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SACLANT ASW
RESEARCH CENTRE

PRINCIPLES AND METHODS OF CORE ANALYSIS AT THE SACLANT ASW RESEARCH CENTRE

by

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ABSTRACT

The methods and accuracy of measuring core parameters at the SACLANTCEN are described. Those for measuring sound velocity and electrical resistivity are explained in detail.

INTRODUCTION

Acousticians already have access to a great deal of literature on the properties of the sea bottom and their influence on submarine sound propagation. It is an admitted fact that, from all the physical parameters of the bottom so far studied, some are recognizably more important than others for a study of sound propagation.

This "limiting philosophy" seems to be in contradiction with the traditional scope of geologists and mineralogists, who often state that the complete and thorough study of one sample can throw light upon the understanding of a large area.

For our part, we have adopted the limited study of a rather large number of samples from one or two acoustic model zones, with the intention of later correlating these results with some acoustical or physical measurements made "in situ".

Because of limited technical means and personnel, the bottom-studies programme being carried out at the Centre does not pretend to be complete. It is merely an attempt to understand bottom-reverberation problems in the most practical way in the light of experience gained from past and present experiments in the field.

The following parameters are at present being measured:

a. Wet or unit weight.
b. Water content.
c. Porosity.
d. Void ratio.
e. Density of solid particles.
f. Grain size.
g. Geological and mineralogical constituents.
h. Longitudinal sound velocity.
i. Electrical resistivity.

Details of the measuring processes and the accuracy obtained are given in Ch. 2.

In the future it might appear that there are other more important parameters that should be measured, or that some of the parameters at present being measured are of less value than was originally thought. In any case, one of the practical objects has been to devise means whereby a large number of measurements can be made by semi-skilled personnel. This has permitted the analysis of a greater number of separate samples than would otherwise have been possible, and is thus appropriate to the author's general philosphy. The design and procedure of the work-bench used are described in Ch. 1. No actual results are presented in this report, but these will be the subject of future communications.

1. METHOD AND CHRONOLOGY OF THE ANALYSIS

1.1 General

The method to be described has been designed specifically for the analysis of cores obtained with the 120 m SACLANTCEN Sphincter Corer, which has been described in full in Ref. 1. The principal characteristics of this corer are:

a. The core is secured in a sealed plastic liner by the action of a diaphragm core catcher.

b. The piston is deactivated during the withdrawal and hoisting of the corer.

c. The sampling characteristics of the corer are close to Hvorslev's (Ref. 2) recommendations.

Most of the deep-sea cores so far obtained have been 7 to 11 m long, but this can be increased by adding more weight to the corer. Each core — still contained in the corer's plastic liner — is cut into 70 cm lengths, this being a length that is easy for a single man to handle and that is convenient for the analysis bench. Each 70 cm long section is then sealed with rubber caps and left in a constant-temperature room to stabilize its temperature. It has been found that 30 hours are necessary to bring the core from 14° to 27°C. The temperature variation within the core is exponential with time, with a time constant of 6 hours.

1.2 Analysis Bench

An analysis bench has been designed to expedite the different analyses made and to permit much of the work to be carried out by the laboratory technicians. A general view of this bench is given in Fig. 1; its principal components are:

(a) A hand-operated lift that allows the height of the core section (the white cylinder in the figure) to be moved vertically in relation to the guide frame and the work table.

(b) A guide frame that steadies the drill and hand-corer used for sampling different levels of the core section.

(c) A sound-velocity probe assembly that rotates around a fixed axis and positions itself opposite the sampling holes drilled through the liner.

(d) A 7-mm diameter resistivity probe for vertical sampling of the core section. This is connected to the lift (a) and is made to penetrate the core section — which is clamped alongside the lift — by moving the lift downwards.

(e) A synchronized helical potentiometer used for measuring the vertical movement of the lift when using the resistivity probe (d).

(f) An X-Y plotter to which are connected the resistivity probe (d) and the potentiometer (e); it thereby plots resistivity as a function of the probe's penetration into the core section.

1.3 Chronological Procedure

1.3.1 Electrical resistivity measurement along the core

This uses the thin resistivity probe described in (d) of Sect. 1.2 and shown in Fig. 2. Its principle of measurement is identical with that of the probe used for analyzing individual samples; details are provided in App. B.

The core section is mounted on a support alongside the lift and the lift is cranked downwards so that the probe penetrates the sediments. The X-Y plotter, which is linked to both the probe and the lift, then records electrical resistivity as a function of the depth within the sediment.

This analysis determines — with surprising definition — the changes of porosity within the core. It is carried out before the other analyses so as to give a guide to the most interesting levels to be studied.

1.3.2 Opening holes in the surrounding plastic liner

So that the acoustic probes can be placed in contact with the sediments, two 15 mm holes must be bored through opposite sides of the plastic liner. In addition, another hole must be made in the liner at right angles to the first two so that a small core sample can be taken.

The 70 cm core section is placed on the hand-operated lift (a in Fig. 1), and raised so that the required level of the core is opposite the guide frame (b on Fig. 1). A drill is then positioned on each of the three guides in turn and the holes cut (Fig. 3a & b). When the sound velocity measurements have been made and a small core taken (see Sects. 1.3.3 and 1.3.4 below) at this level, the lift is raised until the next required level is opposite the guide frame, and the process if repeated.

1.3.3 Sound Velocity measurement, at a given level

The rotating arm of the sound-velocity probe assembly (c in Fig. 1) is swung forward and automatically positions the two probes opposite the prepared holes (Fig. 4). The assembly is slid sideways so that the fixed, left-hand probe is in contact with the sediment; the adjustable right-hand probe is then moved up towards the opposite face of the sediment by a precise locking system that automatically positions it at a distance of 85 ± 0.01 mm from the left-hand probe.

Sound velocity measurements are then made and read on a digital counter. Full details of this equipment are given in App. A.

Each time that a sound velocity measurement is made, a corresponding measurement of the temperature at that level is made with a thermistor probe passed through the same holes in the liner.

1.3.4 Secondary coring, at a given level

This is, in effect, a coring of the core perpendicular to its main axis and is made – for each level level investigated – through the third hole bored in the liner; it is therefore at right angles to the direction of sound velocity measurements. A small corer is mounted on the guide frame (b) of Fig. 1 and forced into the sediments by hand (Fig. 5). On extraction it carries with it a 120 mm long, 14 mm diameter lateral core, the central 7.5 cm^3 of which provides the subject of all the succeeding analyses.

1.3.5 Electrical resistivity measurement across the core

Resistivity along the length of the main core was measured as described in Sec. 1.3.1. Its measurement across the core at each level is made along the central section of the small lateral core just taken.

For this purpose the lateral core is fed from the corer into a 120 mm, 14 mm-bore resistivity cell fitted with two pairs of electrodes: one pair – through which a constant current is sent – comprising electrodes spaced at 50 mm from the centre, and the other pair – across which the voltage is measured – comprising electrodes spaced at 15 mm from the centre (Fig. 6). Thus the resistivity is measured along the central 7.5 cm^3 (about 50 mm long) that will later be analyzed for water content, porosity, density, etc. The measurement process is explained in full in App. B.

The temperature of the sample is recorded after each resistivity measurement.

1.3.6 Extraction of the central 7.5 cm^3 of the lateral core

The central 7.5 cm^3 of the lateral core is bottled for the later analyses. This is easily and rapidly accomplished by means of a plunger extractor fitted with two pre-set stops. The core is pushed out of the resistivity cell as far as the first stop will allow; this length (approx. 35 mm) is then cut off and thrown away (Fig. 7a). The core is again pushed out, as far as the second stop will allow; this length (approx. 50 mm) is the required central 7.5 cm^3 and is fed directly into a sample bottle (Fig. 7b). The remaining length of core (approx. 35 mm) is pushed out of the resistivity cell and thrown away.

