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The Ahuachapán Geothermal Field, El Salvador—Reservoir Analysis Volume II: Appendices A through E

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Volume II: Appendices A through E

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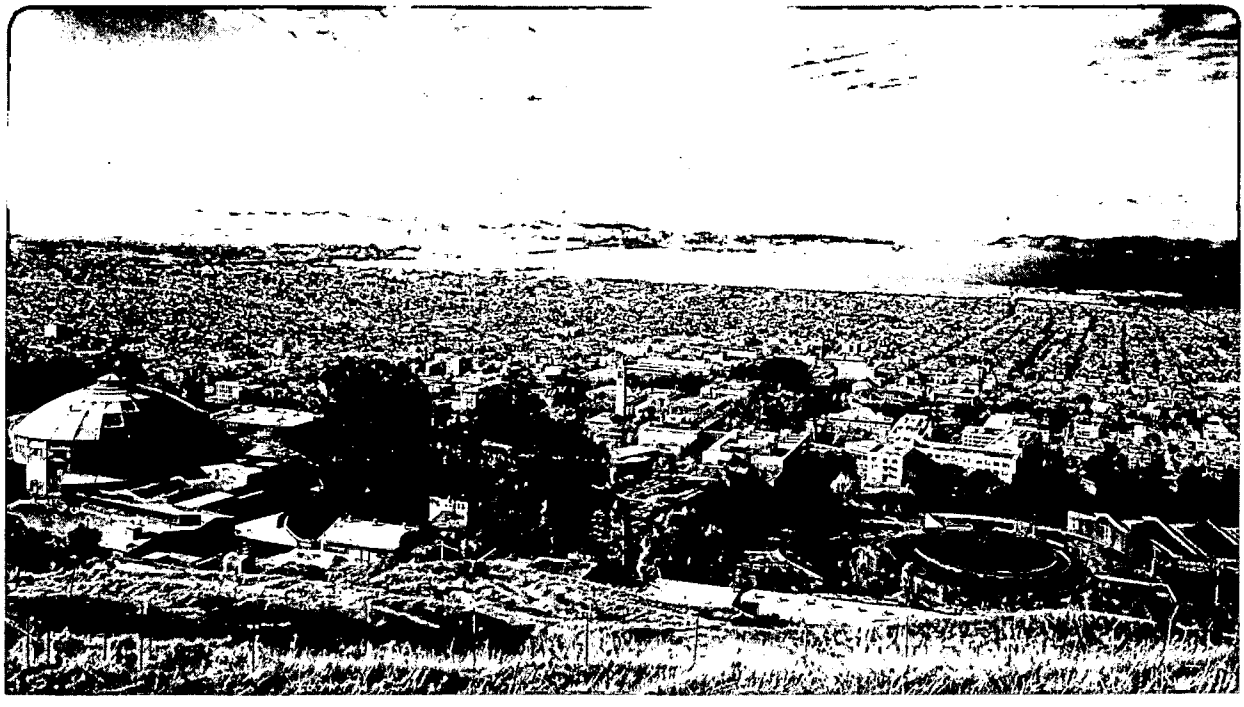
August 1989



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DISCLAIMER

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The Ahuachapán Geothermal Field, El Salvador
— Reservoir Analysis —

Volume II: Appendices A through E

by

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August 1989

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APPENDIX A

(Mineralogy Contours)

KEY

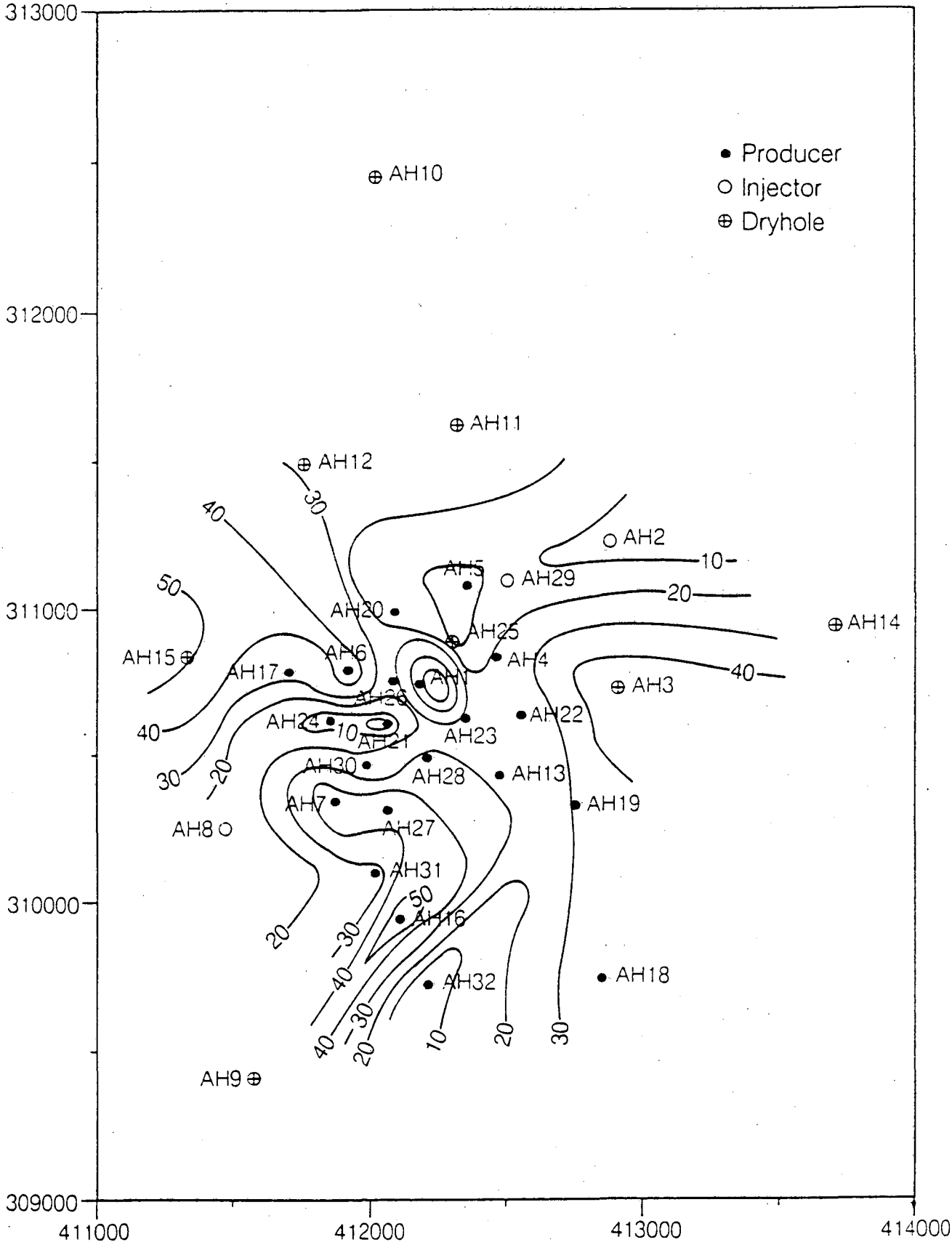
MA-SE : Clay minerals and Sericite

HE-OX : Hematite and Oxides

CL-PE : Chlorite and Pennantite

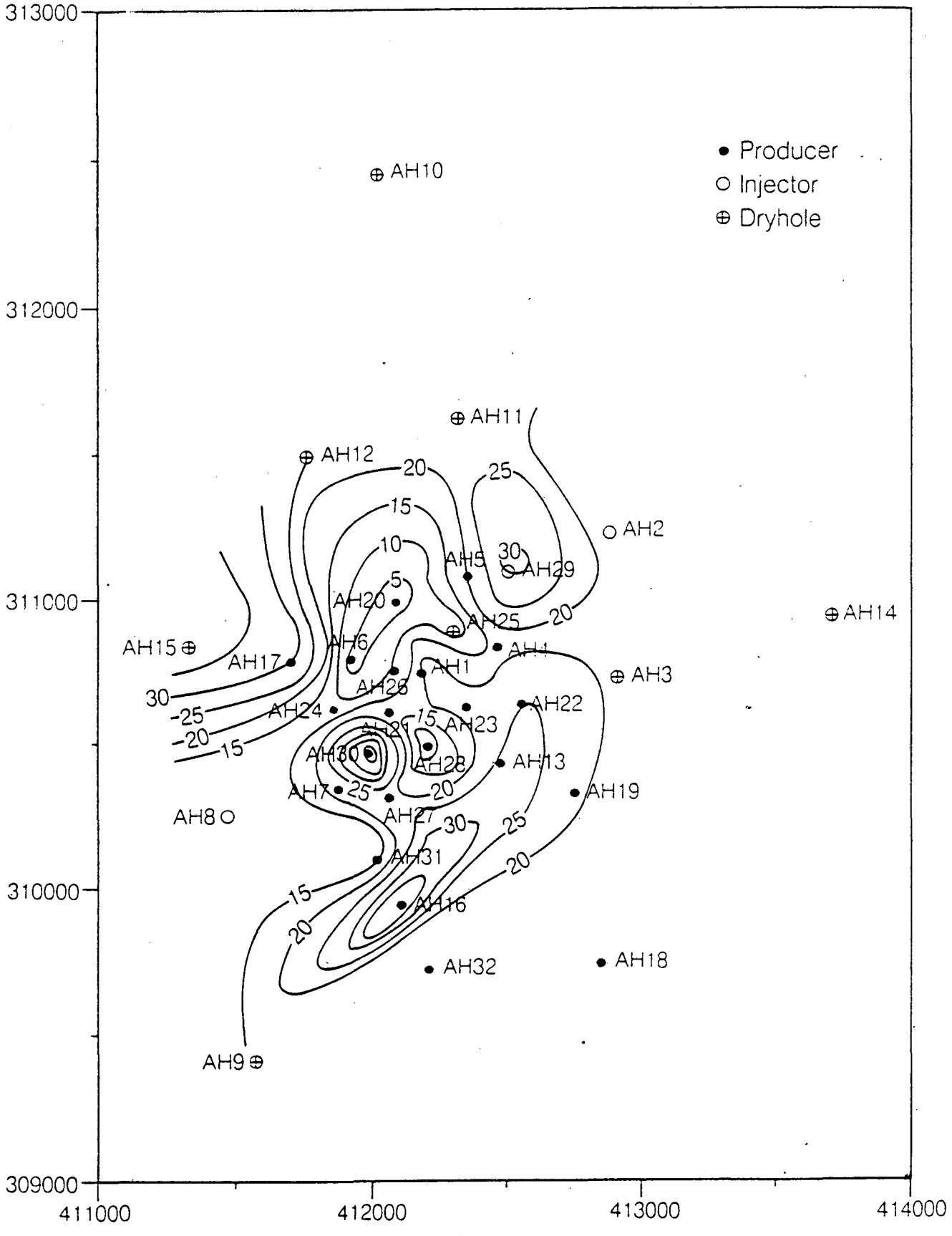
Q : Quartz

Ca : Calcite



Contour of MA–SE 600 masl

XBL 886-10300



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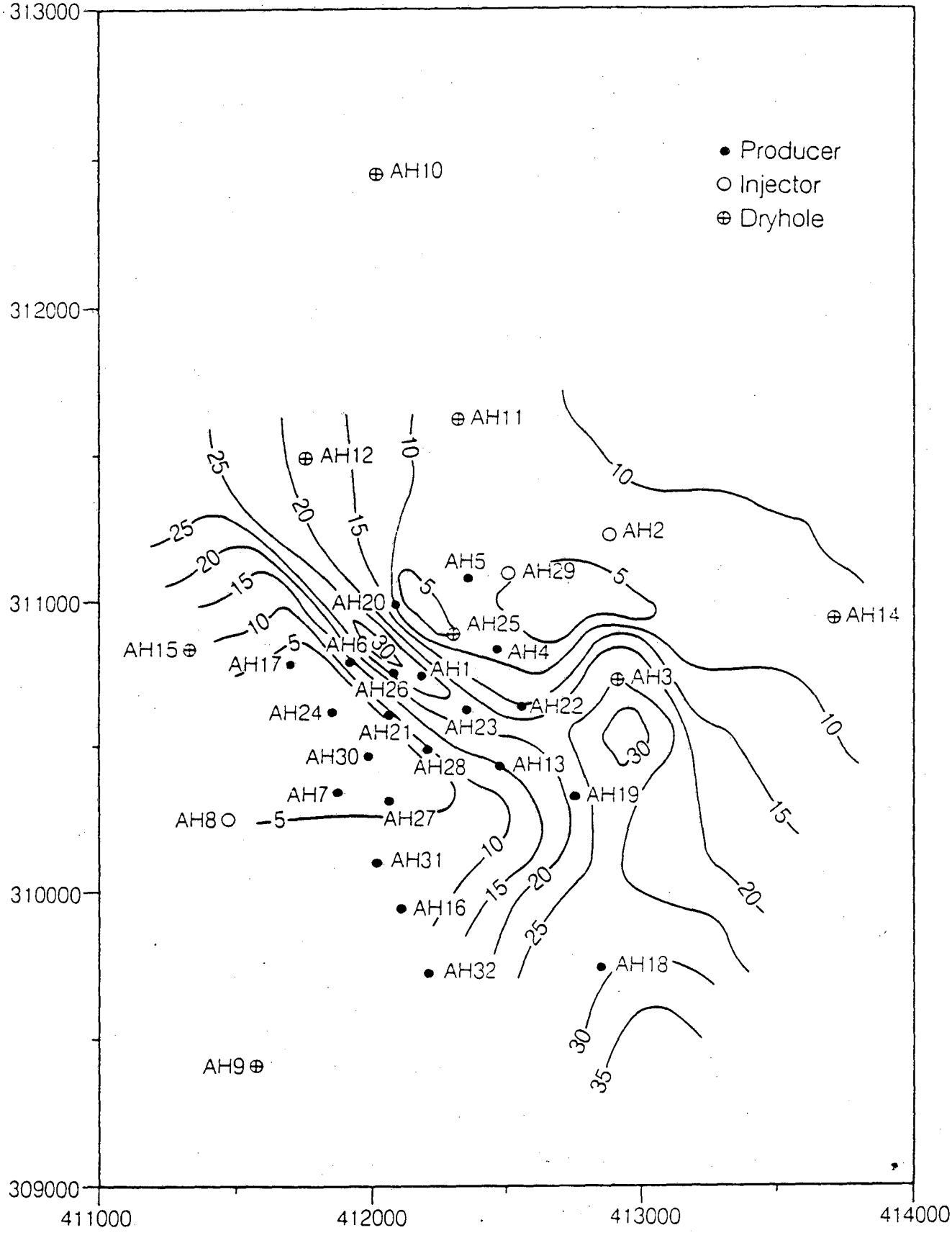
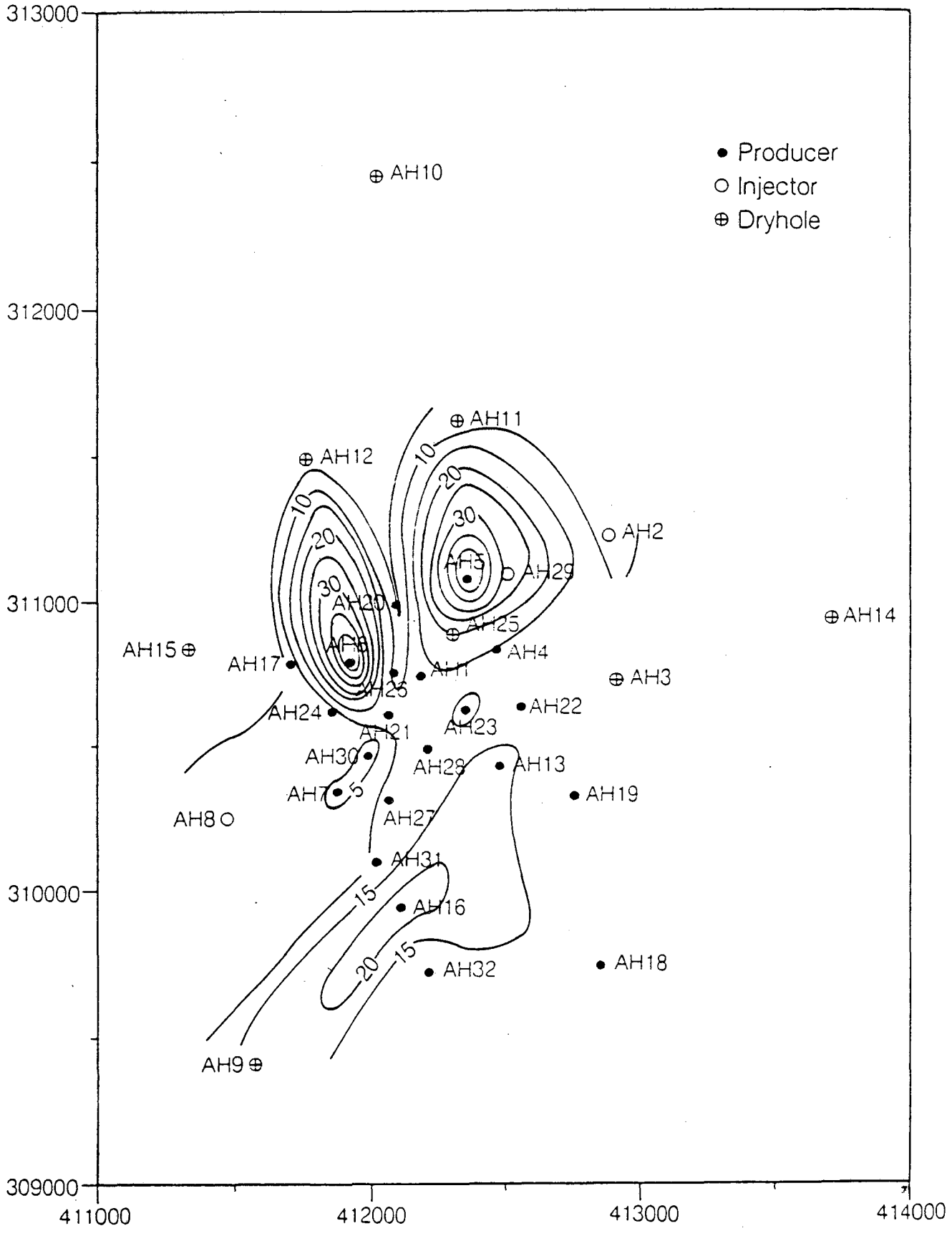


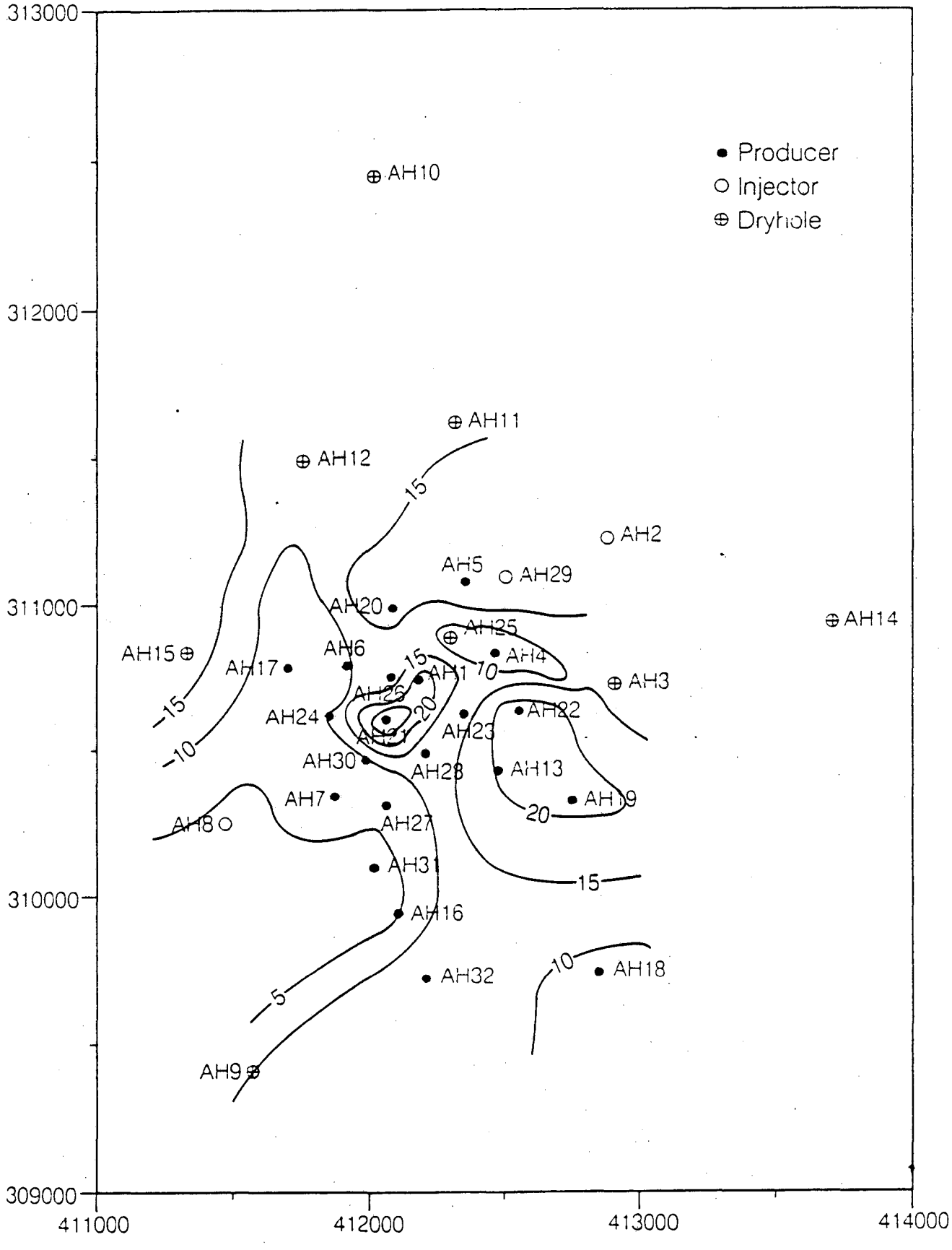
Contour of MA–SE 200 masl

XBL 886-10302



Contour of HE-OX 600 masl

XBL 886-10301



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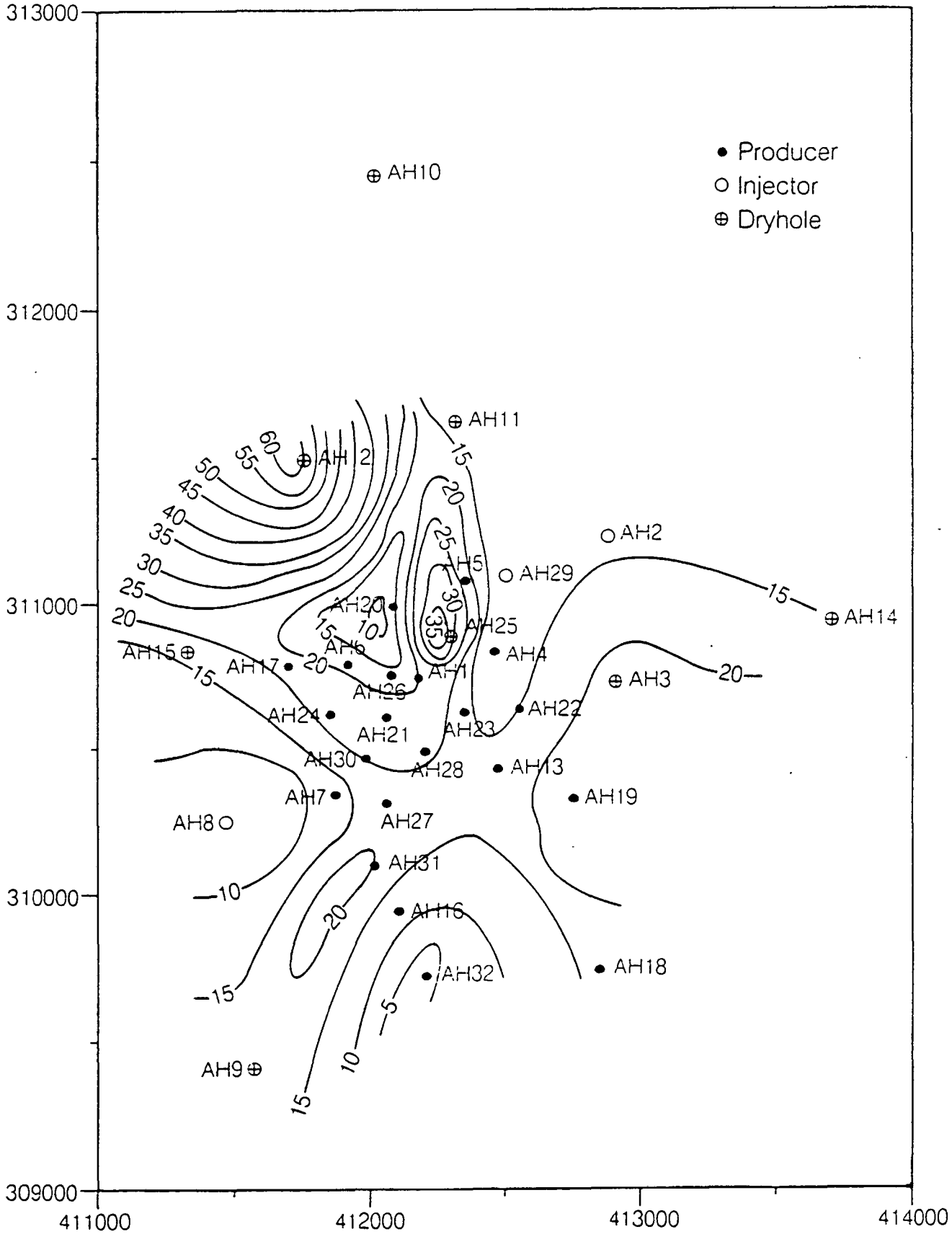

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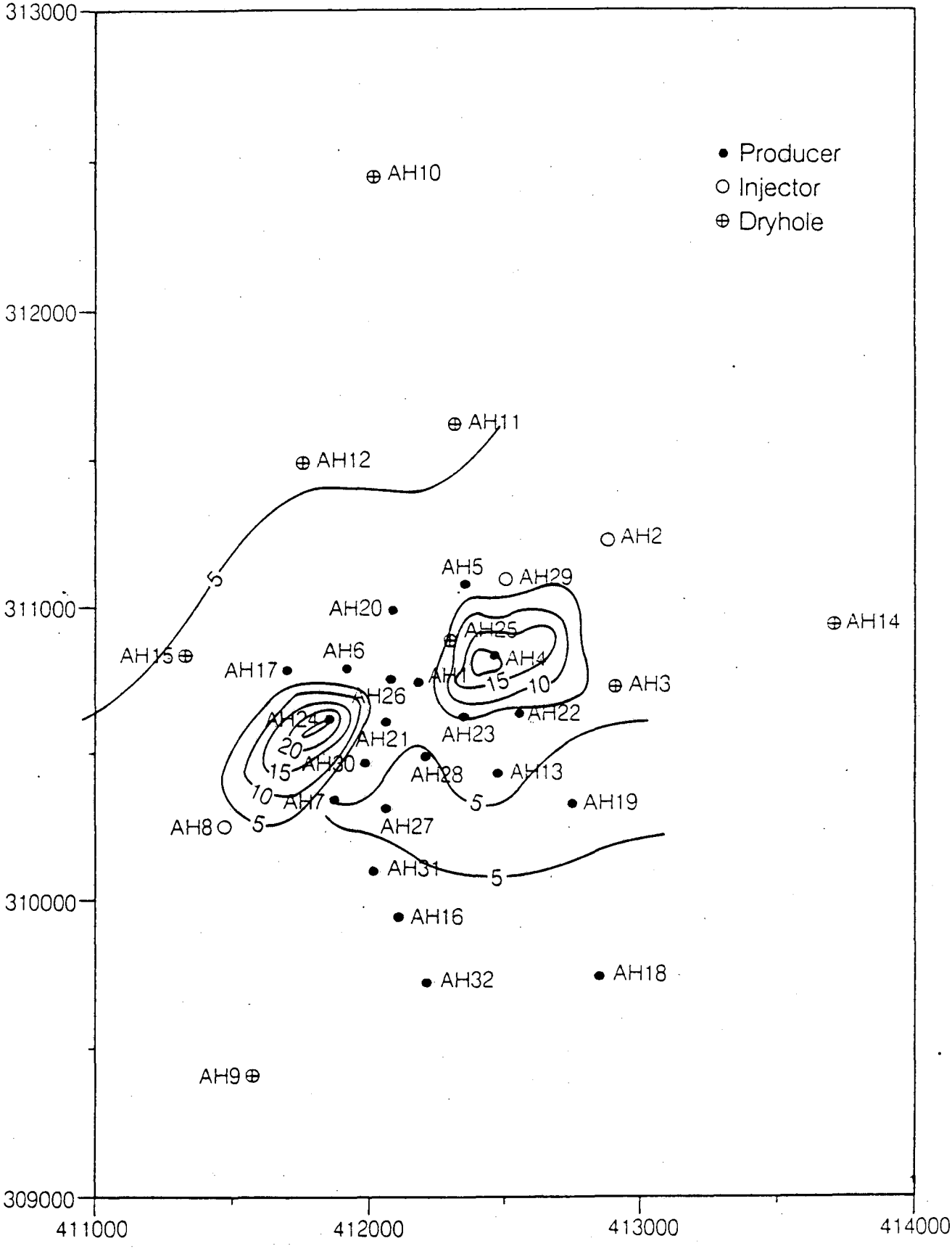
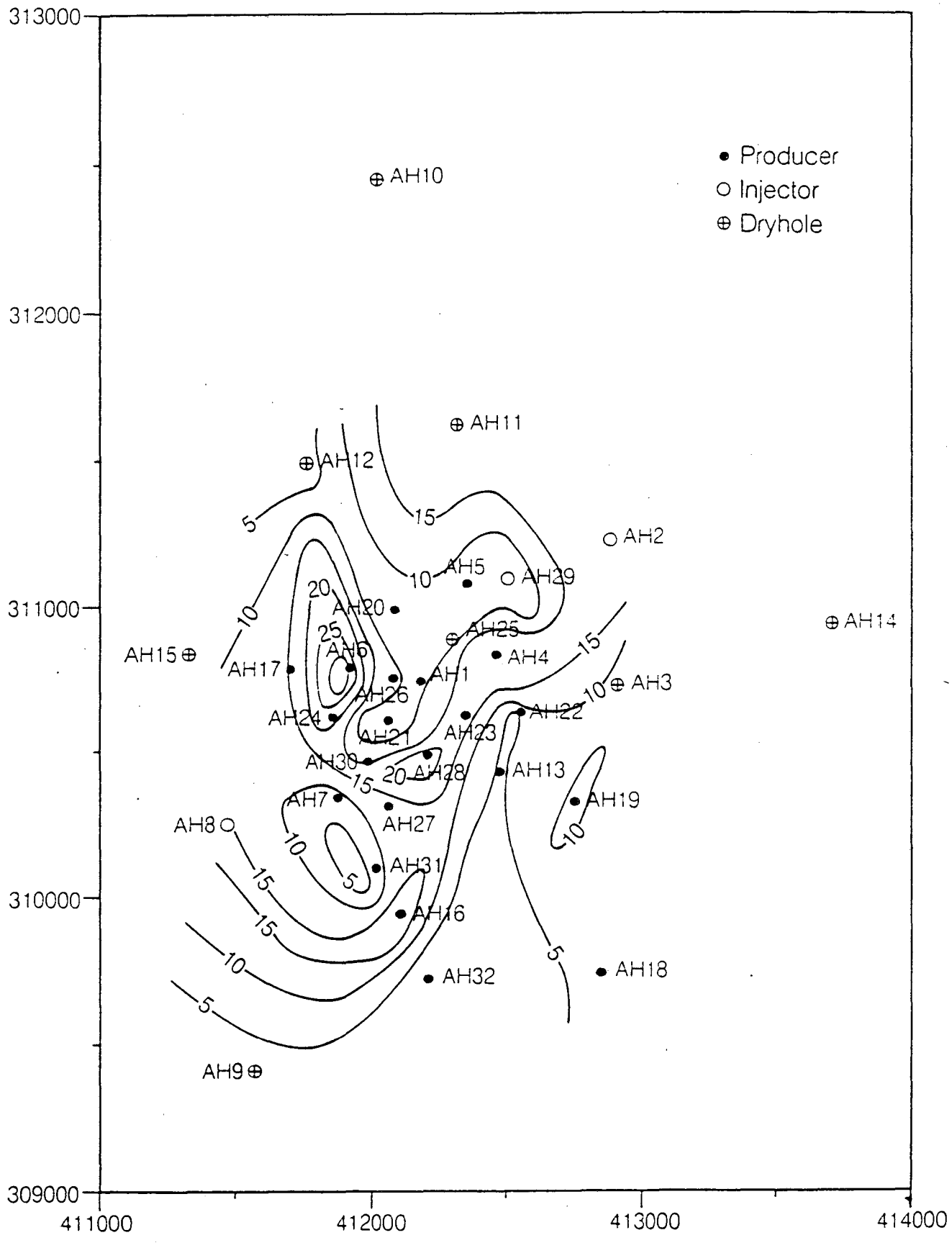


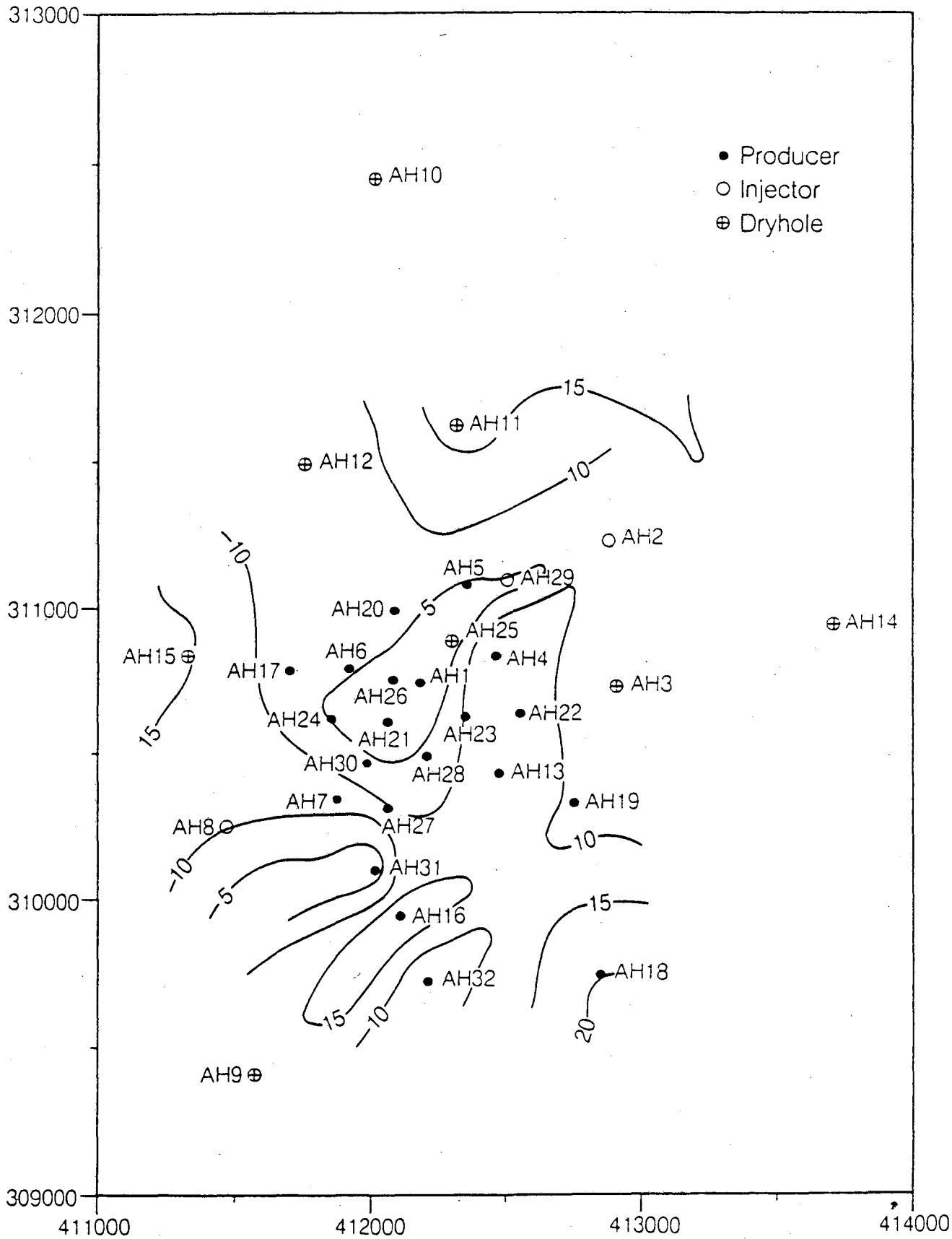
Contour of Cl–PE 600 masl

XBL 886-10291



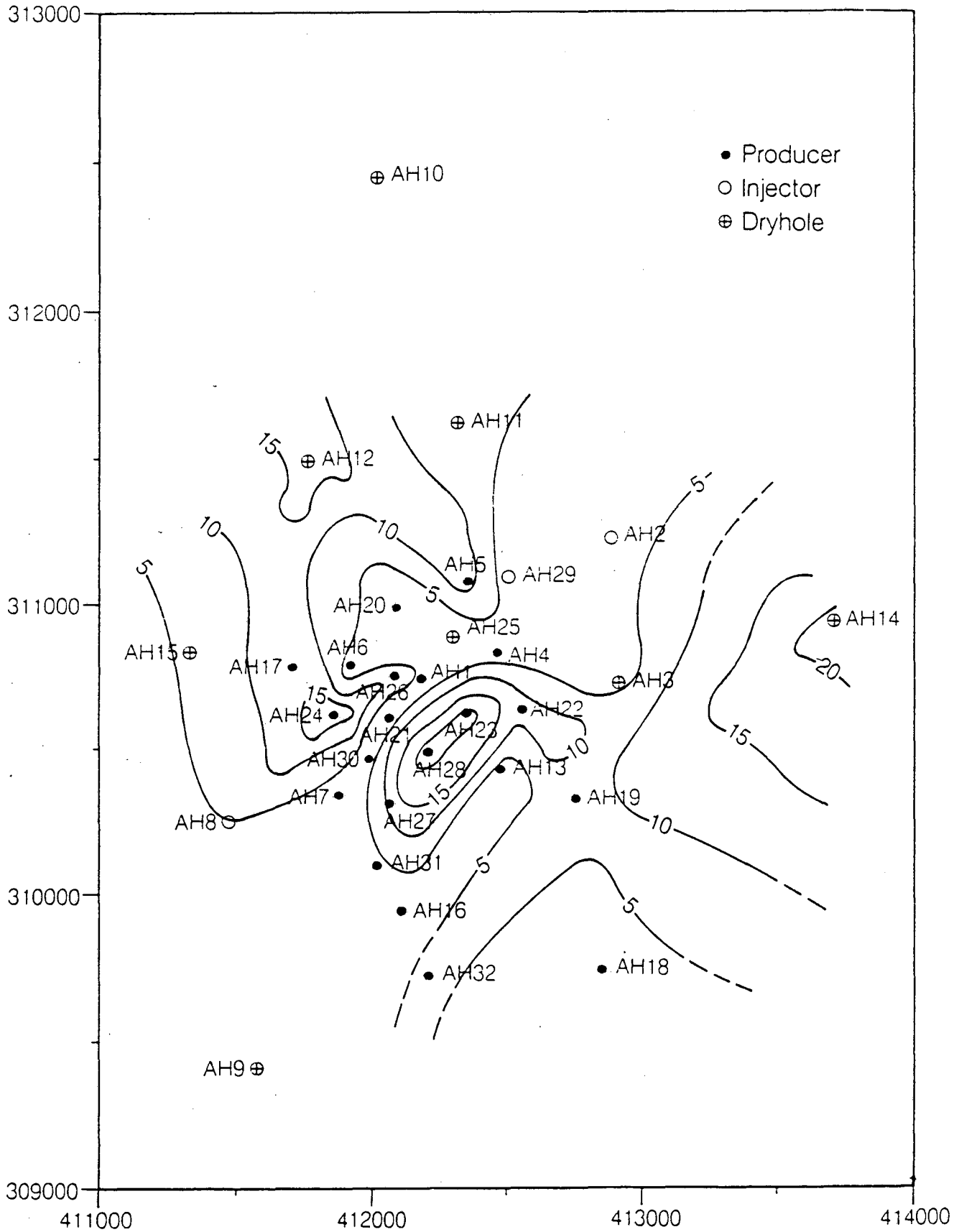
Contour of CL–PE 400 masl

XBL 886-10305



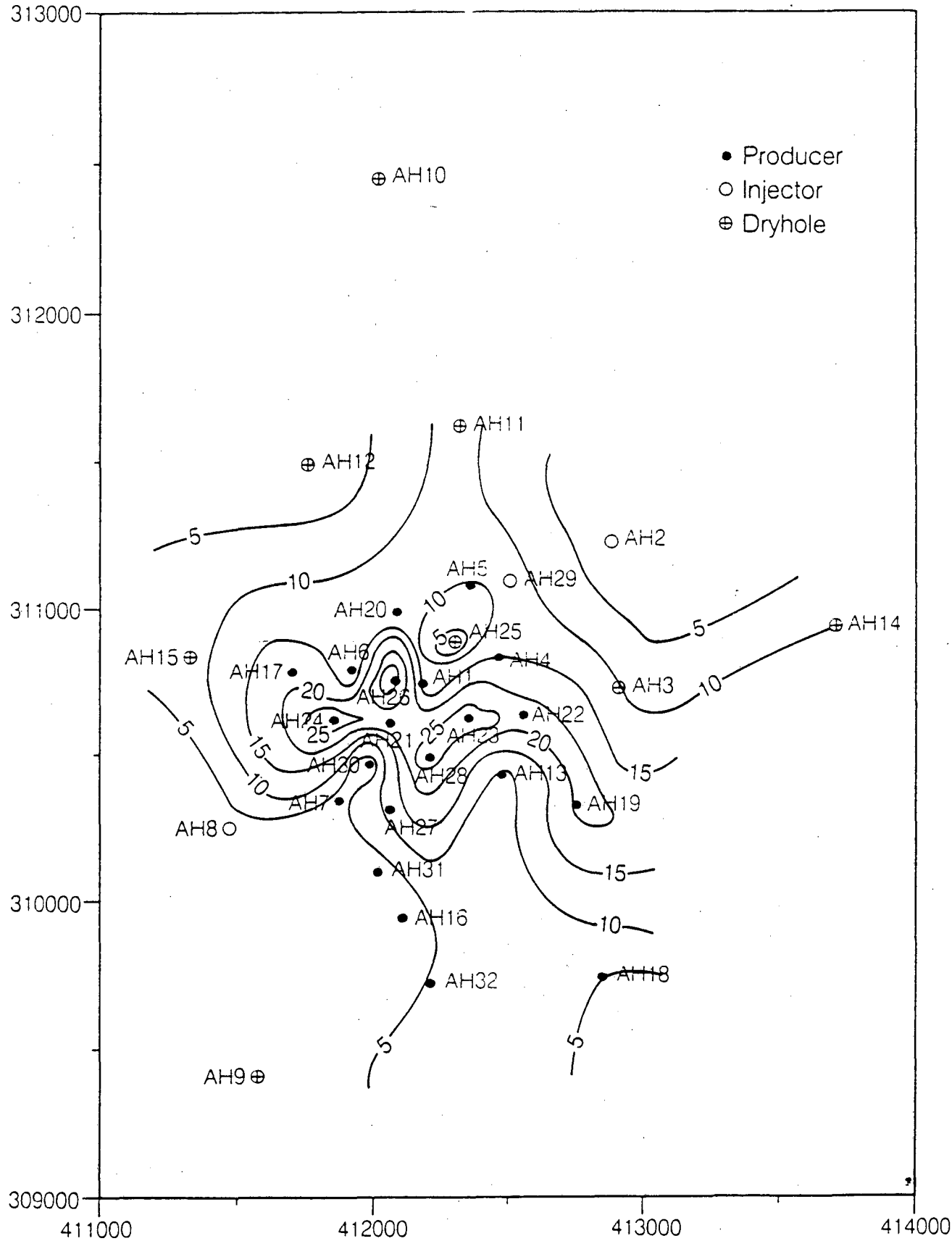
Contour of CL–PE 200 masl

XBL 886-10307



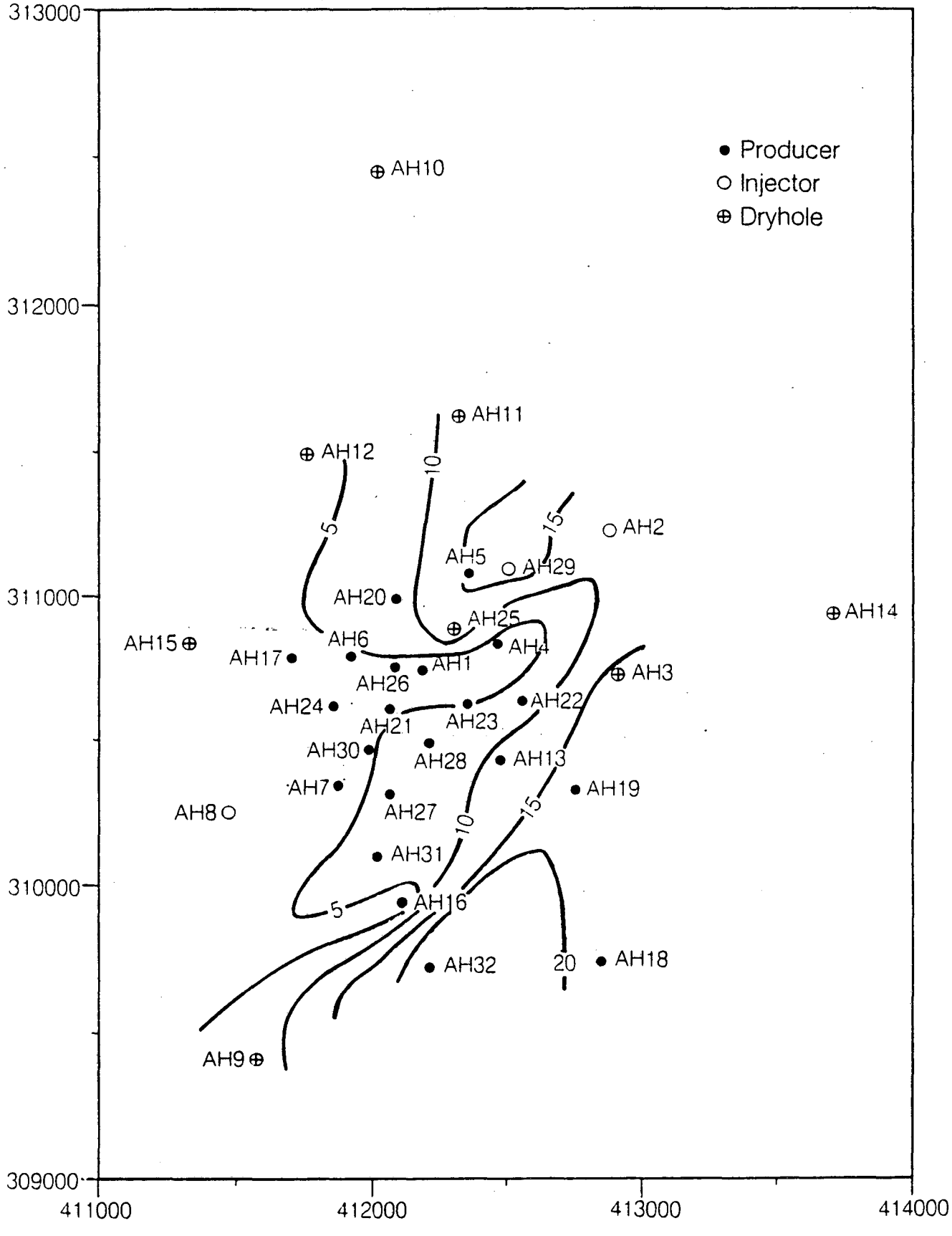
Contour of Q 600 masl

XBL 886-10309



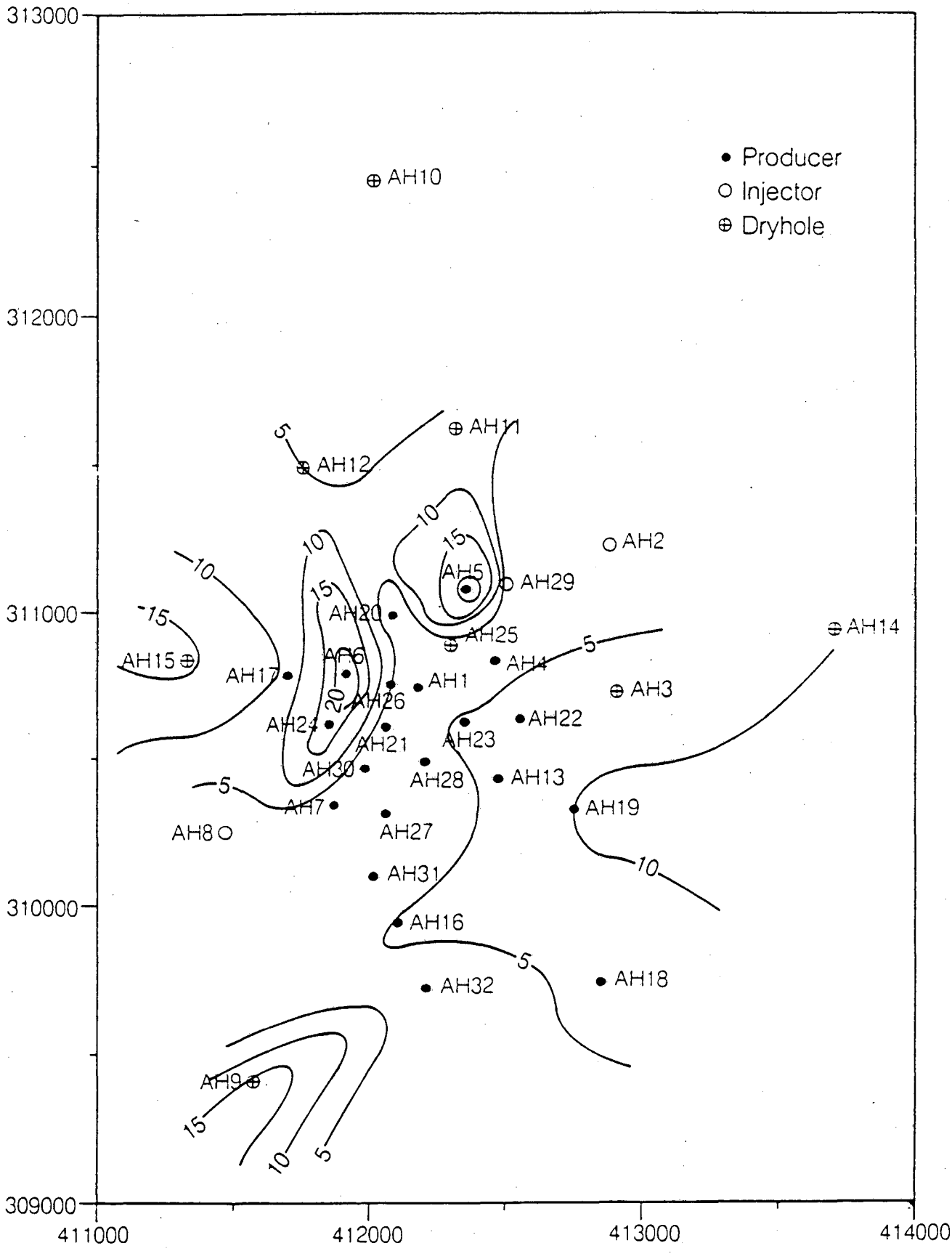
Contour of Q 400 masl

XBL 886-10312



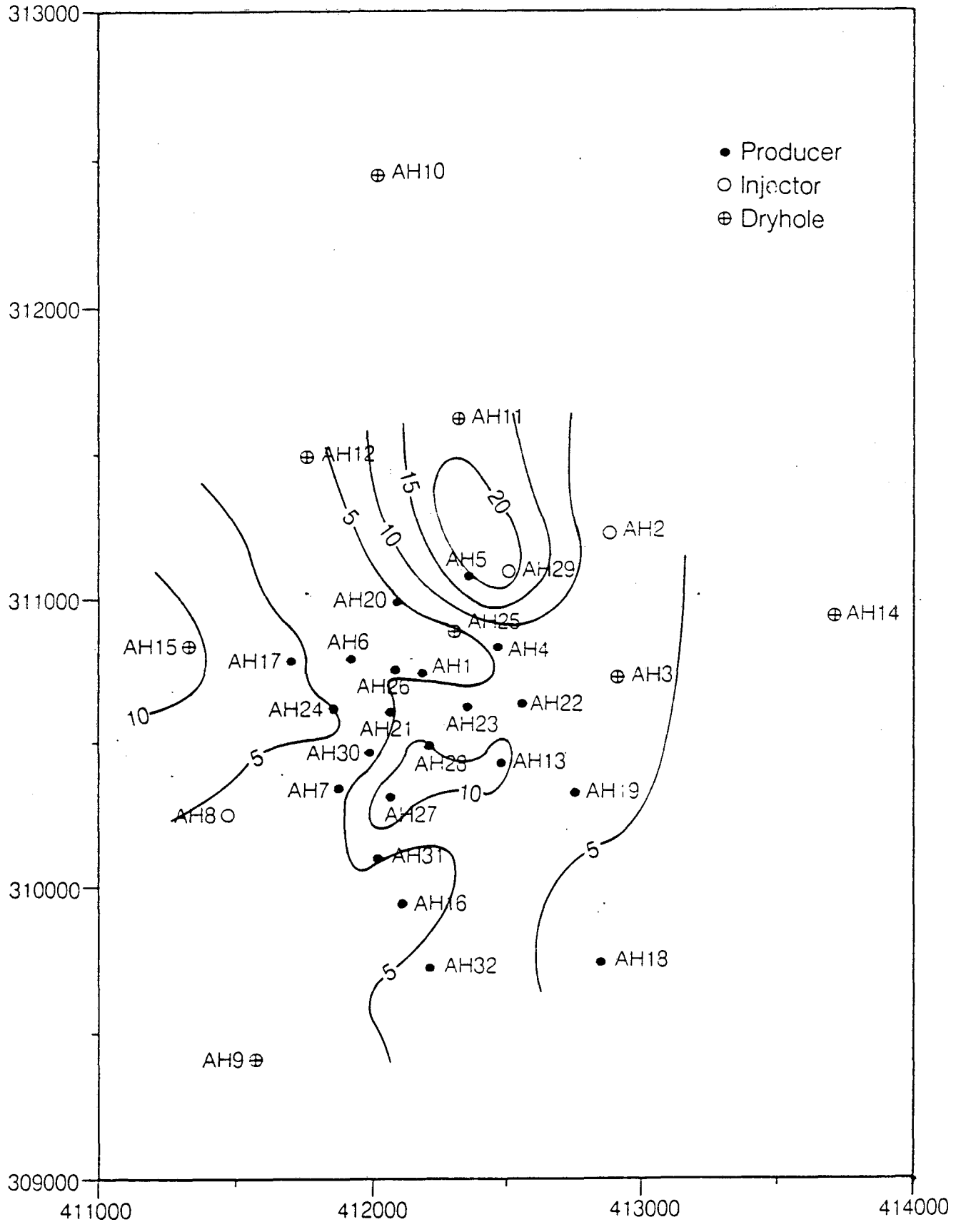
Contour of Q 200 masl

XBL 886-10313



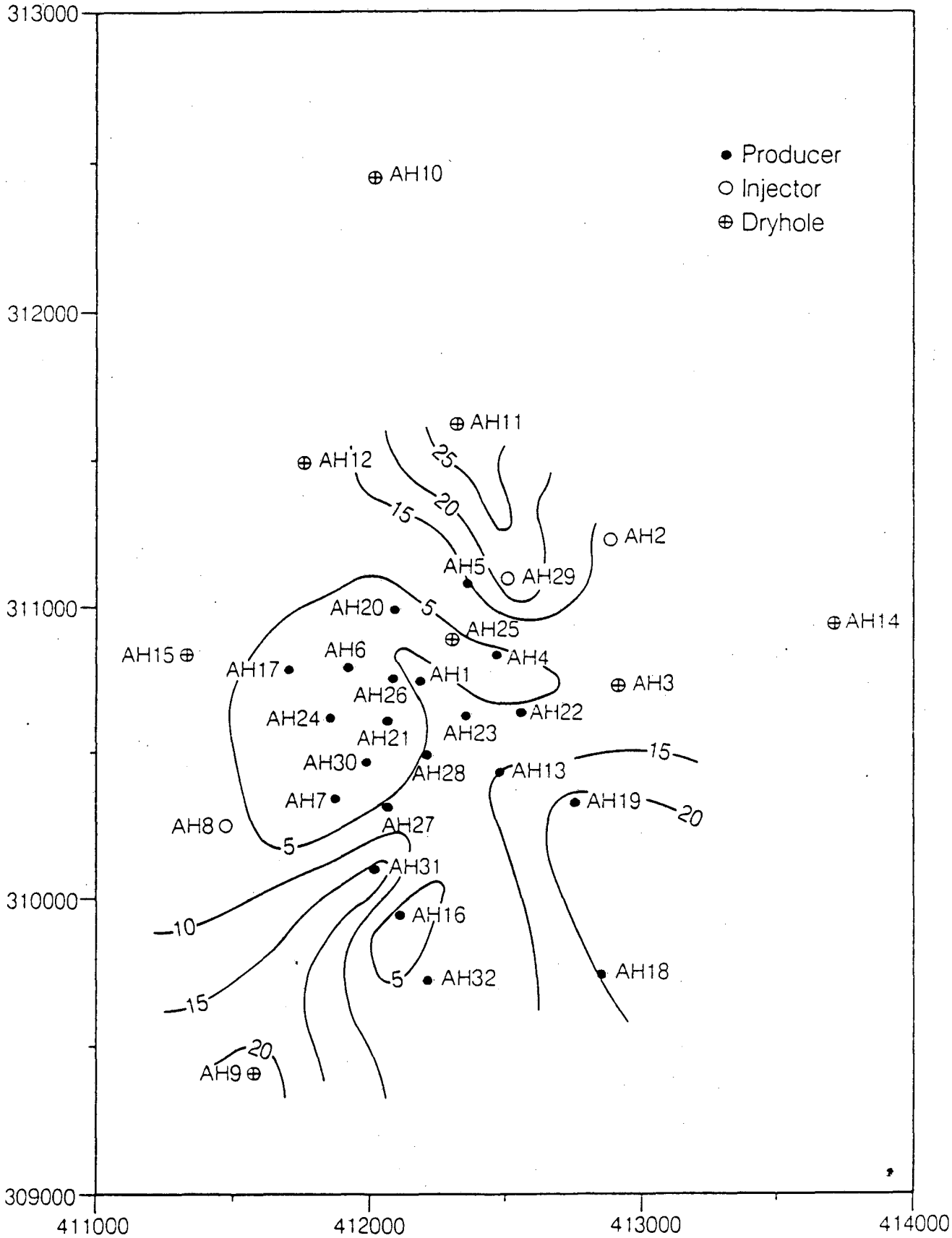
Contour of Ca 600 masl

XBL 886-10308



Contour of Ca 400 masl

XBL 886-10310

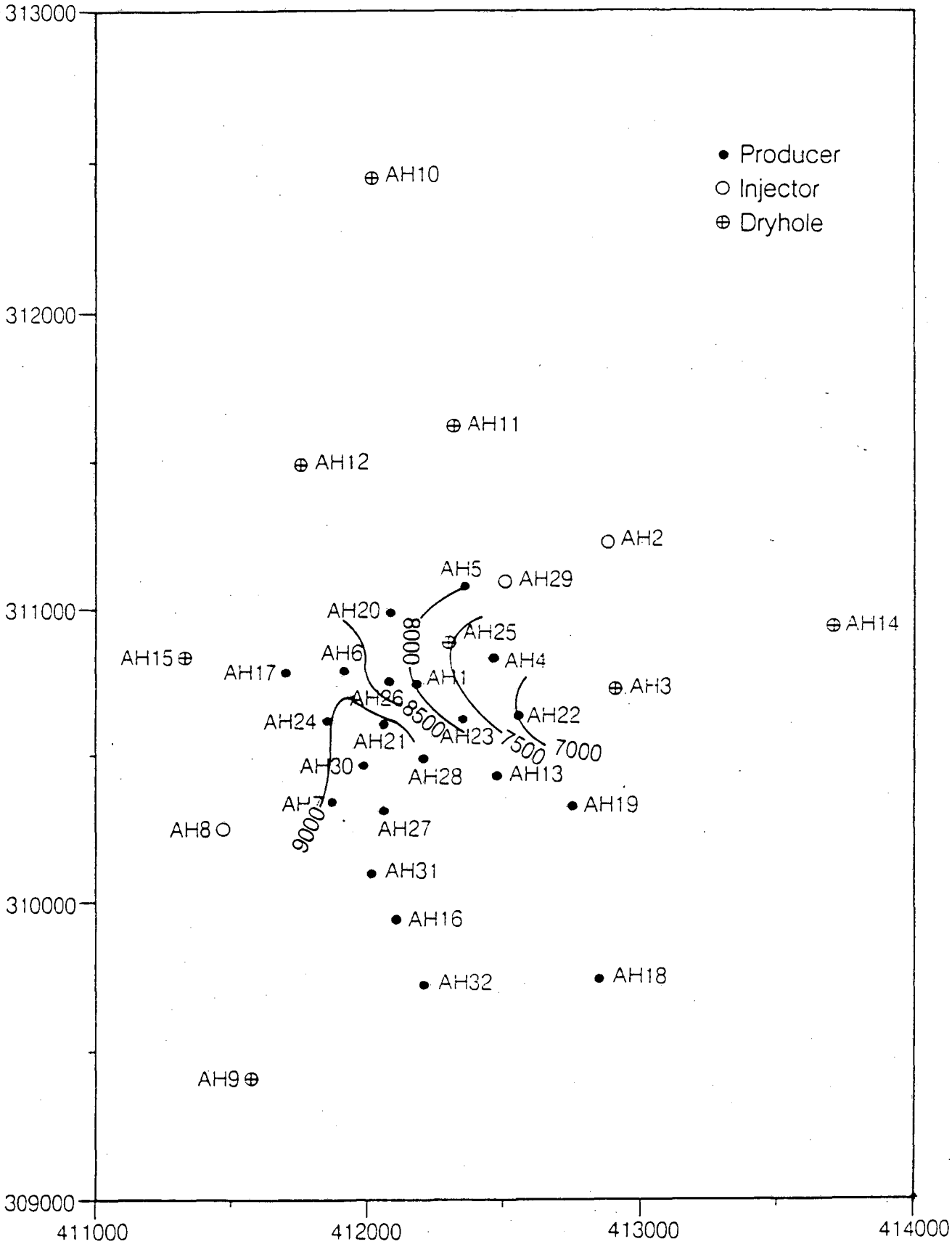


Contour of Ca 200 masl

XBL 886-10306

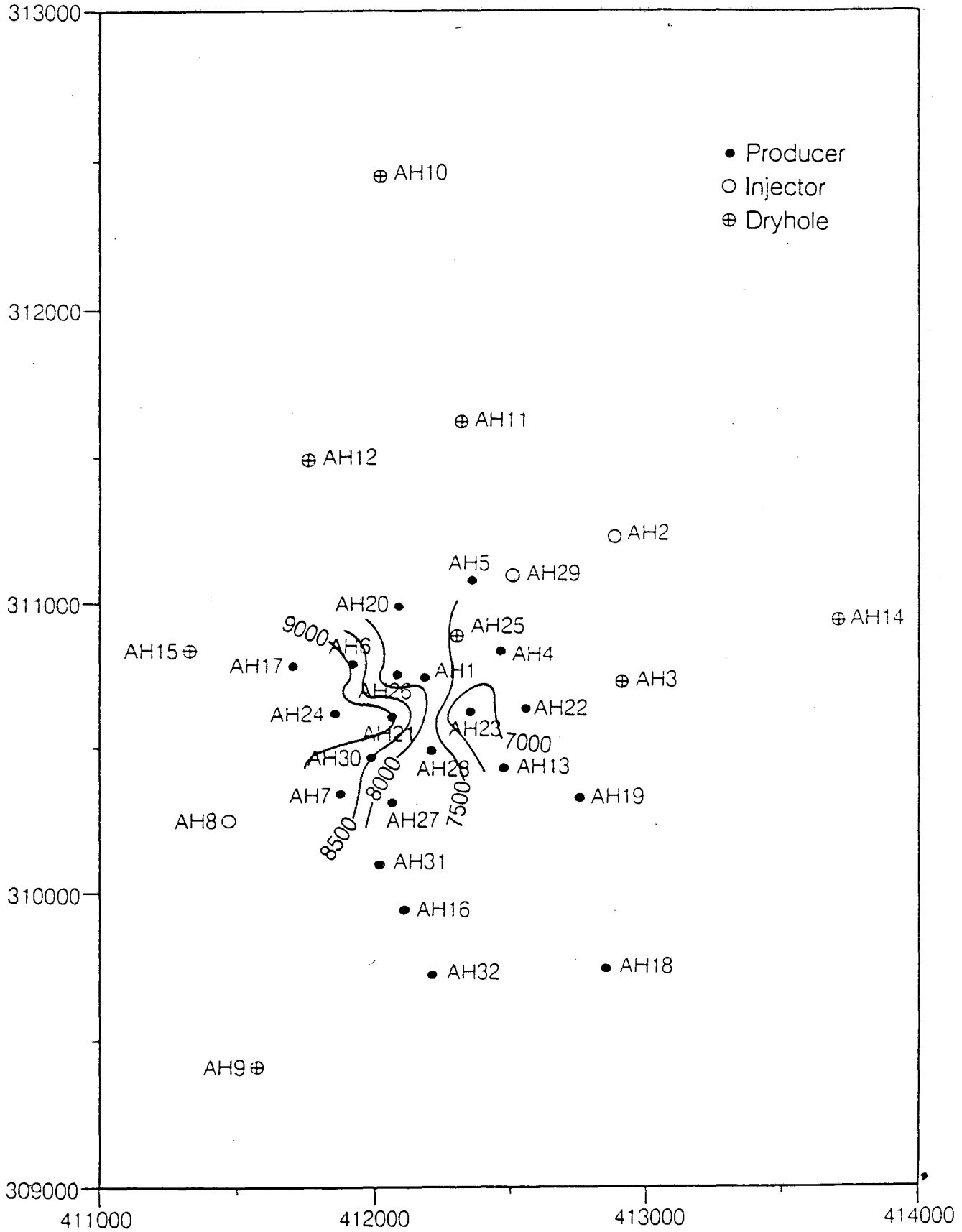
APPENDIX B

(Cl^- and SiO_2 Contours)



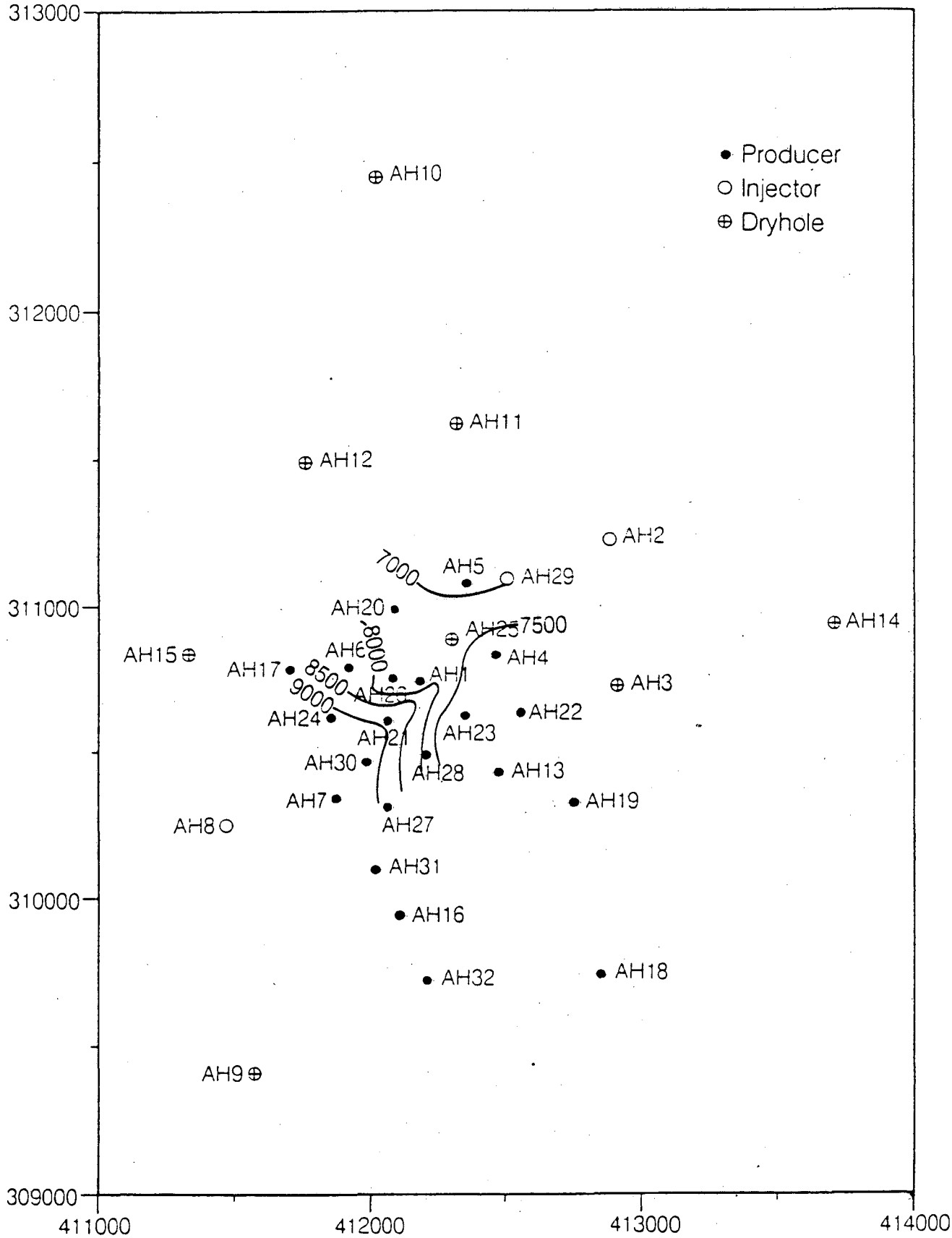
Contour of Cl^- (1978)

XBL 886-10295



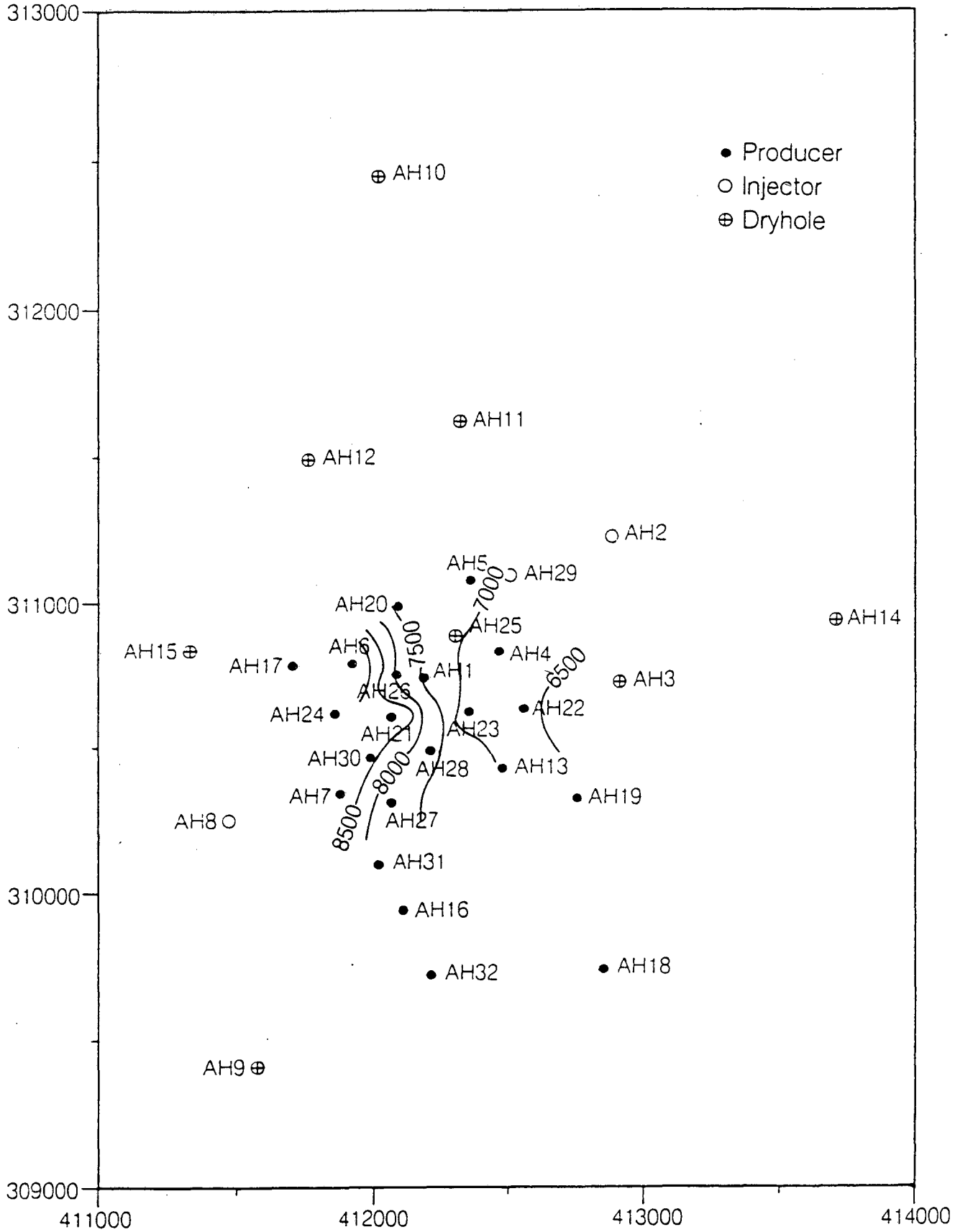
Contour of Cl^- (1980)

XBL 886-10294



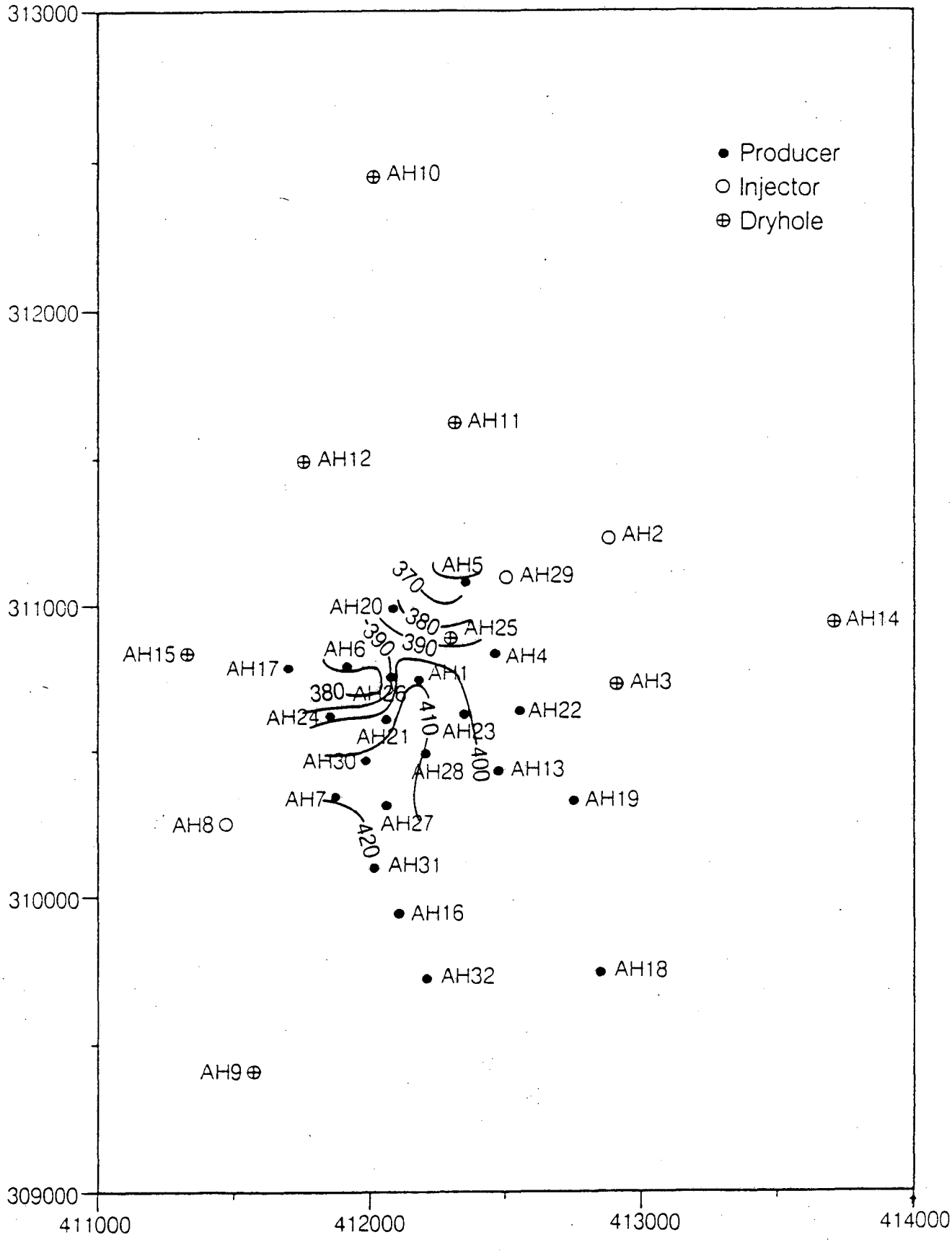
Contour of Cl^- (1982)

XBL 886-10293



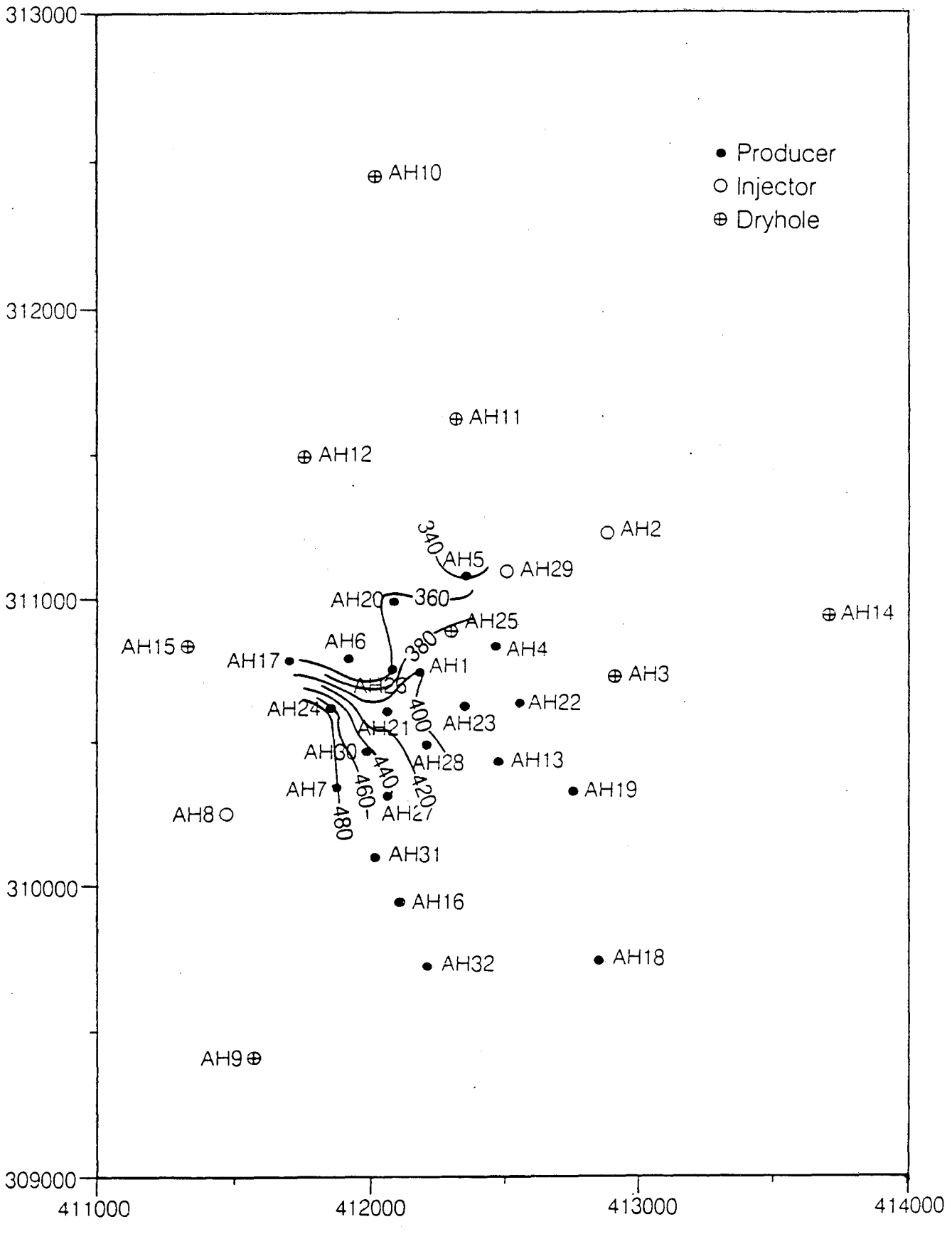
Contour of Cl^- (1984)

XBL 886-10292



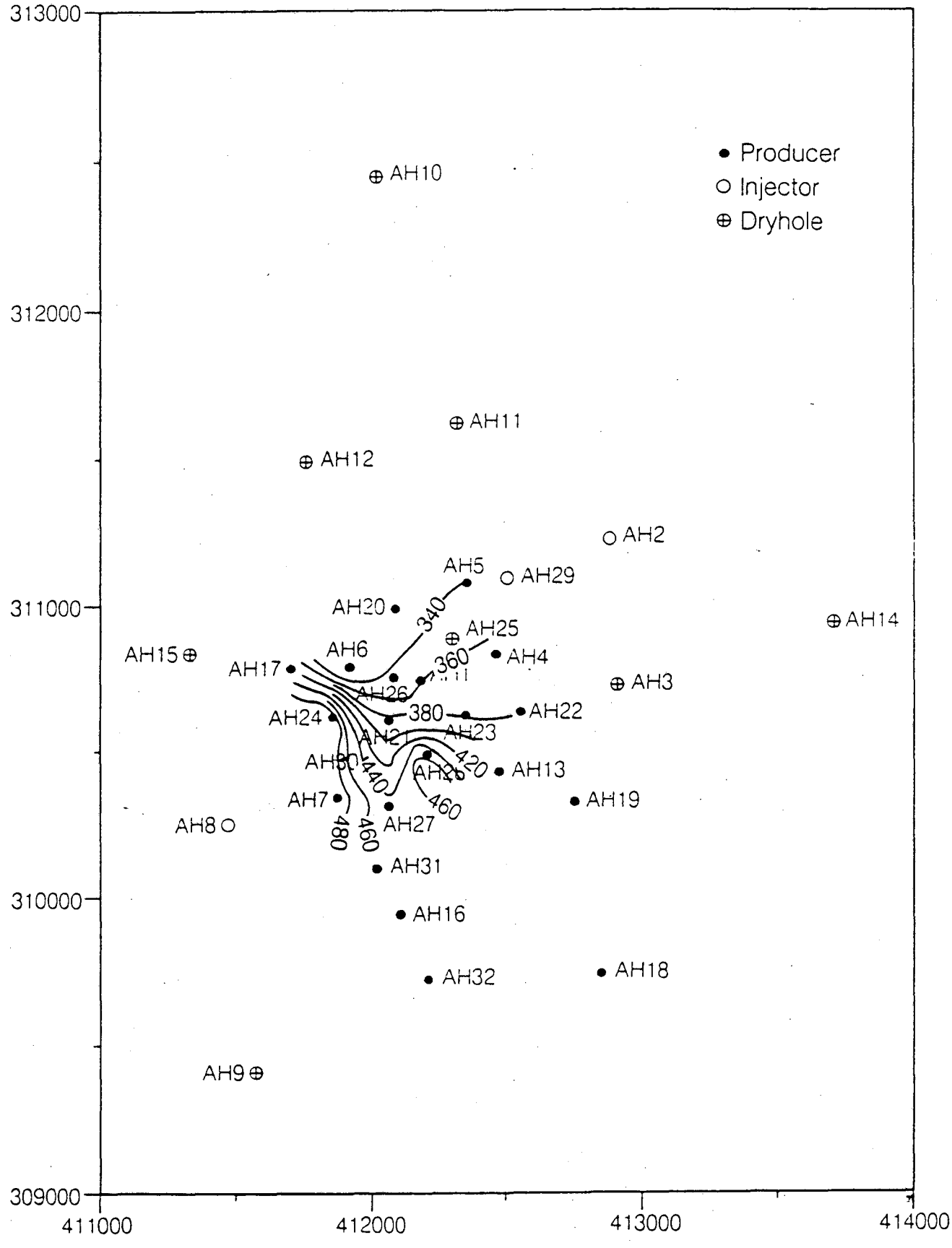
Contour of SiO_2 (1978)

XBL 886-10299



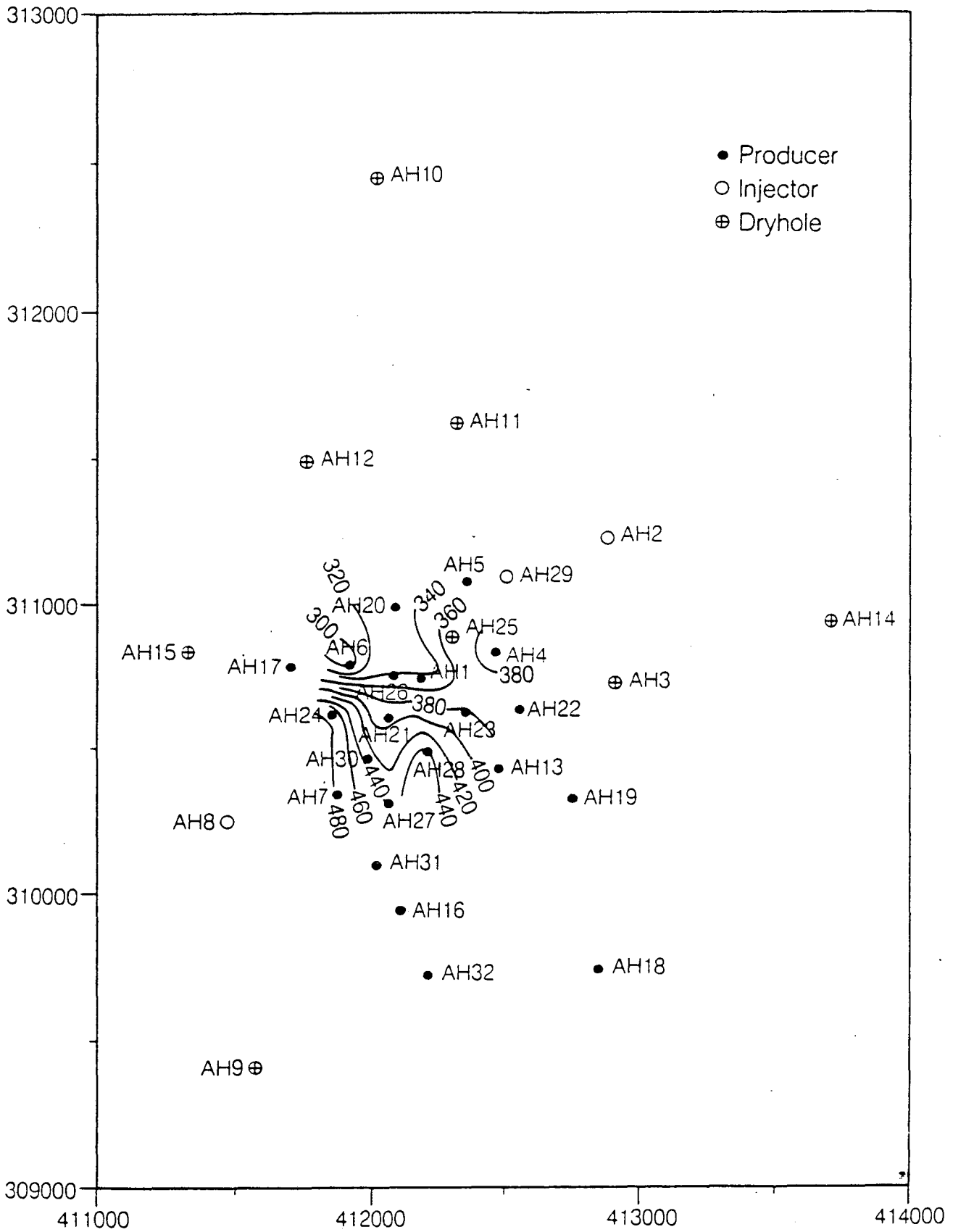
Contour of SiO_2 (1980)

XBL 886-10298



Contour of SiO_2 (1982)

XBL 886-10296



Contour of SiO_2 (1984)

XBL 886-10297

APPENDIX C

(Well Summaries)

WELL AH-1

PRODUCTION WELL

Coordinates:

Latitude : 310,740.74 m

Longitude: 412,185.10 m

Drilling Dates:

Started : April 30, 1968

Finished: June 4, 1968

Elevation: 802.79 m

Depth: 1195.12 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	35.02	$13\frac{3}{8}$"	23.21
$12\frac{1}{4}$"	488.90	$9\frac{5}{8}$"	486.46
$8\frac{3}{4}$"	1195.12		

No liner

Circulation losses:

Depth m	Type	Aquifer	Remarks
35			No cuttings at 20-75 m
550			No cuttings below 575 m

Relevant Information:

Pivot point can't be seen in the pressure logs.

Flowing pressure survey done in August 1979 with Q=65 kg/s shows the boiling level at 500-600 m depth. The log does not exclude a deep liquid inflow.

Flowing spinner survey with Q=60 kg/s shows that all the fluid enters the well above 552 m depth. (44% above 503, 12% between 503 and 512 m and finally 44% between 512 and 552 m depth). It should be noted though that the spinner signal disappears at the boiling level.

Two pairs of flowing temperature and pressure surveys done by Los Alamos in September 1987 at flowrates of 30 and 54 kg/s indicated feedzones at 750 and 775 m depth.

All available temperature run in the well showed full recovery after drilling. The location of the feed zones, therefore, does not show up in the logs. Maximum temperatures of 230- 239°C are found at 600-700 m depth in all the logs until 1979, with bottomhole temperature (BHT) around 225°C. Logs run after 1979 show no temperature inversion and decreasing temperatures (in time) at 500-800 m depth. In 1987 temperature of 215°C was measured at 700 m depth. BHT seems to have remained constant (within the measuring error) about 225°C.

Flowrates have decreased drastically but enthalpy has remained, more or less,

constant with most values around 1050 kJ/kg (250 kcal/kg). Other wells producing mainly from the shallow two phase zone have increased in enthalpy in the last ten years. This suggests that the main feed into AH-1 is actually deeper than what has been believed and within the liquid portion of the reservoir.

Aquifers:

Depth m	Aquifer	Contribution	Remarks
35	Ground water	Major	Cased-off
500	Reservoir	Major	Two phase
510	Reservoir	Minor	Two phase
550	Reservoir	Major	Two phase
750	Reservoir	Major	Liquid
775	Reservoir	Minor	Liquid

Geochemistry:

Data:

Chemical Data : 08/71-04/87 (complete from 10/73)

Physical Data : 01/75-12/84 (limited by enthalpy)

Initial Conditions:

255°C and 7700 ppm Cl.

Early analyses yielded Na-K-Ca temperatures near 260°C (1972-1976) and a few T_{SIL} values were near 250°C. Most silica and enthalpy temperatures were lower, near 240°C (1974-1976). This suggests that near-well temperatures were near 240°C, but at a distance from the well there were higher temperatures. Temperature logs suggest inflow at 240°C before 1979.

Chloride concentrations in the aquifer were constant from 1972 to 1981 at 7700±200 ppm. This might be somewhat in error if the assumed separator pressure of 6.5 kg/cm^2g used for samples without physical data (before 1/75) is incorrect.

Changes With Time:

After 1976, all indicated temperatures decreased. T_{NKC} decreased most rapidly from 1976 to 1980 and became nearly constant after 1980 at 240±6°C. T_E dropped more than T_{SIL}, especially after 1981. The order of these indices in 1985 was $T_{NKC}>T_{SIL}>T_E$, suggesting separate hot and cold entries but the similarity of T_E and T_{SIL} suggests that mixing also occurred in the reservoir. The 1985 temperatures were T_{NKC}=240°C, T_{SIL}=225°C and T_E=215°C. Temperature logs in 1987 suggest a 215°C feed at 700m and a bottomhole temperature of 225°C.

Aquifer chloride showed a positive perturbation between 1977 and 1979, but stayed at 7700±200 ppm. From 1981 to 1985, chloride dropped but apparently stabilized afterward at 6600±200 ppm. Chloride calculated from measured enthalpy are about 500 ppm higher than chloride calculated from T_{NKC}.

Summary:

The decrease in chloride and the large decrease in T_E started in 1981, suggesting that the cooler entry affected the actual temperature and chloride from that time. Earlier indicated temperature decreases in 1976 (T_{NKC} and some T_E values) are not reflected in the aquifer Cl.

WELL AH-2

INJECTION WELL

Coordinates:

Latitude : 311,228.86 m

Longitude: 412,885.54 m

Drilling Dates:

Started : June 14, 1973

Finished: September 6, 1973

Elevation: 808.00 m.

Depth: 1200.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	96	20"	94
$17\frac{1}{2}$"	700	$13\frac{3}{8}$"	686
$12\frac{1}{4}$"	1200		

No liner

Circulation Losses:

Depth m	Type	Aquifer	Remarks
20	Total		
75	Total		
325	Total		
700-800	Partial		
820-850	Total		

Relevant Information:

No cuttings below 900 m.

Early pressure surveys indicate a pivot point at 700 m depth.

Spinner survey shows 40% loss at 700 m depth, 40% loss at 900 m and the deepest loss between 950 and 1050 m depth.

The aquifer at 700 m depth is seen in temperature logs. The logs also show that the injected water cools the well down to the bottom (1200 m), indicating some fluid flow down to the bottom region. Before injection started the temperature profile showed maximum at 750 m depth 225°C. BHT (900 m) was less than 220°C. In 1987, several years after injection was stopped, the highest temperatures were found at 600 m depth, only 206°C. Temperature measured were 201°C at 750 m, 197°C at 900m and only 188°C at 1000m (present bottom).

Aquifers:

Depth m	Aquifer	Contribution	Remarks
20	Ground water	Major	Cased-off
75	Ground water	Major	Cased-off
325	Saturated zone	Major	Cased-off
700	Reservoir	Major	Liquid
900	Reservoir	Major	Liquid
1000	Reservoir	Minor	Liquid
1200	Reservoir	Minor	Liquid

Geochemistry:

No data.

WELL AH-3

COLLAPSED DURING DRILLING AT 414 m.

Coordinates:

Latitude : 310,726.43 m

Longitude: 412,915.81 m

Drilling Dates:

Started : March 3, 1973

Finished: June 1, 1973

Work-over:

Started : January 17, 1974

Finished: January 28, 1974

Purpose : To remove blockage and place a liner

Elevation: 855.5 m

Depth: 802.20 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	105	20"	80
$17\frac{1}{2}$"	475	$13\frac{3}{8}$"	472
$12\frac{1}{4}$"	802.2	$9\frac{5}{8}$"	334-696

Liner slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
10	Partial	Ground water	Cased-off
55	Partial	Ground water	Cased-off
115	Partial	Ground water	Cased-off
155	Total	Saturated zone	Cased-off
330	Total	Saturated zone	Cased-off
585	Total	Reservoir	Major feed
750	Total	Reservoir	Major feed

Relevant Information:

The well collapsed during or shortly after drilling at 413 m depth. Only one temperature and a few pressure logs were available up to this depth. Water level is close to 280 m depth and the temperature was 84°C at the water table and 118°C at 413 m depth.

Aquifers:

The only available information on the location of the aquifers is the list of circulation losses.

Geochemistry:

No data

WELL AH-4

PRODUCTION WELL

Coordinates:

Latitude : 310,835.13 m

Longitude: 412,470.45 m

Drilling Dates:

Started : June 1, 1972

Finished: August 4, 1972

Work-over:

Started : October 23, 1982

Finished: November 25, 1982

Purpose : To remove blockage

Elevation: 812.23 m

Depth: 788.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	52	20"	50
$17\frac{1}{2}$"	485	$13\frac{3}{8}$"	481.55
$12\frac{1}{4}$"	514	$9\frac{5}{8}$"	509.65
$8\frac{1}{2}$"	788	$7\frac{5}{8}$"	472.43-788

Liner slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
50	Total	Ground water	Cased-off
170	?	Saturated zone	Cased-off
350	?	Saturated zone	Cased-off
485	Partial	Reservoir	
540	Total	Reservoir	

Relevant Information:

No cuttings below 540 m depth.

All logging runs before 1982 reached only to 540 m depth. These logs were run when the well had fully recovered after drilling and aquifers did not show up in the logs. The well produced fluids of high enthalpy with increasing enthalpy from 1200 kJ/kg in 1975 to more than 1800 kJ/kg in 1982. This indicates that the main production came from the two phase zone of the reservoir.

In 1982 a work-over was done on the well, after which the well had been open to 780 m depth. The work-over totally changed the characteristics of the well. Productivity decreased more than 50 % and enthalpy decreased to less than 1000 kJ/kg such that its enthalpy corresponds now to the liquid temperatures in the reservoir. What really happened during the work-over is not clear to us. But it seems that the feed zones in the two phase zone are now sealed and the well produces from a deeper liquid feed. The location of that feed can't be seen from the data we have received.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
50	Ground water	Major	Cased-off
170	Saturated zone	Minor	Cased-off
350	Saturated zone	Minor	Cased-off
485	Reservoir	Minor	Two phase (plugged?)
540	Reservoir	Major	Two phase (plugged?)
700	Reservoir	Major	Liquid

Geochemistry:

Data:

Chemical Data : 09/74-08/85

Physical Data : 01/75-12/84

Initial Conditions:

240°C and 7200 ppm Cl.

Scattered 1975 and all 1976 data indicate very constant Na-K-Ca temperatures of 240±3°C. Silica temperatures are also constant at 235±3°C. T_E values are 20°C higher than T_{NKC}, possibly suggesting boiling and heat transfer from rocks. The initial temperature is probably 240°C.

Aquifer chloride is also constant from mid-1977 to 1981 at 7200±100 ppm. Earlier Cl values are lower except for a few values in late 1976. The low Cl values are considered an artifact. The initial value is probably 7200 ppm.

Changes With Time:

After early 1980, T_E, which had been about constant at 260±10°C, suddenly increased to about 370°C in mid-1981 and started to decrease in 1982. Lack of data interrupted our view of this decrease, but T_E values were 240°C or lower by 1985-86. The increase in enthalpy is mainly due to near-well boiling and heat transfer from rock (the temperature order $T_E >> T_{NKC} > T_{SIL}$ indicates this) but there may also be addition of steam formed elsewhere (the differences between T_{NKC} and T_{SIL} are small). The small differences between indicated temperatures before 1980 suggest an equilibrated liquid with a small steam feed.

Chloride was constant at 7200±100 ppm until mid-1980, then climbed a small amount and after mid-1981 decreased to 6500 ppm in 1985. The climb in Cl was simultaneous with the increase in enthalpy, indicating heat transfer from rock.

Summary:

The large increase in T_E without much difference between T_{NKC} and T_{SIL} suggests entry of steam formed elsewhere. This possibly resulted from the formation of a steam cap when pressures dropped due to the stopping of injection. The simultaneous increase then small decrease in chloride suggests boiling followed by limited cold-water entry also from pressure decrease.

WELL AH-5

PRODUCTION WELL

Coordinates:

Latitude : 311,081.09 m

Longitude: 412,357.66 m

Drilling Dates:

Started : June 6, 1970

Finished: June 30, 1970

Work-over:

Started : October 8, 1972

Finished: October 20, 1972

Purpose : To remove slotted liner

Elevation: 789.45 m

Depth: 957.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	104.6	$13\frac{3}{8}$"	98.19
$12\frac{1}{2}$"	468.8	$9\frac{5}{8}$"	456.93
$8\frac{3}{4}$"	957		

No liner

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
50	?	Ground water	Cased-off
325	?	Saturated zone	Cased-off
565	?	Reservoir	
585	?	Reservoir	

Relevant Information:

No cuttings between 320-468 m and below 585 m depth.

Temperature logs show an internal flow in the well during recovery after drilling. Aquifers are seen at bottom (920 m), 720 m, 590 m and 515 m depths. The discharge enthalpy of the well has remained around 1000 kJ/kg indicating that the main feed zone might be in the liquid portion of the reservoir. Pressure logs from 1970 show scattering values, but in at least three logs, a pivot point is seen at around 700 m depth.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
50	Ground water	?	Cased-off
325	Saturated zone	Major	Cased-off
515	Reservoir	Minor	Two phase
590	Reservoir	Minor (?)	Two phase
720	Reservoir	Major	Liquid
920	Reservoir	Minor	Liquid

Geochemistry:

Data:

Chemical Data : 02/73-05/80 (plus few 1972 and 1987 analyses)

Physical Data : 04/75-05/80

Initial Conditions:

248°C and 8100 ppm Cl.

Changes in chemical temperatures occurred from the start of production. The earliest T_{NKC} are about 248°C and later data, despite scatter, extrapolates to near this value. Much earlier data on Cl are quite variable, but 1973 and 1978-1980 data are reasonably constant at 8100±100 ppm.

Changes With Time:

We have no enthalpy before 1975 and the pre-1975 T_{NKC} and T_{SIL} values are highly variable. After 1975, all temperatures decrease rapidly with $T_{NKC}>T_{SIL}>T_E$, indicating cold fluid entry. Based on T_E, the fluid temperature was as low as 210-215°C in 1979-1980. The single 1987 measurement suggest a small heating up or at least no further cooling. The sharp drop in Cl in 1974 and recovery in 1978 suggest a break in the casing with entry of cold water. If this entry occurred below the casing, then it slowed (in 1976) and stopped (in 1978) with time.

Summary:

Scattered data suggesting cold-water entry starting as early as 1974.

WELL AH-6

PRODUCTION WELL

Coordinates:

Latitude : 310,791.22 m

Longitude: 411,921.01 m

Drilling Dates:

Started : February 2, 1970

Finished: February 24, 1970

Elevation: 782.97 m

Depth: 591.16 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	95.25	$13\frac{3}{8}$"	90.68
$12\frac{1}{2}$"	455.22	$9\frac{5}{8}$"	454.30
$8\frac{3}{4}$"	591.16		

No liner

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
140	?	Saturated zone	Cased-off
250	?	Saturated zone	Cased-off
480	Total	Reservoir	

Relevant Information:

No cutting below 520 m.

This well was completed into the two phase zone of the reservoir. The discharge enthalpy was about 1000 kJ/kg when production started but has since increased to more than 2200 kJ/kg. The production zone of AH-6 is only 150 m long. Temperature logs during and just after drilling in 1970 indicate a minor aquifer at 460 m depth but the main aquifers are inferred to be at 480 m depth (the total loss of circulation) and 550 m depths.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
140	Saturated zone	Minor	Cased-off
250	Saturated zone	Minor	Cased-off
460	Reservoir	Minor	Two phase
480	Reservoir	Major	Two phase
550	Reservoir	Major	Two phase

Geochemistry:

Data:

Chemical Data : 02/72-04/87

Physical Data : 07/76-12/83 (limited by enthalpy measurement)

Initial Conditions:

255°C and 8200 ppm Cl.

Reasonably constant initial T_{NKC} of 255±5°C and a few T_{SIL} values near 245°C suggest 255°C and with T_{SIL} affected by near-well boiling. Initial chloride values (in part extrapolated from later production) are also well behaved at 8200 ppm.

Changes With Time:

The first measured T_E values in 1976 are only 10°C higher than T_{NKC} values, but T_E increases rapidly due to near-well boiling and heat gain from rocks (with order $T_E > T_{NKC} > T_{SIL}$). Maximum T_E values of 370+°C are reached in 1981-84. Enthalpy values continue to increase after 1984 but cannot be plotted as T_E values. T_{NKC} and T_{SIL} gradually decline from 255° and 230°C to 245° and 215°C. Chloride values are very scattered and show an apparent increase from 8000 ppm in 1974 to 9000 ppm in 1987 and increasing instability after 1978 and amounting to about 1000 ppm in 1987. This is probably due to near-well boiling related to the high excess enthalpy.

Summary:

AH-6 became an excess enthalpy well soon after production started and produced, after 1981, small flows with twice as much steam as water. These conditions and near-well boiling produced varying solute concentrations.

WELL AH-7

PRODUCTION WELL

Coordinates:

Latitude : 310,342.10 m

Longitude: 411,868.14 m

Drilling Dates:

Started : May 22, 1970

Finished: June 4, 1970

Work-over:

Started : September 21, 1972

Finished: November 5, 1972

Purpose : To deepen the well

Elevation: 804.79 m

Depth: 950.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	103.63	$13\frac{3}{8}$"	96.73
$12\frac{1}{2}$"	486.33	$9\frac{5}{8}$"	483.36
$8\frac{3}{4}$"	950.00		

No liner

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
520	?	Reservoir	

Relevant Information:

No cuttings below 520 m depth.

Temperature logs after drilling show internal flow in the well between aquifers at 520-530 m and 750 m depth. Rapid recovery at the casing shoe at 485 m depth can be explained by a minor two phase feed. Both pressure and spinner logs were conducted during discharge. The spinner survey shows that the inflows are from aquifers above 525 m depth (80%) and from an aquifer at 700-750 m depth (20%).

The discharge enthalpy of AH-7 has varied between 1000 and 1200 kJ/kg. This indicates that the deeper feed might be contributing more than the spinner log suggests.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
490	Reservoir	Minor	Two phase
520	Reservoir	Major	Two phase
750	Reservoir	Major	Liquid

Geochemistry:

Data:

Chemical Data : 12/73-04/87

Physical Data : 02/77-10/84

Initial Conditions:

262°C and 8600 ppm Cl

The first T_{NKC} and T_{SIL} temperatures are near 255°C. These values diverge immediately, T_{NKC} to oscillate around 262±5°C and T_{SIL} around 245±5°C. T_{SIL} has been lowered by in-well dilution, so 262°C seems reasonable as the initial temperature. Initial aquifer Cl is near 8600 ppm with later values slightly lower (calculated from T_{NKC}) and higher (calculated from T_{SIL}). A reasonable initial value is 8600±200 ppm Cl.

Changes With Time:

As mentioned above, T_{NKC} values oscillate around 260±5°C until 1981-1982 when they decline slowly to 257±3°C in 1987. T_{SIL} oscillates around 245±5°C until 1981-82 then increases slightly to 250±2° in 1987. The T_E values are highly variable starting at 227±8°C and becoming bimodal in 1979-81, with most values centering on 235±5°C and some values following T_{SIL} at 250±5°C. The general patterns of $T_{NKC}>T_{SIL}>T_E$ and $T_{NKC}>T_{SIL}=T_E$ suggest mixture of cooler water alternately in and close to the well with higher temperature (255°C) fluid further from the well cooled by mixture with cooler water to 245°C near the well and possibly 230°C in the well. The calculated temperature of the cool water is near 85°C.

Chloride has also been relatively constant with 8600±200 ppm values declining after 1981 and possibly stabilizing after 1985 at 8350±200 ppm. Chloride calculated from measured enthalpy is more variable at 9200±400 ppm.

Summary:

This very well-behaved well shows evidence of constant mixing of cooler and warmer waters at a variable distance from the well.

WELL AH-8

INJECTION WELL

Coordinates:

Latitude : 310,251.43 m

Longitude: 411,457.71 m

Drilling Dates:

Started : August 8, 1972

Finished: September 18, 1972

Work-over:

Started : September 12, 1973

Finished: October 13, 1973

Purpose : To remove blockage

Elevation: 810.99 m

Depth: 988.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	110	20"	107
$17\frac{1}{2}$"	467	$13\frac{3}{8}$"	463.75
$12\frac{1}{4}$"	988	$10\frac{3}{4}$"	354-434
$9\frac{5}{8}$"	434-582		

Redrilled with 8 1/2"bit at 582-710 m. Liner Slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
235	Partial	Saturated zone	Cased-off
350	Partial	Saturated zone	Cased-off
485	Partial	Reservoir	
865	Partial	Reservoir	
890	Partial	Reservoir	
950	Partial	Reservoir	
988	Total	Reservoir	

Relevant Information:

All available logs reached only as deep as 675 m. In 1975 the pressure at 200 masl was 36 bar but had declined to 25 bar in 1987. Extremely high pressure values in the years 1976 to 1982 are due to reinjection into the well. Temperature logs show an aquifer at 510 m. Reinjection cools the well as deep as the logs were run so the deep loss zone was probably receiving some of the reinjection despite the obstruction at 675 m depth.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
235	Saturated zone	?	Cased-off
350	Saturated zone	?	Cased-off
485	Reservoir	?	Two phase
510	Reservoir	?	Two phase
865	Reservoir	?	Liquid
890	Reservoir	?	Liquid
950	Reservoir	?	Liquid
988	Reservoir	?	Liquid

Geochemistry:

No data.

WELL AH-9

DRY HOLE

Coordinates:

Latitude : 309,408.23 m

Longitude: 411,572.57 m

Drilling Dates:

Started : March 1, 1970

Finished: March 27, 1970

Work-over:

First:

Started : March 1, 1970

Finished: March 27, 1970

Second:

Started : July 2, 1970

Finished: July 18, 1970

Purpose : To deepen the well

Elevation: 871.33 m

Depth: 1424.03 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	94.64	$13\frac{3}{8}$"	90.83
$12\frac{1}{4}$"	488.14	$9\frac{5}{8}$"	484.48
$8\frac{5}{8}$"	1424.03	$7\frac{5}{8}$"	469.43-961
7"	1140.6	5"	1424.03

Liner slotted below 634 m depth.

Circulation Losses: None.

Relevant Information:

Several temperature logs were obtained from this well just after drilling in 1970 and then almost every year since 1977. In 1970, the well was open to about 1200 m depth. No aquifers are seen in the logs during the recovery. The temperatures are above 200°C below 700 m depth with a maximum of 235°C at 1170 m. Since 1977, no logs have reached deeper than 732 m depth. There appeared to be several obstructions in the well and most logs only reached to 611 m depth. Temperature at that depth is about 180°C but in the few logs that reach to 732 m temperature as high as 225°C was measured. In the depth interval 500-700 m temperature show a linear gradient of 0.3°C/m.

In 1976-78, the water level in the well was close to 300 m depth (294 m). This corresponds to a pressure of approx. 35 bars at 200 masl or similar pressure as in the geothermal reservoir. In later years, however, the water level has risen to 210 -220 m depth. This is a similar pressure potential as in the saturated zone.

Aquifers:

There are "no" aquifers in AH-9.

Geochemistry:

No data.

WELL AH-10

DRY HOLE

Coordinates:

Latitude : 312,447.81 m

Longitude: 412,014.72 m

Drilling Dates:

Started : March 31, 1970

Finished: May 18, 1970

Elevation: 723.78 m

Depth: 1524.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	102.11	$13\frac{3}{8}$"	96.37
$12\frac{1}{2}$"	492.86	$9\frac{5}{8}$"	485.59
$8\frac{3}{4}$"	1542	$7\frac{5}{8}$"	460.31-1524

Slotted below 1162 m

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
375	Total	Saturated zone	Cased-off

Relevant Information:

No cuttings 375-492 m depth.

We have only three temperature log from this well and no pressure logs. Two of the temperature logs were run two months apart in 1970 when the well was open to 1250 m depth. They differ by about 10°C indicating heating up after drilling. Maximum temperature at 1250 m (bottom) is only 122°C. The temperature gradient in the deepest 500 m is 0.09 C/m. No aquifers can be seen in the logs. The water level in the well is not noted on the graphs we received for the logs run in 1970. The third log is from 1975. At that time the well was blocked at 414 m depth with water table at 105 m depth. As the elevation of the well is 724 masl, this corresponds to a pressure of 42 bar at 200 masl.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
375	Saturated zone		Cased-off

This well is truly a dry well.

Geochemistry:

No data.

WELL AH-11

DRY HOLE

Coordinates:

Latitude : 311,619.32 m

Longitude: 412,319.08 m

Drilling Dates:

Started : October 25, 1972

Finished: January 11, 1973

Work-over:

Started : October 18, 1973

Finished: October 30, 1973

Purpose : To clean out the well

Elevation: 759.3 m

Depth: 943.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	100	20"	96.60
$17\frac{1}{2}$"	464	$13\frac{3}{8}$"	462
$12\frac{1}{4}$"	943	$10\frac{3}{4}$"	600

Liner slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
30	Total	Ground water	Cased-off
325	Total	Saturated	Cased-off
610	Partial	Reservoir	
760	Partial	Reservoir	
785	Absorpt.	Reservoir	
806	Absorpt.	Reservoir	

Relevant Information:

In 1973-75, the well was open to 940 m depth, but since 1976, the well has been blocked at about 340 m depth. The water level was at 195 m depth in this well after drilling but has sunk to 295 m depth in 1987. This is about 2/3 of the draw-down observed in the main well field. It is possible that the reinjection into well AH-2 has influenced the pressure in AH-11.

The early temperature logs, when the well was open to total depth, do not show any internal flow in the well and the only location where the logs indicate a possible aquifer is around 500 m depth. Although well AH-11 seems to reflect the pressure in the reservoir zone, maximum temperatures at 940 m depth are relatively low, only 190°C. In the saturated zone temperatures of 100-140°C are seen.

Aquifers:

Well AH-11 has no major feed zone.

Depth (m)	Aquifer	Contribution	Remarks
30	Ground water	?	Cased-off
325	Saturated zone	?	Cased-off
500	Saturated zone	?	
610	Reservoir	?	
760	Reservoir	?	
785	Reservoir	?	
806	Reservoir	?	

Geochemistry:

No data.

WELL AH-12

DRY HOLE

Coordinates:

Latitude : 311,493.50 m

Longitude: 411,758.10 m

Drilling Dates:

Started : January 15, 1973

Finished: March 16, 1973

Elevation: 758.80 m

Depth: 1003.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	100.00	20"	96.00
$17\frac{1}{2}$"	500.56	$13\frac{3}{8}$"	496.00
$12\frac{1}{2}$"	728.50	$8\frac{3}{4}$"	1003.00

No liner

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
0-50	Total	Ground water	Cased-off
710	Absorption	Reservoir	
740	Absorption	Reservoir	

Relevant Information:

No well logs penetrated to total depth in this well. After drilling in 1973 to 1977 all logging tools reached only to 562 m depth. In 1978 the well was found to be blocked at 183 m depth. No logs are available after 1978.

The logs show temperatures of 100-135°C down to 562 m depth. Water level remained stable in this 5 year period at 142 m depth and pressures at 200 masl is approximately 43 bar. The well is not connected to the geothermal reservoir, but gives on the other hand information on temperature and pressure conditions in the saturated zone. The high water table indicates that the pressure potential of the saturated zone is much higher than that of the reservoir.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
0-50	Ground water	?	Cased-off
710	Reservoir	?	
740	Reservoir	?	

Geochemistry:

No data.

WELL AH-13

PRODUCTION WELL

Coordinates:

Latitude : 310,428.40 m

Longitude: 412,479.68 m

Drilling Dates:

Started : August 9, 1974

Finished: August 21, 1974

Elevation: 859.60 m

Depth: 831.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	98.00	20"	97.00
$17\frac{1}{2}$"	490.00	$13\frac{3}{8}$"	480.00
$12\frac{1}{4}$"	831.00	$10\frac{3}{4}$	453.53-812.00

Liner slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
50	Absorption	Ground water	Cased-off
75	Total	Ground water	Cased-off
98	Total	Ground water	Cased-off
450	Total	Saturated(?)	Cased-off
490	Partial	Reservoir	
540	Total	Reservoir	
560	Total	Reservoir	
580	Total	Reservoir	
660	Absorption	Reservoir	
770	Total	Reservoir	

Relevant Information:

No cuttings below 770 m depth.

Temperature logs shortly after drilling in January 1974 and work-over in August 1974 show at least three aquifers. These found at about 550, 600 and 750 m depth and are in good agreement with the list of circulation losses. The fast recovery of the feed zone at 550 m indicates small cooling during drilling. This is therefore judged to be a minor feed. We have no data to determine which of the deeper two feeds dominates. This could possibly be seen from the discharge enthalpy as the aquifer at 600 m depth and is in the two phase portion of the reservoir where as the feed at 770 m depth is in the liquid portion. Despite the fact that this well is characterized as a production well we have no data on productivity and enthalpy.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
50	Ground water	?	Cased-off
75	Ground water	?	Cased-off
98	Ground water	?	Cased-off
450	Saturated(?)	?	Cased-off
490	Reservoir	?	Two phase
540	Reservoir	Two phase	
560	Reservoir	Two phase	
580	Reservoir	Two phase	
660	Reservoir	Liquid(?)	
770	Reservoir	Liquid	

Geochemistry:

No data.

WELL AH-14

DRY HOLE

Coordinates:

Latitude : 310,938.58 m

Longitude: 413,705.56 m

Drilling Dates:

Started : February 1, 1974

Finished: May 12, 1974

Work-over:

Started : October 19, 1976

Finished: November 25, 1976

Elevation: 821.77 m

Depth: 1056.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	97.00	20"	96.00
$17\frac{1}{2}$"	550.00	$13\frac{3}{8}$"	348.00
$12\frac{1}{4}$"	570.00	$9\frac{5}{8}$"	464.60
$8\frac{1}{2}$"	800.00	$7\frac{5}{8}$"	450-698
$6\frac{1}{8}$"	1056.00		

Liner slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
90	Total	Ground water	Cased-off
150	Partial	Saturated(?)	Cased-off
260	Total	Saturated(?)	Cased-off
360	Total	Saturated(?)	Cased-off
420	Partial	Saturated(?)	Cased-off
550	Partial	Reservoir(?)	
600	Total	Reservoir(?)	
640	Total	Reservoir(?)	

Relevant Information:

No cuttings below 640 m depth.

This well is considered dry despite of the total losses of circulation. The well is in pressure communication with the geothermal reservoir and a pressure drawdown of 6 bar has been observed since 1975. The temperature profile is conductive down to 800 m depth with a gradient of about 0.2°C/m. Temperature at the total loss zones at 600-640 m depth is 185-190°C. The well has been plugged at about 800 m depth since 1980. Earlier logs show that the temperature increases only slightly from 800 to 1000 m depth reaching a maximum of about 240°C at bottom. The temperatures in AH-14 are well below boiling at all depths. Further it should be noted that the temperature at 1000 m depth is one of the hottest temperature measured in Ahuachapan.

Temperature logs run right after drilling show aquifers around 550, 650 and 720 m depth. There seems to be an internal flow between these aquifers. The total loss zone at 600 m depth is not seen in the logs. Temperature profiles in the well after full recovery from drilling didn't show any internal flow. We have no data other than the circulation losses to determine the relative productivity of these aquifers.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
90	Ground water	Major	Cased-off
150	Ground water/Saturated(?)	Minor	Cased-off
260	Saturated	Major	Cased-off
360	Saturated	Major	Cased-off
420	Saturated	Minor	Cased-off
550	Reservoir	Minor(?)	Liquid.
640	Reservoir	Major(?)	Liquid
720	Reservoir	Minor(?)	Liquid

Geochemistry:

No data.

WELL AH-15

DRY HOLE

Coordinates:

Latitude : 310,834.44 m

Longitude: 411,334.22 m

Drilling Dates:

Started : August 26, 1974

Finished: October 19, 1974

Elevation: 772.68 m

Depth: 704.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	99.72	20"	98.00
$17\frac{1}{2}$"	505.00	$13\frac{3}{8}$"	491.00
$12\frac{1}{4}$"	704.00		

No liner

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
505	Absorption	Saturated zone(?)	

Relevant Information:

In 1974 to 1976, all logging runs reached to 558 m depth. Later logs only reached down to 390 m. This is within the 9 5/8" casing. The water level is at about 140 m depth and has not changed since 1974. The well is obviously not connected to the geothermal reservoir but the question is whether the water level corresponds to the pressure in the saturated zone or the well is totally plugged at 390 m depth. Temperatures are close to 100°C at the water table increasing to 125-130°C at 390 m depth. This is one of the few wells where information on temperatures is available in the saturated zone.

Aquifers:

This seems to truly a dry well. The only indication of an aquifer is the absorption of the circulating at:

Depth (m)	Aquifer	Contribution	Remarks
505	Saturated zone	Minor	

Geochemistry:

No data.

WELL AH-16

PRODUCTION WELL

Coordinates:

Latitude : 309,948.09 m

Longitude: 412,106.16 m

Drilling Dates:

Started : May 19, 1974

Finished: August 5, 1974

Work-over:

Started : December 1, 1976

Finished: February 28, 1977

Purpose : To deepen the well

Elevation: 868.76 m

Depth: 1006.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	101.00	20"	101.00
$17\frac{1}{2}$"	510.00	$13\frac{3}{8}$"	510.00
$12\frac{1}{4}$"	1006.00	$10\frac{3}{4}$"	485.10-750
$9\frac{5}{8}$"	1006		

The liner is slotted from top to bottom.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
60	Total	Ground water	Cased-off
140	Total	Saturated(?)	Cased-off
300	Total	Saturated	Cased-off
600	Partial	Reservoir	
650	Total	Reservoir	

Relevant Information:

No cuttings below 930 m depth.

We have several temperature logs after work-over in 1977. The heat recovery after the work-over is dominated in the upper portion of the well by a steam rich aquifer at about 620 m The fast recovery indicates small cooling of this aquifer during the work-over. Below 620 m, the temperature profile is near isothermal indicating an internal flow in the well. The flow direction can't be determined from the logs but normally a downflow is observed in wells after drilling and work-over. In this well, the flow seems to be from the total loss zone at 650 m depth to an aquifer close to bottom at 1000 m. Further, the logs show an anomaly at about 850 m indicating an aquifer at this depth.

The well produces a high enthalpy fluid (1800 kJ/kg). This indicates that the main feed zone is located in the two phase portion of the well.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
60	Ground water	Major	Cased-off
140	Ground/Saturated	Major	Cased-off
300	Saturated zone	Major	Cased-off
600	Reservoir	Minor	Two phase
650	Reservoir	Major	Two phase
850	Reservoir	Minor	Liquid
1000	Reservoir	Minor	Liquid

Geochemistry:

Data:

Chemical Data : 12/86-03/87 (2 analyses)

Physical Data : none

Summary:

The few data indicate a T_{NKC} of 243±3°C and T_{SIL} of 237±3°C. These are reasonable when compared to other wells. The data are too few to suggest changes with time or production mechanism.

WELL AH-17

INJECTION/PRODUCTION WELL

Coordinates:

Latitude : 310,781.95 m

Longitude: 411,697.32 m

Drilling Dates:

Started : June 29, 1976

Finished: August 30, 1976

Work-over:

Started : February 22, 1979

Finished: March 8, 1979

Purpose : To place a slotted liner

Elevation: 773.00 m

Depth: 1200.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	105	$13\frac{3}{8}$"	104.5
$12\frac{1}{4}$"	452	$9\frac{5}{8}$"	450.0
$8\frac{1}{2}$"	1200	$7\frac{5}{8}$"	440-1200

The liner is slotted from top to bottom.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
130	Total	Saturated(?)	Cased-off
468	Total	Reservoir	

Relevant Information:

No cuttings below 780 m depth.

Spinner log shows that 98% of the injected fluid reaches 773 m depth but no spinner signal was detected at 873 m depth. Almost none of the injected fluid enters the feed zone at 468 m depth. This is rather unusual as the liner is slotted at that depth. When discharged the well produces dry steam so the main feed zone during discharge must be the aquifer at 468 m. Temperature logs shortly after drilling show clearly the aquifer at 468 m depth. Logs in 1980/81 show aquifer at about 600 m depth. The loss zone during reinjection is not easily seen in the logs. Earlier logs show, though, small cooling below the 468 m aquifer down to about 870 m depth. Bottom hole temperatures in AH-17 have been fairly stable since 1976 at 210-215°C.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
130	Saturated(?)	Major aquifer	Cased-off
468	Reservoir	Major feed	Two phase
600	Reservoir	Minor feed	Two phase
870	Reservoir	Major (injection)	Liquid

Geochemistry:

Data:

Chemical Data : 02/85-04/87

Physical Data : 12/81-12/86

Summary:

The well produces dry steam. The few water analyses are of condensate and a small amount (5%) of deep water. They do not yield useful geothermometers or aquifer chlorides.

WELL AH-18

PRODUCTION WELL

Coordinates:

Latitude : 309,745.32 m

Longitude: 412,852.31 m

Drilling Dates:

Started : March 9, 1977

Finished: May 24, 1977

Elevation: 926.28 m

Depth: 1256.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	108	$13\frac{3}{8}$"	105.0
$12\frac{1}{4}$"	625	$9\frac{5}{8}$"	624.2
$8\frac{1}{2}$"	1256	$7\frac{5}{8}$"	614-1256

Liner is slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
31	Total	Ground water	Cased-off
43	Total	Ground water	Cased-off
53	Total	Ground water	Cased-off
175	Total	Ground water(?)	Cased-off
225	Total	Ground water	Cased-off
325	Partial	Saturated	Cased-off
540	Partial	Saturated	Cased-off
790	Total	Reservoir	
906	Total	Reservoir	

Relevant Information:

No cuttings below 930 m depth.

Very good temperature and pressure logs are available for this well during the heating up period after drilling. The pressure logs show a pivot point at about 800-850 m depth, in good agreement with the circulation losses. The temperature logs show gradual increasing temperatures and the recovery seems to be disturbed only to a small degree by internal flow. We have very little productivity data from this well. A flow test report from 1984 does not say anything about flow rate and enthalpy as no lip pressure readings were obtained because of the large lip pipe used (6"). It is clear, though, that the flow rate is low and as the main loss zones during drilling are relatively deep, liquid enthalpy is to be expected. Logs run shortly after the flow test show cooling down to at least 1000 m depth. The well has therefore boiled during discharge to at least that depth indicating a feed zone below 1000 m.

It should be noted that the temperature logs show increasing temperature with depth. Before 1983, bottom hole temperature was measured at approximately 240°C but later most values show temperature of 244-245°C. This increase is large enough to be explained solely as a calibration error of the gauges, so possibly the temperatures in the south around well AH-18 has increased with time.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
31	Ground water	Major	Cased-off
43	Ground water	Major	Cased-off
53	Ground water	Major	Cased-off
175	Ground/Saturated(?)	Major	Cased-off
225	Ground/Saturated(?)	Major	Cased-off
325	Saturated zone	Minor	Cased-off
540	Saturated zone	Minor	Cased-off
790	Reservoir	Major	Two phase/liquid
906	Reservoir	Major	Liquid

Geochemistry:

No data.

WELL AH-19

PRODUCTION WELL

Coordinates:

Latitude : 310,331.55 m

Longitude: 412,759.49 m

Drilling Dates:

Started : October 20, 1977

Finished: February 28, 1978

Elevation: 873.3 m

Depth: 1415.50 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	92.0	$13\frac{3}{8}$"	92.0
$12\frac{1}{4}$"	707.3	$9\frac{5}{8}$"	676.0
$8\frac{1}{2}$"	1415.5	$7\frac{5}{8}$"	655-1009.5

The liner is not slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
40	Total	Ground water	Cased-off
50	Total	Ground water	Cased-off
60	Total	Ground water	Cased-off
80	Total	Ground water	Cased-off
120	Partial	Ground/Saturated	Cased-off
220	Partial	Saturated	Cased-off
290	Total	Saturated	Cased-off
300	Total	Saturated	Cased-off
700	Total	Reservoir	
770	Total	Reservoir	

Relevant Information:

The well was cased to the bottom of the two phase zone. During heating up after drilling in 1978, temperature logs show an internal flow in the well between the aquifers at 700, 770, 1100 m depth and possibly the bottom (1370 m depth). Reservoir temperature is approximately 230°C. and the discharge enthalpy about is 1050 kJ/kg, which is close to the liquid enthalpy of 230°C water. It is inferred that the total loss at 700 m depth is the main feed zone but we have very little data to support this.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
40	Ground water	Major	Cased-off
50	Ground water	Major	Cased-off
60	Ground water	Major	Cased-off
80	Ground water	Major	Cased-off
120	Ground/Saturated	Minor	Cased-off
220	Saturated zone	Minor	Cased-off
290	Saturated zone	Major	Cased-off
300	Saturated zone	Major	Cased-off
700	Reservoir	Major	Two phase/Liquid
770	Reservoir	Major(?)	Two phase/Liquid
1100	Reservoir	Minor(?)	Liquid
1370(?)	Reservoir	Minor(?)	Liquid

Geochemistry:

Data:

Chemical Data : 07/84-04/87

Physical Data : 12/83-12/86

Initial Conditions:

233°C and 6100 ppm Cl.

T_{NKC} and T_{SIL} are remarkably constant and nearly the same for the entire chemical record except for the first 6 months. T_{NKC} is 240±5°C from July 1984 to February 1985 and 234±3°C from February 1985 to April 1987. T_{SIL} is 230±3°C for the entire period. It seems most likely that the initial

temperature was 233°C. The aquifer Cl was also constant at 6100±100 ppm until 1986. Initial aquifer Cl was therefore 6100±100 ppm.

Changes With Time:

Enthalpy temperatures (T_E) were 233°C when first measured but declined to 220±5°C rapidly and remained constant thereafter. The T_{NKC} exceeded T_{SIL} by about 5°C, except late in 1985 when they were fairly similar. The T_E is about 10°C lower than other indicated temperatures, which suggests a small amount of cooler water mixture. The differences are small and it seems likely that the well produces from a single-phase, equilibrated fluid without either boiling or major mixing with cold water. Chloride was constant at 6100±100 ppm from 1984-86 and then decreased to 5700 ppm in 1987.

Summary:

An unusual behavior for Ahuachapan well with no excess or deficiency in enthalpy. A well-behaved single-phase, single-feed well.

WELL AH-20

PRODUCTION WELL

Coordinates:

Latitude : 310,986.42 m

Longitude: 412,087.47 m

Drilling Dates:

Started : October 24, 1974

Finished: December 20, 1974

Work-over:

Started : July 27, 1982

Finished: August 8, 1982

Purpose : To place a slotted liner

Elevation: 792.93 m

Depth: 850.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	86	20"	86.0
$17\frac{1}{2}$"	455	$13\frac{3}{8}$"	449.5
$12\frac{1}{4}$"	850	$9\frac{5}{8}$"	426.0-850

Liner slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
50	Absorption	Ground water	Cased-off
460	Total	Reservoir	

Relevant Information:

No cuttings below 600 m depth.

Temperature logs show an aquifer at 500 m depth. A pivot point is seen at that depth from the pressure logs in 1976. As the well produces a high enthalpy fluid (1200-1500 kJ/kg), most of the fluid must be from the two phase portion above 600 m depth. The work-over in 1982 did not change the production characteristics of the well.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
50	Ground water	Minor	Cased-off
460	Reservoir	Major	Two phase
500	Reservoir	Major(?)	Two pahse

Geochemistry:

Data:

Chemical Data : 06/76-04/87 (+2 analyses in early 1975)

Physical Data : 06/76-12/86

Initial Conditions:

252°C and 7900 ppm Cl.

Values of T_{NKC} were 260±5°C for early 1975 and 257±1°C for June to October 1976 with a steady decline afterward. T_{SIL} was 234±2°C for the same period. Initial T_E values were 247±6°C but increased rapidly after a year. This well probably had near-well boiling (indicated by increase in T_E) so T_{SIL} is probably low. The likely initial temperature is 252±5°C. Initial chloride values of 7700±100 ppm (April 1975-March 1977) are probably low. Constant Cl of 7900±100 ppm measured from April 1977 to August 1978 are more likely to reflect initial values.

Changes With Time:

After a year of production, T_E rapidly increased to a maximum of 360°C in 1982 and declined afterward to about 300°C. T_{NKC} and T_{SIL} declined steadily from 260°C and 234°C to 240°C and 220°C, respectively. This temperature behavior ($T_E > T_{NKC} > T_{SIL}$) indicates near-well boiling from January 1977 (and possibly earlier) with heat transfer from the rock. This process declined in intensity after 1982. Chloride in the aquifer fluid declined steadily after 1977. The declines in T_{NKC}, T_{SIL} and chloride may indicate increasing dilution with cooler, more dilute water.

Summary:

A classical excess-enthalpy well with near-well boiling.

WELL AH-21

PRODUCTION WELL

Coordinates:

Latitude : 310,601.15 m

Longitude: 412,059.04 m

Drilling Dates:

Started : December 27, 1974

Finished: March 4, 1975

Elevation: 795.0 m

Depth: 849.40 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
26"	96.0	20"	94.0
$17\frac{1}{2}$"	500.0	$13\frac{3}{8}$"	472.0
$12\frac{1}{4}$"	849.4	$9\frac{5}{8}$"	444-849.4

Liner slotted below 500 m depth.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
430	Total	Saturated/Reservoir	Cased-off
510	Total	Reservoir	

Relevant Information:

Temperature logs after drilling in 1975 and work-over in 1976 show aquifers at 450-500 m. The cooling after work-over also indicates loss of circulation fluid at 550-600 and 849 m depths. The enthalpy is relatively high, 1100-1200 kJ/kg, indicating that most of the fluid produced must be from the two phase portion of the reservoir.

Flowing temperature and pressure surveys conducted in 1983 at a rate of 76 kg/s showed main feedzone at 500-600 and a minor inflow at the bottom of the well.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
430	Saturated/Reservoir(?)	Major	Cased-off
500-550	Reservoir	Major	Two phase
600	Reservoir	Major	Two phase/Liquid
800-849	Reservoir	Minor	Liquid

Geochemistry:

Data:

Chemical Data : 04/75-04/87

Physical Data : 08/76-10/86

Initial Conditions:

257°C and 8500 ppm Cl.

Temperatures indicated for this well are difficult to interpret. T_{NKC} suggests 257°C but both T_{SIL} and T_E suggest much lower temperatures near 230°C. Although higher temperature fluids were not far away, mixing with cooler water has reduced the temperature feeding the well to 230°C. Initial chlorides oscillated but must have been near 8500 ppm.

Changes With Time:

As noted above, cooler water mixture is indicated from the start but rising values of T_E until 1981 with T_E falling afterward could result from decreasing and increasing cold-water mixture. Chloride contents showed a slow decline, however, without evidence of decreased dilution so it appears probable that the enthalpy perturbation was due to addition of excess steam. T_{NKC}, T_{SIL} and chloride show a slow decline, suggesting stable inflow of water from cooler parts of the reservoir. After 1979, the $T_{NKC}>T_E=T_{SIL}$ pattern indicates mixture with cooler water far enough from the well for silica to be fully equilibrated.

Summary:

An unusual well with both cold-water at a distance (high T_{NKC}) and excess enthalpy probably from addition of steam.

WELL AH-22

PRODUCTION WELL

Coordinates:

Latitude : 310,632.21 m

Longitude: 412,558.65 m

Drilling Dates:

Started : March 9, 1975

Finished: April 21, 1975

Elevation: 842.0 m

Depth: 659.50 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	93.0	$13\frac{3}{8}$"	89.5
$12\frac{1}{4}$"	517.0	$9\frac{5}{8}$"	508.8
$8\frac{3}{4}$"	659.5		

No liner.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
20-70	Total	Ground water	Cased-off
89	Partial	Ground water	Cased-off
130	Partial	Saturated(?)	Cased-off
270	Partial	Saturated	Cased-off
310	Partial	Saturated	Cased-off
500	Partial	Reservoir	Cased-off
520	Partial	Reservoir	

Relevant Information:

This well has a high discharge enthalpy of 1200 kJ/kg indicating that the main feed zone is within the two phase region. The loss zone at 520 m depth is most likely the main feed. This aquifer doesn't show up in the temperature logs but irregularities in the logs at about 600 m depth indicate a feed zone at that depth.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
20-70	Ground water	Major	Cased-off
89	Ground water	Minor	Cased-off
130	Saturated zone	Minor	Cased-off
270	Saturated zone	Minor	Cased-off
310	Saturated zone	Minor	Cased-off
500	Reservoir	Minor	Cased-off
520	Reservoir	Major	Two phase
600	Reservoir	Minor(?)	Two phase/Liquid

Geochemistry:

Data:

Chemical Data : 07/76-04/87

Physical Data : 07/76-12/86

Initial Conditions:

240°C and 6900 ppm Cl.

T_{NKC} and T_{SIL} are remarkably similar and constant, indicating initial temperatures of 240±4°C and 236±4°C. T_E is higher, suggesting boiling (and steam entry), which might explain the slightly lower T_{SIL} value. 240°C seems a good initial temperature. Chloride initially at 6900±100 ppm shows a slow rise.

Changes With Time:

High and variable T_E values suggest boiling or the addition of excess steam. Near concordance of T_{NKC} and T_{SIL} suggests limited boiling, so the major cause of high enthalpy is probably addition of steam ($T_E > T_{NKC} = T_{SIL}$). Chloride shows a rapid decrease in 1981, indicating the arrival of the chemical (or "hydraulic") front. Chloride values more or less stabilize after 1983, suggesting that the cooler water (now heated by reservoir rock) had about 6200 ppm Cl.

Summary:

Addition of steam causing high T_E with no effects on T_{NKC} or T_{SIL} and the arrival of a lower chloride water without effect on indicated temperatures suggests both independent steam entry and arrival of a chemical front.

WELL AH-23

PRODUCTION WELL

Coordinates:

Latitude : 310,621.45 m

Longitude: 412,349.73 m

Drillind Dates:

Started : July 7, 1977

Finished: September 10, 1977

Elevation: 825.4 m

Depth: 924.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	101.0	$13\frac{3}{8}$"	98.0
$12\frac{1}{4}$"	459.5	$9\frac{5}{8}$"	459.5
$8\frac{5}{8}$"	875.0	$7\frac{5}{8}$"	437-924.0
$8\frac{1}{2}$"	924.0		

Liner slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
50	Total	Ground water	Cased-off
125	Total	Saturated(?)	Cased-off
225	Partial	Saturated(?)	Cased-off
240	Total	Saturated(?)	Cased-off
270	Total	Saturated(?)	Cased-off
350	Partial	Saturated(?)	Cased-off
460	Partial	Reservoir	
525	Total	Reservoir	

Relevant Information:

No cuttings below 775 m depth.

Early temperature logs show an aquifer at 525 m depth. High discharge enthalpy of 1200 kJ/kg indicates that the main feed zone is in the two phase portion of the reservoir but the temperature logs do not exclude a minor deep liquid inflow.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
50	Ground water	Major	Cased-off
125	Ground/Saturated(?)	Major	Cased-off
225	Saturated zone	Minor	Cased-off
240	Saturated zone	Major	Cased-off
270	Saturated zone	Major	Cased-off
350	Saturated zone	Minor	Cased-off
460	Reservoir	Minor	Two phase
525	Reservoir	Major	Two phase

Geochemistry:

Data:

Chemical Data : 01/80-04/87

Physical Data : 01/80-12/86

Initial Conditions:

245°C and 7100 ppm Cl.

Although the earliest T_E and T_{SIL} indicate 227°C, all T_{NKC} and some T_{SIL} and T_E values (at times when there is no excess enthalpy and no expansion of boiling) are near 245°C; this seems to be the real initial temperature. Initial chloride (extrapolated from later measurements) is near 7100 ppm from T_{NKC} and 7400 ppm from T_{SIL}. The best guess is 7100 ppm.

Changes With Time:

This well shows clear evidence of episodic boiling and heat transfer as the boiling zone expanded. At various times, $T_E=T_{NKC}>T_{SIL}$, indicating near-well boiling without heat transfer from the rock (in 1981 and 1983); $T_E>T_{NKC}>T_{SIL}$, indicating boiling with heat transfer (in 1981 and after 1984); and $T_E=T_{NKC}=T_{SIL}$, indicating an all-liquid feed (in 1982). Chloride decreased steadily (with a small increase in from 1983-1984 related to boiling and increase in T_E) from 7100 ppm in 1980 to 6100 ppm in 1981.

Summary:

A well with excess enthalpy due to boiling not addition of steam.

WELL AH-24

PRODUCTION WELL

Coordinates:

Latitude : 310,616.08 m

Longitude: 411,852.48 m

Drilling Dates:

Started : April 27, 1975

Finished: June 23, 1975

Work-over:

Started : March 22, 1976

Finished: June 14, 1976

Purpose : To repair casing break. Well has now a constriction.

Elevation: 783.1 m

Depth: 850.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	98	$13\frac{3}{8}$"	95.0
$12\frac{1}{4}$"	453	$9\frac{5}{8}$"	258.5
		$9\frac{5}{8}$"	307.6-411
		7"	234-435
$8\frac{1}{2}$"	850	$7\frac{5}{8}$"	435-844

Liner slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
96	Total	Ground water	Cased-off
452	Total	Reservoir	

Relevant Information:

No cuttings below 730 m depth.

Early temperature logs show an aquifer at 450 m depth with a temperature of 225°C. No internal flow was observed in the well during recovery after drilling and temperatures at 630 m depth increase slowly from 120°C in May 1975 to 215°C in March 1976. After work-over in spring of 1976, a temperature minimum is seen at 650 m.

Low discharge enthalpies (800-900 kcal/kg) in 1977 are hard to explain unless the main inflow came from the cooled interval around 650 m.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
96	Ground water	Major aquifer	Cased-off
452	Reservoir	Minor(?)	Two phase
650	Reservoir	Major(?)	Two phase/Liquid

Geochemistry:

Data:

Chemical Data : 07/78-04/87

Physical Data : 11/78-12/86

Initial Conditions:

260°C and 8500 ppm Cl.

This is a high-temperature well that was cooled almost from the start by cold water. Initial T_{NKC} is near 260°C with the first T_E near 257°C and T_{SIL} near 250°C. Initial chloride is 8500 ppm.

Changes With Time:

T_E is extremely variable but appears to have decreased rapidly to about 220°C, much lower than other indicators. $T_{NKC}>T_{SIL}>T_E$, indicating mixture with cold water in the wellbore and near the well and partial re-equilibration of T_{SIL}. The fraction of cold water has varied a bit as indicated by higher Cl when T_E is higher (as in January 1981 and June 1982, as well as the reverse in September 1981). The partial re-equilibration of T_{SIL} prevents calculation of the cool water temperature.

Summary

A deficient enthalpy well with evidence of variable cold-water admixture.

WELL AH-25

DRY HOLE

Coordinates:

Latitude: 310,887.24 m

Longitude: 412,303.58 m

Drilling Dates:

Started : May 29, 1975

Finished: August 27, 1975

Elevation: 798.5 m

Depth: 943.30 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	96.5	$13\frac{3}{8}$"	94.8
$12\frac{1}{4}$"	507.0	$9\frac{5}{8}$"	506.0
$8\frac{3}{4}$"	943.0	$7\frac{5}{8}$"	485-928

Liner slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
50	Total	Ground water	Cased-off
175	Partial	Saturated zone	Cased-off
200	Partial	Saturated zone	Cased-off
425	Partial	Saturated zone	Cased-off
590	Partial	Reservoir	
675	Total	Reservoir	

Relevant Information:

This well is considered dry, however, a total circulation loss occurs at 675 m depth during drilling. Temperature logs shortly after drilling indicate no internal flow in the well. A minor feed zone is inferred at 800 m depth and a feed zone at 500-600 m depth. As the logs do not show any anomaly at 675 m depth, it is suspected that the total loss might have occured shallower at 500-600 m depth. The latest logs show an isothermal temperature profile from 550 m depth down to the bottom at a temperature of 210-215°C. The highest temperature of 230°C was measured in 1975-77 at 500-650 m depth and at the bottom at 220°C.

A pair of pressure logs from 1975 and 1977 show a pivot point at 600 m depth. This indicates that the circulation loss at 590 m depth is the "best" feed of this well.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
50	Ground water	Major	Cased-off
175	Saturated zone	Minor	Cased-off
200	Saturated zone	Minor	Cased-off
425	Saturated/Reservoir(?)	Minor	Cased-off
590	Reservoir	"Best" feed	Two phase
67	Reservoir	?	Liquid
800	Reservoir	Minor	Liquid

Geochemistry:

No data.

WELL AH-26

PRODUCTION WELL

Coordinates:

Latitude : 310,750.00 m

Longitude: 412,080.00 m

Drilling Dates:

Started : September 5, 1975

Finished: October 30, 1975

Elevation: 791.1 m

Depth: 804.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	97	$13\frac{3}{8}$"	96.0
$12\frac{1}{4}$"	413	$9\frac{5}{8}$"	399.0
$8\frac{1}{2}$"	804		

No liner.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
48	Partial	Ground water	Cased-off
54	Total	Ground water	Cased-off
411	Total	Reservoir	
413-461	Partial	Reservoir	
470	Total	Reservoir	

Relevant Information:

A spinner log was run in this well during discharge in 1979. The log show half of the inflow was from the interval 410-450 m and the rest from 450-500 m depth. These were in good agreement with the circulation losses. High discharge enthalpies of 1600-2200 kJ/kg also indicate that most of the fluid is from the two phase zone that extends in this well to about 550 m depth. Pressure log during discharge show that the well boils to the deepest measuring point at 616 m. Some inflow must, therefore, be below that depth but it is difficult to estimate the amount of fluid coming from this deep feed from the log profile. The exact location of this feed is believed to be at 650 m based from the temperature logs.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
48	Ground water	Minor	Cased-off
54	Ground water	Major	Cased-off
411	Reservoir	Major	Two phase
470	Reservoir	Major	Two phase
650	Reservoir	Minor	Liquid

Geochemistry:

Data:

Chemical Data : 07/76-04/87

Physical Data : 08/76-12/87

Initial Conditions:

254°C and 8000 ppm Cl.

This well had elevated T_E and depressed T_{SIL} (due to boiling) from the start of data collection. The initial T_{NKC} was 254±3°C, which was near constant until 1979. Except some initial scatter, aquifer chloride was constant at 8000±100 ppm from 1977 to 1979.

Changes With Time:

The entire history of this well shows the pattern $T_E > T_{NKC} > T_{SIL}$ and near constant temperature differences, suggesting stable boiling and heat transfer from rock. The near stable temperature values suggest that the boiling was at some distance from the well (but not far enough for NKC re-equilibration). The start of boiling is not shown in our data and may have been caused by production of another well or during well tests. A slow decrease of 8-10°C is seen in T_{NKC} and T_{SIL} (1977-1987), with an increase in T_E in 1978 followed by a slow decrease (and decreasing scatter). Chloride decreased slowly to 7000±150 ppm in 1987.

Summary:

A well with uniform boiling and conductive heating at a moderate distance from the well. Some cold-water addition (and boiling?) has slowly decreased temperatures and chloride concentrations.

WELL AH-27

PRODUCTION WELL

Coordinates:

Latitude : 310,313.00 m

Longitude: 412,067.00 m

Drilling Dates:

Started : March 6, 1978

Finished: April 29, 1978

Elevation: 822.47 m

Depth: 800.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	112	$13\frac{3}{8}$"	110.0
$12\frac{1}{4}$"	424	$9\frac{5}{8}$"	412.0
$8\frac{1}{2}$"	800	$7\frac{5}{8}$"	333.5-729.2

Liner slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
0-90	Partial	Ground water	Cased-off
50	Total	Ground water	Cased-off
425	Partial	Reservoir	
500	Total	Reservoir	

Relevant Information:

No cuttings below 500 m depth.

Temperature and pressure logs indicate the "water level" under pressure at 550 m depth. WHP has decreased from 23 bar in 1979 to 17 bar in 1987. Pressure decline at bottom during this period is 6 bar.

In the temperature logs, a 10°C temperature peak at 722 to 772 m depth indicates a feed zone in this interval. Bottom hole temperature values are among the highest measured in the field (240°C at 796 m depth) and it is likely that the well boils up to the bottom during discharge. The discharge enthalpy is between 1060-1200 kJ/kg.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
0-90	Ground water	Minor	Cased-off
50	Ground water	Major	Cased-off
425	Reservoir	Minor	Two phase
500	Reservoir	Major	Two phase
750	Reservoir	Major(?)	Two phase/Liquid

Geochemistry:

Data:

Chemical Data : 01/81-04/87

Physical Data : 10/80-12/86

Initial Conditions:

260°C and 7500 (7900?) ppm Cl.

The first six months of production show the influence of near-well boiling and excess enthalpy from rock heating, but this changes to stabilized boiling soon with $T_E=T_{NKC}$. Until 1983, T_{NKC} is 260±5°C. Earliest aquifer chloride is near 7900 ppm but rapidly decreases to 7500±200 ppm. The higher concentrations may be influenced by boiling.

Changes With Time:

Chloride and enthalpy tend to change together with peaks in 1980-81, 1983-84 and possibly (with scatter) in 1986-87 and valleys in 1982-83 and 1985. T_E drops below T_{NKC} and T_{SIL} in 1983 but is above them in 1981 and 1985. The order changes from $T_E>T_{NKC}>T_{SIL}$ to $T_{NKC}>T_{SIL}>T_E$ and back but remains at $T_E=T_{NKC}>T_{SIL}$ for much of the time. All this suggests boiling with and without heat transfer from rock and sporadic near-well mixing with cool water. The reverse could also be true or the process could alternate because $T_{NKC}>T_{SIL}$ (found throughout) is characteristic of both.

Summary:

An interesting well on the border of boiling and mixing zones.

WELL AH-28

PRODUCTION WELL

Coordinates:

Latitude : 310,490.00 m

Longitude: 412,207.22 m

Drilling Dates:

Started : September 16, 1978

Finished: November 29, 1978

Elevation: 829.29 m

Depth: 1000.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	112.0	$13\frac{3}{8}$"	110.9
$12\frac{1}{4}$"	431.5	$9\frac{5}{8}$"	428.0
$8\frac{3}{4}$"	904.0	$8\frac{1}{2}$"	1000.0
$7\frac{5}{8}$"	416.5-994.5		

Liner slotted.

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
190	Partial	Saturated	Cased-off
210	Partial	Saturated	Cased-off
440	Partial	Reservoir	
450	Total	Reservoir	
500	Total	Reservoir	

Relevant Information:

Temperature logs show aquifers at 600 and 850 m depth. The well has been on line since 1981 producing fluids with enthalpy of 240 kcal/kg (1000 kJ/kg). This correlates well with the liquid temperature of 225-230°C at 700-800 m depth. Bottom temperature is 220°C. The well has showed little or no temperature decline but pressure drawdown during the period 1979-1987 is 7 bar. The "water level" under pressure has sunk from about 550 m depth in 1979 to 600 m depth in 1987.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
190	Saturated zone	Minor	Cased-off
210	Saturated zone	Minor	Cased-off
440	Reservoir	Minor	Two phase
450	Reservoir	Major	Two phase
500	Reservoir	Major	Two phase
600	Reservoir	?	Two phase/Liquid
850	Reservoir	?	Liquid

Geochemistry:

Data:

Chemical Data : ---

Physical Data : ---

Initial Conditions:

253°C and 7400 ppm Cl.

Initial T_{NKC} was 253±2°C; T_E (except for one value) and T_{SIL} were not much lower at 249°C and 246°C. Initial aquifer chloride based on both T_{NKC} and T_E was 7400±200 ppm.

Changes With Time:

After 6 months of production, T_E started to drop and the order remained $T_{NKC}>T_{SIL}>T_E$ for the rest of the history, indicating mixture of cooler water in the wellbore that lowered actual fluid temperatures (T_E), lowered T_{SIL} by dilution, but affected T_{NKC} very little. Calculated cool water temperature was 60±40°C throughout (see figure 8.1, Chapter 8).

Chloride calculated from measured enthalpy is possibly a bit more constant than chloride calculated from T_{NKC} and significantly higher, averaging 7700 ppm rather than 6800 ppm.

Summary:

Drawdown rapidly caused inflow of cooler water into the well from an overlying aquifer.

WELL AH-29

INJECTION WELL

Coordinates:

Latitude : 311,096.89 m

Longitude: 412,510.50 m

Drilling Dates:

Started : November 6, 1975

Finished: February 11, 1976

Elevation: 794.75 m

Depth: 1198.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	101	$13\frac{3}{8}$"	99.0
$12\frac{1}{4}$"	550	$9\frac{5}{8}$"	545.5
$8\frac{1}{2}$"	1198	$7\frac{5}{8}$"	486.82-816

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
85	Total	Ground water	Cased-off
570	Total	Reservoir	
580-630	Partial	Reservoir	
610	Total	Reservoir	
680	Total	Reservoir	

Relevant Information:

Reinjecton was stopped since it is close to AH-5.

Spinner survey shows that almost half of the injected water disappears at the end of the liner. It is likely that this water flows upwards in the annulus behind the liner towards the aquifers at 570-680 m depth. The spinner shows also that about 20% of the water leaks out at 840-870 m depth and 35% continues down to the deeper portion of the well.

The temperature logs show that the injection cools the well to the "bottom" (1144 m). All earlier logs show the same characteristics: sharply rising temperatures to a maximum at 500 m depth (200-220°C) but with an isothermal or a slight negative gradient from 600 to 1144 m depth (170-180°C). After reinjection was stopped, the well developed a 20 bar pressure on top with "water table" around 600 m depth. The temperature measured was 210°C in 1987 decreasing to 180°C at 1050 m depth, the deepest point measured in the well.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
85	Ground water	Major	Cased-off
570	Reservoir	Major	Two phase
580-630	Reservoir	Minor	Two phase
680	Reservoir	Major	Two phase/Liquid
840-870	Reservoir	Major	Liquid
1140	Reservoir	Major(?)	Liquid

Geochemistry:

No data.

WELL AH-30

PRODUCTION/STAND-BY WEll

Coordinates:

Latitude : 310,461.09 m

Longitude: 411,989.59 m

Drilling Dates:

Started : December 5, 1978

Finished: February 17, 1979

Work-over:

Started : September 17, 1985

Finished: October 4, 1985

Purpose : To deepen the well

Elevation: 803.97 m

Depth: 1200.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	117.5	$13\frac{3}{8}$"	115.0
$12\frac{1}{4}$"	462.5	$9\frac{5}{8}$"	460.0
$8\frac{3}{4}$"	1200.0	$7\frac{5}{8}$"	434.78-1195

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
25	Partial	Ground water	Cased-off
70	Partial	Ground water	Cased-off
260-450	Partial	Saturated zone(?)	Cased-off
465	Partial	Reservoir(?)	
500	Partial	Reservoir	
525	Partial	Reservoir	
550	Total	Reservoir	

Relevant Information:

No cuttings were obtained below 675 m depth.

No production data is available from this well (discharge measurements, spinner, flowing temp. and pressure logs).

The well was drilled in 1978/9 and worked over in September 1985. The well was deepened during the work-over from 900 to 1200 m. No pivot point coulb be obtained from the pressure logs. Pressure drawdown during 1979-1986 is in the order of 5 bar. This drawdown developed during the first three years.

Aquifers seen in the temperature logs, just after drilling and work-over, are at the following depths: 450, 500, 550, 600 and 1150 m. Prior to the work-over, temperatures in the liquid part of the well were almost constant at 220°C (down to 900 m). Since fall of 1985, the liquid portion showed the same isothermal profile but the temperature dropped to 215°C. This can be explained by an upward cross flow in the well. Before the work-over the aquifer close to 900 m depth is the source for this flow (T=220°C). Later as the well was deepened, fluids from colder aquifers at 1050 and 1150 contributed to the upflow.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
25	Ground water	Minor	Cased-off
70	Ground water	Minor	Cased-off
260-450	Saturated zone	Minor	Cased-off
465	Reservoir	Minor	Two phase
500	Reservoir	Minor	Two phase
525	Reservoir	Minor	Two phase
550	Reservoir	Major	Two phase
600	Reservoir	Major(?)	Two phase
900	Reservoir	?	Liquid
1050	Reservoir	?	Liquid
1150	Reservoir	?	Liquid

Geochemistry:

No data.

WELL AH-31

PRODUCTION WELL

Coordinates:

Latitude : 310,098.48 m

Longitude: 412,021.66 m

Drilling Dates:

Started : August 1, 1981

Finished: September 29, 1981

Elevation: 845 m

Depth: 1502.00 m

Casing Design:

Depth (m)	Type	Aquifer	Remarks
$17\frac{1}{2}$"	110.5	$13\frac{3}{8}$"	109
$12\frac{1}{4}$"	492.0	$9\frac{5}{8}$"	489.8
$8\frac{1}{2}$"	1500.0	$7\frac{5}{8}$"	468.7-1495
$6\frac{1}{8}$"	1502.0		

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
30	Total	Ground water	Cased-off
50	Total	Ground water	Cased-off
250	Partial	Saturated	Cased-off
560	Total	Reservoir	

Relevant Information:

No cuttings were obtained below 1000 m depth.

No flowing surveys were available from this well (temperature, pressure and spinner).

The first pressure survey available was run in January 1982 about 3 months after completion. The well had recovered at that time and no pivot point can be seen in the later pressure logs. Pressure drawdown between 1982 and 1986 is in the order of 2-3 bar.

Maximum temperature of 230-235°C was measured at about 800 m depth. Below 1000 m an almost constant temperature is observed in the logs down to the present bottom at 1450 m depth (220-225°C). Earlier surveys (1981/2) reached down to 1475 m depth and showed a temperature inversion of few degrees between 1450 and 1475 m. The temperature profiles indicate a crossflow down the well with the deepest inflow at 1000 m and the deepest outflow at 1450 m depth.

Reservoir temperatures around this well seem to have remained unchanged since it was drilled in 1981.

From the information on circulation losses, one would expect the main production aquifer to be at 560 m depth where total loss was encountered or around 1000 m depth where drill cutting recovery ceased. The aquifer at 560 m is within the two phase region of the reservoir and pressure and temperature in the well were less than 20 bar and 210°C respectively. As discharging enthalpies (240-260 kJ/kg) indicate a liquid water inflow during discharge, it is unlikely that the main inflow is within the two phase zone.

Aquifers:

Depth (m)	Aquifer	Contribution	Remarks
30	Ground water	Major	Cased-off
50	Ground water	Major	Cased-off
250	Saturated zone	Minor	Cased-off
560	Reservoir	Minor	Two phase
1000	Reservoir	Major	Liquid
1450	Reservoir	Minor	Liquid

Geochemistry:

Data:

Chemical Data : 01/85-04/87

Physical Data : 04/85-12/86

Initial Conditions:

258°C and ?.

The data on this well is scant and starts with $T_{NKC}>T_{SIL}>>T_E$, suggesting mixing in the well from start of production. Fluid not affected by mixing was near 258°C (T_{NKC}) or 250°C (T_{SIL}) and after mixing wellbore liquid was near 228°. Chloride calculated from enthalpy was near 8700 ppm. This was after mixing.

Changes With Time:

From the start, temperatures and chloride concentrations were nearly constant, suggesting that mixing in the well occurred from the start. No calculation could be made of the cool water chloride because T_{SIL} was too close to T_{NKC} (see figure 8.1, Chapter 8). This behavior could also result from conductive cooling in the wellbore.

Summary:

A well with cold-water mixing or conductive cooling in the wellbore.

