Mem. Natl Inst. Polar Res., Spec. Issue, **56**, 264–274, 2002

The EPICA borehole logger

Eric Lefebvre, Laurent Augustin and Marcel Maitre

LGGE, 54 rue Moli re, BP 96, 38402 St.Martin d'H res Cedex, France
(lefebvre@glaciog.ujfgrenoble.fr) (augustin@glaciog.ujf-grenoble.fr)
(maitre@glaciog.ujf-grenoble.fr)

Abstract: The EPICA borehole logger has been developed in order to measure the characteristics of the borehole. The accuracy of the measurement allows the exploitation of data for scientific purposes. Developed on the mechanical basis of the Danish logging tool, completely new electronic equipment has been designed in order to measure diameter, pressure, temperature, inclination and azimuth. To check the good functioning of the embedded electronic equipment, additional parameters are transmitted: input voltage, input current, ADC temperature, pressure and power supply. A microcontroller supervises all data acquisition and transmission to the surface through the modem at every second. The logger uses a single conductor coaxial cable to supply DC power and transmit data. The surface computer displays and stores data and depth measurements. Two pantographs are used both to center the logger in the borehole and to measure hole diameter. For EPICA application, the drill is removed from the cable and the logger is connected to the anti-torque section and operated with the cable and EPICA winch. Complete records of the hole geometry and characteristics have been obtained successfully, at Dome C in the 1998/1999 and 2000/2001 seasons.

1. Introduction

The first goal of the logger is to facilitate the drilling by measuring essential parameters giving information about the geometry of the hole. The logger also records physical data for scientific programs. The logging of the hole take place before and after each drilling season. For EPICA program at Dome C and as long as the drilling activity continues on, the logger is attached under the anti-torque section of the drill. This has the advantage of using the same cable and winch that are used for the EPICA program. Except for the compass, all the electronic equipment was developed with military components, which allow operation to $-55°C$.

2. Mechanic

The mechanism of the logger (Fig. 1) is inspired from the logger developed at the University of Copenhagen (UCPH) (Gundestrup *et al.*, 1994). The logger consists of a long tube, which contains the electronic equipment and can resist high pressure. This tube is a laminated stainless steel tube. The stainless steel type is 304 L. When 304 L is laminated it is less magnetic than when 304 L is drawn. Some tests were done with the

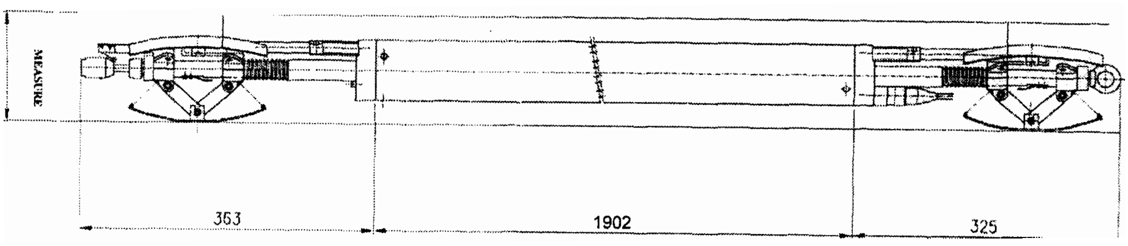

Fig. 1. General view of the logger.

compass inside a 304 L stainless steel tube sample and no deviation could be noticed. The KVH C100 compass can operate correctly with moderate magnetic interference. The compass has been placed inside the tube as far as possible from iron, steel, magnets, motors and other magnetic material. The minimum separation of 304.8 mm (12 inches), recommended by the manufacturer has been observed.

The total length of the logger is 2.59 m. The tube itself is 1.9 m long; the outer diameter is 80 mm and the inner diameter 65 mm. This tube withstands a pressure of 400 bars. Mounted on each end of this tube together with the plugs are two three-leg pantographs which centre the logger inside the borehole and measure the diameter. The distance between the two pantographs is 2.53 m. Different types of skates can be mounted on the pantographs. Two sets are available allowing a diameter measuring range of 73 mm to 145 mm for the first one and 100 mm to 162 mm for the second one.