1.3.7 Weight and Volume measurements

The following weights and volumes of the 7.5 cm^3 sample and its container are determined by a chemical balance, a helium comparison pycnometer (Fig. 8), a drying oven, and a few simple calculations:

	Weight	Volume
Bottle	W_o	V_o
Wet sample + bottle	W_1	V_1
Dry sample + bottle	W_2	V_2
Wet sample	W_3	V_3
Dry sample	W_4	V_4
Difference between wet and dry sample (= water content)	W_5	V_5

These values are then used to calculate the unit weight (Sect. 2.1), the water content (Sect. 2.2), the porosity (Sect. 2.3), the void ratio (Sect. 2.4), and the density of the solid particles (Sect. 2.5).

1.3.8 Grain Size measurement

Sand-sized grains are dry-sieved through a Wentworth standard sieve. Silt-sized and clay-sized particles are separated in a sedimentation tube by measuring the rate of precipitation. This latter separation -- which is more complicated than the separation of the sand -- is only carried out when important changes in the sedimentation are observed. (See Sect. 2.6).

1.3.9 Geological and Mineralogical constituents

This work is performed outside the Centre. If a significant layer appears in one particular area, a limited amount of isotope dating is carried out.

1.4 Speed of Operation

Most of the instrumentation described is fully automatic and can be operated by unqualified personnel. All the results are fed into the computer through the digital printer, and the correlation curves are automatically drawn on the X-Y plotter. Two people can analyze 50 to 60 levels per day on the work bench; thus this part

of the analysis of an 8 m long core takes three days. The volume measurements made with the helium pycnometer are, however, much slower and only 24 levels can be analyzed per day. Thus to maintain a steady output requires at least two pycnometers to every work bench. As complete grain-size measurements can only be made on 4 samples per day, these measurements have to be rigidly restricted to only the most interesting layers.

2. THEORY, PRINCIPLES, AND ACCURACY OF THE MEASUREMENTS

In the following description the measurements are described in the logical order listed in the Introduction, and not in the chronological order (Ch. 1) in which they are made.

2.1 Wet or Mass Unit Weight (m)

2.1.1 Definition

"The weight per unit volume of a 100%-saturated sediment mass."

The saturation level of a sediment is the ratio between the total volume of water it contains and the total volume of its voids. A submarine sediment "in situ" is therefore 100% saturated and, because the core samples are subjected to minimum handling, it is assumed that their saturation level is very close to 100% when they are analyzed. This parameter is therefore that of the "in situ" density of the sample.

2.1.2 Procedure

The measurements made on the 7.5 cm^3 sample (Sect. 1.3.7) are used to calculate the formula:

$$m = W_3/V_3$$

$$= \left(W_1 - W_0\right)\Big/\left(V_1 - V_0\right)$$

2.1.3 Accuracy

The relative error in measuring m is given by:

$$\Delta m/m = \left[\Delta W_1 + \Delta W_0\right] \Big/ \left[W_1 - W_0\right] + \left[\Delta V_1 + \Delta V_0\right] \Big/ \left[V_1 - V_0\right] ,$$

where the Δ-values are the maximum absolute errors.

The lowest value of W_1 is approximately 29 g and the highest value of W_0 is approximately 21 g. The maximum absolute error in weighing both W_1 and W_0 is 2×10^{-3} g.

The volume of the sample, given by $(V_1 - V_0)$, is approximately 7.5 cm^3. The weight of the empty bottle (V_0) is obtained by calculating the ratio

$$V_0 = \frac{\text{Weight of empty bottle}}{\text{Specific weight of glass}} = \frac{W_0}{d_g} ,$$

The specific weight of glass is obtained from an average of measurements made on several of the bottles, the volume measurement for this purpose being made with a water pycnometer that has a relative accuracy of 1:1000. The maximum absolute error in calculating V_0 is therefore obtained from

$$\Delta V_0/V_0 = (\Delta W_0/W_0) + (\Delta d_g/d_g),$$

i.e.

$$\Delta V_0 = V_0\left[(\Delta W_0/W_0) + (\Delta d_g/d_g)\right].$$

The volume of the empty glass bottle, V_o, is approximately 6 cm^3. From the earlier figures it was seen that the relative error in W_o is $(2 \times 10^{-3})/21$, and that the relative error in d_g is 1×10^{-3}. Therefore

$$\Delta V_o = 6\ (0.0001 + 0.001) \approx 6 \times 10^{-3}\ cm^3.$$

The maximum absolute error, ΔV_1, made by an experienced operator with the Beckmann air pycnometer can be as low as 5×10^{-2} cm^3.

Thus, substituting in the first equation, we obtain a relative error in measuring m of

$$\Delta m/m = \left[(4 \times 10^{-3})/8\right] + \left[(6 \times 10^{-3} + 5 \times 10^{-2})/7.5\right]$$

$$= 8 \times 10^{-3} \approx 1/100$$

2.2 Water Content (w)

2.2.1 Definition

"The weight of water expressed as a percentage of the weight of dry material."

2.2.2 Procedure

The measurement made on the 7.5 cm^3 sample (Sect. 1.3.7) are

used to calculate the formula:

$$w = \left(W_5 / W_4\right) \times 100\%$$

$$= \left[\left(W_1 - W_2 / \left(W_2 - W_0\right)\right]\right. \times 100\%$$

2.2.3 Accuracy

This depends on the drying process. It was found that keeping the samples in the oven for 48 hours at 105°C evaporated all the water, no matter in which part of the oven the sample was placed. The dried samples are not weighed until they are cool, being kept in a dessicator until that time (about 2 hours).

The maximum absolute errors ΔW_0, ΔW_1, and ΔW_2 are 2×10^{-3} g each. The maximum relative error on w is

$$\Delta w/w = \left[\left(\Delta W_1 + \Delta W_2\right) / \left(W_1 - W_2\right)\right] + \left[\left(\Delta W_2 + \Delta W_0\right) / \left(W_2 - W_0\right)\right]$$

The minimum value of $\left(W_1 - W_2\right)$ is of the order of 4 g, that of $\left(W_2 - W_0\right)$ is of the order of 3.5 g. Thus

$$\Delta w/w = \left(1 \times 10^{-3}\right) + \left(1.15 \times 10^{-3}\right)$$

$$\approx 1/500$$

2.3 Porosity (n)

2.3.1 Definition

"The volume of the voids expressed as a percentage of the total volume."

In a submarine sediment the volume of the voids is equal to the volume of the water it contains; porosity can thereby be more easily defined in terms of water volume.

2.3.2 Procedure

The measurements made on the 7.5 cm^3 sample (Sect. 1.3.7) are used to calculate the formula:

$$n = \left(V_5 / V_3\right) \times 100\%$$

2.3.3 Accuracy

V_5 is equal to $(W_1 - W_2)$ / density of water evaporated. The density of water is unity and therefore the error made on V_5 is the same as that made on $(W_1 - W_0)$.

V_3 is measured by the air pycnometer and the relative error of measurement has been shown (Sect. 2.1.3) to be 7.5×10^{-3}.

The maximum relative error made on n is therefore:

$$\Delta n/n = (\Delta W_1 + \Delta W_2) \Big/ (W_1 - W_2) + 7.5 \times 10^{-3}.$$

As the minimum value encountered for $(W_1 - W_2)$ is of the order of 4.5 g,

$$\Delta n/n = \left(4 \times 10^{-3}\right) \Big/ 4.5 + \left(7.5 \times 10^{-3}\right)$$

$$\approx 1/100$$

2.4 Void Ratio (e)

2.4.1 Definition

"The ratio between the volume of the voids and that of the solid particles."