WELL AH-32

PRODUCTION WELL

Coordinates:

Latitude : 309,721.00 m

Longitude: 412,210.00 m

Drilling Dates:

Started : October 13, 1981

Finished: December 31, 1981

Work-over:

Started : August 15, 1985

Finished: August 30, 1985

Elevation: 882.03 m

Depth: 1504.00 m

Casing Design:

Casing size	Depth (m)	Casing size	Depth (m)
$17\frac{1}{2}$"	140	$13\frac{3}{8}$"	136.48
$12\frac{1}{4}$"	491	$9\frac{5}{8}$"	487.46
$8\frac{1}{2}$"	1500	$7\frac{5}{8}$"	472.25-1499
$7\frac{7}{8}$"	1504		

Circulation losses:

Depth (m)	Type	Aquifer	Remarks
142.3-146	Partial	Ground water	Cased-off
148.38-155	Partial	Ground water	Cased-off
159.25-191.25	Partial	Ground/Saturated	Cased-off
211.3-227	Partial	Saturated zone	Cased-off
246-256	Partial	Saturated zone	Cased-off
260.8-262	Partial	Saturated zone	Cased-off
279.5-288	Partial	Saturated zone	Cased-off
312.5-359	Partial	saturated zone	Cased-off
391.5-393	Partial	Saturated zone	Cased-off
407-473.49	Partial	Saturated zone	Cased-off
689.9-694	Partial	Reservoir	
694-848.49	Total	Reservoir	
1003.5-1500	Total	Reservoir	

Relevant Information:

No cuttings below 775 m depth were obtained.

Temperature logs shortly after drilling indicate a cross flow in the well from aquifers at about 800 m and 1000 m depth into the aquifer at about 1400 m depth. The dominant aquifers are inferred to be at 1000 and 1400 m depths. Similar temperature profiles were obtained after work-over in 1985.

Analysis of flowing temperature and pressure surveys conducted in April 1988 at flowrates of 20 and 45 kg/s showed a major feedzone at 975 m and a high enthalpy inflow at 775-800 m.

No pivot point is seen in the pressure logs either after drilling in 1981 or after work-over in 1985 not only due to small temperature variations in the well between logs but also because most of the pressure logs were run only to 700-800 m depth.

The pressure logs in 1982 and 1986/7 show little or no drawdown. There were no pressure logs from 1983 and 1984. Pressures after work-over in 1985 are low and may have indicated some drawdown at that time. These low pressures can, on the other hand, be explained as a cooling effect after the work-over, if the best feed zone is much deeper in the well than the deepest pressure values.

Aquifers:

Inferred locations of the production aquifers are:

Depth (m)	Aquifer	Contribution	Remarks
775-800	Reservoir	Minor	Two phase
975-1000	Reservoir	Major	Liquid
1100	Reservoir	Minor	Liquid
1400	Reservoir	Minor	Liquid

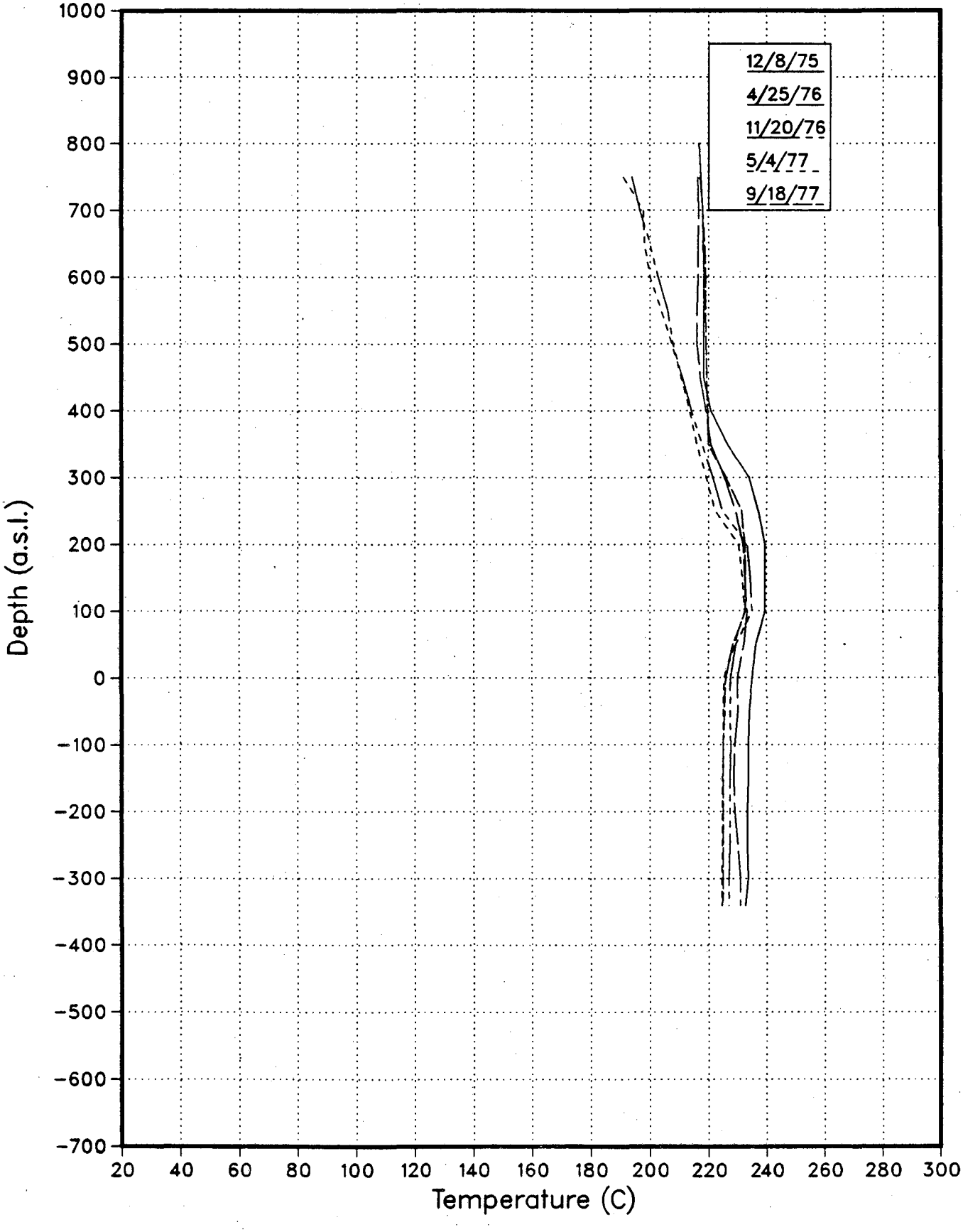
Geochemistry:

No data.

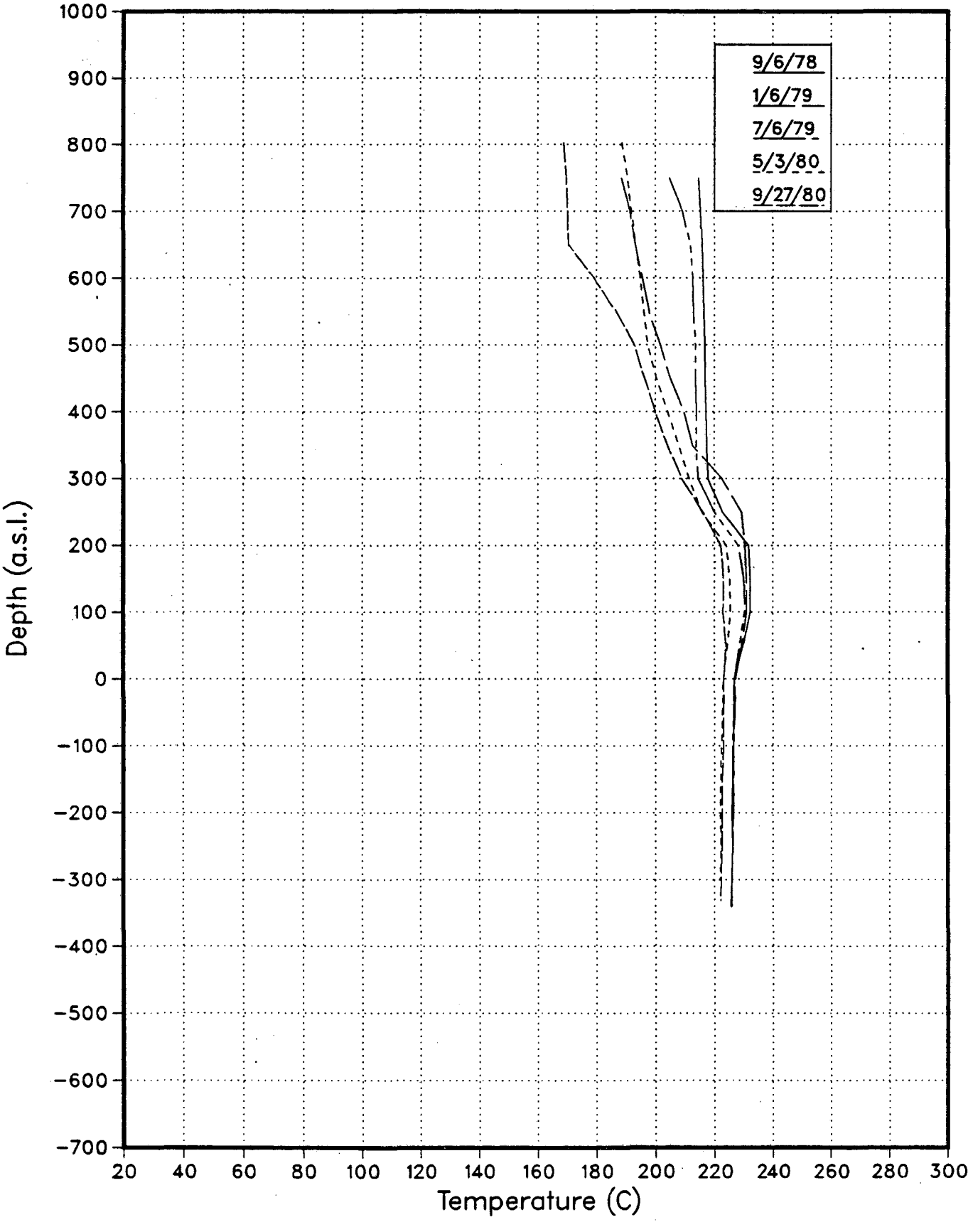
APPENDIX D

(Temperature Logs)

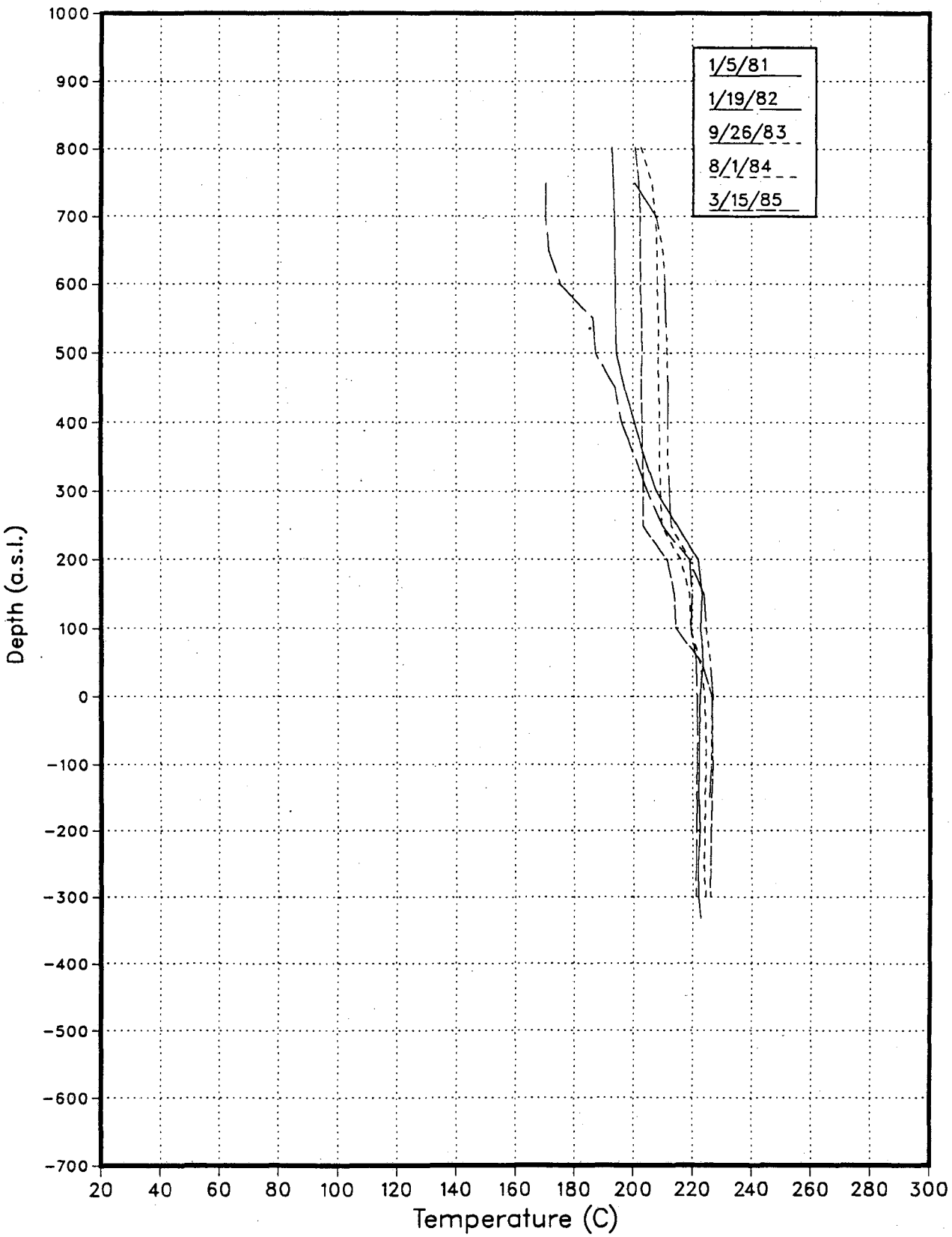
AH1 Temperature Surveys



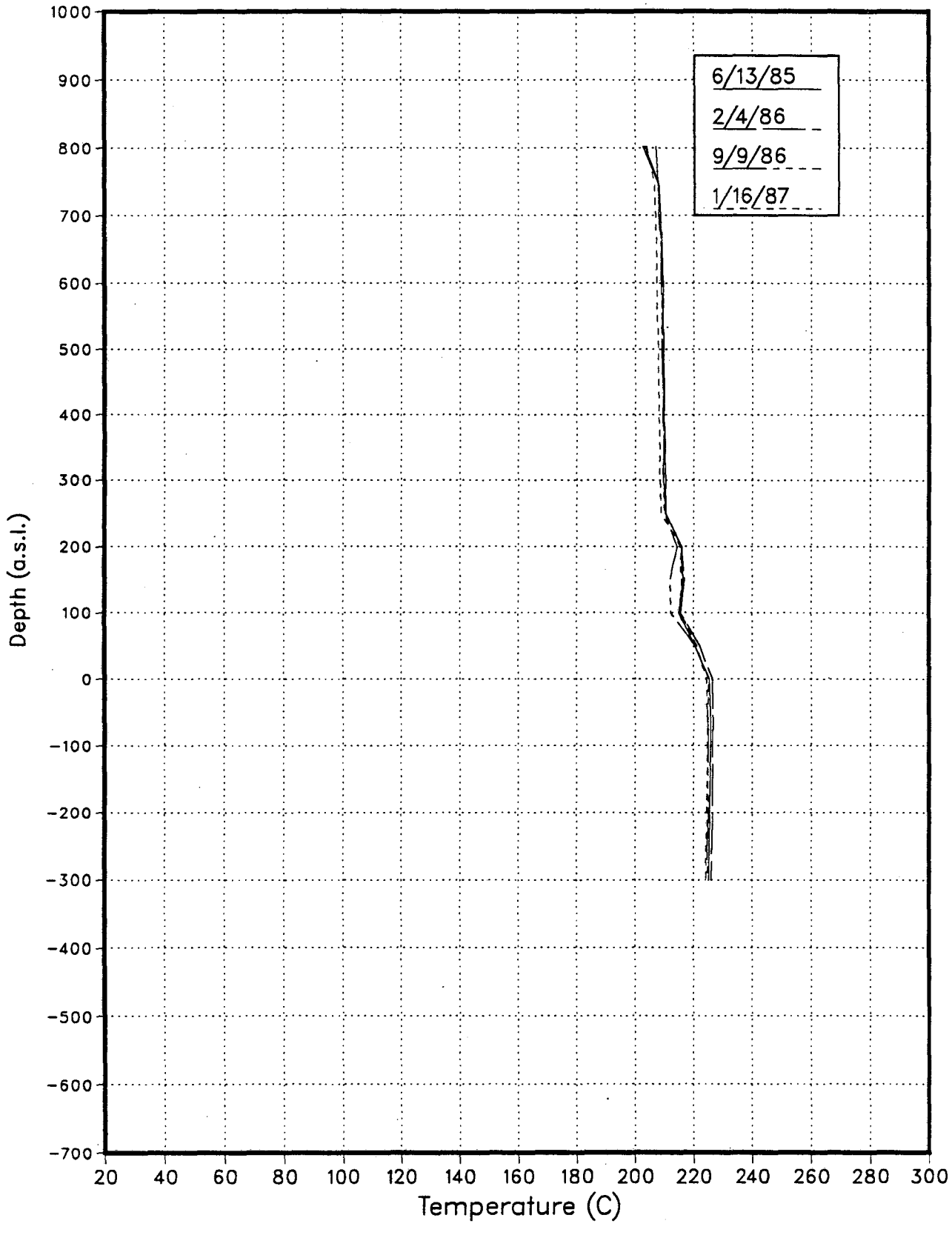
AH1 Temperature Surveys



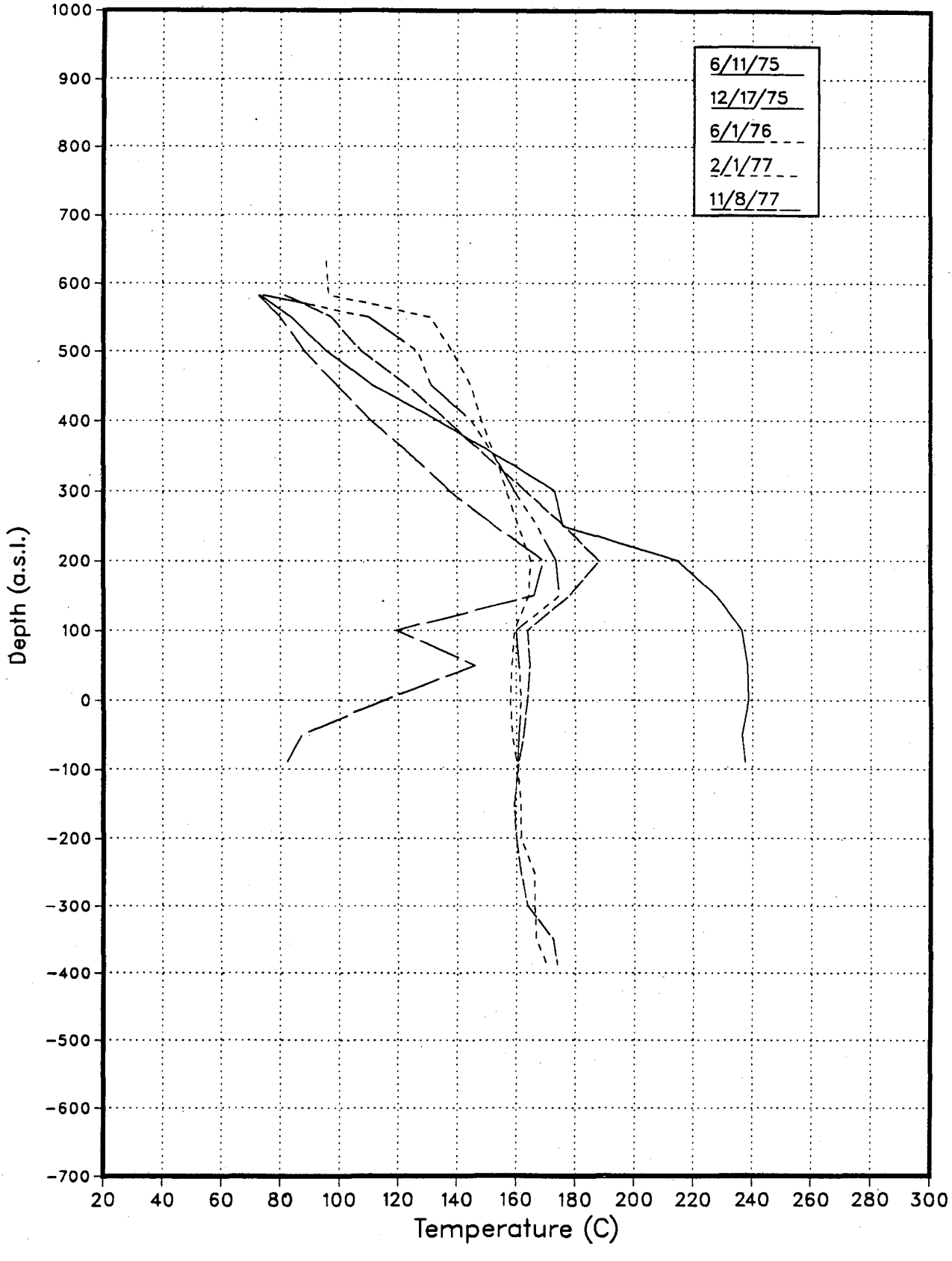
AH1 Temperature Surveys



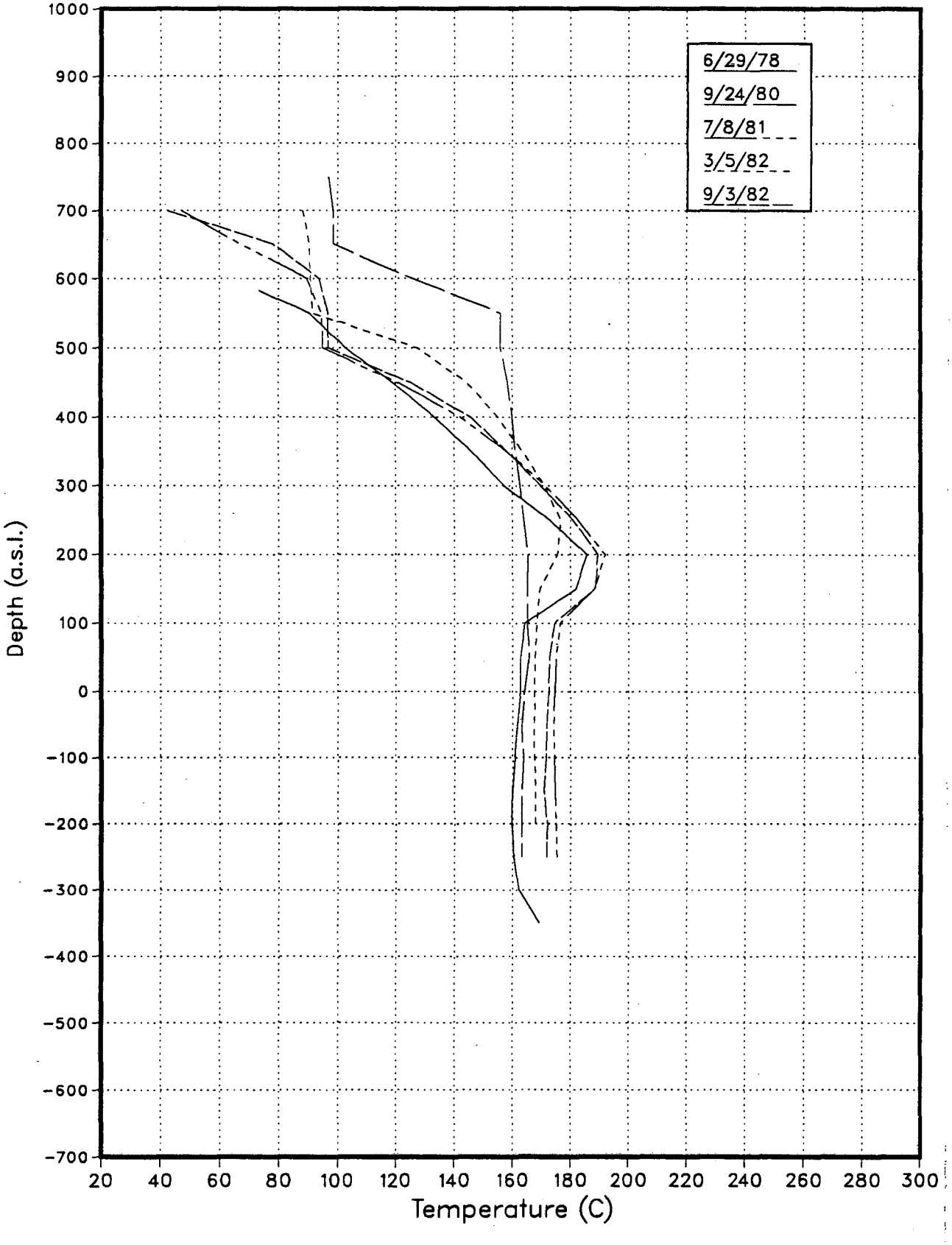
AH1 Temperature Surveys



AH2 Temperature Surveys



AH2 Temperature Surveys



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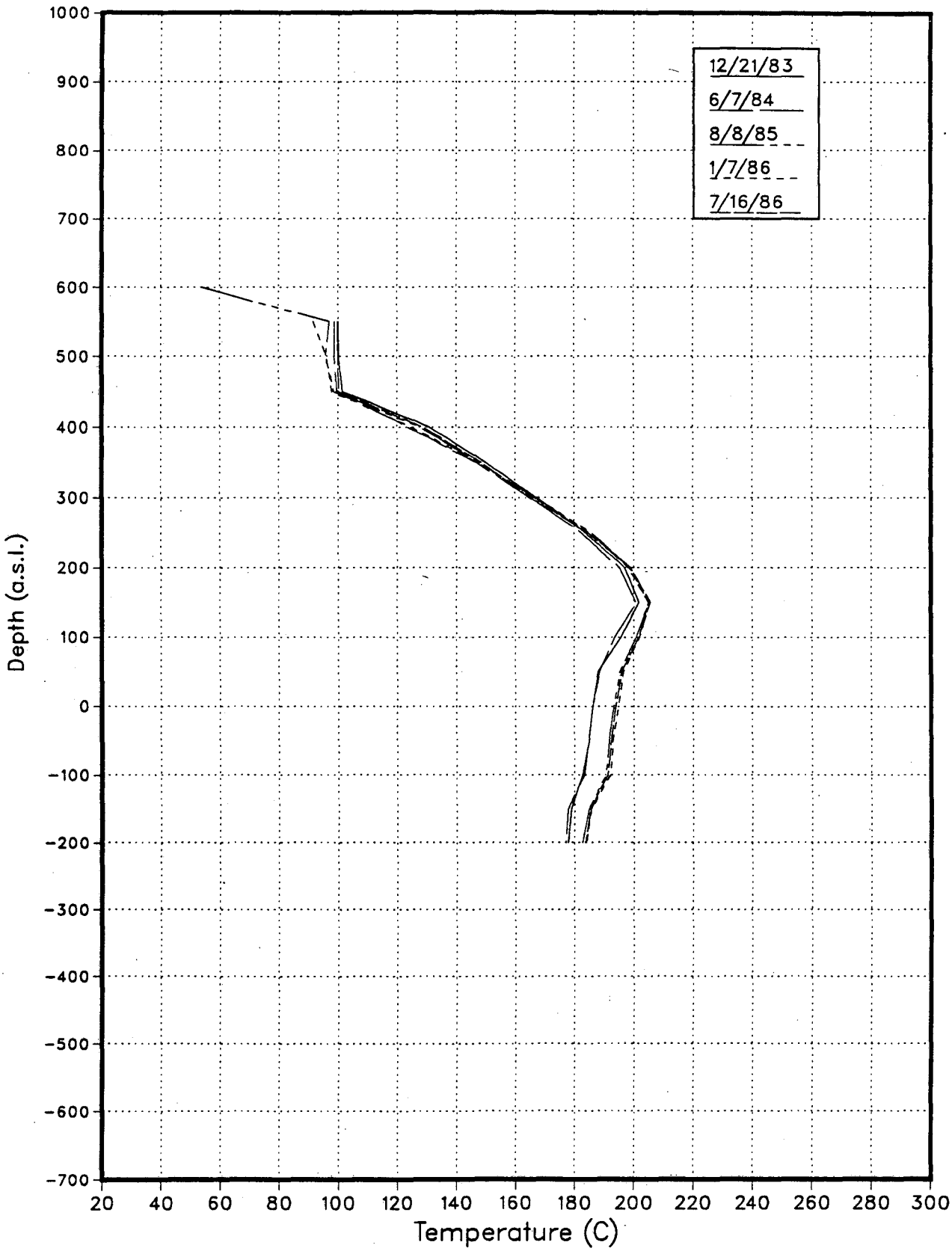

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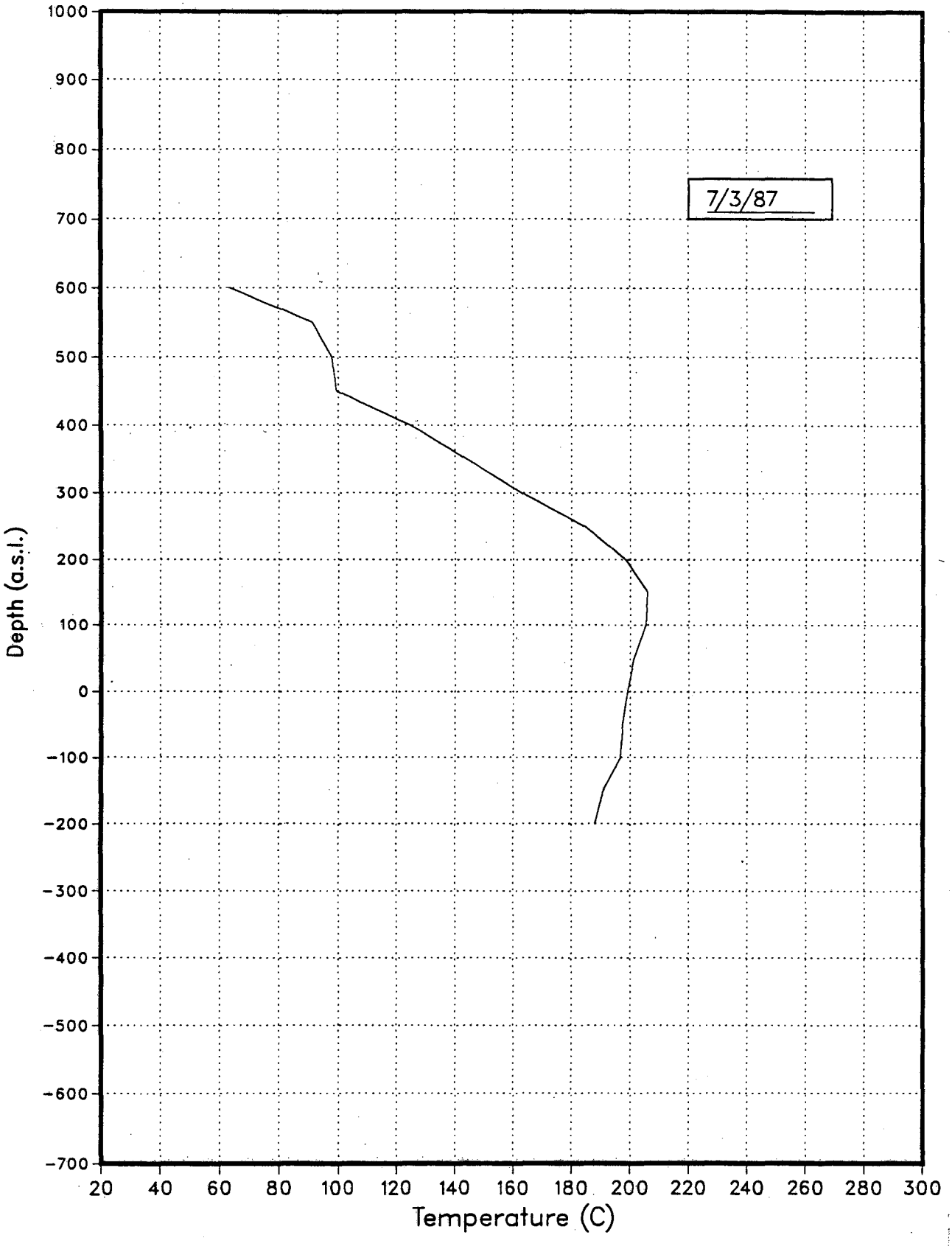
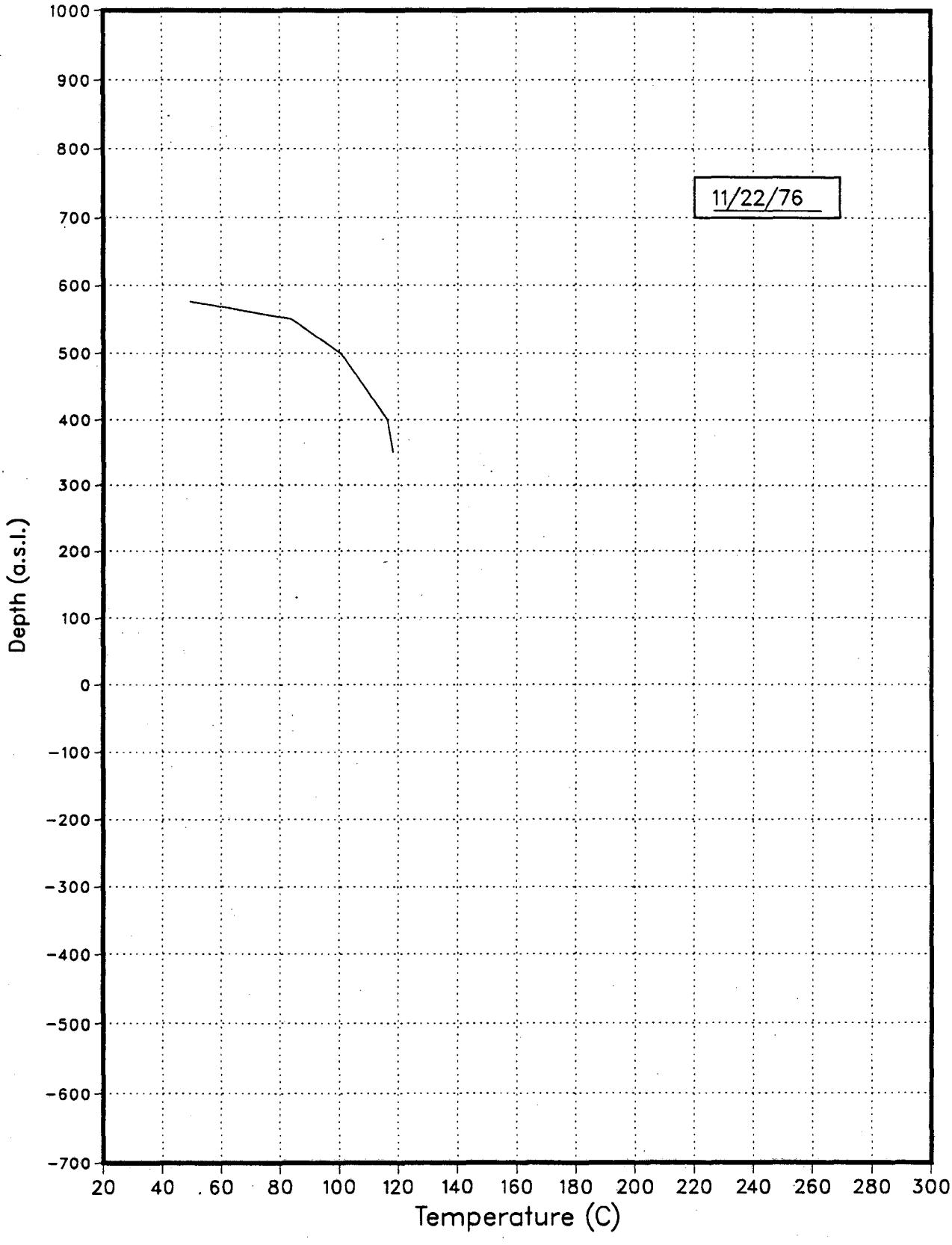
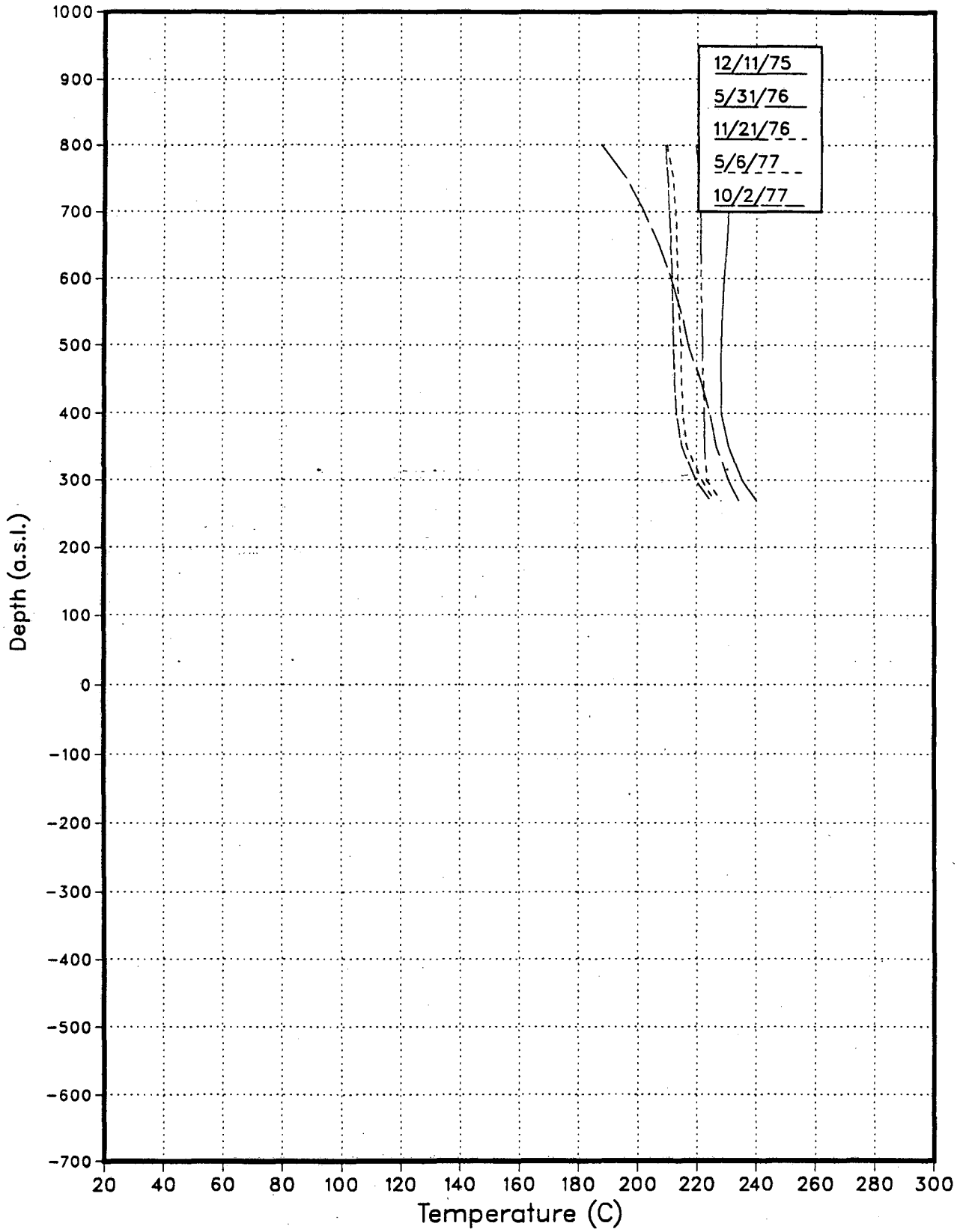


AH3 Temperature Surveys



AH4 Temperature Surveys



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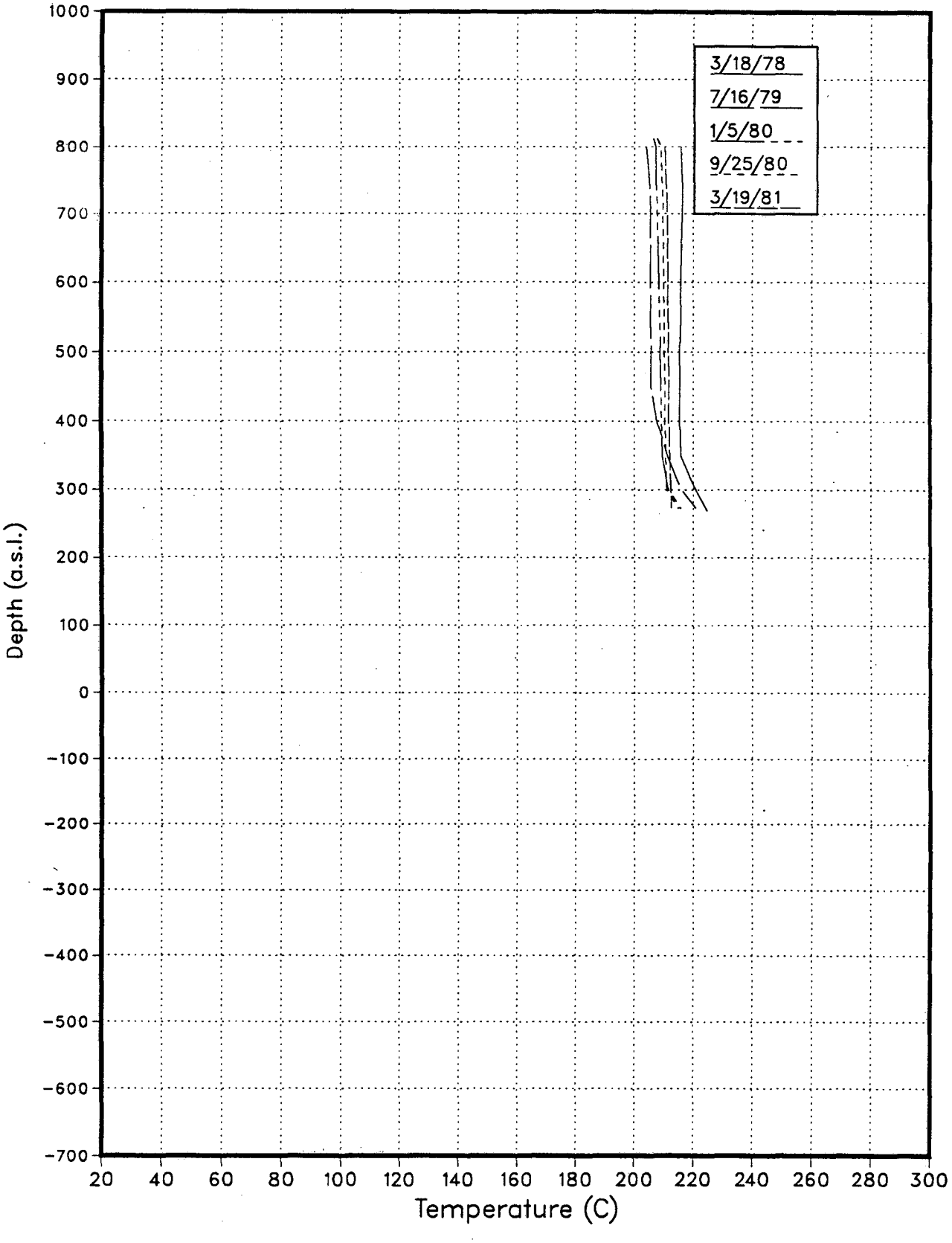

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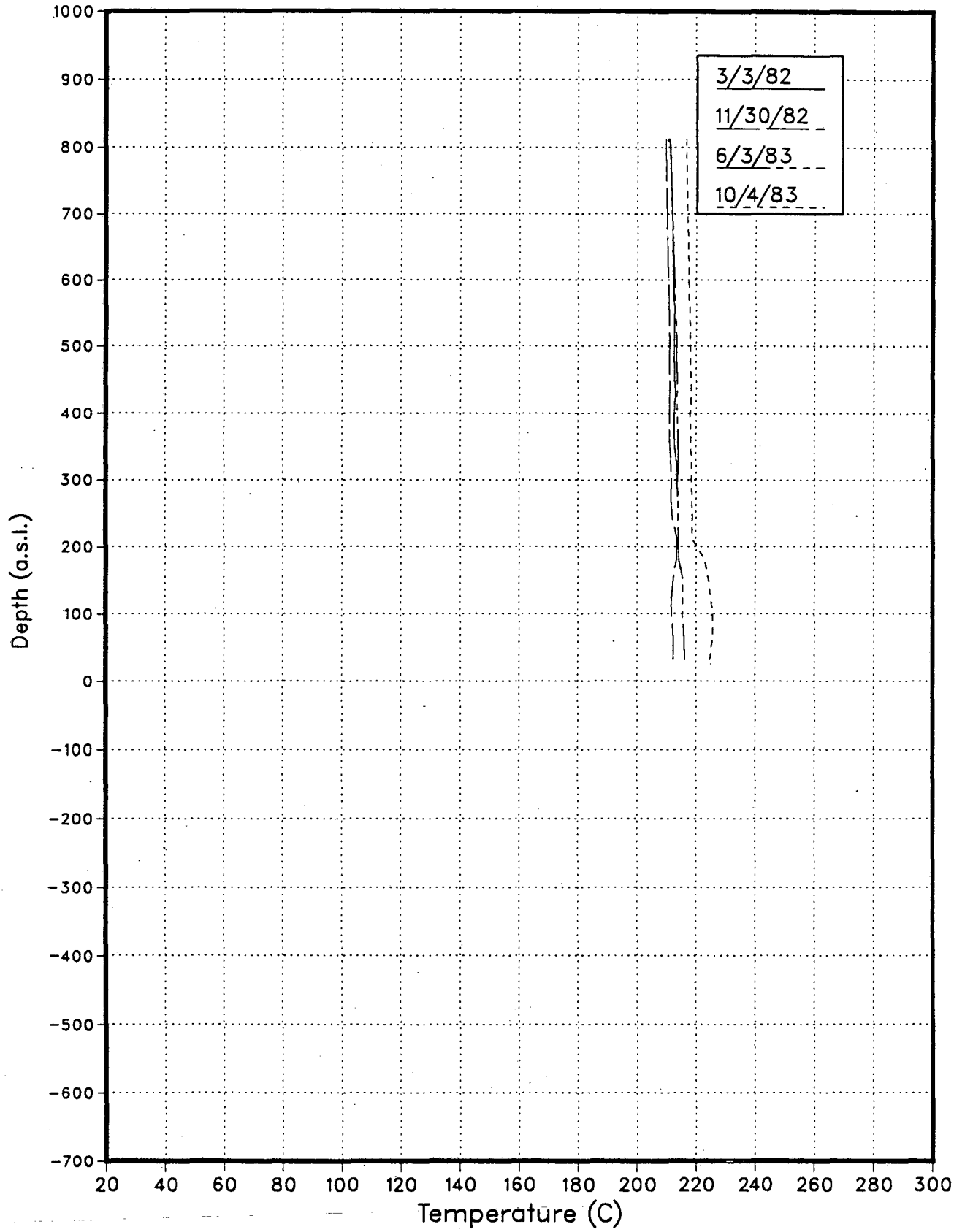

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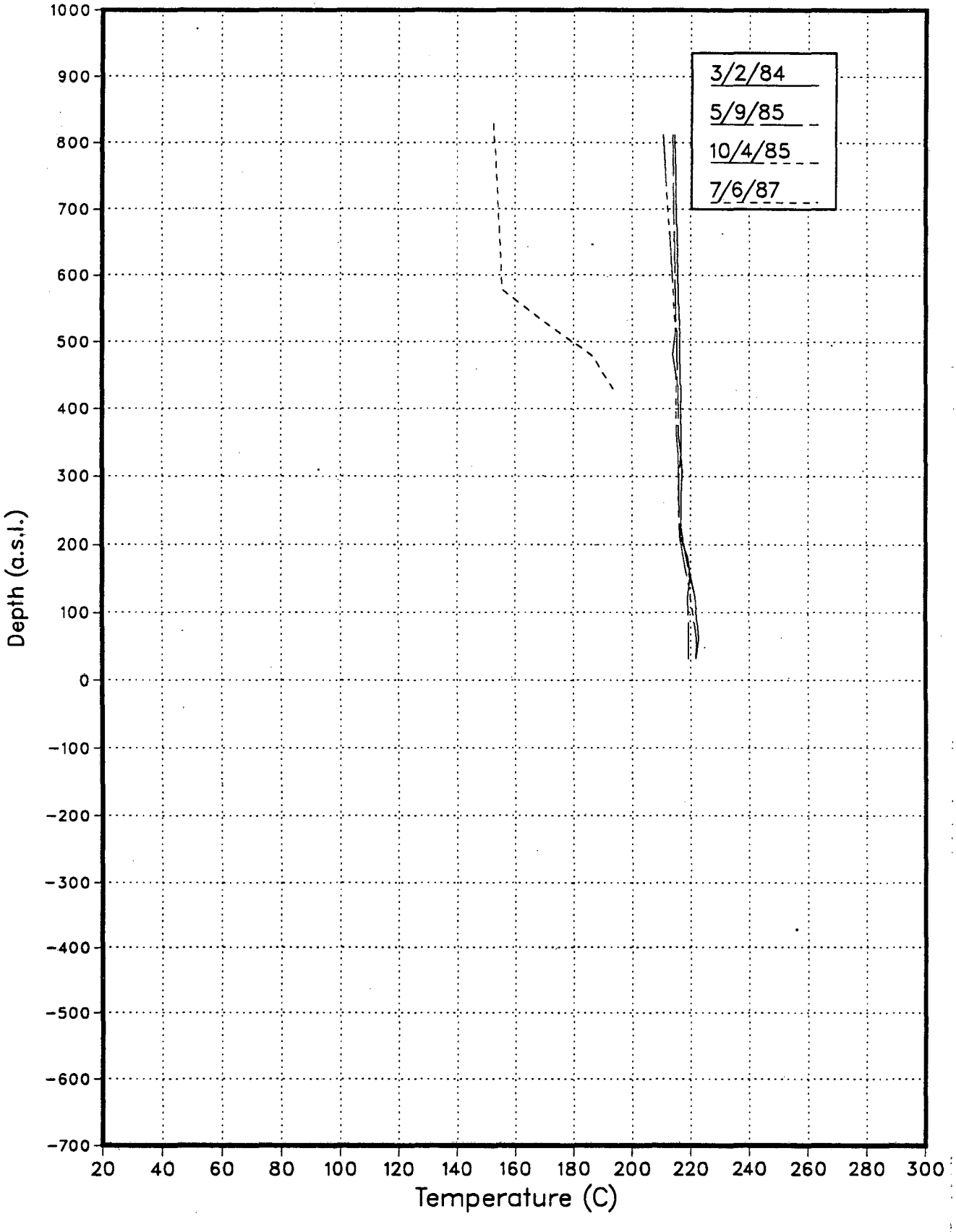
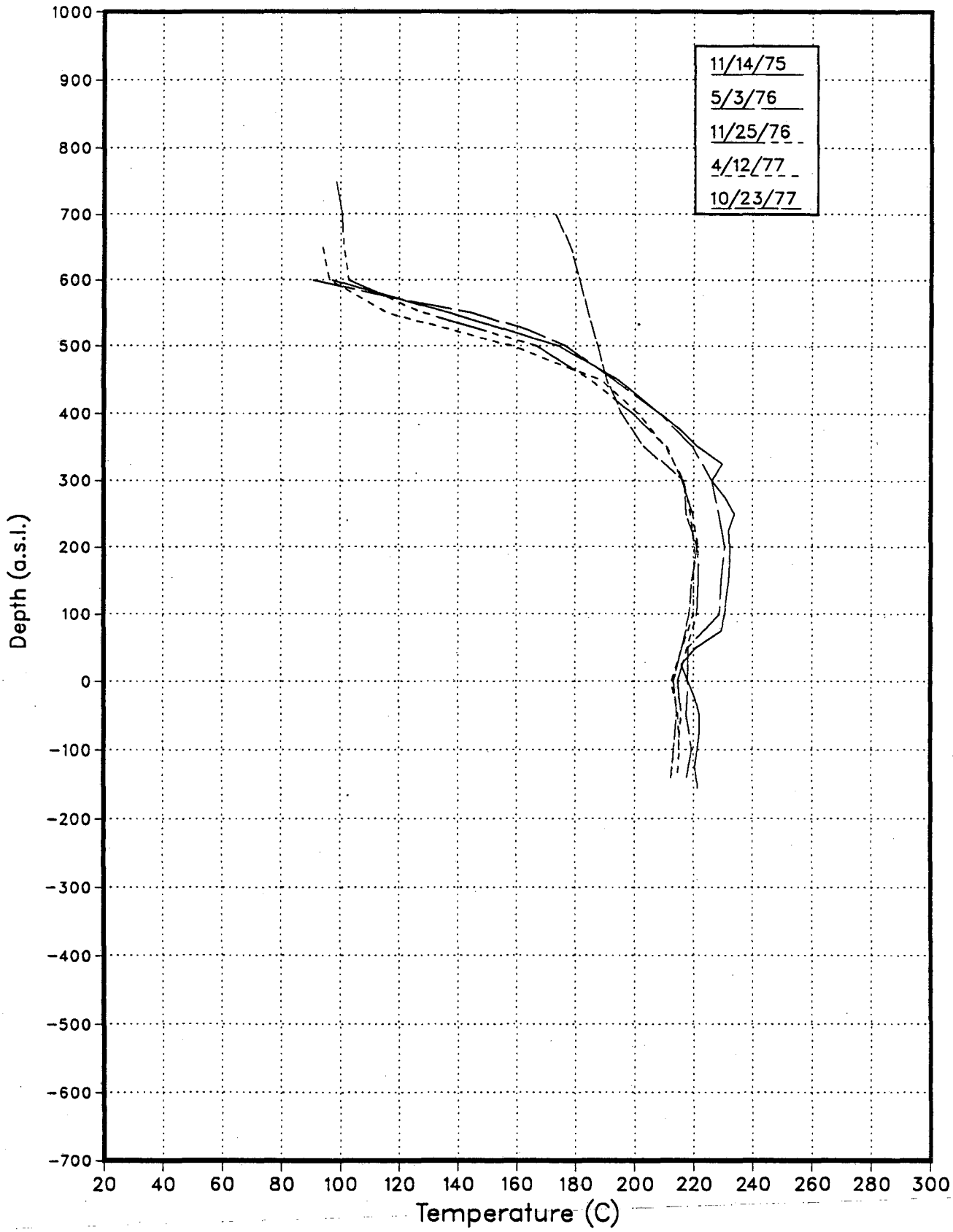


AH5 Temperature Surveys



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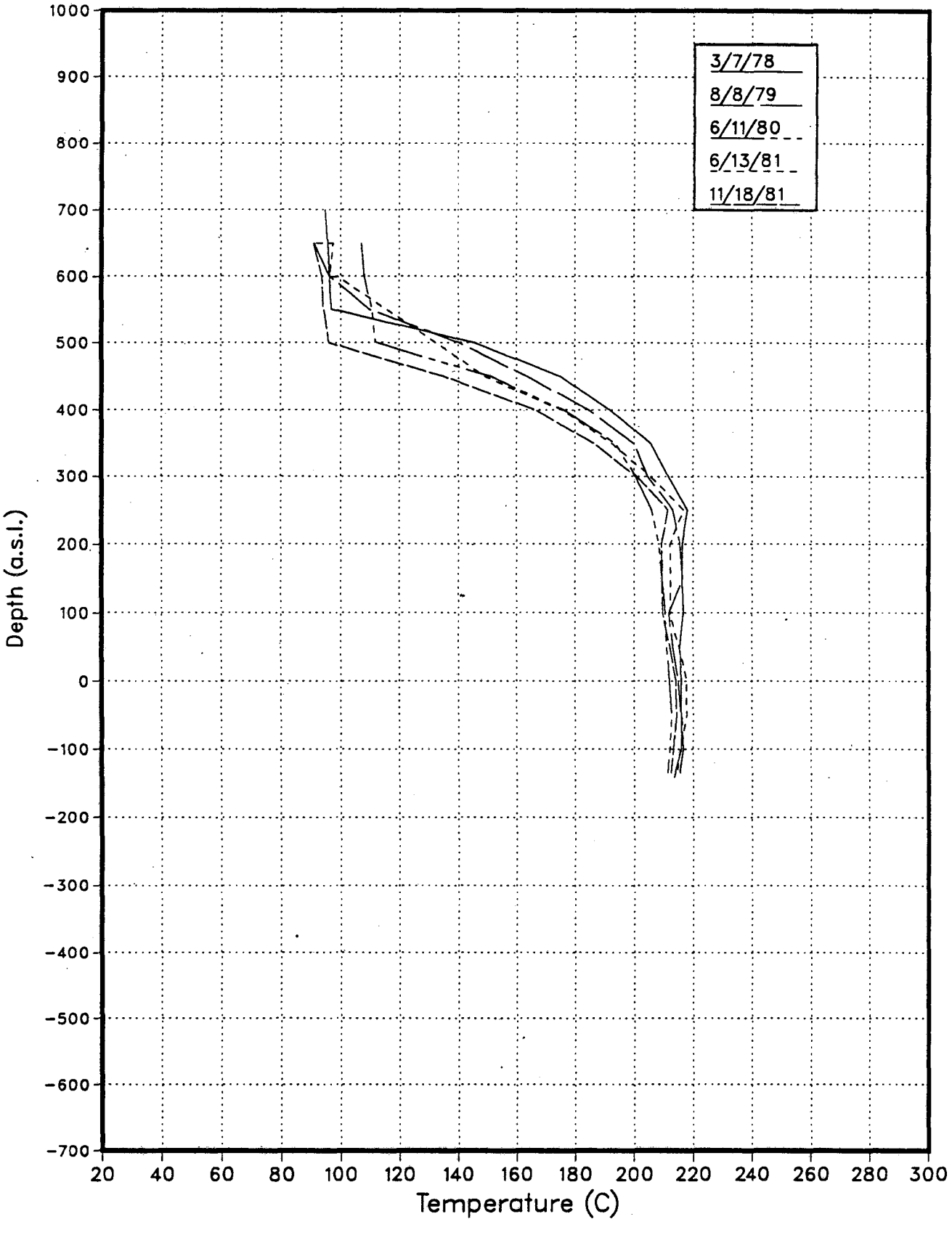

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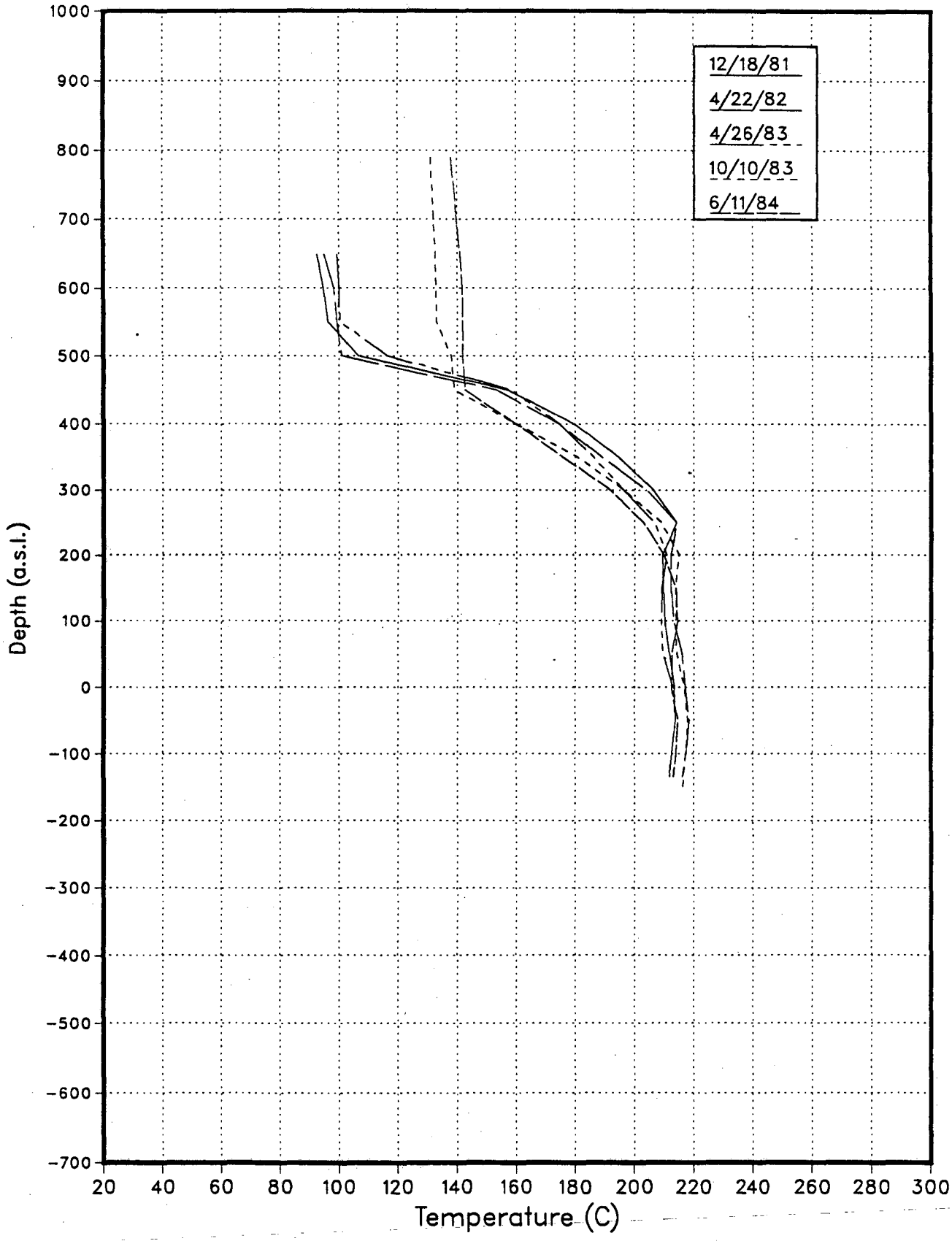
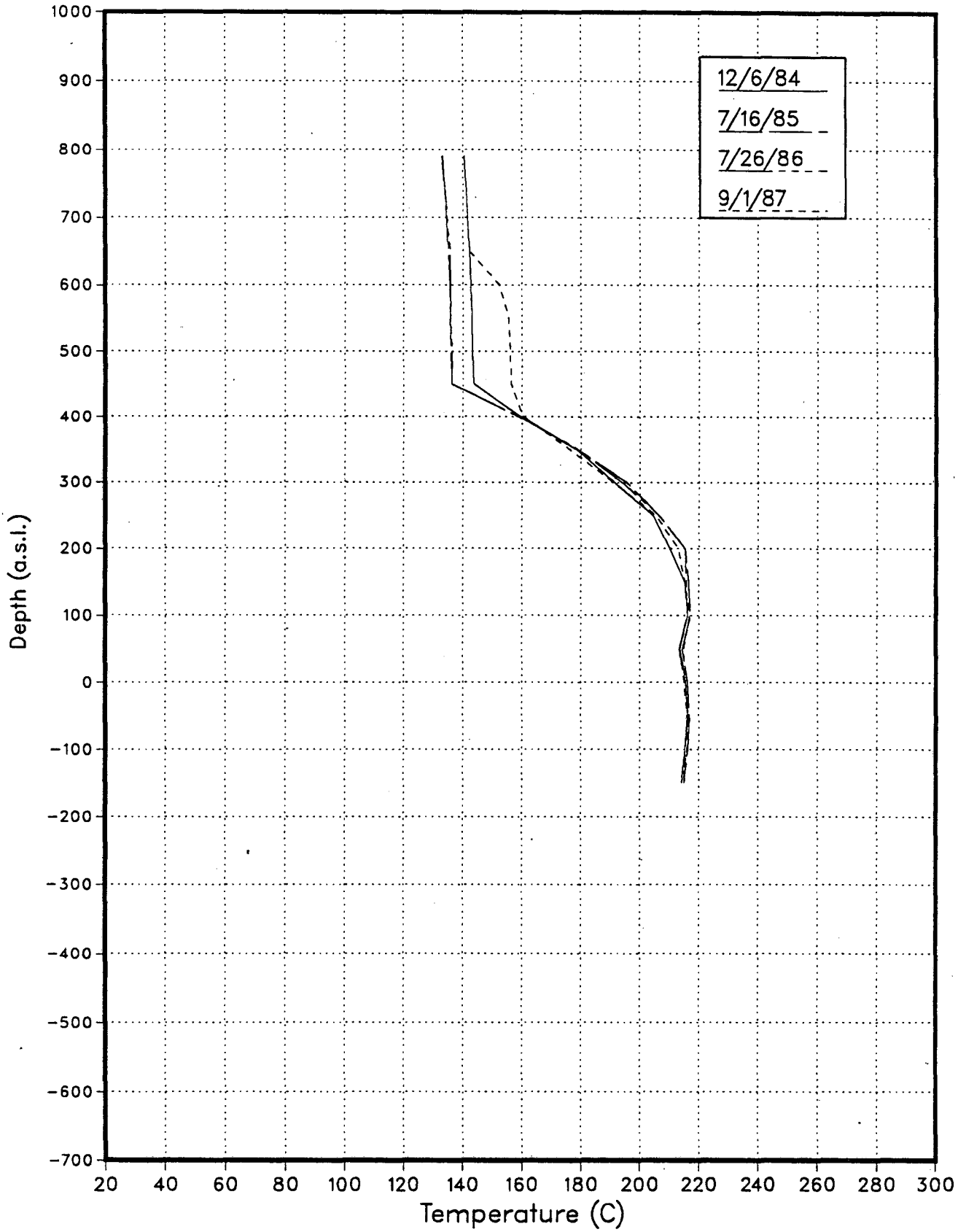
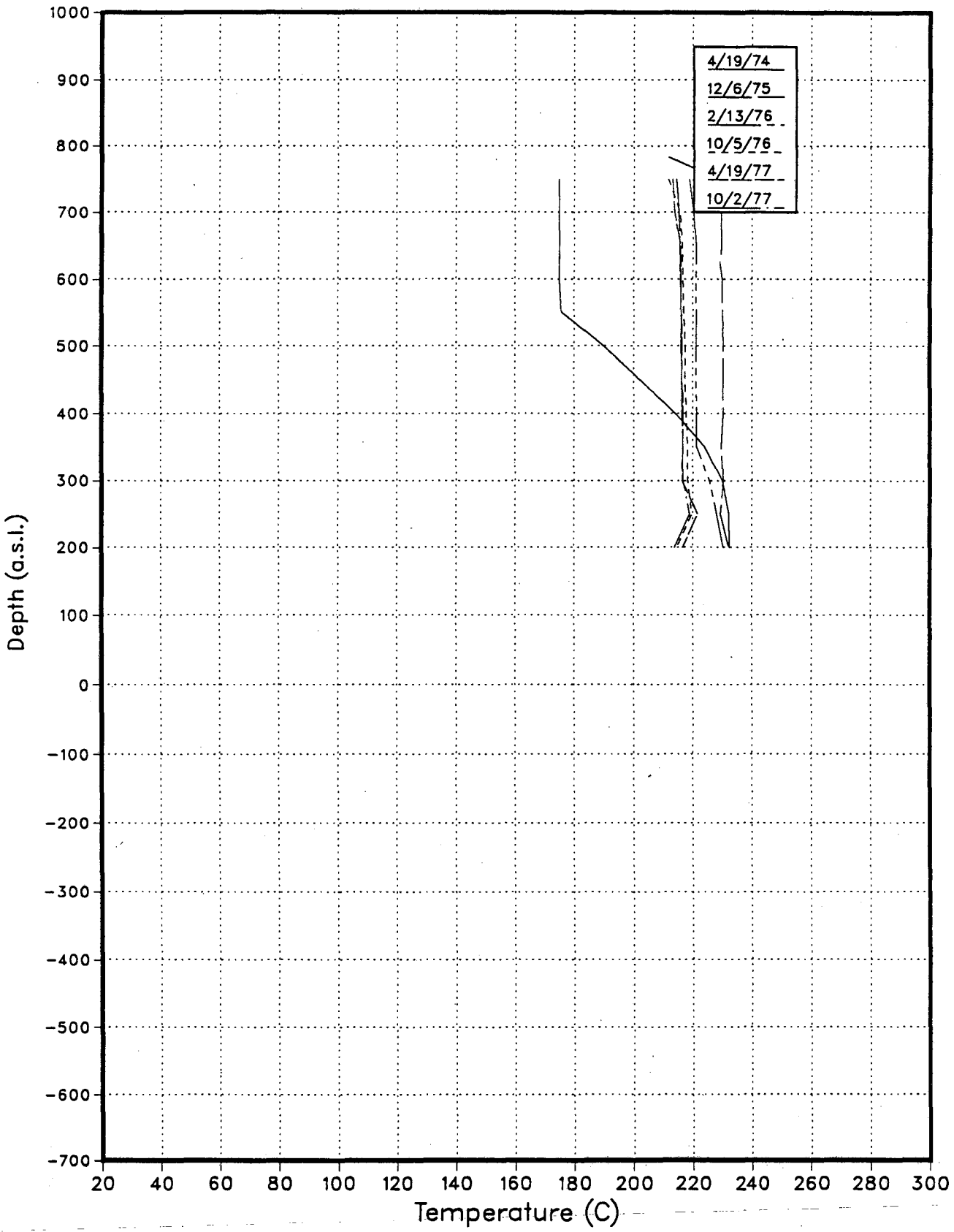


AH5 Temperature Surveys



AH6 Temperature Surveys



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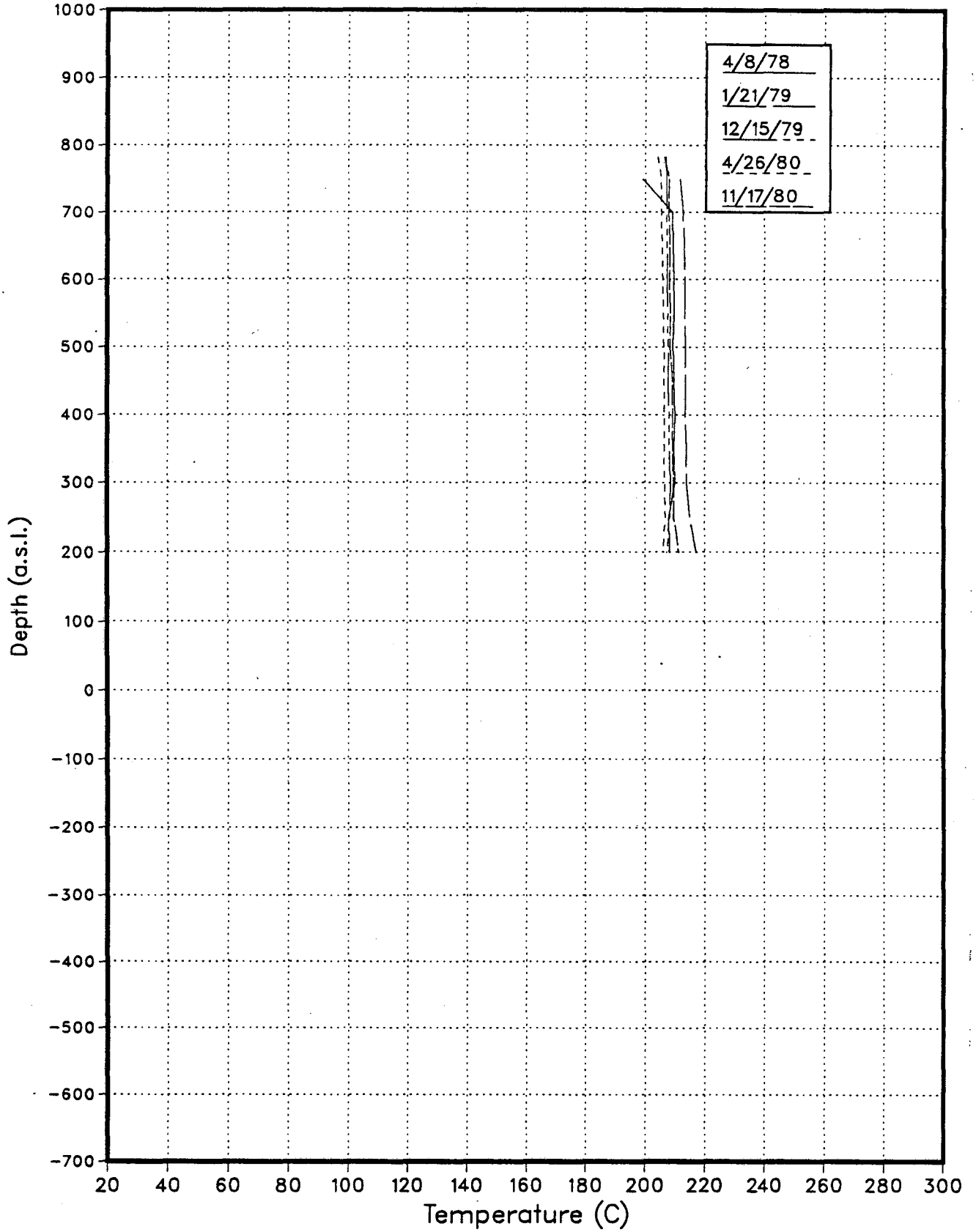
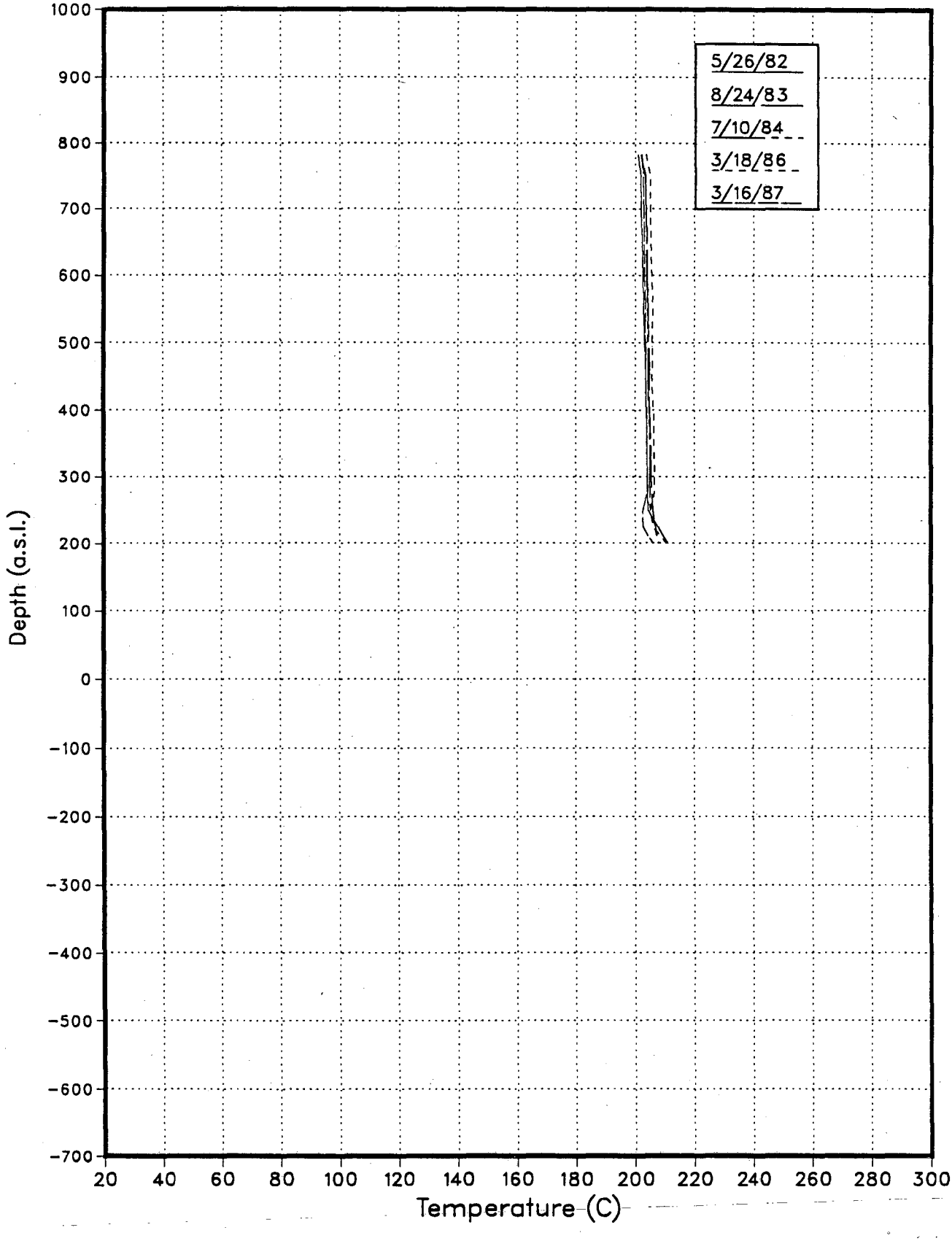
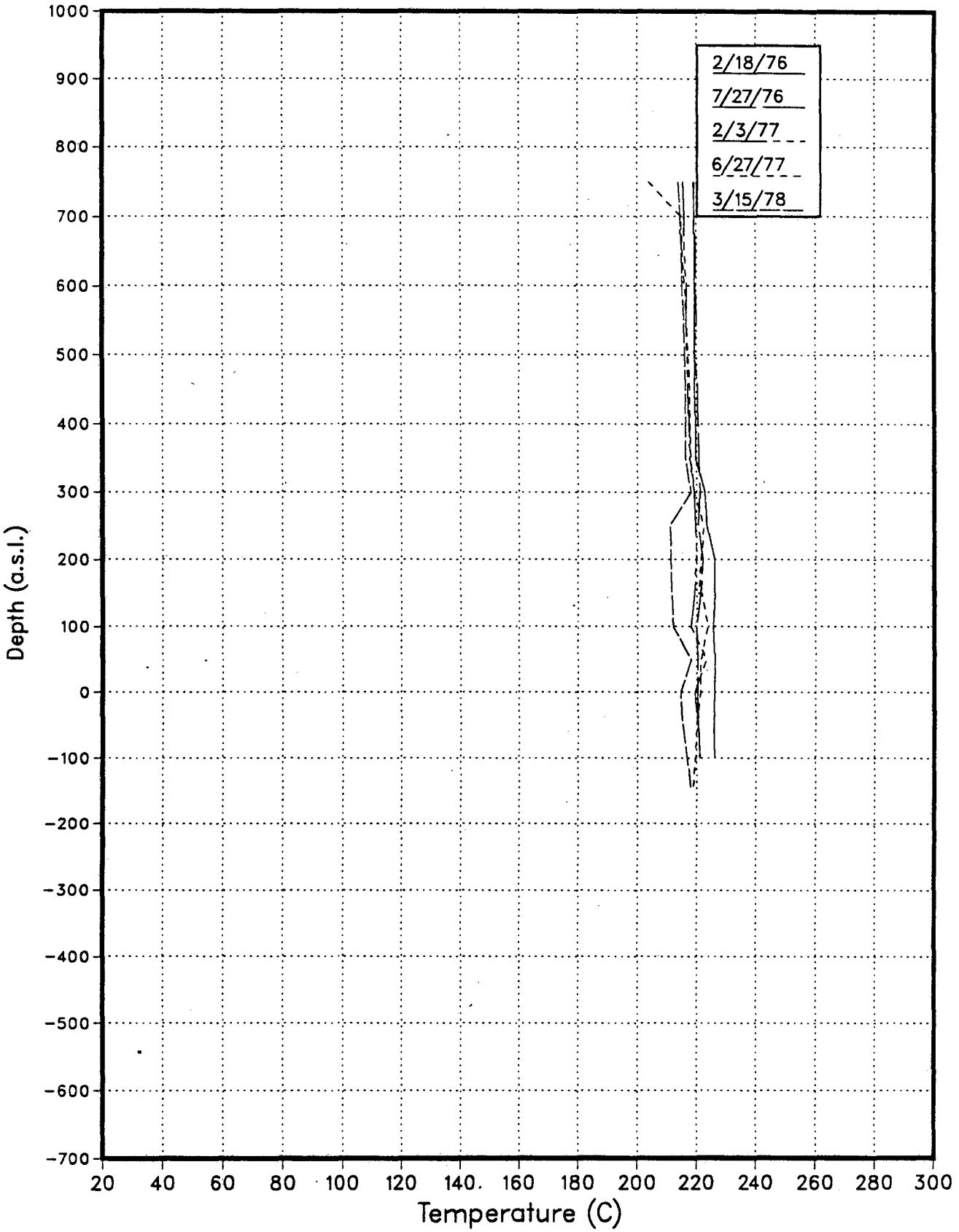


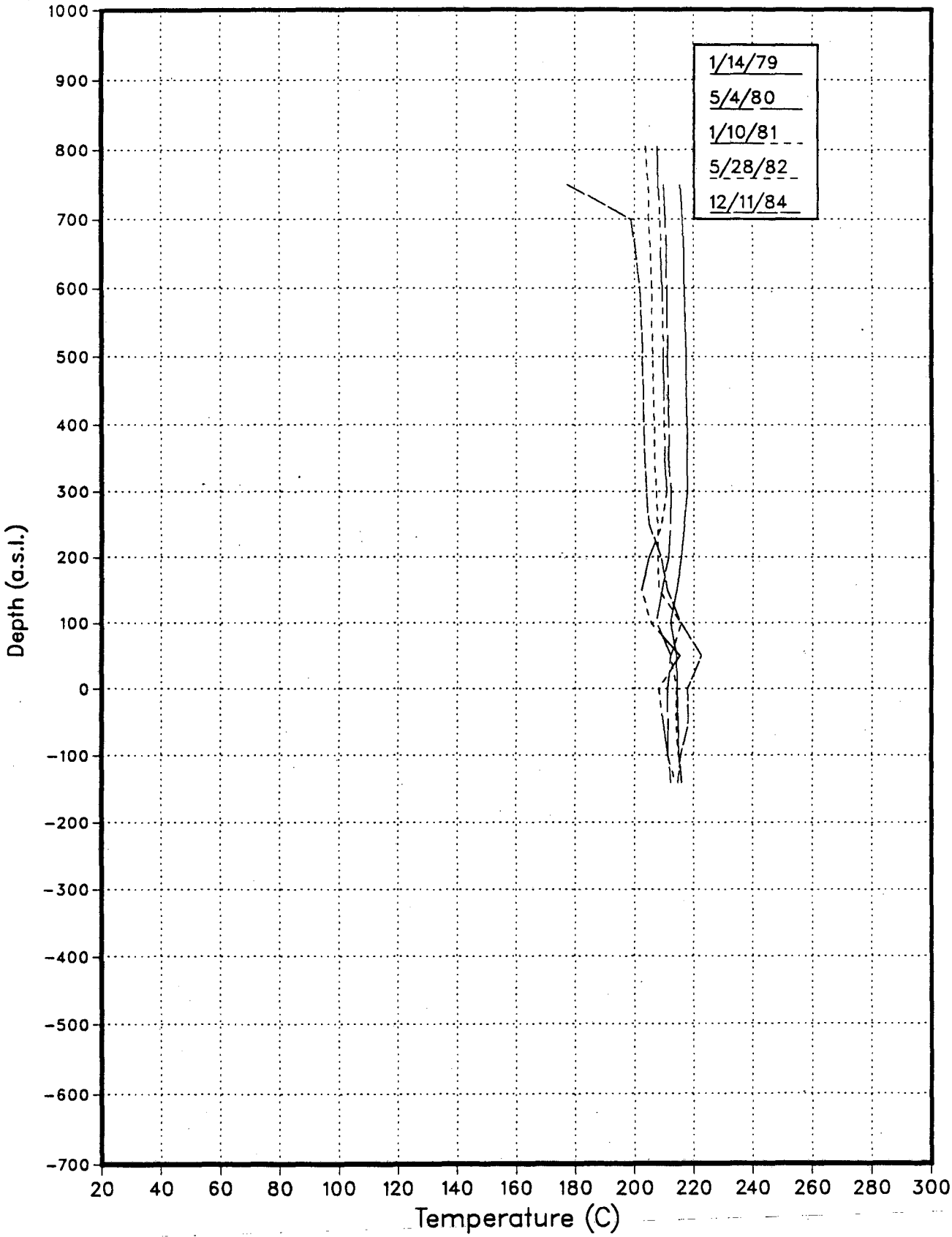
AH6 Temperature Surveys



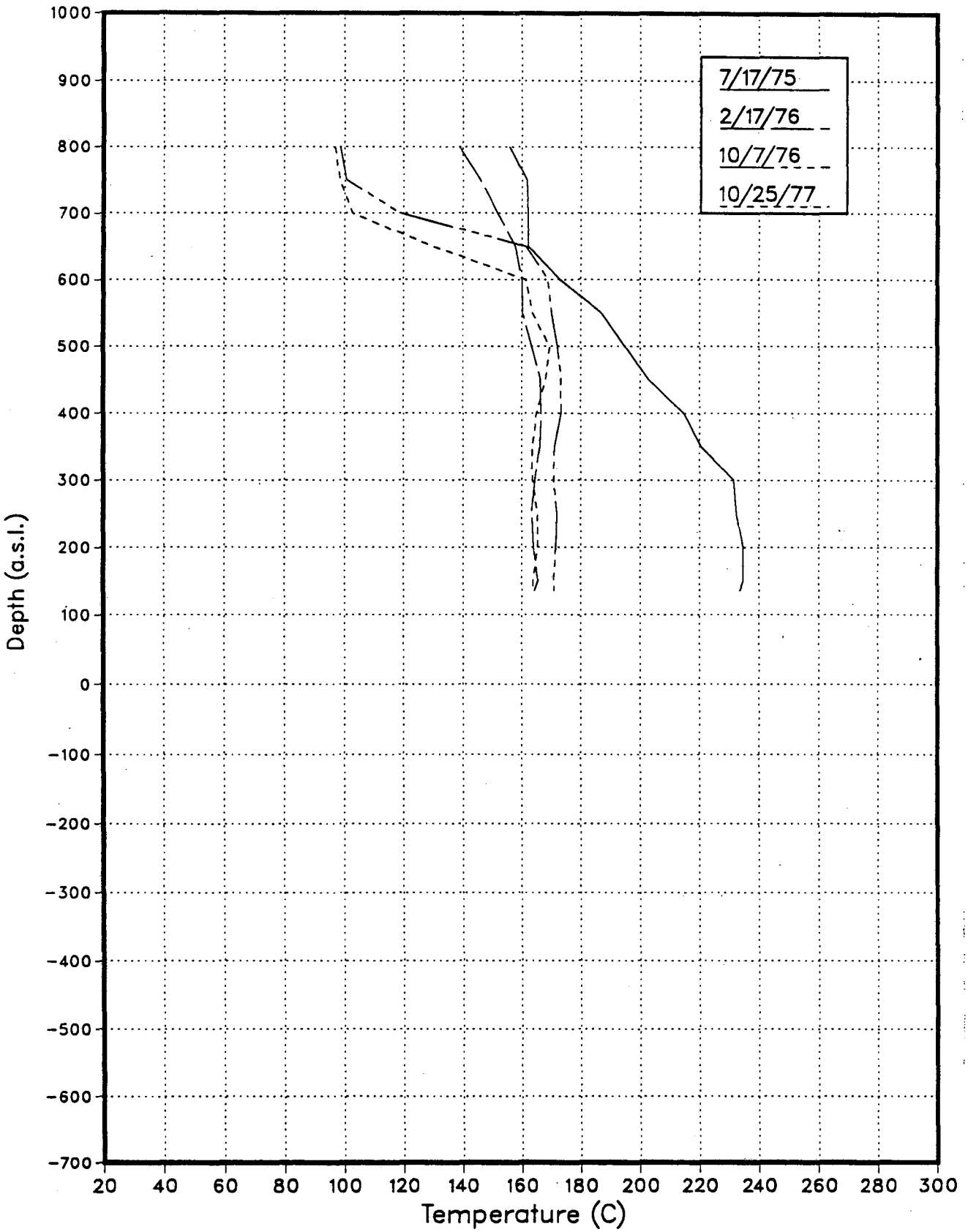
AH7 Temperature Surveys



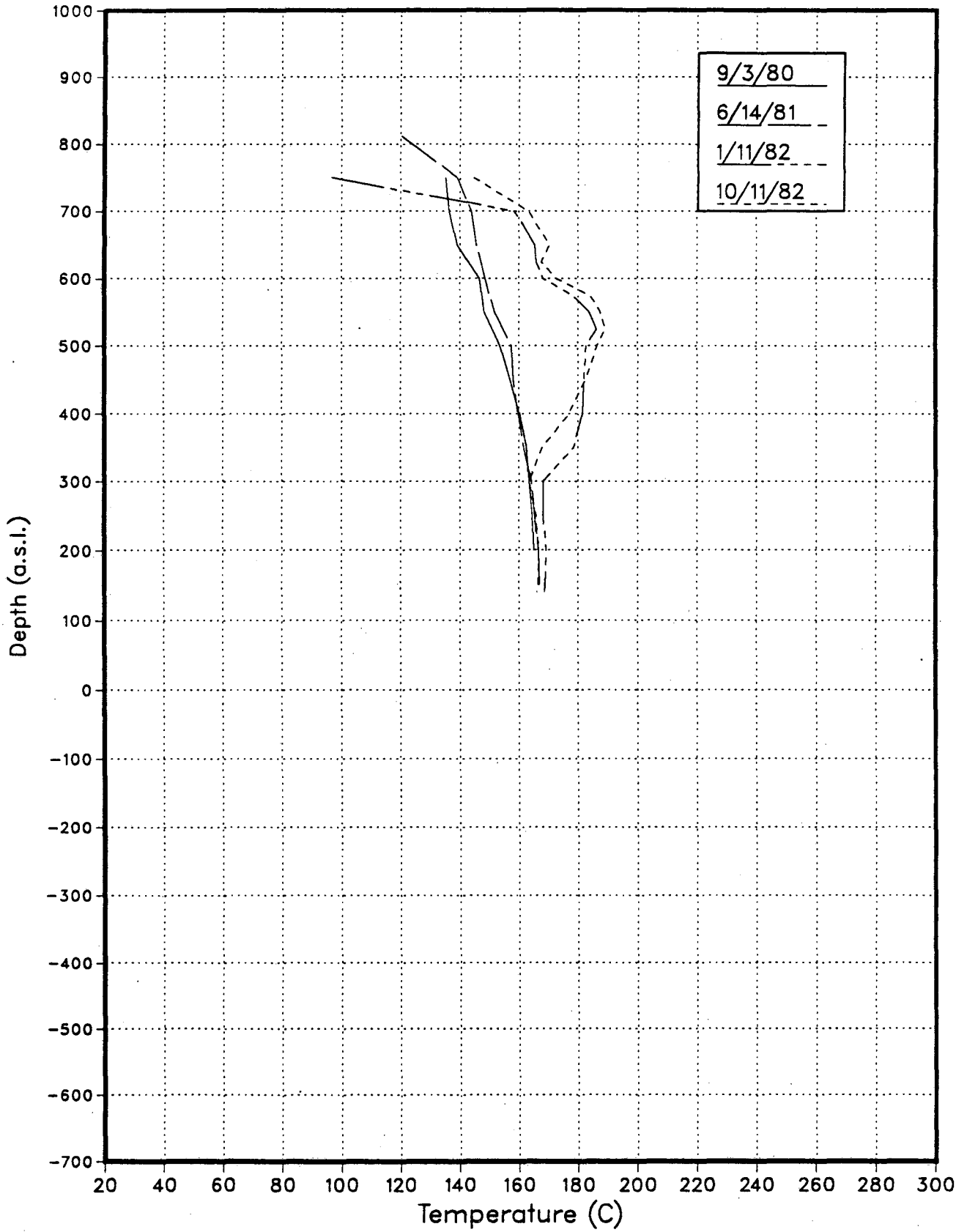
AH7 Temperature Surveys



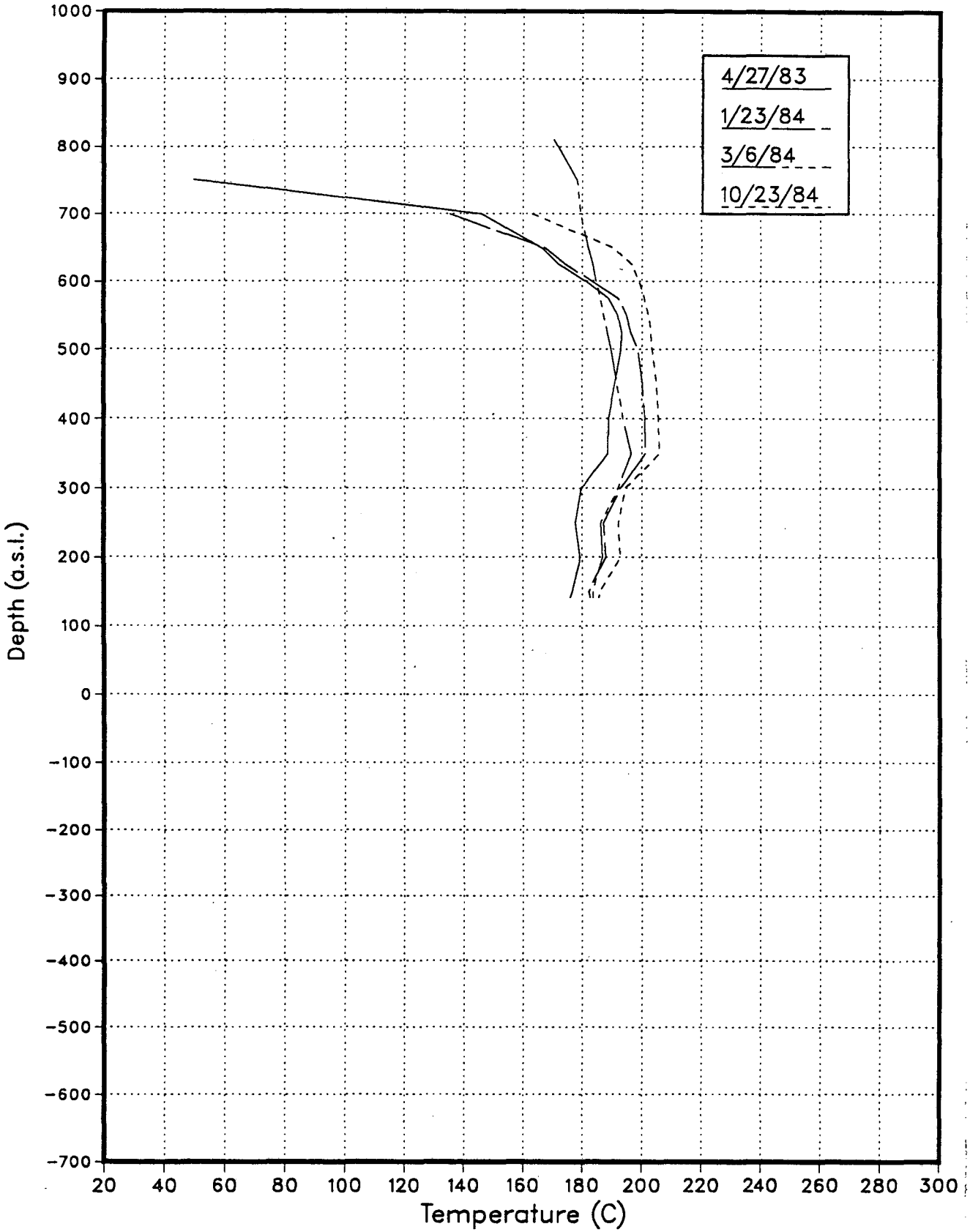
AH8 Temperature Surveys



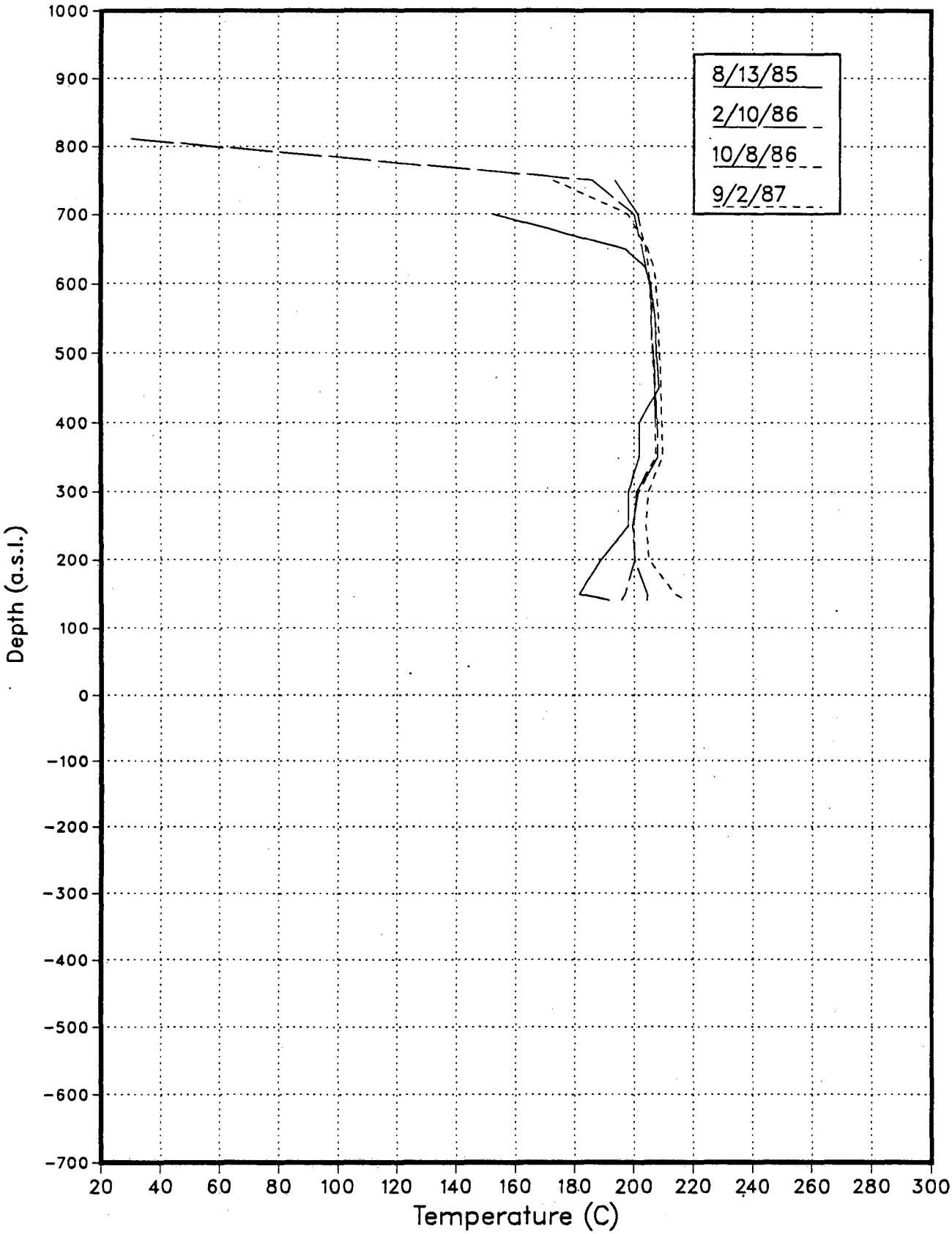
AH8 Temperature Surveys



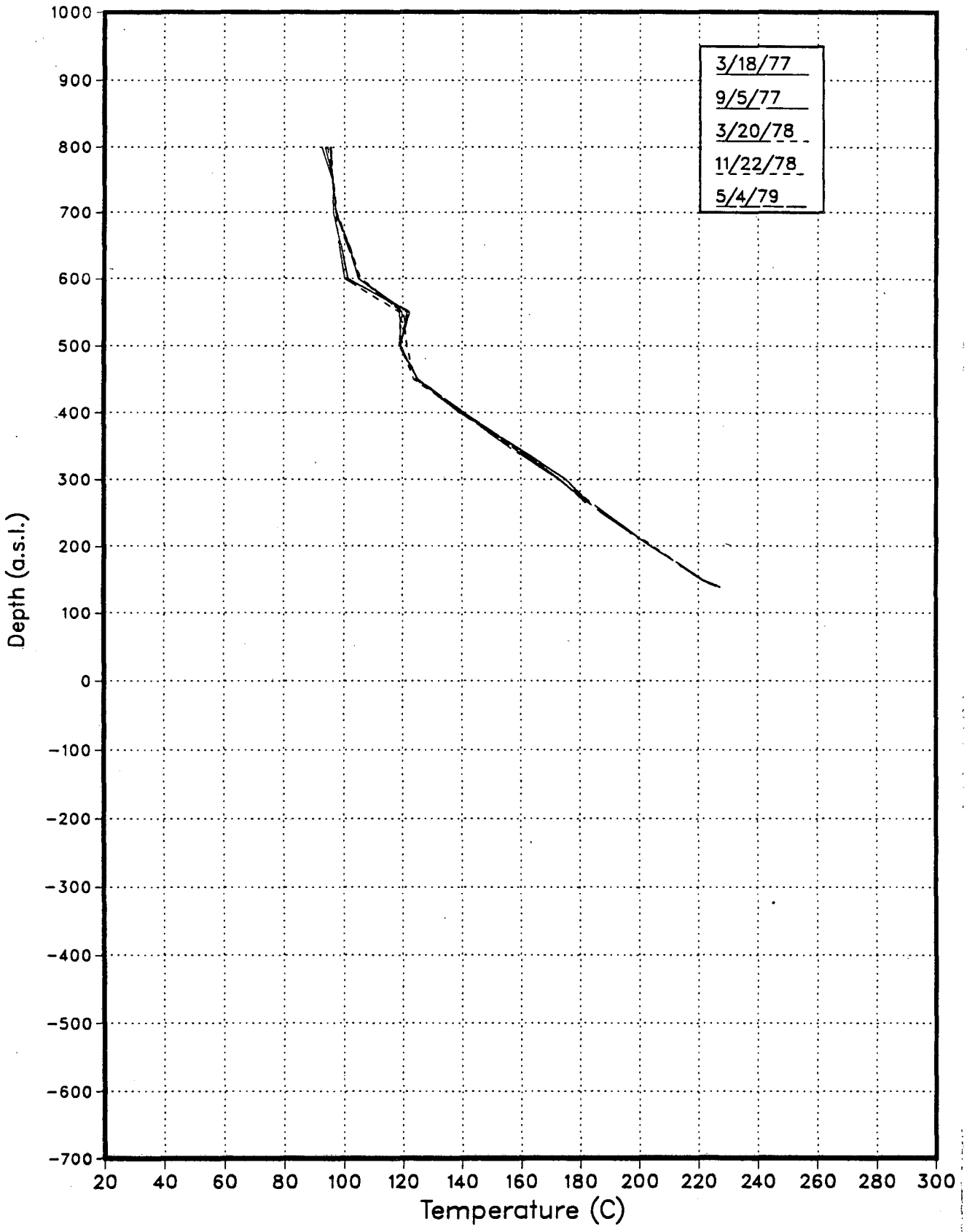
AH8 Temperature Surveys



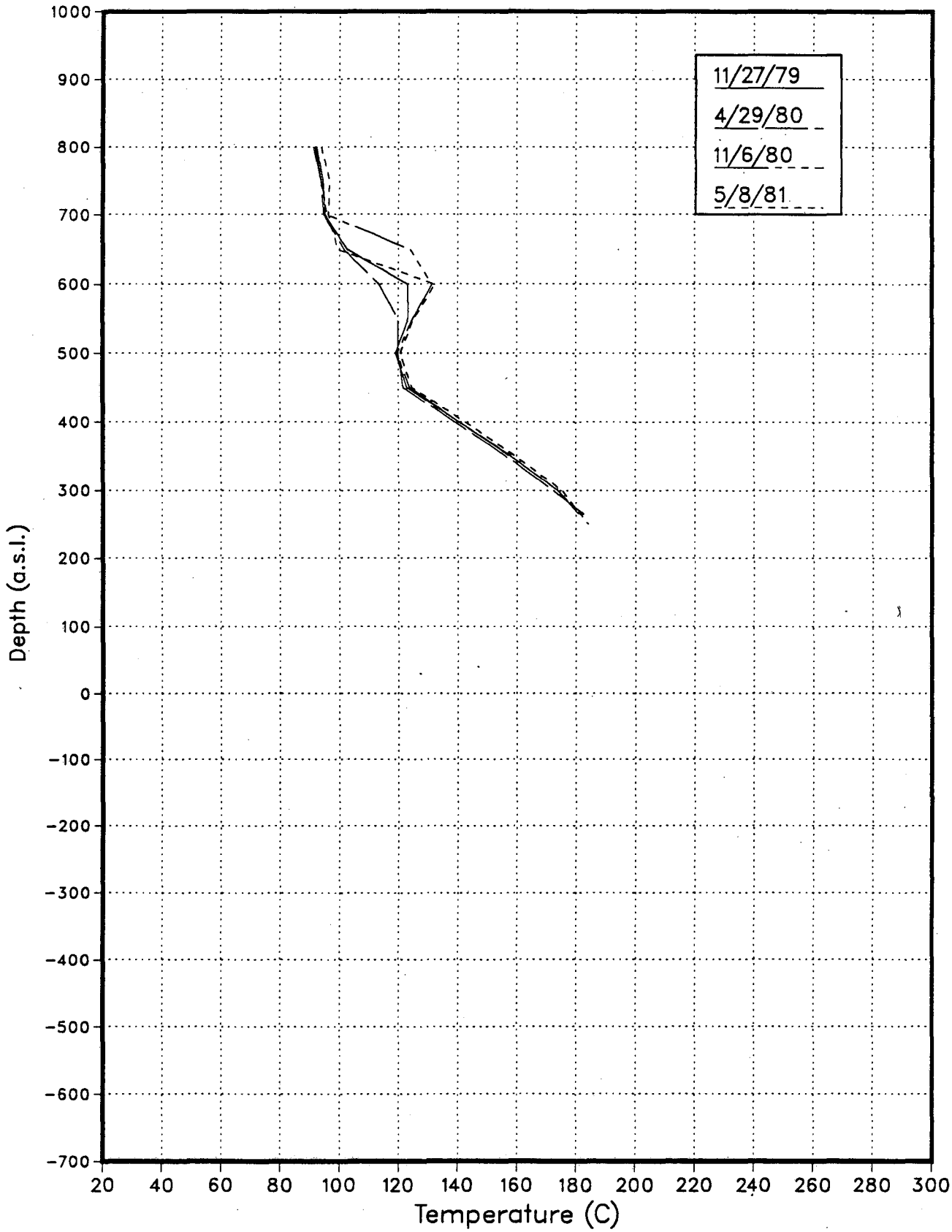
AH8 Temperature Surveys



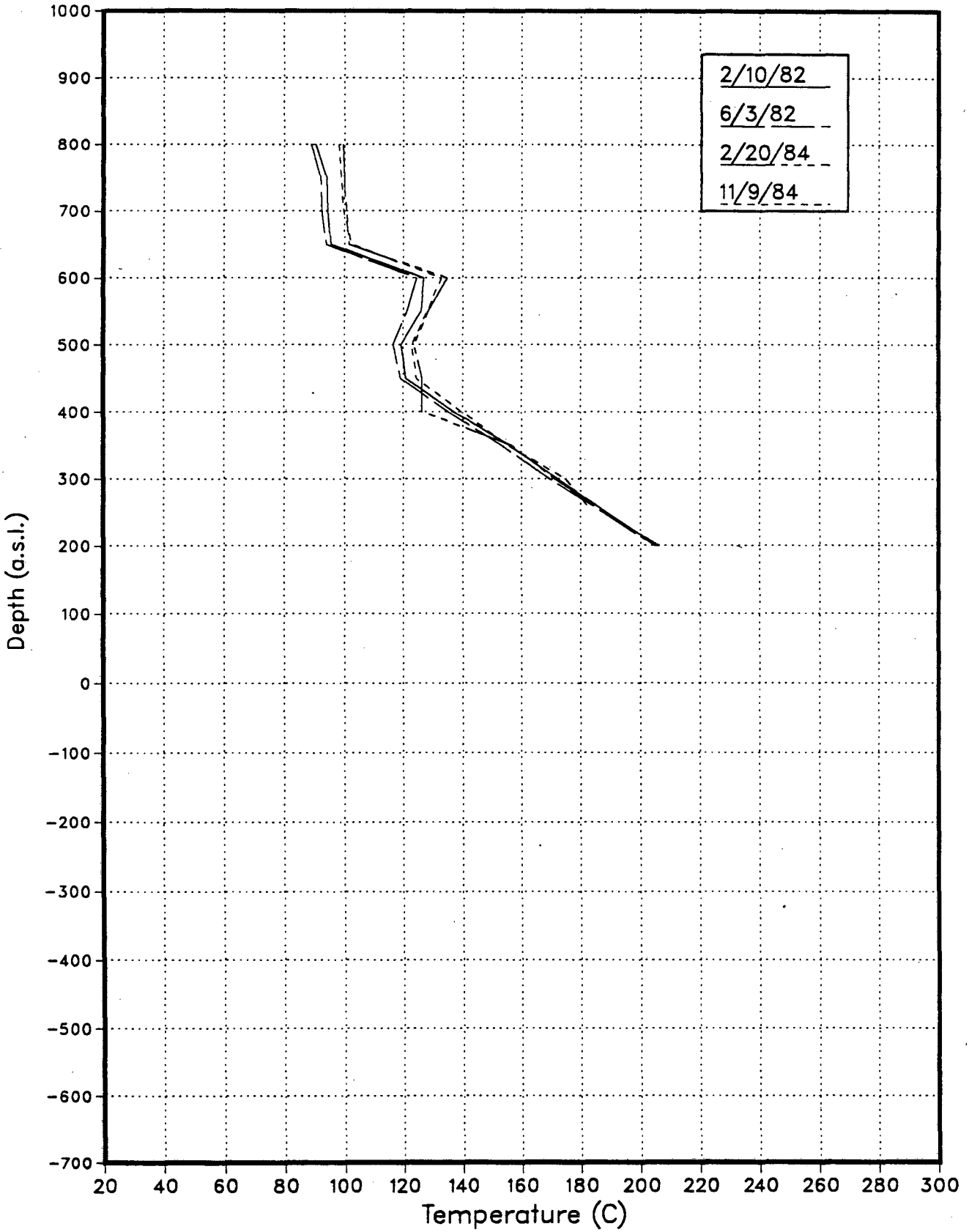
AH9 Temperature Surveys



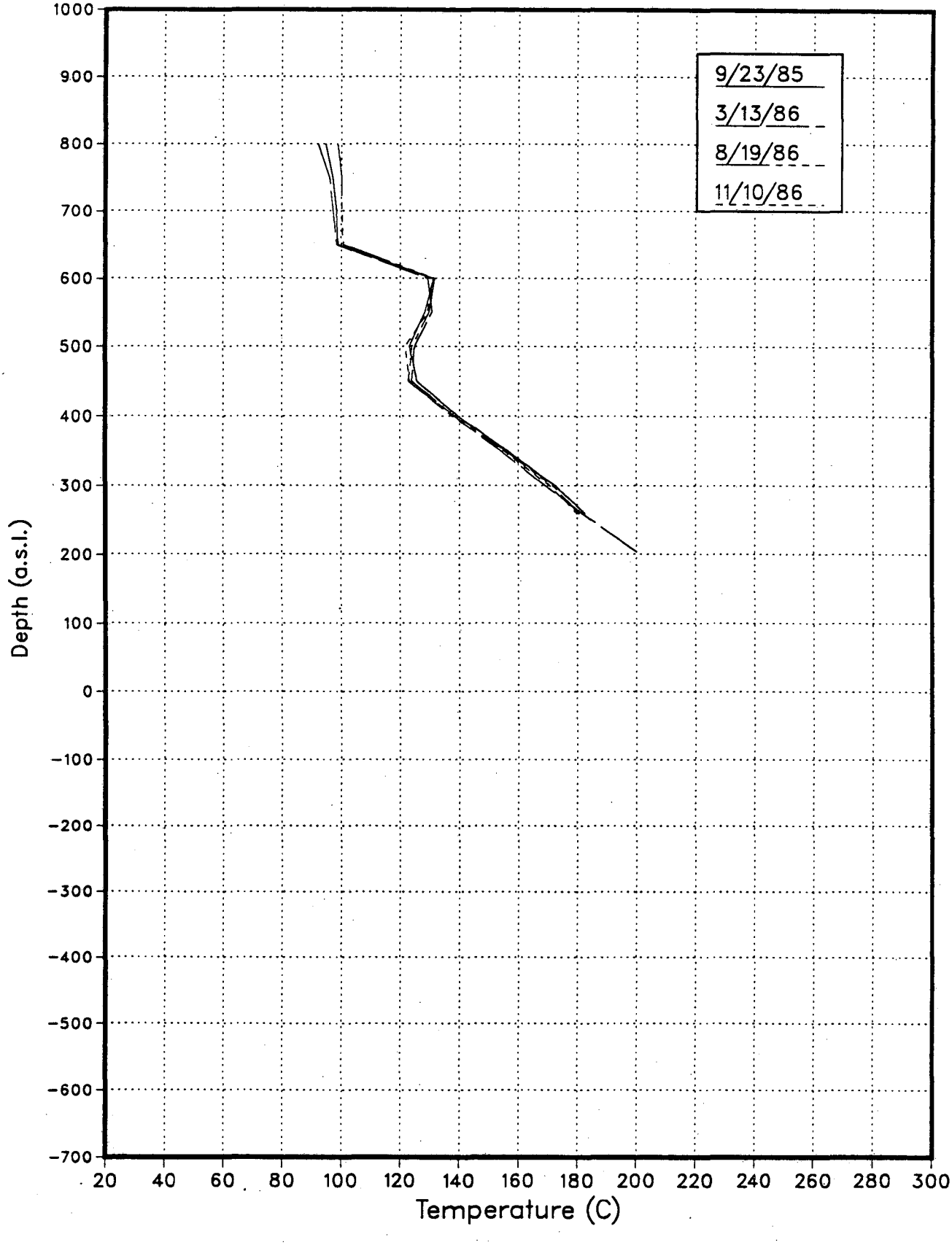
AH9 Temperature Surveys



AH9 Temperature Surveys



AH9 Temperature Surveys



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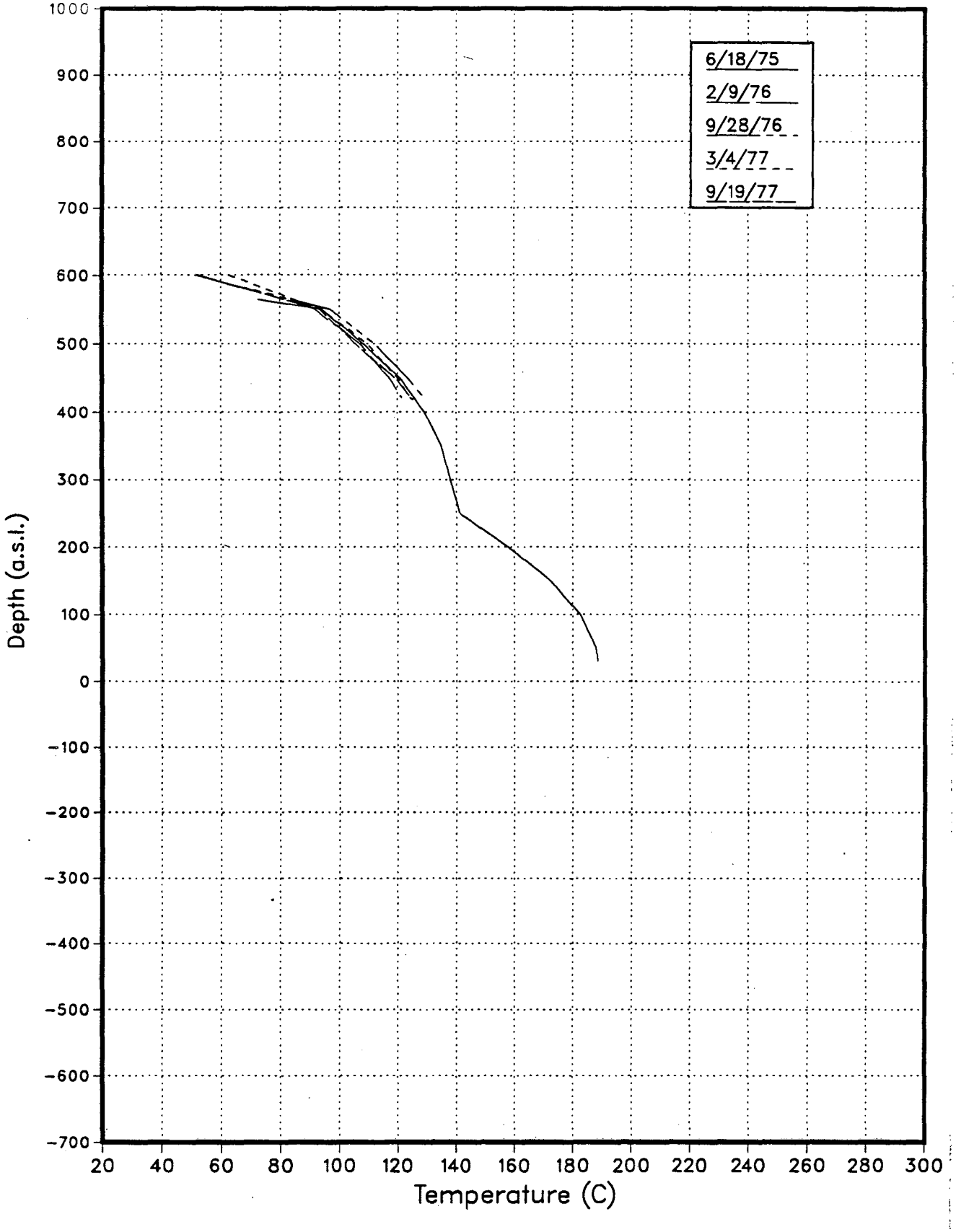

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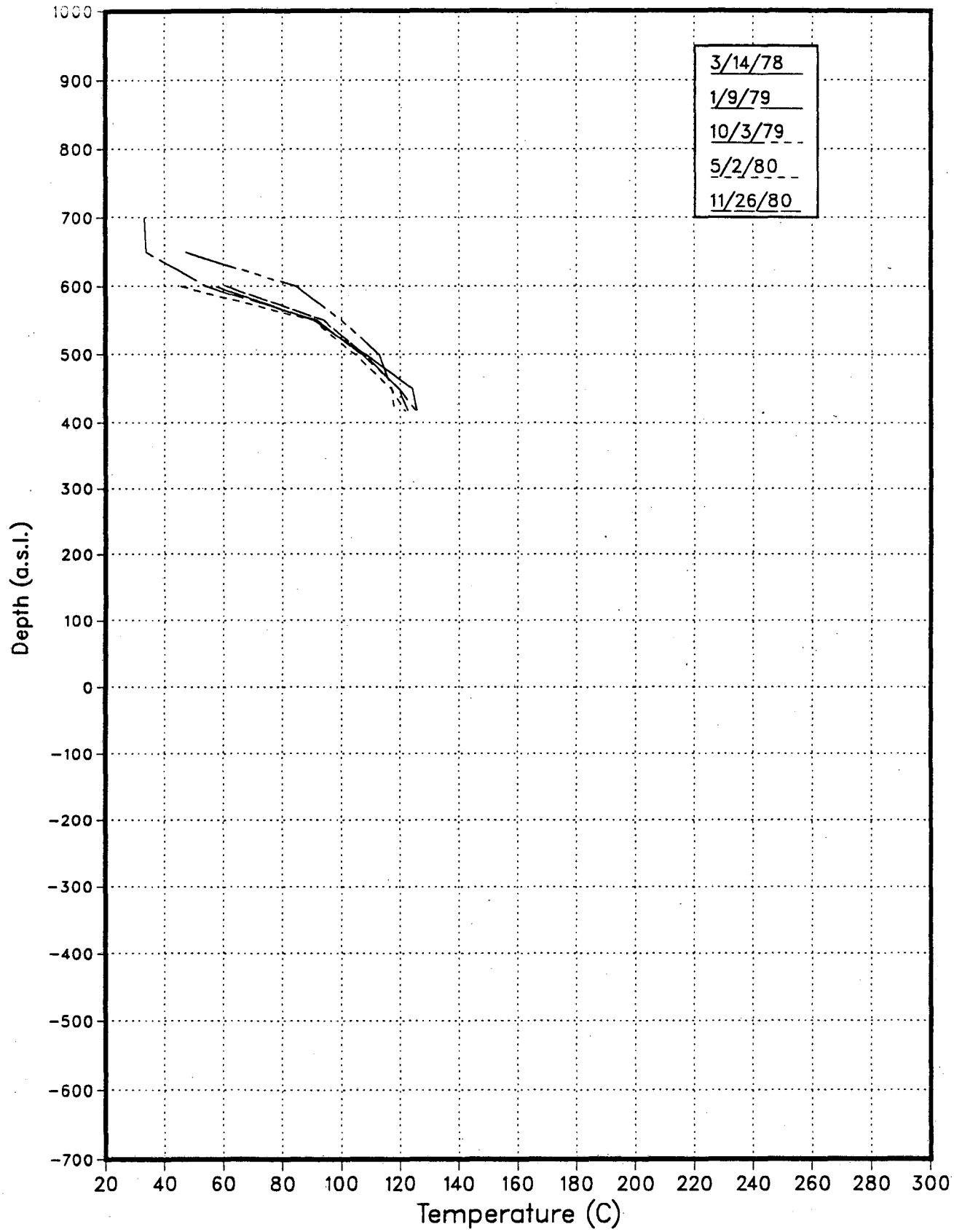

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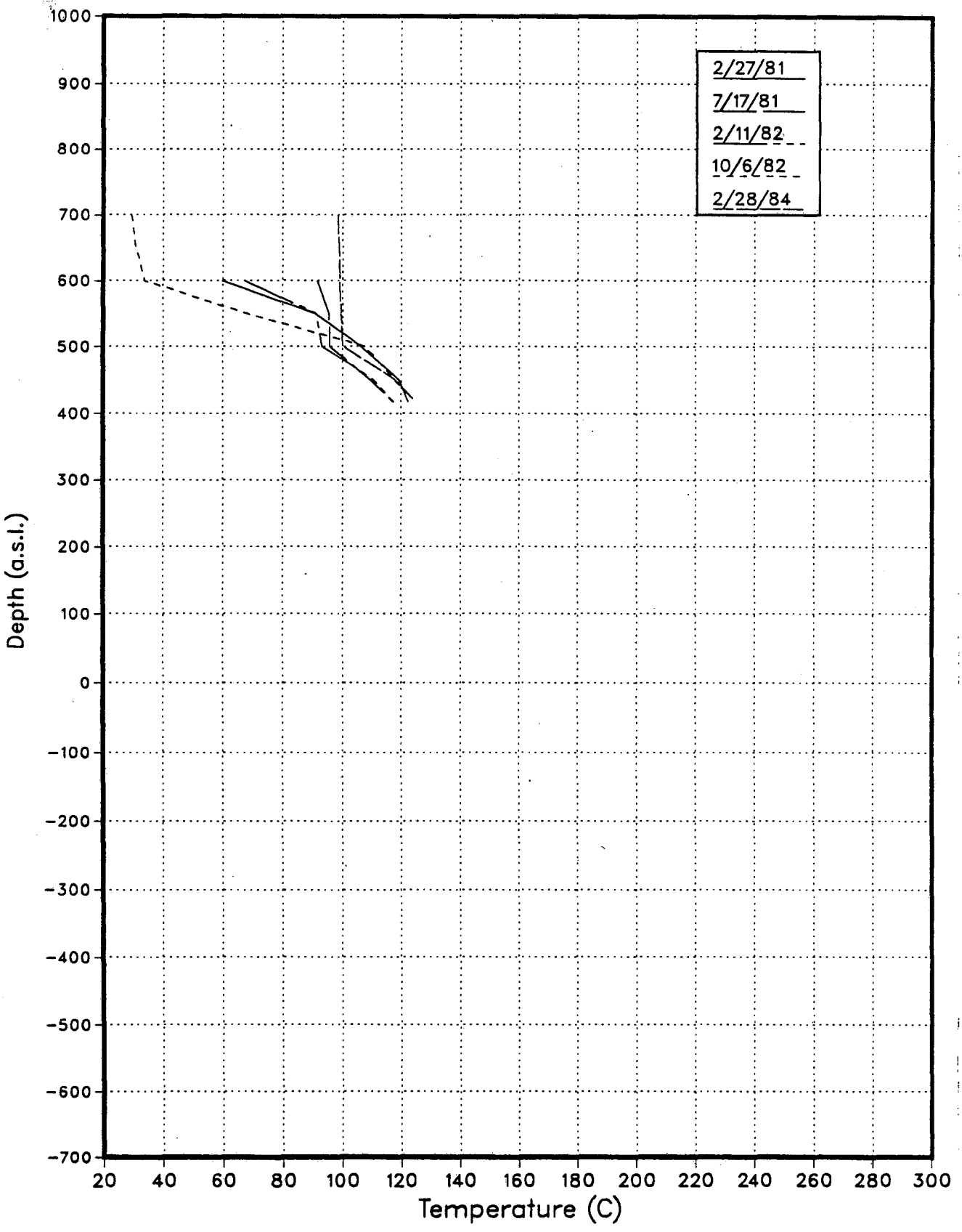

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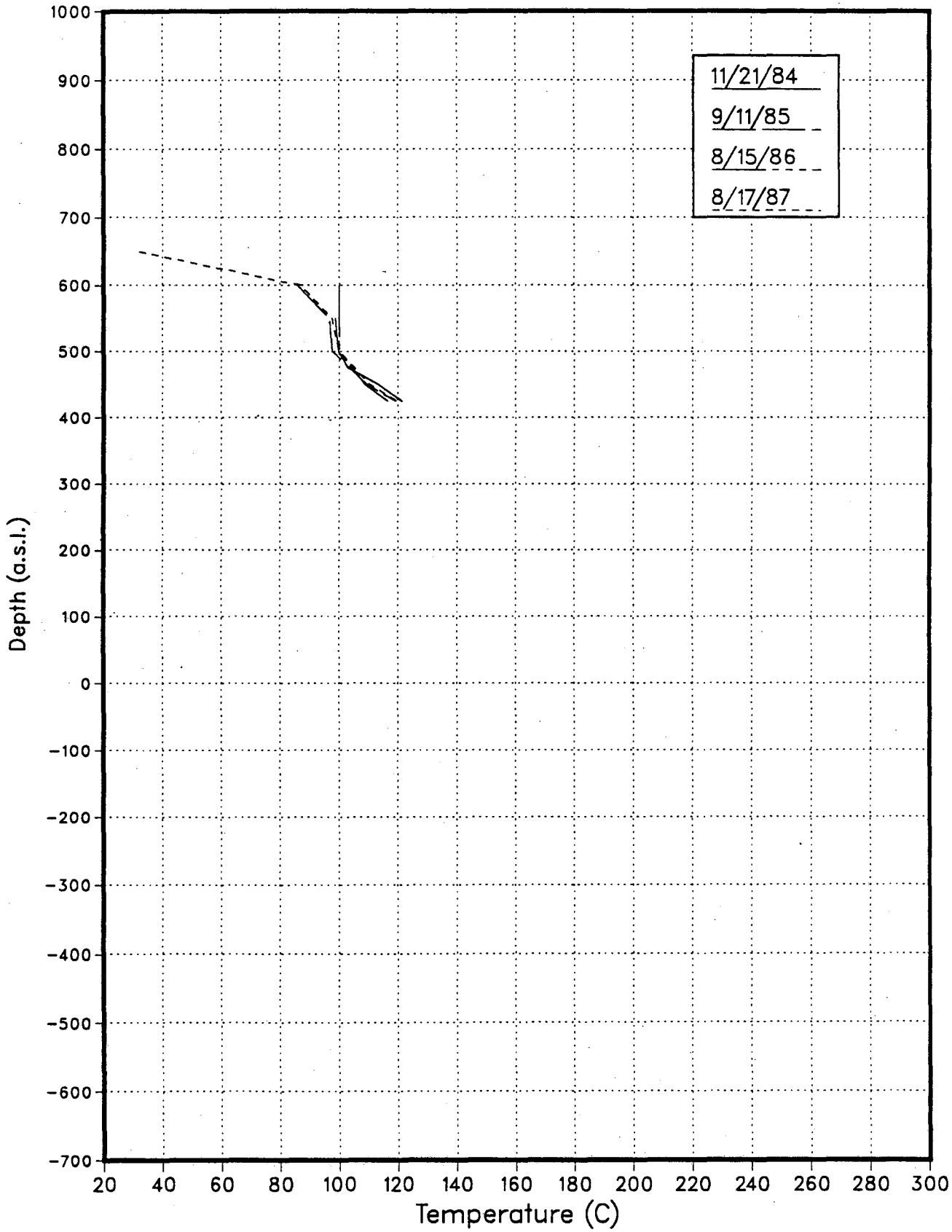

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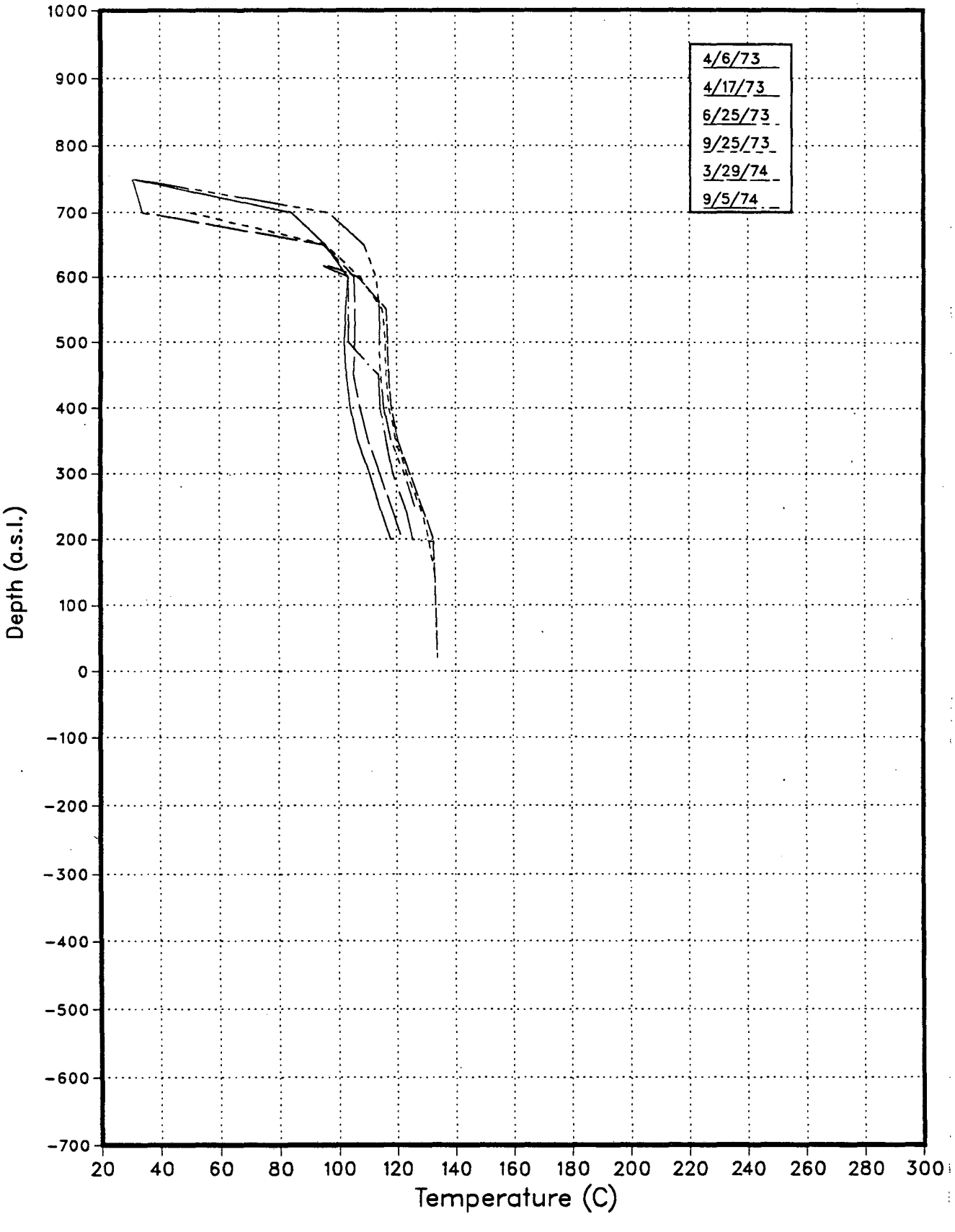

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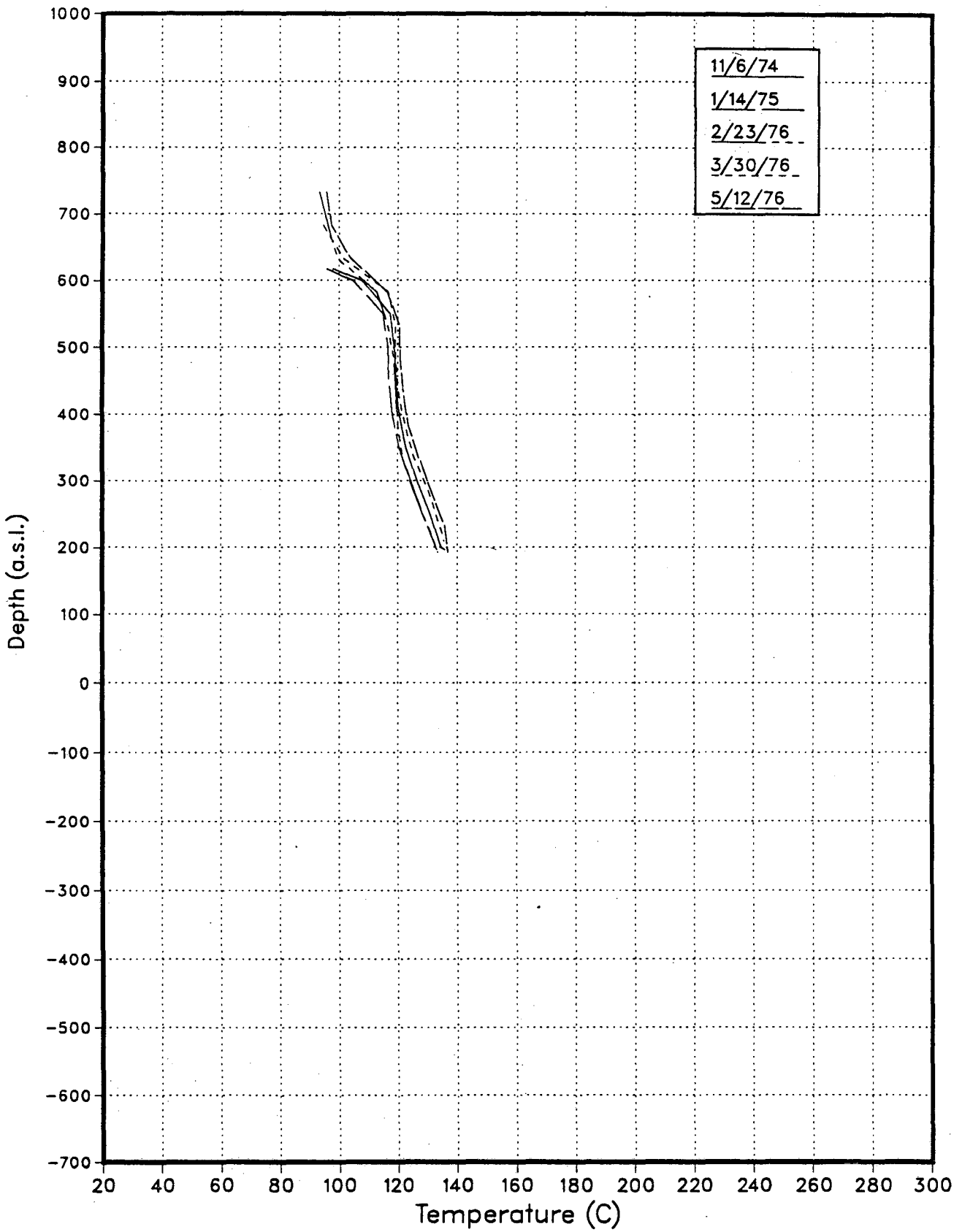
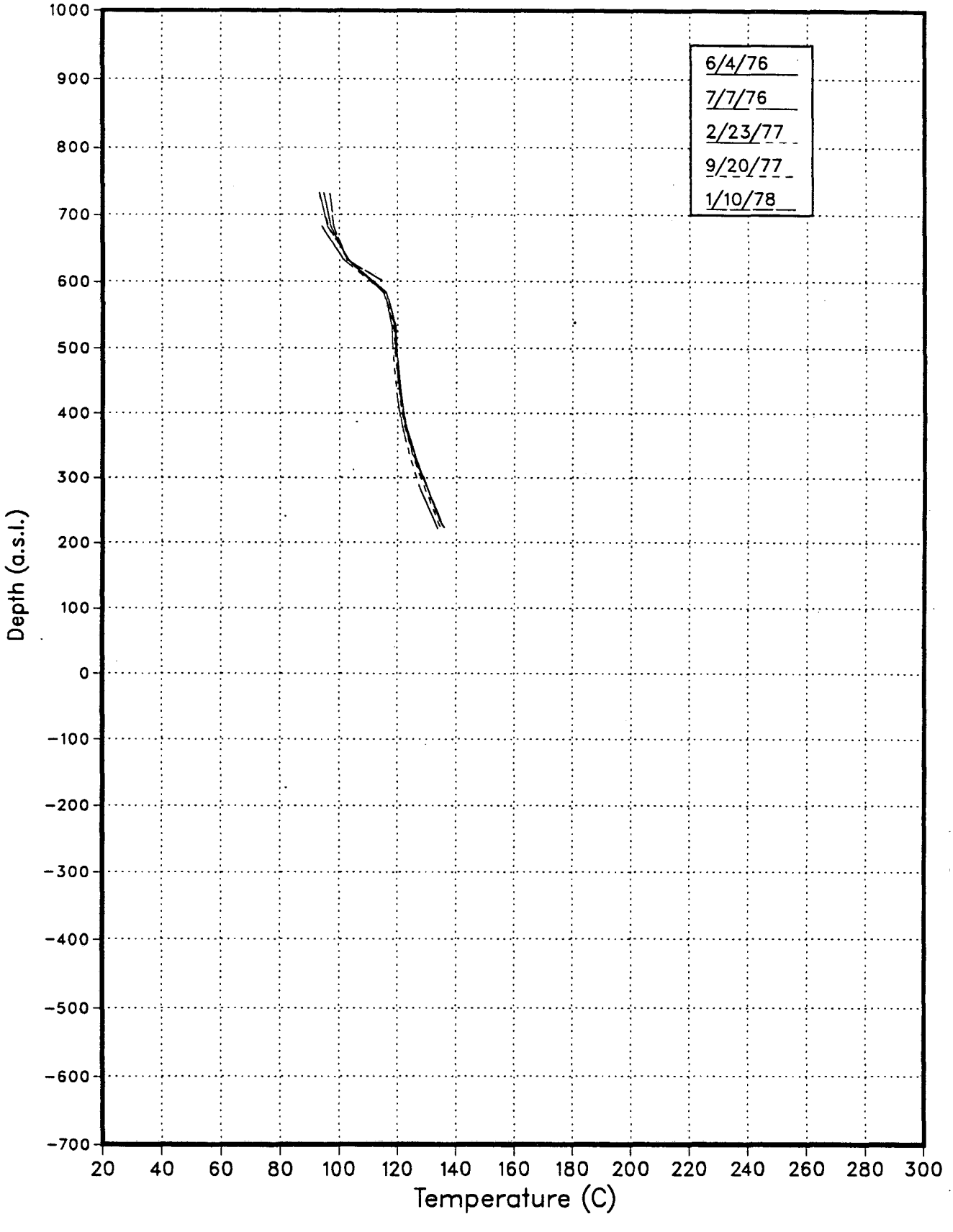


AH12 Temperature Surveys



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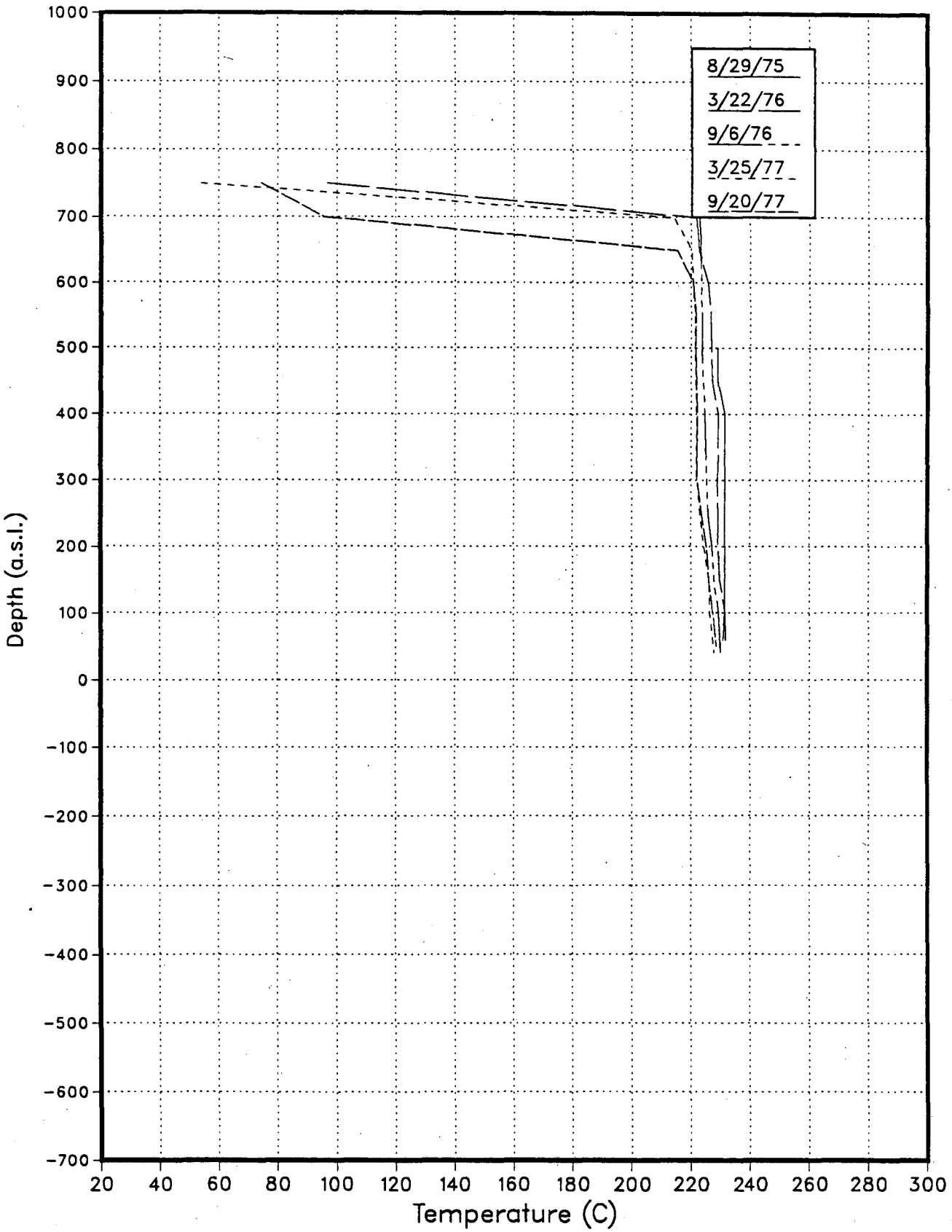

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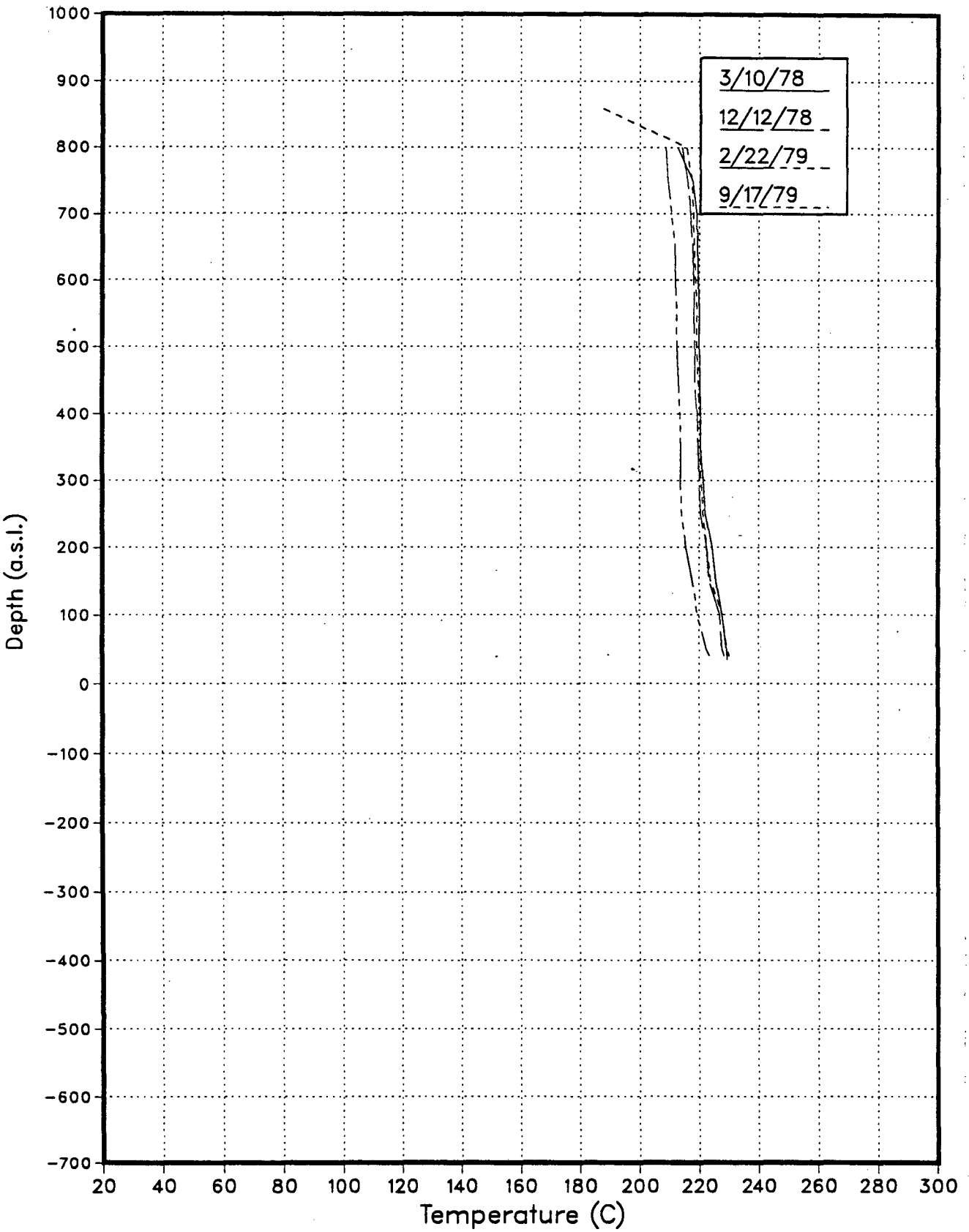

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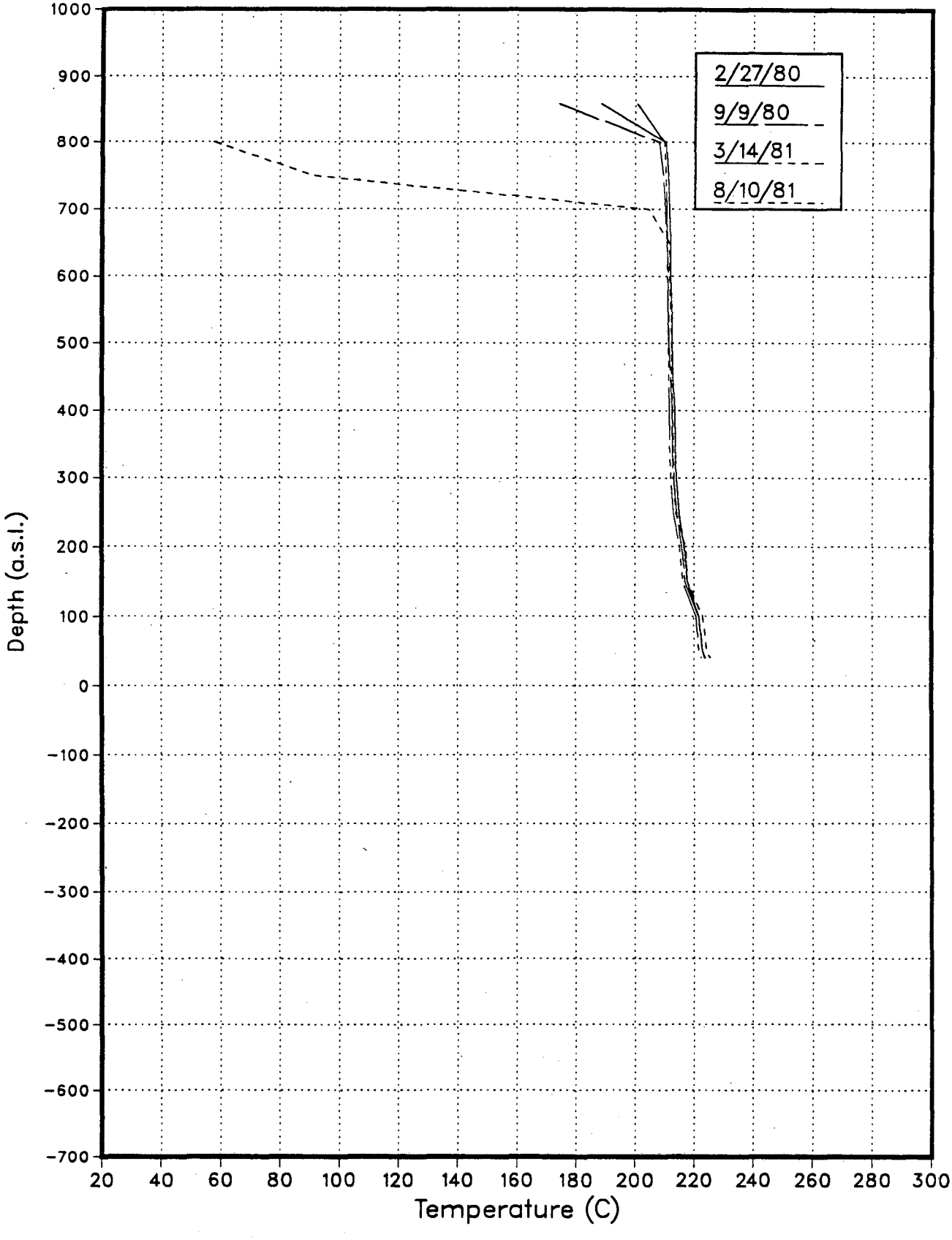

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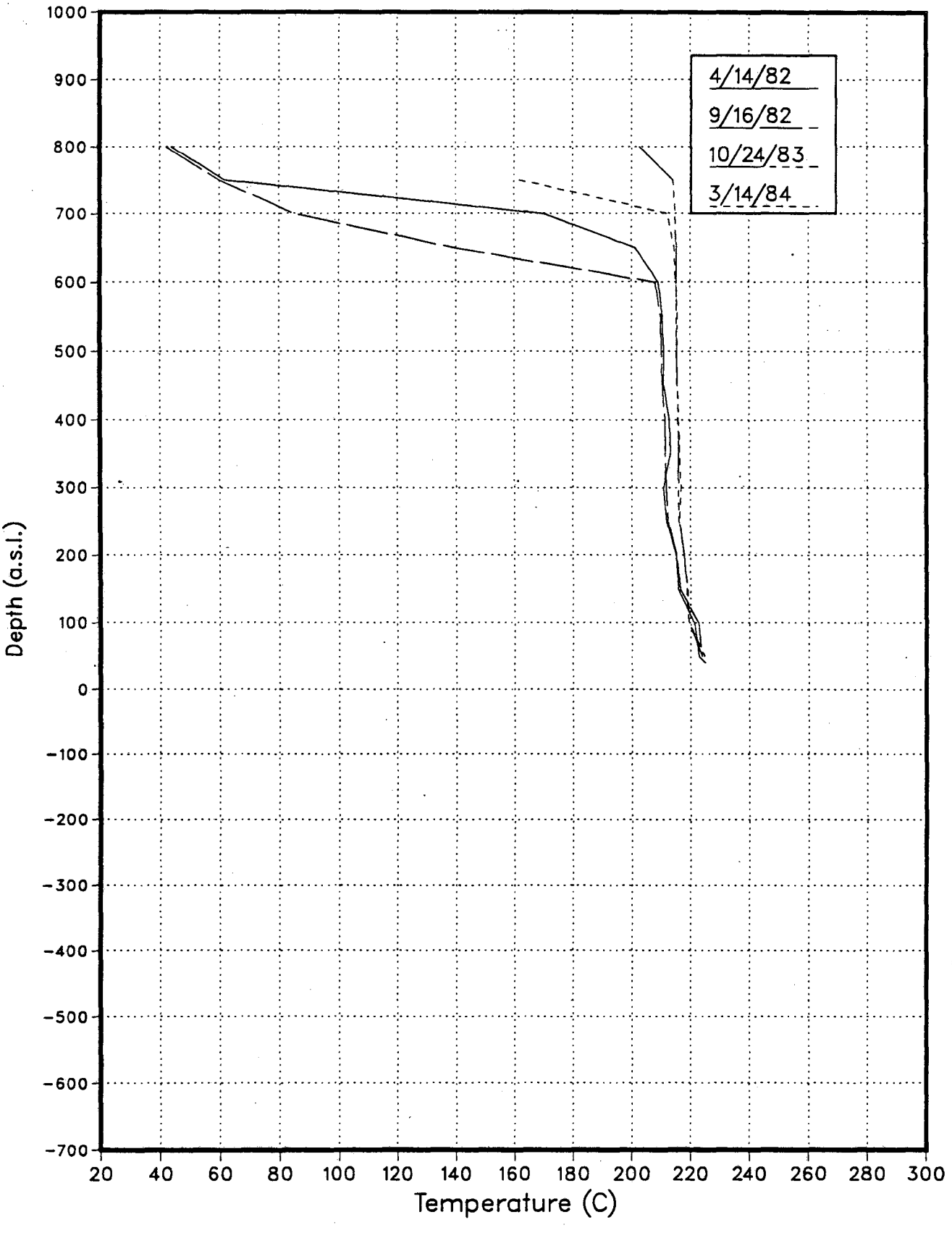

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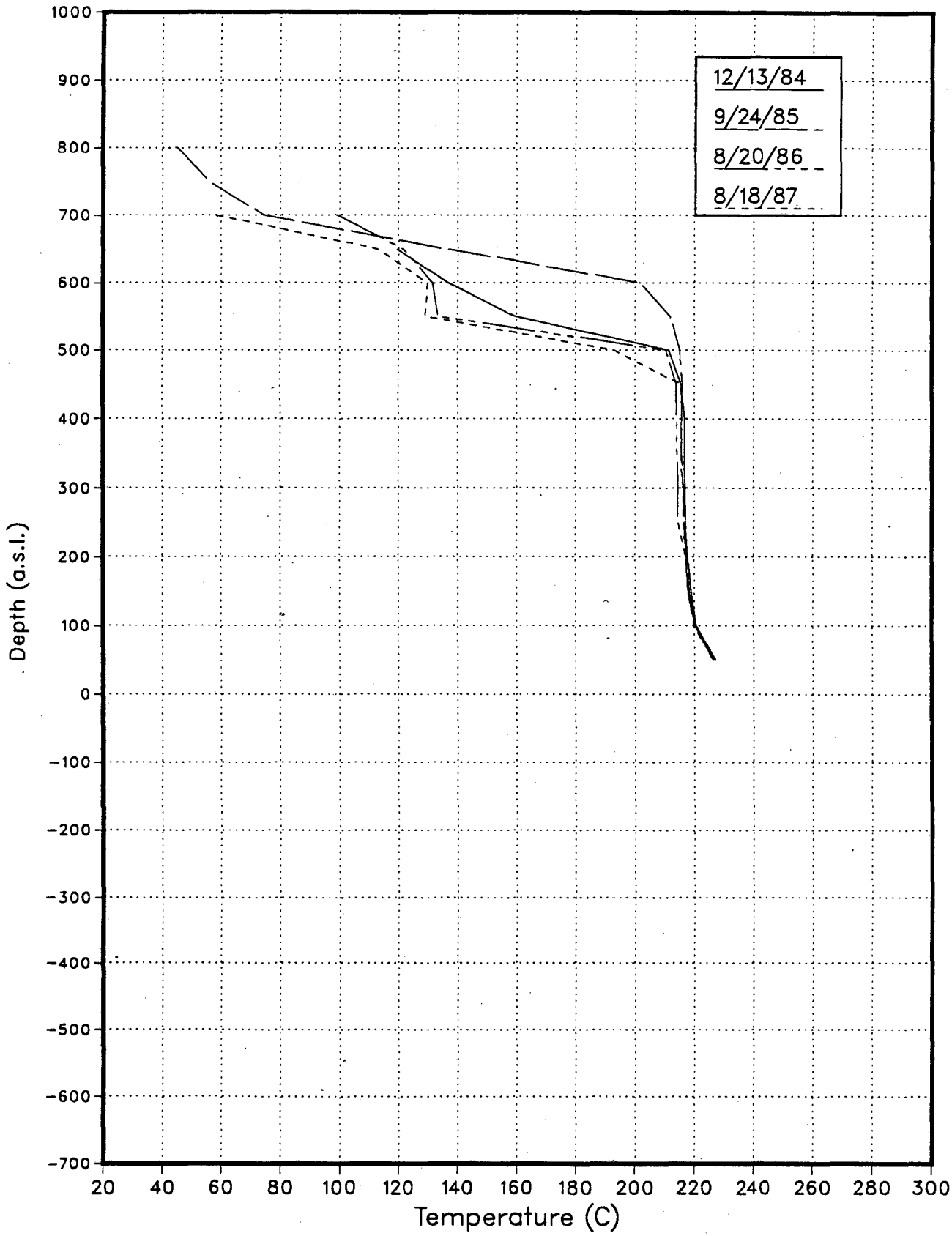

