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INSTRUMENTS AND METHODS

MEASUREMENT OF ICE MOVEMENT IN SUBGLACIAL CAVITIES: A NEW CAVITOMETER BENEATH THE GLACIER D'ARGENTIÈRE (MT BLANC, FRANCE)

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Abstract. The study of subglacial movements taking place in regions of cavitation beneath the Glacier d'Argentière, has demonstrated the necessity for using several cavitometers. The very unusual conditions in which such apparatus is installed to measure simultaneously the velocity and the position of the ice vault have led us to design and produce a prototype of a portable cavitometer which records the data on magnetic tape (cassettes).

Résumé. *Mesures des mouvements dans les cavités sous-glaciaires: un nouveau cavitomètre sous le Glacier d'Argentière (Mt-Blanc, France).* L'étude des mouvements sous-glaciaires à partir des zones de cavitation du Glacier d'Argentière, a montré la nécessité d'utiliser plusieurs cavitomètres. Les conditions très particulières dans lesquelles sont installés ces appareils qui mesurent simultanément les vitesses et les positions de la voûte de glace, ont conduit à concevoir et à réaliser un prototype de cavitomètre portable, enregistrant les données sur bandes magnétiques (cassettes).

Zusammenfassung. *Messung der Eisbewegung in subglazialen Hohlräumen: ein neues Cavitometer unter dem Glacier d'Argentière (Mt Blanc, Frankreich).* Die Untersuchung der subglazialen Bewegung in hohlraumdurchsetzten Bereichen unter dem Glacier d'Argentière hat die Notwendigkeit des Einsatzes verschiedener Cavitometer erwiesen. Die sehr ungewöhnlichen Bedingungen, unter denen ein solches Gerät zur gleichzeitigen Messung der Geschwindigkeit und der Lage des Eisgewölbes installiert ist, führten zur Konstruktion und Bau eines Prototyps für ein tragbares Cavitometer mit Magnetbandaufzeichnung (Kassetten) für die Messdaten.

Introduction

Under the Glacier d'Argentière, the water-collection tunnels constructed by Emosson S.A. beneath the Lognon ice fall (2 180 m a.s.l.) have allowed access to several natural and permanent subglacial cavities which correspond to regions where the glacier no longer maintains contact with the bedrock (Vivian 1971[a], [b]; Vivian and Bocquet, 1973). These separations are very interesting locations, but special apparatus has to be envisaged to study them. The cavitometer is one such apparatus: it measures simultaneously the glacier velocity and the height variation of the separation.

A cavitometer was installed inside the first cavity to be discovered (christened S6) in 1970. But this large prototype was fixed, practically sealed, to the rock. Since that date, the reconnaissance work on the subglacial topography undertaken by Emosson S.A. has allowed access to further cavities.

In addition, movement studies conducted inside S6 and inside other separations, have shown that the velocities and deformations are far from being uniform and vary from place to place. Also it seemed desirable, if not essential, to install further cavitometers to study in detail the various component movements which occur at the base of the glacier and whose resultant is the general movement.

With the collaboration of J. L. Mermier we have developed a second type of apparatus which satisfies two complementary conditions: to be portable and to be self-contained as regards its supply of electricity.

1. Principle

The principle on which the cavitometer is based is shown diagrammatically in Figure 1. It was designed in order to utilize a data-recording system on magnetic tape. The velocity is measured using two types of acoustic signals, the first corresponding to the distance travelled,

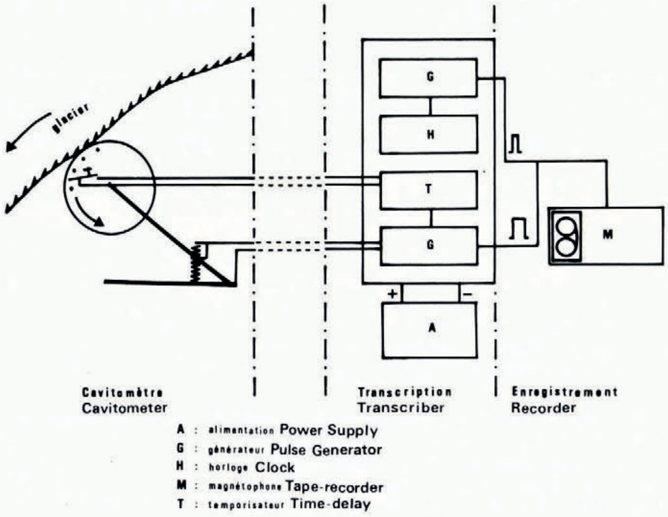

Fig. 1. Principle of the cavitometer.

the second measuring known time intervals. The height variations of the ice vault above the bedrock are recorded based on the distance signals whose intensity is made to be a function of this height.

