GEOLOGICAL SURVEY OF CANADA

OPEN FILE 2227

MODELLING OF OFFSHORE TEMPERATURE PROFILES, FINAL RESULTS FOR AMAULIGAK AND ANGASAK, BEAUFORT SHELF

EBA ENGINEERING CONSULTANTS LTD.

1990

Energy, Mines and Resources Canada

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Civil, Geotechnical and Materials Engineers

1990 01 03

Permafrost Research Section
Geological Survey of Canada
1 Observatory Crescent
Ottawa, Ontario

EBA File: 0101-10228

Attention: Mr. A.E. Taylor

Subject: Modelling of Offshore Temperature Profiles,
Final Results for Amauligak and Angasak

EBA Engineering Consultants Ltd. (EBA) was retained by the Geological Survey of Canada (GSC) to carry out thermal modelling of offshore temperature profiles to predict the degradation of permafrost on the Beaufort Shelf. The scope of work was to use EBA's geothermal computer program, "GEOTHERM" to model from the time of marine transgression to present day and into the future for Esso's Angasak and Gulf's Amauligak wellsites.

"GEOTHERM" is a finite element analysis computer program that can simulate transient one or two-dimensional heat conduction with change of phase, for a variety of boundary conditions. The program can account for saline depressed freezing points and temperature-phase change relationships for individual soil layers. A description of the model is presented in Hwang (1976).

The temperature-phase change relationship is calculated by combining the Anderson and Tice (1972) unfrozen moisture content model for adsorbed water and the sea ice model described by Ono (1966) for the free porewater.

The input required for the model includes the following:

- initial temperature profile
- sea temperature
- soil thermal properties
- unfrozen moisture content curve
- geothermal heat flux

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A range of properties was provided by GSC. The properties used in the analyses are presented in Table 1. Some parametric analyses were carried out for the Amauligak site to determine the influence of varying the seabed temperature and the thermal conductivity and latent heat of the stratigraphic profile. The initial surface temperatures were assumed to be -14°C and -12°C at Amauligak and Angasak, respectively. The initial depths of permafrost were assumed to be 600 m and 500 m at Amauligak and Angasak, respectively. The analyses were carried out by assigning a temperature boundary at the seabed and a geothermal flux at the base of the mesh. The base of the mesh set at a depth of 800 m and 600 m at Amauligak and Angasak, respectively. The geothermal flux was set at 60 mW/m. The mean sea temperature was assumed to equal -0.3°C at Angasak and to vary between -1.0°C and -1.5°C in the parametric runs for Amauligak.

The calculated unfrozen moisture content curves used in each run are presented in Table 1. At the present day geothermal temperatures of approximately -2.5°C within the permafrost interval at Amauligak, the calculated unfrozen moisture content is 7% for a silty sand with a total moisture content of 25% and salinity of 10 ppt. Therefore, the analysis models the absorption of some latent heat within the permafrost zone as the permafrost warms from its initial temperature to its present day temperature. To determine the sensitivity of the unfrozen moisture content curve on the thermal results, an additional analysis was carried out with lower unfrozen moisture contents.

The results of the analysis are presented in the following figures. The figures show temperature profiles at various times. The time required to obtain present day measured temperatures are summarized in Table 2.

The analyses carried out for Amauligak indicate that a mean sea temperature of -1.5 is required to provide a best fit to the measured temperatures in the upper interval. The calculated time of marine transgression varied between 4000 and 4700 years, depending on the input parameters. The parametric analyses indicate that an increase of 24% in the thermal conductivity decreases the time to reach present day thermal regime by 15%. Increasing the moisture content from 25 to 30% had only a small effect on the time prediction. This is attributed to the fact that the unfrozen moisture content curve at low temperatures is similar for the two analyses, resulting in similar amounts of latent heat absorption.

Run No. 5 was carried out with a lower unfrozen moisture content curve. A reduction in the unfrozen moisture content of 3.6% at -2.5°C decreased the time of marine transgression by 700 years.

Two runs for Angasak were carried out. The two runs investigated the effect of varying the assumed thermal conductivity of the sediments below 56 m. The conductivity was varied between 2.5 and 4.0 W/mC. The run with the higher conductivity had warmer temperatures below 56 m, however, the temperatures above 56 m were not greatly effected by the change in conductivity. Both runs took approximately 700 years to reach the present day geothermal regime.

EBA is pleased to have participated in the first phase of the Beaufort Sea geothermal modelling study. We trust that the results of our analysis will assist you in assessing the importance and sensitivity of the various input parameters affecting thermal studies. Please call if there are any questions you wish to discuss, or if we can provide any further assistance to your study.

Yours truly,

EBA Engineering Consultants Ltd.

