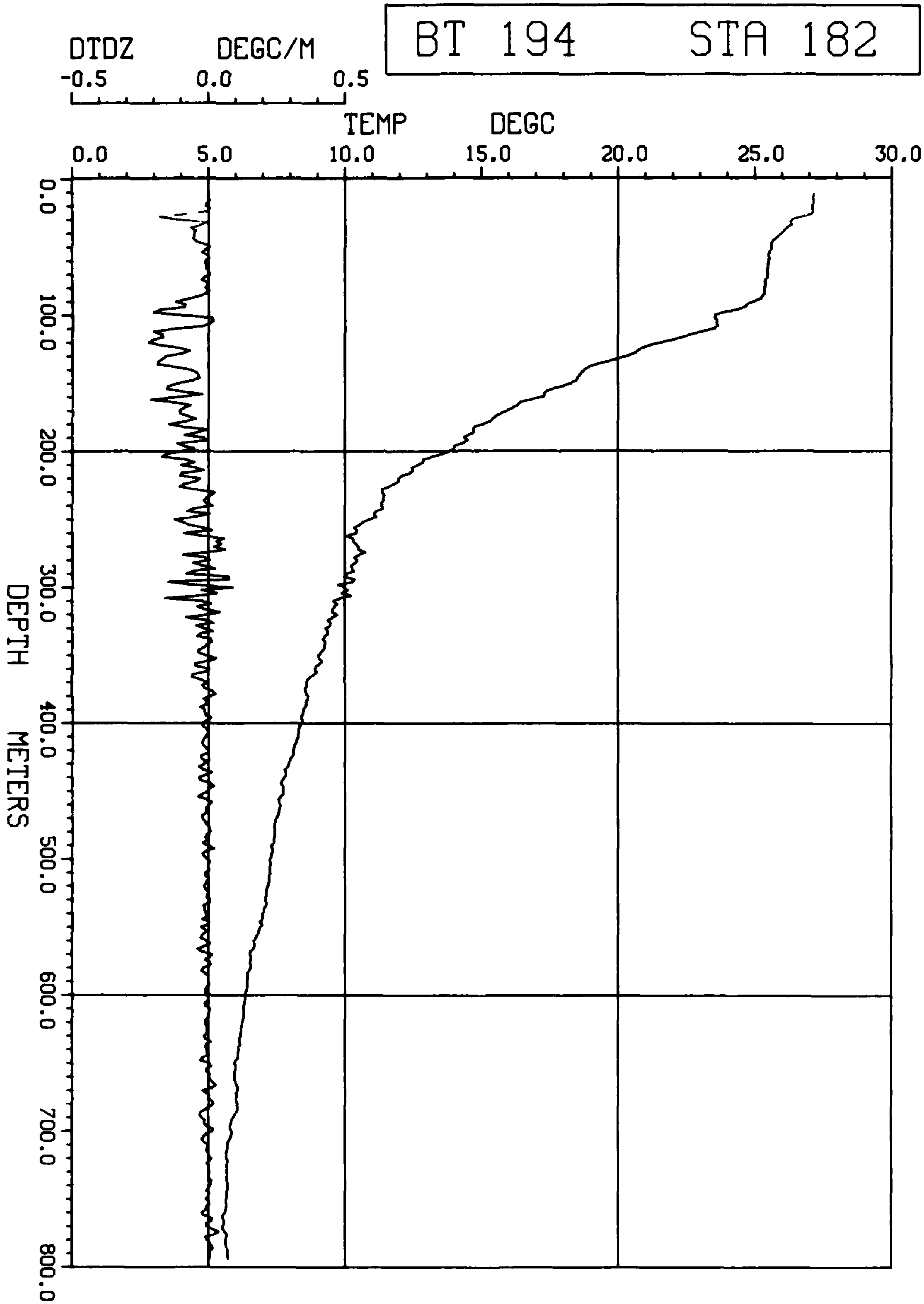

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500.0
600.0
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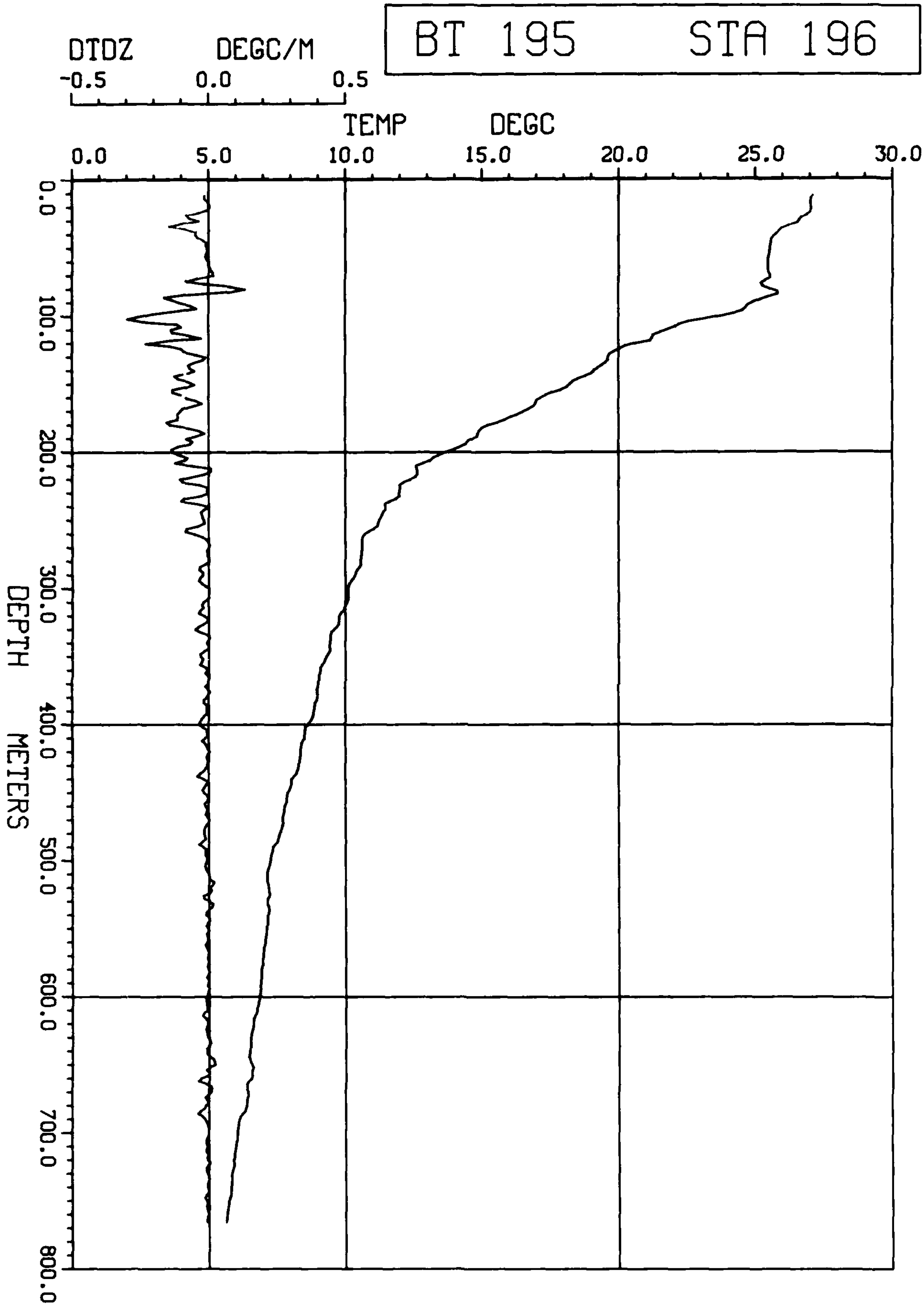
800.0
DEPTH METERS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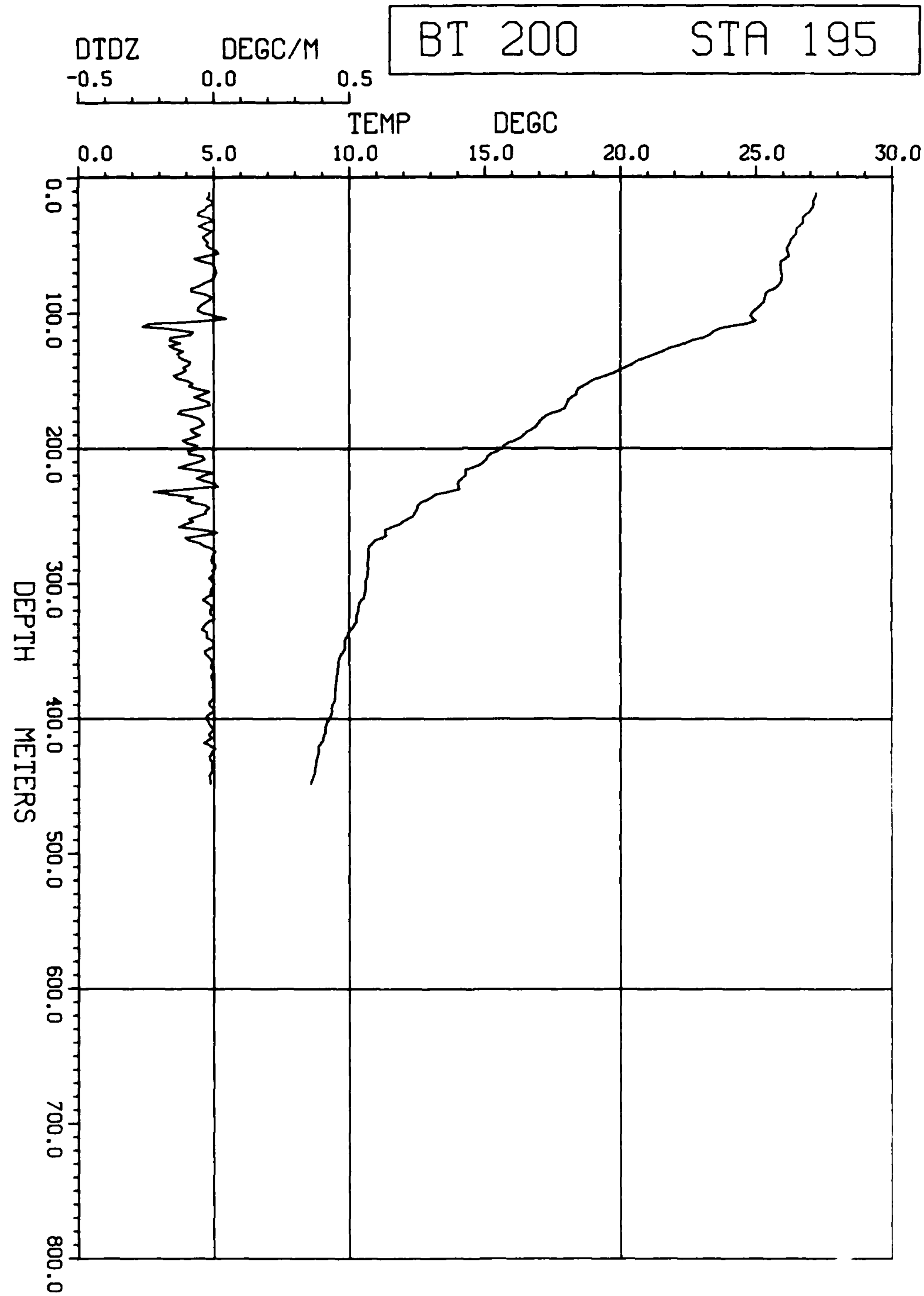
800.0
DEPTH METERS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DTDZ DEGC/M
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TEMP DEGC
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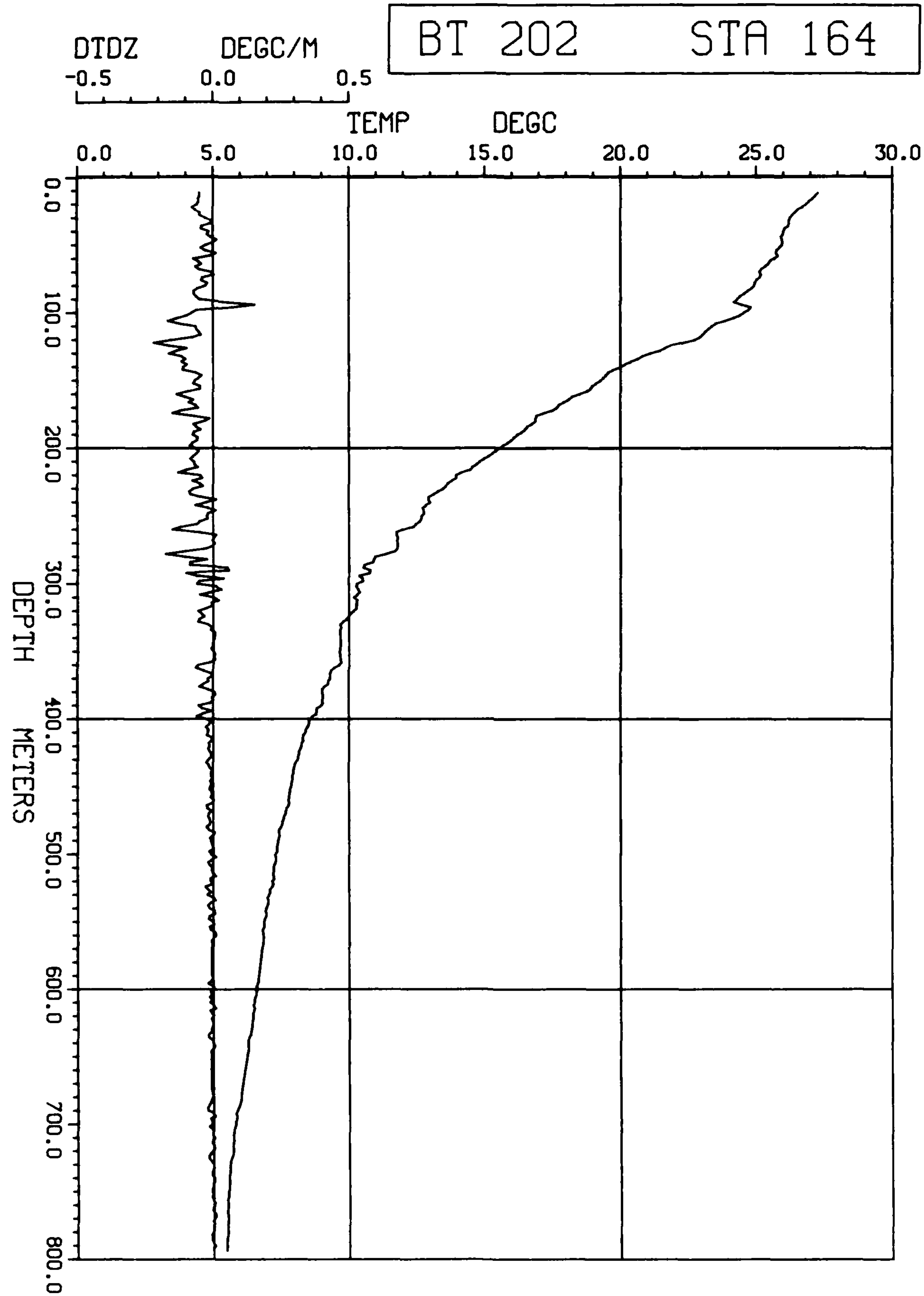
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0
DEPTH METERS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TEMP DEGC
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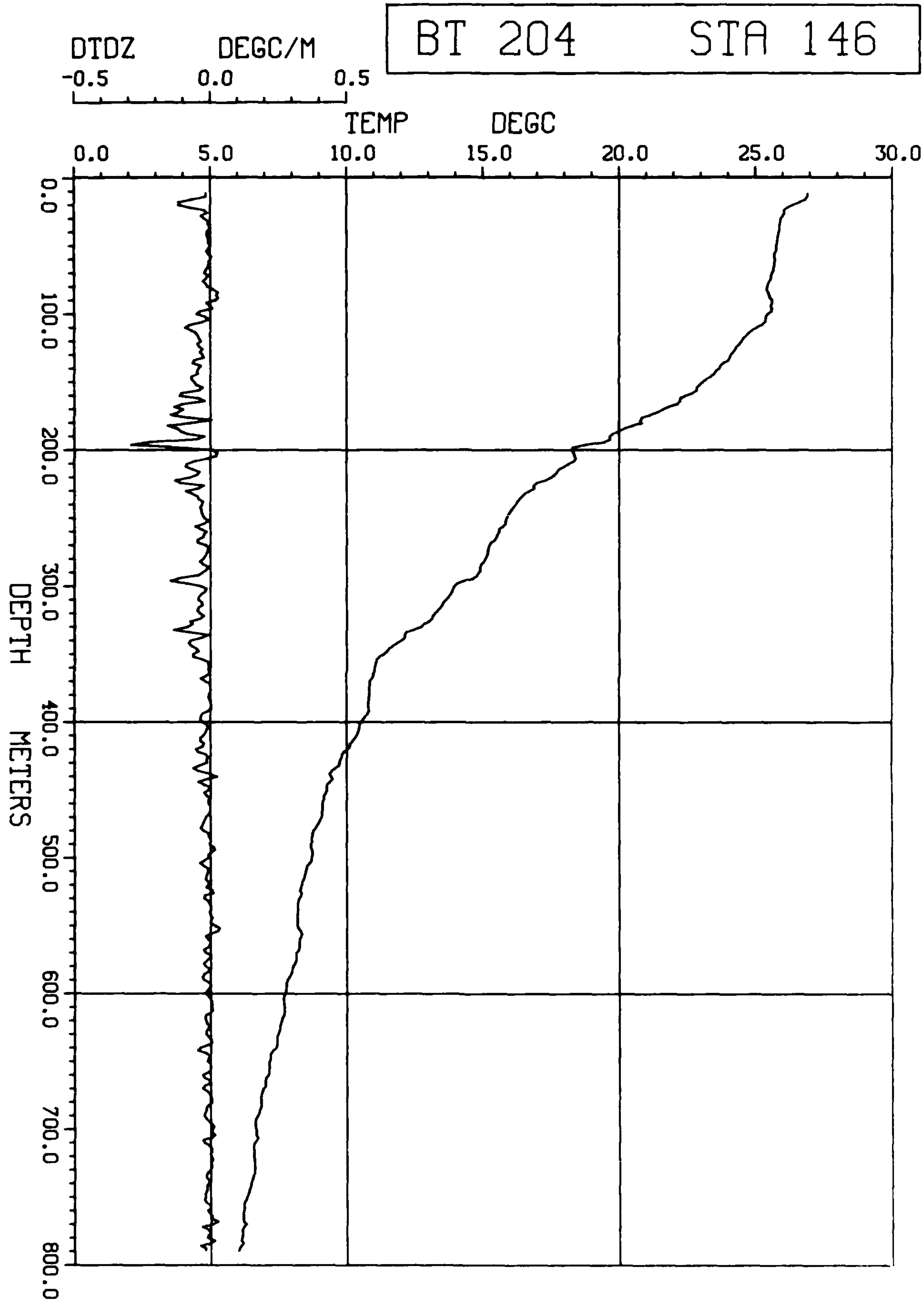
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20.0
25.0
30.0
DEPTH METERS
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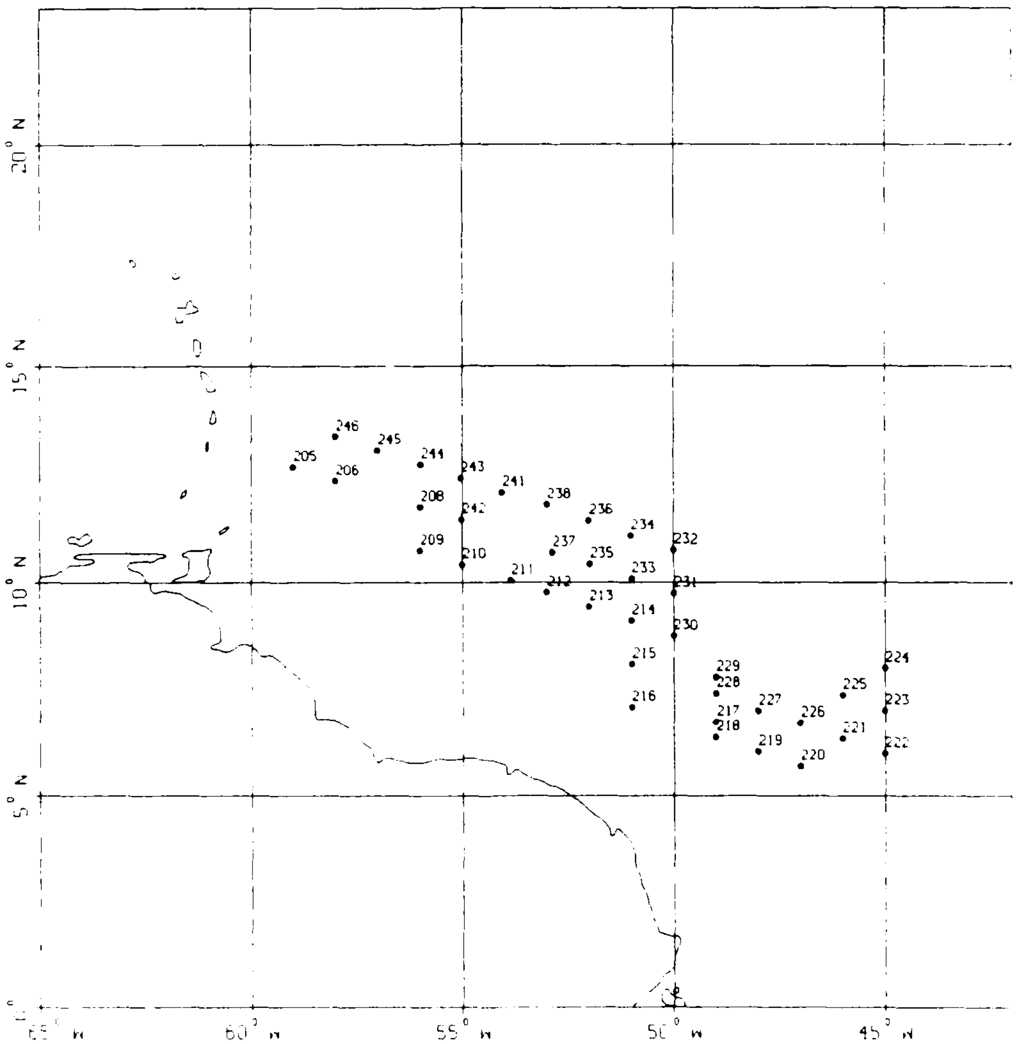
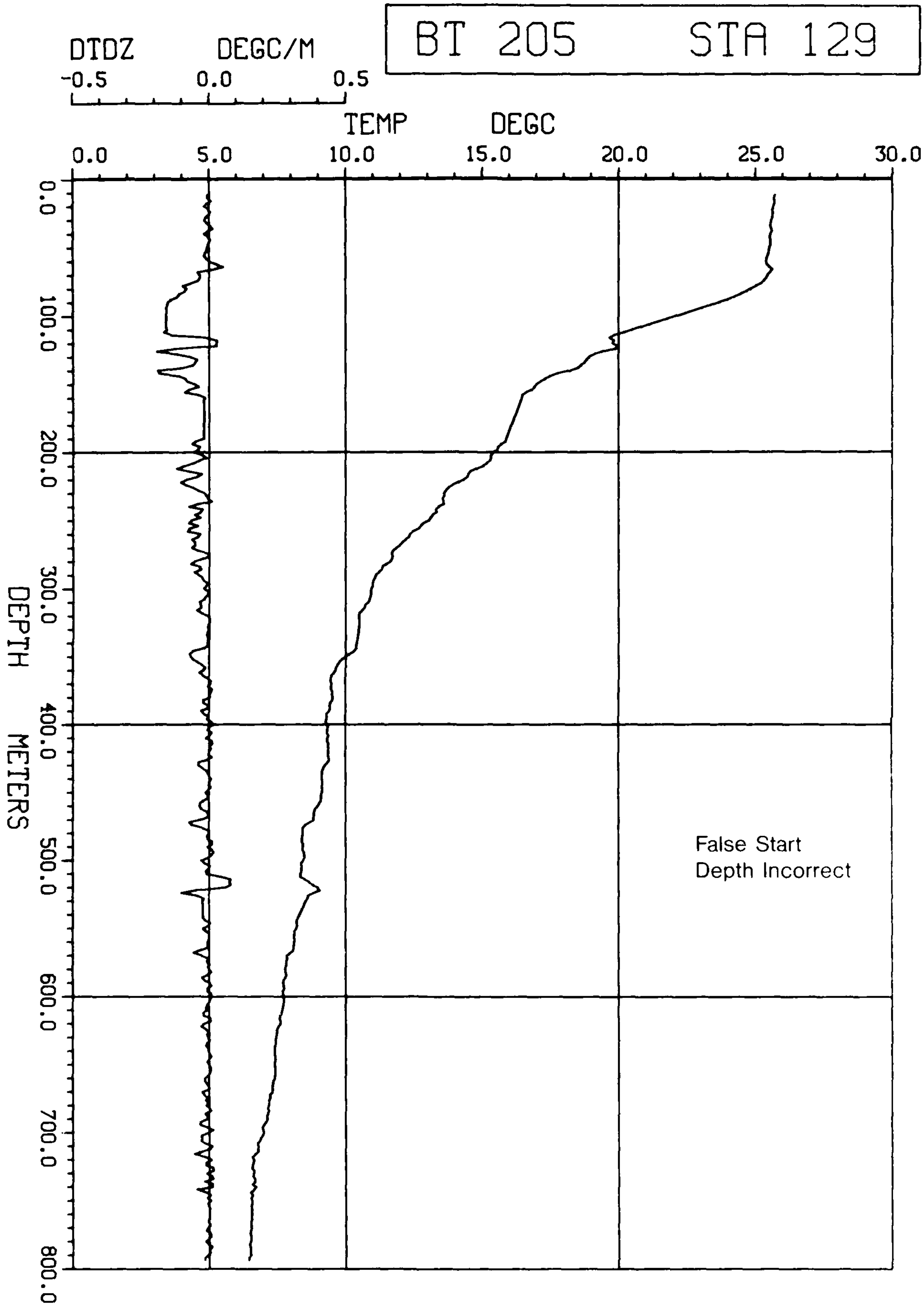
700.0
800.0