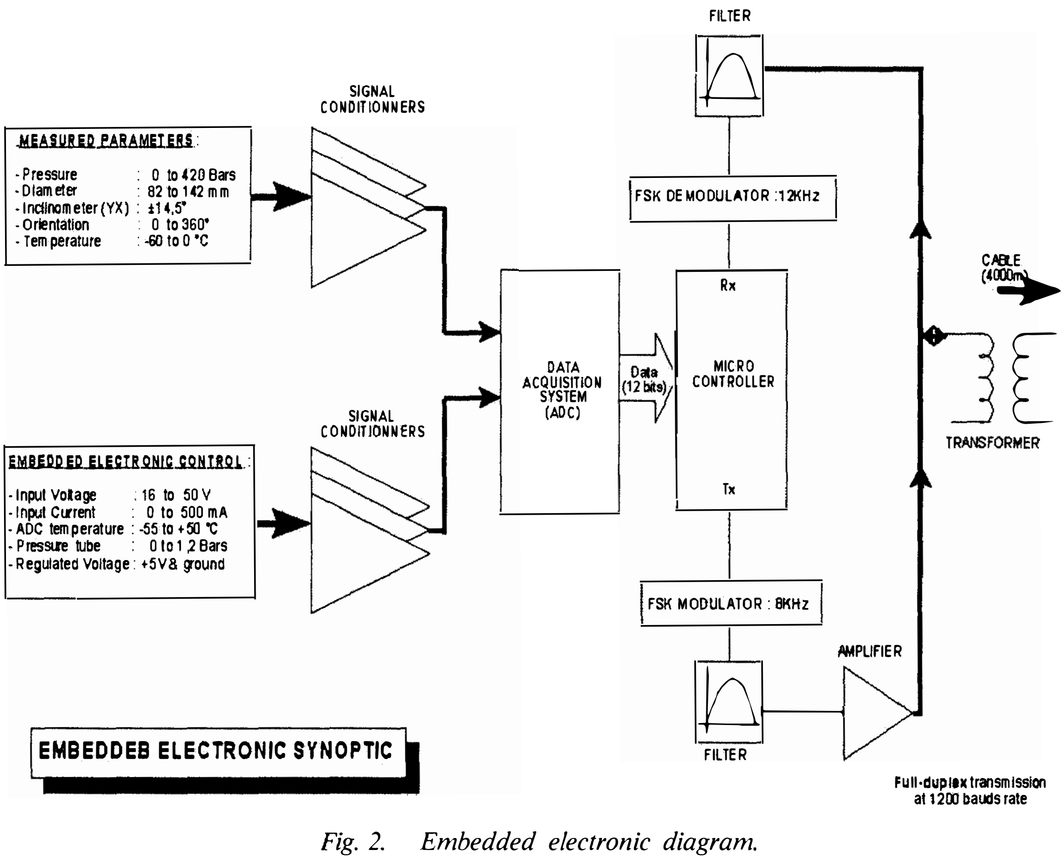

Fig. 2. Embedded electronic diagram.

3. Embedded electronic equipment

The embedded electronic equipment has three different sections: sensors and conditioners, microcontroller and data acquisition system, and data transmission (Fig. 2).

3.1. Sensors and conditioners

A Quartz pressure sensor, Paroscientifique type Digiquartz 46K-101, measures the absolute pressure in the hole. Its pressure range is 0 to 413.69 bars (0 to 6000 psi). Its operating temperature is $-54°C$ to $+125°C$. Remarkable performance is achieved through the use of a precision quartz crystal oscillator, whose oscillation frequency varies with pressure induced stress. A second quartz, whose resonant frequency is a function of temperature (45 ppm/°C), is used to correct the measured pressure and achieve high accuracy over a wide range of temperatures.

Microcontroller programmable timers and counters (PCA) were used to measure these two frequencies. In order to obtain good precision the microcontroller is cadenced by a temperature compensated crystal oscillator (TCXO): measured stability ± 2 ppm/°C

