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GEOTHERMAL SERVICE OF CANADA

A PERMAFROST MONITORING PROGRAM AT ALERT, N.W.T.

-- PROJECT DESCRIPTION AND PRELIMINARY RESULTS

R.J.E. Brown(1), A.S. Judge(2), J. Pilon(3),
A.E. Taylor(2), and P.E. Gratton-Bellew(1)

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Earth Physics Branch Open File Number 79-5
Ottawa, Canada 1979

iv + 48 pp. including 17 figures, 5 tables
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SUMMARY

This report outlines the background and preliminary results of a permafrost study undertaken jointly by the Department of National Defence, the National Research Council of Canada and the Department of Energy, Mines and Resources at Canadian Forces Station Alert, N.W.T. The project commenced in September, 1978 with the drilling of five shallow holes to maximum depths of 61m in areas that would demonstrate the diverse nature of permafrost and the active layer at Alert.

Temperature cables were installed in the drillholes and frequent measurements are being taken by DND personnel. A geologic description of the drill core has been made and measurements of some physical properties of the core are in progress.

This information will be used to study the thermal sensitivity of the terrain and to develop hitherto lacking thermal parameters needed for engineering calculations of the response of the permafrost to future development in the Alert area. Such detailed thermal measurements have never been made this far north and a substantial contribution to the scientific knowledge of high latitude permafrost will result.

RESUME

Ce rapport détaille la base et les résultats préliminaires d'une étude du pergélisol entreprise conjointement par le Ministère de la défense nationale, le Conseil national des recherches du Canada et le Ministère de l'énergie, des mines et des ressources à la base des forces canadiennes, Alert, T.N.O. Le projet commença en septembre 1978 avec le forage peu profond de cinq trous, atteignant une profondeur maximum de 61m, dans des régions qui démontreraient le caractère divers du pergélisol et de la couche active à Alert.

Des câbles de température furent installés dans les trous de forage et des mesures fréquentes sont prises par le personnel de la défense nationale. Une description géologique des carottes à été faite et la mesure de certaines de leurs propriétés physiques est en cours d'exécution.

Cette information sera utilisée pour étudier la sensibilité thermique du terrain et pour développer les paramètres thermiques, jusqu'à présent absents, nécessaires au calcul technique de la réaction du pergélisol à l'aménagement futur dans la région d'Alert. De telles mesures thermiques détaillées n'ont jamais été prises si loin au nord et une contribution appréciable à la connaissance scientifique du pergélisol des régions de haute latitude en résultera.

ACKNOWLEDGEMENTS

This project was undertaken with permission of the Canadian Armed Forces Communication Command. The authors appreciate the arrangements for transportation of personnel and equipment to Alert made through Capt. W.T.C. Wood.

The Commanding Officer at Alert, Major A. Hurd, extended warm hospitality to us and offered logistic support without which we could not have managed. We thank him sincerely for this assitance and his interest. The drilling went smoothly through the dedication of Fern Falardeau and Paul Powers of Canadian Longyear and invaluable and varied assistance provided by WO R. Green. Excellent temperature logs at each site are being taken every three weeks under the direction of MWO R.J. Higgins and MWO R. Stover. The success of this project is due in large measure to such enthusiastic cooperation and to all of the above we offer our special thanks.

The Project was conceived originally by Mr. Jean Pilon of DND; the remaining authors appreciate his efforts in coordinating the three government agencies and bringing the project to reality.

CONTENTS

BENEFITS TO THE DEPARTMENT OF NATIONAL DEFENCE OF THE PERMAFROST MONITORING PROGRAM AT C.F.S. ALERT

J. Pilon [(1)]

Arctic surfaces sustain very large changes of bearing strength with the annual freeze-thaw cycle. At certain times of the year, the surfaces can be considered hard and unyielding while for the duration of the thaw season they may become sufficiently soft as to be impassible to presently designed vehicles.

An understanding of the active layer regime which governs these changes is very important. The studies on permafrost and active layer characteristics presently carried out by DND, EMR and NRC at C.F.S. Alert will be very helpful to DND in any assessment of the present vehicle fleet off-road capability in the Alert region. It also will enable DND's defence science group to draft minimal specifications for new vehicles with a higher cross-country capability. Optimally this new vehicle family would be able to use the off-road surfaces at all times of the year.

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Ottawa, Ontario

The ability to better determine the ground thermal sensitivity and to predict more accurately the response of the permafrost to new construction at Alert should result from this program. The Department stands to benefit substantially in better site selection through the identification of the more stable ground areas for projects such as pipeline laying, antenna construction, fuel storage, road maintenance and airport construction and maintenance. The results of these studies can also help significantly in improved stability and anchoring systems for the existing base structures.

A better understanding of the local and regional ground characteristics may enable us eventually to design a better, more efficient grounding system for the base installations (especially in respect to RF hazards).

PERMAFROST GROUND TEMPERATURE INVESTIGATIONS AT ALERT, N.W.T.

R.J.E. Brown(1)

The first consideration of this project arose in the fall of 1976 when Mr. Jean Pilon, Defence Research Establishment, Ottawa, mentioned to the author the possibility of obtaining ground temperature measurements in permafrost at Alert, N.W.T. This location at 82° 30' N is the most northerly habitation in Canada and the northern hemisphere. It is situated in the extreme northern reaches of the continuous zone where permafrost conditions are the most severe in Canada. The opportunity for the National Research Council of Canada and the Department of Energy, Mines and Resources to install thermistor cables in boreholes at Alert was raised and investigated by the Department of National Defence. This Department operates the Canadian Forces Base at Alert and a support air transport service from CFB Trenton, Ontario.

Mr. Pilon enquired about the possibility of transporting a diamond drill and ancillary equipment from Trenton and obtaining accommodation, meals and logistical support at Alert. The Department of National Defence expressed interest in the project and detailed planning began in the spring of

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1978. It was decided that 4 persons from Ottawa would carry out the work - Dr. R.J.E. Brown and Mr. W.G. Cooke, Geotechnical Section, Division of Building Research, National Research Council of Canada (NRC); Dr. A.S. Judge, Division of Seismology and Geothermal Studies, Earth Physics Branch, Department of Energy, Mines and Resources (EMR); Mr. Jean Pilon, Defence Research Establishment, Ottawa, Department of National Defence. The National Research Council contracted with Canadian Longyear Company Limited, North Bay, Ontario to carry out the drilling of the boreholes - a $17,000 job with $12,000 coming from NRC and $5,000 from EMR. Five thermistor cables, each with 11 sensors, were fabricated - three of 60 m length by EMR and two of 15 m length by NRC.

A few days before our proposed departure date from Ottawa, Dr. Judge and Mr. Pilon had to leave the project because of other commitments. Mr. Alan Taylor replaced Dr. Judge from his Division in Ottawa.

The three people from Ottawa and the two man drill crew travelled to Trenton on Sunday, September 24, 1978. The drilling equipment was sent earlier from North Bay. The group stayed at CFB Trenton until its departure for Alert. There was a delay of one day but we left Trenton on a military Hercules flight, Tuesday, September 26 at 07.35 (EST). There were about 15 passengers on board and all of the drilling equipment which virtually filled the aircraft. The flight arrived in Thule, Greenland at 14.20 (EST) where the plane stayed overnight. Next morning, Wednesday, September 27 the group left Thule at 09.00 (EST) and arrived in Alert at 10.30 (EST). Accommodation was provided in the Officers quarters for Brown, Cooke and Taylor, and in an adjacent building for the drill crew.

A meeting was held the same afternoon with the Officers whose sections were involved with providing logistical support for the project. Afterwards a visit was made by Nodwell to locate five favourable sites for the boreholes. Drilling commenced on Friday afternoon, September 29, and finished Wednesday, October 4. The usual pattern was for a hole to be started one day and finished the next. Moving between holes, setting up and dismantling at each site required several hours. The actual drilling and coring using the wireline (3m) long core barrel arrangement, which eliminated the necessity of pulling up the drill string at the end of each 3m of coring, allowed for hole penetration of about 6m per hour. The drill shack was hauled to the sites with a bulldozer. Diesel fuel, used as a chilled fluid, was also hauled in a steel tank mounted on a tracked trailer. The diesel fuel was circulated through a closed system from two storage watering tanks. The air temperatures at the time of drilling ranged from about -15°C to -20°C, about the same as the ground temperatures in the permafrost. (The snow cover was generally uncompacted varying in depth from 30 to 60 cm depending on exposure.) Thus drilling was carried out with a minimum of disturbance to the ground thermal regime at the borehole sites. Environmental requirements necessitated the burning of the drilling fluid after each hole was completed in the presence of the fire chief and his equipment. All support vehicles including trucks, bulldozers and other offroad tracked vehicles were provided by the motor pool.

As soon as a hole was completed, a thermistor cable was inserted to the bottom. The drill-core was collected in 1.5m long wooden core trays, each with 4 rows to hold 6m. It was brought back to the base where a descriptive identification was made. Samples were selected for analysis in Ottawa of lithological composition and thermal conductivity. A stand with cable connector was installed above each hole for the reading equipment. Arrangements were made with the Department of National Defence for readings to be taken every three weeks.

NRC 15 metre Thermistor Cables

Thermistors were installed in holes located in a typical south facing slope and north facing slope, supplementary to the three 60 m cables, to ascertain the influence of aspect at high latitudes on the permafrost ground tempertures. Four months of readings show the temperatures in Hole No. 4 on the south facing slope to be about 0.5°C colder than in Hole No.5 on the north facing slope. This is the reverse of the situation usually prevailing on adjacent north and south facing slopes. Observations through the remainder of the first 12 month period to the fall of 1979 are necessary before definitive relationships can be established. Nevertheless, effects due to variations in snow cover, vegetation and even rock type (thermal conductivity) may be sufficient to maintain the present trends.

Water Treatment Plant

NRC is involved in monitoring ground temperatures in the foundation of the water treatment plant. This building was constructed on a fill of local crushed shale, placed in two stages, which was completed in the spring of 1978. A concrete pad underlain by a 15 cm layer of styrofoam insulation was placed on top of the fill. Four open air conduits, about 35 cm in diameter, were placed in the fill. They are open in winter to allow free circulation of cold air through the fill and closed in summer. Thermistors are located at each end of the two middle conduits. A network of thermistor cables was installed above and below the insulation and at each end of the conduits. Early measurements indicate that the fill is frozen and the frost table is just below the insulation. The design expectation is that the ground will remain frozen to a high level in the fill.

PRELIMINARY ANALYSIS OF PERMAFROST OBSERVATIONS AT ALERT

A.E. Taylor and A.S. Judge[(1)]

Alert has a mean annual air temperature of -18°C and experiences one of the shortest frost-free seasons in Canada - an average of 4 days. One expects, then, to find thick permafrost, and only a thin active layer above the permafrost layer which seasonally freezes and thaws.

What does drilling special test holes and instituting a temperature monitoring program add to this general picture? First, we hope to quantify the thermal regime at Alert - the thickness of permafrost, its temperature, how it varies locally and its susceptibility to change due, for instance, to heat losses from buildings or to varying surface conditions such as runway construction. Secondly, we hope such carefully measured data as are currently being accumulated will contribute to the scientific knowledge of the thermal history of the area. Even a modest program should reveal some details of the glacial history of the region and of the post-glacial rise of the land relative to the sea. Past climatic changes tend to be preserved for long periods in underground temperature profiles and evidence of any such changes in the past few centuries should be observable.

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Similar programs have been undertaken in other areas of Canada. In the past, our group has been able to take advantage of drilling being done by the mining companies or oil industry. Temperature measurements to depths greater than 125m exist at 100 sites in the permafrost region of Canada largely through such cooperative programs. The principal sites and the location of Alert are shown in Fig. 1.

Regional and local Geology

This summary is based except where noted on publications by Christie (1964) and Blackadar (1954).

Early expeditions travelling north in the channel between Ellesmere and Greenland contributed the first physiographic data on this region in the latter half of the nineteenth century. The Nares expedition wintered over at Cape Sheridan near Alert, and long treks were made along the northern coast and up the Wood River just west of Alert. Extensive collections of rocks and fossils made by this expedition permitted it to publish the first geologic map of the region in 1878. Later expeditions and explorers added to this sound foundation. The establishment of the Alert weather station in 1950 made access somewhat easier, although geologists for some time after still travelled by dog-team and hiked long distances on foot. The most recent mapping (Christie, 1964) has, of course, relied considerably on investigation by light aircraft.

Alert lies within the Cape Rawson formation - a rock group of Palaeozoic age extending from Archer Fiord in the south to Porter Bay, about 30 km NW of Alert. The group was named in the 1878 map after type rocks conspicuous at Cape Rawson, 20 km east of Alert. In the vicinity of Alert, the structural trend is northeast with a steep to vertical dip of the bedding.