PROFESSIONAL ENGINEER ALBERTA
WILLIAM T. HORNE
90/01/08

W.T. Horne, P. Eng.
Project Engineer

Reviewed by,

PROFESSIONAL ENGINEER ALBERTA
DEREK C. CATHRO
90/01/08

PERMIT TO PRACTICE
EBA ENGINEERING CONSULTANTS LTD.
Signature
Date 90-01-08
PERMIT NUMBER: P 245
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

D.C. Cathro, P. Eng.
Senior Project Engineer

WTH:chb

Attachment

TABLE 1 PARAMETERS FOR THERMAL ANALYSIS

RUN	LITHOLOGY			SEA		BULK		THERMAL CONDUCTIVITY	
	MATERIAL	FROM (m)	TO (m)	TEMP. (C)	M.C. (%)	DENSITY (Mg/m3)	SAL. (ppt)	FROZEN (W/mC)	UNFROZEN (W/mC)
Amauligak									
1	Silty Sand	0	800	-1.0	25	1.95	10	2.5	2.0
2	Silty Sand	0	800	-1.5	25	1.95	10	2.5	2.0
3	Silty Sand	0	800	-1.5	30	1.95	10	2.5	2.0
4	Silty Sand	0	800	-1.5	30	1.95	10	3.1	2.0
5	Silty Sand	0	800	-1.5	25	1.95	10	2.5	2.0
Angasak									
1	Sand	0	32	-0.3	21	1.94	34	4.0	4.0
	Silty Clay	32	41	-0.3	30	2.08	30	1.8	1.8
	Fine Sand	41	52	-0.3	24	1.98	13	2.5	2.5
	Silty Clay	52	56	-0.3	29	2.06	29	1.8	1.8
	Silty Sand	56	600	-0.3	25	1.95	10	2.5	2.0
2	Sand	0	32	-0.3	21	1.94	34	4.0	4.0
	Silty Clay	32	41	-0.3	30	2.08	30	1.8	1.8
	Fine Sand	41	52	-0.3	24	1.98	13	2.5	2.5
	Silty Clay	52	56	-0.3	29	2.06	29	1.8	1.8
	Silty Sand	56	600	-0.3	25	1.95	10	4.0	2.0

TABLE 1 PARAMETERS FOR THERMAL ANALYSIS (cont'd)

RUN	SPECIFIC HEAT Frozen (KJ/kgC)	SPECIFIC HEAT Unfrozen (KJ/kgC)	TOTAL LATENT HEAT (MJ/m3)	UNFROZEN MOISTURE CONTENT (%) -0.6C	-1.5C	-2.5C	-5.0C	-10.0C
Amauligak								
1	1.0	1.4	129	25.0	12.2	7.4	3.8	1.7
2	1.0	1.4	129	25.0	12.2	7.4	3.8	1.7
3	1.0	1.5	149	30.0	14.2	8.5	4.4	2.0
4	1.0	1.5	149	30.0	14.2	8.5	4.4	2.0
5	1.0	1.4	129	25.0	8.0	3.8	1.9	0.8
Angasak								
1	1.0	1.3	111	21.0	21.0	16.2	8.3	4.2
	1.0	1.4	119	30.0	30.0	26.9	15.7	10.4
	1.0	1.4	127	24.0	11.9	7.3	3.0	1.6
	1.1	1.5	145	29.0	29.0	25.5	13.8	10.6
	1.0	1.4	129	25.0	12.2	7.4	3.8	1.7
2	1.0	1.3	111	21.0	21.0	16.2	8.3	4.2
	1.0	1.4	119	30.0	30.0	26.9	15.7	10.4
	1.0	1.4	127	24.0	11.9	7.3	3.0	1.6
	1.1	1.5	145	29.0	29.0	25.5	13.8	10.6
	1.0	1.4	129	25.0	12.2	7.4	3.8	1.7