With submarine sediments, the volume of the voids is that of the water content.

2.4.2 Procedure

The measurements made on the 7.5 cm^3 sample (Sect. 1.3.7) are used to calculate the formula:

$$e = V_5 \Big/ V_4$$

$$= V_5 \Big/ \left(V_3 - V_5\right)$$

2.4.3 Accuracy

The calculation formula can also be written as

$$e = \frac{\frac{W_1 - W_2}{1}}{V_3 - \frac{W_1 - W_2}{1}}$$

The maximum relative error made on e is therefore

$$\Delta e/e = \frac{\Delta\left[W_1 - W_2\right]}{W_1 - W_2} + \frac{\Delta\left[V_3 - \left(W_1 - W_2\right)\right]}{V_3 - \left(W_1 - W_2\right)}$$

$$= \frac{\Delta\left[W_1 - W_2\right]}{W_1 - W_2} + \frac{\Delta V_3 + \Delta W_1 + \Delta W_2}{V_3 - W_1 + W_2}$$

We have seen that $\frac{\Delta\left(W_1 - W_2\right)}{W_1 - W_2} = 0.9 \times 10^{-3}$

ΔV_3 was previously calculated as $6 \times 10^{-3} + 5 \times 10^{-2}$ cm^3

$\Delta W_1 = \Delta W_2 = 2 \times 10^{-3}$ g

The minimum value for $V_3 - W_1 + W_2$ is $7.5 - 6.5 = 1$

$$\frac{\Delta V_3 + \Delta W_1 + \Delta W_2}{V_3 + W_1 - W_2} = \frac{6 \times 10^{-3} + 5 \times 10^{-2} + 4 \times 10^{-3}}{1}$$

$$= 6 \times 10^{-2}$$

$$\Delta e/e = 0.9 \times 10^{-3} + 6 \times 10^{-2}$$

$$\approx 7 \times 10^{-2}$$

2.5 Density of Solid Particles (d)

2.5.1 Definition

"The ratio between the weight and volume of a dried sample."

2.5.2 Procedure

The measurements made on the 7.5 cm^3 sample (Sect. 1.3.7) are used to calculate the formula:

$$d = W_4 / V_4$$

$$= \left(W_2 - W_o\right) / \left(V_2 - V_o\right)$$

2.5.3 Accuracy

The relative error $\frac{\Delta d}{d}$ made on d is

$$\frac{\Delta d}{d} = \frac{\Delta W_2 + \Delta W_0}{W_2 - W_0} + \frac{\Delta V_2 + \Delta V_0}{V_2 - V_0}$$

We have seen that $\frac{\Delta W_2 + \Delta W_0}{W_2 - W_0} = 1.15 \times 10^{-3}$

The admissible absolute error made on V_2 is $\Delta V_2 = 0.05\ cm^3$
It has been shown previously that $\Delta V_0 = 6 \times 10^{-3}\ cm^3$
The minimum value of $(V_2 - V_0)$ is of the order of magnitude of 1
Therefore,

$$\frac{\Delta d}{d} = 1.15 \times 10^{-3} + \frac{0.05 + 0.006}{1}$$

$$\approx 57 \times 10^{-3}$$

$$\approx 6/100$$

2.6 Grain Size

2.6.1 Definition

To facilitate comparison with the already extensive literature

on the subject published in the U.S.A., the Wentworth grain-size scale, which is in common use by geologists and civil engineers in the U.S.A., has been adopted. This is as follows:

Sand	2000 - 62.5 microns
Silt	62.5 - 3.9 microns
Clay	< 3.9 microns

It must be emphasised that the terms merely distinguish between grain size and are not used in their other connotation as a description of mineralogical constituents.

2.6.2 Procedure

The sand-sized grains are dry-sieved through a Wentworth standard sieve. The silt and clay-sized particles are separated in a sedimentation tube by measuring the rate of precipitation. This latter separation, which is more complicated than the separation of the sand, is only carried out when important changes of sedimentation are observed in the core.

2.6.3 Accuracy

The accuracy is difficult to evaluate, but it is apparent that — especially for the silt/clay separation — it is very much a function of the time that can be devoted to the measurements.

2.7 Geological and Minerological Constituents

This analysis is made outside the Centre and no details will be given here.

2.8 Longitudinal Sound Velocity (c)

2.8.1 Definition

"The time taken for a sound pulse to travel a known distance through the sediments."

2.8.2 Procedure

Measurements are made with the sound-velocity probe assembly referred to in Sect. 1.3.3 and described in detail in App. A.

A 70 kHz sound pulse is emitted by energizing a stack of lead zirconate, piezo-electric crystals by means of a high-voltage electrical pulse. The sound pulse is transmitted to the sediments of the core section through a steel coupling rod, and after passing through the sediments is fed by another coupling rod to a second stack of crystals (Fig. 9).

The shapes of the pulse at emission and reception are as shown in Fig. 10. The time between the emission and reception of predetermined levels of the pulse represents the travel time through the crystals, the coupling rods, and the sediments. It is automatically recorded by the triggering of the digital counter.

In making the measurements, the time difference, Δt, between two different levels, A and B, of the leading edge of the received pulse (Fig. 11) is kept constant by changing the amplification — and thereby the slope — of the received pulse. A second digital counter is used to control this value. The purpose is to maintain a standard shape for the leading edge of the received pulse, irrespective of the attenuation due to the particular medium being analyzed. This assumption was found to be valid for various media: distilled water, sea water, clay, silt, and sand. For each of these media, several pictures of received signals were inspected and it was found that, with a constant Δt, all the measurements of the slope of the pulse before point A fell within $\pm 0.1\,\mu s$, the greatest discrepency being that found in sand. Calibration of this process is made by using standard distilled water at a known temperature.

Hamilton (Ref. 3), used the bathyscaphe TRIESTE to measure sound velocities in the surficial sediments off San Diego down to a depth of 1235 m. Cores taken from the TRIESTE at the same places were examined in the laboratory to determine the proper corrections to apply to laboratory measurements to get good estimates of "in situ" sound speeds.

Quoting Hamilton "these studies showed that predictions within one per cent accuracy are possible if full temprature and pressure corrections are made (laboratory to "in situ") to the sediment sound speed,using Wilson's tables for the speed of sound in sea water."

The porosity-pressure effect as well as the change of cohesion mentioned by Hamilton have been neglected.

The porosity-pressure effect or overburden pressure effect consists of the weight of mineral gain in water (hydrostatic uplift) with no relation to water depth. With short cores this effect is negligible, as is the consequent alteration of cohesion.

It should be noted that at the stage of our present knowledge the correction factor for hydrostatic pressure and temperature is much below the accuracy of our measurements.

Some laboratory work is planned for the future in order to define this law of correction more precisely.

2.8.3 Accuracy

The precision and stability of the measurement depends on three factors:

(a) The stability of the delay of the electronics.

(b) The noise disturbance of the received signals.

(c) The reproducibility of the shape of the received pulse.

The mechanical parts of the apparatus are sufficiently rigid, and the distance is sufficiently reproducible, for the error to be negligible.

The delay of the electronics is highly stable and depends on the ambient temperature. When the calibration signals are fed into the electronics the mean value of the time difference is about 83 μs and is constant, ± 10 ns, for a period of 8 hours. The dispersion of the measurement is about 10 ns and is due to the noise. In this control, the level of the calibration signal is the same as a normal received signal after travelling through clay sediments. The noise that accompanies the received signal from the sediments has, in general, a level that gives a dispersion of measurements of about 20 ns. This error can be decreased by averaging the results of a series of time-difference readings, an operation that is facilitated by the digital printer associated with the equipment.