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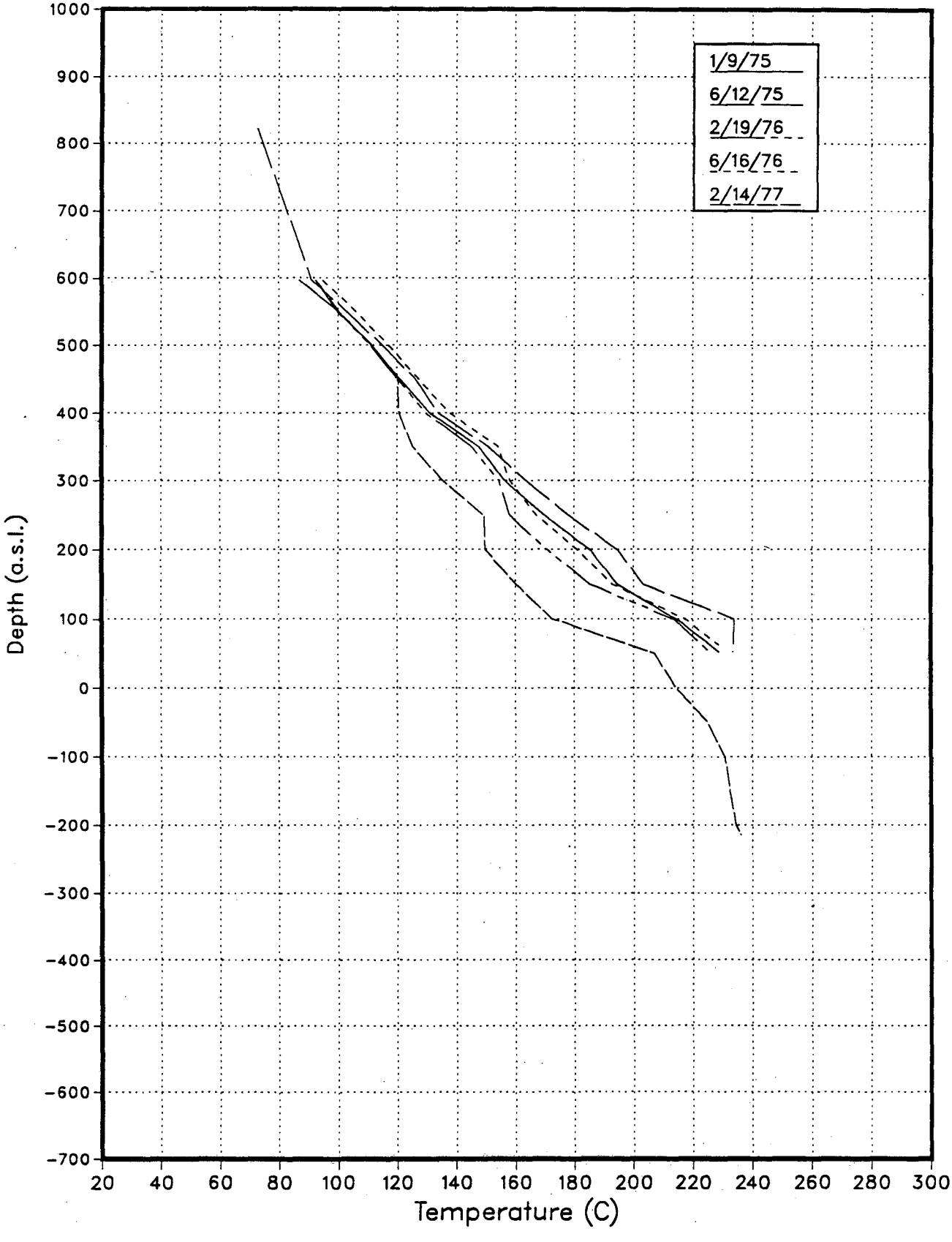

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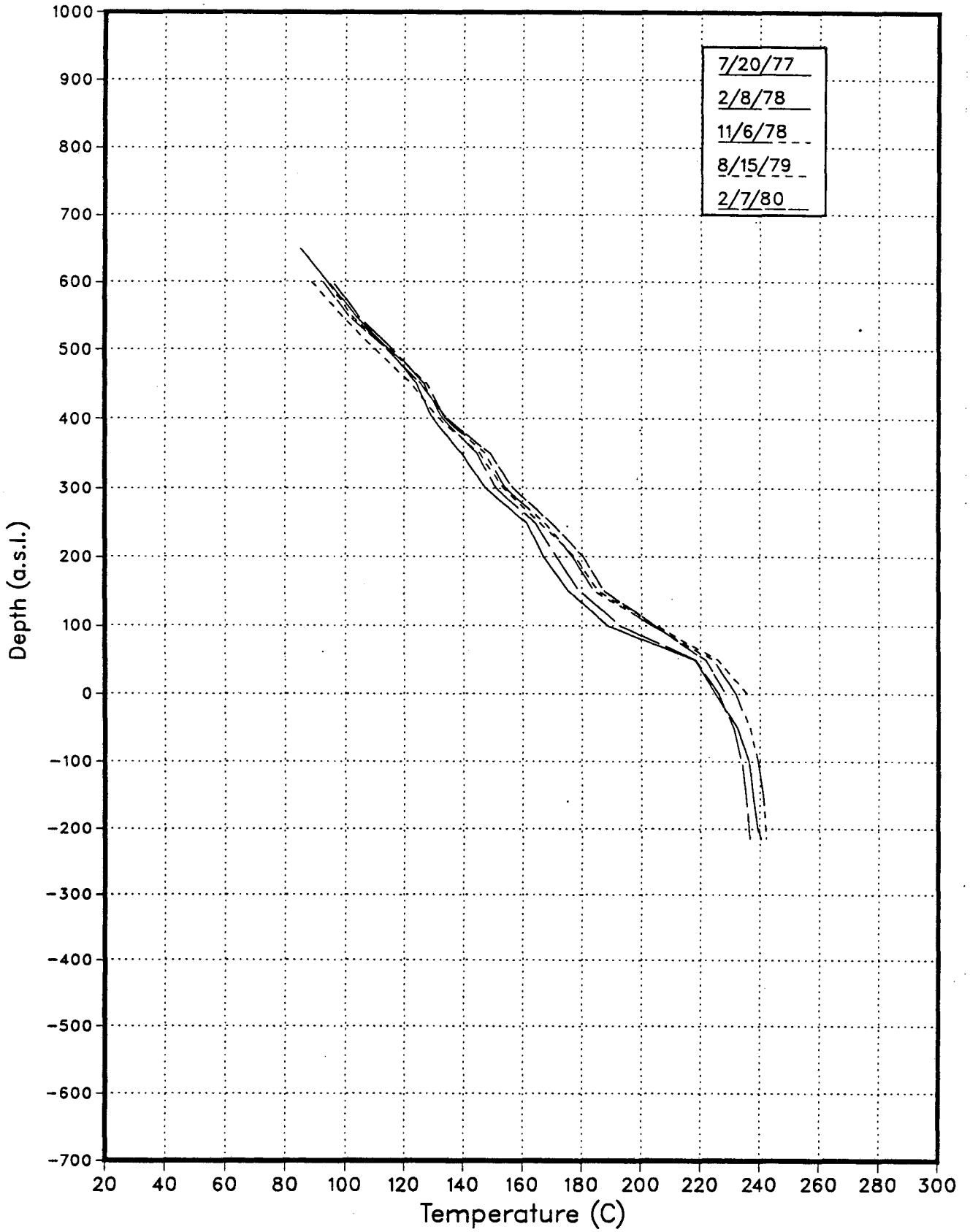

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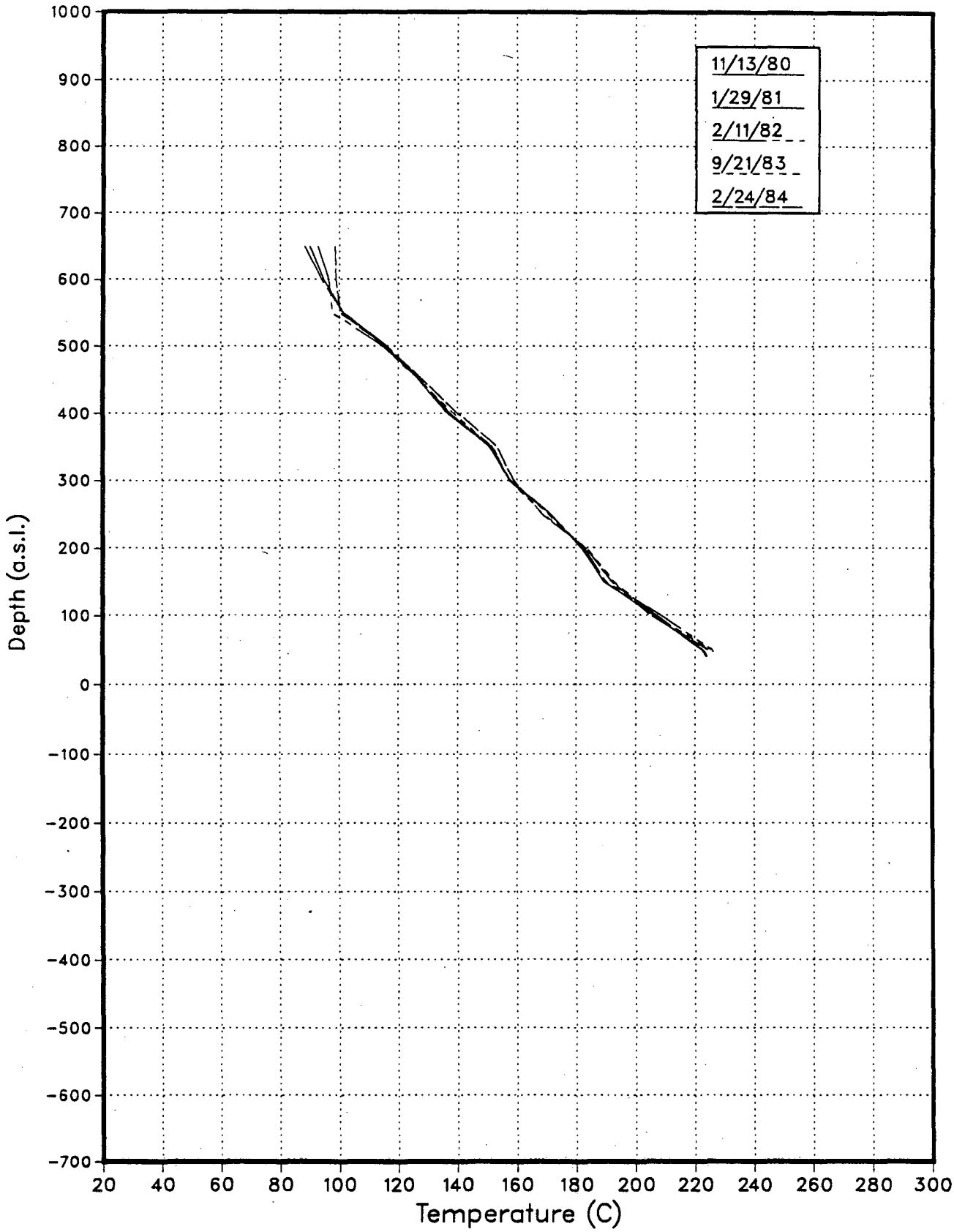

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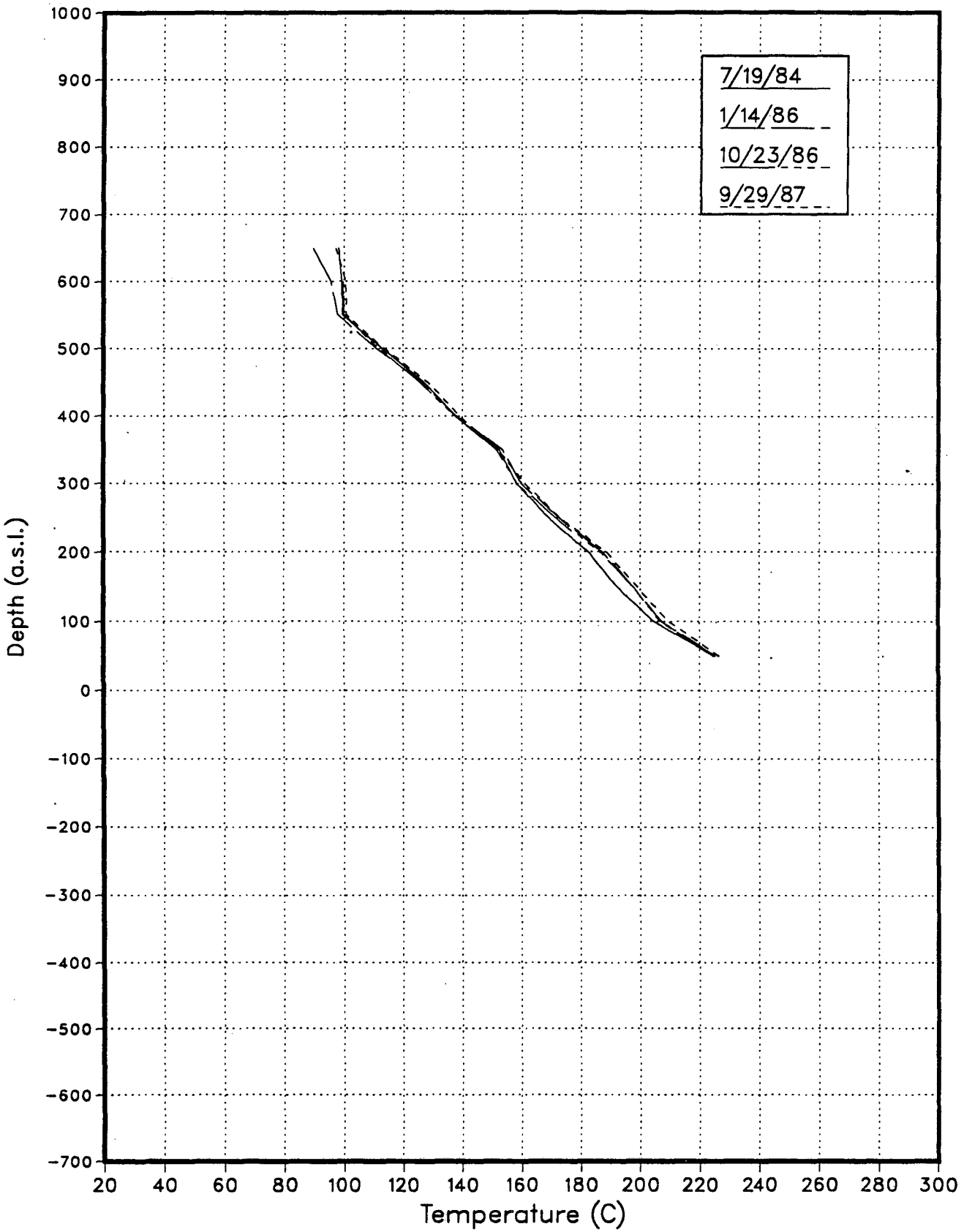
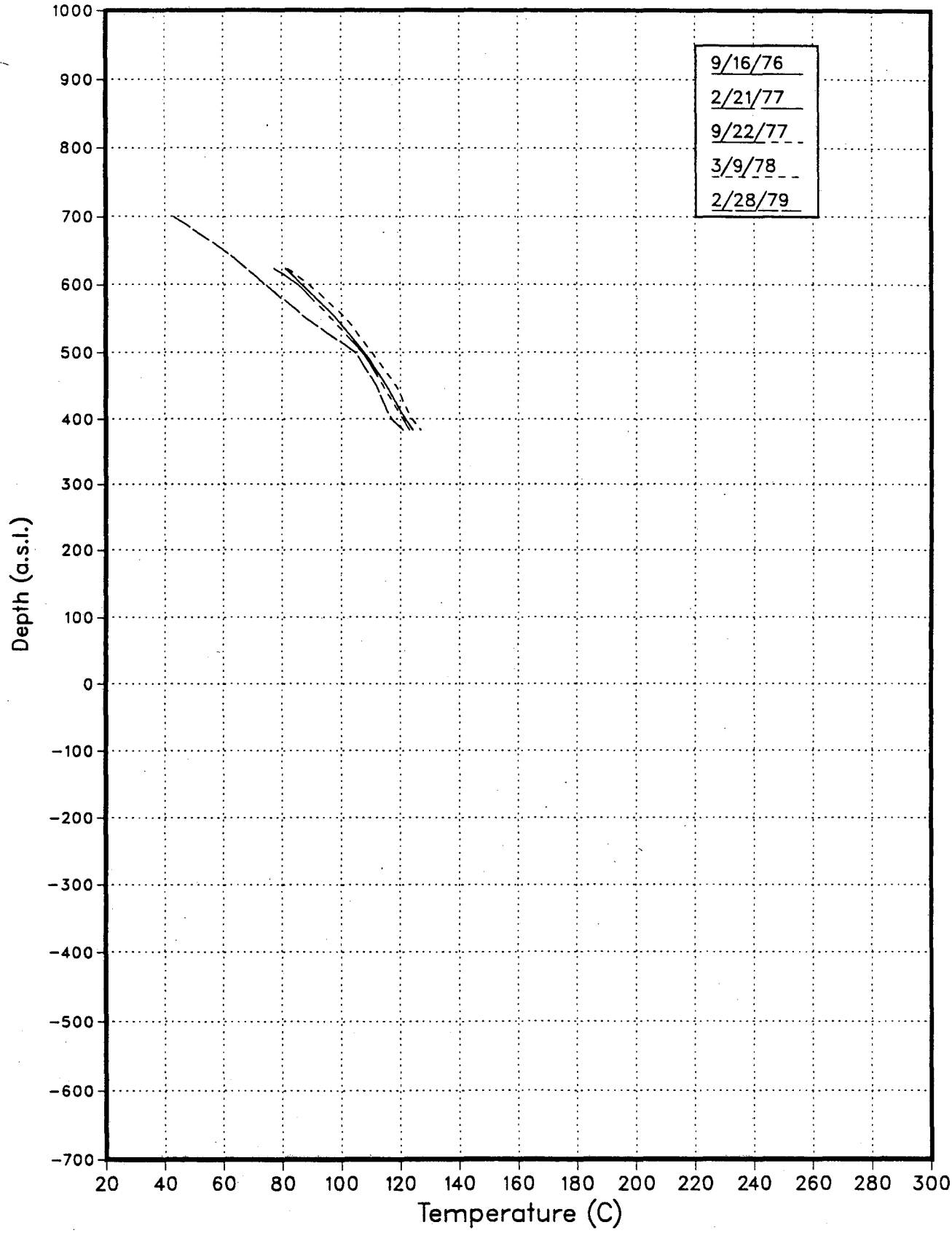


AH15 Temperature Surveys



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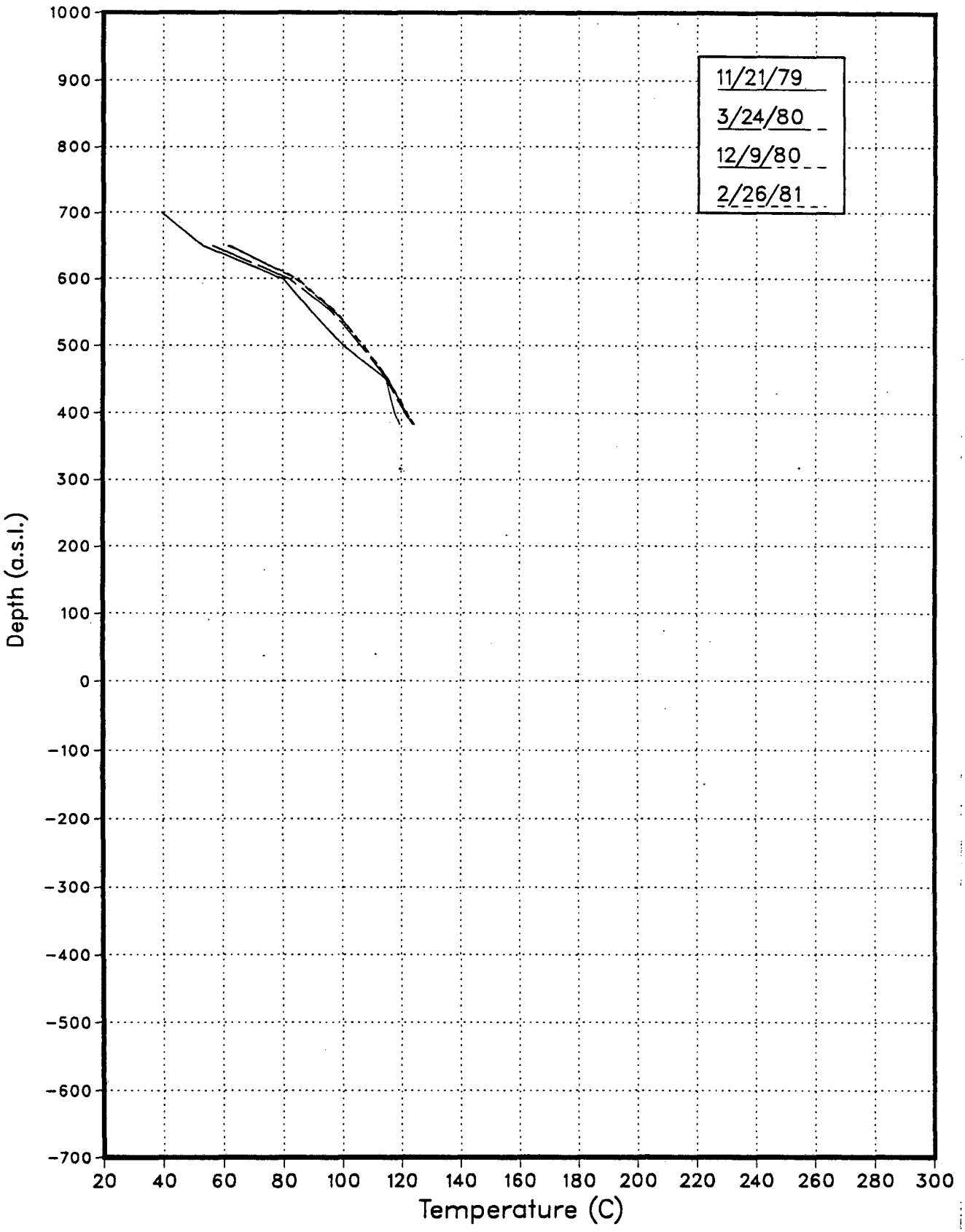

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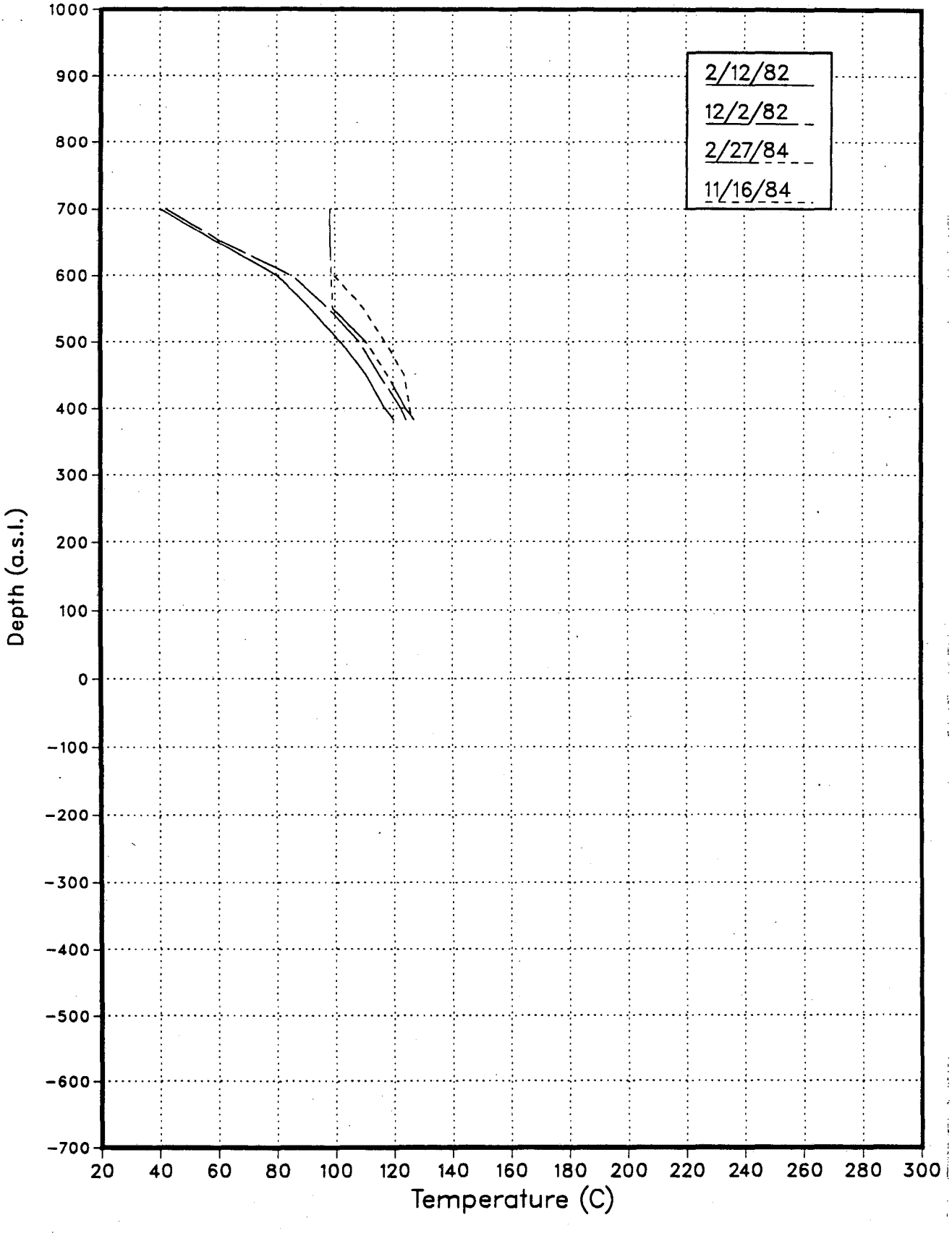

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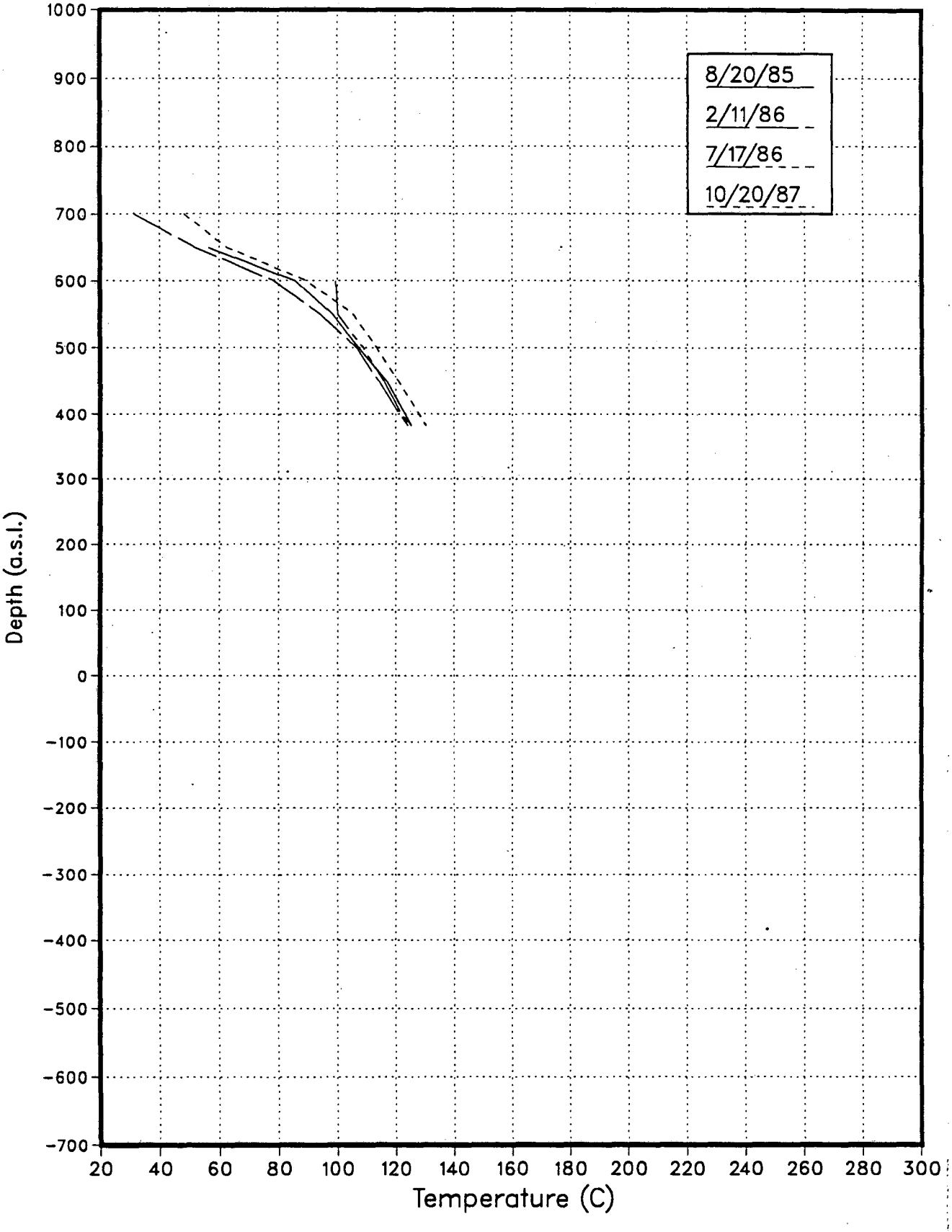
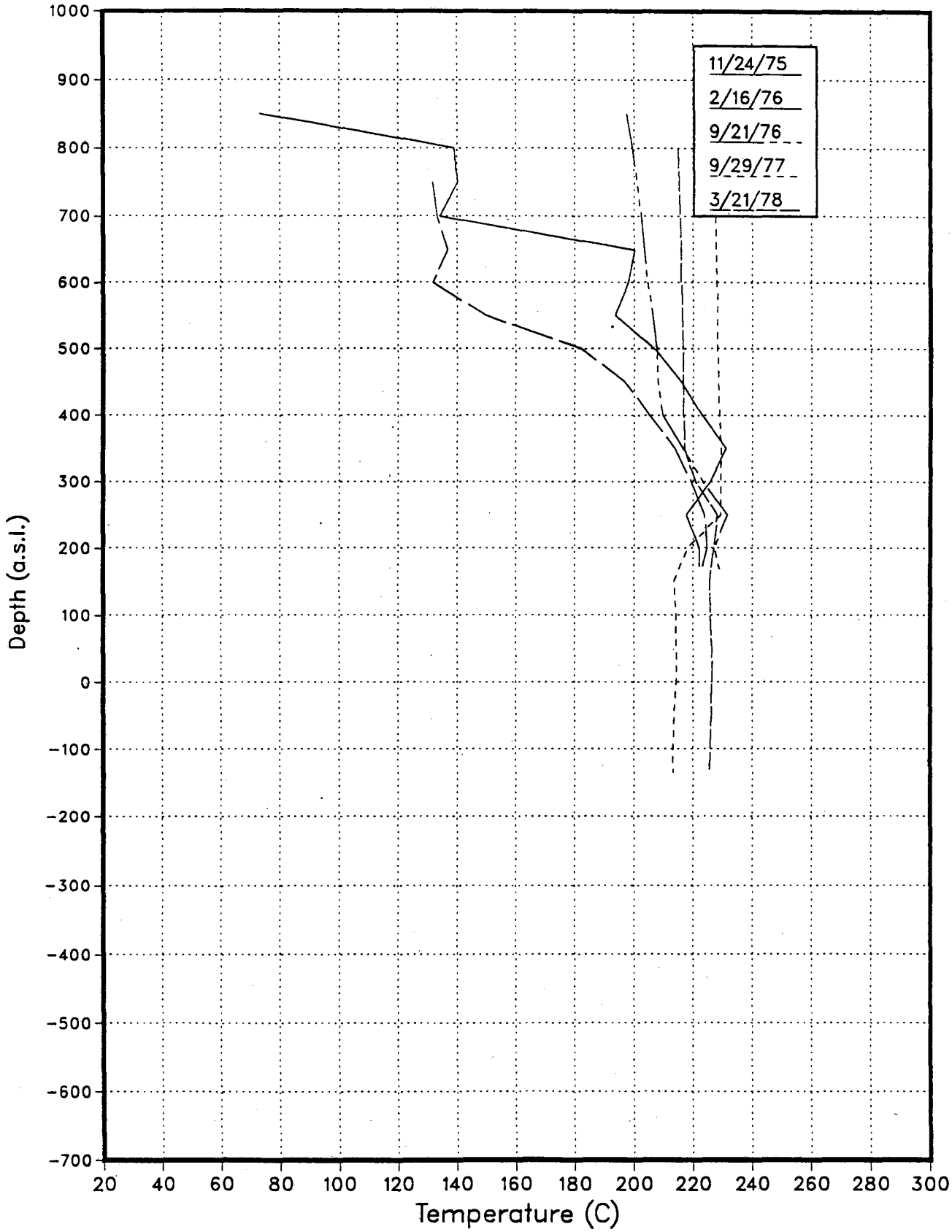


AH16 Temperature Surveys



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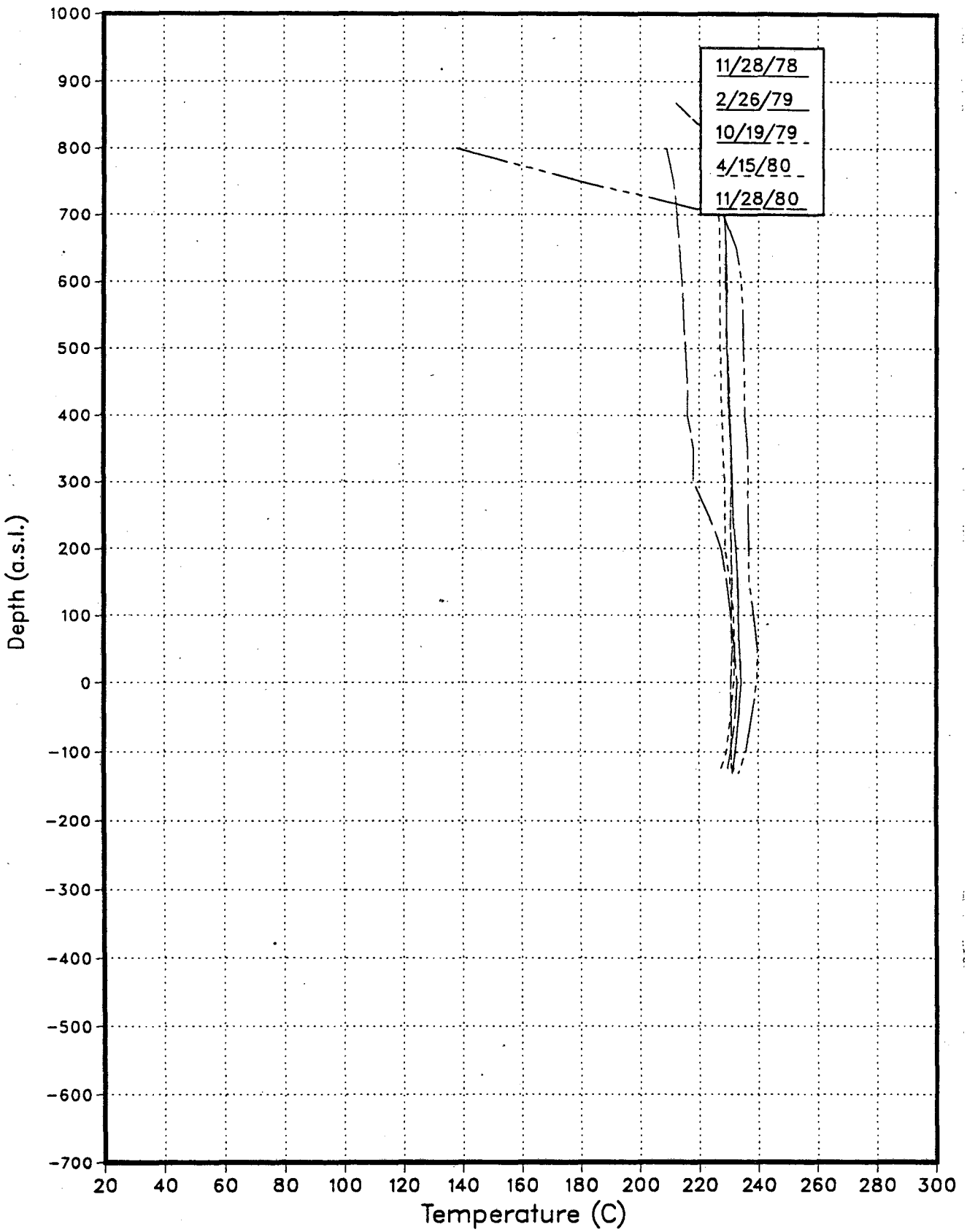

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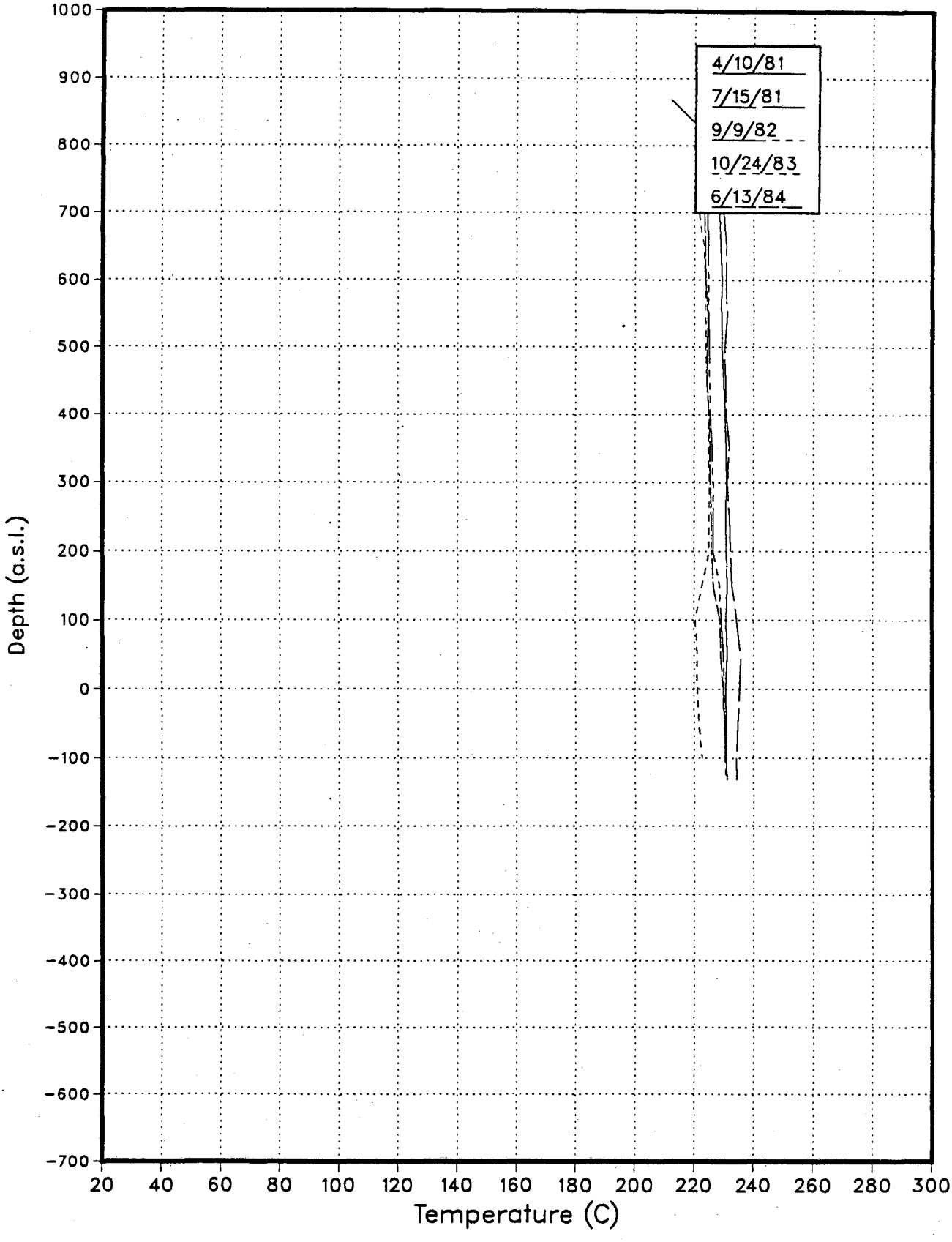

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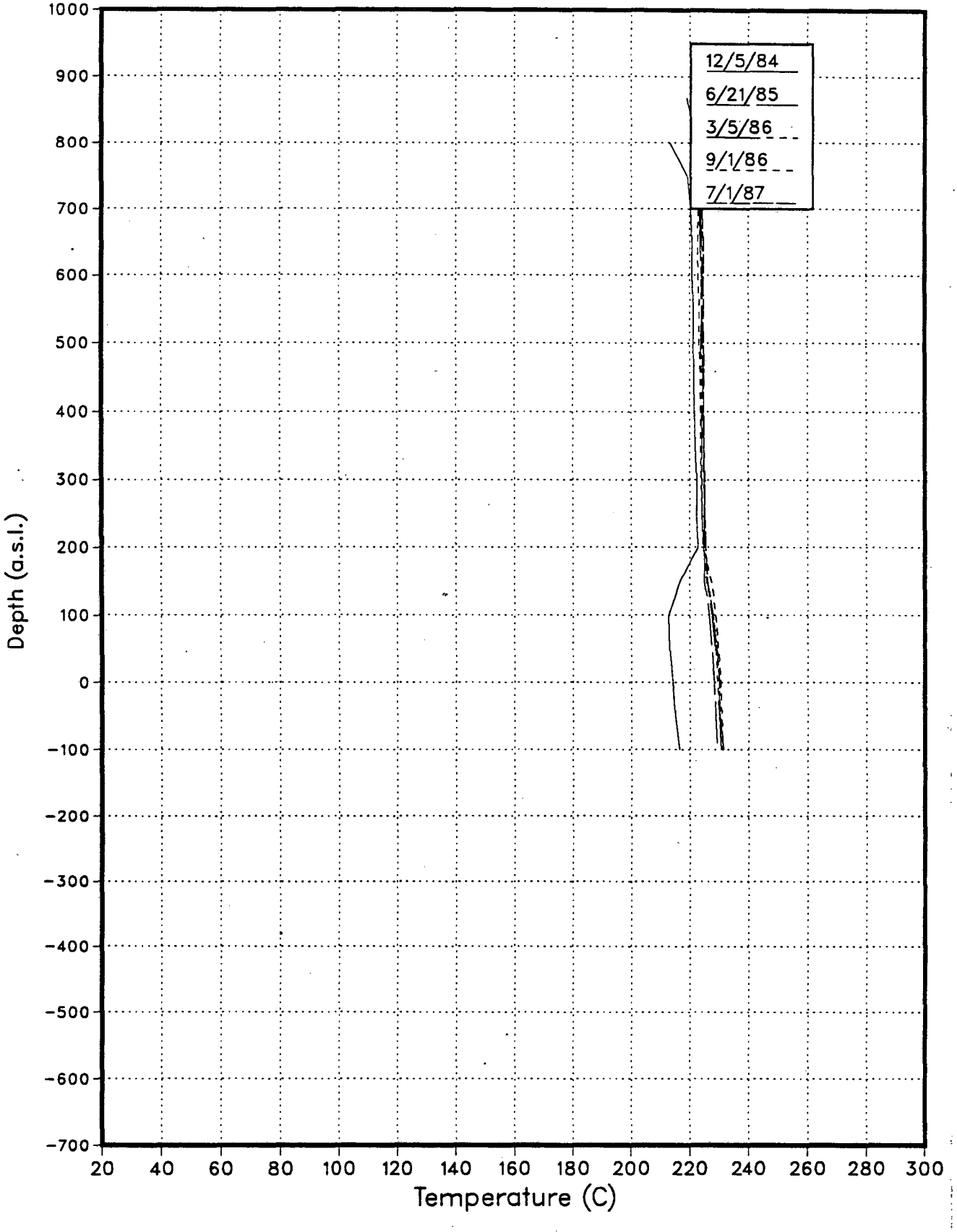

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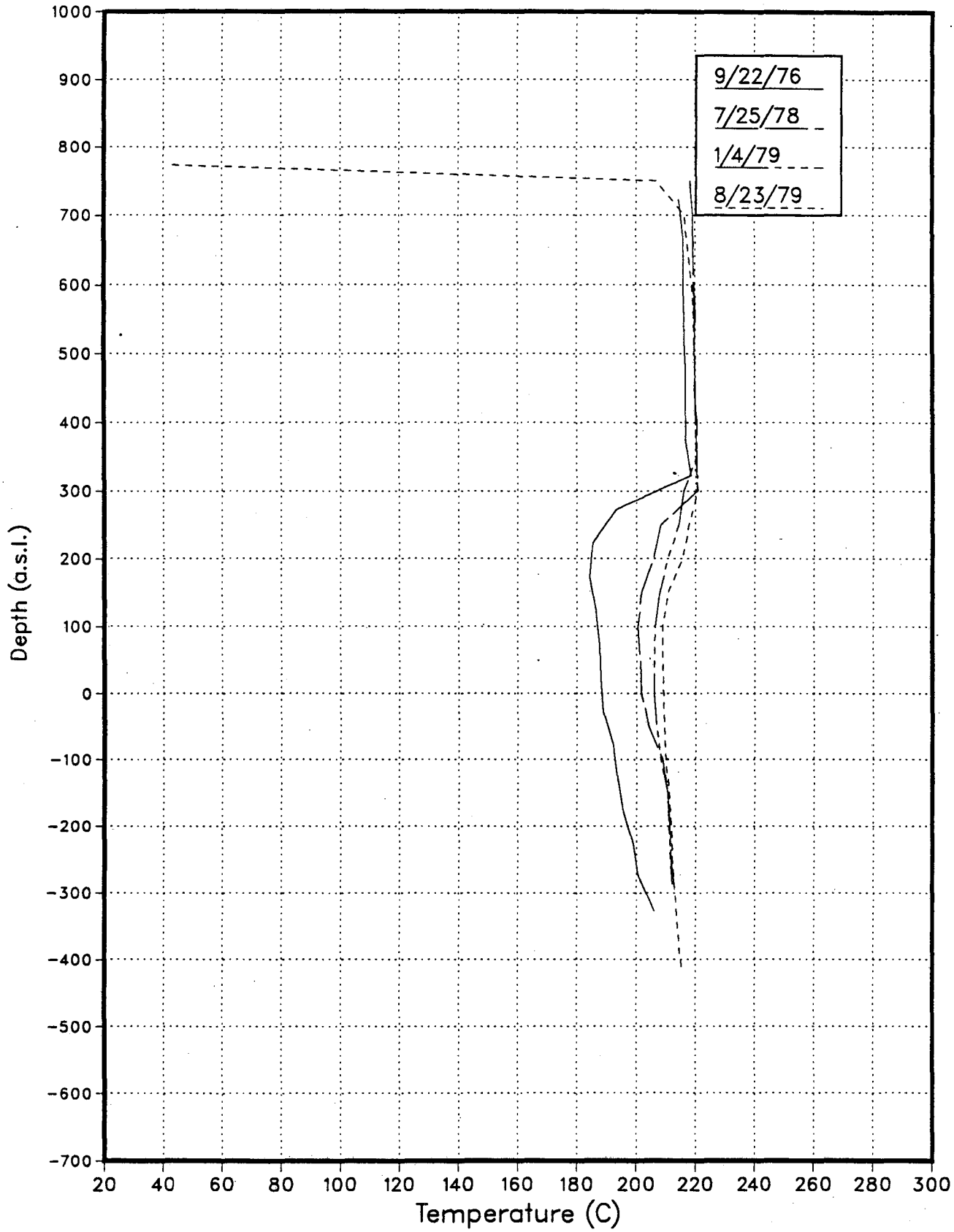

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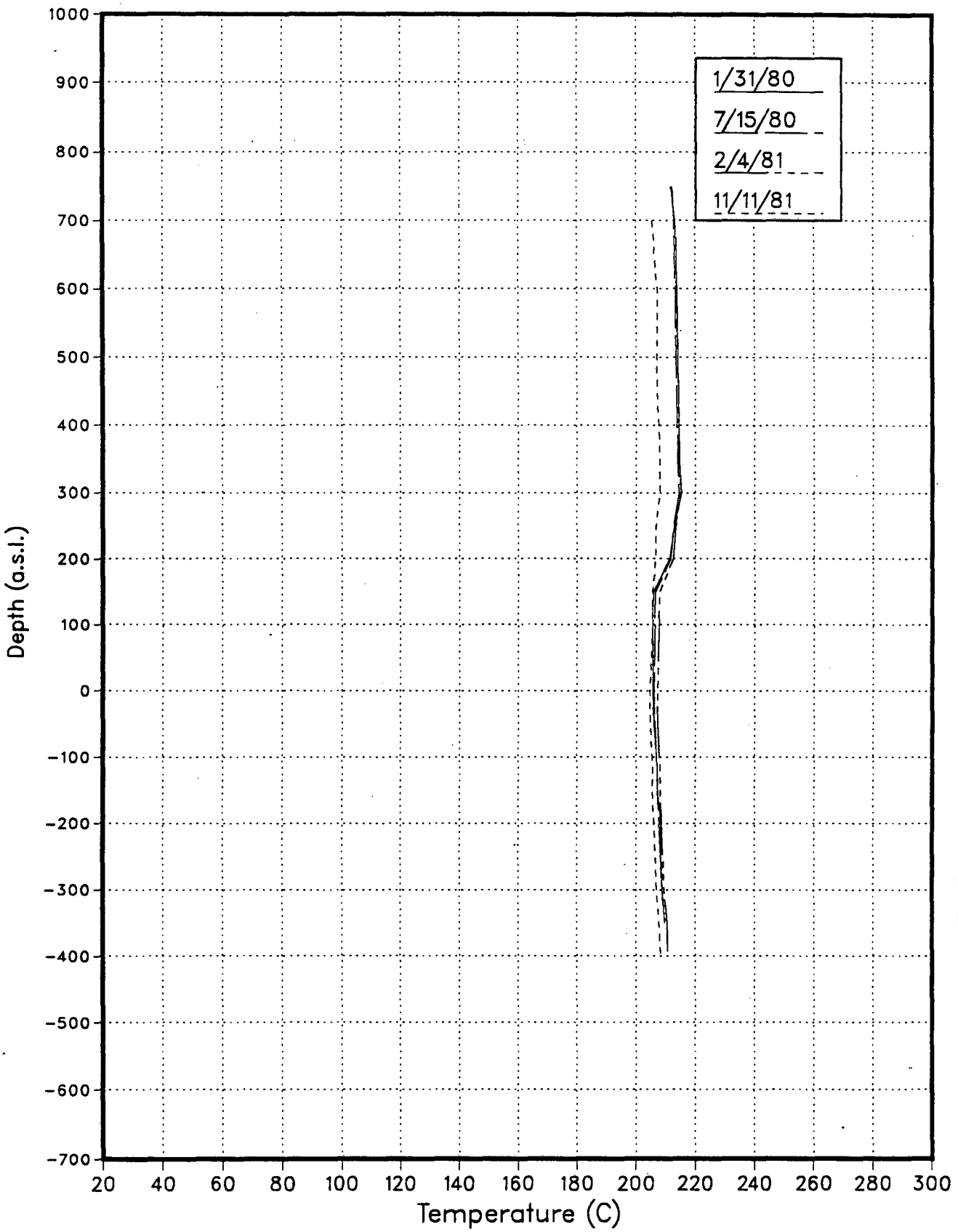

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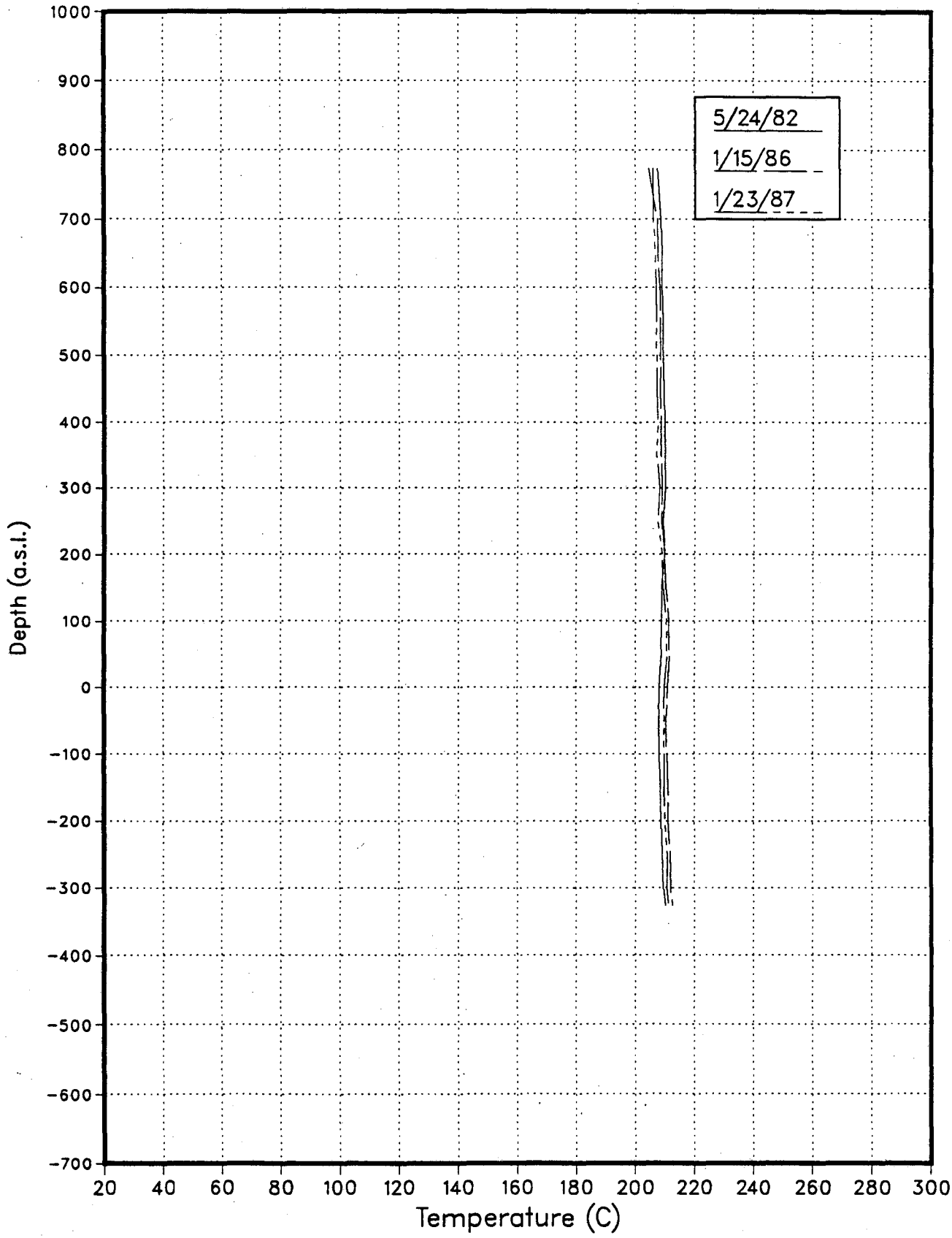
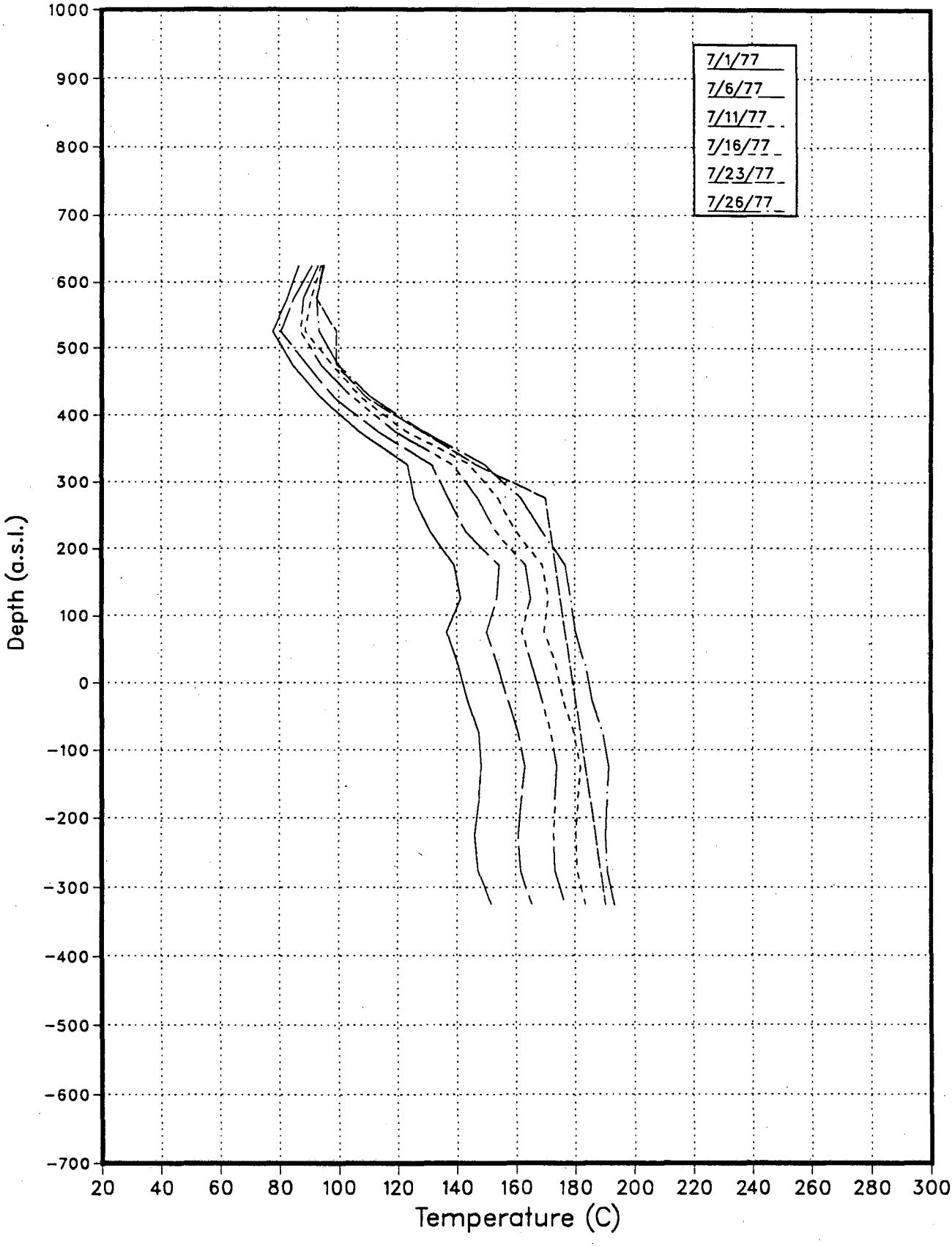


AH18 Temperature Surveys



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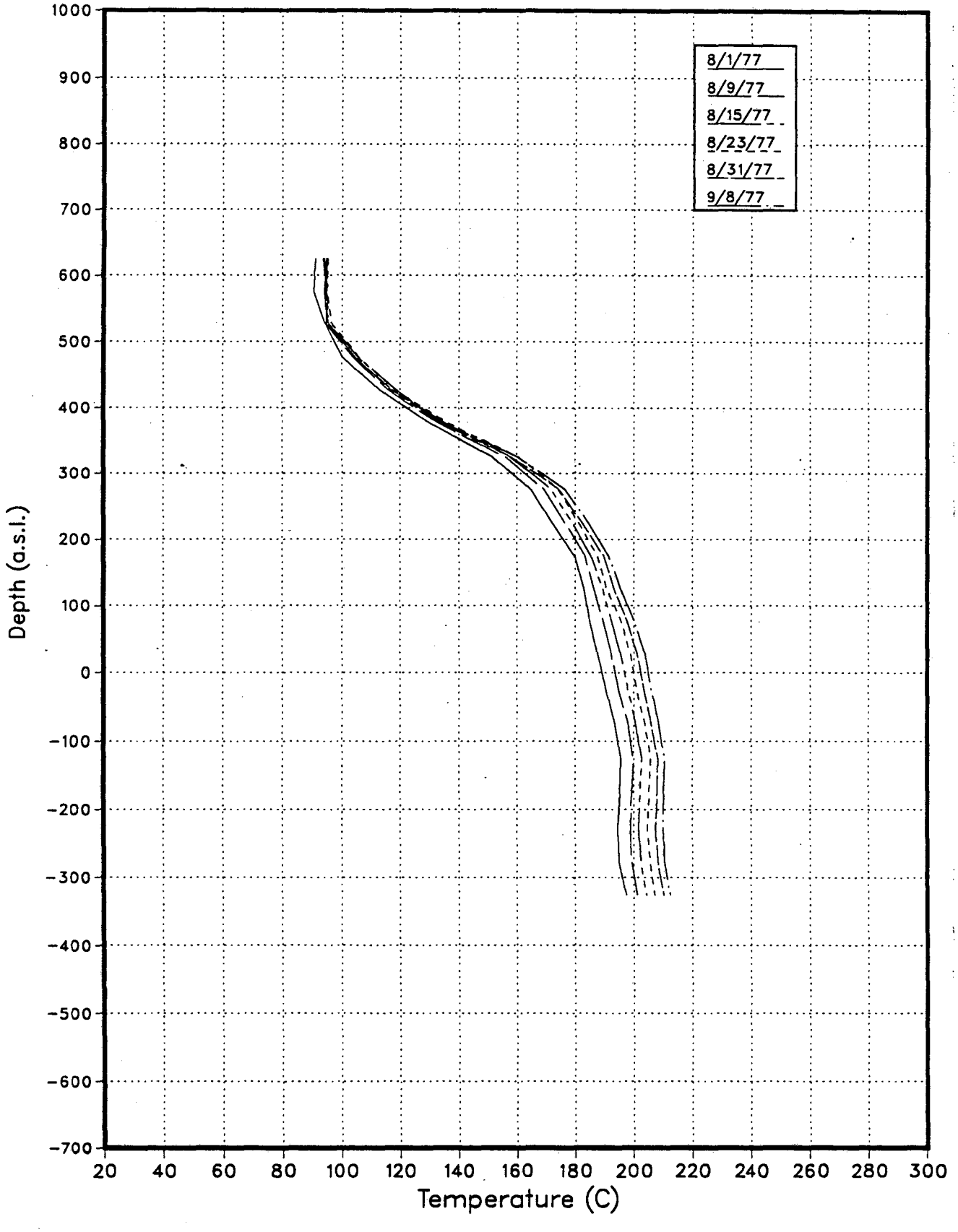

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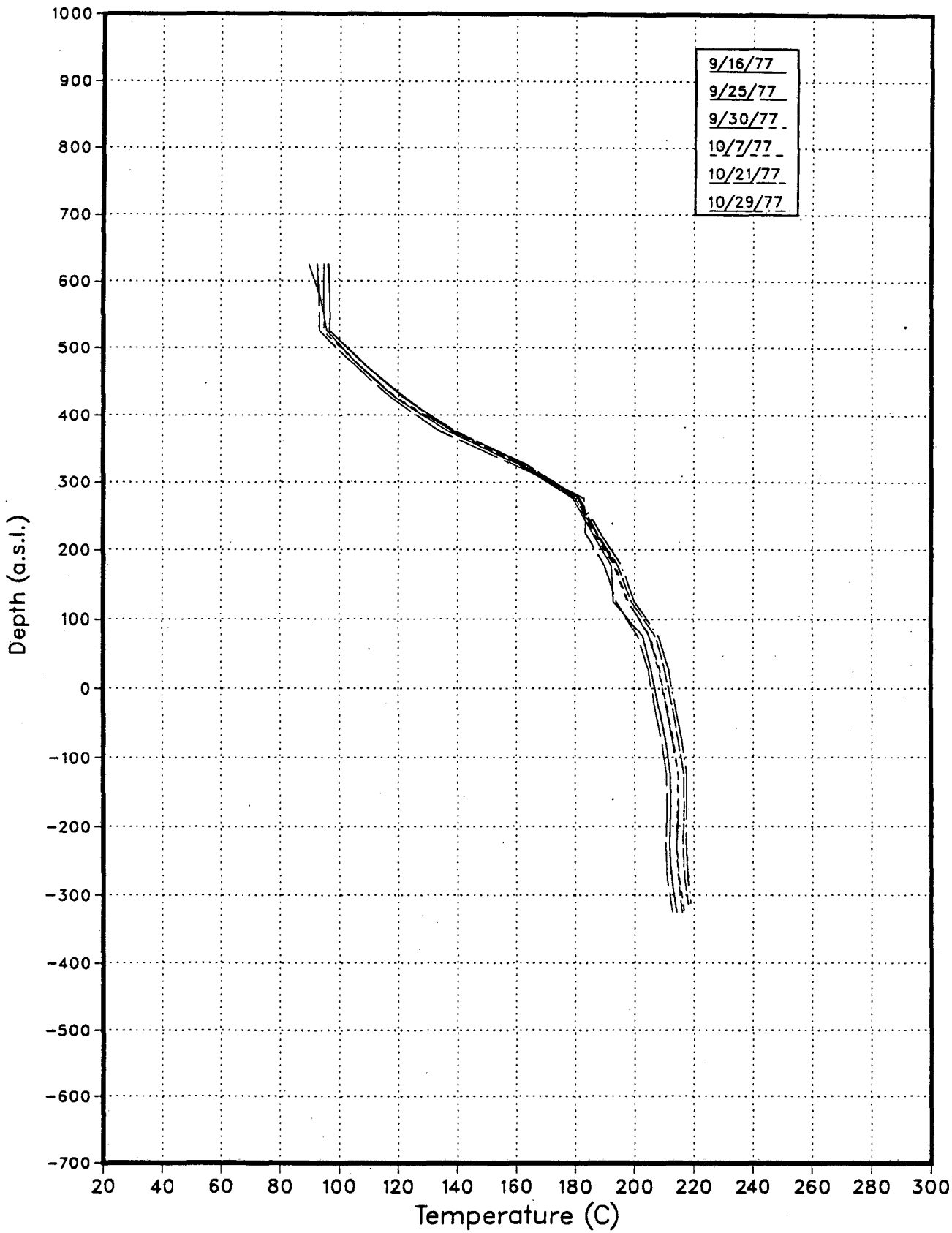

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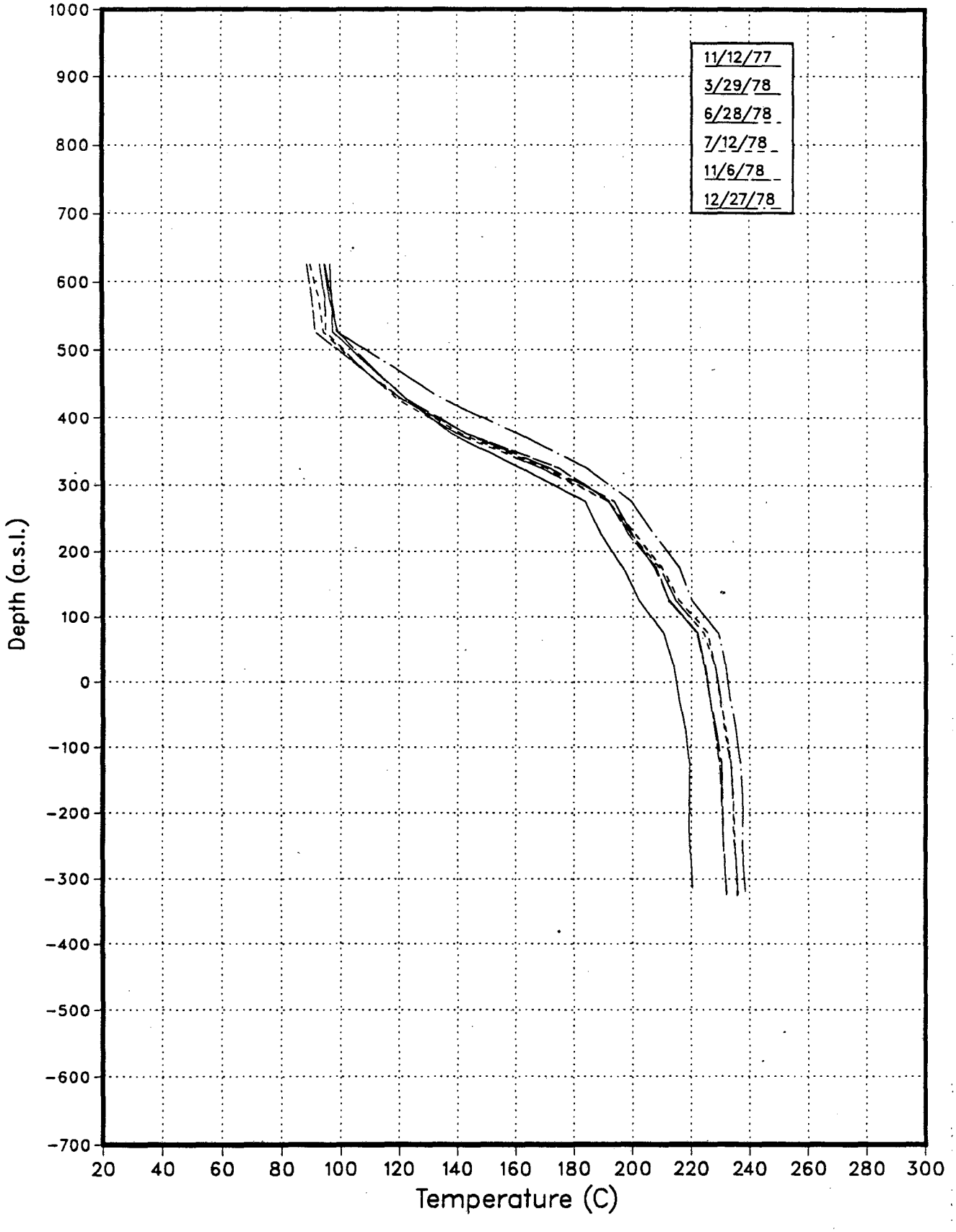

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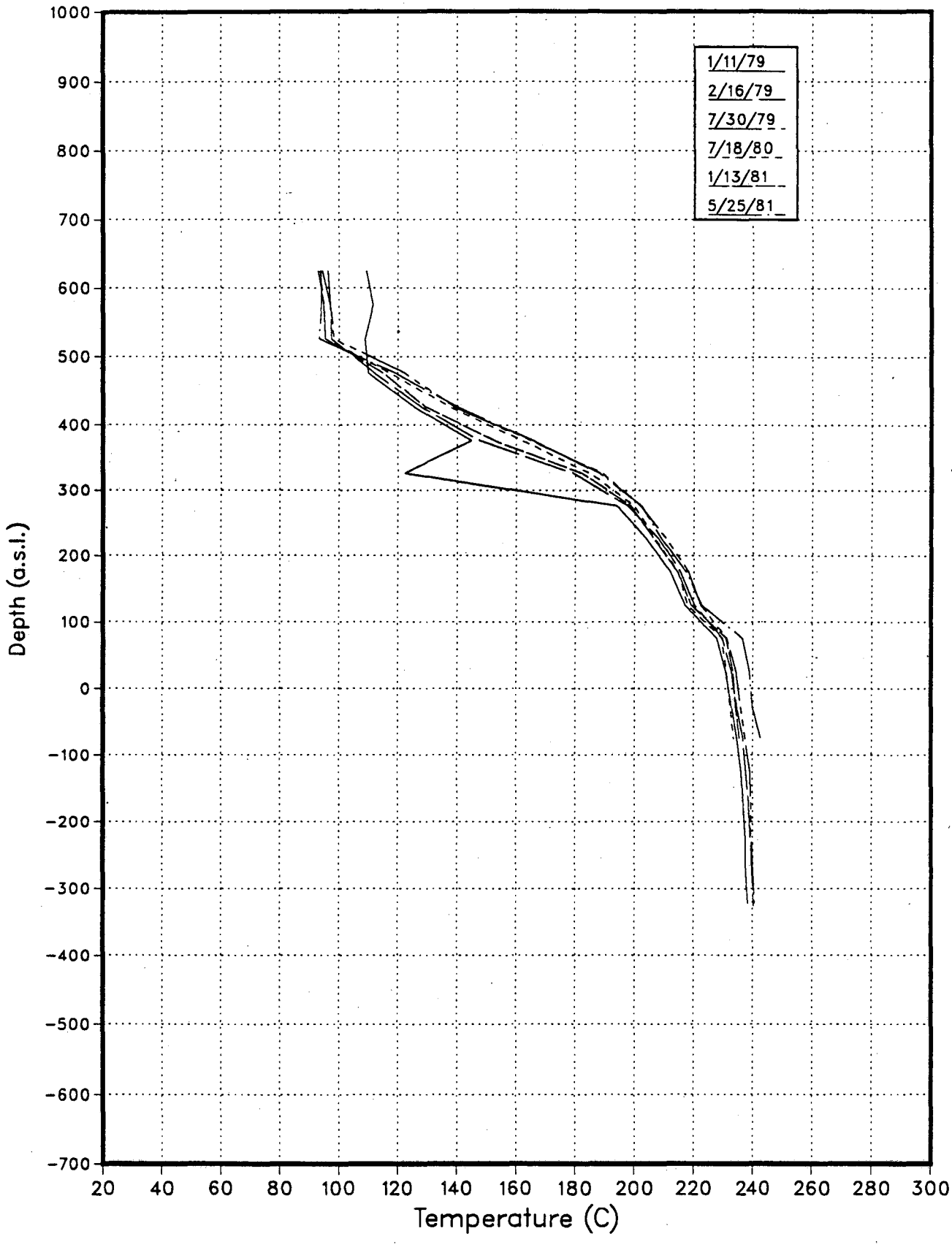

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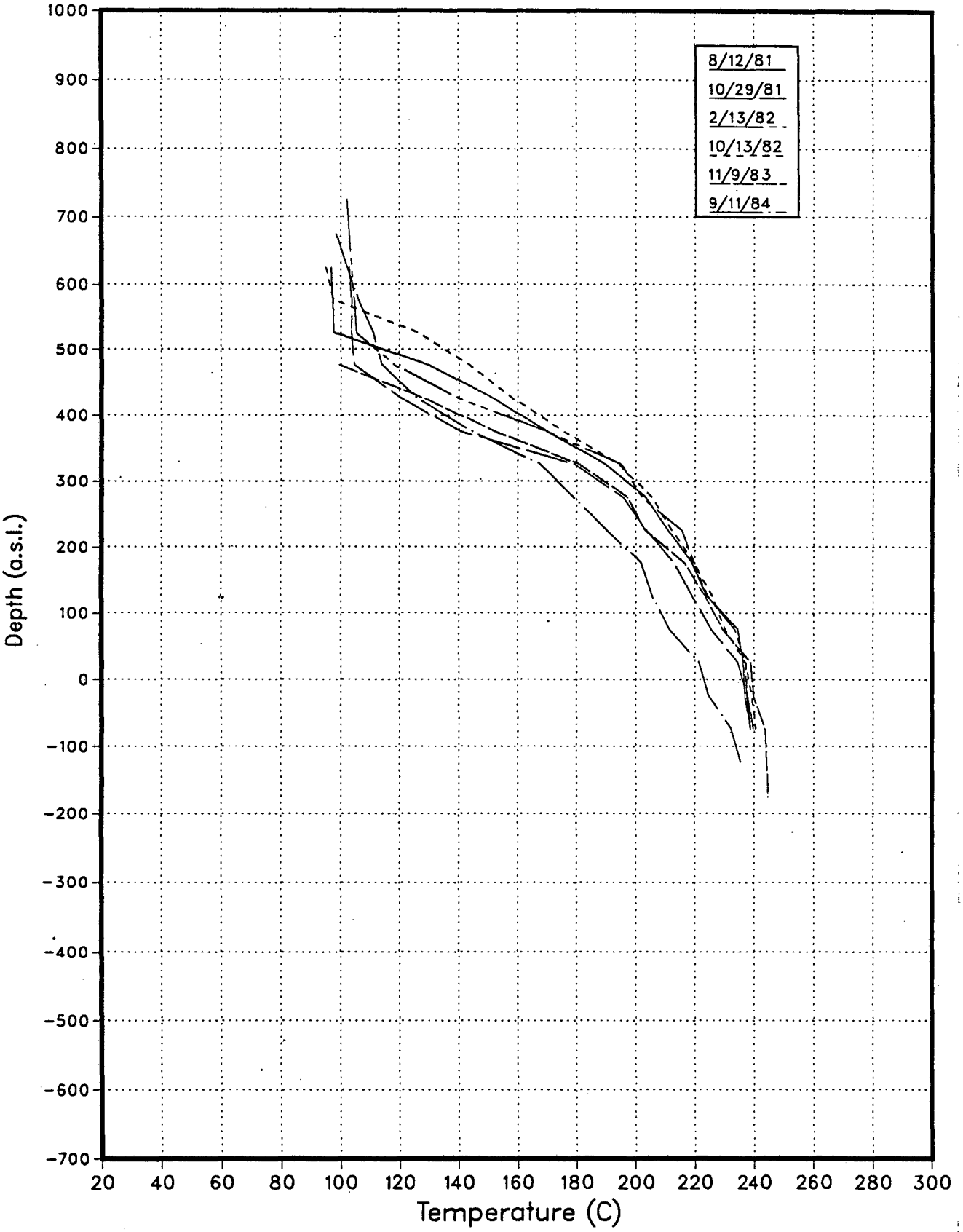

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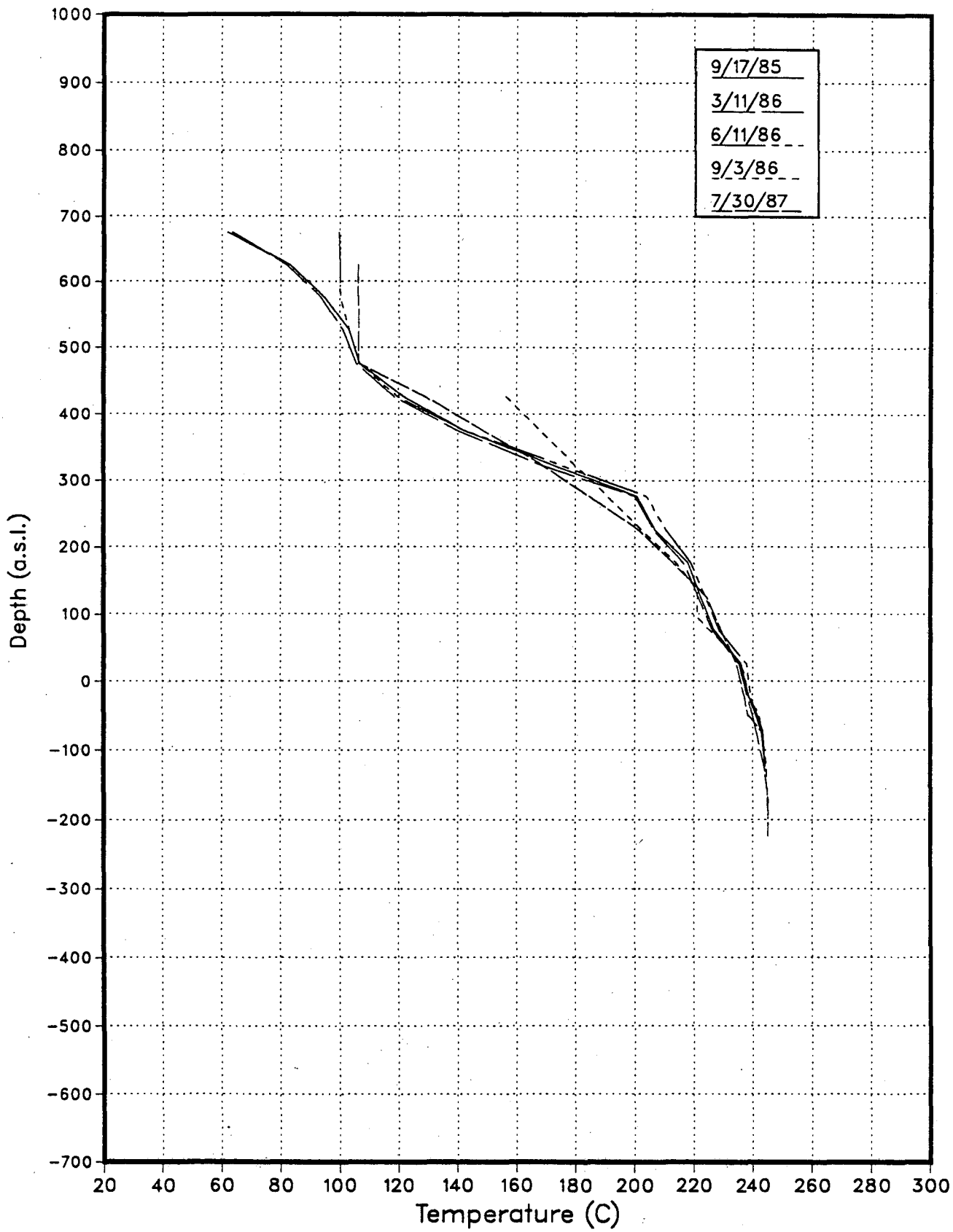
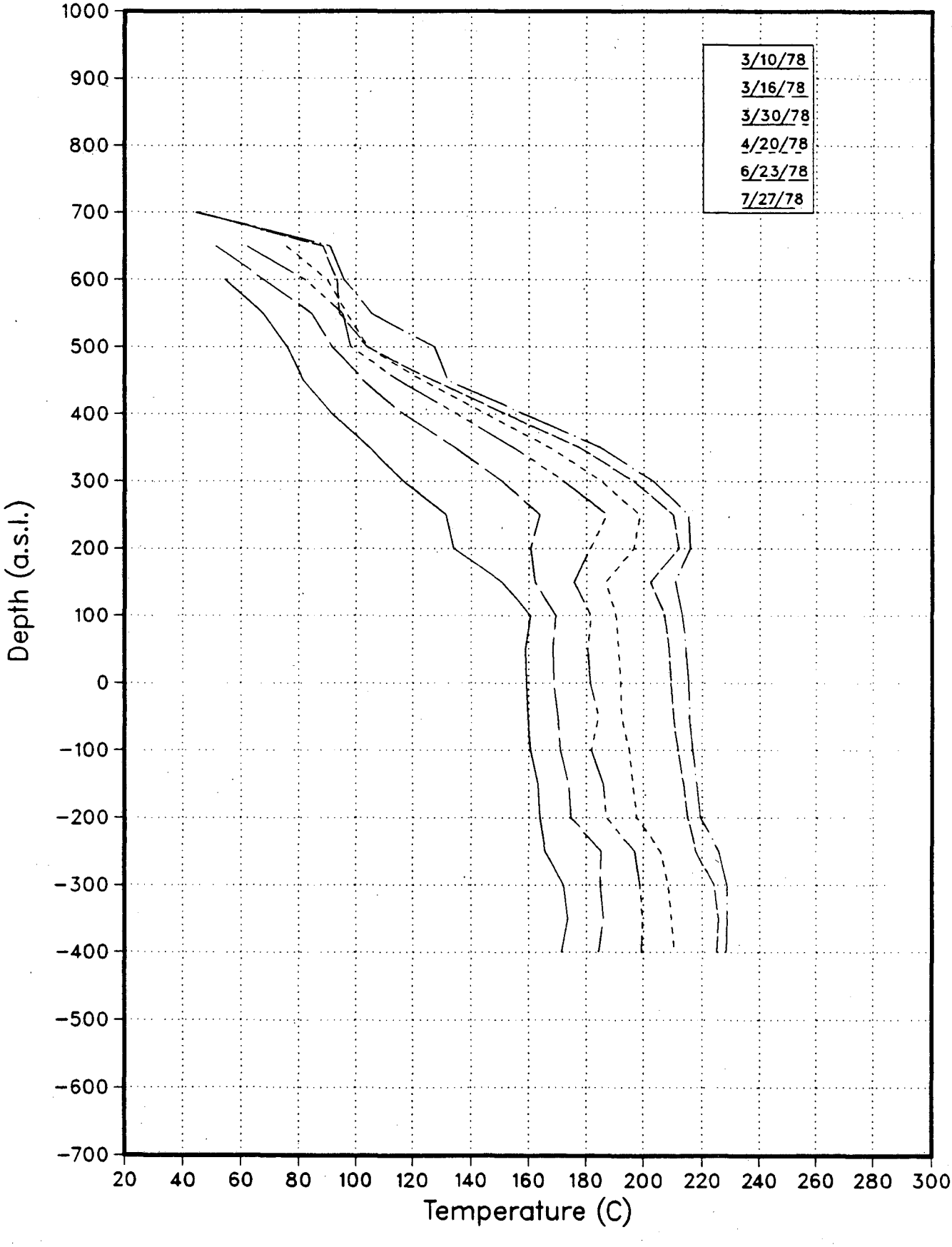
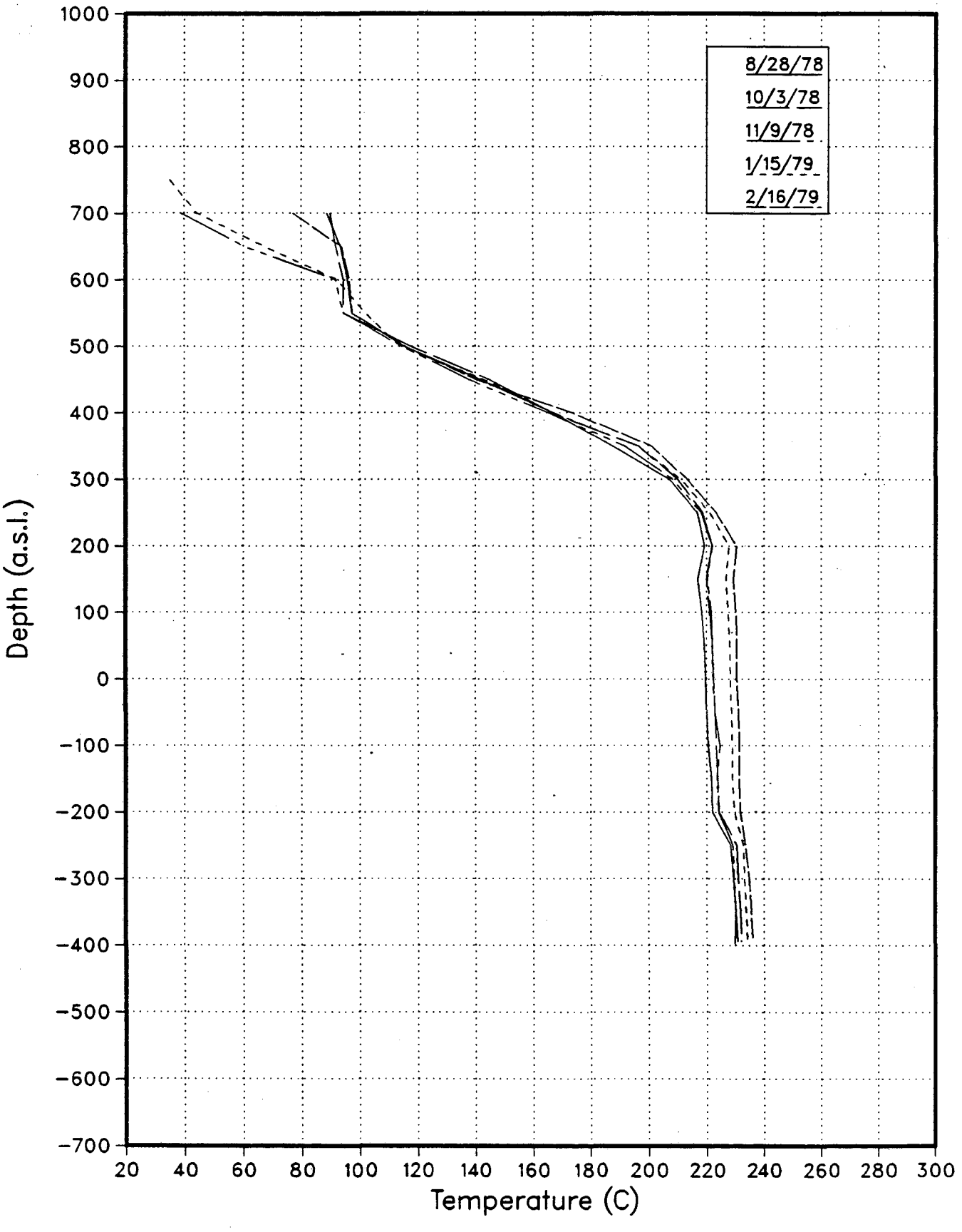


AH19 Temperature Surveys



AH19 Temperature Surveys



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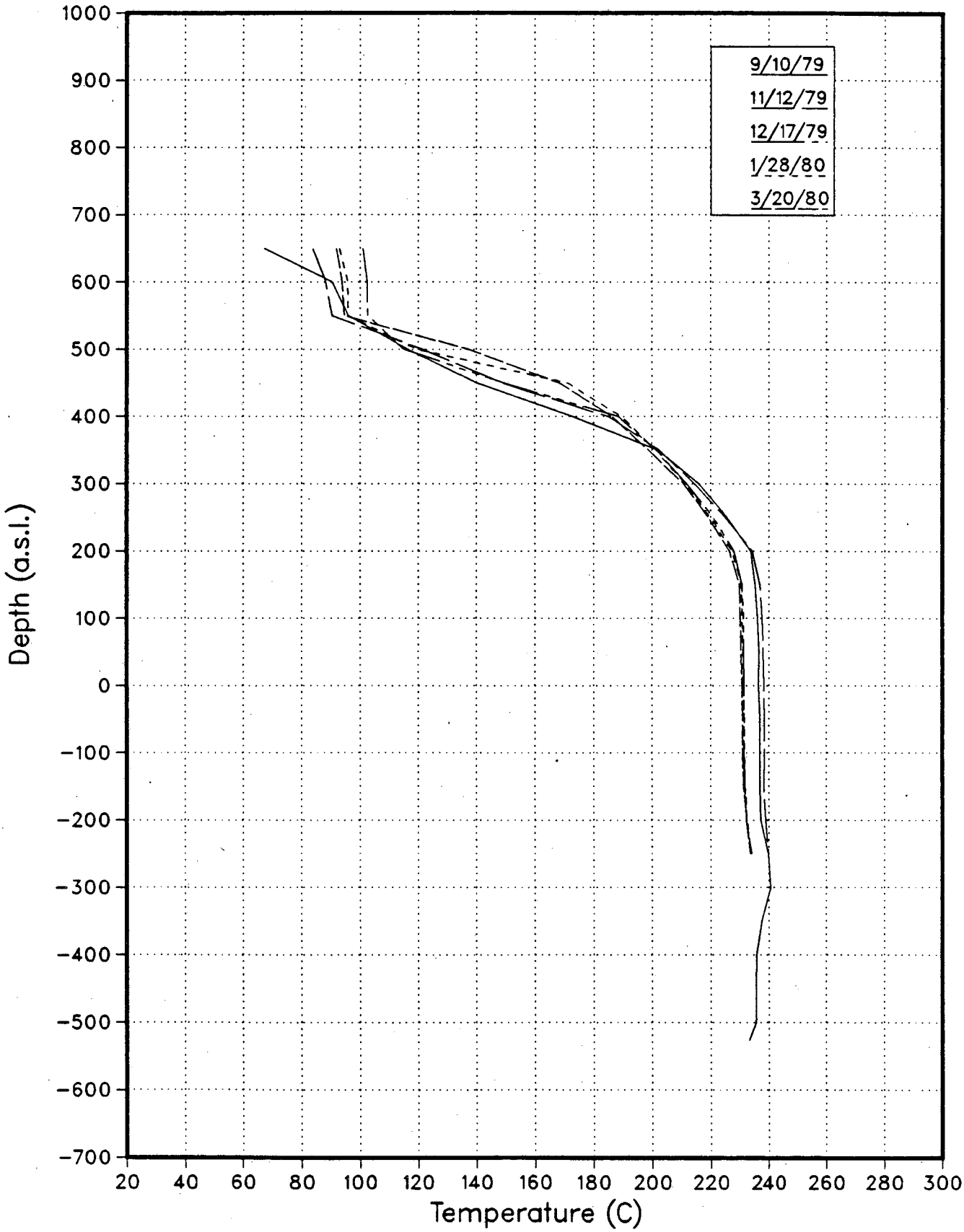

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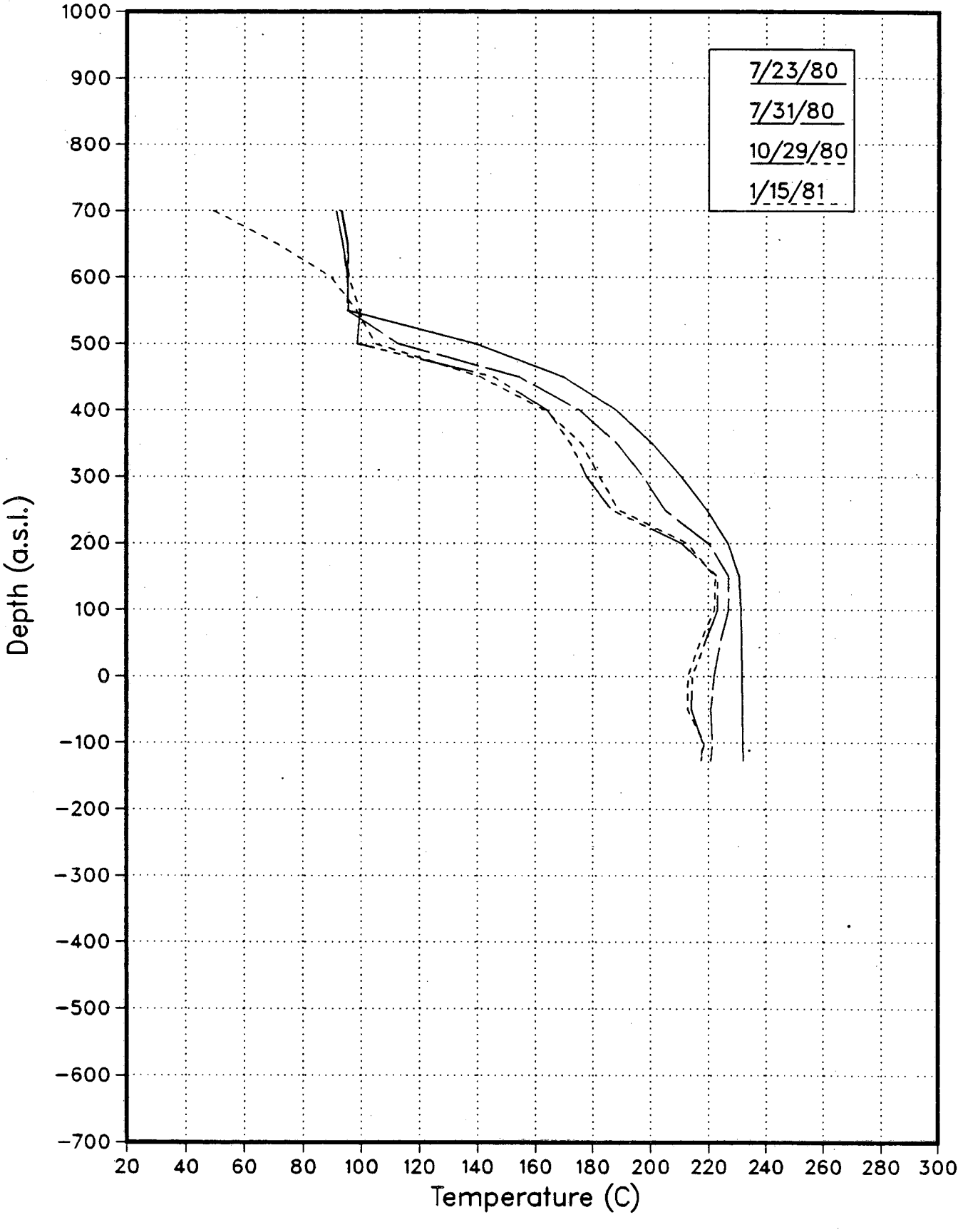

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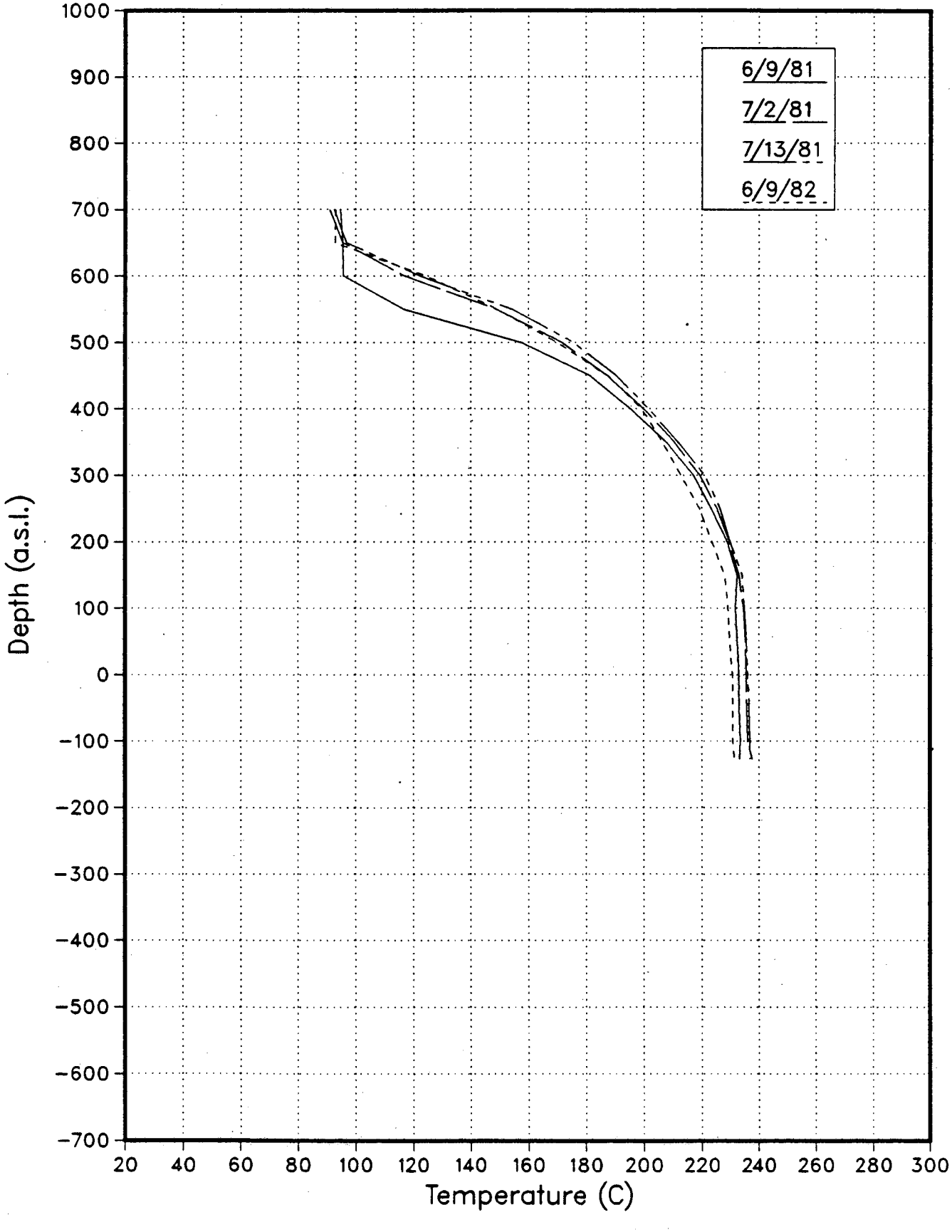

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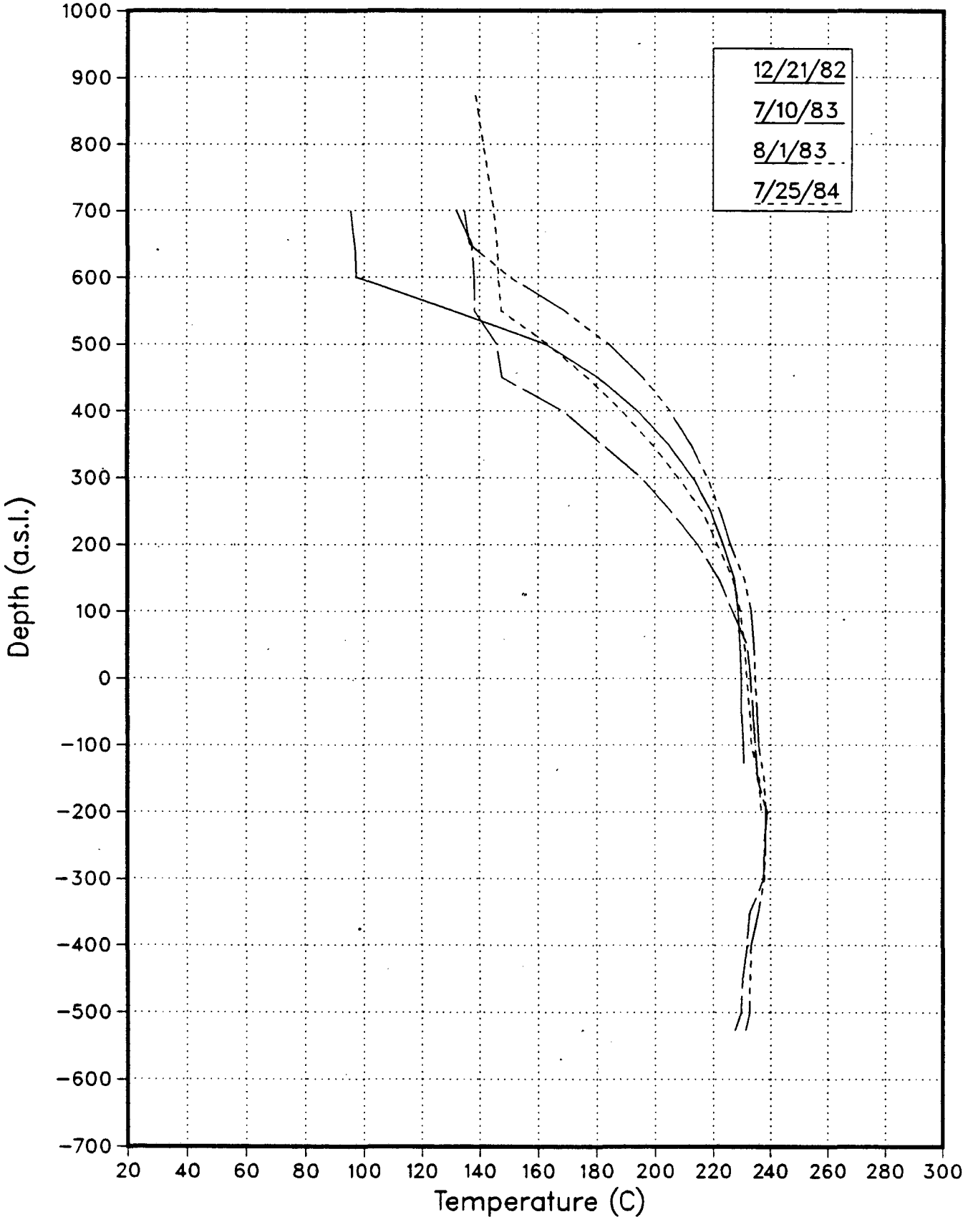

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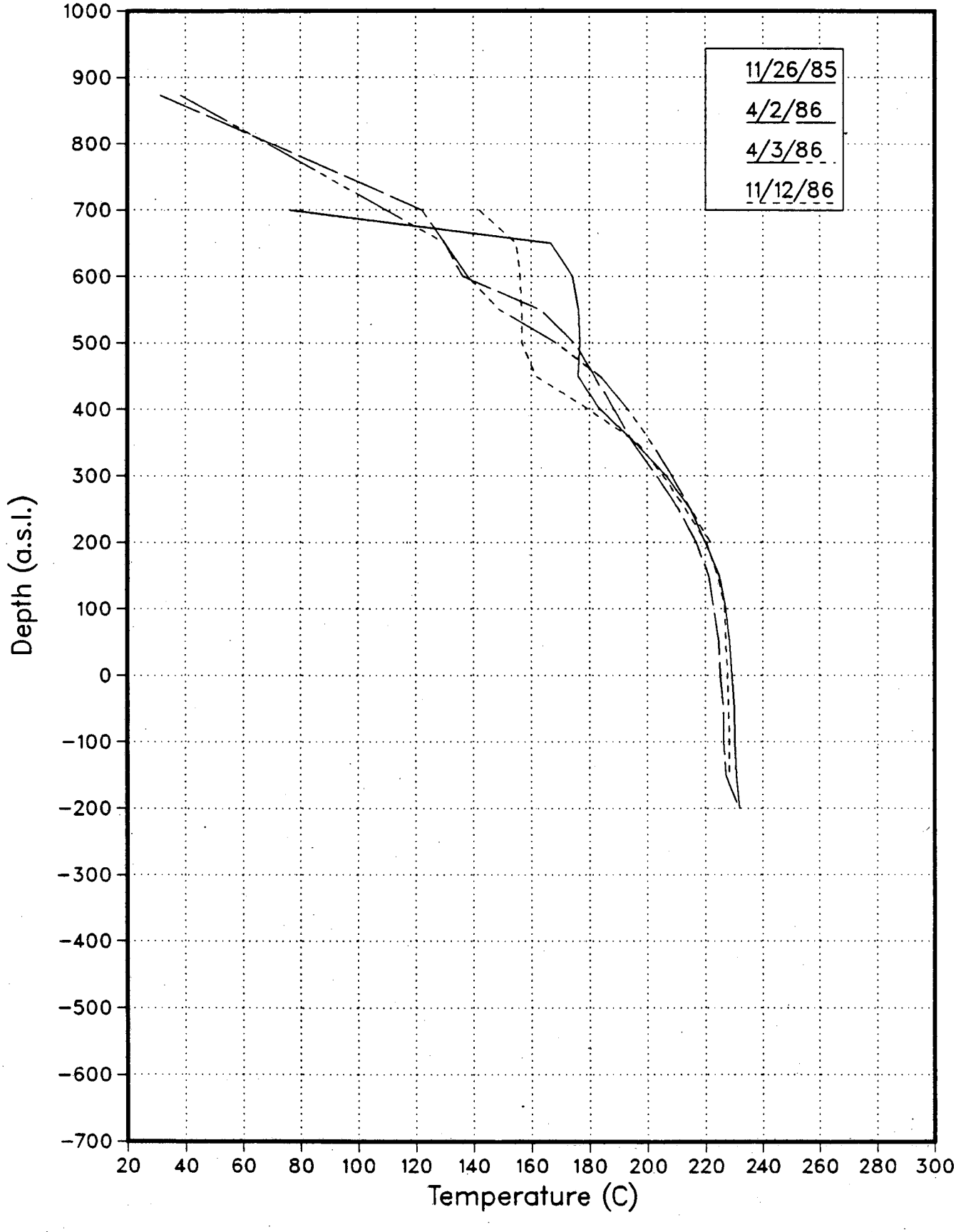
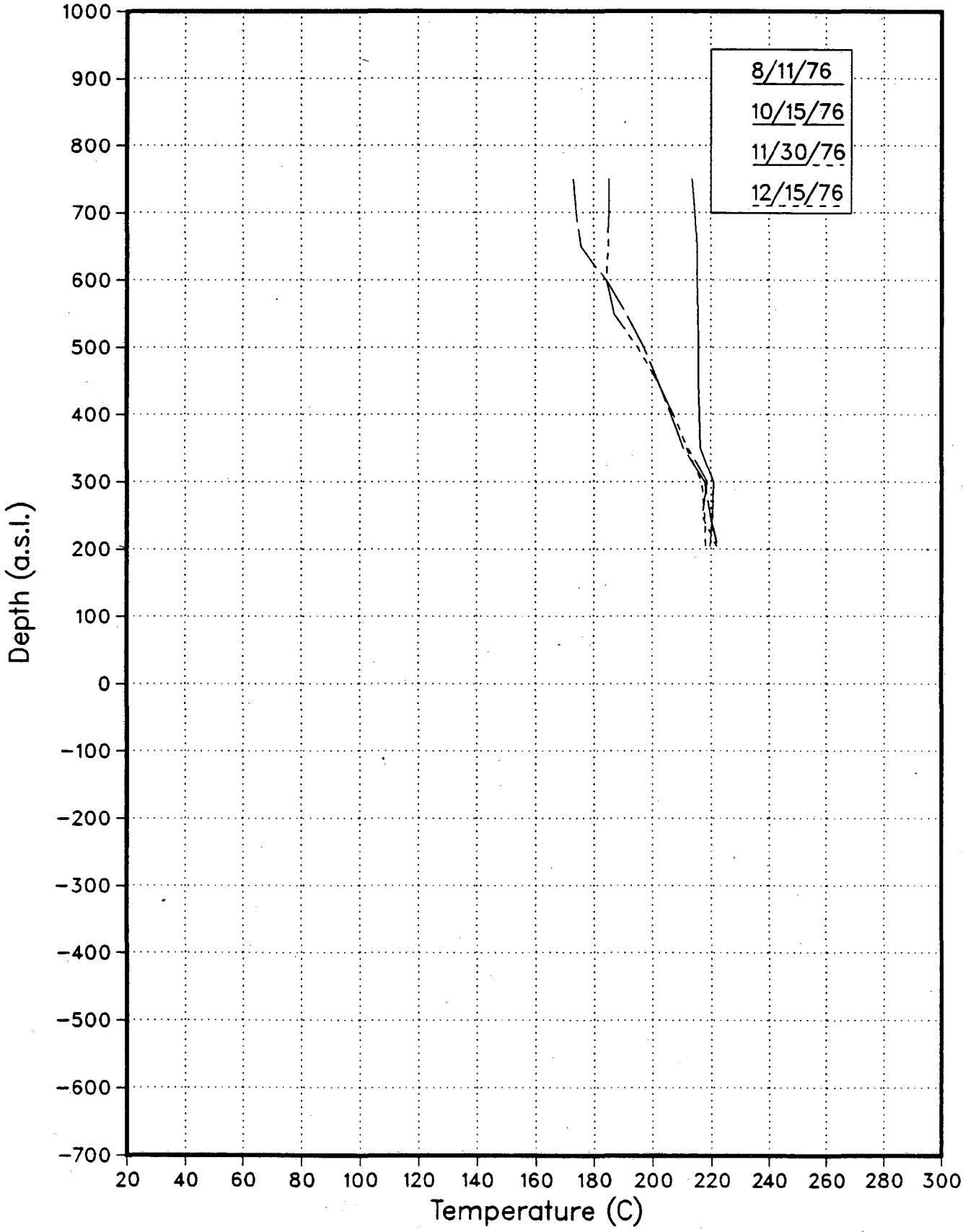
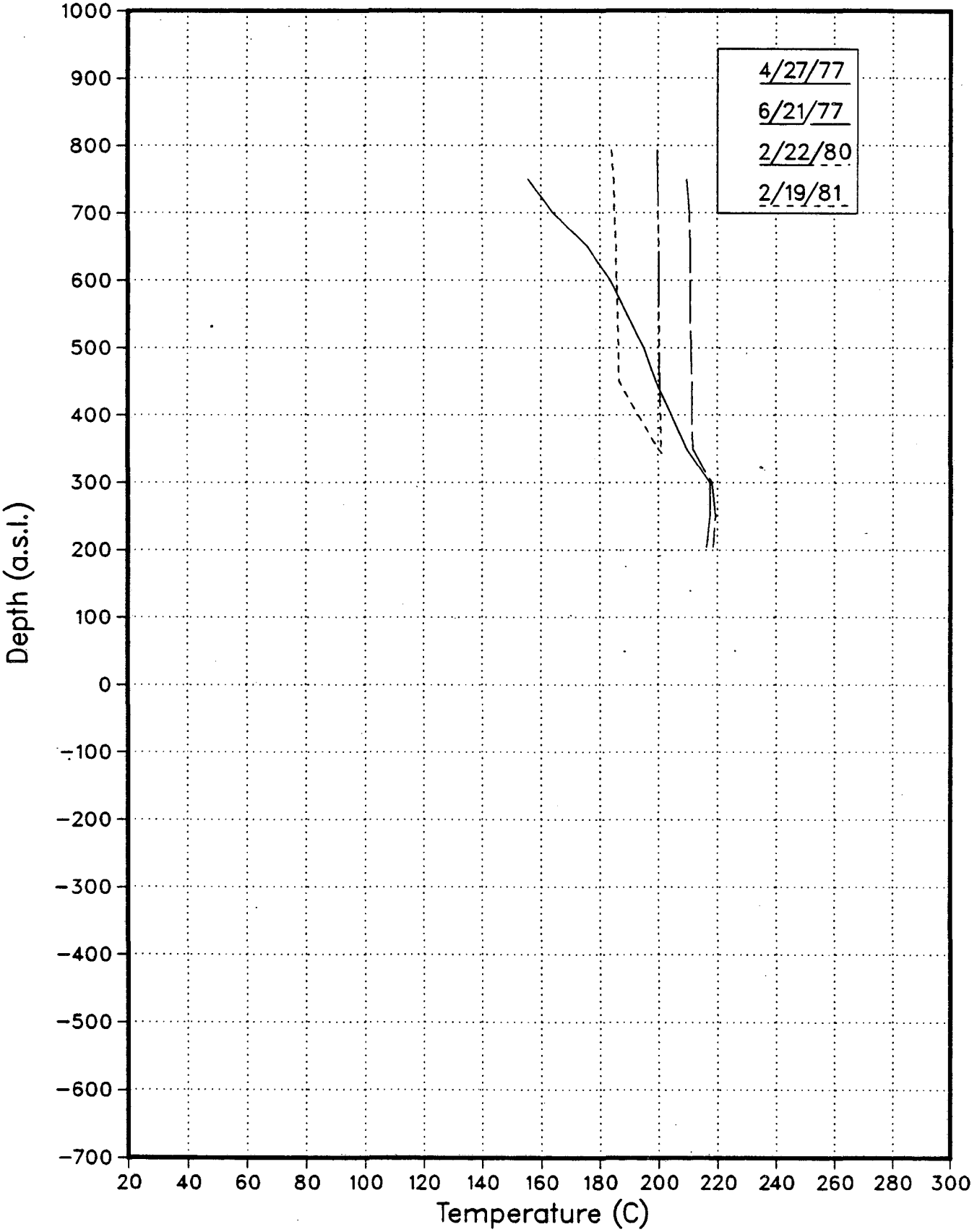


AH20 Temperature Surveys



AH20 Temperature Surveys



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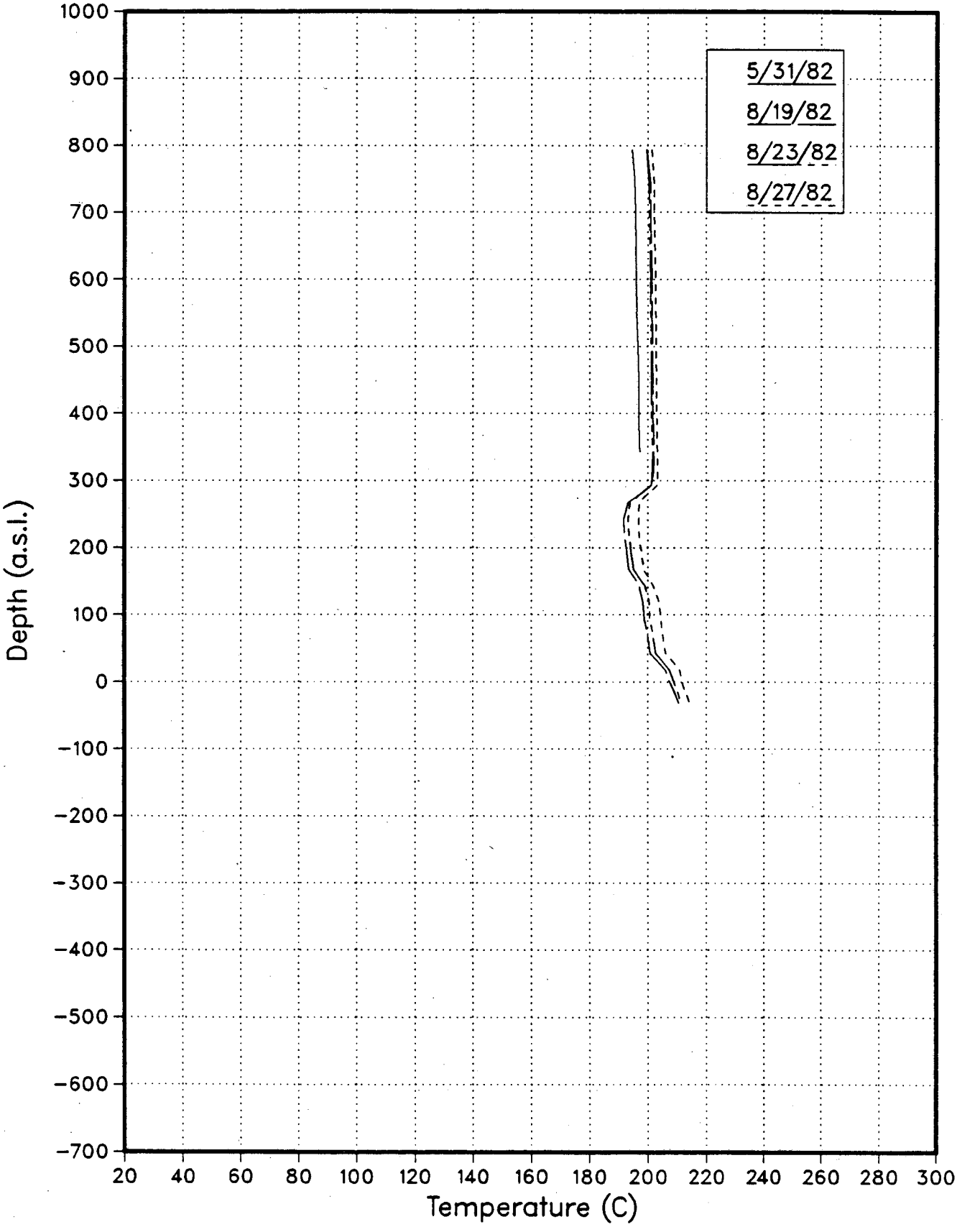

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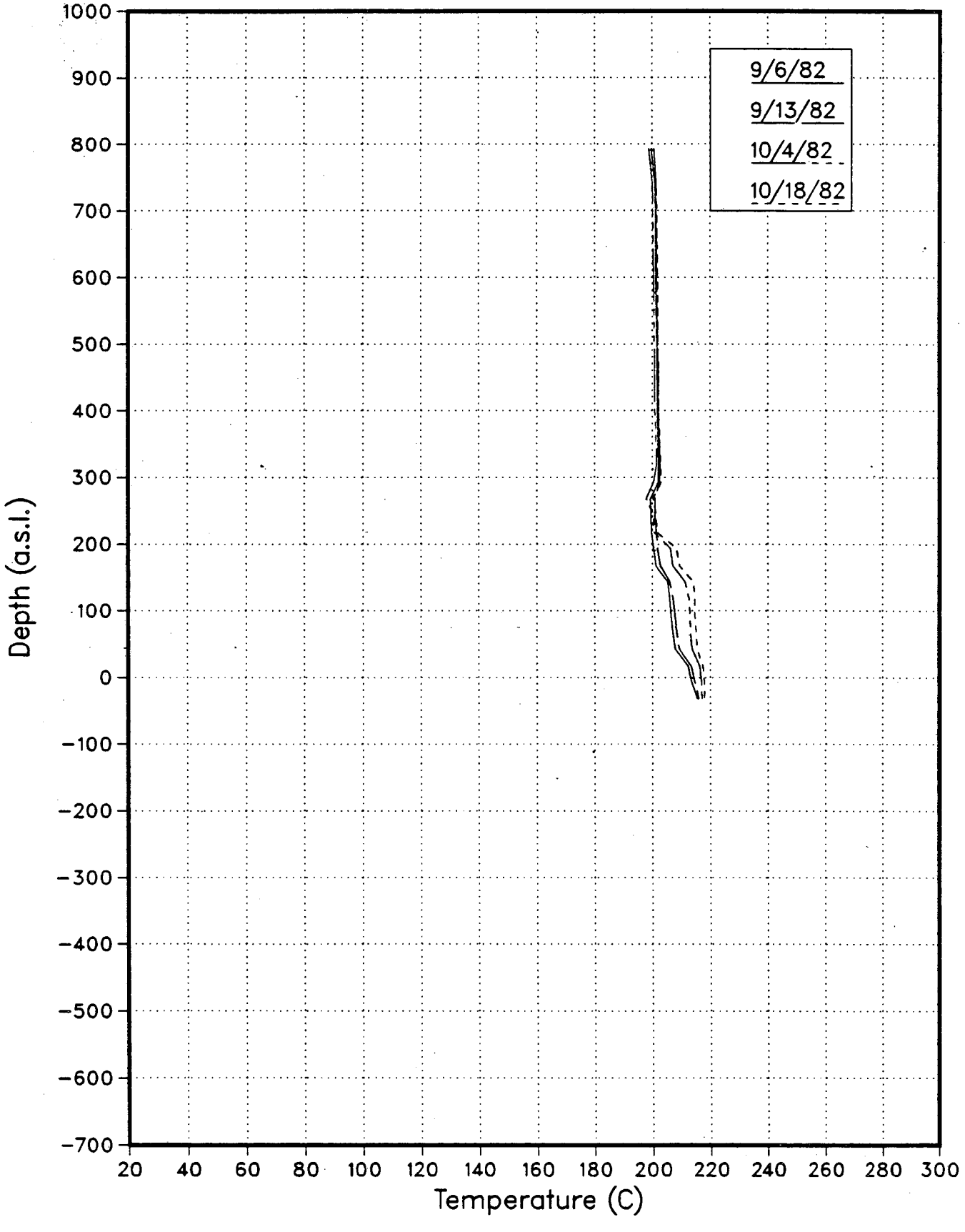

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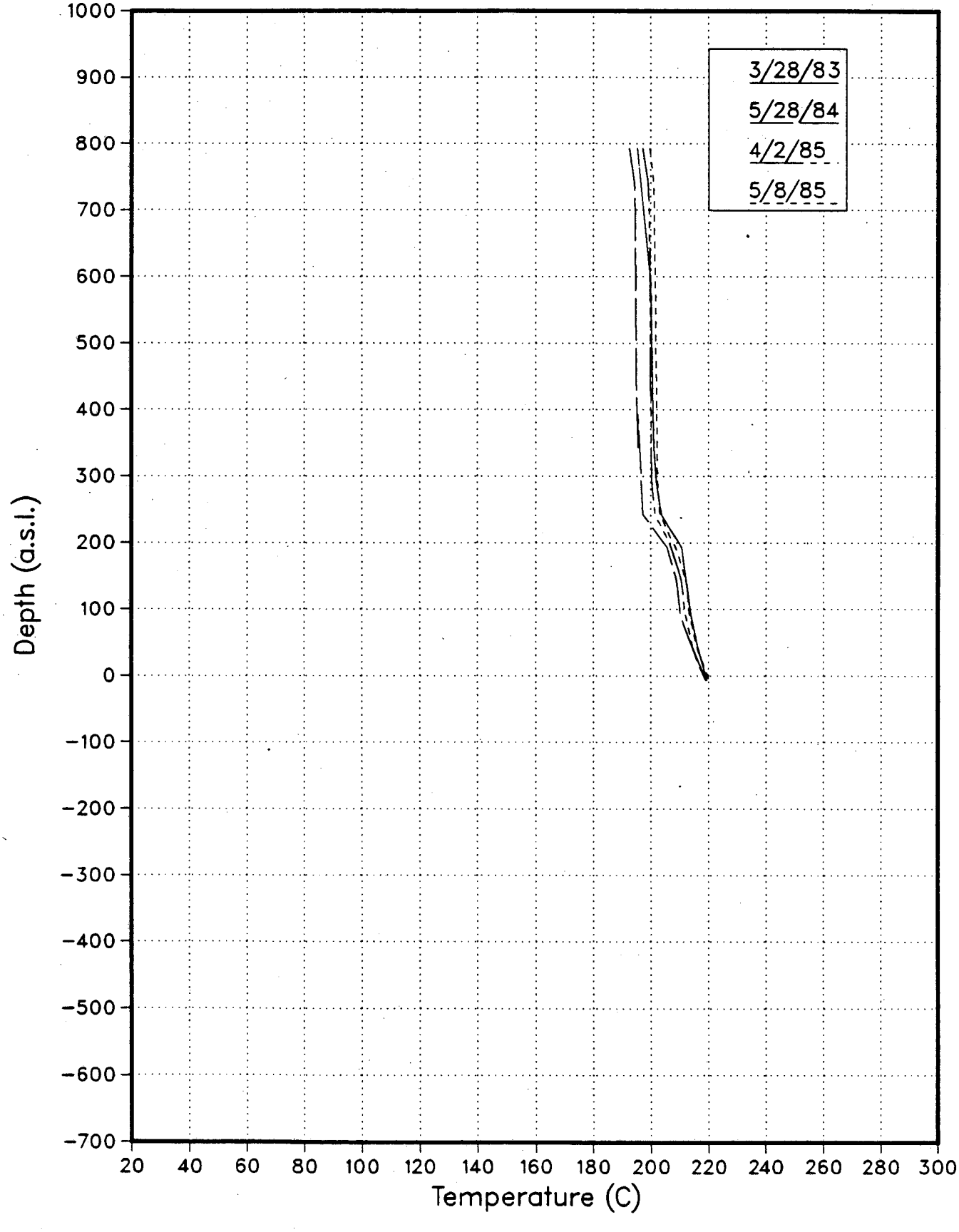

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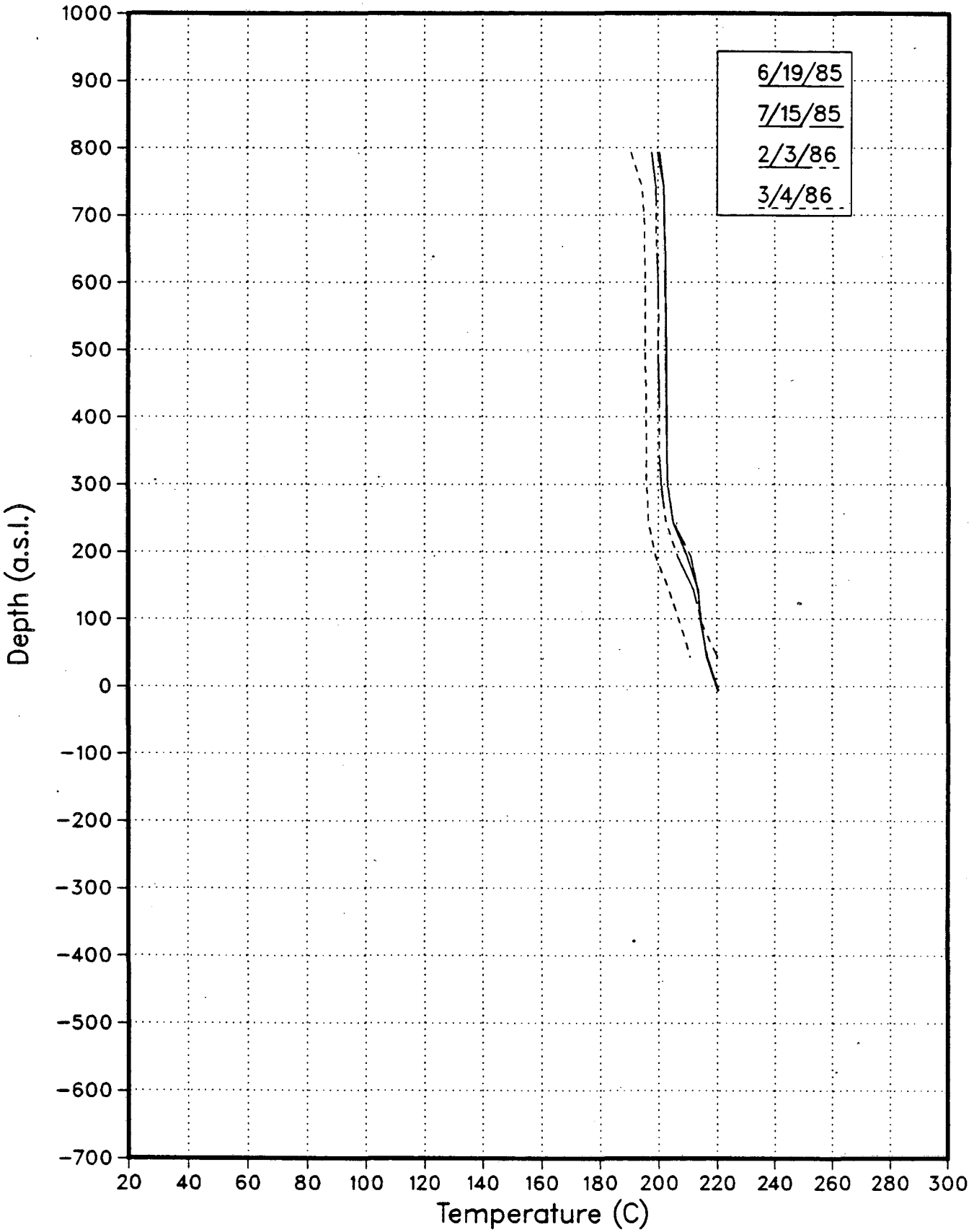
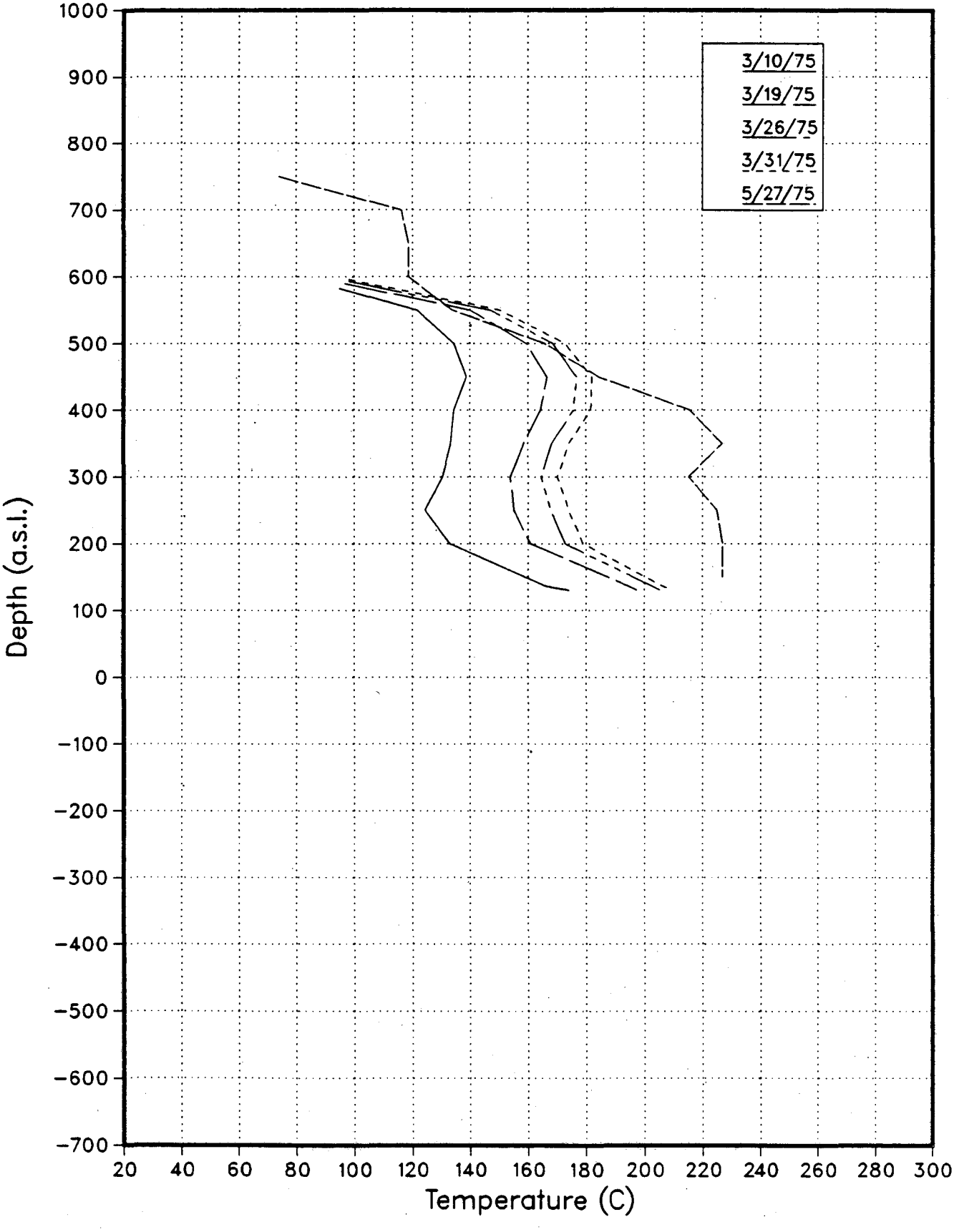


AH21 Temperature Surveys



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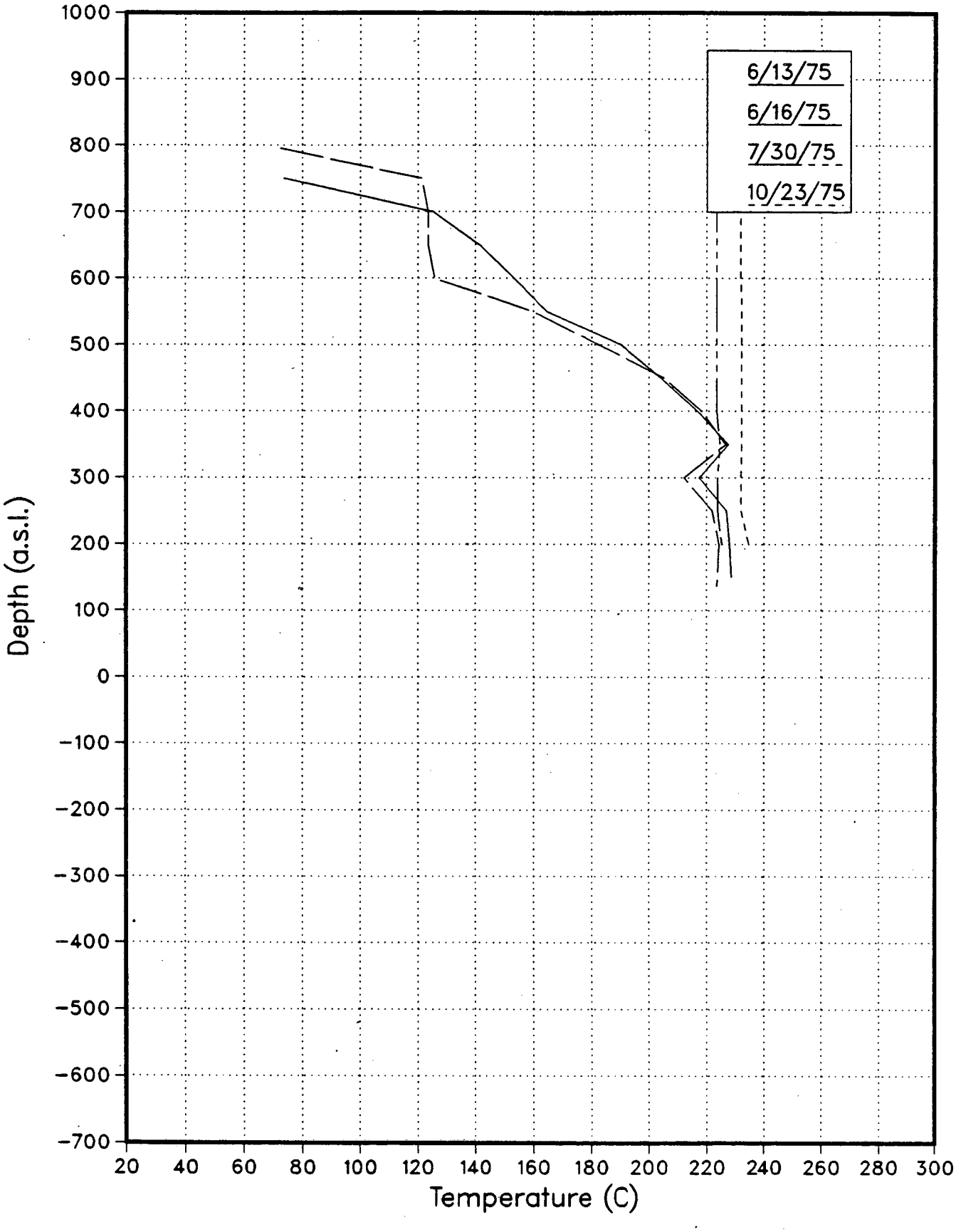

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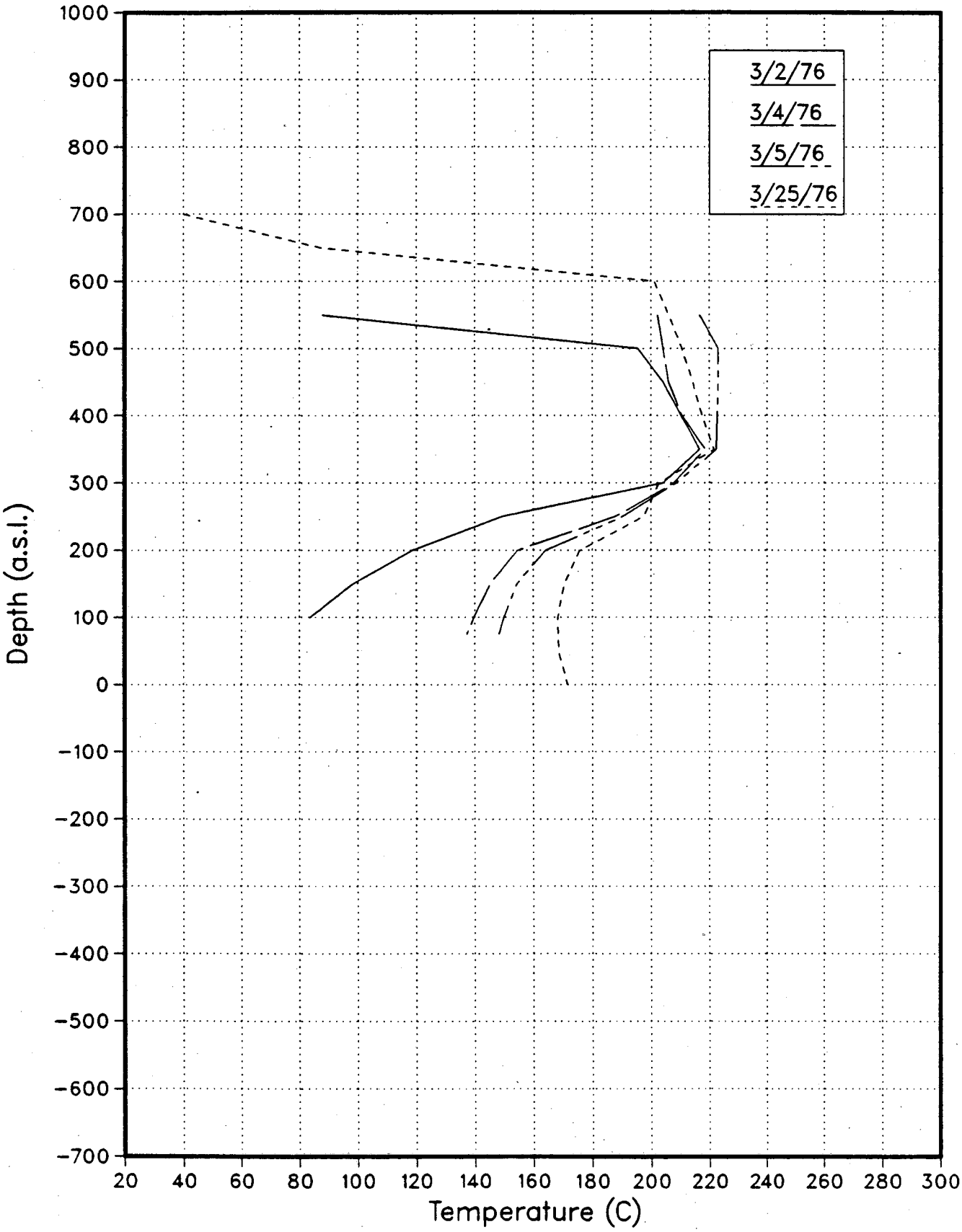

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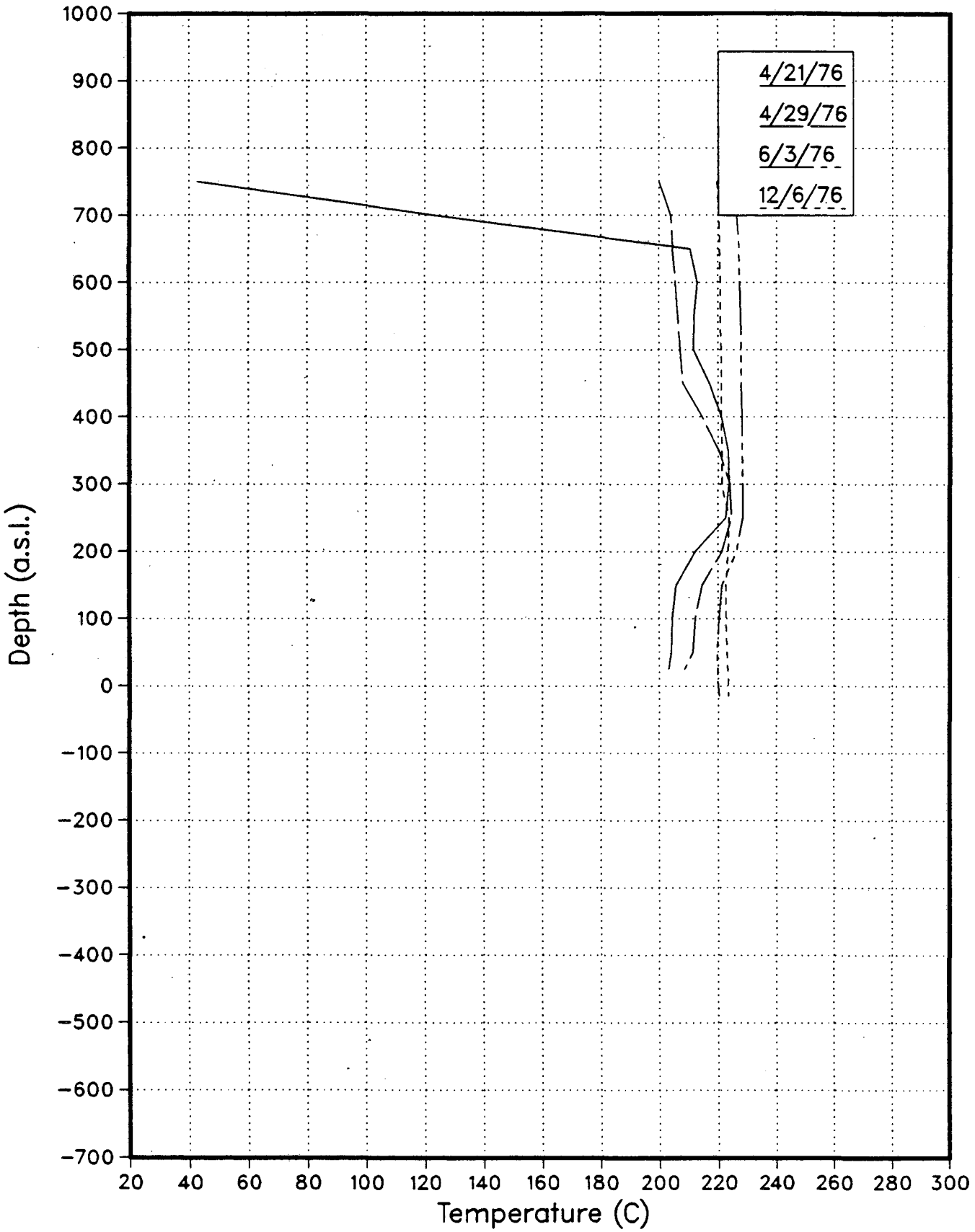

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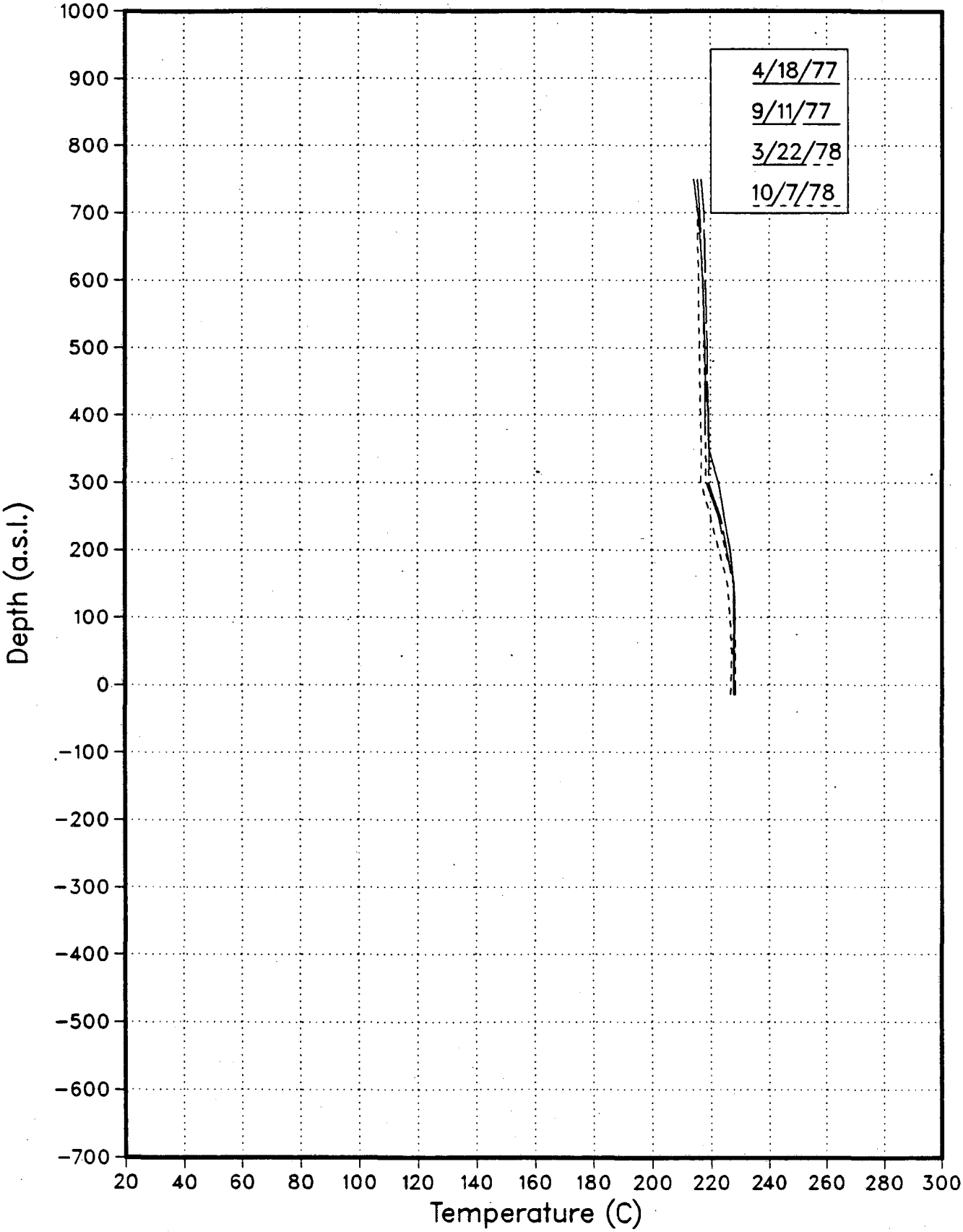

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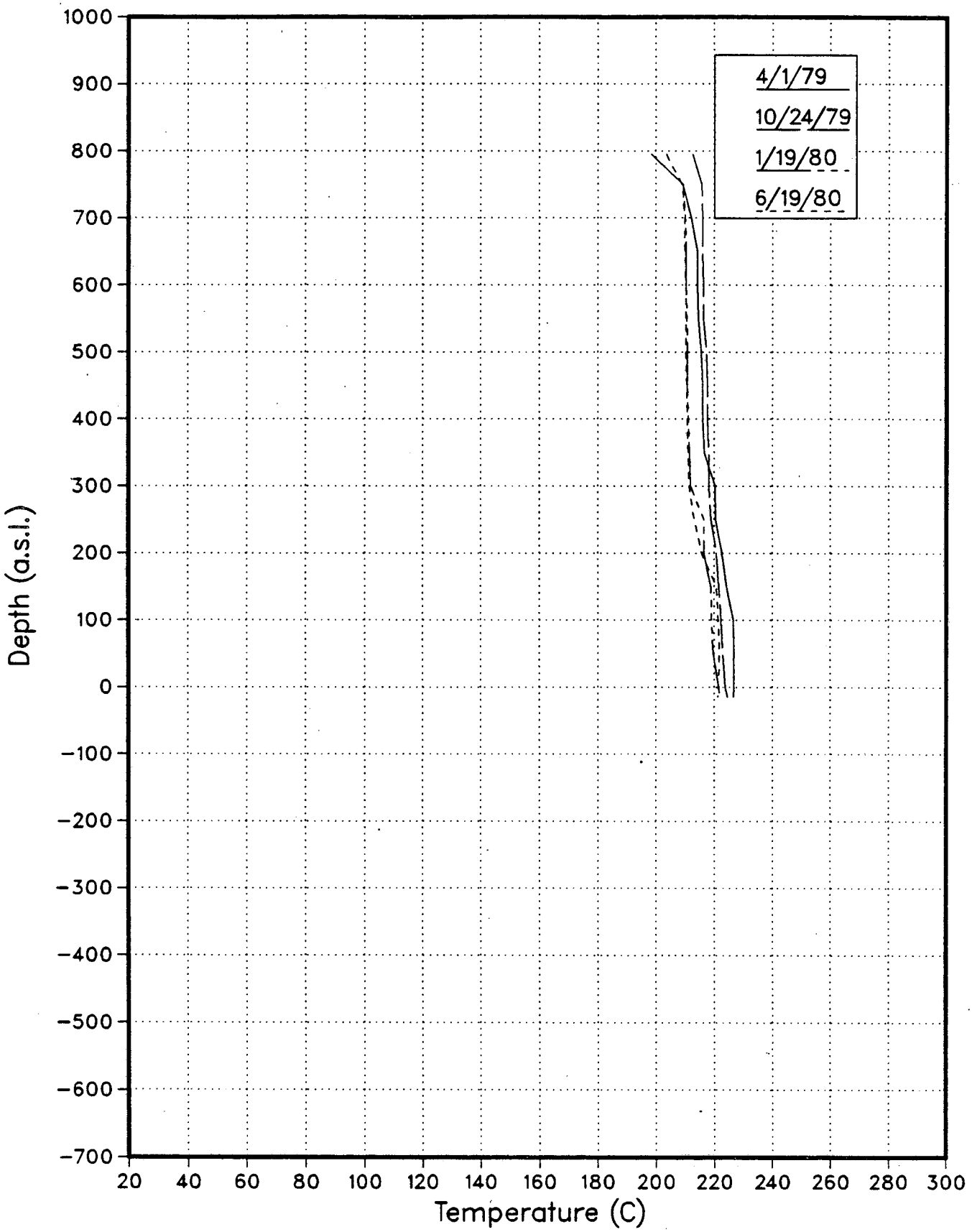

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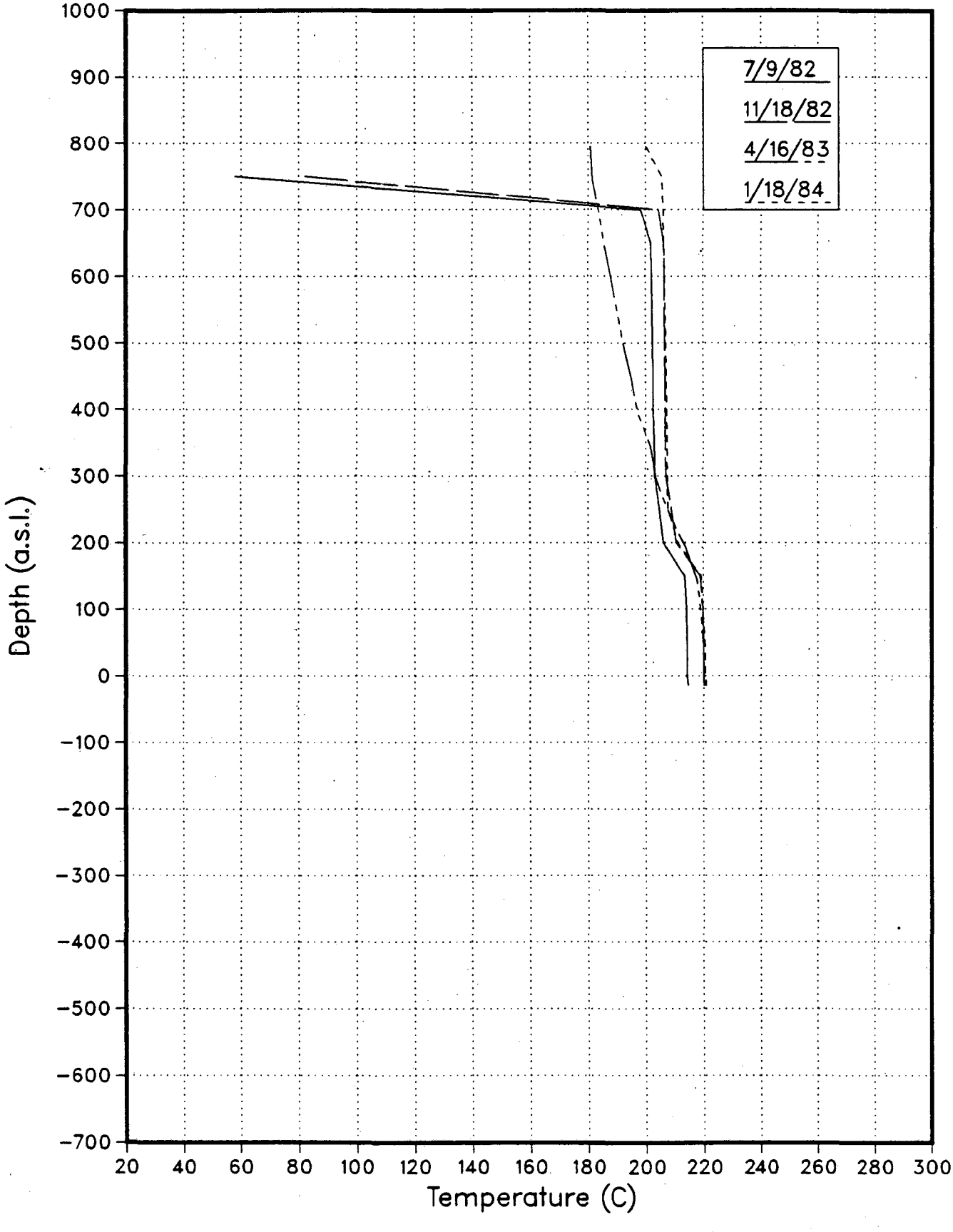

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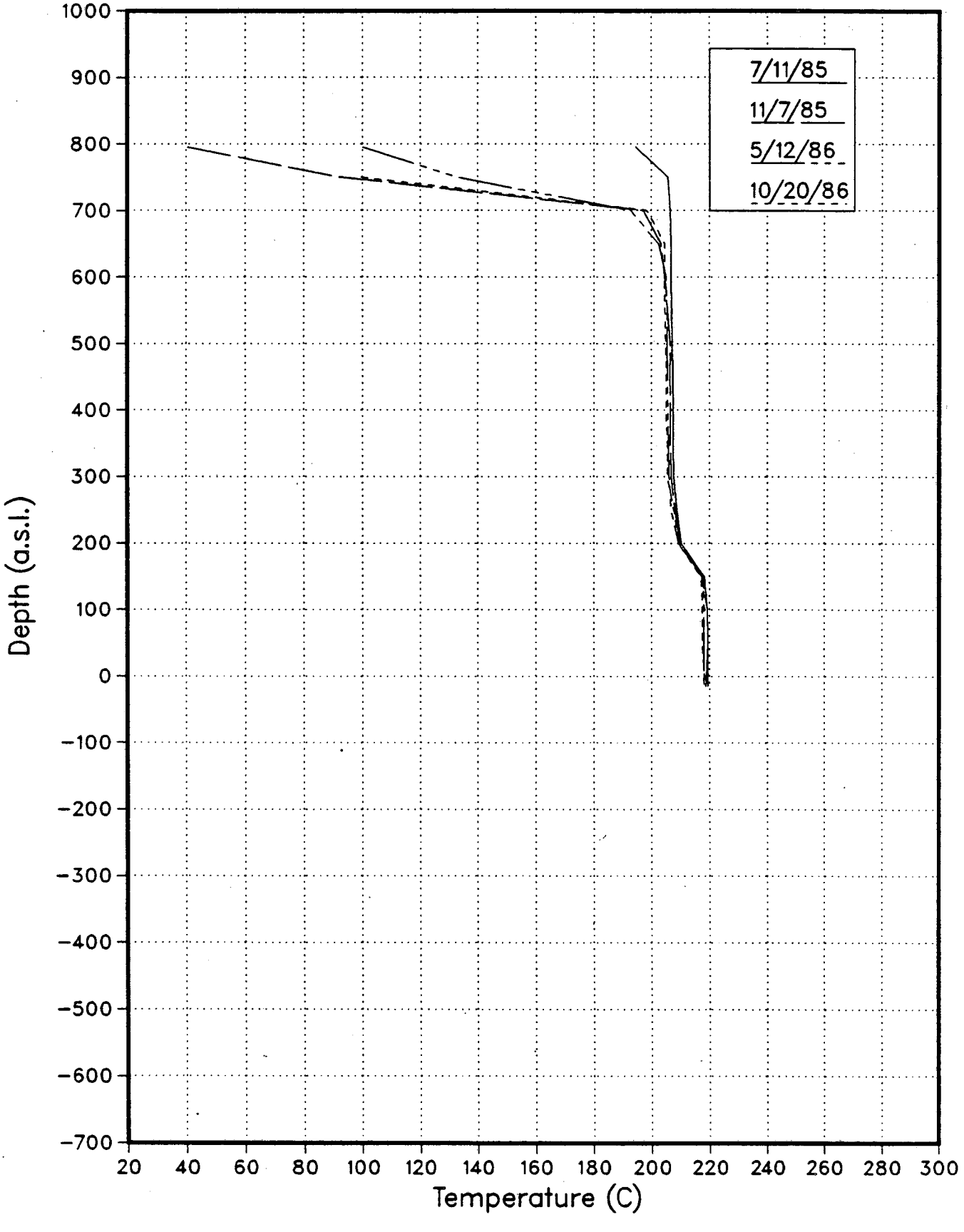
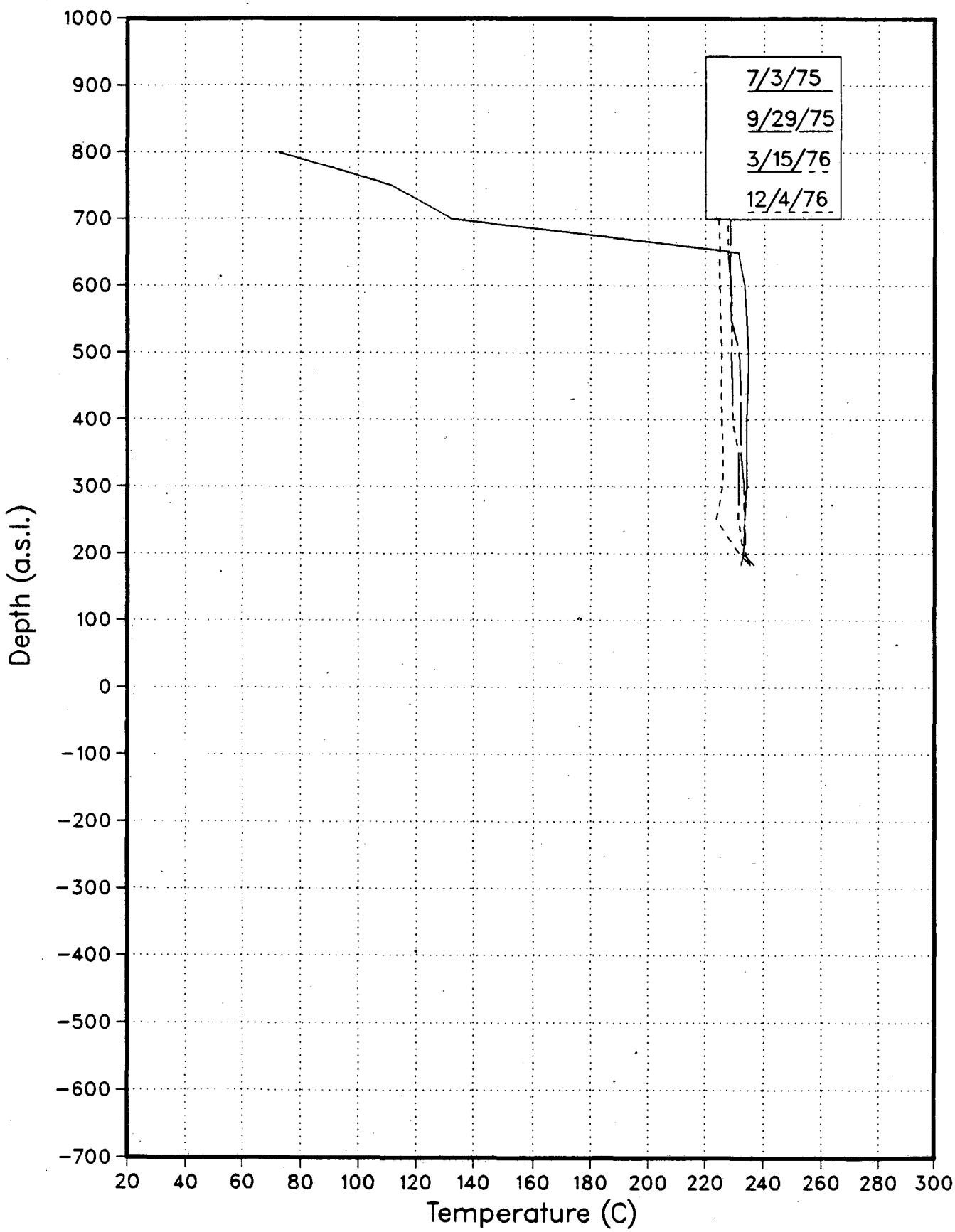