TABLE 2 SUMMARY OF THERMAL ANALYSES

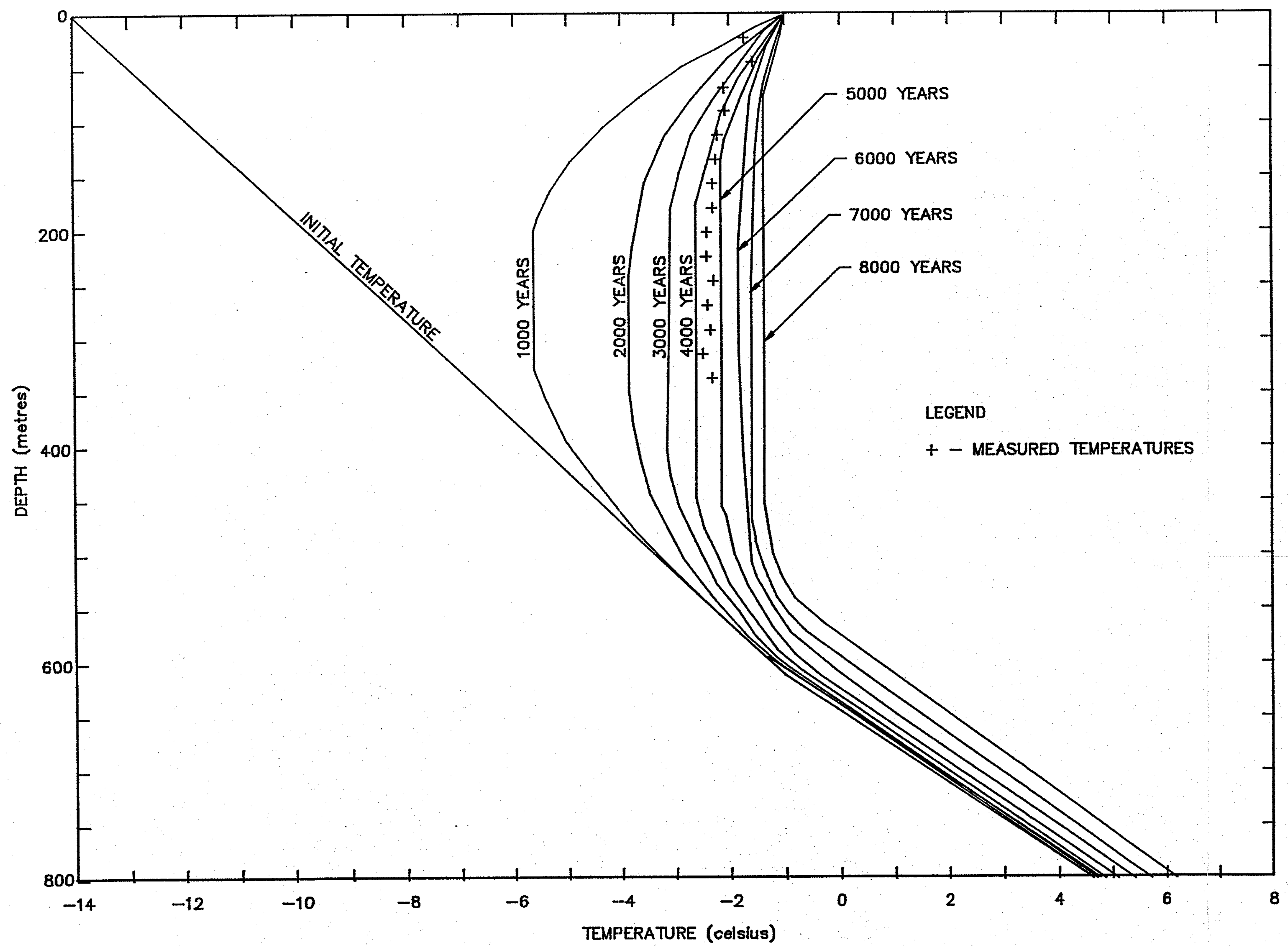
Run No.	Sea Temperature (°C)	Moisture Content (%)	Frozen Thermal Conductivity (W/mC)	Time to Reach Present Geothermal Regime (years)
Amauligak				
1	-1.0	25	2.5	4500
2	-1.5	25	2.5	4600
3	-1.5	30	2.5	4700
4	-1.5	30	3.1	4000
5*	-1.5	25	2.5	4000
Note: * Lower unfrozen moisture content.				
Angasak				
1	-0.3	varies with depth	2.5 (below 56 m)	700
2	-0.3	varies with depth	4.0 (below 56 m)	700