A *clock* (cyclic minute-wheel) sends, at regular and settable intervals, impulses lasting a short time (from one to two seconds) to a magnetic tape-recorder which records a signal of constant height and width.

A *contactor*, activated by contact points regularly spaced around a studded wheel pressed against the glacier, initiates the recording of further signals, of greater length to assist in their subsequent identification, which indicate the distance transversed by the glacier (Fig. 2a).

A rotating potentiometer measures the angle subtended between the cavitometer support, fixed to the rock, and the movable arm which carries the wheel in contact with the ice. The height of this latter signal, determined by the potentiometer, is proportional to this angle and thus measures the position of the ice vault above the rock.

The cassette containing the recorded signals is subsequently read and the signals transferred to a chart by a laboratory potentiometer (see Fig. 3 below). To interpret this it is only necessary to count the number of time signals between two distance signals to obtain the mean velocity. The vertical variations in vault height are obtained by comparing the height of the distance signals with a calibration curve established when the cavitometer was installed. The tape-recorder only needs to operate for a few seconds at the time of emission of signals, so that a 45 min cassette allows a measurement over a period as long as three weeks to a month depending on the part of the glacier under study.

2. TECHNICAL ASPECTS

2.1 *The mechanical part*

This part was constructed by J. L. Mermier and is installed beneath the glacier in three sections (Fig. 2a): (i) A Y-shaped metallic support fixed to the rock by bolts or rapid-hardening cement. (ii) A 200 mm arm, which can have added a 400 mm extension, is articulated on the support Y and activates the rotating potentiometer. It ends in a fork which contains the third element. (iii) A studded wheel, 330 mm in diameter, kept in contact with