AH22 Temperature Surveys



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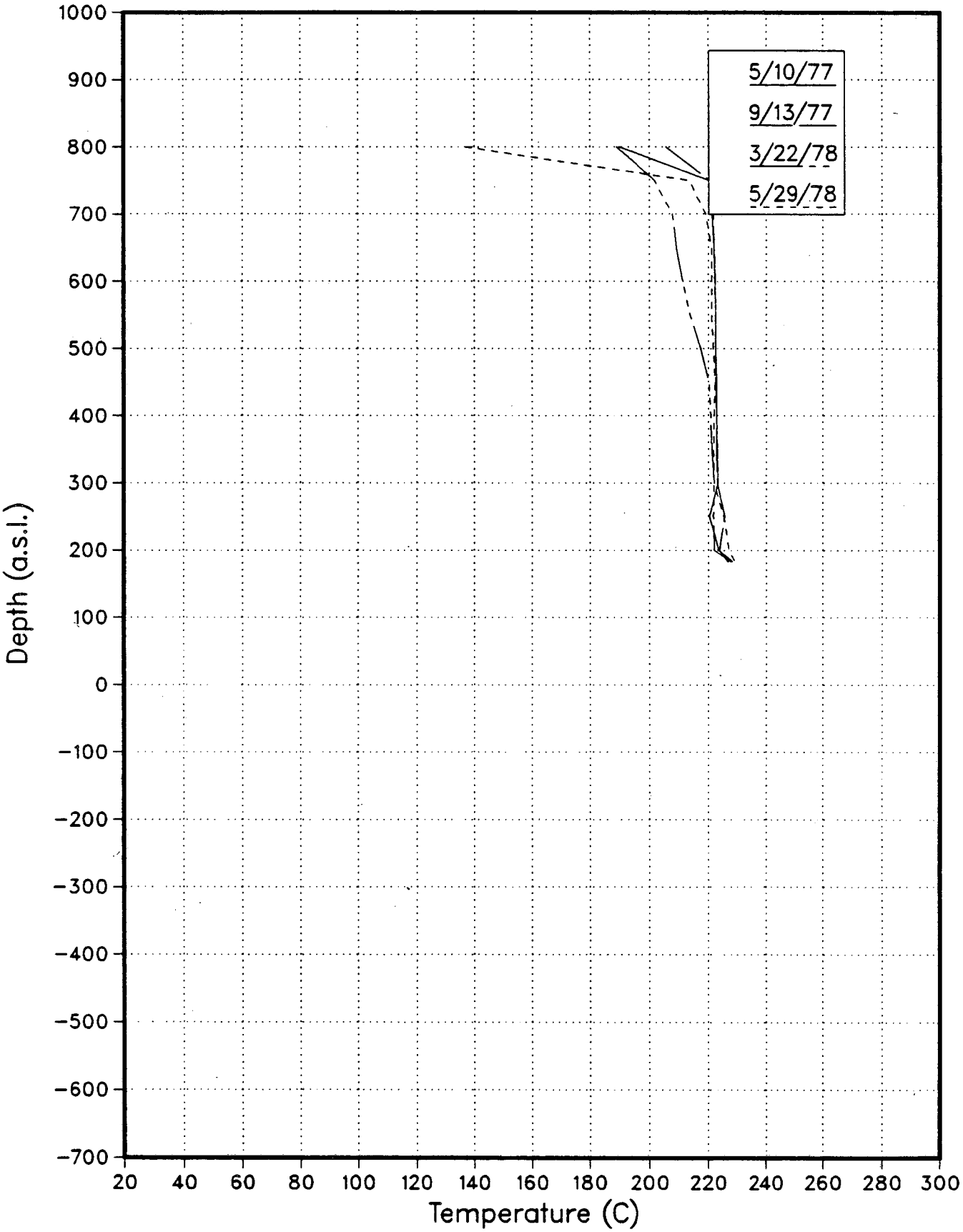

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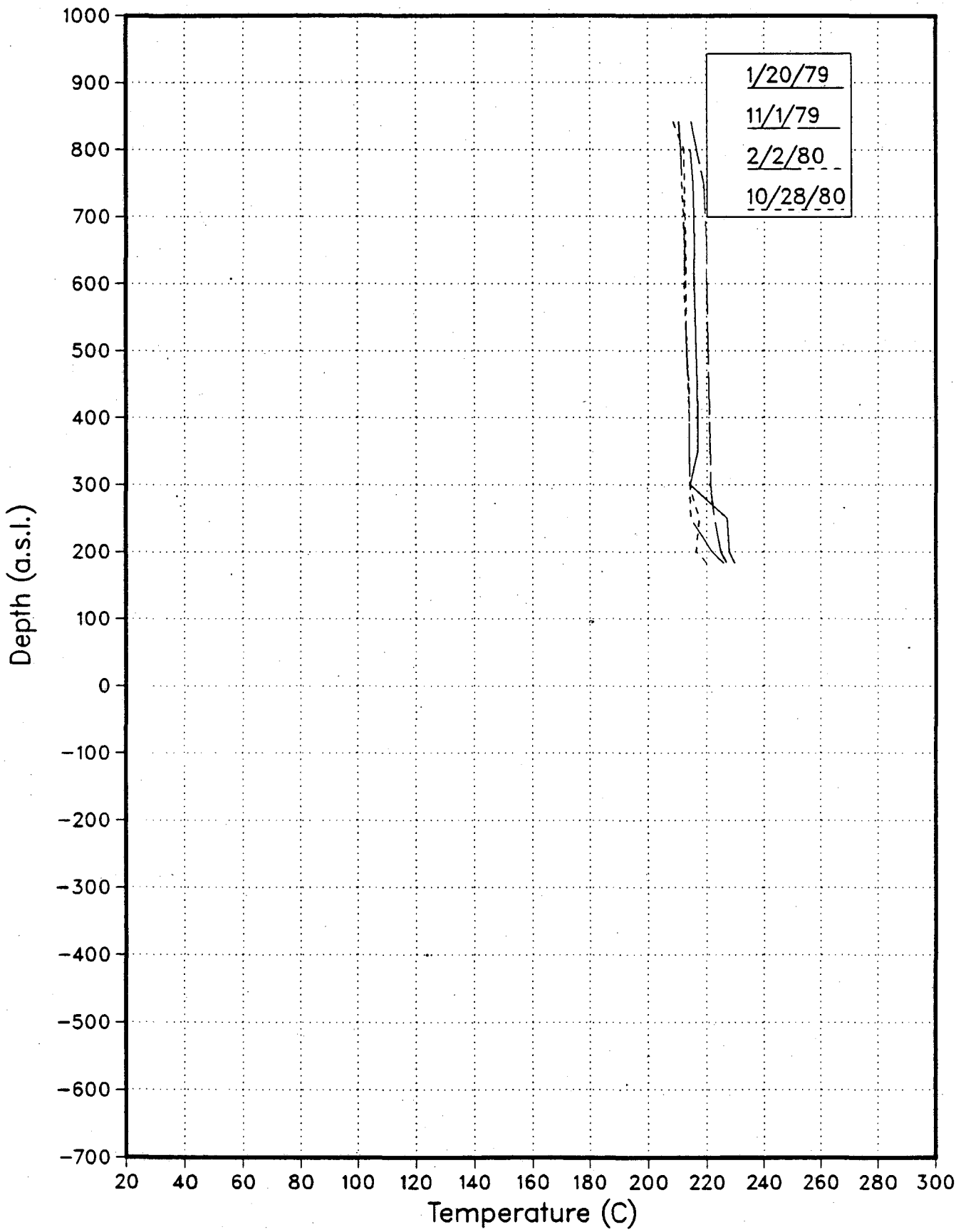

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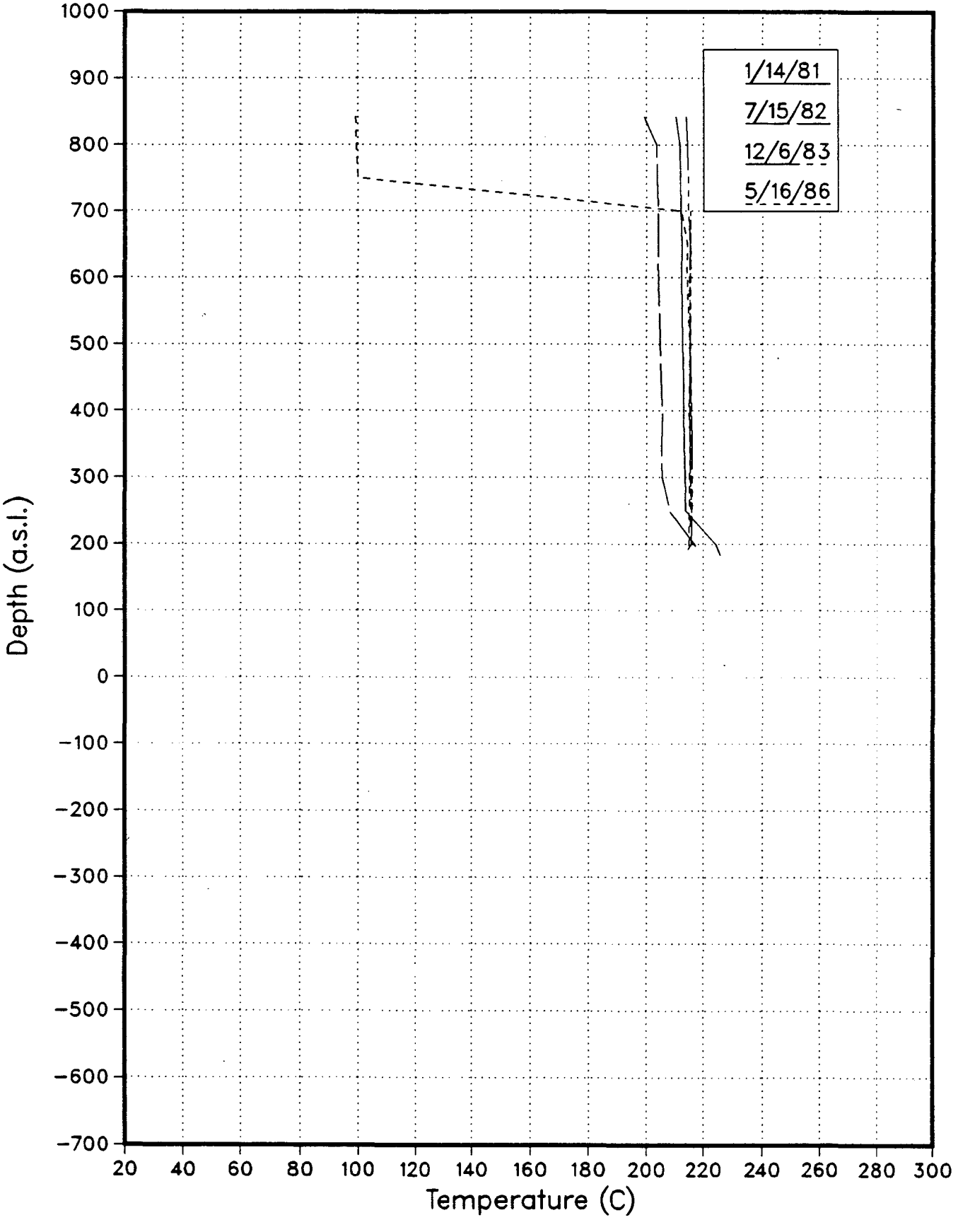

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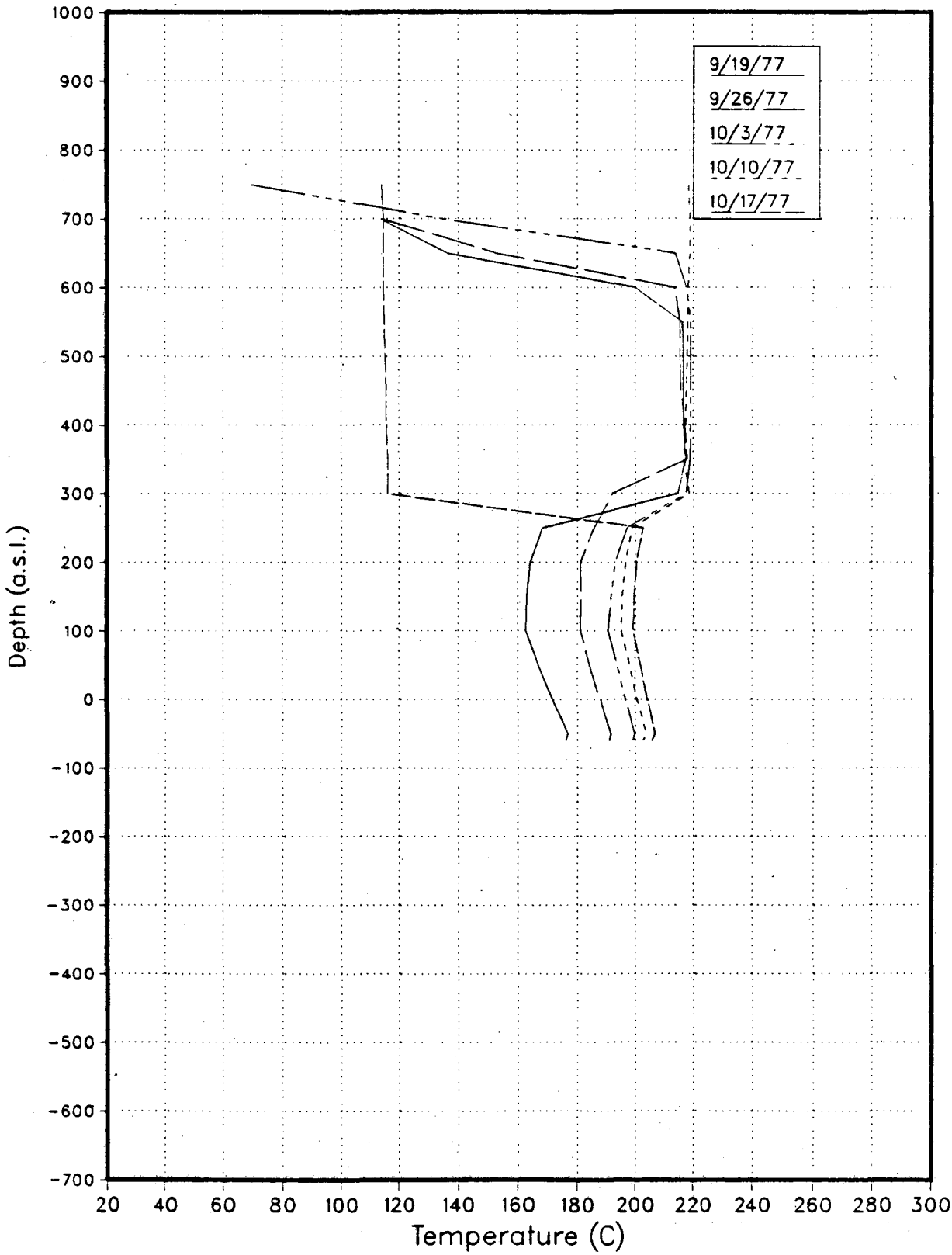

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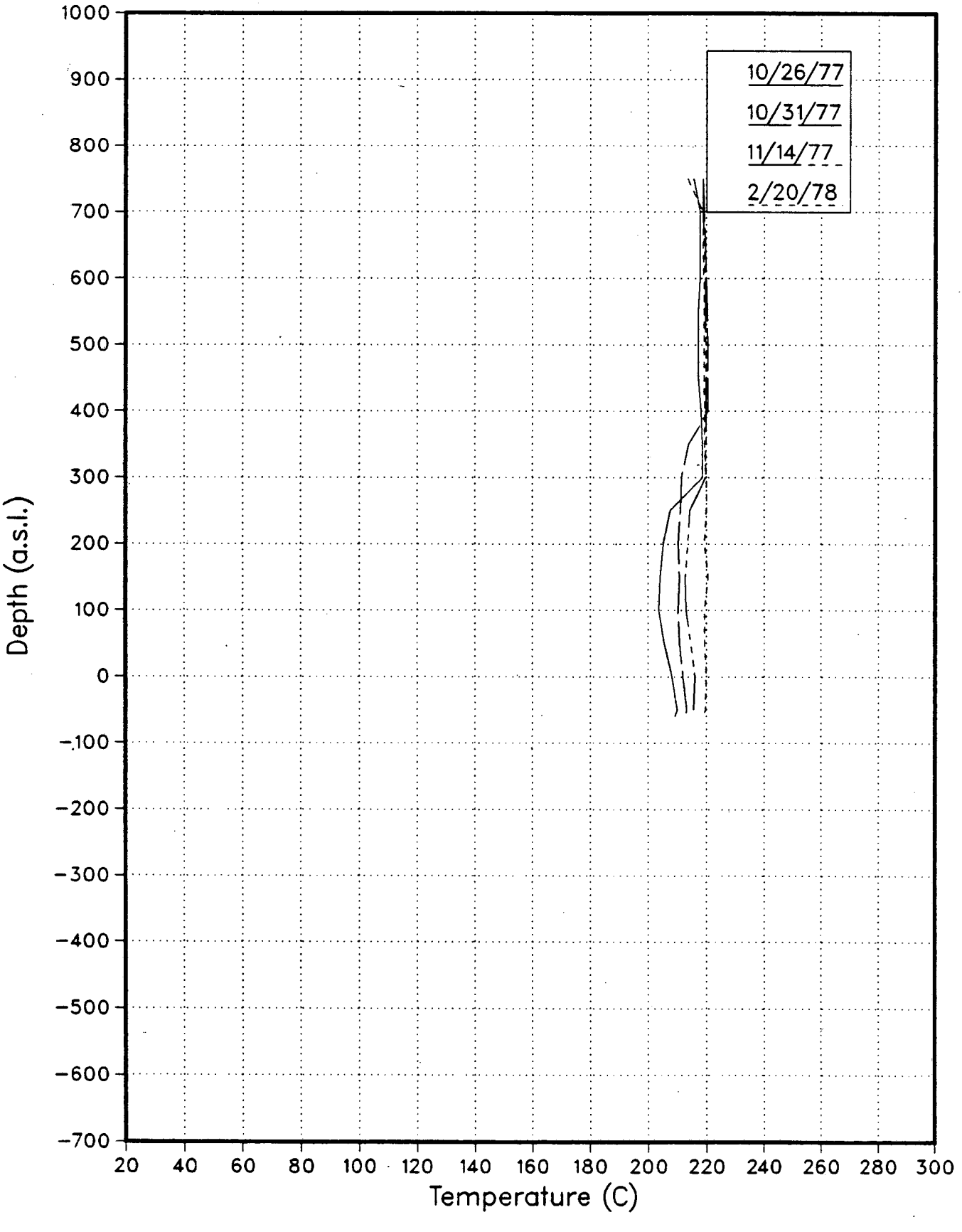

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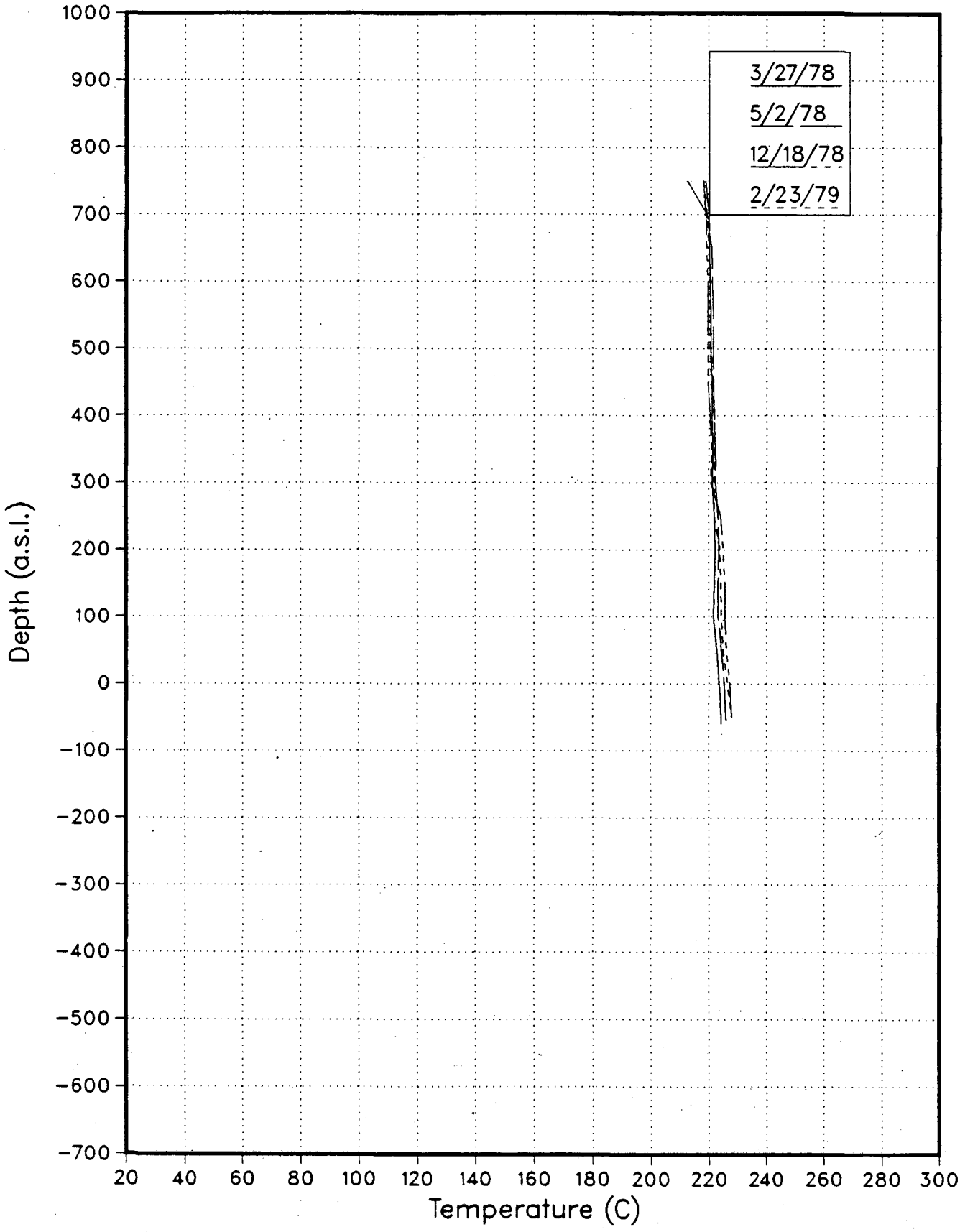

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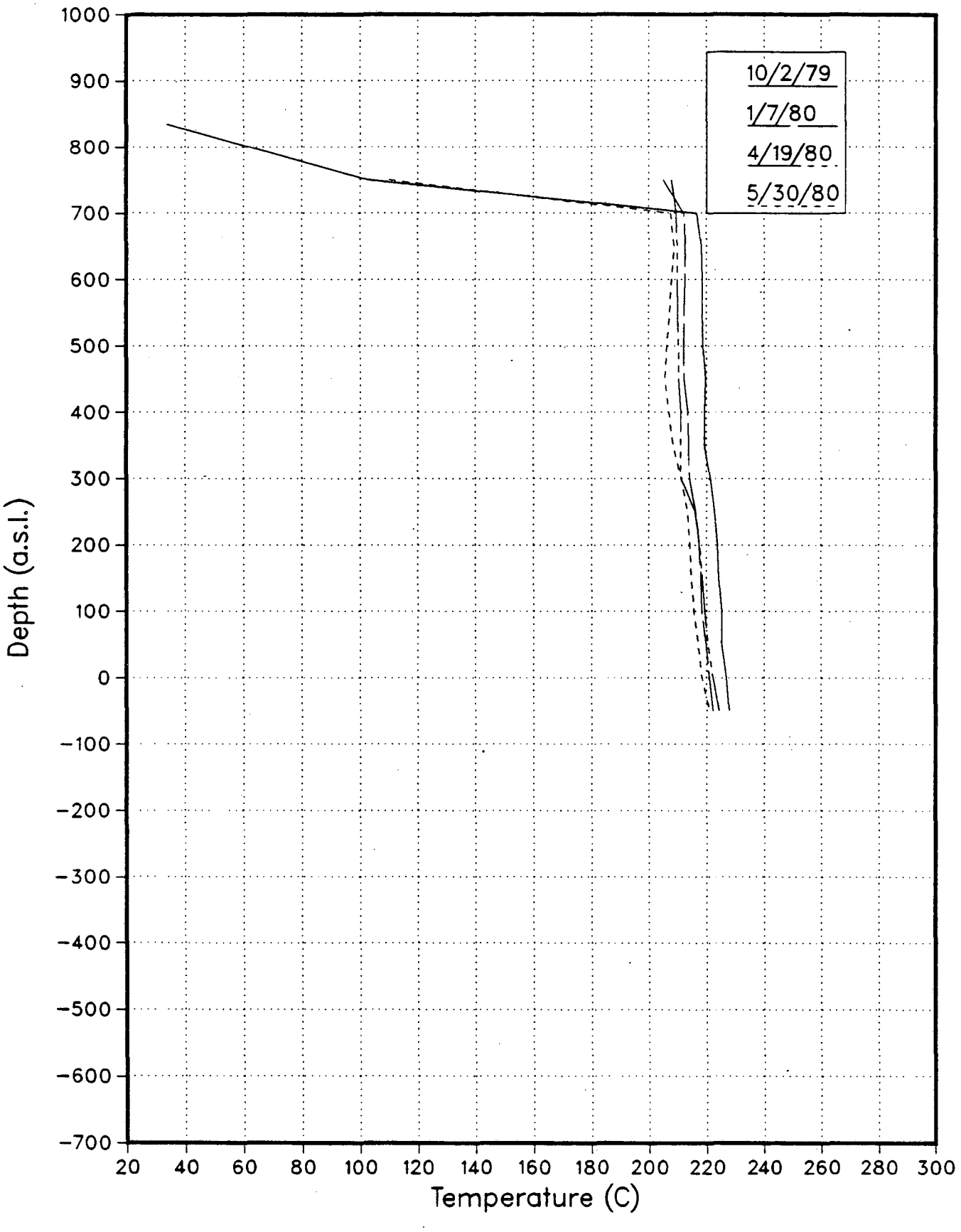

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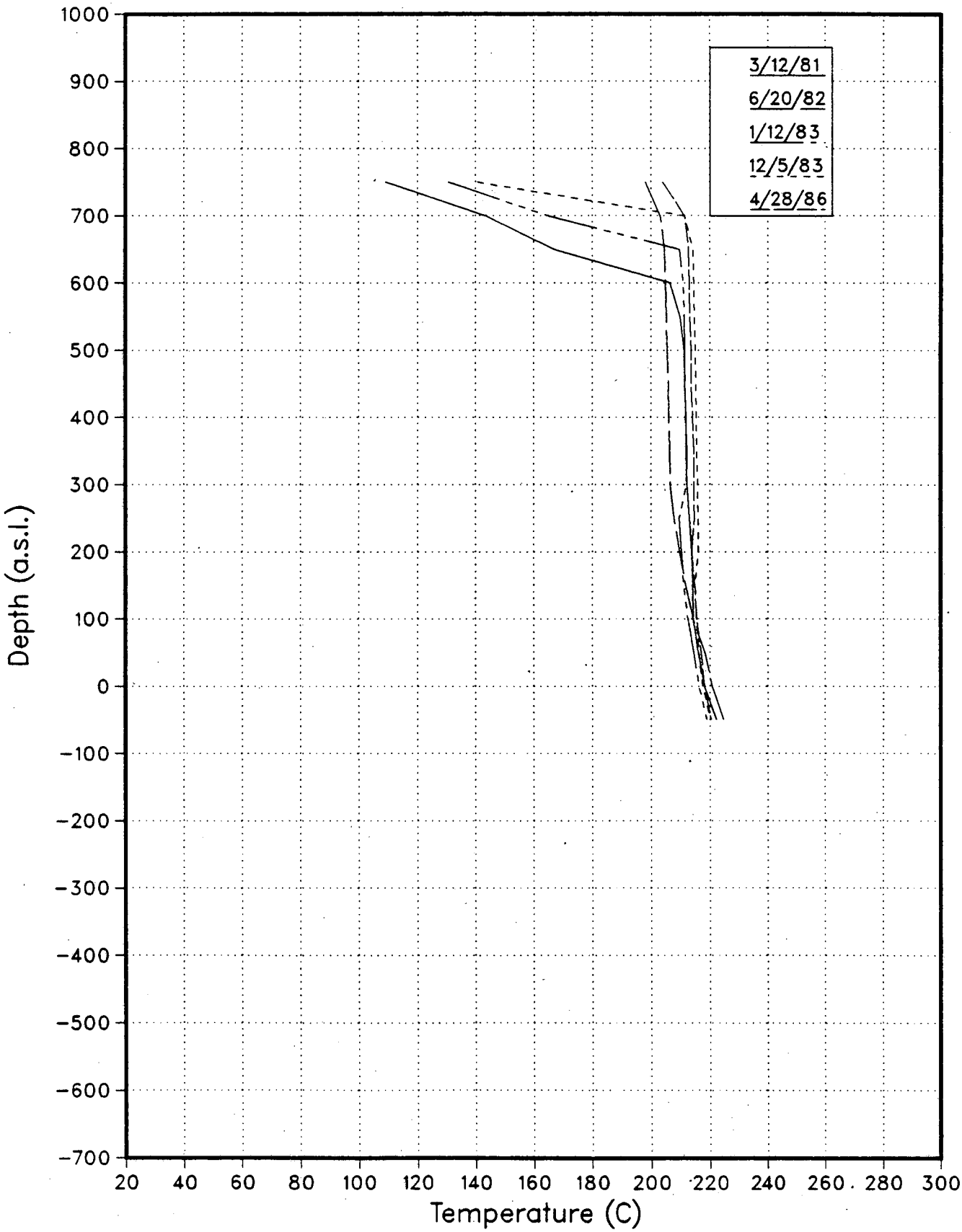

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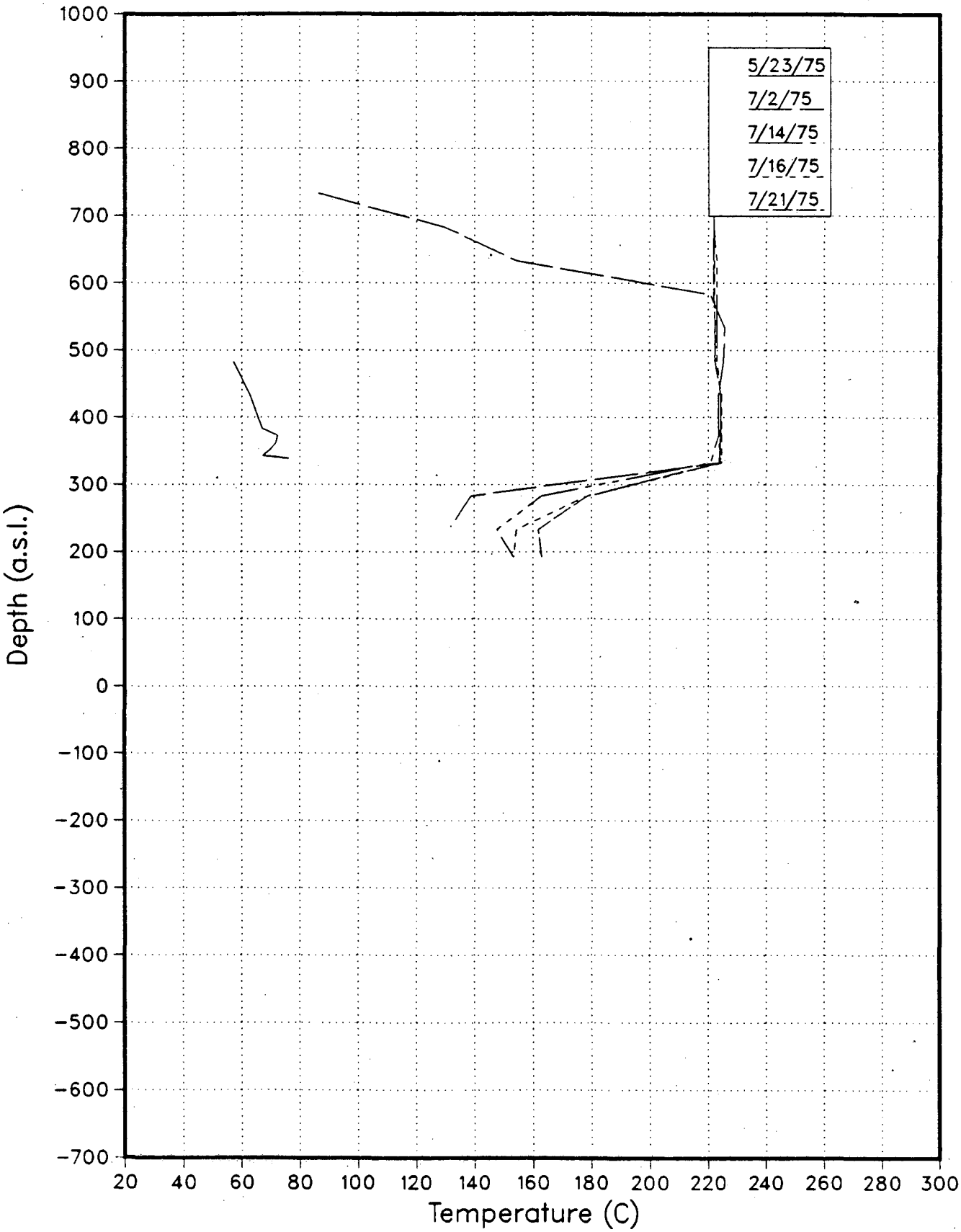

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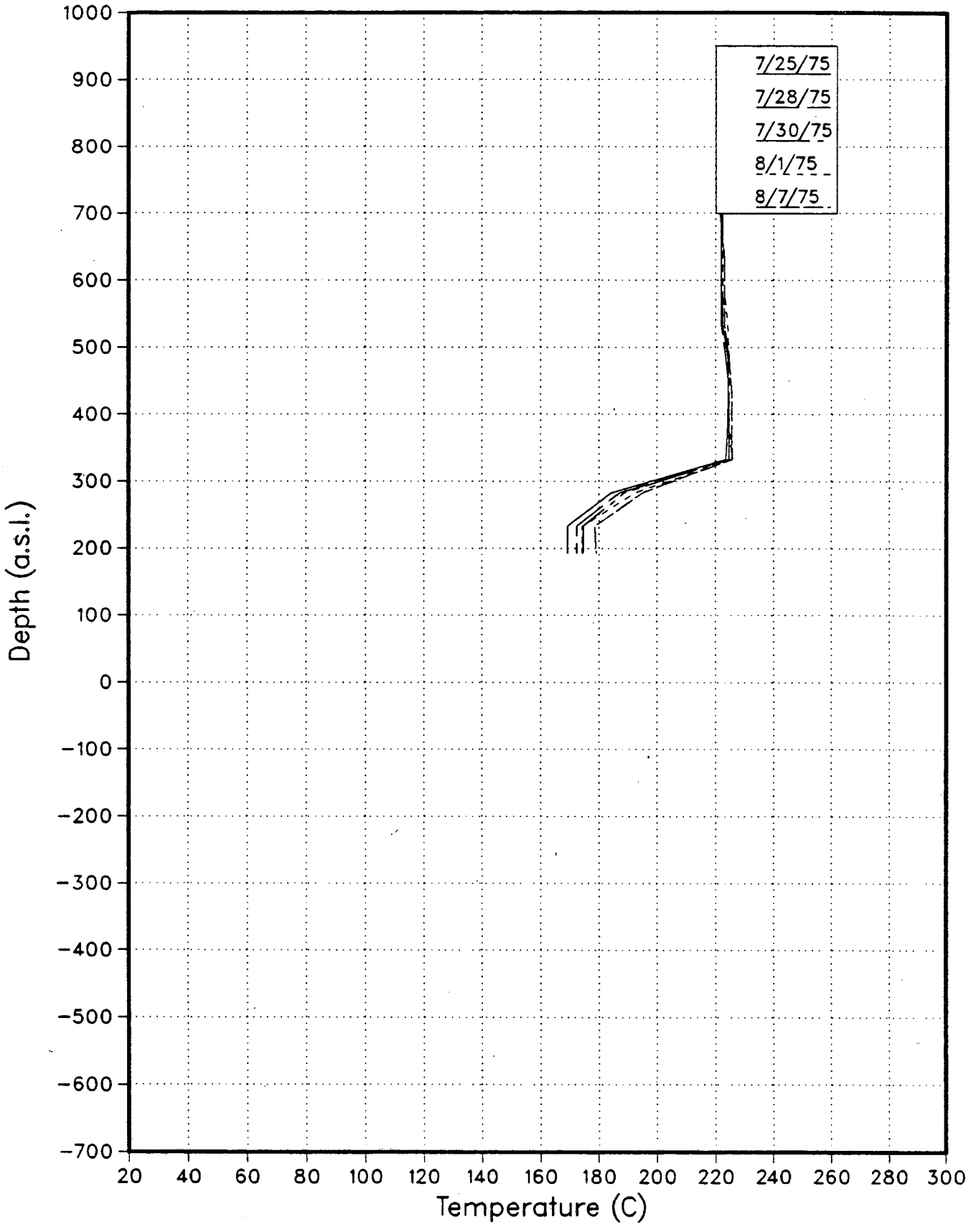

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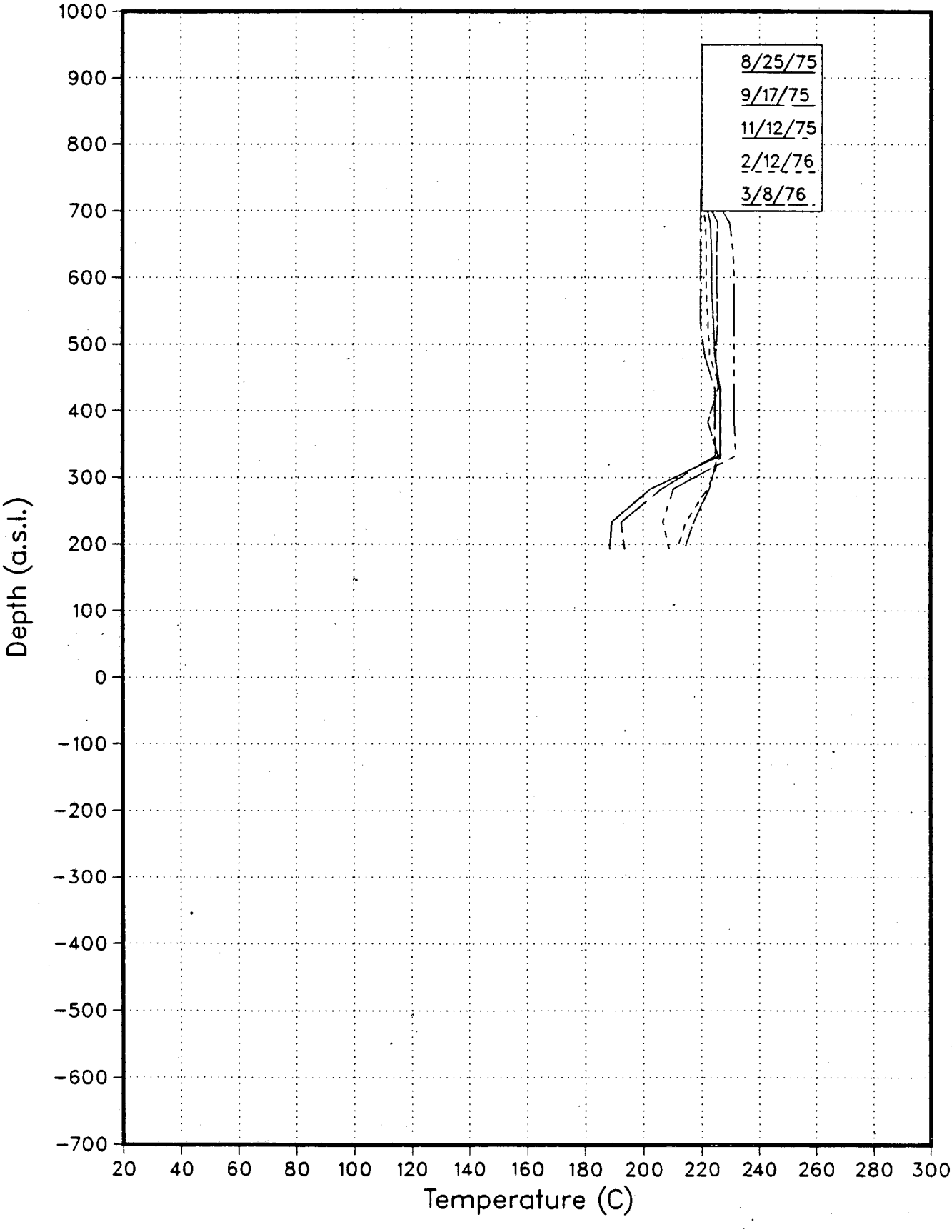

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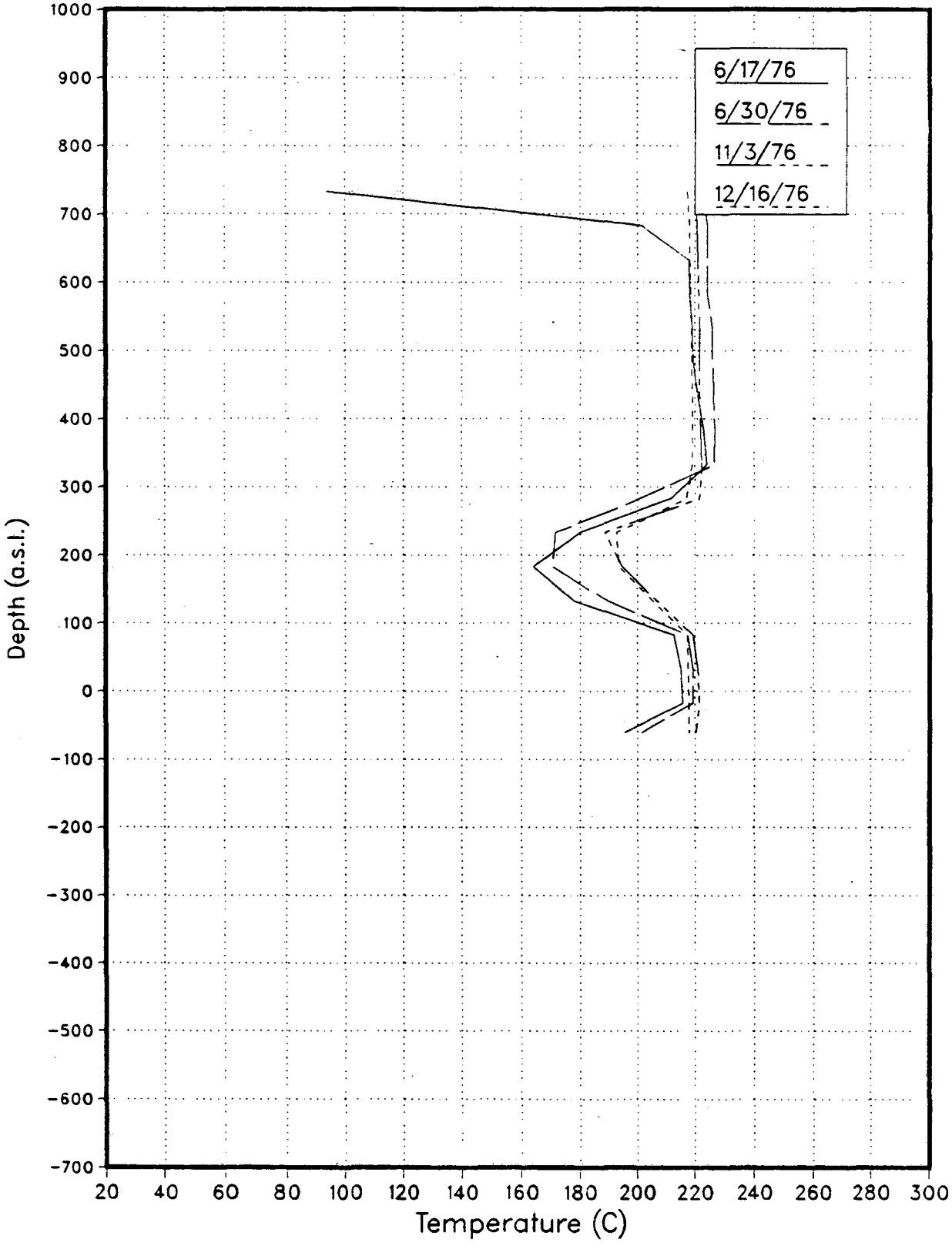

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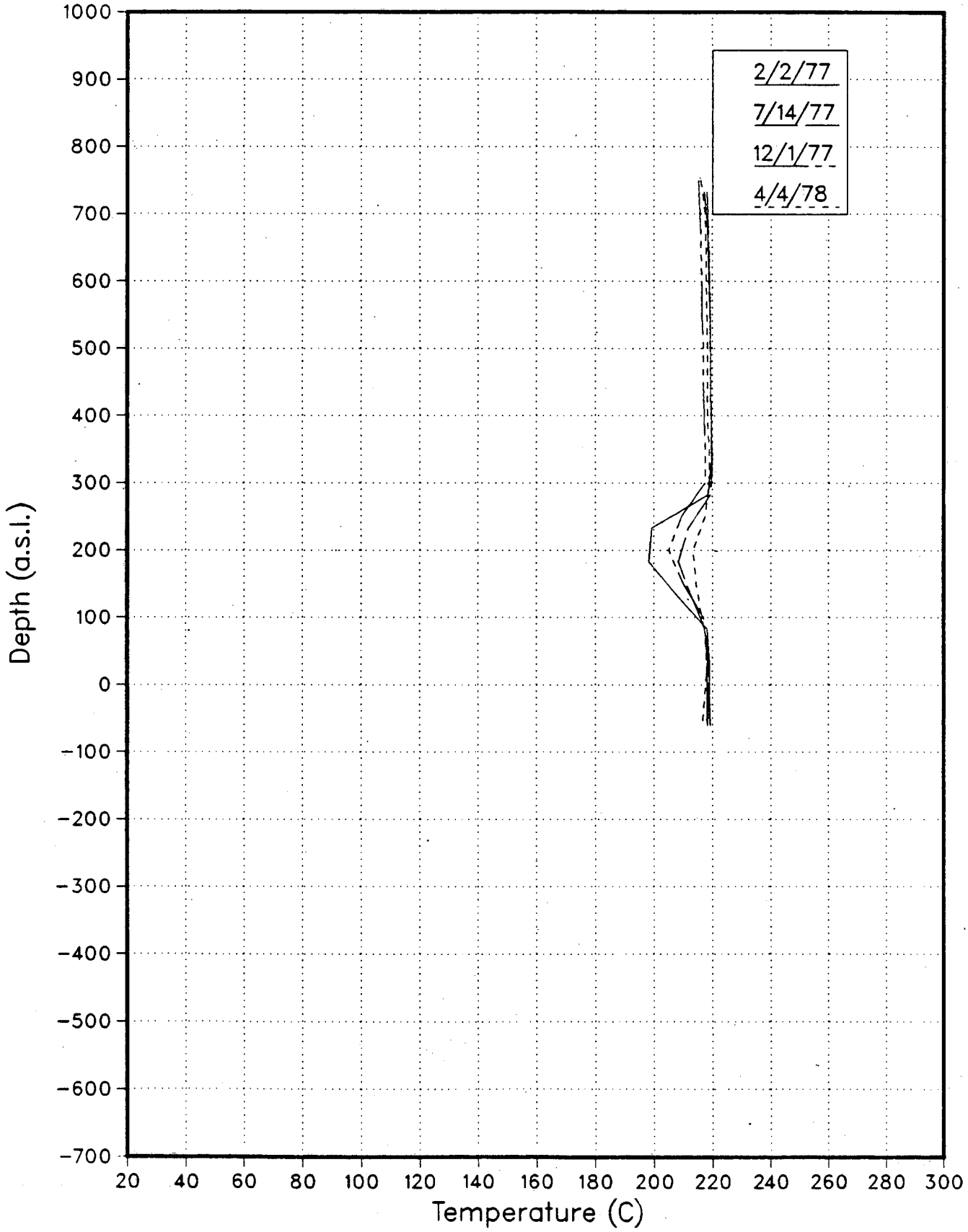

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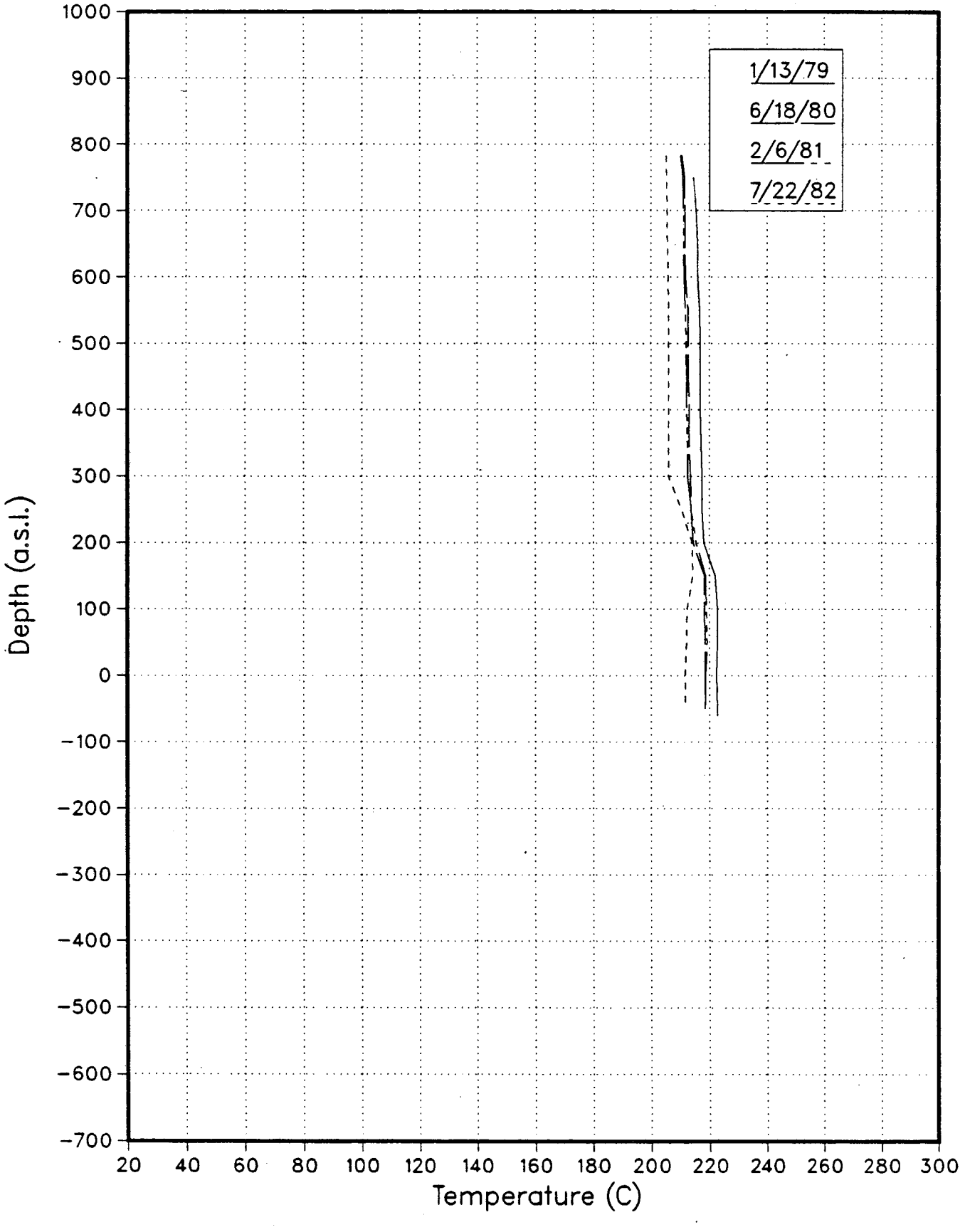

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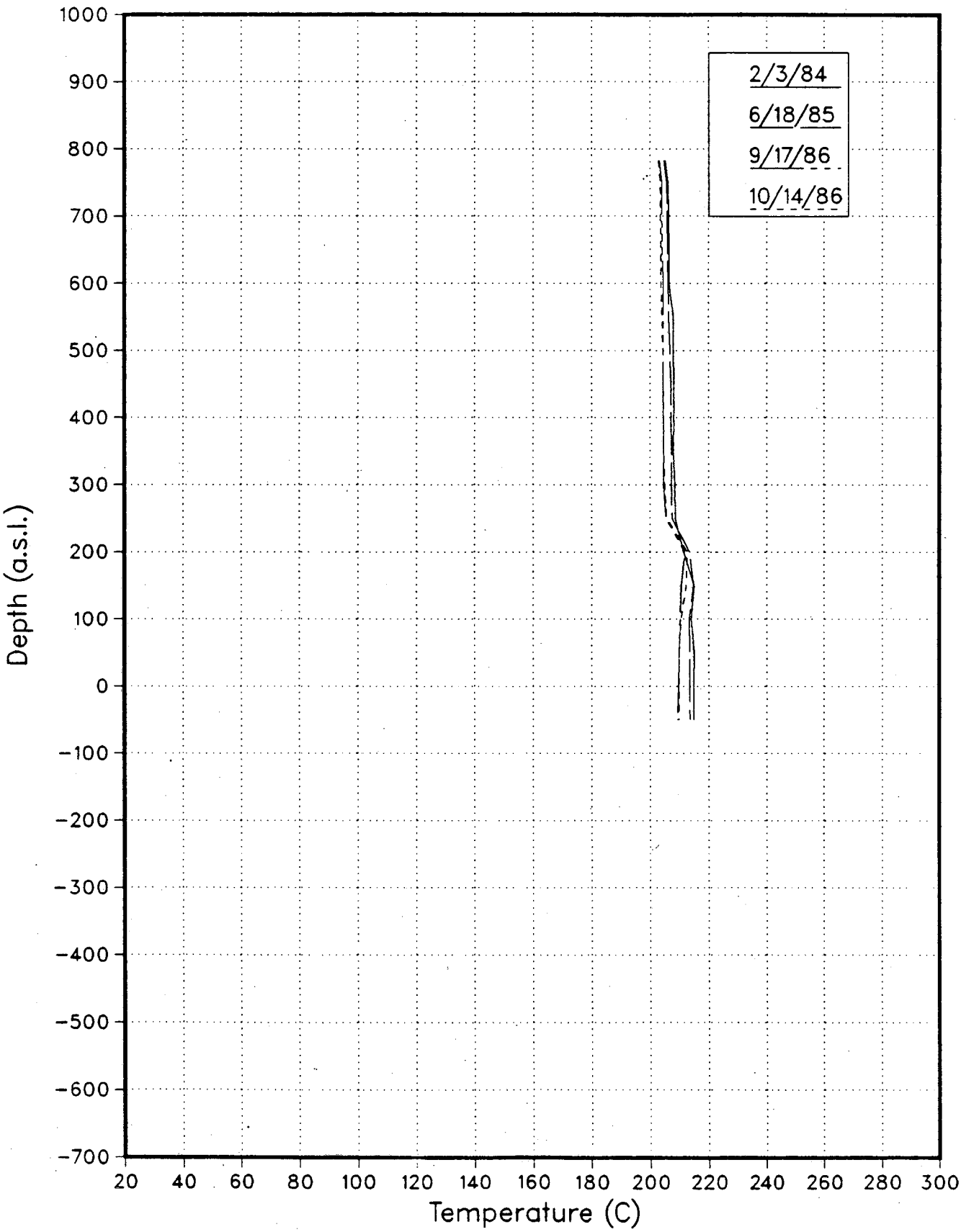
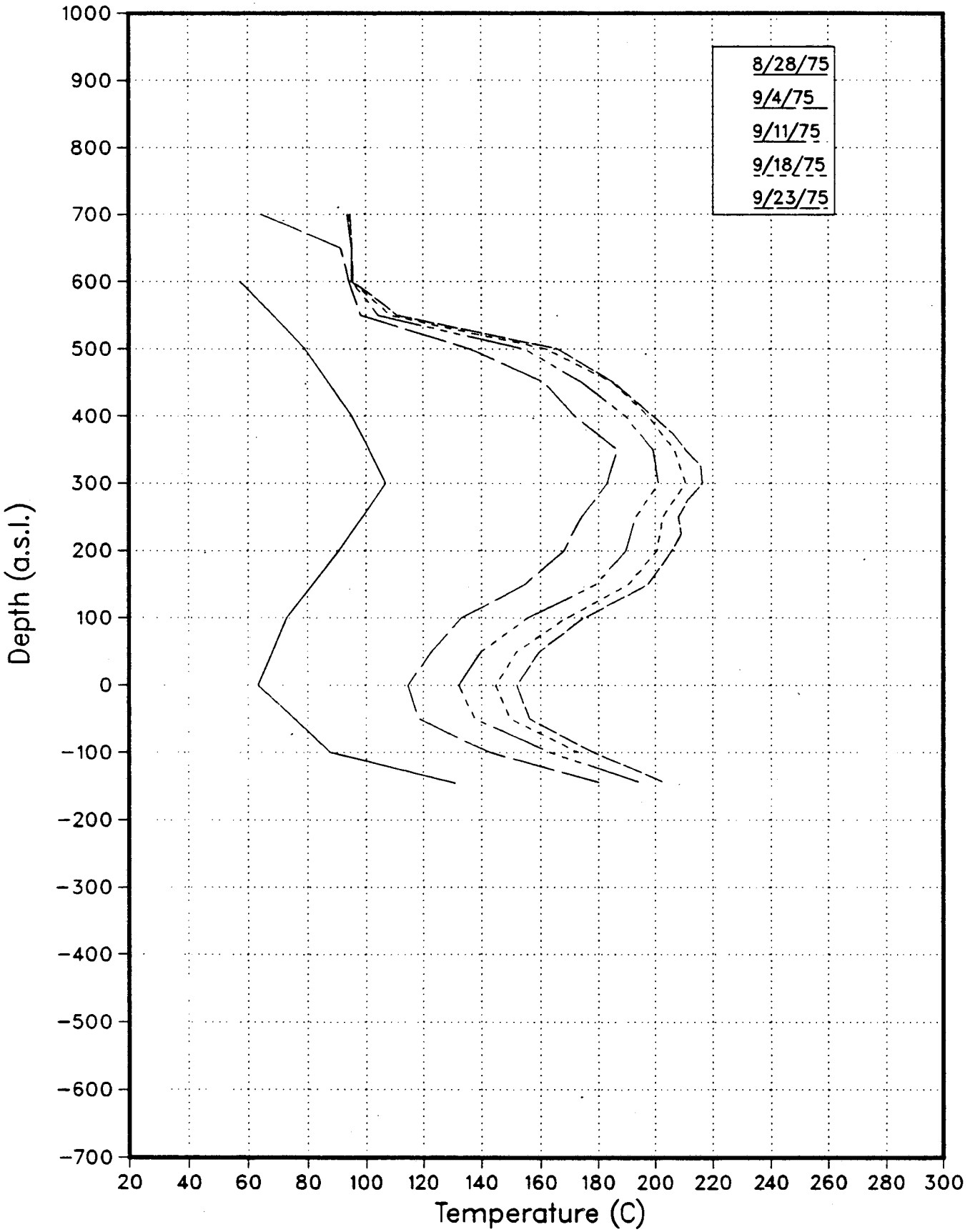


AH25 Temperature Surveys



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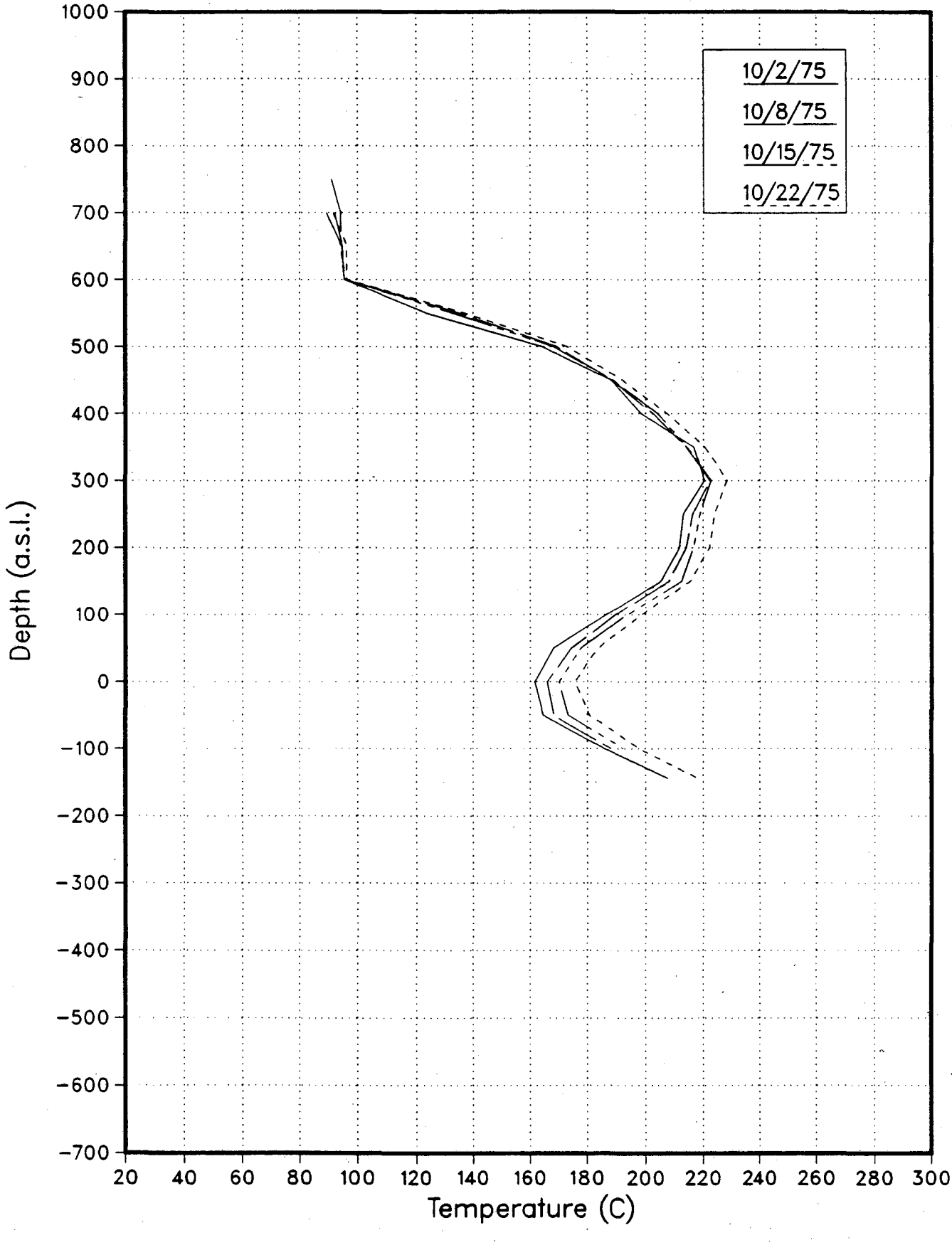

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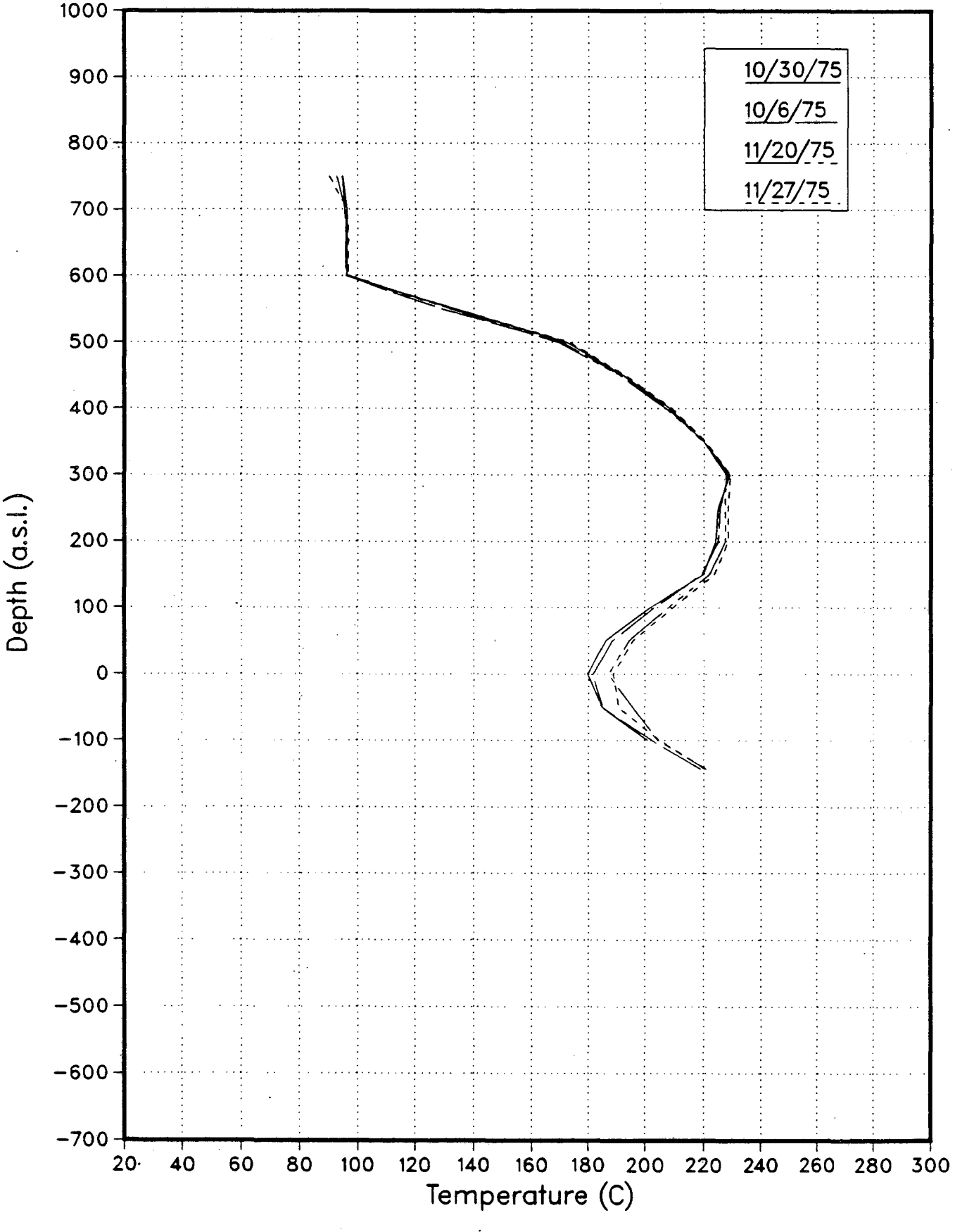

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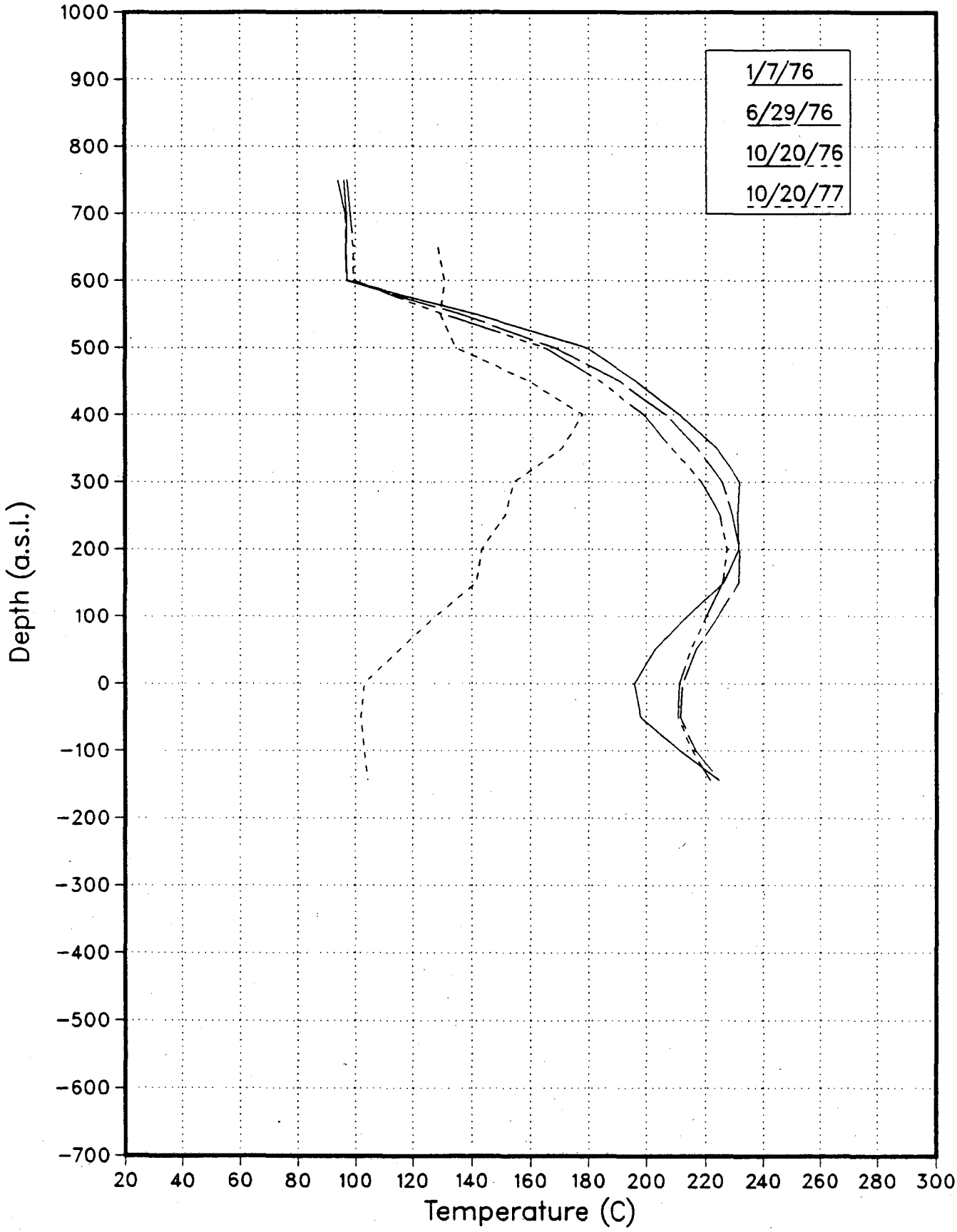

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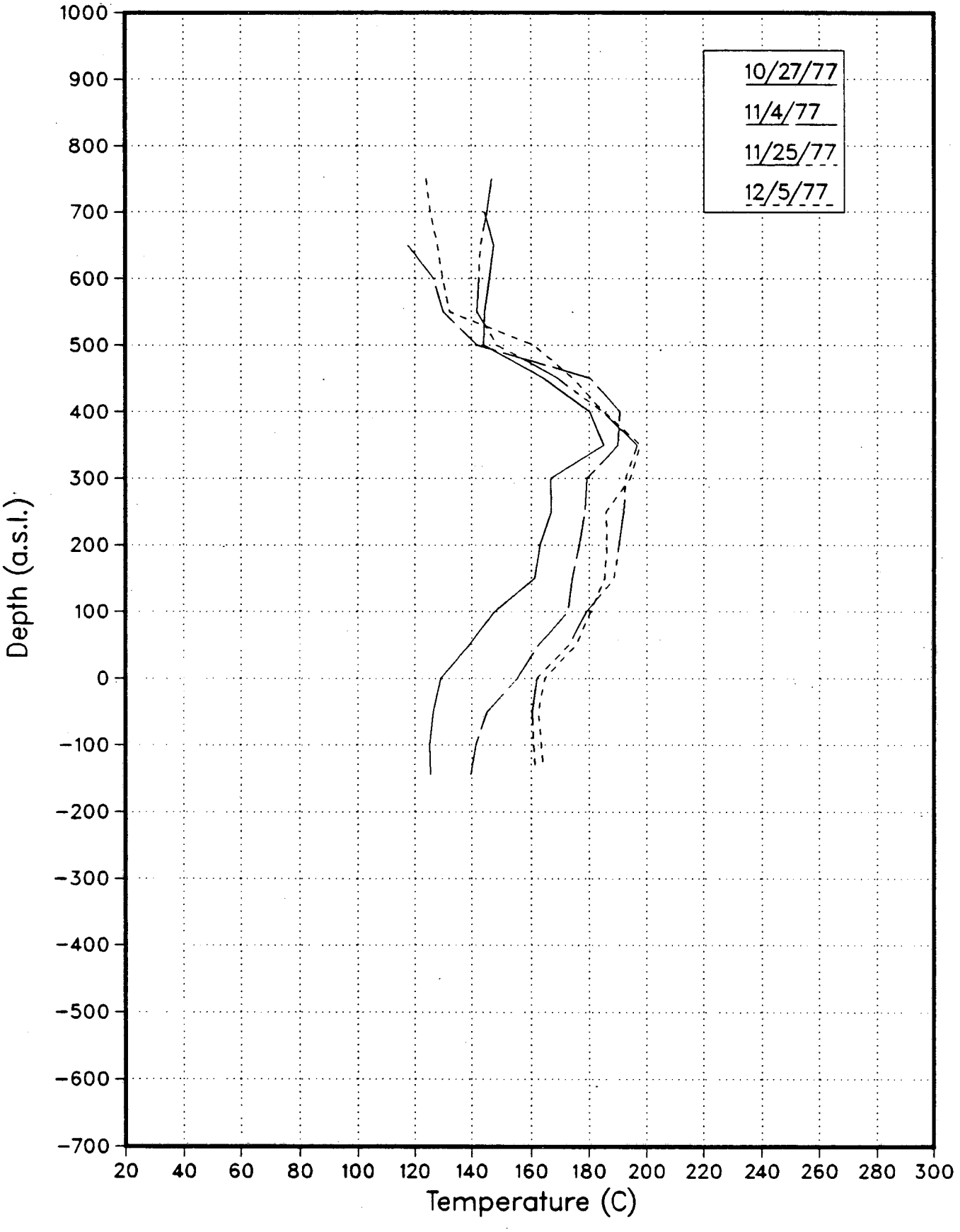

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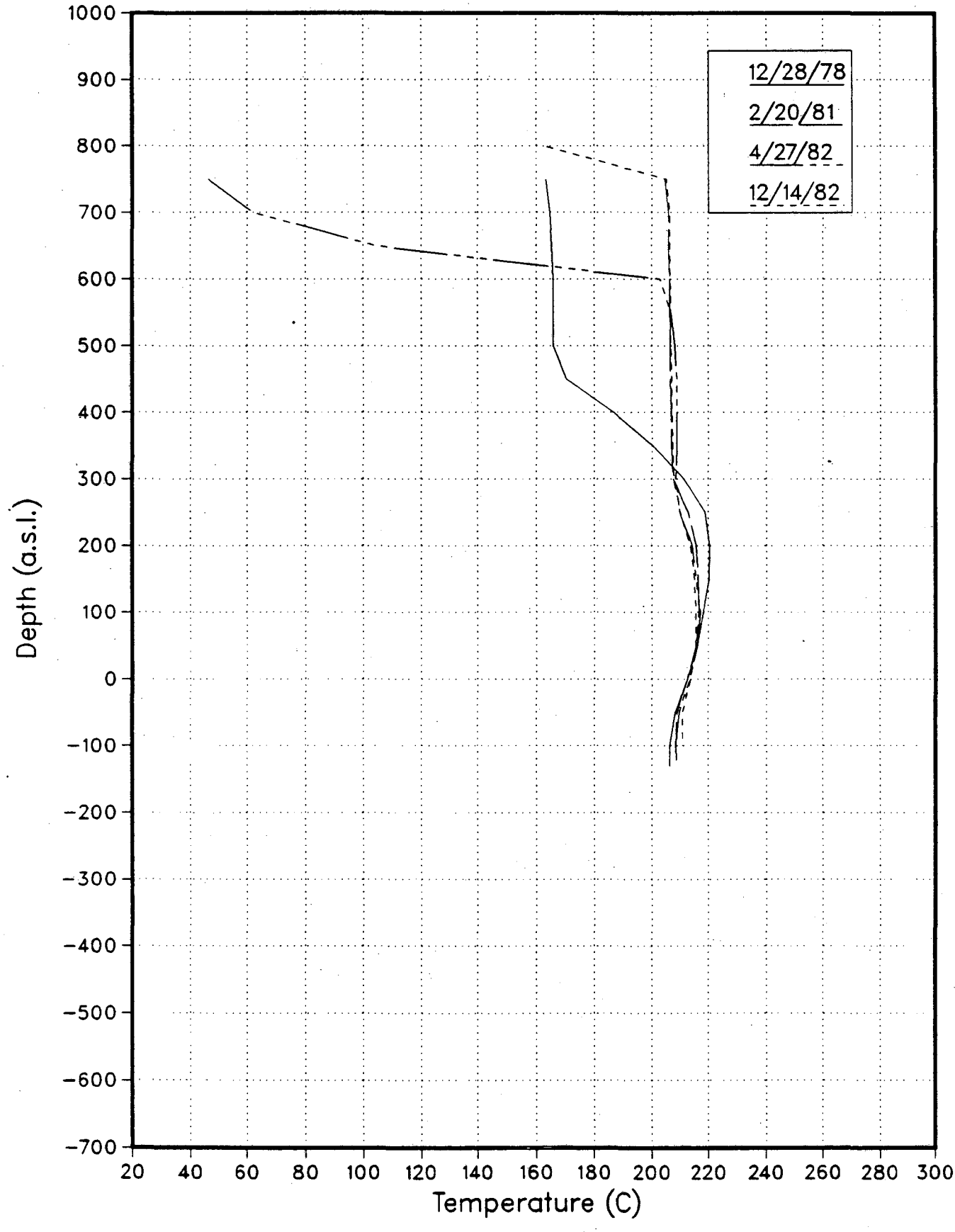

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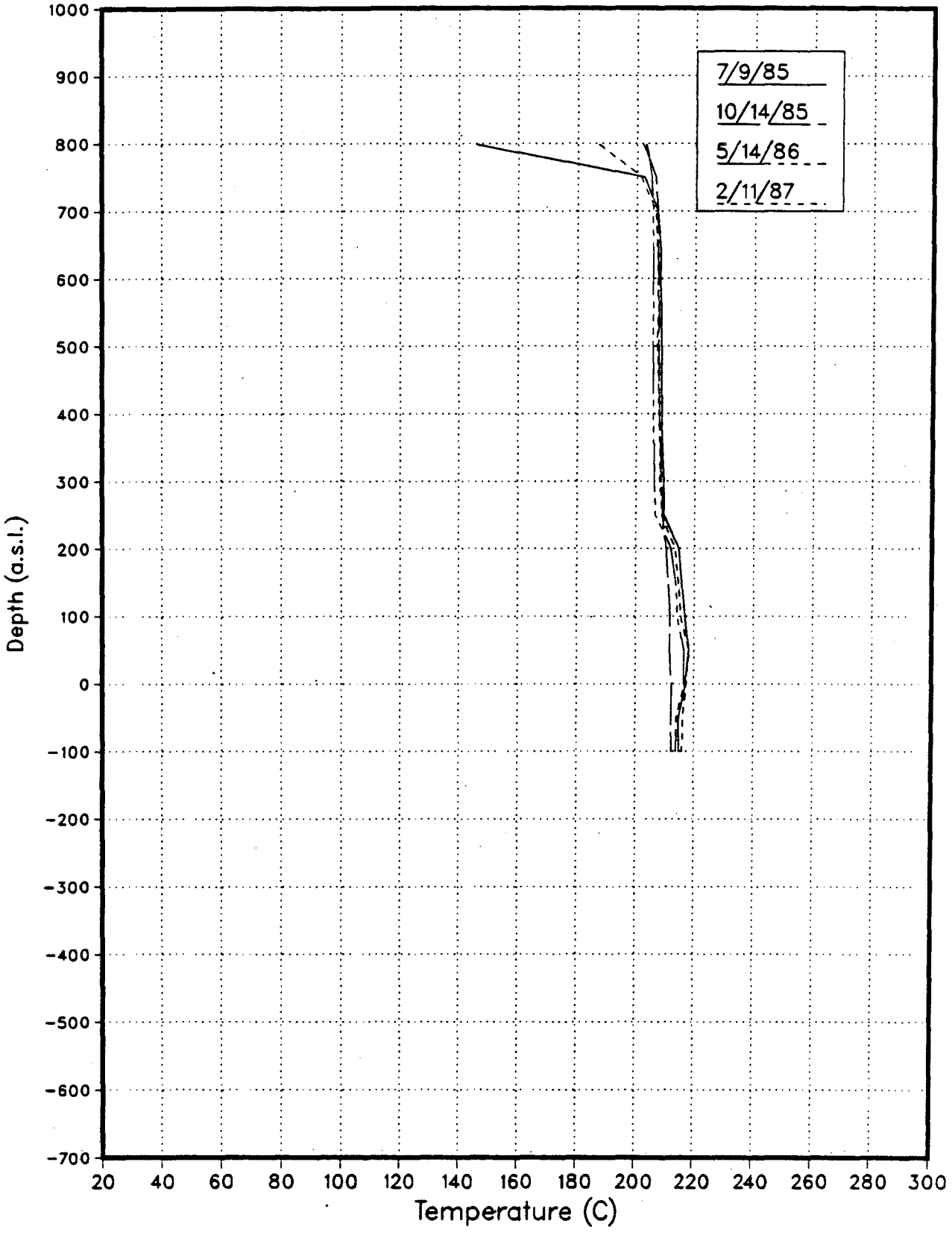
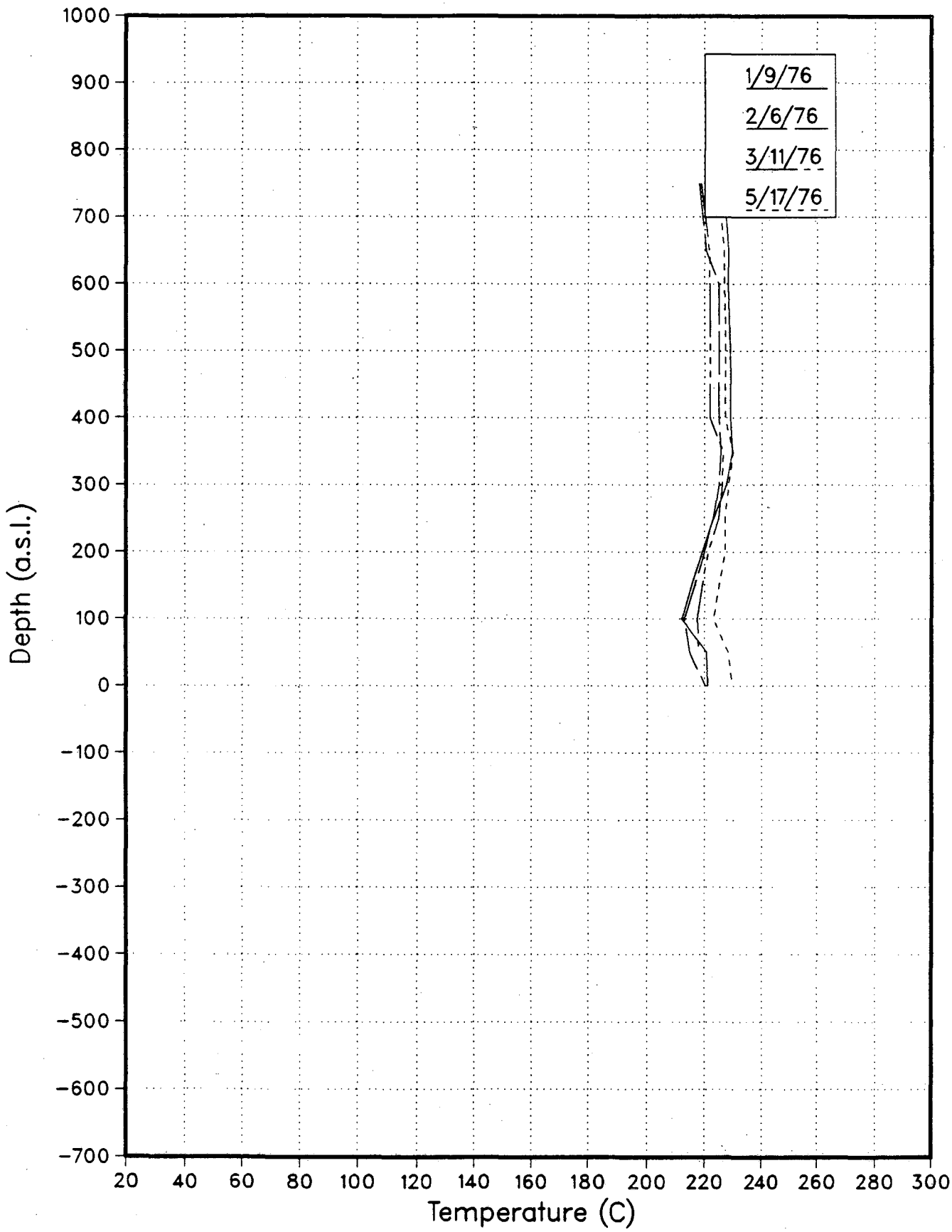


AH26 Temperature Surveys



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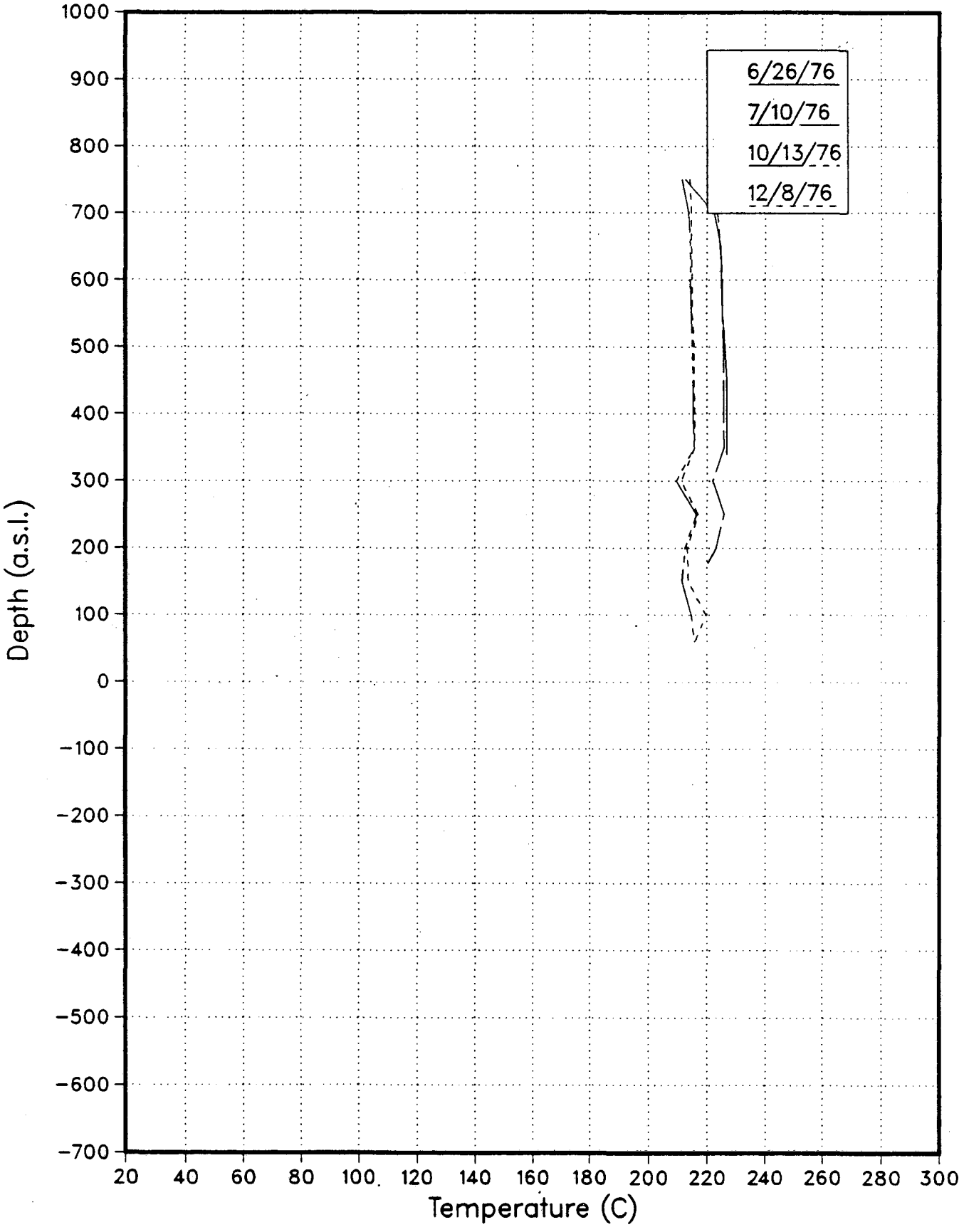

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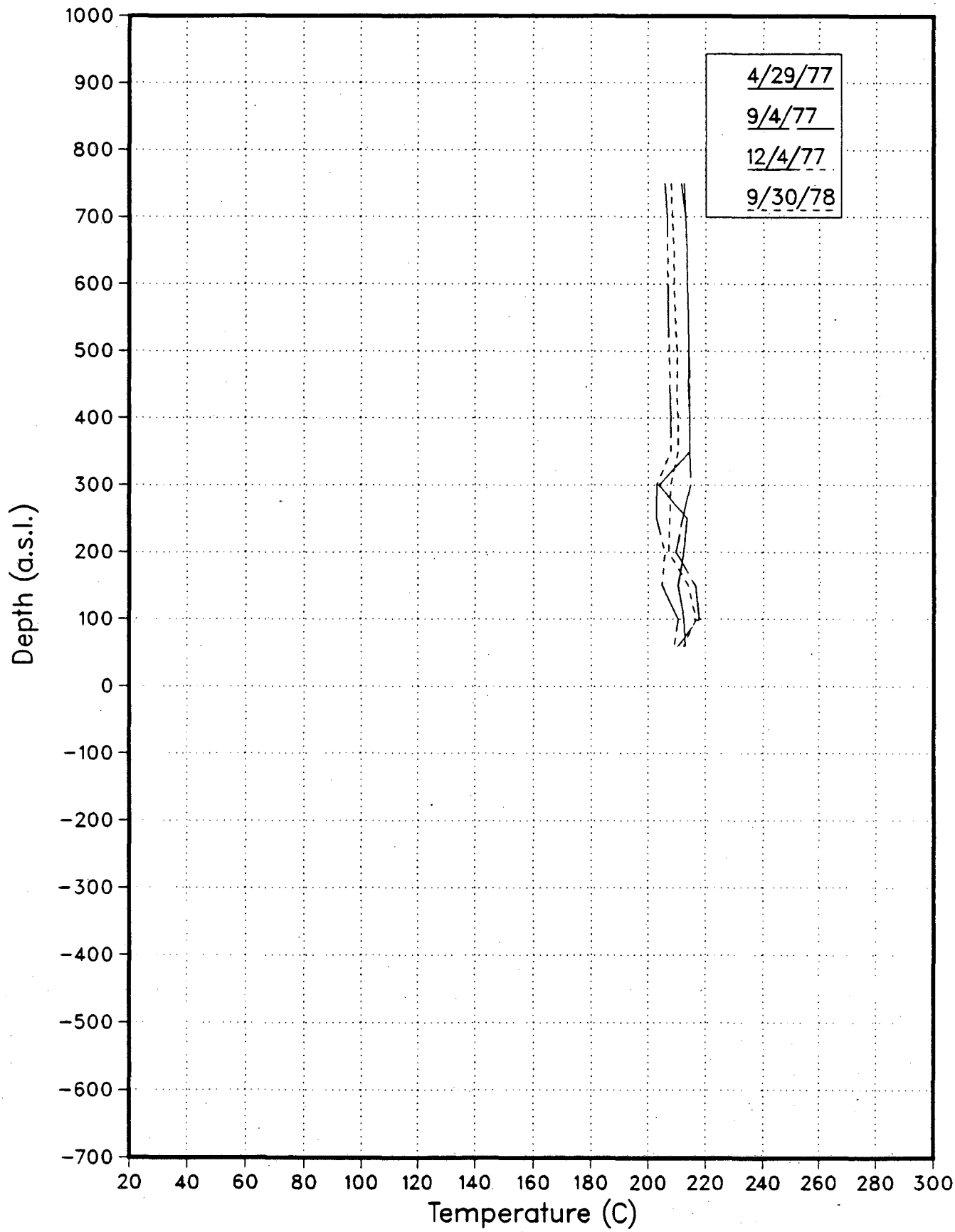

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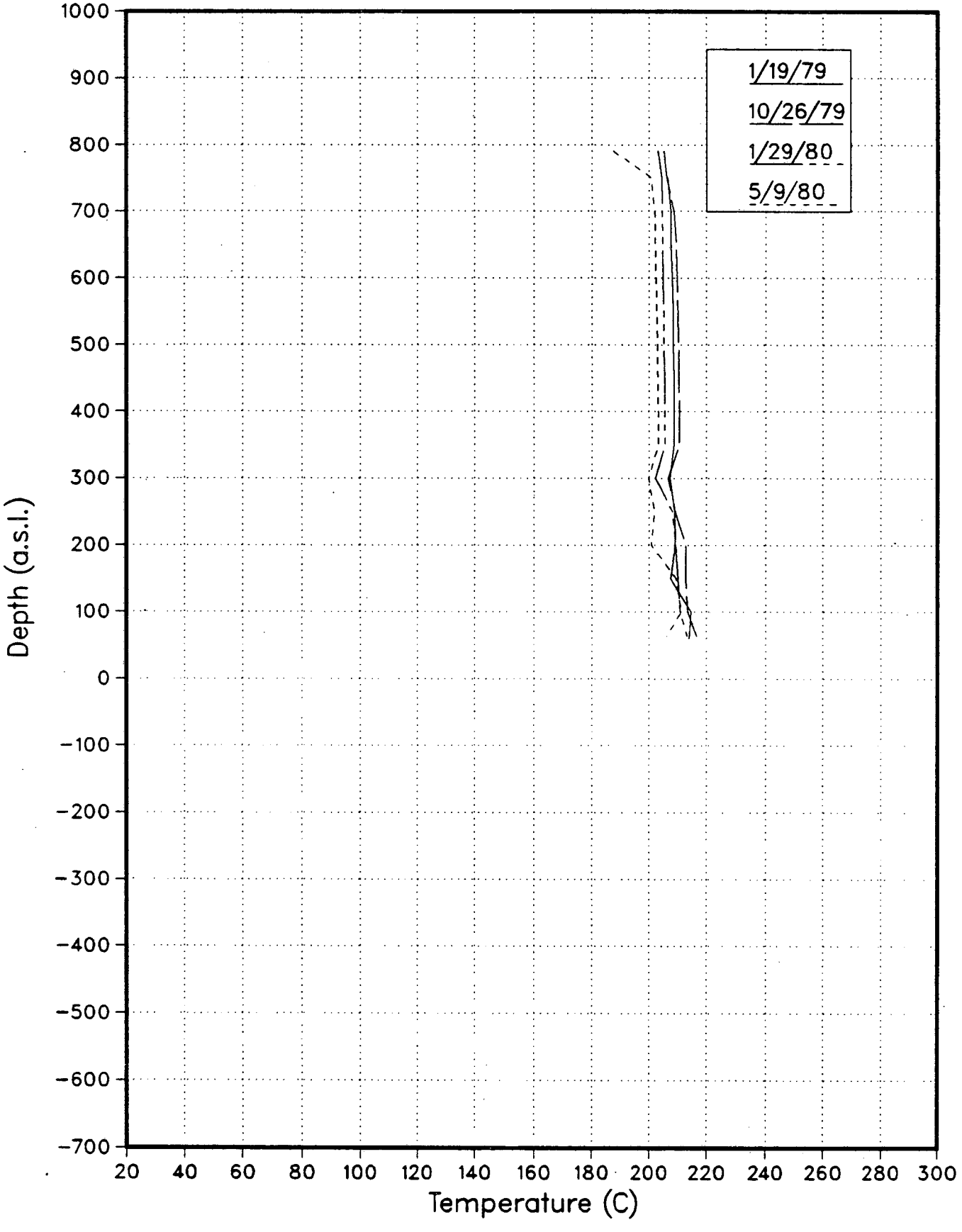

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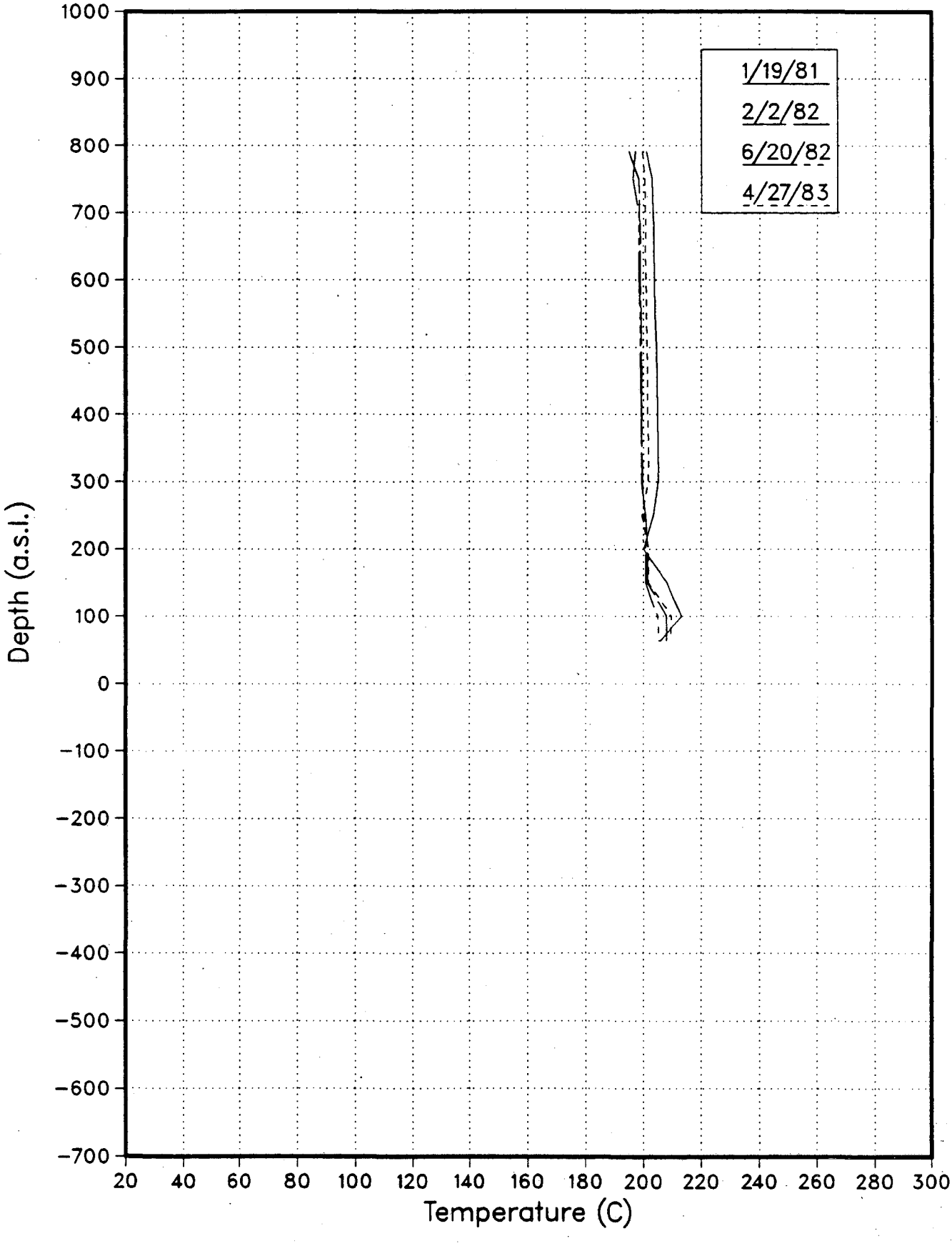

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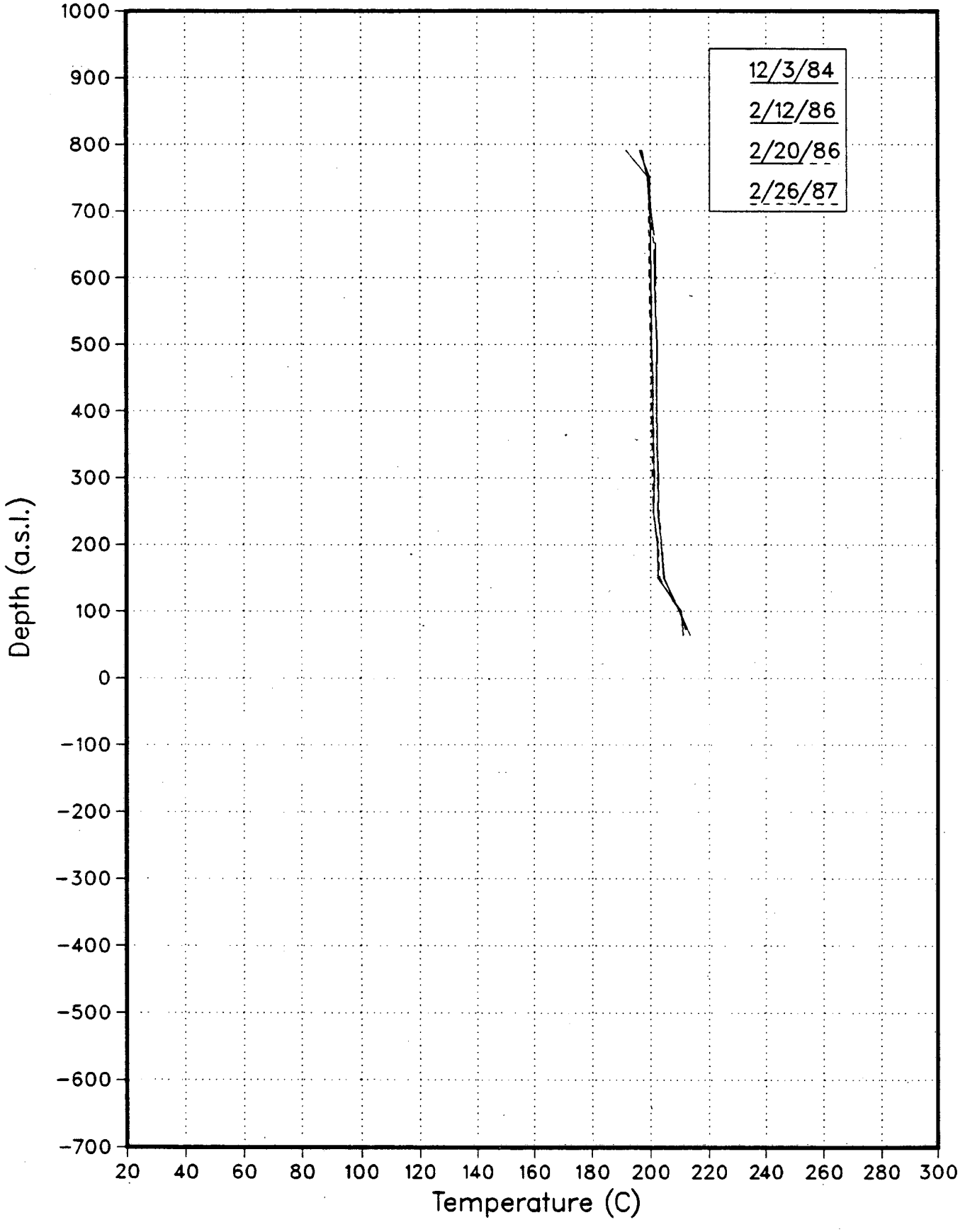

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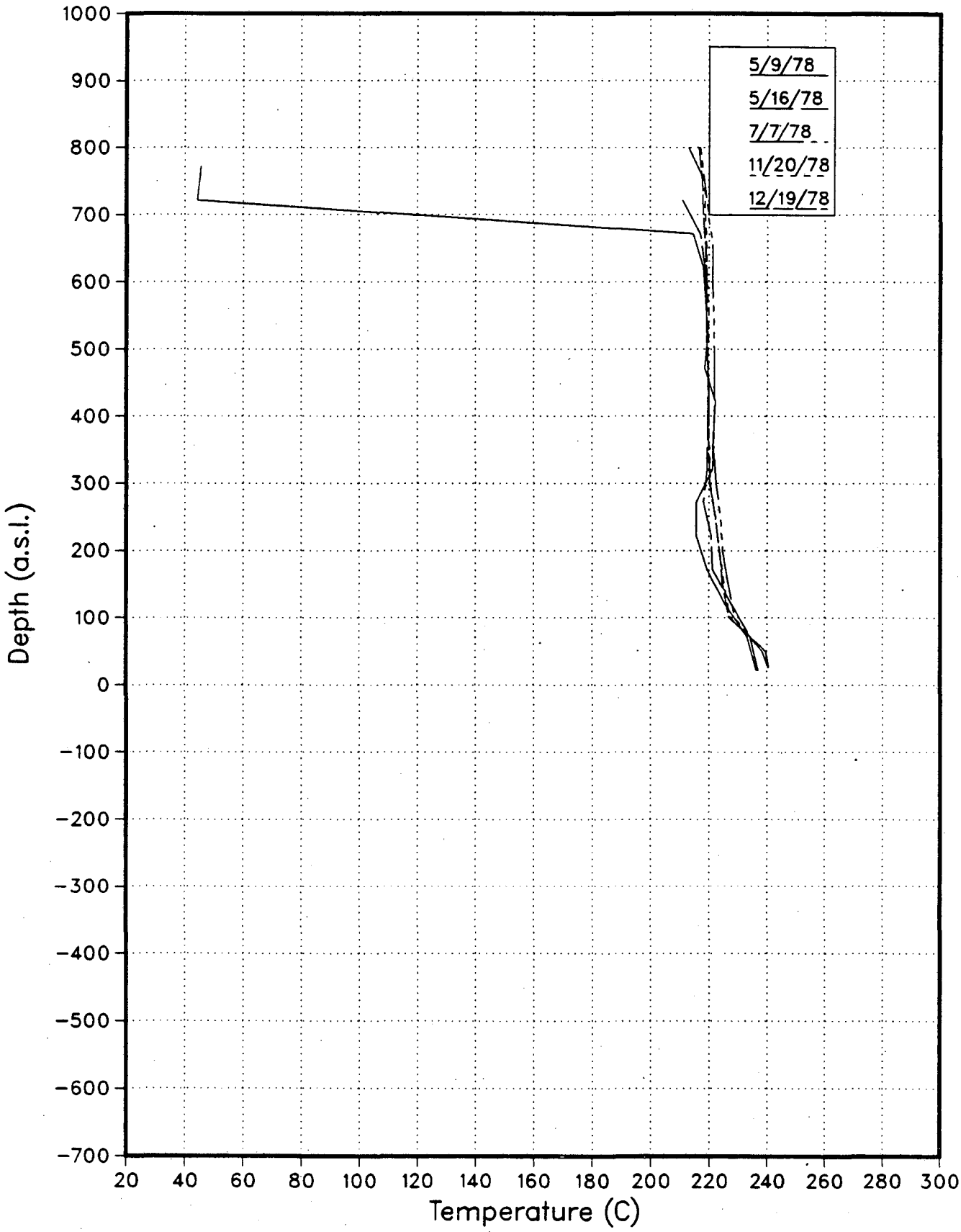

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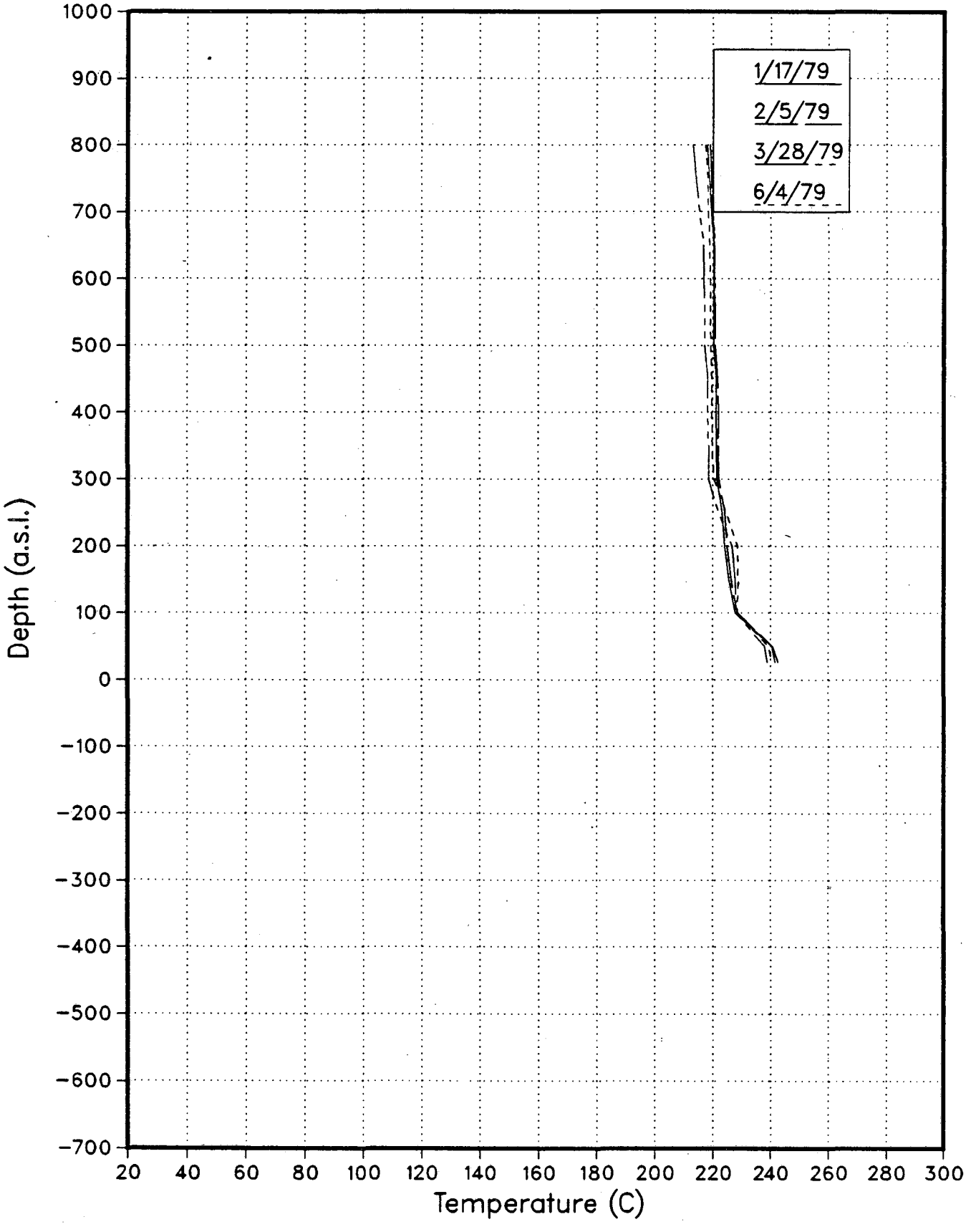

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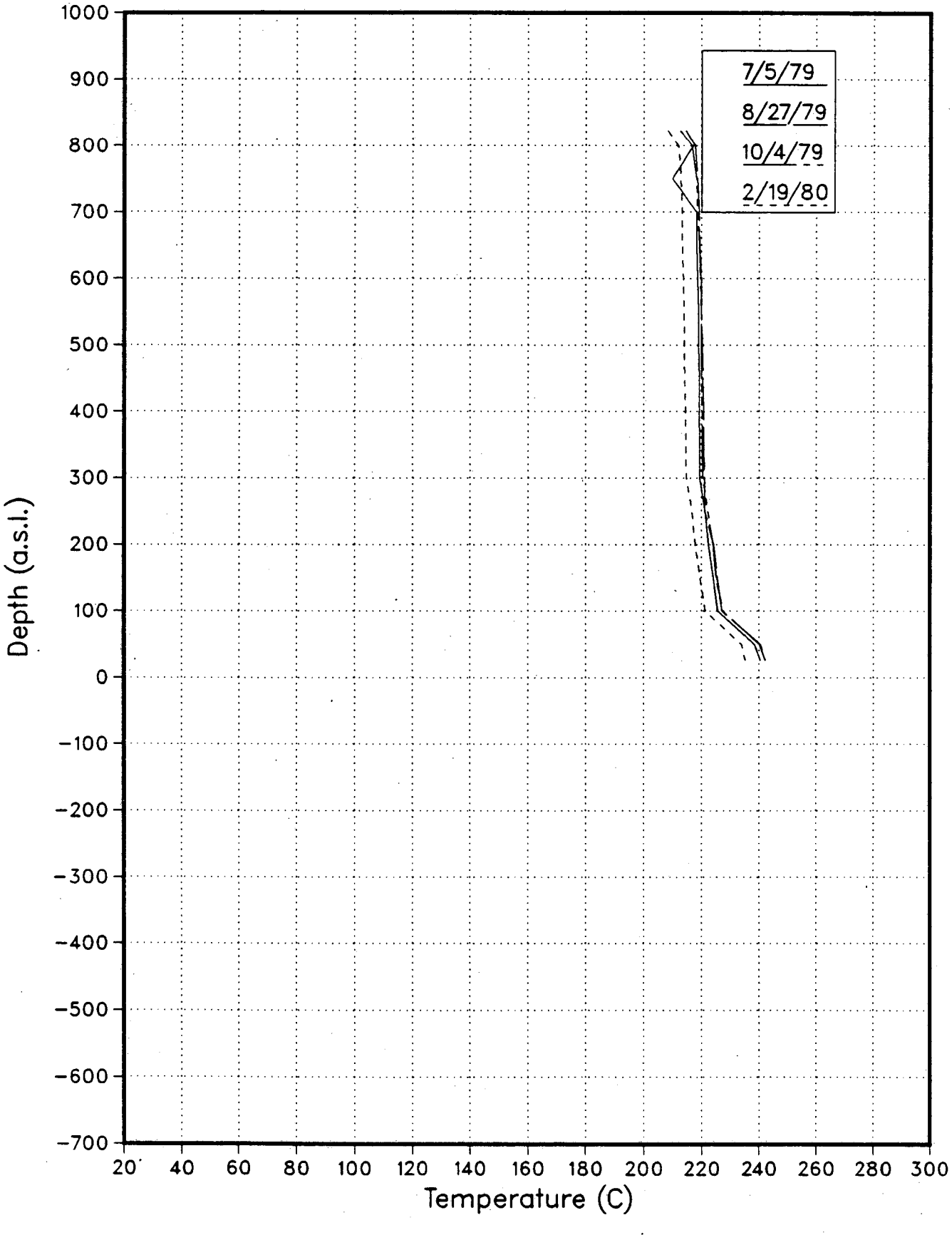

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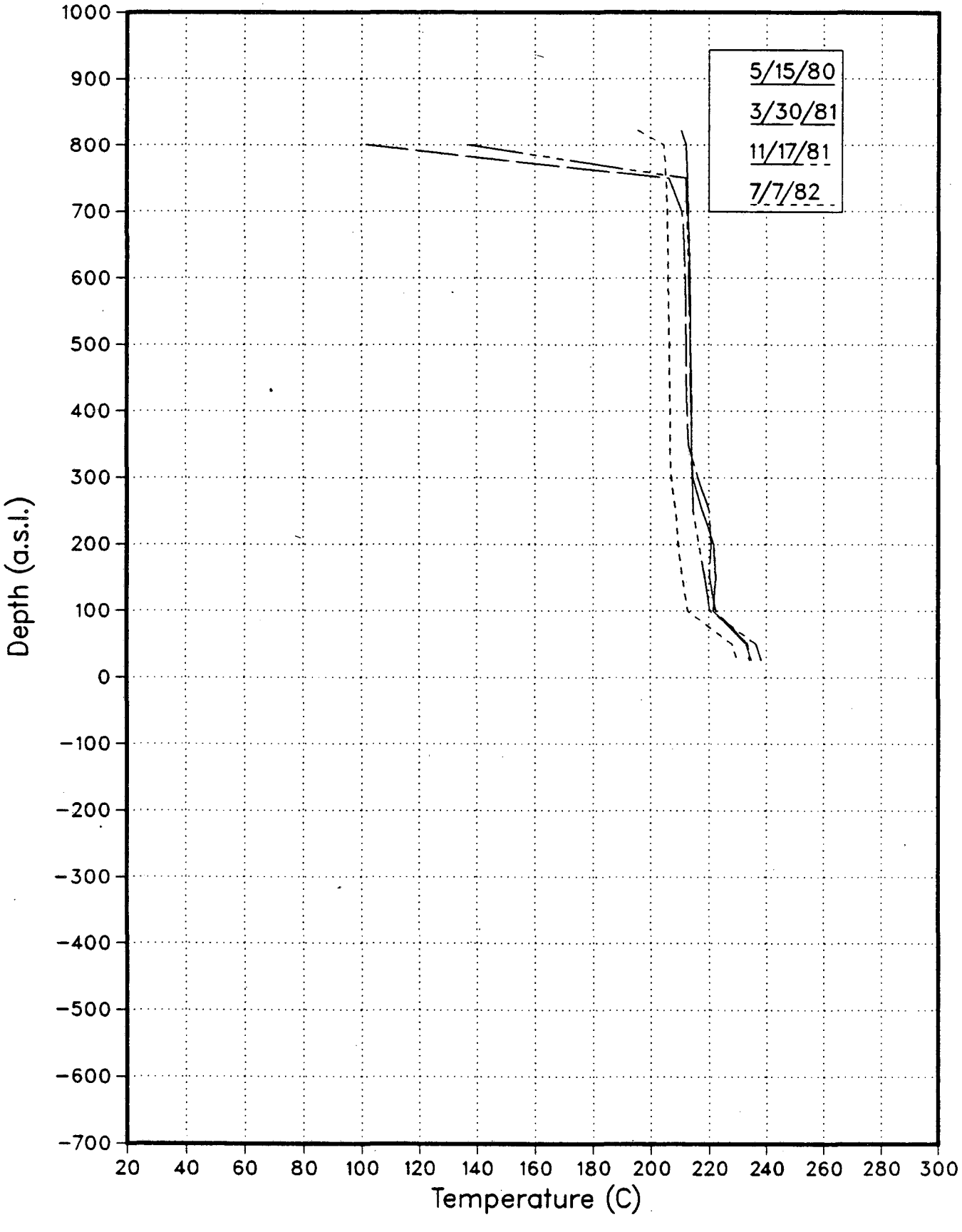

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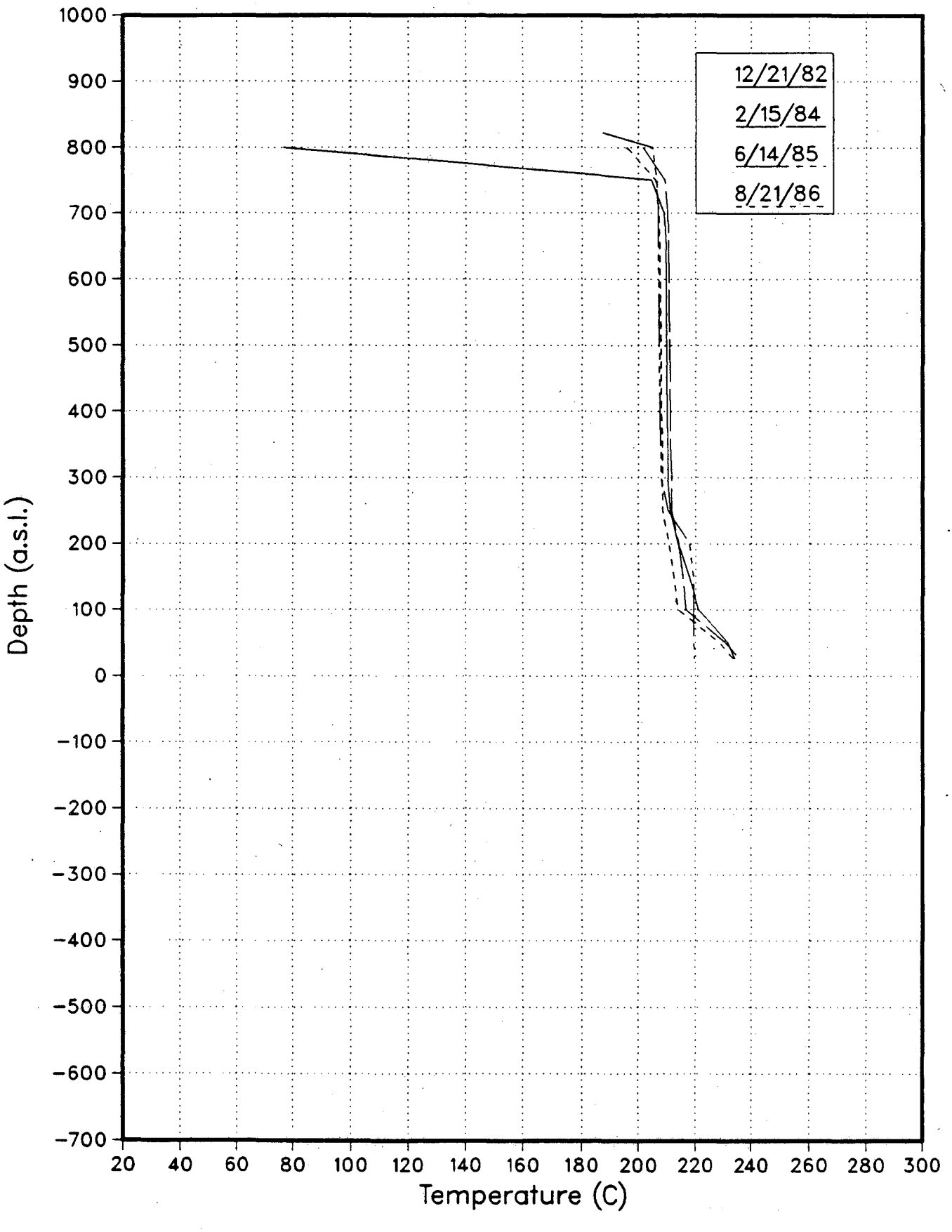
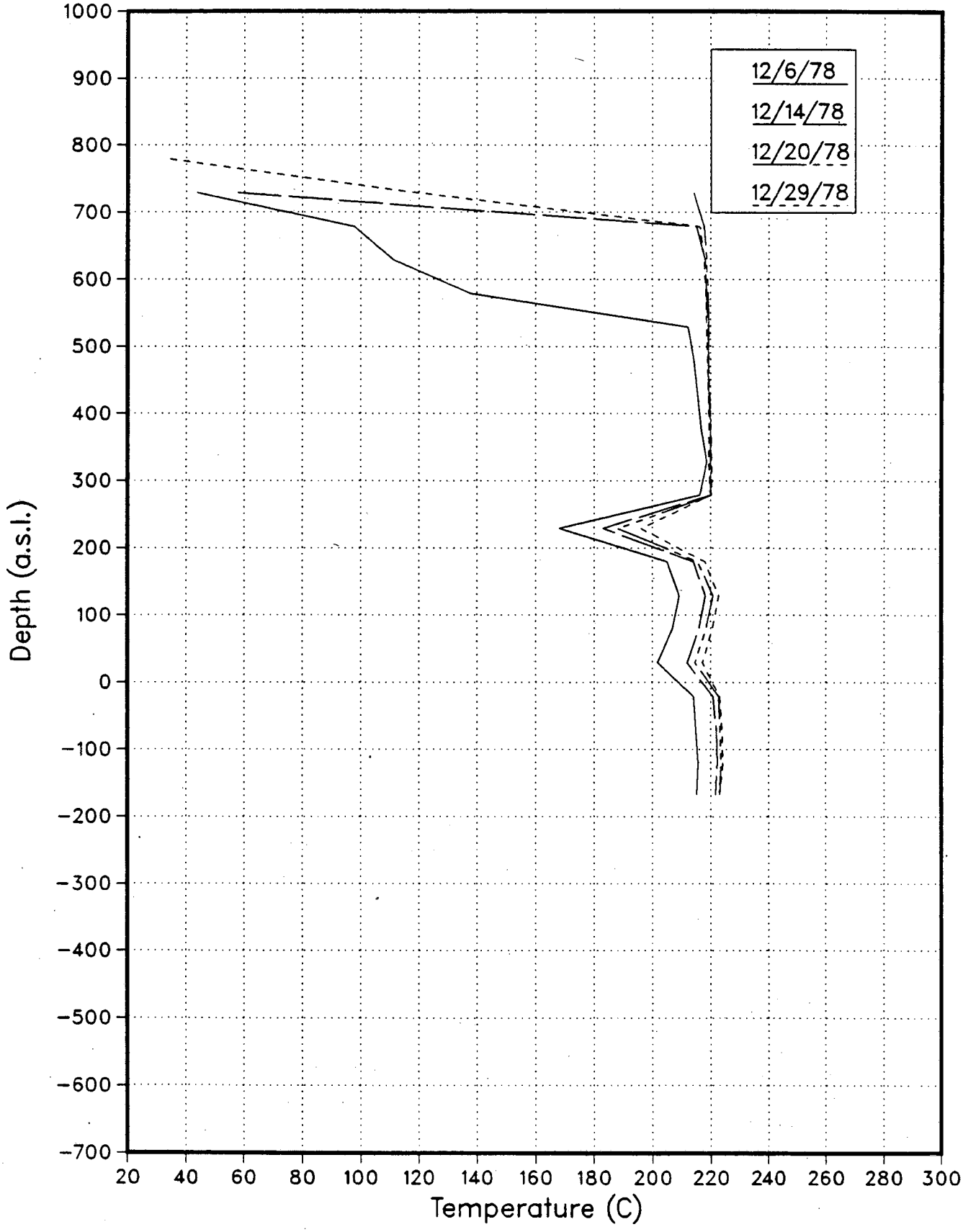


AH28 Temperature Surveys



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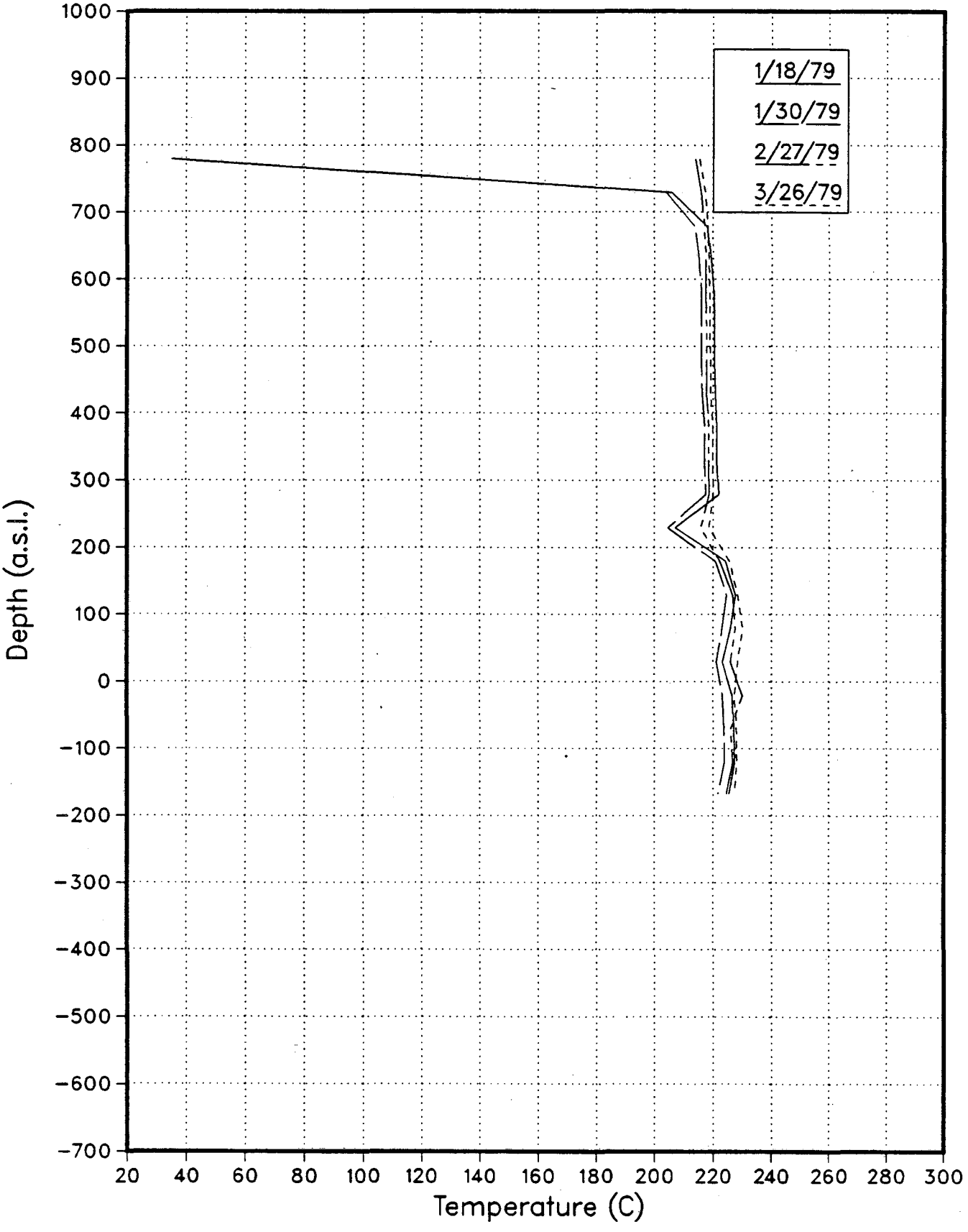

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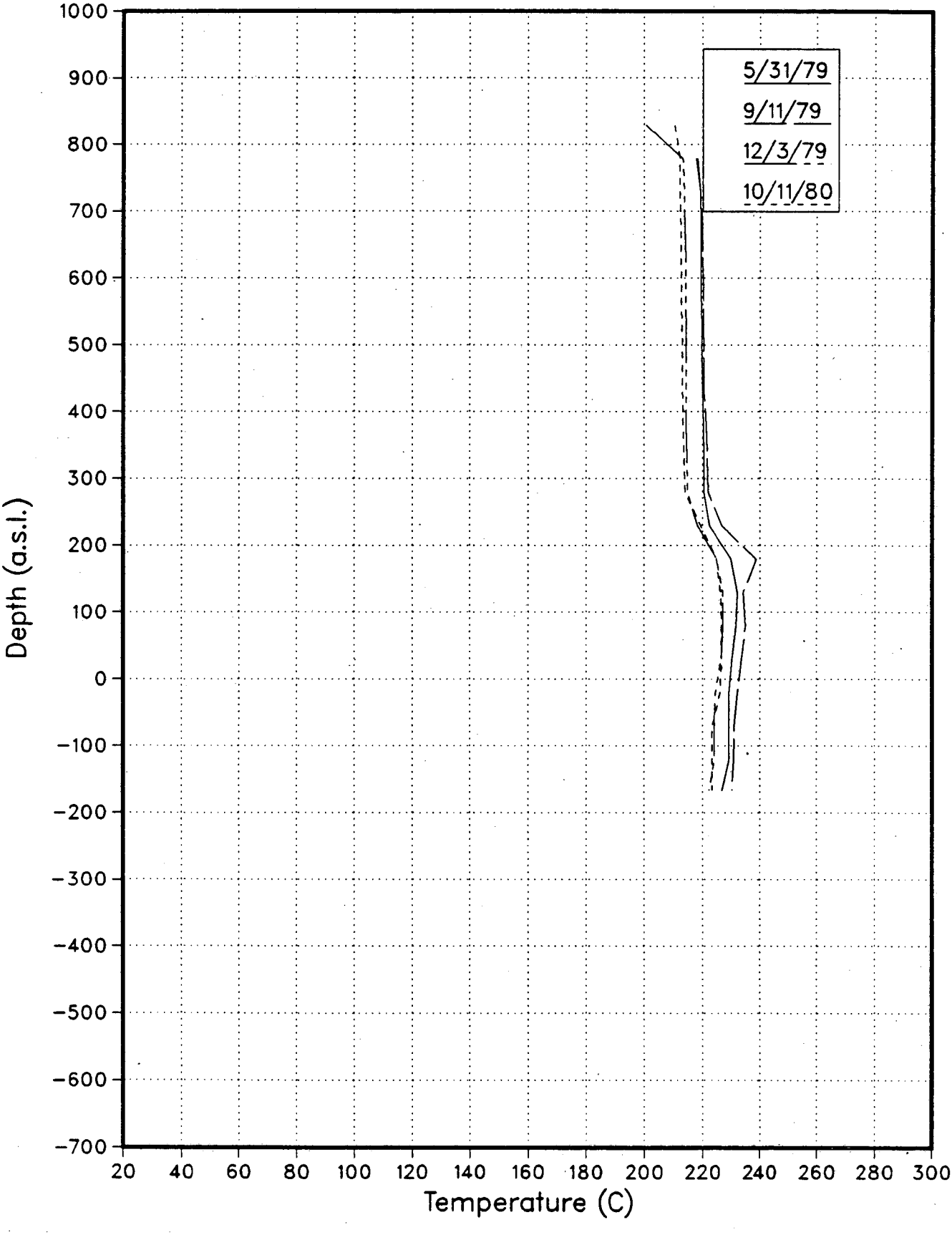

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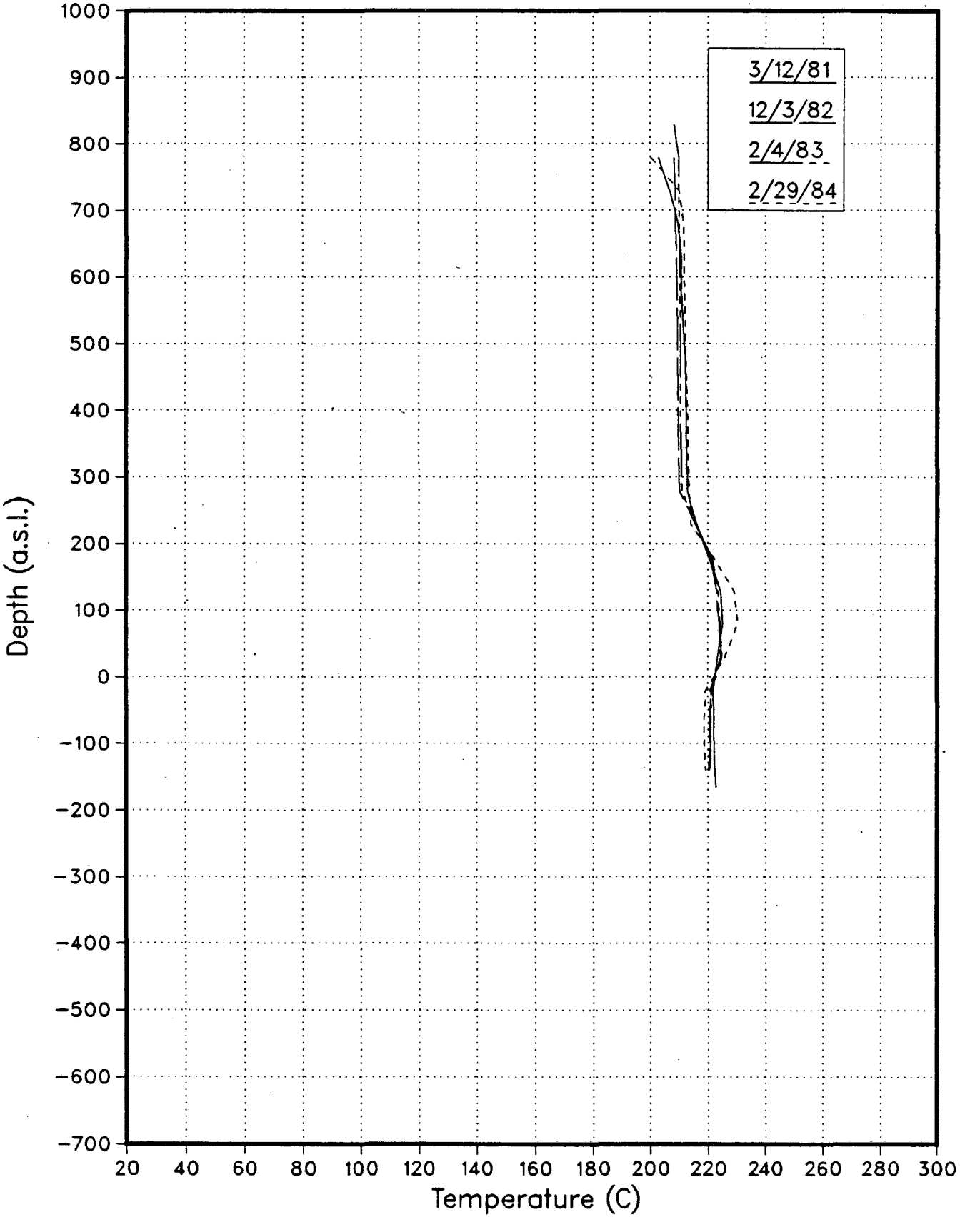

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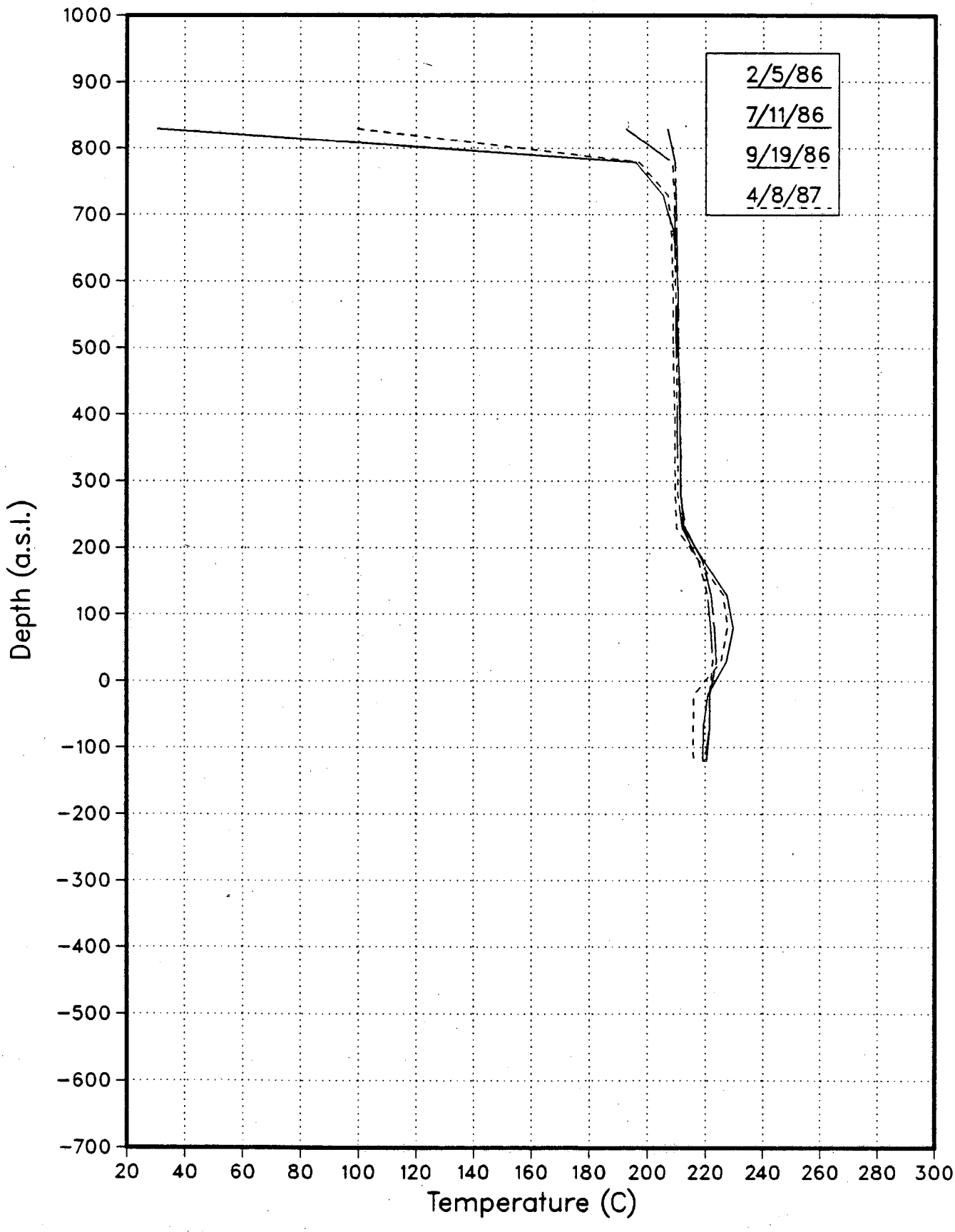

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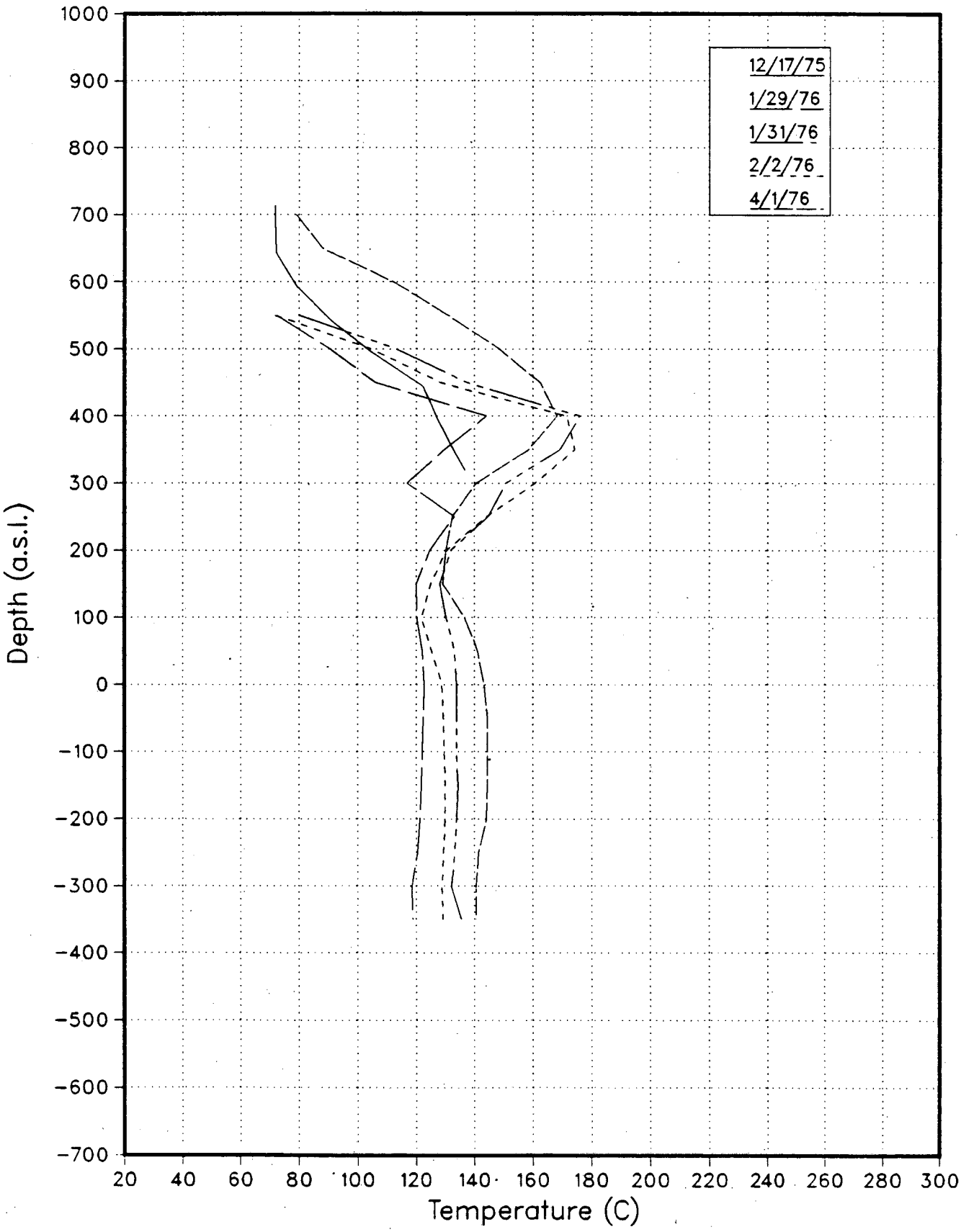

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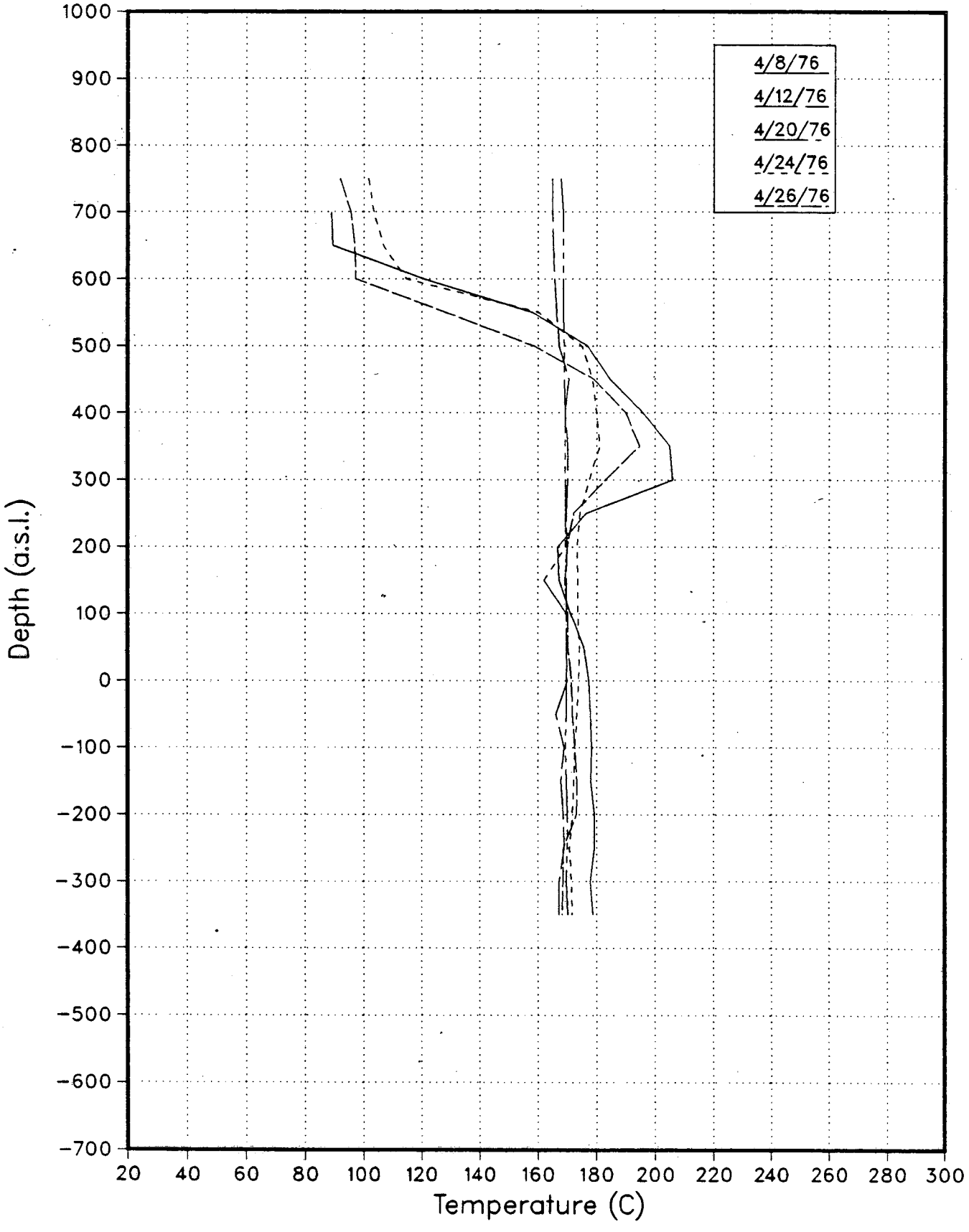

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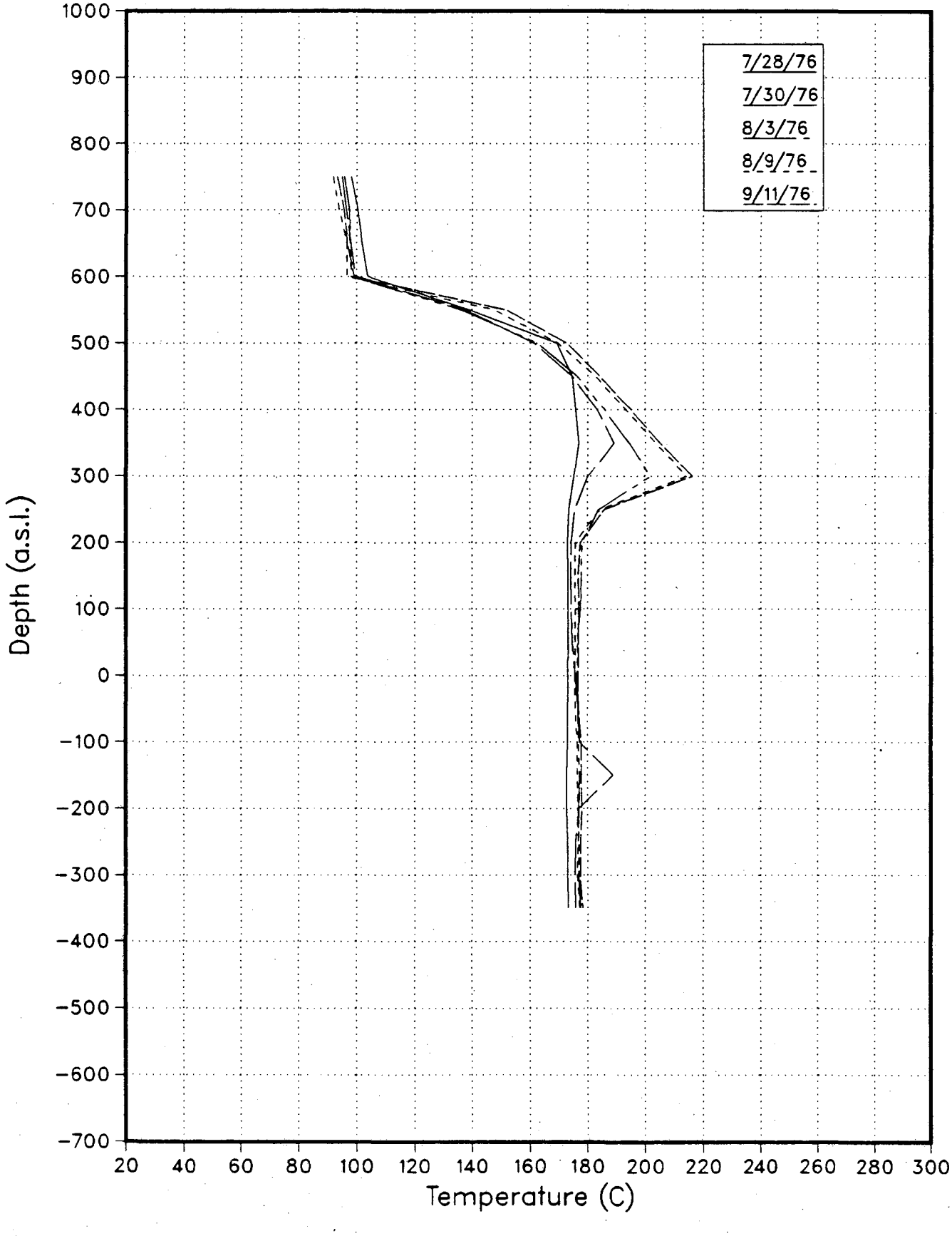

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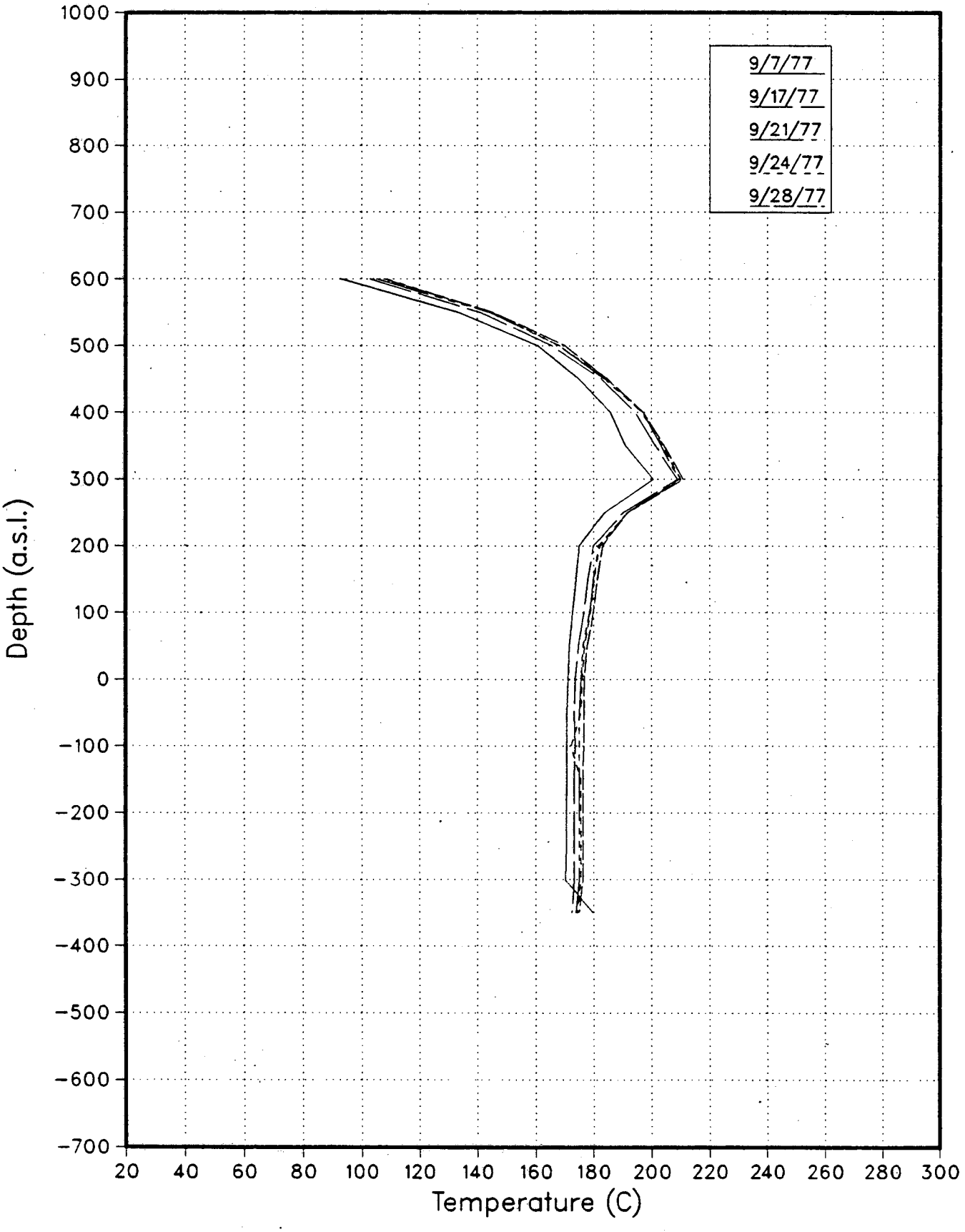

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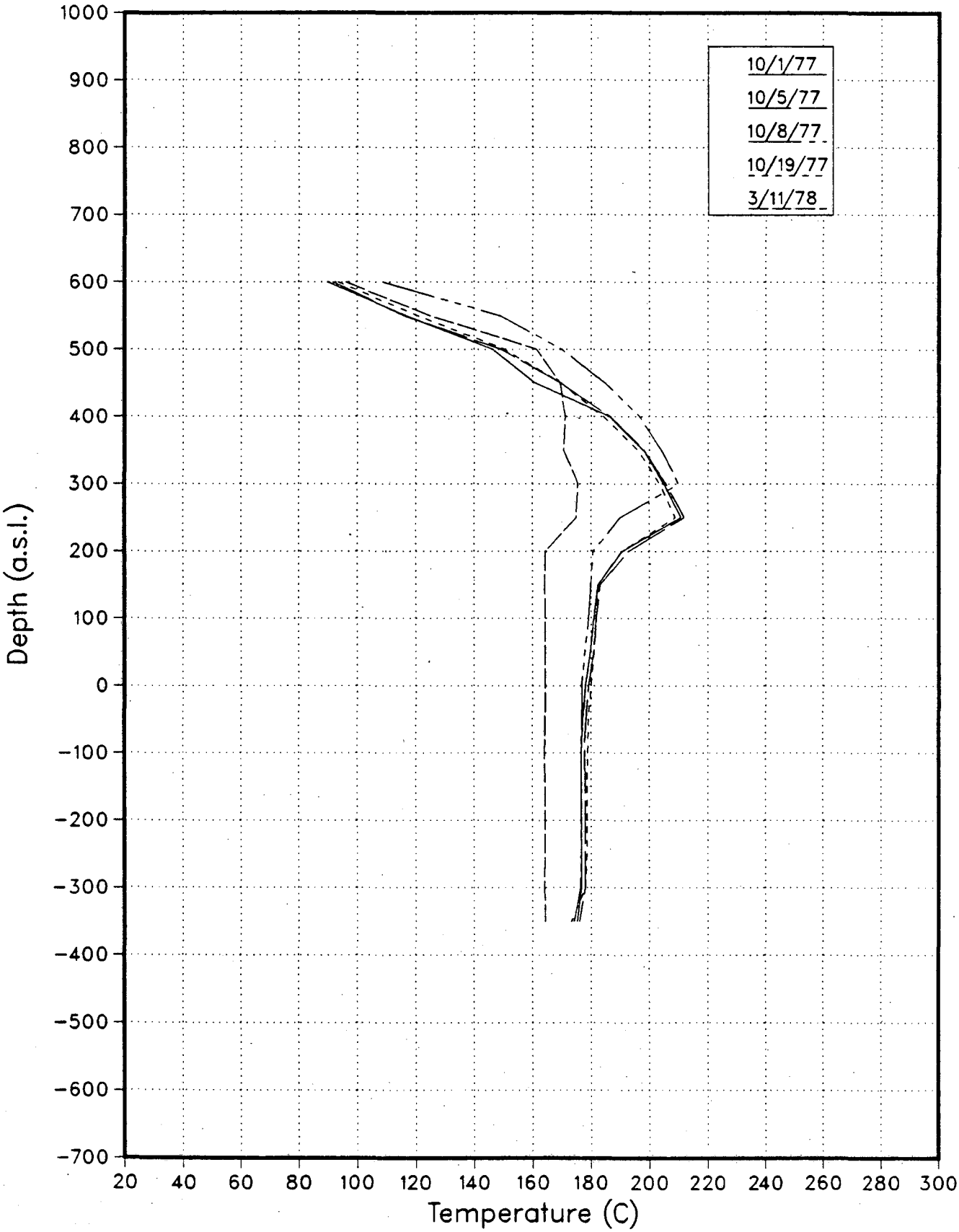