The reproducibility of the shape of the received pulse has been estimated by photographic methods and gives an error estimated as less than 1/1000. We can conclude from all the measurements carried out that the error in the sound velocity measurement remains smaller than 1/1200 in water, silts, and clays. When the sound velocity must be measured in sand, the coupling losses between rod and sediments seem to increase with the decrease of water content. In this case the accuracy of the measurements is often reduced and can be as low as ± 1% when the water content of the sand is low (40 to 50%).

2.9 Measurement of Electrical Resistivity

2.9.1 Definition

The parameters described in the previous paragraphs, and their correlation with the acoustical properties of sediments, have been

measured and reported by many workers in what is already an impressive bibliography on the subject. The parameter of electrical resistivity, however, is less well known in this field and therefore requires a longer explanation.

For more than twenty years, petroleum geophysicists have successfully correlated the physical parameters of reservoir rocks with their electrical resistivity (Ref. 4). The sandstones investigated had porosities of from 10% to 40% and were saturated with brine of known salinity. Under these particular conditions it was found that

$$R_e = FR_w , \qquad \text{(Eq. 1)}$$

where R_e is the resistivity of the sand when completely saturated with brine, R_w is the resistivity of the brine, and F is a function of the type and character of the formation. This factor F is the "formation resistivity factor".

It was found that this formation resistivity factor varied with, among other things, the porosity of the reservoir rock and that a reasonably accurate relationship could be established between the two. Thus, knowing the porosity of the rock being studied, a fair estimate could be made of the value to be assigned to F in Eq. 1.

The relationship between the resistivity (R_e) of the sandstone when saturated and its porosity (φ) is given by a linear correlation between the logarithms of the two variables. The

formation resistivity factor is then given by

$$F = 1/\varphi^m ,$$

where m is the slope of the regression line. Equation 1 therefore becomes

$$R_e = R_w/\varphi^m .$$

For the consolidated sandstones studied by the petroleum geophysicists the value of m was found to range between 1.8 and 2.0. Tests in the laboratory with clean, packed, but unconsolidated sand have given similar values.

The range of porosities encountered in deep sea sediments, however, varies from about 40% to 100% and, since they are unconsolidated, it is obvious that the electrical paths will be mostly affected by the conductive interstitial water, the electrical effect of the "matrix" being less preponderent even when this matrix is slightly conductive. Morever, Kullenberg (Ref. 5) has shown that the difference between the salinity of the interstitial water of some deep sea sediments and that of the bottom water is, on the whole, rather small. Therefore the R_w of Eq. 1 is readily obtainable.

The measurement of electrical resistivity — either on cores or in situ — is easy, so that this would provide a very convenient method by which to calculate parameters that are more difficult to measure. However, a lot of data has to be collected and analyzed before

electrical resistivity can be correlated successfully with other physical parameters in deep sea sediments.

2.9.2 Procedure

The electrical resistivity along the length of each 70 cm long core section is first made with the probe referred to in Sect. 1.3.1, but this is done only to determine the most interesting levels at which to make the secondary corings (Sect. 1.3.4). When a secondary core has been taken, its electrical resistivity is measured in the resistivity cell referred to in Sect. 1.3.5.

With both instruments a square-wave alternating current is used to minimize the polarization of the metallic electrodes. Details of the principles and electronics are given in App. B.

2.9.3 Accuracy

Electrical resistivity changes by about 10% for a change of temperature of 5°C, when measured at temperatures around 25°C. As it is expected that the room temperature will be known to within ± 0.5°C, the accuracy of the electrical resistivity measurements should vary by only 1/100th due to the influence of temperature.

Polarization is practically eliminated by the use of a square-wave alternating current and the reading error is reduced by the use of a digital voltmeter. We can therefore assume that the principle error is due to temperature changes and that the maximum relative error is 1/100.