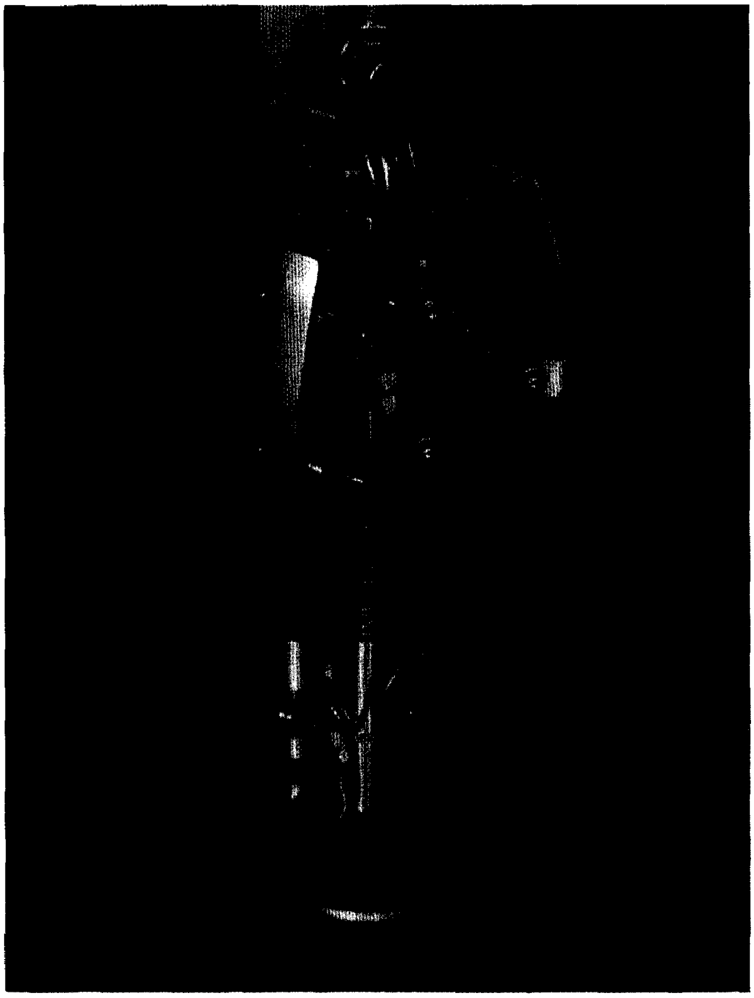

Fig. 3. Upper pantograph.

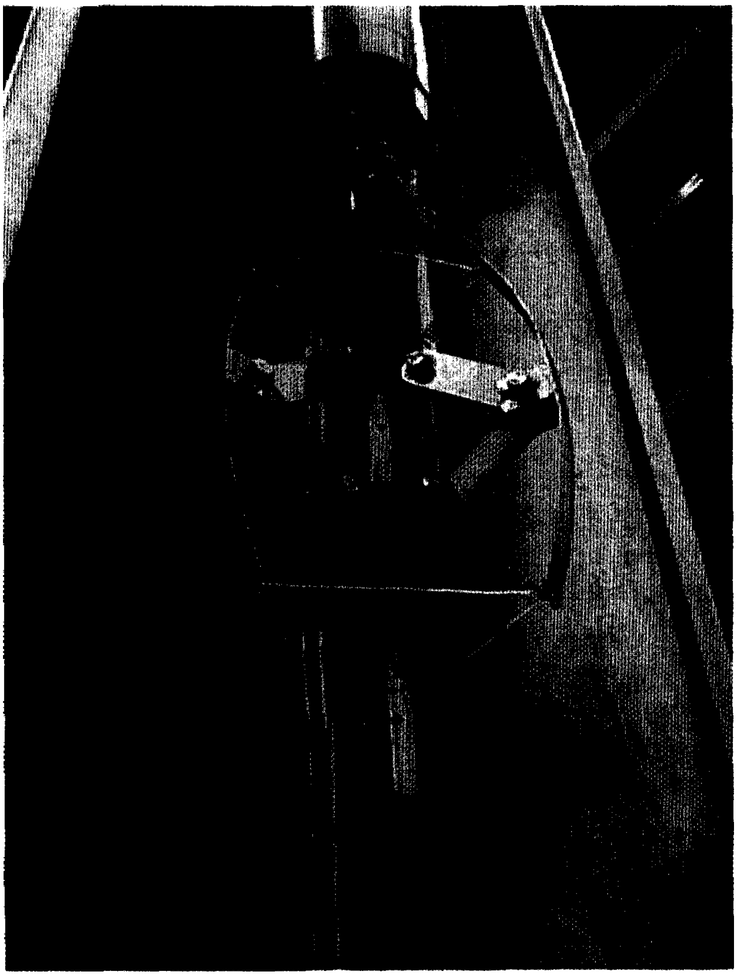

Fig. 4. *Lower pantograph.*

from $-55°C$ to $+55°C$ (± 5 ppm/°C given by the manufacturer). Integration time for a data measurement is three seconds. The system gives about 0.0015% resolution full scale.

Two hybrid linear potentiometers, Penny and Giles, located at the upper and lower ends of the pressure tube (Figs. 3 and 4) give the hole diameter. A precision voltage reference source with a very low temperature coefficient (max 1 ppm/°C) is used. The pantographs measure borehole diameter from 82 mm to 162 mm with a resolution of 0.02 mm.