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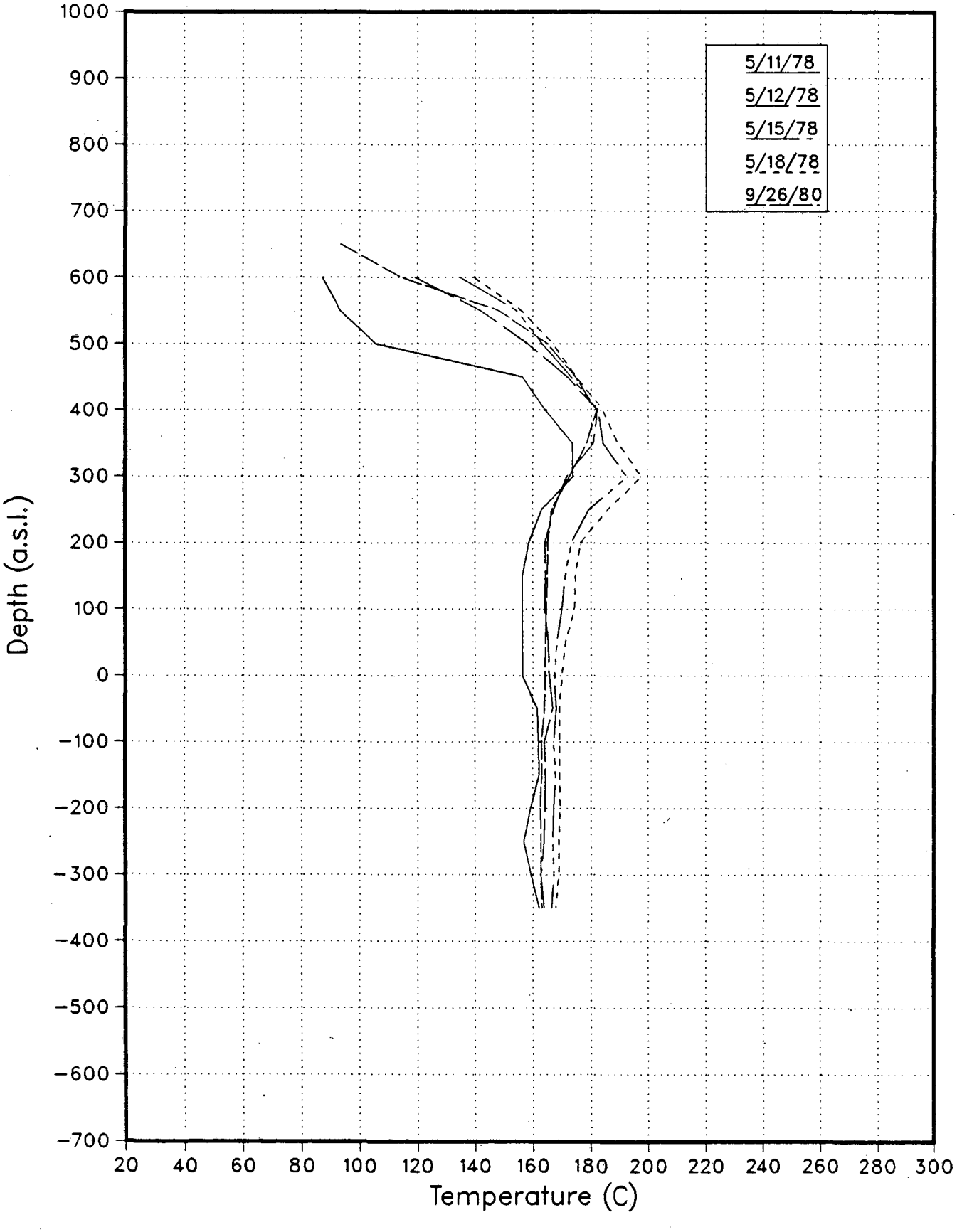

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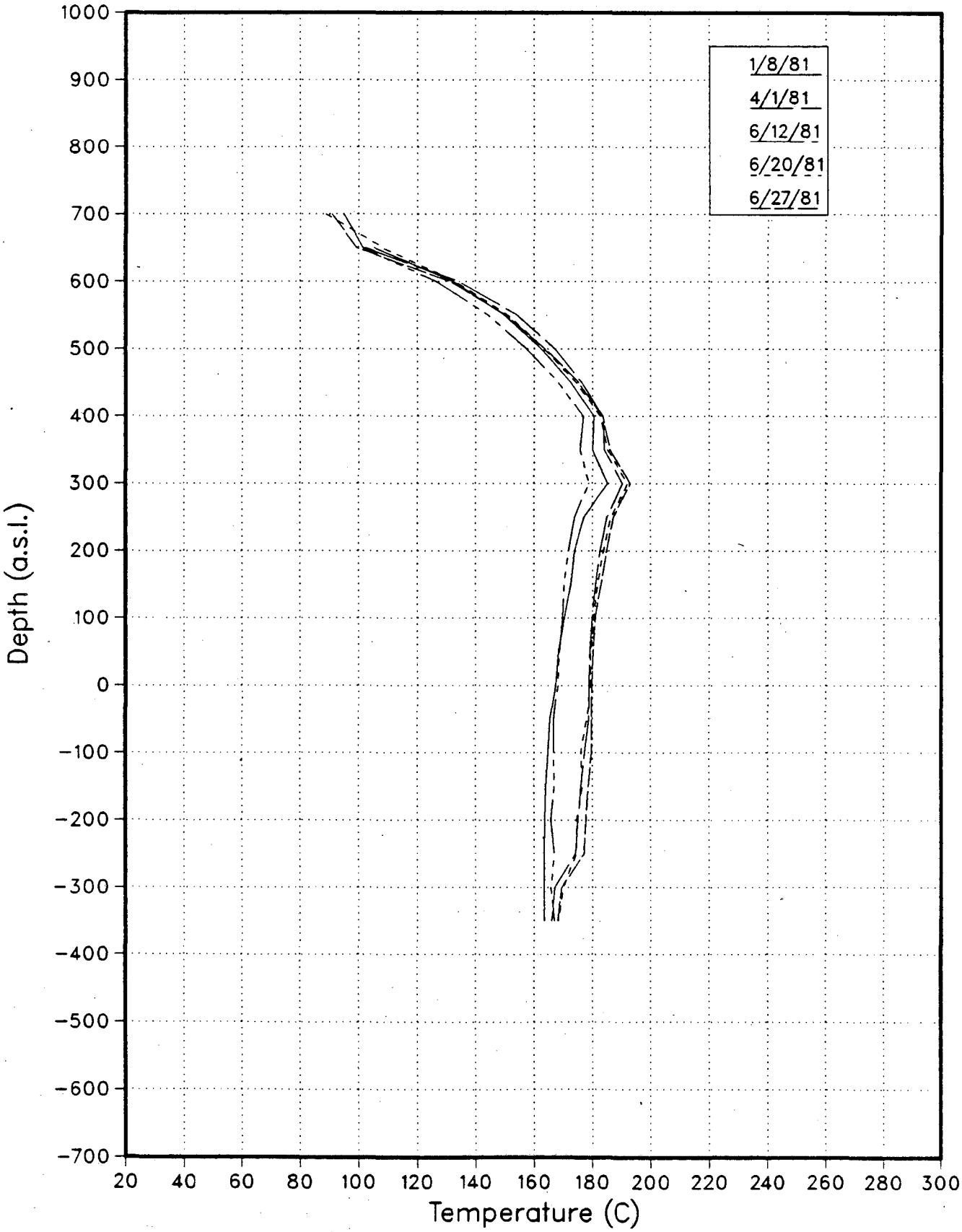

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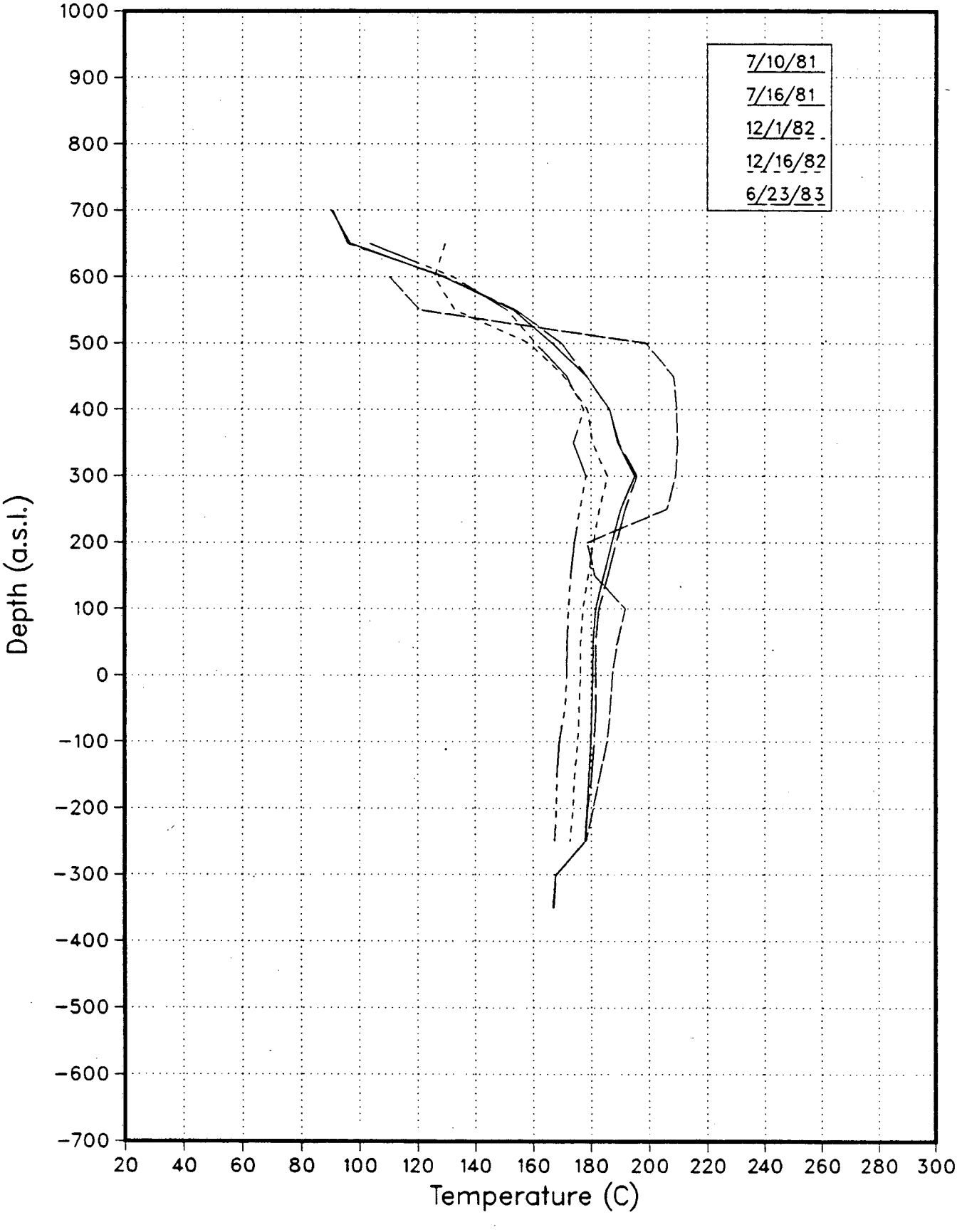

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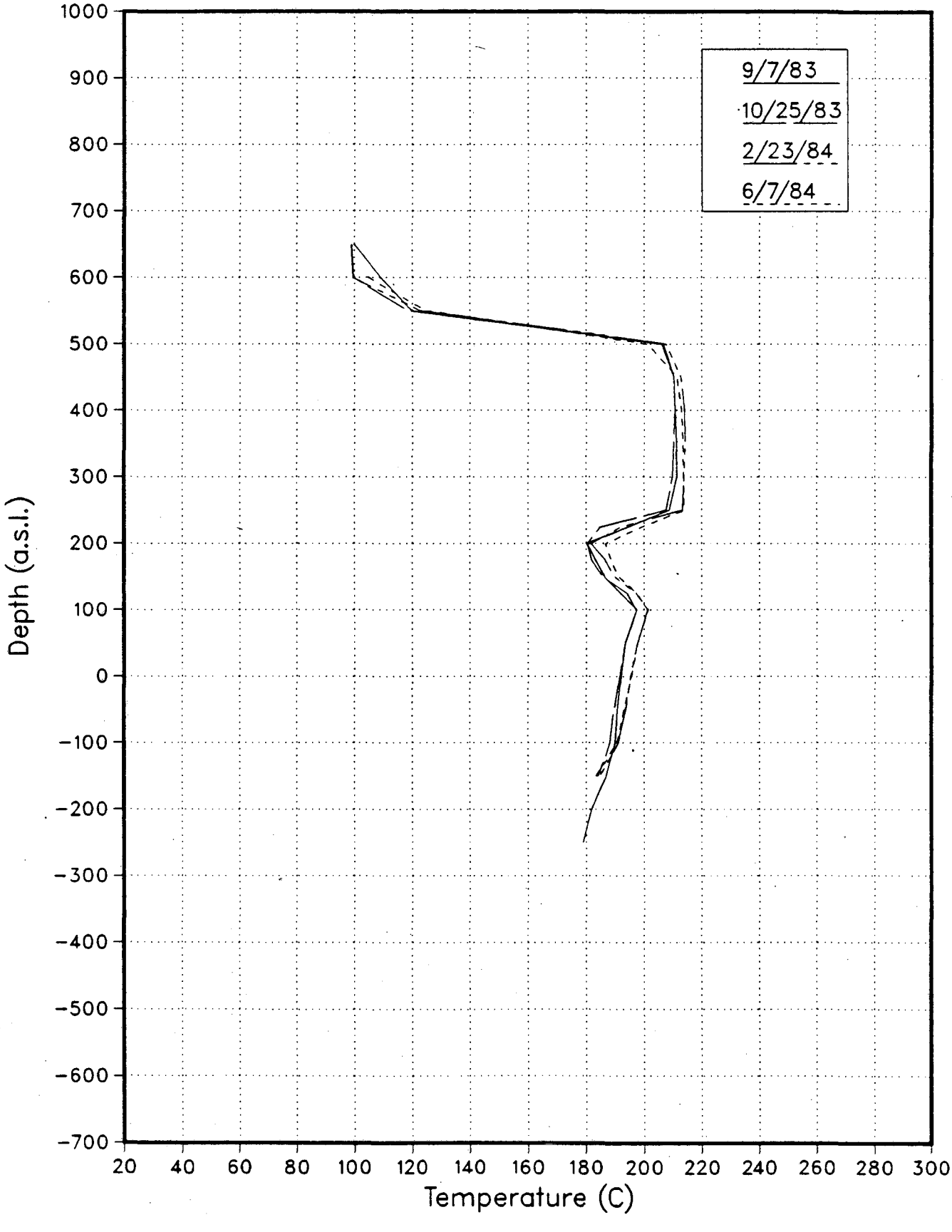

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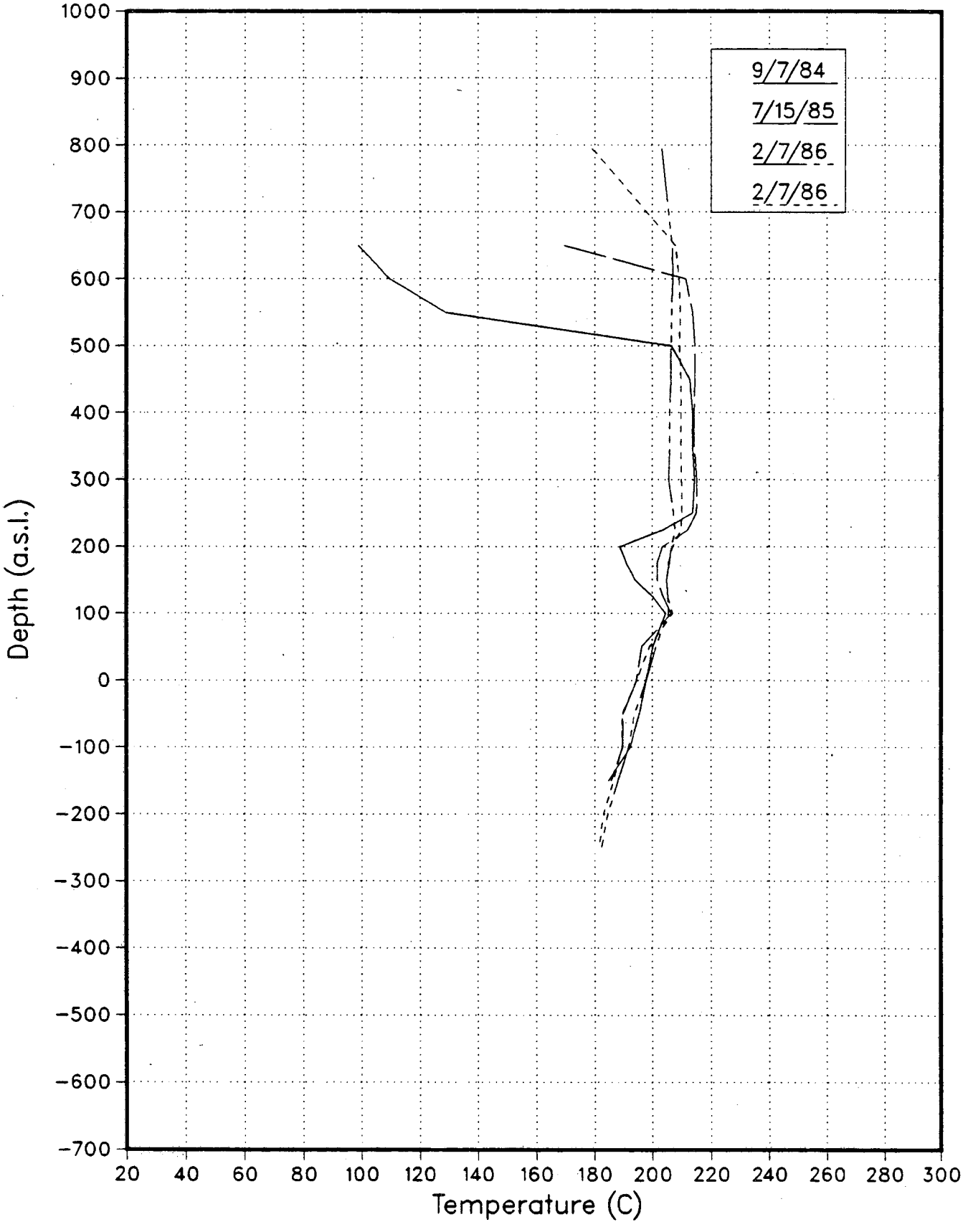

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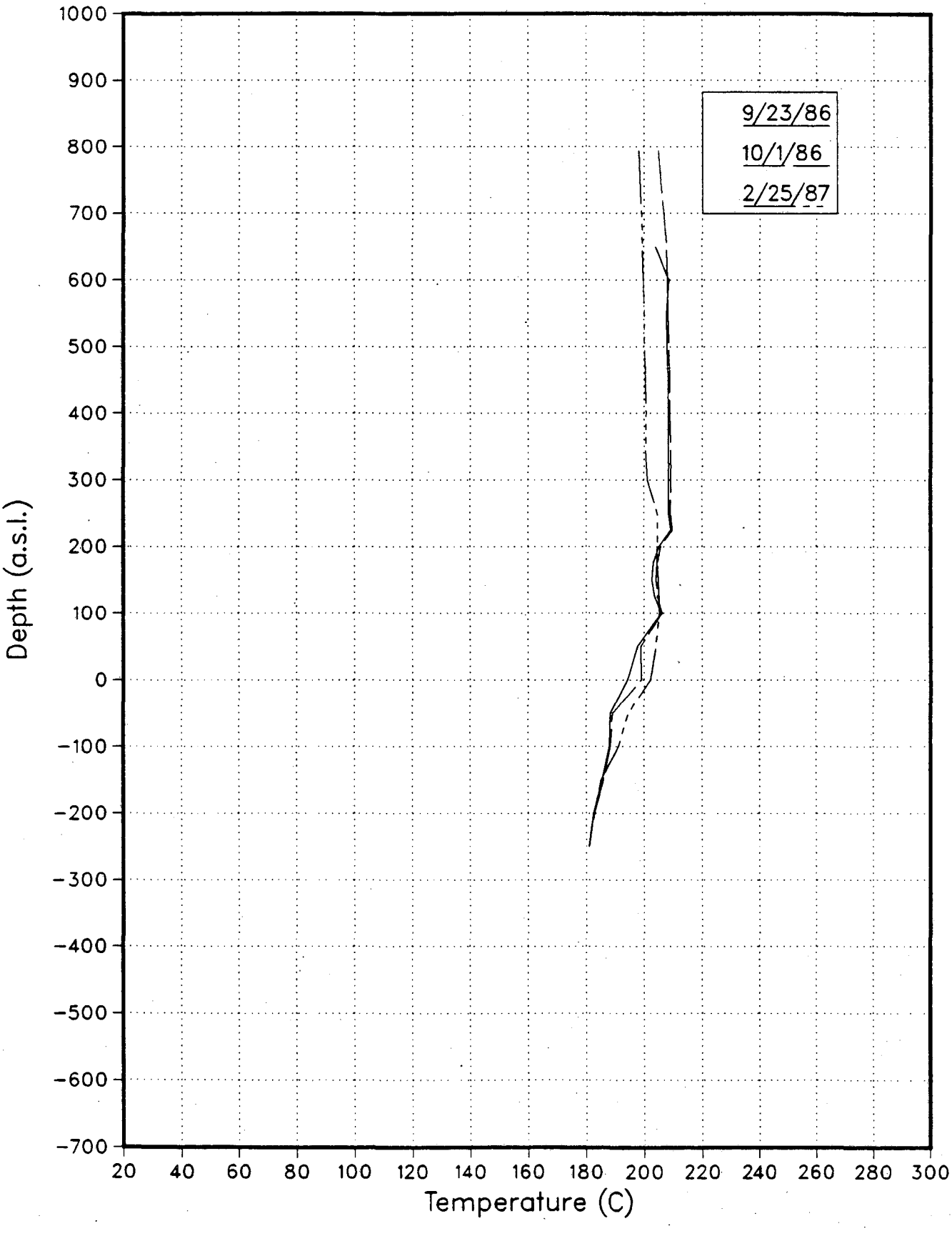

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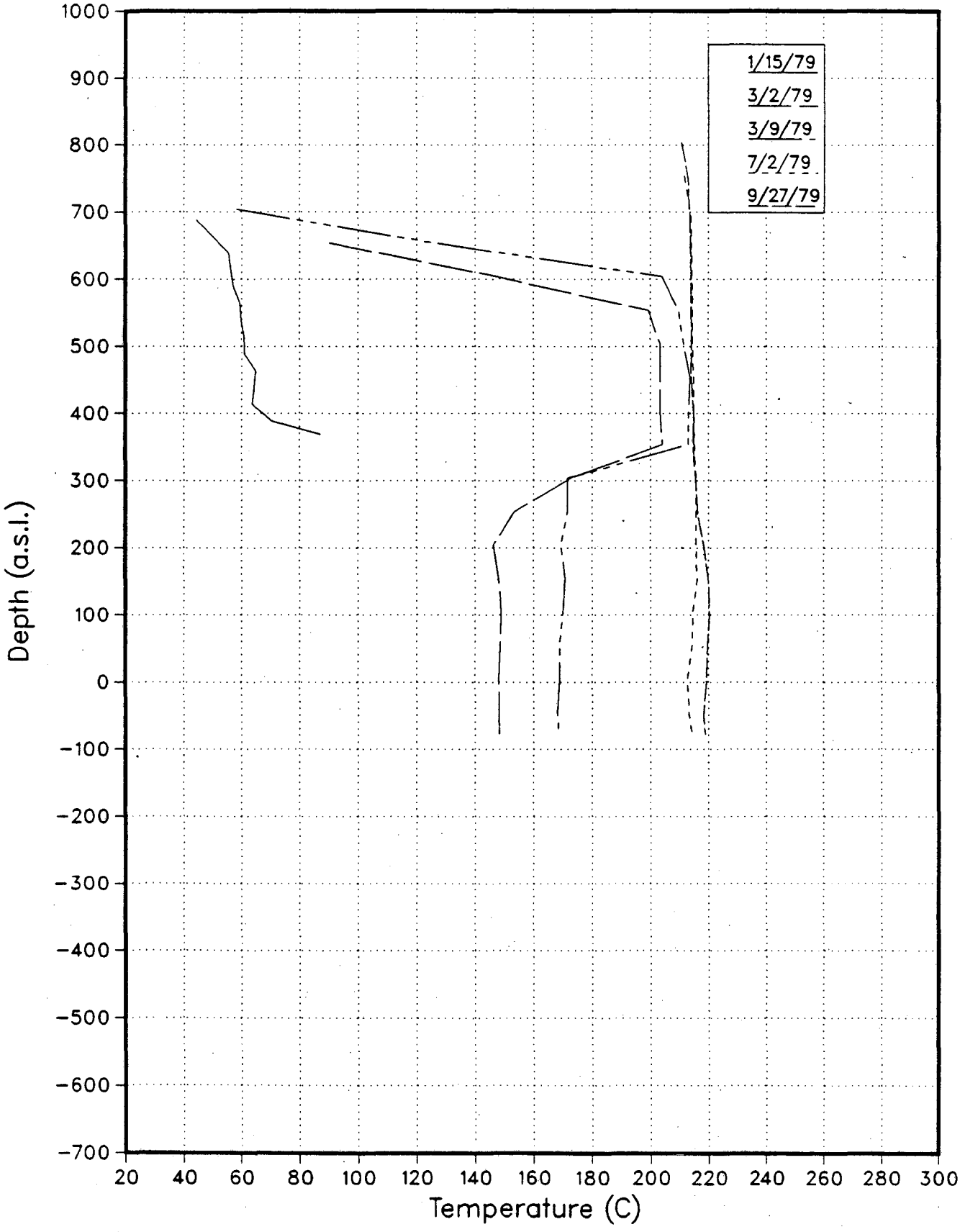

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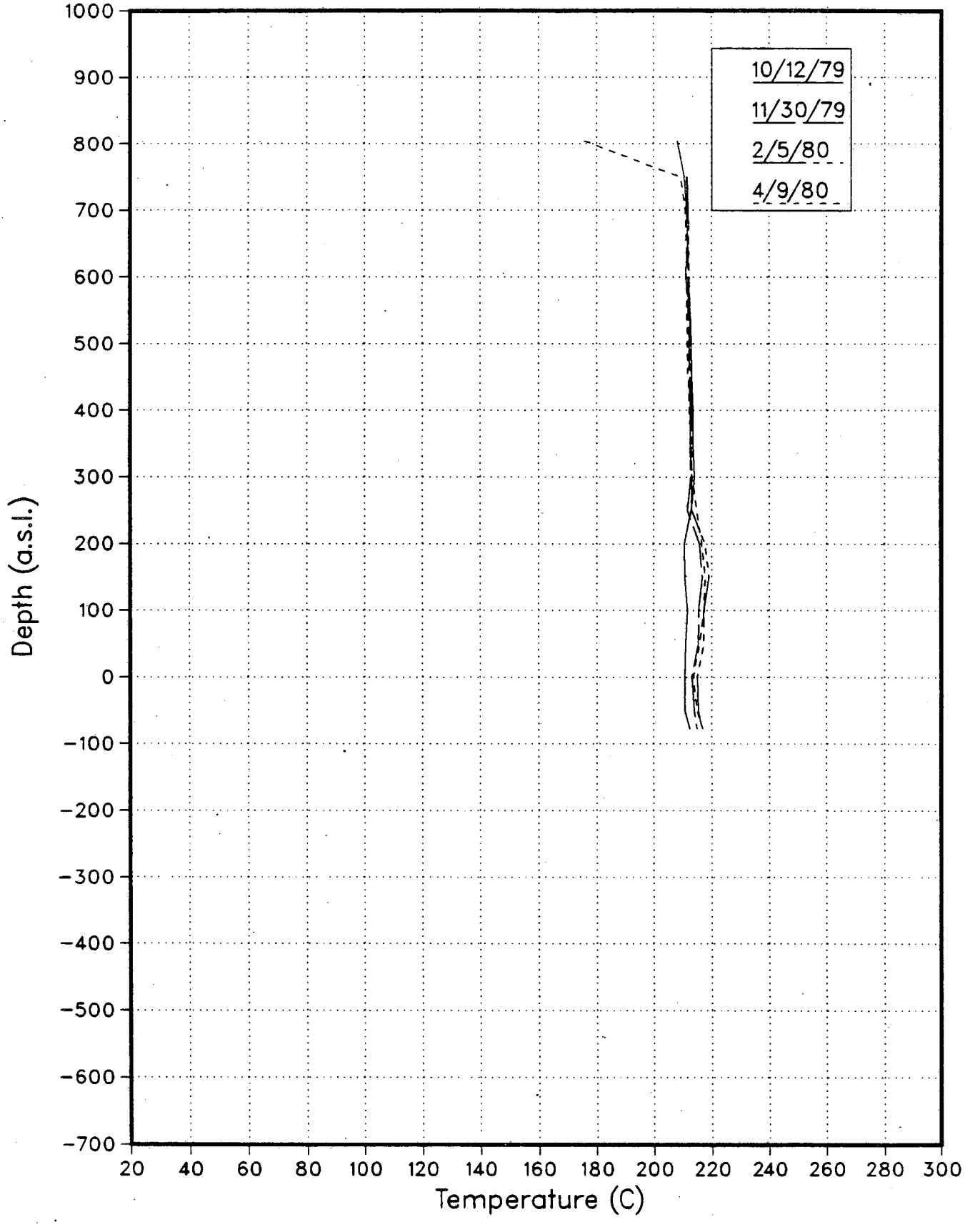

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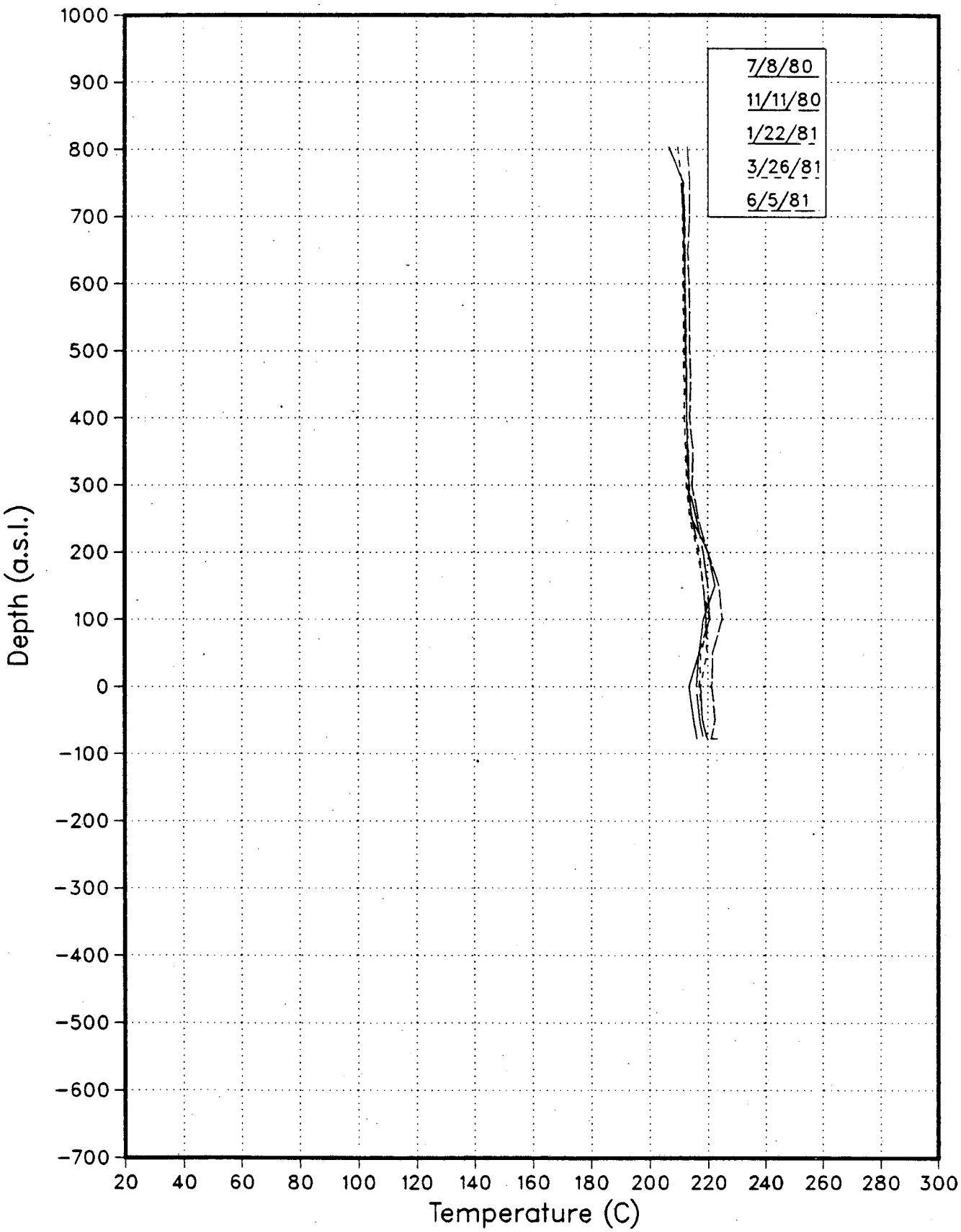

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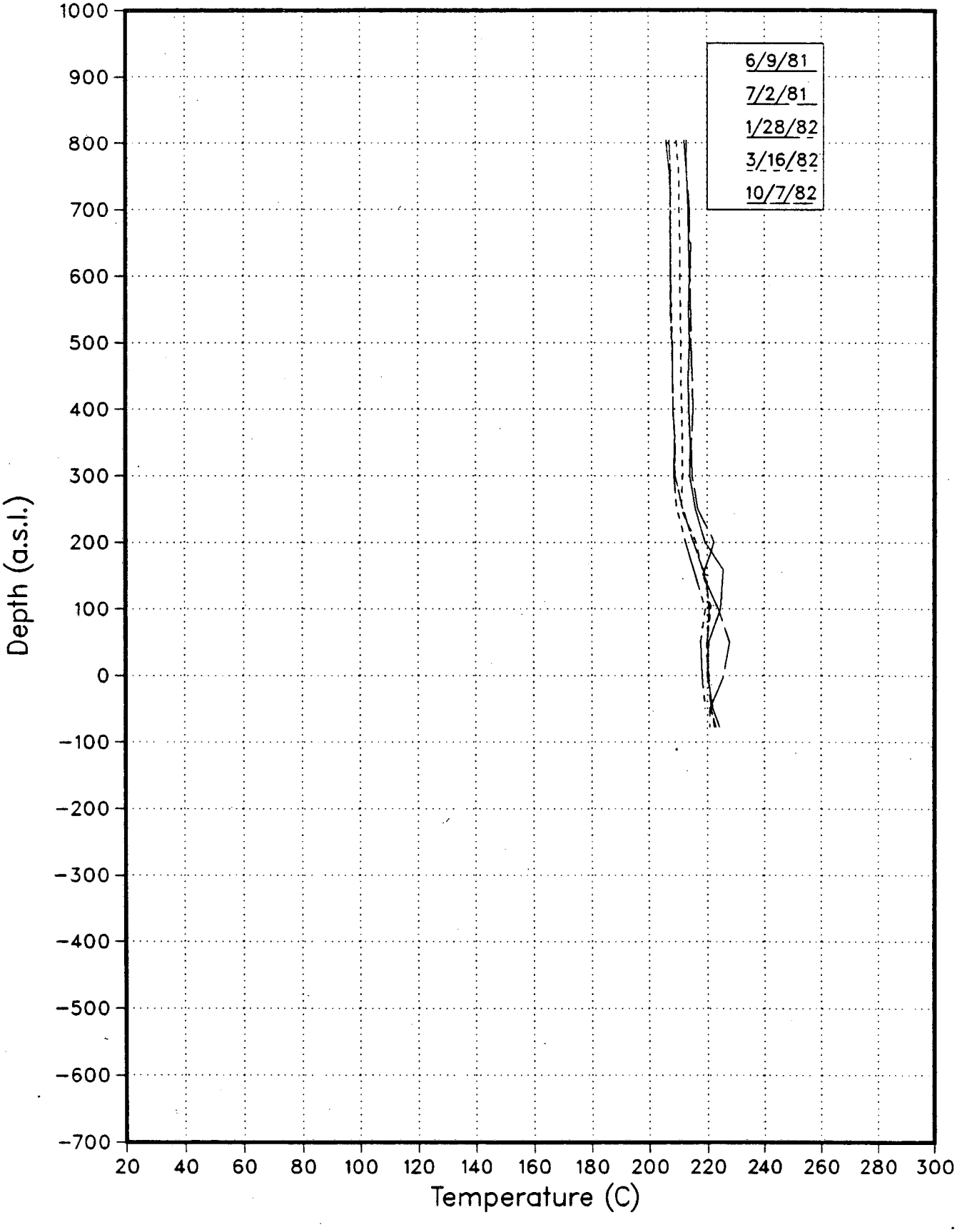

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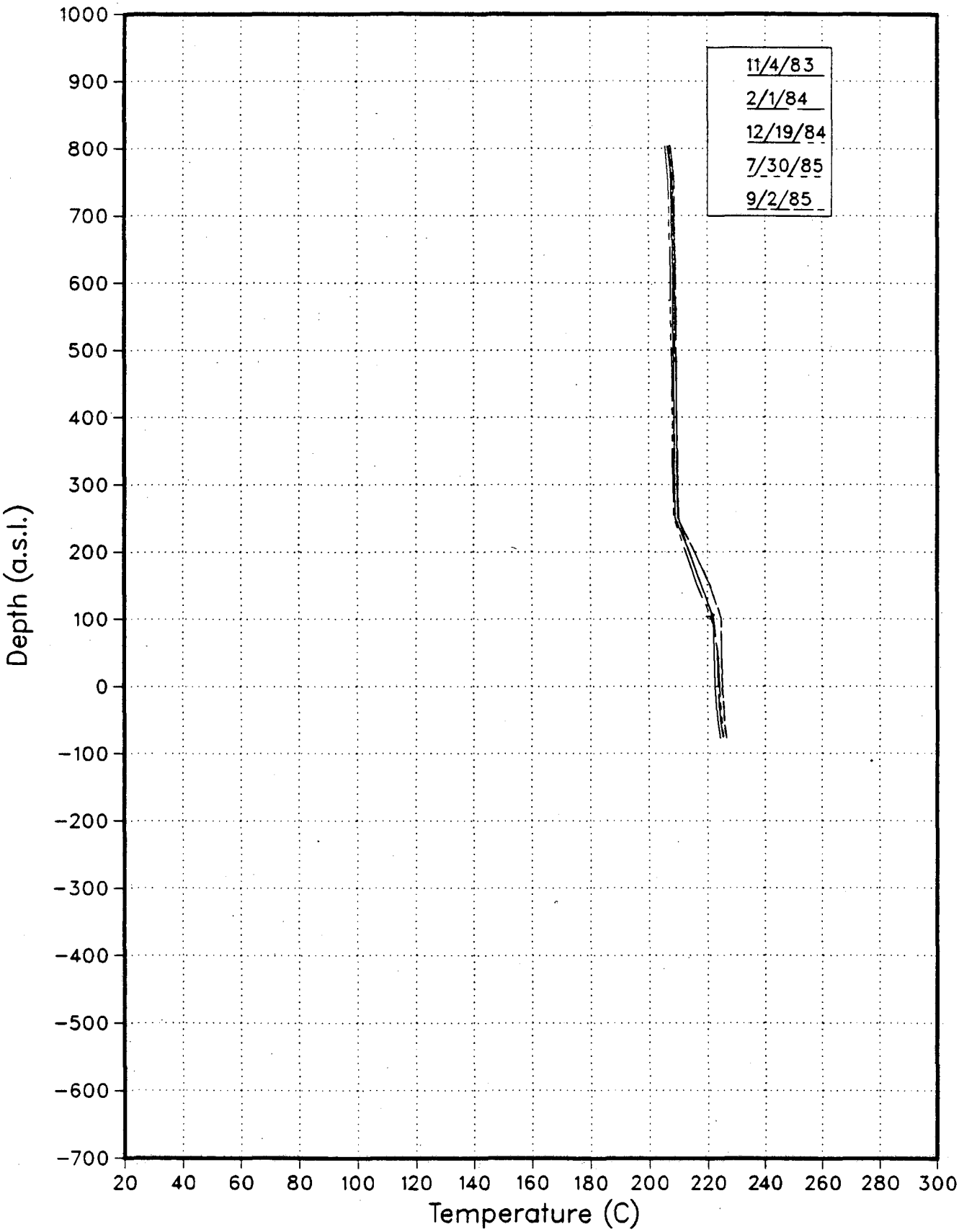

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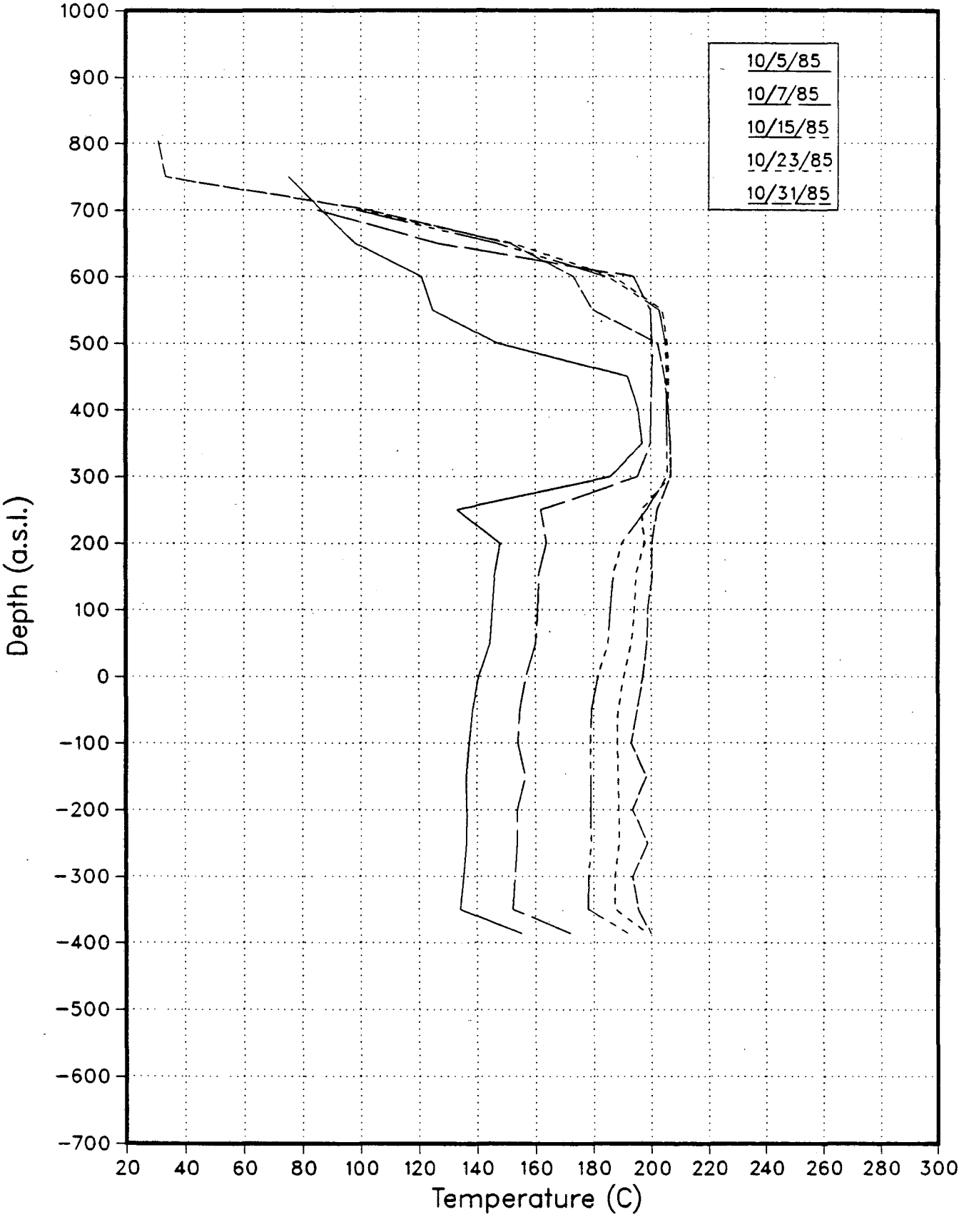

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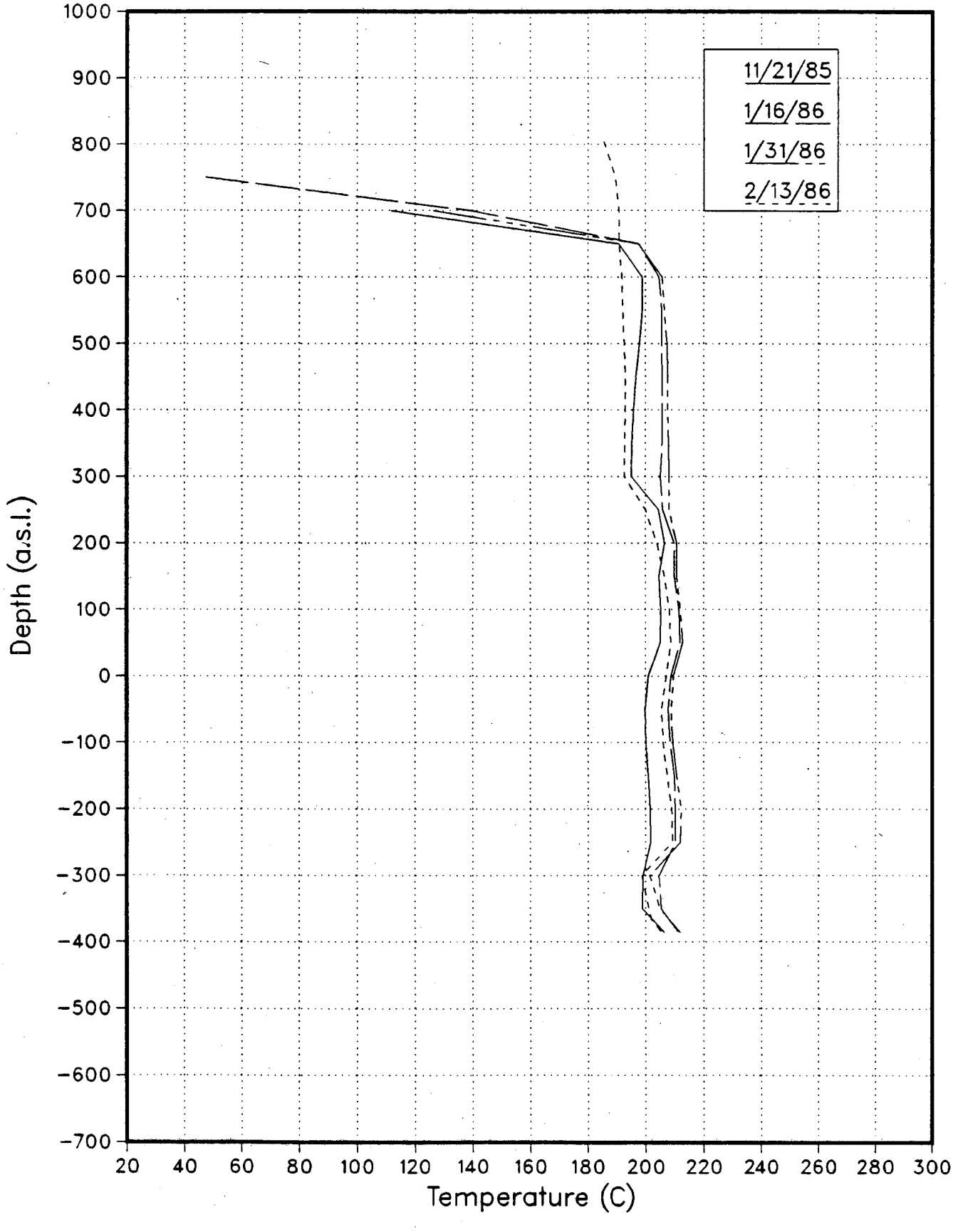

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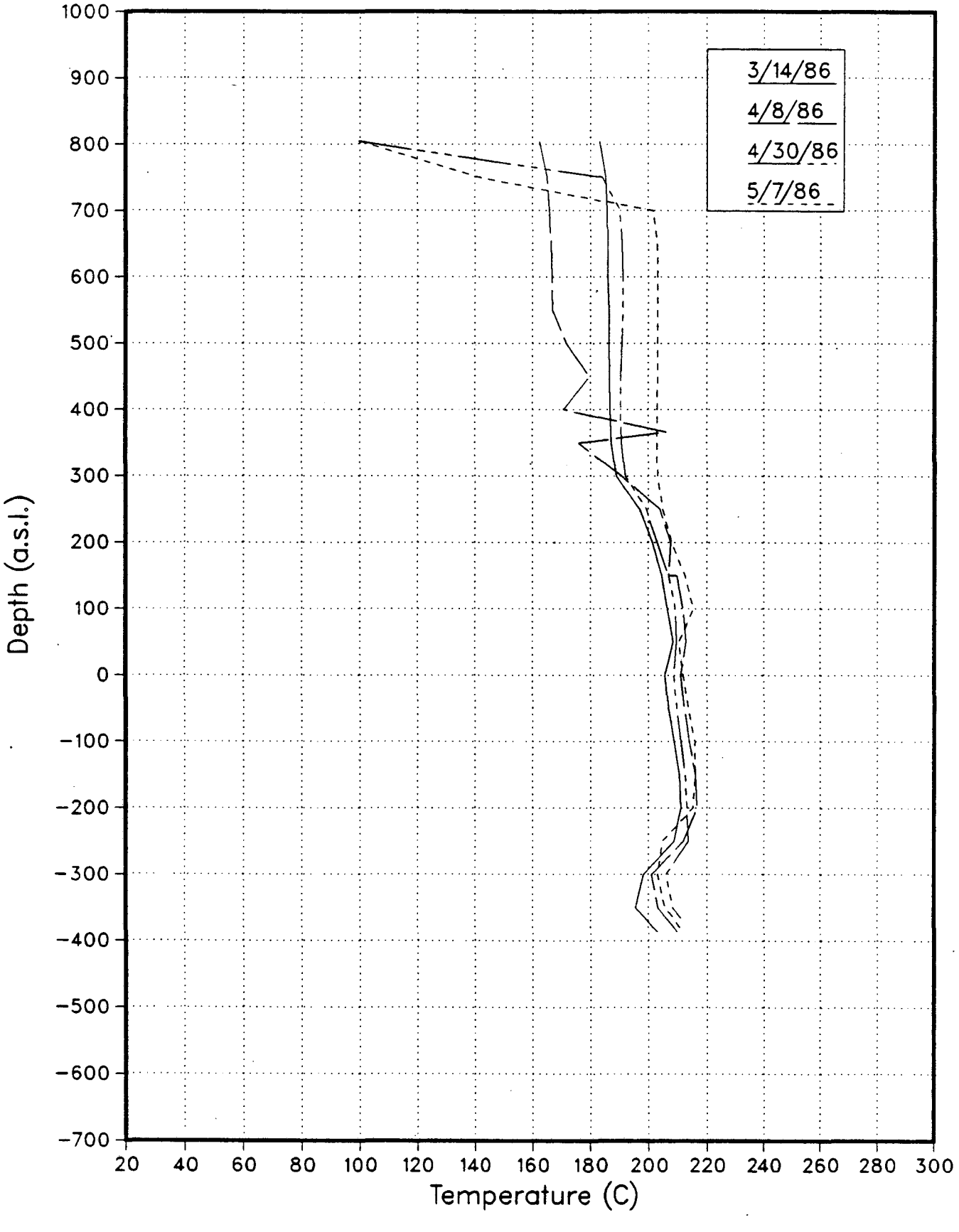

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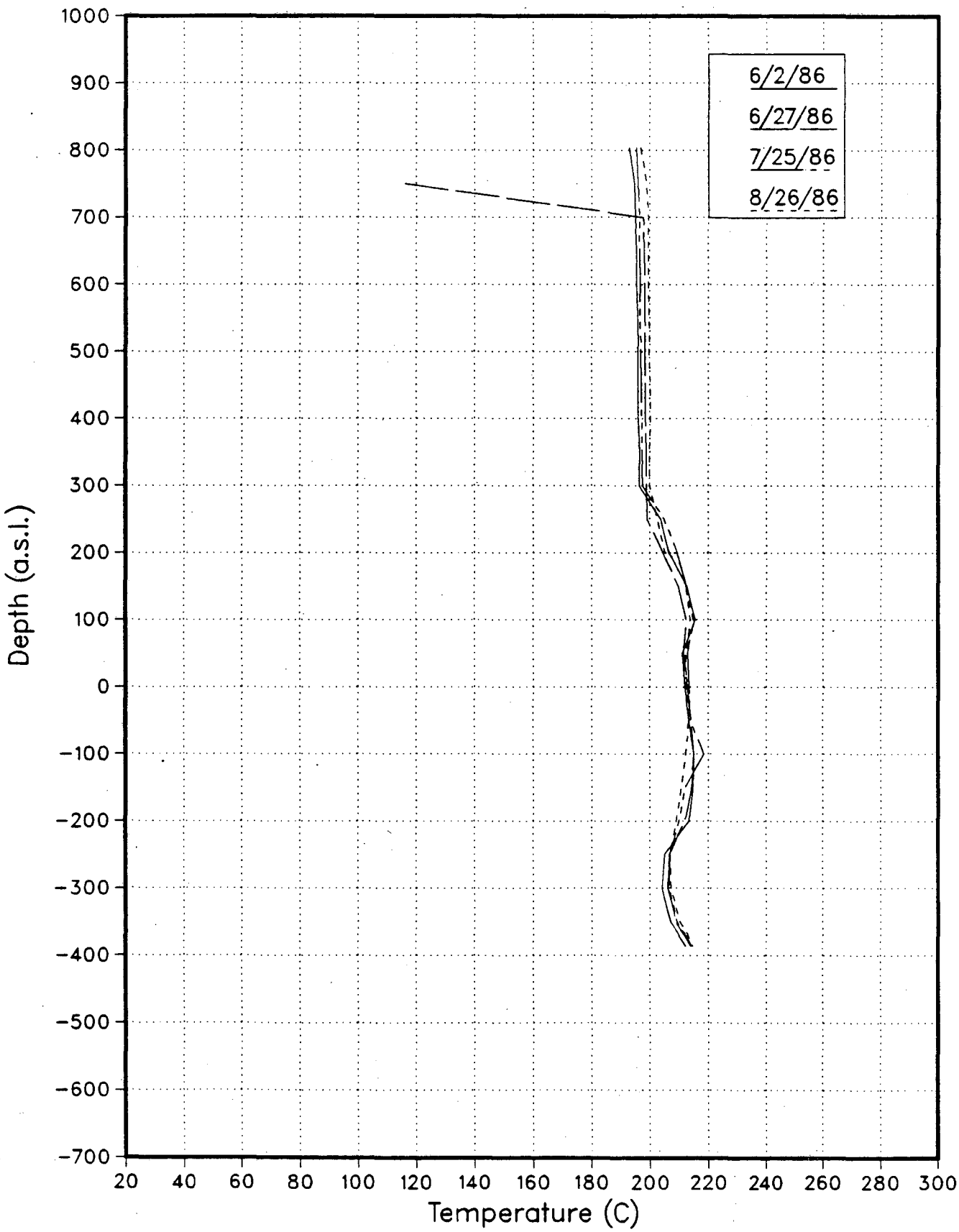

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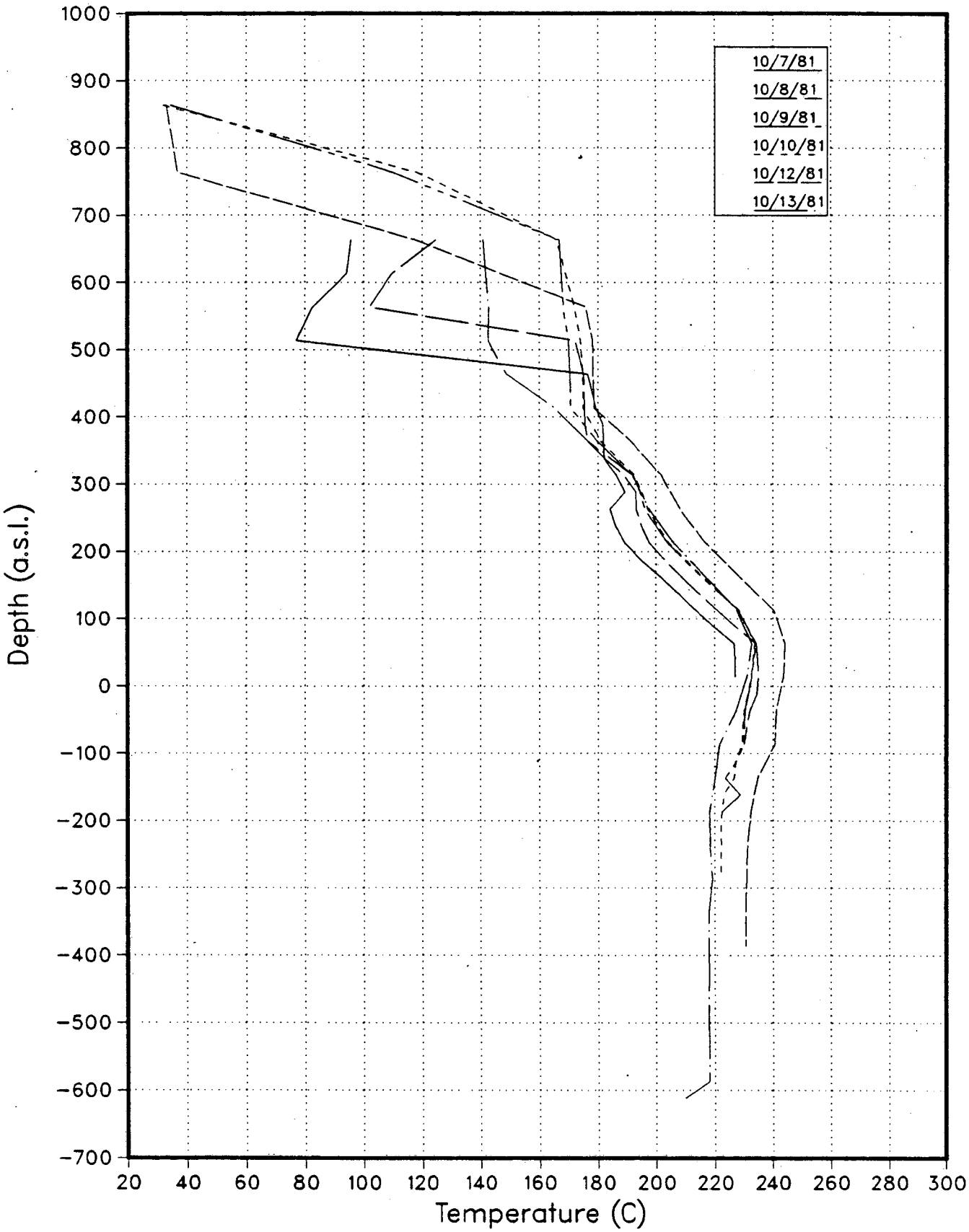

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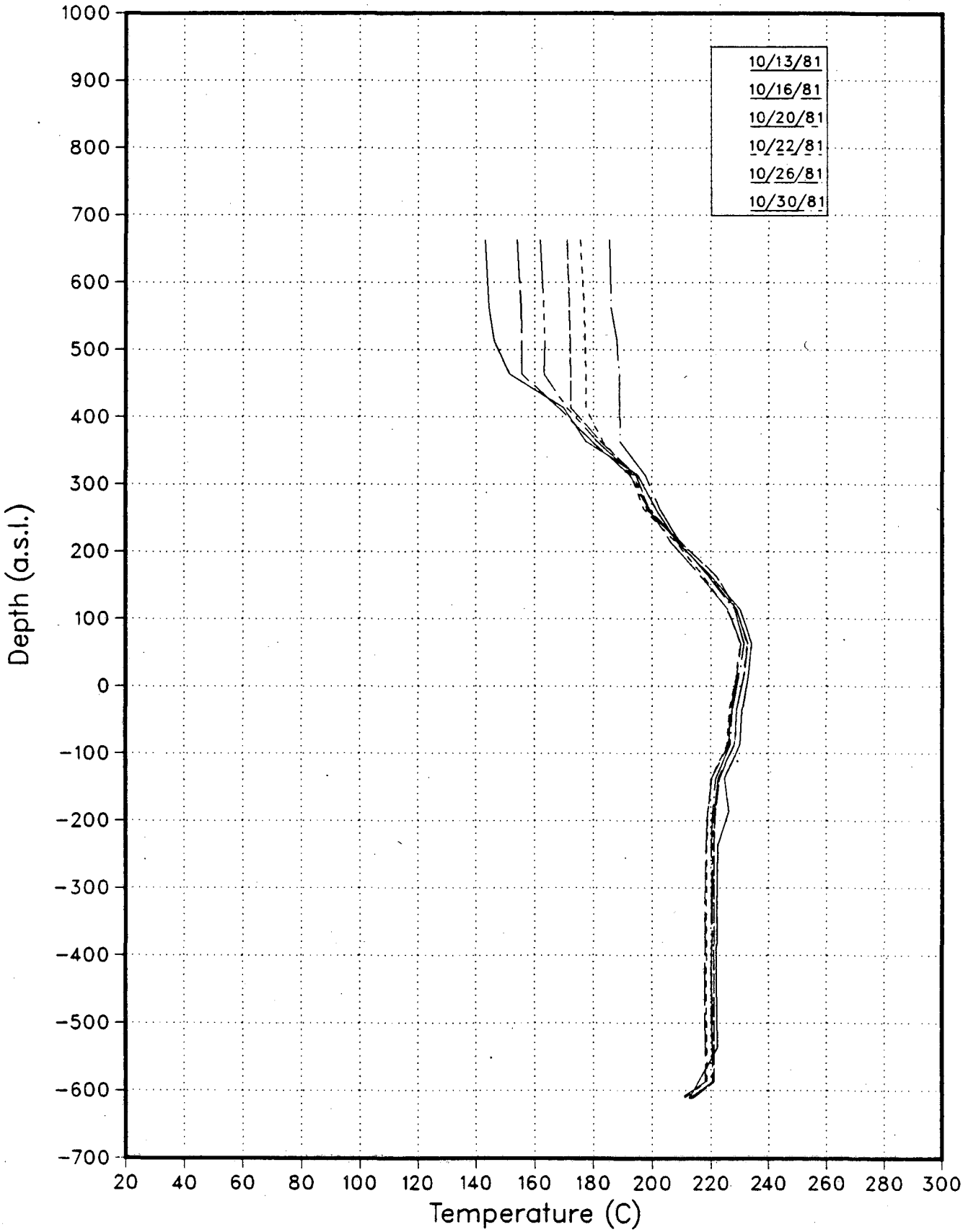

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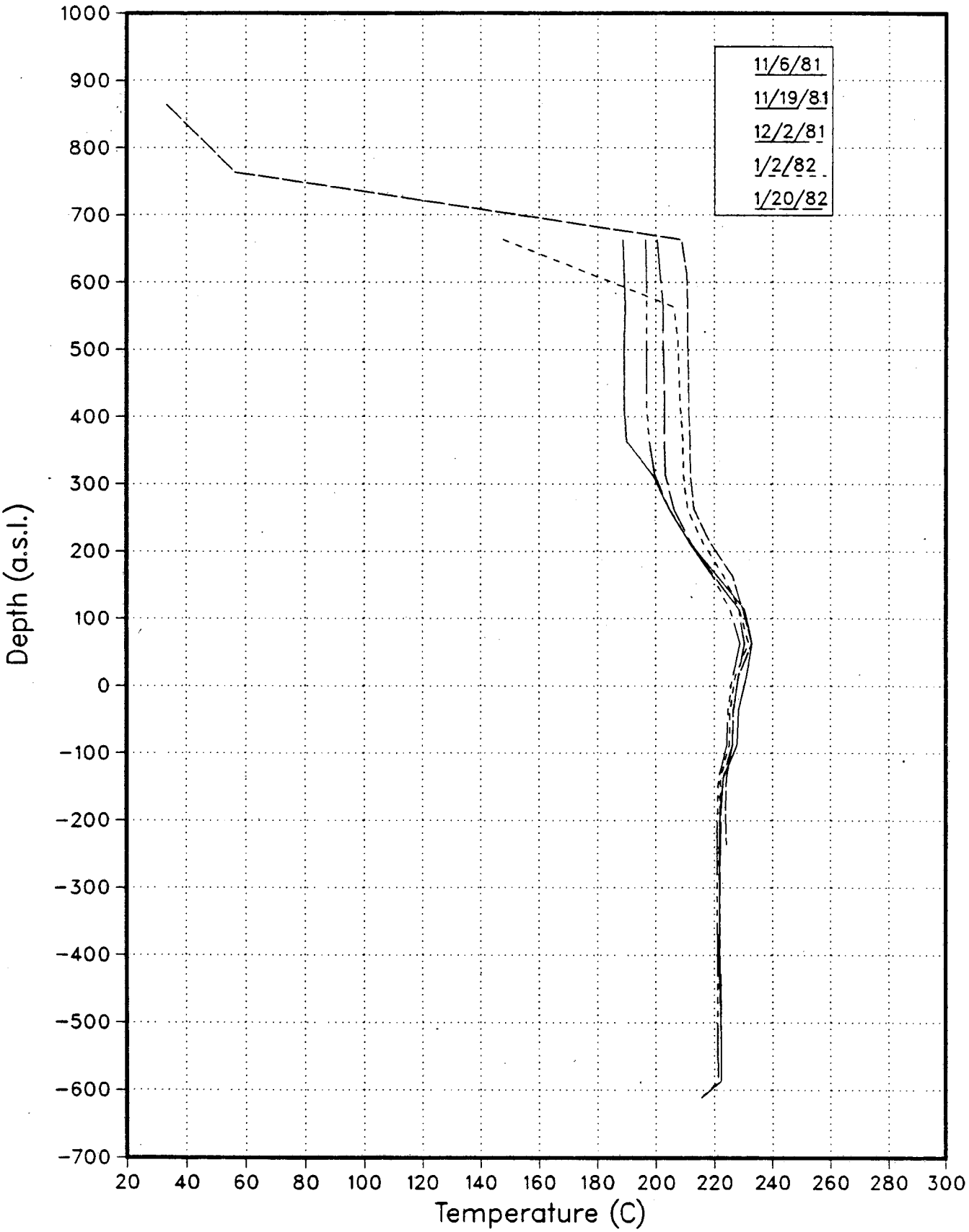

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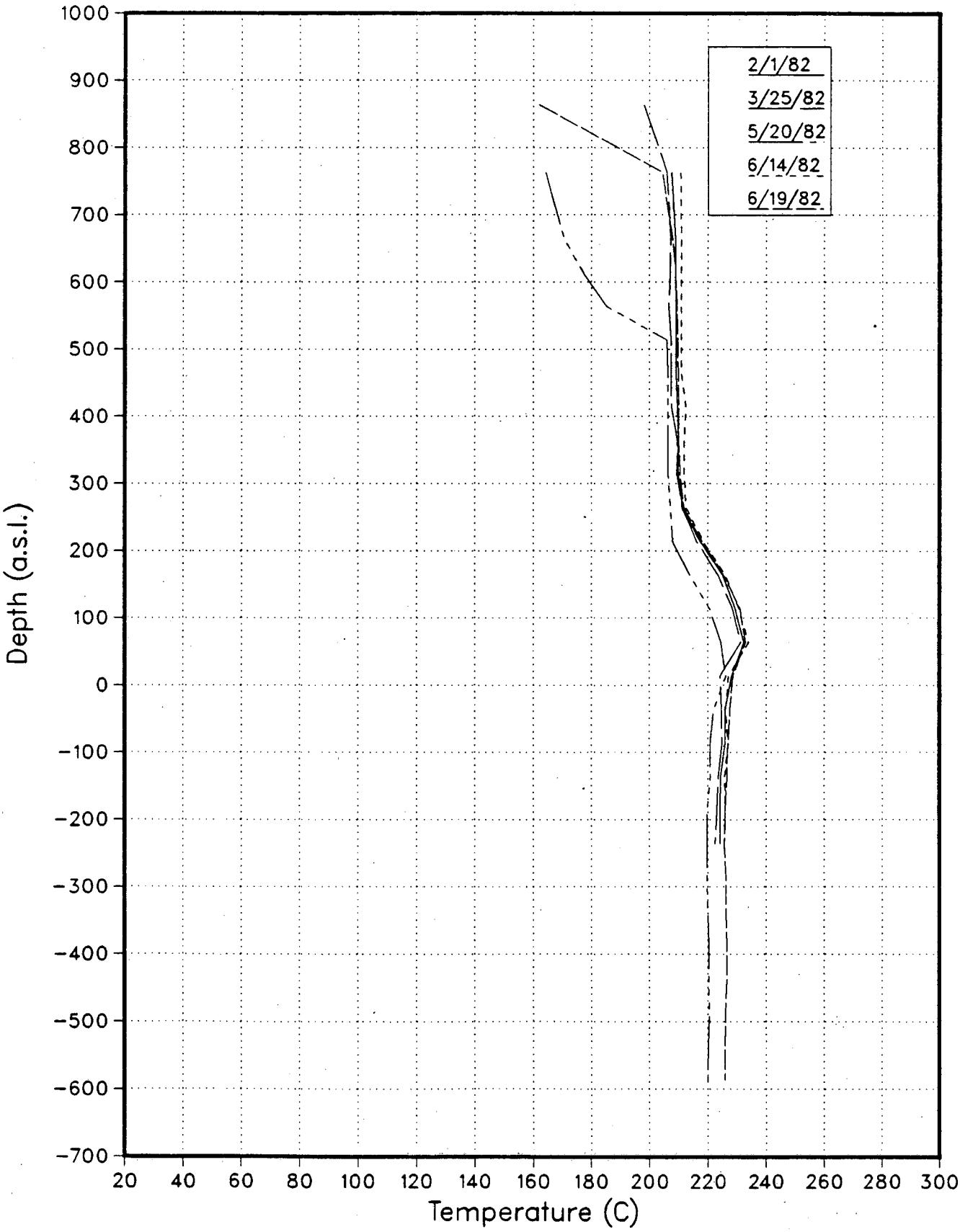

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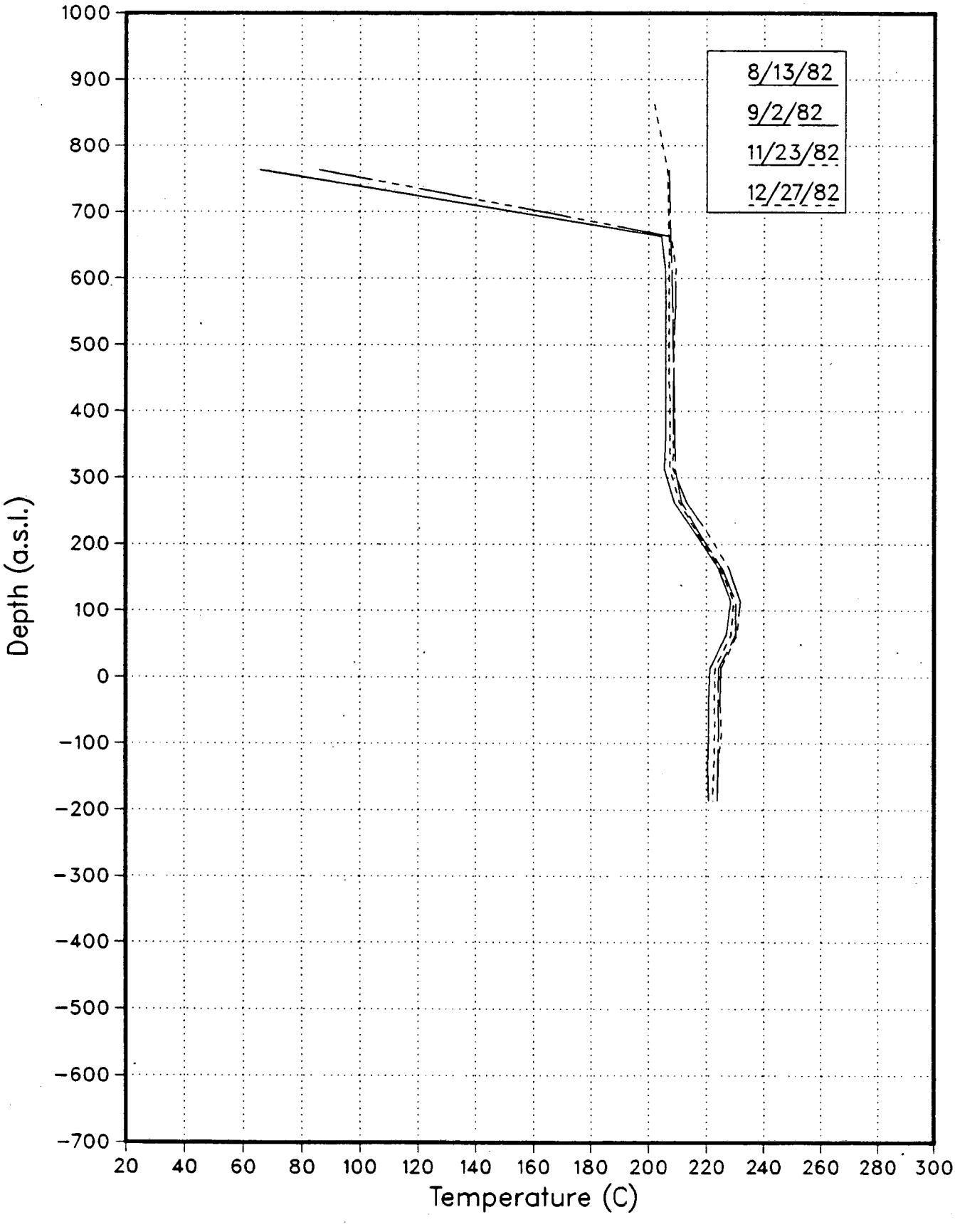

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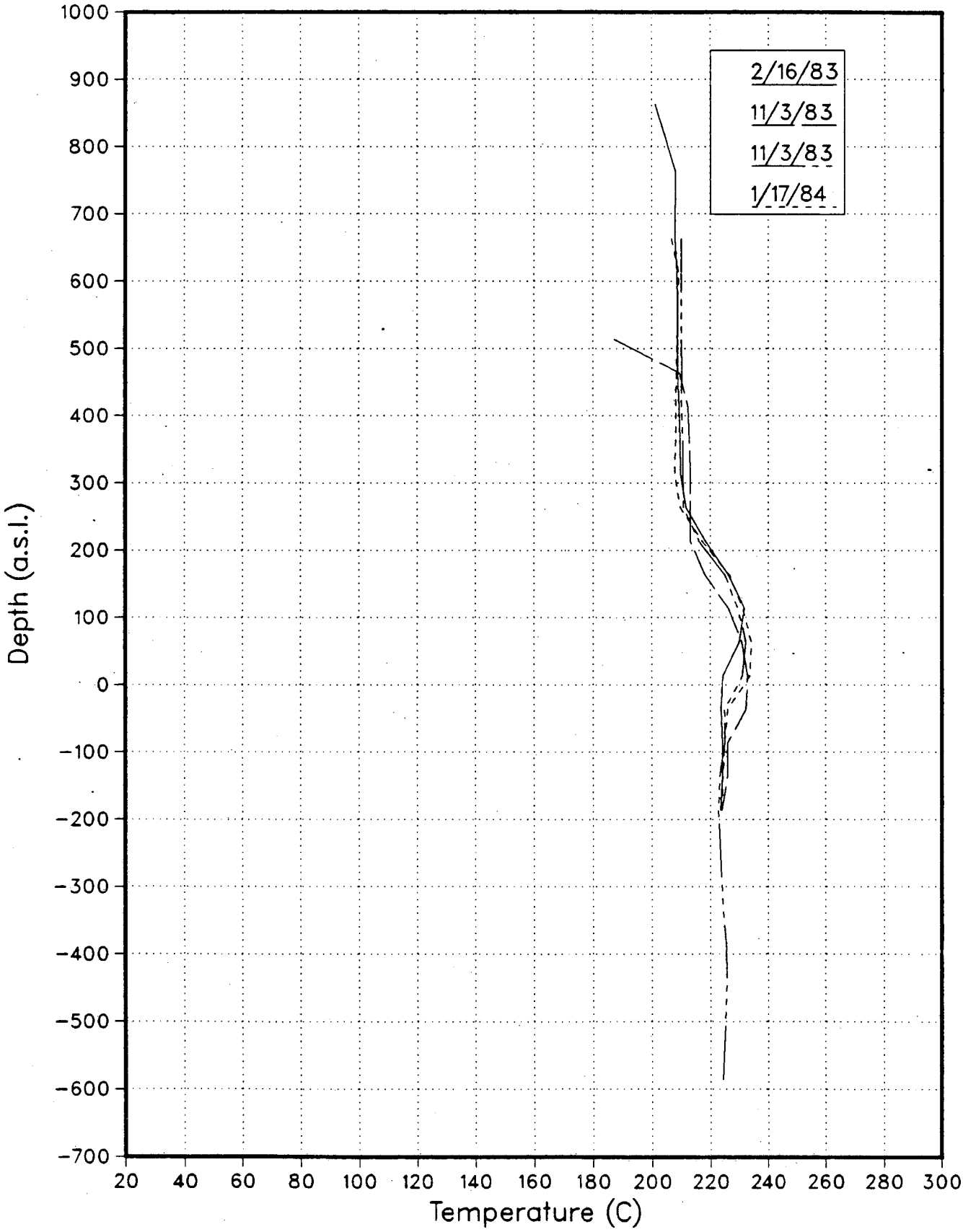

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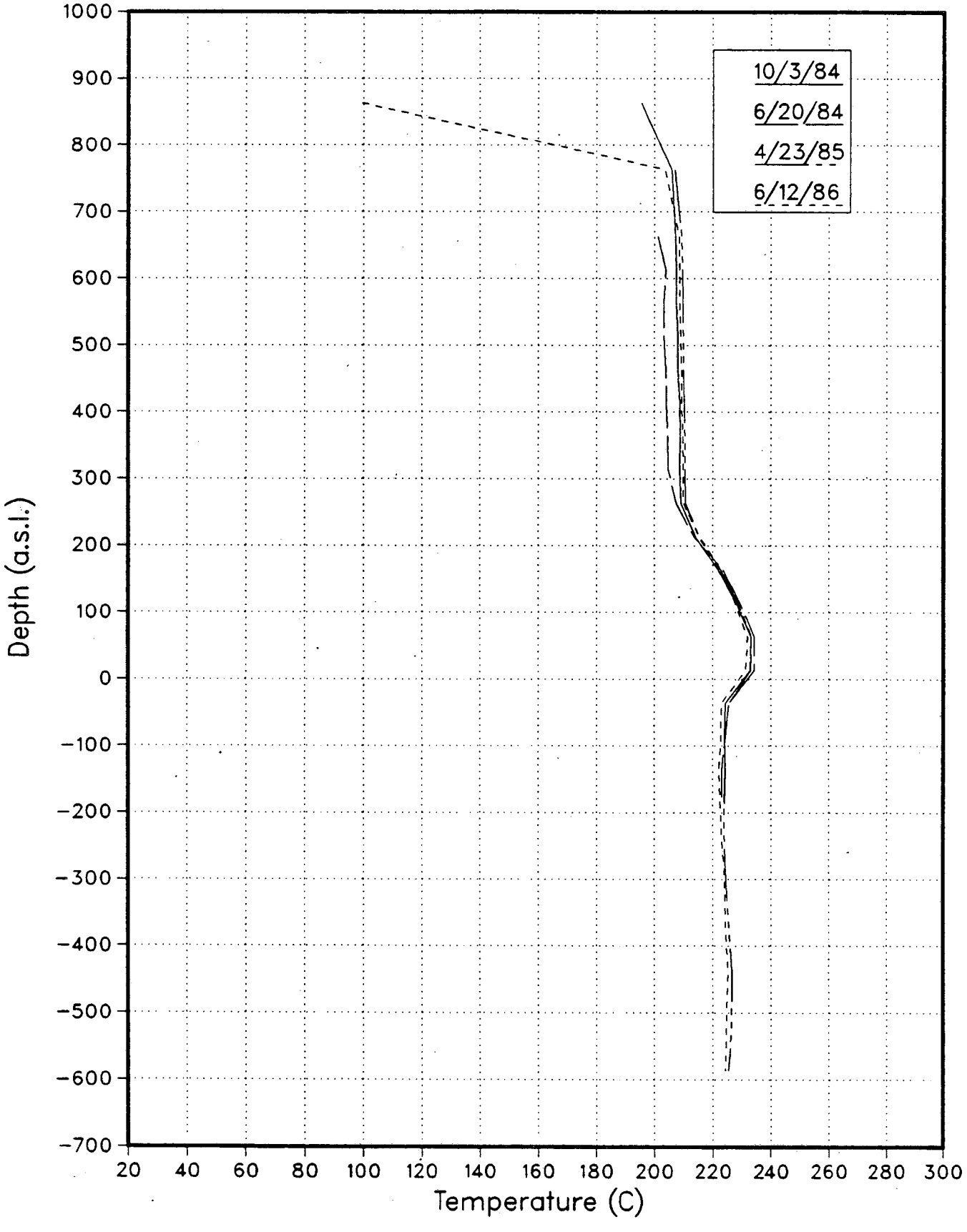
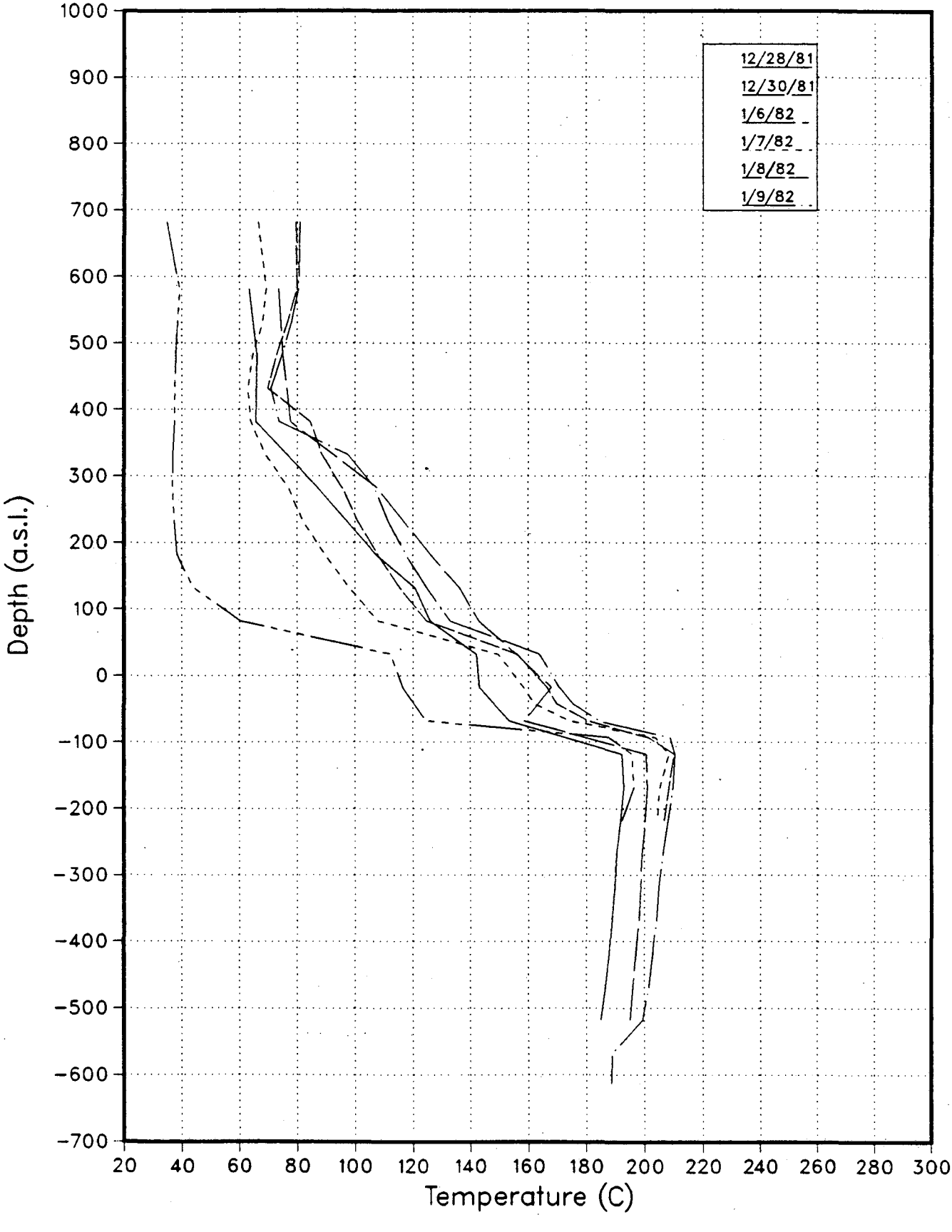


AH32 Temperature Surveys



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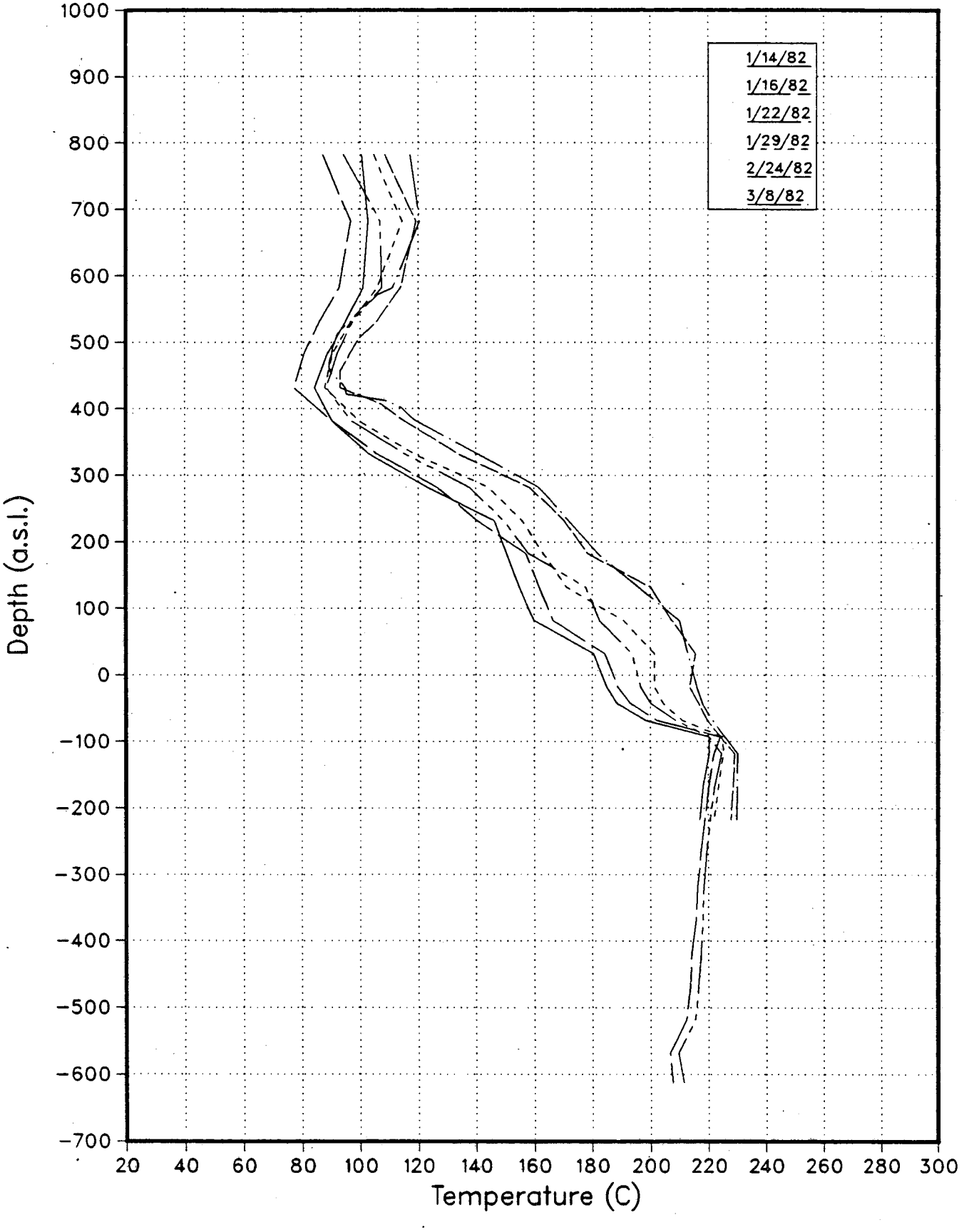

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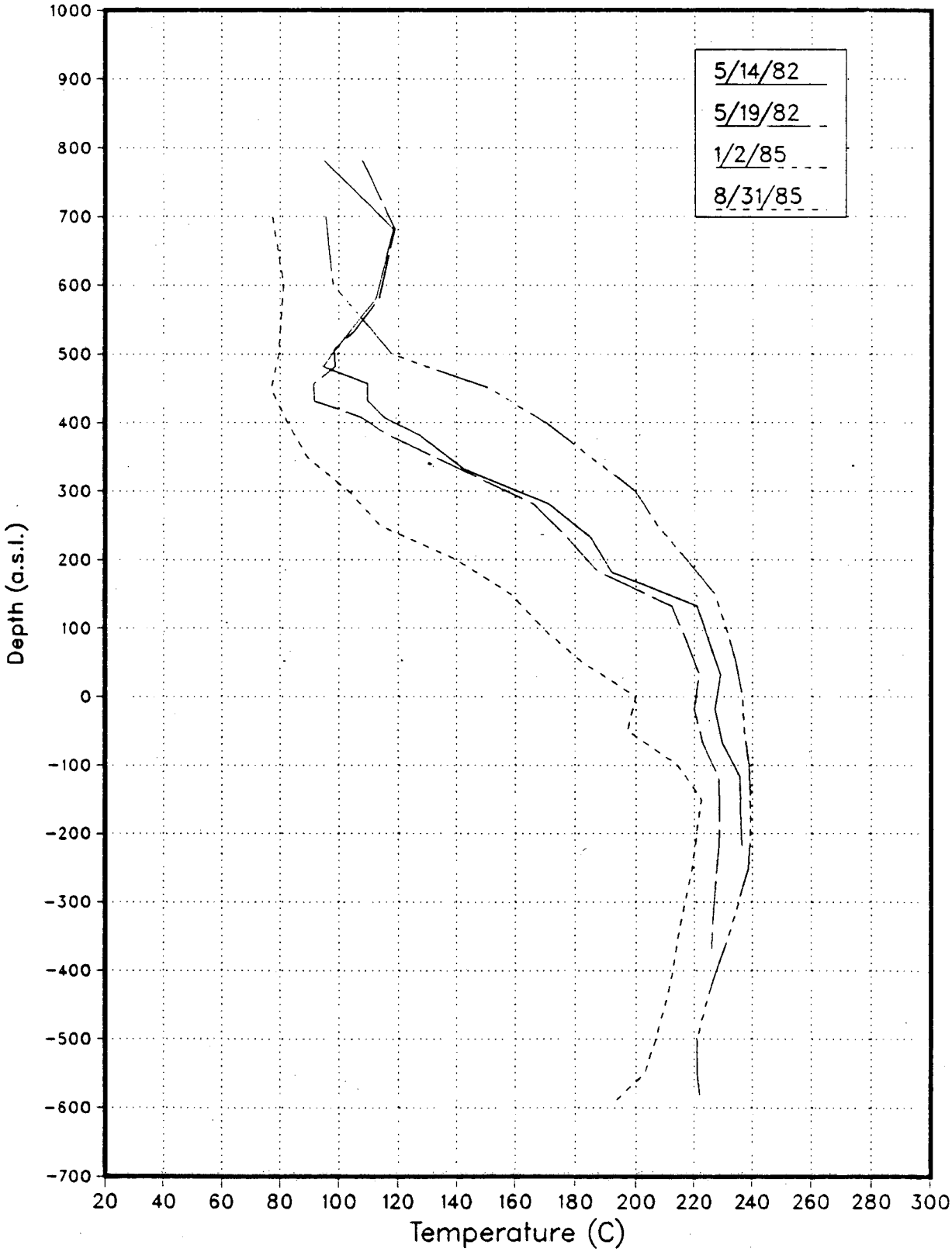

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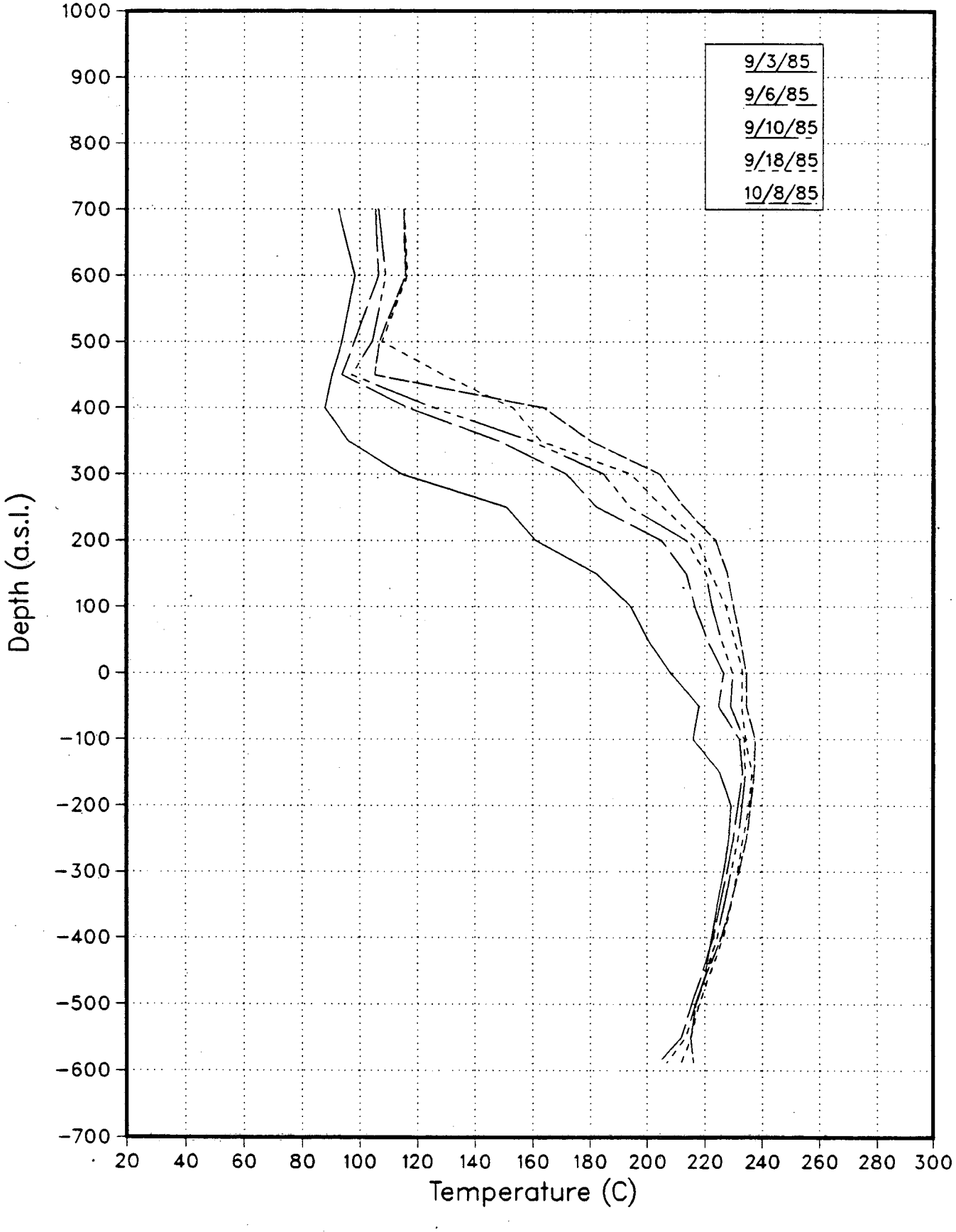

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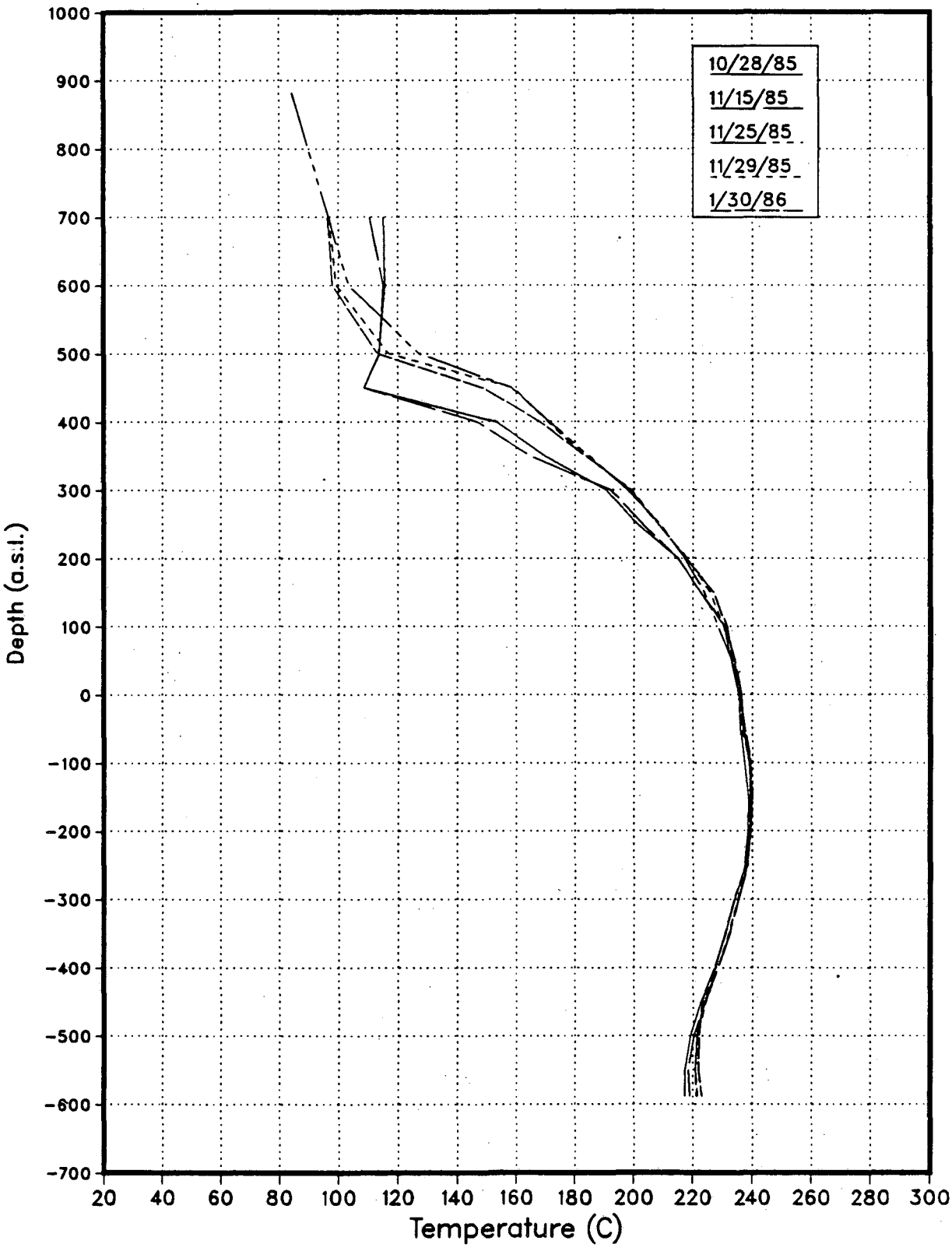

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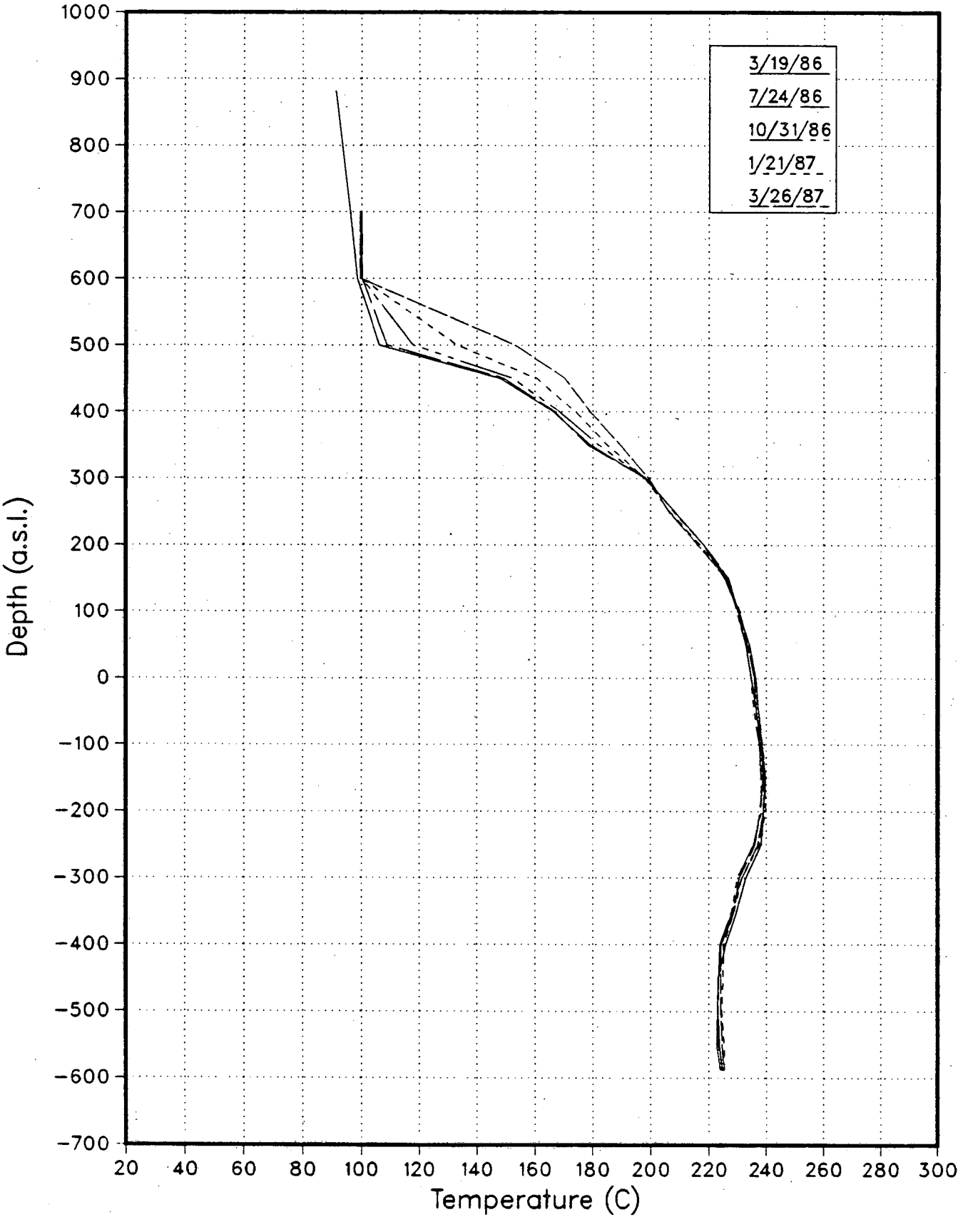
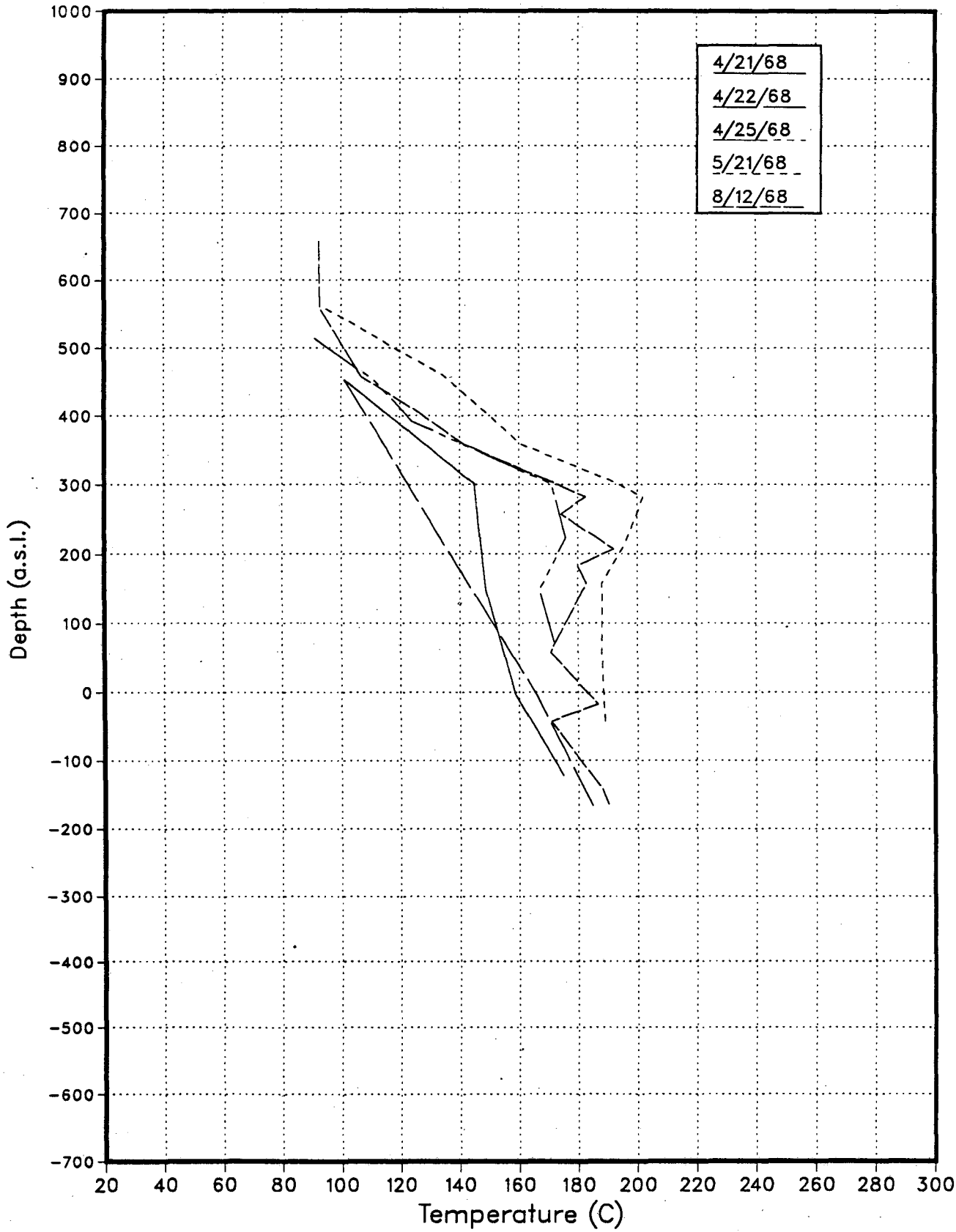
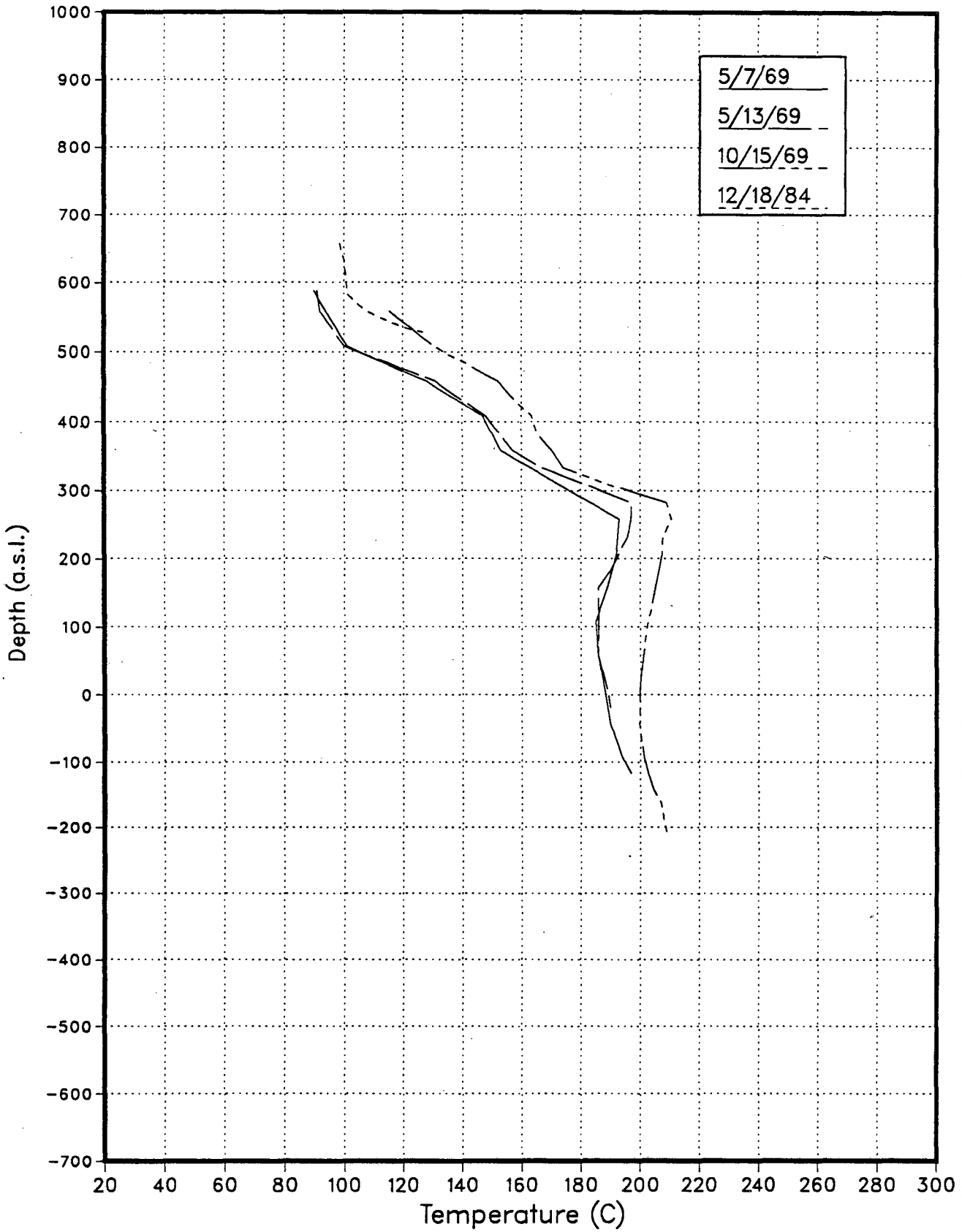


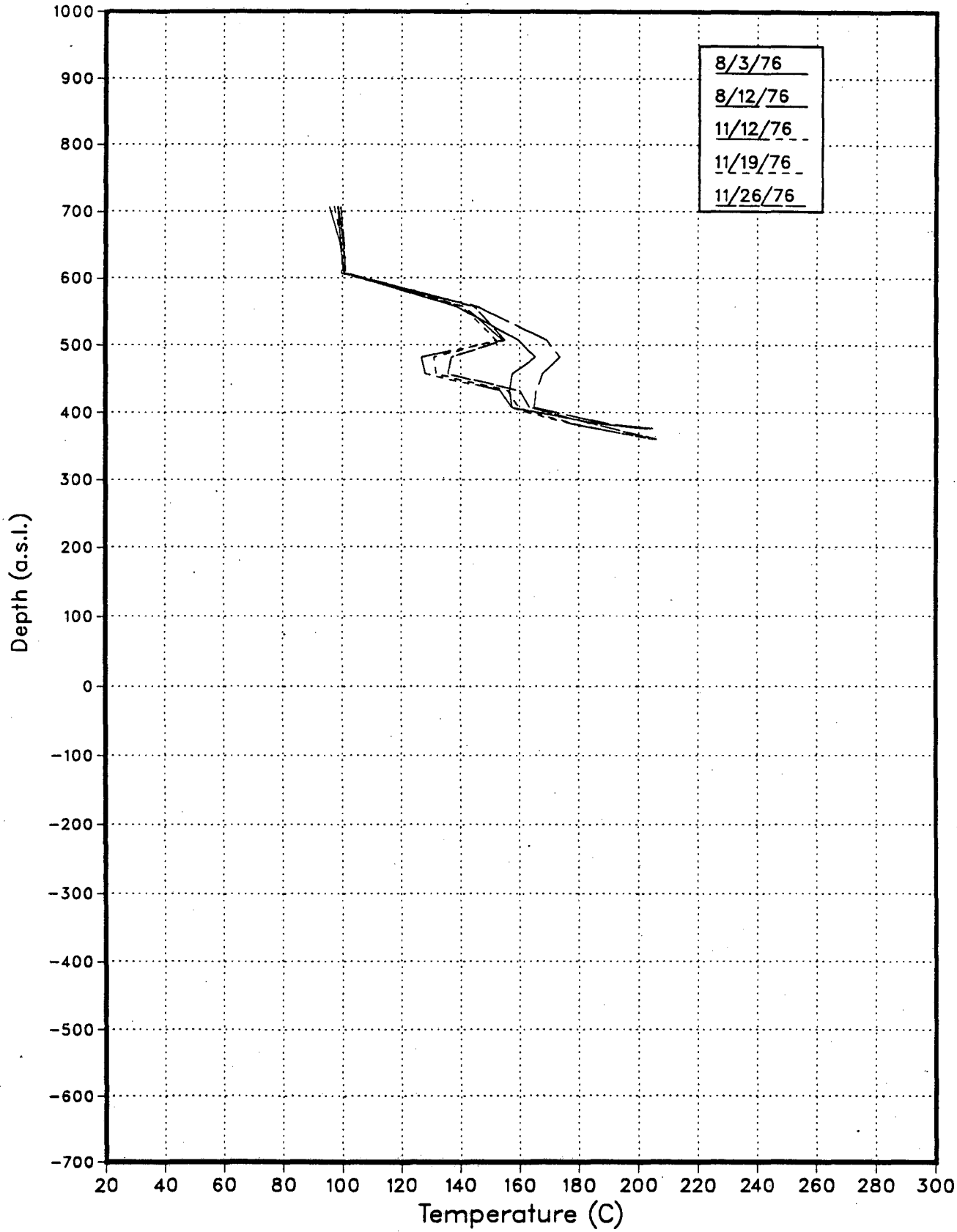
CH 1 Temperature Surveys



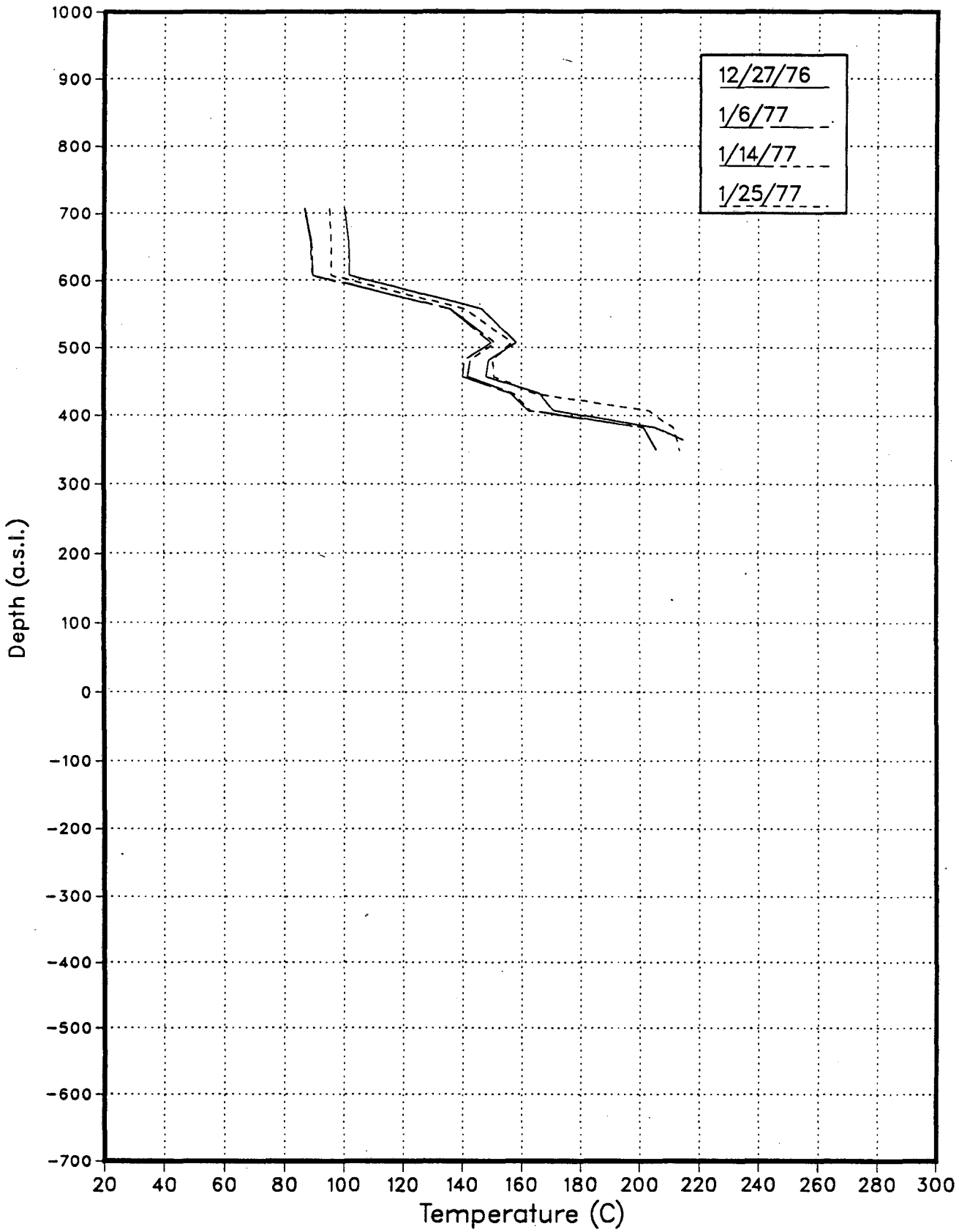
CH 1 Temperature Surveys



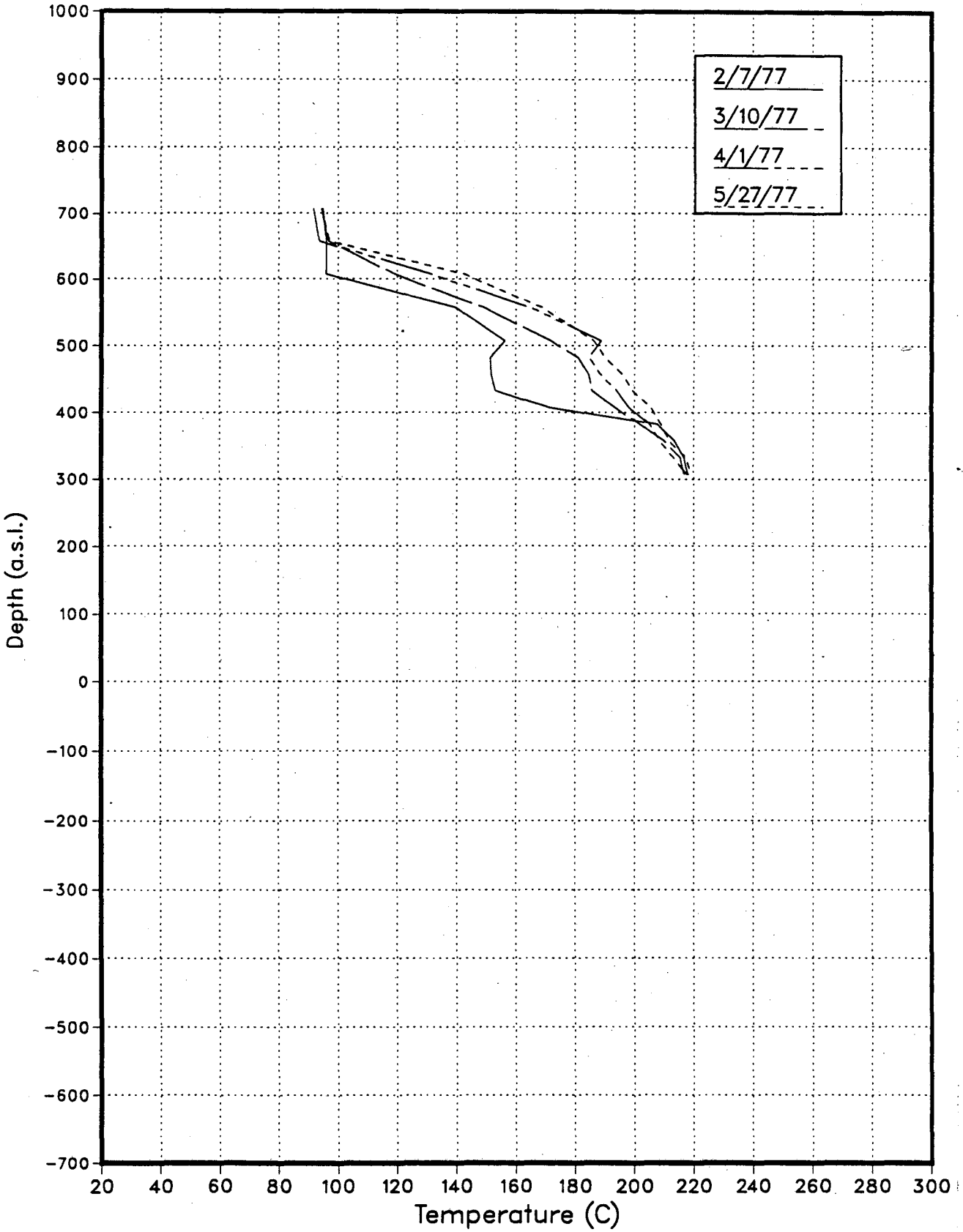
CHE 1 Temperature Surveys



CHE 1 Temperature Surveys



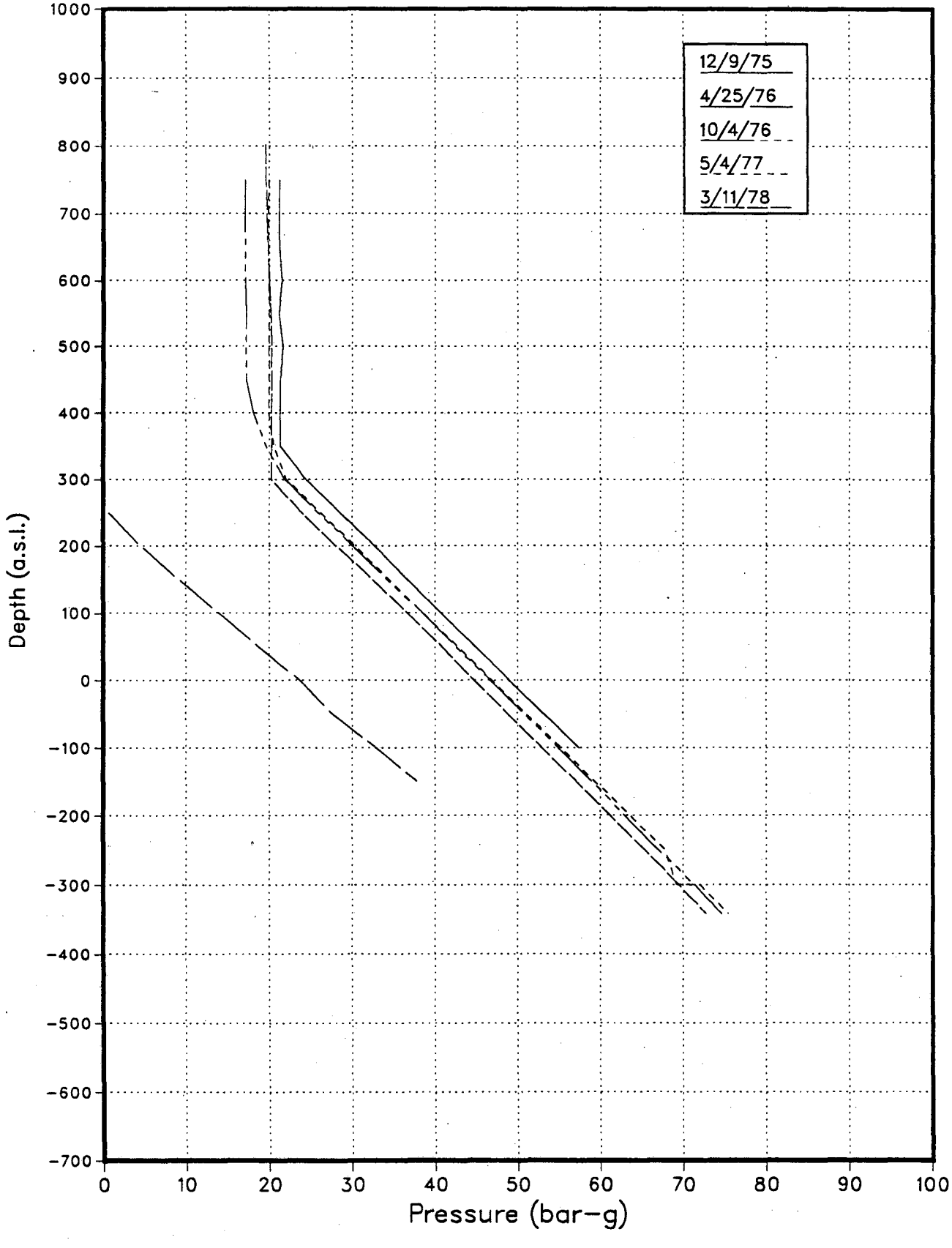
CHE 1 Temperature Surveys



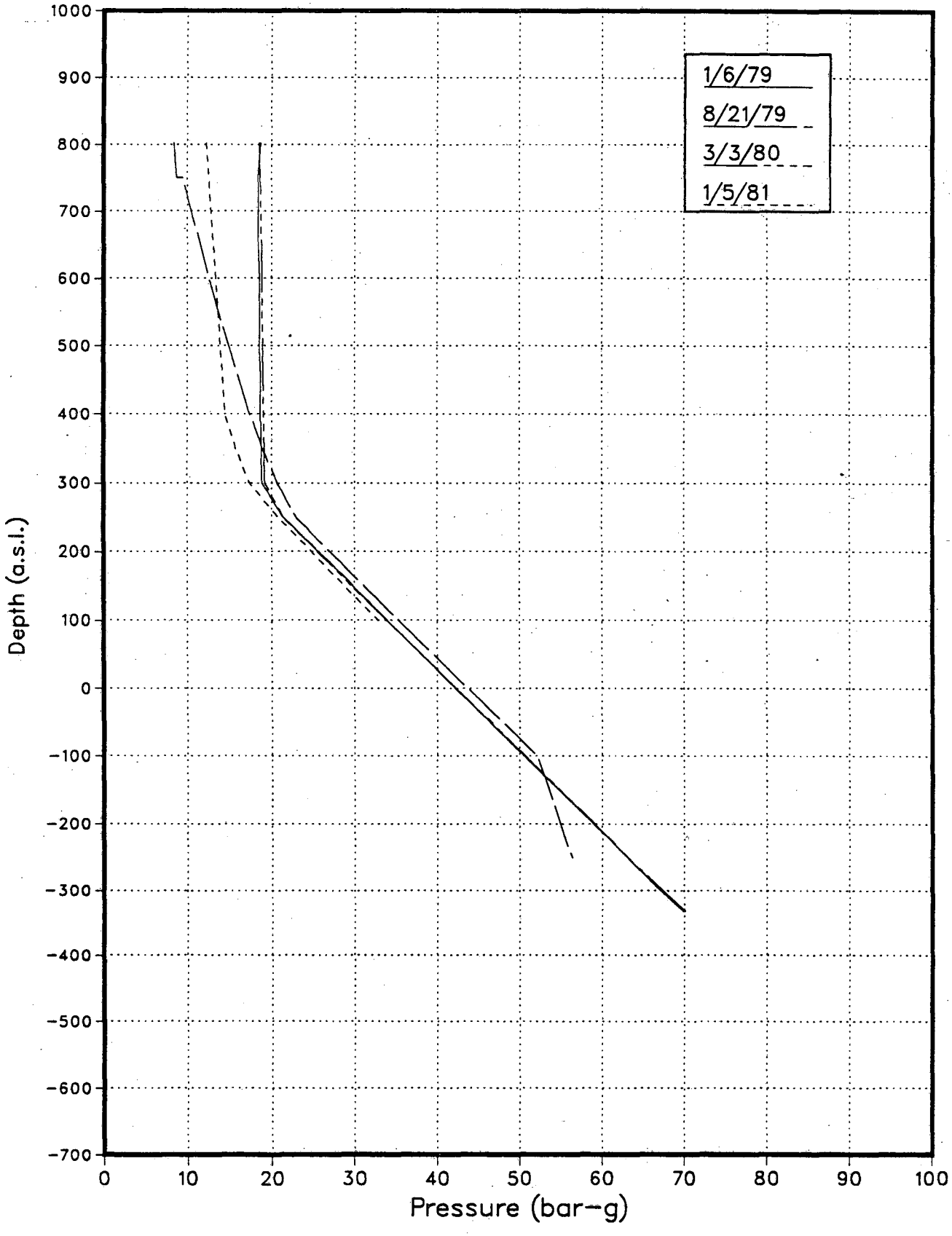
APPENDIX E

(Pressure Logs)

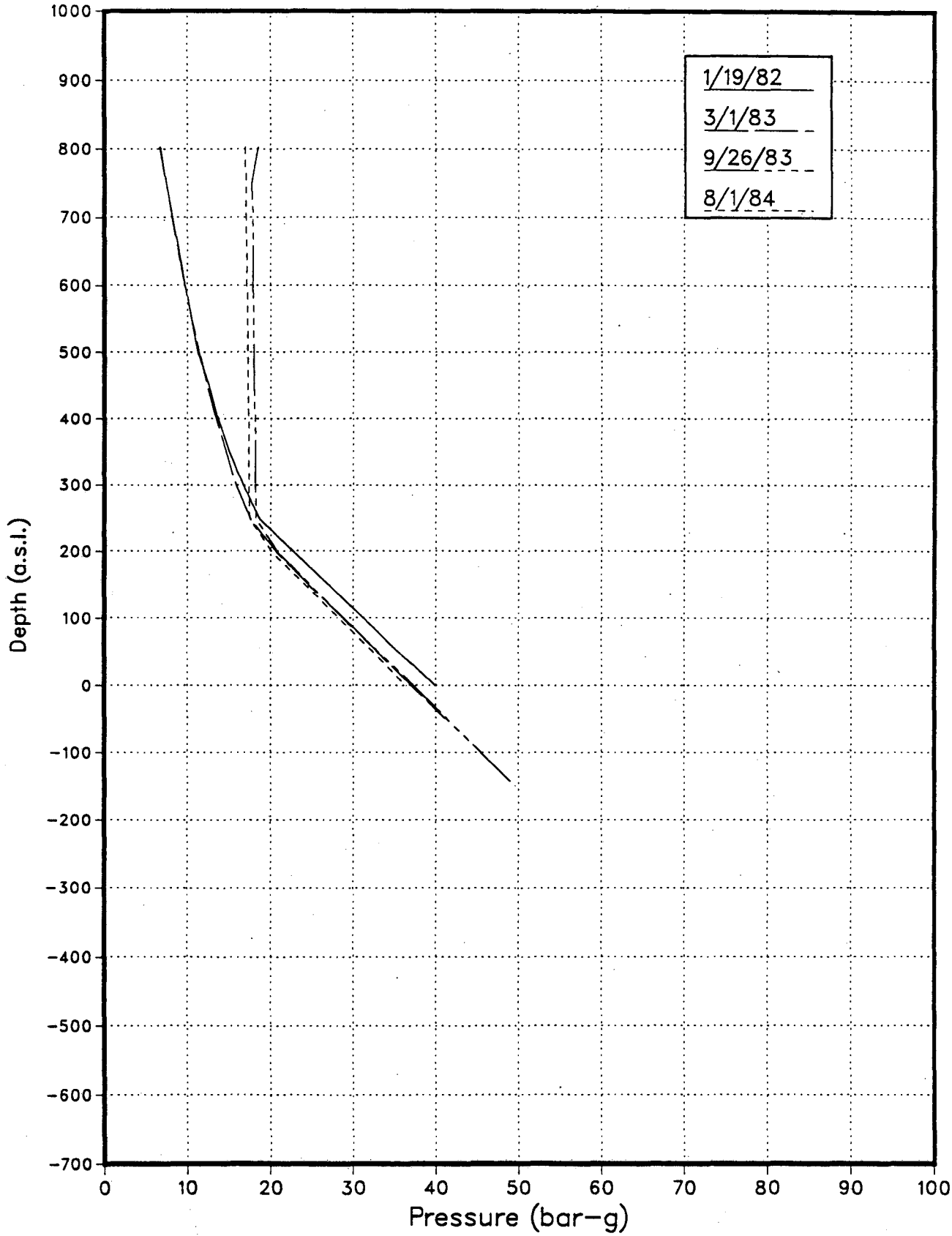
AH1 Pressure Surveys



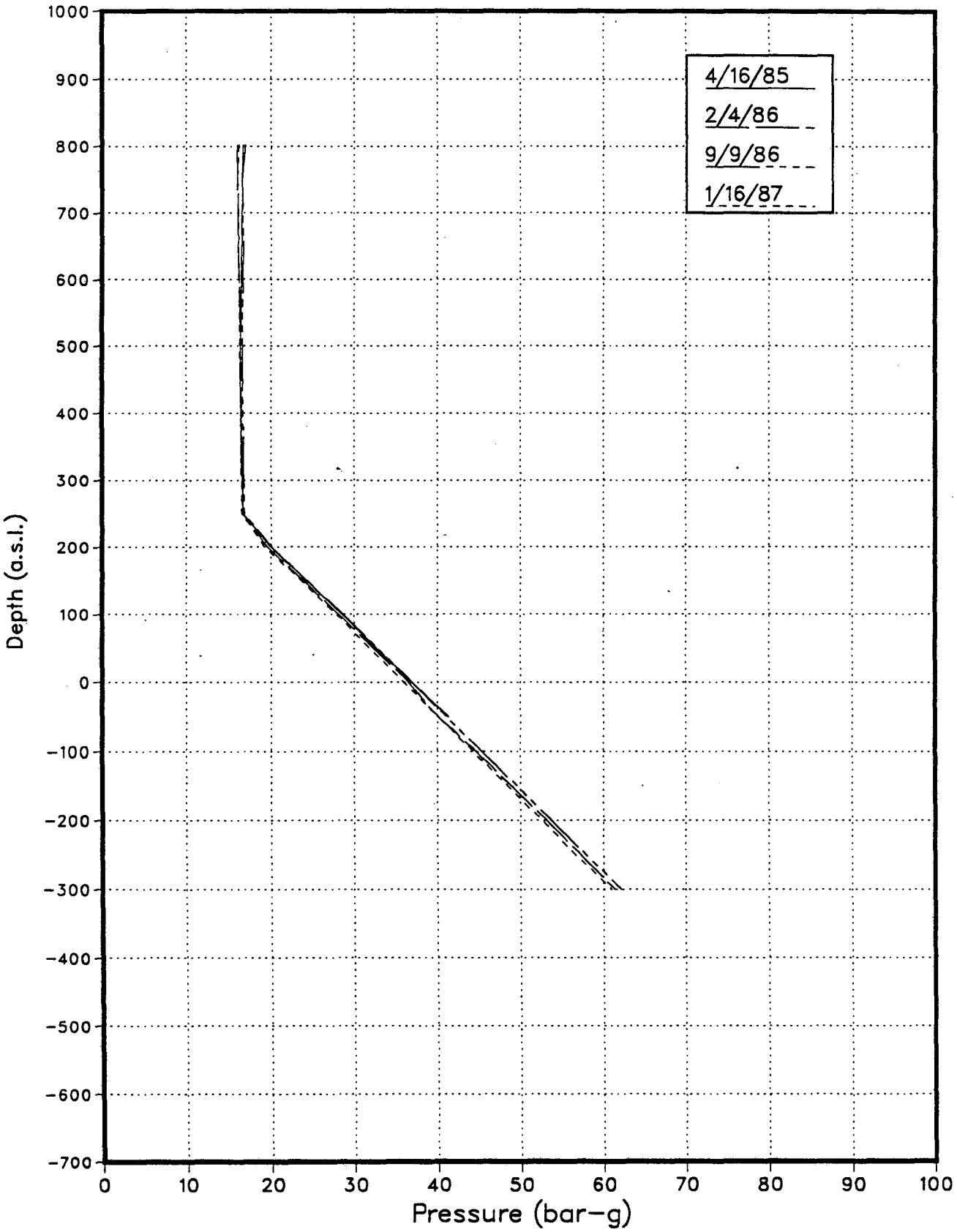
AH1 Pressure Surveys



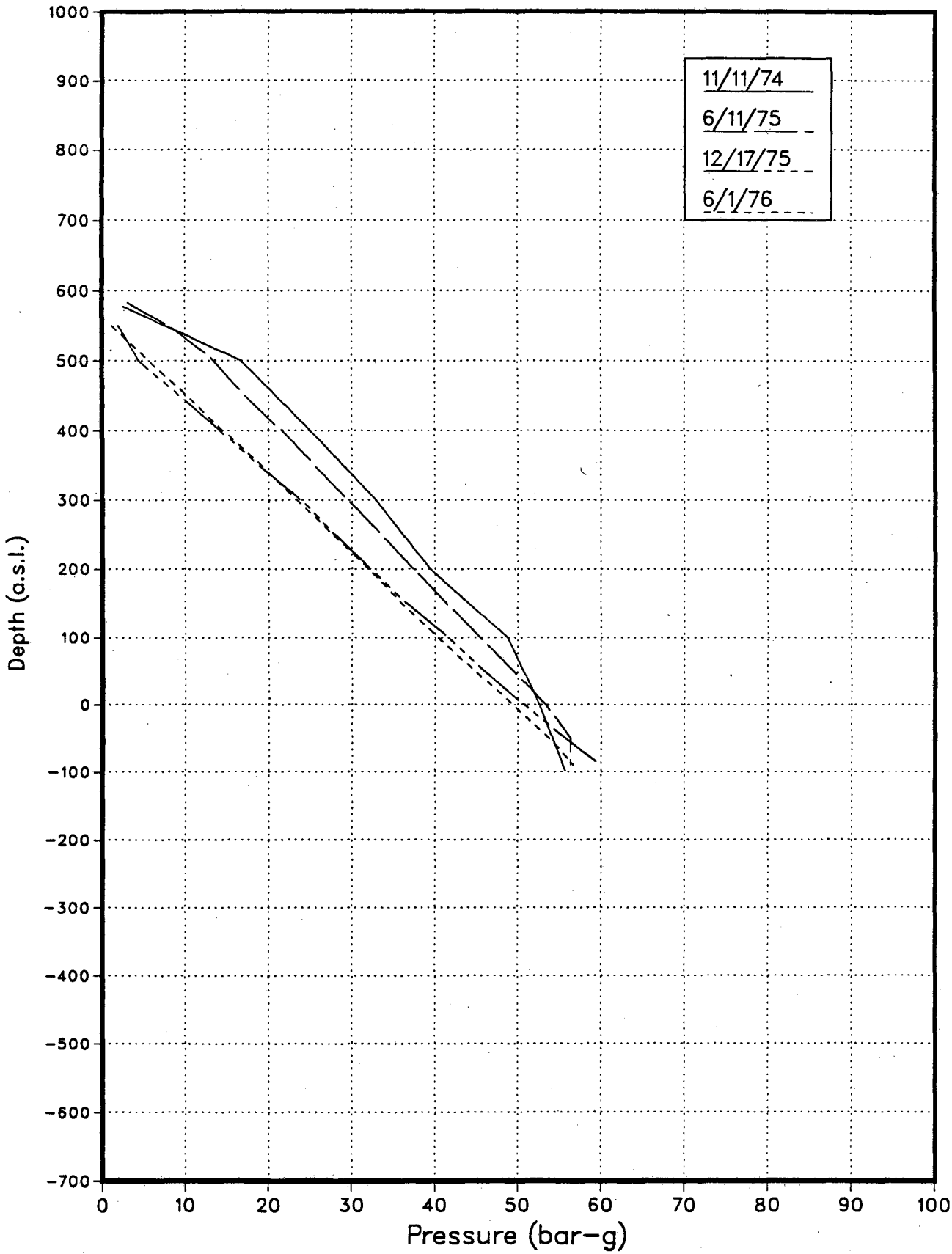
AH1 Pressure Surveys



AH1 Pressure Surveys



AH2 Pressure Surveys



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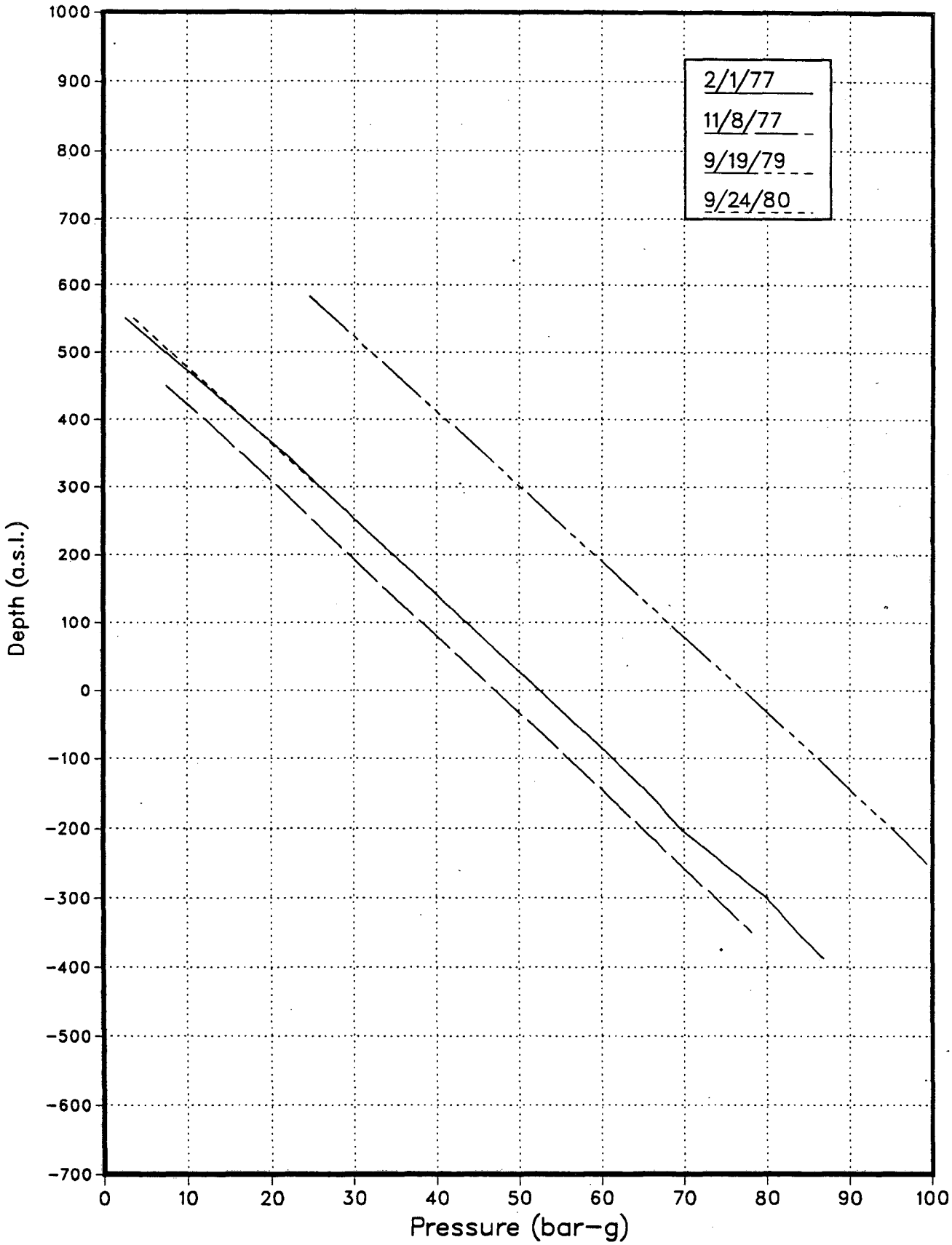

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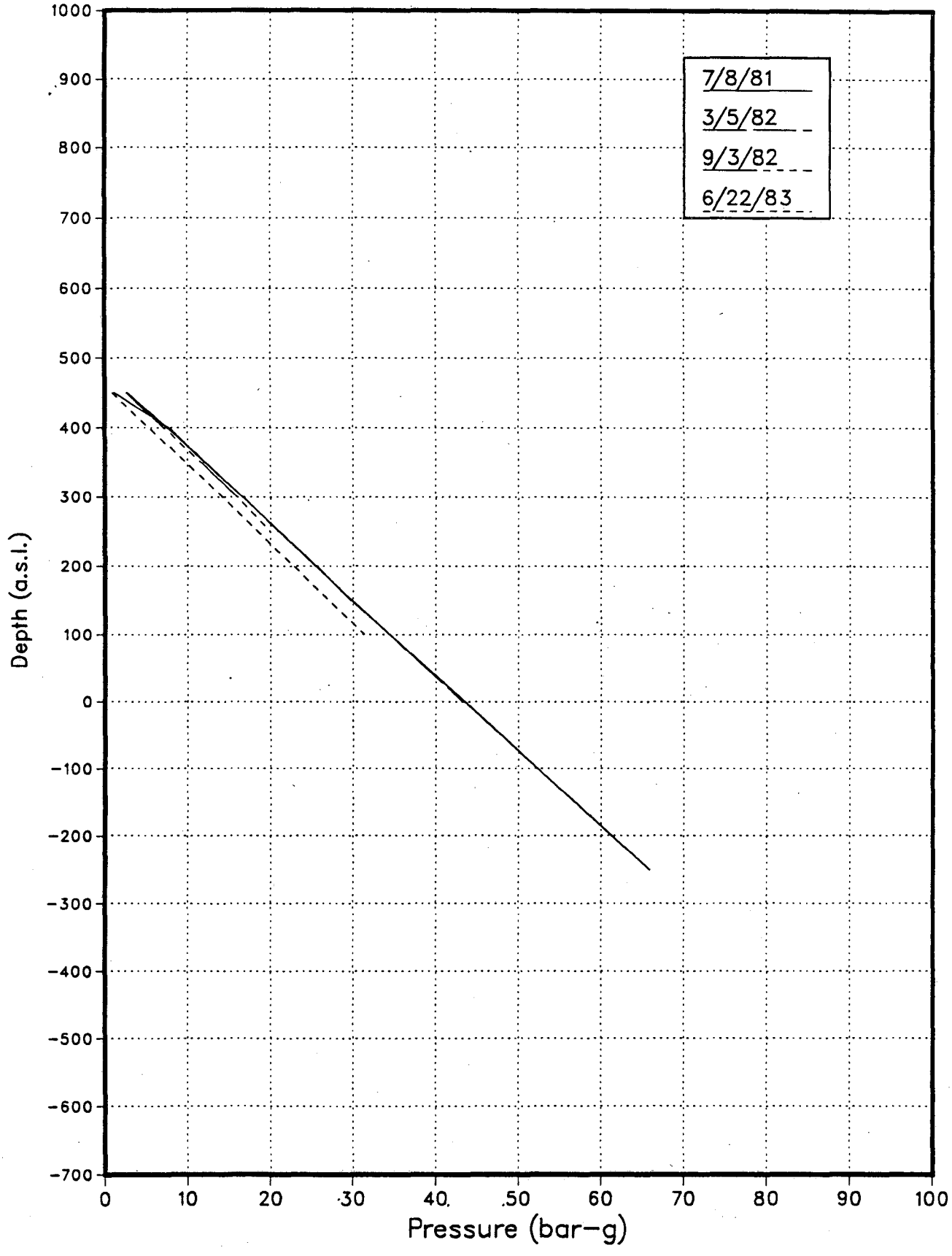

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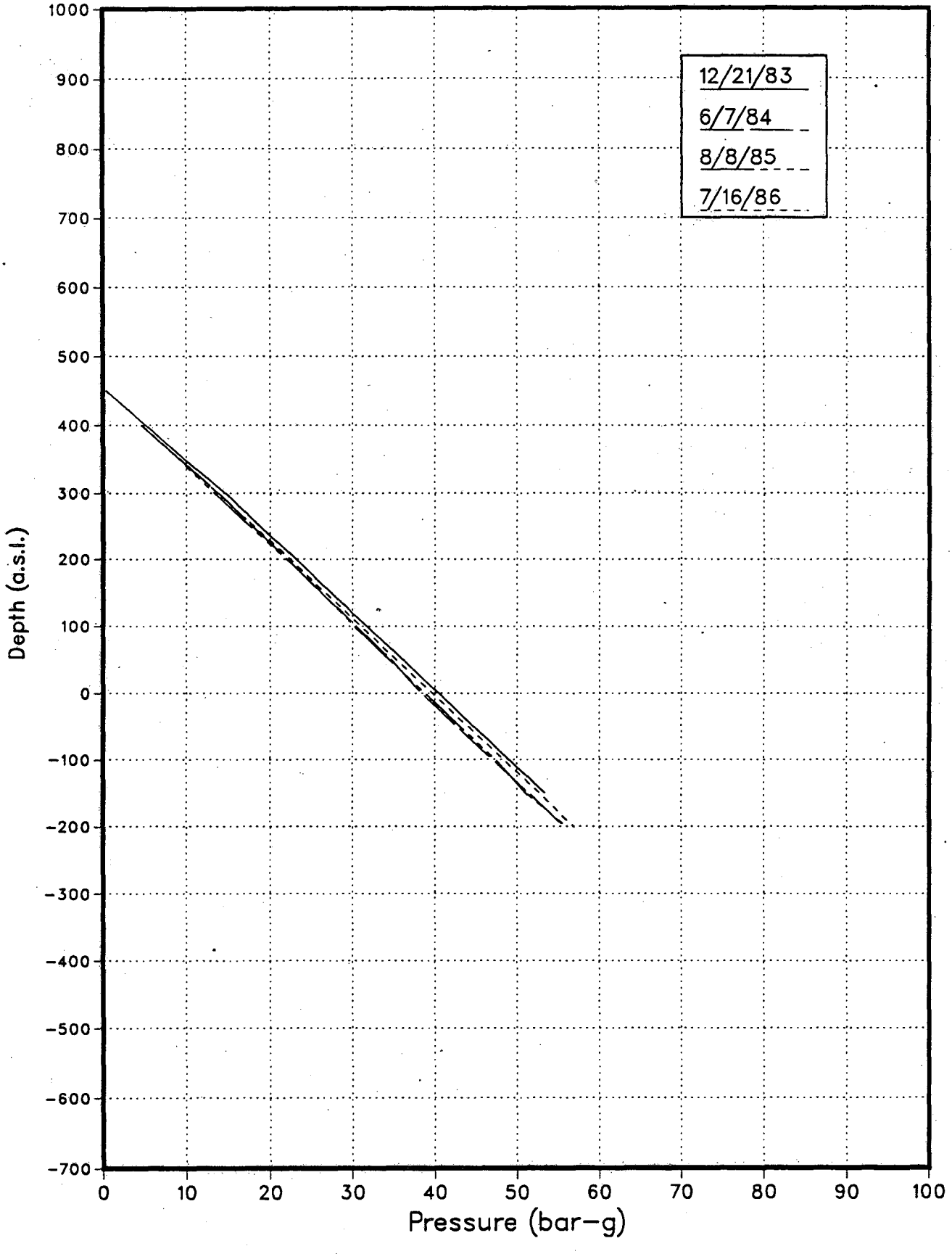
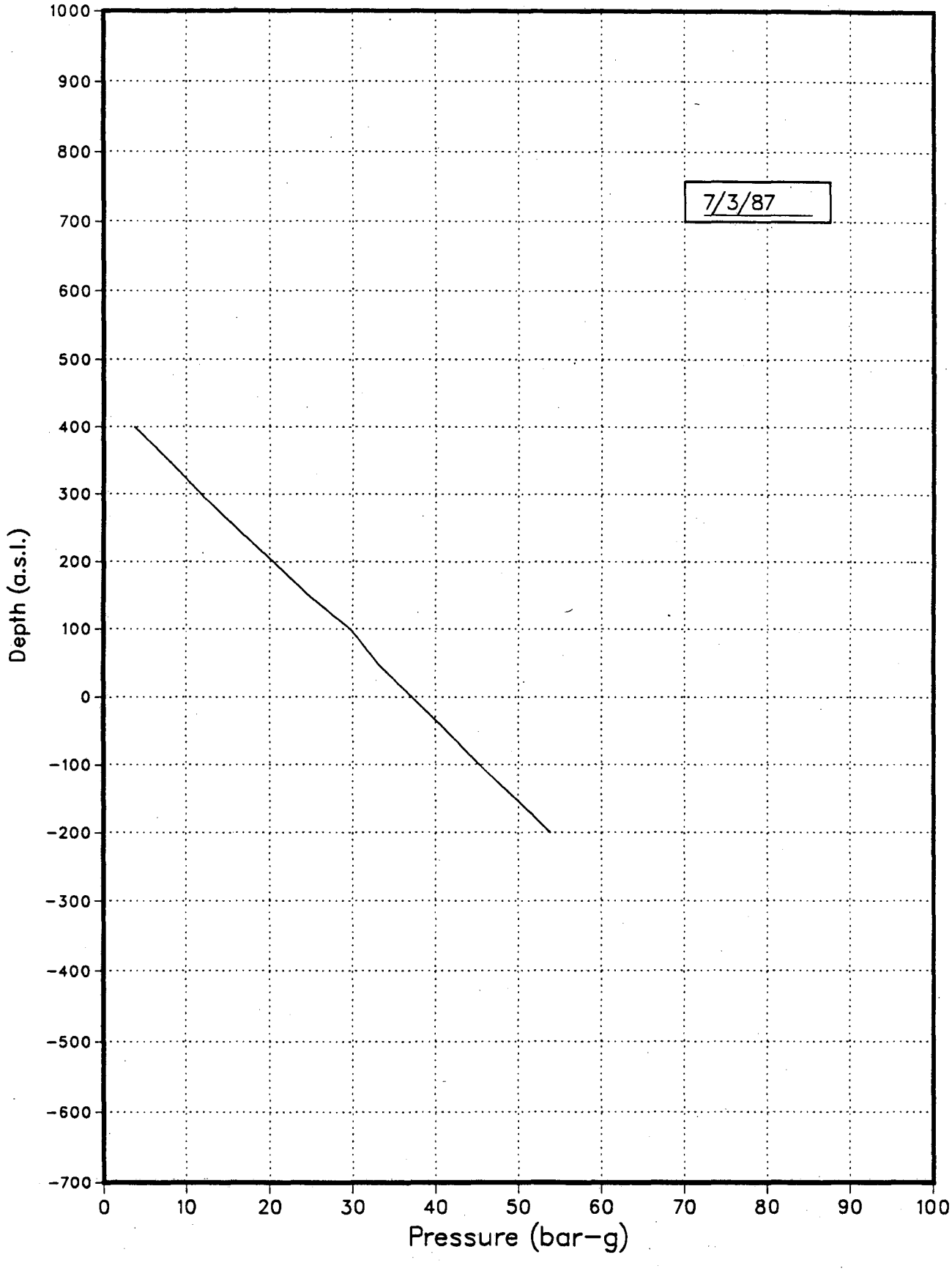
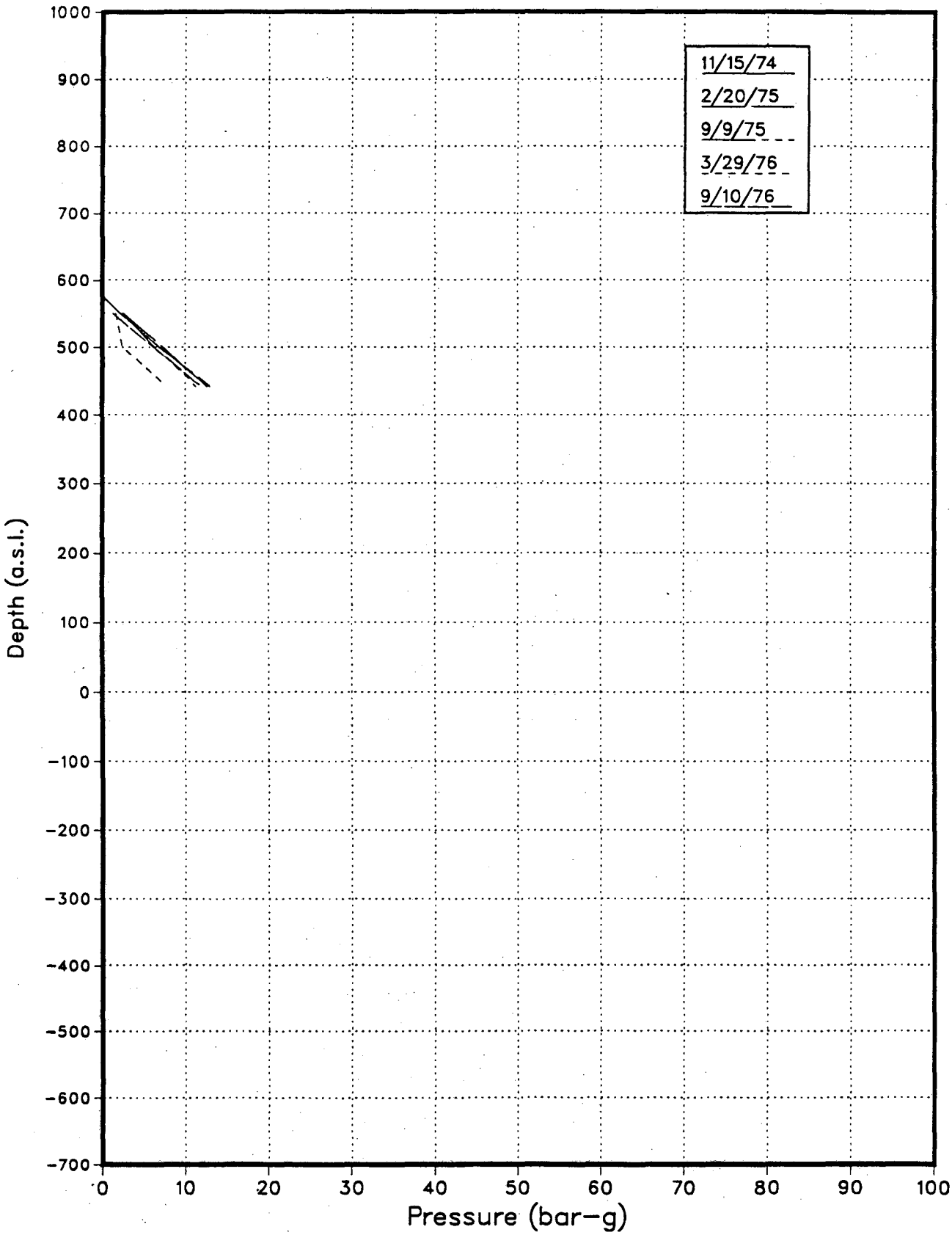