Station Positions Flight 6
10 May 1985

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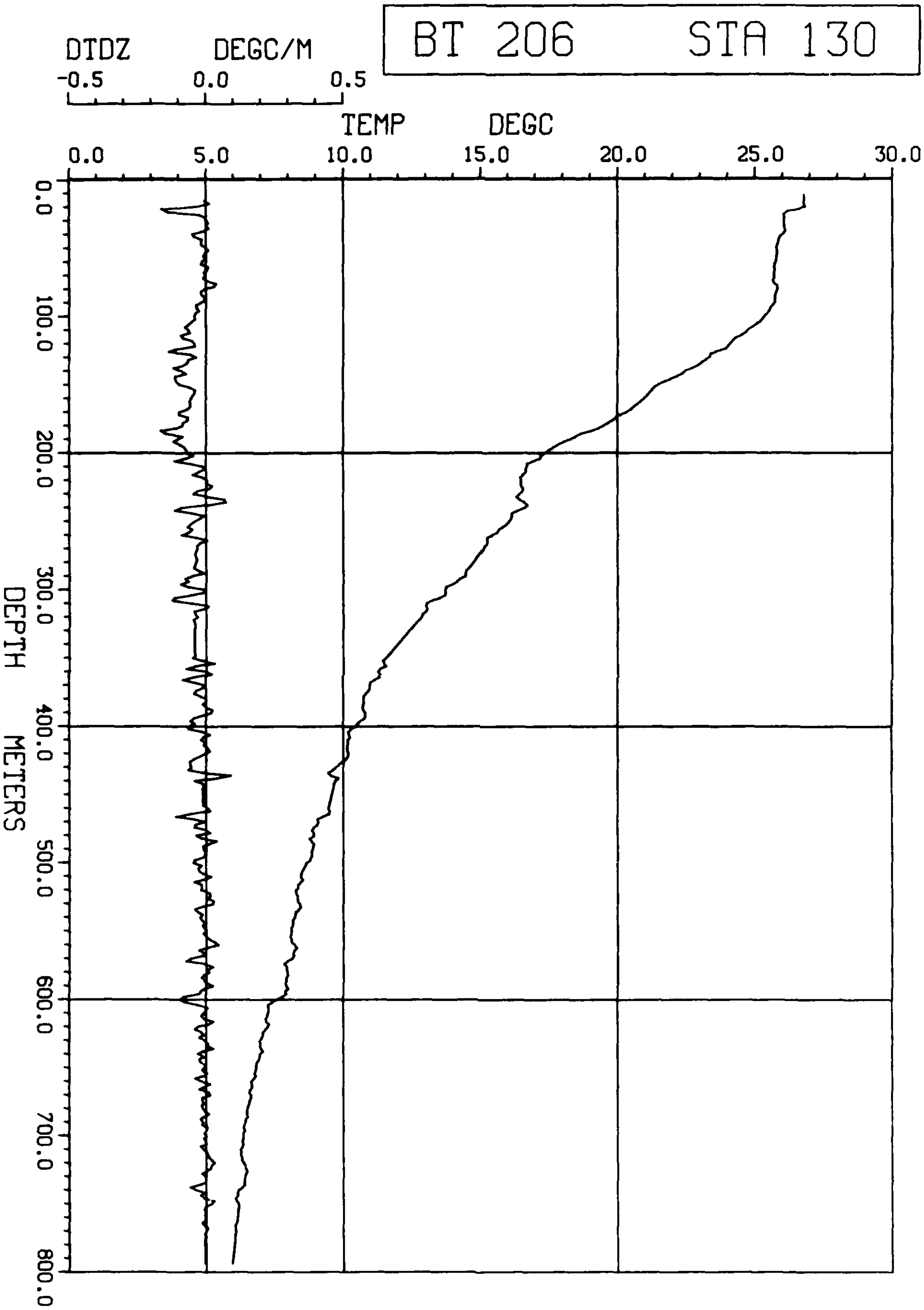
0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0
DEPTH METERS
False Start
Depth Incorrect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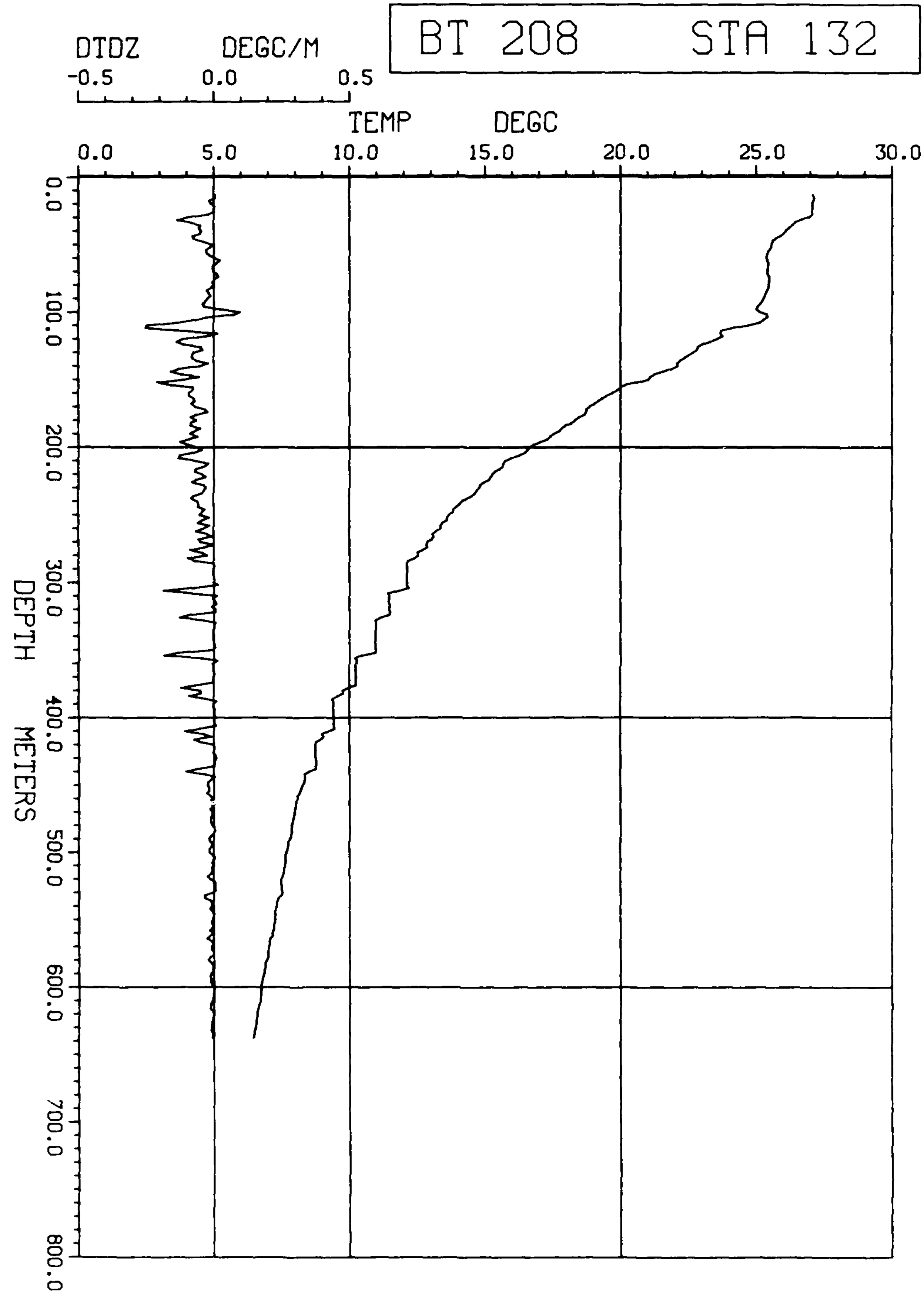
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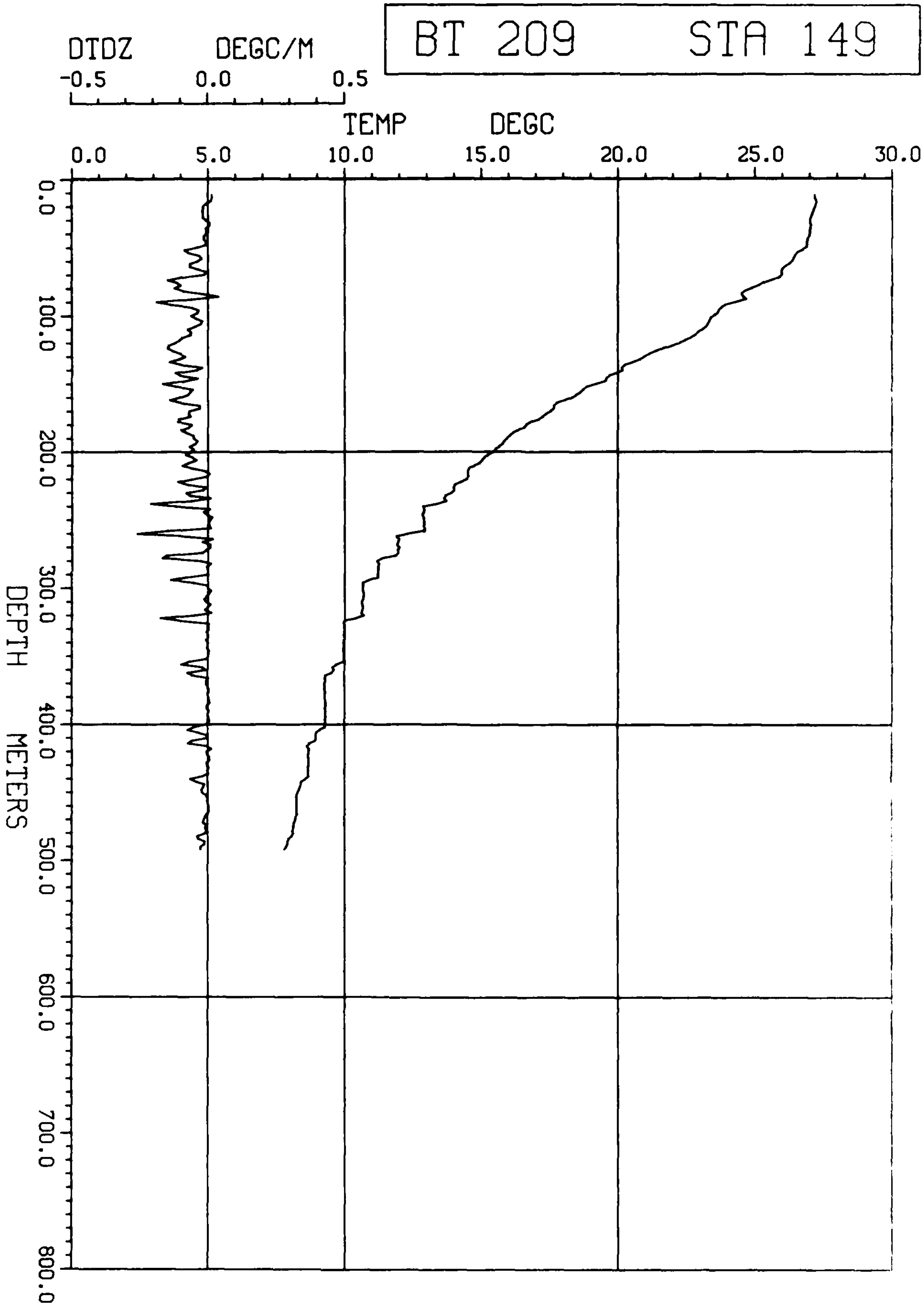
DEPTH METERS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TEMP DEGC
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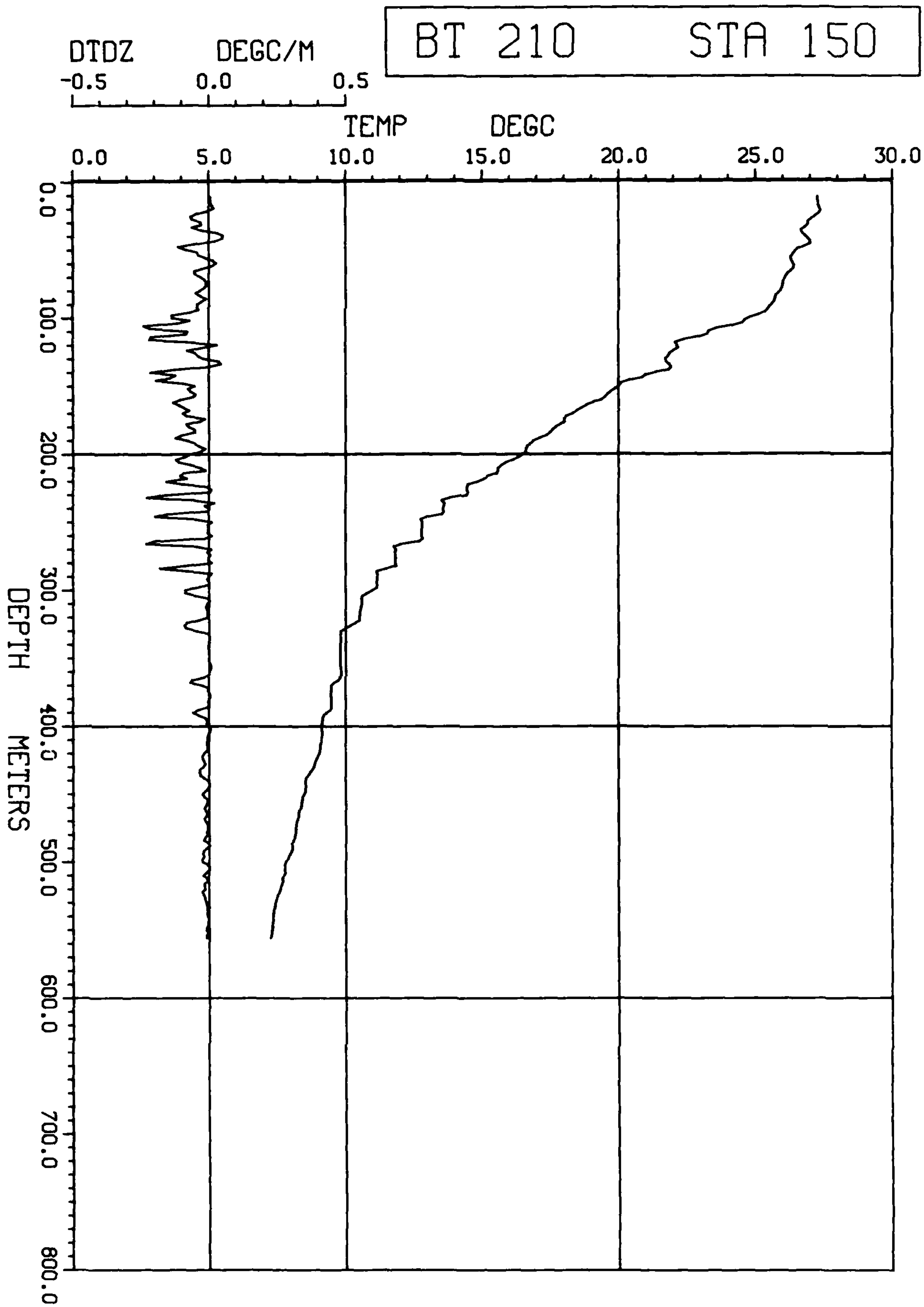
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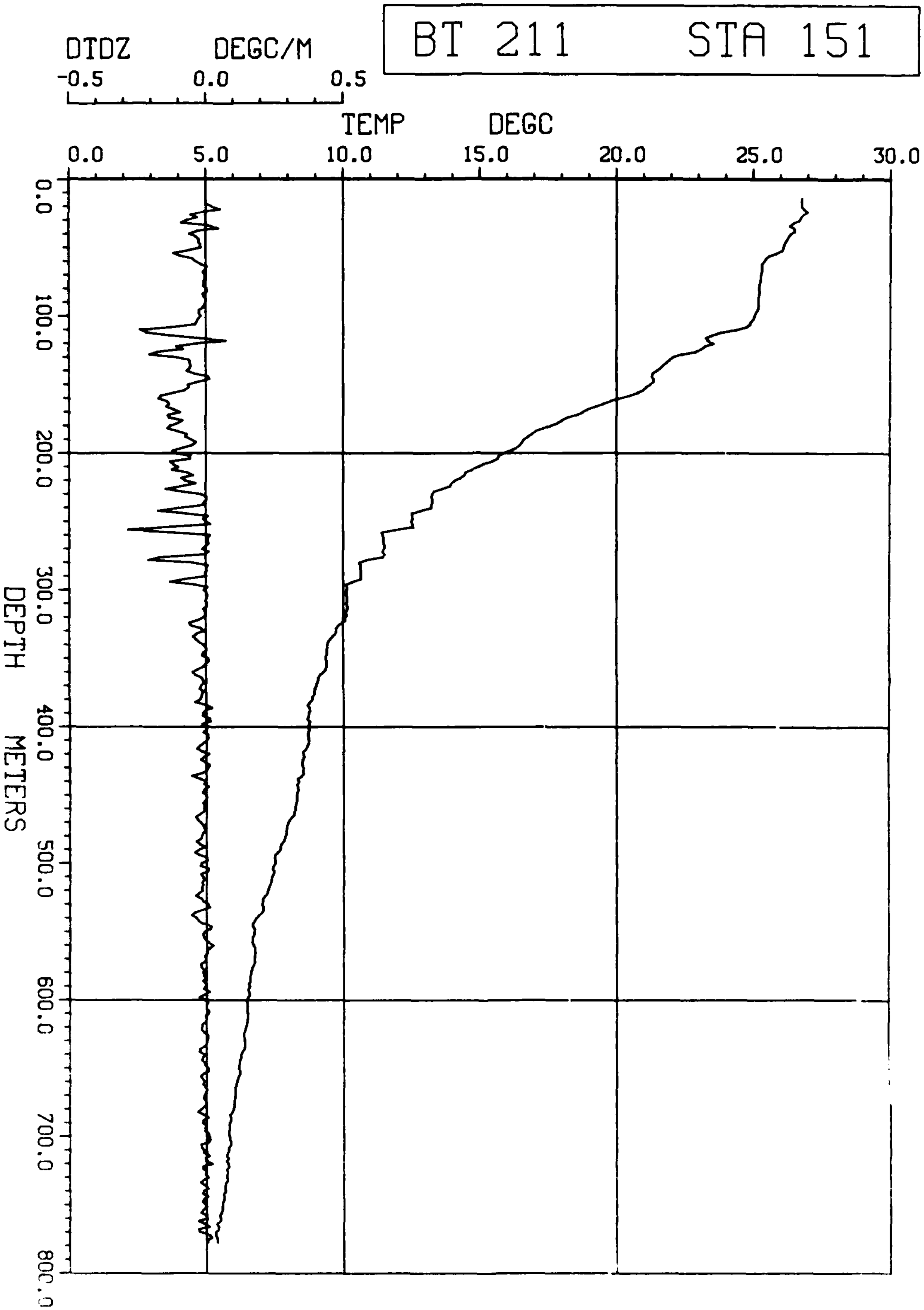
DEPTH METERS



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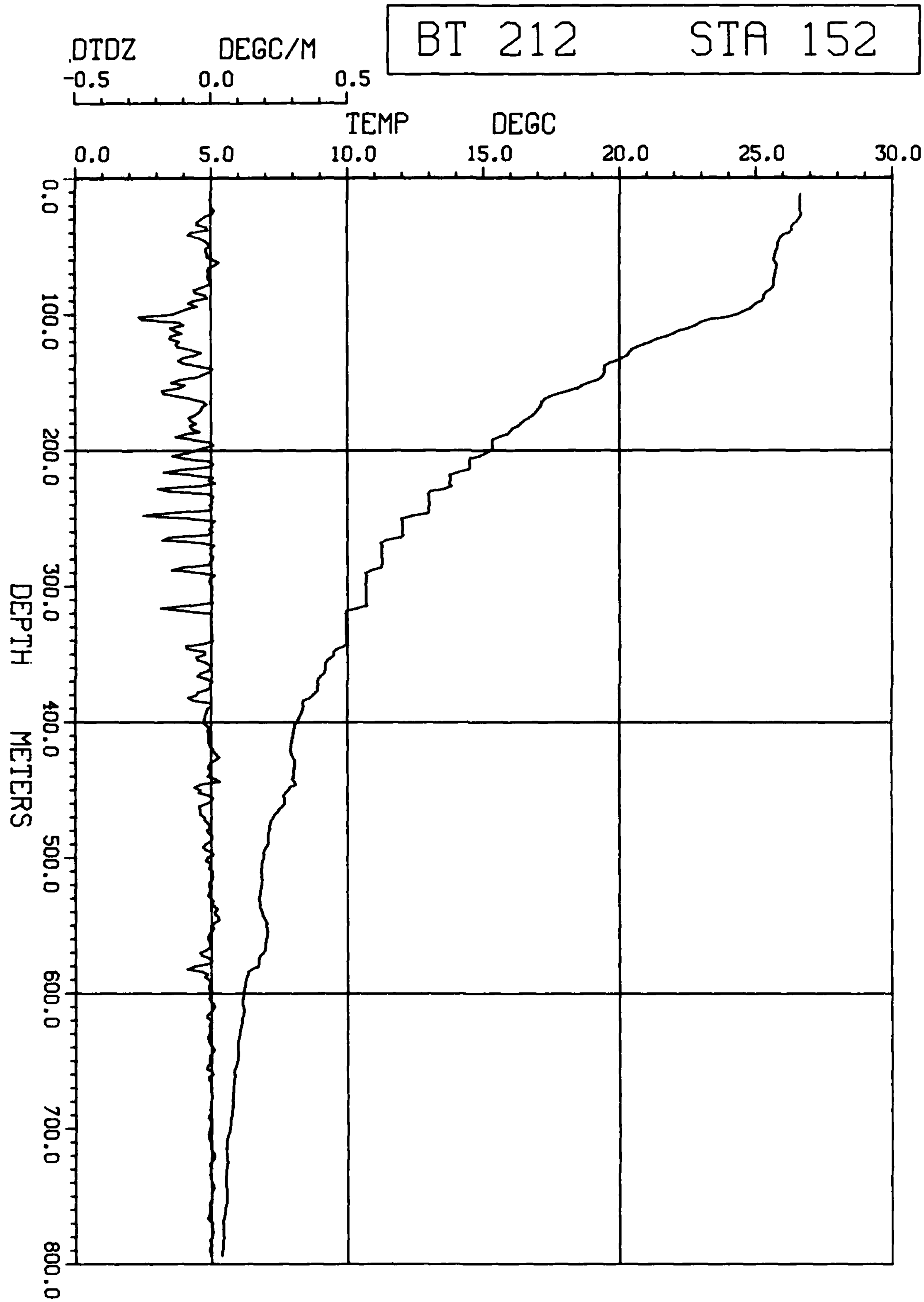
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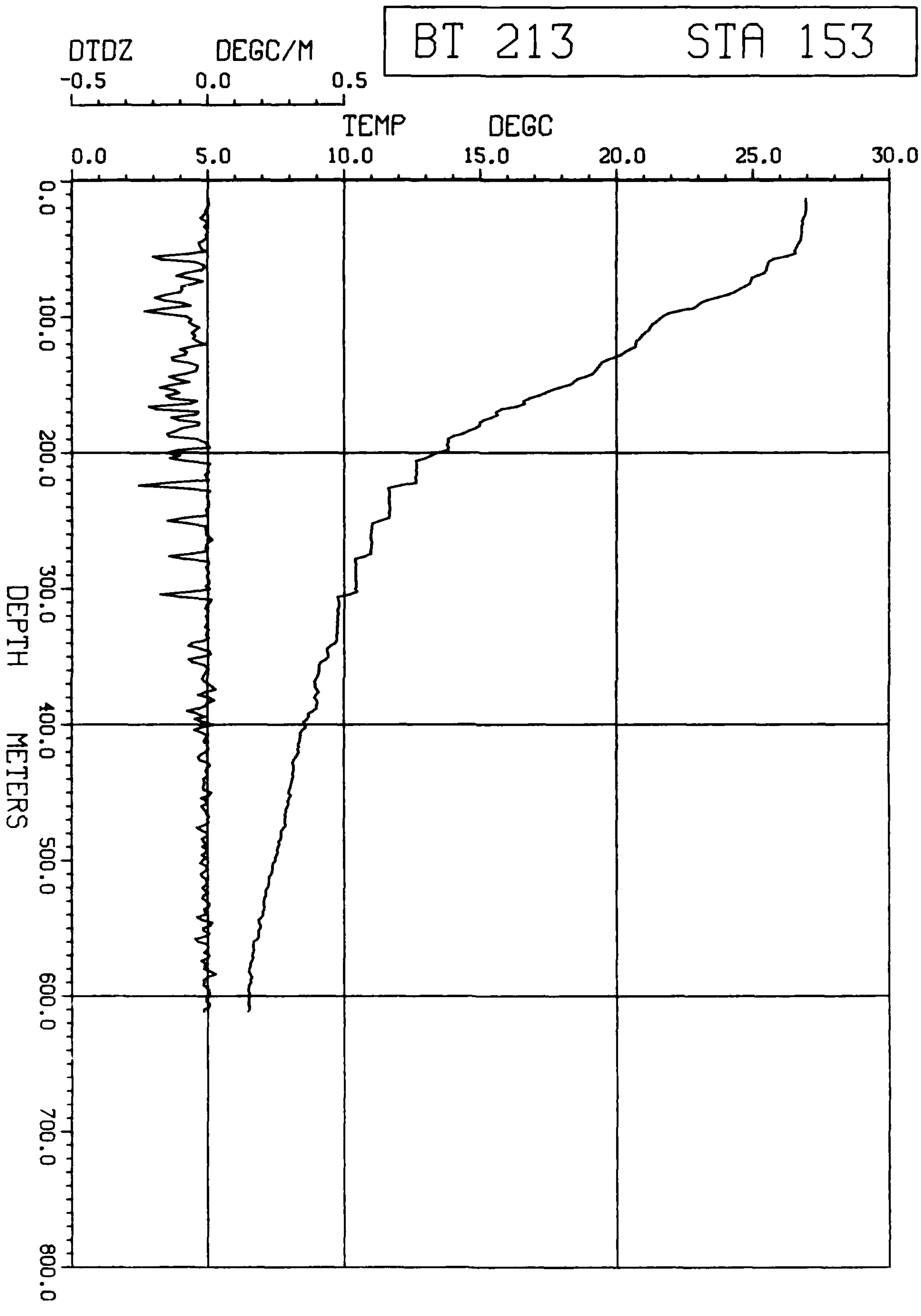
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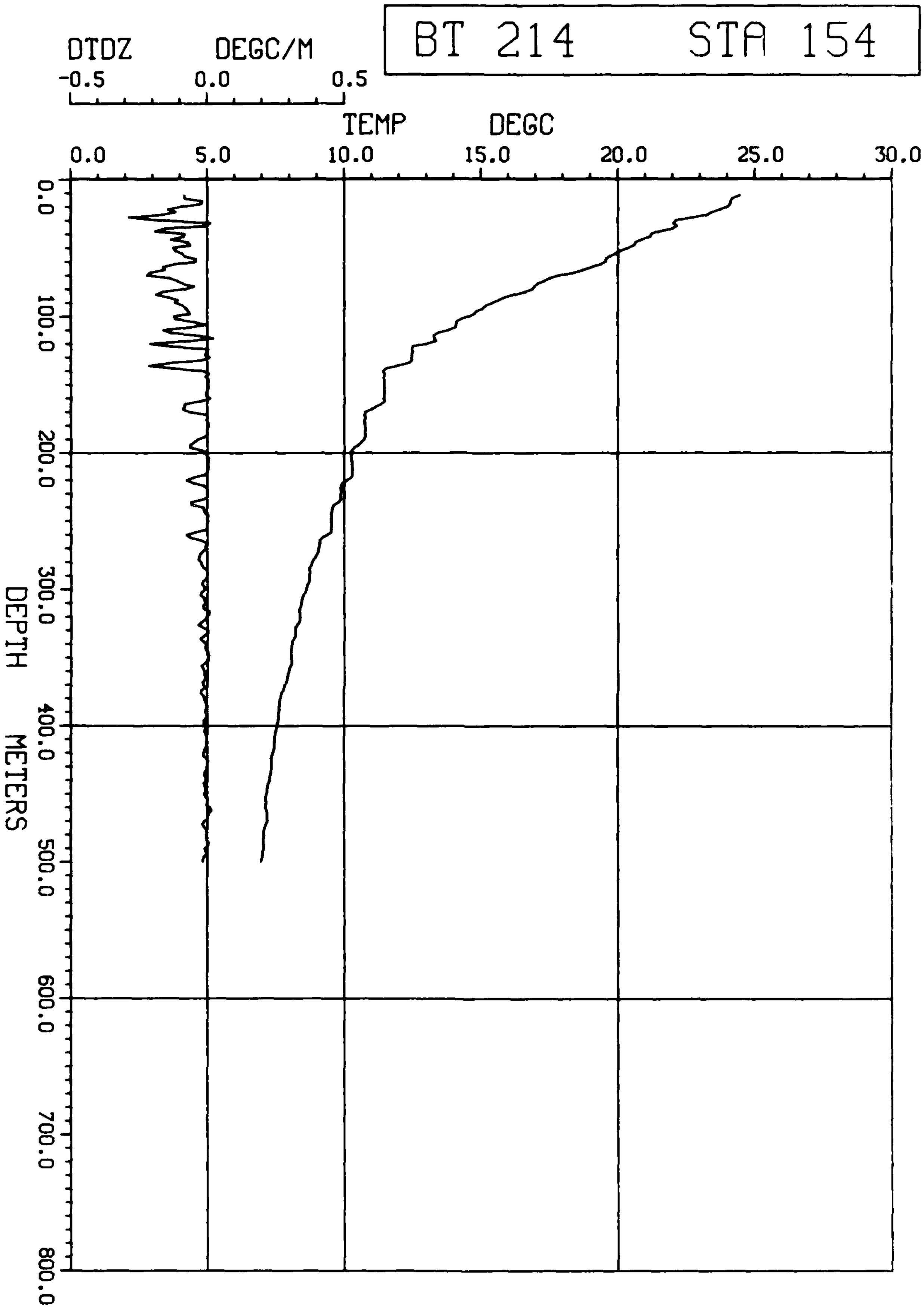
DEPTH METERS