The Cape Rawson group consists mainly of dark coloured greywacke, sandstone, slate and limestone. Inclusions of pyrite crystals are common and veins of milky quartz are frequent. Mica flakes and small amounts of chlorite, lying parallel to the bedding, commonly contribute to a weak cleavage in the rock.

The present day ice caps in the interior of Ellesmere Island are remnants of the last major glaciation tens of thousands of years ago (Prest, 1970). The additional land covered, and the thickness at that time of the ice is uncertain but the Alert area was probably overlain by ice until at least 10,000 years ago. Blackadar (1954) suggests that the hills southeast of Alert (Dean Hill being one, Fig. 2) were moulded to their rounded shape by the advancing glacial ice. Following deglaciation, there has been a general uplift of the land resulting from the removal of the ice load over much of the Canadian Arctic. At Alert, this has amounted to the land rising about 25m in the past 5000 years (Farrand, 1962; Blake, Jr. 1969).

Site Selection

The five sites were chosen in areas that would illustrate the diversity of the underground thermal regime at Alert. Site 1 (Fig. 2) was chosen deliberately within 100m of the shoreline to allow comparison with sites 2 and 3 which are progressively further inland. Both sites 2 and 3 are plateau areas - the investigators had to abandon the plan of having site 3 atop Dean Hill because of difficulty of access. Much further south, the solar radiation received by north and south facing slopes is considerably different. This imbalance is expected to be minimal at Alert because of the sun's more equal elevation at all azimuths throughout the 24 hour day-light period. The effect on underground temperatures may be assessed from results obtained at sites 4 and 5 on opposite facing hillsides.

These five sites are believed to embrace the span of diverse thermal regimes easily accessible for drilling and measurement in the Alert area.

Instrumentation

In order to monitor temperatures at various levels within each of the drillholes, cables were made containing thermistors at selected intervals. Thermistors are semiconductive elements which have a large negative temperature coefficient of resistance. The thermistors used in these cables have a resistance of about 7300 ohms at $0^{\circ}C$ and have proven to be stable within thousandths of a degree per year Eleven or twelve thermistors were mounted into each cable, according to the detail desired. Immediately upon completion of each drillhole, a cable was lowered to the bottom, and suspended from a tripod near the surface. Subsequently, a sensitive Wheatstone bridge is attached to the cablehead at the surface and a series of resistance readings taken. These are then converted to temperature, using a set of tables based on the thermistor calibration points.

Logging of each site at approximately 3 week intervals has been carried out by the electronics engineers associated with CFS Alert. Such carefully taken measurements have never been available in the far north, and a year's suite of these will show the response of subsurface temperatures to the seasonal air temperature and other seasonal variations. The data will form the basis of a comprehensive study of the dynamic response of the permafrost to thermal changes at the surface.

Properties of Subsurface Rock

Complete core was taken at each drillhole, and a preliminary core log was made at the site. A number of samples representative of each hole were taken for geological identification (see section by Gratton-Bellew). A second suite was reserved for measurements of physical properties such as thermal conductivity, density and porosity needed for the scientific investigation and for future engineering calculations.

All holes encountered about 3m of unconsolidated overburden containing visible ice. Sites 2 and 3 were particularly ice-rich in this interval, while a 3cm lens of ice was intersected at a depth of 2m at site 5.

Ice was observed at greater depths, either as small lenses or as cement in highly fractured quartz. Core from site 2 had ice lenses in the upper 30m and two intervals of ice-cemented quartz, one around 34m and a pronounced section from 43 to 47m. Part of an ice lens 2cm thick was intersected at 37m in hole 3.

Thirty-six one centimetre thick discs have been cut for the measurement of physical parameters. The set has been sent to Professor Michael King, University of Saskatchewan, who will make these measurements under contract. Although results are not expected until early summer, the geological examination shows that most of the holes penetrated argillite. The thermal conductivity, then, can be expected to be moderate in value, perhaps around 3.3 $Wm^{-1}K^{-1}$, somewhat higher than shales (about 2 $Wm^{-1}K^{-1}$) but lower than sandstones (around 4 $Wm^{-1}K^{-1}$).

Alert Climatic Data

The Atmospheric Environment Service operates a weather station at Alert. Accurate air temperatures may be compared with subsurface temperatures recorded in this study.

Mean monthly temperatures, based on over 20 years records, are available in Environment Canada's publication - "Canadian Normals - Temperature 1941-70". If these long term averages are plotted versus time, the sinusoidal curves of Fig. 3 result. They illustrate that on average, monthly mean air temperatures vary over a range of about 37 K [(1)] centered at the annual mean of -18^{o}C. The temperatures actually measured may depart from these, but measured monthly means will normally lie within the maximum-minimum curves of Fig. 3.

The actual temperatures measured at the weather station since this project started are available on monthly climatological summary sheets, and such have been obtained to the end of December, 1978. The weekly mean temperatures observed in that period are plotted in Fig. 4.

Preliminary Temperature Results

The temperature sets collected so far are assembled in Tables 1 to 5, and Figures 5 to 9, representing about 5 months of data. This is sufficient to make an initial assessment and to discuss some possible implications.

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(1) By common scientific usage of the SI units, a temperature interval or difference is quoted in Kelvin. A temperature is written in degrees Celsius (^{o}C).

The Deep Sites

Sites 1, 2 and 3 were drilled to 61m, although mud problems at site 3 prevented the temperature cable from reaching more than 57m. These holes were drilled such that temperatures below the major effect of seasonal variation could be obtained in three areas typical of the diverse terrain at Alert.

Temperature logs to date are shown in Figures 5, 6 and 7. The upper 20m segment of each profile will be interpreted later along with the shallow sites, 4 and 5. These three sites are most interesting for the considerable differences they show amongst themselves at greater depths. The cable at site 3 failed in early January, 1979 so Fig. 10 compares results logged on December 28, 1978.

Two principal features are evident in Fig. 10. First, site 1 is about 3 to 4 K warmer than site 3 and up to 5 K warmer than site 2. These differences arise from the comparatively more complex thermal surface history at site 1.

Two effects may be considered. First, there is the "topographic" effect of the adjacent ocean, whose temperature is 16 to 18 K warmer than the annual mean air temperature. The second effect results from the sea level history, and the ample evidence that site 1 was at one time covered by the ocean.

Sites 2 and 3, with present elevations of 92 and 160m ASL respectively, are more than a kilometre from the present shoreline and undoubtably were exposed land when the glaciers retreated. Site 1, however, is at a present elevation of less than 10m and lies within a hundred metres of the present shoreline. The supposed uniform rising of the land by 25m over the past 5000 years suggests site 1 was under seawater for half of that period, perhaps being exposed land for only 2000 or 3000 years before the present.

The surface temperature history over the past several thousand years at each site is the major condition affecting the underground thermal regime. Because thermal conductivities and thermal diffusivities are relatively low for rock, the underground regime takes a very long time to respond to various changes at the surface. The much warmer subsurface temperatures and higher temperature gradients measured at site 1 are partially an expression of the higher surface temperatures there in the past. The surface temperatures at this site while inundated by the sea may well have been 16 to 18 K warmer than today's surface temperature. Indeed, underground temperatures at all sites are responding to present conditions, which may vary somewhat from site to site - due to weather patterns (e.g. moderating effect of coastal fogs, different snow cover thickness or persistance, vegetation and surface moisture, etc.)

Temperature gradients - the rate of change of temperature with depth seen as the slope of the profiles in fig. 10 - yield additional important information for the longer holes.

Looking at only the lower 25m of each of the logs of the three deep sites, considerable variation in the temperature gradient is evident. Site 1 has the highest value (53 K km^{-1}), about twice that of site 2 (27 K km^{-1}) and four times that of site 3 (14 K km^{-1}). The latter two values are in the range expected for the Alert area. The very high gradient at site 1 is not surprising, however, from the discussion above relating to sea-level history.

When the data set is complete (and thermal conductivities of the core samples are measured) it will be possible to model these three diverse sites mathematically. Lachenbruch (1957), for instance, has shown mathematically the effect on underground temperatures measured in a borehole near the regressing shoreline at Resolute. Other models may be used to demonstrate effects such as recent glaciation, uplift, and long term changes in climate. This should lead to a better understanding of such terrain-modifying forces in the Alert region.

The Shallow Sites

Sites 4 and 5 were drilled to a depth of 15.2m and each instrumented with cables containing 11 thermistors. Such fine spacing of the sensors should allow close monitoring of the response of the near-surface to seasonal variations in temperature.

The results so far (Figures 8 and 9) show the considerable variation of near-surface temperatures to the onset of winter. Fig. 11 typifies the envelope of temperatures experienced by the upper 8m of rock at these sites so far. Some thermistors have failed recently at site 5 (table 5), so direct comparison can be made only at some levels. However, there is a tendency for the temperature envelope to be somewhat larger at site 4. These envelopes will broaden (especially towards colder temperatures) as data for the rest of the year is collected.

Site 4 is located on a southerly facing hillside while site 5 is across the valley on a northerly facing exposure. Comparison of the temperature envelopes for both sites after one year's records will emphasize any basic thermal difference between these two aspects. Although less detailed, envelopes constructed for sites 1, 2 and 3 would similarly reflect their differing environments.

The profiles observed so far (Fig. 8 and 9) generally show an increase in temperature with depth for a metre or so, then a decrease in temperature until some common value is reached, around the bottom few metres of the hole. This creates a prominent temperature peak which decreases in magnitude and deepens as winter progresses - eventually disappearing from the January logs. This peak is an expression of the summer heating and it is the ground's slow response and large heat capacity which allows it to persist well into winter. The opposite effect - a winter peak towards colder temperatures - should be observable in the temperatures logged during the summer.

The above describes the change of the underground temperatures in response to the seasons. Even with only 5 months data, it is possible to see expressions of the Alert weather variations over that period. Daily mean temperatures from the Alert AES weather station have been examined and weekly mean air temperatures for September to December, 1978 have been plotted in Fig. 4. They show a reasonably uniform decrease in temperature from September until about November 20, when milder temperatures appear and persist with few exceptions to the end of the year.

These pronounced variations of air temperatures propagate downwards with an attenuated amplitude and a phase lag, depending on the thermal properties of the snow layer and of the underlying rock. Some evidence for a correlation between this warm interval following Nov. 20 and our subsurface measurements may be seen for site 4 (Fig. 12).

Temperatures at 0.8m below ground surface show a pronounced increase in temperature after the Nov. 18th log until colder temperatures are recorded again in January. The phase lag is apparent at the 1.5m depth since the temperature increase occurs there only following the Dec. 5th log. Similar correlations can be seen in the other sites, although the data is not as good.

The response of underground temperatures to changes at the surface may be used to determine the in situ thermal diffusivity of the ground. This is probably the most important thermal parameter related to the dynamic behaviour of permafrost, including as it does both the thermal properties of the rock and of any moisture present in pores and fractures.

Conclusion

The temperature data being accumulated at the five thermistor cable sites at Alert is of high quality. This brief report has demonstrated general features of the data so far available, and has suggested some preliminary interpretations.

A more exhaustive and varied treatment will be published when a full year of observations is available.