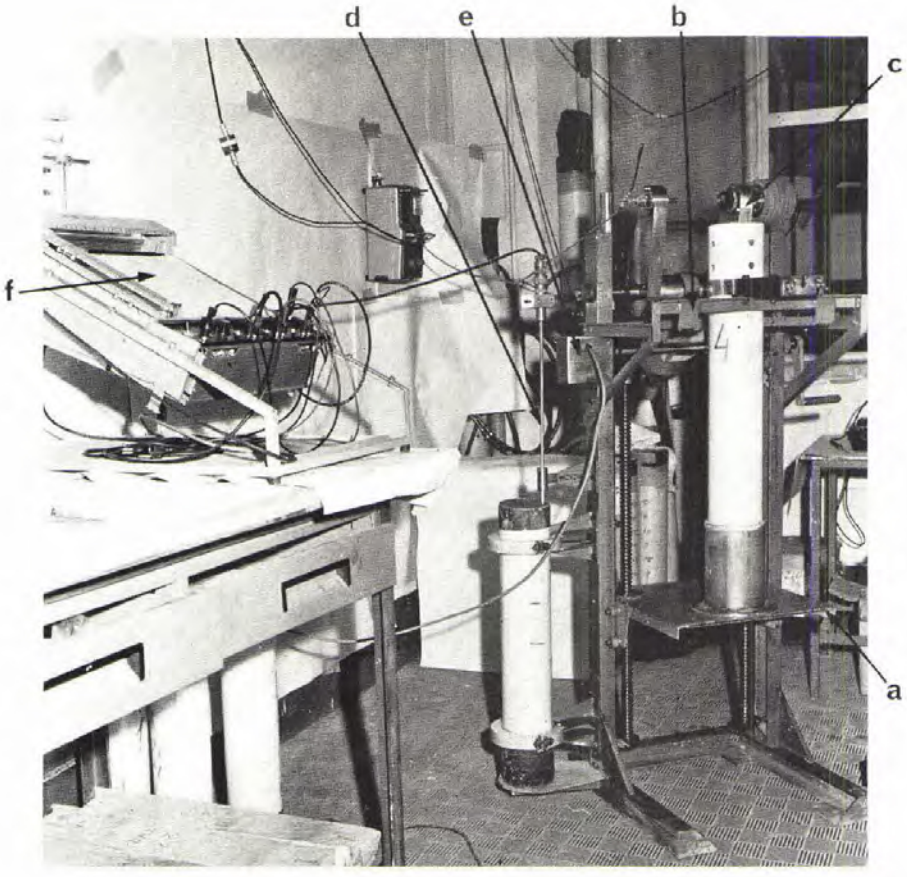


FIG. 1 GENERAL VIEW OF THE ANALYSIS BENCH

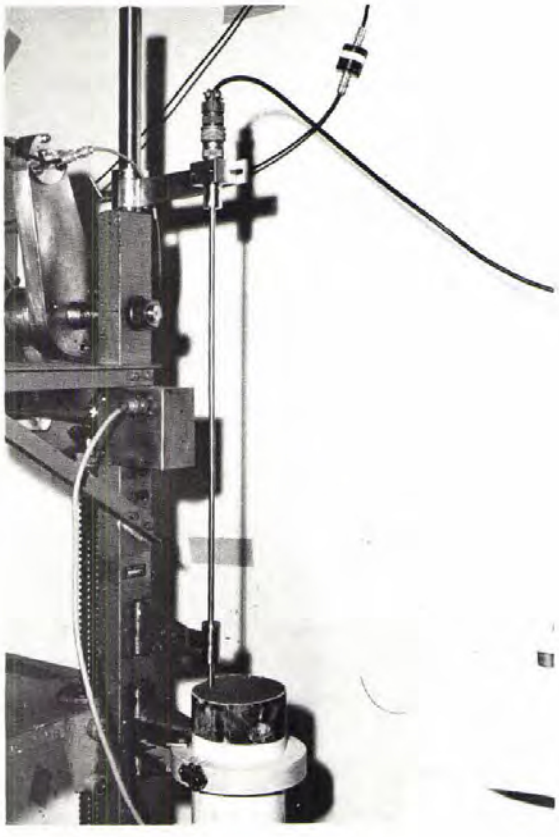
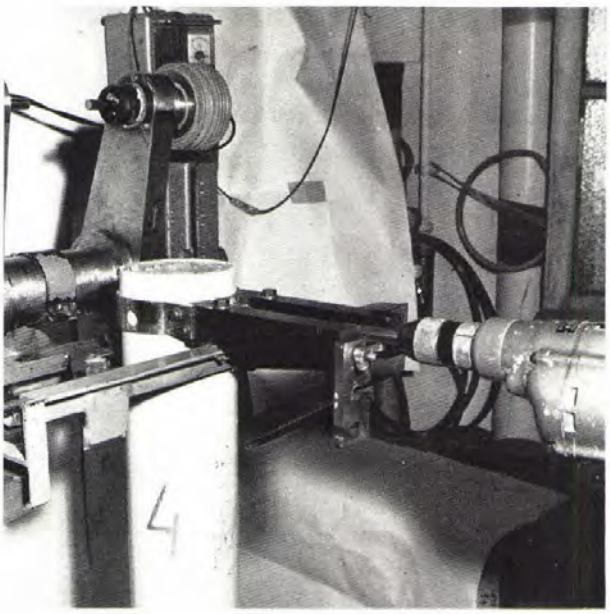
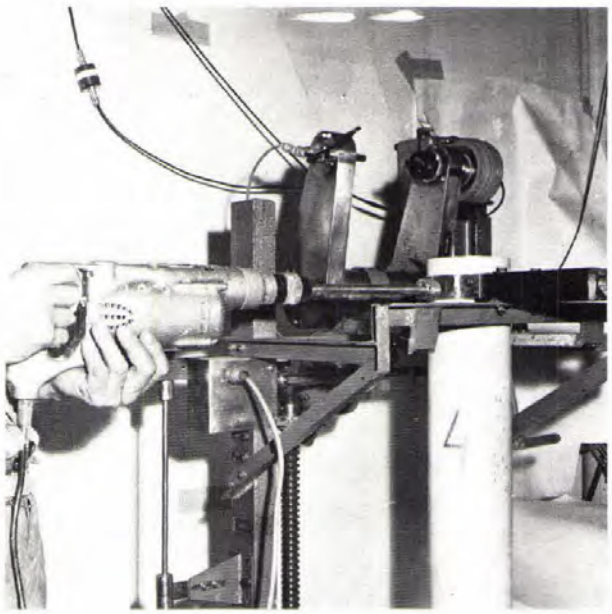


FIG. 2 MAKING ELECTRICAL RESISTIVITY MEASUREMENTS ALONG THE CORE



a



b

FIG. 3 OPENING HOLES IN THE PLASTIC LINER:
(a) Hole for secondary coring,
(b) Holes for Sound–Velocity probe

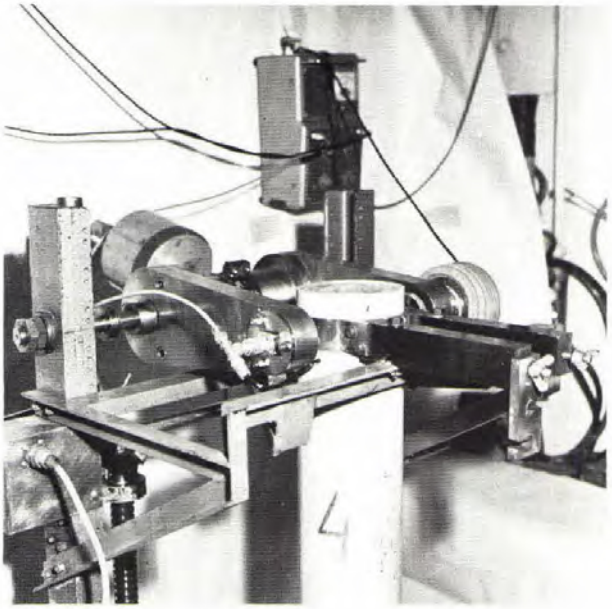


FIG. 4 SOUND–VELOCITY PROBE ASSEMBLY IN POSITION

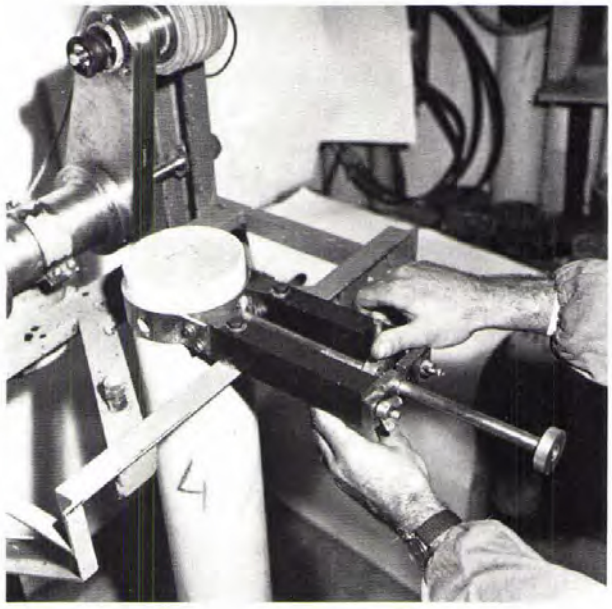


FIG. 5 SECONDARY CORING ACROSS THE MAIN CORE

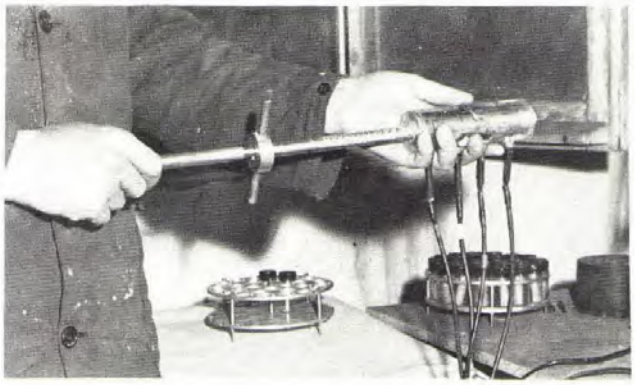
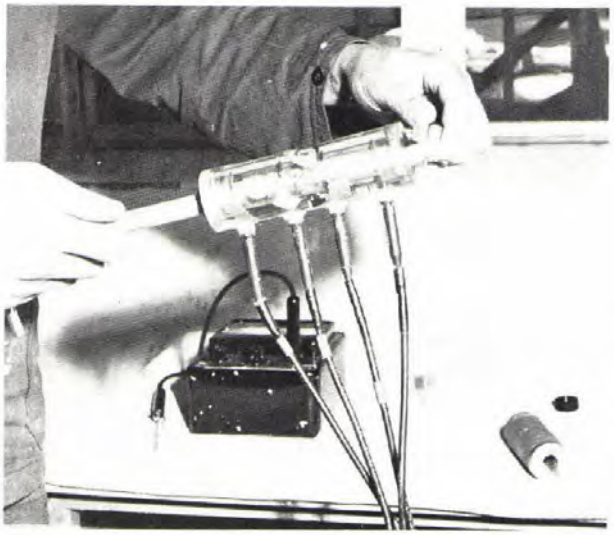