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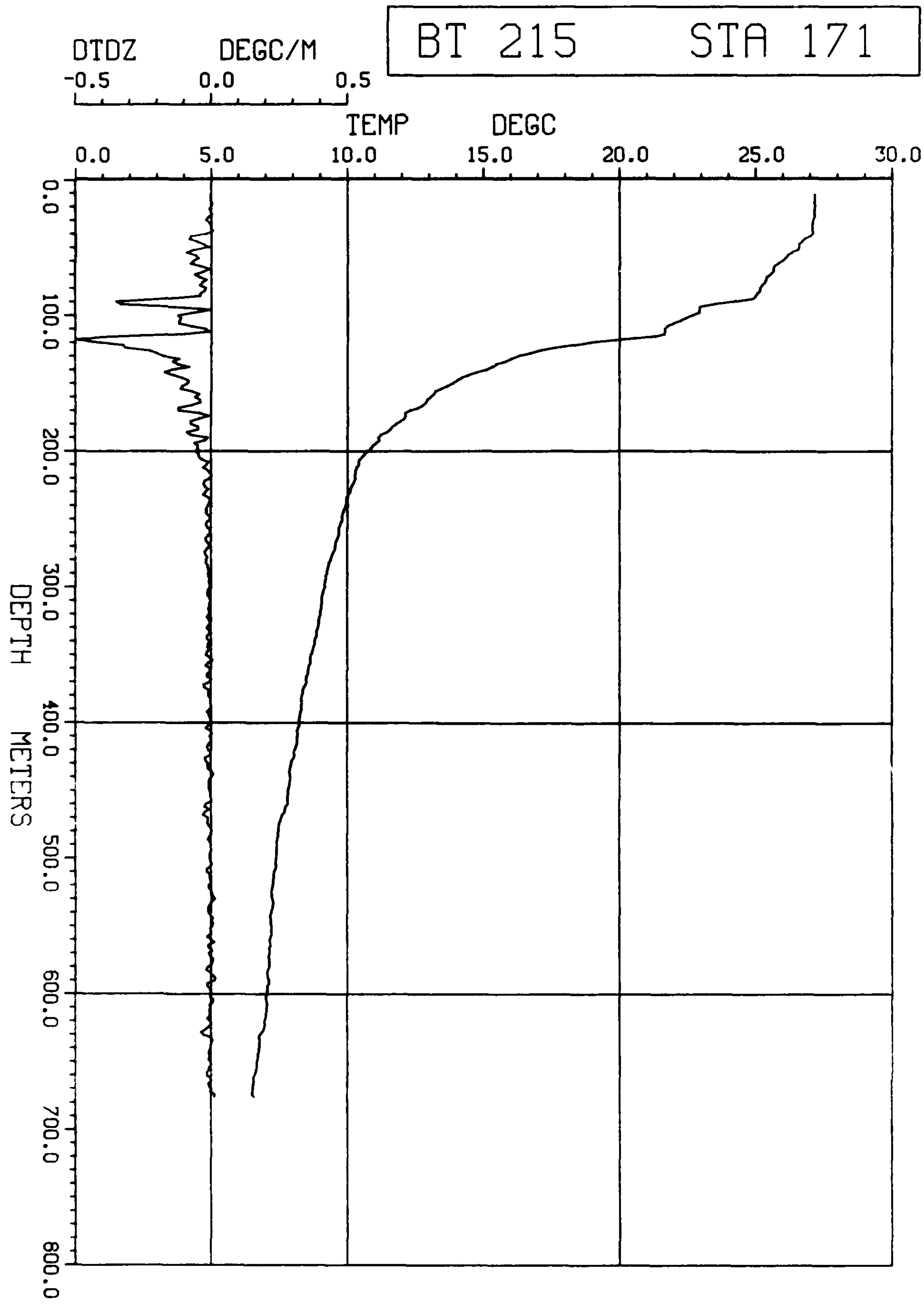
DEPTH METERS



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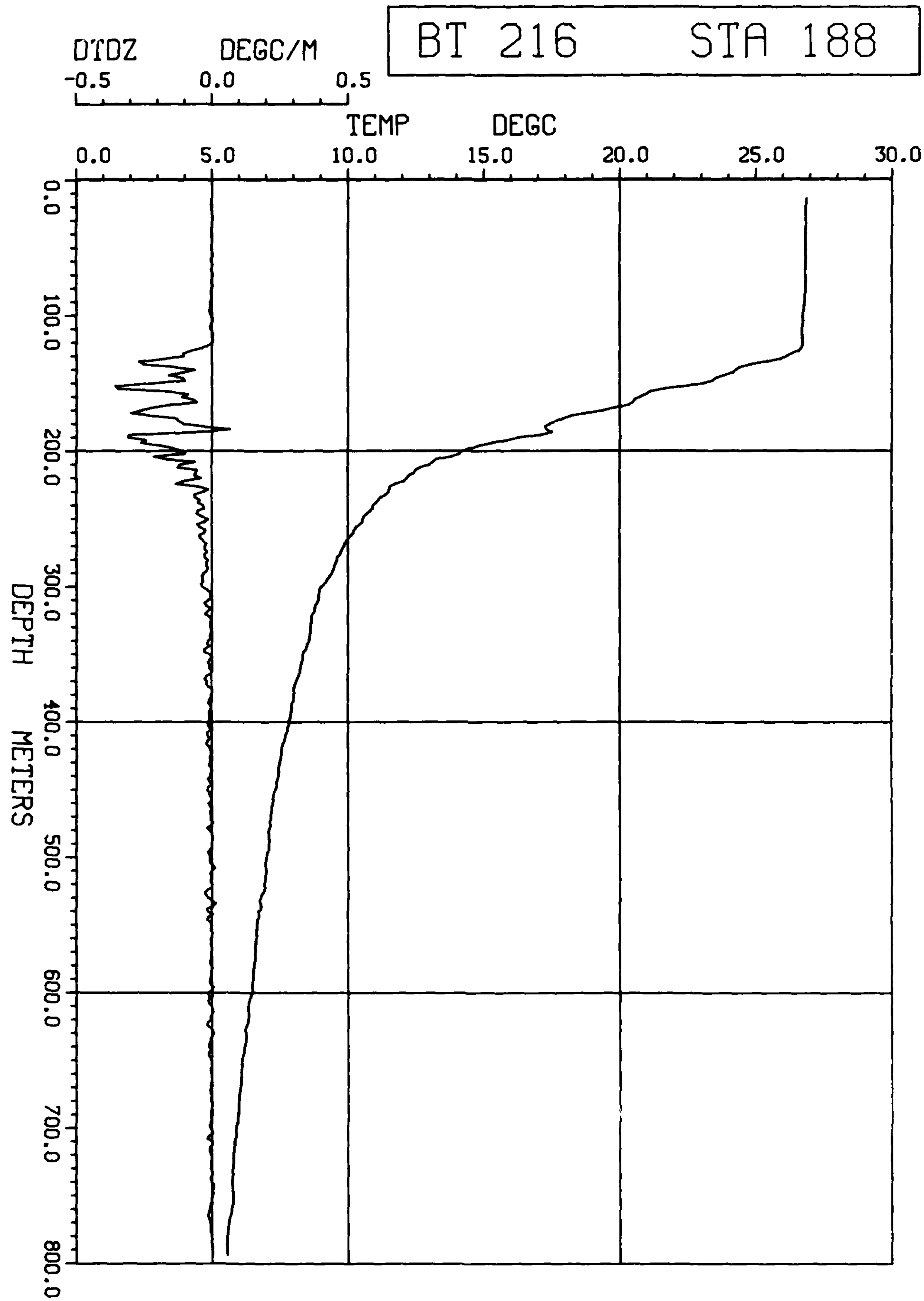
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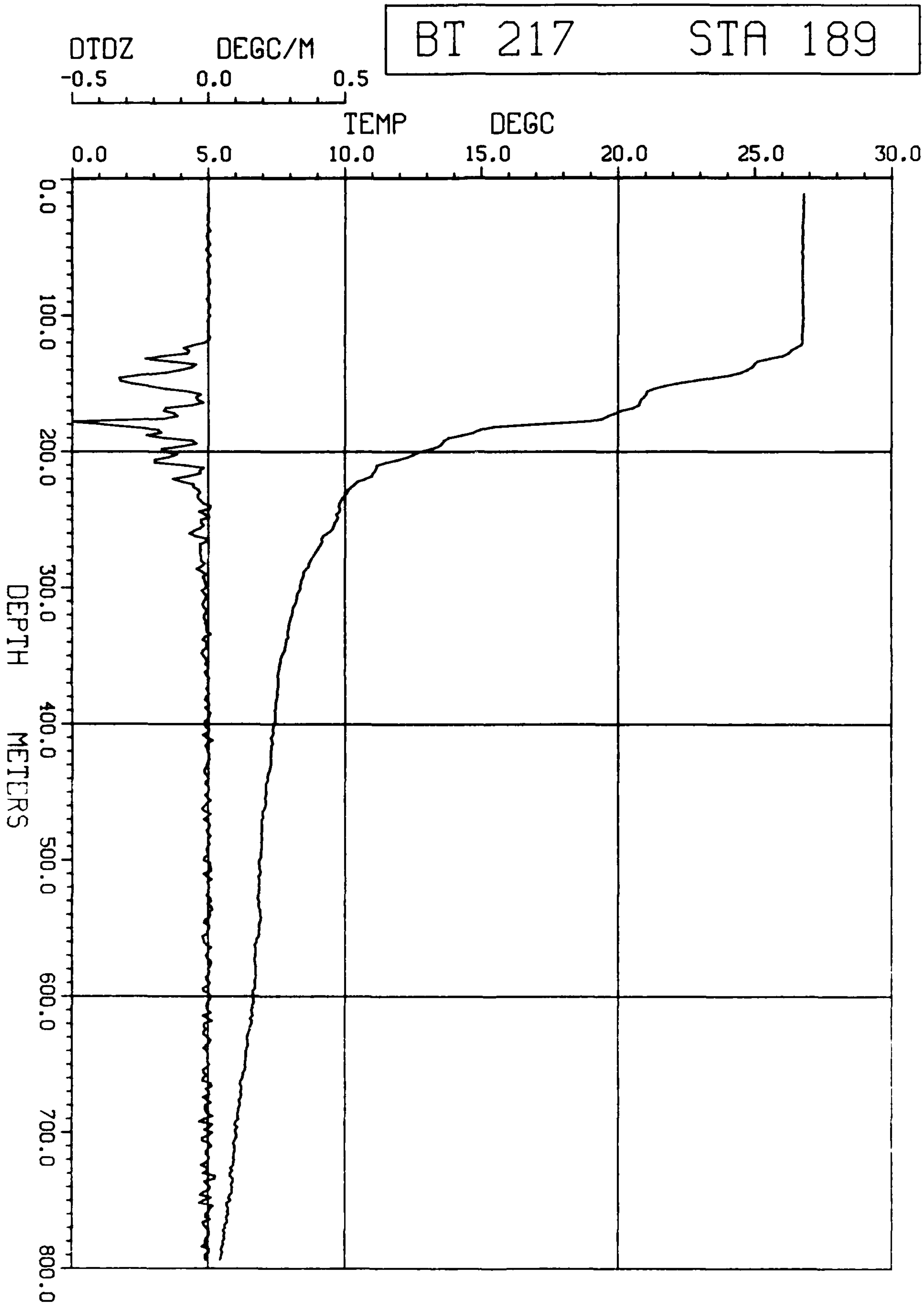
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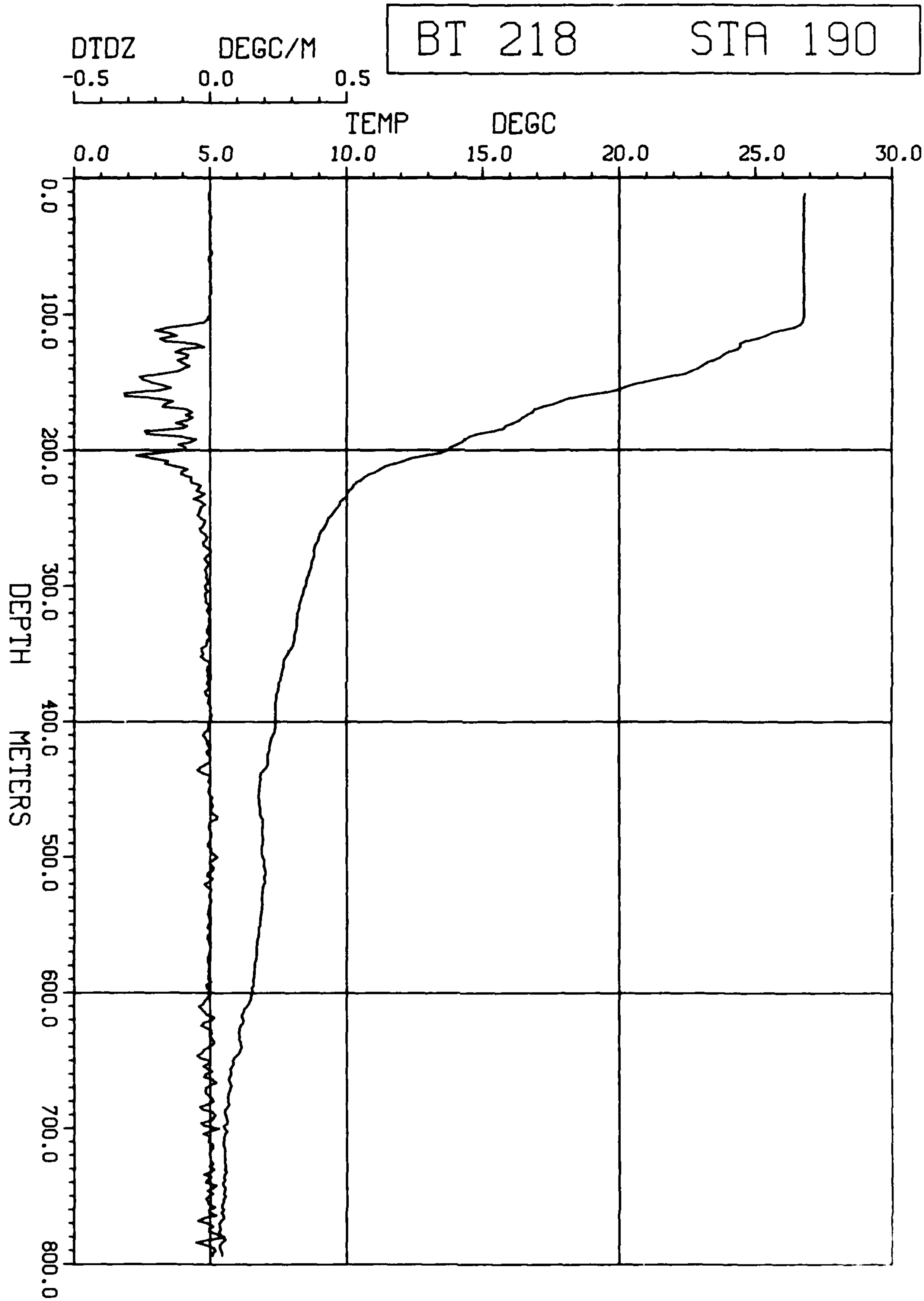

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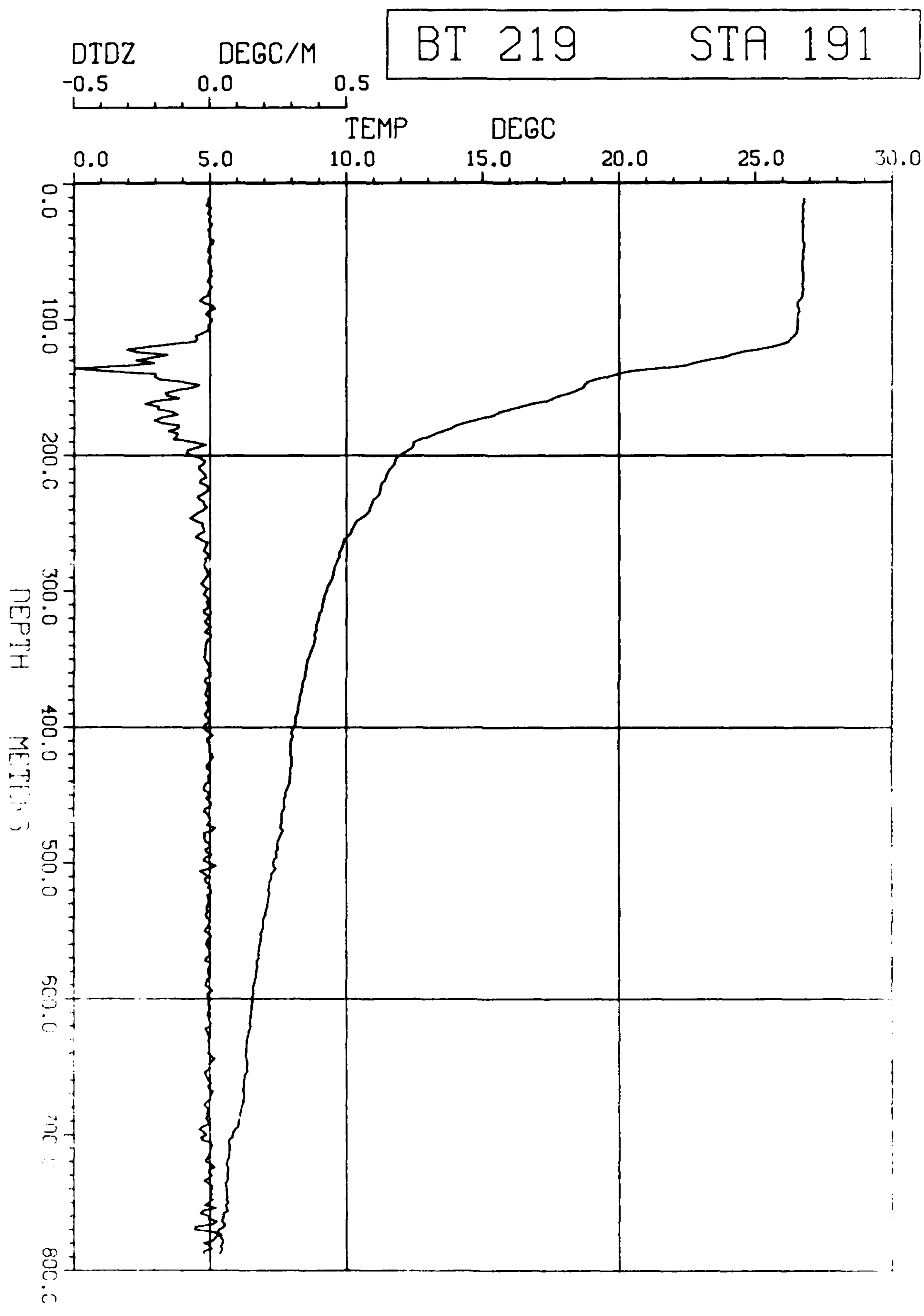
DEPTH METERS



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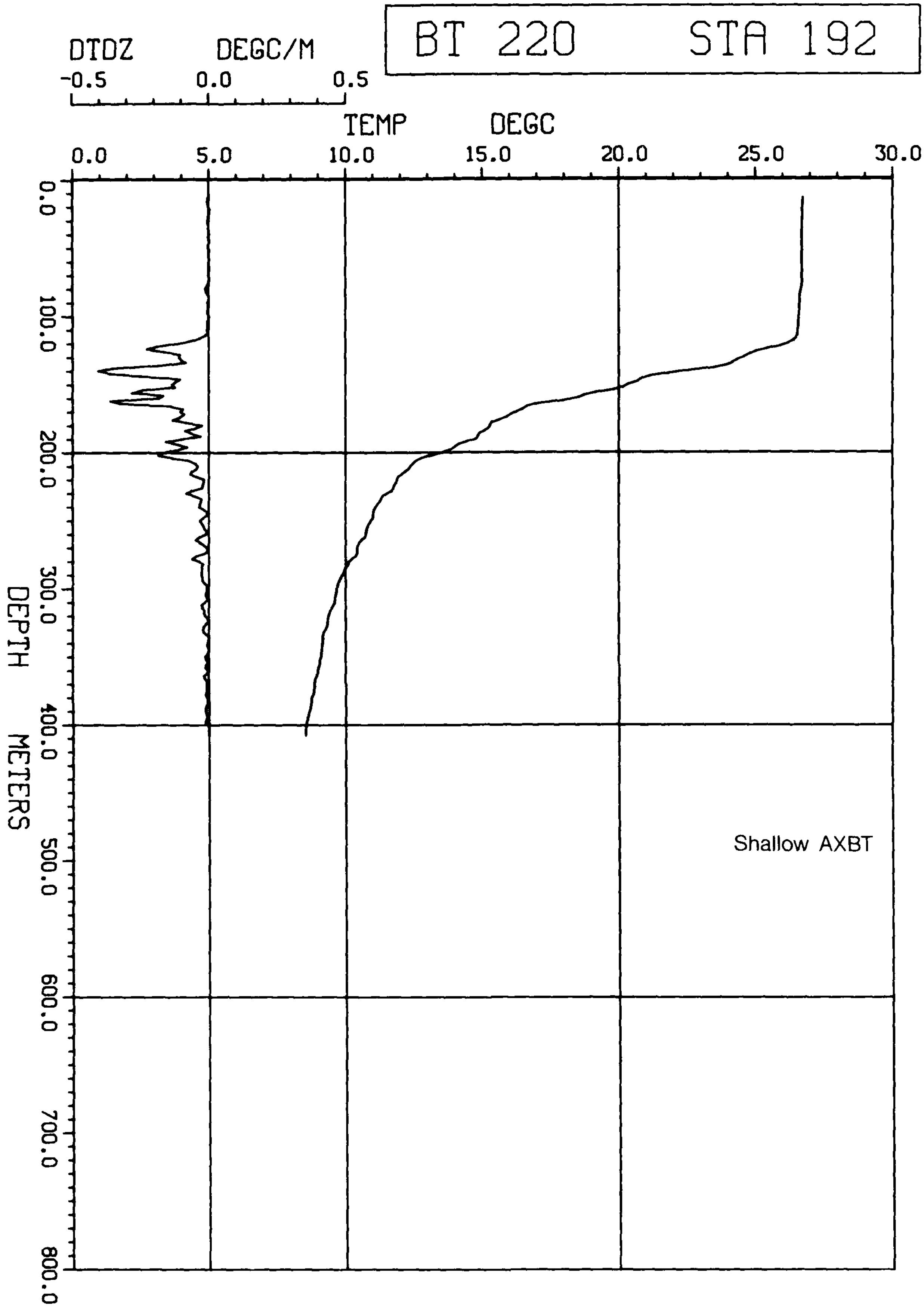
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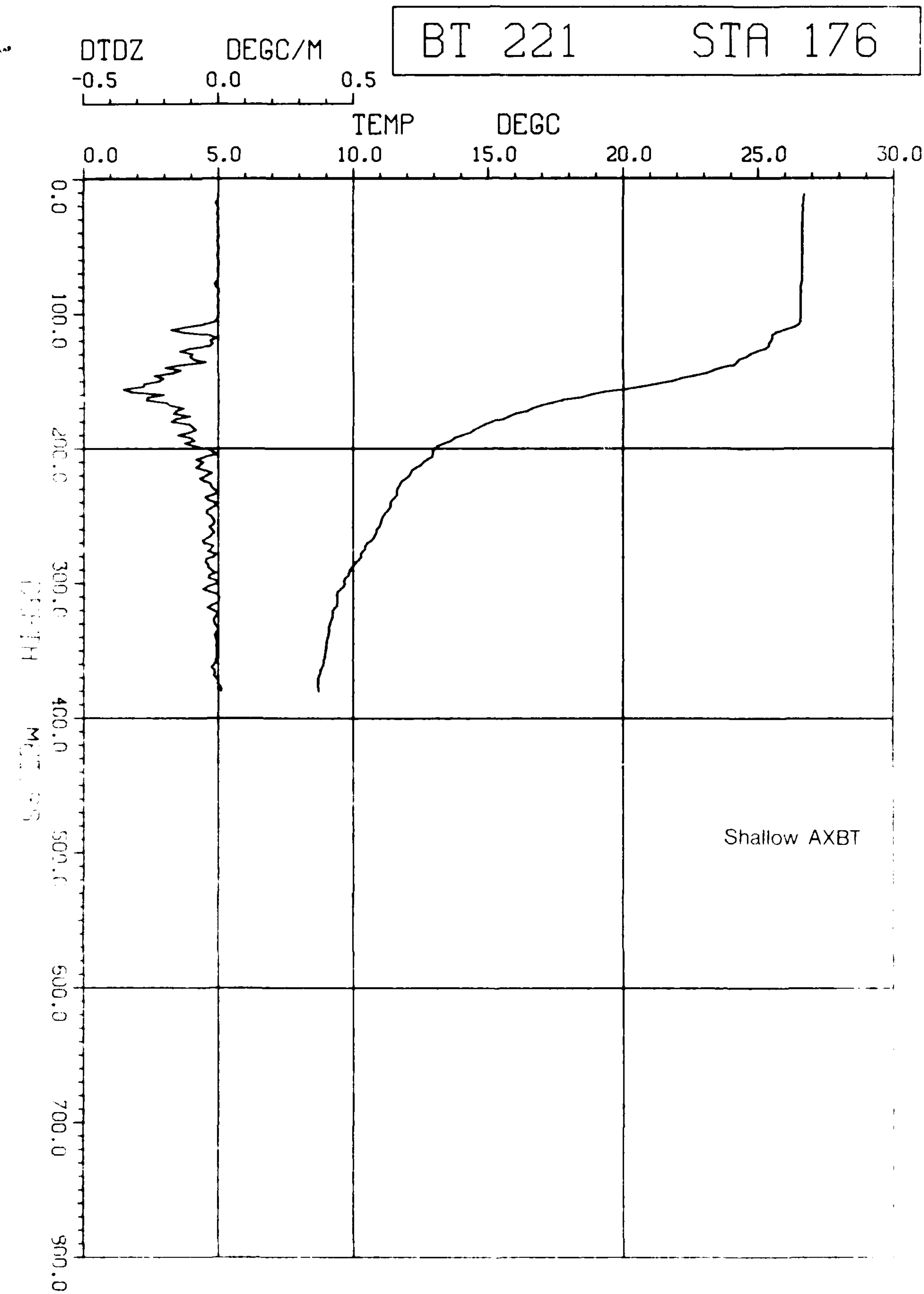
Shallow AXBT