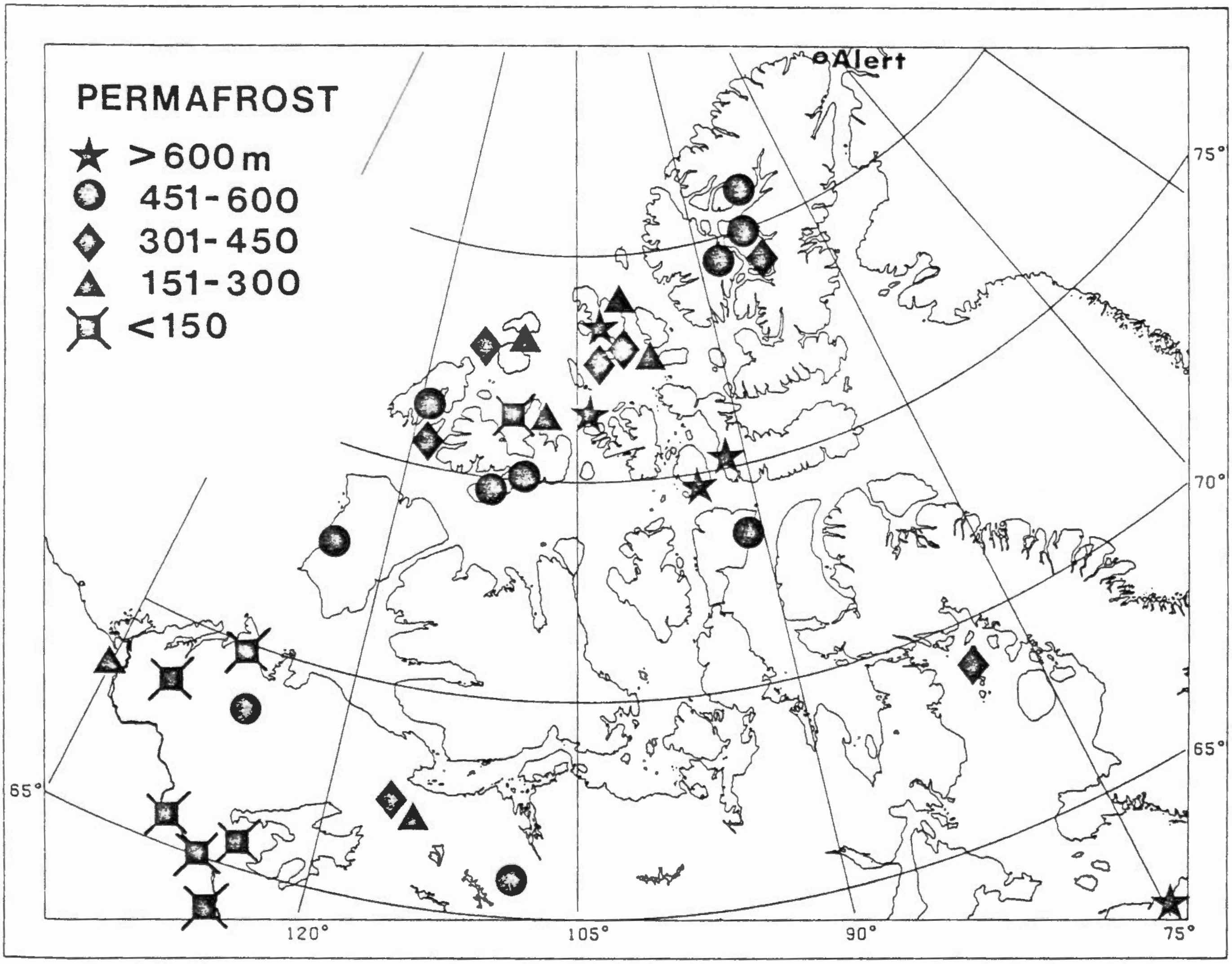
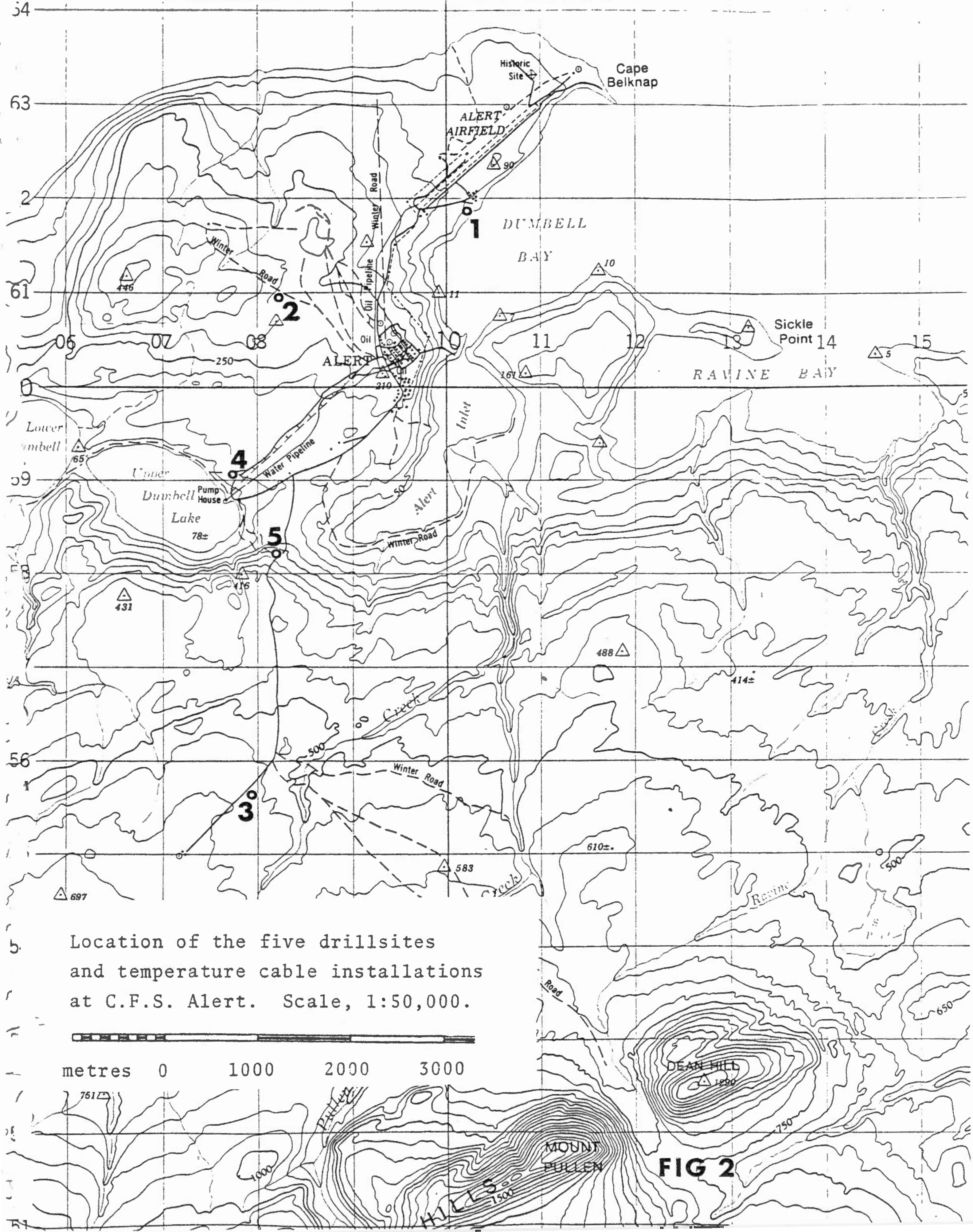


FIG 1

Major permafrost thickness determinations in Arctic Canada. Not shown are 40 sites in the Mackenzie Delta. A complete set of maps and tables is contained in Judge, Taylor and Burgess (1979).

PERMAFROST CABLE SITES



Location of the five drillsites and temperature cable installations at C.F.S. Alert. Scale, 1:50,000.

metres 0 1000 2000 3000

FIG 2

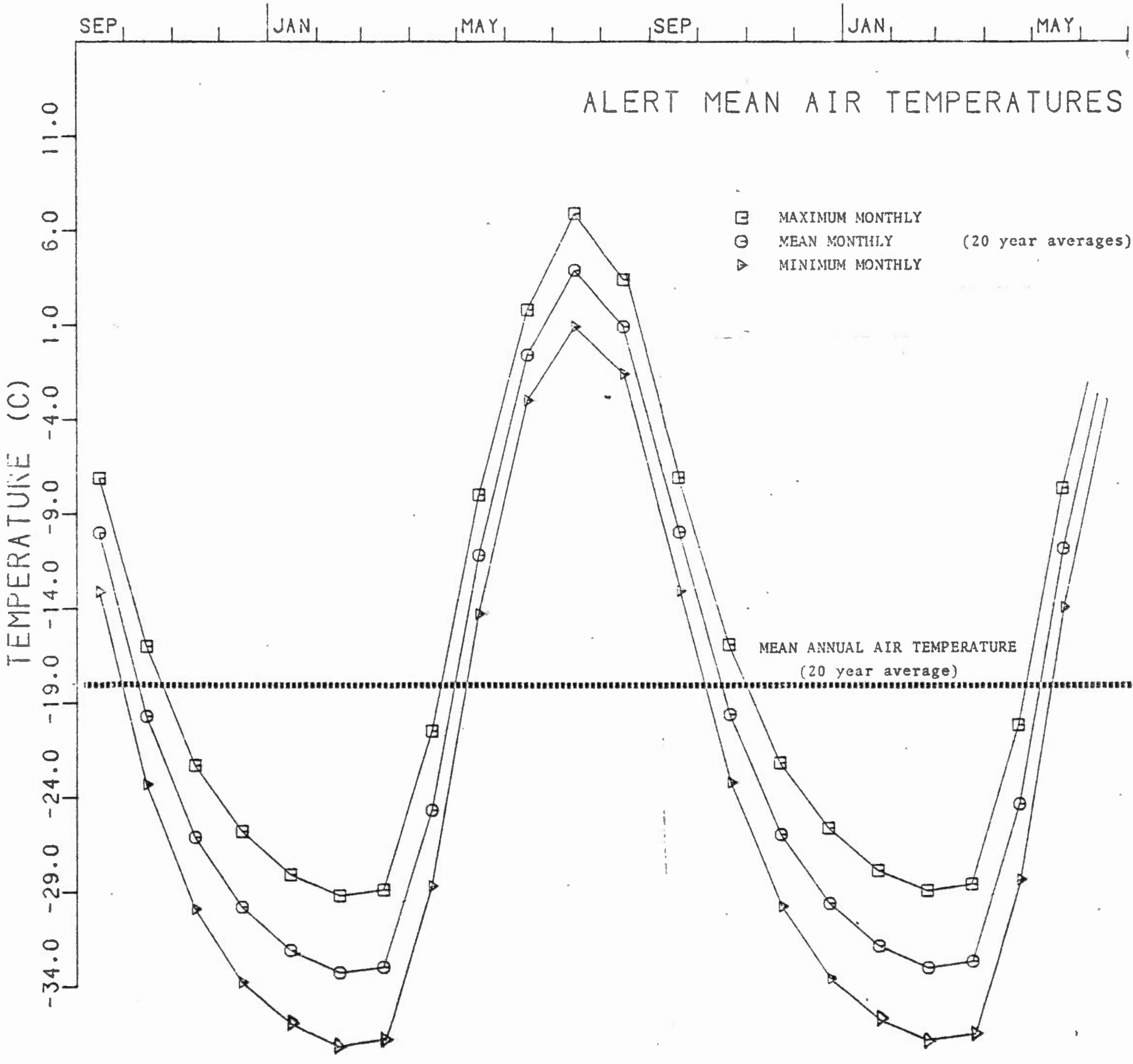


FIG 3

Mean air temperatures recorded over 20 years at the Alert AES Weather Station (Environment Canada, 1975)

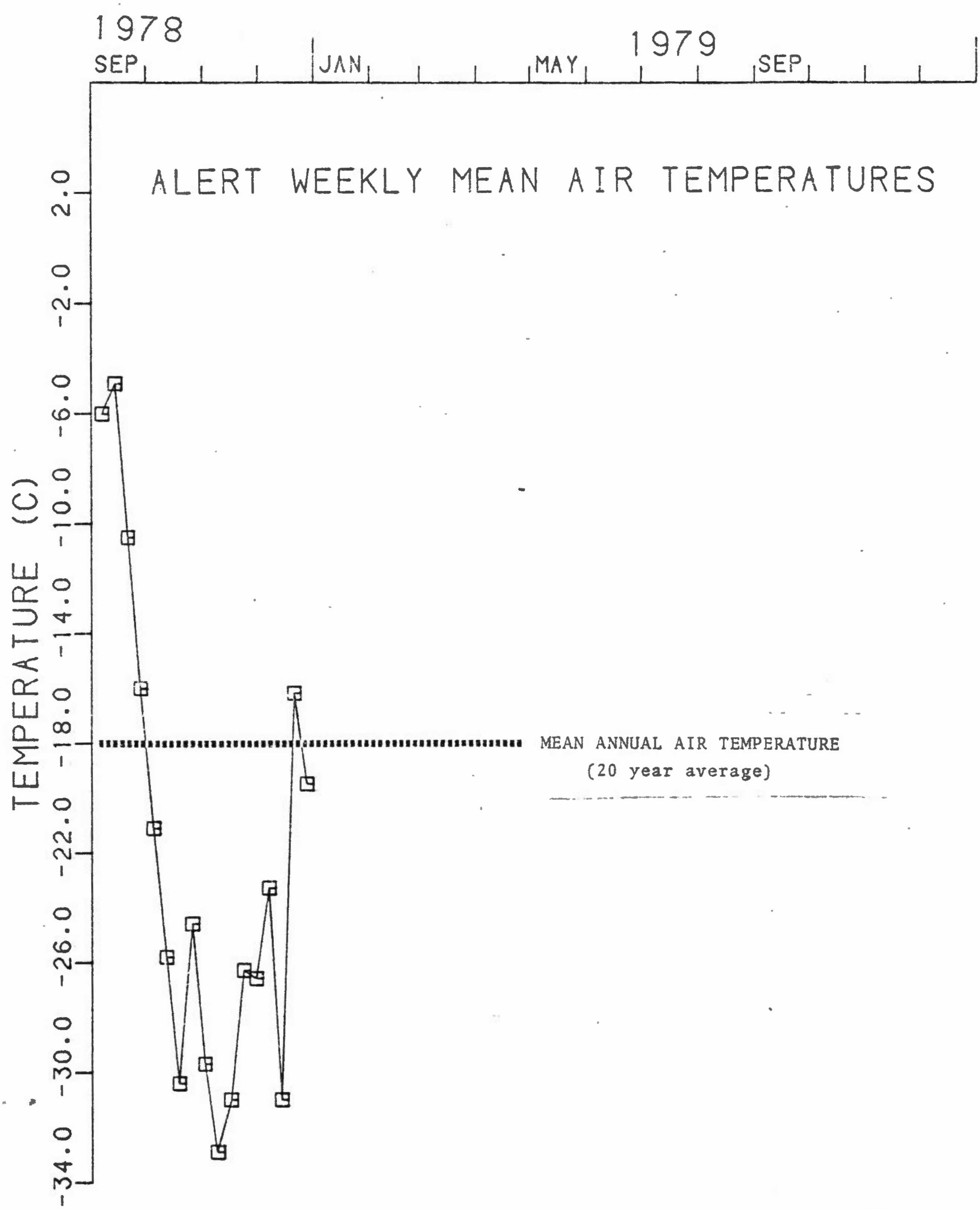


FIG 4

Weekly mean air temperatures at Alert, Sept. to Dec. 1978, covering the first 4 months of this project. (Monthly Climatological Summary Sheets, Environment Canada, unpubl.)