AH2 Pressure Surveys



AH3 Pressure Surveys



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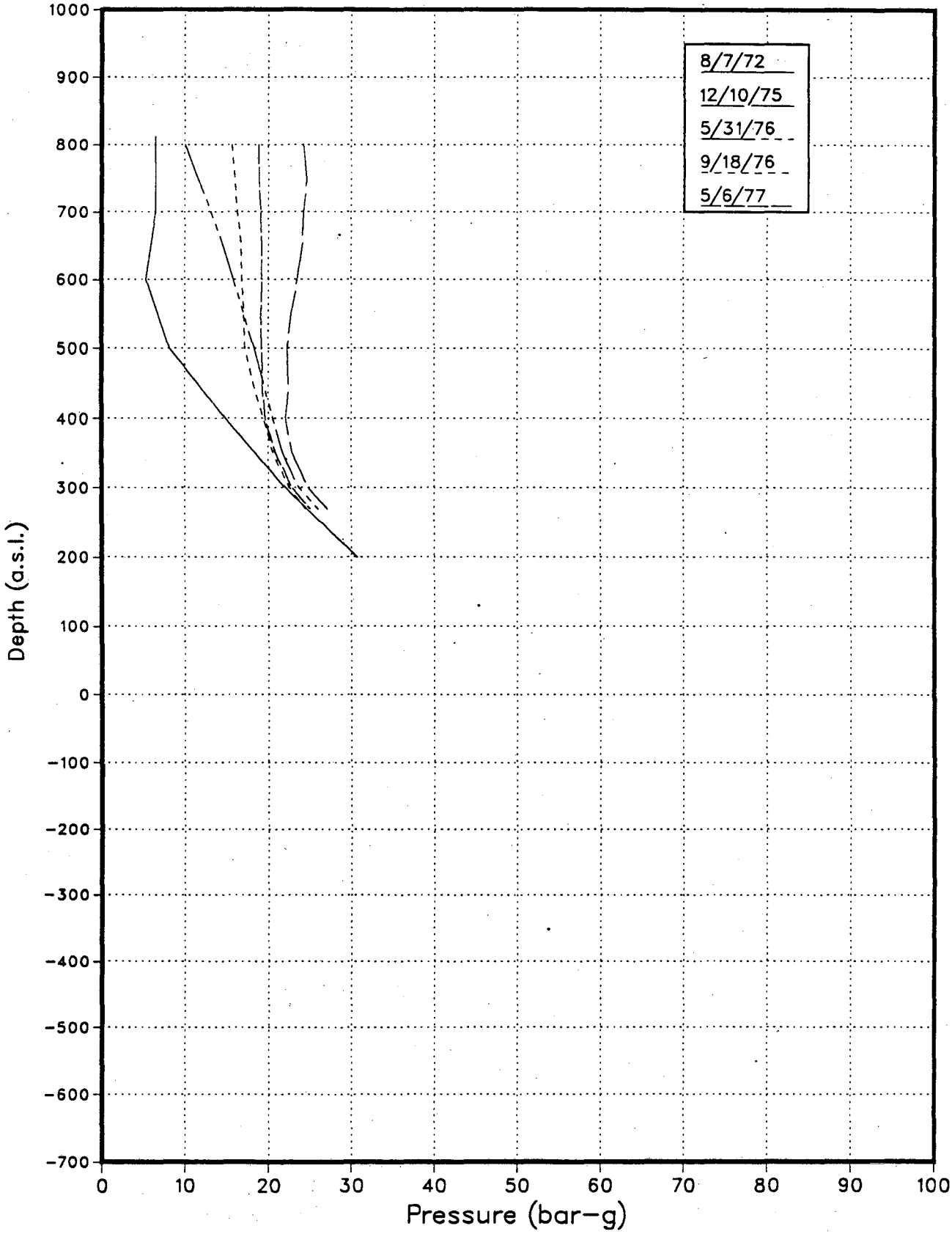

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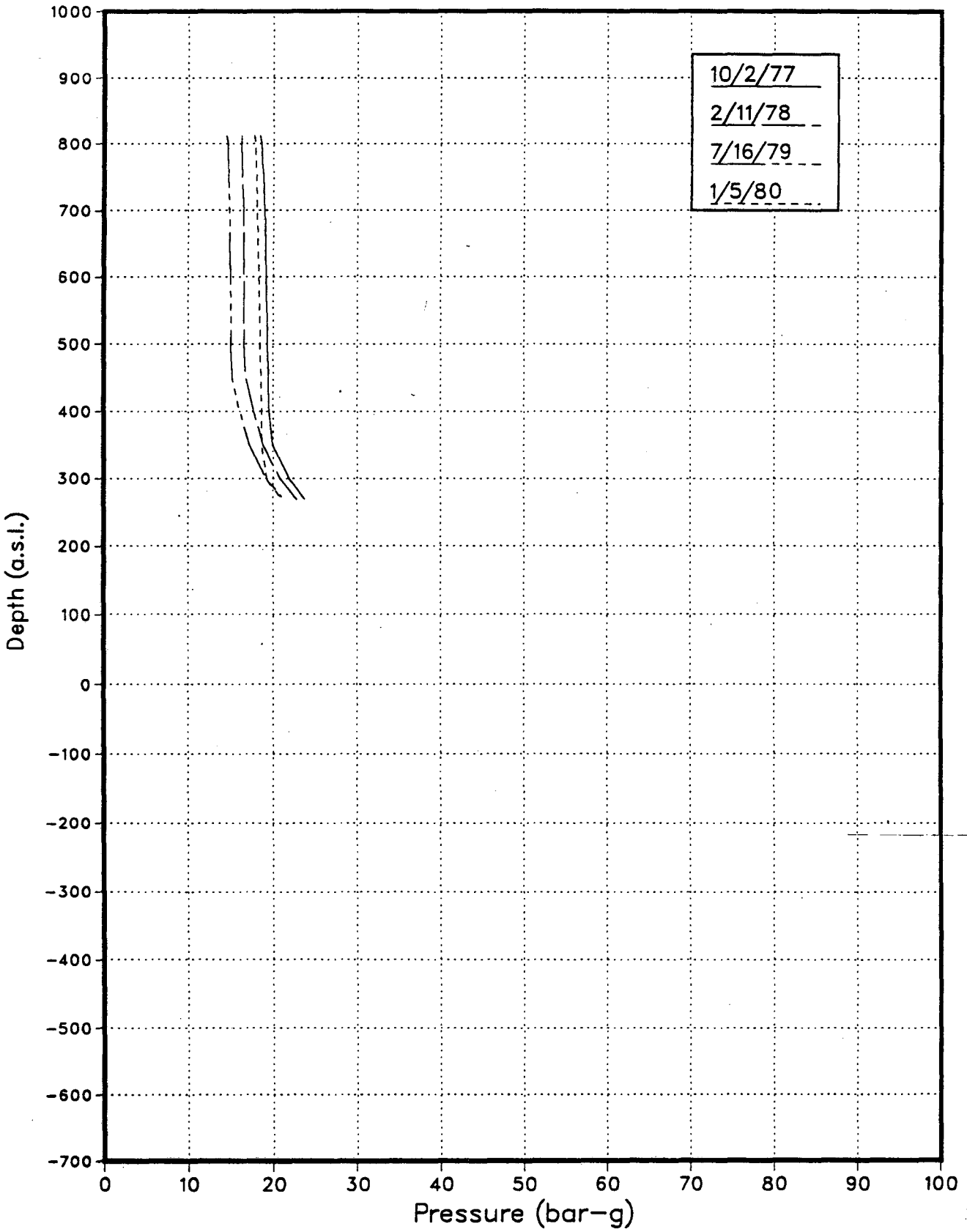

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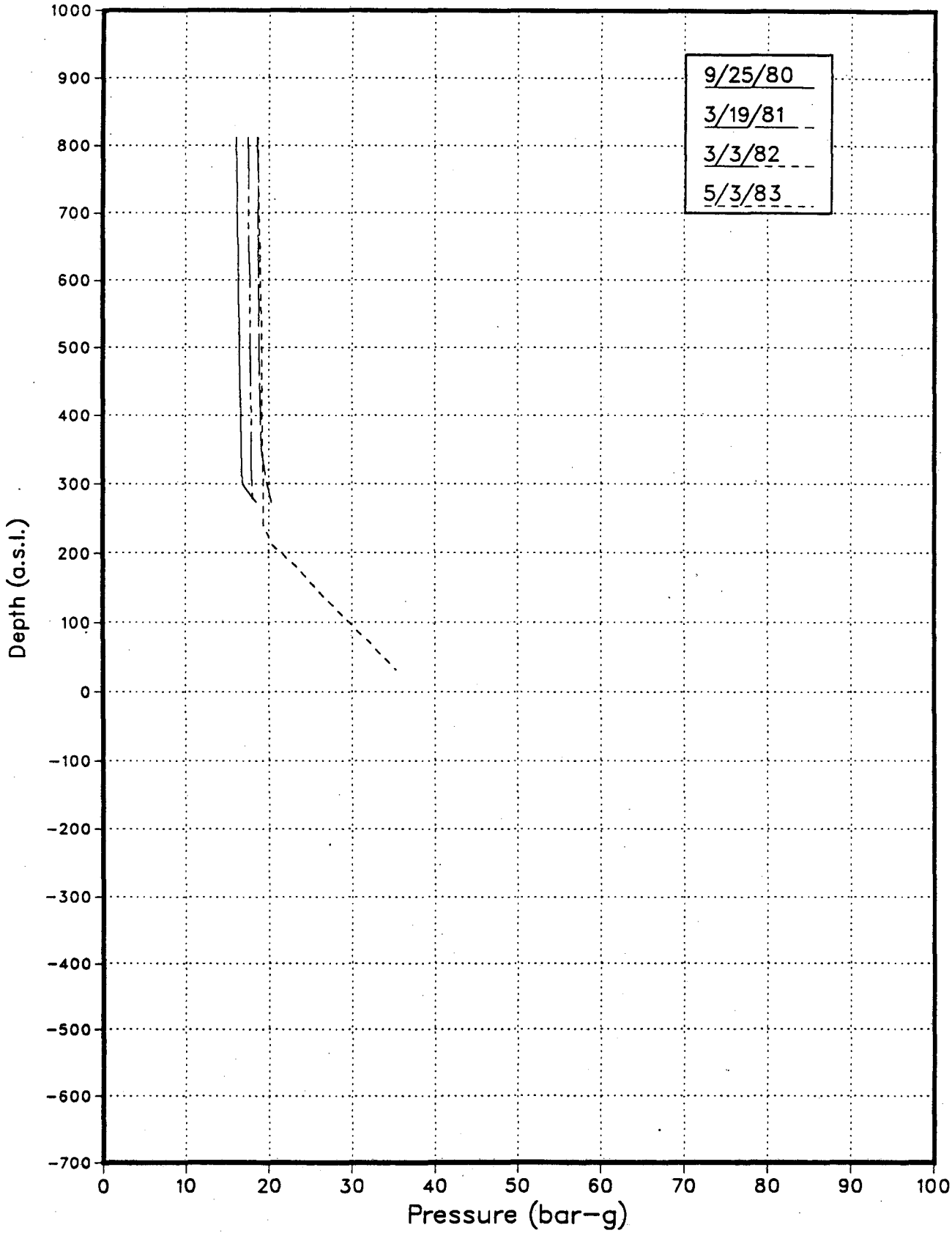
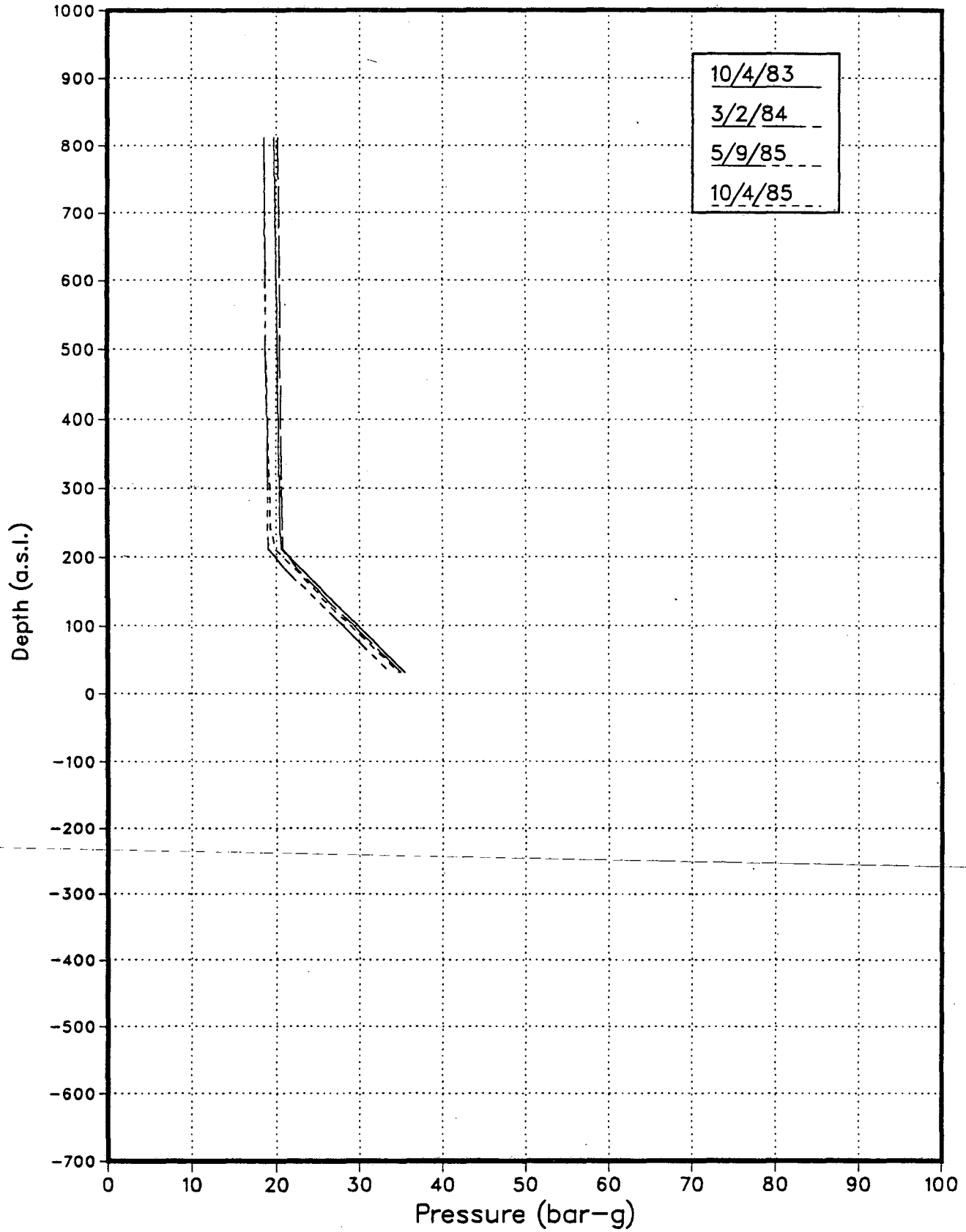
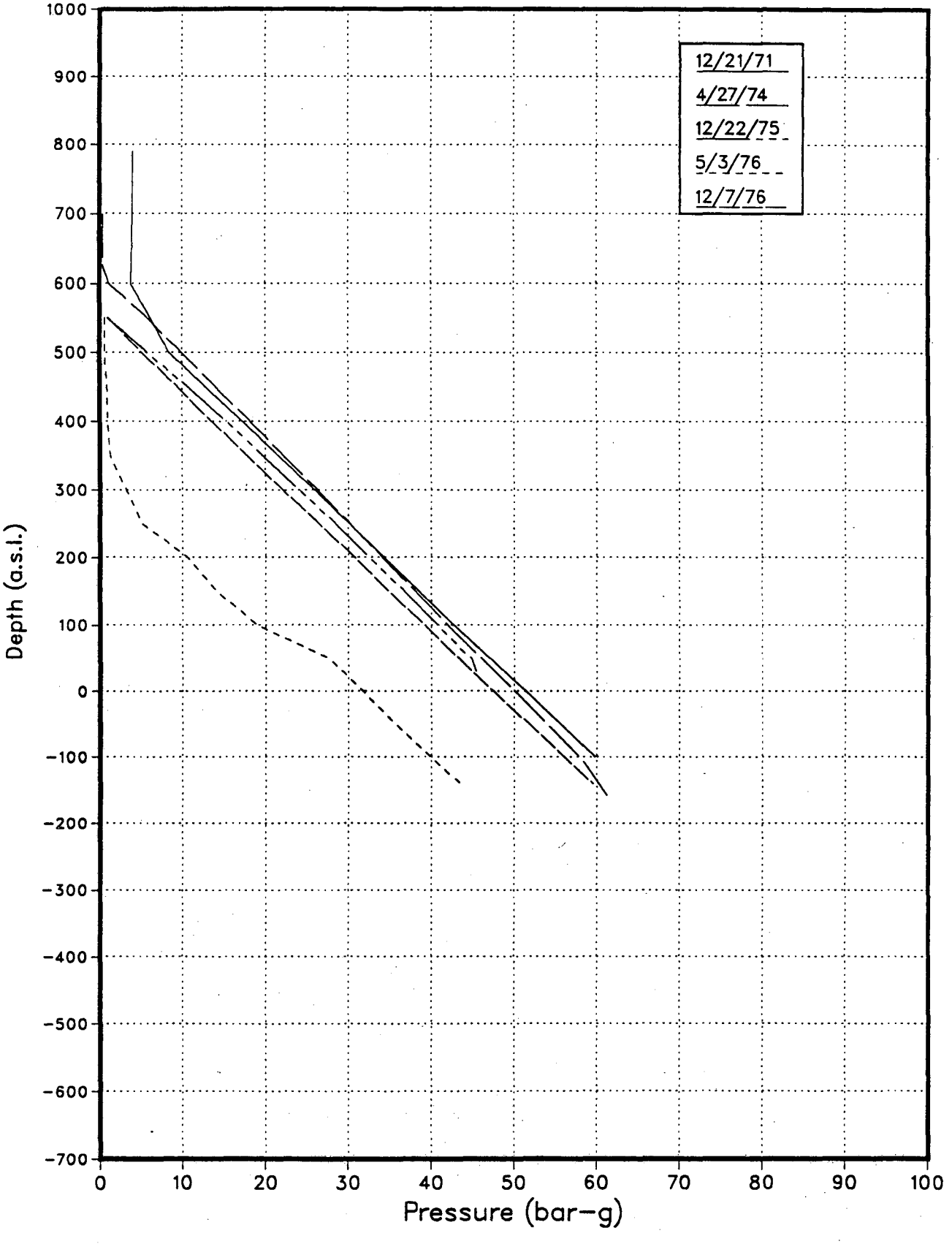


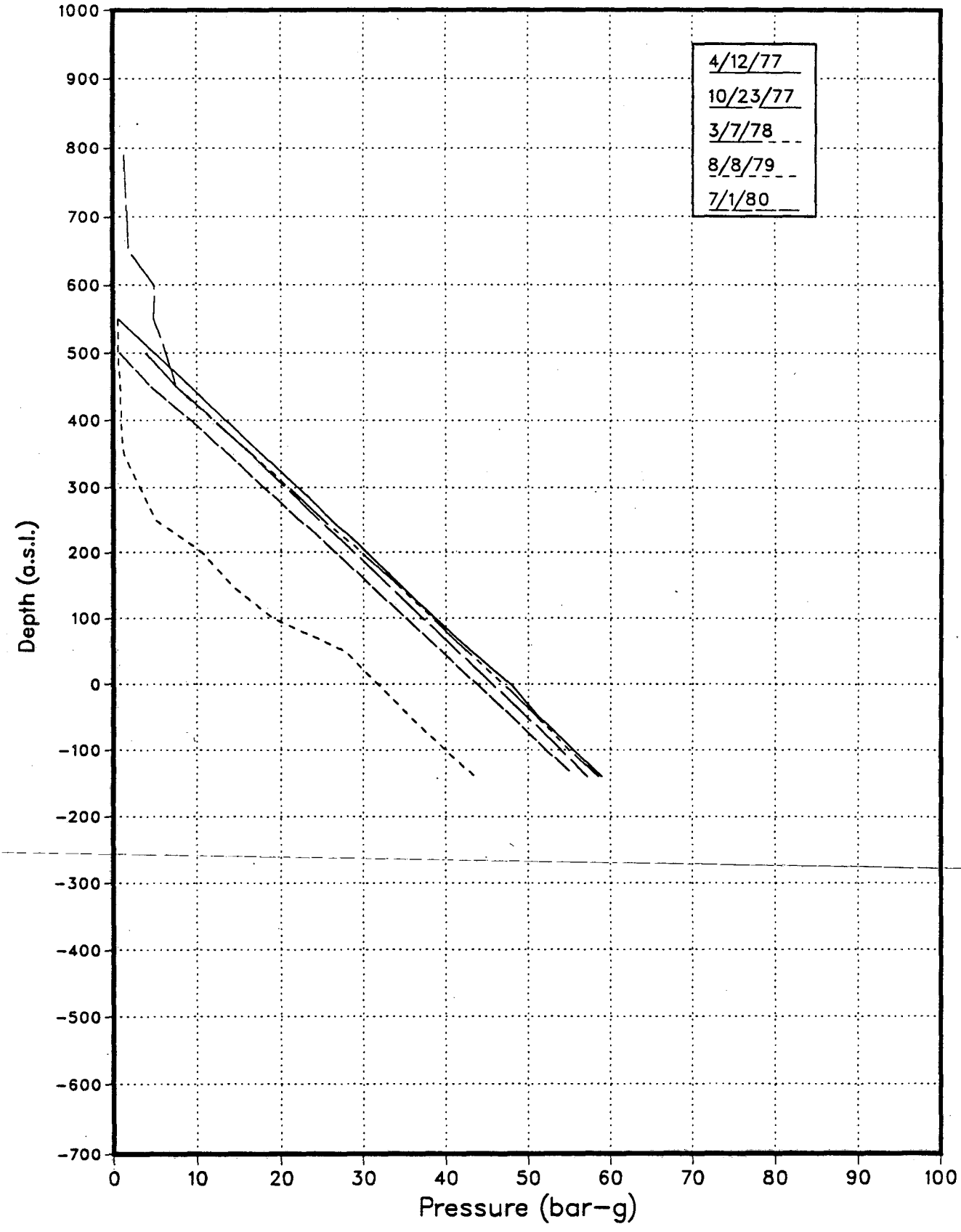
AH4 Pressure Surveys



AH5 Pressure Surveys



AH5 Pressure Surveys



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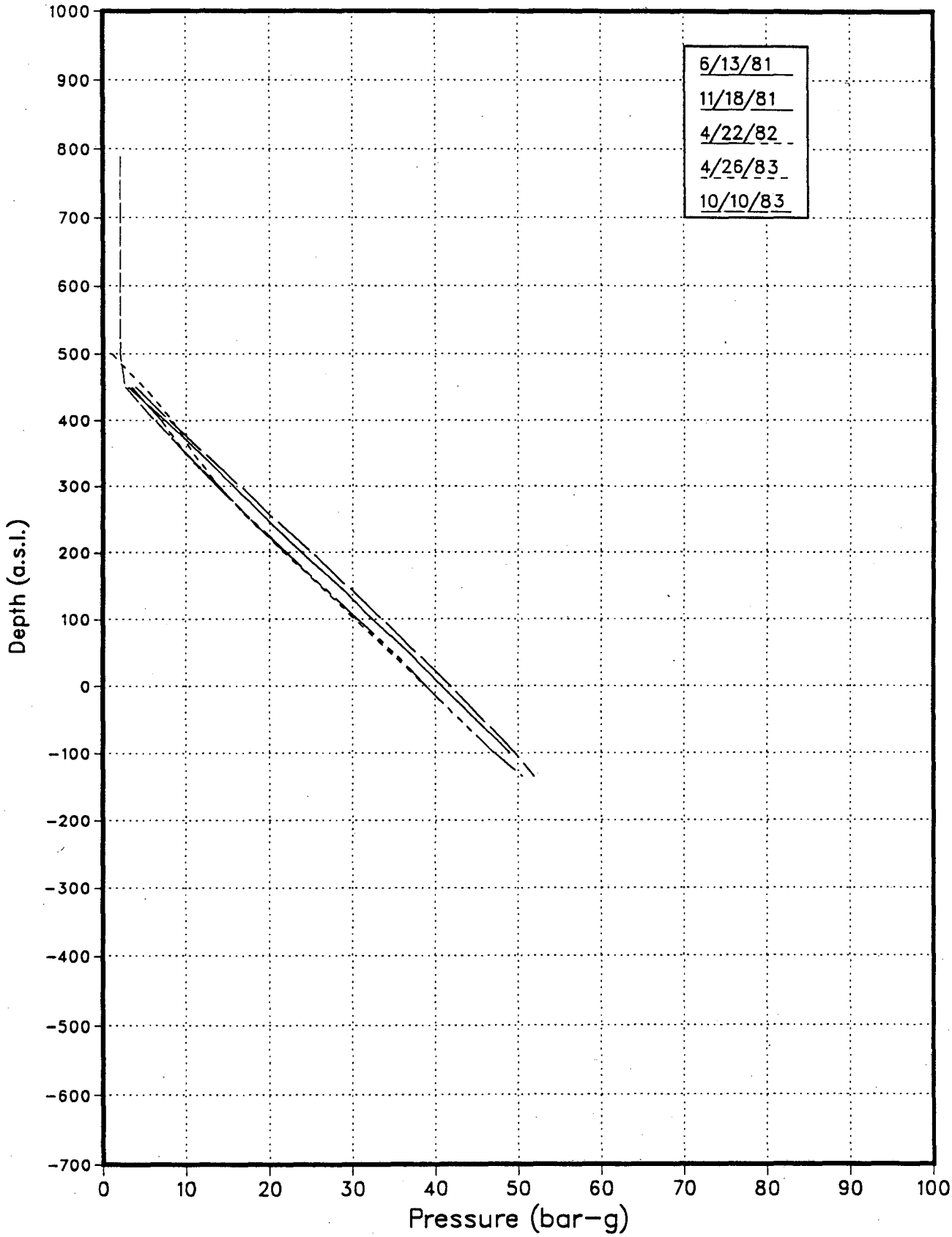
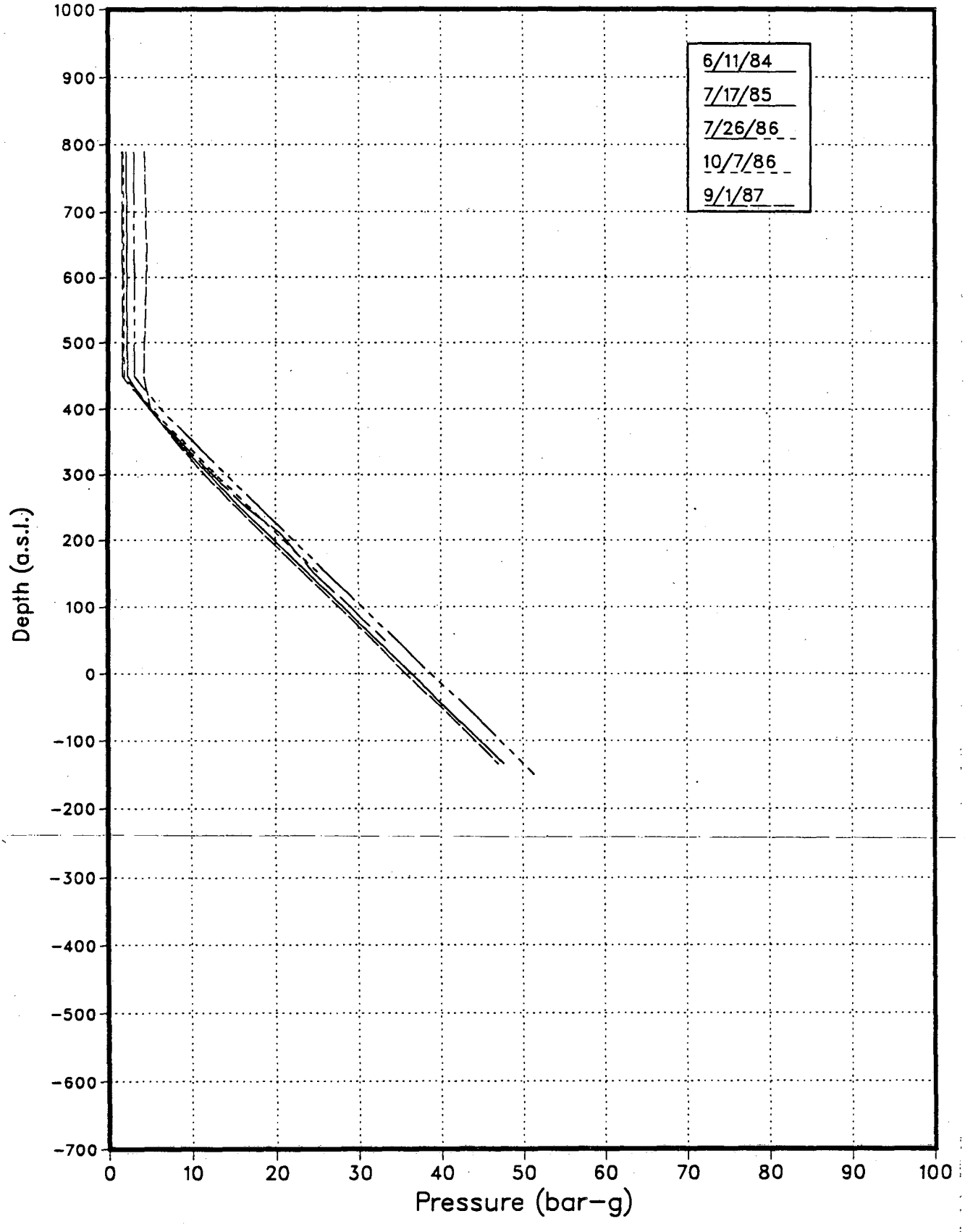


AH5 Pressure Surveys



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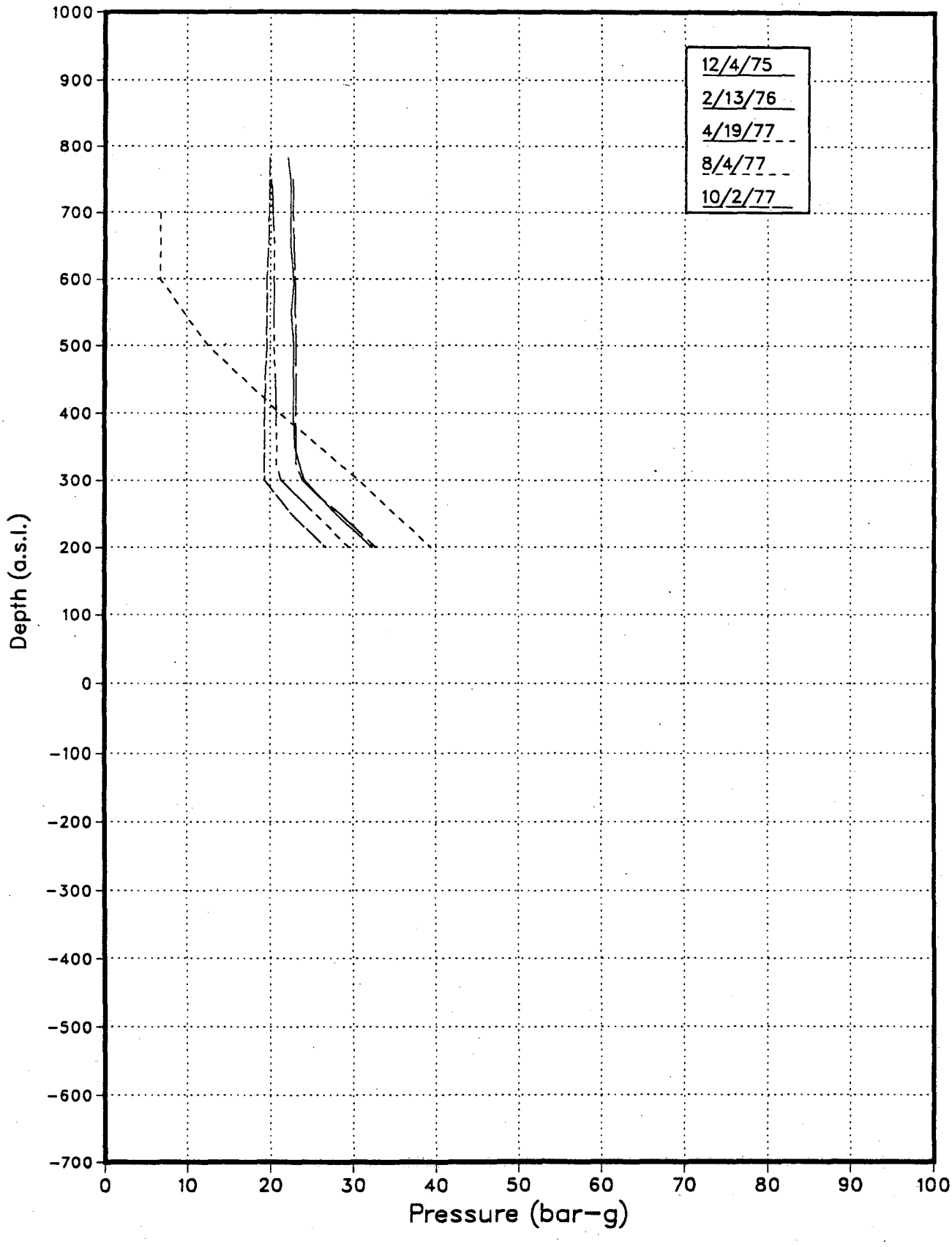

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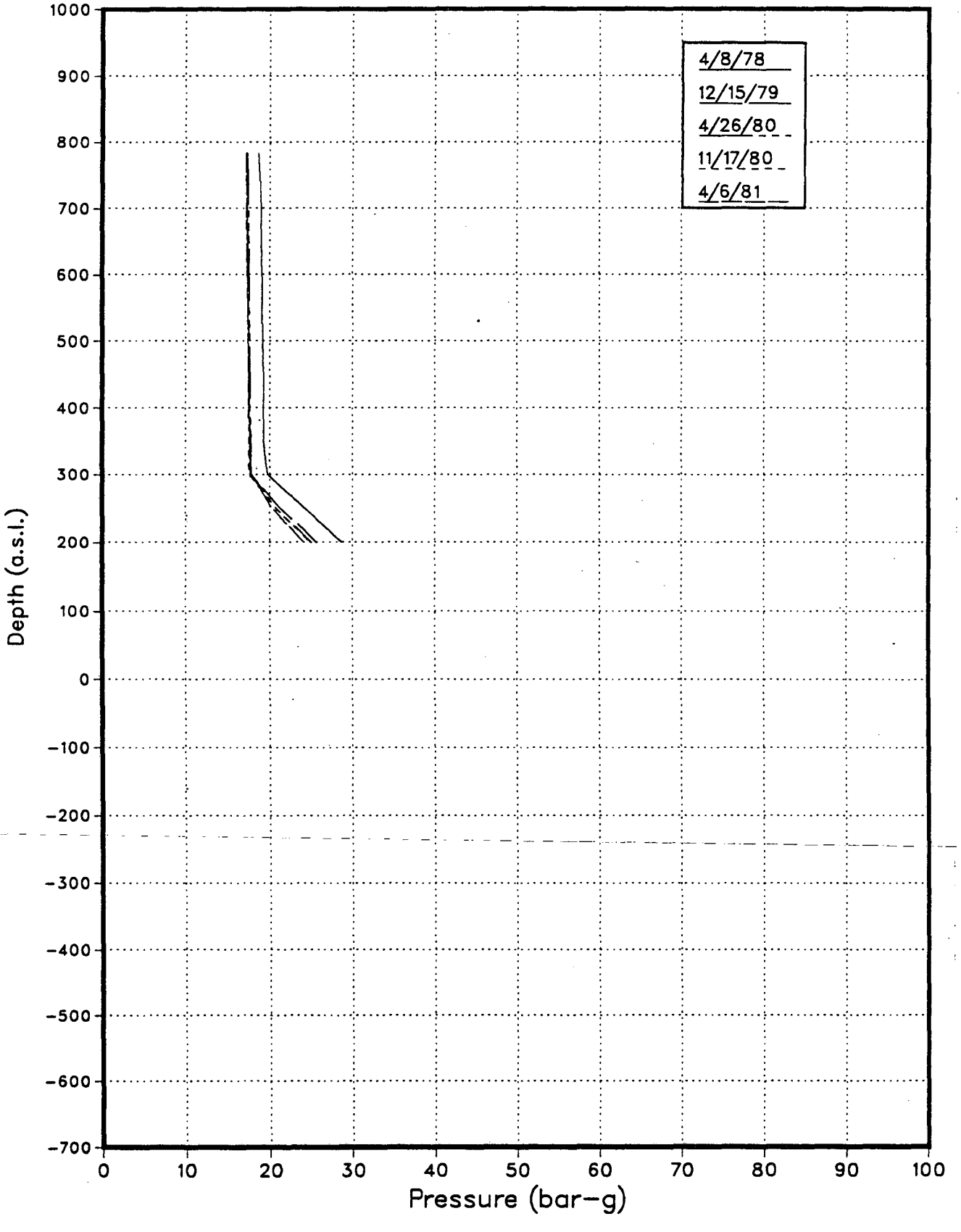

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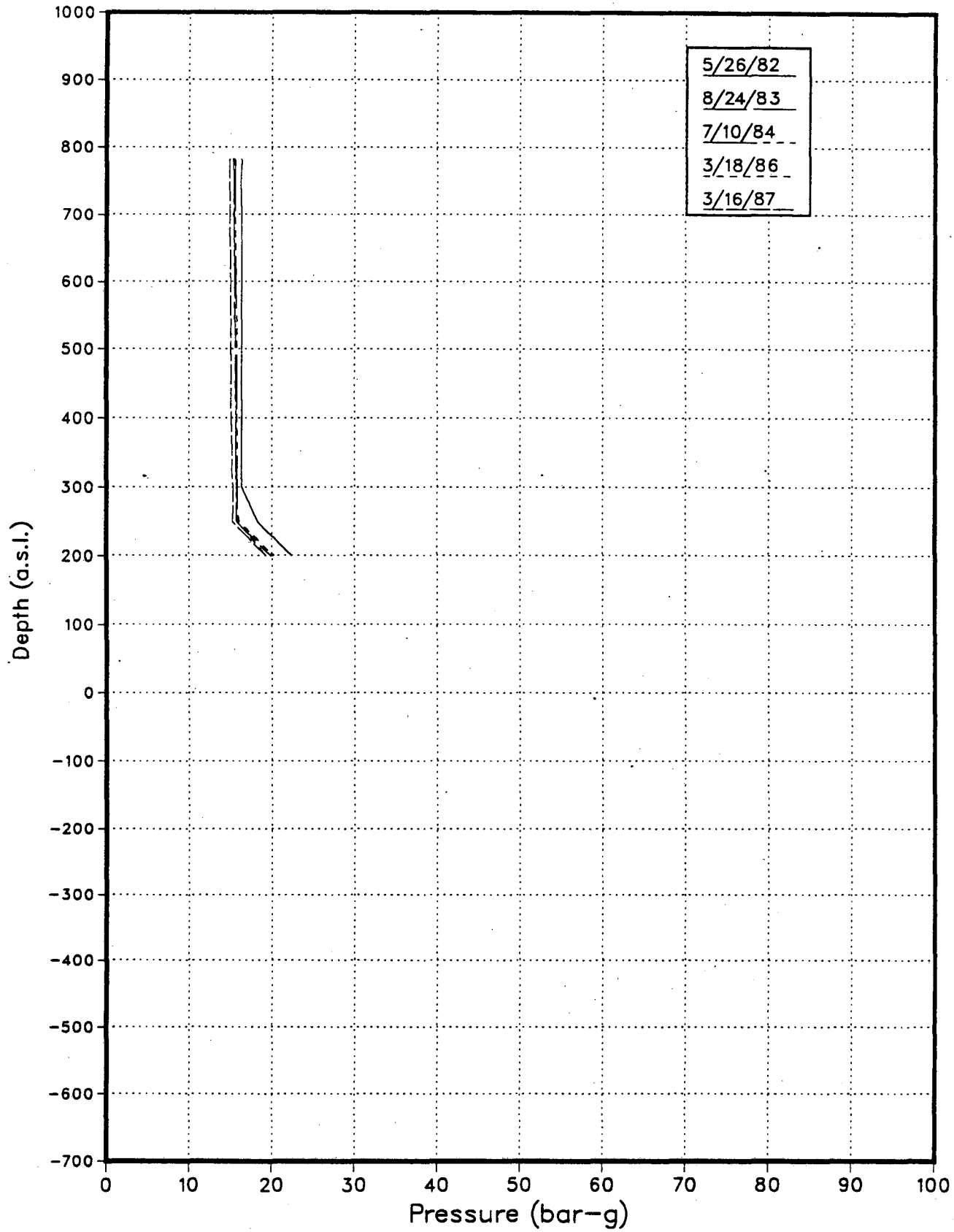

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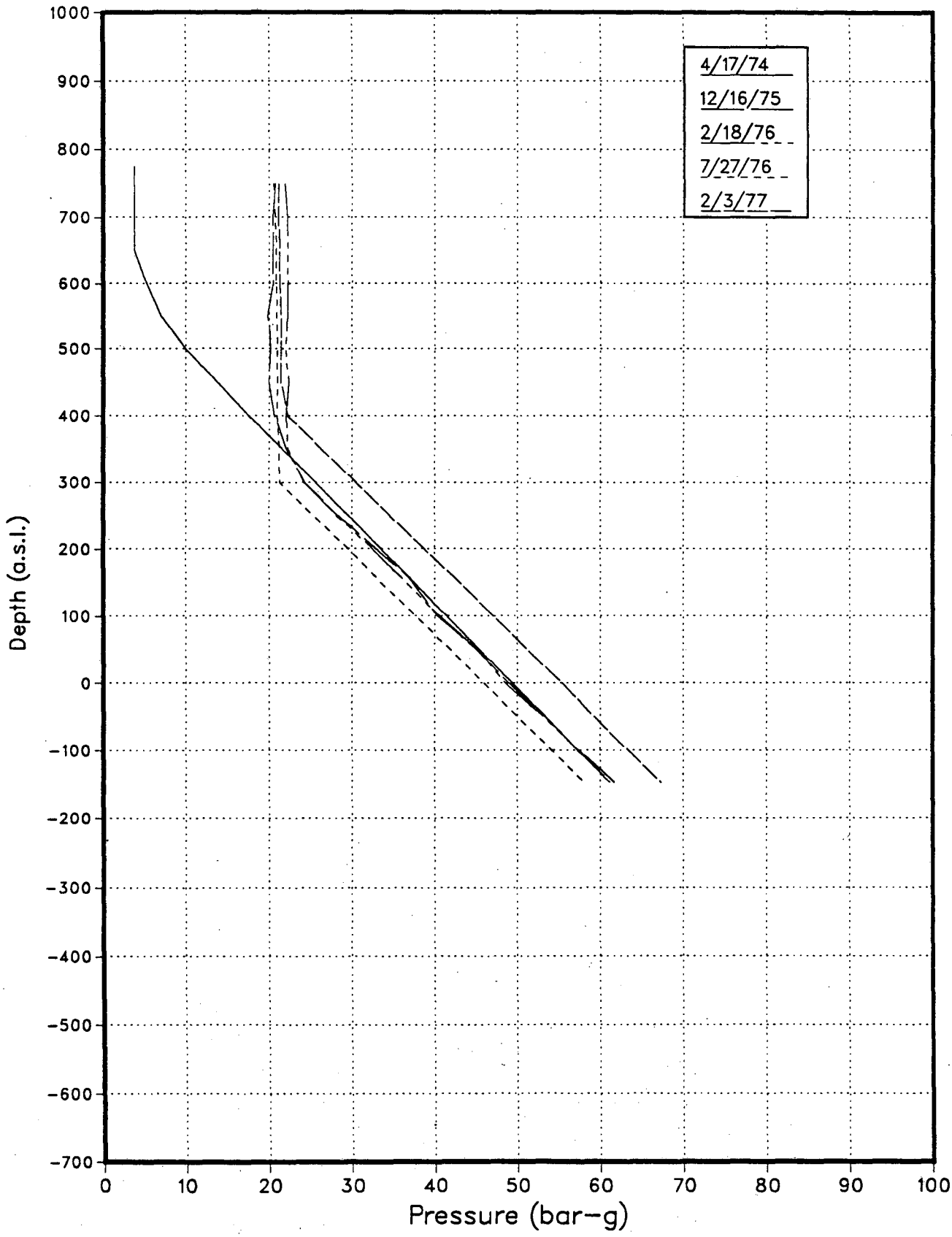

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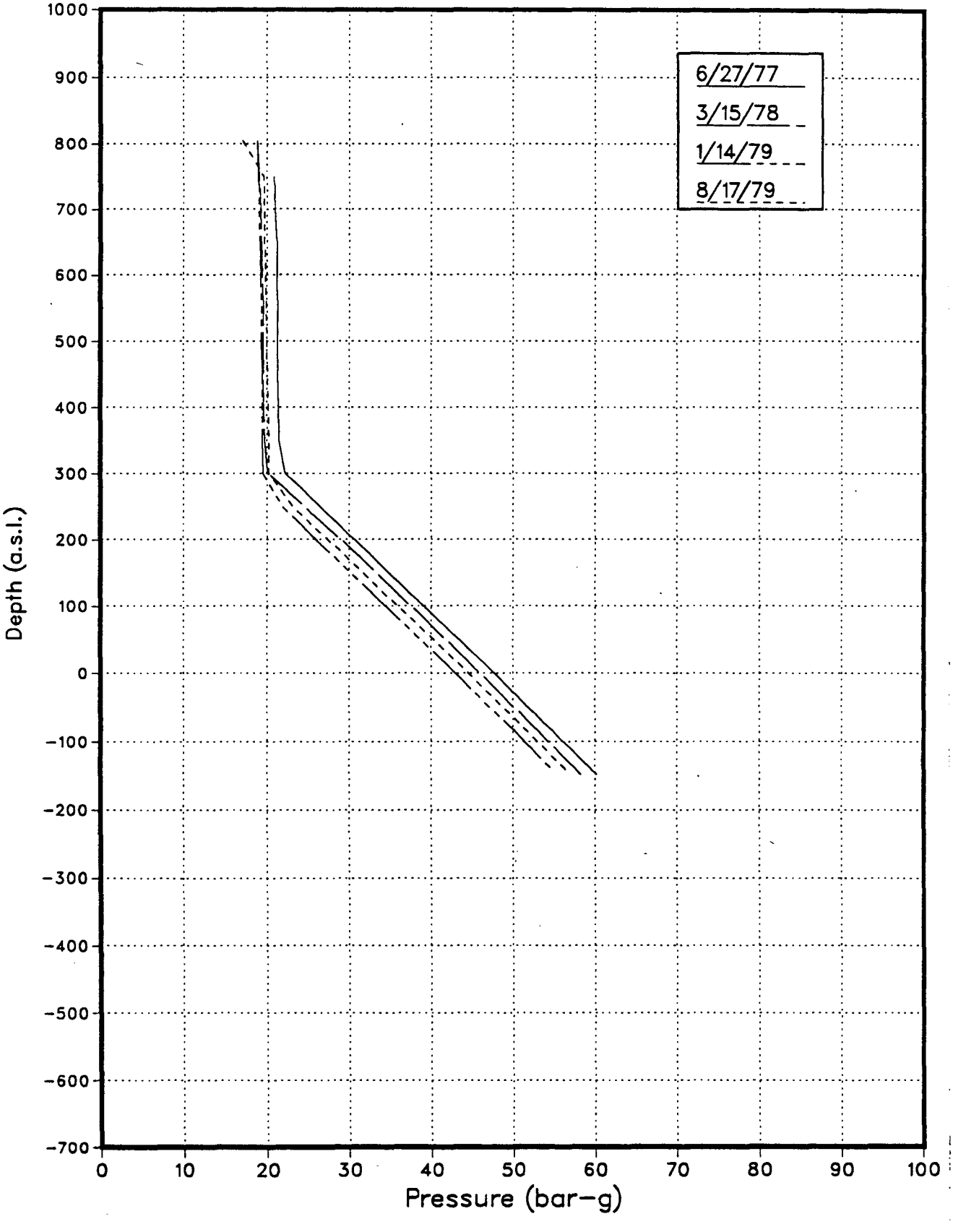

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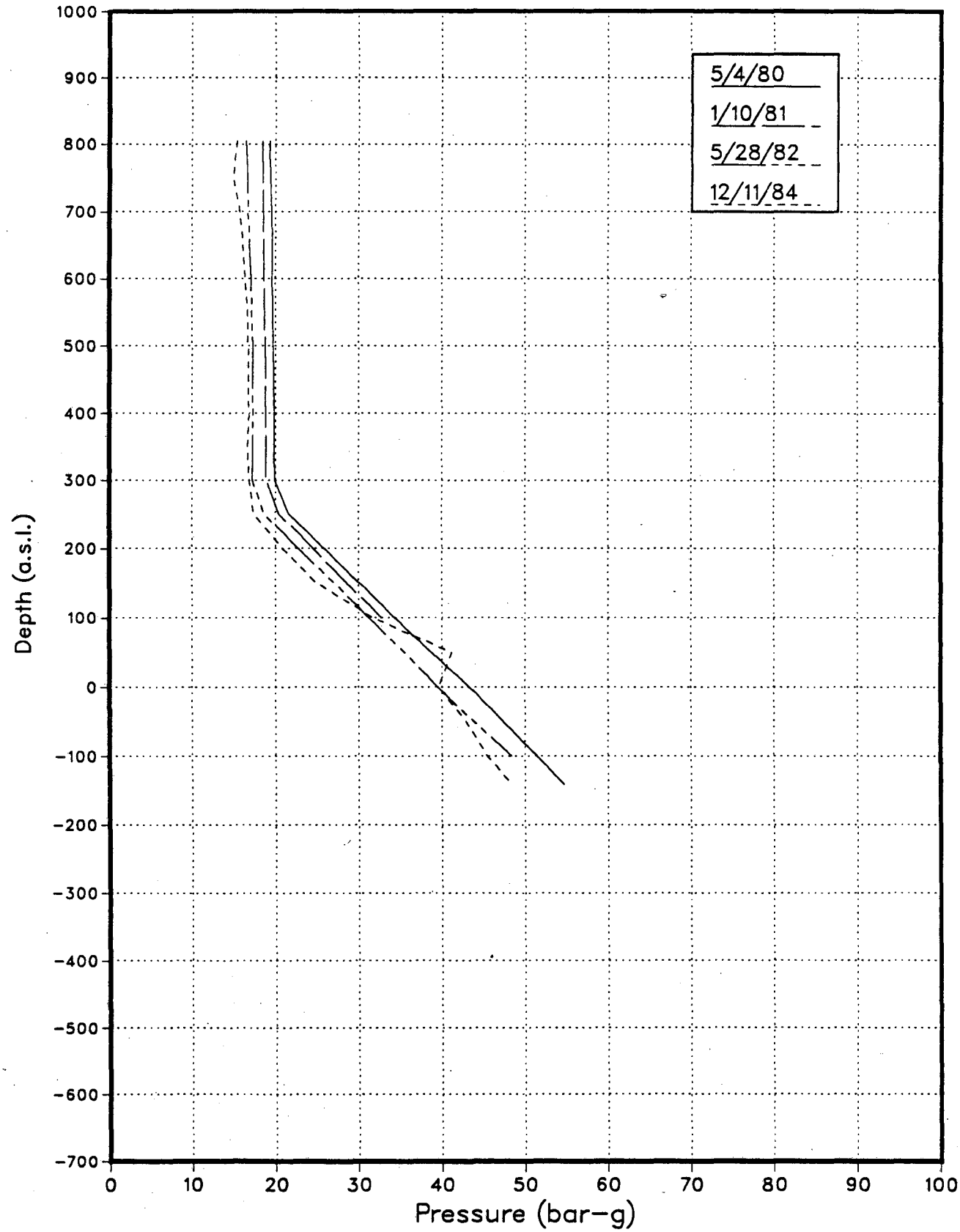

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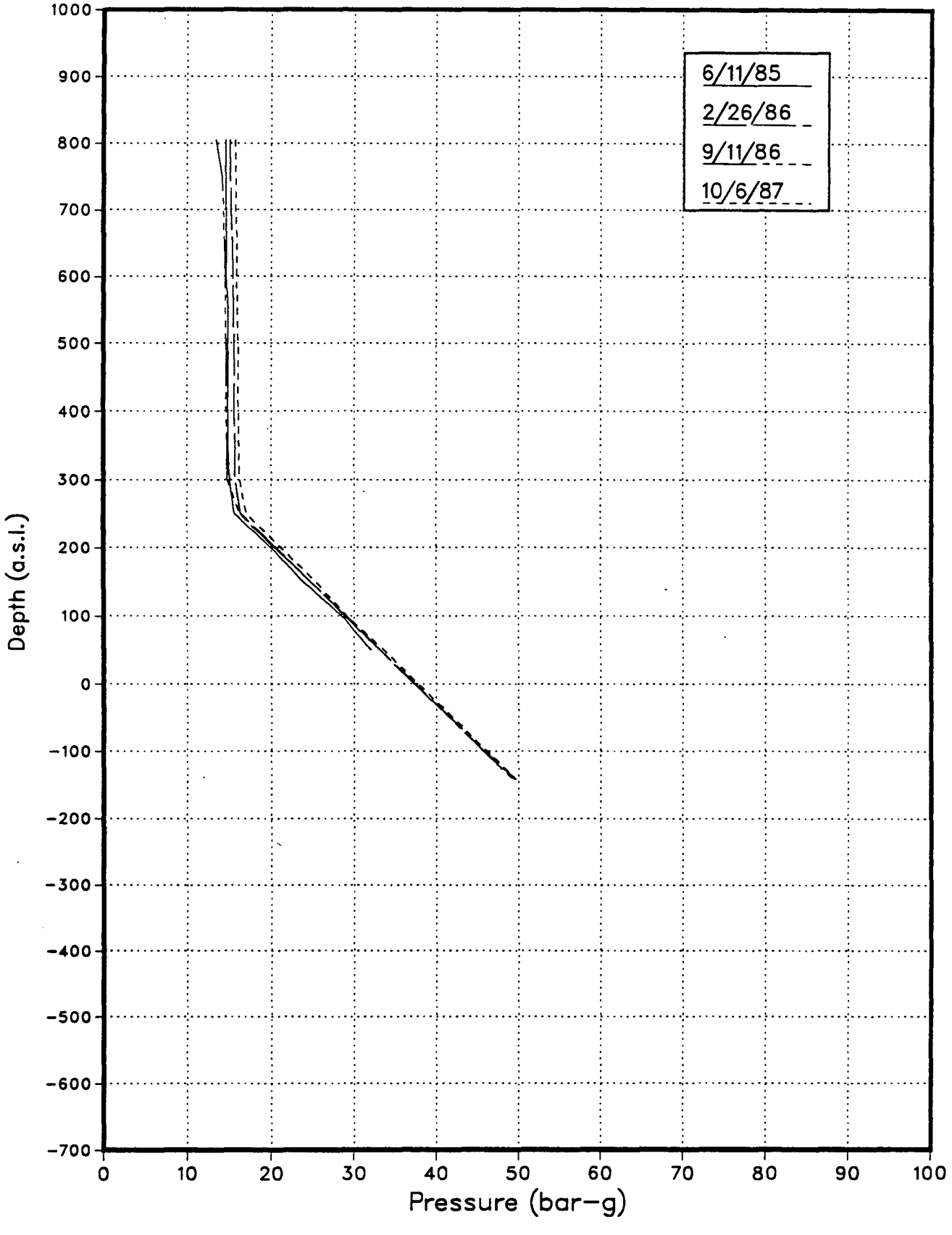
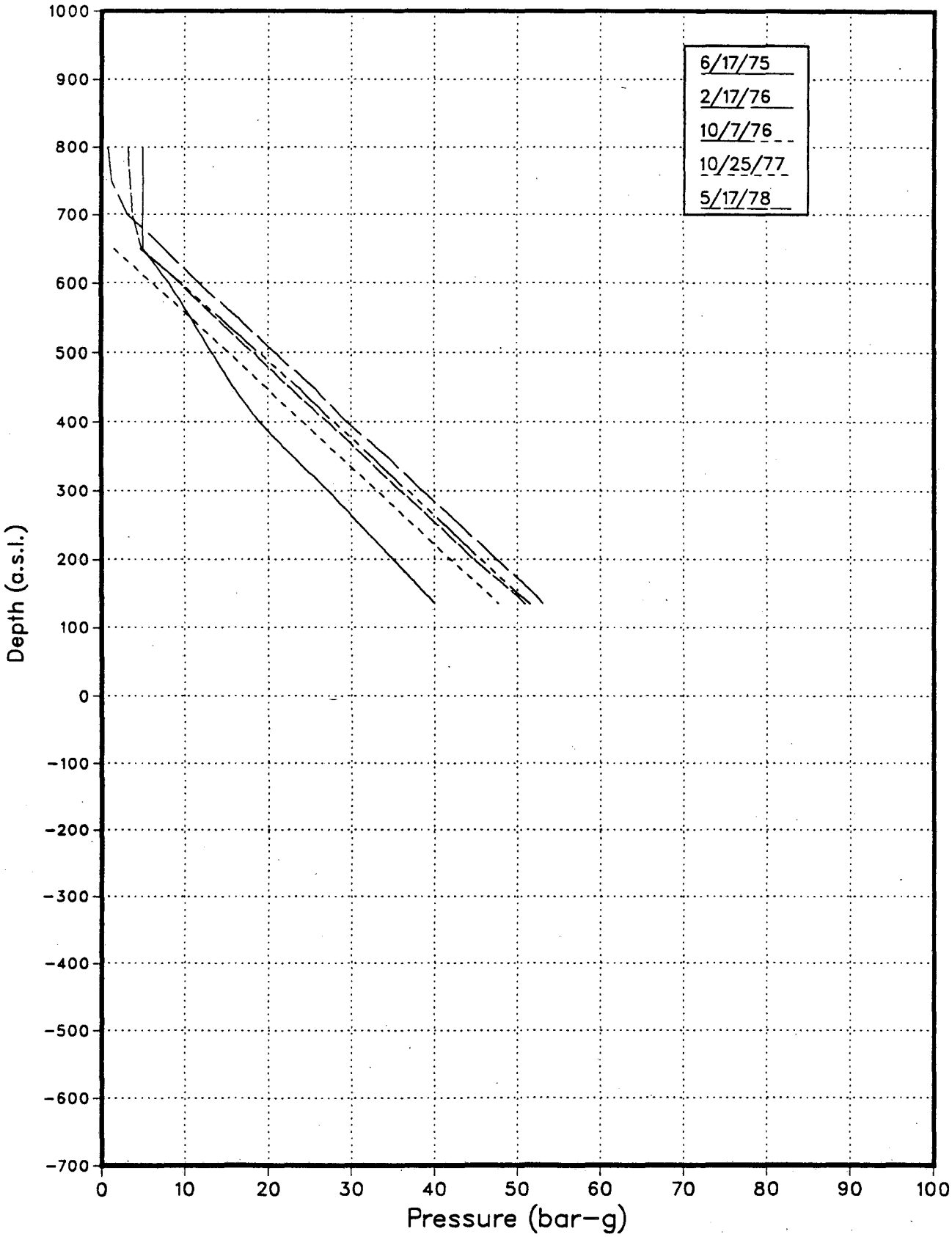


AH8 Pressure Surveys



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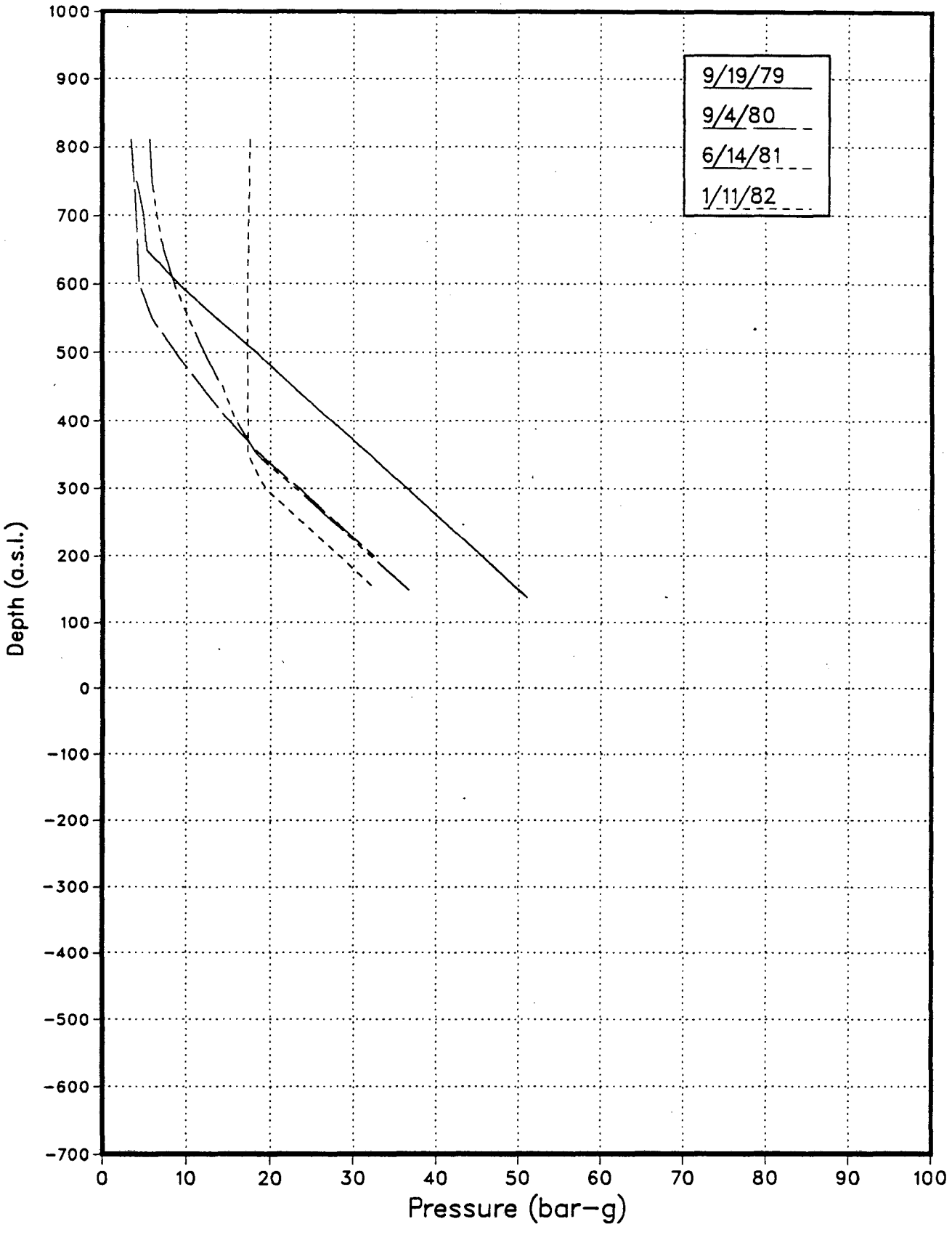

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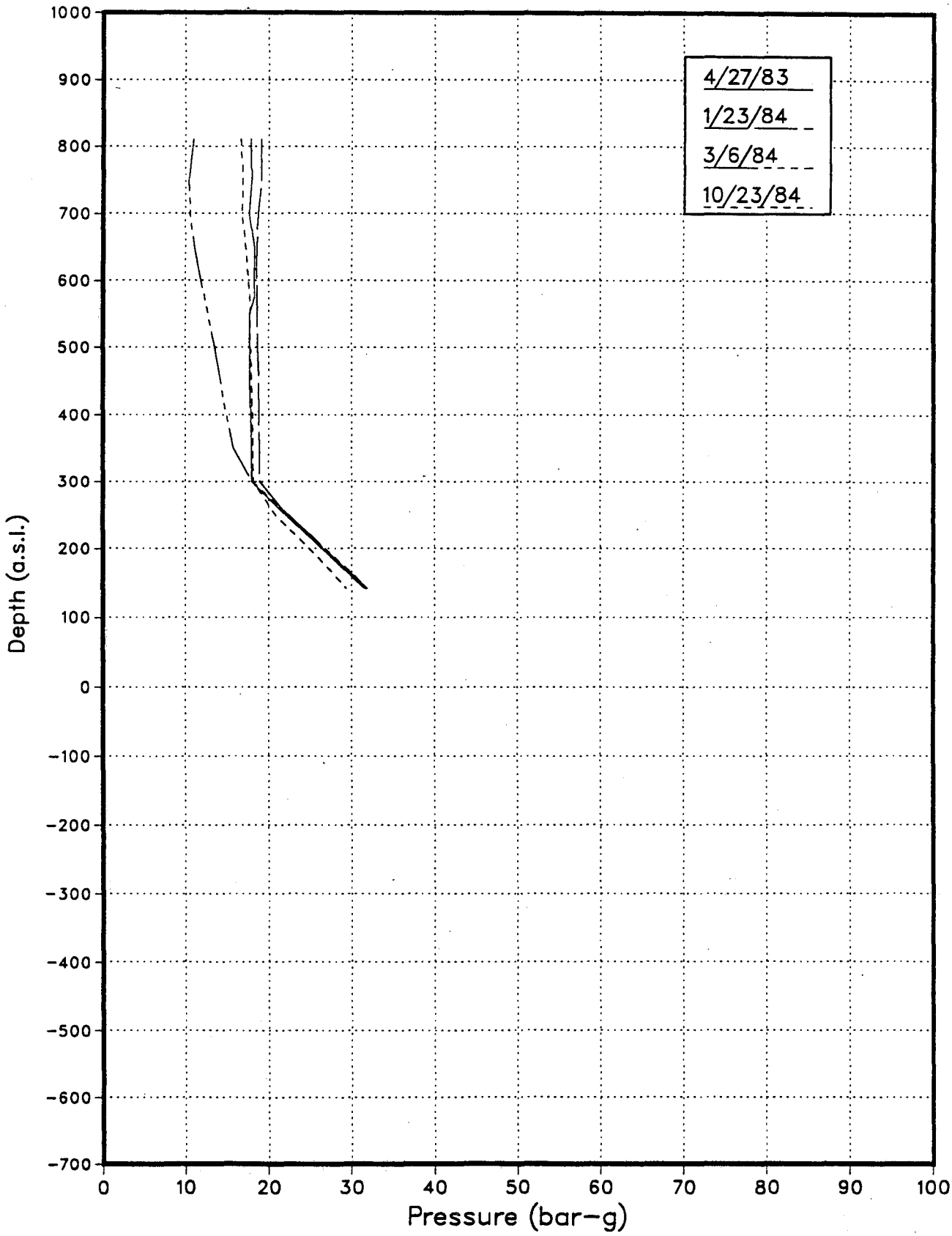

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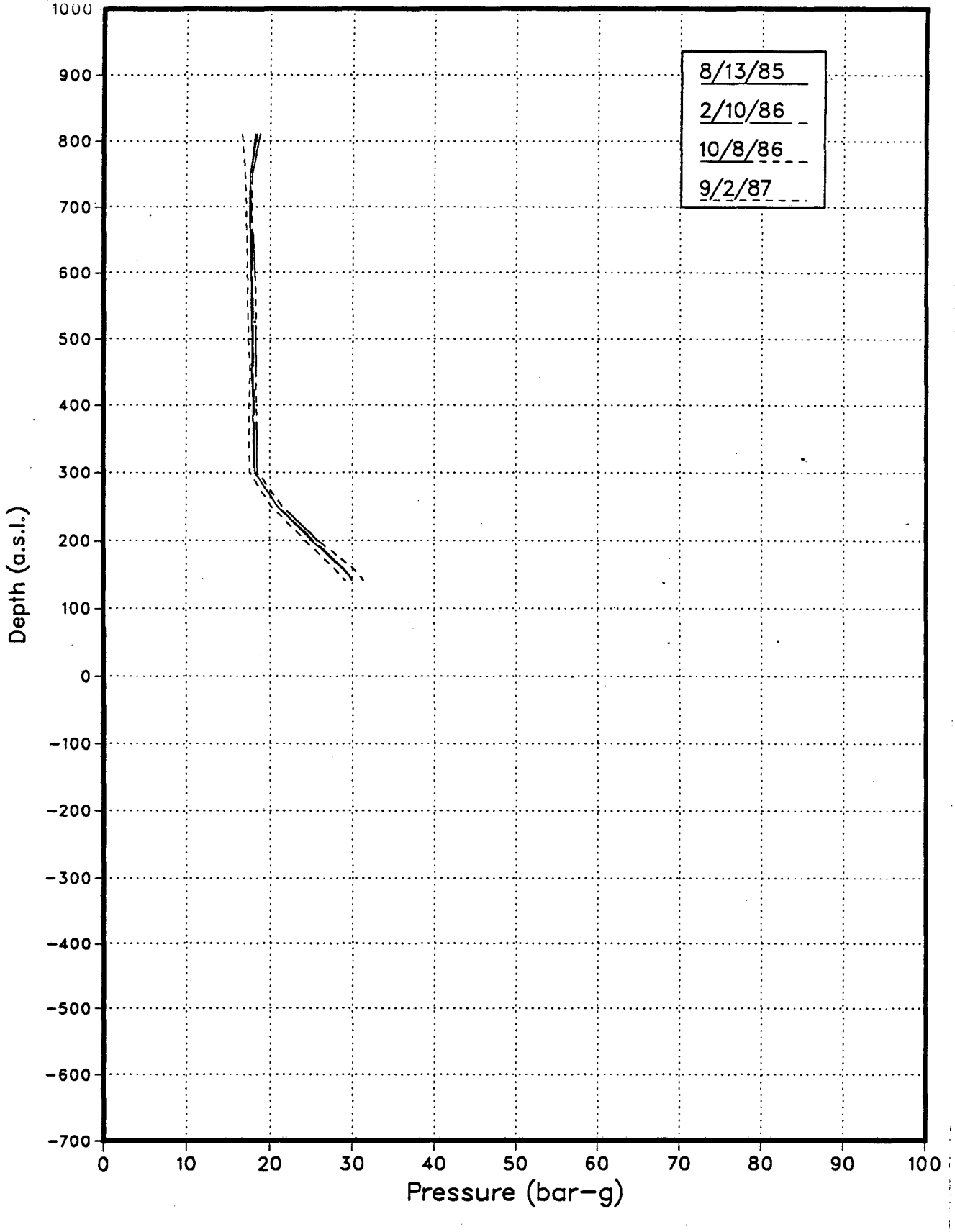

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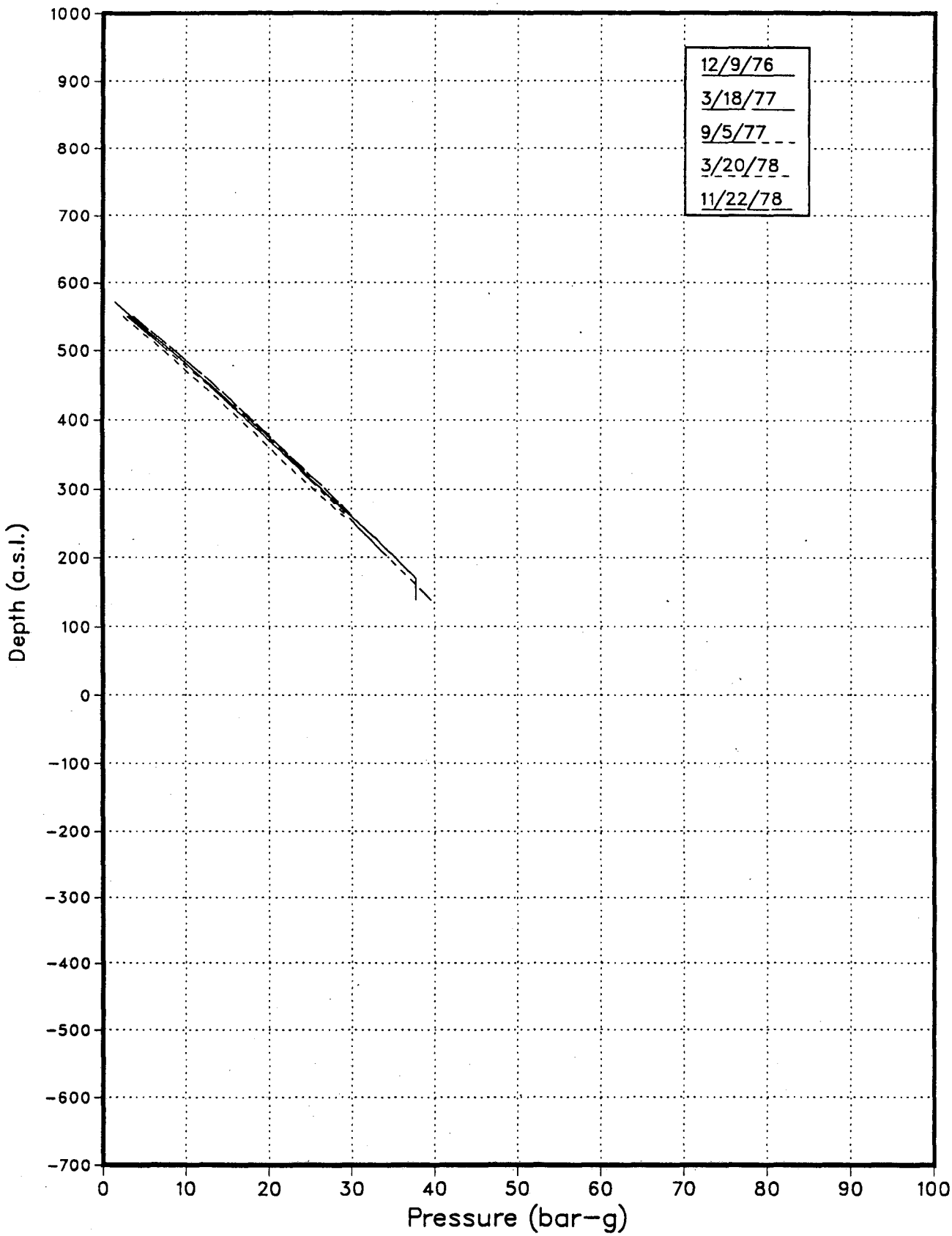

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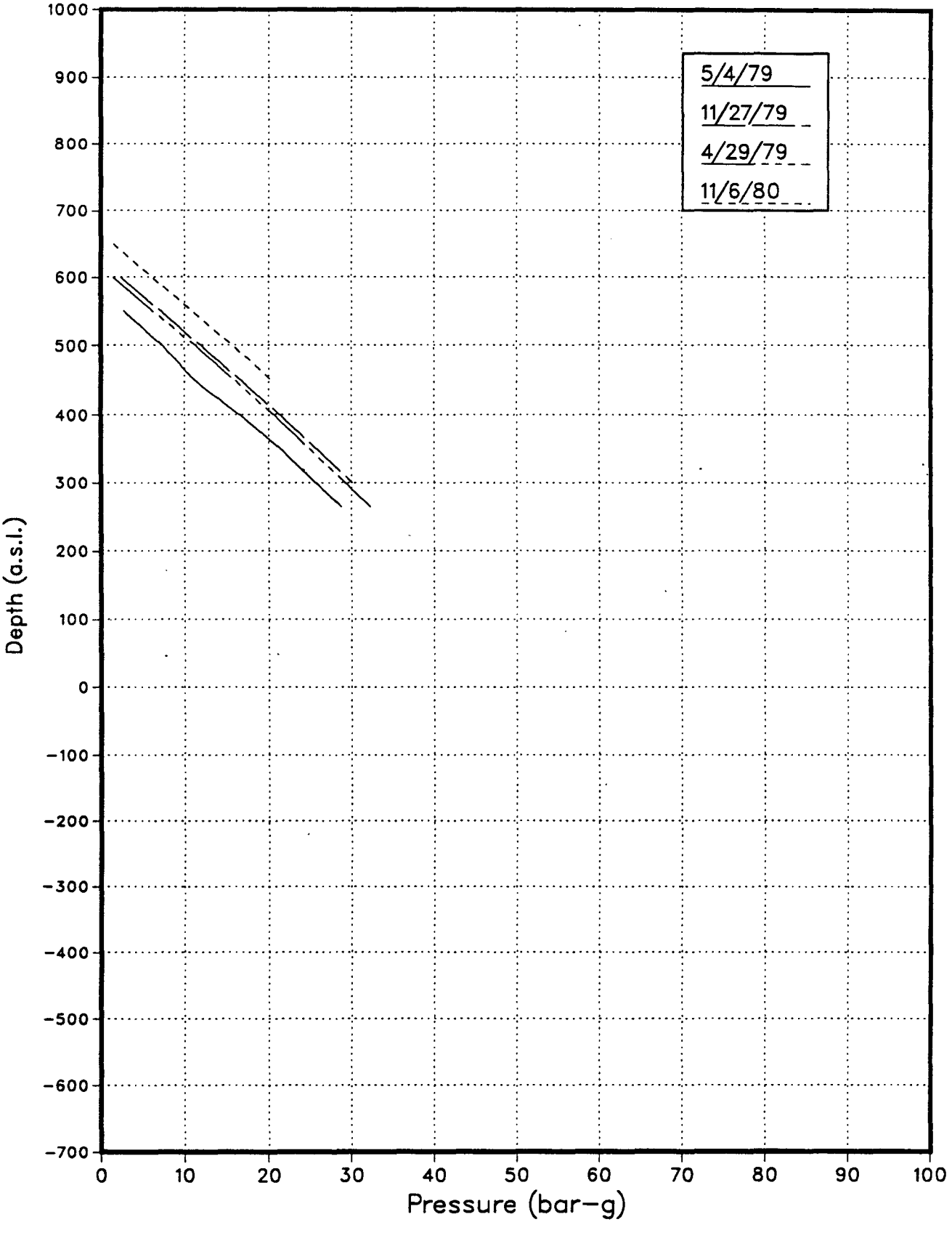
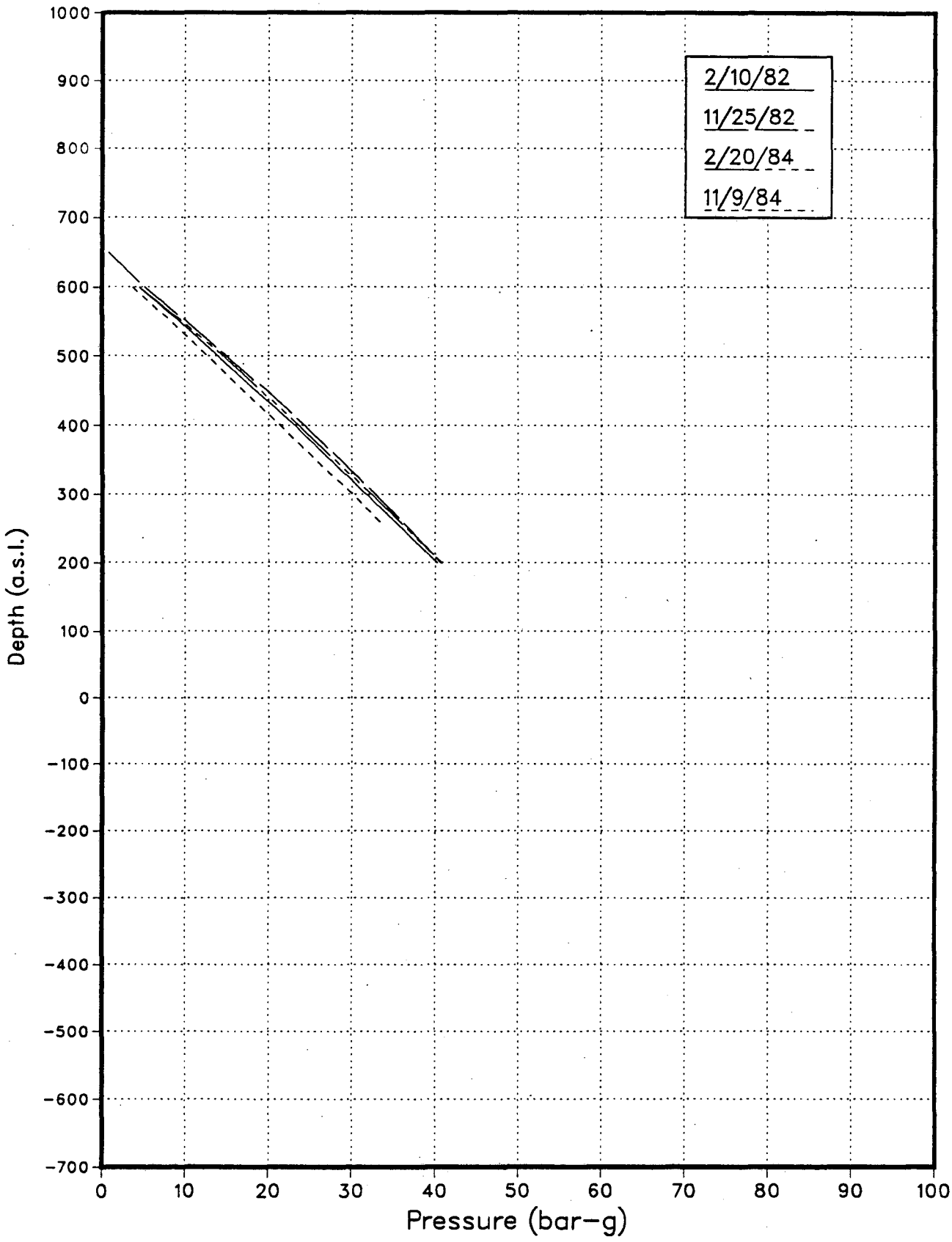


AH9 Pressure Surveys



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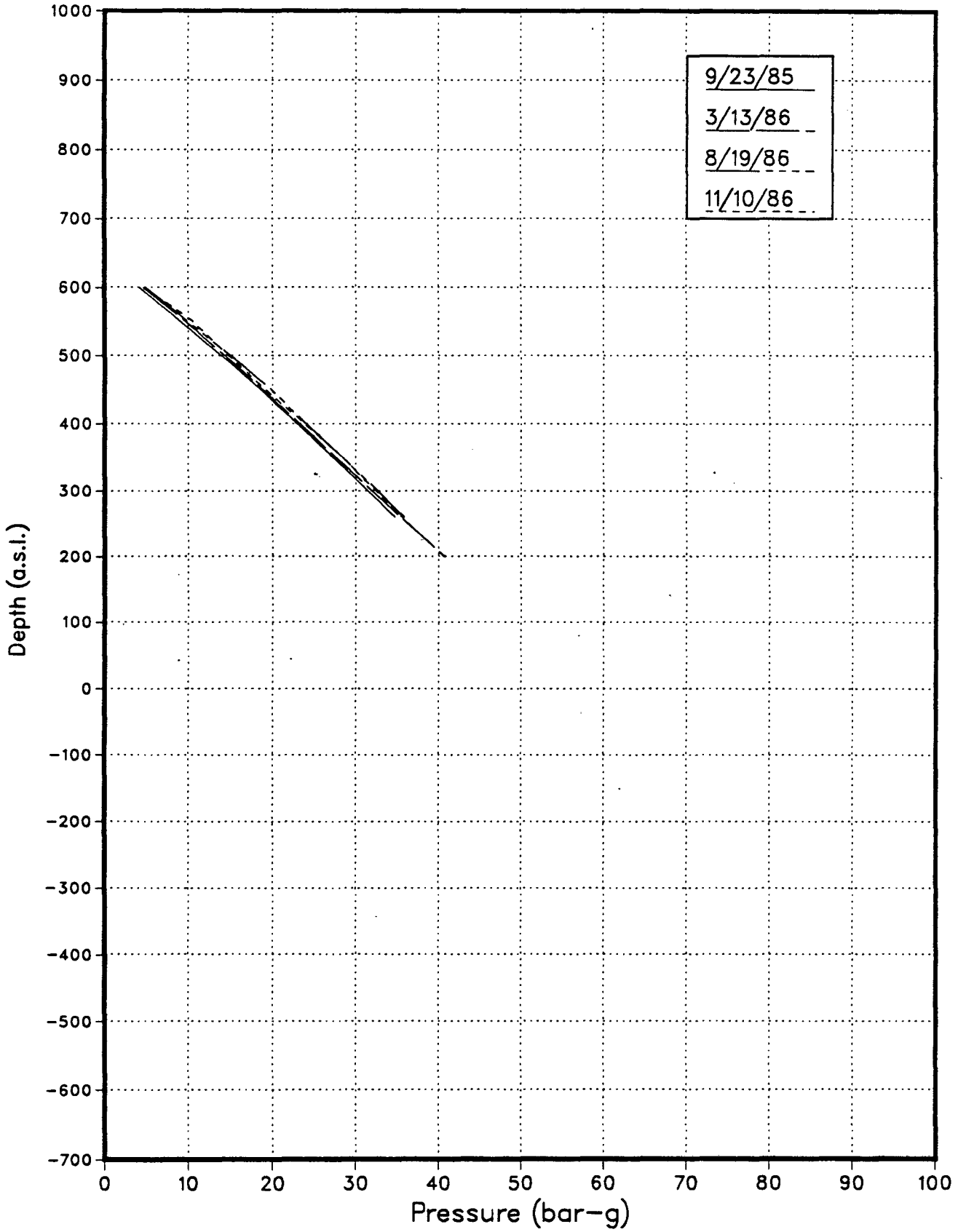
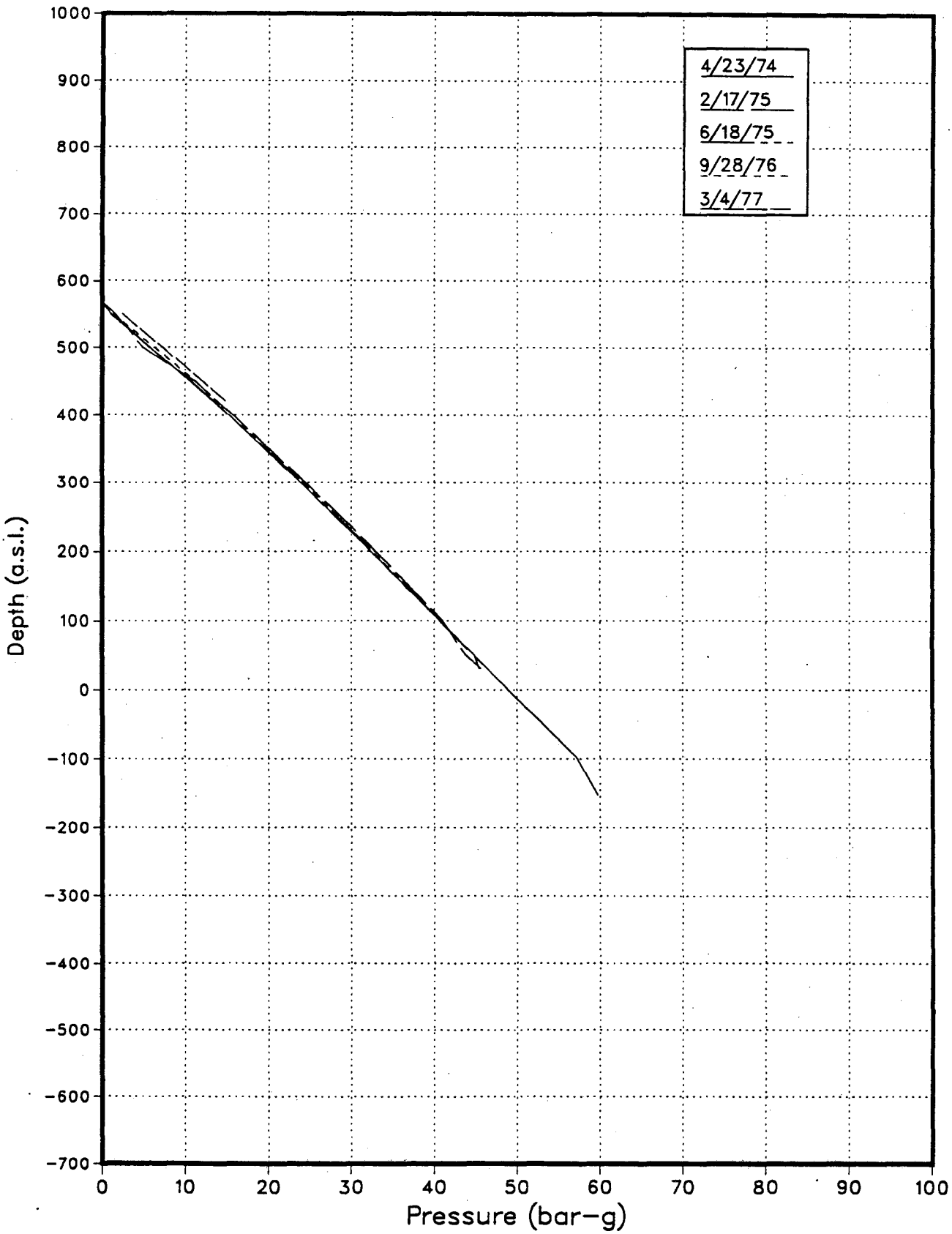


AH11 Pressure Surveys



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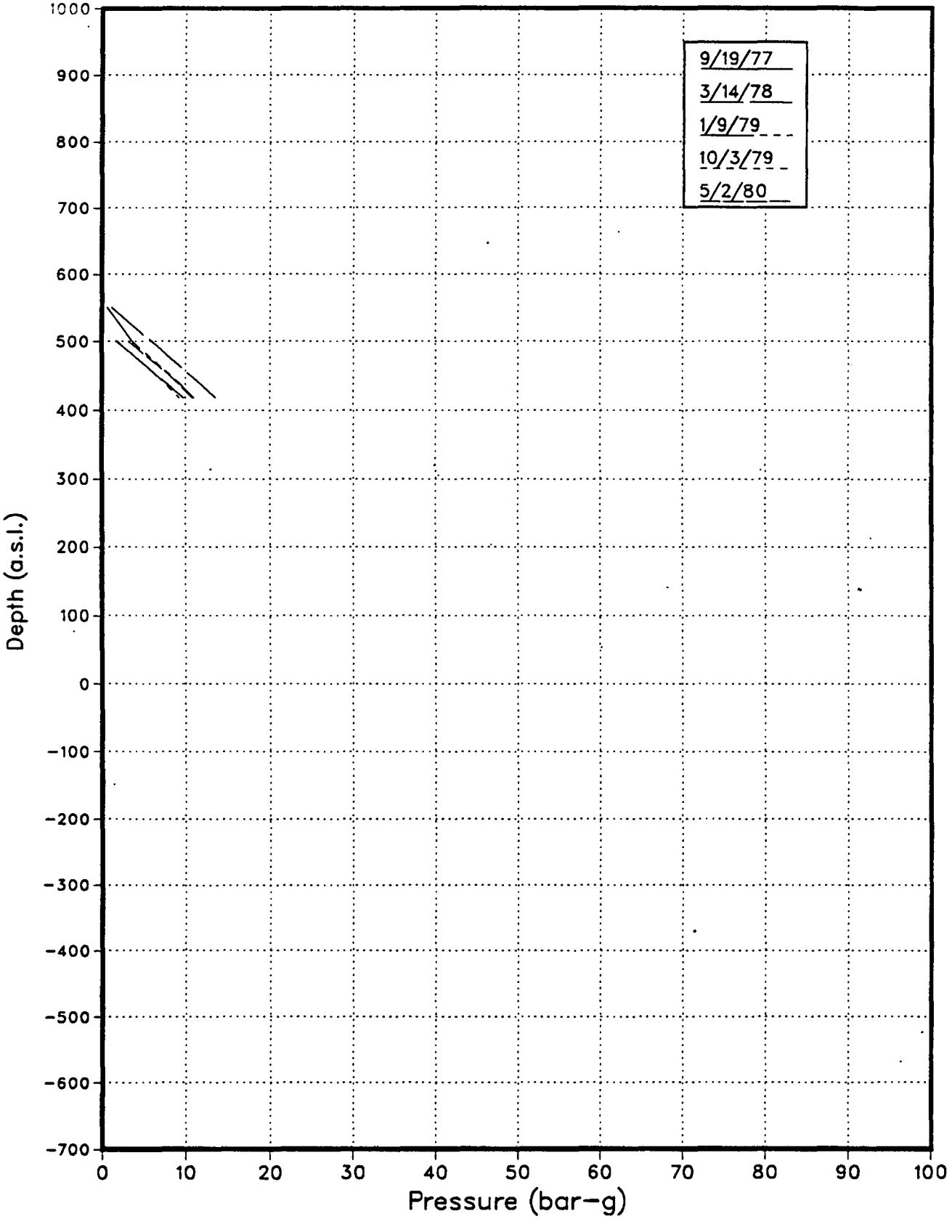

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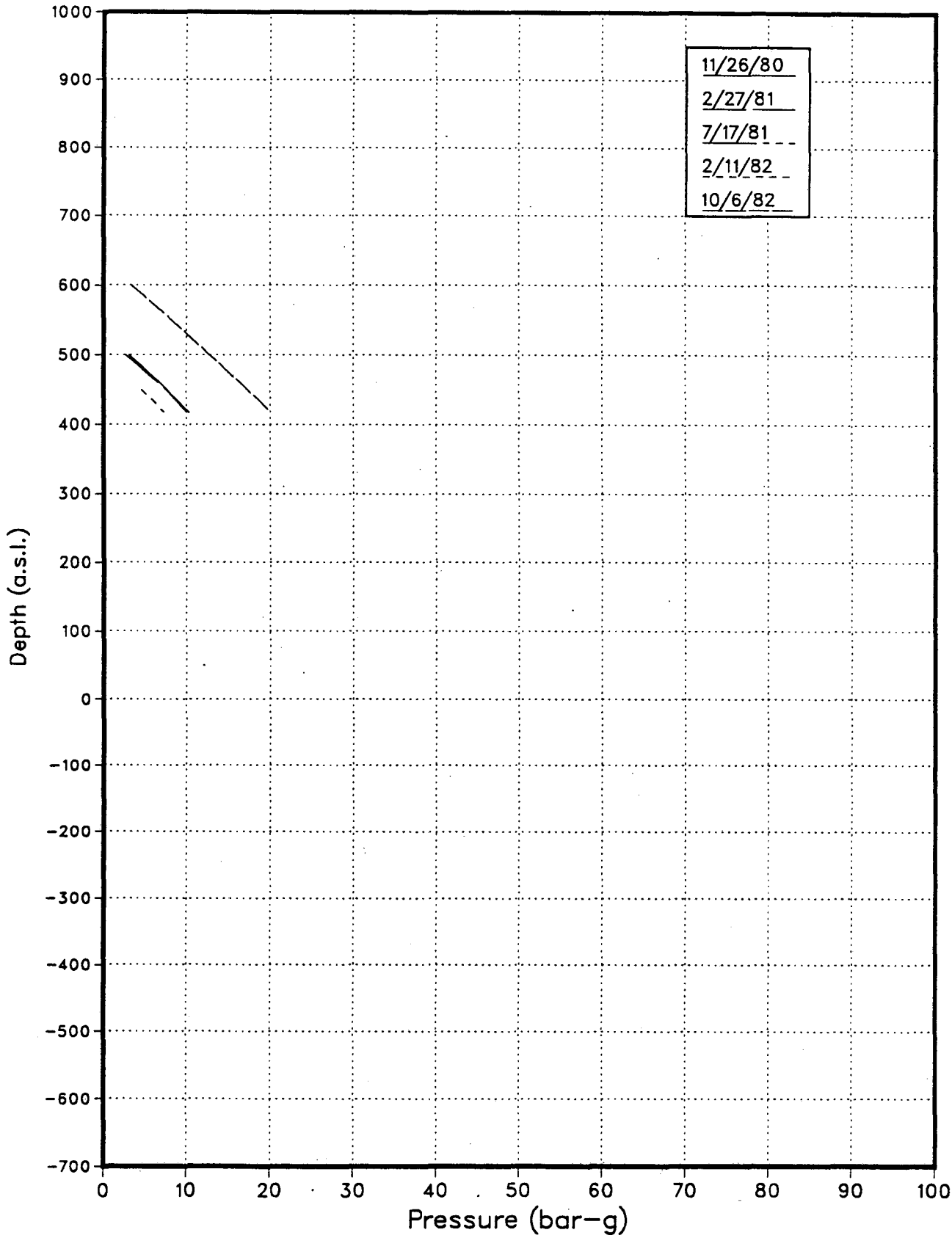

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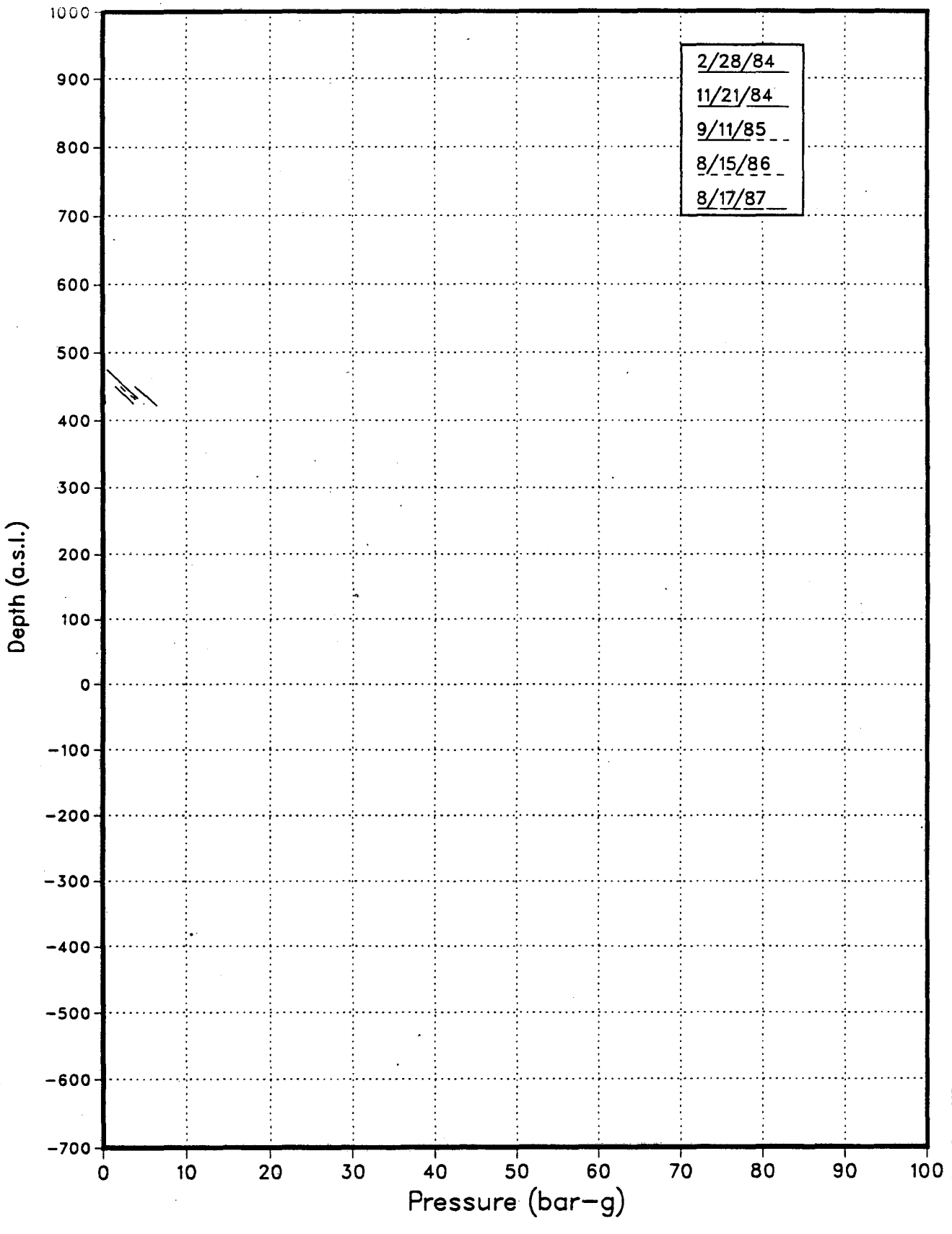

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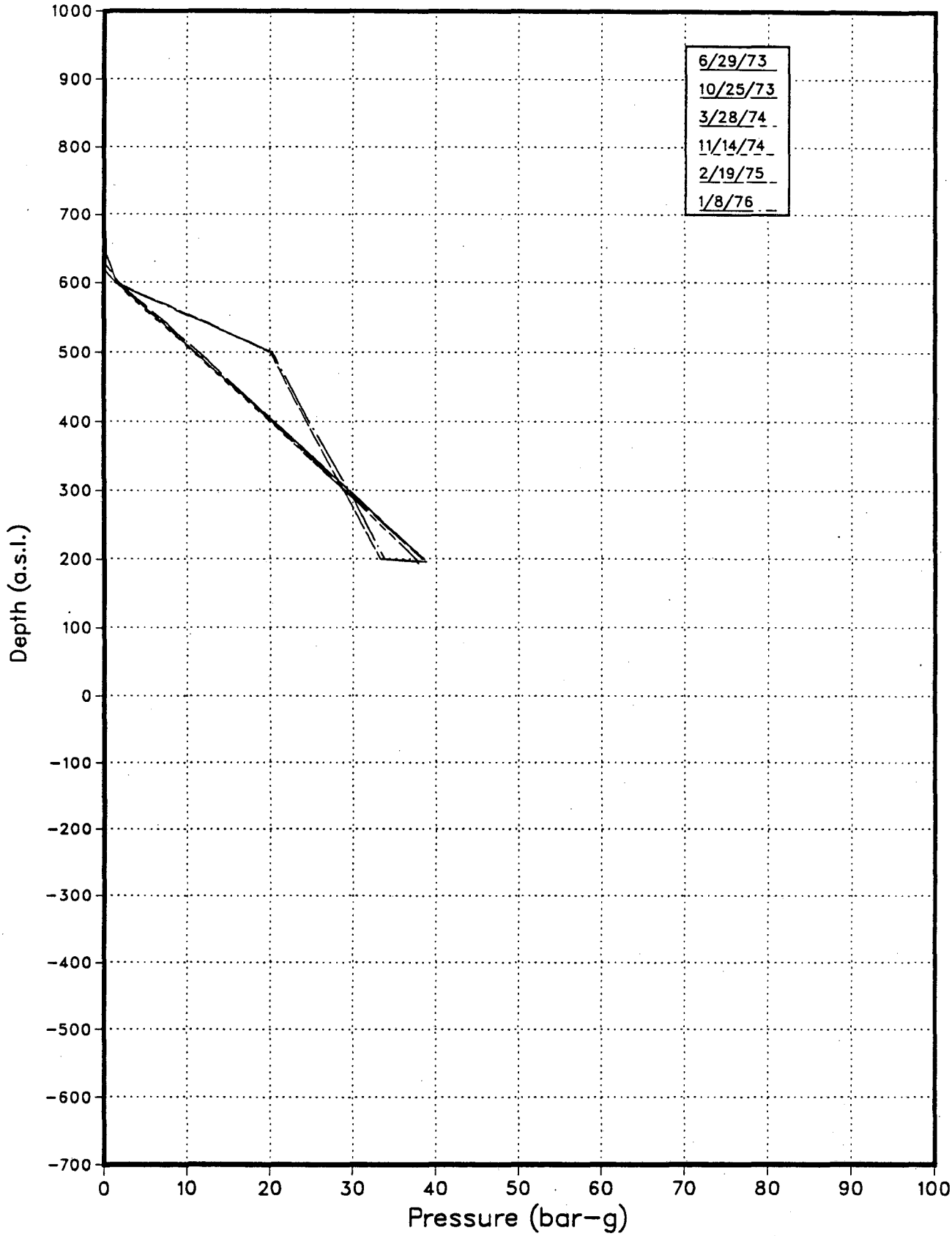
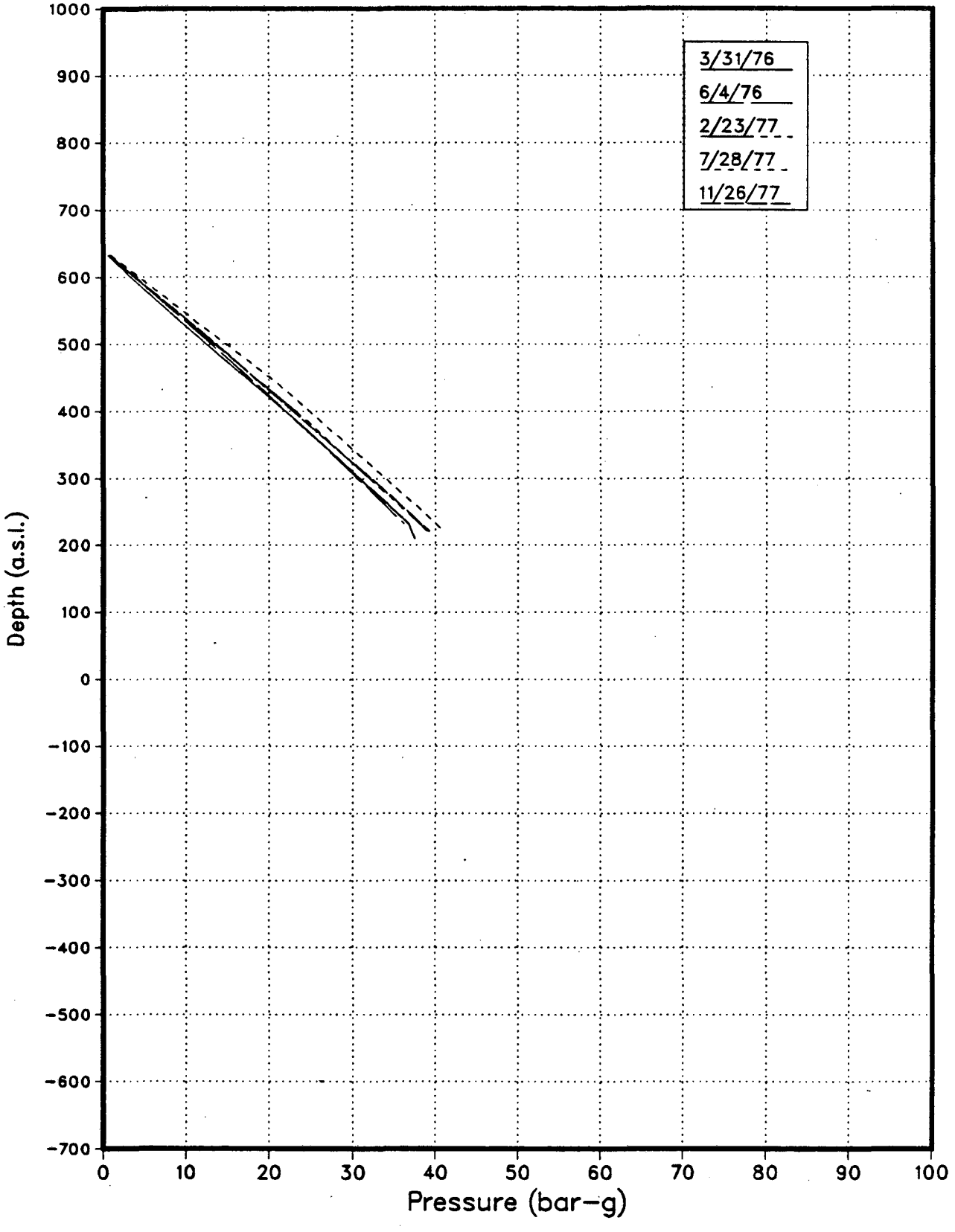


AH12 Pressure Surveys



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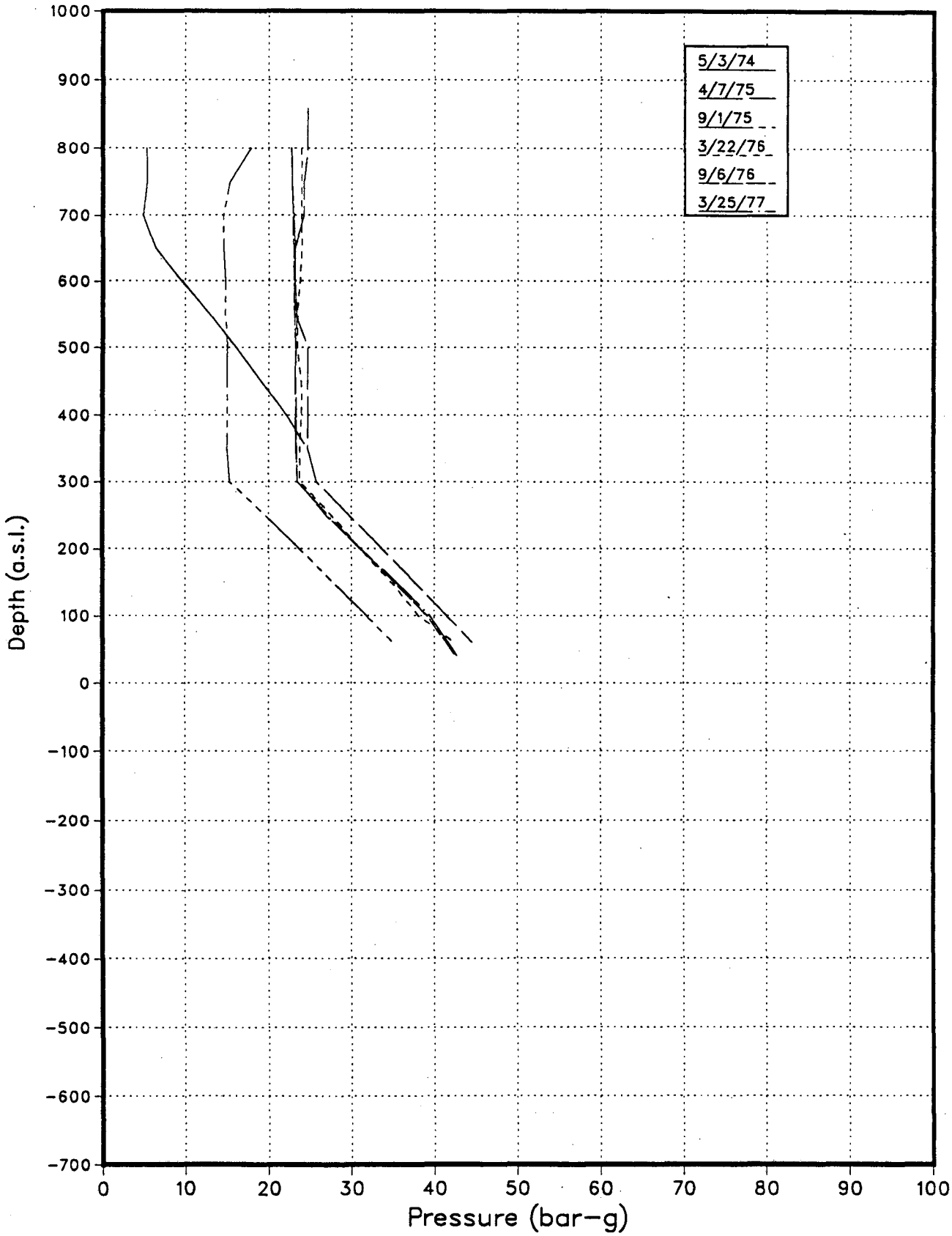
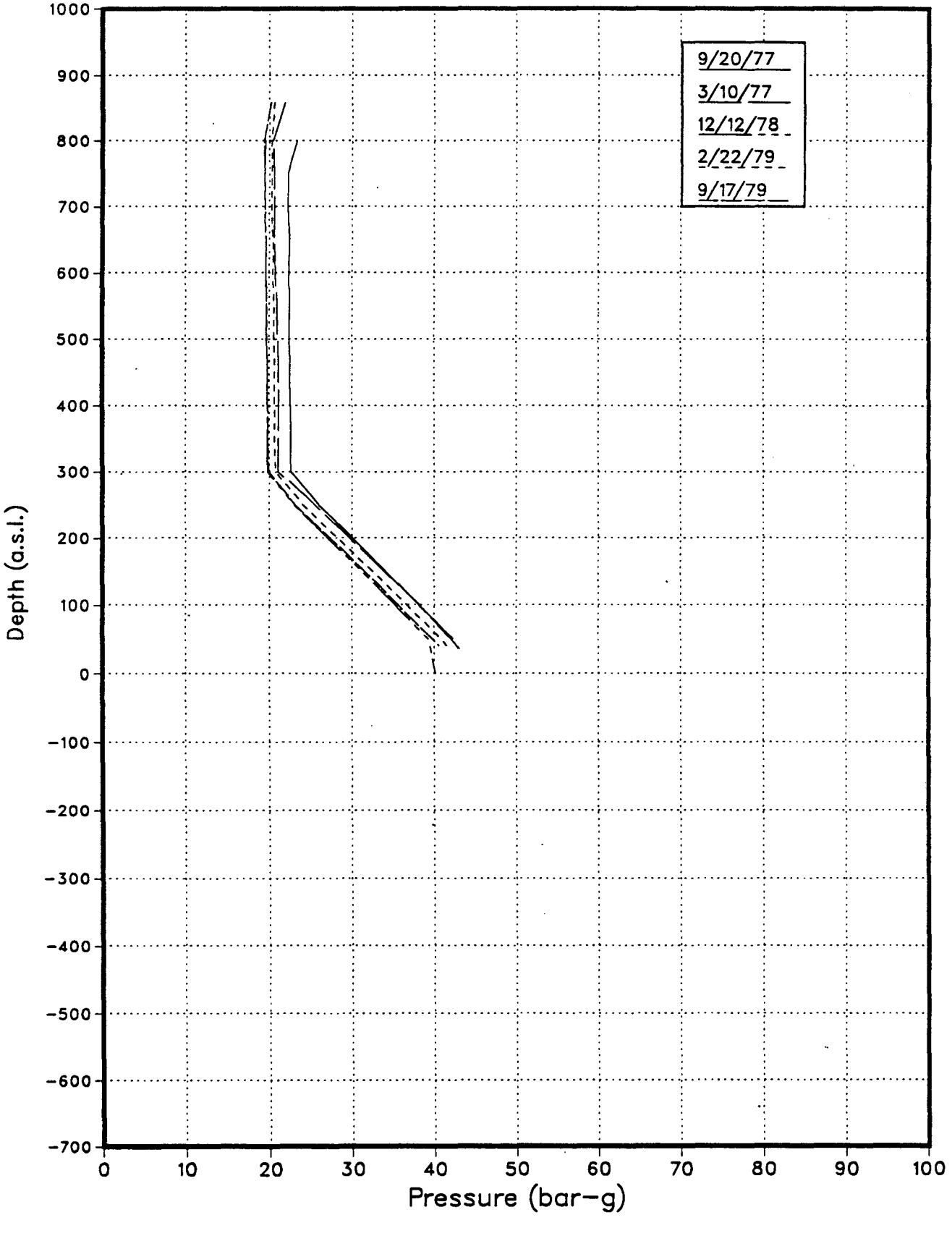


AH13 Pressure Surveys



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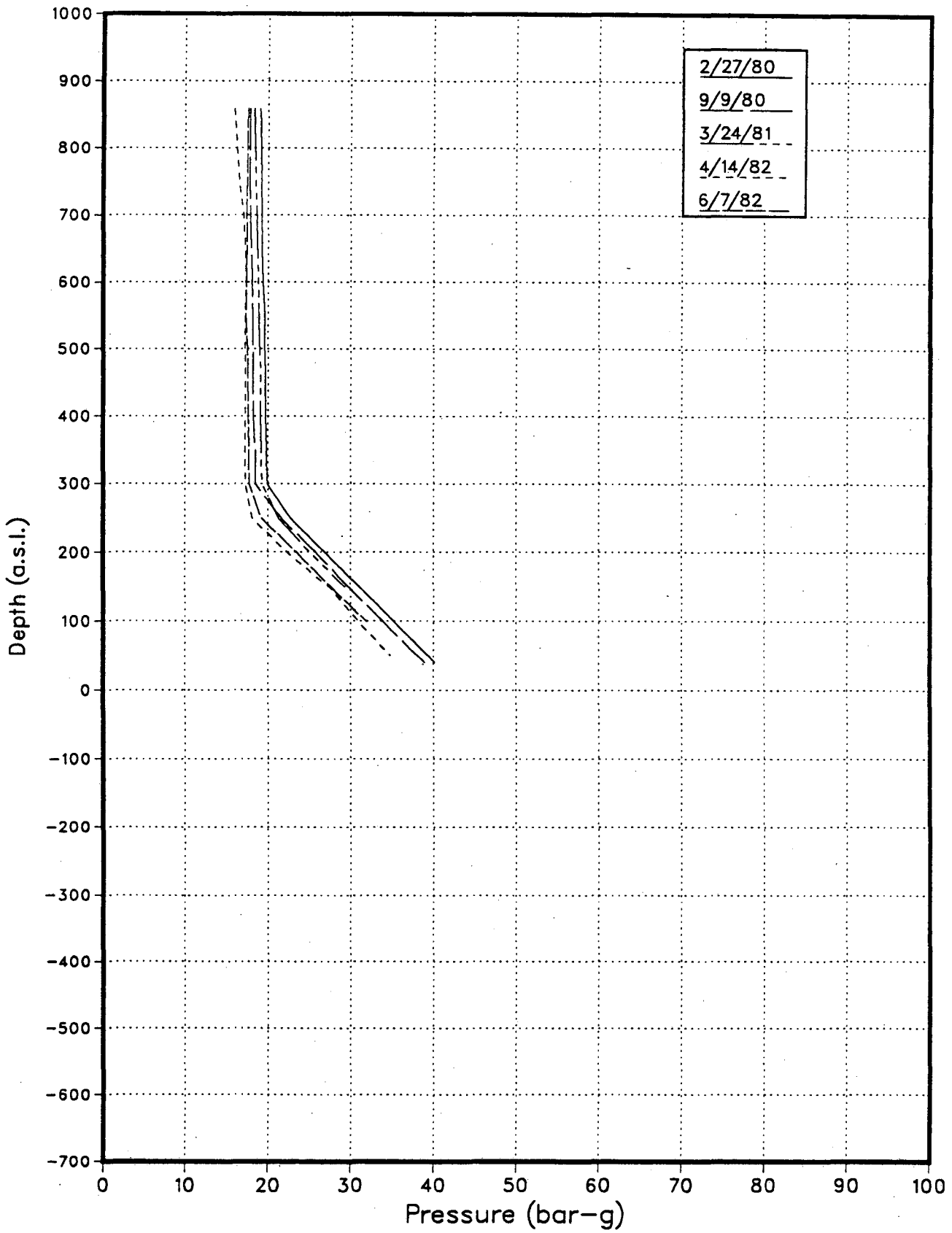

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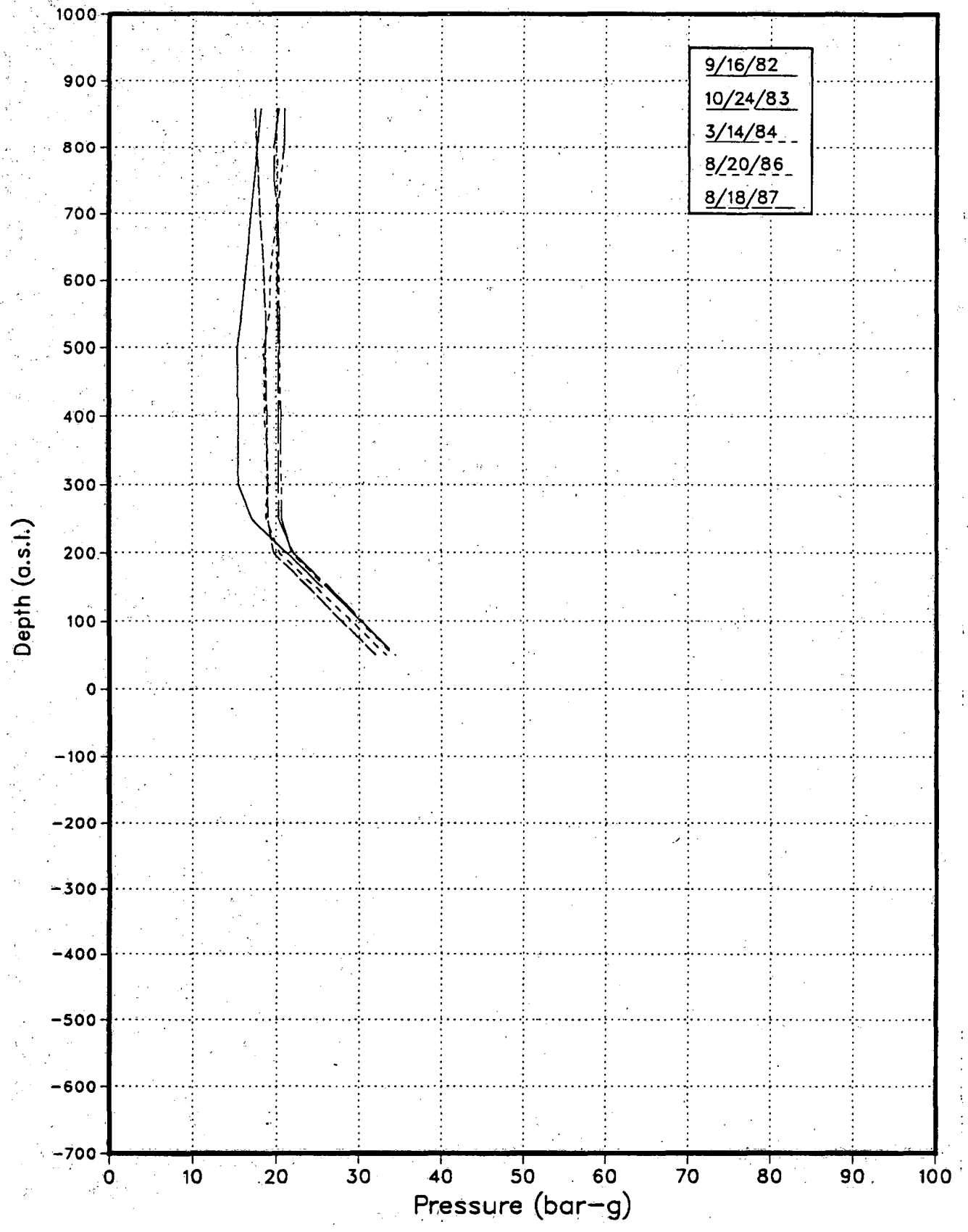
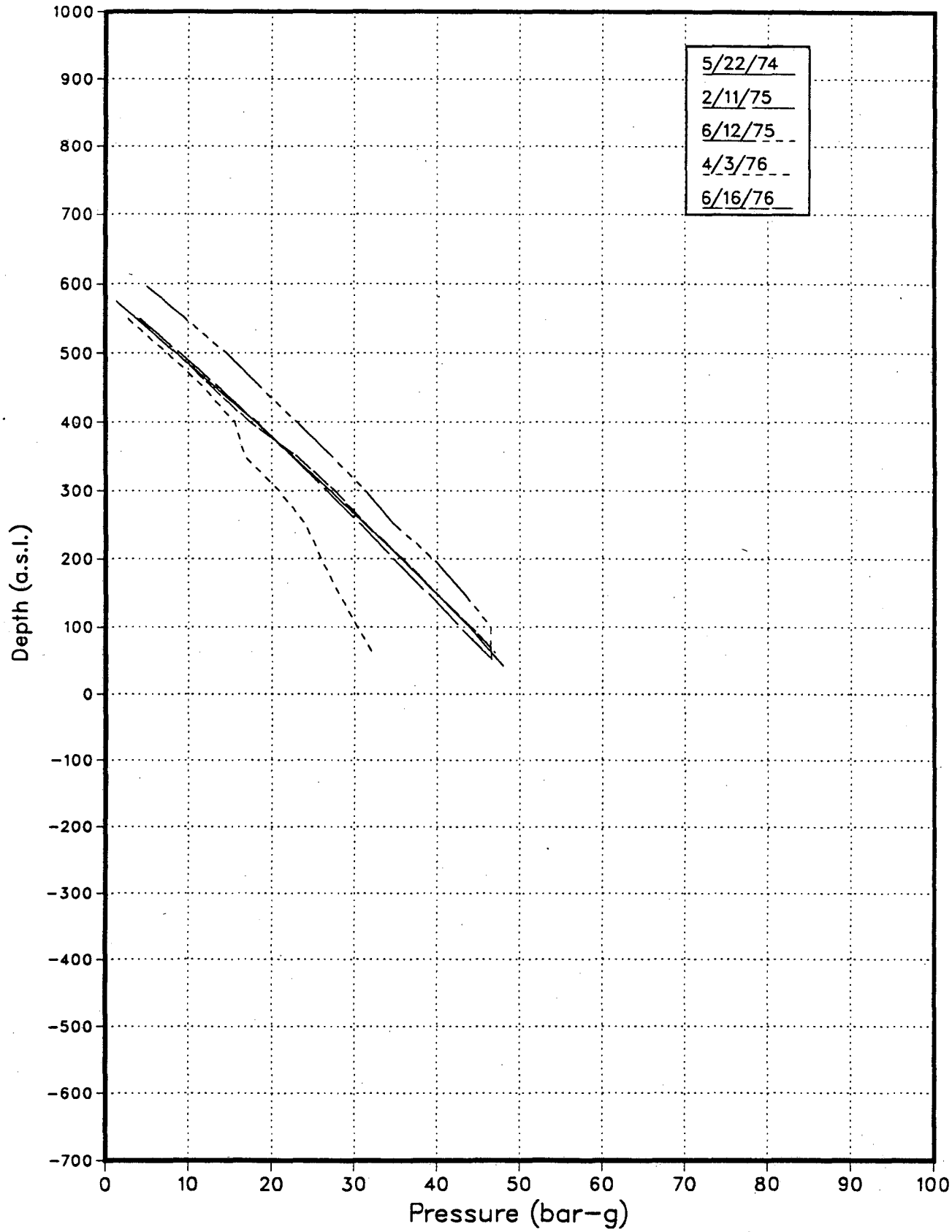


AH14 Pressure Surveys



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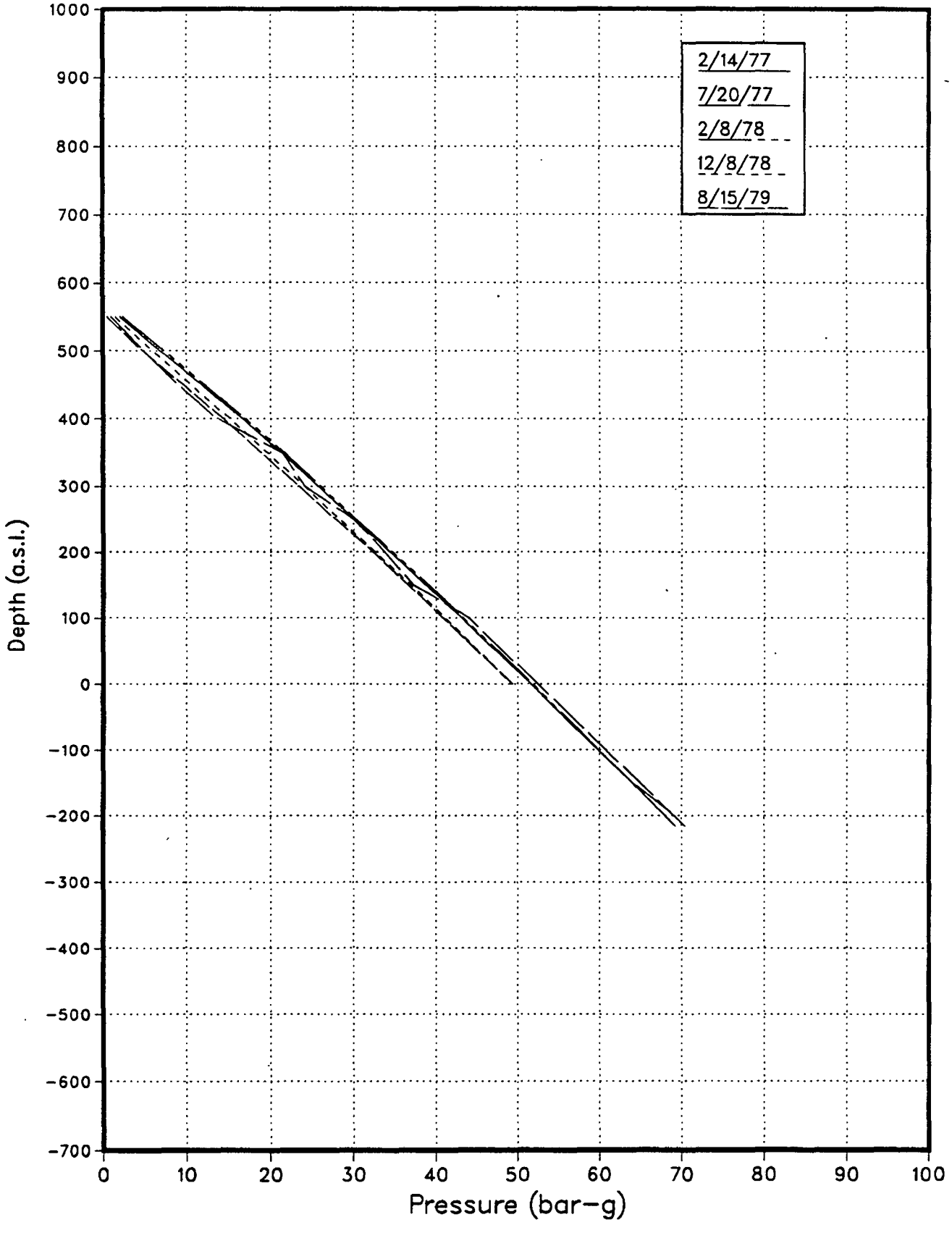

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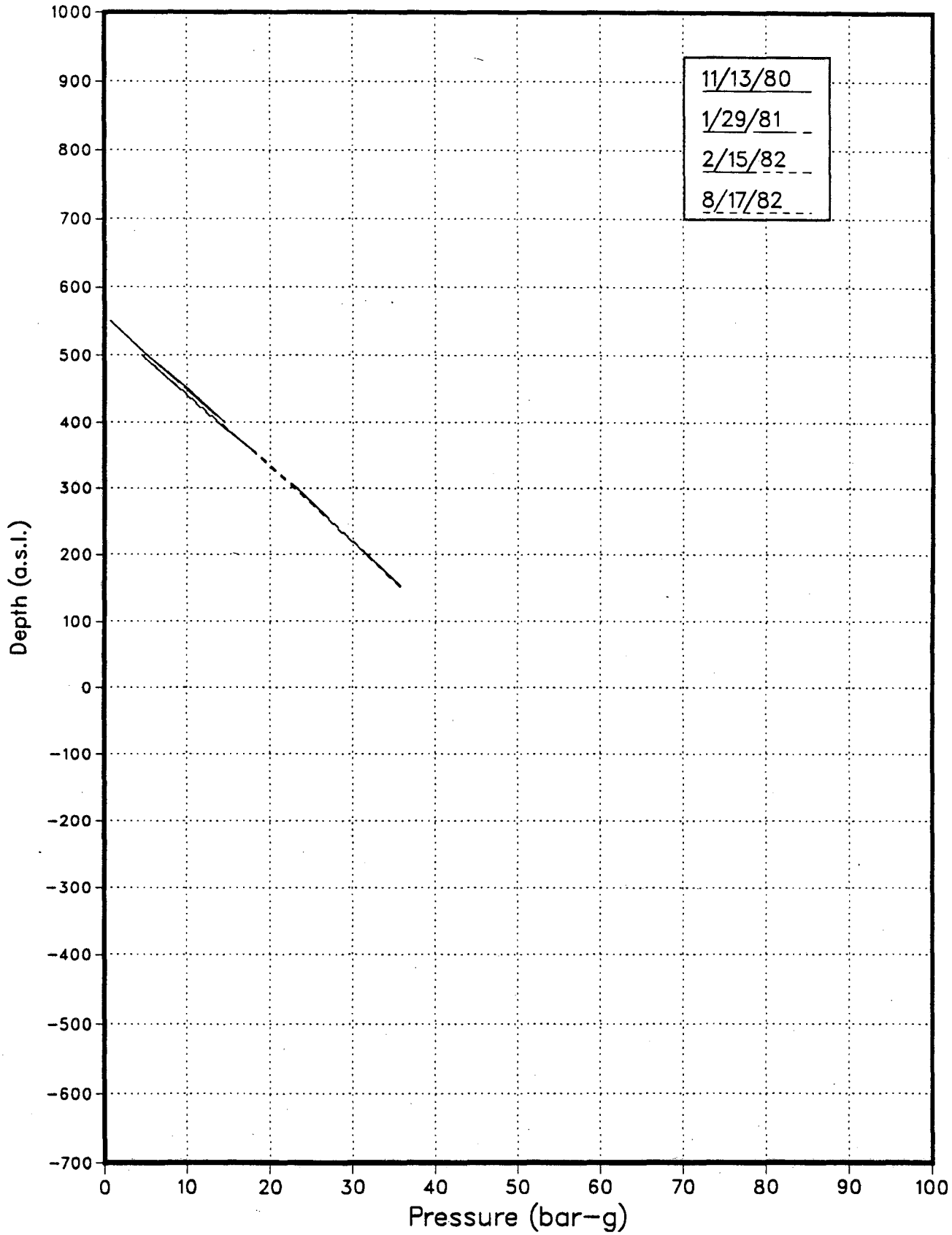

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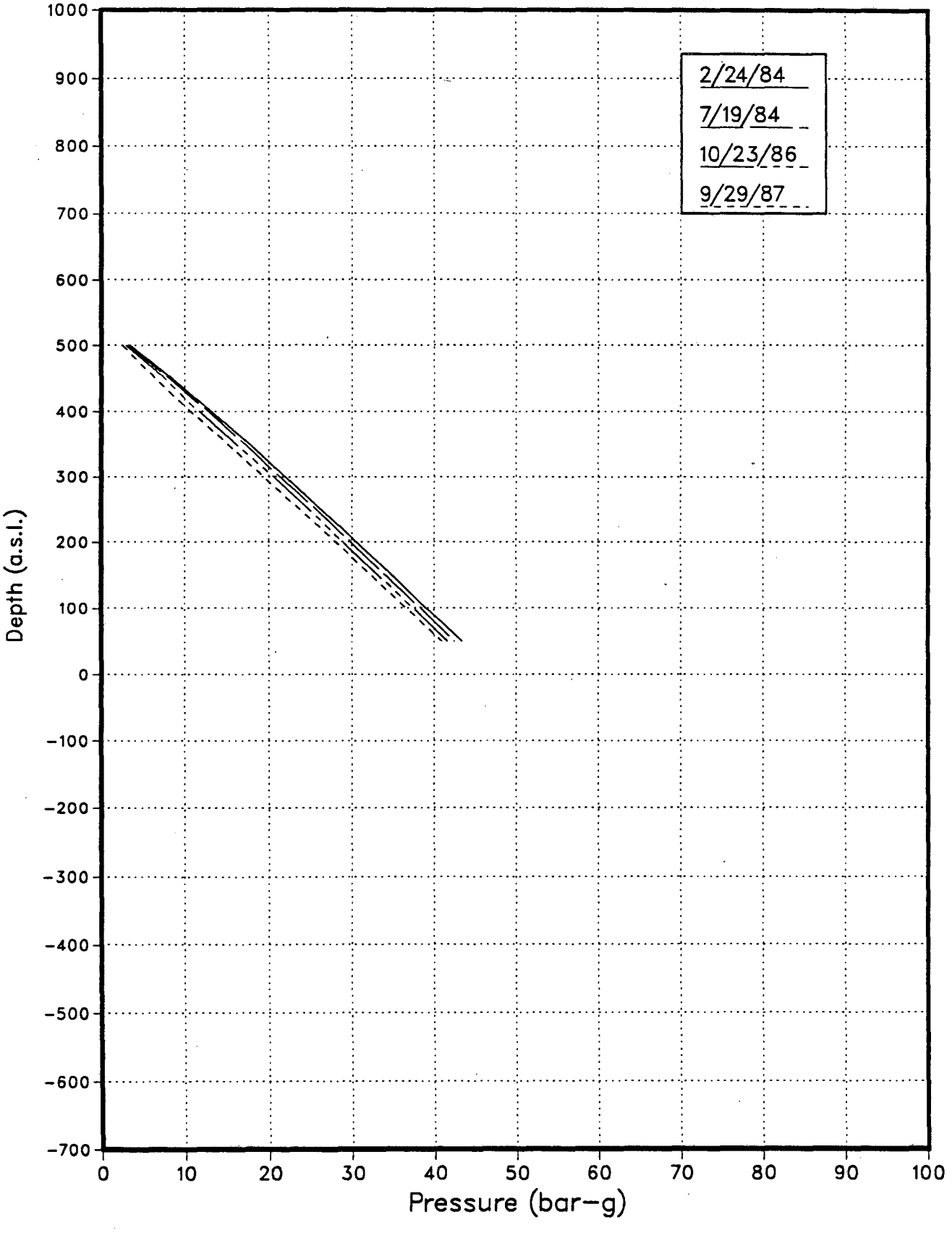
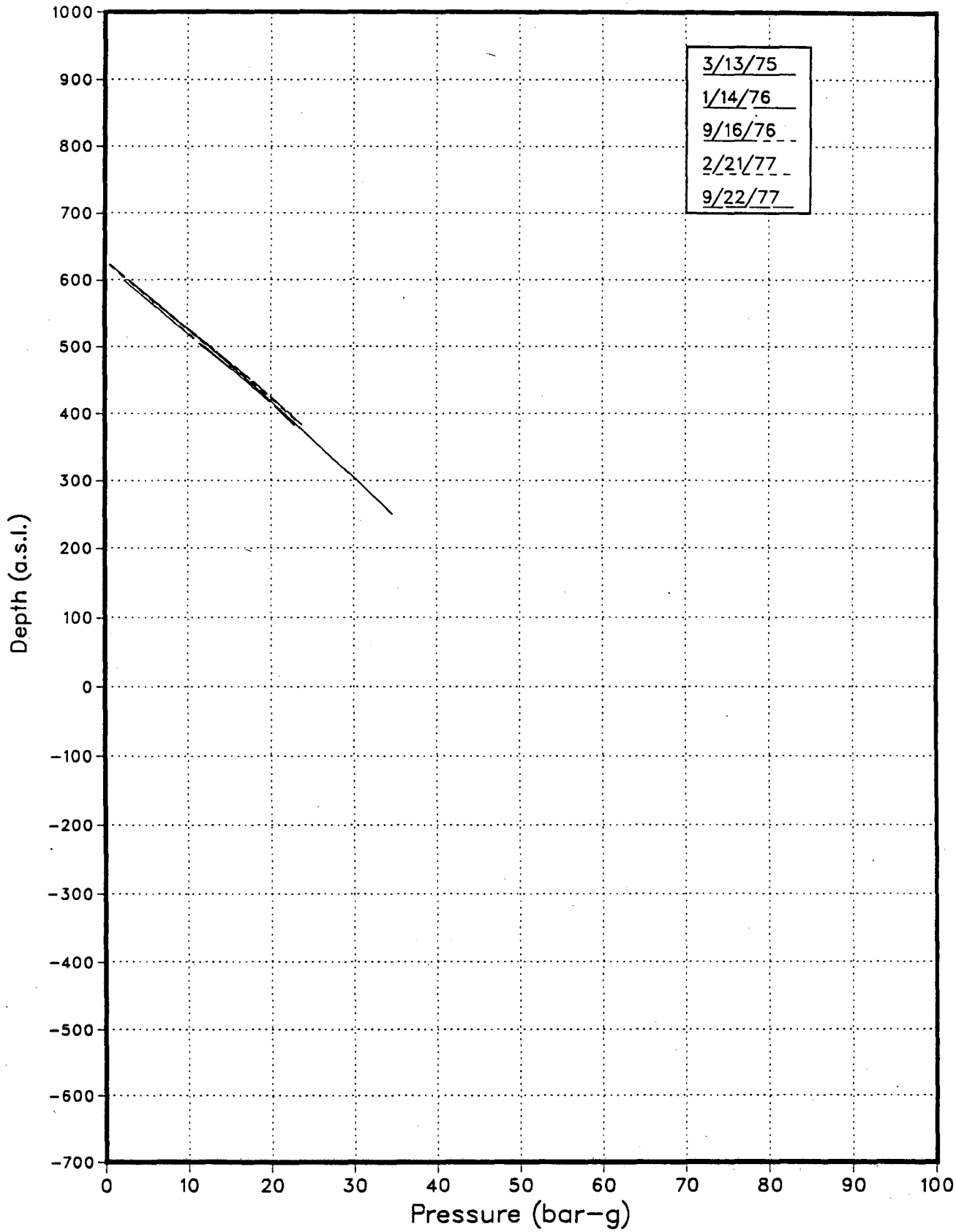


AH15 Pressure Surveys



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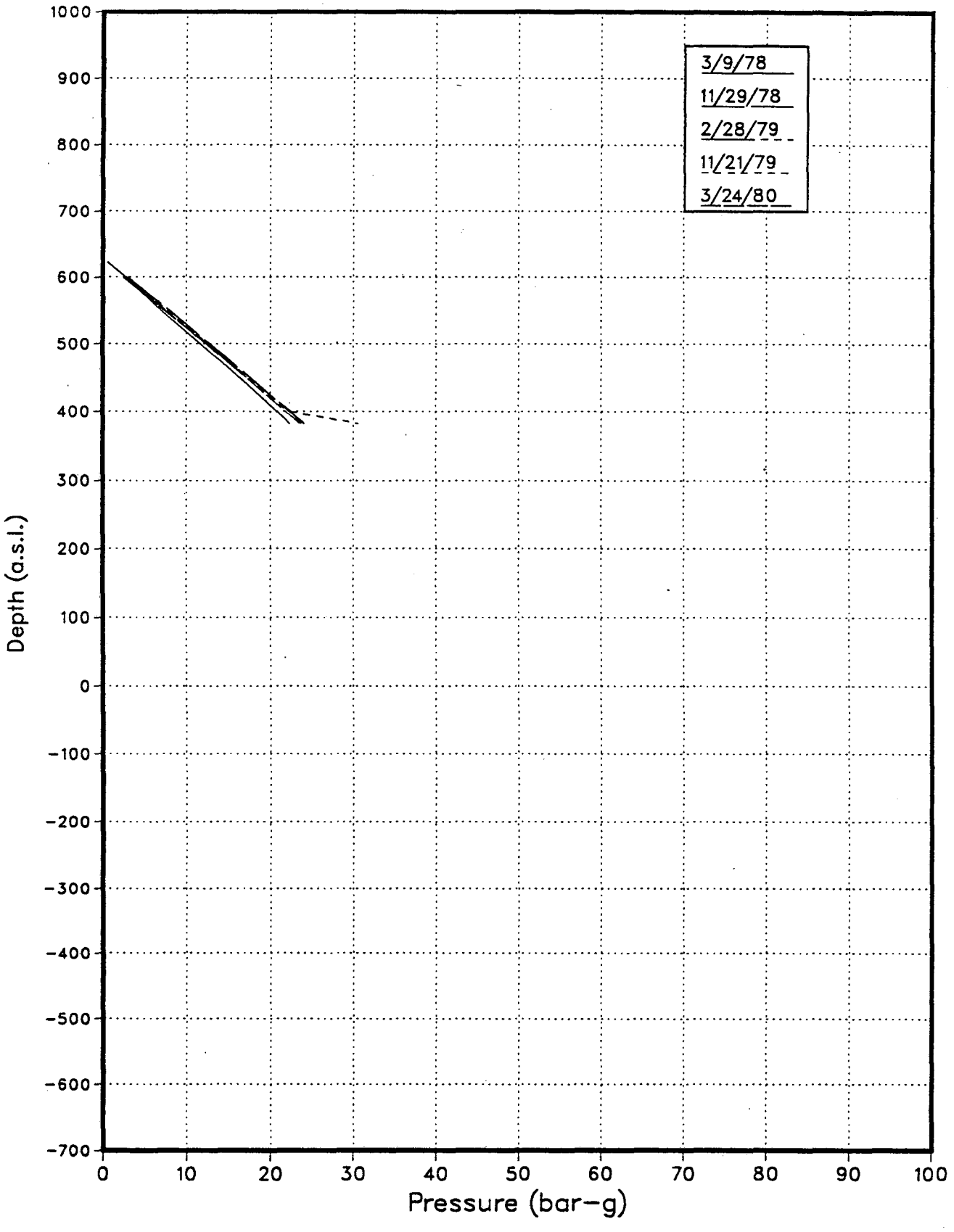

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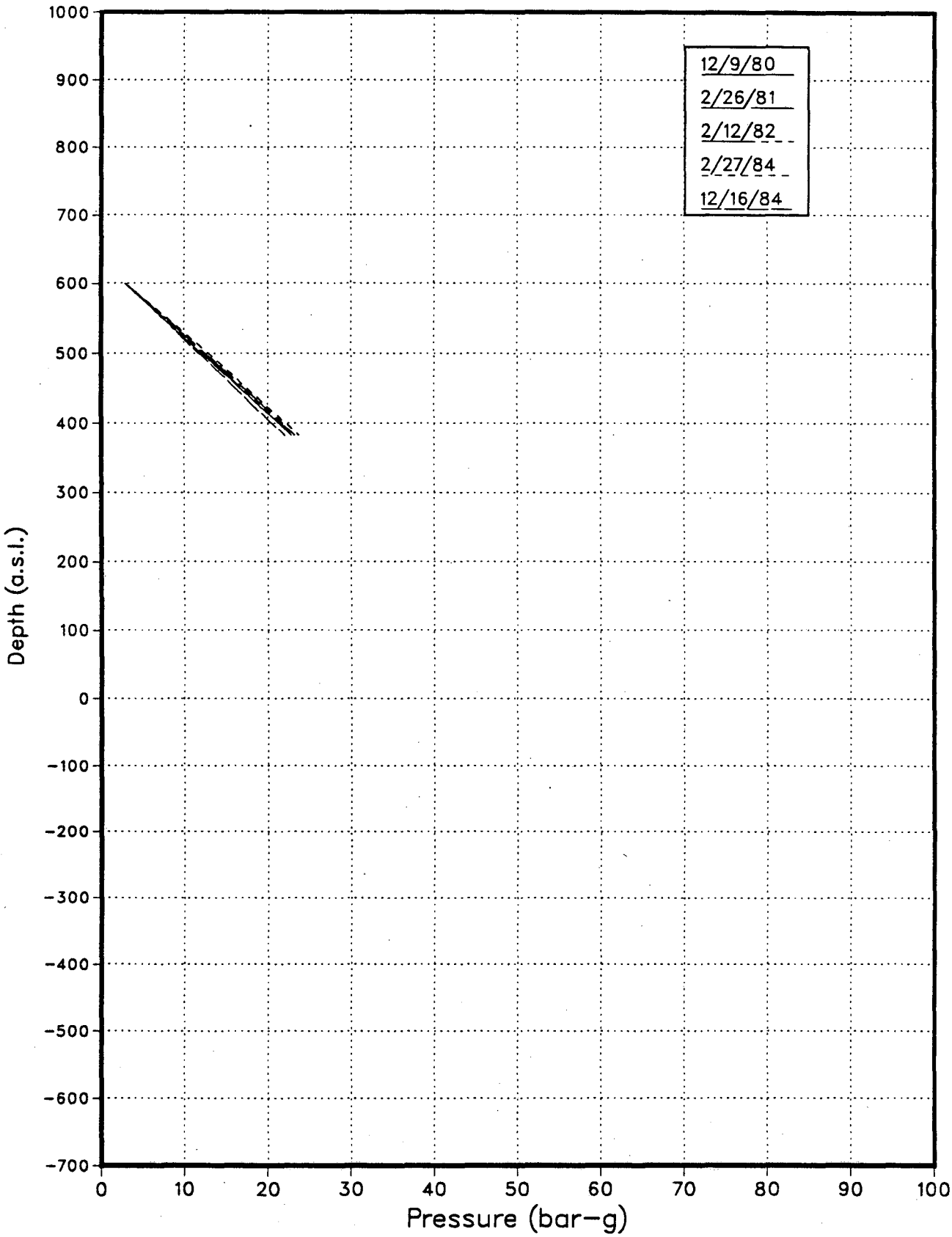

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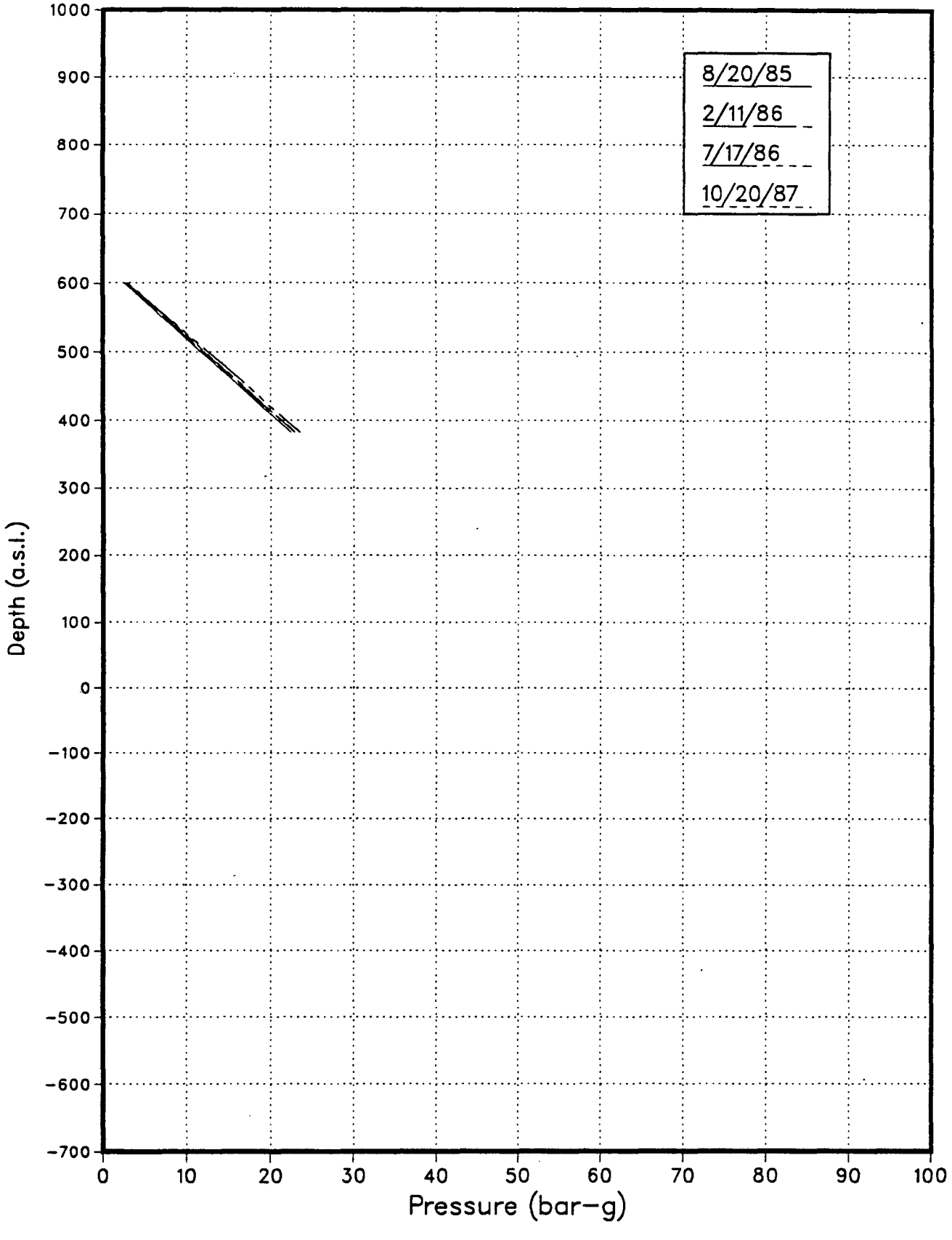
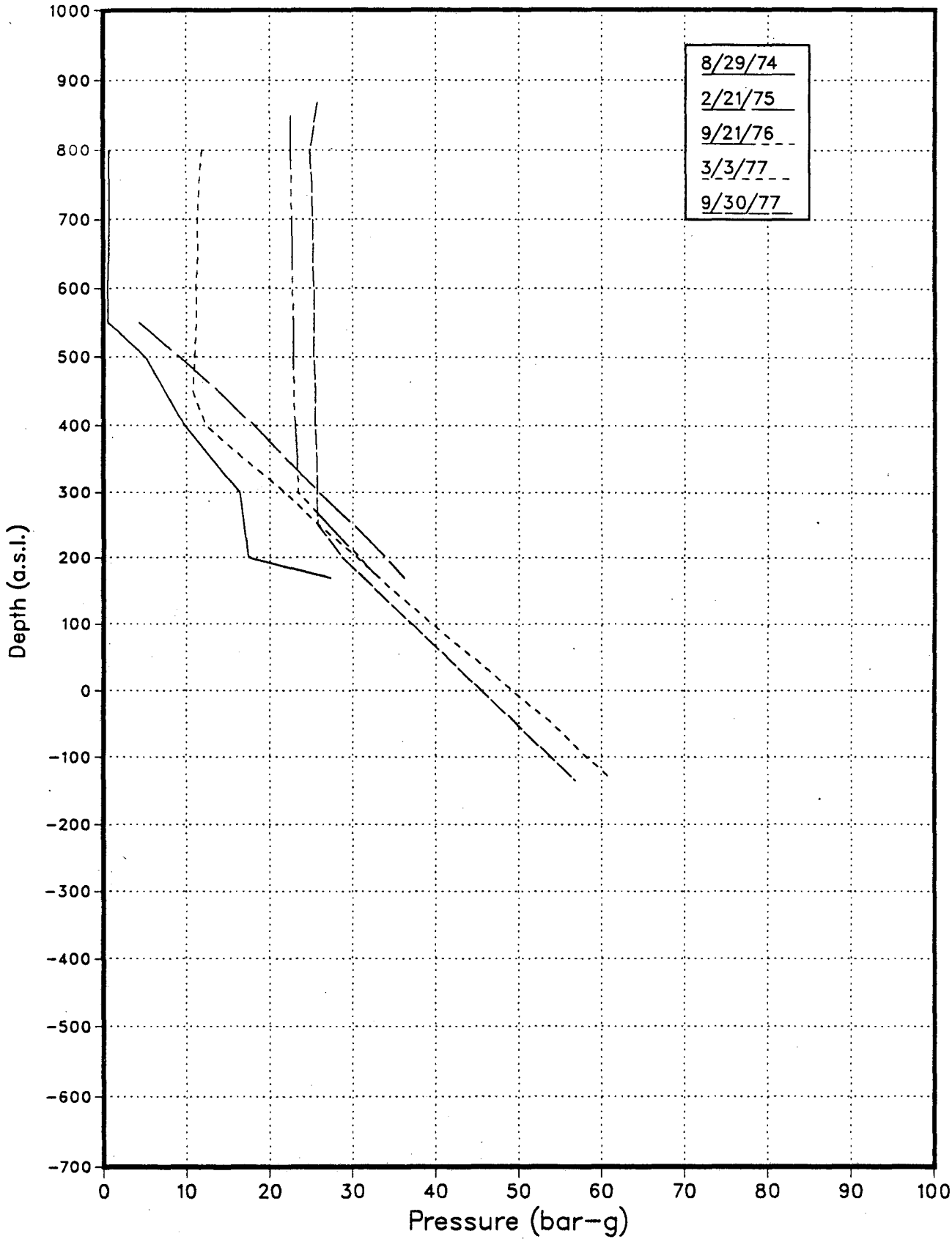


AH16 Pressure Surveys



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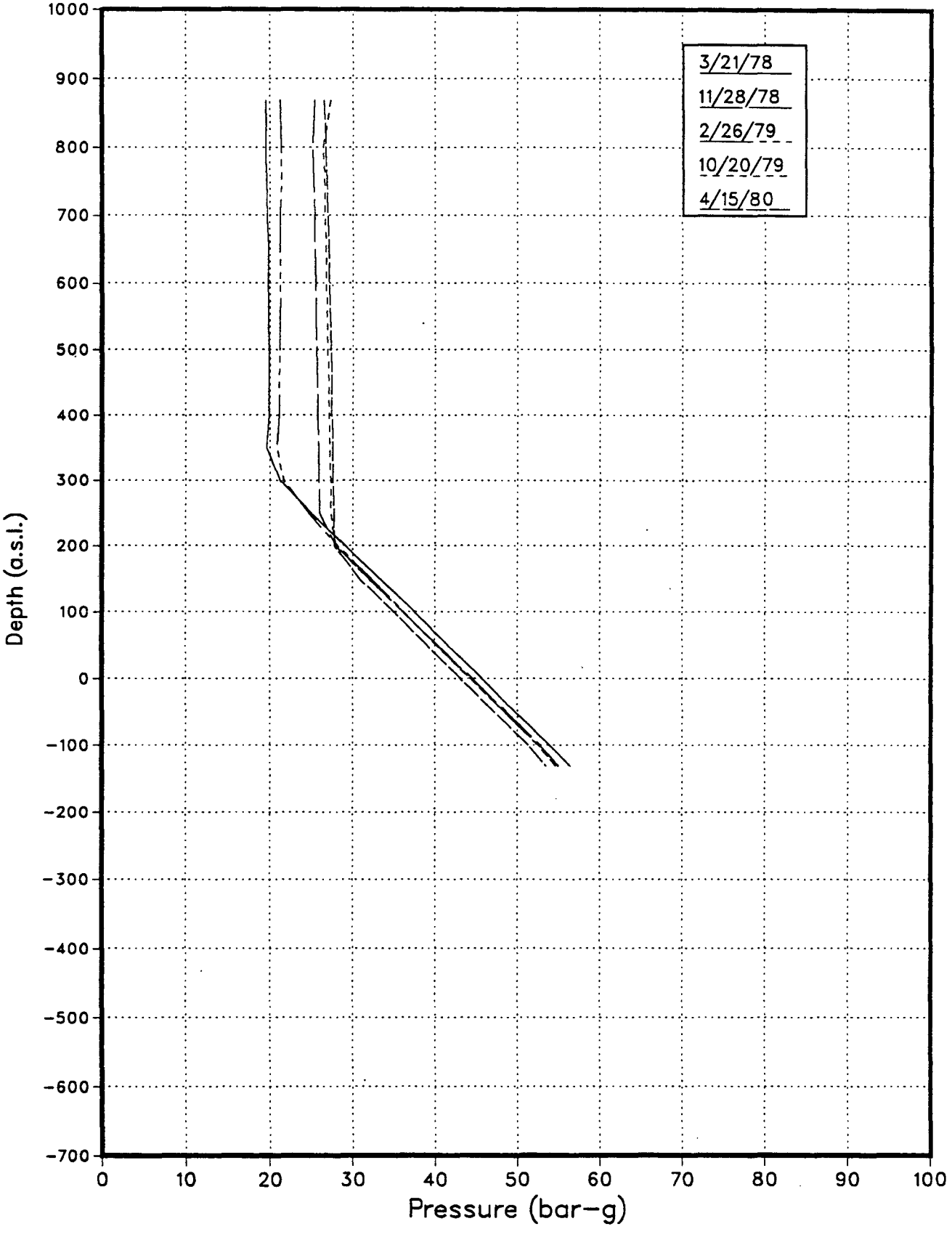