A PT100 probe was used for temperature measurement. This probe is used in a bridge connection; the thermal drift of the voltage supply is 1 ppm/°C max. All parts of the measuring system are calibrated: sensor, conditioner and analog to digital converter. The resolution for the fluid temperature measurement in the hole was 0.015 K while the precision was 0.05 K.

Two Schaevitz LSRP-14.5 inclinometers gave the inclination of the hole. They were assembled in X/Y pairs and compensated in temperature to work from $-50°C$ to 0°C. The range for each inclinometer was $\pm 14.5°$ for a resolution of 0.007°.

The KVH C100 compass measured the hole orientation. It was a complete off the shelf unit, integrating a toroidal fluxgate sensing element detector controlled by a microprocessor. This sensor operated through tilt (pitch and roll) ranges of $\pm 16°$ without affecting of the measurement. The resolution for the all data acquisition chain was 0.4°. The accuracy of the compass was 0.5°. The combination of the inclination and orientation gave the geometry of the hole and by successive comparisons the deformation was calculated.

In addition, six other channels allowed control of the embedded electronic equipment. These parameters are: input voltage, cable current, A/D converter temperature, pressure inside the electronic compartment, logic +5 V supply and ground reference.

A dedicated DC/DC converter and isolated amplifiers were used for fully insulated measurement circuits for the voltage and the current in the cable.

3.2. Microcontroller and data acquisition system

A microcontroller is used to:

1) Drive the data acquisition system. After conditioning, the signals to be measured are transmitted to the acquisition system, which converts the analog signal into digital data. The 16 channels for the measure are sampled at every second. This gives 20 data per meter when the winching speed is 5 cm/s.
2) Measure pressure sensor frequencies with an integrating time of 3 seconds.
3) Supervise data transmission and command reception, sent from the surface.
4) Manage the commands and the alarms:

- A self-test can be required at any time. This self-test checks the good functioning of the A/D converter and the frequencies output from the pressure sensor. This self-test also gives the number of self reset by watchdog and the information on the total running time since the last switch on (Warm-up time).
- An automatic reset commanded from the surface.
- A watchdog circuit monitors the microcontroller's activity. If a default occurs, a reset is generated automatically, which creates a time out on the screen display.
- A switch at the lower part of the logger detects the bottom of the hole and an alarm is immediately sent to the surface.

3.3. Data transmission

The principle used for transmission was the same as that used in the thermal probe "Climatopique" and the thermal drill "Forage 4000 m" (Marec *et al*., 1998). The data were transmitted by frequency modulation (FSK modem). The modulator and demodulator used were identical. The main difference was some modification of the filter circuits. Two communication channels were used: One channel for data transmission from logger to surface and the second for command transmission from surface to logger as the transmission channels were fully independent and operated in full-duplex, so that there was no waiting time between data transmission and command words. Except for the pressure sensor, data were transmitted by package every second at 1200 baud. Pressure data were sent only every three seconds.