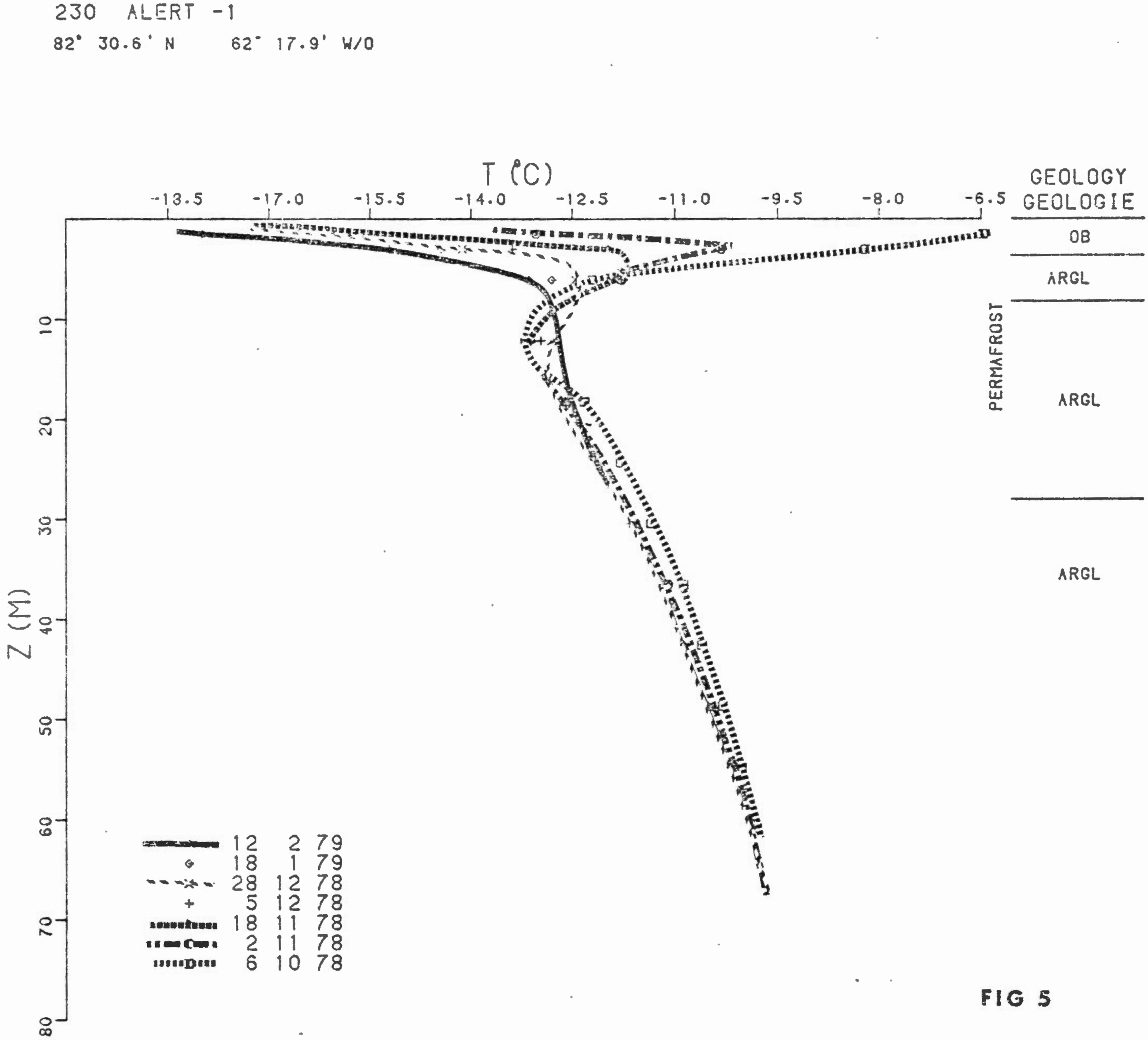


FIG 5

Temperature profiles measured on various dates at site 1. The geologic section combines the preliminary log taken on site and the identification made by Gratton-Bellew. OB, overburden; ARGL, argillite

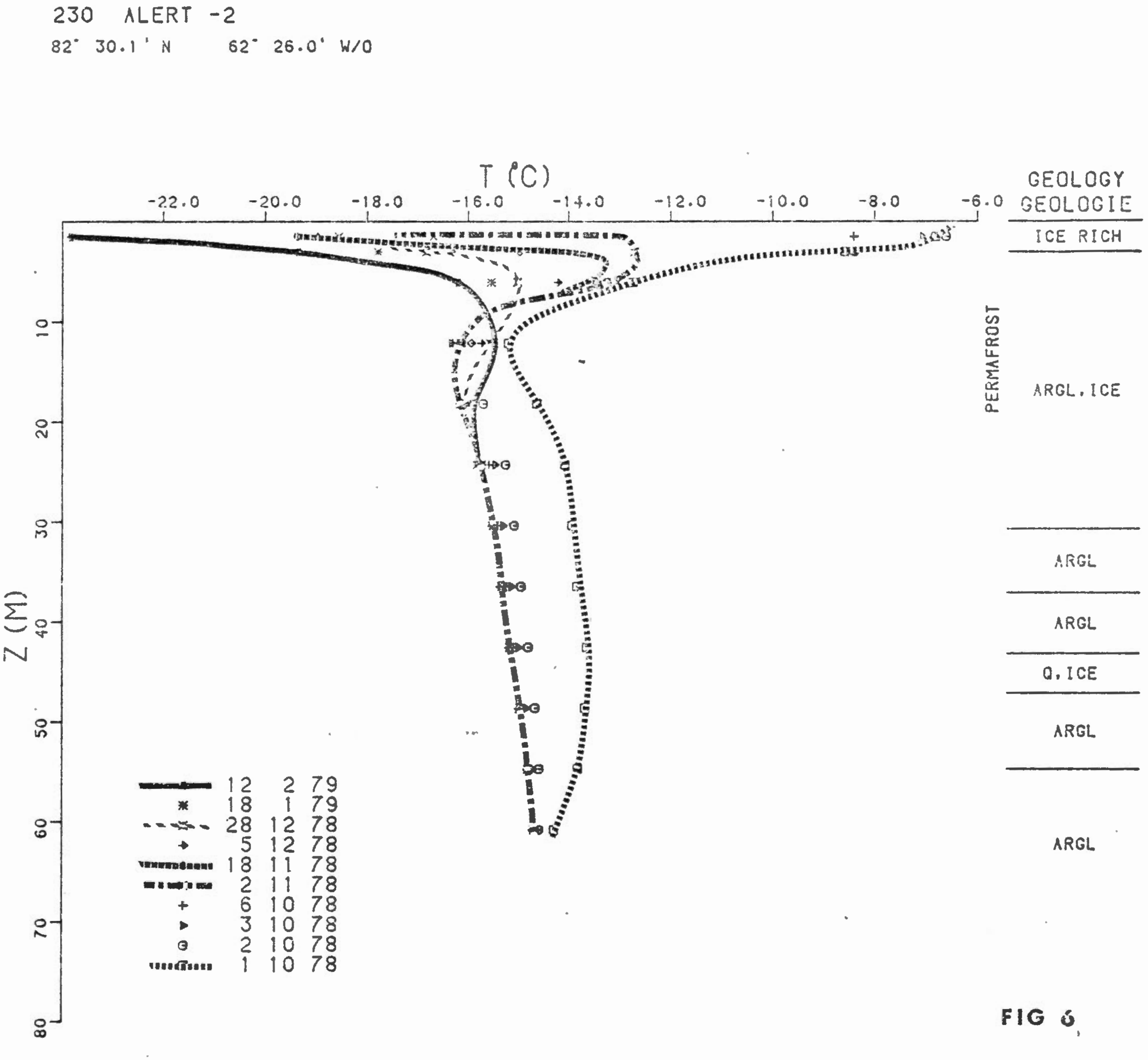


FIG 6

Temperature profiles measured on various dates at site 2. The geologic section combines the preliminary log taken on site and the identification made by Gratton-Bellew. ARGL, argillite; Q, quartz.

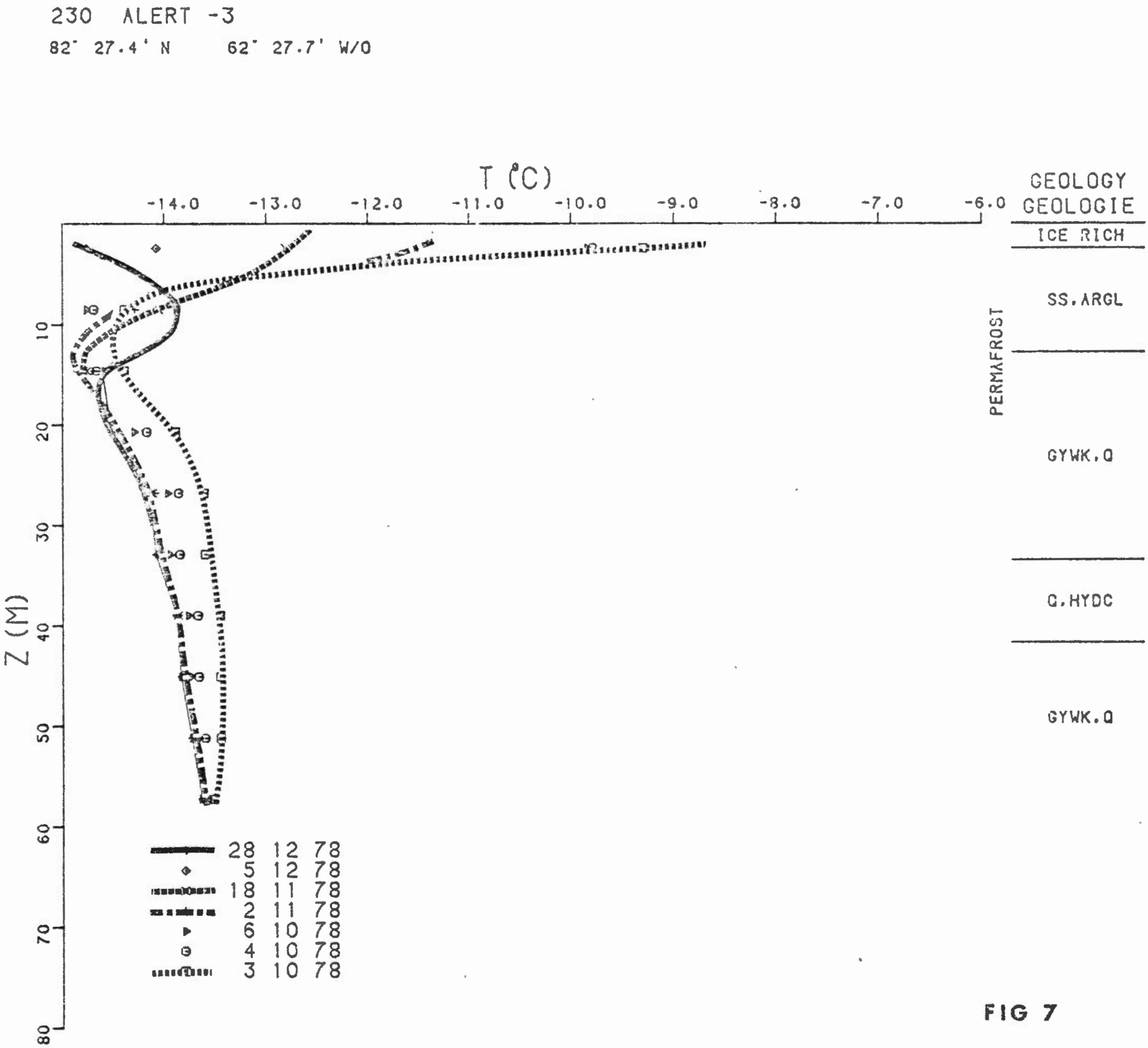


FIG 7

Temperature profiles measured on various dates at site 3. The geologic section combines the preliminary log taken on site and the identification made by Gratton-Bellew. SS, sandstone; ARGL, argillite; GYWK, greywacke; Q, quartz; HYDC, hydrocarbon.