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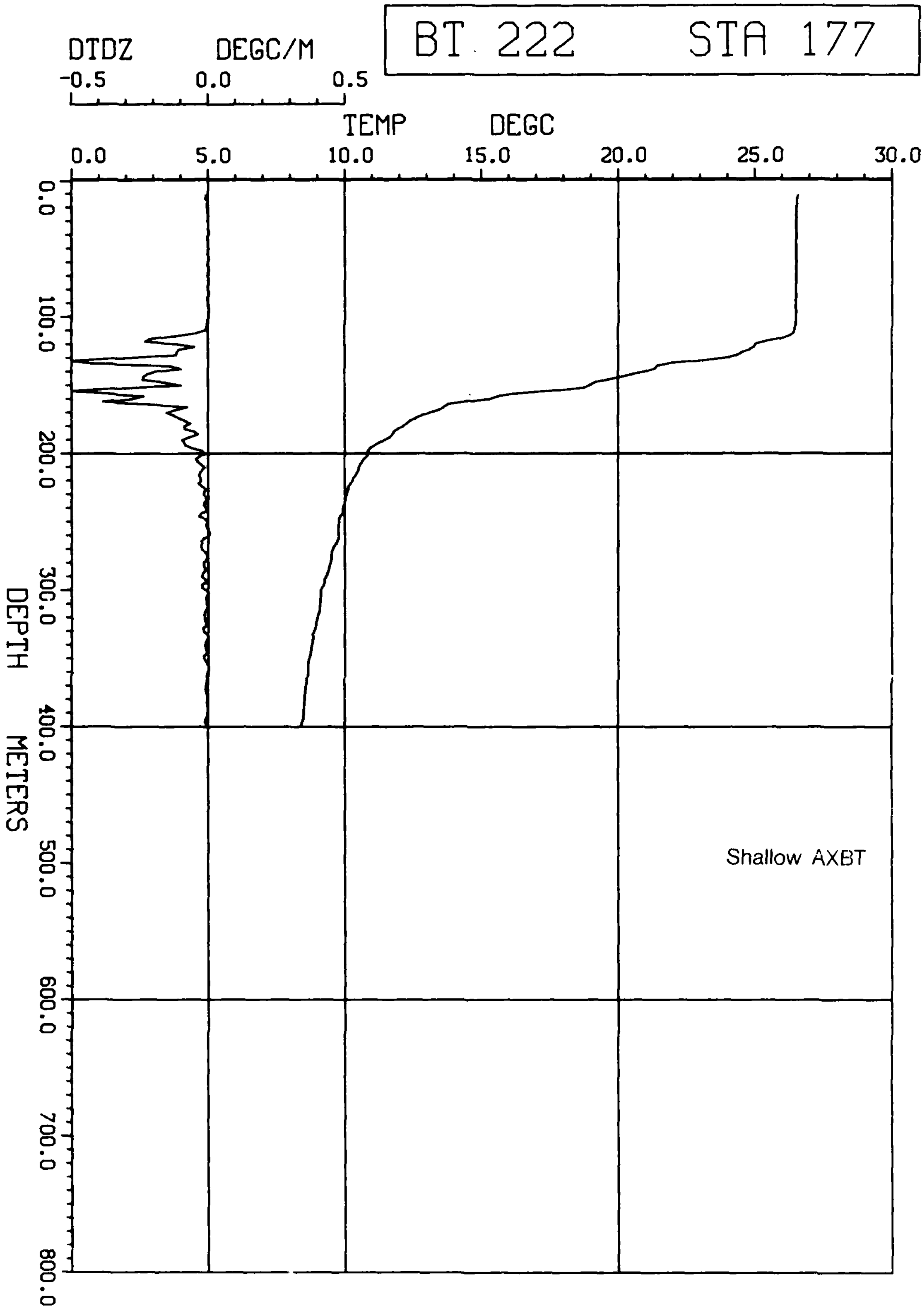
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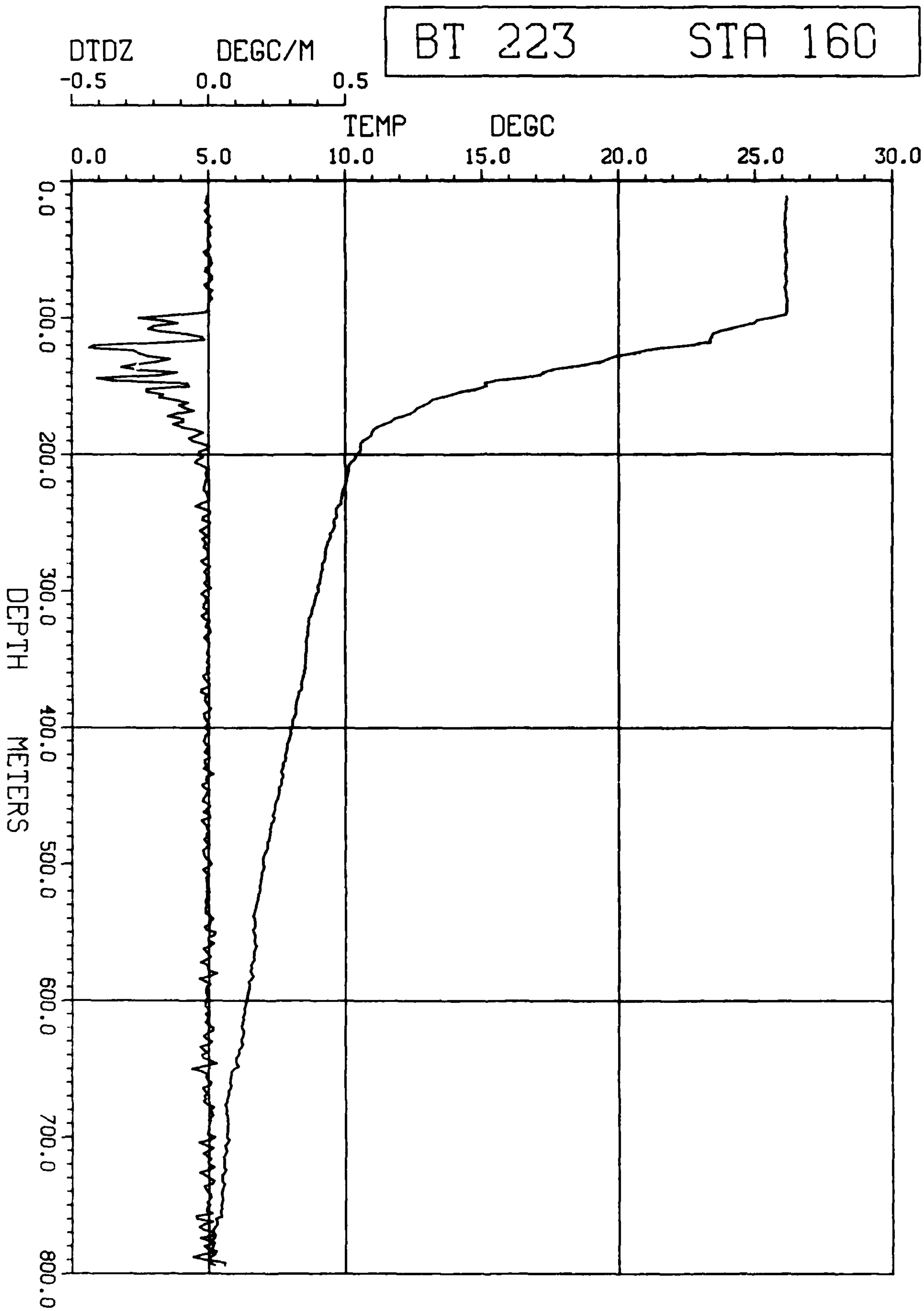
Shallow AXBT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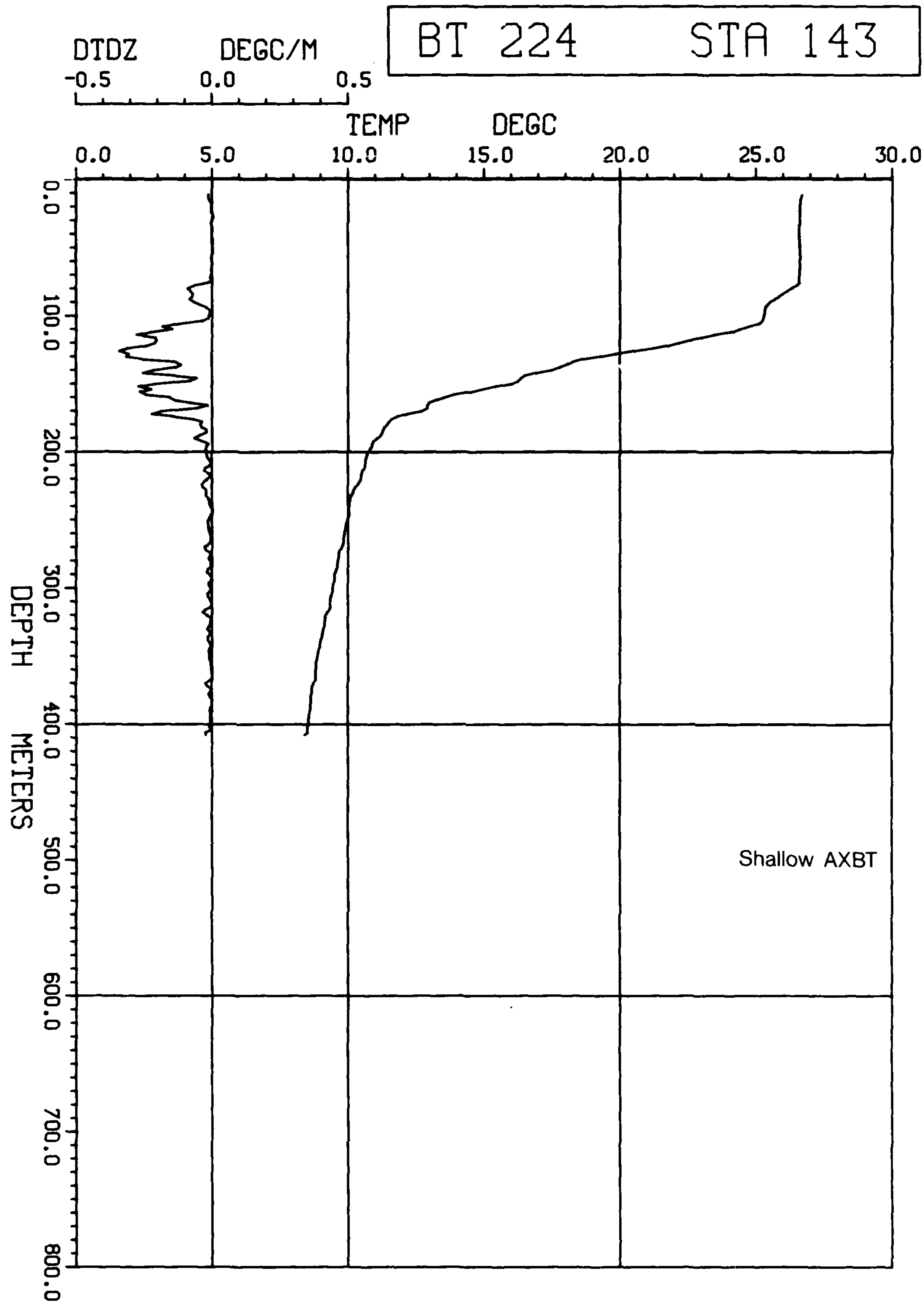
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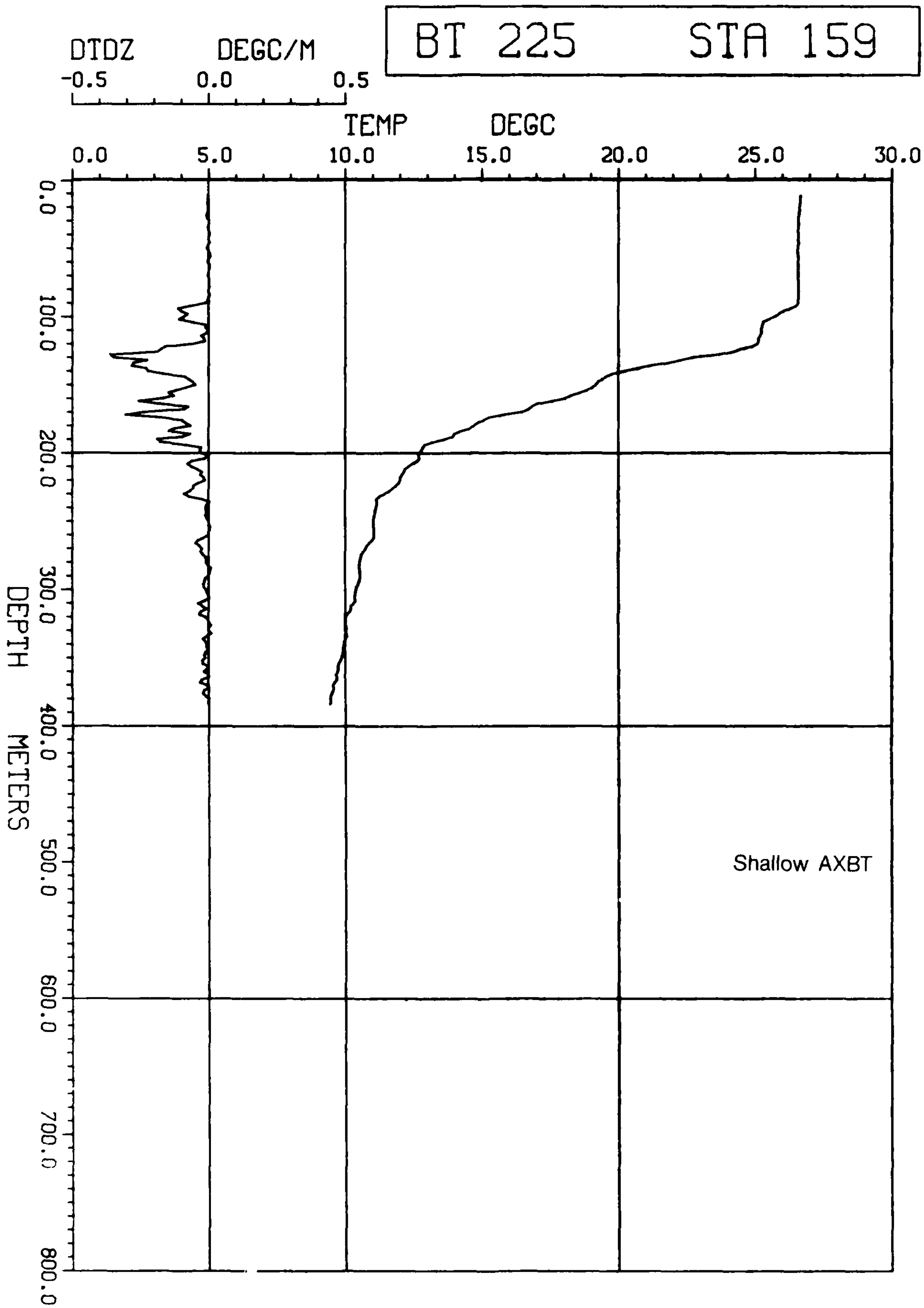
DEPTH METERS
Shallow AXBT



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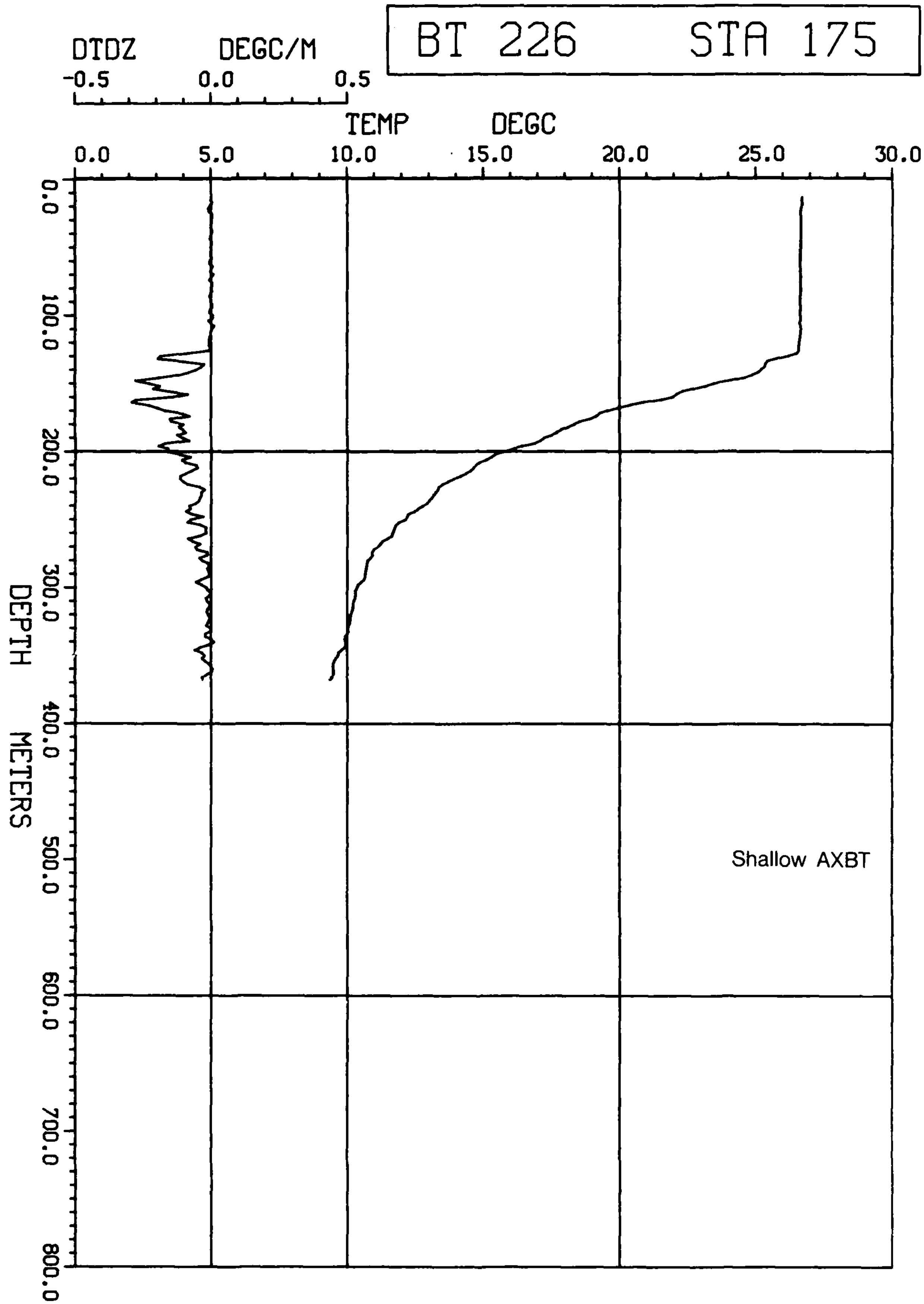
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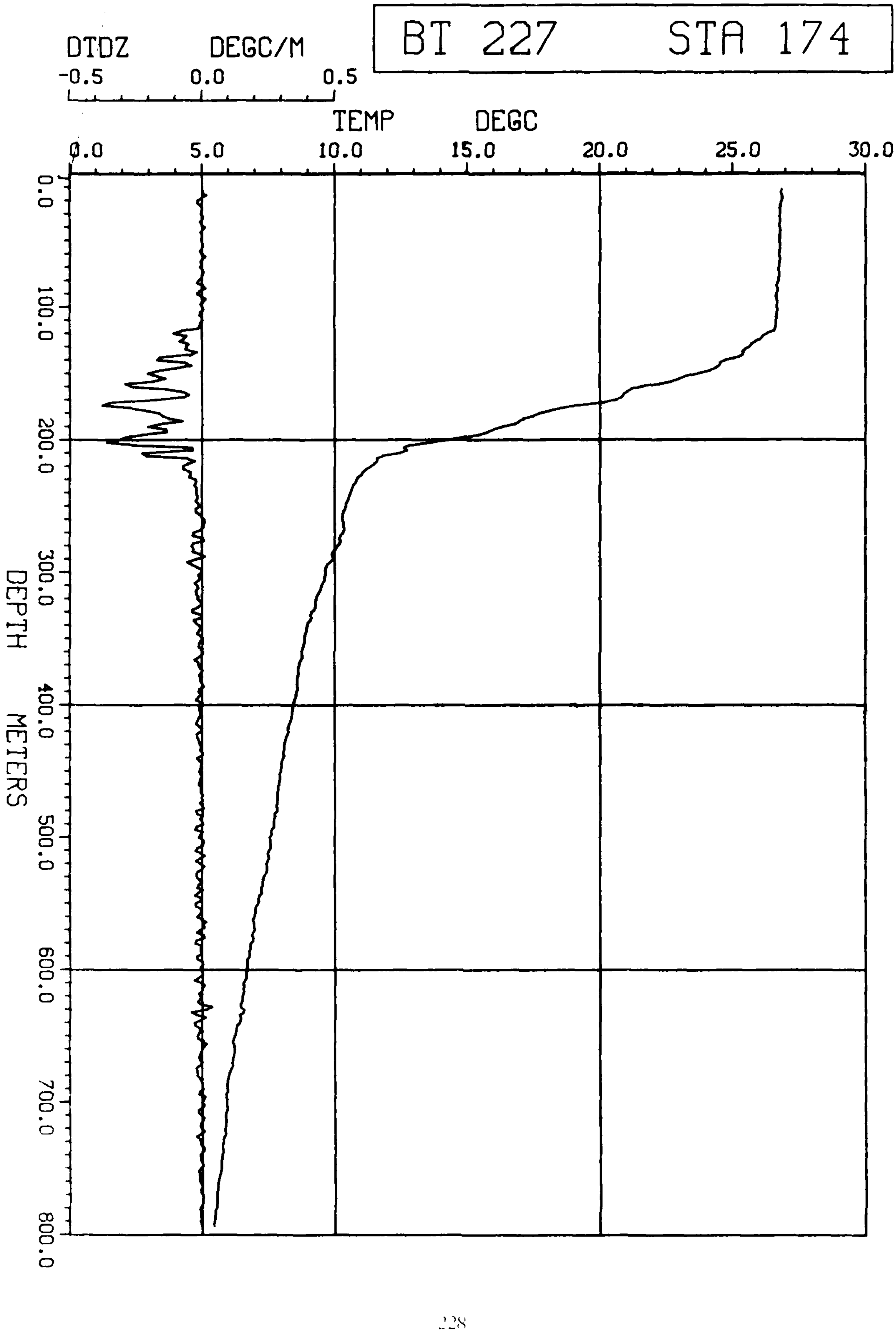