REFERENCES

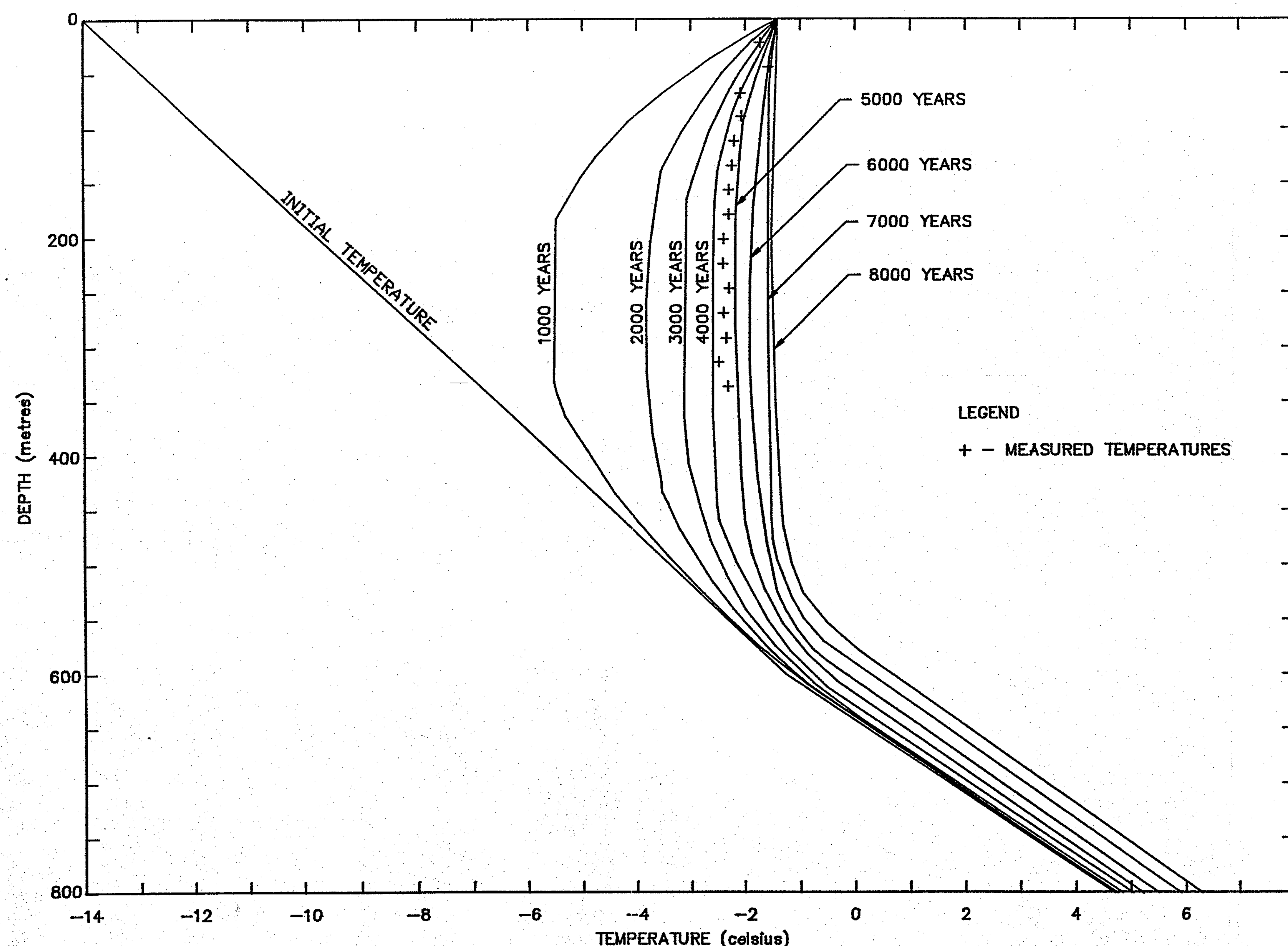
Anderson, D.M. and Tice, A.R. 1972. Predicting unfrozen water contents in frozen soils from surface area measurements. U.S. Highway Research Board, Record 393, pp. 12-18.

Hwang, C.T. 1976. Predictions and observations on the behaviour of a warm gas pipeline on permafrost. Canadian Geotechnical Journal, Vol. 13, No. 4, pp. 452-480.

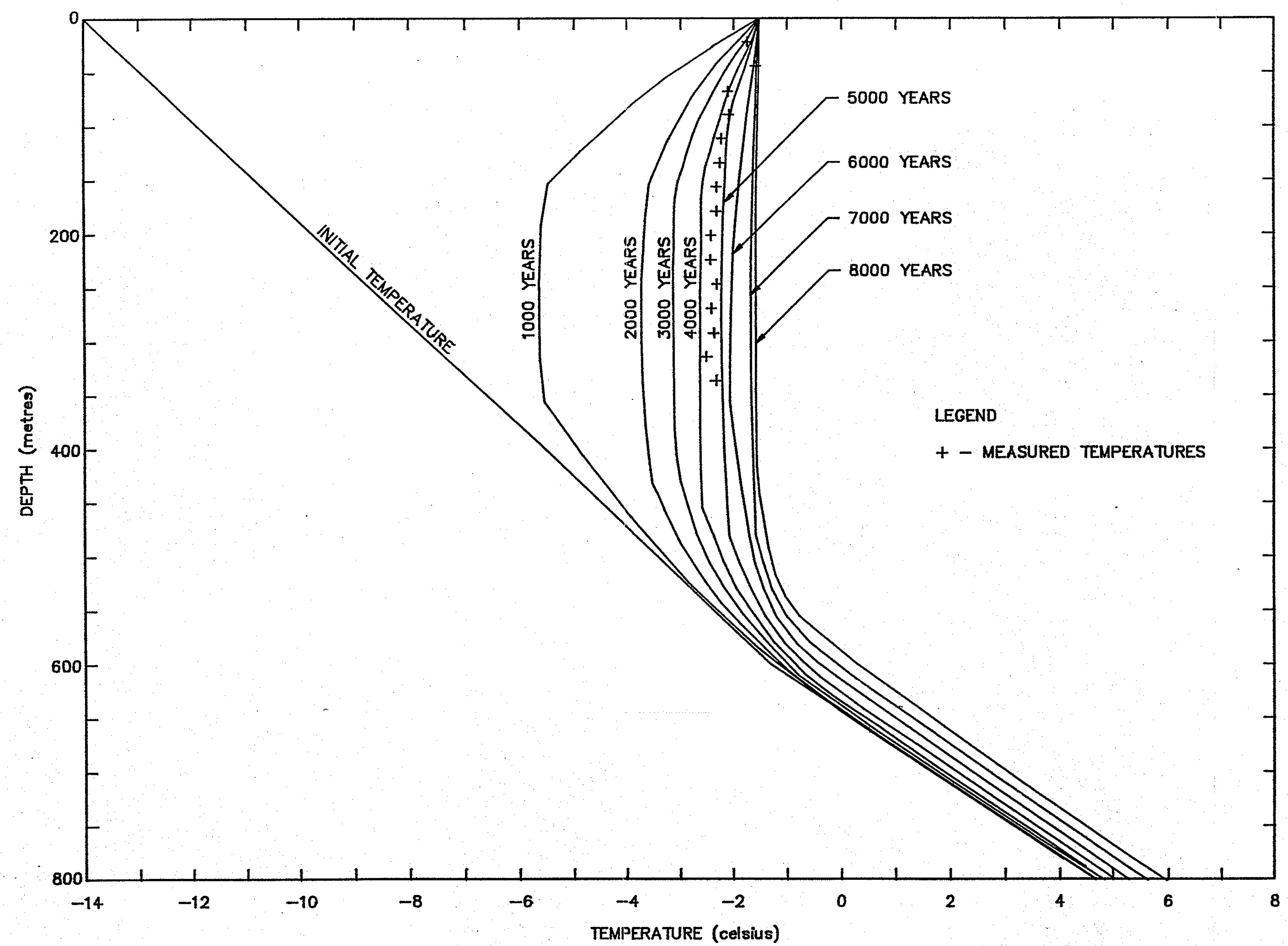
Ono, N. 1966. Specific heat and heat of fusion of sea ice. Proceedings of International Conference on Low Temperature Sciences, Physics of Snow and Ice, Vol. 1, Part 1, The Institute of Low Temperature Science Publication, pp. 599-610.