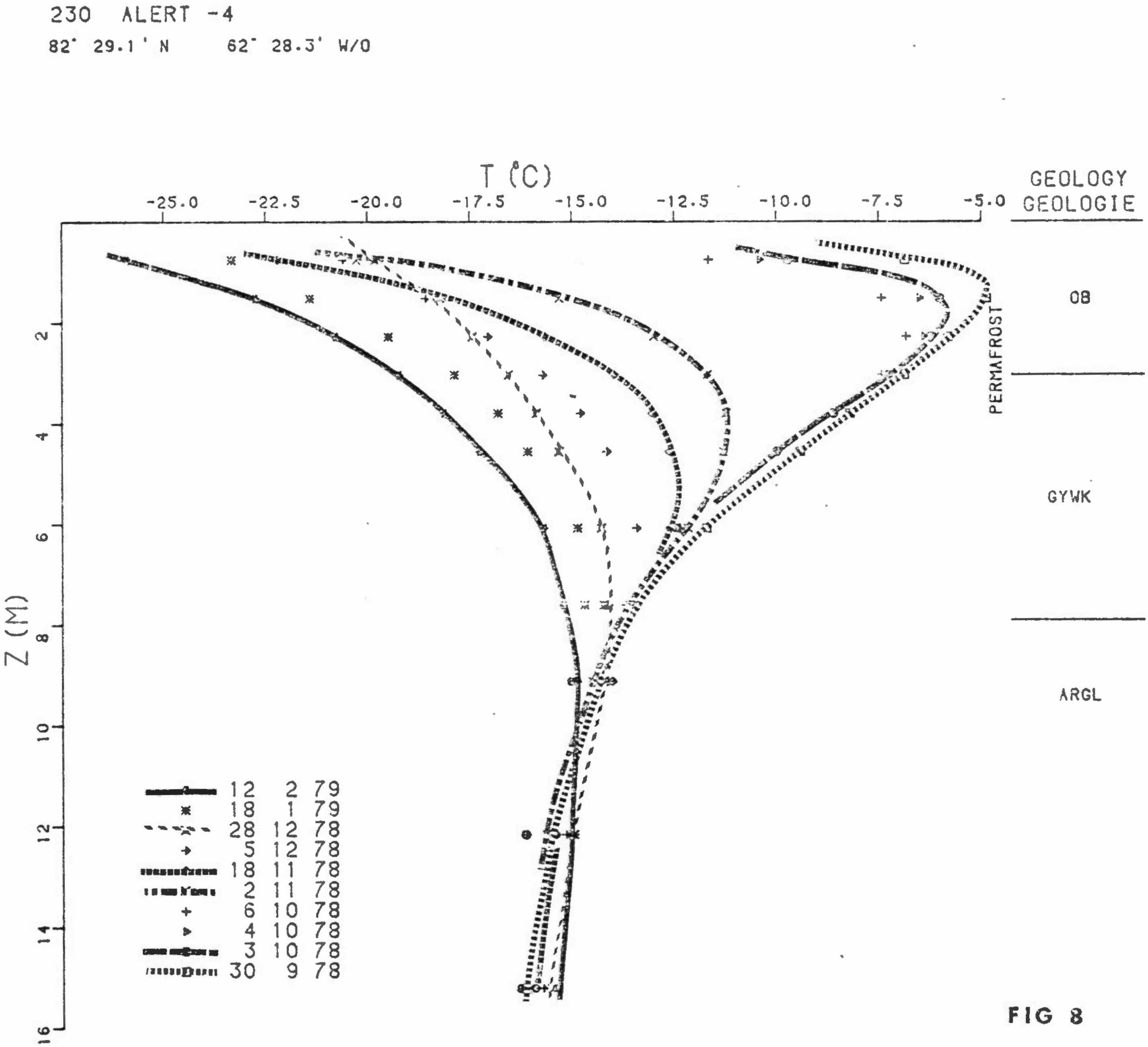


FIG 8

Temperature profiles measured on various dates at site 4. The geologic section combines the preliminary log taken on site and the identification made by Gratton-Bellew. OB, overburden; GYWK, greywacke; ARGL, argillite

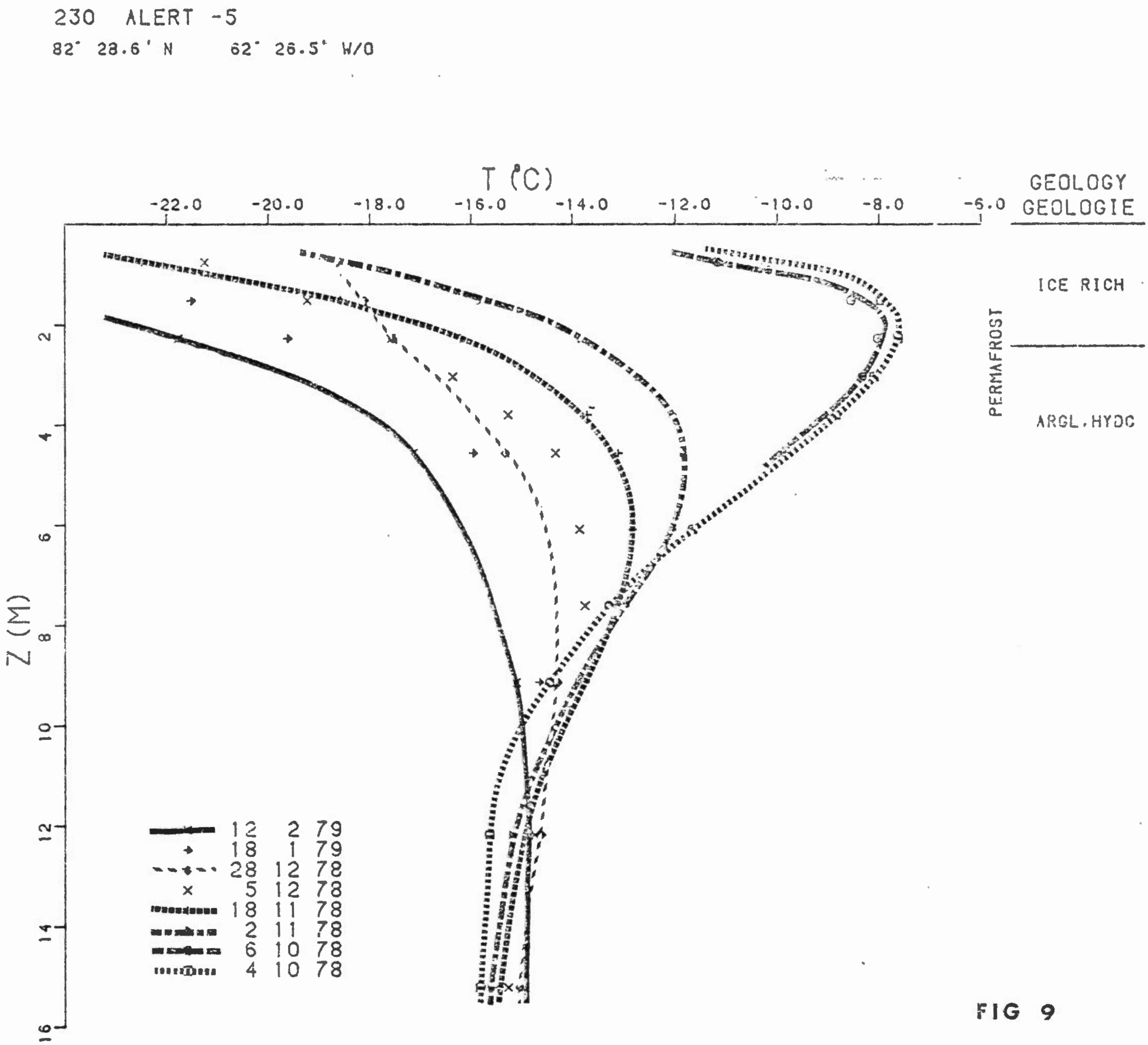


FIG 9

Temperature profiles measured on various dates at site 5. The geologic section combines the preliminary log taken on site and the identification by Gratton-Bellew. ARGL, argillite; HYDC, hydrocarbon.

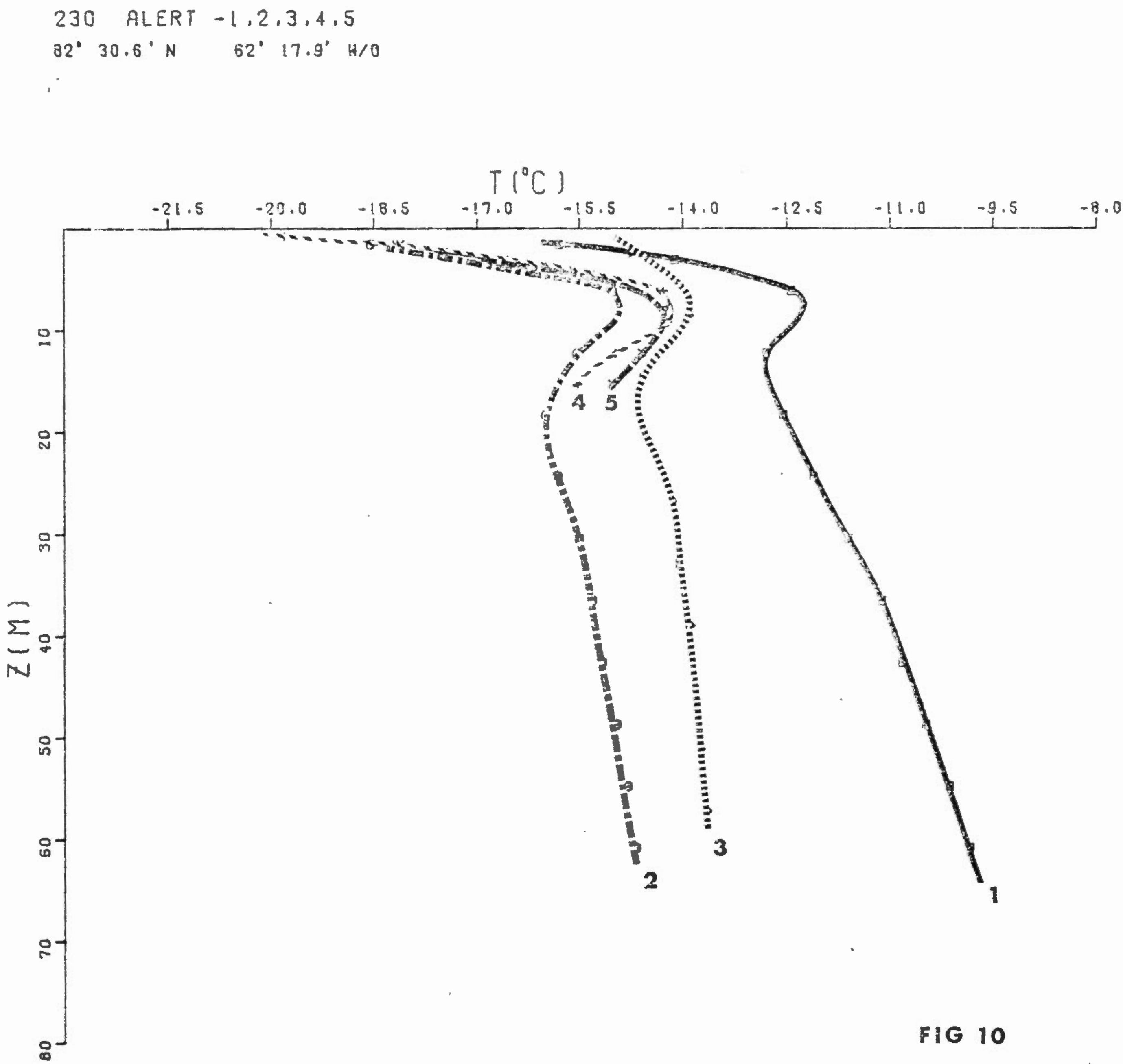


FIG 10

Temperature profiles measured on Dec. 28, 1978 at the 5 sites.