FIG. 6 MAKING ELECTRICAL RESISTIVITY MEASUREMENT OF THE LATERAL CORE



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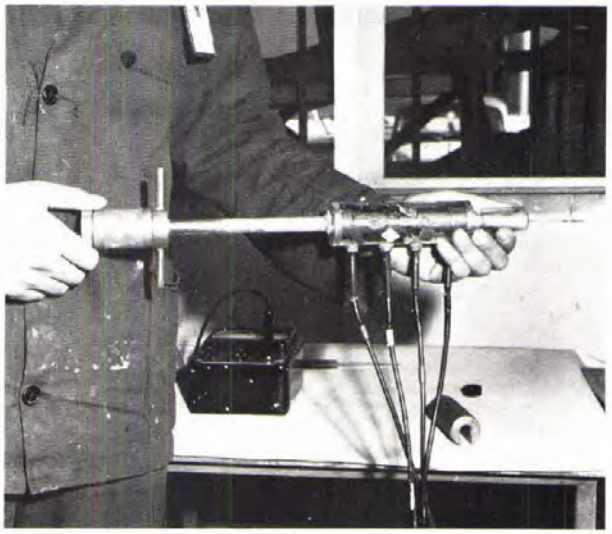

b

FIG. 7 EXTRACTION OF THE CENTRAL PORTION OF THE LATERAL CORE

(a) Cutting off outside portion

(b) Bottling central portion

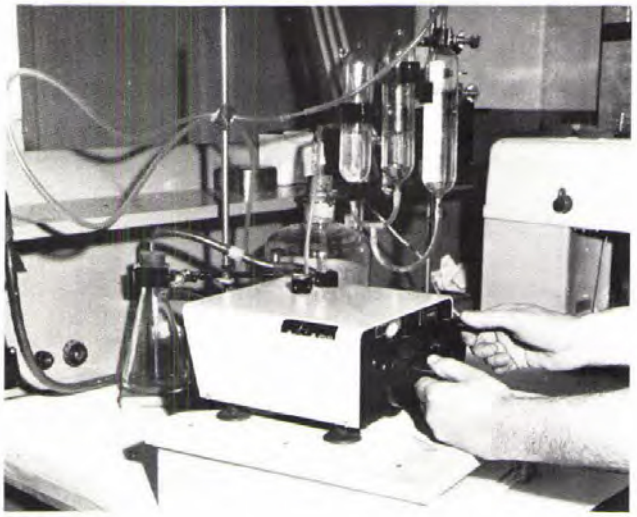

FIG. 8 USE OF THE HELIUM COMPARISON PYCNOMETER

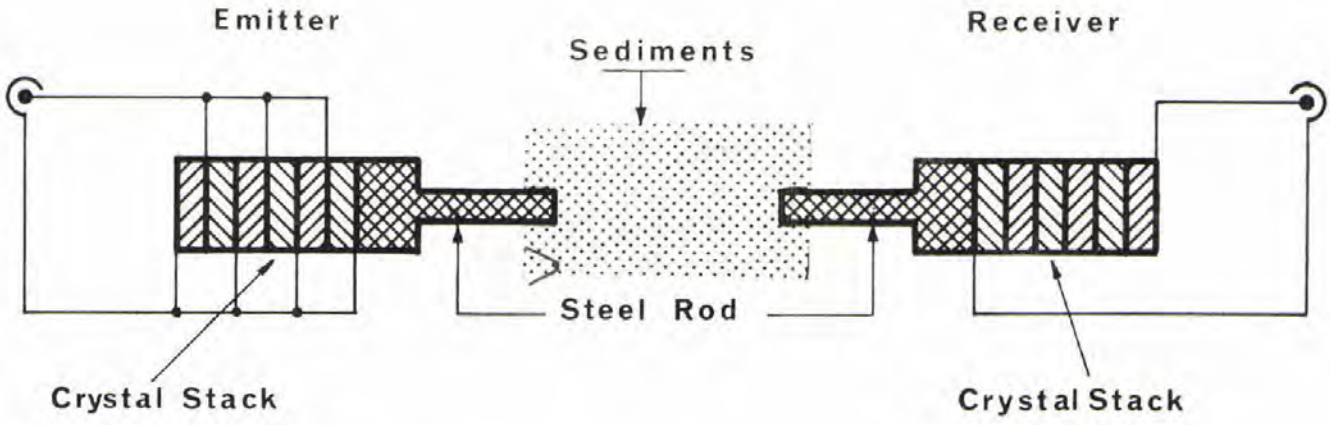

FIG. 9 SCHEMATIC DIAGRAM OF THE SOUND-VELOCITY MEASURER

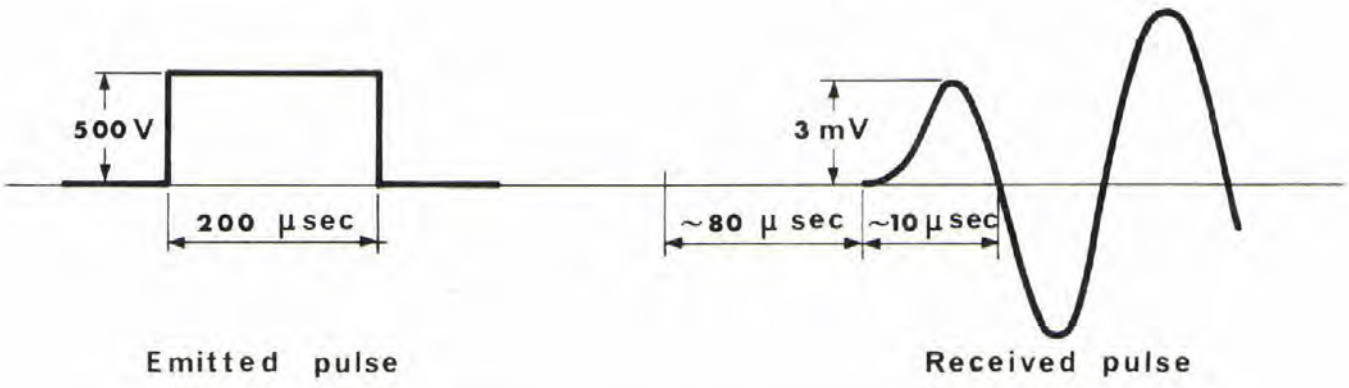

FIG. 10 SHAPES OF PULSES EMITTED AND RECEIVED BY THE SOUND-VELOCITY MEASURER

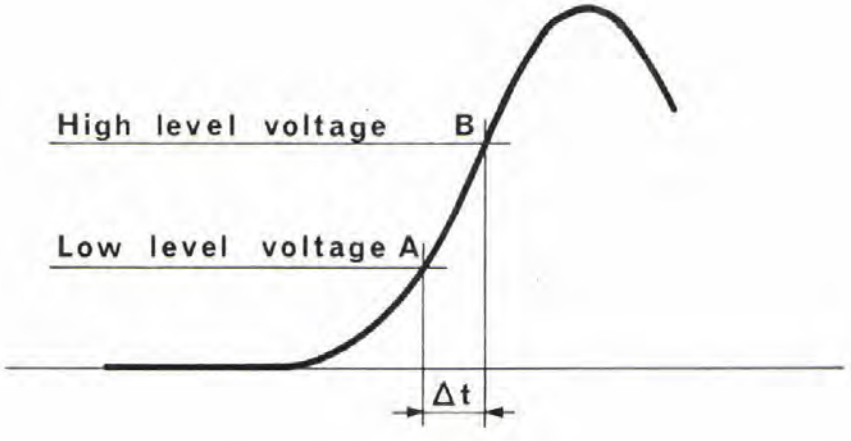

FIG. 11 LEADING EDGE OF THE RECEIVED PULSE OF THE SOUND-VELOCITY MEASURER

APPENDIX A

EQUIPMENT FOR THE MEASUREMENT OF SOUND VELOCITY IN CORES

1. Construction (Fig. A.1)

The apparatus consists essentially of two crystals (a) & (b) mounted on opposite arms of a rotatable frame (c).