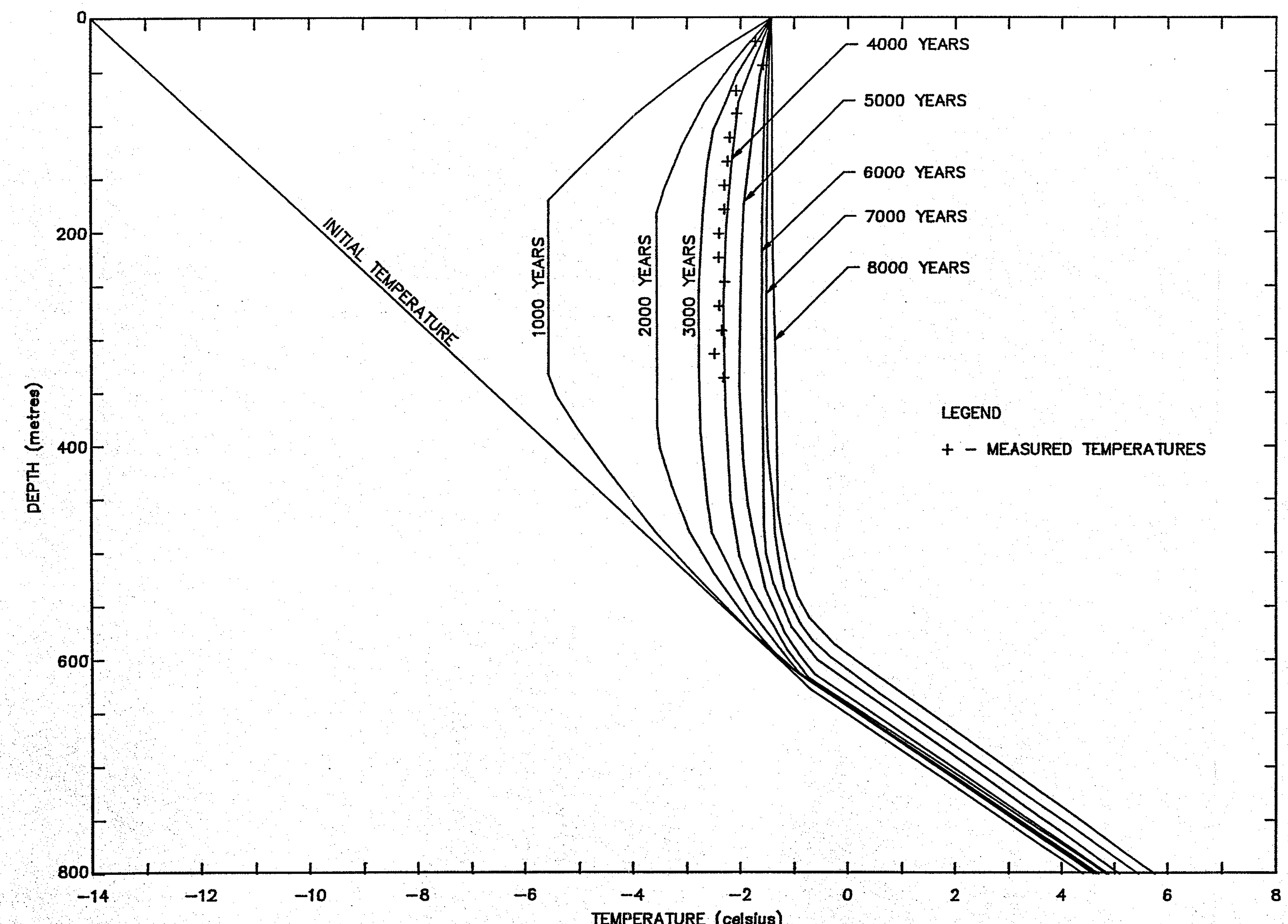
EBA Engineering Consultants Ltd.				PROJECT	MODELLING OF OFFSHORE TEMPERATURE PROFILES
CLIENT GEOLOGIC SURVEY OF CANADA				TITLE	AMAULIGAK – RUN 1 (SEA TEMP.=1.0°C, MC=25%, TC=2.5w/mK)
DATE 90-01-02	DWN. WMG	CHKD. WTH		FILE NO. 10228001	FIGURE 1