230 ALERT

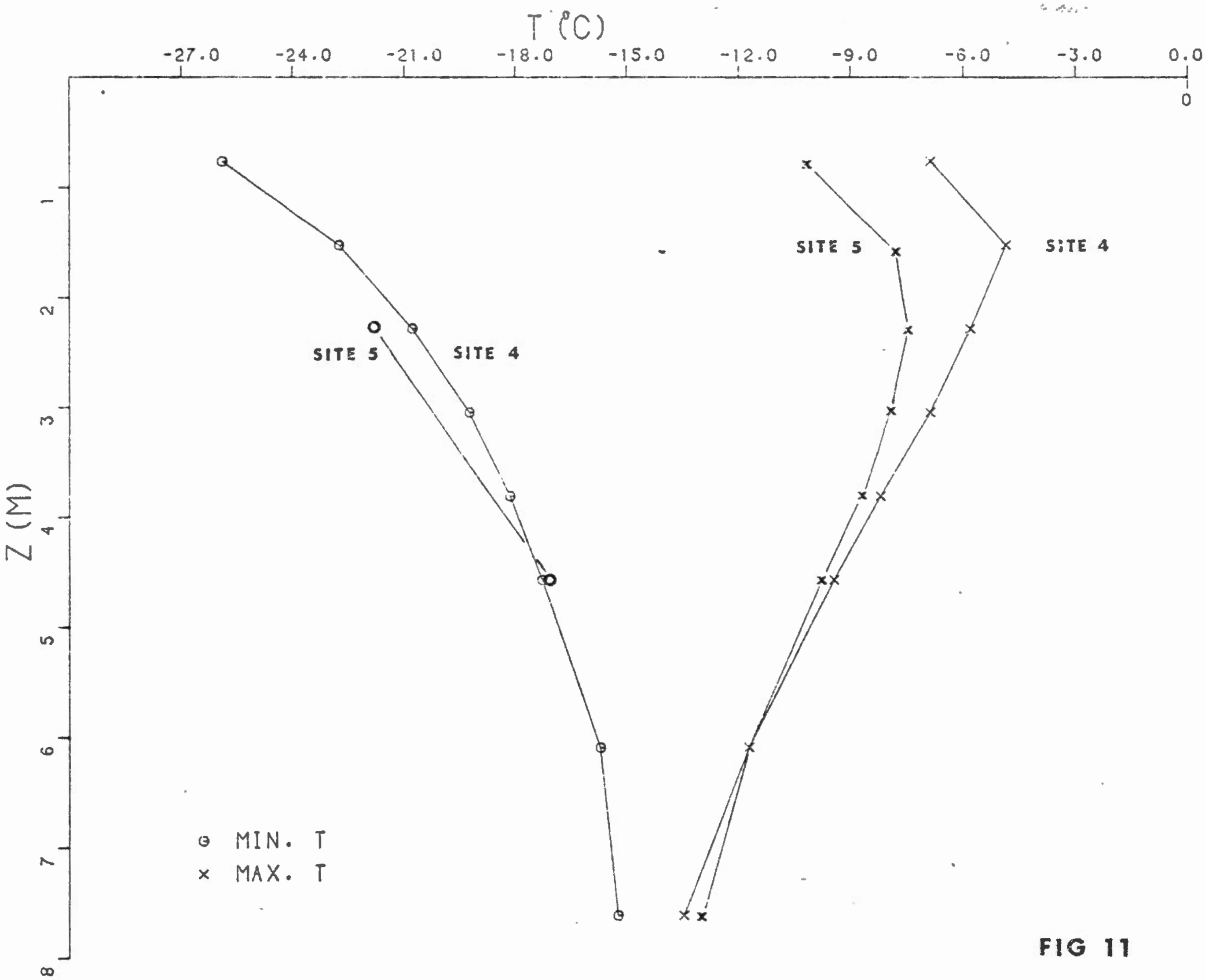


FIG 11

Minimum to maximum temperature envelope observed in the upper 8m of the two shallow sites, for the period Sept. 30, 1978 - Feb. 12, 1979.

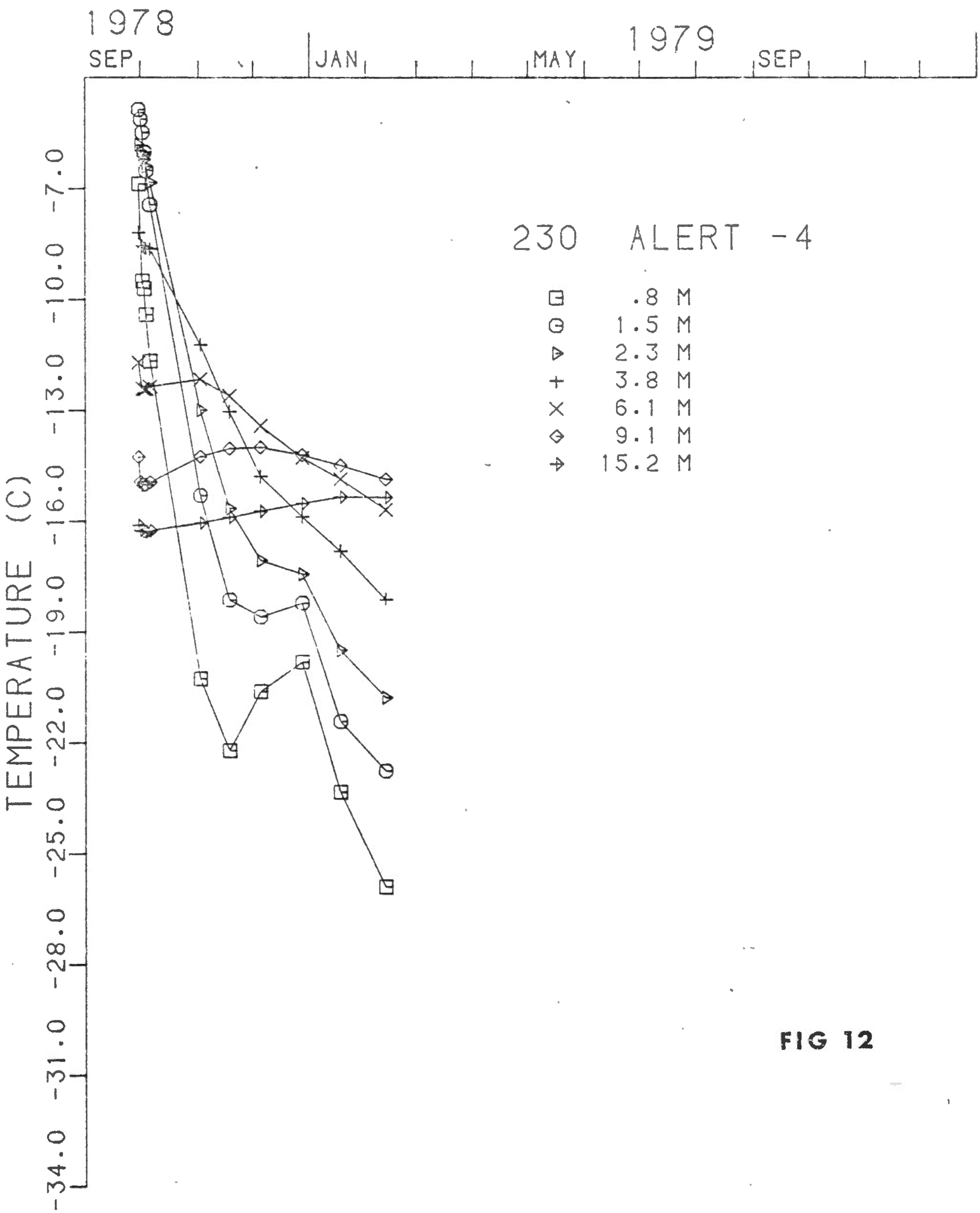


FIG 12

Variation of temperature with time at selected depths at site 4.

EARTH PHYSICS BRANCH NO.
DIRECTION DE LA PHYSIQUE DU GLOBE NO. 230 ALERT -1

****

82 DEGREES 30.6 MINUTES NORTH
62 DEGREES 17.9 MINUTES WEST

82 DEGRES 30.6 MINUTES NORD
62 DEGRES 17.9 MINUTES OUEST

ELEVATION 10 METRES

SUMMARY OF DEPTH-TEMPERATURE LOGS

DIAGRAPHIES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR

	DATE 6 10 78	DATE 2 11 78	DATE 18 11 78	DATE 5 12 78	DATE 28 12 78	DATE 18 1 79	DATE 12 2 79
Z (M)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)
1.5	-6.47	-13.03	-15.57	-16.08	-15.80	-16.57	-17.99
3.0	-8.20	-10.33	-11.95	-13.38	-14.13	-14.43	-15.22
6.1	-12.20	-11.78	-11.76	-11.99	-12.45	-12.80	-13.15
12.2	-13.16	-13.20	-13.09	-12.96	-12.80	-12.72	-12.72
18.3	-12.32	-12.58	-12.59	-12.57	-12.56	-12.53	-12.52
24.4	-11.80	-12.06	-12.09	-12.11	-12.11	-12.12	-12.16
30.5	-11.35	-11.58	-11.59	-11.61	-11.61	-11.61	-11.65
36.6	-10.87	-11.10	-11.11	-11.12	-11.12	-11.12	-11.16
42.7	-10.60	-10.81	-10.83	-10.83	-10.82	-10.83	-10.86
48.8	-10.30	-10.46	-10.47	-10.49	-10.47	-10.48	-10.51
54.9	-10.62	-10.13	-10.14	-10.14	-10.13	-10.13	-10.18
61.0	-9.80	-9.82	-9.83	-9.84	-9.83	-9.83	-9.87

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. FURTHER TEMPERATURE LOGS ARE EXPECTED FOR THIS HOLE.

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES. ON PREVOIT ENTREPRENDRE D'AUTRES SONDAGES DE LA TEMPERATURE DE CE PUITS.

DND-NRC-EMR ALERT PERMAFROST EXPT
-WELL SPUDDED 3 10 78
-DRILLING FOR 1 DAYS
-TOTAL DEPTH 61 METRES
-DRILLING STOPPED 4 10 78

DND-NRC-EMR ALERT PERMAFROST EXPT
-DEMARRAGE DU PUITS LE 3 10 78
-FORAGE PENDANT 1 JOURS
-PROFONDEUR TOTALE 61 METRES
-FORAGE ARRETE LE 4 10 78

LOCATIONS AND ELEVATIONS APPROX.

TABLE I

EARTH PHYSICS BRANCH NO.

DIRECTION DE LA PHYSIQUE DU GLOBE NO. 230 ALERT -2

****

82 DEGREES 30.1 MINUTES NORTH
62 DEGREES 26.0 MINUTES WEST

82 DEGRES 30.1 MINUTES NORD
62 DEGRES 26.0 MINUTES OUEST

ELEVATION 92 METRES

SUMMARY OF DEPTH-TEMPERATURE LOGS

DIAGRAPHIES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR

Z (M)	DATE 1 10 78 TEMP (C)	DATE 2 10 78 TEMP (C)	DATE 3 10 78 TEMP (C)	DATE 6 10 78 TEMP (C)	DATE 2 11 78 TEMP (C)	DATE 18 11 78 TEMP (C)	DATE 5 12 78 TEMP (C)	DATE 28 12 78 TEMP (C)	DATE 18 1 79 TEMP (C)	DATE 12 2 79 TEMP (C)
1.5	-6.81	-6.61	-7.07	-8.41	-16.68	-19.38	-18.99	-18.56		-23.83
3.0	-8.59	-8.40	-8.40	-8.53	-12.71	-14.98	-16.32	-16.83	-17.79	-19.36
6.1	-12.74	-13.24	-13.33	-13.29	-13.04	-13.45	-14.22	-15.02	-15.54	-16.20
12.2	-15.21	-16.14	-16.33	-16.30	-16.13	-15.93	-15.73	-15.55	-15.49	-15.52
18.3	-14.64	-15.70	-15.90	-16.11	-16.15	-16.16	-16.05	-16.01	-15.94	-15.94
24.4	-14.07	-15.25	-15.46	-15.58	-15.73	-15.72	-15.76	-15.82	-15.73	-15.73
30.5	-13.92	-15.08	-15.31	-15.40	-15.48	-15.48	-15.51	-15.50	-15.50	-15.52
36.6	-13.82	-14.94	-15.14	-15.23	-15.31	-15.30	-15.34	-15.32	-15.32	-15.36
42.7	-13.63	-14.80	-15.00	-15.09	-15.16	-15.17	-15.18	-15.17	-15.15	-15.19
48.8	-13.66	-14.66	-14.84	-14.89	-14.95	-14.96	-14.97	-14.96	-14.96	-14.99
54.9	-13.81	-14.58	-14.70	-14.76	-14.79	-14.79	-14.81	-14.80	-14.80	-14.82
61.0	-14.28	-14.58	-14.63	-14.64	-14.66	-14.67	-14.69	-14.67	-14.67	-14.70

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. FURTHER TEMPERATURE LOGS ARE EXPECTED FOR THIS HOLE.