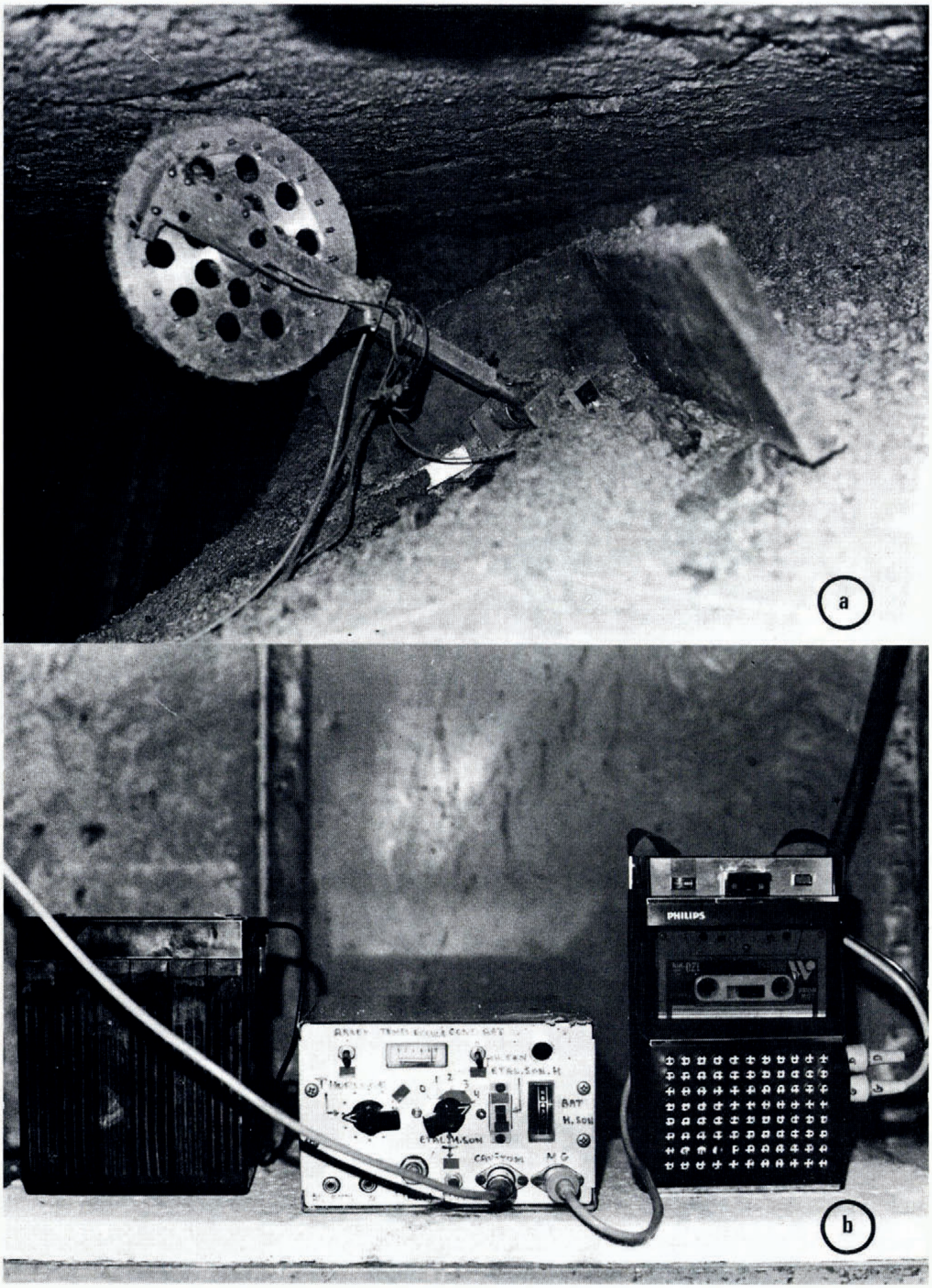

Fig. 2. The cavitometer in position (photographs by J. C. Ricq). (a) mechanical part, (b) the transcription and recording apparatus.

the ice by a spring acting on the articulated arm. The wheel carries on one of its faces 22 cylindrical studs regularly spaced. These release as they pass an ILS contacter which initiates the emission of the distance signals. Thus between the passing of two successive studs, the distance moved by the glacier is $d = (330\pi/22)$ mm. The whole assembly constructed of an aluminium alloy (ISO standard AU4G), weighs from 6 to 7 kg according to the length of arm used, and is easily installed.

2.2 *The transcription and recording part*

This part was constructed by J. C. Ricq and consists essentially of four pieces (Fig. 2b): (i) A clock which is a standard kind of cyclical minute-wheel. (ii) A transistorized electronic module consisting of a time-delay reacting to the passing of a stud, and two acoustic generators, one commanded by the clock, the other by the time-delay. A calibration circuit was planned for the potentiometer to calibrate the heights. It also serves to eliminate errors due to variations in voltage of the electric power sources (battery and tape-recorder cells). (iii) A portable

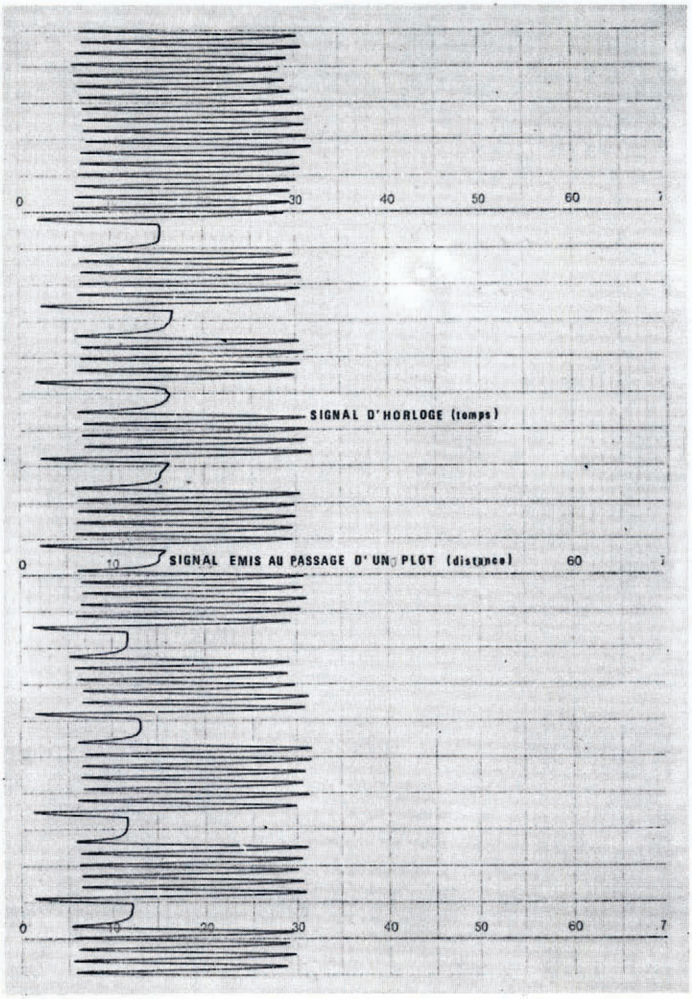

Fig. 3. Chart obtained after reading the magnetic tape using the potentiometric chart recorder (photograph by G. Bocquet).