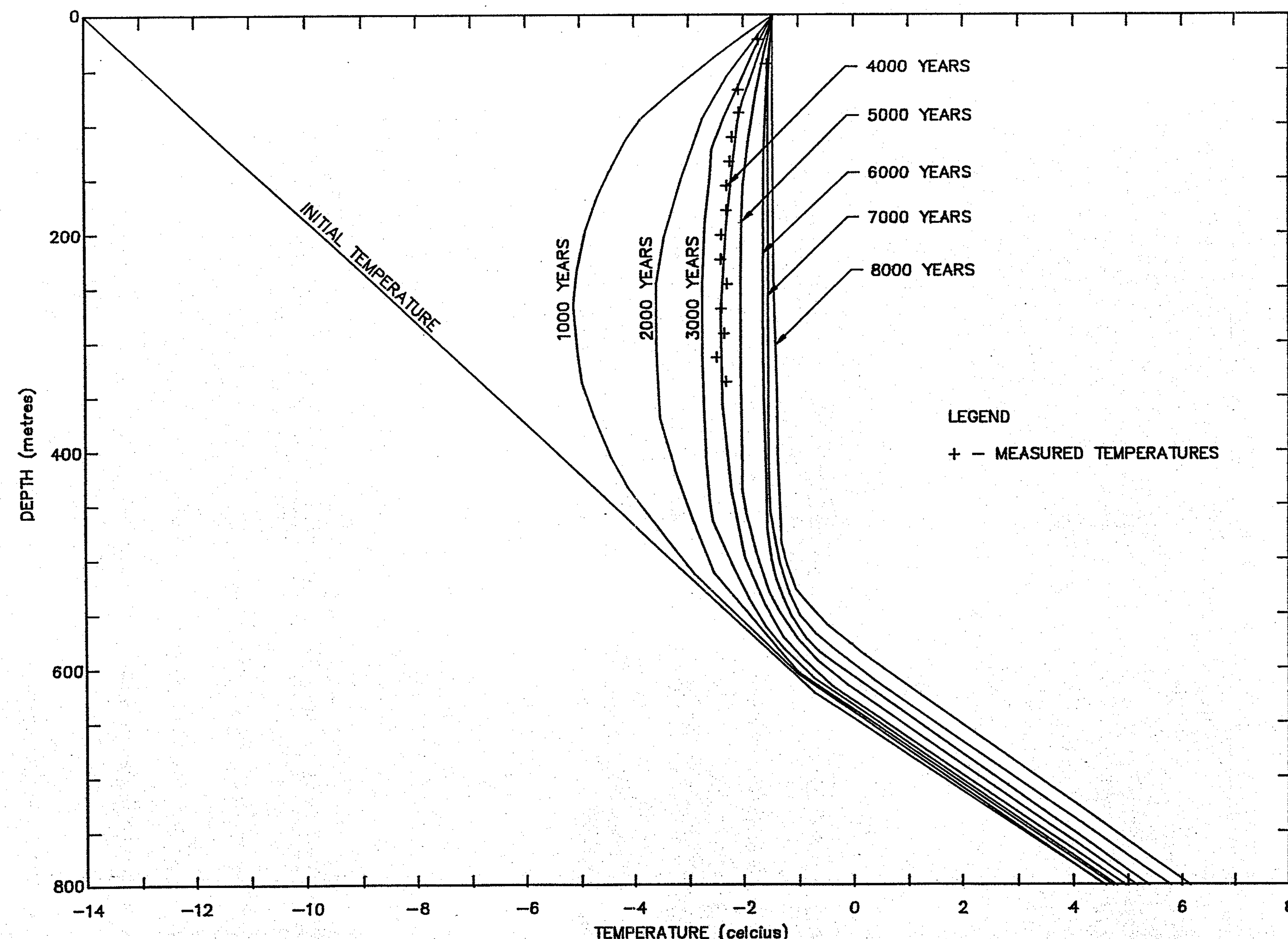
EBA Engineering Consultants Ltd.	PROJECT: MODELLING OF OFFSHORE TEMPERATURE PROFILES
CLIENT: GEOLOGIC SURVEY OF CANADA	TITLE: AMAULIGAK − RUN 2 (SEA TEMP.=−1.5°C, MC=25%, TC=2.5W/mK)
DATE 90−01−02 · DWN. WMG · CHKD. WTH	FILE NO. 10228002 · FIGURE 2