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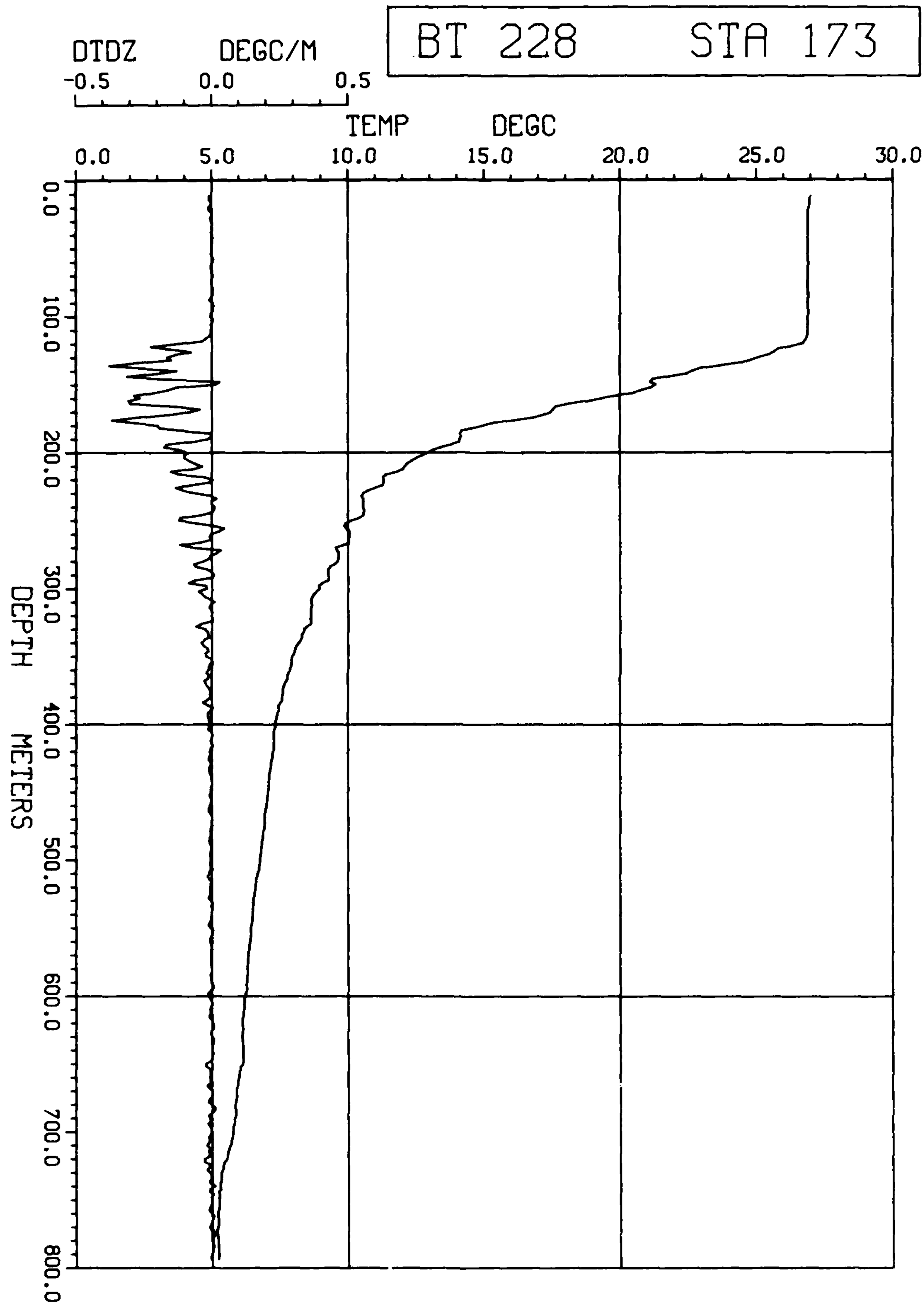
DEPTH METERS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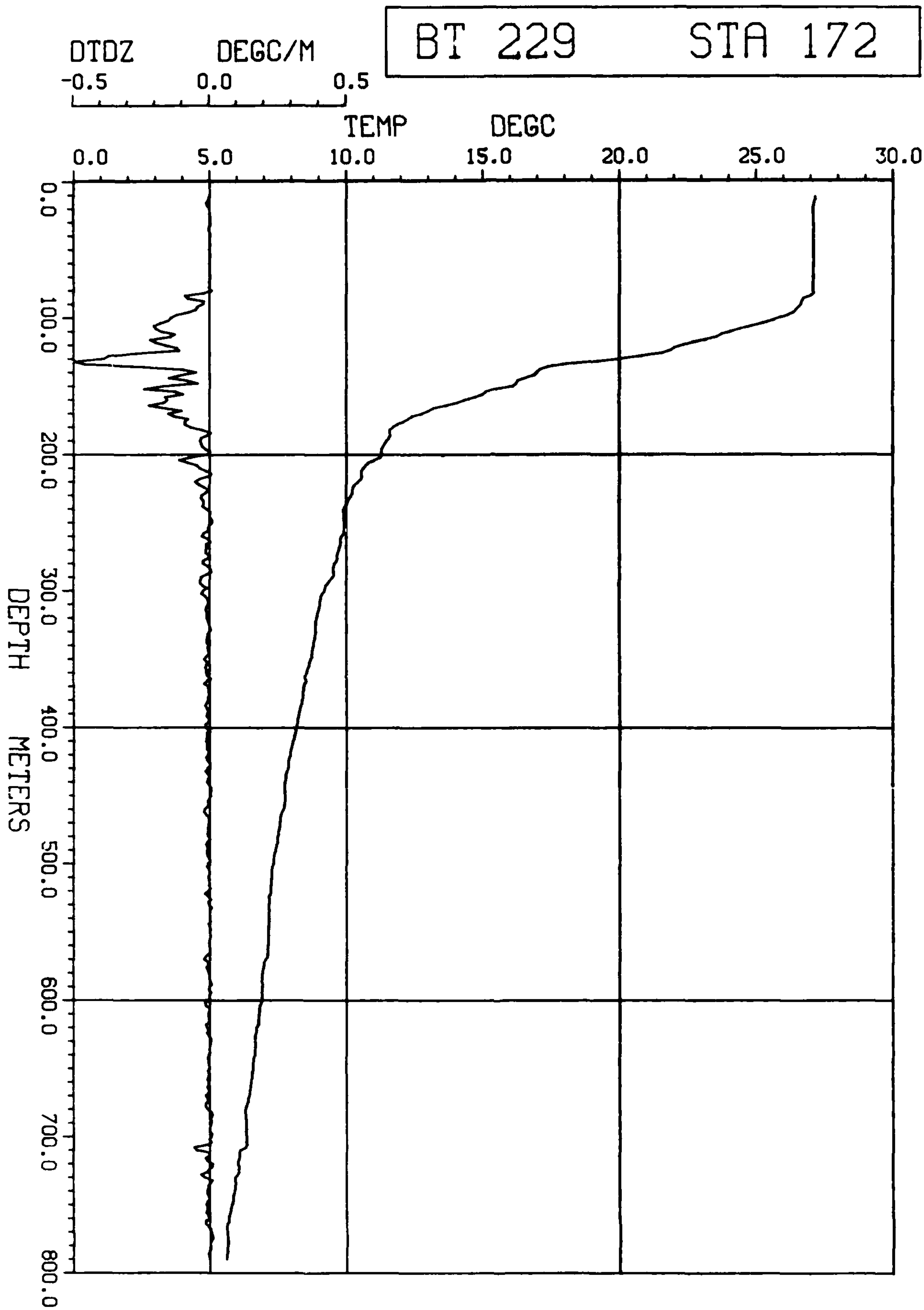
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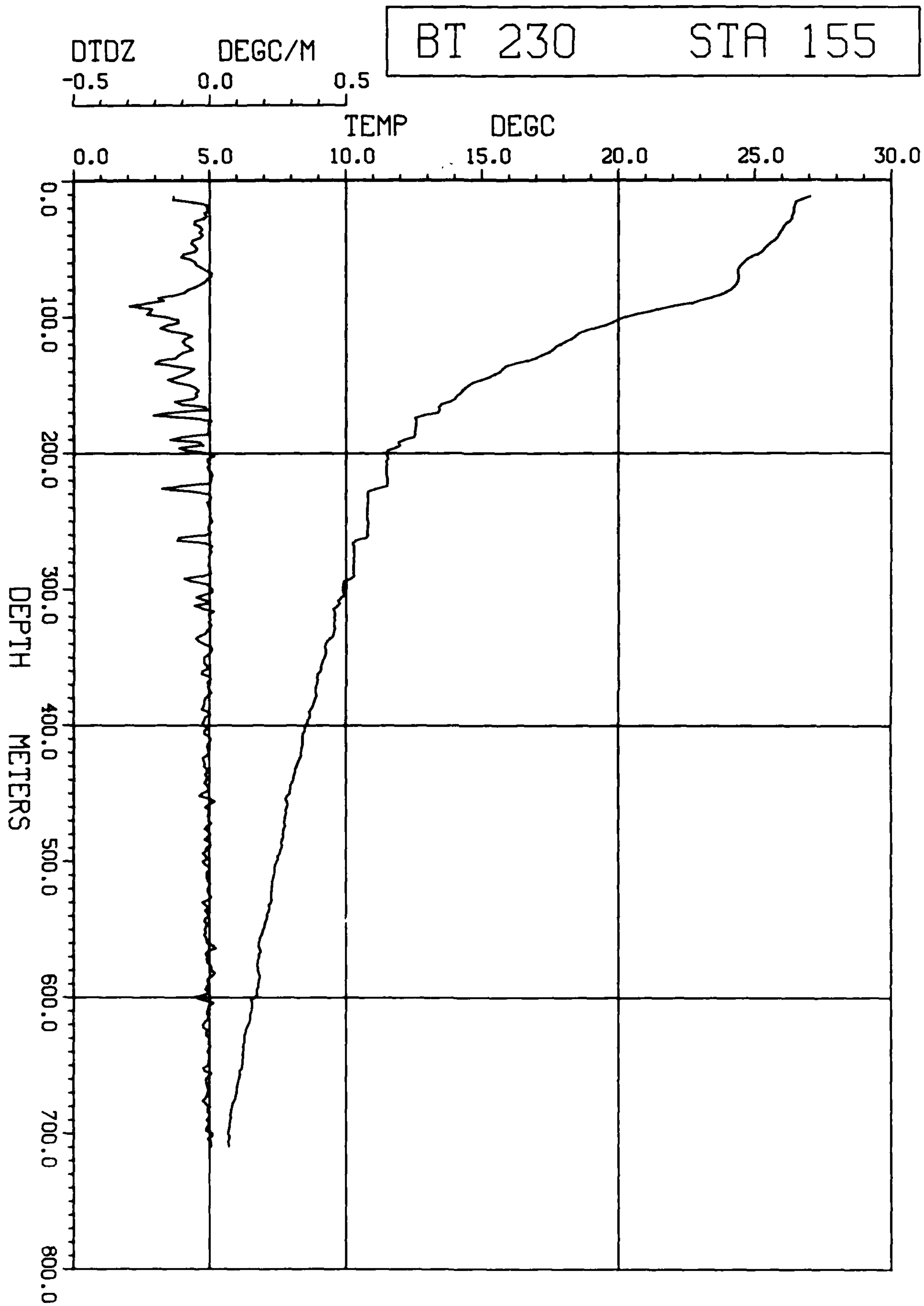
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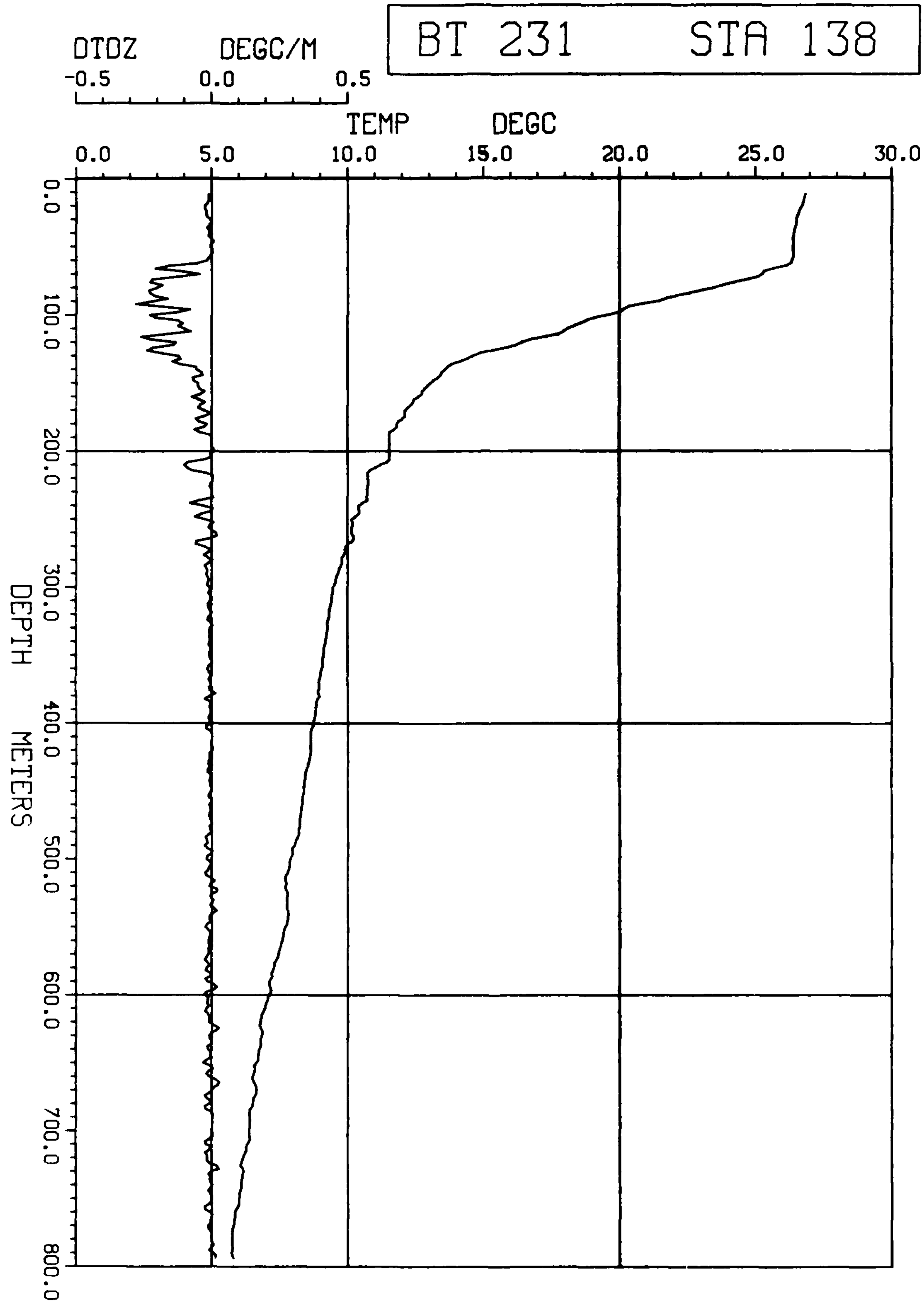
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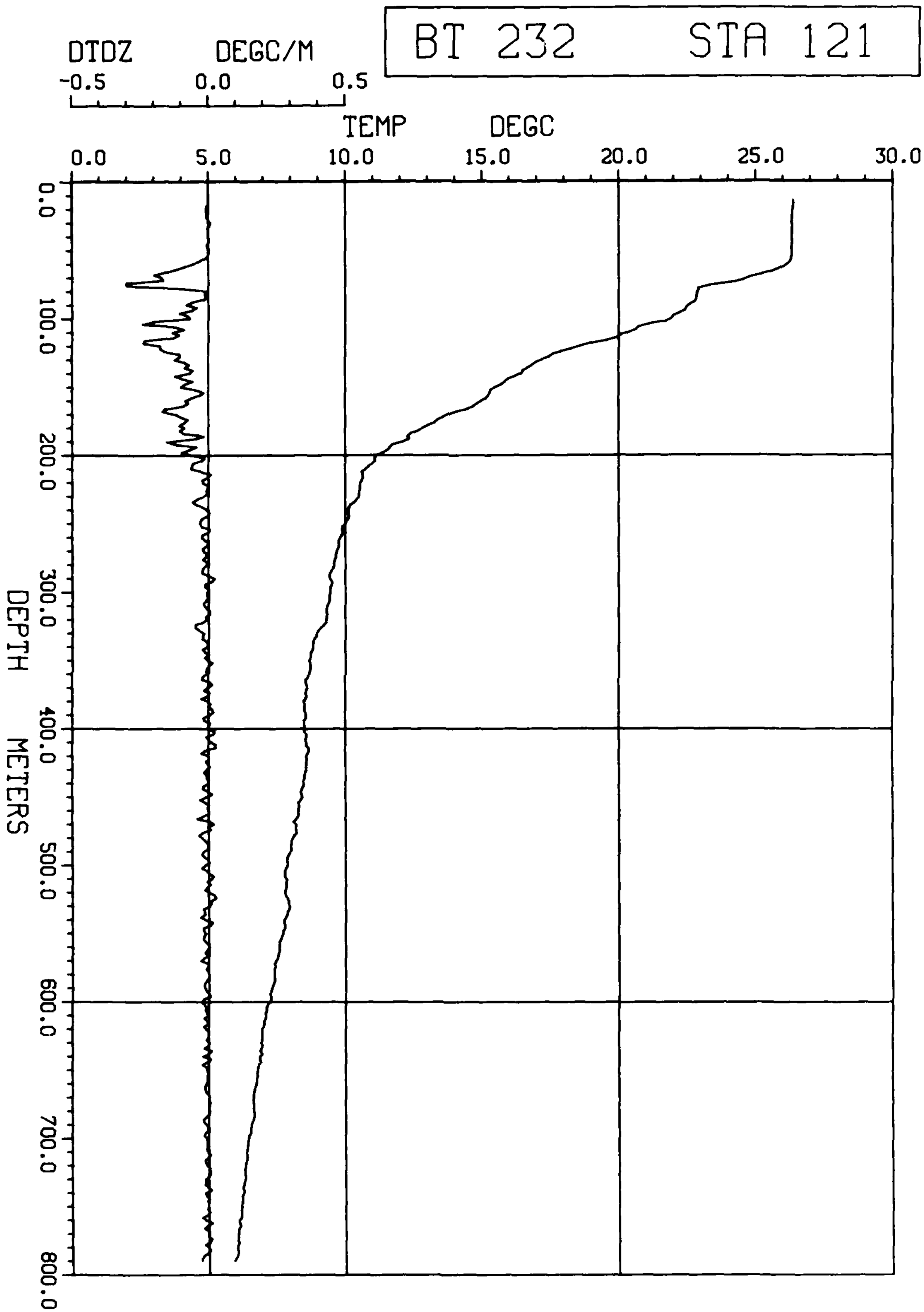
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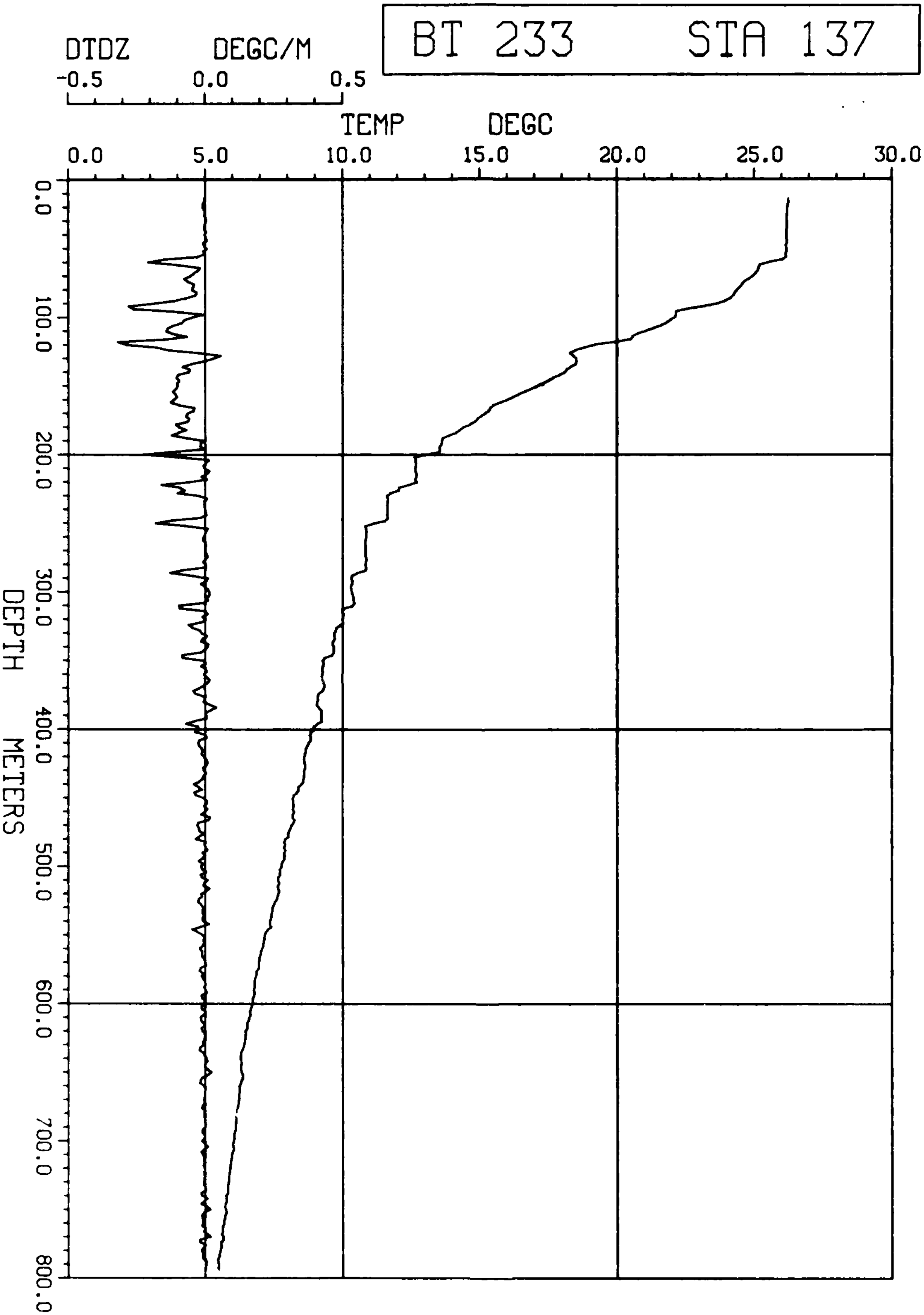