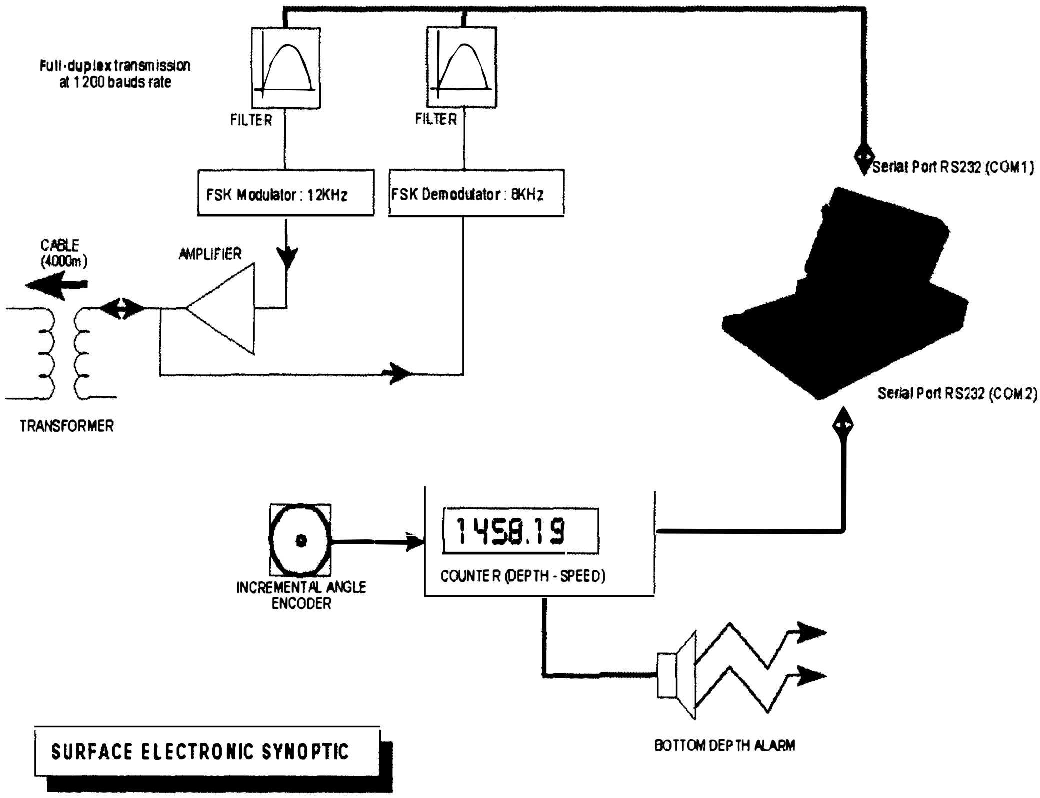

Fig. 5. *Surface electronic diagram.*

Fig. 6. *Surface rack, the PC and the logger in front.*

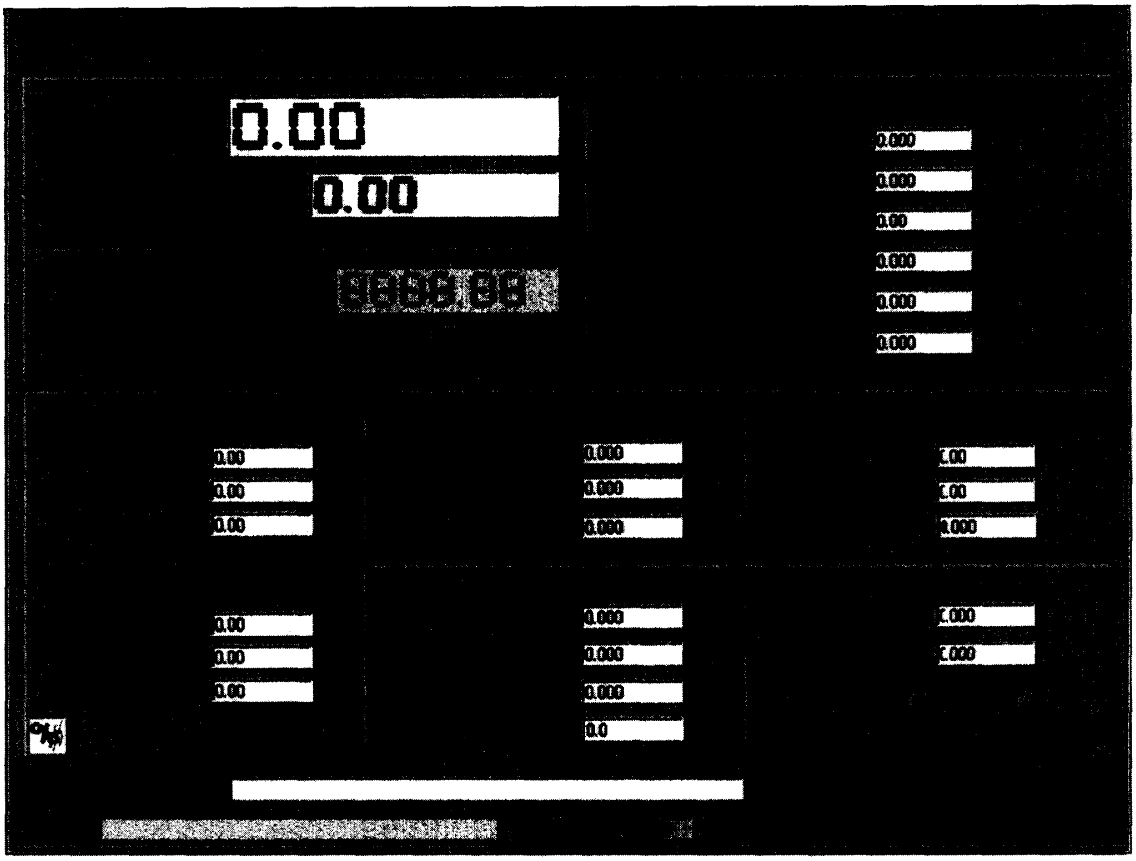

Fig. 7. Surface software window.