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES. ON PREVOIT ENTREPRENDRE D'AUTRES SONDAGES DE LA TEMPERATURE DE CE PUITS.

DND-NRC-EMR ALERT PERMAFROST EXPT
- -WELL SPUDDED 30 9 78
- -DRILLING FOR 1 DAYS
- -TOTAL DEPTH 61 METRES
- -DRILLING STOPPED 1 10 78

DND-NRC-EMR ALERT PERMAFROST EXPT
- -DEMARRAGE DU PUITS LE 30 9 78
- -FORAGE PENDANT 1 JOURS
- -PROFONDEUR TOTALE 61 METRES
- -FORAGE ARRETE LE 1 10 78

LOCATIONS AND ELEVATIONS APPROX.

TABLE 2

EARTH PHYSICS BRANCH NO. 230 ALERT -3
DIRECTION DE LA PHYSIQUE DU GLOBE NO.

****

82 DEGREES 27.4 MINUTES NORTH
62 DEGREES 27.7 MINUTES WEST

82 DEGRES 27.4 MINUTES NORD
62 DEGRES 27.7 MINUTES OUEST

ELEVATION 160 METRES

SUMMARY OF DEPTH-TEMPERATURE LOGS

DIAGRAPHIES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR

Z (M)	DATE 3 10 78 TEMP (C)	DATE 4 10 78 TEMP (C)	DATE 6 10 78 TEMP (C)	DATE 2 11 78 TEMP (C)	DATE 18 11 78 TEMP (C)	DATE 5 12 78 TEMP (C)	DATE 28 12 78 TEMP (C)
2.4	-9.30	-9.79	-9.84	-11.50	-12.81	-14.08	-14.77
8.5	-14.39	-14.70	-14.77	-14.29	-14.05	-13.92	-13.91
14.6	-14.39	-14.67	-14.79	-14.86	-14.80	-14.72	-14.61
20.7	-13.85	-14.17	-14.30	-14.46	-14.48	-14.52	-14.52
26.8	-13.62	-13.86	-13.97	-14.10	-14.12	-14.13	-14.15
32.9	-13.60	-13.85	-13.95	-14.05	-14.05	-14.08	-14.08
39.0	-13.45	-13.68	-13.77	-13.87	-13.87	-13.88	-13.88
45.1	-13.45	-13.67	-13.74	-13.82	-13.82	-13.84	-13.84
51.2	-13.45	-13.60	-13.66	-13.72	-13.72	-13.73	-13.73
57.3	-13.52	-13.59	-13.60	-13.62	-13.62	-13.63	-13.63

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE.
FURTHER TEMPERATURE LOGS ARE EXPECTED FOR THIS HOLE.

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES.
ON PREVOIT ENTREPRENDRE D'AUTRES SONDAGES DE LA TEMPERATURE DE CE PUITS.

DND-NRC-EMR ALERT PERMAFROST EXPT
-WELL SPUDDED 1 10 78
-DRILLING FOR 1 DAYS
-TOTAL DEPTH 60 METRES
-DRILLING STOPPED 2 10 78

DND-NRC-EMR ALERT PERMAFROST EXPT
-DEMARRAGE DU PUITS LE 1 10 78
-FORAGE PENDANT 1 JOURS
-PROFONDEUR TOTALE 60 METRES
-FORAGE ARRETE LE 2 10 78

LOCATIONS AND ELEVATIONS APPROX.

TABLE 3

EARTH PHYSICS BRANCH NO.
DIRECTION DE LA PHYSIQUE DU GLOBE NO. 230 ALERT -4

****

82 DEGREES 29.1 MINUTES NORTH
62 DEGREES 28.3 MINUTES WEST

82 DEGRES 29.1 MINUTES NORD
62 DEGRES 28.3 MINUTES OUEST

ELEVATION 38 METRES

SUMMARY OF DEPTH-TEMPERATURE LOGS

DIAGRAPHIES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR

Z (M)	DATE 30 9 78 TEMP (C)	DATE 1 10 78 TEMP (C)	DATE 2 10 78 TEMP (C)	DATE 3 10 78 TEMP (C)	DATE 4 10 78 TEMP (C)	DATE 6 10 78 TEMP (C)	DATE 2 11 78 TEMP (C)	DATE 18 11 78 TEMP (C)	DATE 5 12 78 TEMP (C)	DATE 28 12 78 TEMP (C)	DATE 18 1 79 TEMP (C)	DATE 12 2 79 TEMP (C)
.8	-6.87		-9.49	-9.70	-10.40	-11.66	-20.27	-22.21	-20.61	-19.81	-23.34	-25.90
1.5	-4.86	-5.12	-5.48	-6.01	-6.51	-7.43	-15.31	-18.13	-18.59	-18.22	-21.42	-22.76
2.3	-5.80	-5.98	-6.07	-6.21	-6.39	-6.83	-12.99	-15.66	-17.07	-17.44	-19.49	-20.78
3.0	-6.87	-7.12	-7.15	-7.21	-7.26	-7.42	-11.69	-13.98	-15.72	-16.56	-17.88	-19.23
3.8	-8.19		-8.54	-8.59	-8.60	-8.63	-11.22	-13.04	-14.79	-15.88	-16.82	-18.13
4.6	-9.42		-9.96	-9.98	-9.99	-9.96	-11.29	-12.62	-14.16	-15.32	-16.09	-17.26
6.1	-11.70		-12.41	-12.42	-12.41	-12.35	-12.16	-12.61	-13.42	-14.29	-14.86	-15.69
7.6	-13.46	-14.26	-14.19	-14.19	-14.18	-14.11	-13.46	-13.43	-13.69	-14.23	-14.69	-15.22
9.1	-14.26	-14.92	-15.01	-15.01	-15.01	-14.94	-14.25	-14.03	-14.00	-14.21	-14.49	-14.87
12.2	-15.49	-16.26	-16.14	-16.15	-16.16	-16.12	-15.64	-15.39	-15.15	-14.98	-14.95	-15.03
15.2	-16.11	-16.25	-16.27	-16.27	-16.28	-16.25	-16.05	-15.89	-15.73	-15.52	-15.34	-15.36

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. FURTHER TEMPERATURE LOGS ARE EXPECTED FOR THIS HOLE.

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES. ON PREVOIT ENTREPRENDRE D'AUTRES SONDAGES DE LA TEMPERATURE DE CE PUITS.

DND-NRC-EMR ALERT PERMAFROST EXPT
- -WELL SPUDDED 29 9 78
- -DRILLING FOR 1 DAYS
- -TOTAL DEPTH 15 METRES
- -DRILLING STOPPED 30 9 78

DND-NRC-EMR ALERT PERMAFROST EXPT
- -DEMARRAGE DU PUITS LE 29 9 78
- -FORAGE PENDANT 1 JOURS
- -PROFONDEUR TOTALE 15 METRES
- -FORAGE ARRETE LE 30 9 78

LOCATIONS AND ELEVATIONS APPROX.

TABLE 4

EARTH PHYSICS BRANCH NO.
DIRECTION DE LA PHYSIQUE DU GLOBE NO. 230 ALERT -5

****

82 DEGREES 28.6 MINUTES NORTH
62 DEGREES 26.5 MINUTES WEST

82 DEGRES 28.6 MINUTES NORD
62 DEGRES 26.5 MINUTES OUEST

ELEVATION 87 METRES

SUMMARY OF DEPTH-TEMPERATURE LOGS

DIAGRAPHIES DONNANT LA TEMPERATURE
EN FONCTION DE LA PROFONDEUR

	DATE 4 10 78	DATE 6 10 78	DATE 2 11 78	DATE 16 11 78	DATE 5 12 78	DATE 28 12 78	DATE 18 1 79	DATE 12 2 79
Z (M)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)
.8	-10.23	-11.18	-18.62	-22.49	-21.25			
1.5	-7.96	-8.55	-15.85	-18.59	-19.24	-18.12	-21.53	
2.3	-7.63	-8.02	-13.84	-16.22	-17.59	-17.56	-19.63	-21.78
3.0	-8.10	-8.33	-12.73	-14.77	-16.37			
3.8	-8.85	-8.98	-12.06	-13.71	-15.28			
4.6	-9.82	-9.90	-11.86	-13.11	-14.34	-15.34	-15.97	-17.15
6.1	-11.65	-11.67	-12.06	-12.83	-13.86			
7.6	-13.25	-13.29	-12.97	-13.13	-13.75			
9.1	-14.42	-14.44	-13.89	-13.74	-13.86	-14.29	-14.65	-15.11
12.2	-15.64	-15.65	-15.21	-14.93	-14.74	-14.61	-14.65	-14.85
15.2	-15.82	-15.81	-15.62	-15.43	-15.26	-15.04	-14.94	-14.94

TEMPERATURE RESULTS ARE OBTAINED
FROM A MULTITHERMISTOR CABLE.
FURTHER TEMPERATURE LOGS
ARE EXPECTED FOR THIS HOLE.

TEMPERATURES OBTENUES A PARTIR D'UN
CABLE A THERMISTORS MULTIPLES.
ON PREVOIT ENTREPRENDRE D'AUTRES
SONDAGES DE LA TEMPERATURE DE CE PUITS.

DND-NRC-EMR ALERT PERMAFROST EXPT
- -WELL SPUDDED 3 10 78
- -DRILLING FOR 1 DAYS
- -TOTAL DEPTH 15 METRES
- -DRILLING STOPPED 4 10 78

DND-NRC-EMR ALERT PERMAFROST EXPT
- -DEMARRAGE DU PUITS LE 3 10 78
- -FORAGE PENDANT 1 JOURS
- -PROFONDEUR TOTALE 15 METRES
- -FORAGE ARRETE LE 4 10 78

LOCATIONS AND ELEVATIONS APPROX.

TABLE 5

DESCRIPTION OF CORES FROM BOREHOLES AT ALERT, N.W.T.

P.E. Gratton-Bellew (1)

SUMMARY:

The dominant rock type encountered in the drill holes is a varved argillite. It is a very fine-grained rock consisting dominantly of quartz and calcite with some chlorite and illite. The color of the rock varies from medium grey to dark blue or greenish grey. The foliation and layering is vertical except at the bottom of D.H. #2 where it is sub-horizontal. The rock is cut by several veins of quartz and calcite which may be an inch or more wide. Hydrocarbon material has worked its way along the bedding and foliation planes in the rock and also occurs as large hard pieces up to 1 cm square in the quartz vein at 37m in D.H. #3. Calcareous greywacke occurs at 16 and 28m in D.H. #3 and at the top of D.H. #4. This is a somewhat coarser rock consisting dominantly of angular quartz grains and calcite in a matrix of calcite chlorite and illite. This rock is only weakly foliated. It is a medium bluish to greenish grey color. The results of the petrographic examination of selected pieces of drill core are shown in Figure 1.

---

(1) Building Materials Section,
National Research Council of Canada
Ottawa, Ontario

Descriptions of thin sections from selected pieces of drill core:

Due to the similarity of the argillites and greywackes from the five holes, a typical argillite and a typical greywacke will be described in detail; only points of difference between these and other samples will be discussed.

Argillite:

The argillite is a well-foliated layered rock. The foliation is parallel to the bedding planes. A typical low magnification view of the argillite is shown in Figure 2, in which the alteration of dark and light bands may be clearly seen.

Dark bands:

The dark bands are the most strongly foliated. The foliation is due to the recrystallization of the quartz grains into an elongate shape. The quartz grains are commonly from 75 to 150 μm long by 5 to 25 μm wide. The quartz grains are surrounded by dark coloured clay minerals. See figure 3 (lower half).

Light bands:

The light bands, Figure 3 (upper half), consist of more equidimensional quartz grains 20 to 50 μm in diameter in a matrix of calcite and clay minerals. The light bands are only weakly foliated.