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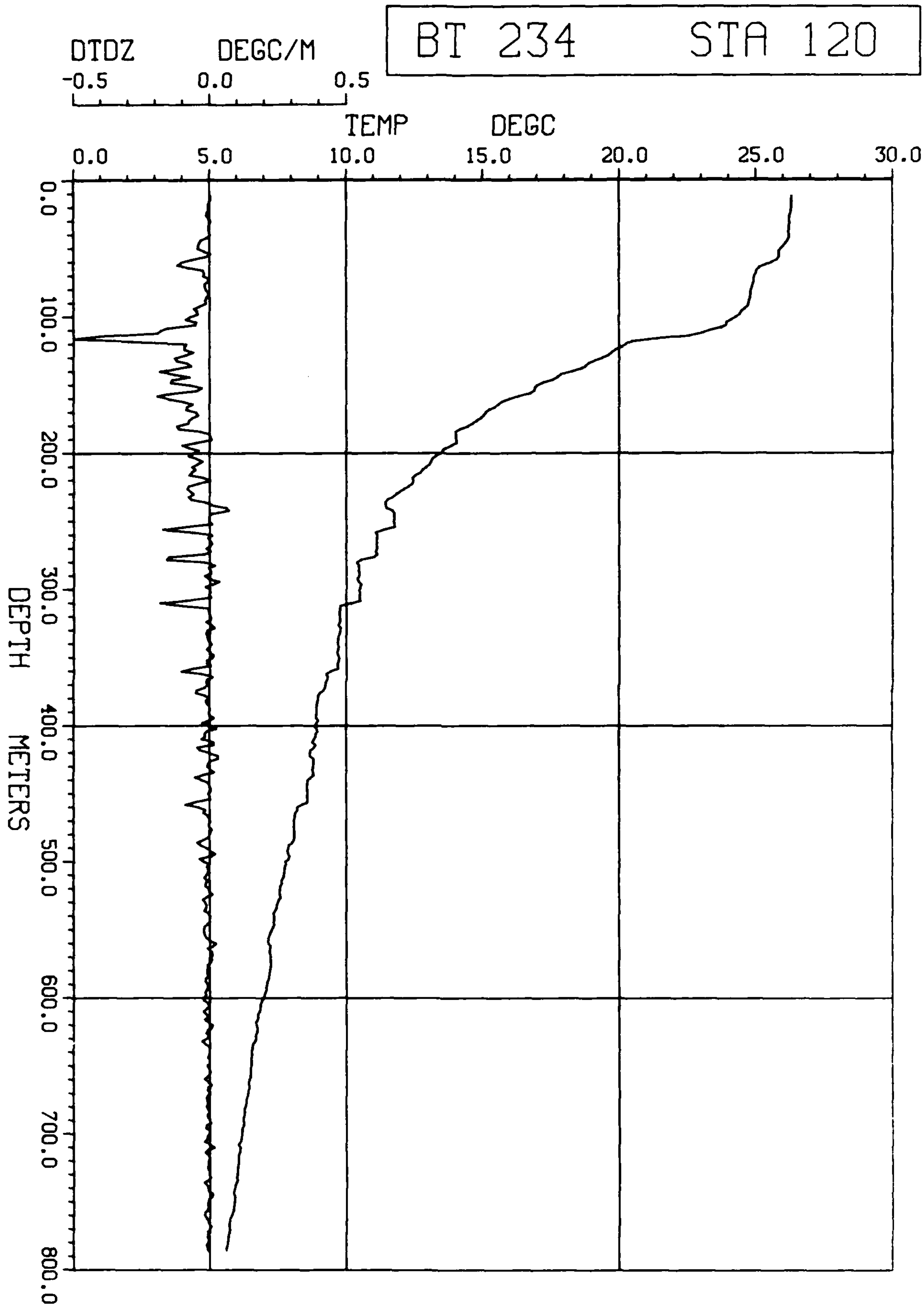
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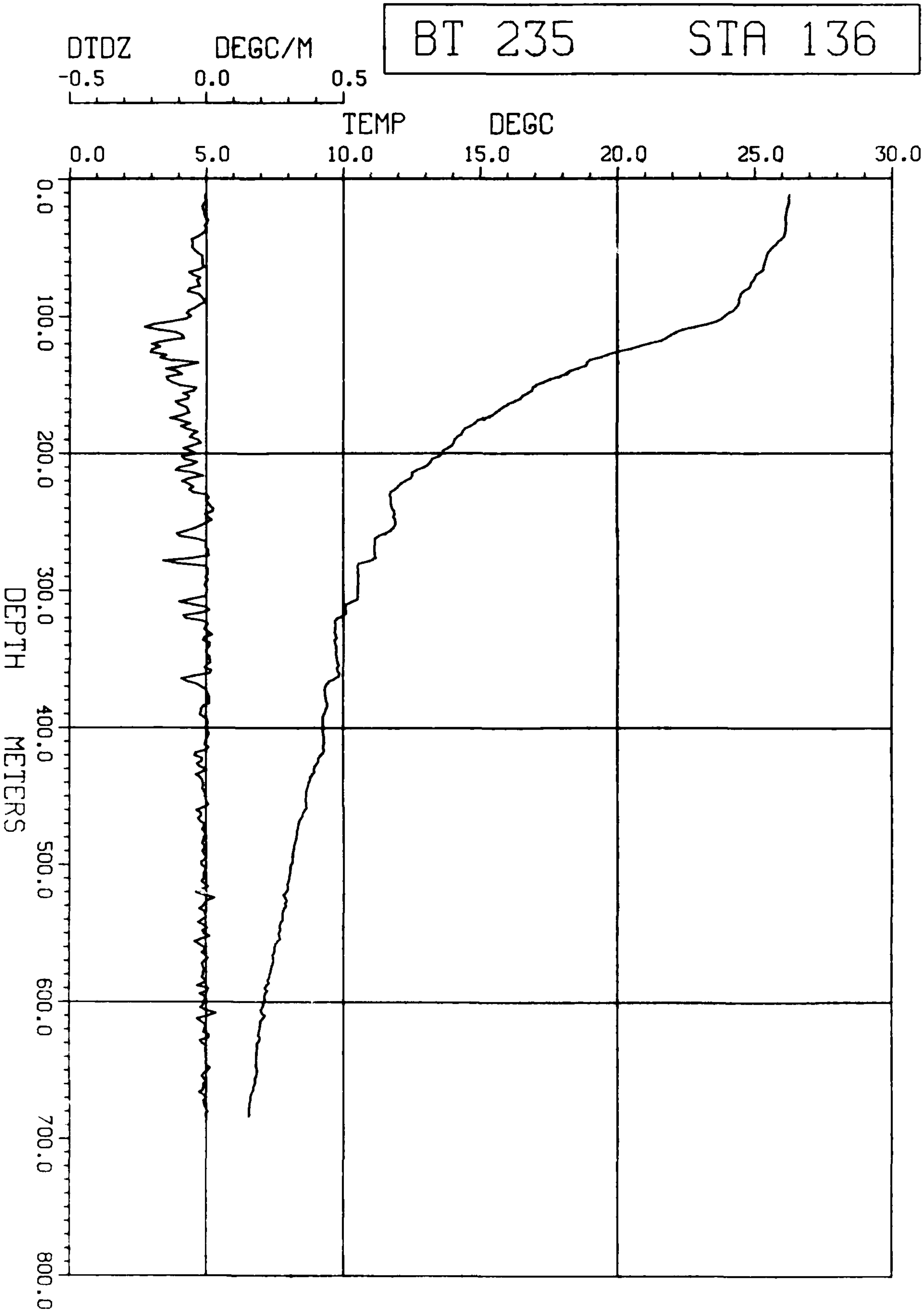
DEPTH METERS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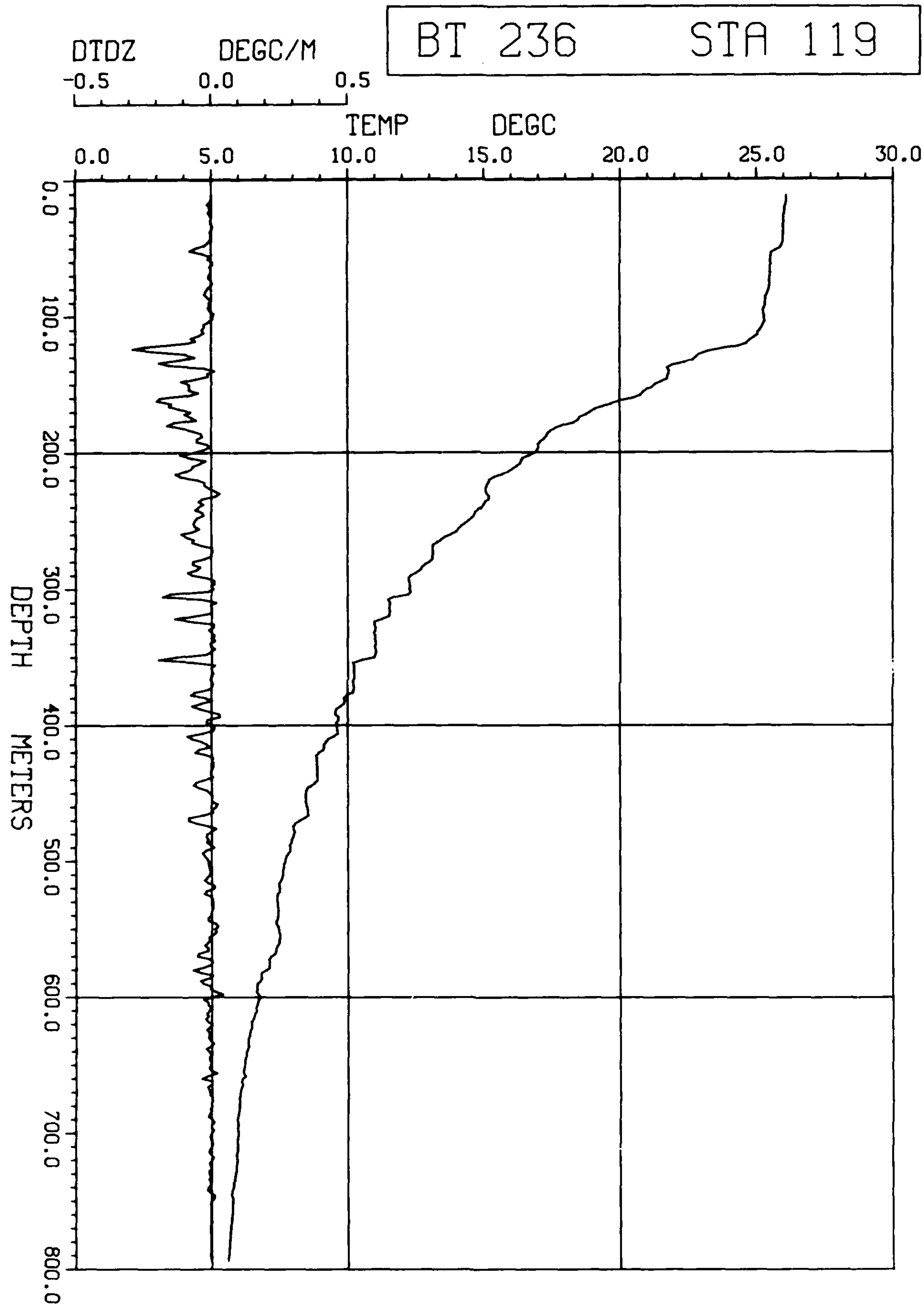
DEPTH METERS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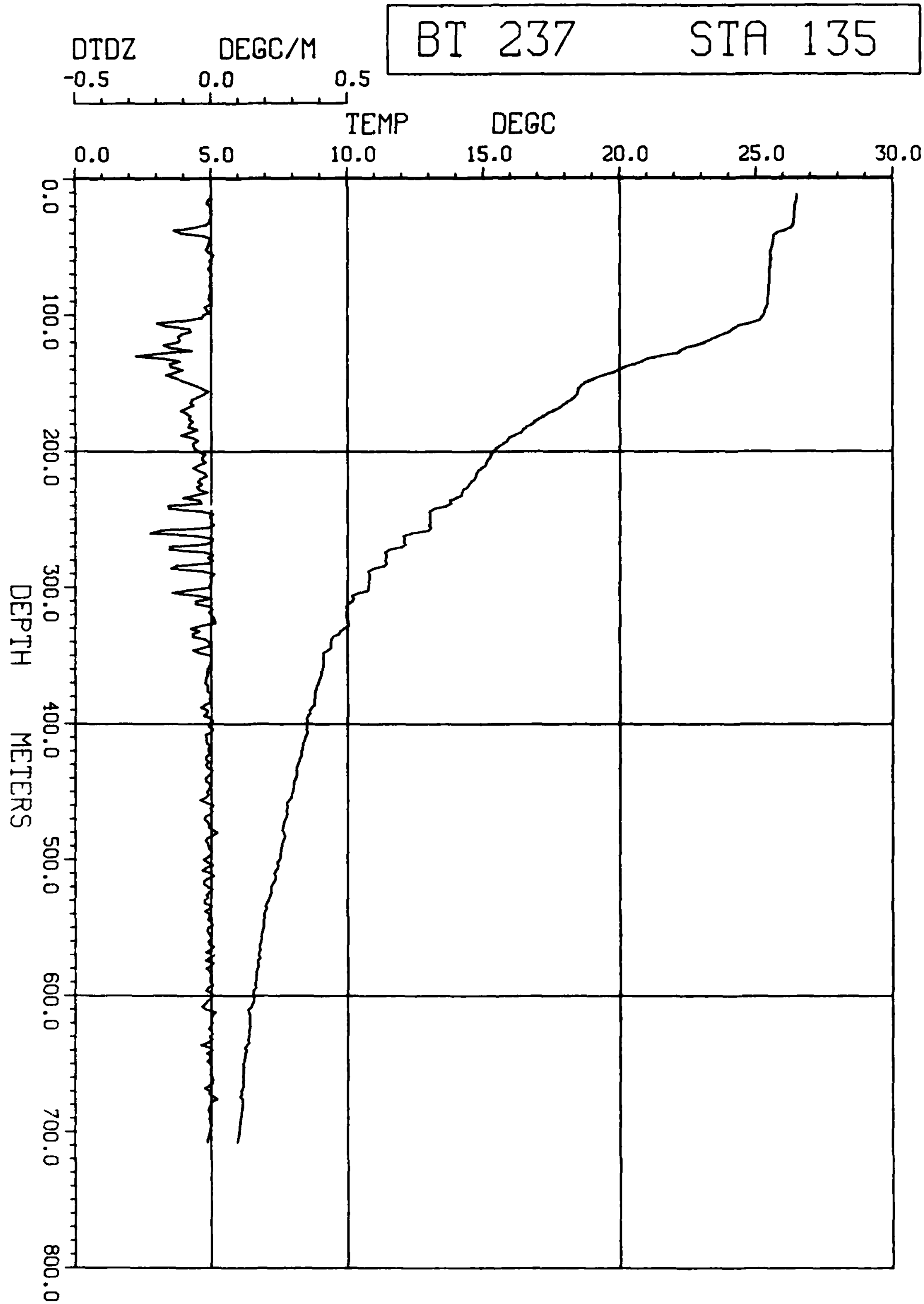
DEPTH METERS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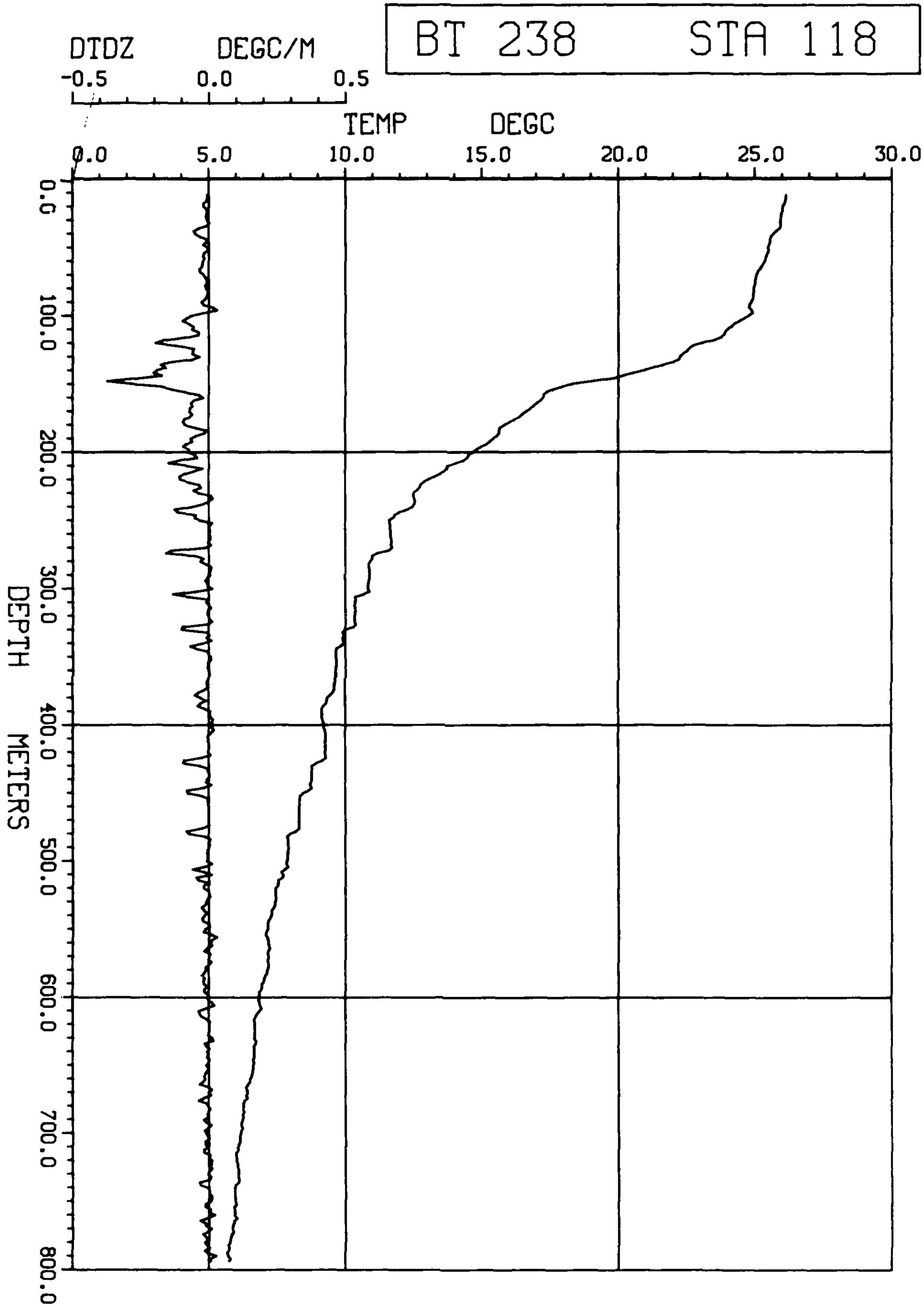

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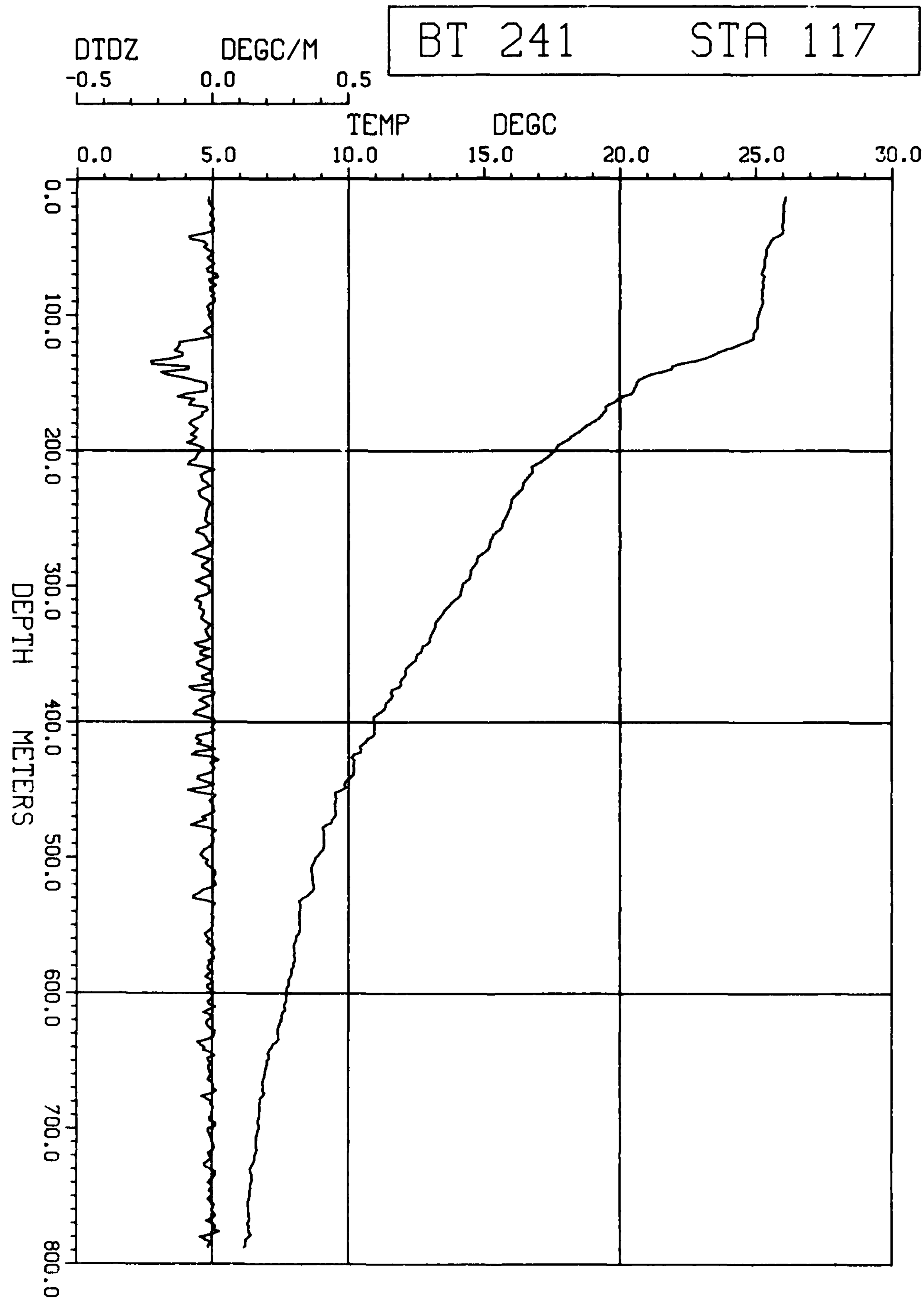
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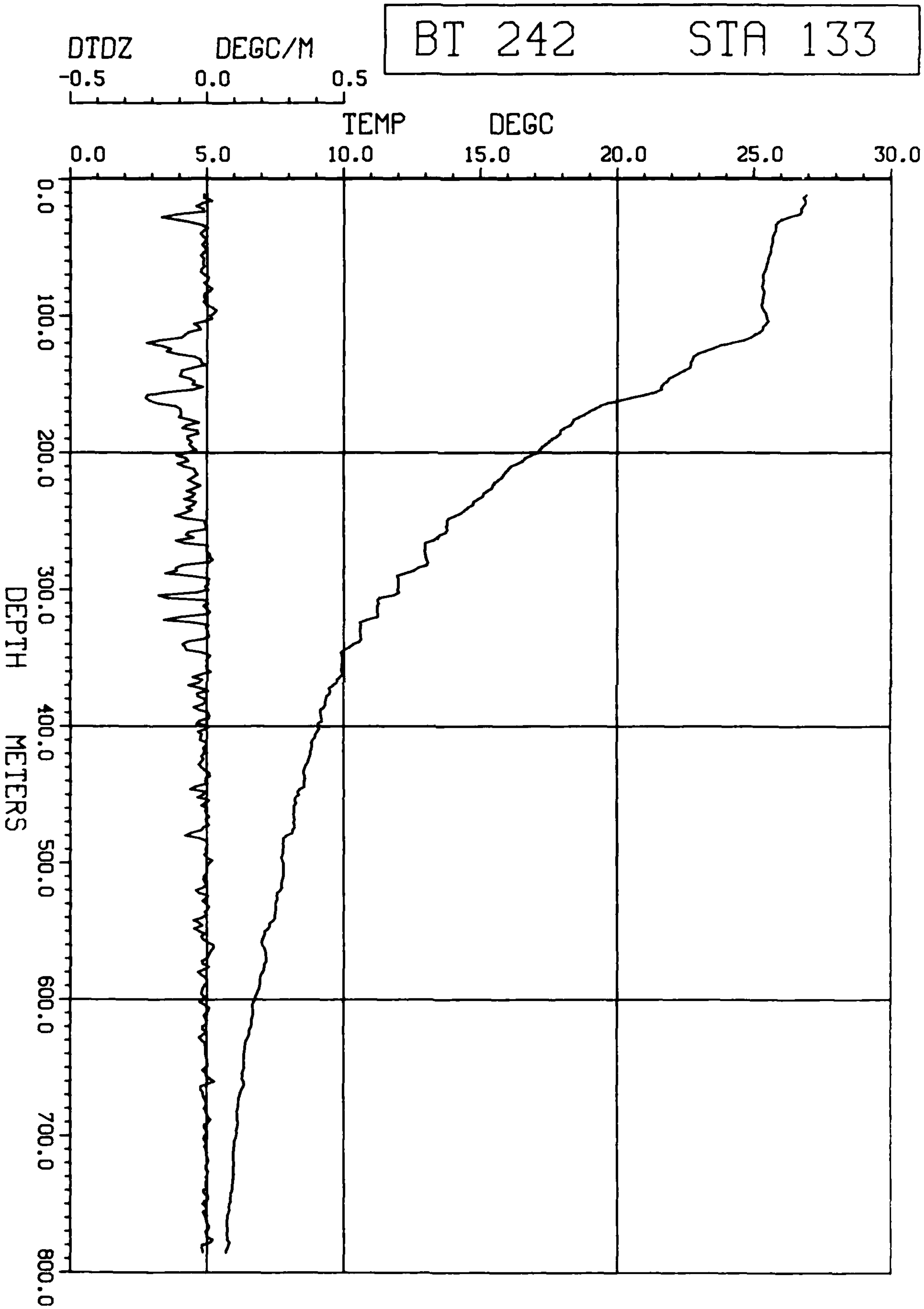

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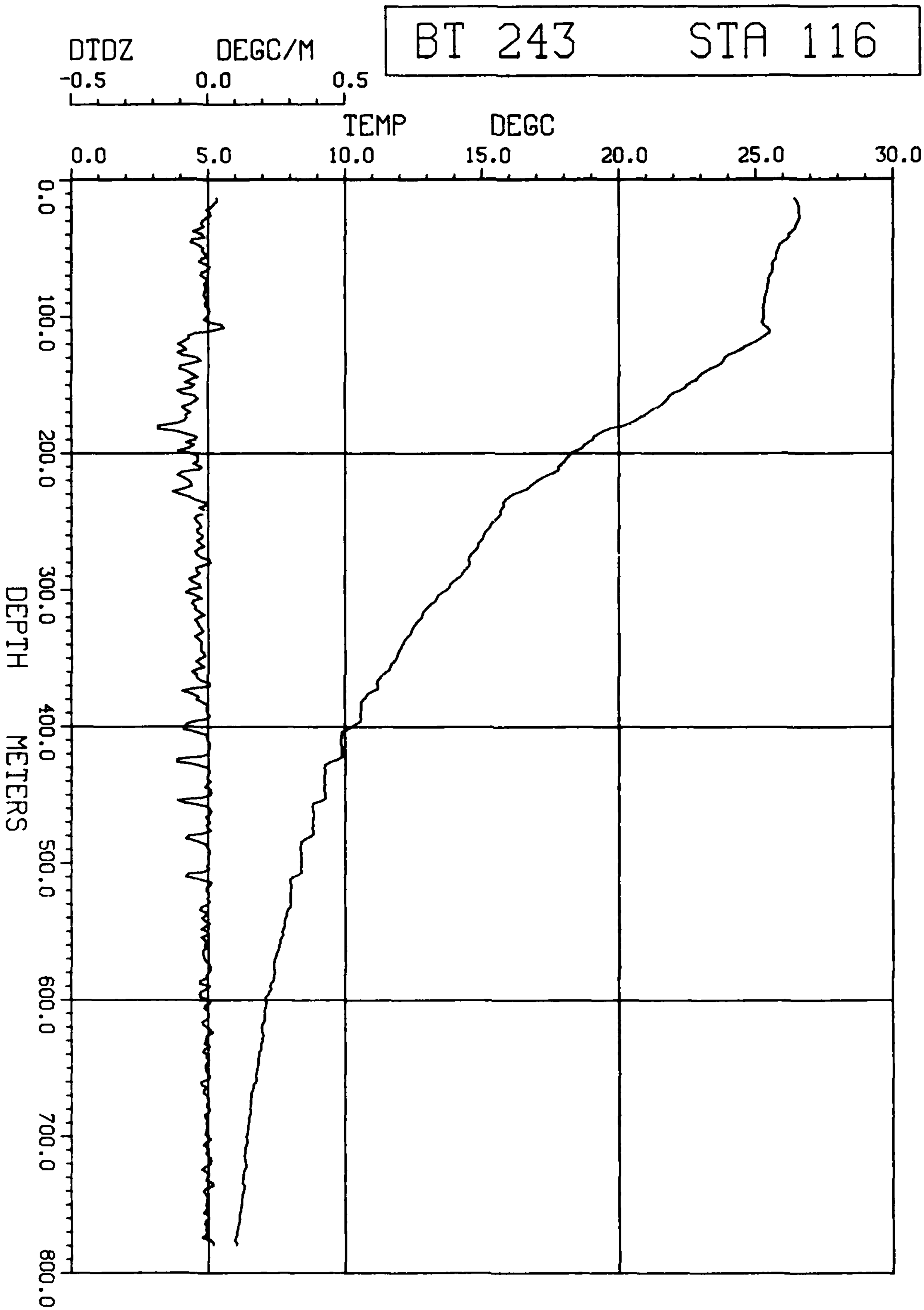