4. Surface electronic equipment

The surface electronic equipment consisted of (Figs. 5 and 6): A rack with the logger power supply (120 V-2.5 A), a modem board for data transmission and reception, a conditioner for measuring depth and speed and an audible alarm, active when the bottom of the hole was reached by the probe; and a laptop PC. After demodulation, the data transmitted were sent to the PC via an RS232 connection. Depth and winch speed were recorded simultaneously.

5. Surface software

The driving software was developed with labwindows (National Instruments). It configures the RS232 ports, communicates with the logger (data reception and commands transmission), reads the depth and winching speed, and sets the alarm depth.

Data are displayed in physical units (Fig. 7). A set of control data are displayed to monitor the logger. In acquisition mode all these data are recorded in different files.

6. Data

The logger was tested successfully in the season of 1998-1999 at Dome C. The hole

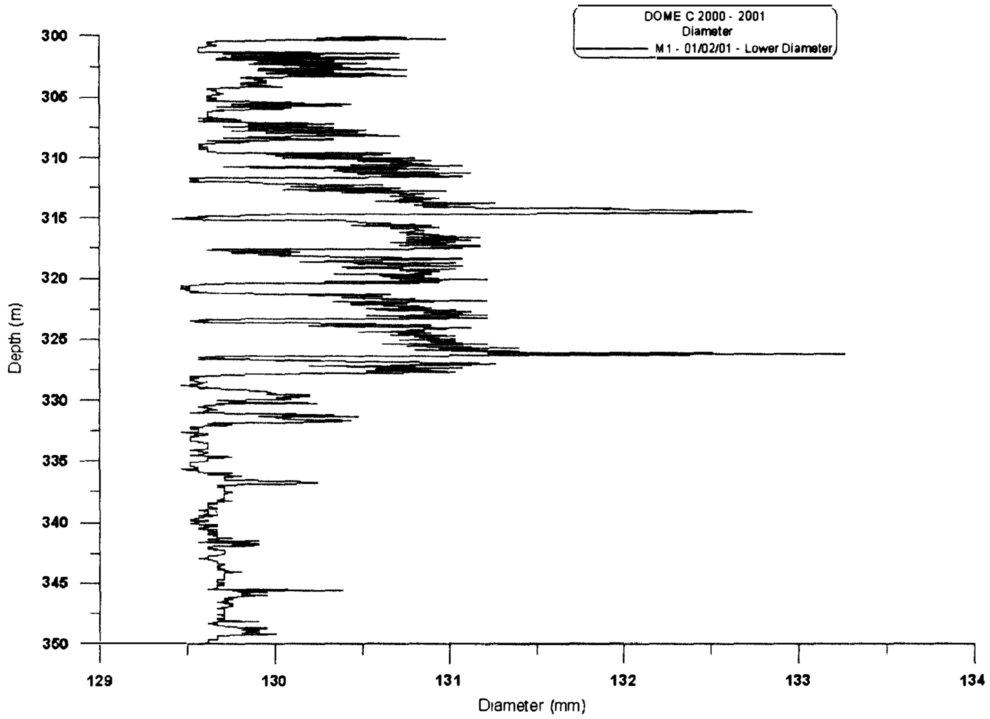

Fig. 8. *The average diameter measured at lower pantograph, in the Dome C second hole in 2001. Diameter detail is between 300 and 350 m, when the drilling was disturbed by mechanical problems.*