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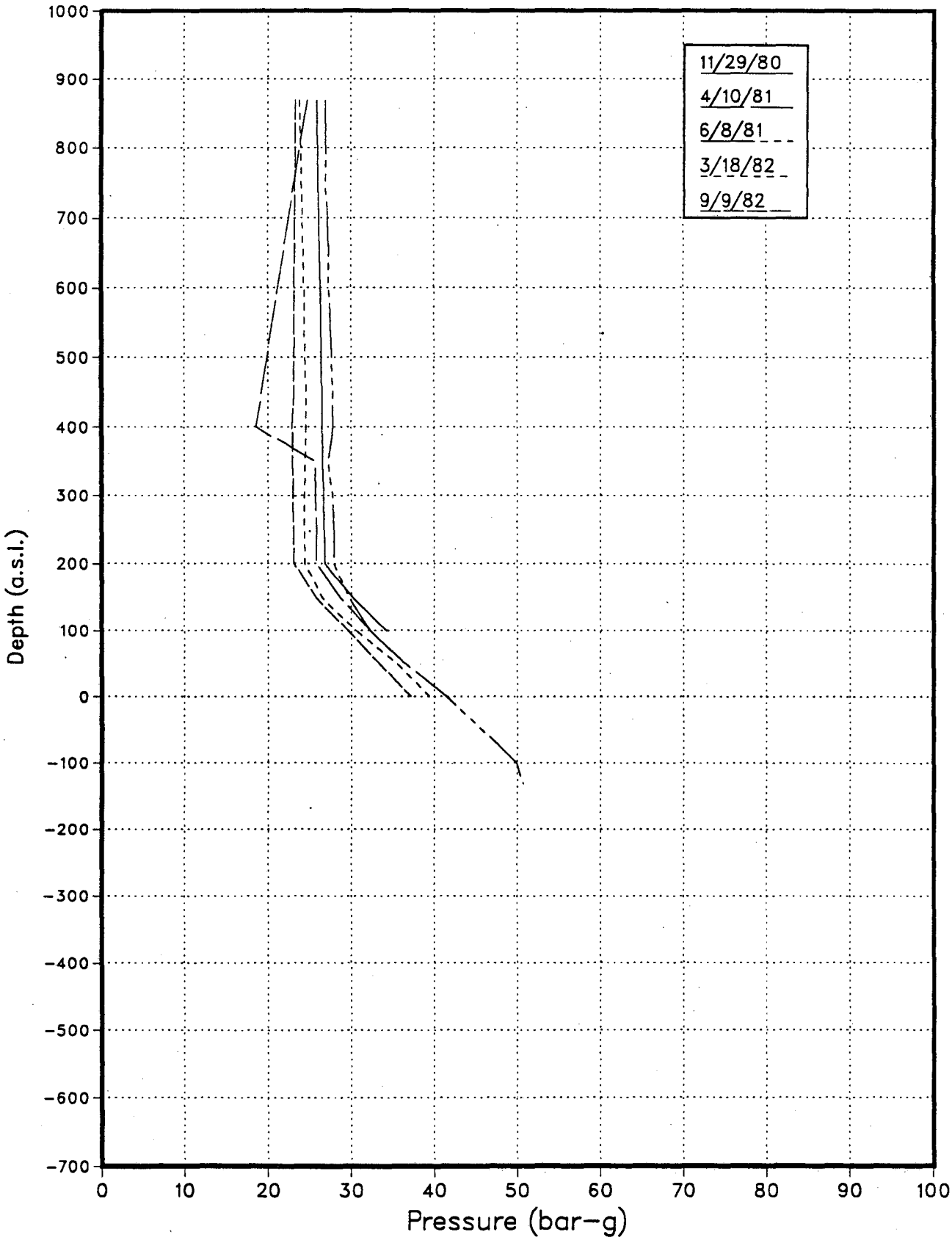

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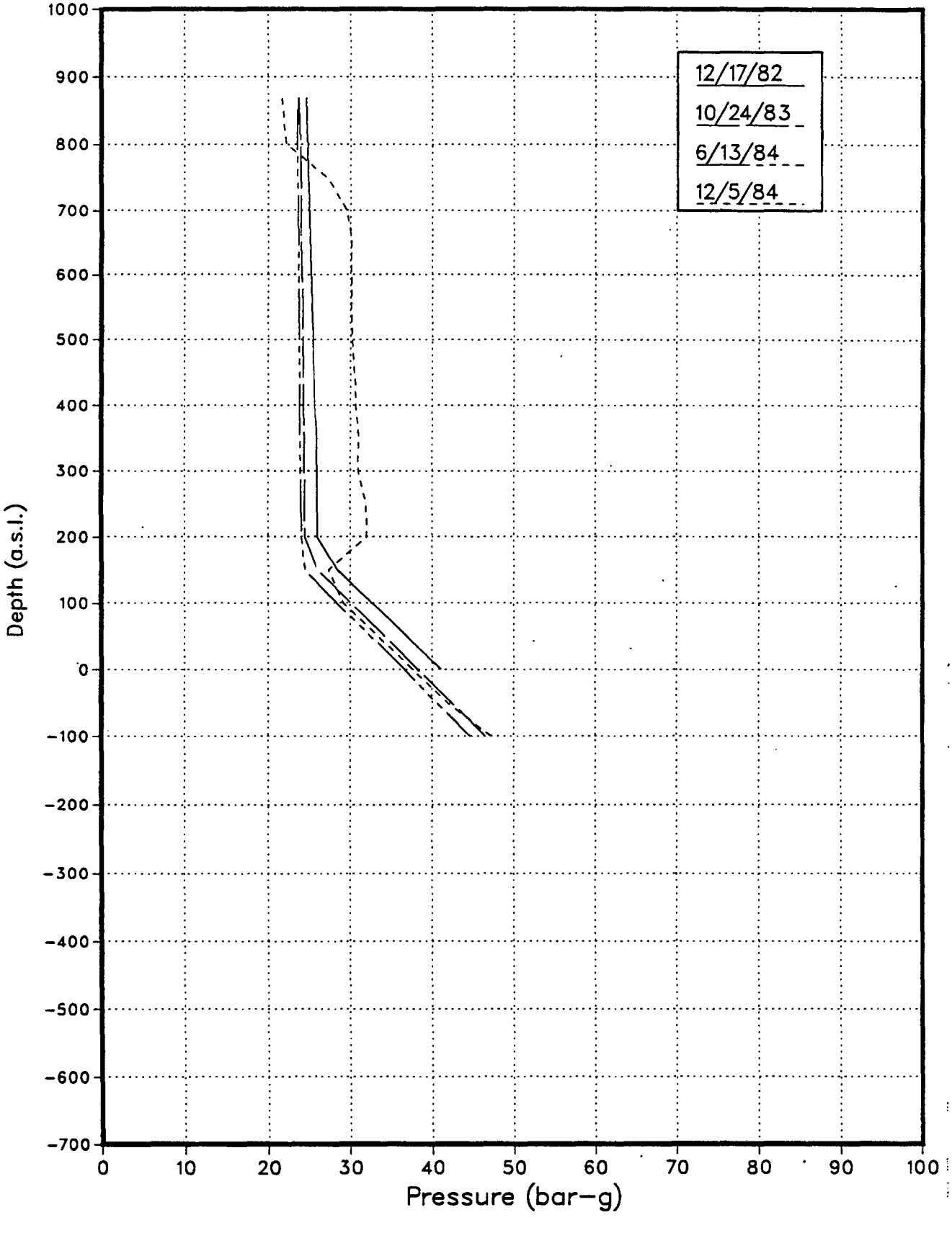

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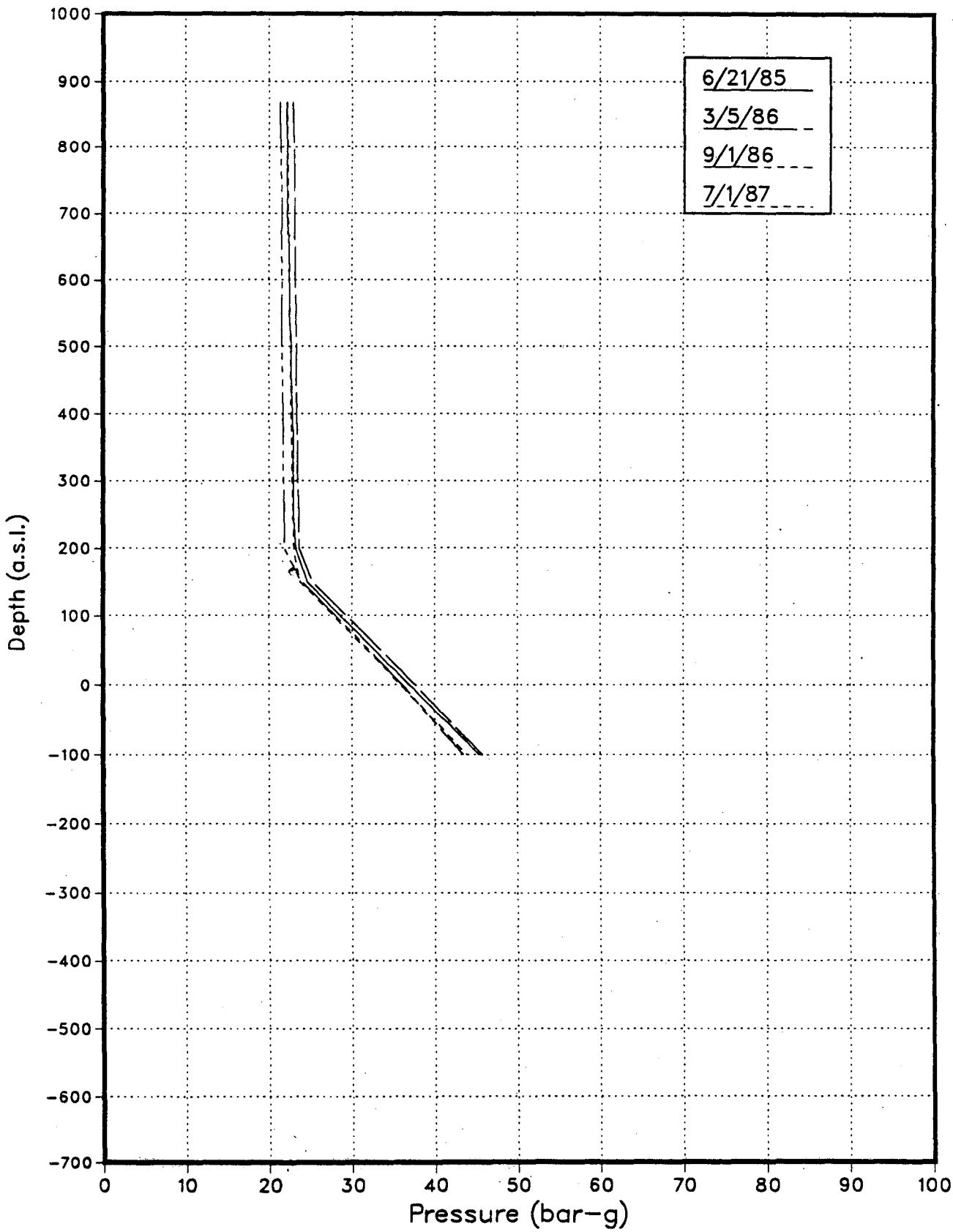

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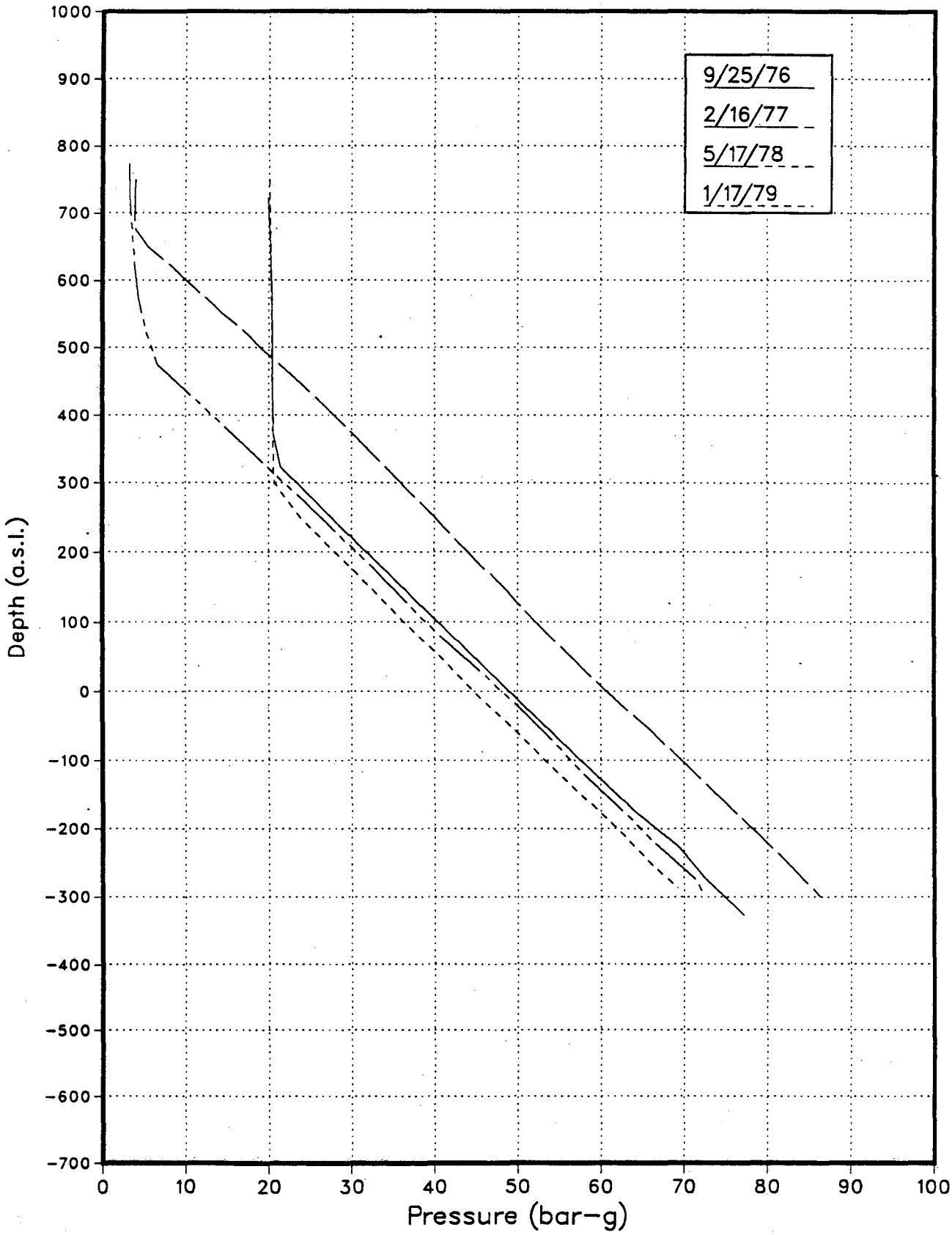

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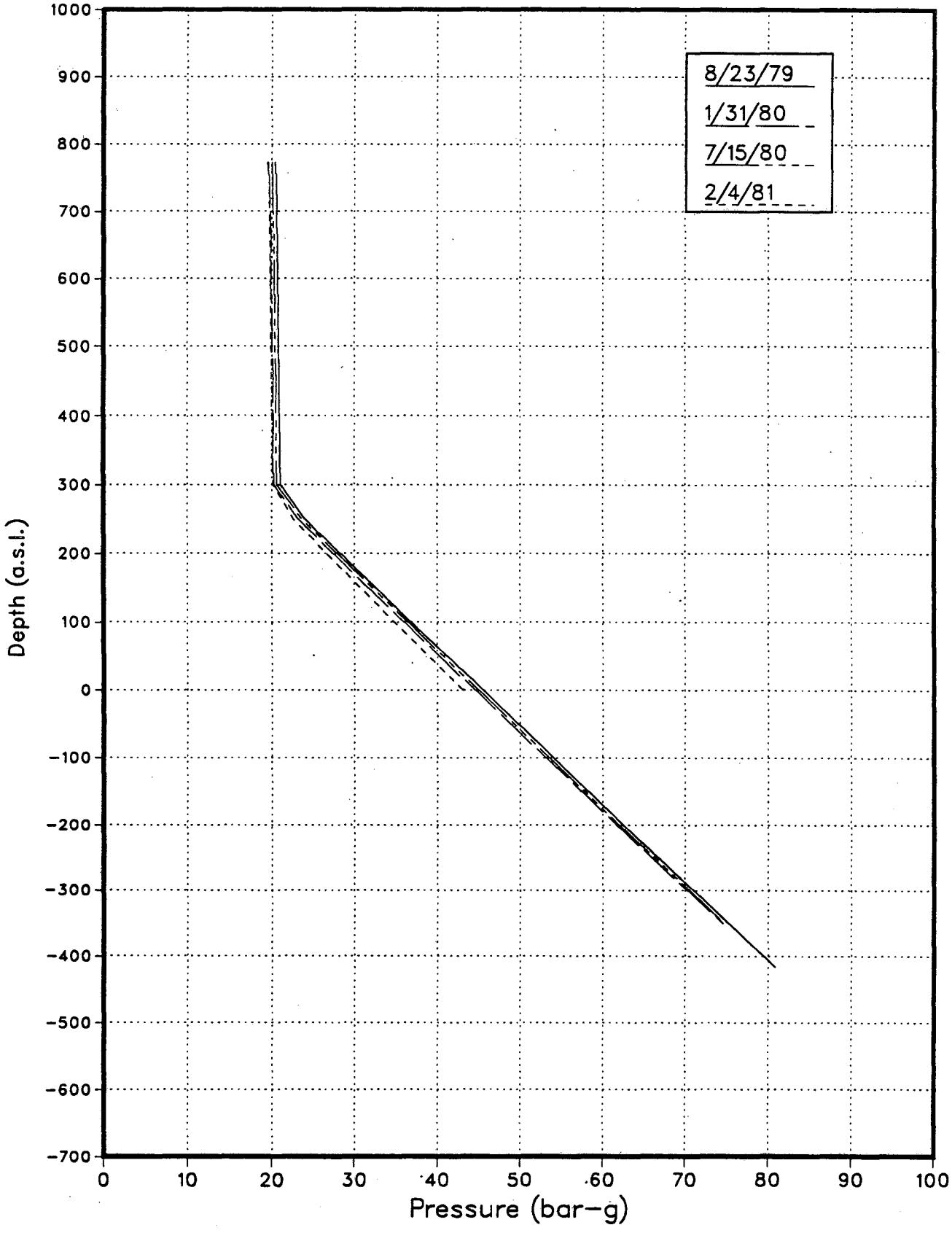

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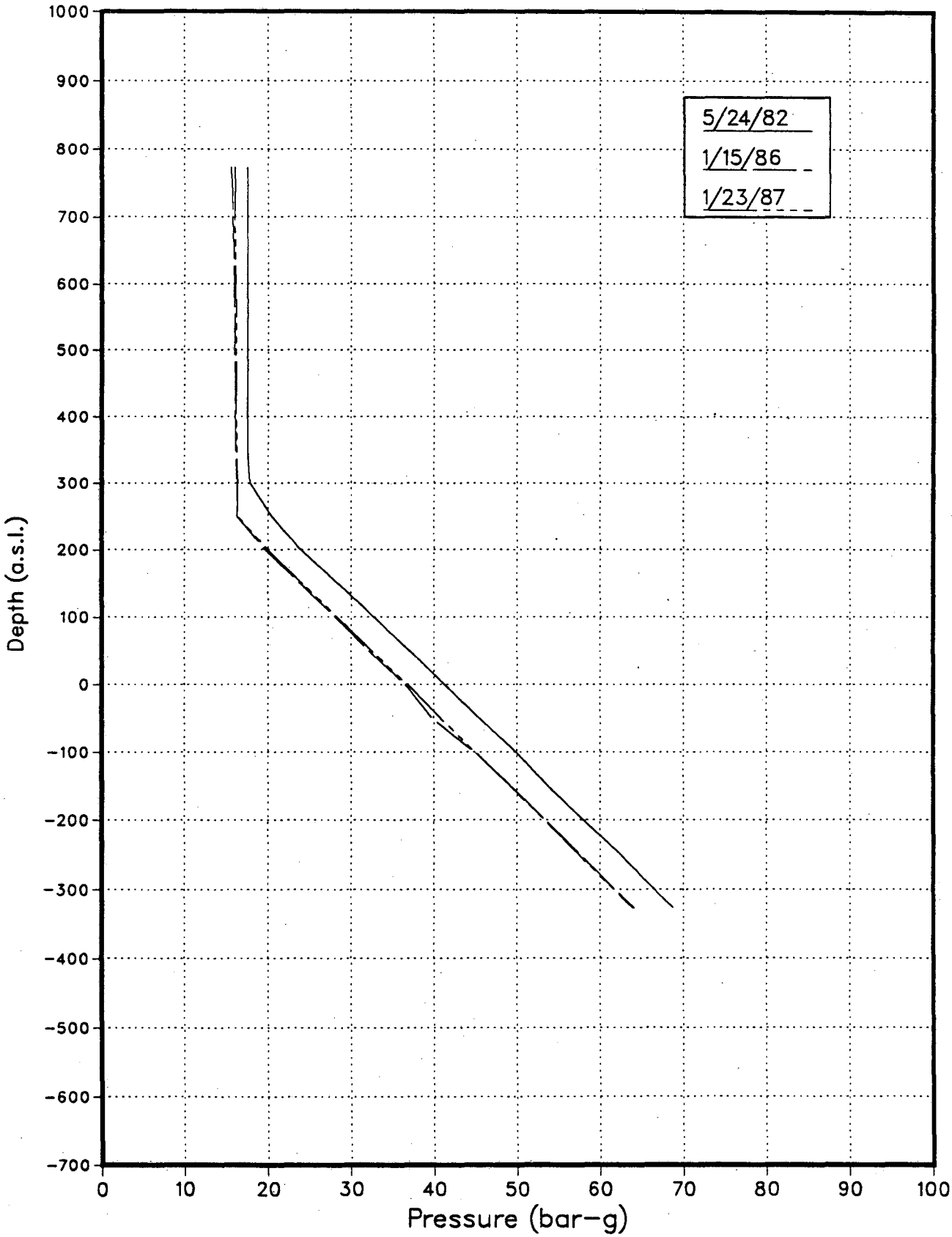

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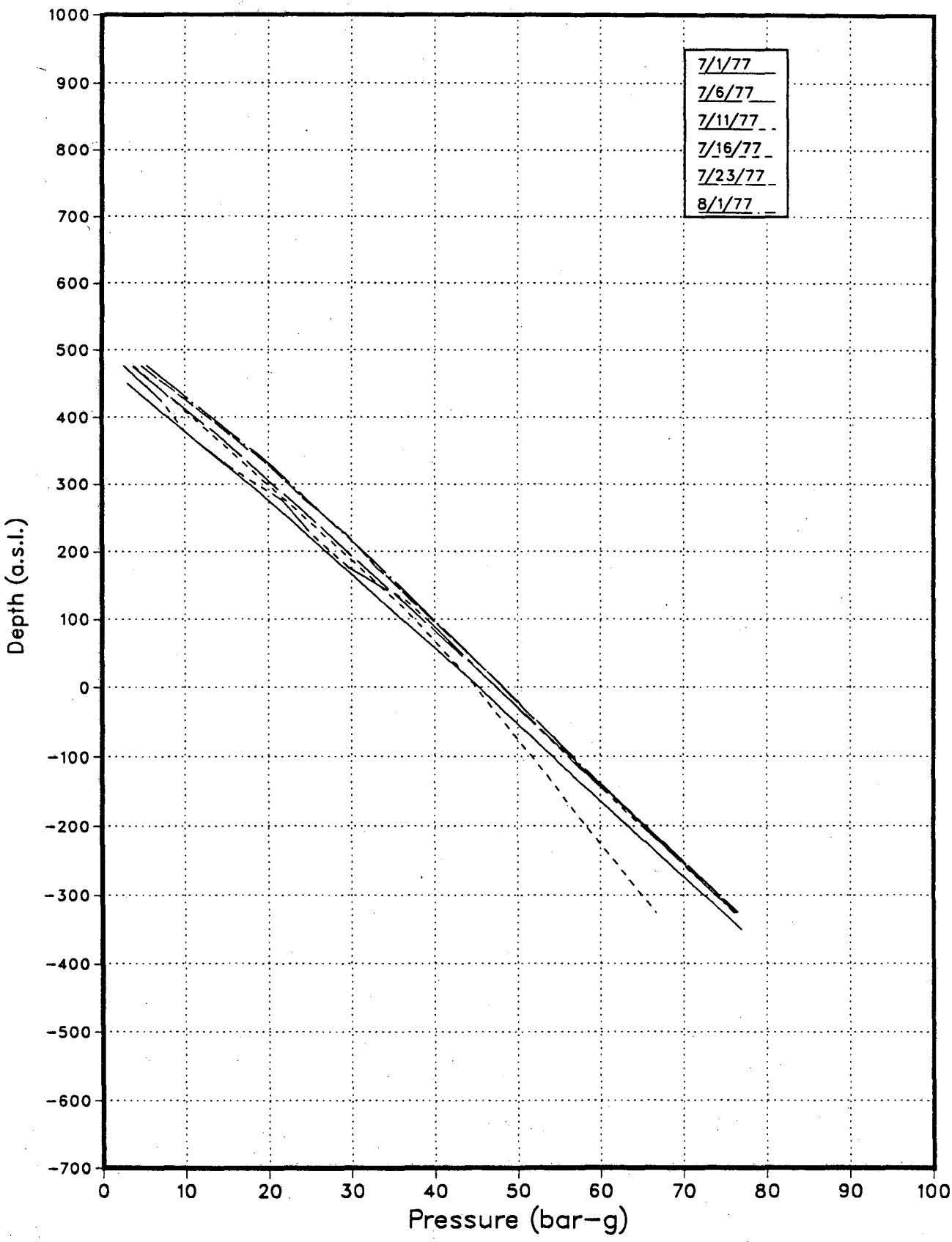

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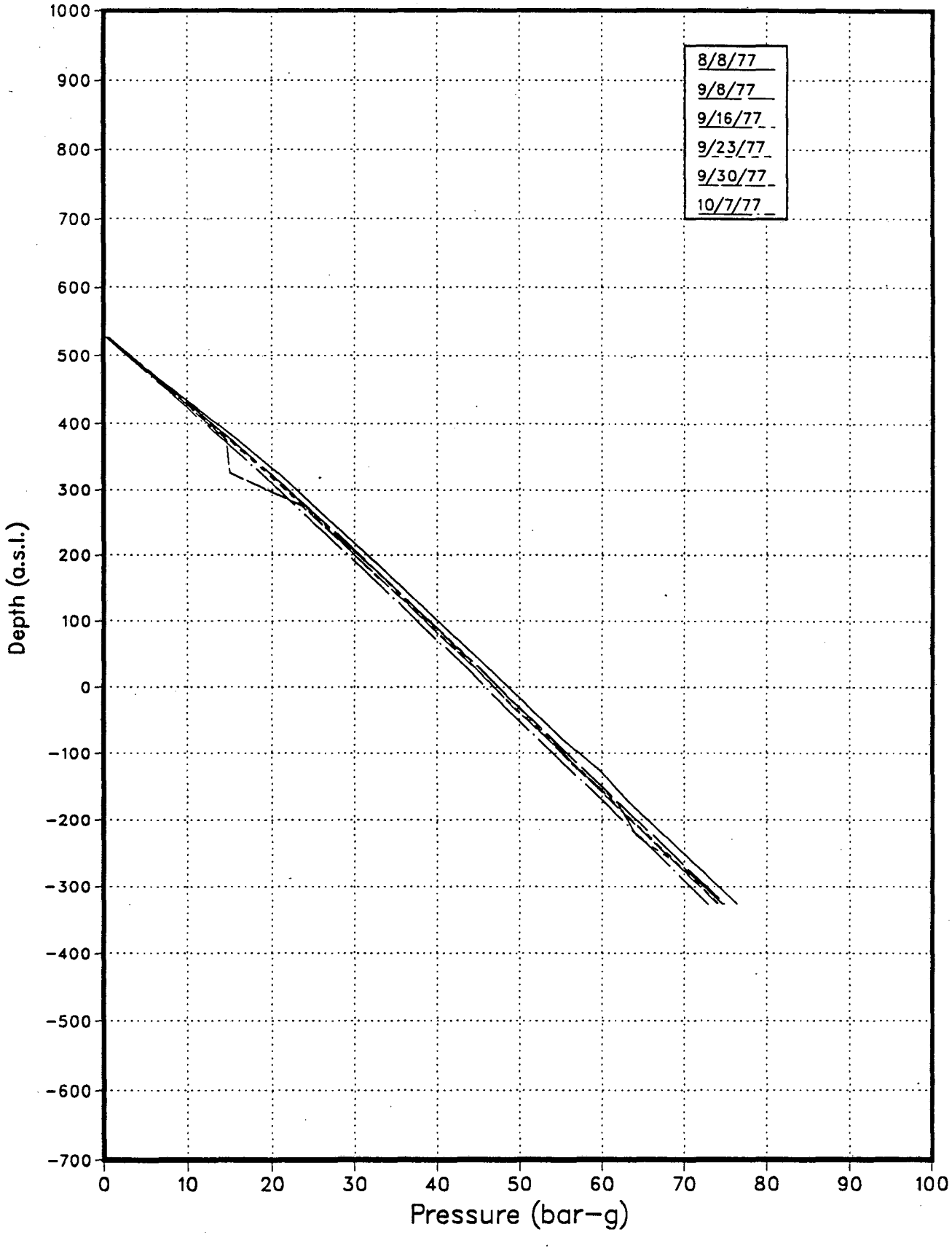

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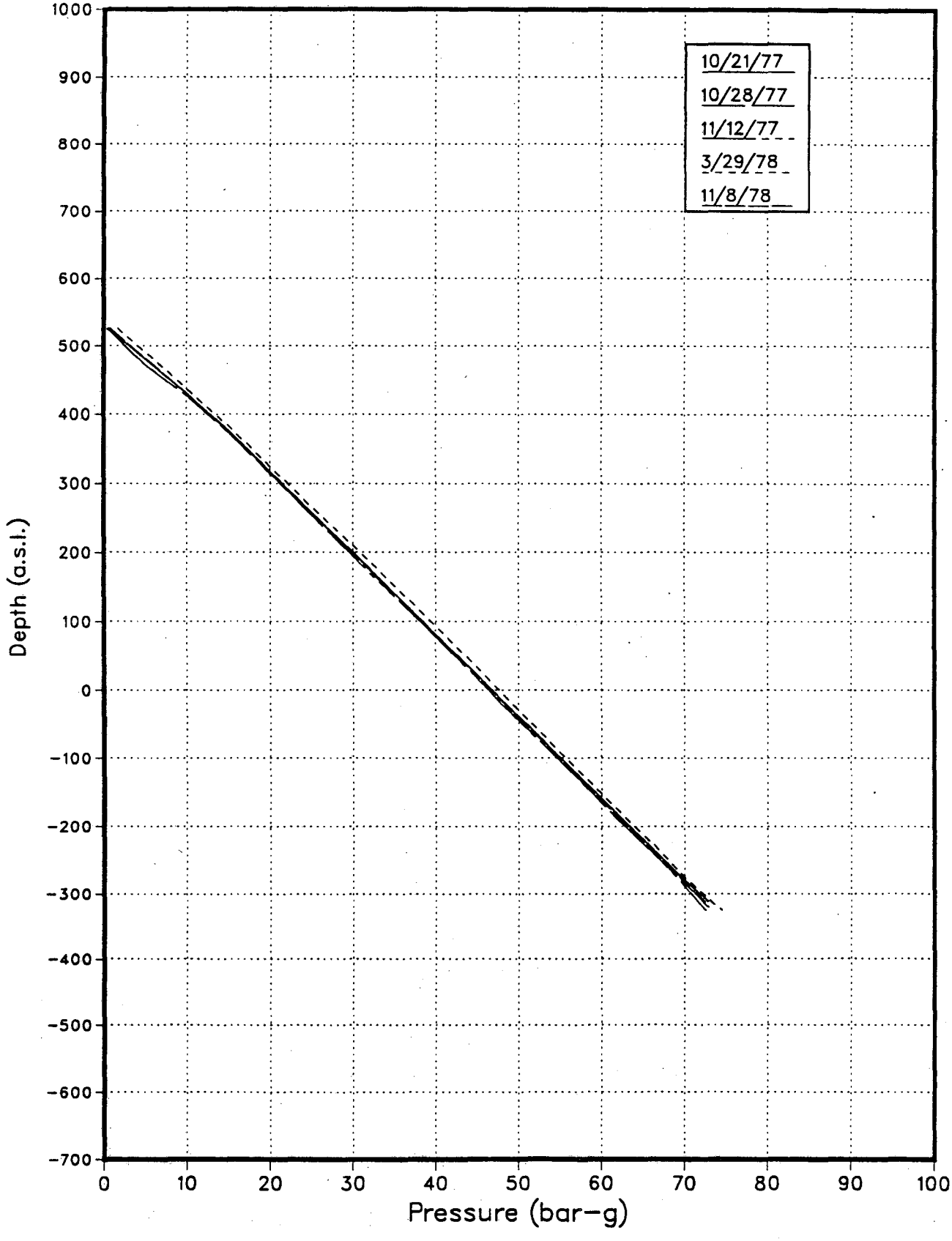

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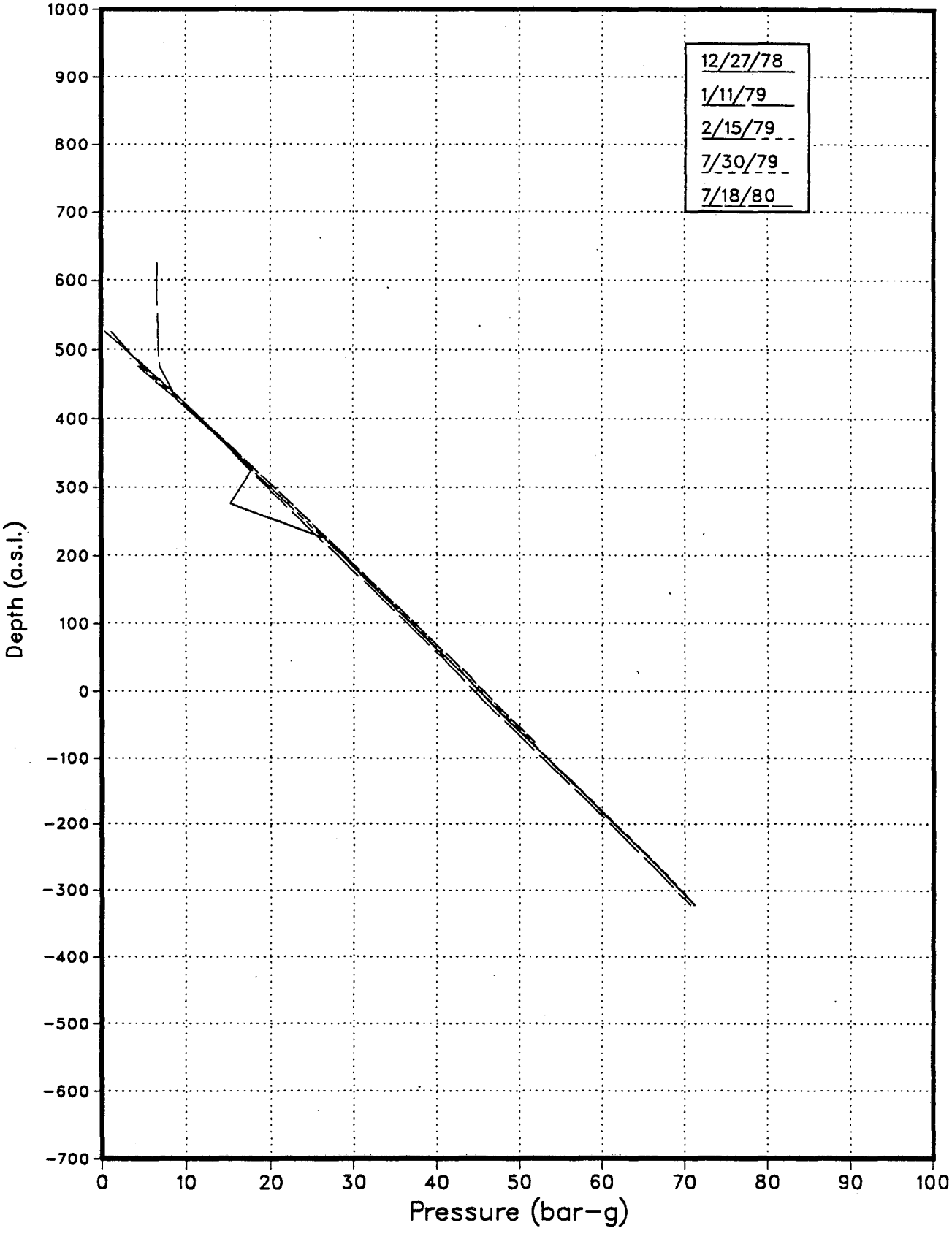

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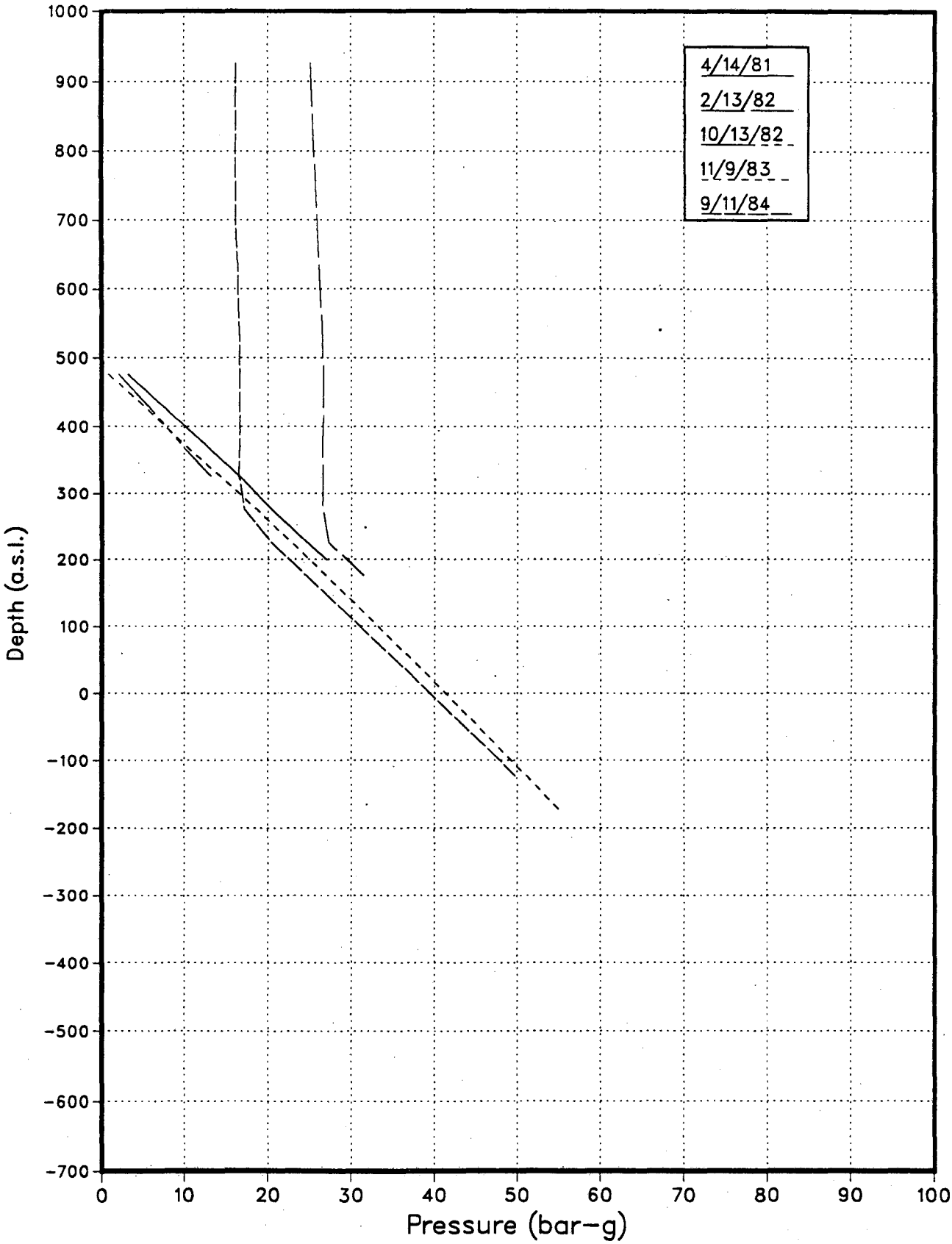

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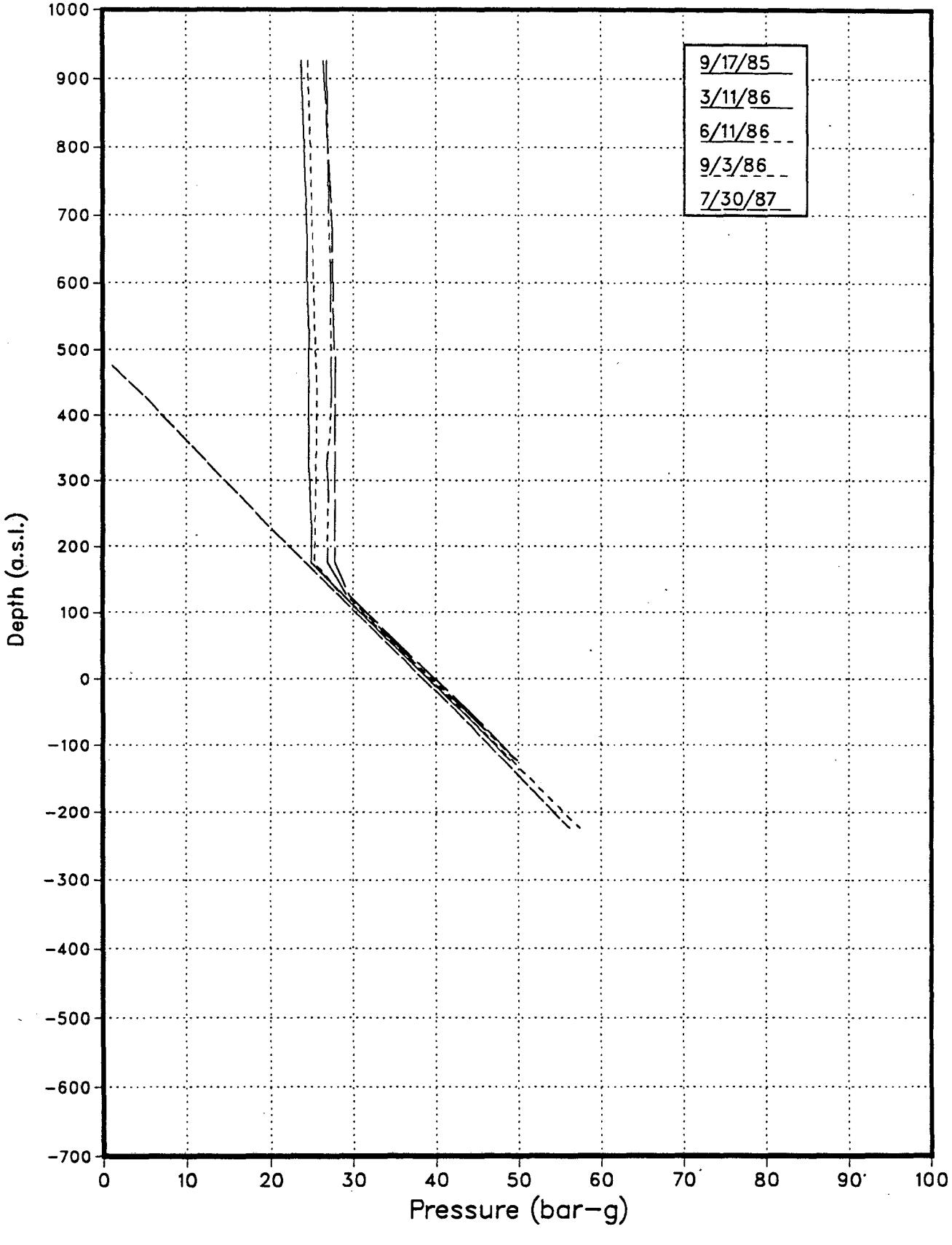
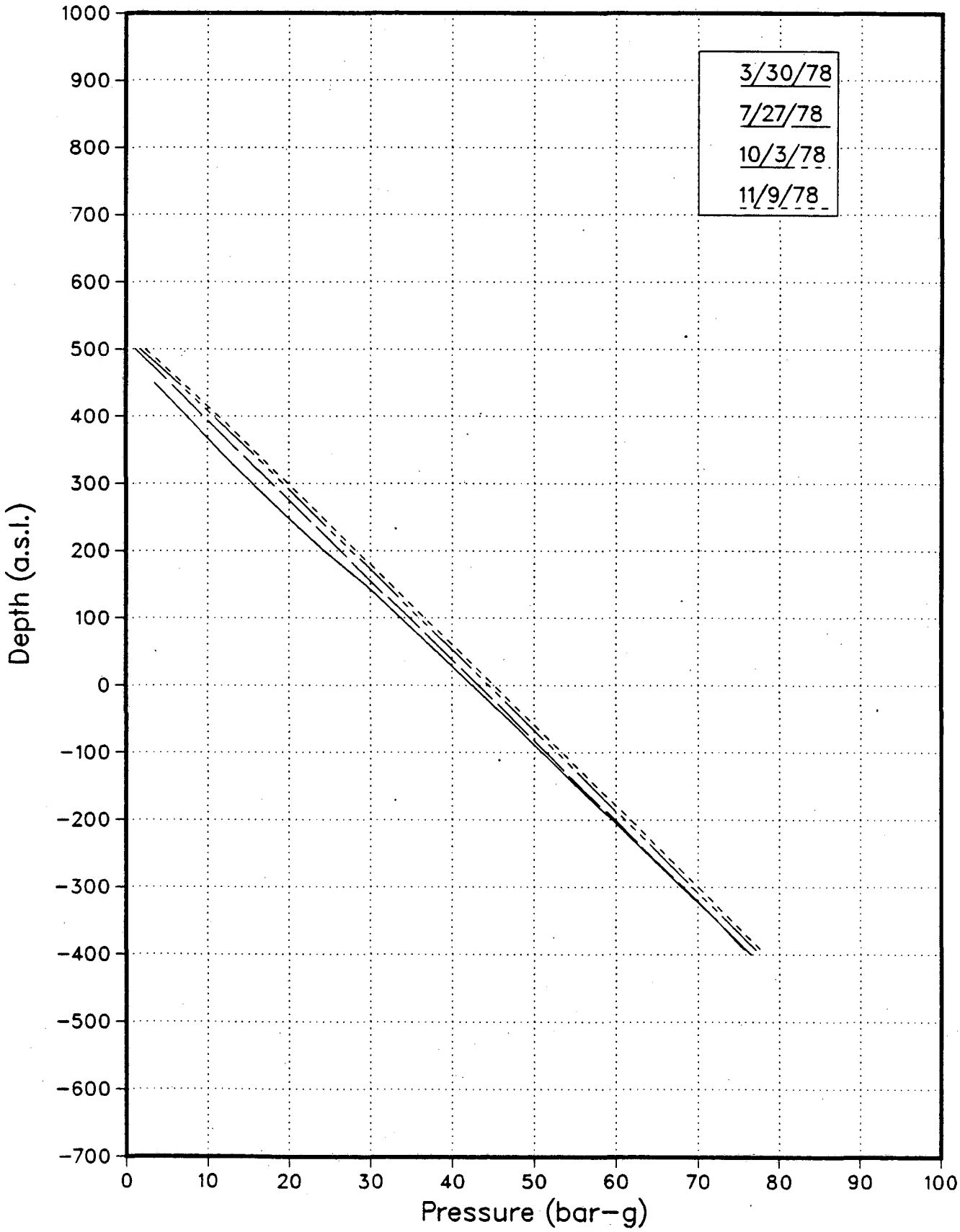


AH19 Pressure Surveys



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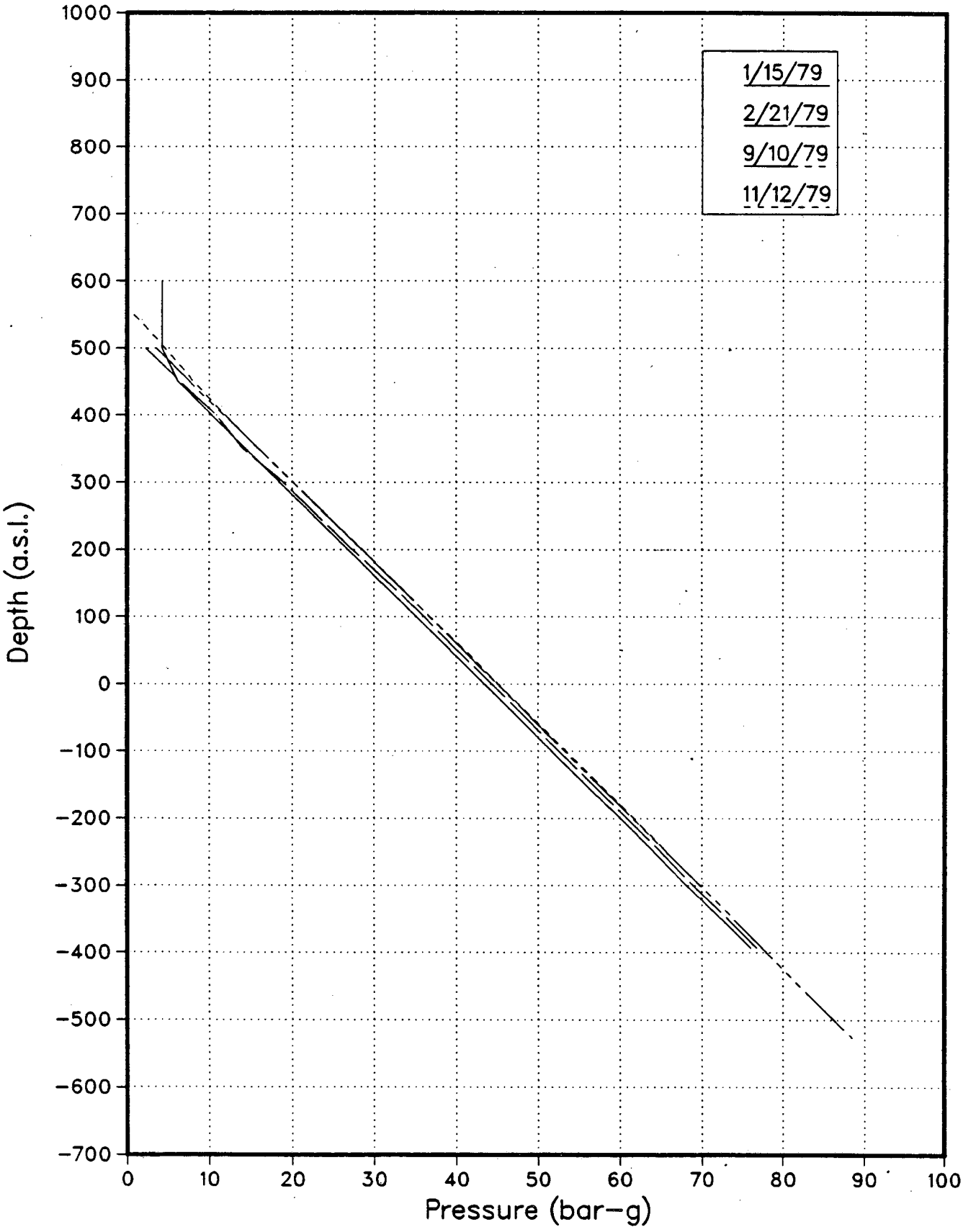

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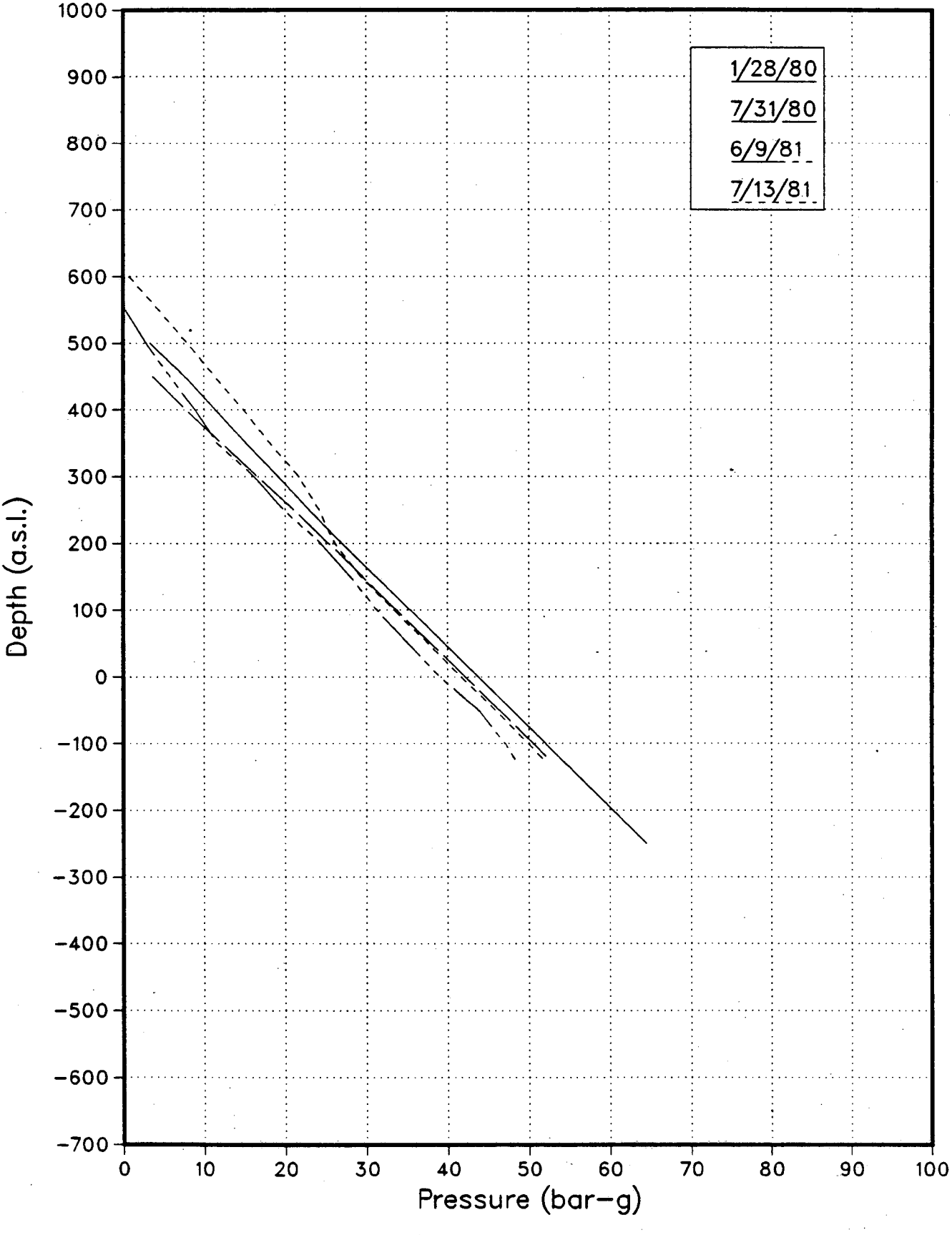

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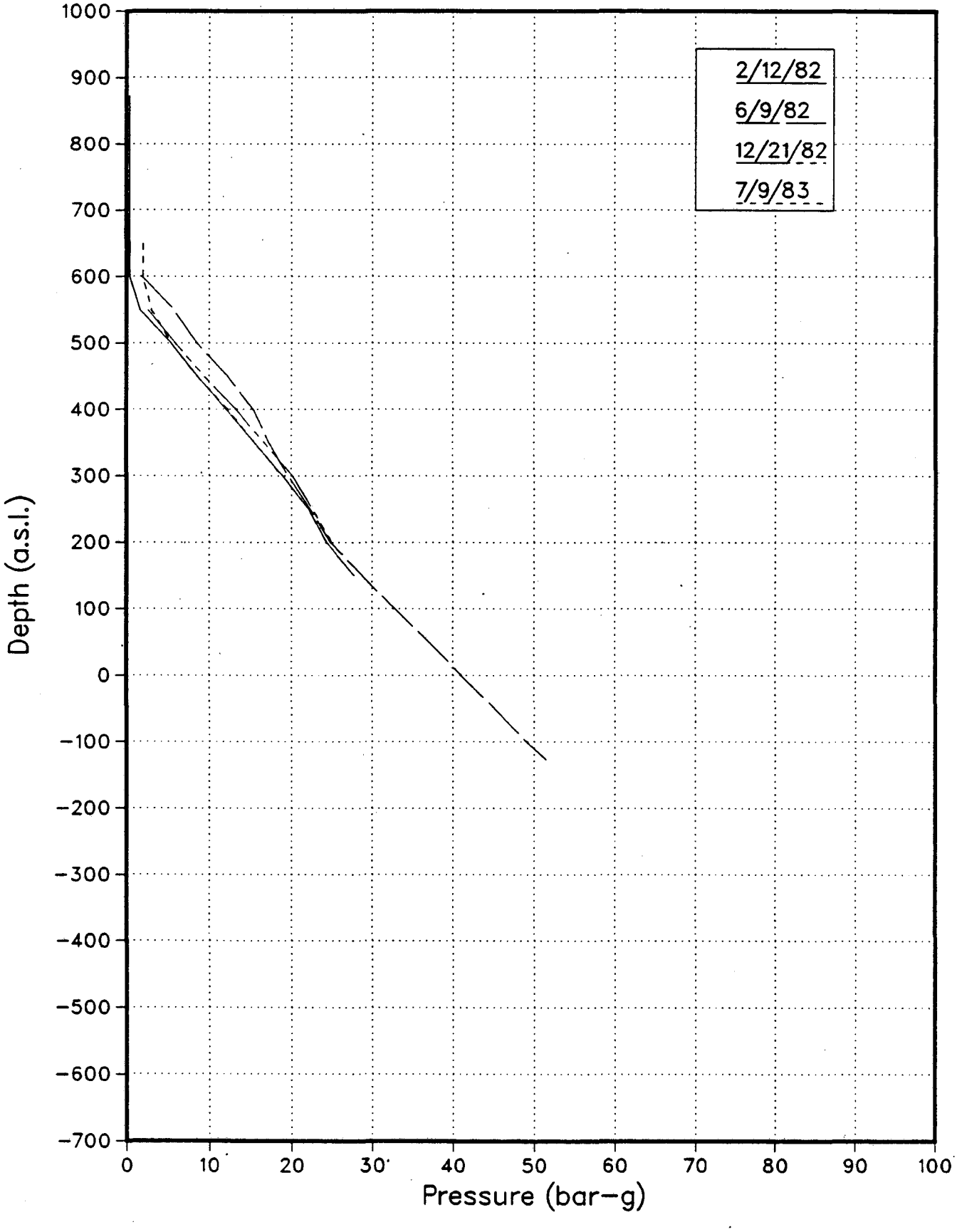

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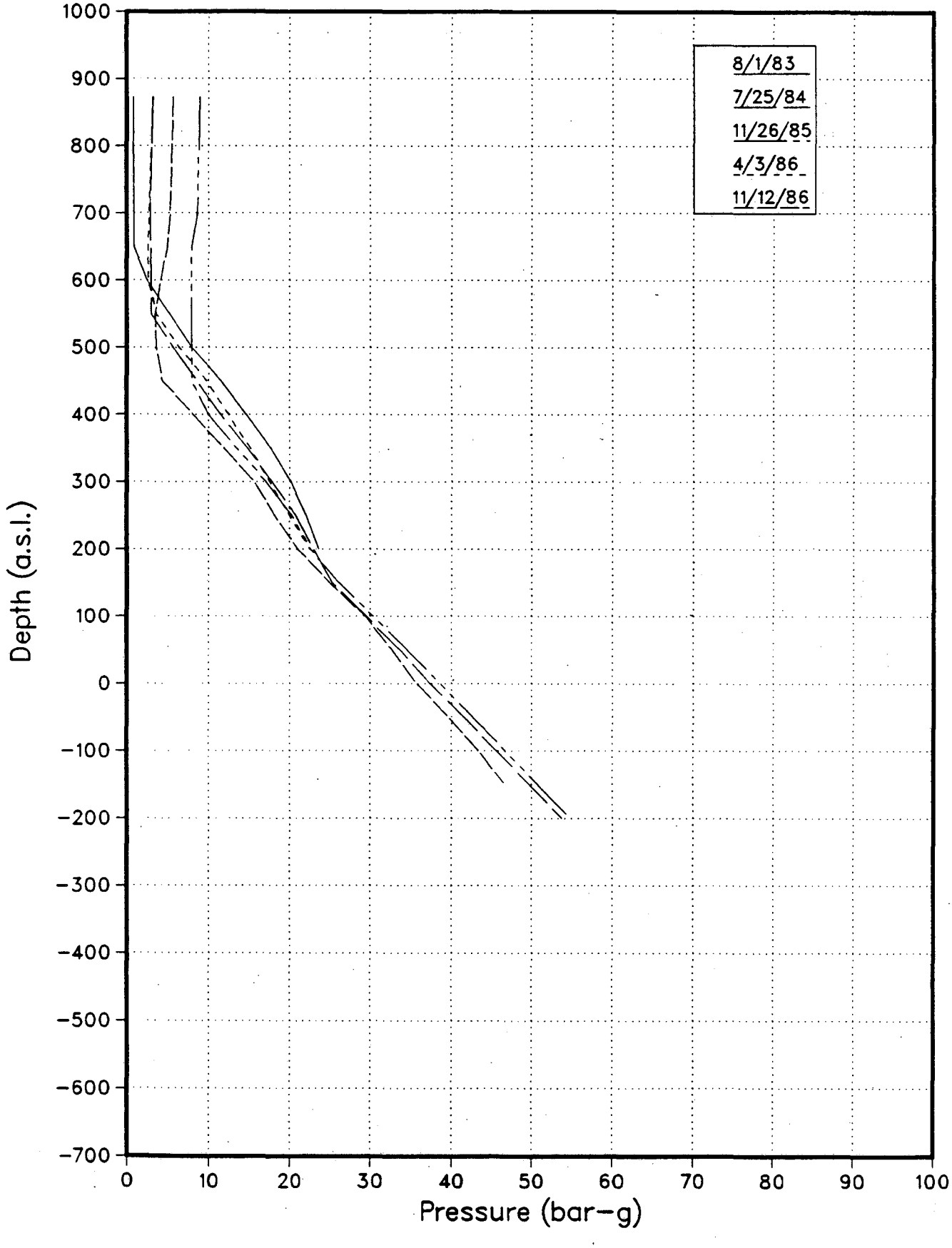
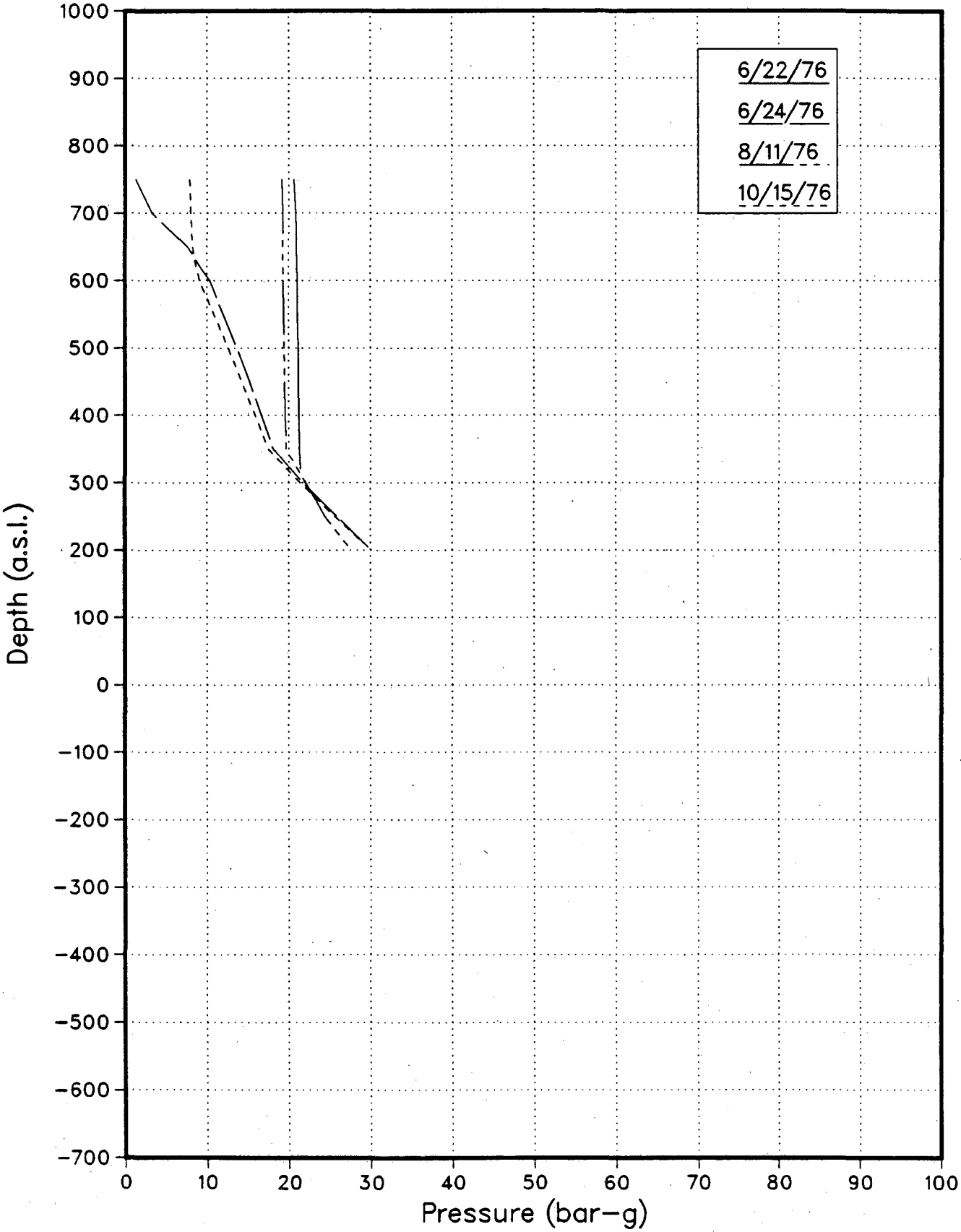


AH20 Pressure Surveys



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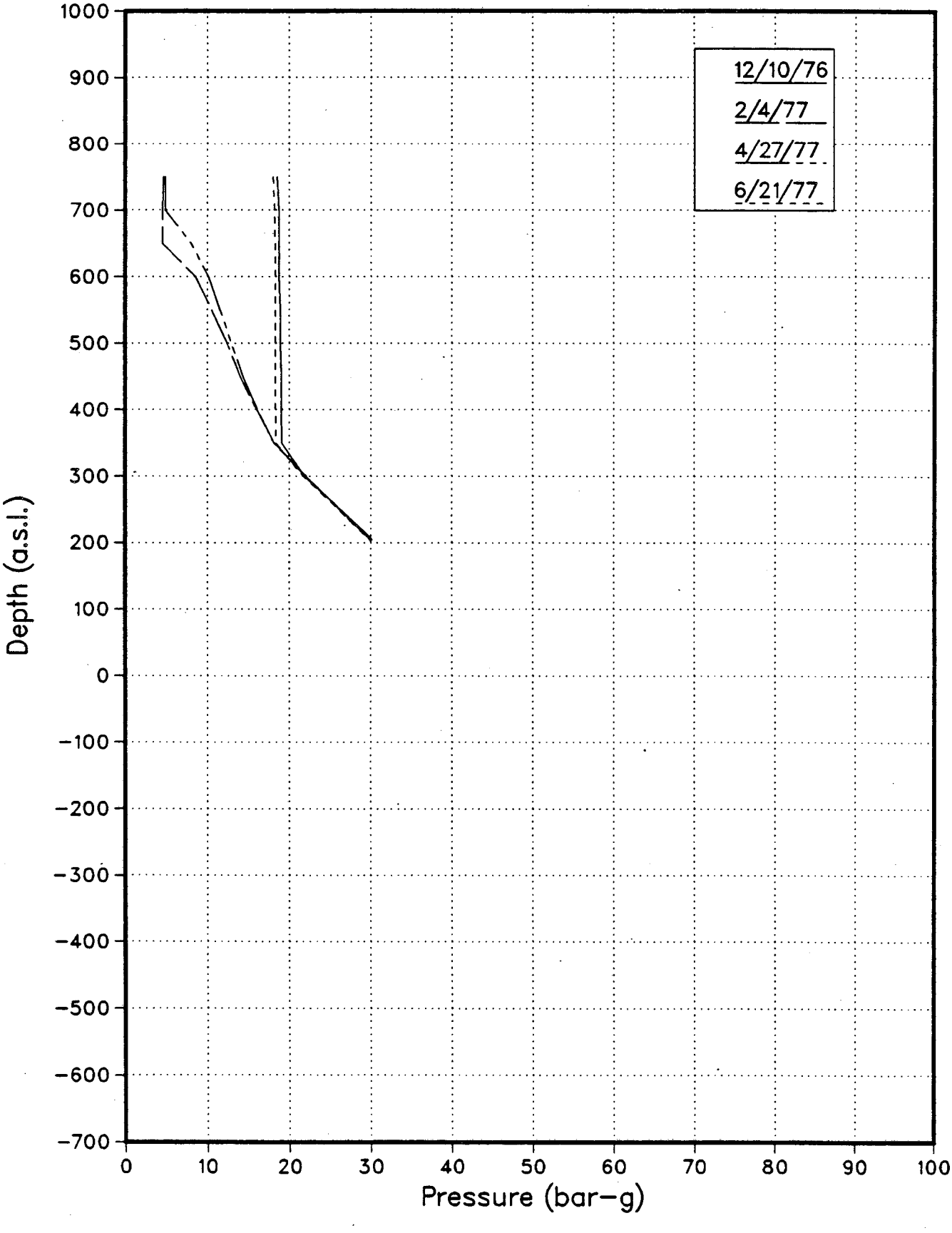

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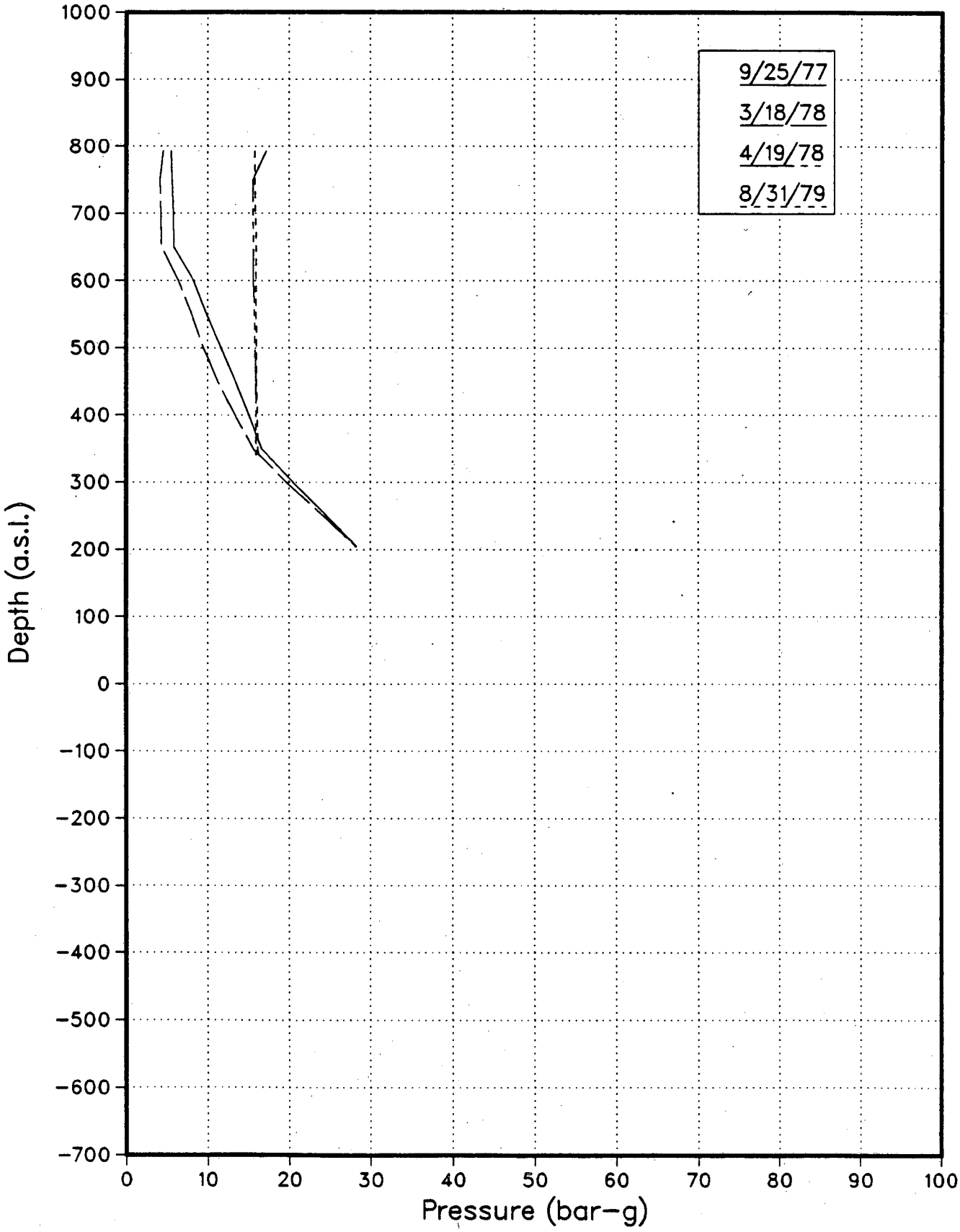

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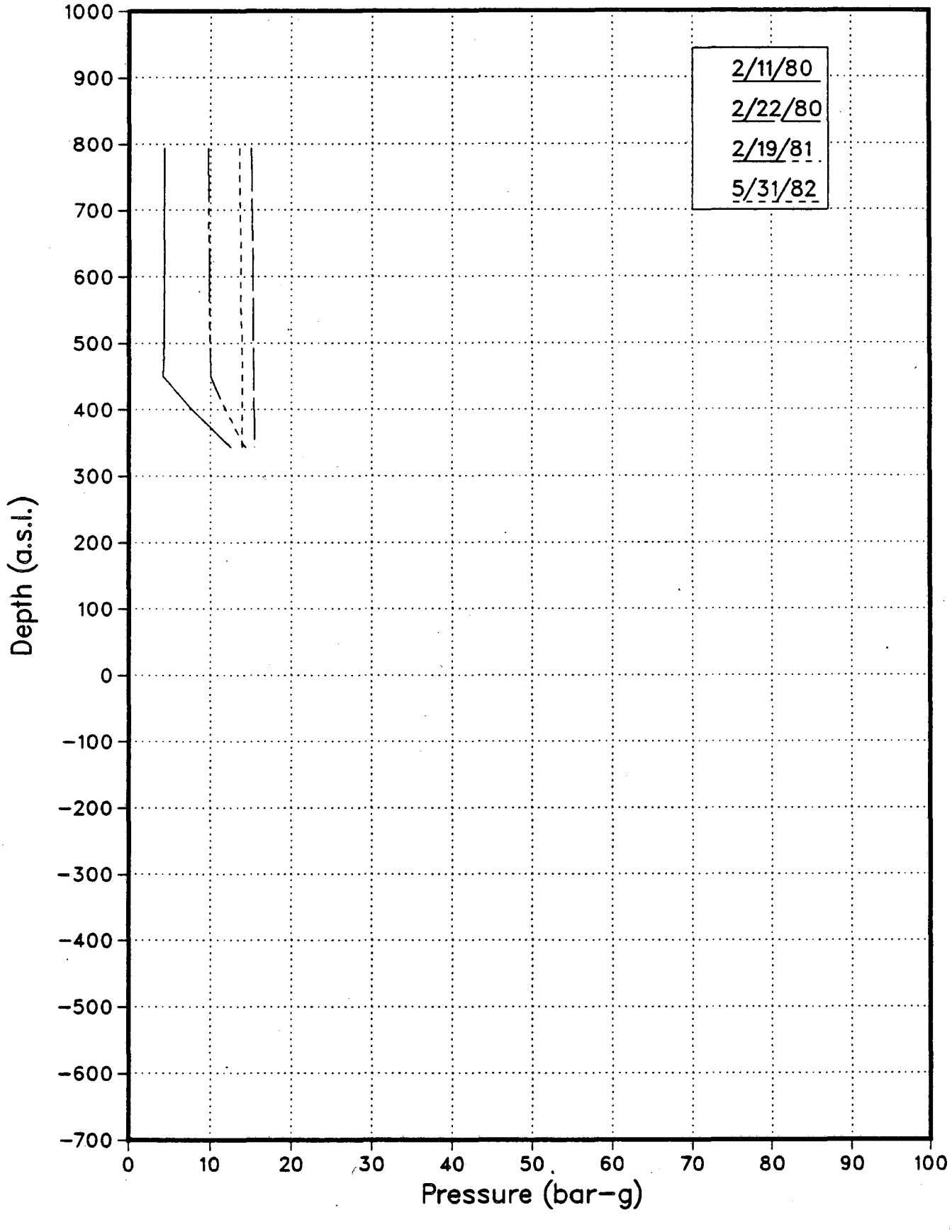

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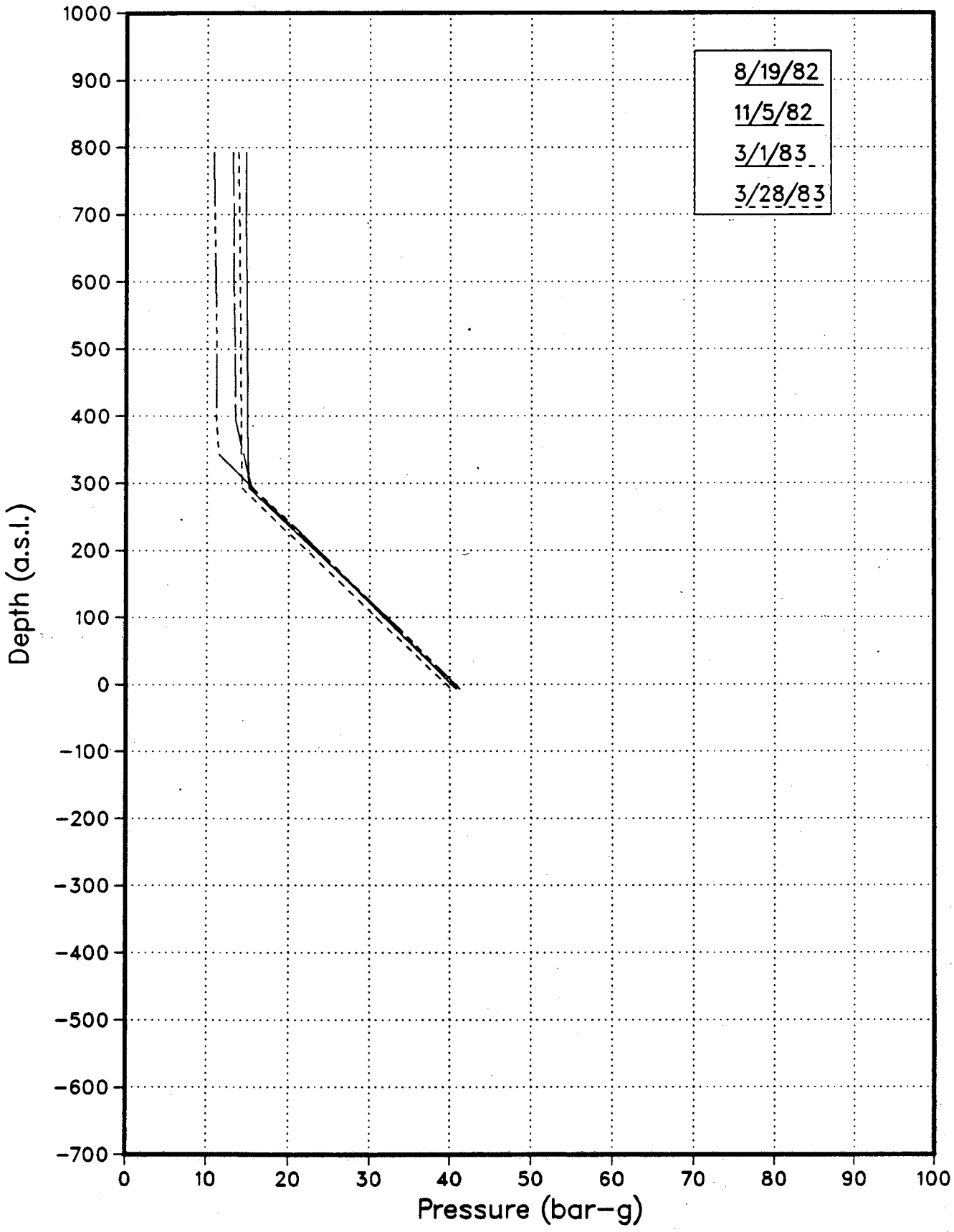

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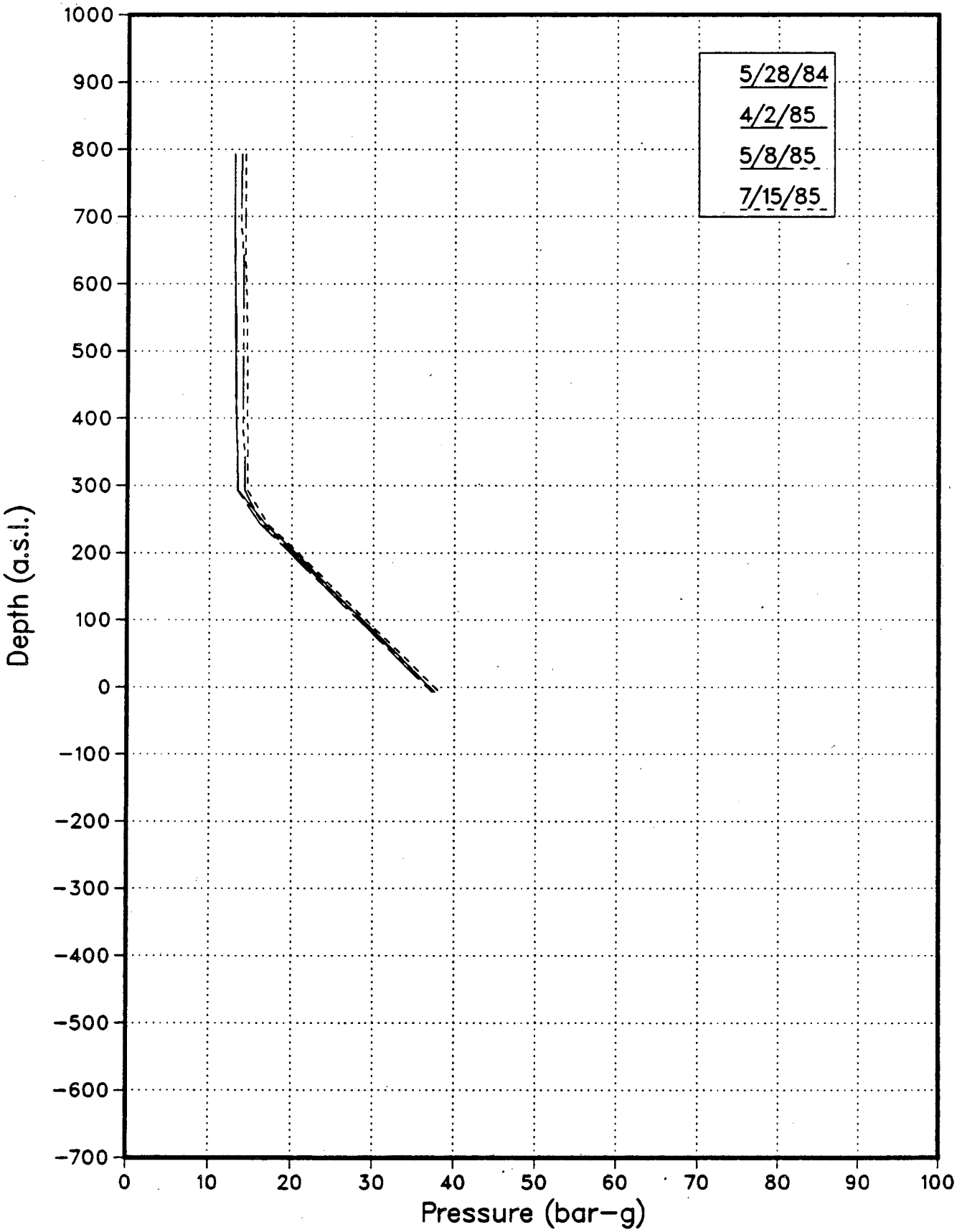

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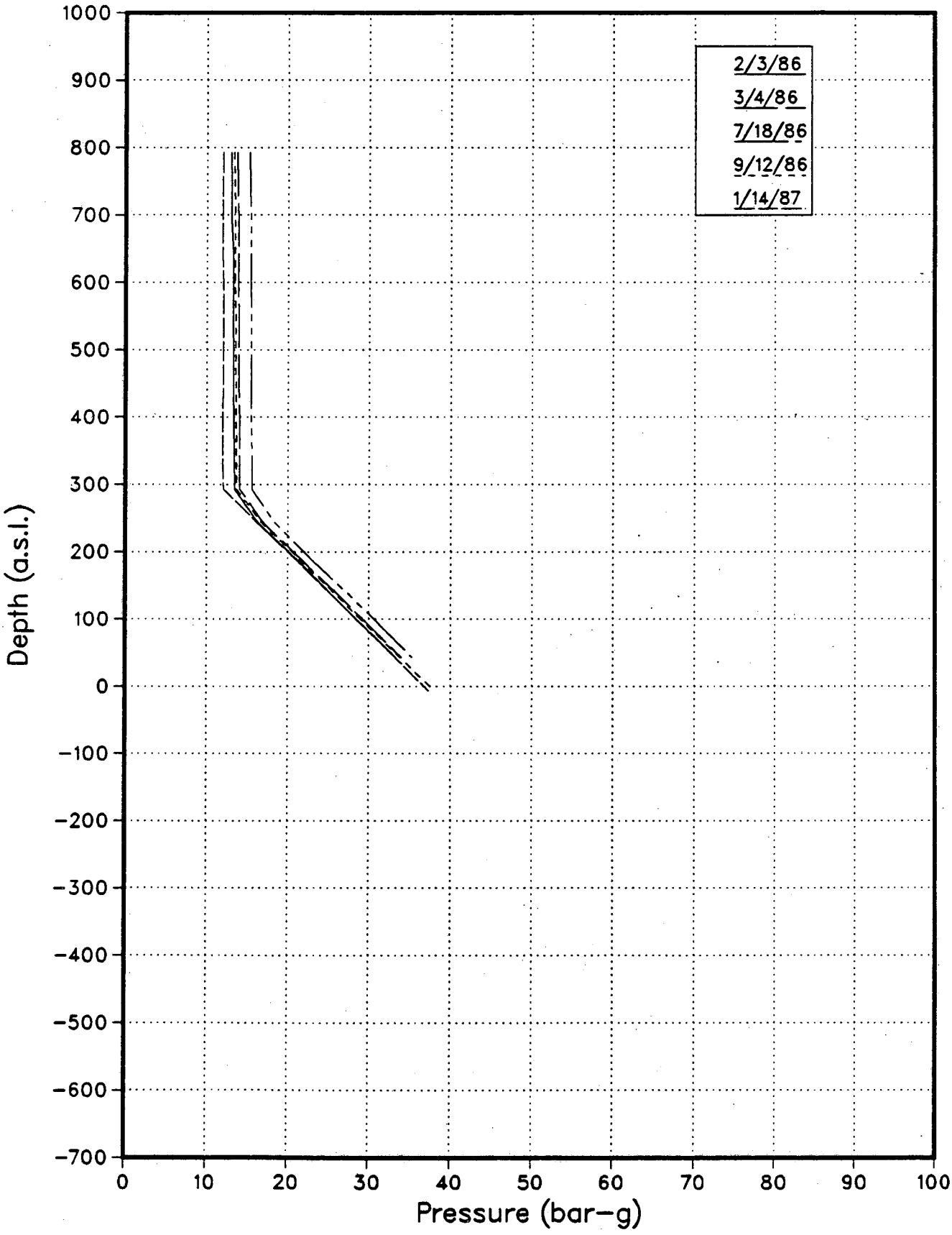
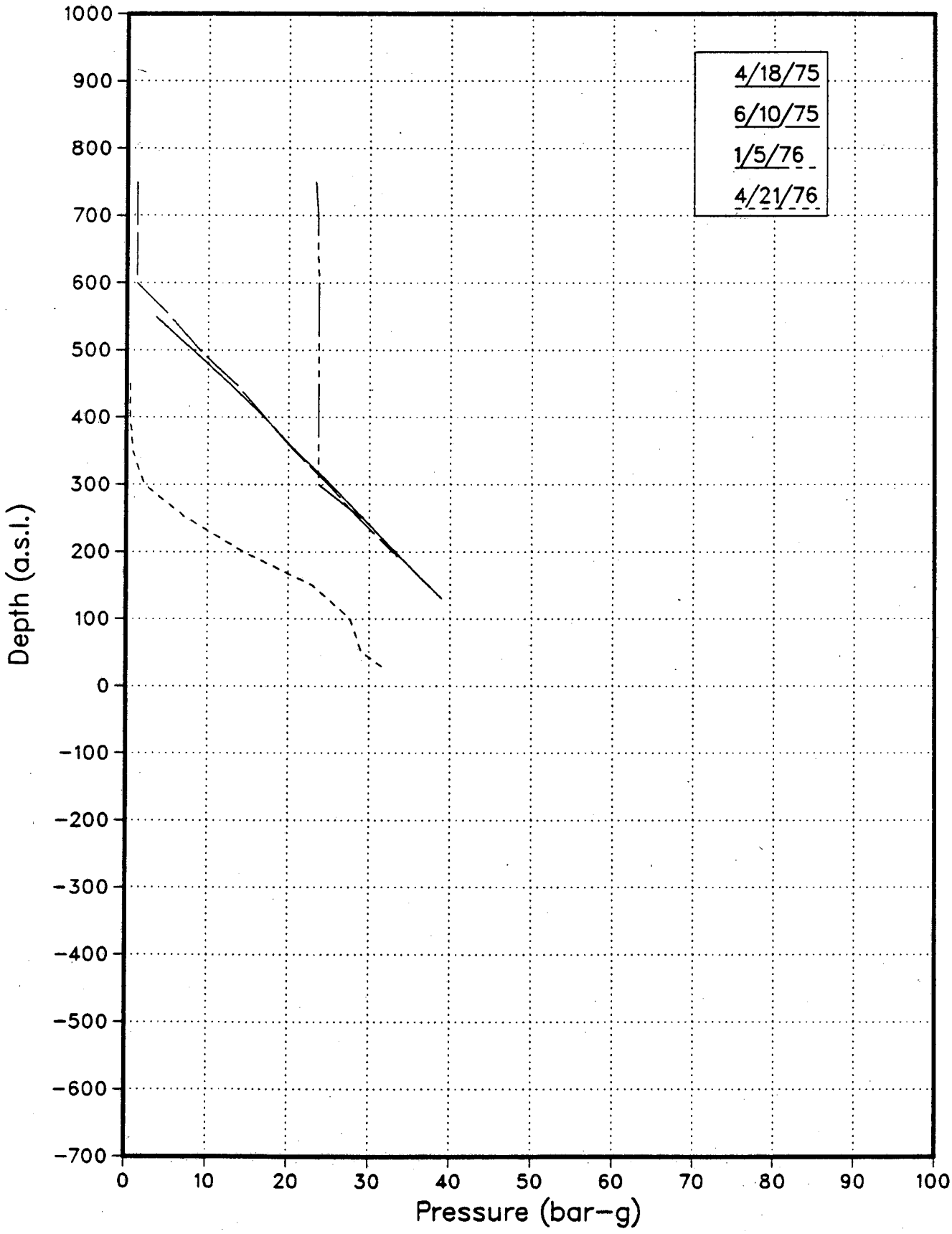


AH21 Pressure Surveys



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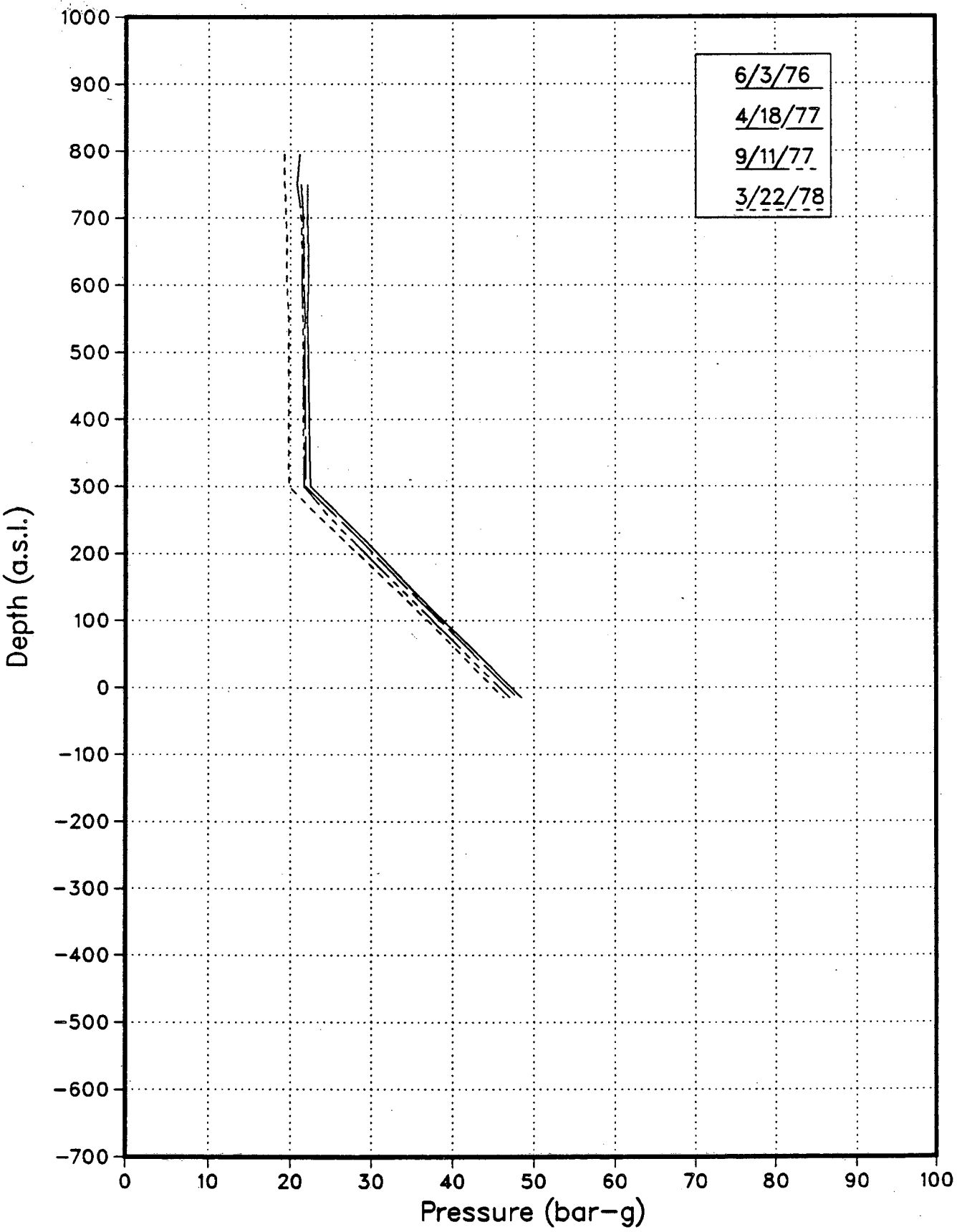

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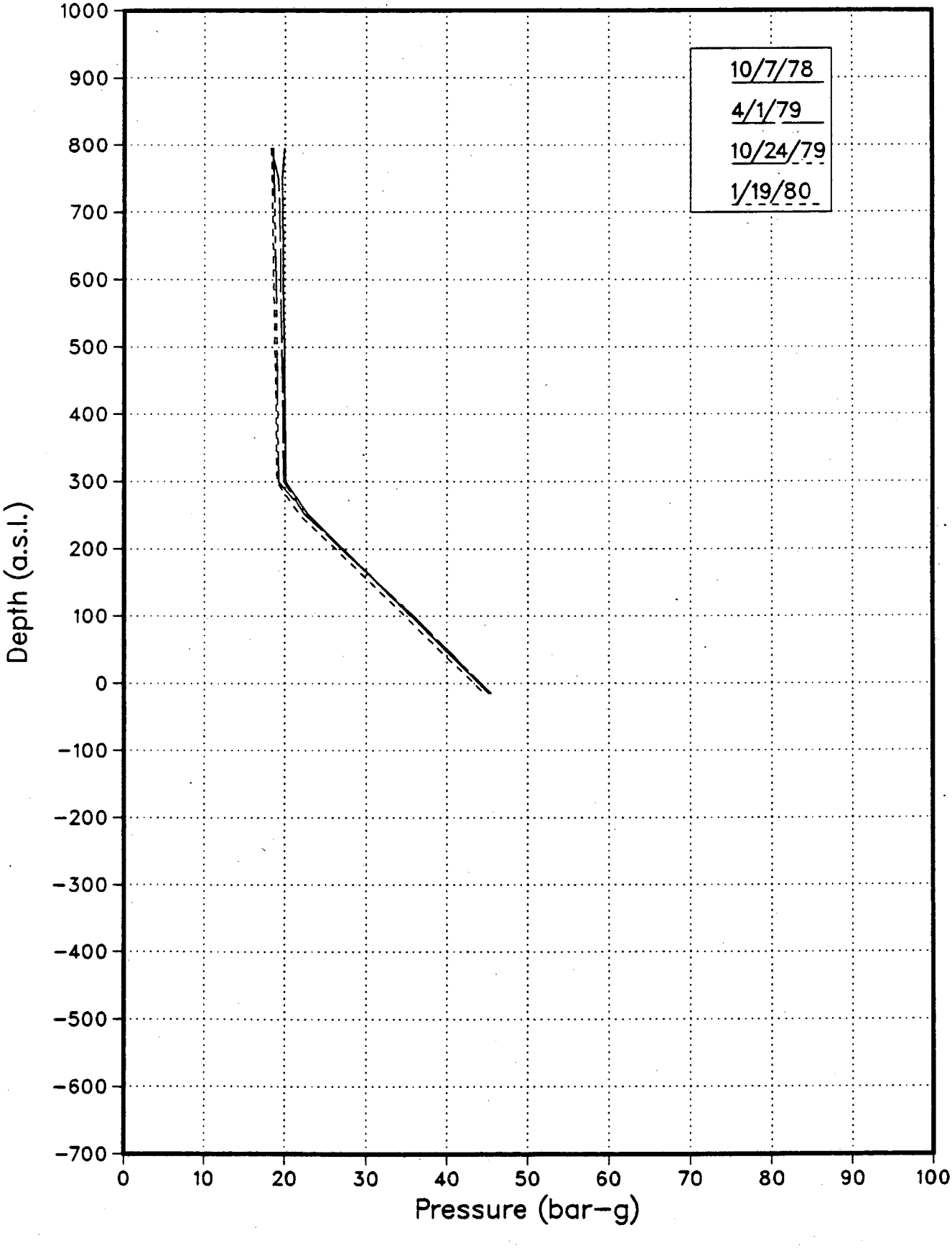

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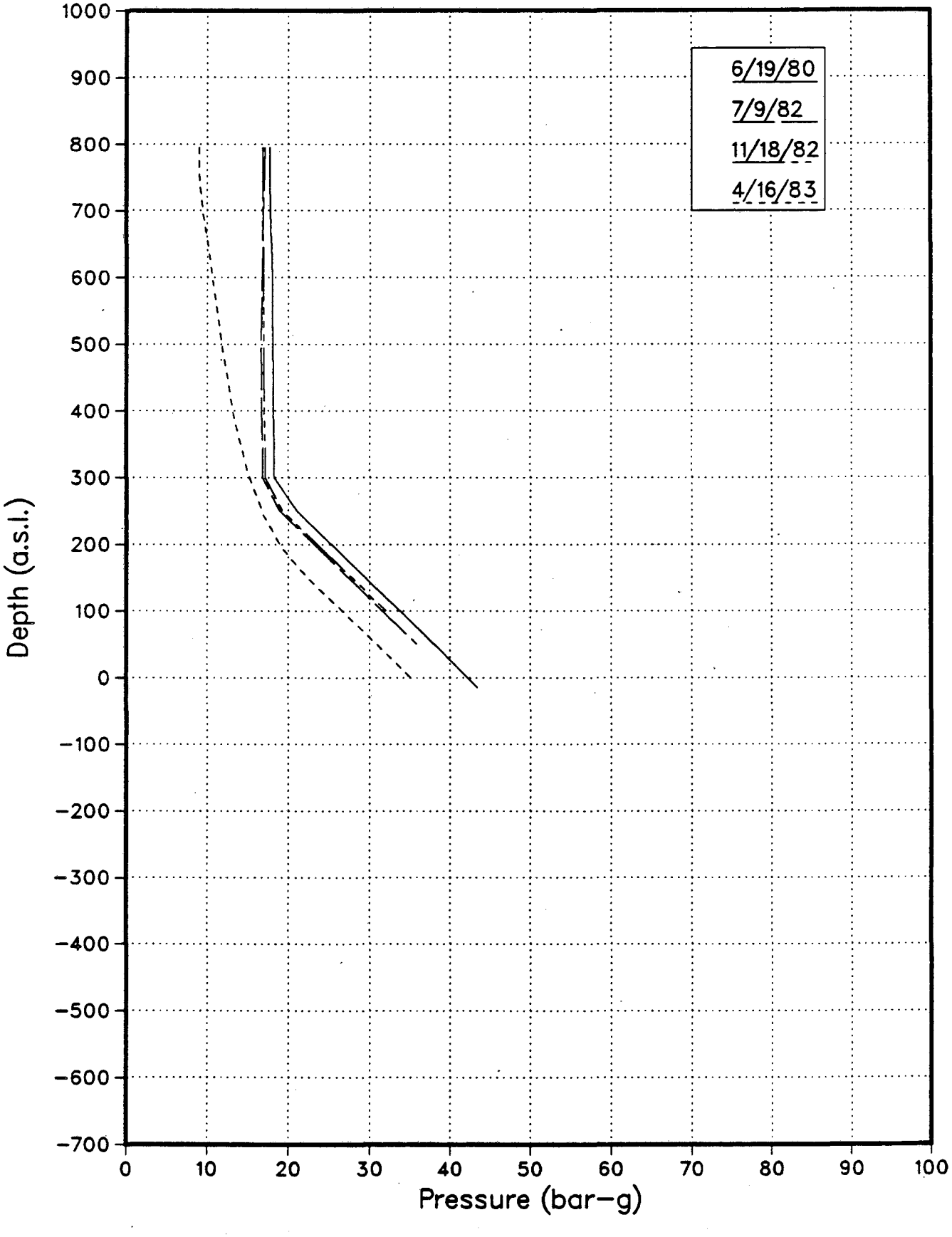

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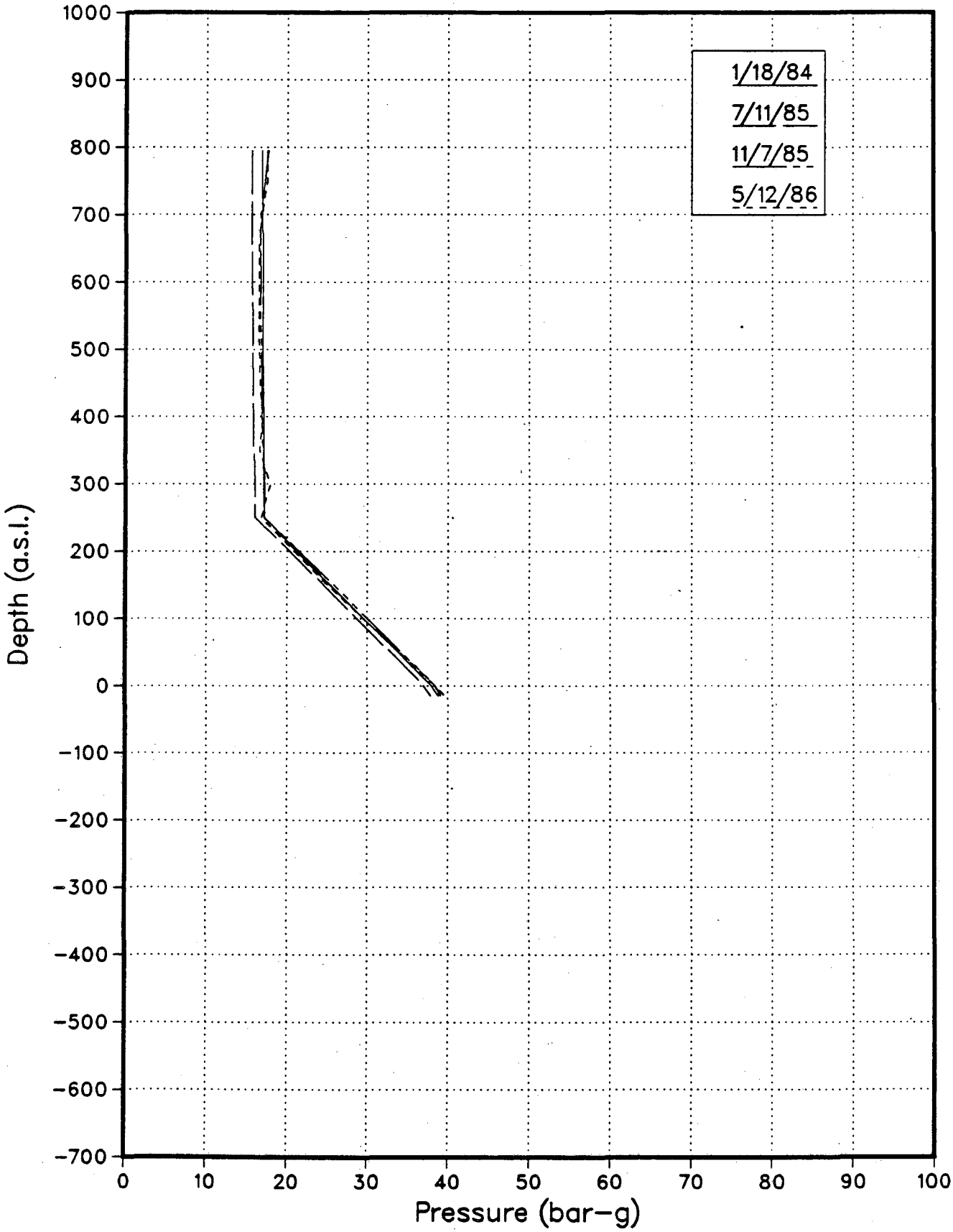

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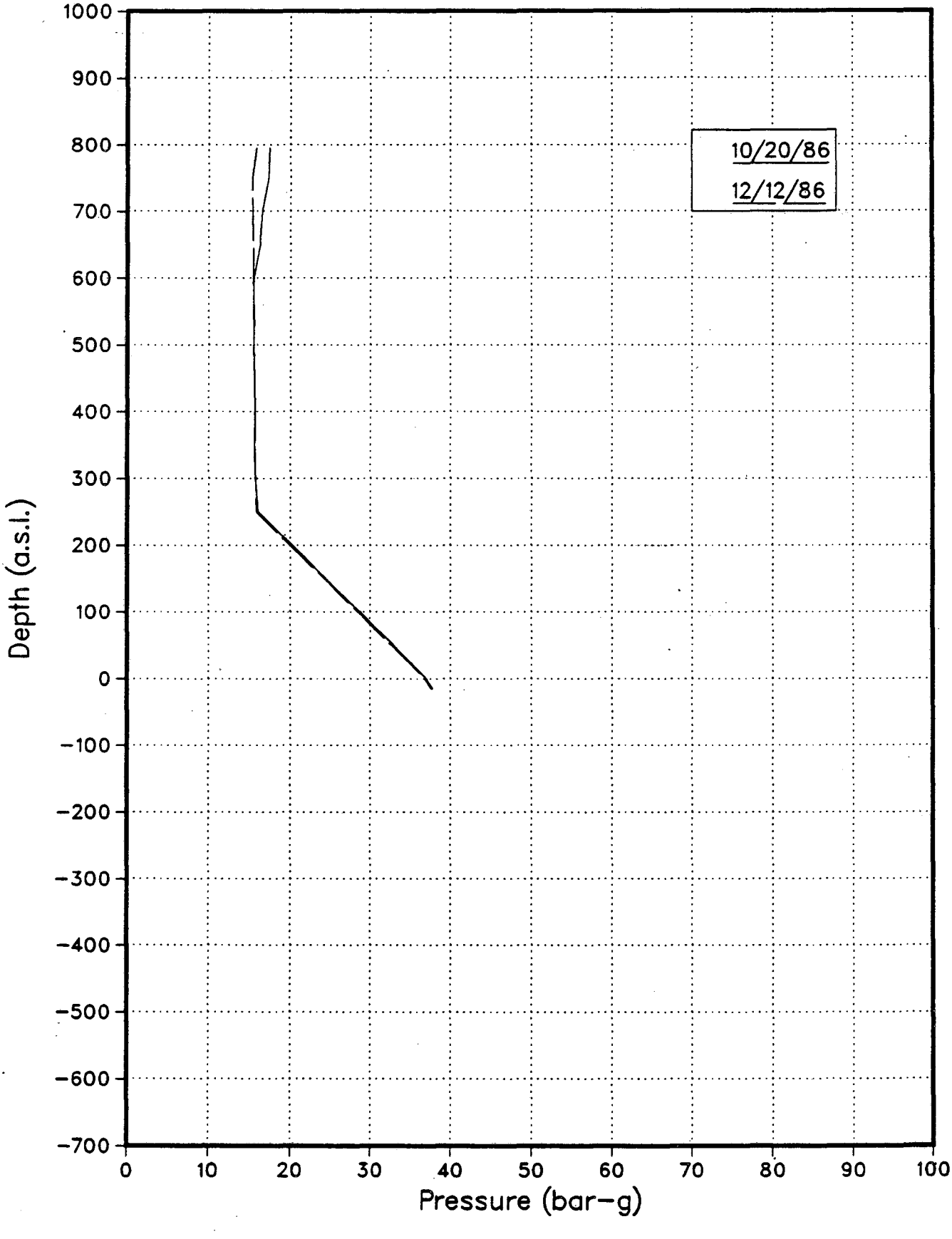

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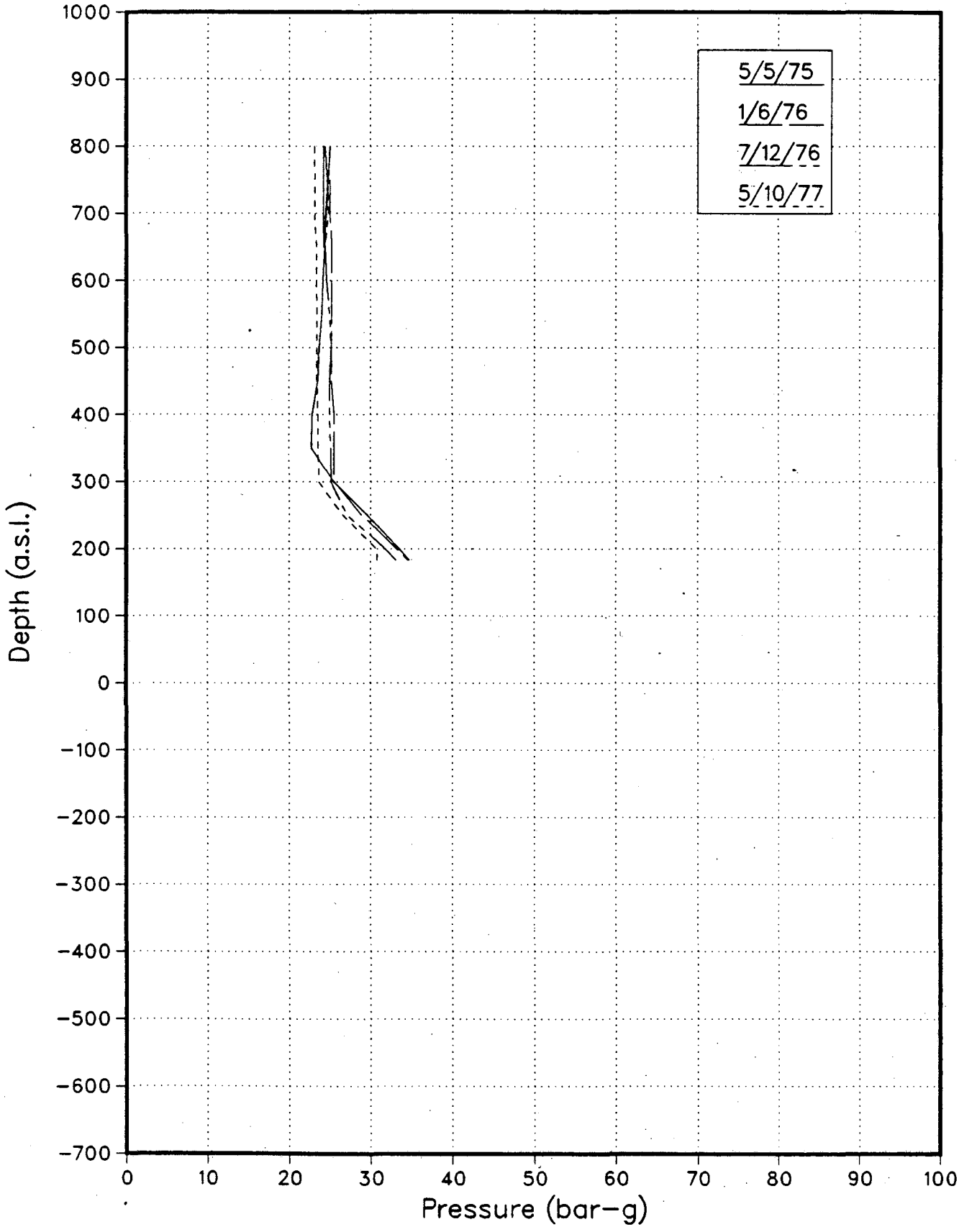

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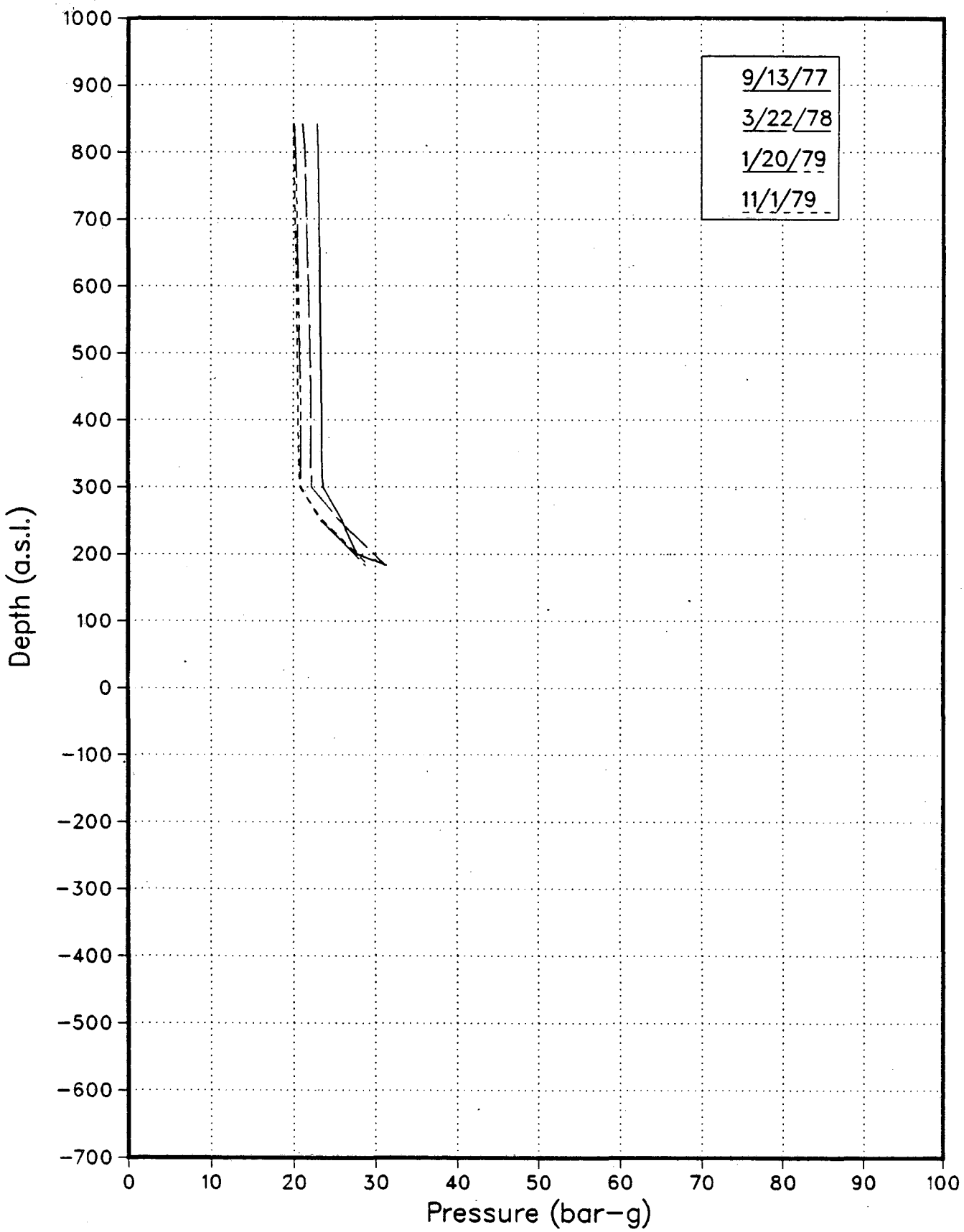

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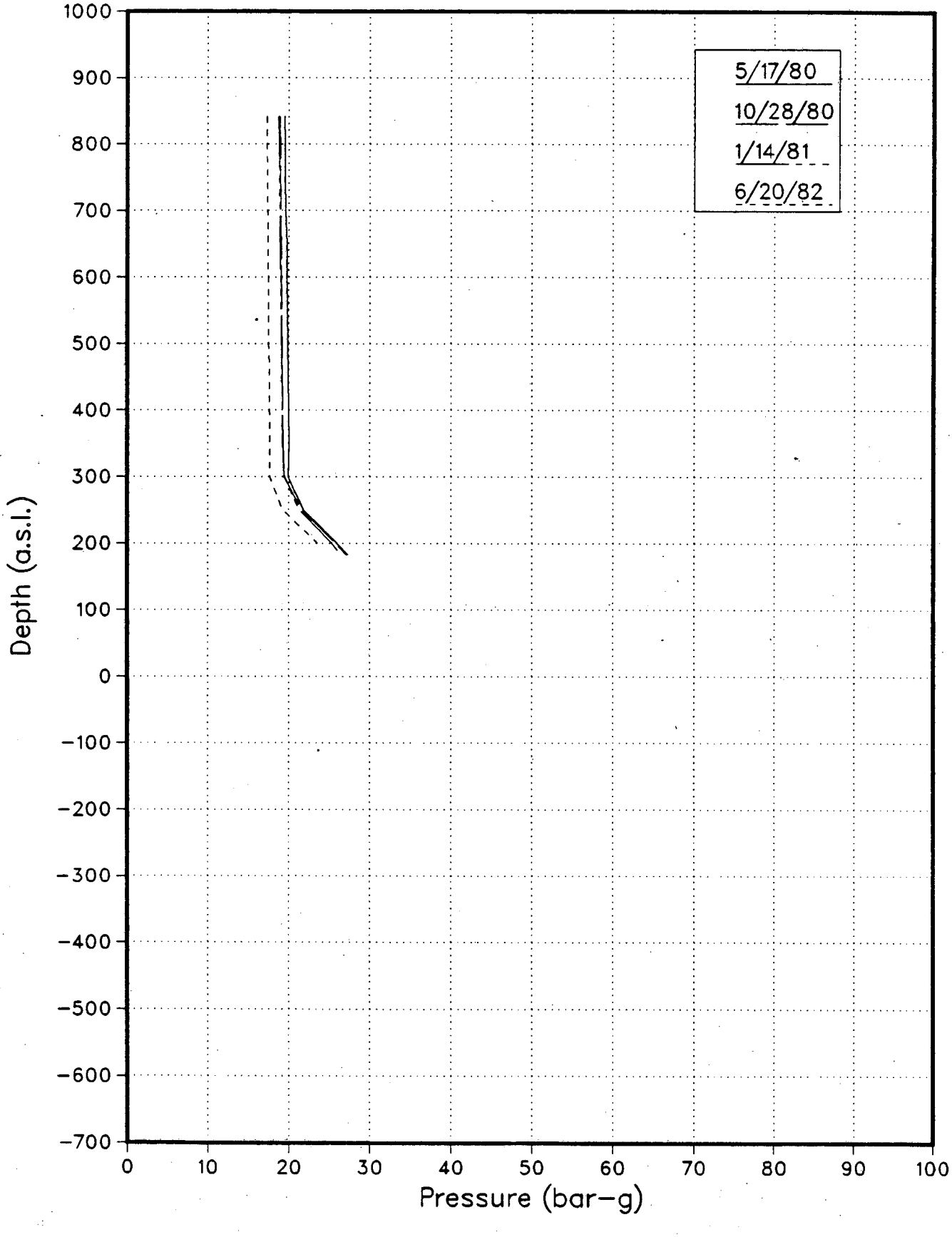

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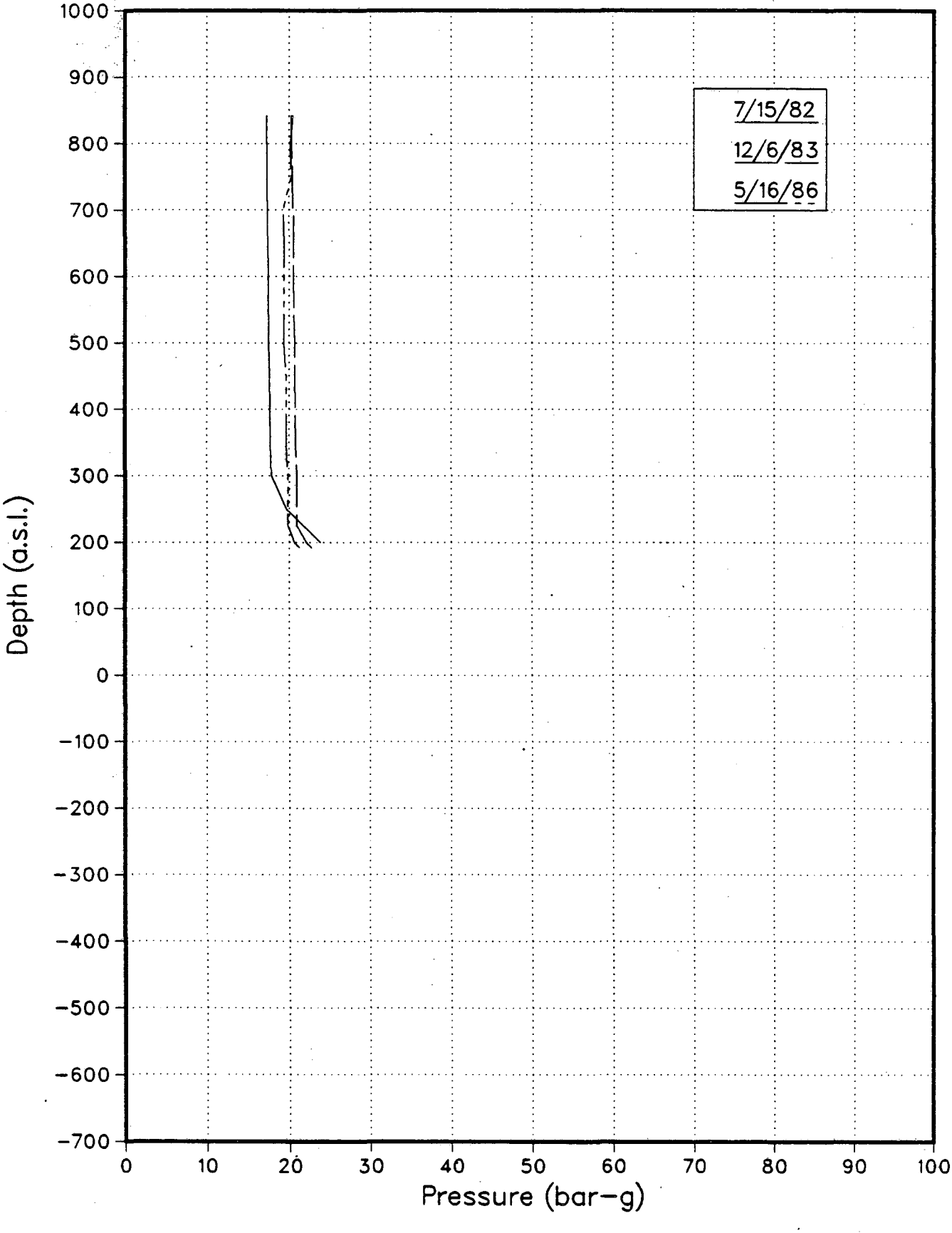

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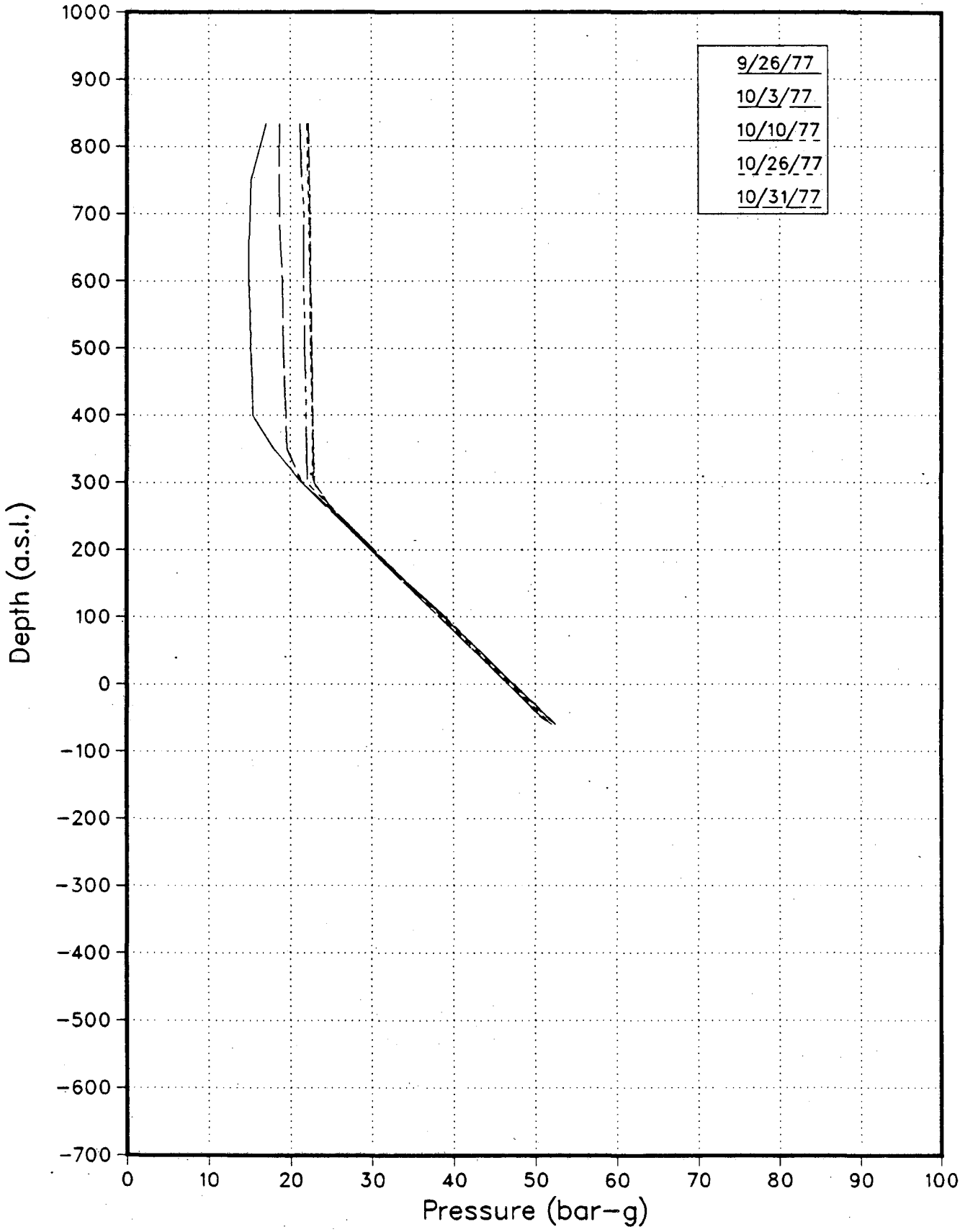

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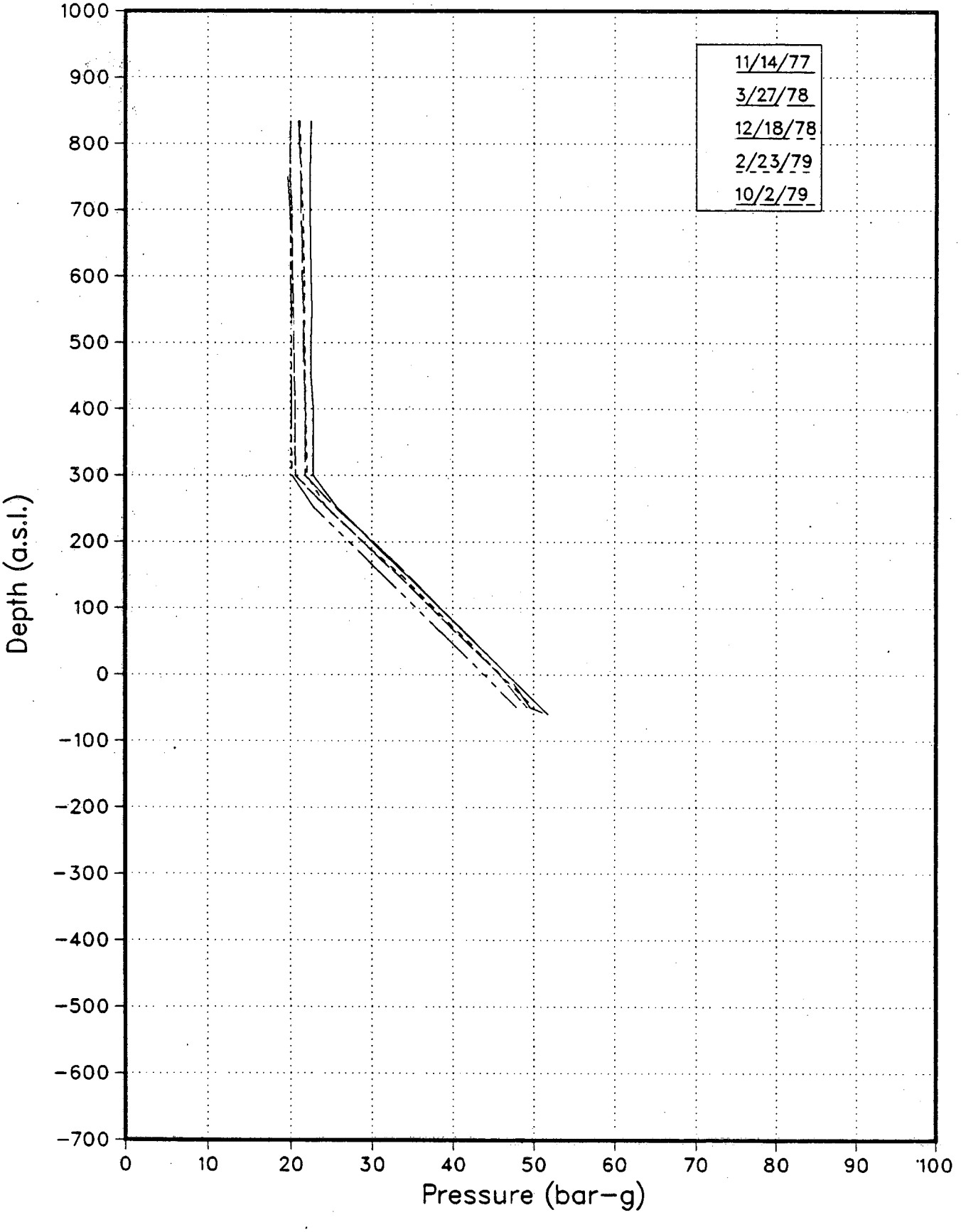

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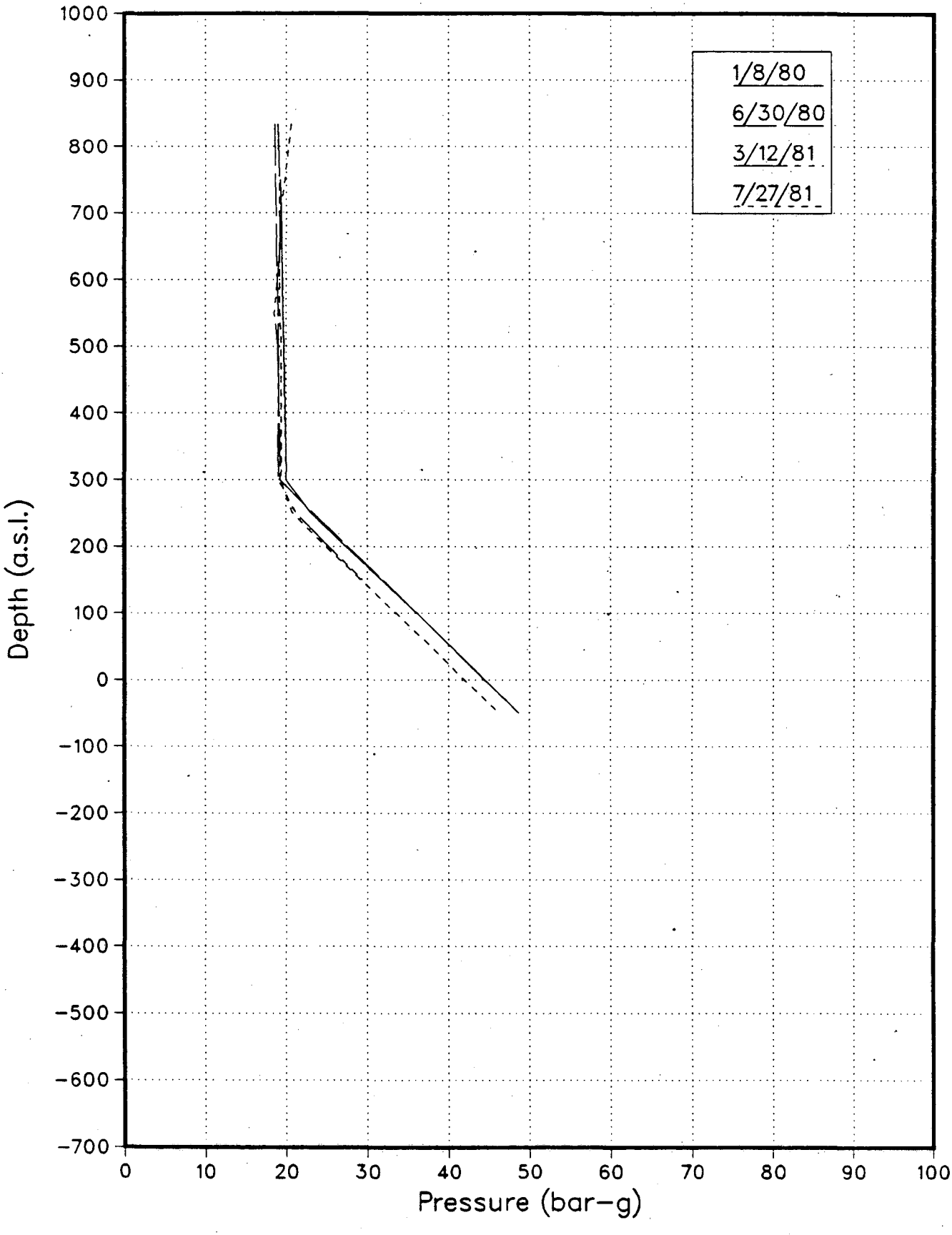

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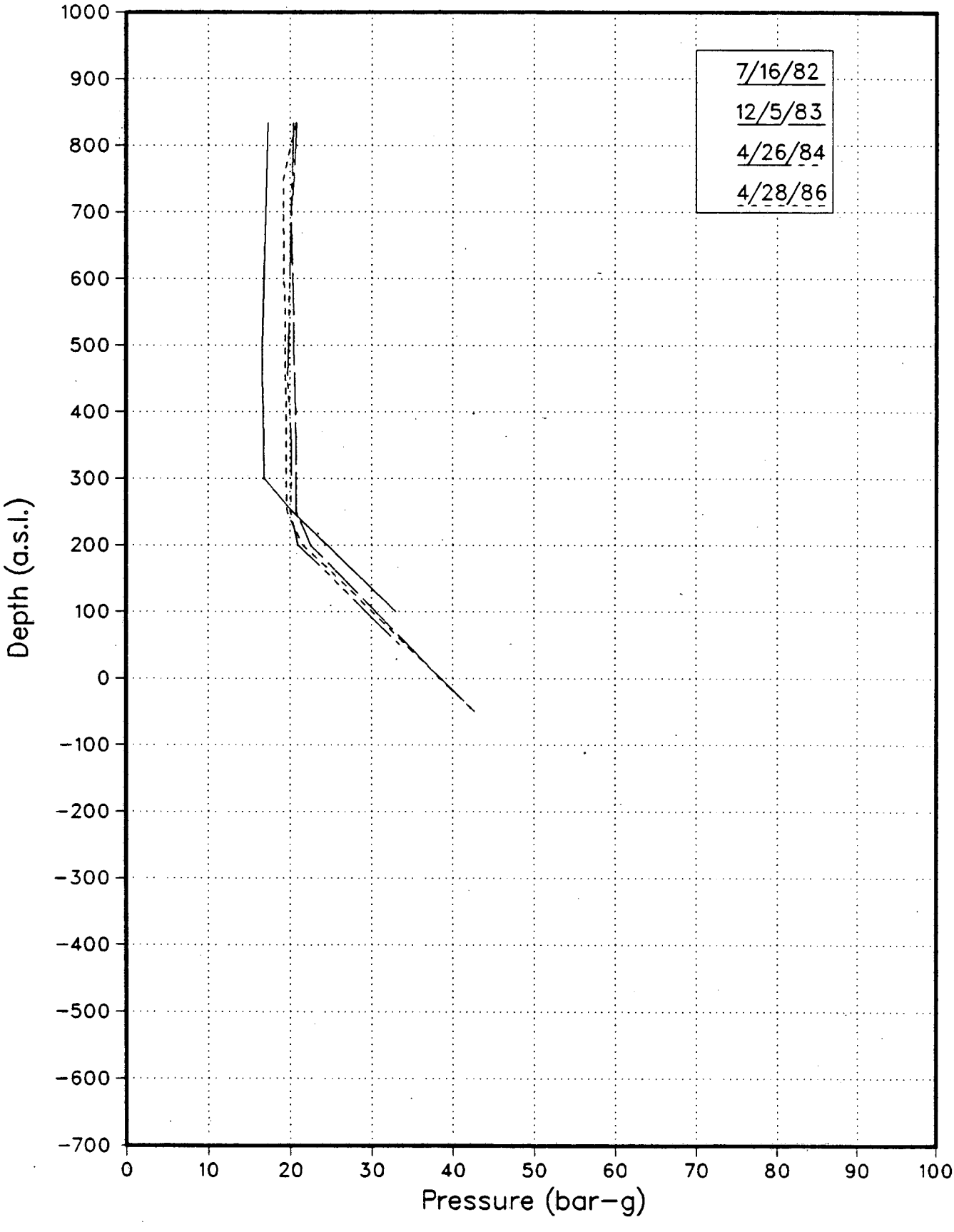

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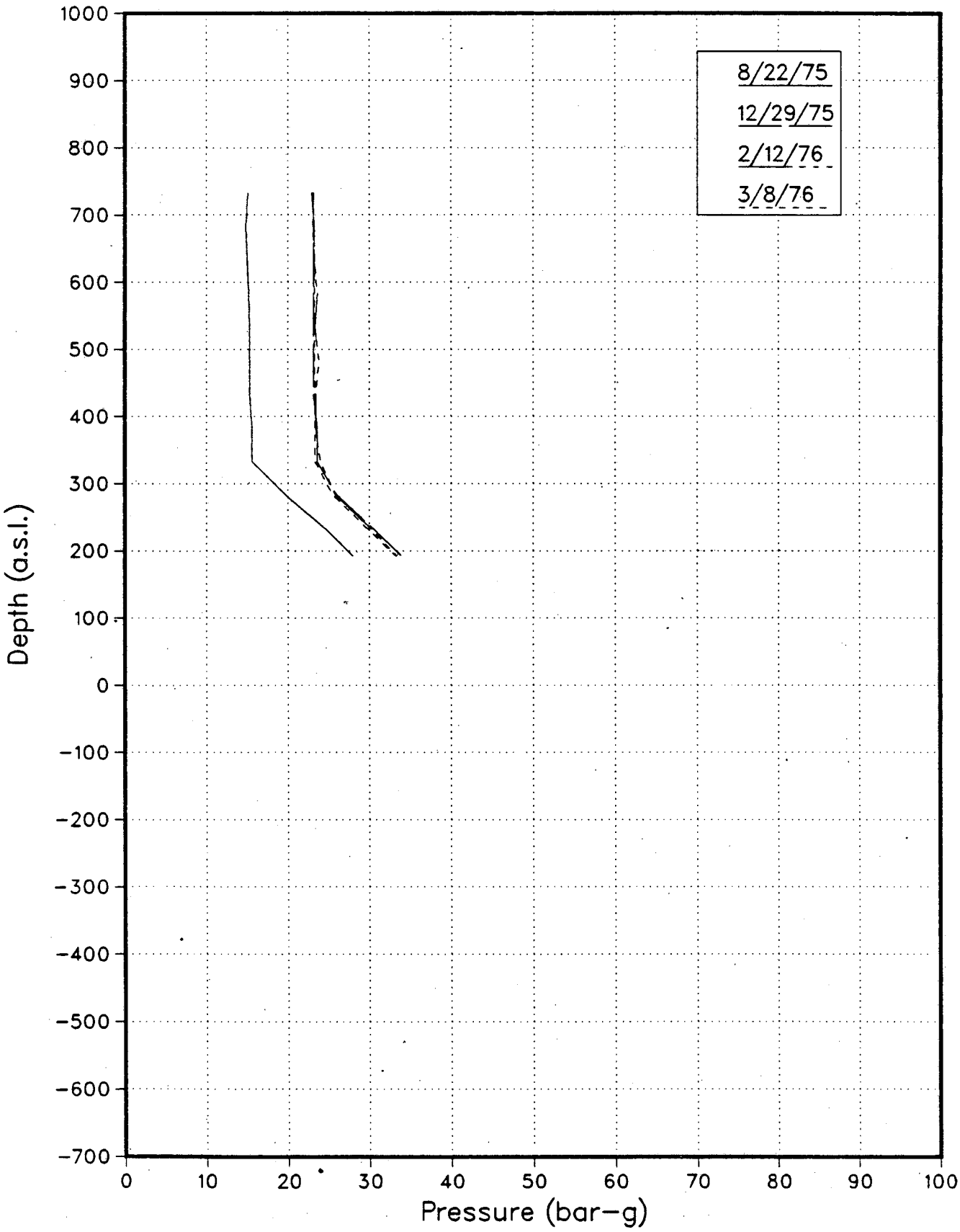

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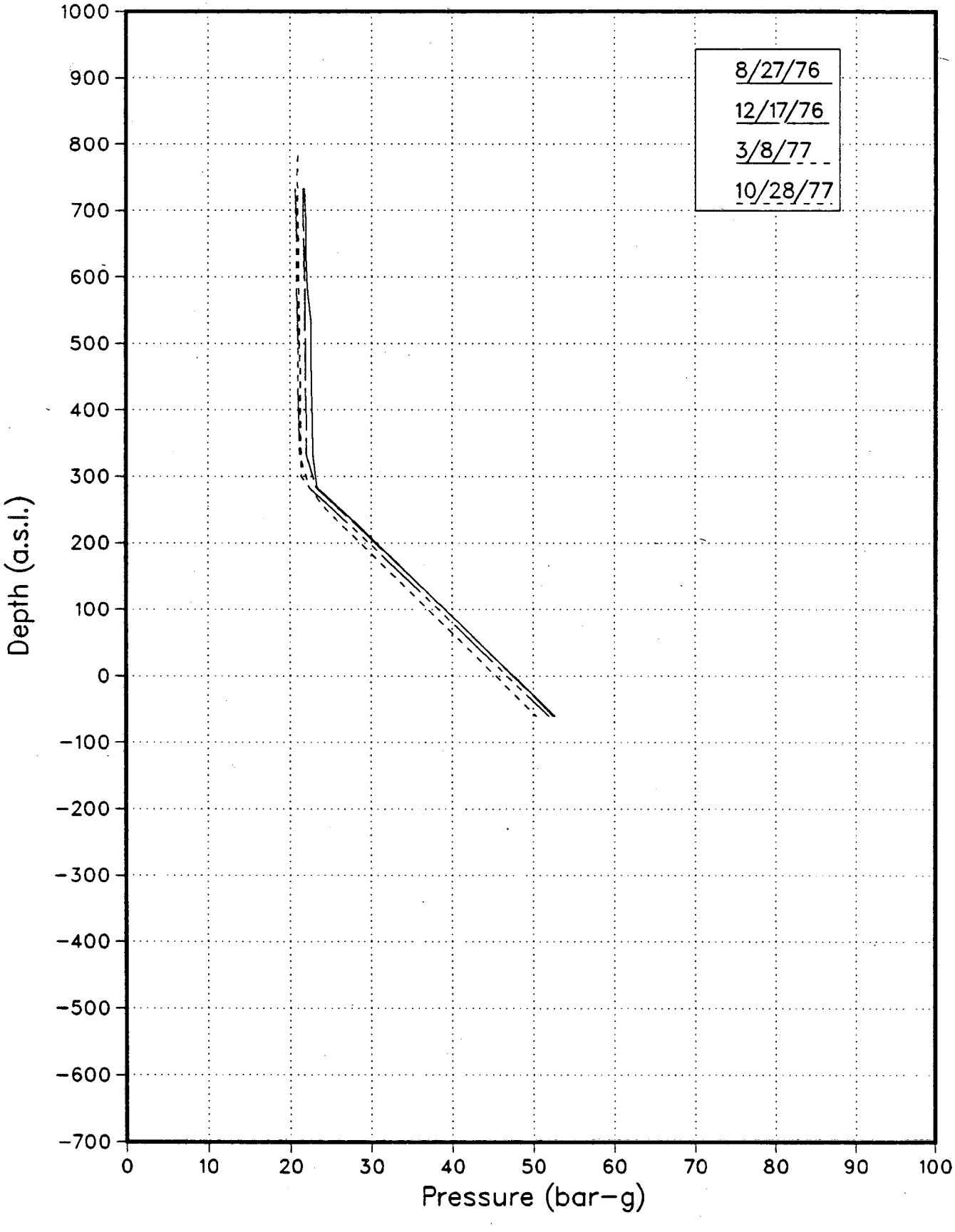

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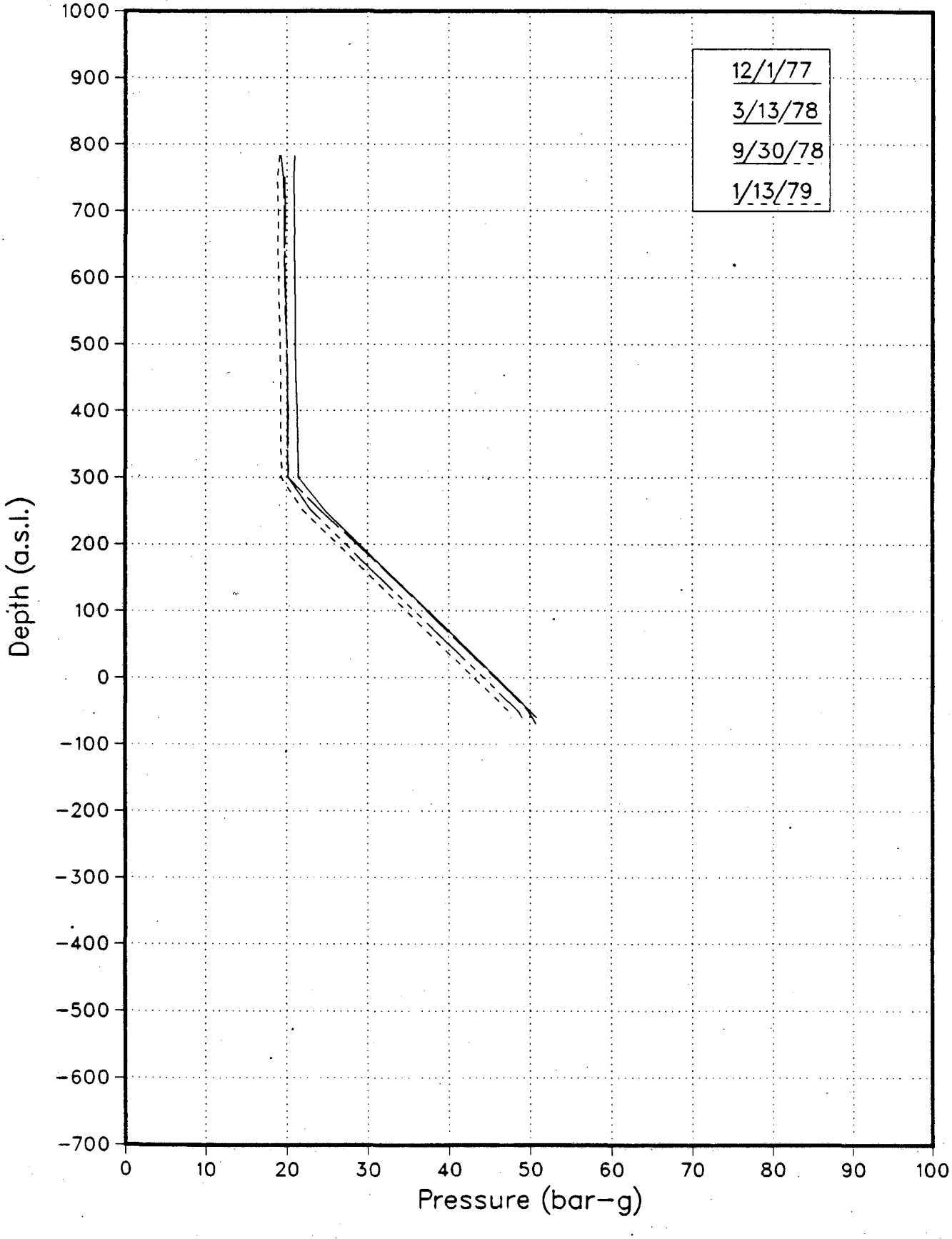

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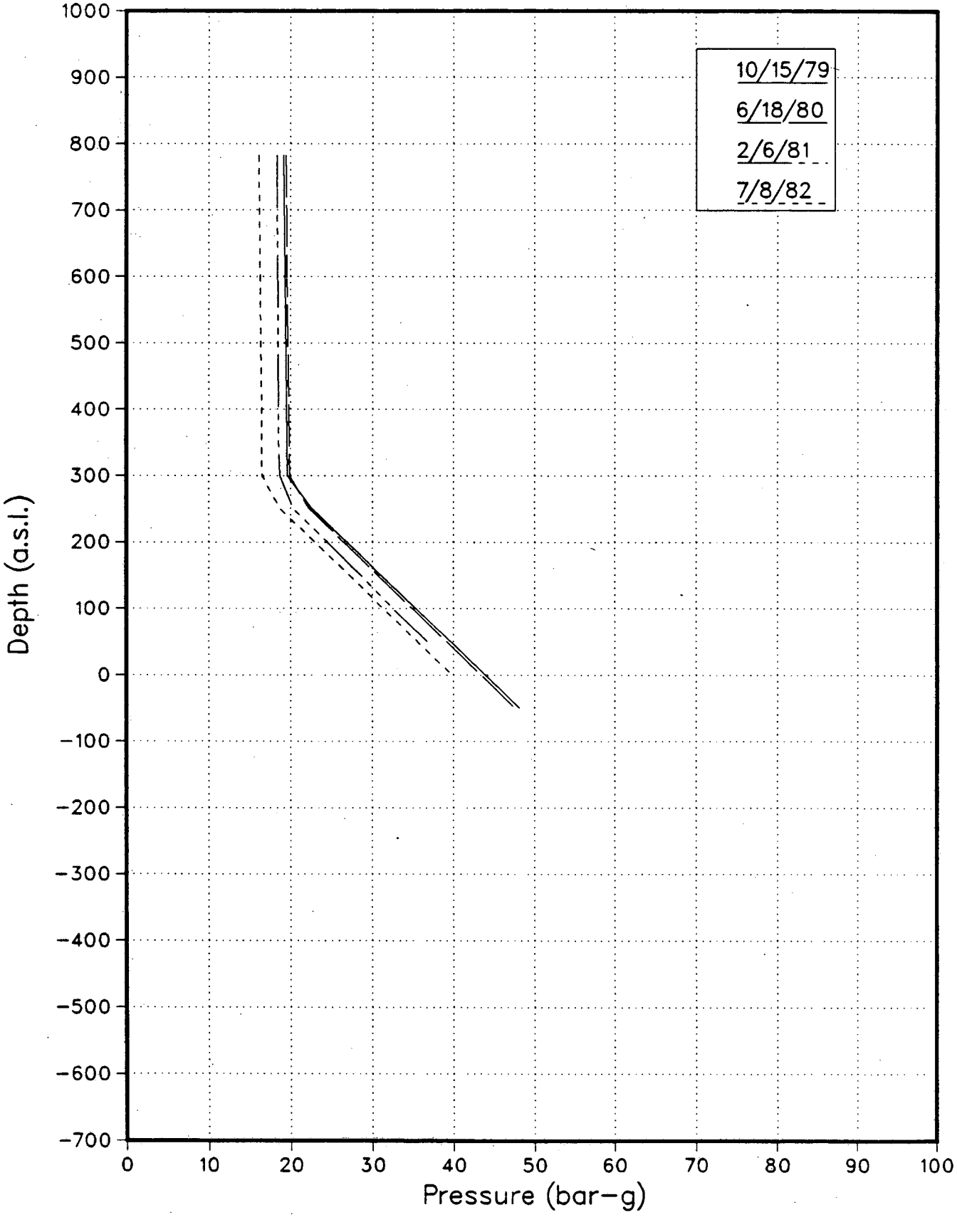

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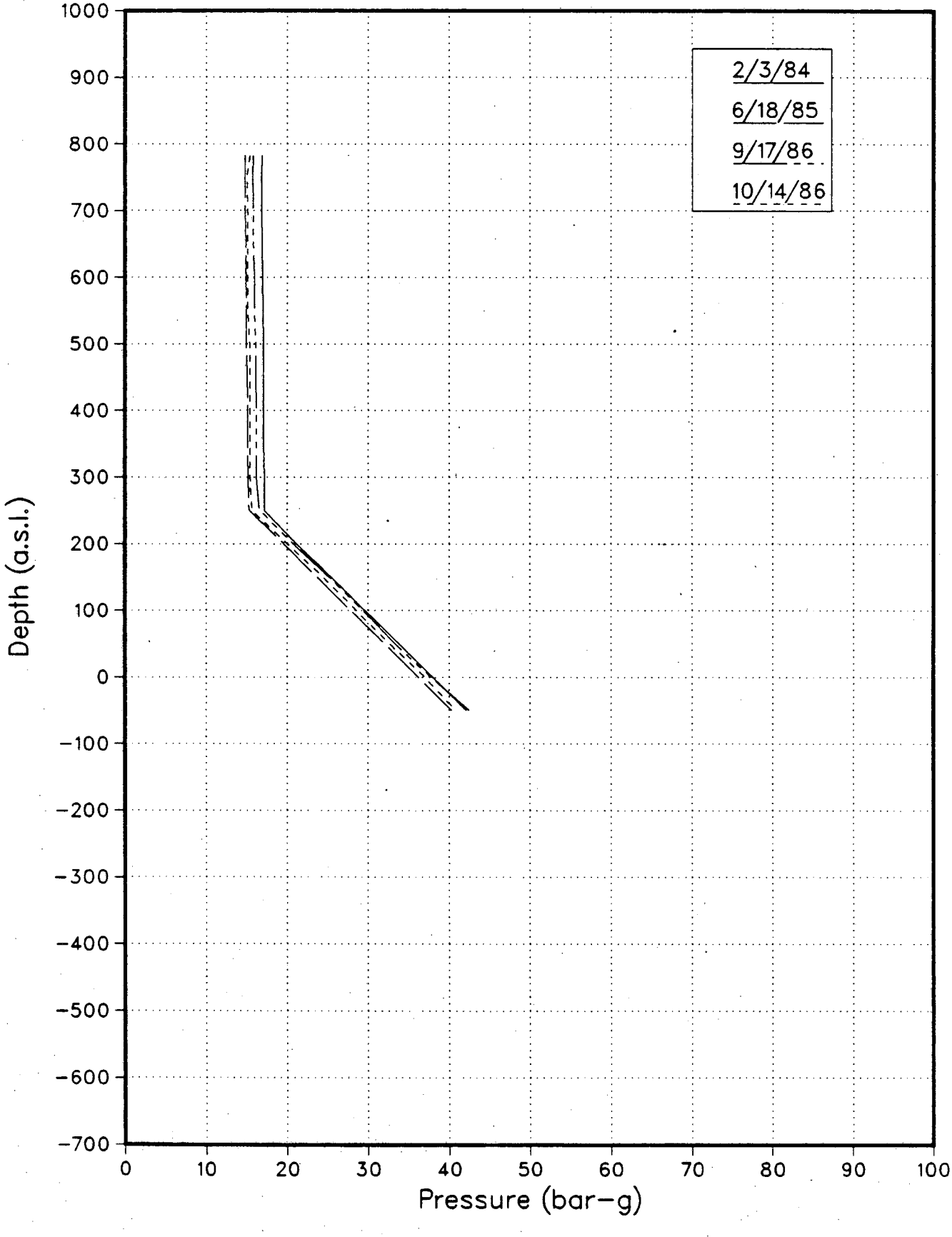