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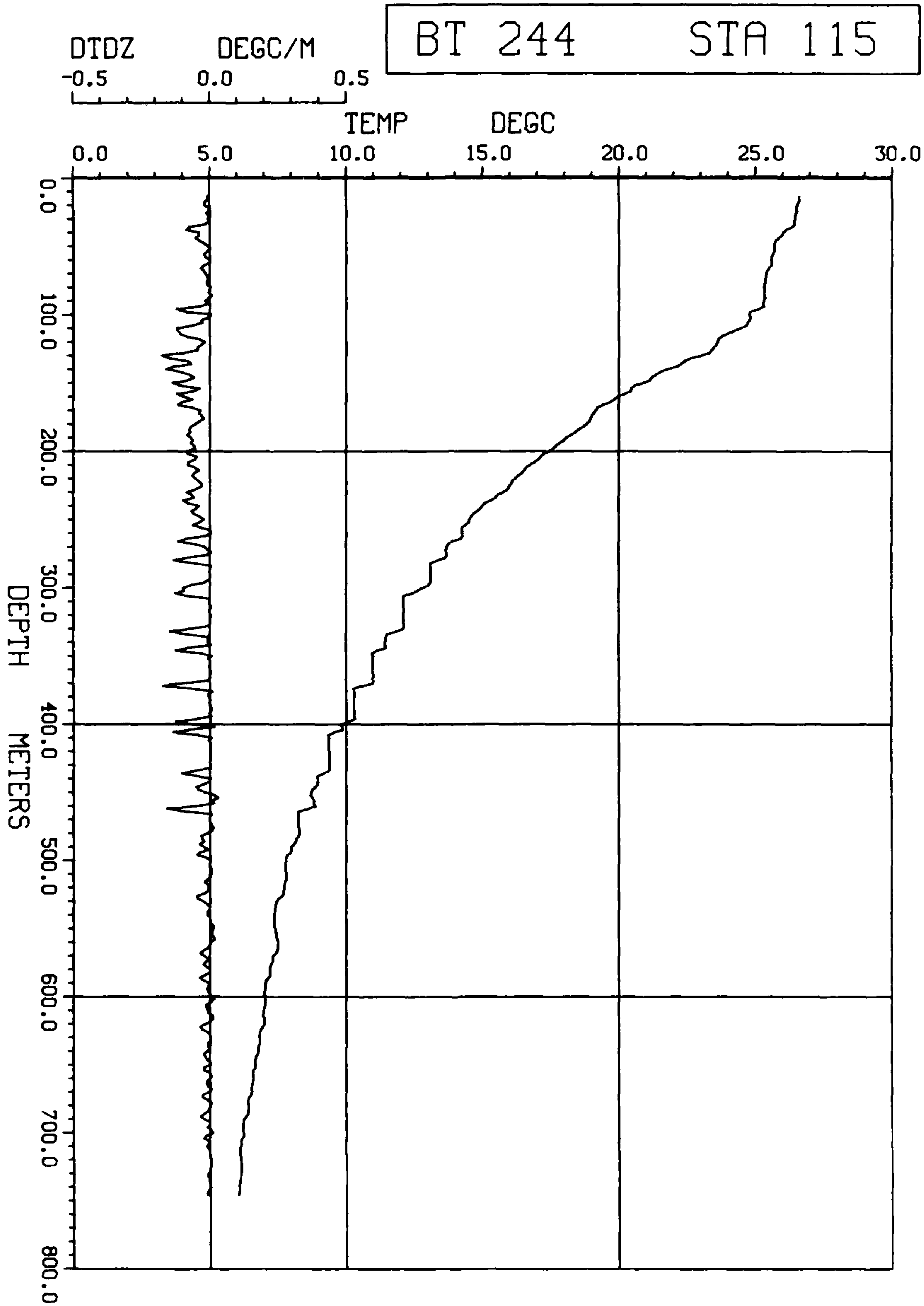
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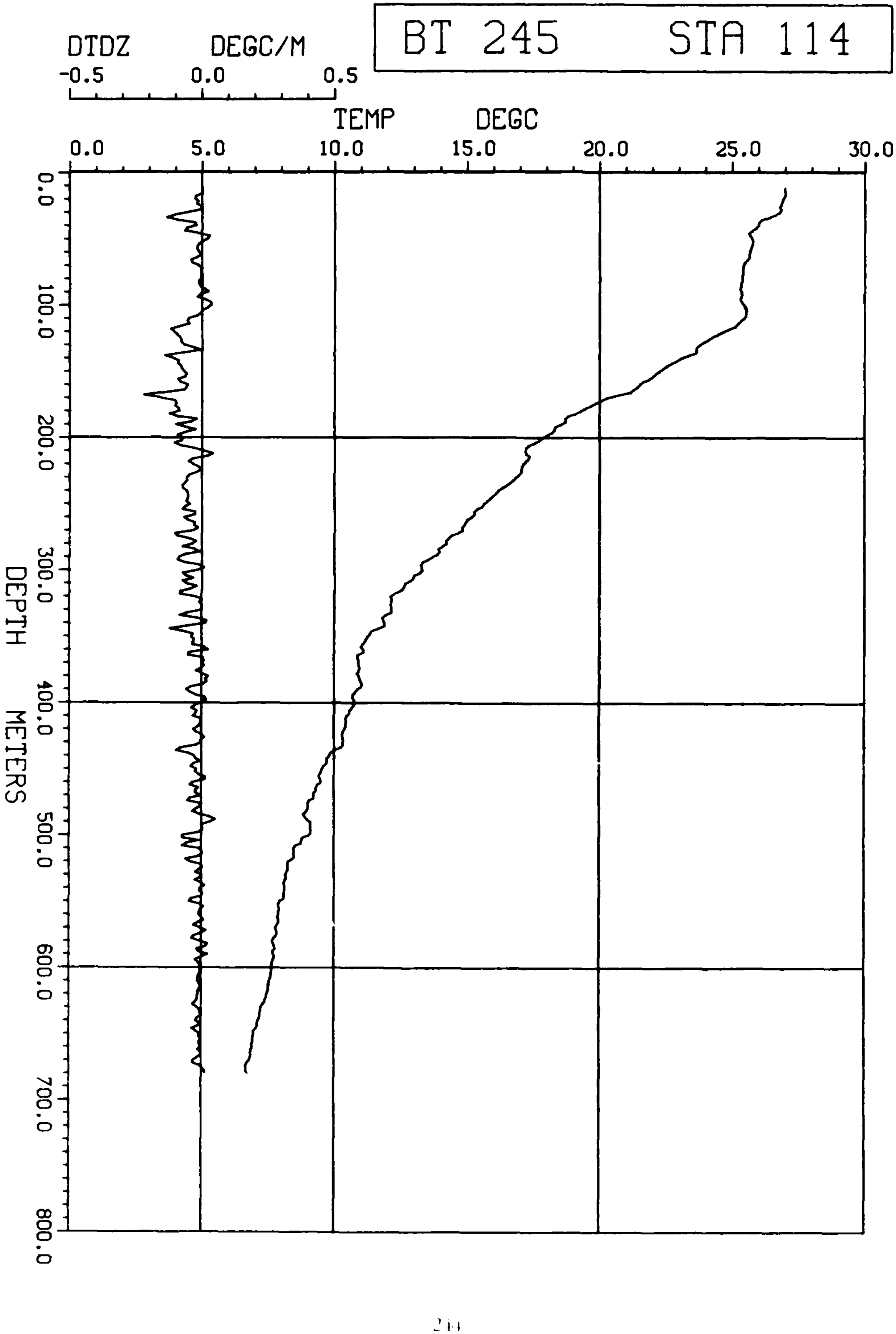
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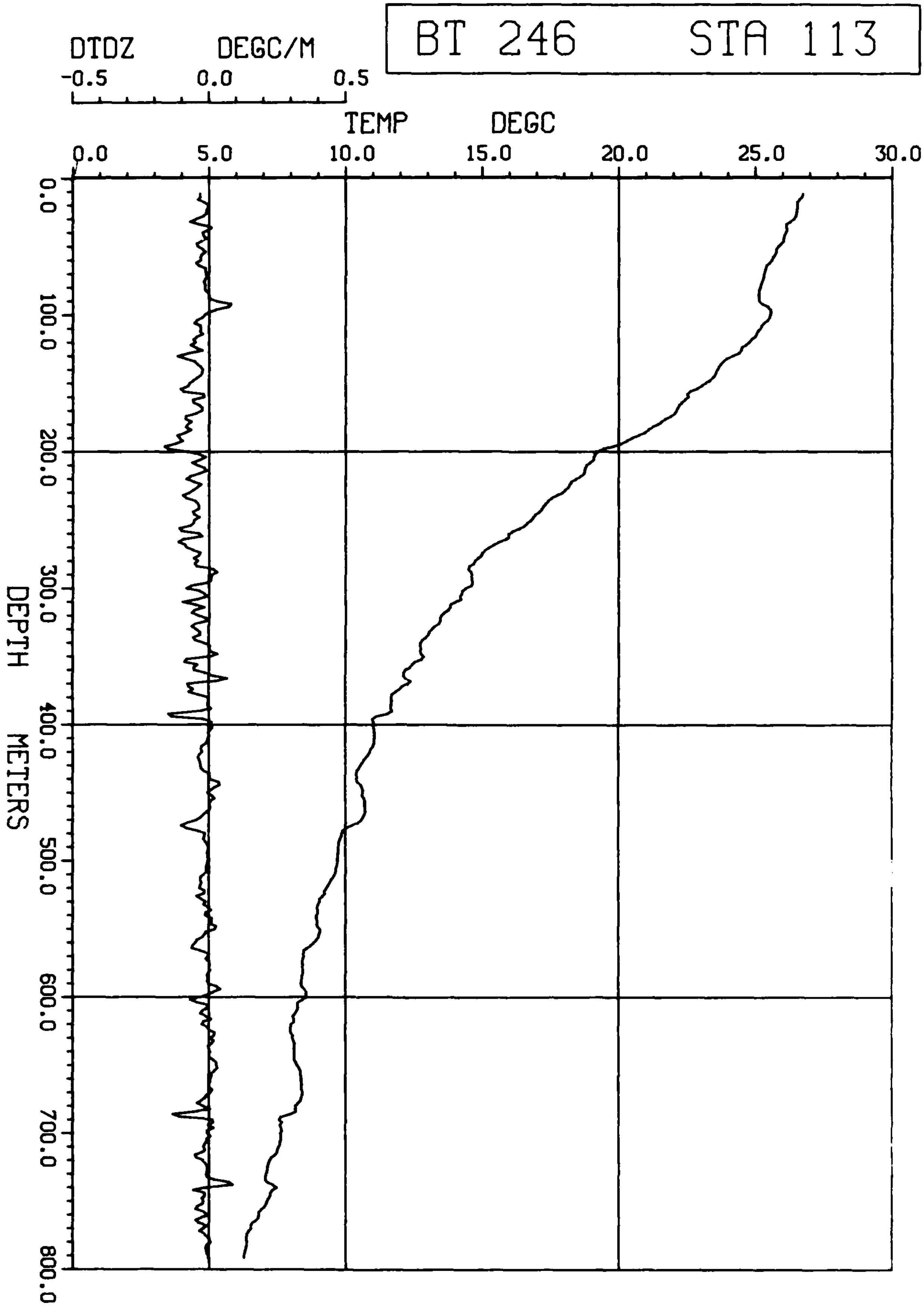
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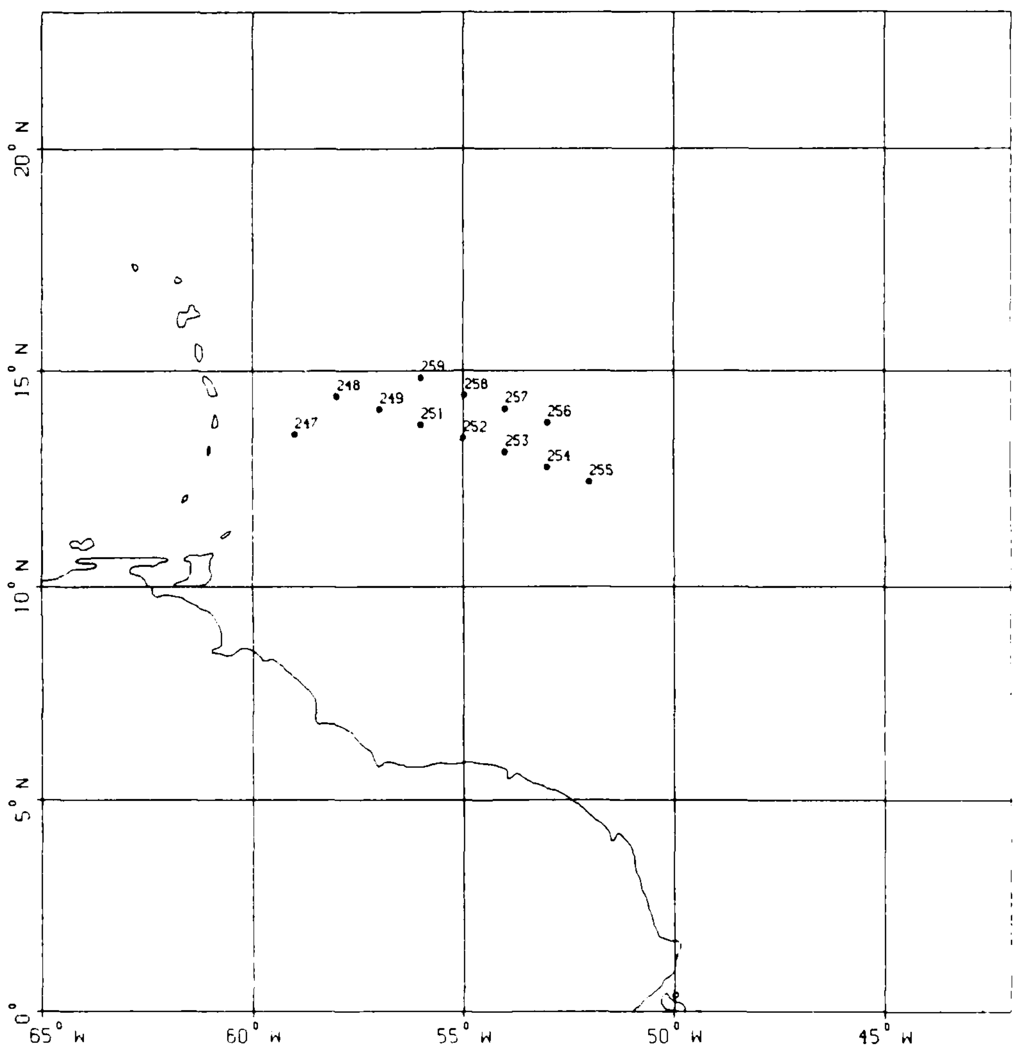
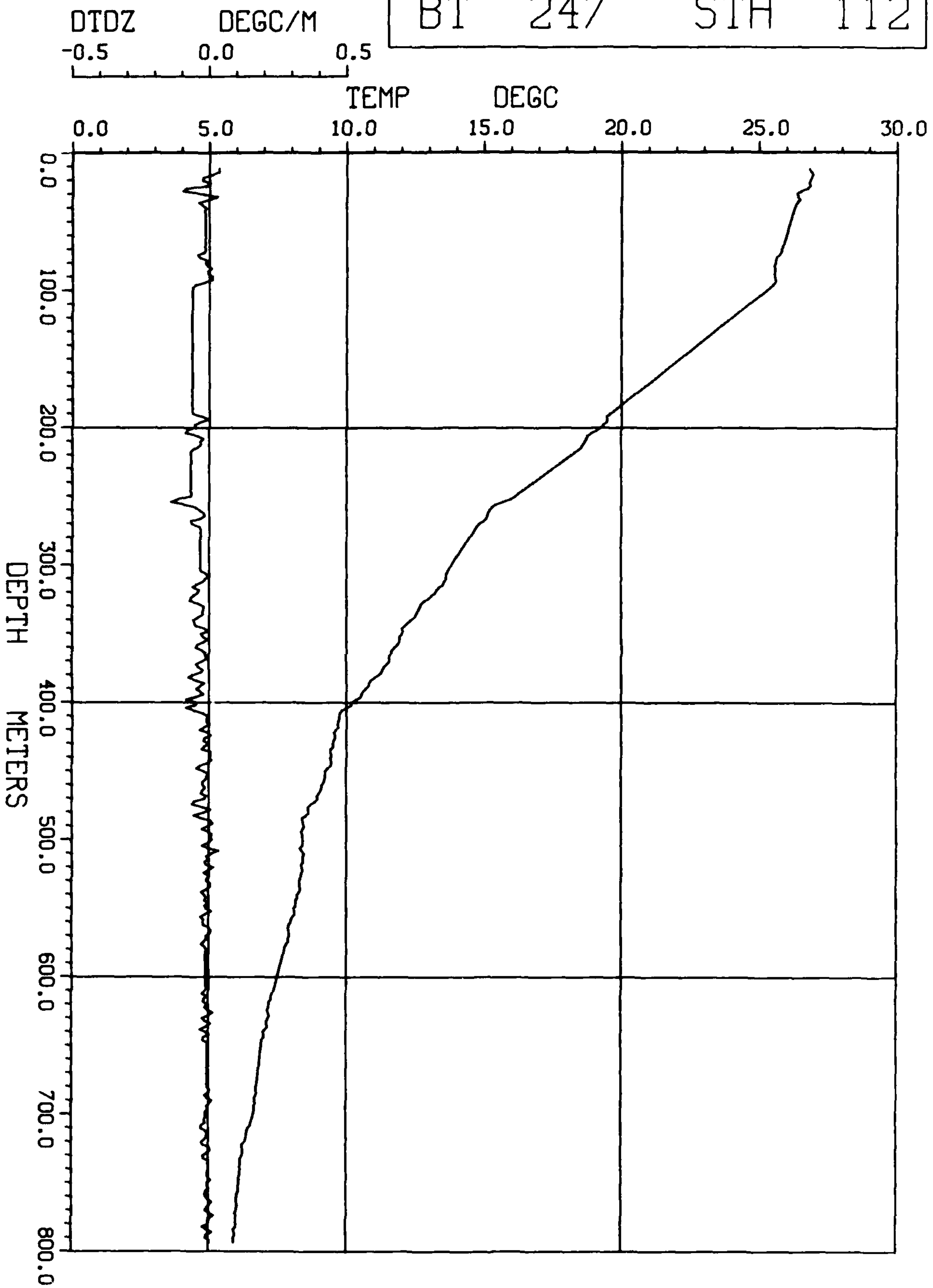
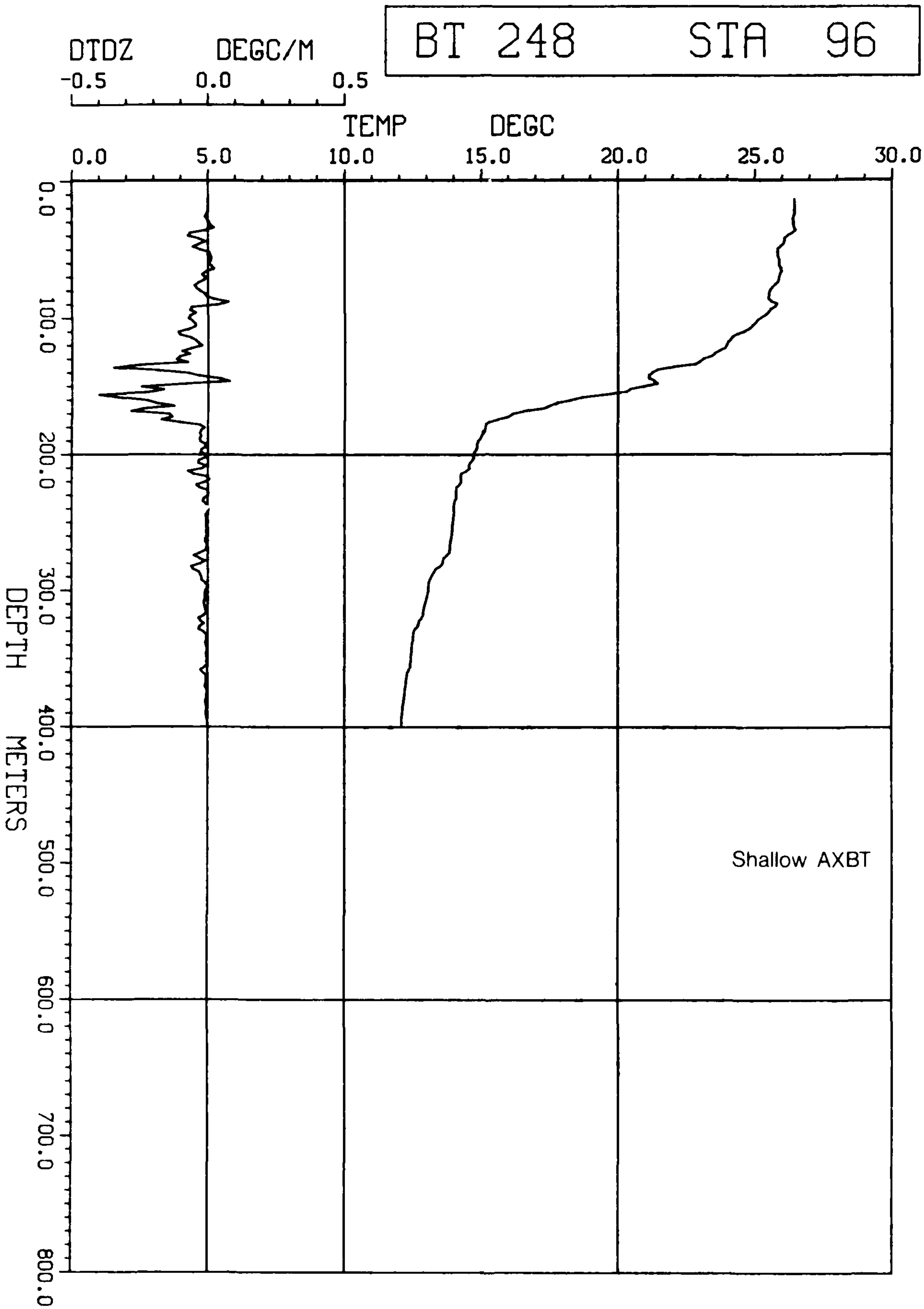
Station Positions Flight 7
13 May 1985