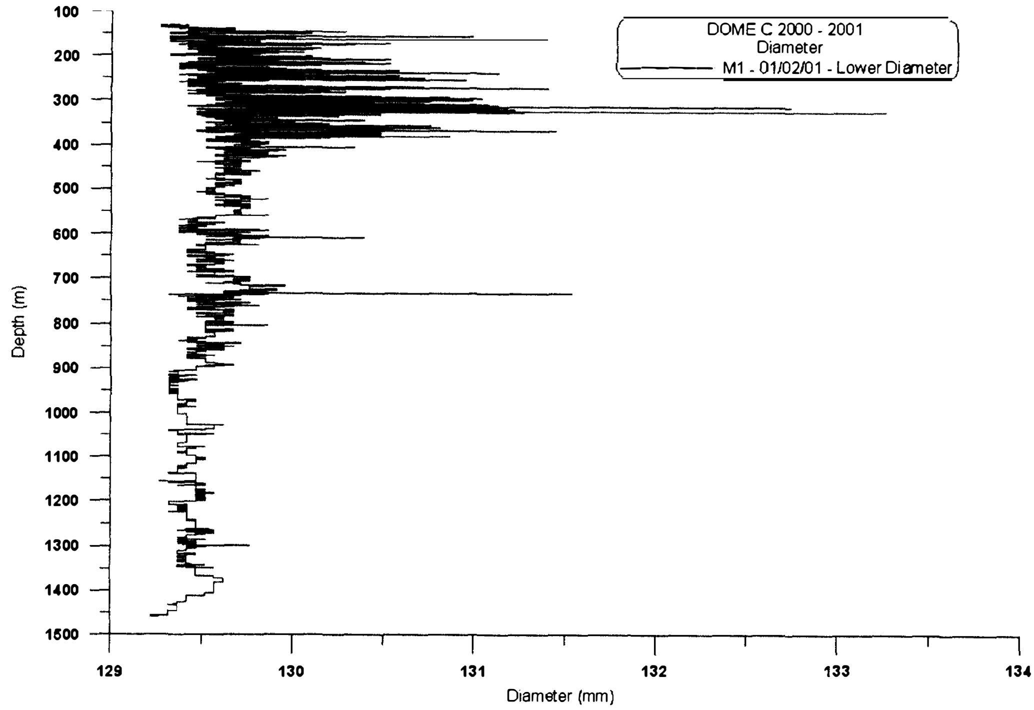

Fig. 9. *The average diameter measured at lower pantograph of a borehole logger, in the Dome C second hole in 2001. The record of the measurements starts below the casing. We noticed many accidents at the beginning of the hole due to the mechanical problems. The second part shows a correct drilling operation.*

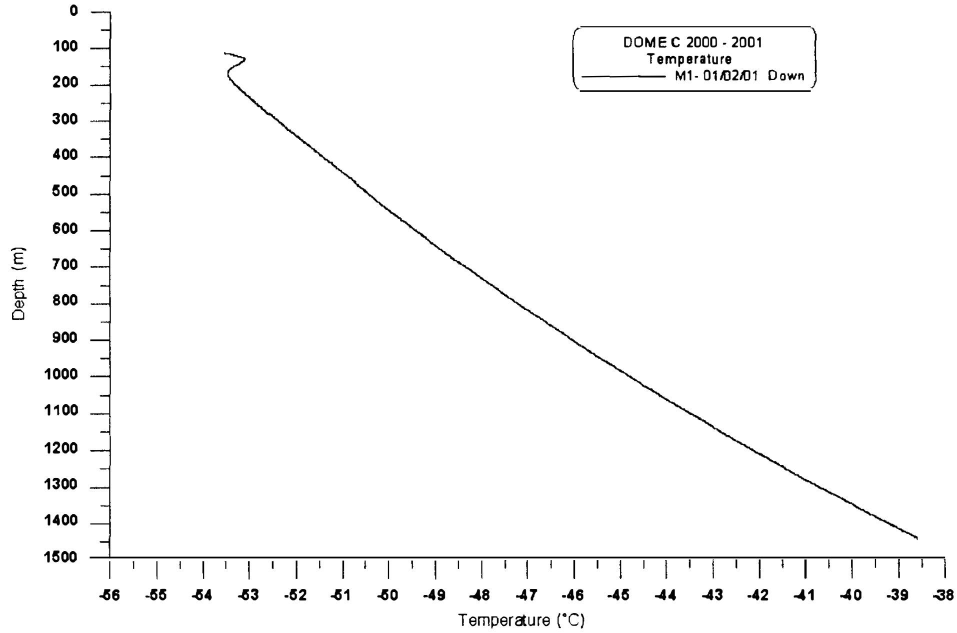

Fig. 10. Temperatures measured in the Dome C second hole in 2001.