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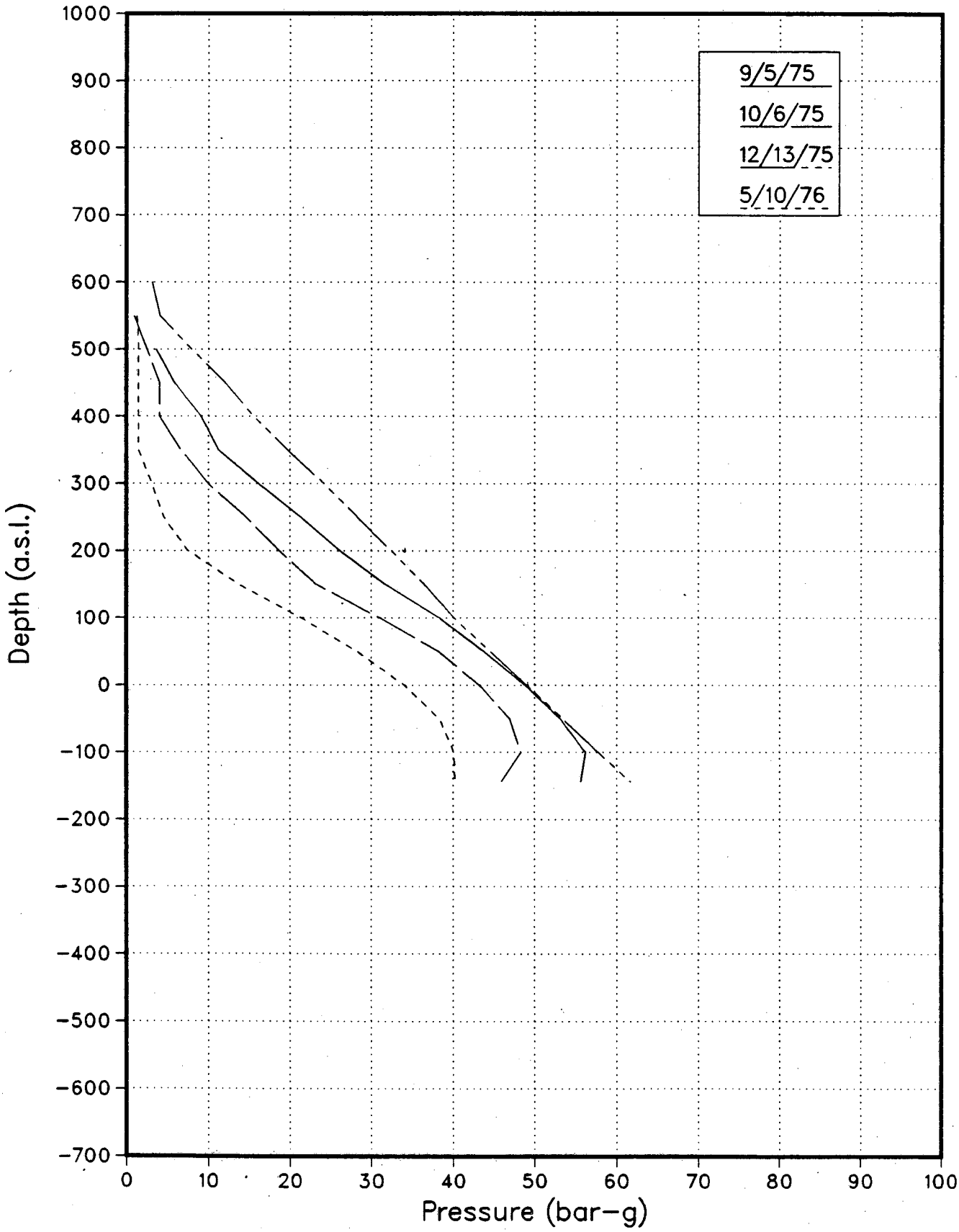

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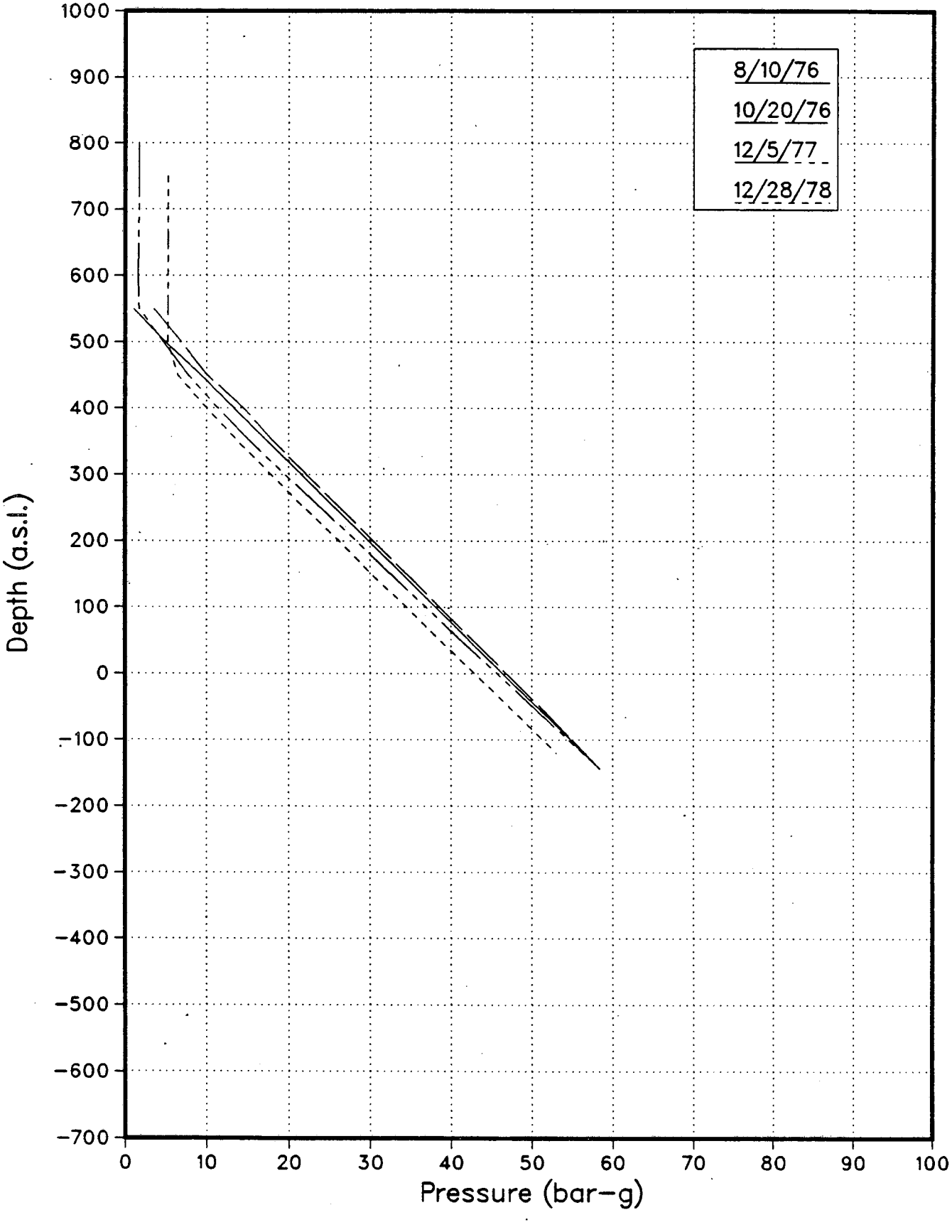

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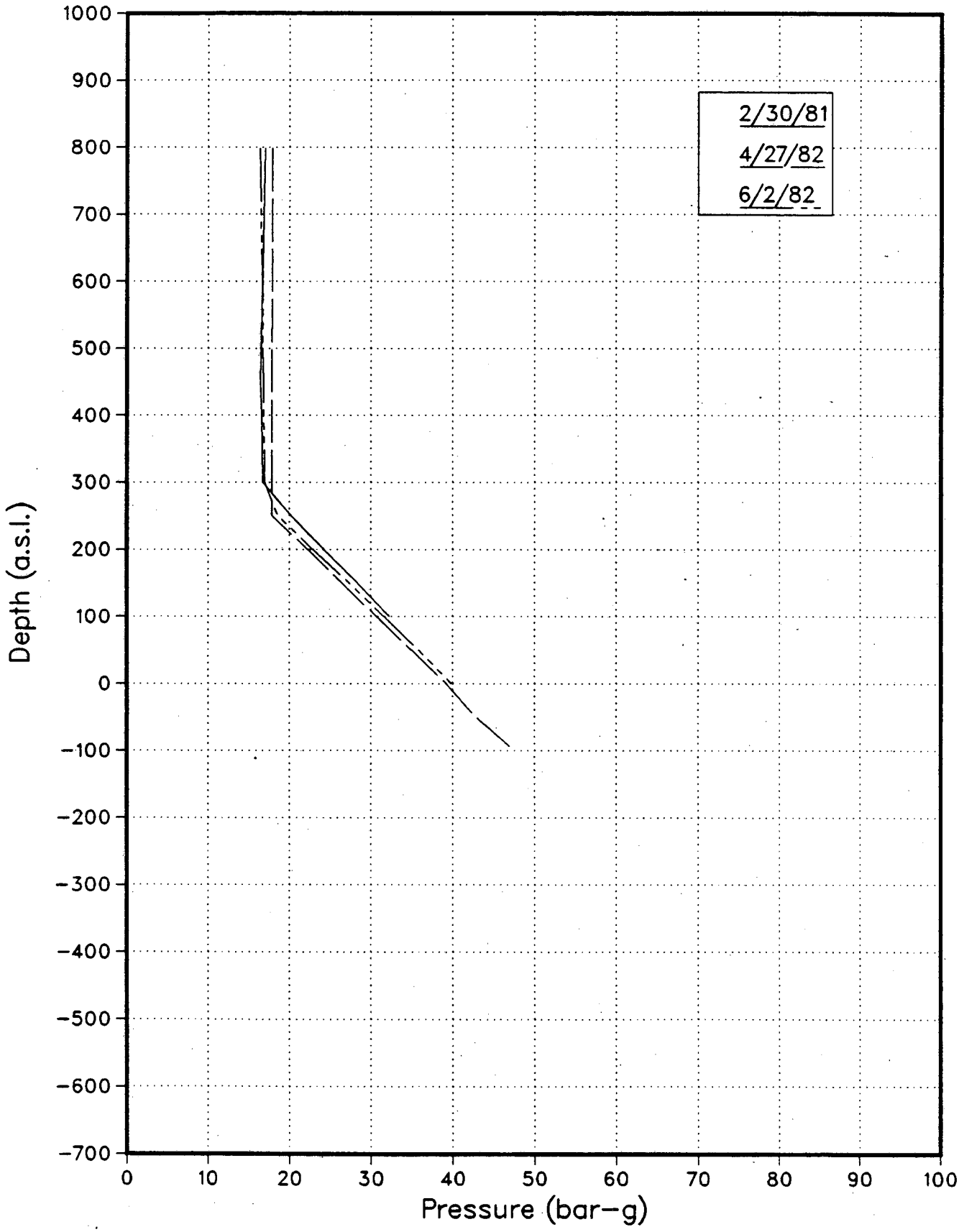

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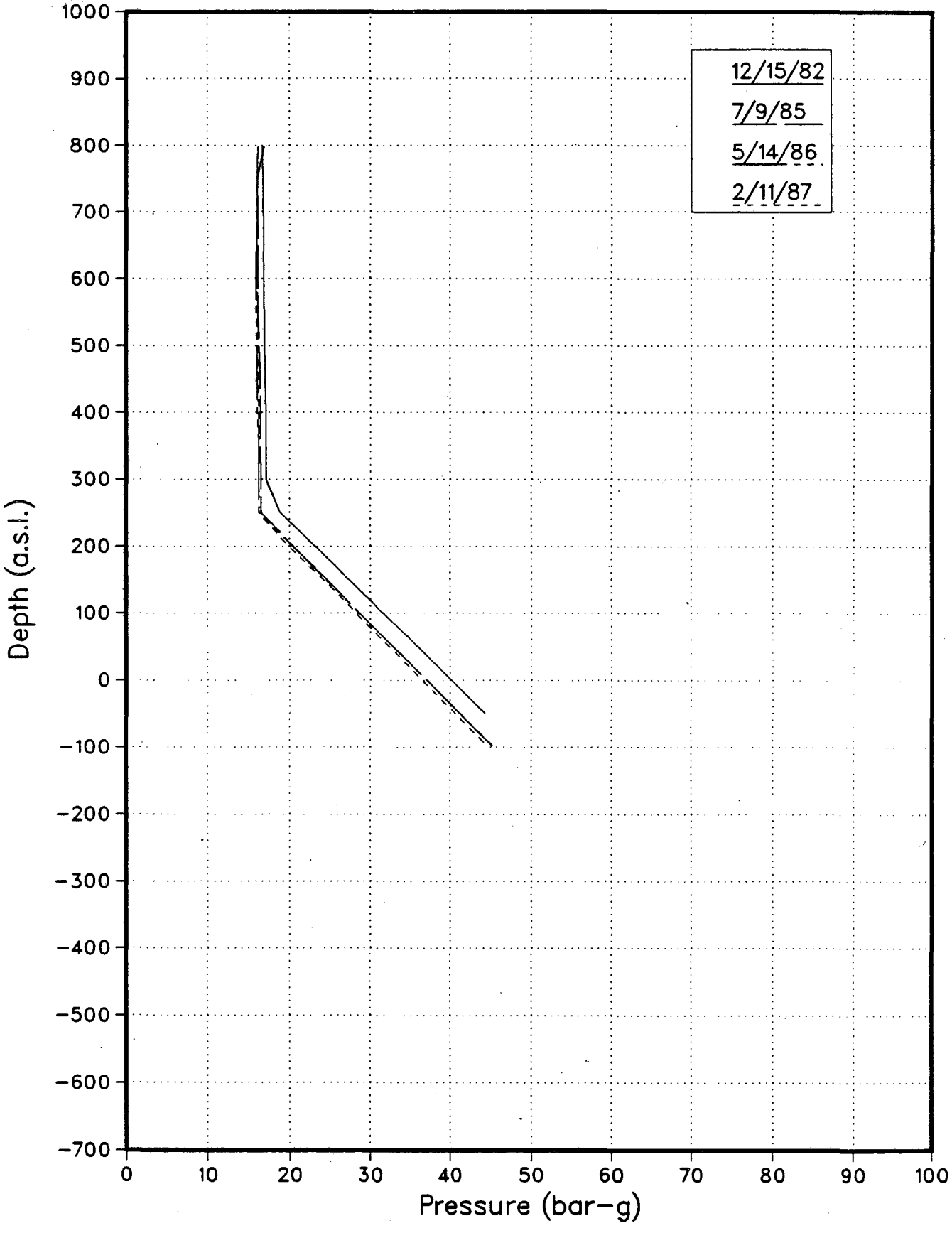

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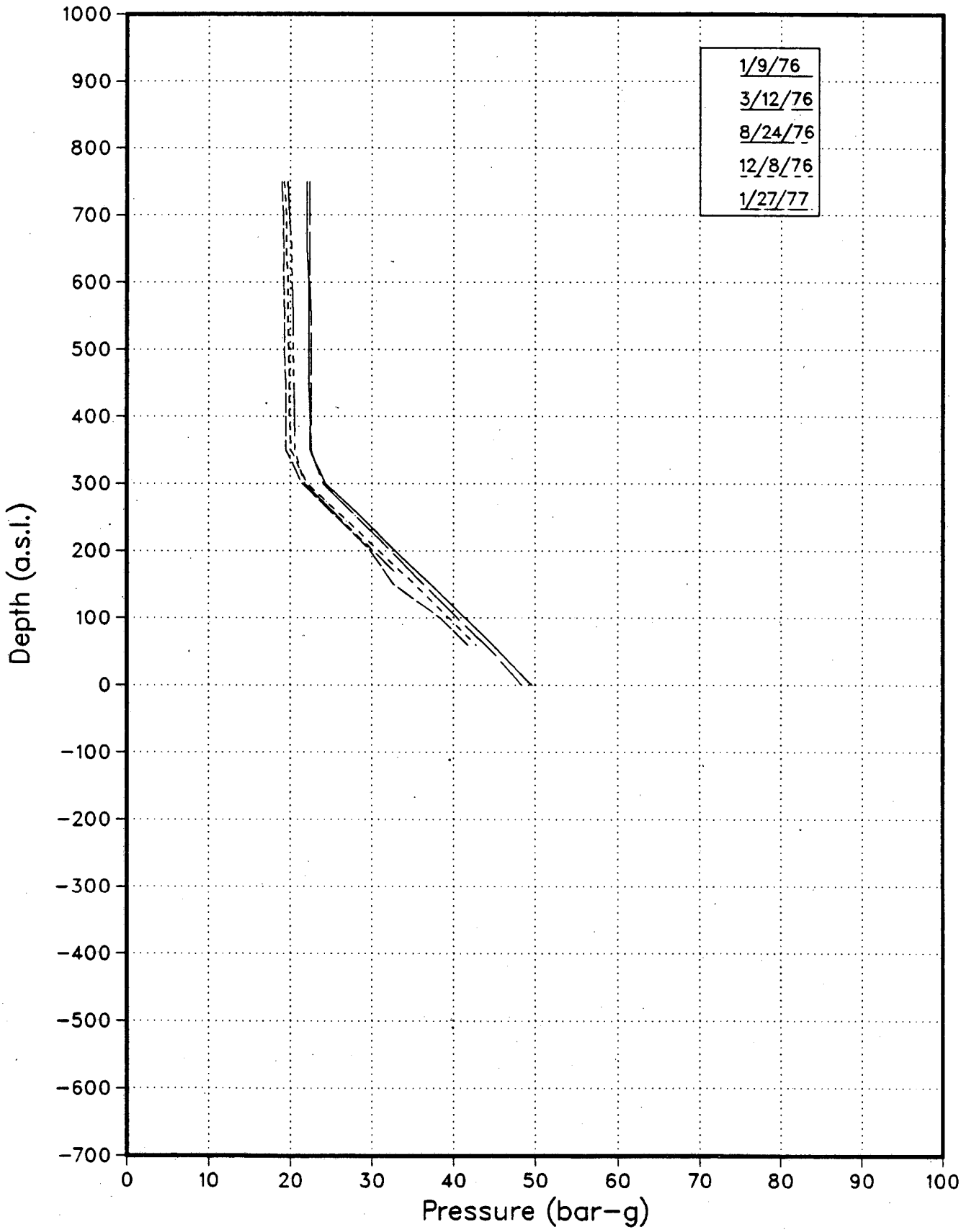

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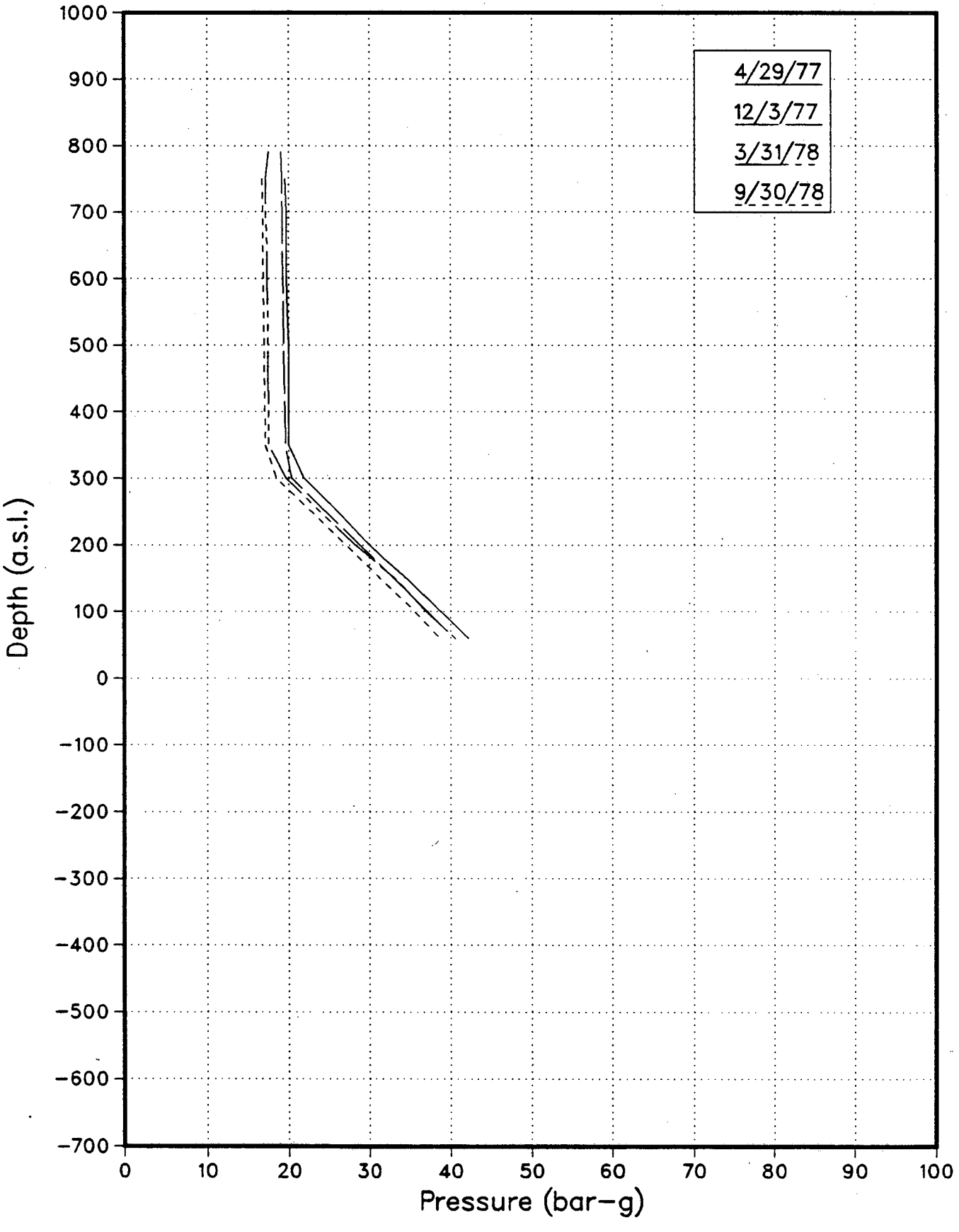

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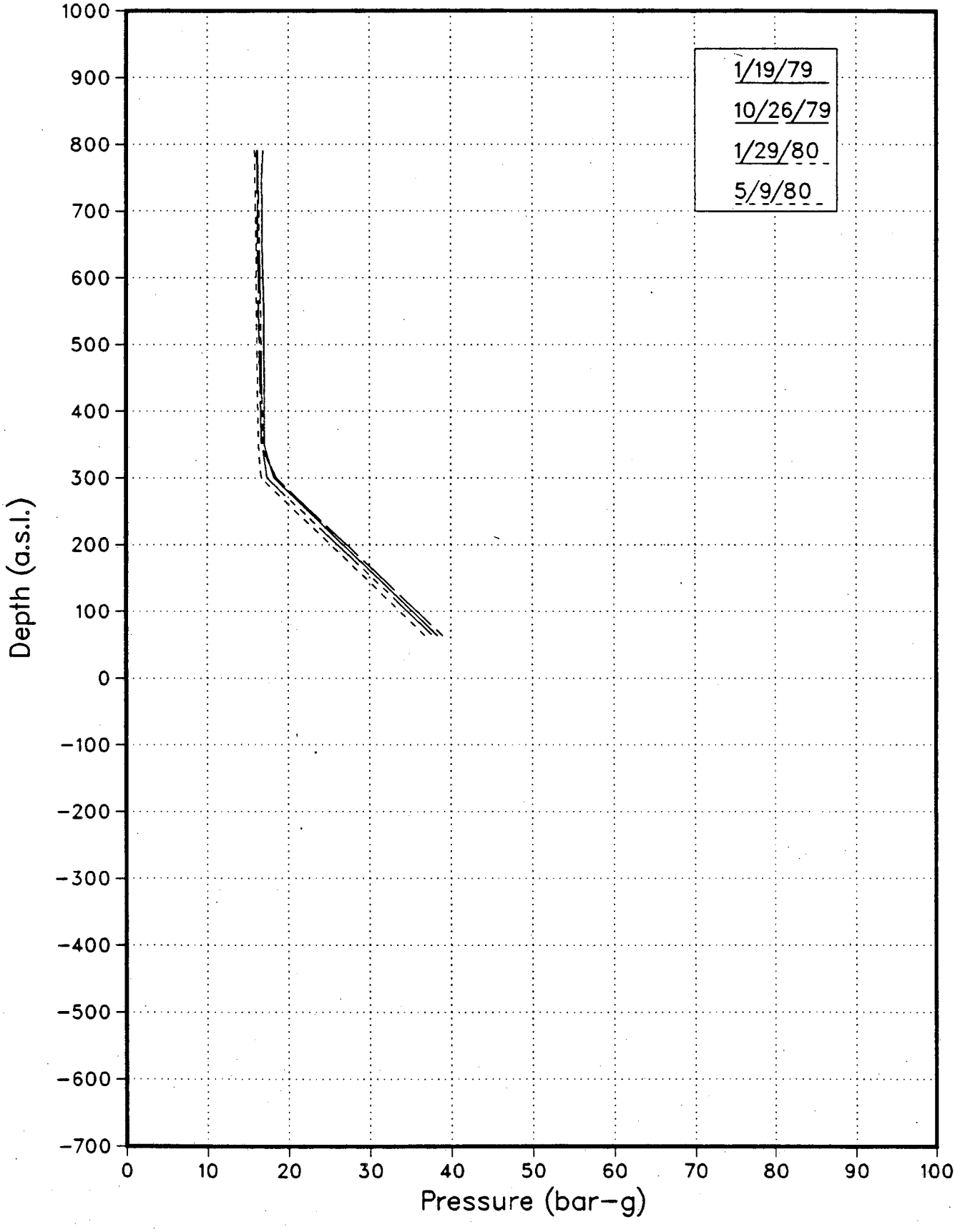

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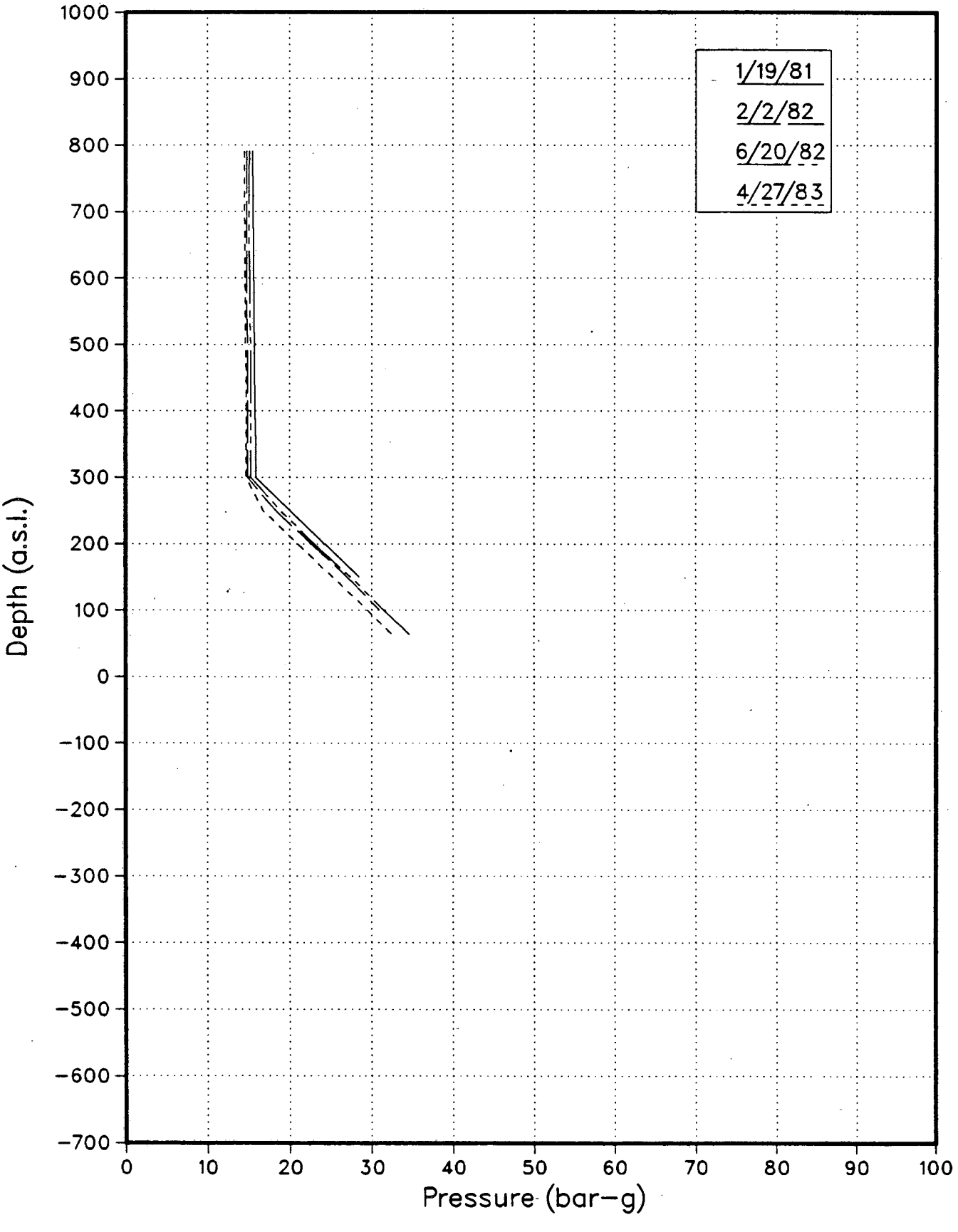

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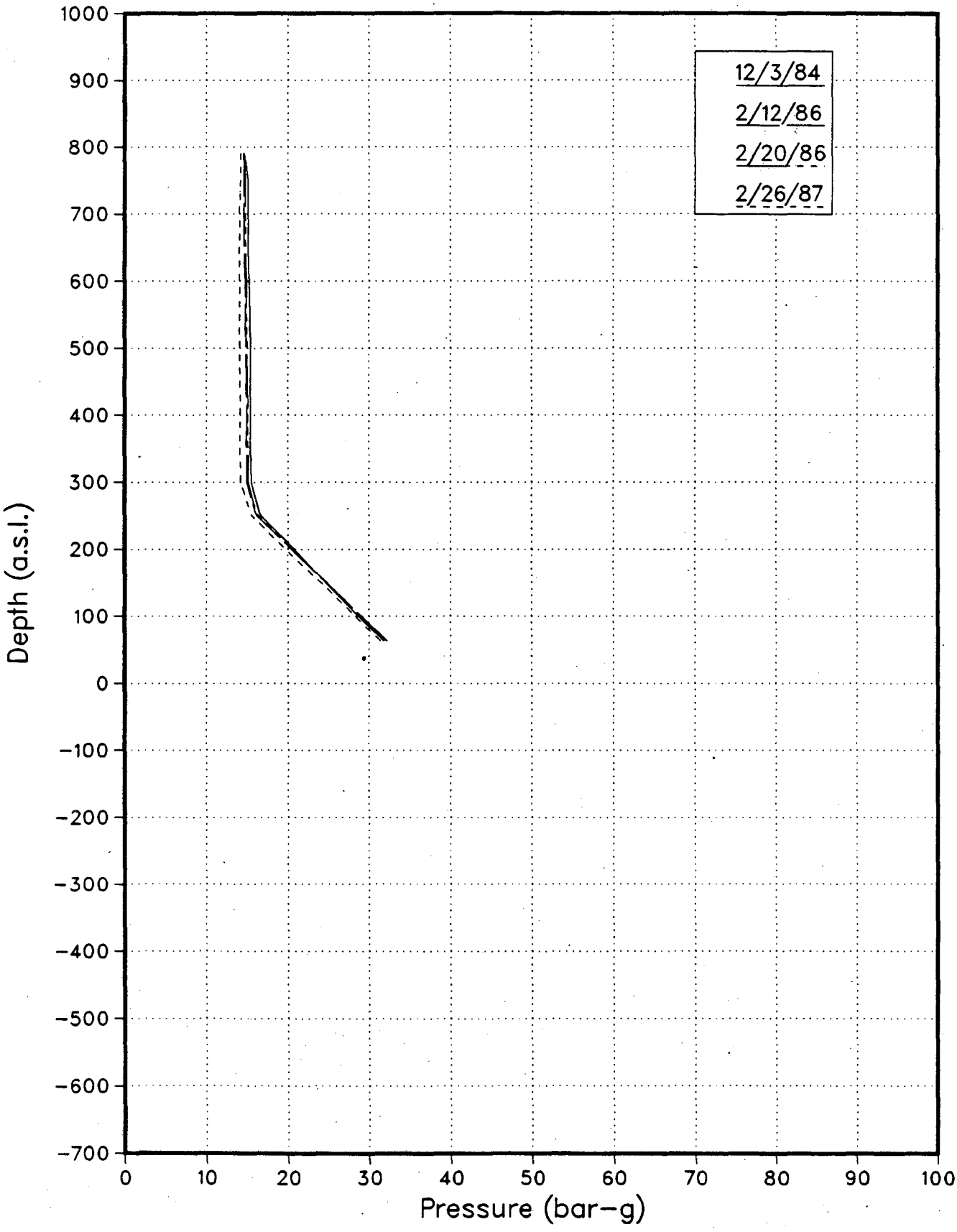

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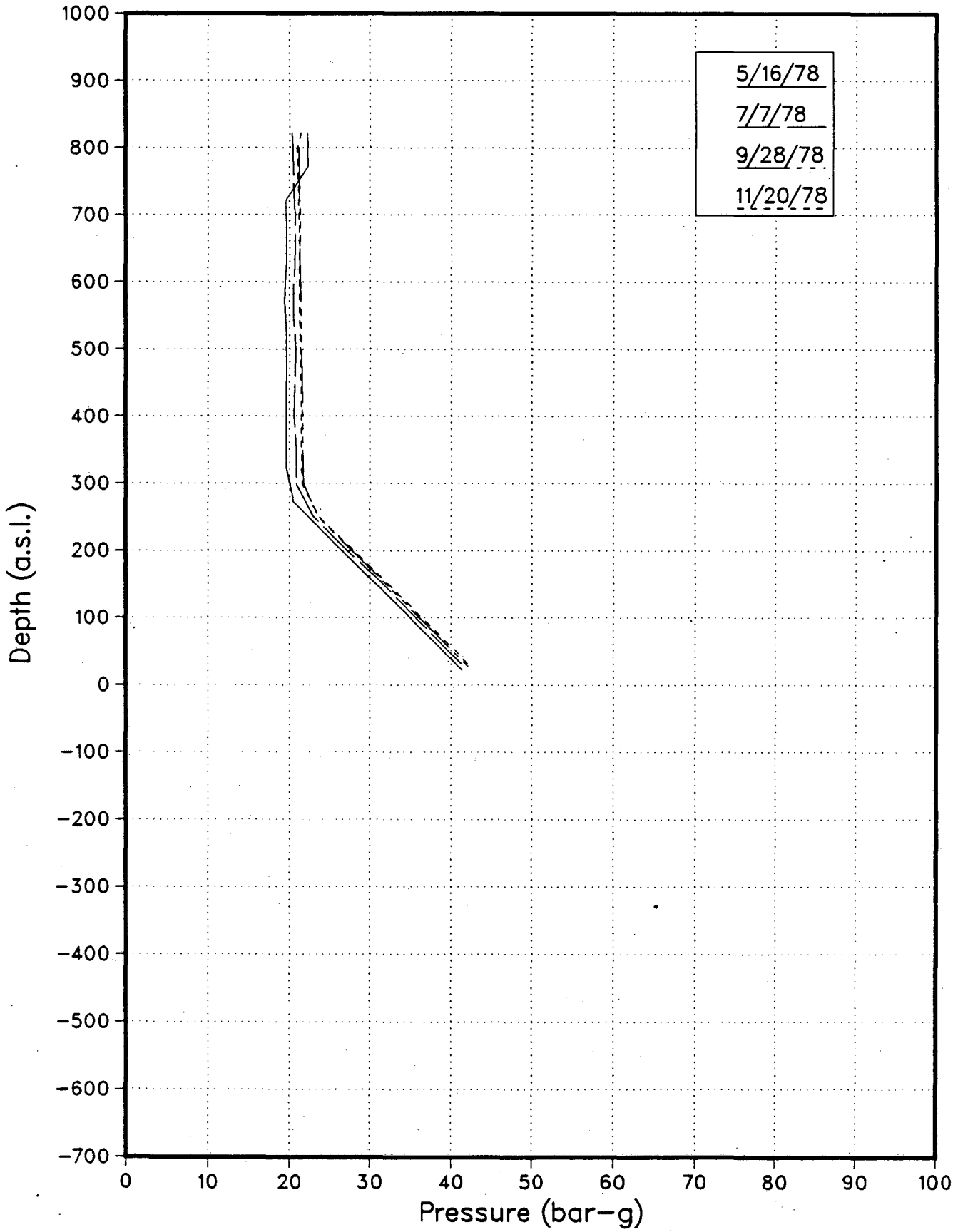

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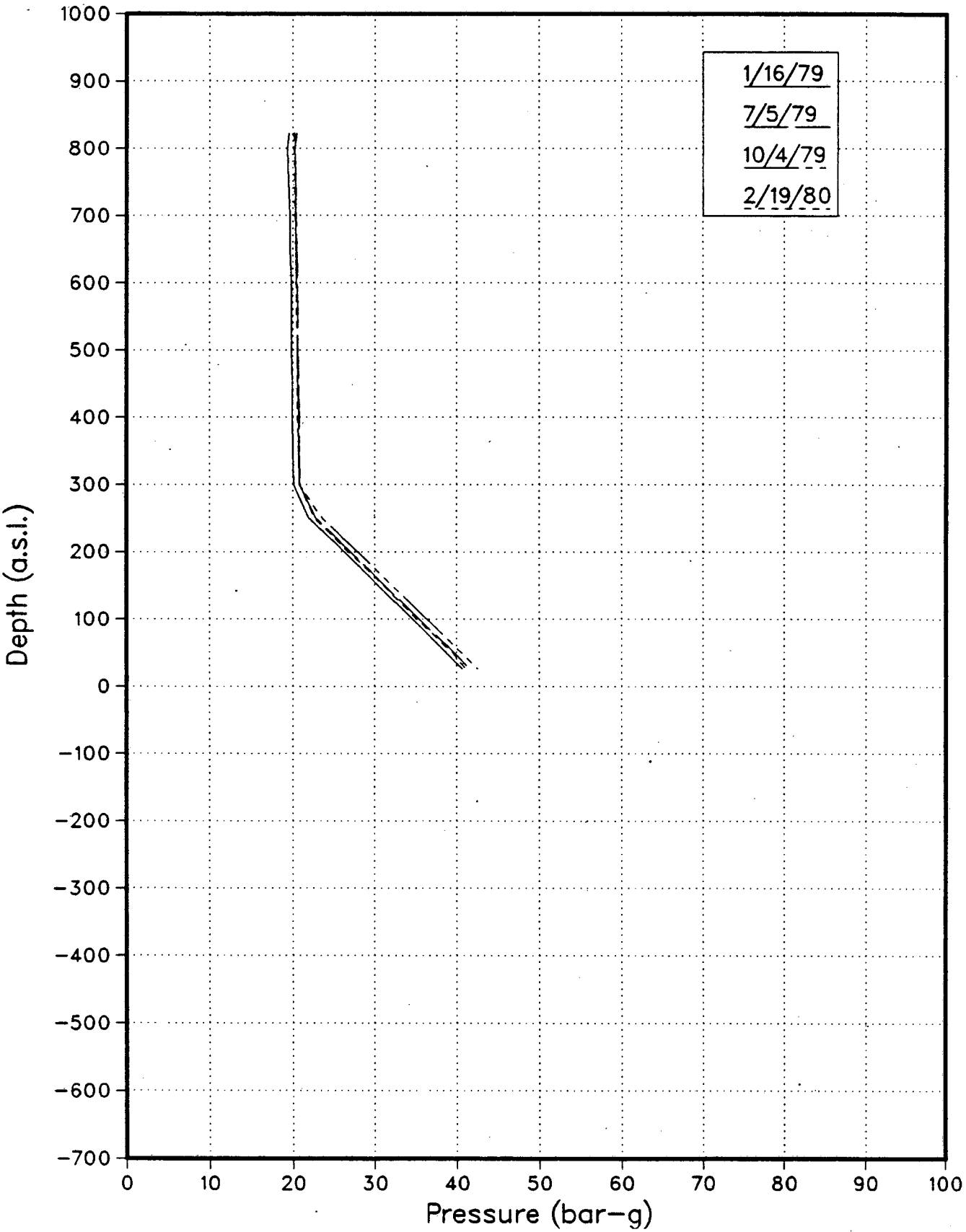

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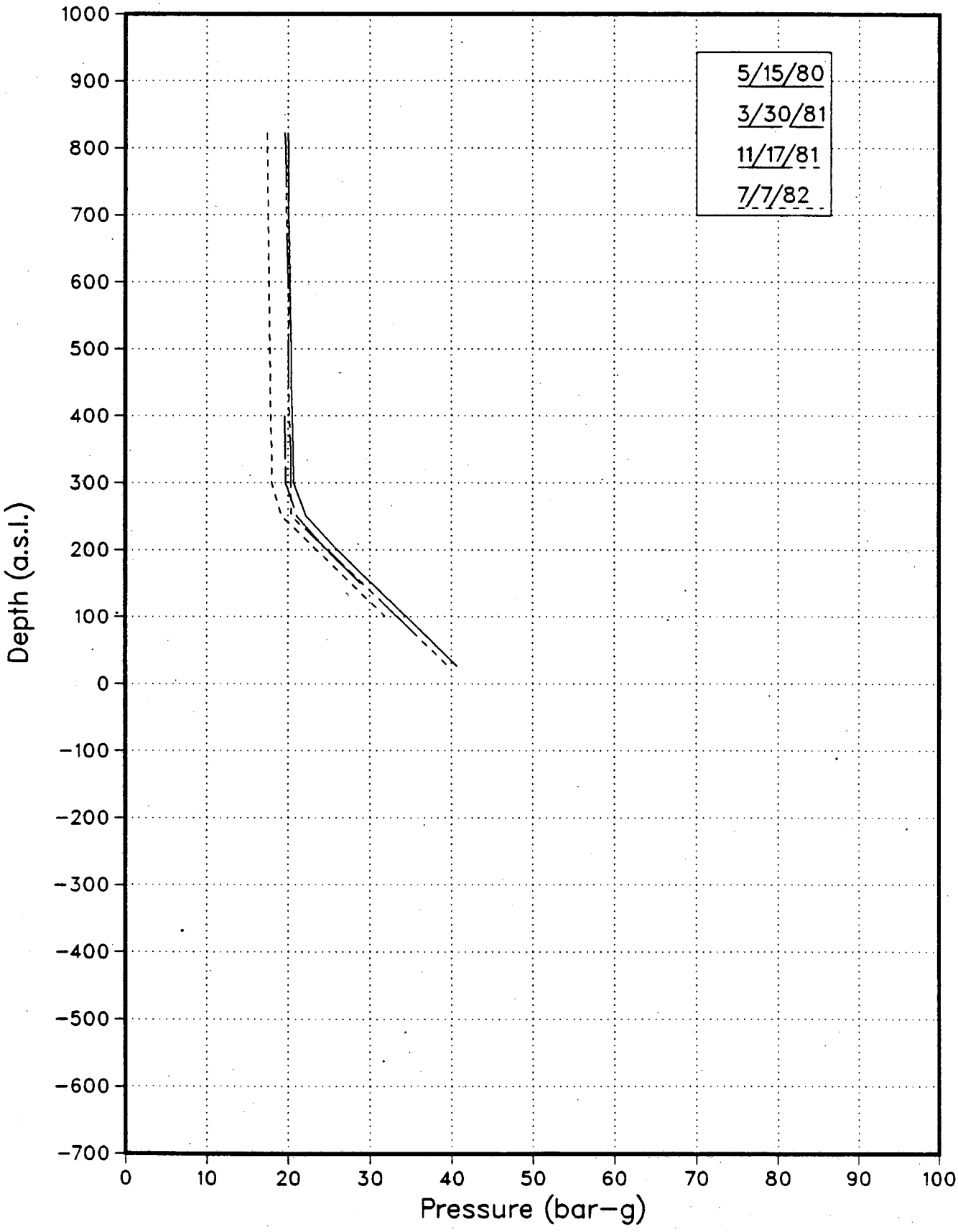

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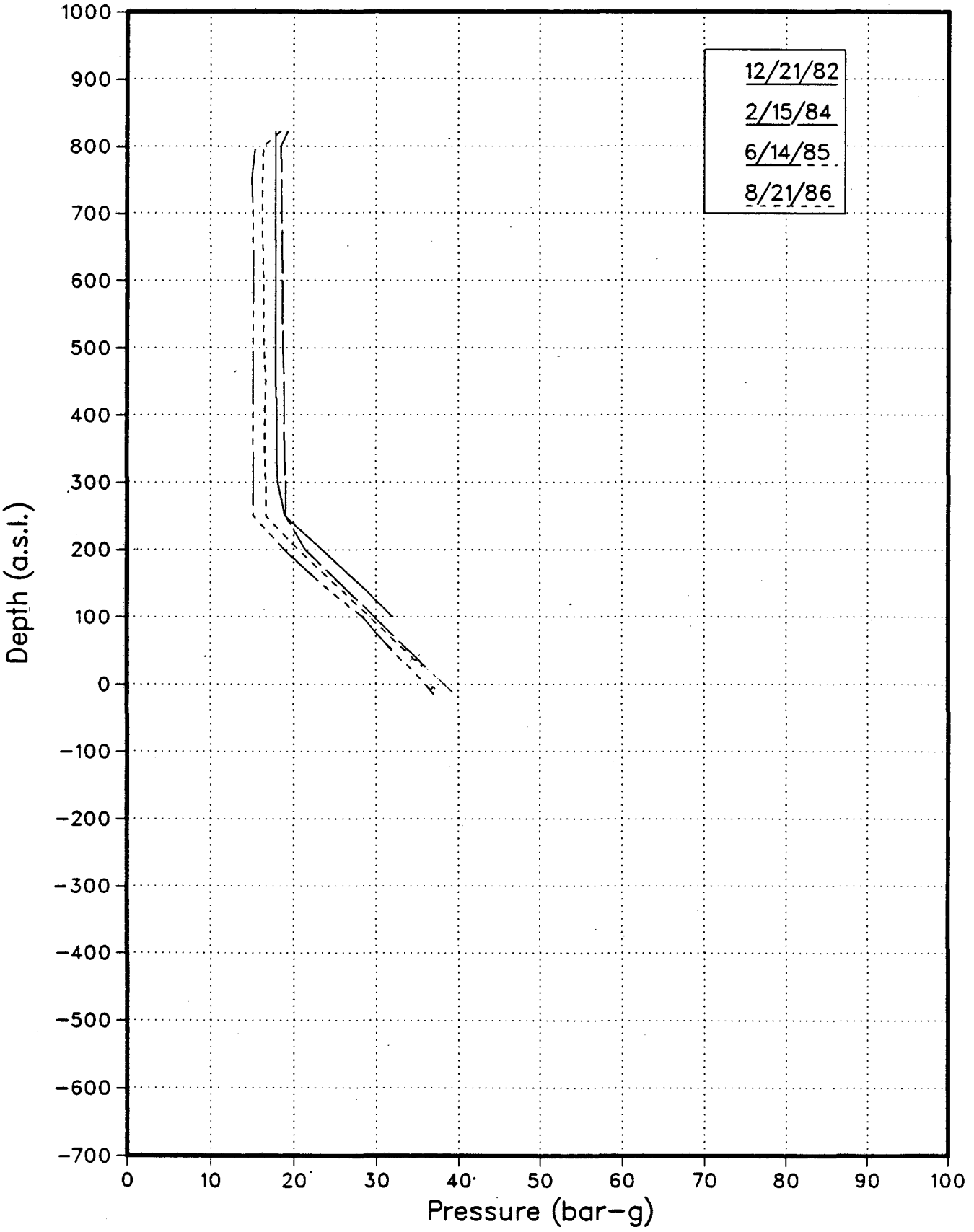

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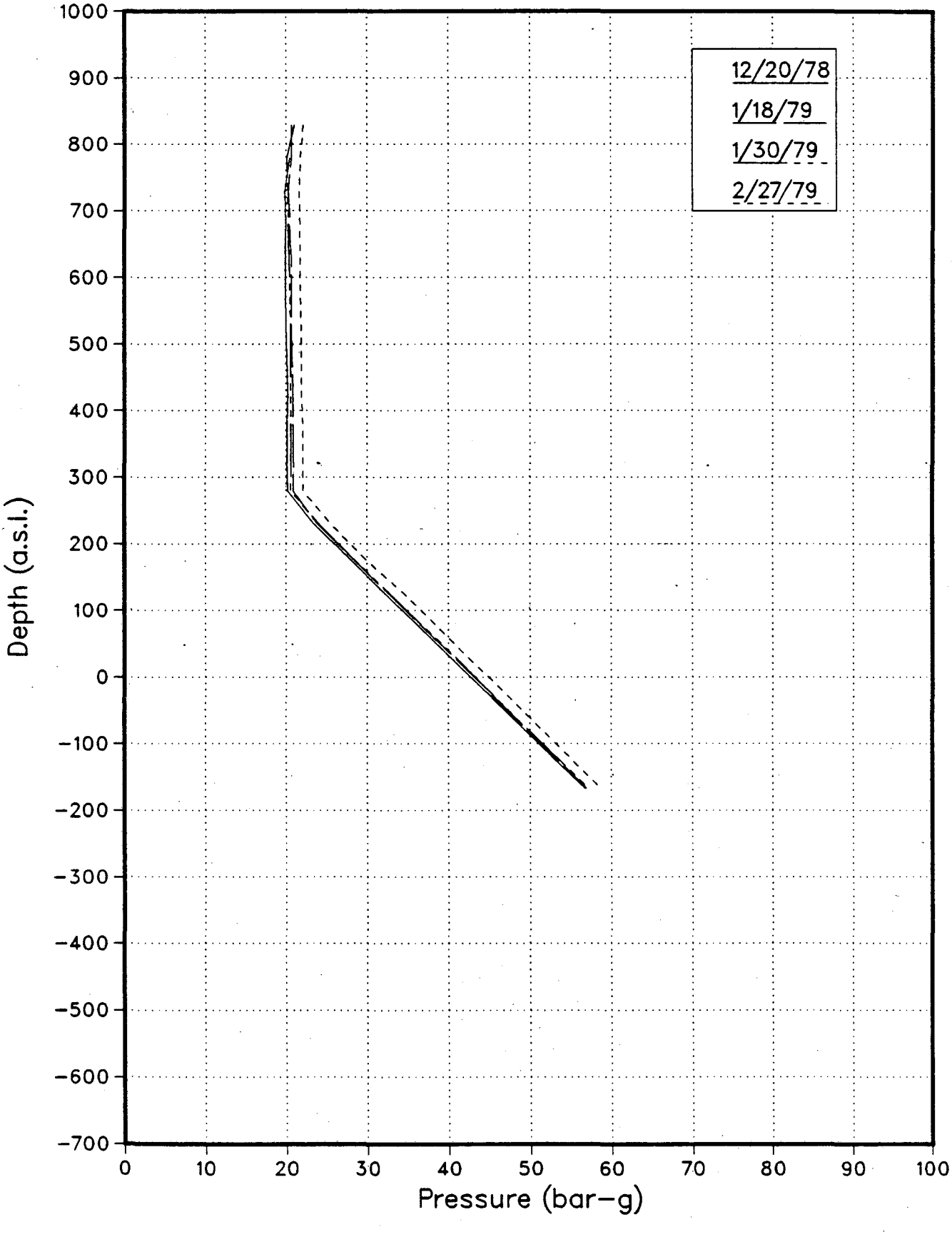

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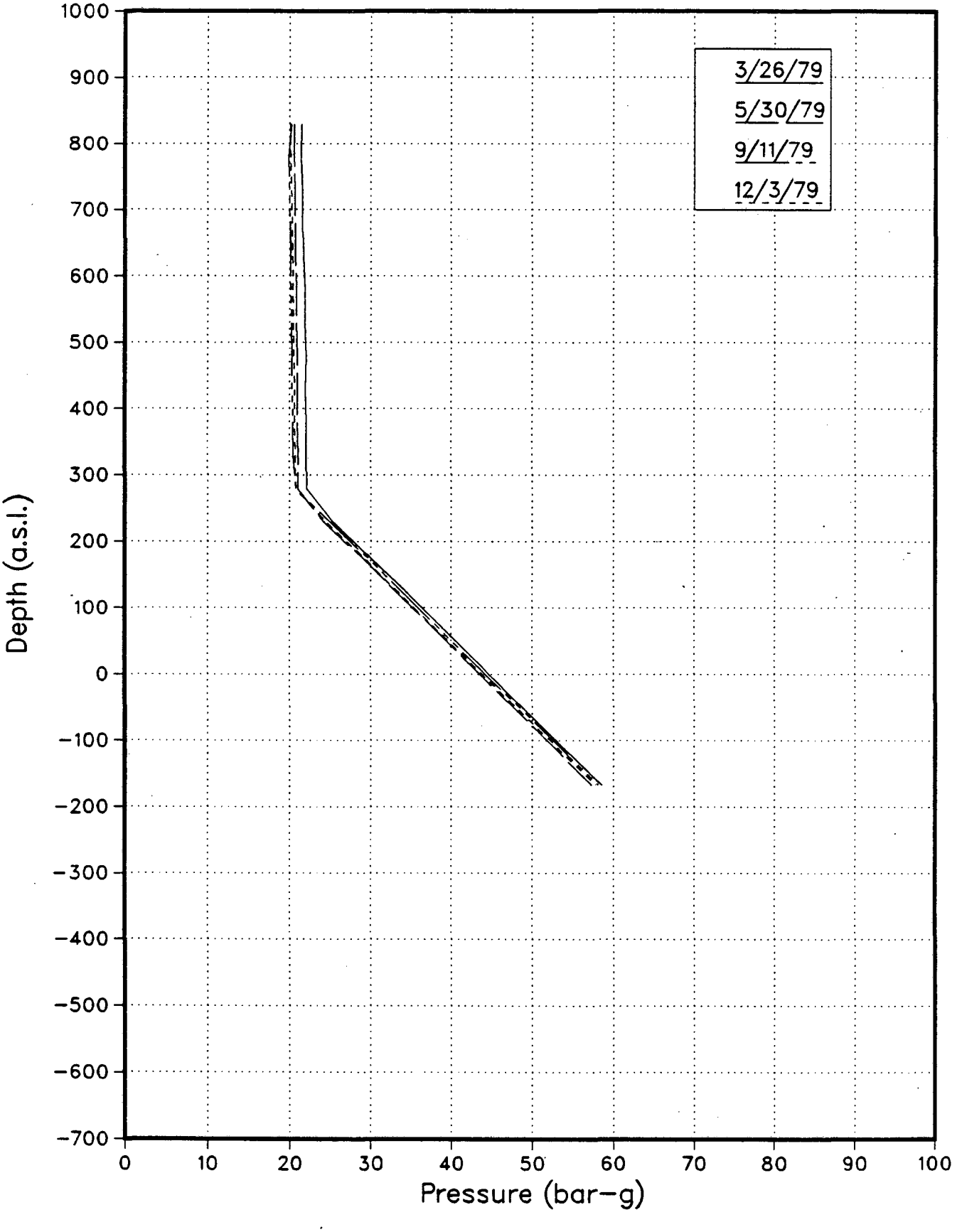

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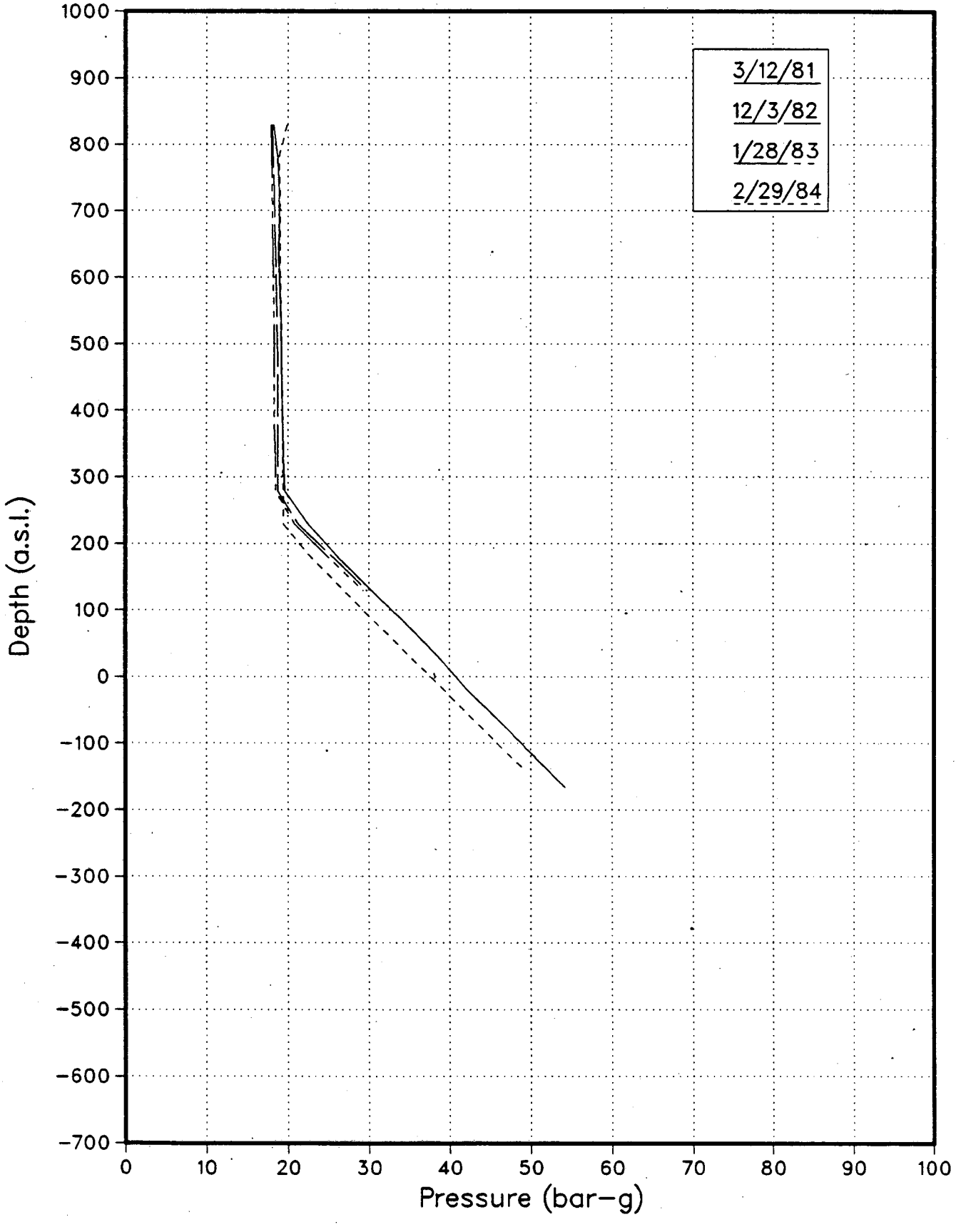

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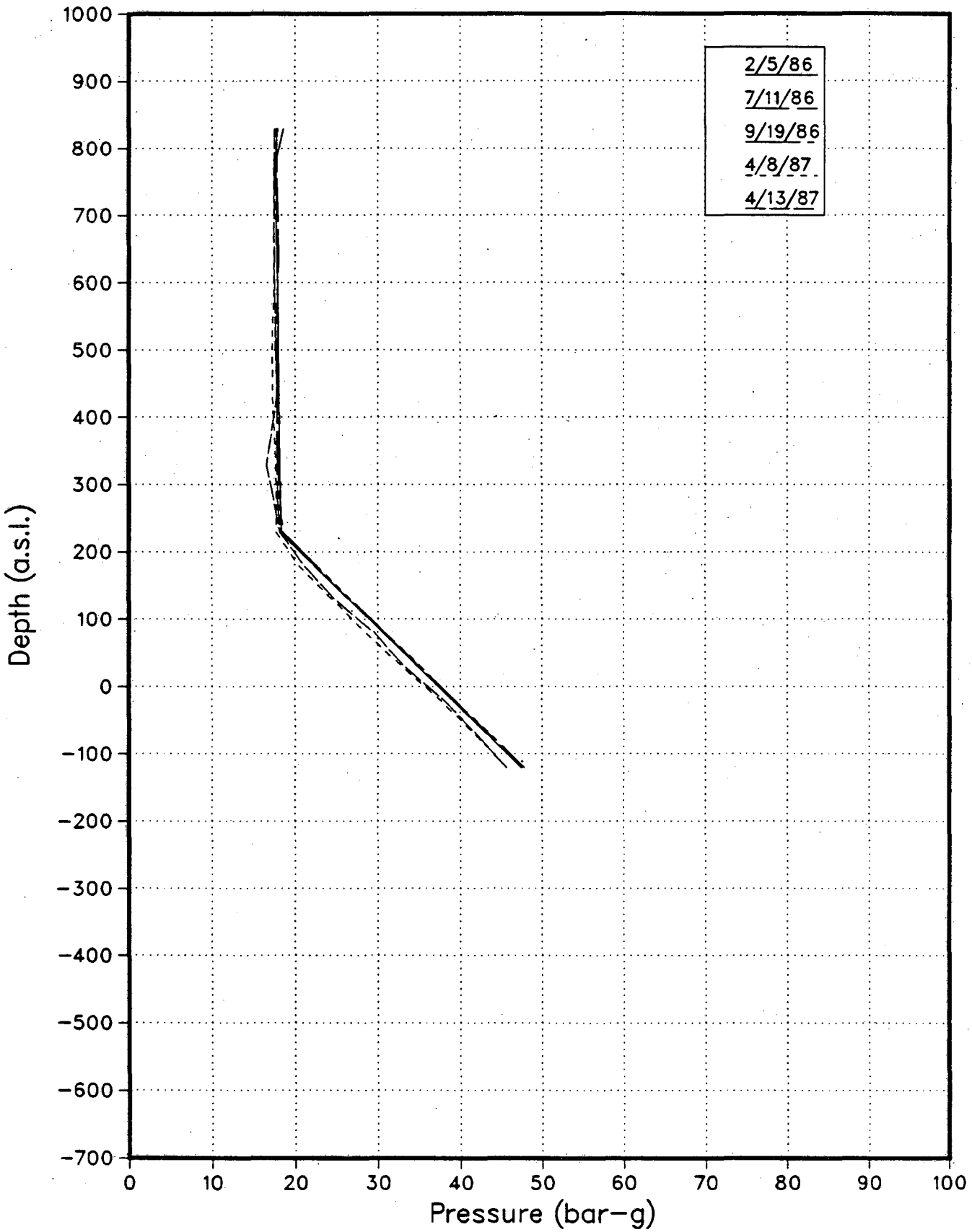

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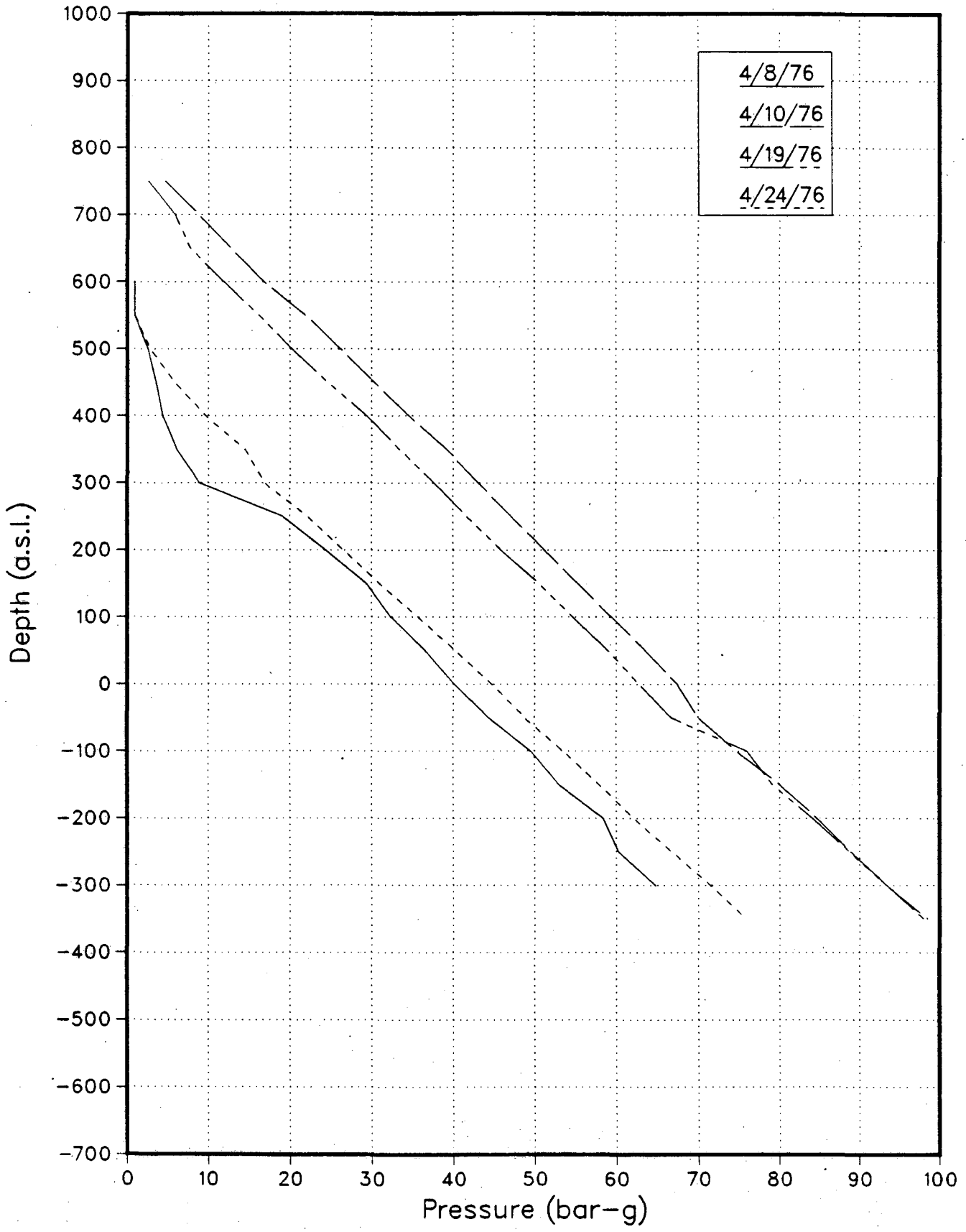

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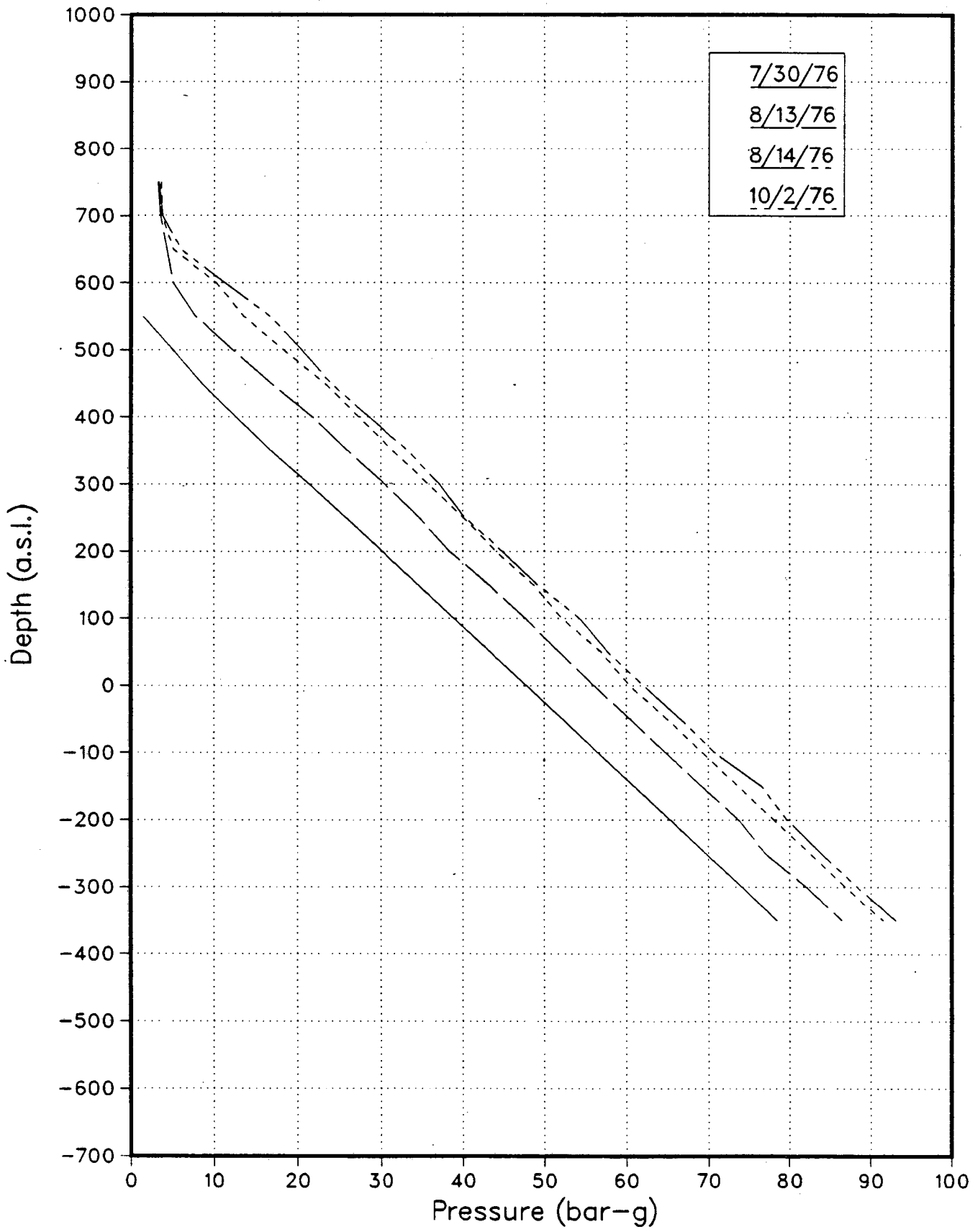

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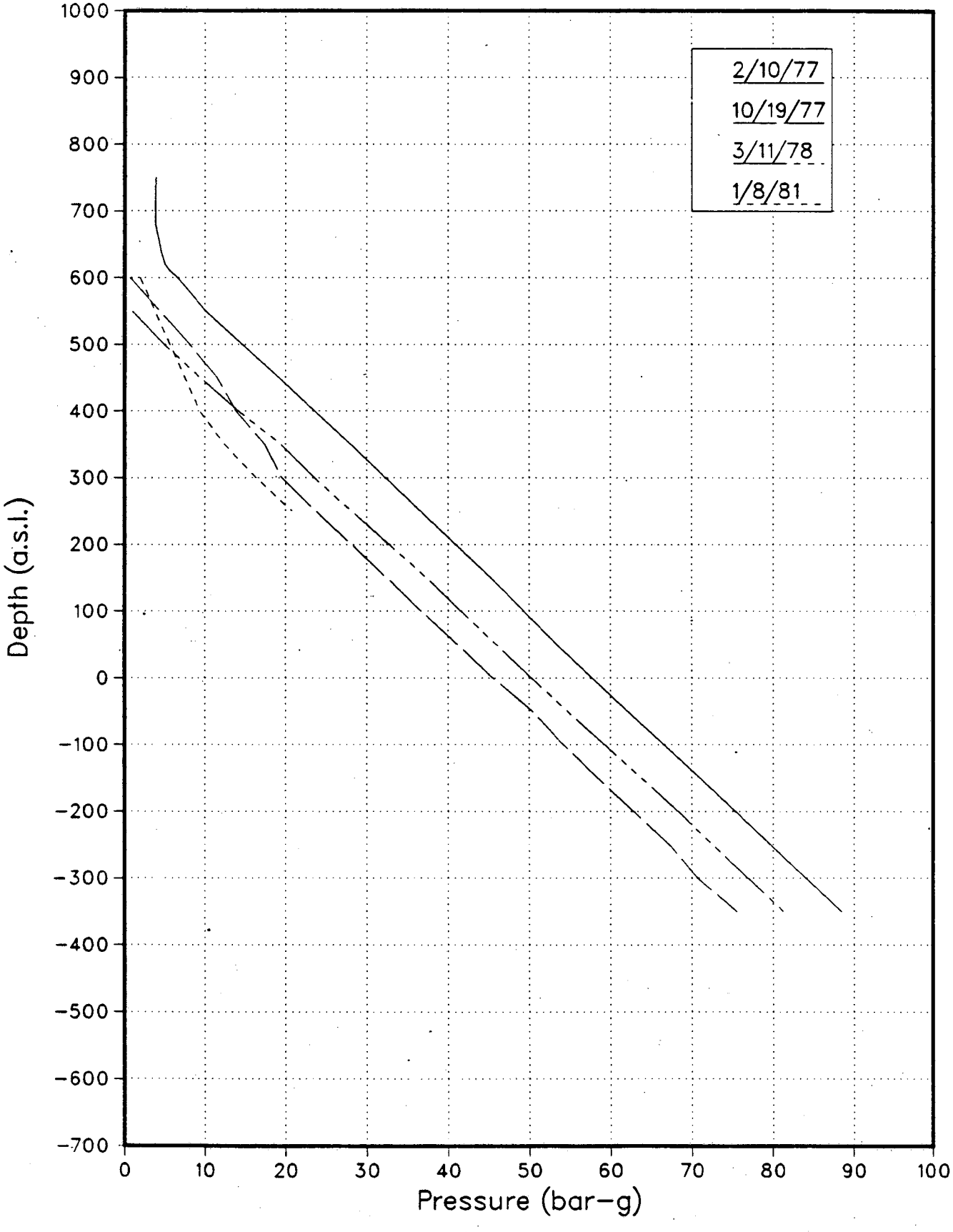

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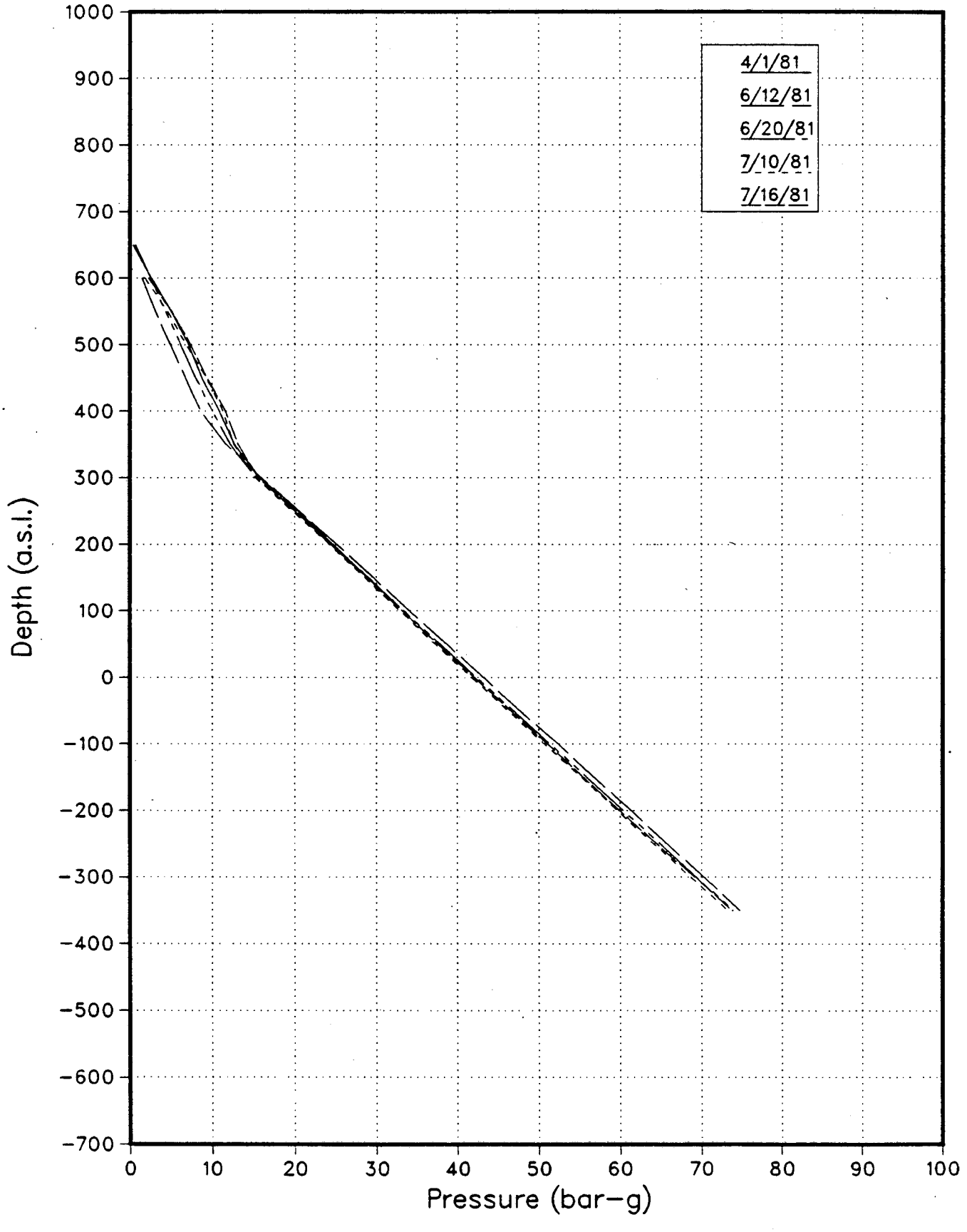

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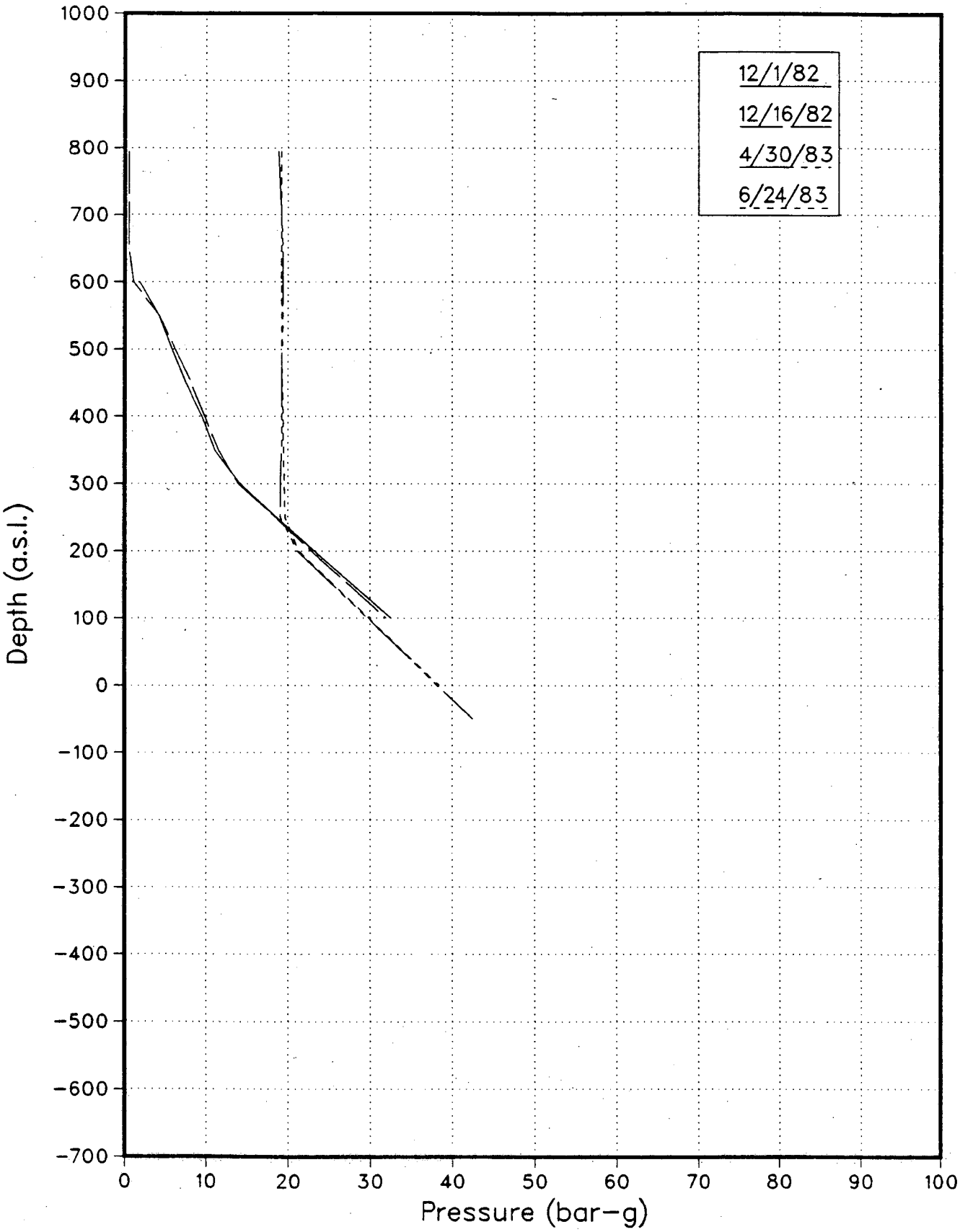

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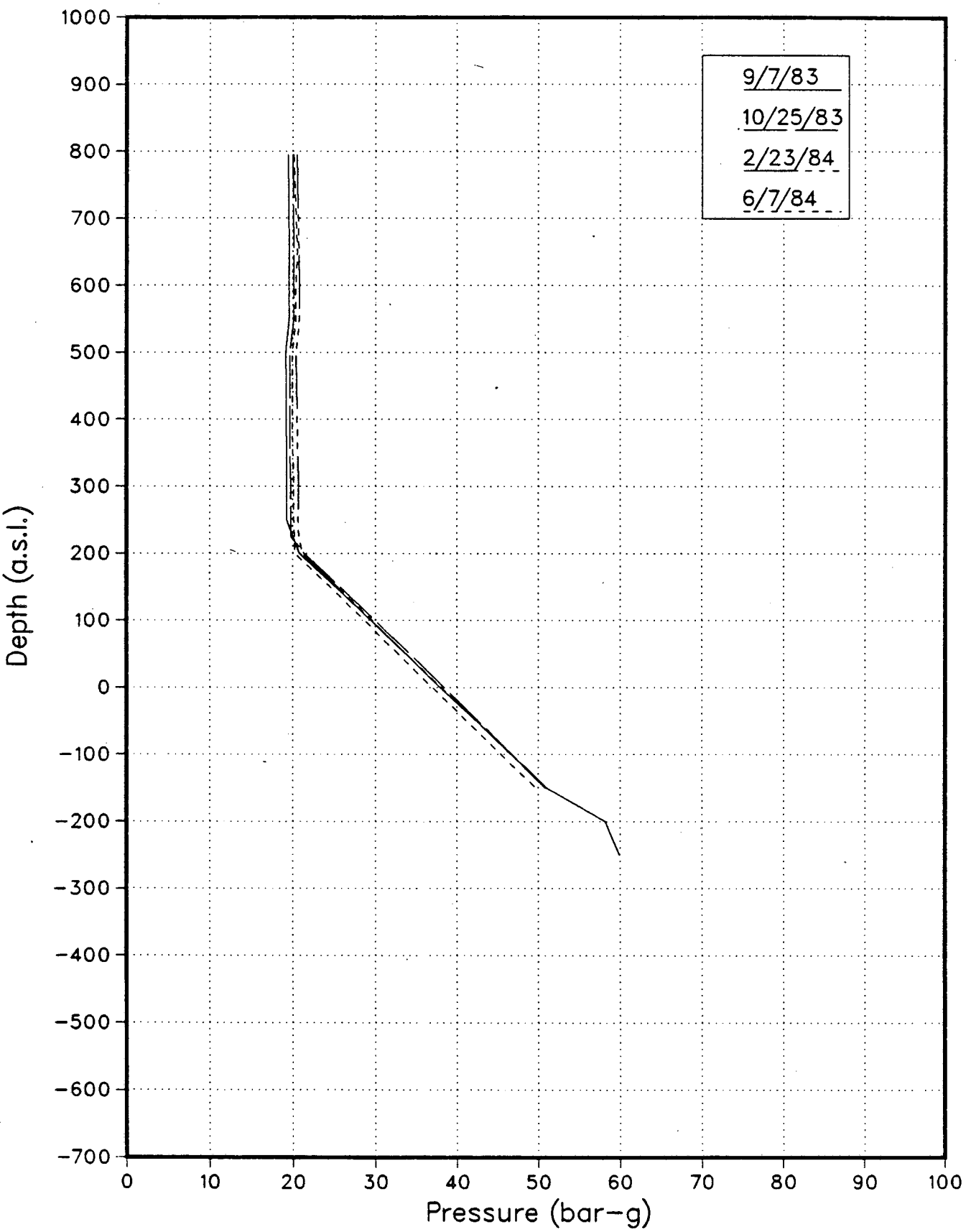

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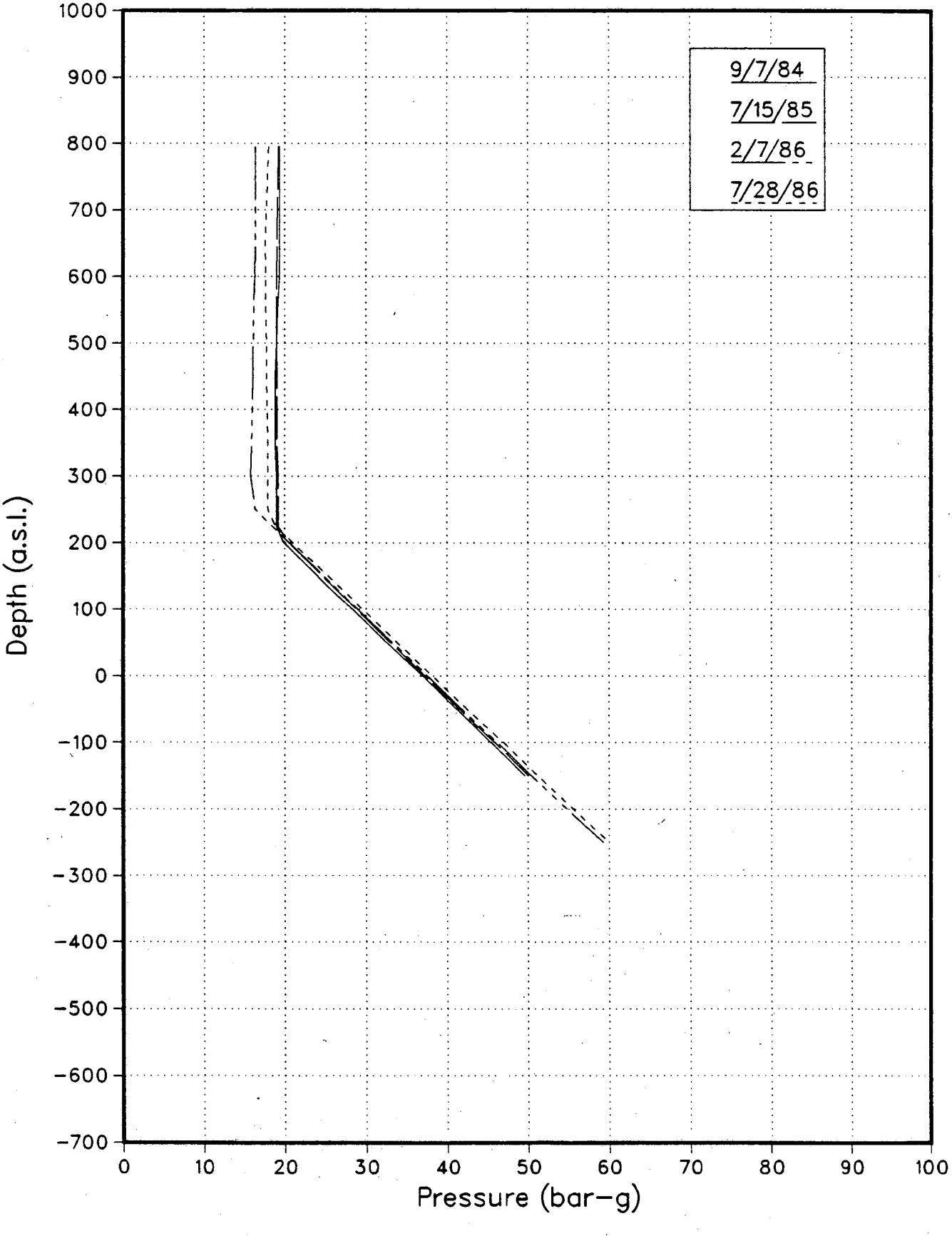

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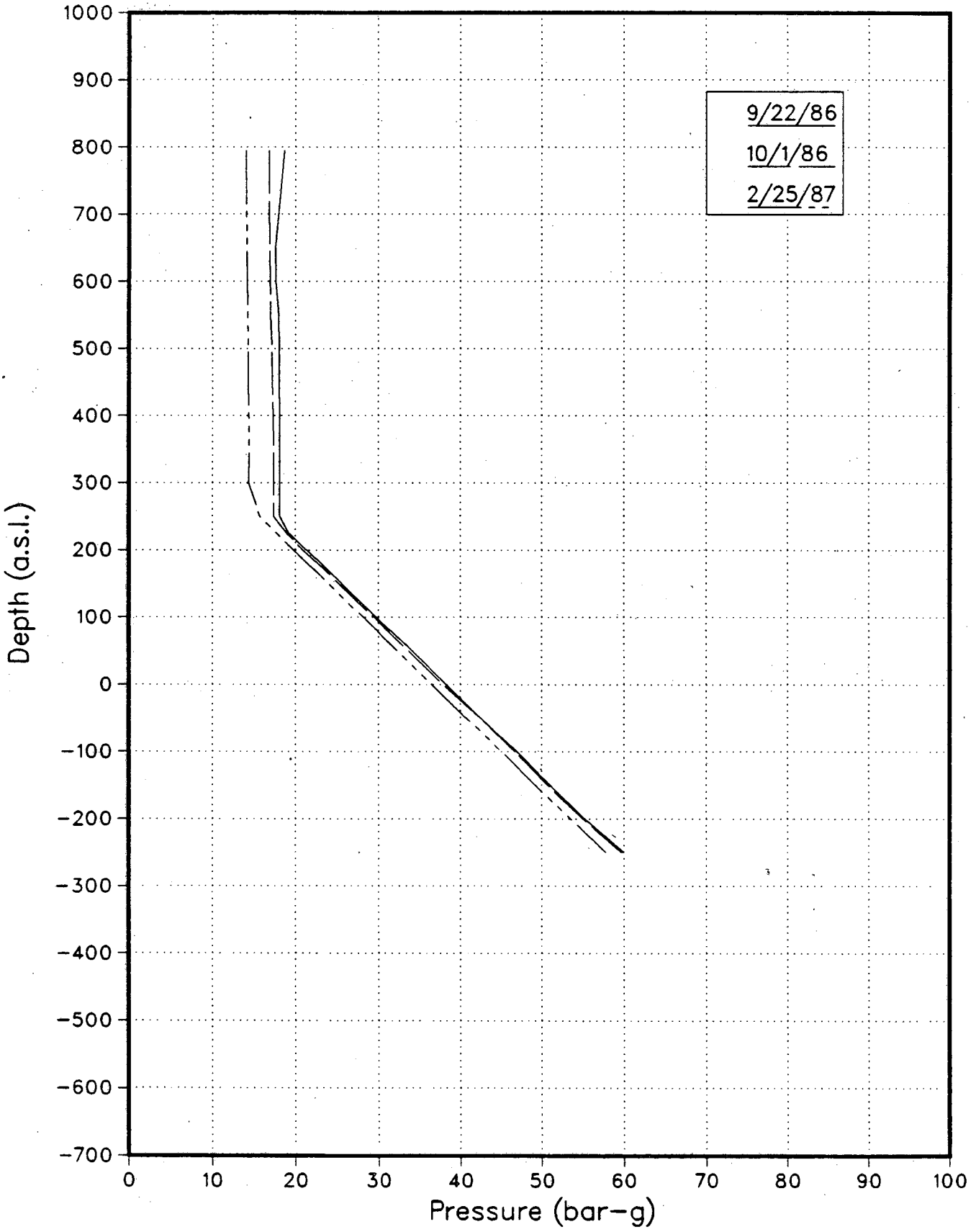

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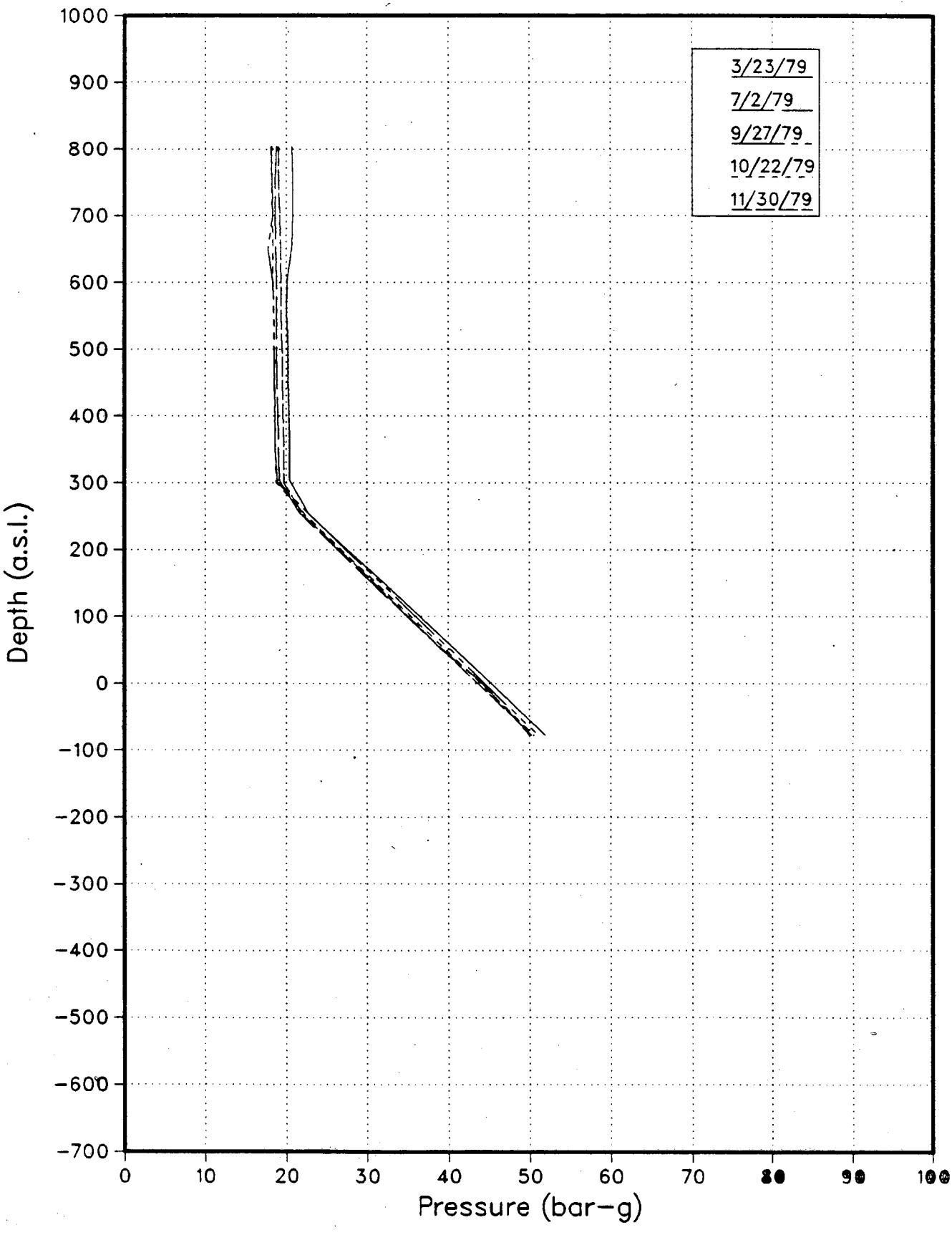

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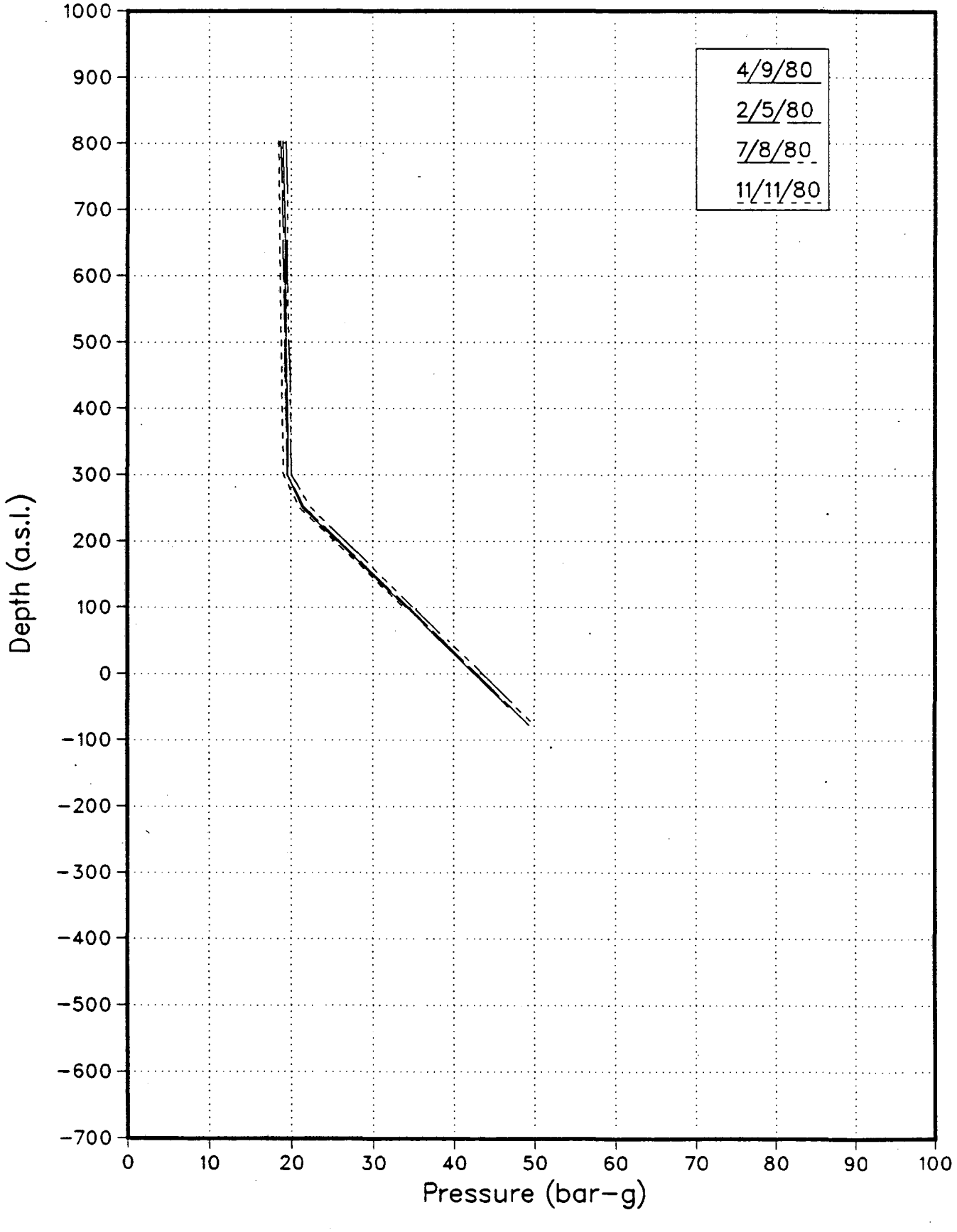

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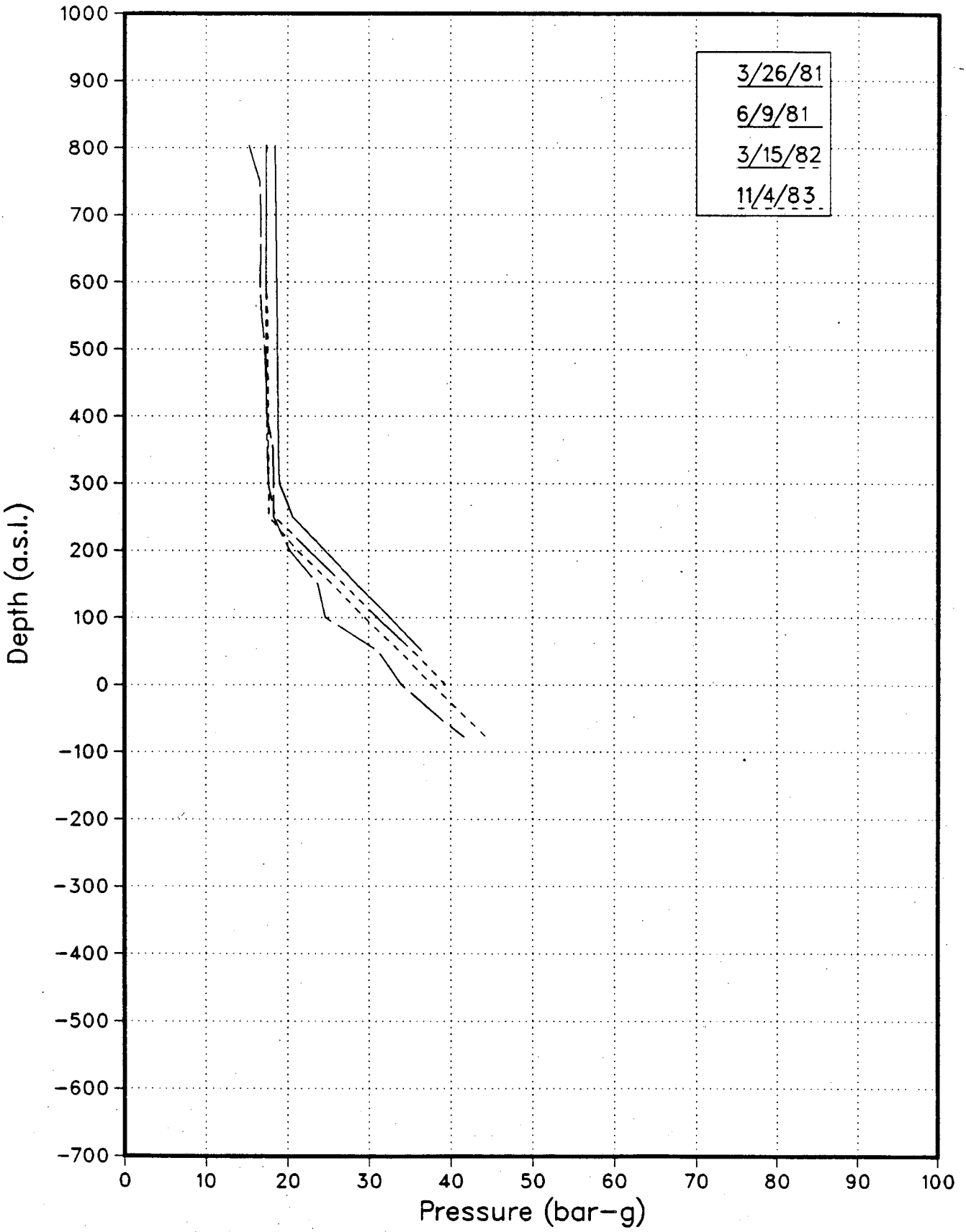

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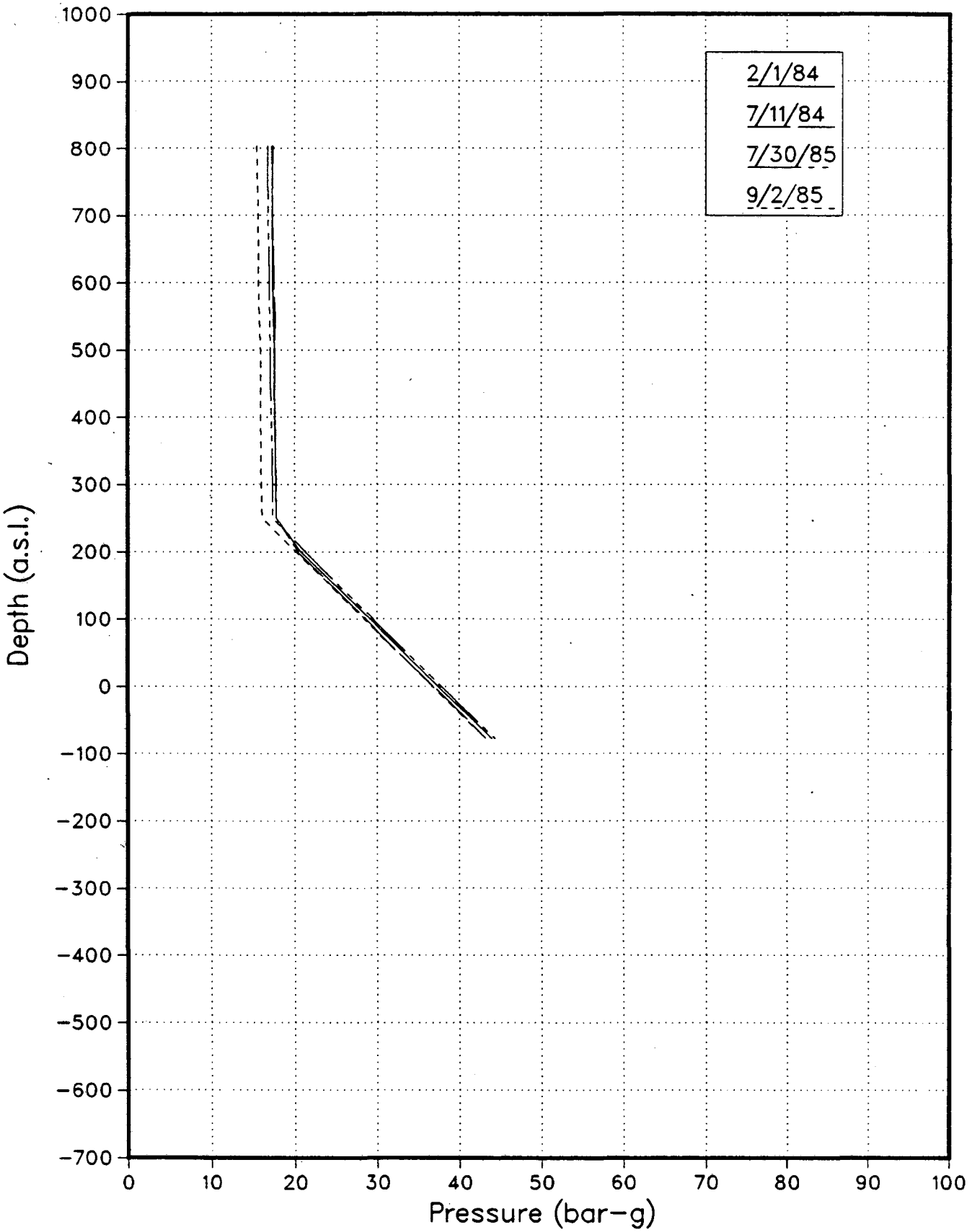

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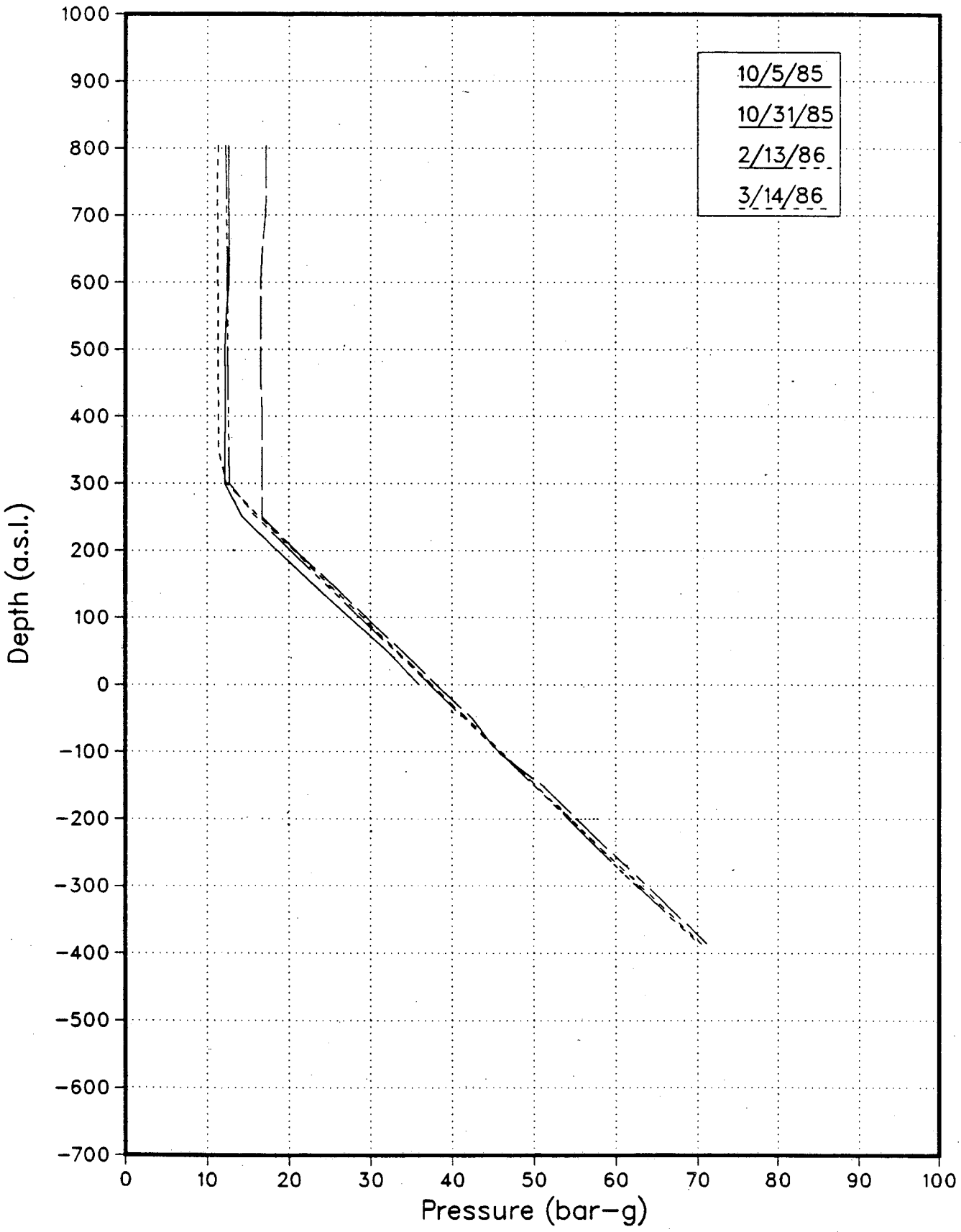

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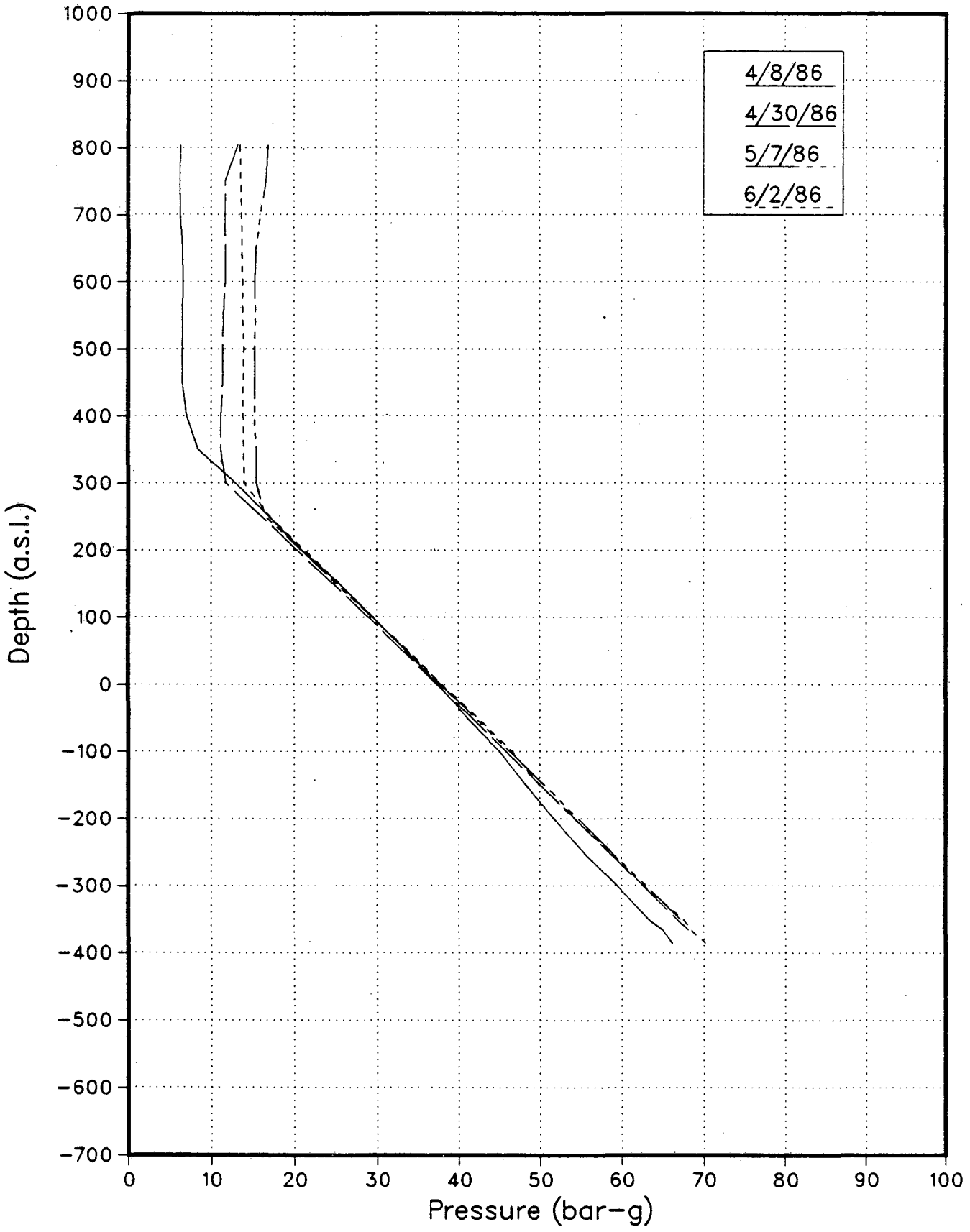

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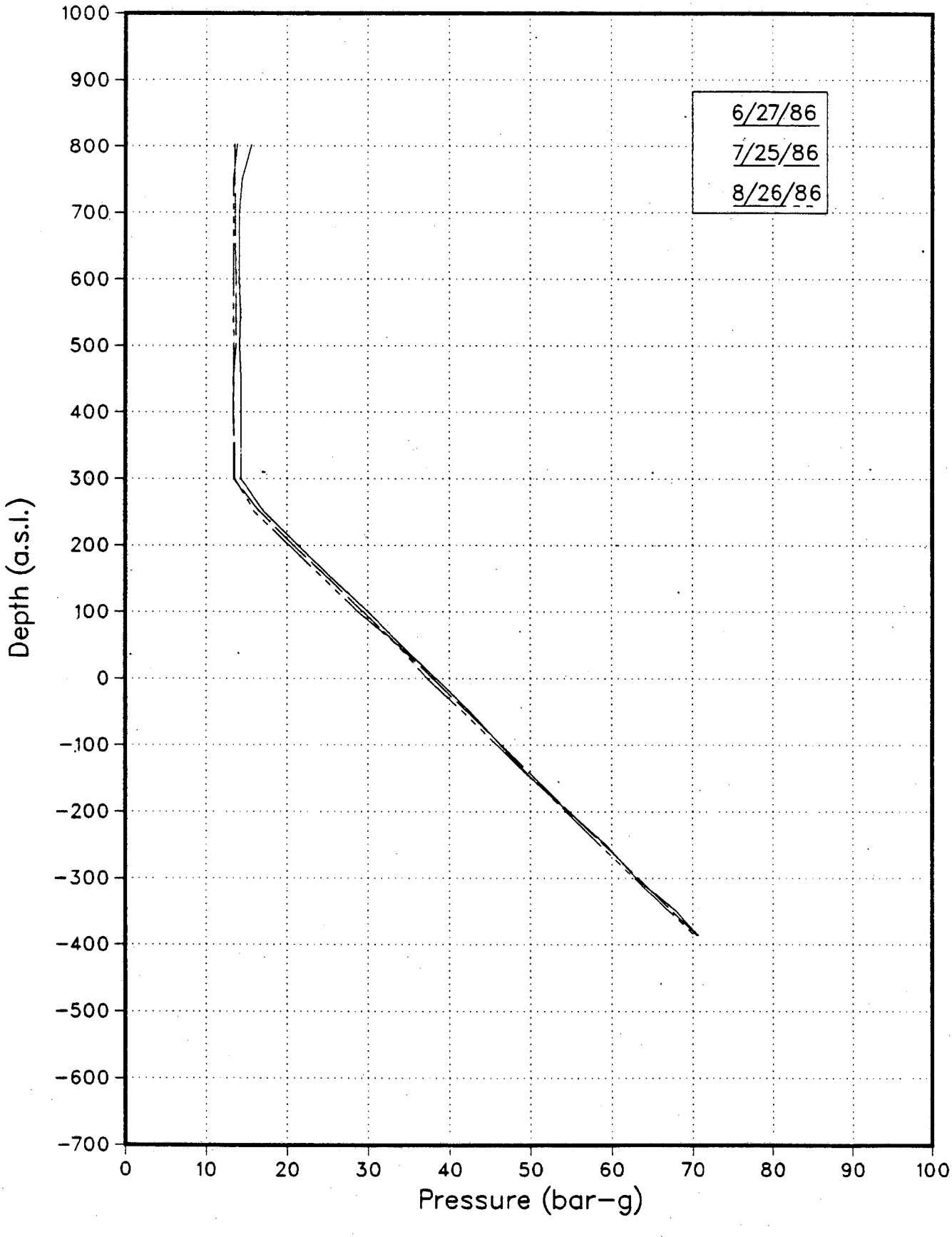

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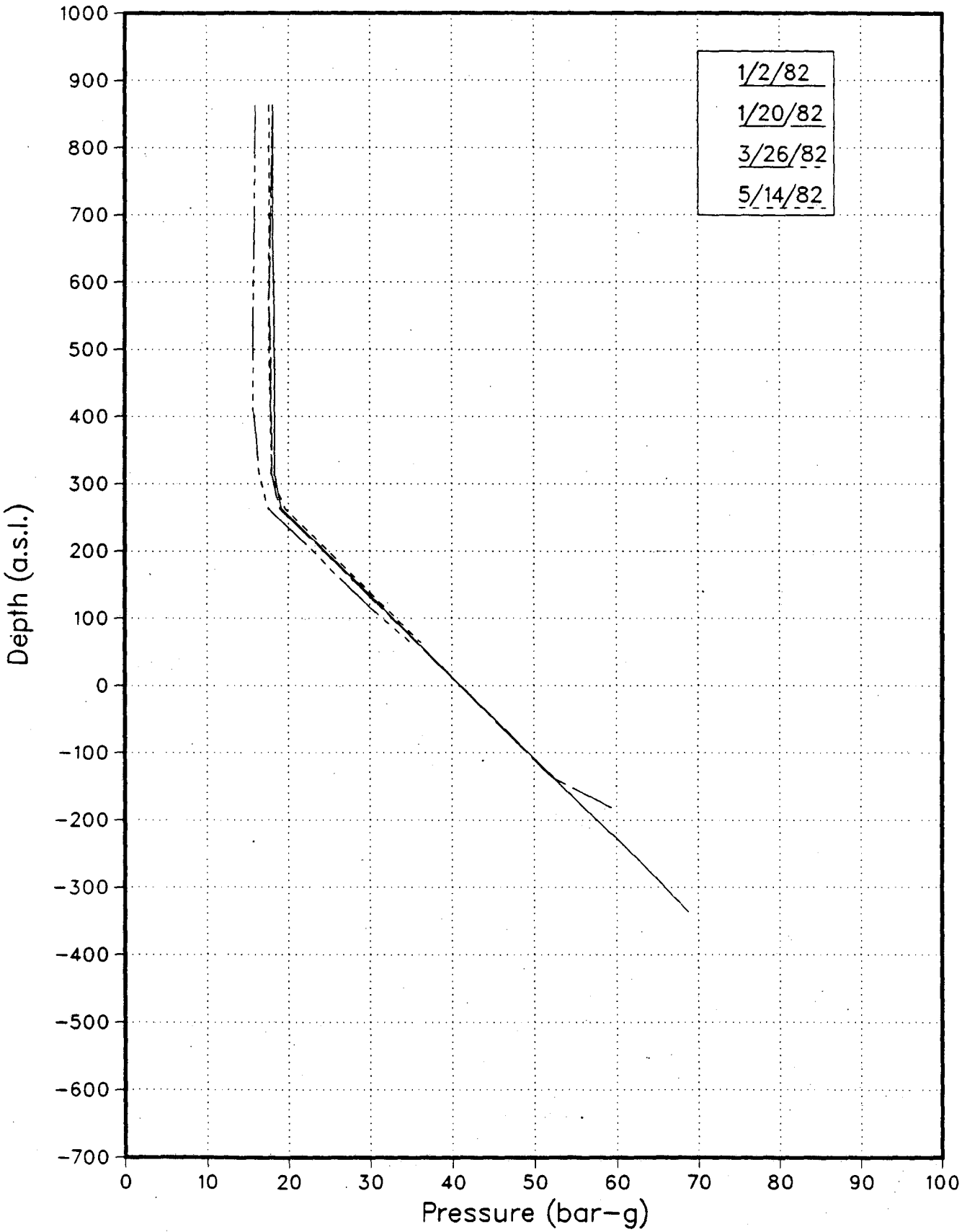

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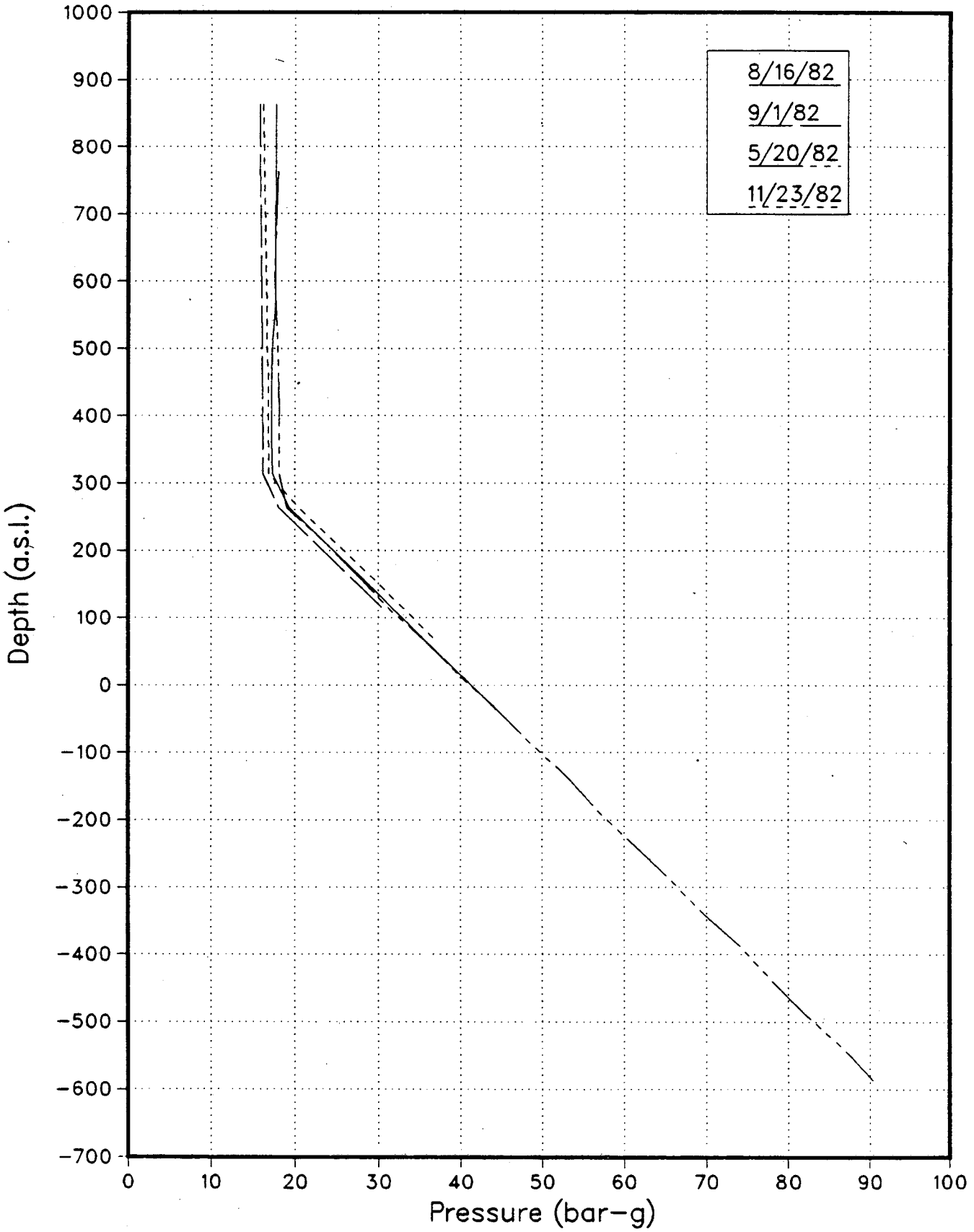

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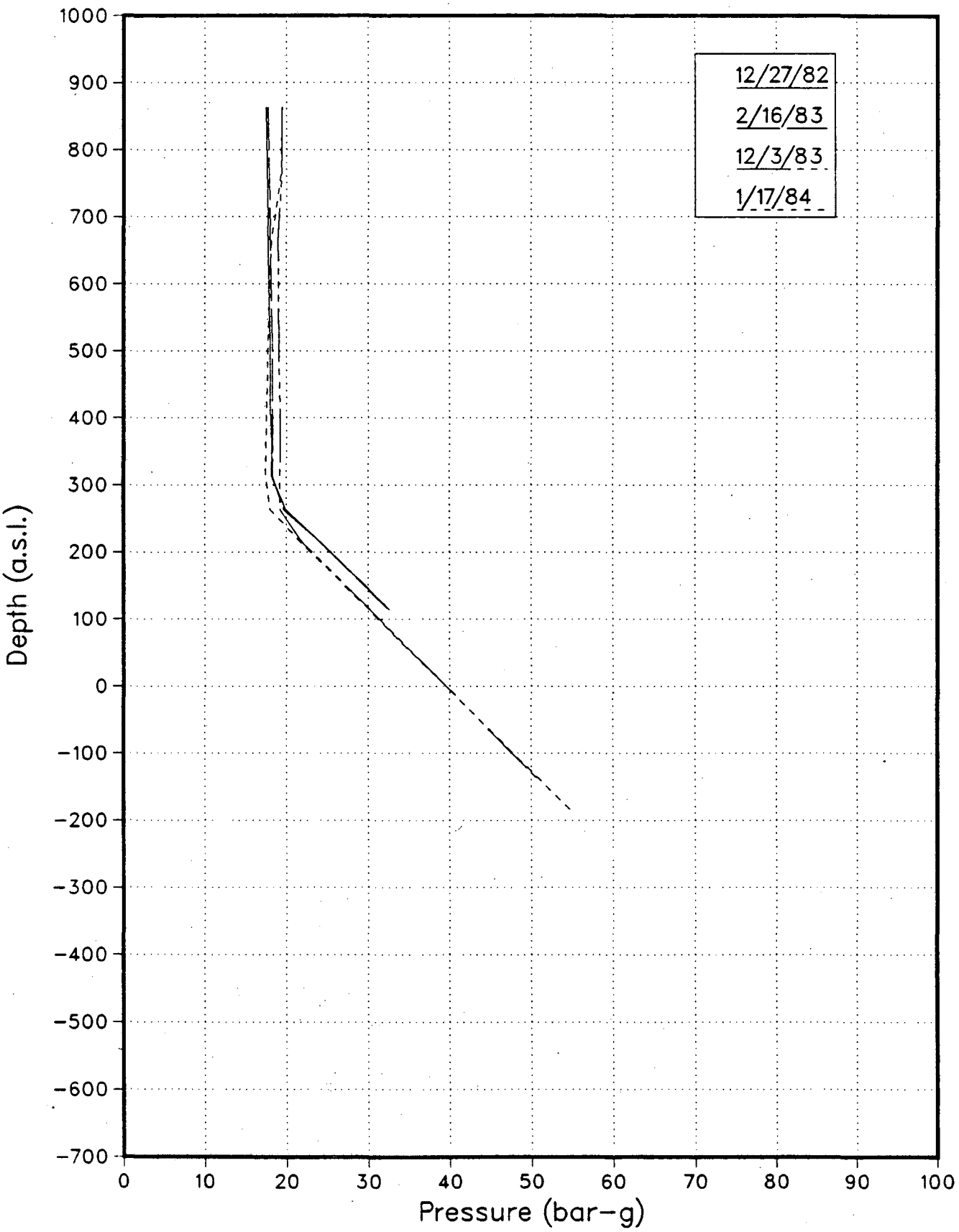

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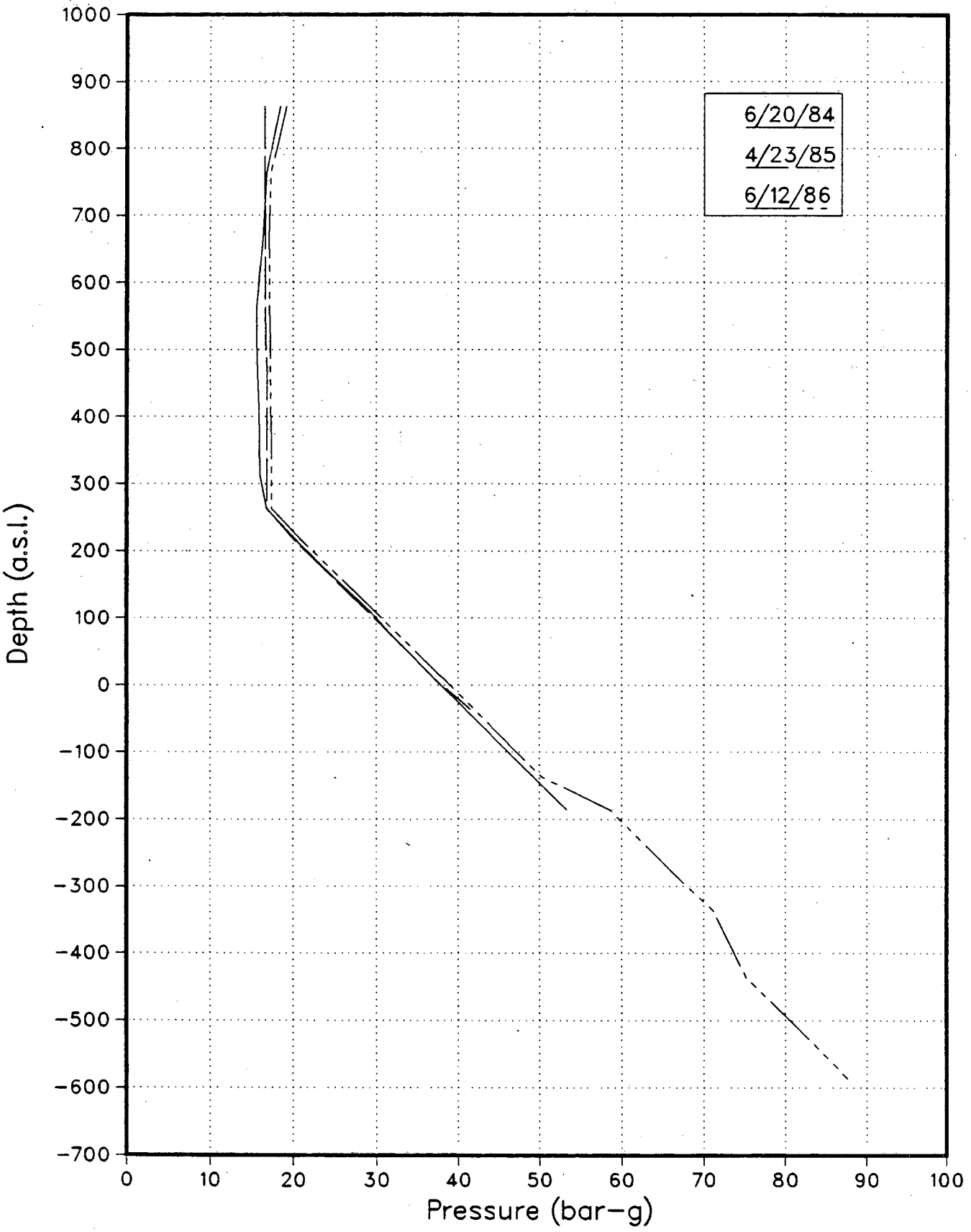

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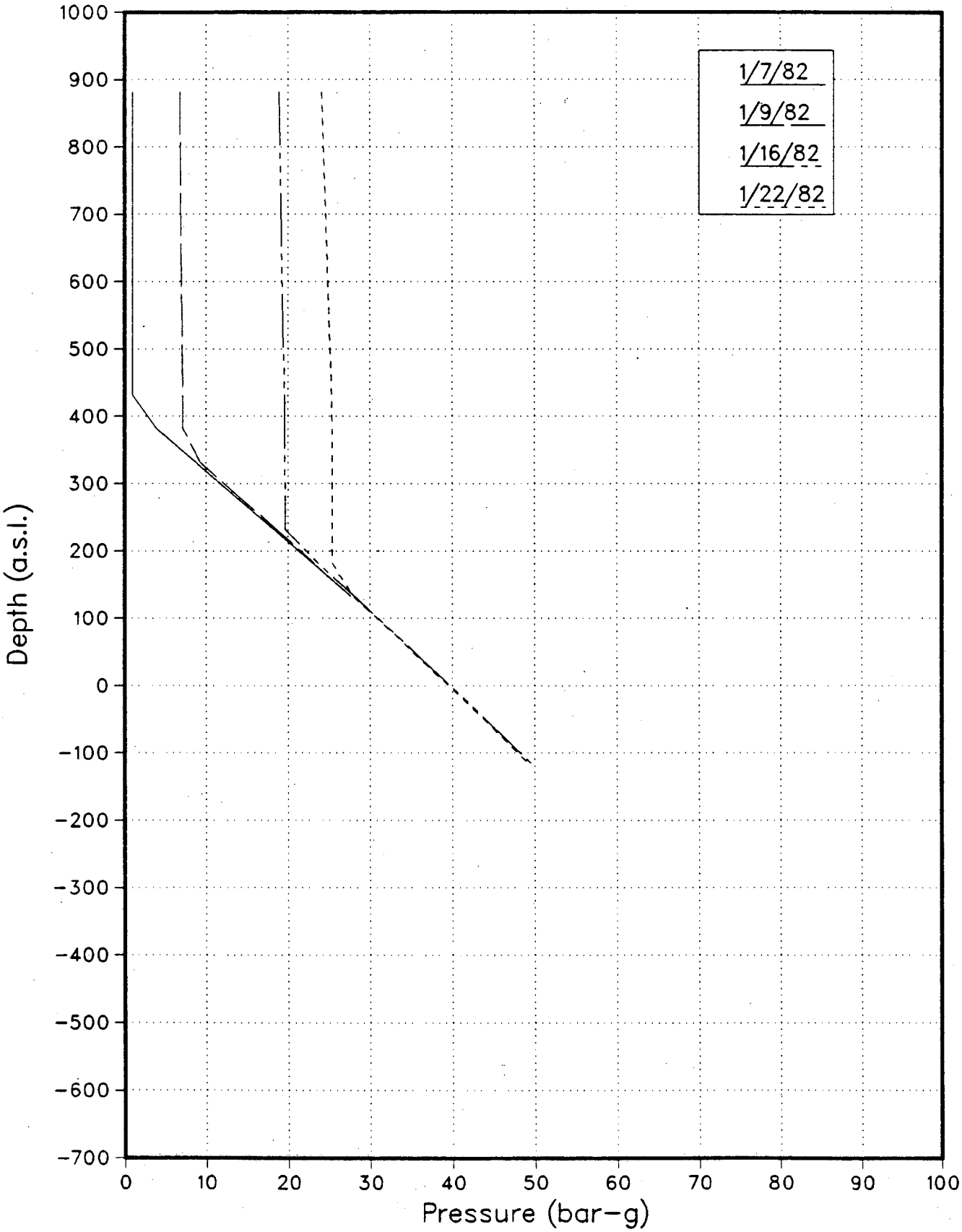

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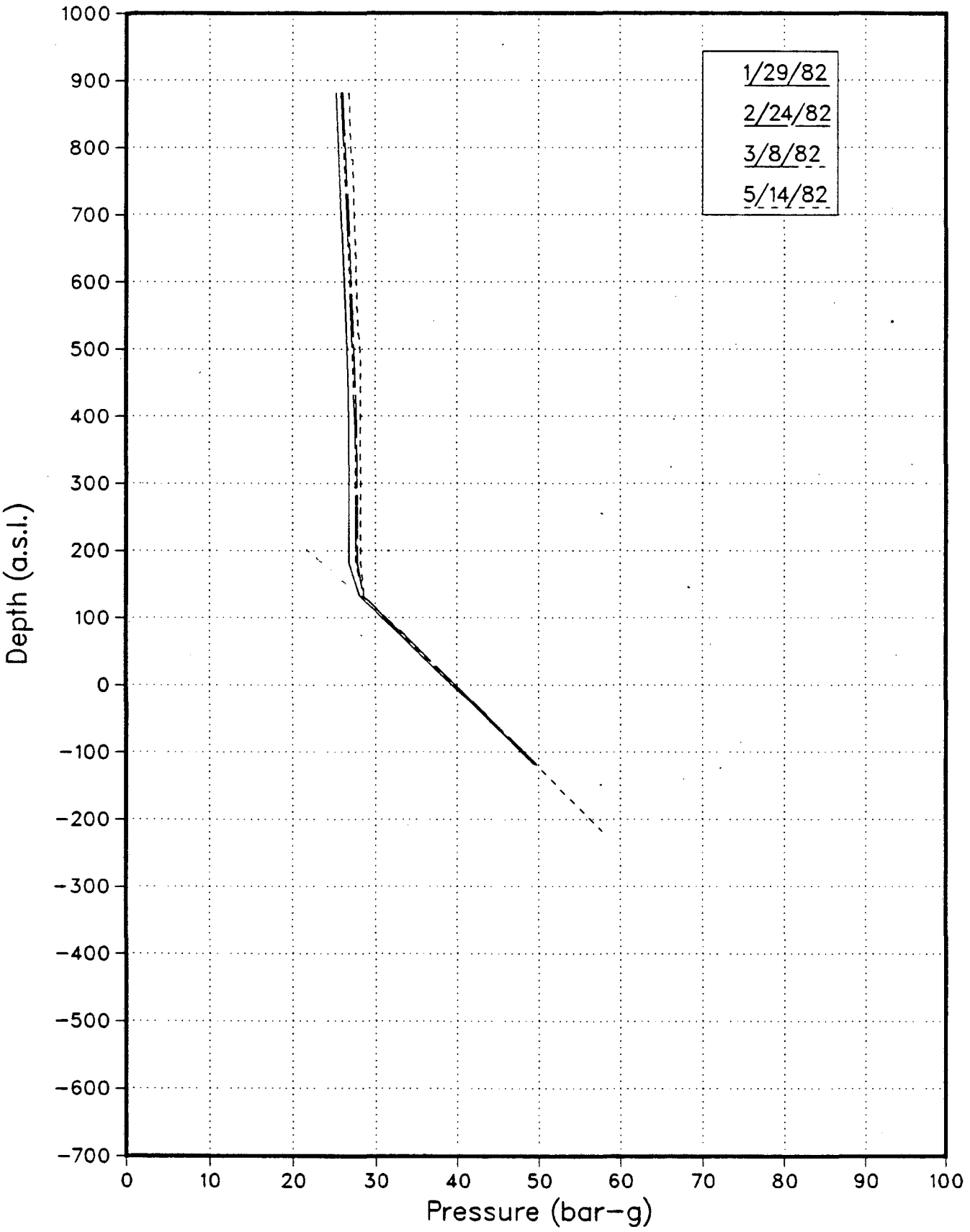

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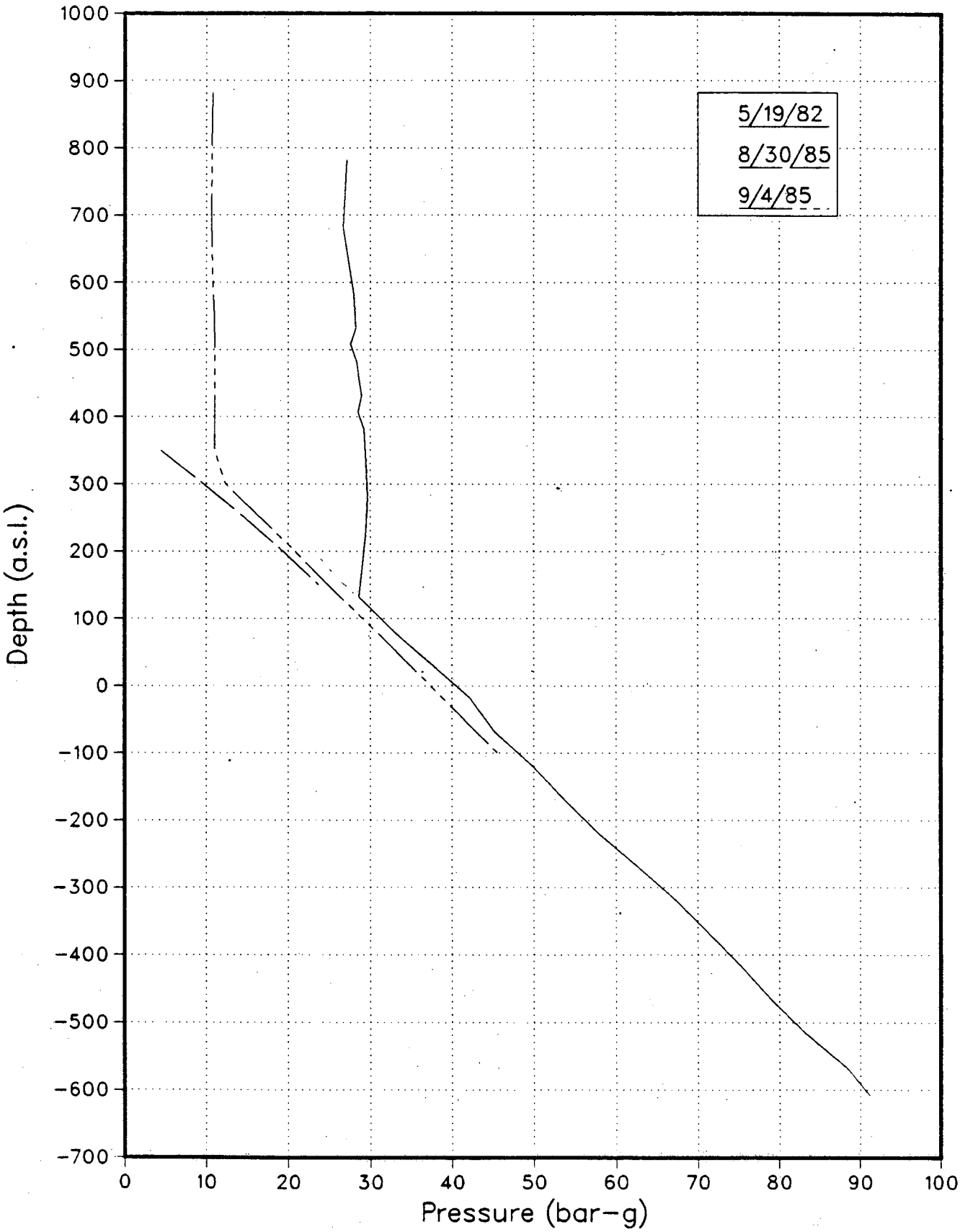

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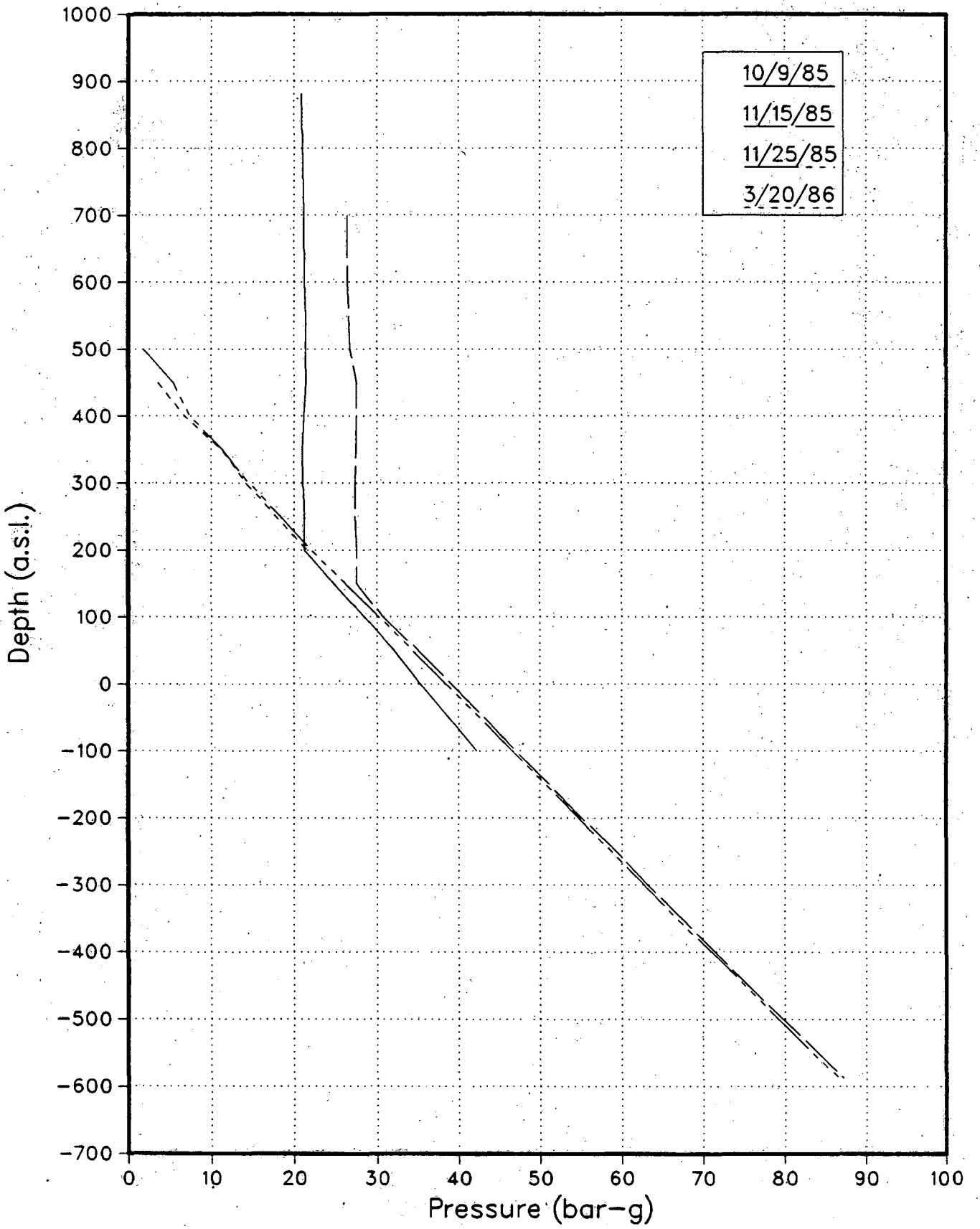

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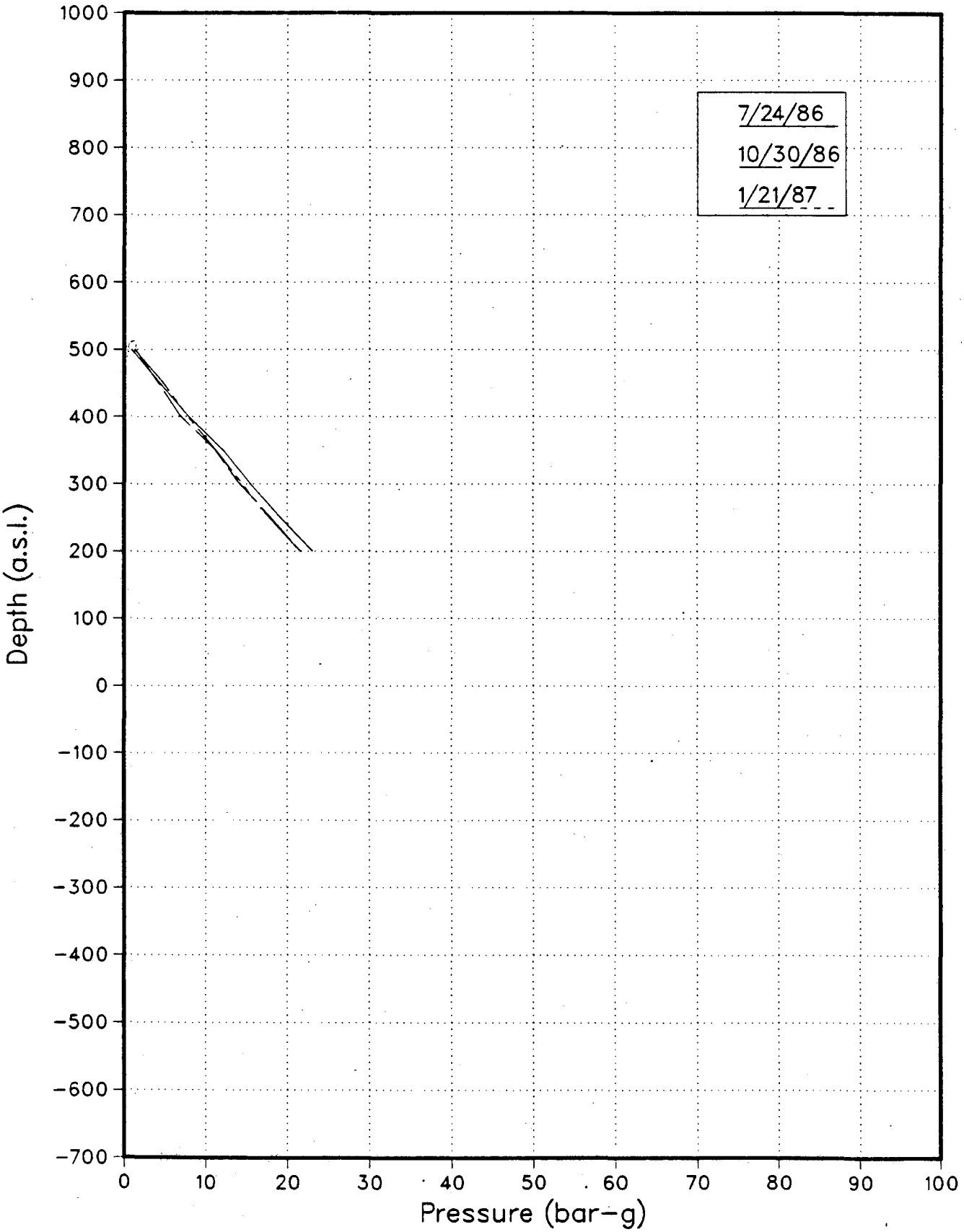
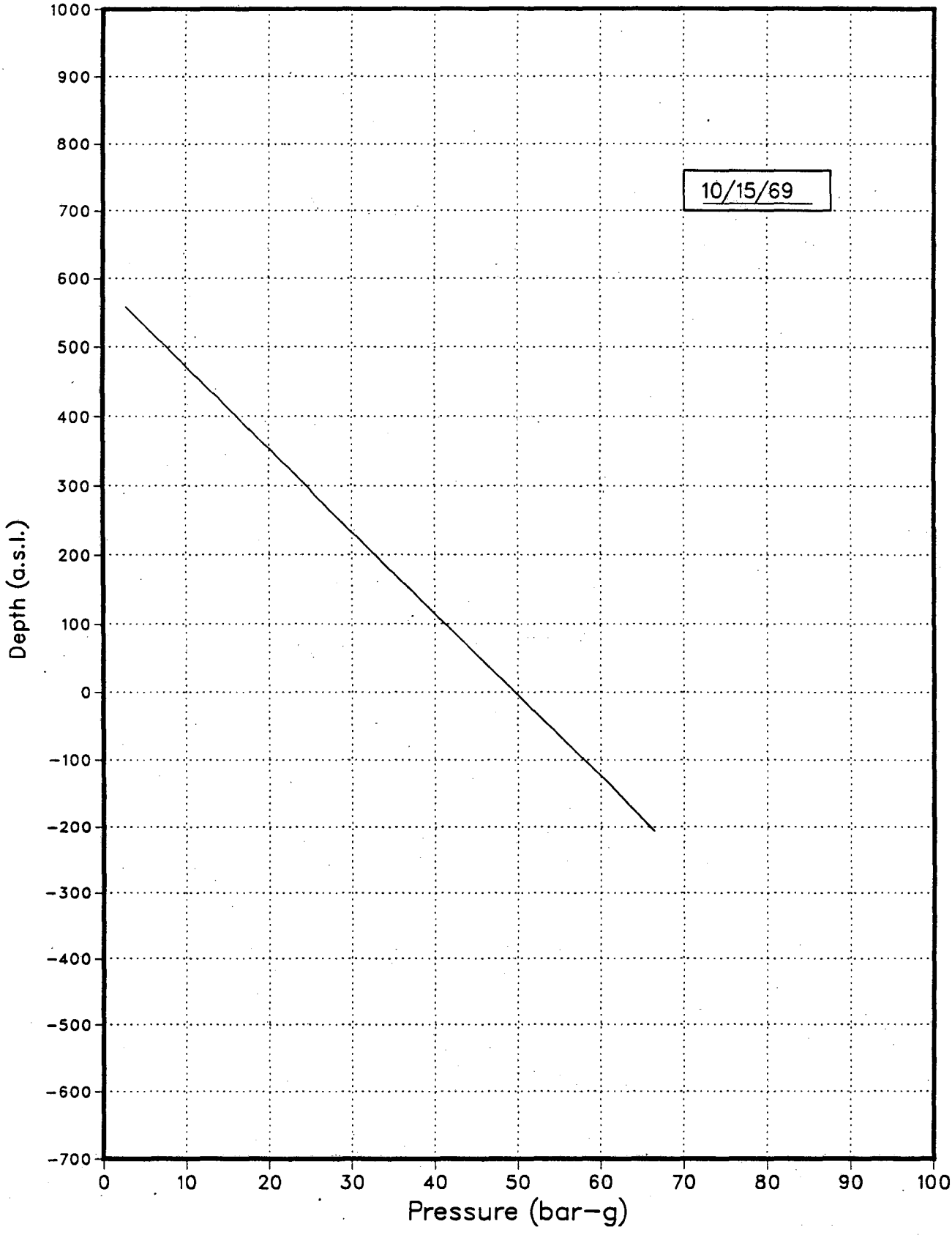


CH 1 Pressure Surveys



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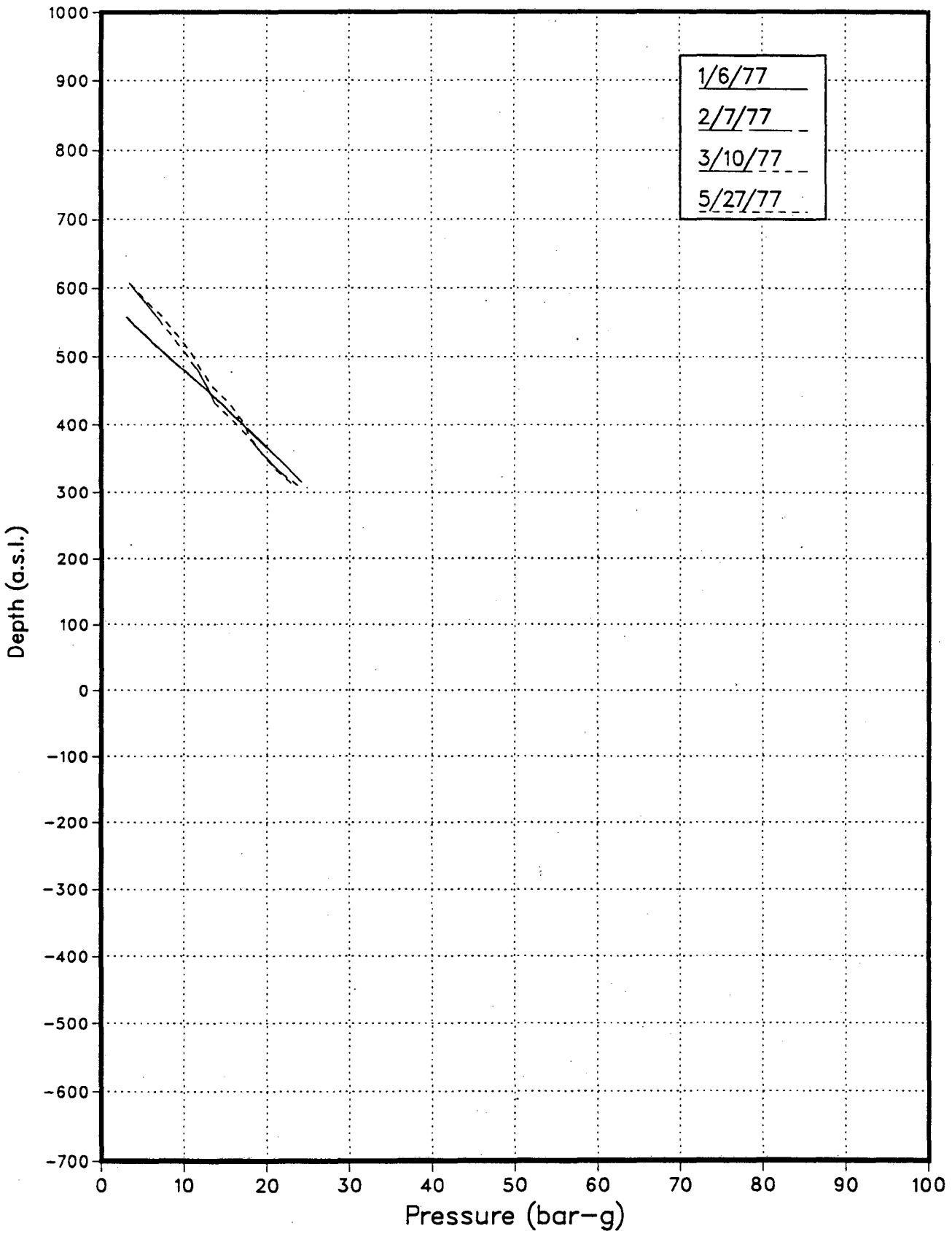

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