BT 247 STA 112





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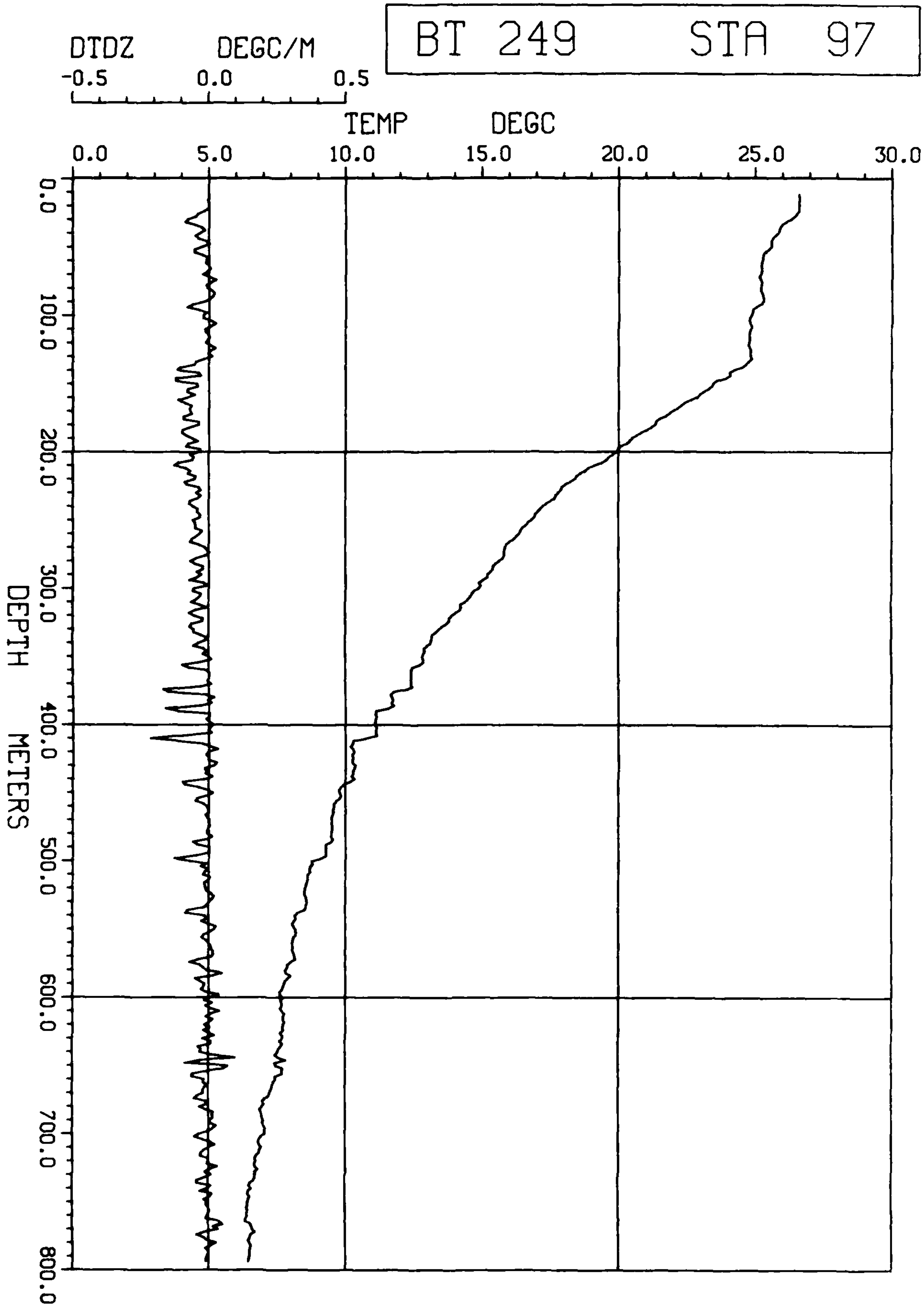
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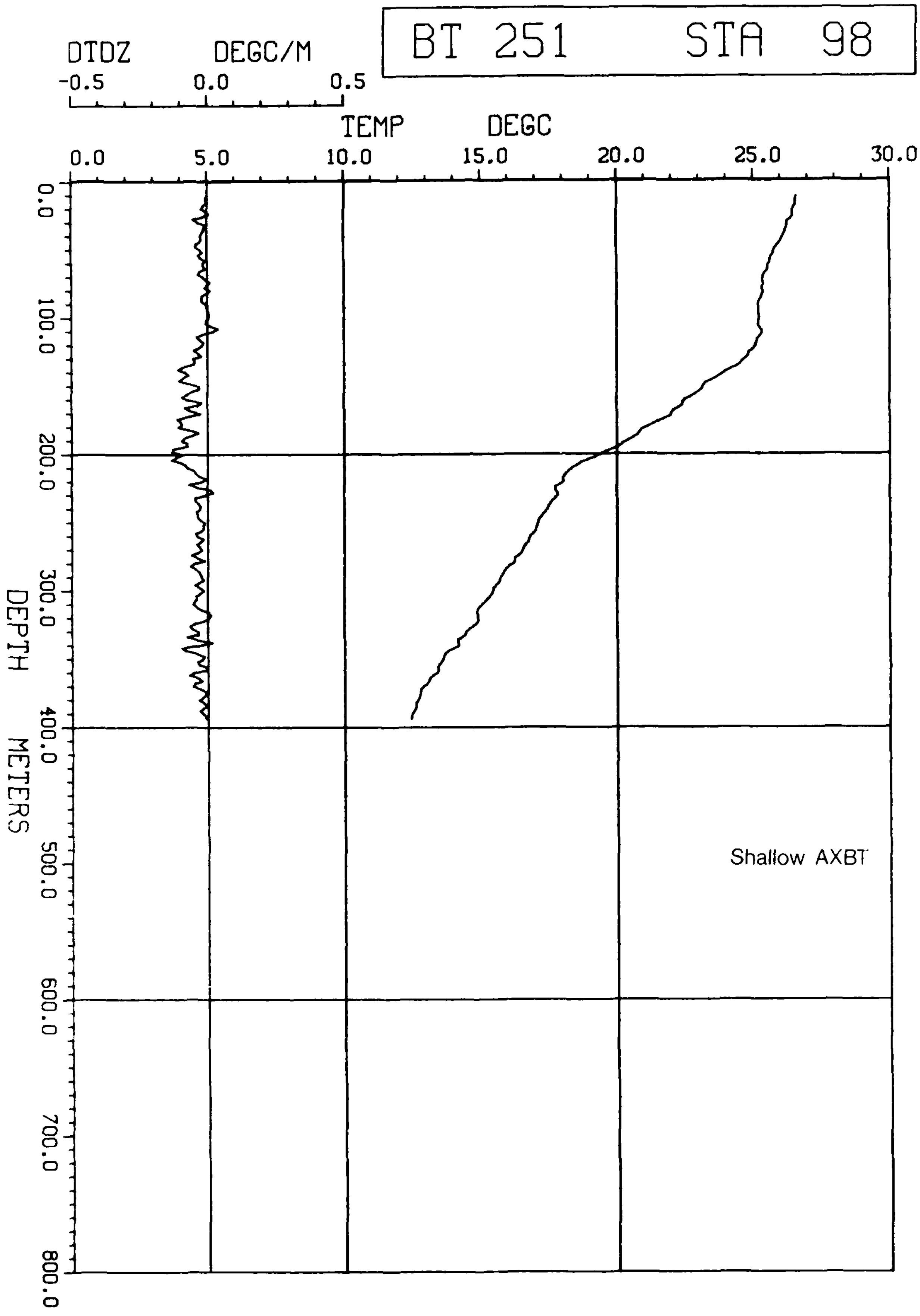
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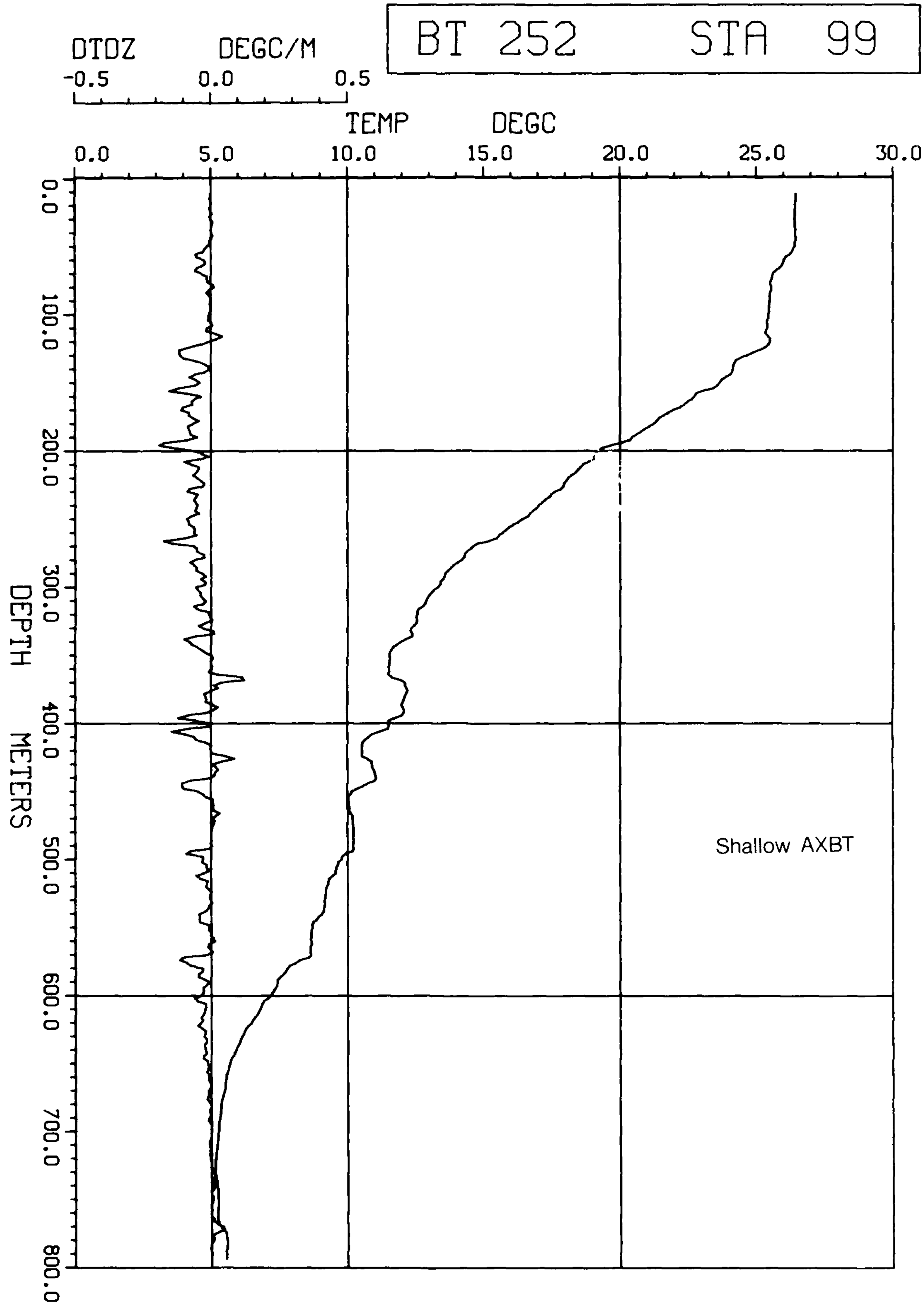
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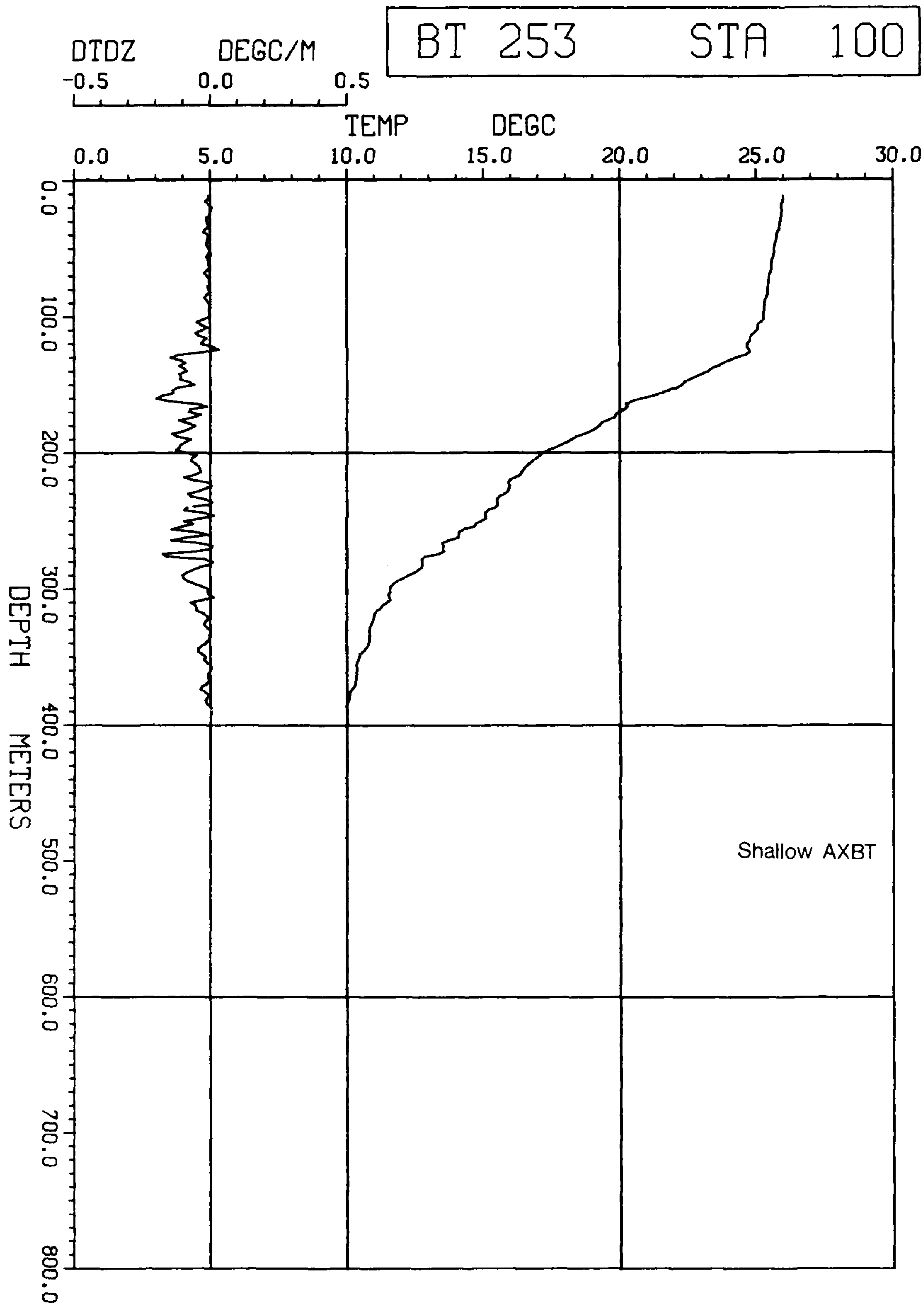
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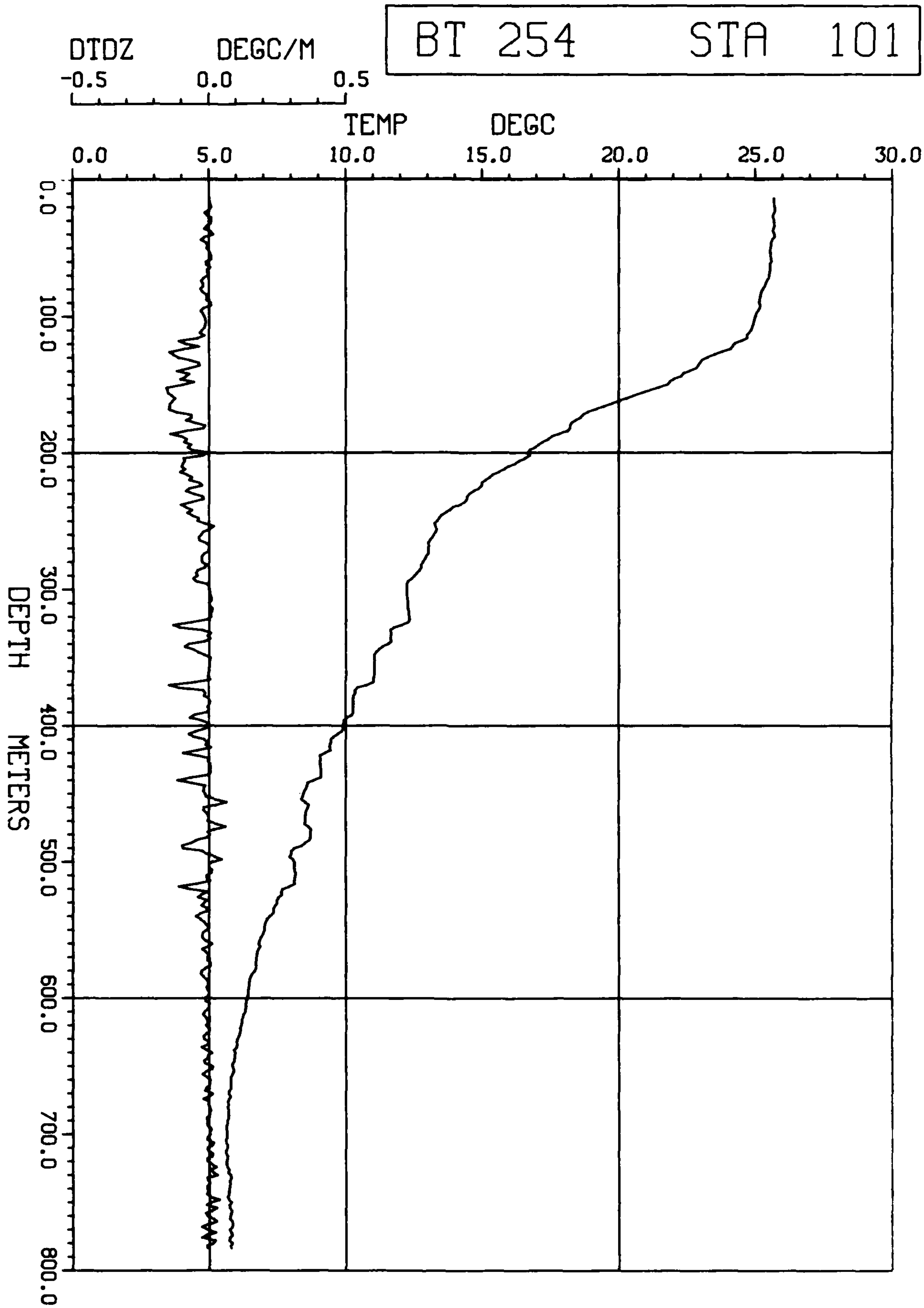
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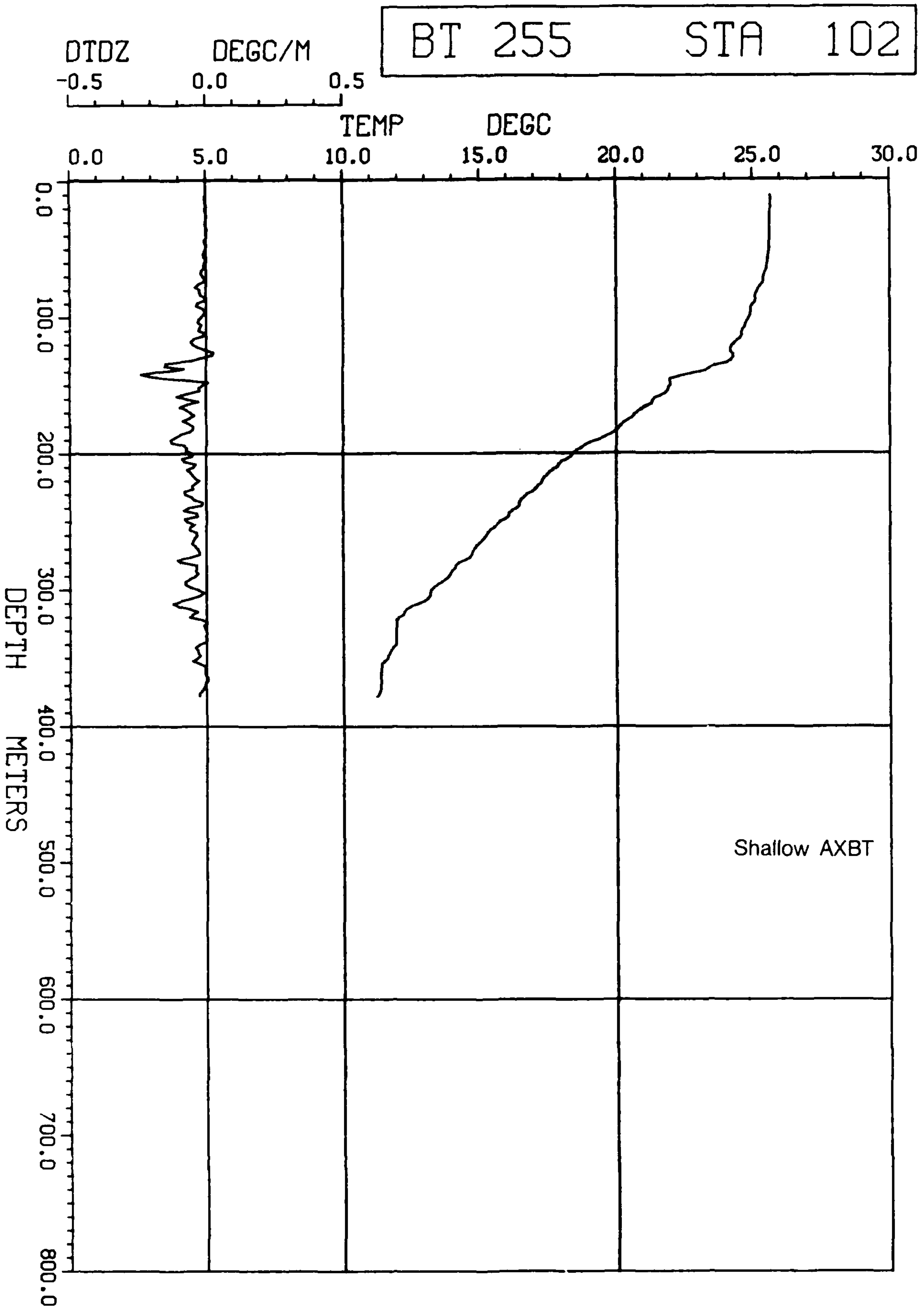
DEPTH METERS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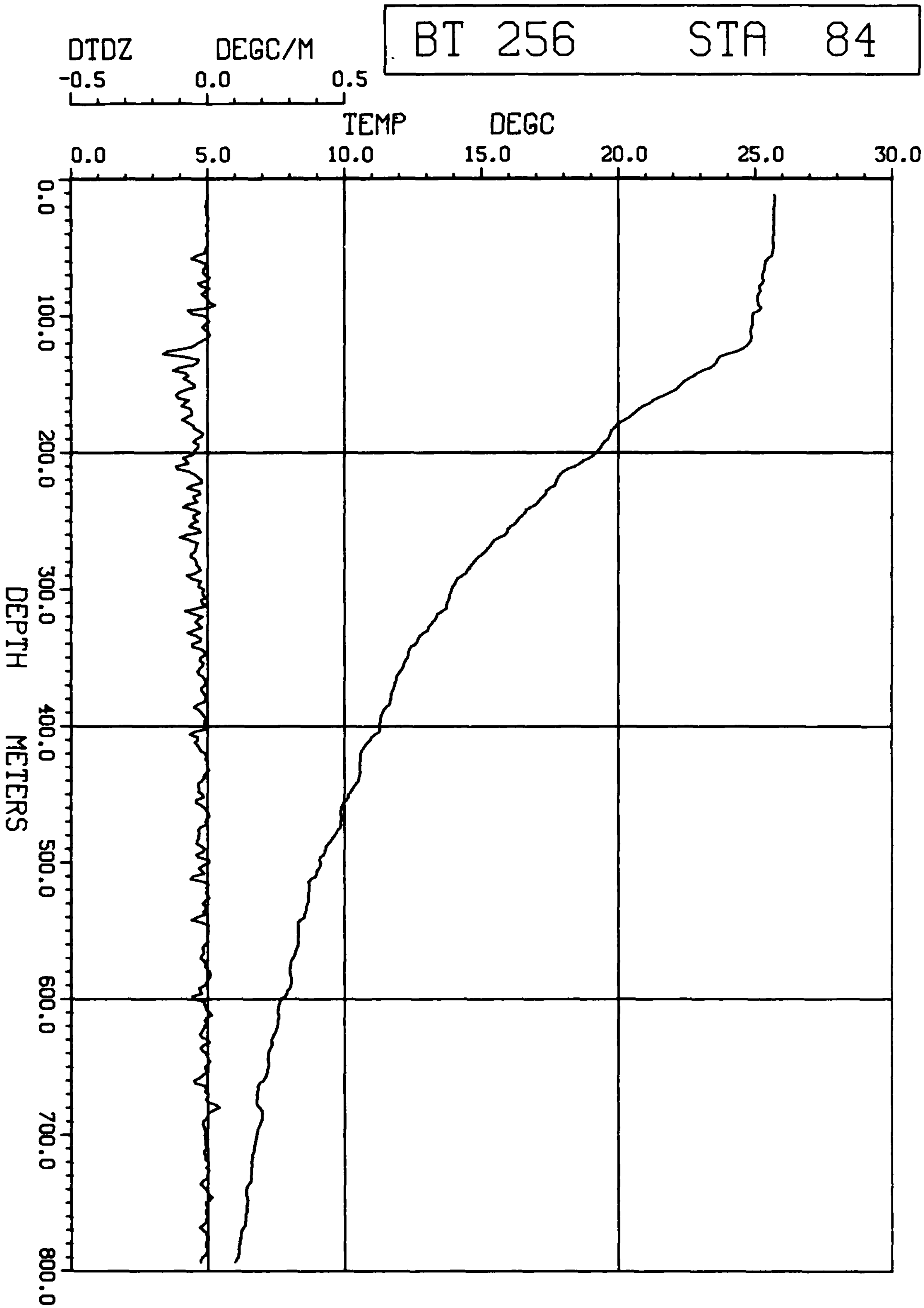

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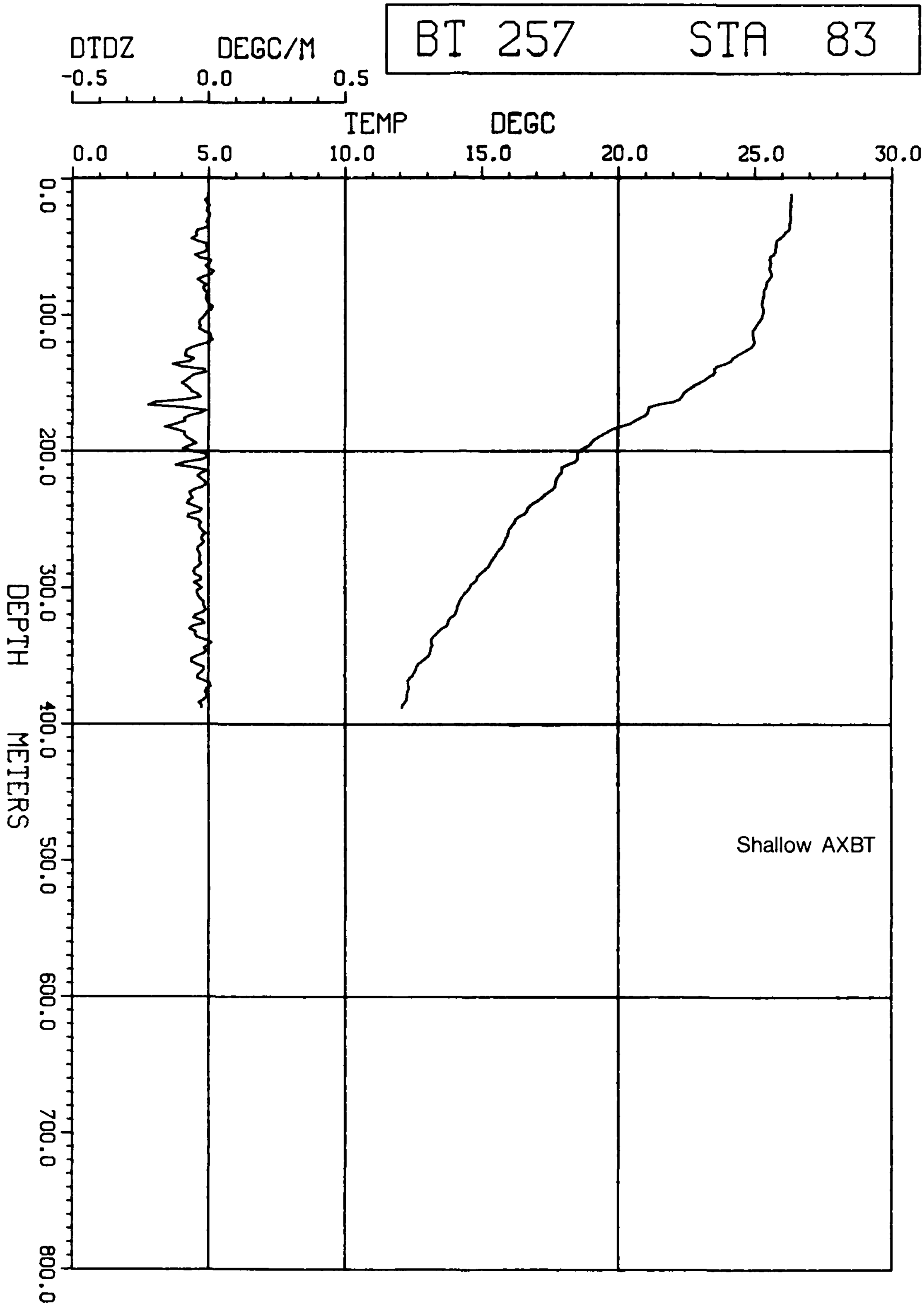
DEPTH METERS



BT 257 STA 83
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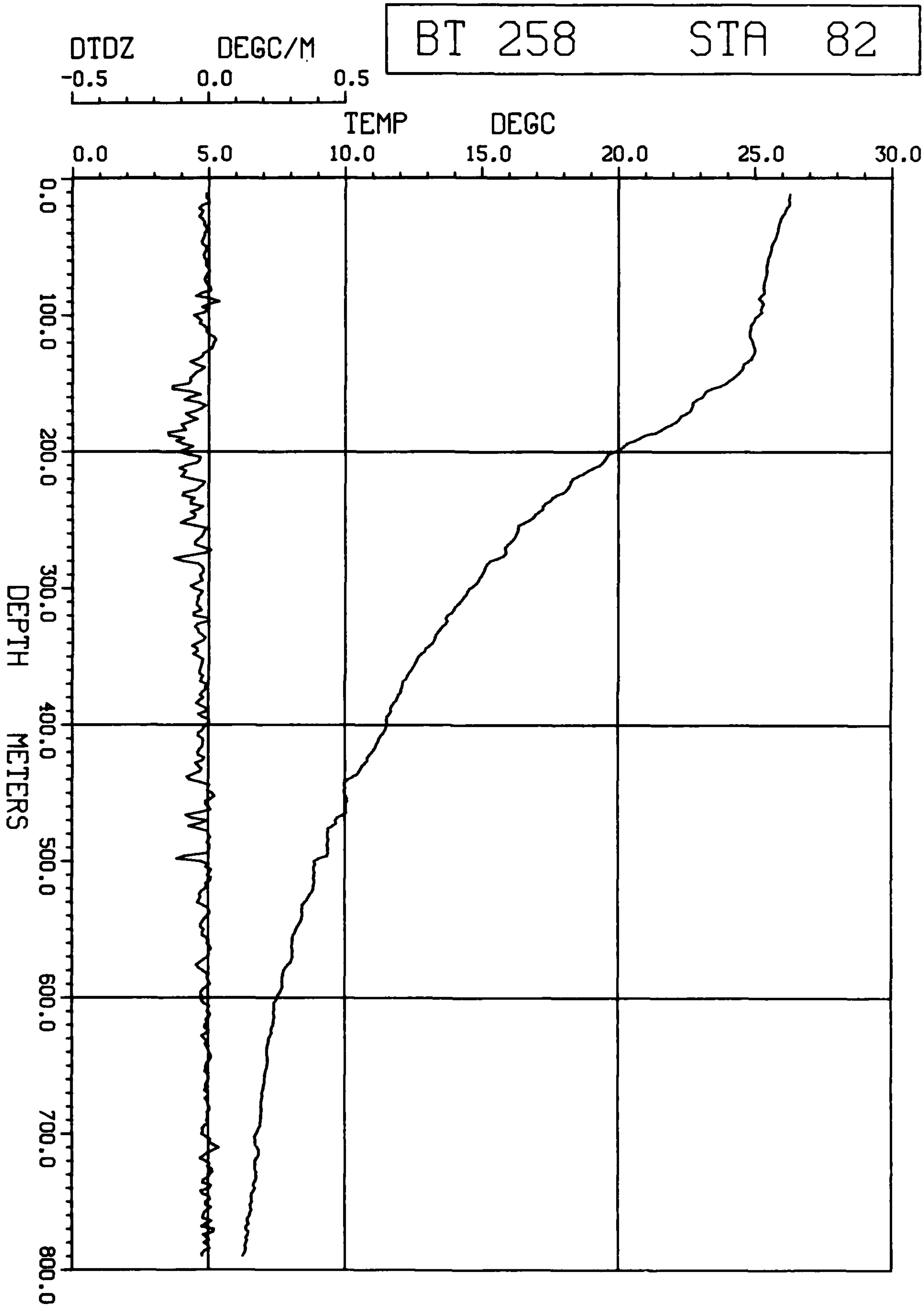
Shallow AXBT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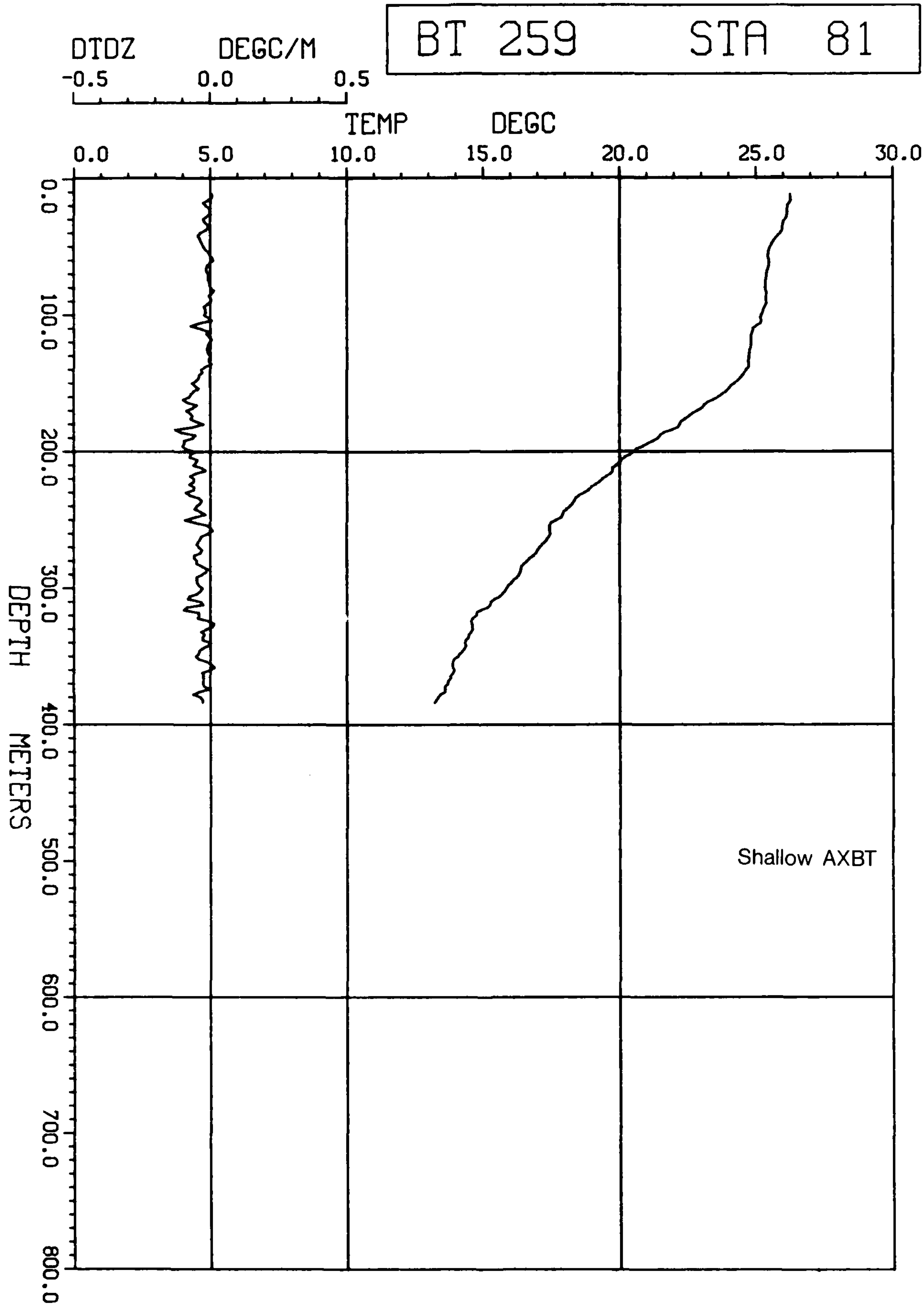
DEPTH METERS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200.0
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500.0
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DEPTH METERS
Shallow AXBT

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In March and May, 1985, 219 air-deployed expendable bathythermograph (AXBT) profiles were taken off the northeast coast of South America in a region of large scale thermohaline steps. Presented in this report are a map of the location of the staircase field during this time, contours of the depths of the 6–22°C isotherms, and individual profile plots. The mesoscale flow patterns are inferred from the isotherm plots, and the location of the staircases in relation to the flow field is discussed.

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