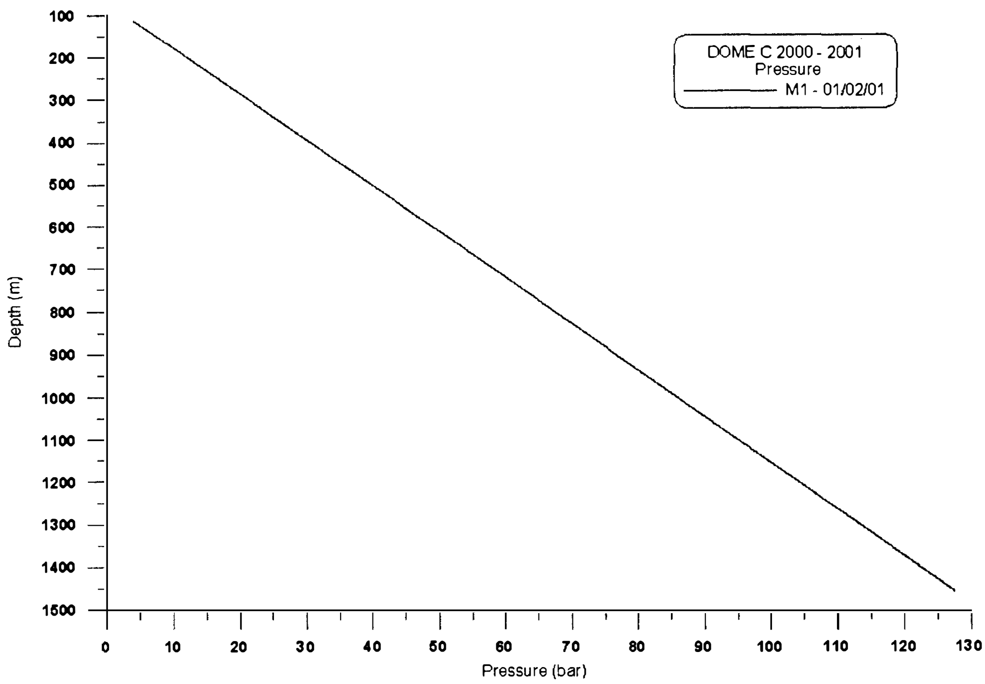

Fig. 11. Hole pressure measured in the Dome C second hole in 2001.

depth was 357 m (Fig. 8). Measurements were made after the filtering of chips in the hole. For this reason there are a few disturbances in the temperature measurement. The logger was used a second time to check the second hole of EPICA Dome C after the 2000-2001 season. Measurements were made at the end of the season. The depth of the hole was

1458 m (Figs. 9, 10 and 11). The logging was done just after the drilling, so temperature measurements are disturbed.

A special procedure was used to use the logger to best advantage. After assembly the logger was hung at 25 m depth in the casing and did not touch the walls. The temperature at Dome C, was −53°C. The electronic equipment was switched on 12 hours before measurement. After the 12 hours the inclinometer was reset before the logger was raised to the surface for calibration of the pantographs. A series of cylindrical callipers was used to establish a reference curve. Those seven cylindrical callipers, one at the nominal diameter, three with a dimension below the nominal diameter and three with a dimension over the nominal diameter, were made from stainless steel and machined with an accuracy of one hundredth of a millimetre. For the calibration they were all placed in the same position with a fixed reference tool.

7. Conclusions

During the first measurements taken in 1998, we noticed that the measurements of the diameter and the inclination were disturbed by excessive winching speed (30 to 10 cm/s). In 2001 we reduced the speed to 5 cm/s, which increased considerably the time of passage of the logger in the hole, but on the other hand gave far better results.

Tests of response time of the temperature sensor were also performed: the logger was stopped at different depths for 10 min. We noticed a negligible variation of the temperature. The probe was perfectly adapted to continuous measurements, with low winching speeds.

The overall operation of the logger was very satisfactory; accuracy of data was very good. Measurements of the next campaigns will be able to give information on the behaviour of the hole.

The accuracy of the temperature measurements is not sufficient to detect variations of surface temperature in the past. A measurement of high precision is required: 0.01 K with a resolution of 0.001 K. This type of measurement is very difficult to obtain with embedded electronic circuits. Currently the laboratory is studying a temperature sensor capable of such performance (Clow *et al*., 1996).

Acknowledgments

This work is a contribution to the EPICA program, which involves 10 European countries with the support of ENEA and IFRTP for the logistics. We would like to express our thanks to Guy Marec of Centre National de la Recherche Scientifique, Grenoble for his strong advice and recommendations and for solving some of the specific difficulties this kind of technology produces. We would like to thank Paul Journ who was in our institution at the very beginning of the project and was able to find the founding for this realization.

References

Clow, G.D., Saltus, R.W. and Waddington, E.D. (1996): A new high-precision borehole-temperature logging system used at GISP2, Greenland, and Taylor Dome, Antarctica. J. Glaciol., **42**, 576-584.

Gundestrup, N.S., Clausen, H.B. and Hansen, B.L. (1994): The UCPH borehole logger. Mem. Natl Inst. Polar Res., Spec. Issue, **49**, 224-233.

Hansen, B.L. and Kelty, J.R. (1994): A new short borehole logging tool. Mem. Natl Inst. Polar Res., Spec. Issue, **49**, 218-223.

Marec, G., Maitre, M., Pinglot, F. and Lefebvre, E. (1998): Telemetering and remote control circuits for 4000 m thermal drill. Proceedings of the third International Workshop on Ice Drilling Technology, Grenoble, October 1988, ed. by Rado. 72-85.

(Received July 1, 2001; Revised manuscript accepted August 29, 2001)