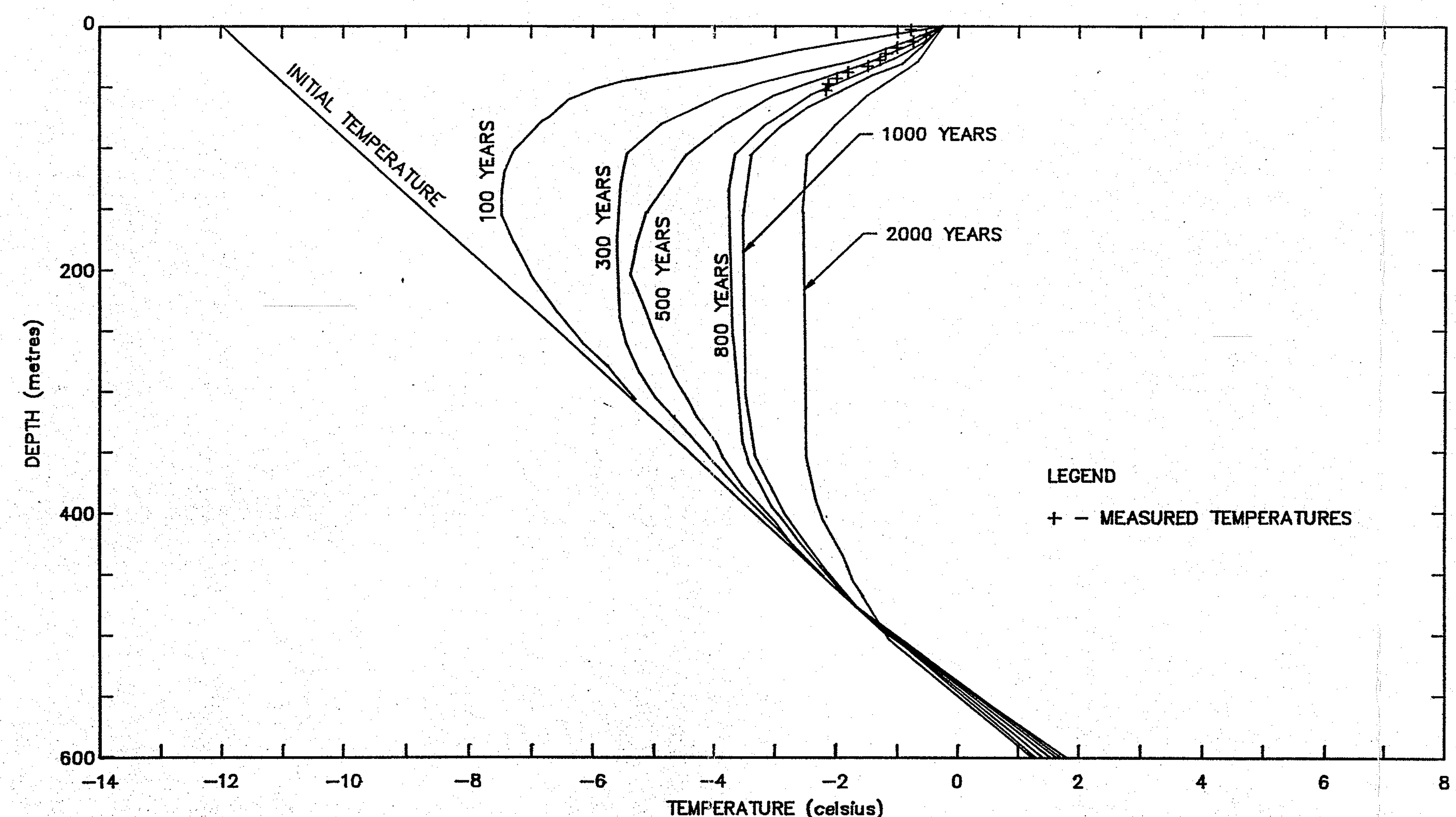
EBA Engineering Consultants Ltd.			PROJECT	MODELLING OF OFFSHORE TEMPERATURE PROFILES	
CLIENT GEOLOGIC SURVEY OF CANADA			TITLE	AMAULIGAK — RUN 3 (SEA TEMP.=−1.5°C, MC=30%, TC=2.5w/mK)	
DATE 90−01−02	DWN. WMG	CHKD. WTH	FILE NO.	10228003	FIGURE 3