cassette tape-recorder, of a usual variety, operating with its own dry cells, but provided with manual controls of the modulation level to allow proper differentiation of the signal heights. (iv) 12 V, 14 A h accumulators of the kind used on a motor-cycle, hence not very bulky. The continuous power consumption is of the order of a few milliamperes, changing to 30 or 40 mA during recording.

This compact assembly is easily arranged in a water-tight enclosure; it is inexpensive, since most of its constituents are units currently sold commercially.

2.3 *Cavitometer behaviour*

The apparatus (Fig. 2) operates under difficult conditions: temperature near to 0°C, 100% humidity, with running water, and falls of stones and mud being among the possible causes of deterioration of the mechanisms. Our first attempts forced us to make certain improvements, above all in connection with reinforcing its protection: use of an ILS relay instead of a mechanical contactor, adding catches, encapsulating conductors in synthetic resins, reduction of the humidity in the recorder section by electric heating or by a chemical process (using silica gel). After these modifications the performance of the apparatus was satisfactory.

3. Discussion of results

The chart obtained after reading the magnetic tape is of the kind shown in Figure 3. To find the velocity, let n be the number of signals corresponding to the passing of studs, d the distance between consecutive studs, N the number of time signals recorded between the passage of the first and last studs, and T the time between two consecutive time signals. The distance traversed is thus $(n-1)\ d$.

According to whether at the two ends of the part of the record studied the stud signals are very close (Fig. 4A) or very far (Fig. 4B) from the clock signals being considered, the time could be either slightly longer than $(N-1)\ T$ or slightly shorter than $(N-1+2)\ T = (N+1)\ T$. The limits on the velocity V are thus

$$\frac{(n-1)\ d}{(N+1)\ T} < V < \frac{(n-1)\ d}{(N-1)\ T}.$$

The uncertainty is therefore the larger the smaller the value of N, the limiting cases being reached for $N = 0$ and $N = 1$.

If $N = 1$ (Fig. 4C), the upper limit for the velocity is therefore defined by a time interval corresponding to the sum $t_c + t_s$ where t_c and t_s are the lengths of a clock signal and a stud signal respectively, whereas the lower limit is calculated using $2T$. Thus

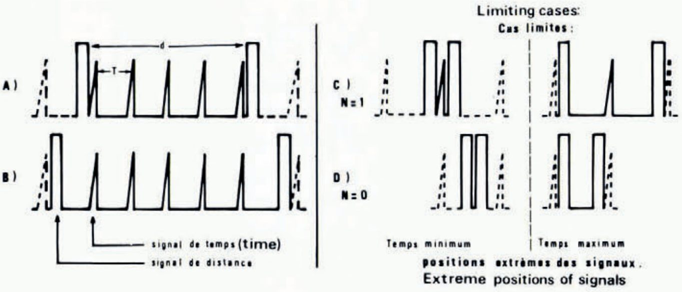

Fig. 4. Interpretation of the records.

$$\frac{(n-1)\,d}{2T} < V < \frac{(n-1)\,d}{t_c+t_s}.$$

If $N = 0$ (Fig. 4D) the minimum time is not negative, but is equal to $2t_s$, the time needed to record the two stud signals, and the maximum time cannot exceed T, so

$$\frac{(n-1)\,d}{T} < V < \frac{(n-1)\,d}{2t_s}.$$

In fact, these extreme situations never have to be taken into consideration, to the extent that we are usually measuring mean daily velocities. In this case N is large (above 70) and the uncertainty in the velocity becomes very small.

From the practical point of view, the mean value (NT) of the time permits measurement of velocity to an allowable approximation (±0.03 cm/h for a mean velocity of 2.3 cm/h over 24 h), whereas, under this capricious glacier, velocity variations are generally much more interesting and significant for the study of movement than the absolute velocities themselves.

CONCLUSION

Undoubtedly the system presented here is capable of many modifications in detail, but it is already operational, and, at the time of these trials, comparison of the results obtained with those of the first cavitometer have been very satisfactory. This new apparatus is therefore now being added to those already operating beneath the Glacier d'Argentière to allow better understanding of subglacial phenomena.

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