The transmitting crystal (a) is made of a stack of six high-Q, lead zirconate, LZ4A, Brush Clevite crystals connected in parallel (Ref. 6), the stack having a resonant frequency of 70 kHz. It is held within a container (d) that can move inside a cylinder (e) firmly fixed to one arm of the frame. The container is closed at one end by a steel rod (f) that couples the crystal to the sediments. A knob (g) at the other end of the container allows the container to be advanced or retracted within the cylinder.

The receiving crystal (b) consists of a stack of six low-Q, lead zirconate, LZ5A Brush Clevite crystals connected in series. A steel rod (h) couples it to the sediments. The whole receiving assembly is rigidly fixed to its arm of the frame.

In operation the frame is swung into position with the arms opposite the holes drilled in the core section's liner. It is then slid along its axis (i) until the receiver's coupling rod is in position against the sediment. The transmitter assembly is then pushed inwards and locked into place by means of its knob. The locking device ensures

that the distance between the faces of the two coupling rods is always 85 ±0,01 mm.

2. Electronics (Fig. A.2)

2.1 Generalities

The travel time of a sonic pulse between the radiating faces of the two coupling rods (about 85 mm) is about 60 μs. Therefore, the propagation delay in the electronics must be highly stable to keep the measured time-difference sufficiently accurate. For the construction of the apparatus we have tried, as much as possible, to use integrated circuits for which the stability of delay versus temperature was found sufficient. The unit of time used in the measurement is 10 ns.

The receiver crystal is connected to a 40 dB preamplifier through an attenuator made of a field-effect transistor. As soon as a pulse is received, the field-effect transistor attenuates the signal coming from the crystal in order to avoid saturation of the preamplifier due to the sound signal travelling through the frame.

The amplifier is connected to a variable attenuator, the output of which is connected to an integrated clipper amplifier. The output of the clipper is then sent into two integrated circuit level detectors, each respectively sending a pulse when the signal reaches two preset level. These pulses are passed through a logic unit, the functions of which will be described below.

The pulse driving the sending crystal is generated in the circuit shown in Fig. A.2 and is sent to the logic unit.

2.2 Logic Unit Functions

The logic unit performs the following functions:

(a) When a start pulse is sent, the stop pulses coming from the level detectors are prevented from travelling through the electronics for about 70 μs.

(b) The stop pulse given by the low level detector inhibits its own circuit until after the delay of about 70 μs derived from the next start pulse.

(c) 10 μs after the pulse coming from the high level detector, the field-effect transistor, set at the input of the preamplifier, is polarized in its attenuating state until the emission of the next start pulse.

2.3 True Measurement

The start pulse and the two stop pulses are sent to a unit that converts them into pulses of about 25 V, 1 ns rise-time in order to activate the two time-interval meters.

The start pulse controls the counting of the time-interval meter 1. The low level stops this time interval-meter 1, and starts the

counting on time-interval meter 2. The high level stop terminates the counting of time-interval meter 2.

A clock frequency of 1 MHz is fed through these counters and through a calibrator. This calibrator delivers, at the same repetition rate as the transmitted pulse, a start and a stop signal that has a shape comparable to a received pulse. Special attention was made to keep a constant time interval of 80 s ± 5 ns between these signals. These signals can be substituted by the normal signals for the checking of the installation. A printer, connected to time-interval meter 1, makes the averaging of the measurement easier in the presence of noise.

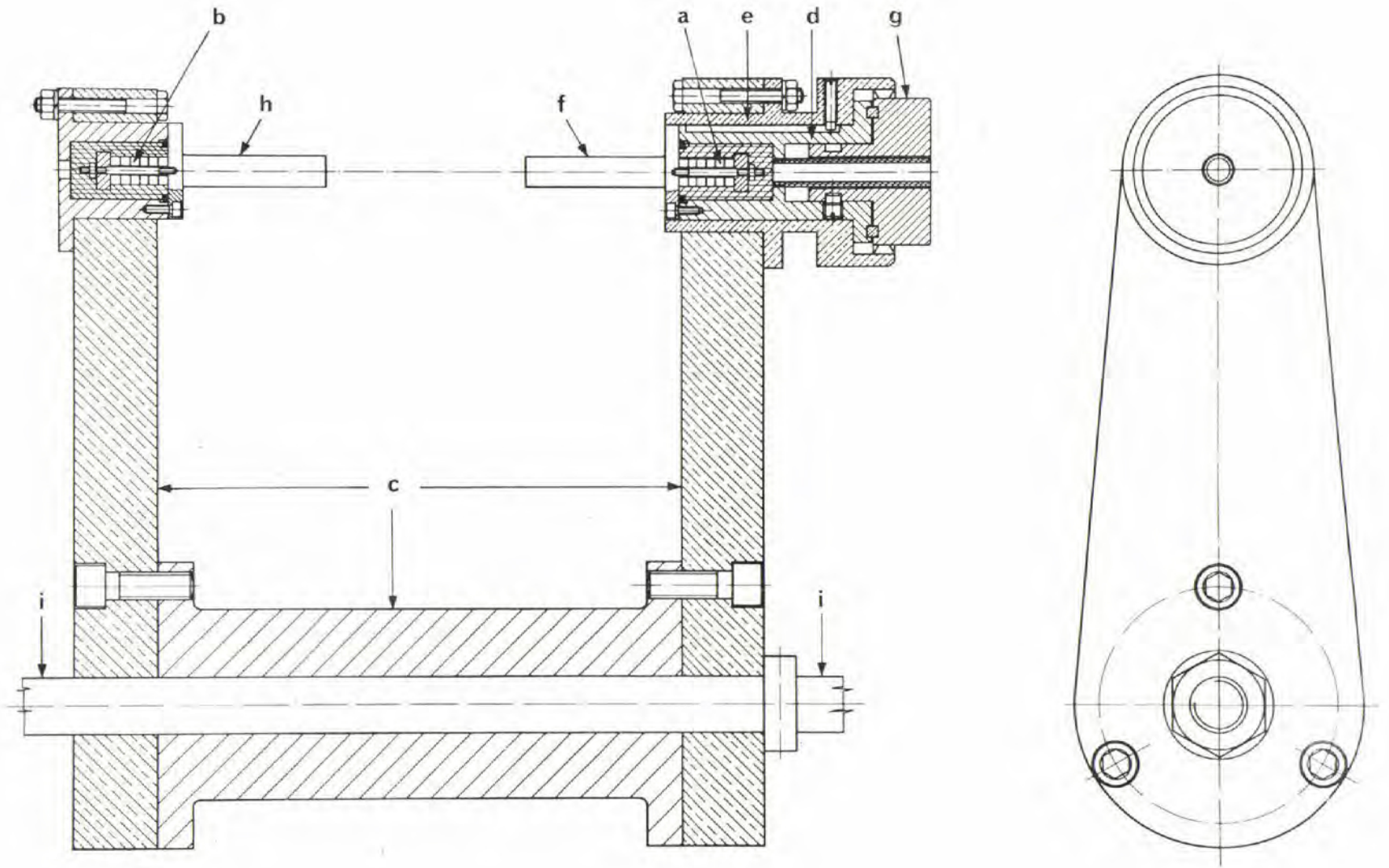

FIG. A.1 APPARATUS FOR THE MEASUREMENT OF SOUND VELOCITY: MECHANICAL CONSTRUCTION
(see also Fig. 4)