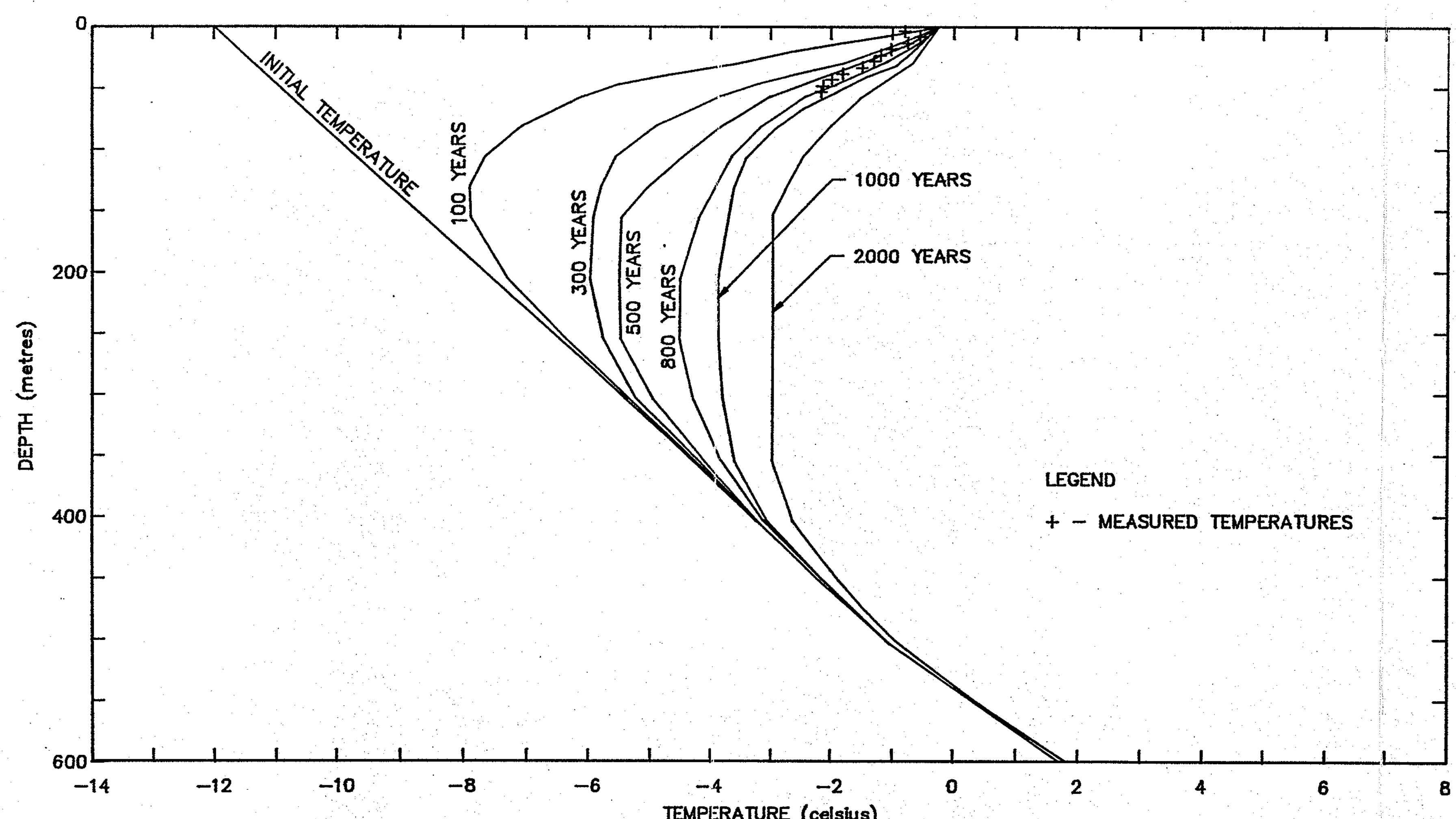
EBA Engineering Consultants Ltd.				PROJECT	MODELLING OF OFFSHORE TEMPERATURE PROFILES	
CLIENT	GEOLOGIC SURVEY OF CANADA			TITLE	AMAULIGAK – RUN 4 (SEA TEMP.=−1.5°C, MC=30%, TC=3.1W/mK)	
DATE 90–01–02	DWN. WMG	CHKD. WTH		FILE NO.	10228004	FIGURE 4



EBA Engineering Consultants Ltd.		PROJECT	MODELLING OF OFFSHORE TEMPERATURE PROFILES
CLIENT GEOLOGIC SURVEY OF CANADA		TITLE	AMAULIGAK – RUN 5 (SEA TEMP.=–1.5°C, MC=25%, TC=2.5W/mK, LOW UNFROZEN MC)
DATE 90–01–02	DWN. WMG / CHKD. WTH	FILE NO. 10228005	FIGURE 5



EBA Engineering Consultants Ltd.				PROJECT	MODELLING OF OFFSHORE TEMPERATURE PROFILES	
CLIENT	GEOLOGIC SURVEY OF CANADA			TITLE	ANGASAK – RUN 1 (TC=4.0W/mK)	
DATE 90–01–02	DWN. WMG	CHKD. WTH		FILE NO.	10228006	FIGURE 6



EBA Engineering Consultants Ltd.				PROJECT	MODELLING OF OFFSHORE TEMPERATURE PROFILES
CLIENT	GEOLOGIC SURVEY OF CANADA			TITLE	ANGASAK – RUN 2 (TC=2.5W/mK)
DATE 90-01-02	DWN. WMG	CHKD. WTH		FILE NO. 10228007	FIGURE 7