X-ray diffraction analysis showed the clay fraction of the argillite to consist of chlorite and illite. The argillite is typically cut through by narrow calcite veinlets. In some of the larger calcite veins, quartz has replaced some calcite along the grain boundaries. A few percent of pyrite occurs in the argillite. Some of it occurs as large cubes up to 3 mm across; the remainder is much finer. Hydrocarbon material has commonly worked its way along some of the foliation planes in the rock and has also deposited in fractures. The color of the argillite varies but it typically consists of alternating layers of greenish grey 5 GY 6/1 (1) and medium grey N5. The pale green color is probably due to the presence of chlorite. Some of the light bands in the argillite are pale olive green 5 Y 6/1, e.g., hole #3 5.2m. Elsewhere, e.g., 59 m D.H. #3, the dark bands in the argillite are a medium dark bluish grey color 4 B 5/1.

Calcareous Greyacke:

The greywacke is a poorly foliated rock. It consists of angular grains of quartz, chert or quartzite, muscovite, chlorite and plagioclase feldspar in a matrix of calcite, chlorite and illite. A typical section of greywacke is shown in Figure 4. The quartz grains vary from 30 to 200 μm in diameter. There is considerable brown staining due to hydrocarbons. The weak foliation is imparted by sub-parallel alignment of muscovite and chlorite flakes in the rock.

There is typically not much difference in color between the greywacke and the argillite. At the 16 m level in D.H. #3, the greywacke is a medium greenish grey 5 GY 5/1. While at the 59 m level in the same hole, it is a medium dark bluish grey 4 B 5/1.

Quartz veins:

Coarsely crystalline veins of white, milky quartz were observed in several holes. The individual crystals are of the order of centimeters. Some crystals show polygonalization indicating that they had been subjected to stress. A quartz vein occurs in D.H. #3 at 37 m. It contains large, angular pieces of hard hydrocarbon material (Figure 5). The largest pieces of hydrocarbon are up to 2 cm long.

In the sections examined, calcite veinlets seemed to be less common in the greywacke than in the argillite. This is probably due to the more competent nature of the former.

Foliation and folding:

The foliation and layering are, for the most part, more or less vertical. The exception is at the bottom of D.H. #2 where the foliation in the argillite is sub horizontal. The rocks must have been folded for the foliation and layering to be vertical. Stress within the rocks is also indicated by small faults which cut some of the calcite veins. For example in D.H. #1 at the 61 m level, a small calcite vein is offset by 6 mm by a small fault.

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1. Rock Color Chart, Geological Soc. Am. (1963).

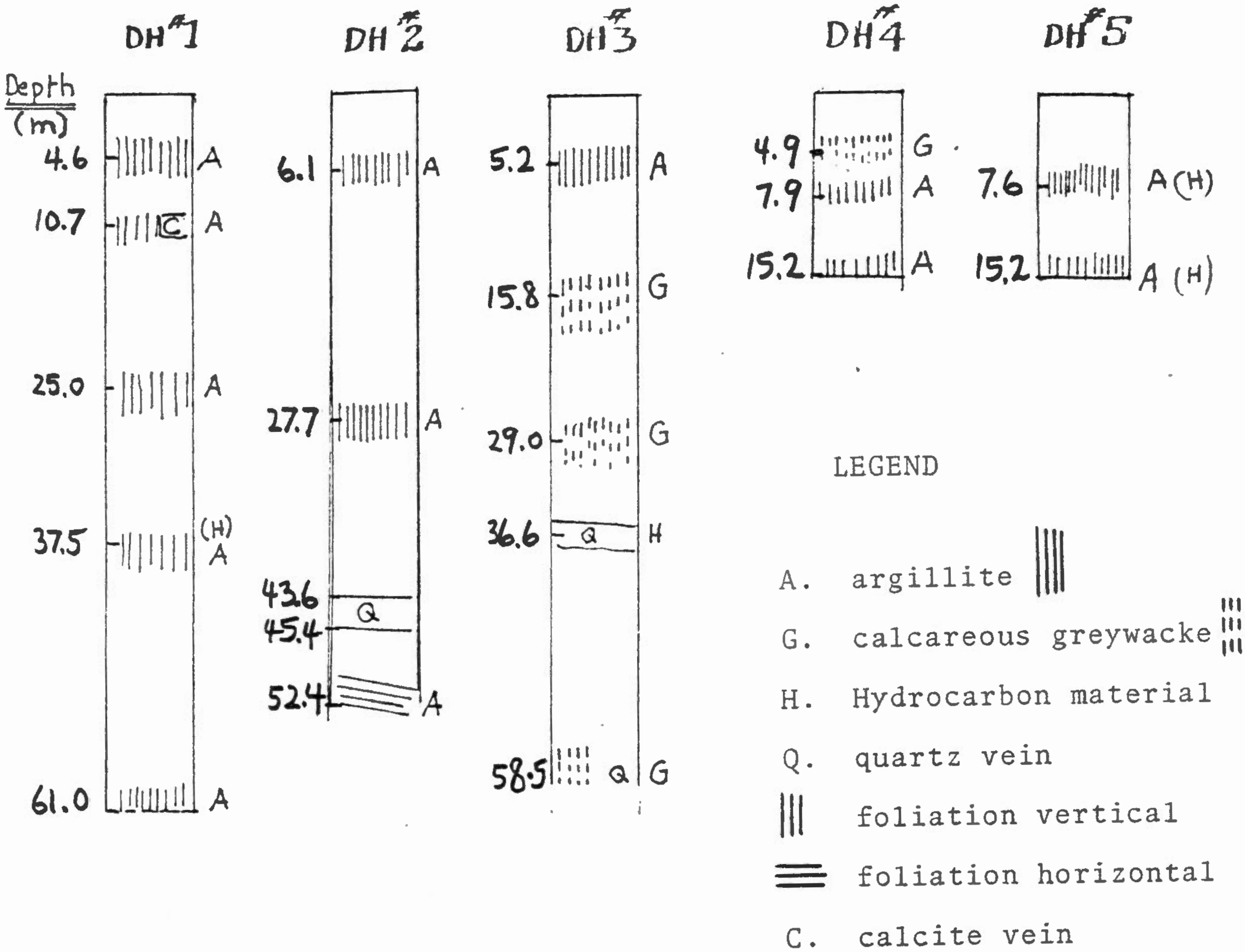

Figure 1. Schematic diagram showing the distribution of rock types in the drillholes. The orientation of the layering and foliation is also indicated, as is the presence of calcite and quartz veins and hydrocarbon.

Figure 2.
Low magnification photograph of argillite showing dark and light layers.

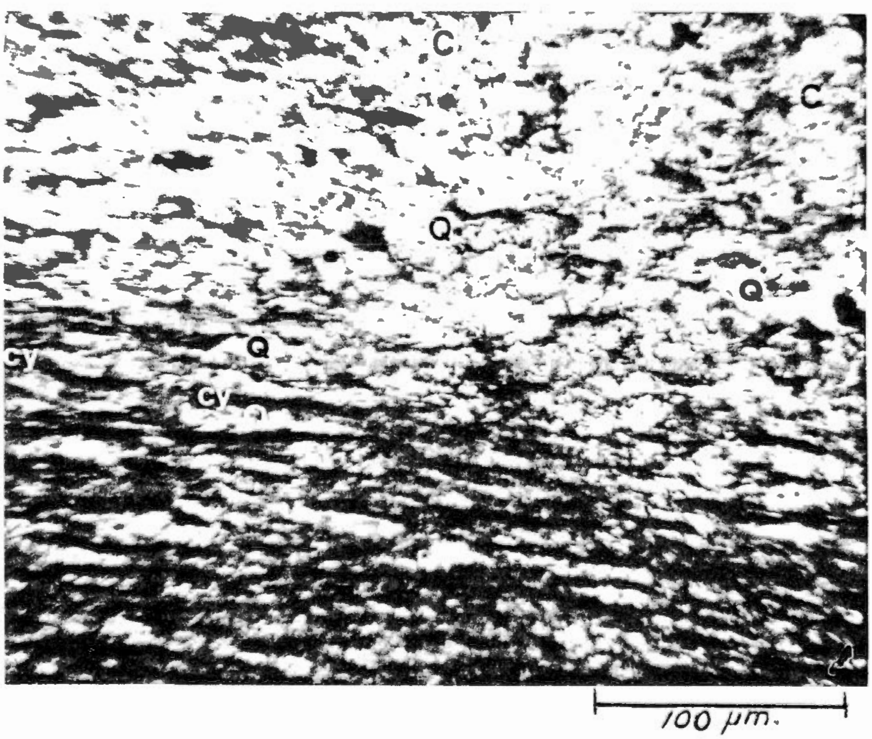

Figure 3.
Optical micrograph showing coarse and fine (light and dark) layers in argillite.

Q. quartz
C. calcite
CY. clays

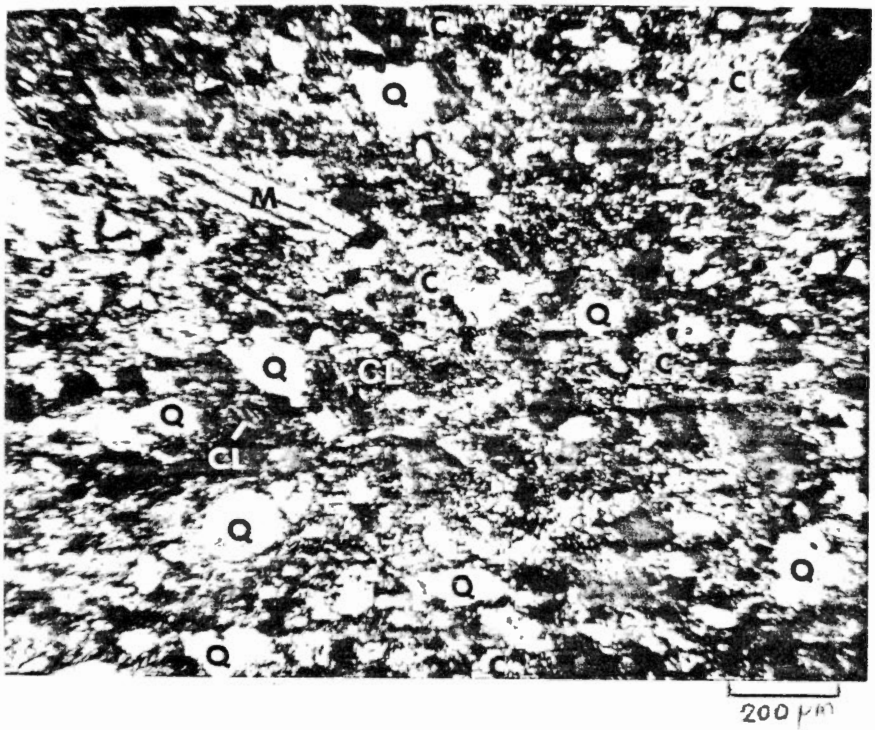

Figure 4.

Optical micrograph of calcareous greywacke

Q. quartz

M. muscovite

C. calcite

CL. chlorite

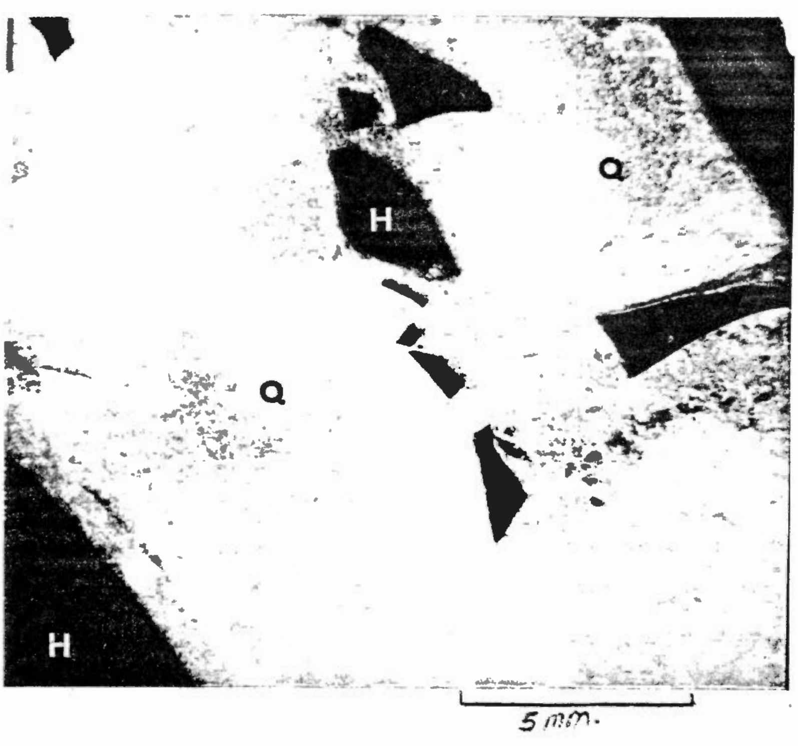

Figure 5.

Quartz vein with solid hydrocarbons.

Q. quartz

H. hydrocarbon

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