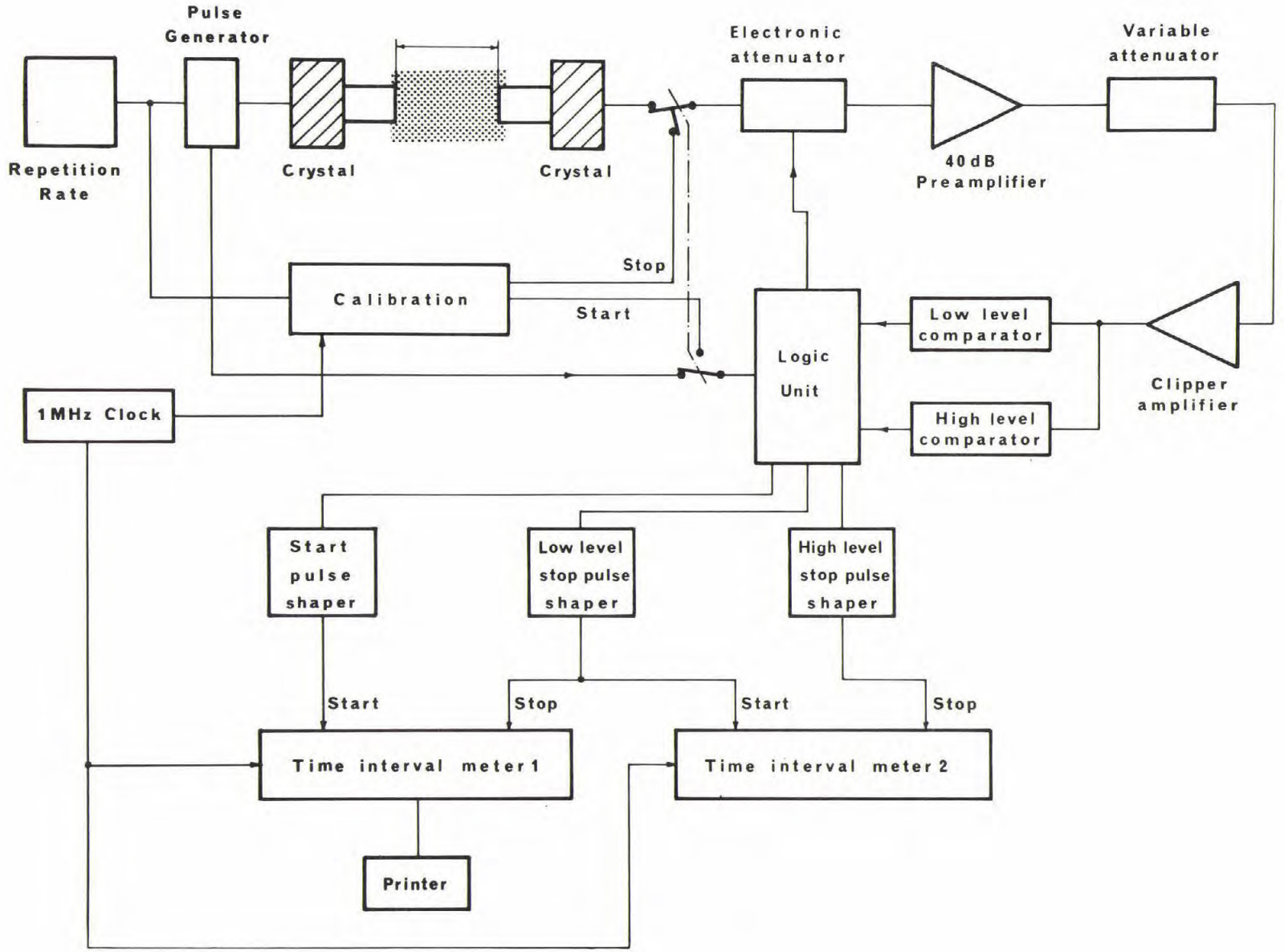

FIG. A.2 APPARATUS FOR THE MEASUREMENT OF SOUND VELOCITY: ELECTRONIC CONSTRUCTION

APPENDIX B

EQUIPMENT FOR THE MEASUREMENT OF ELECTRICAL RESISTIVITY IN CORES

1. Principles of Measurement

From the electrical point of view the equivalent circuit of the sediment is an impedance. The resistivity measured corresponds to the real part of the impedance. Theoretically, such a measurement can be carried out with direct current; however, because of the polarization of metallic electrodes it is preferable to use a square-wave alternating current. A constant current is passed through a cell containing the sediments, and the direction of this current is reversed twelve times per second.

The cell is as shown in Fig. B.1, the outer electrodes (A and D) being for input and the inner electrodes (B and C) being for measurement. If a constant current is fed through electrodes A and D, the voltage read across electrodes B and C will be proportional to the resistivity of the medium. The outer electrodes are each 50 mm from the centre of the cell and the inner electrodes are each 15 mm from the centre.

Figure B.2 shows the wave-forms across the two pairs of electrodes. It can be seen that the voltage read across the measuring electrodes B & C consists of two essential parts: (a) the transient period, mainly due to the imaginary part of the impedance of the combined effect of sediments and electrodes,(b) the steady state,

due to the real resistivity of the sediments. It is part (b) that has to be measured.

2. Electronics (Fig. B.3)

An electronic clock delivers about 1000 pulses per second to a 2^6 binary divider. The output signals of the flip-flop elements of the divider are sent to a decoder that commands, through four flip-flops, the operation of four double-circuit reed relays whose operating time is less than 1 ms.

Flip-flops 1 and 2 close their relays during the time intervals of 0 to 32 ms and 33 to 63 ms respectively, and flip-flops 3 and 4 close their relays during the time intervals of 25 to 31 ms and 56 to 62 ms respectively (Fig. B.4). Thus a square-wave current is fed from the battery B through the equal resistors R and R1 and into electrodes A and D of the resistivity measuring cell. During part of the cycle the digital voltmeter reads the rectified voltage across the measuring electrodes B and C. Because the current sent through electrodes A and D is kept constant, the voltage read across electrodes B and C is proportional to the resistivity of the medium.

The voltage supplied by the battery is adjustable; calibration is carried out by replacing the resistivity measuring cell with a set of known resistances.

The geometrical factor of the cell is calculated by comparing measurements made on salt solutions of known resistivity.

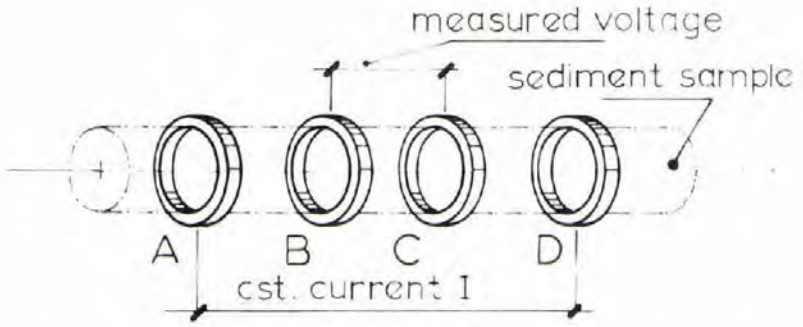

FIG. B.1 CELL FOR THE MEASUREMENT OF ELECTRICAL RESISTIVITY
(see also Figs. 6 & 7)

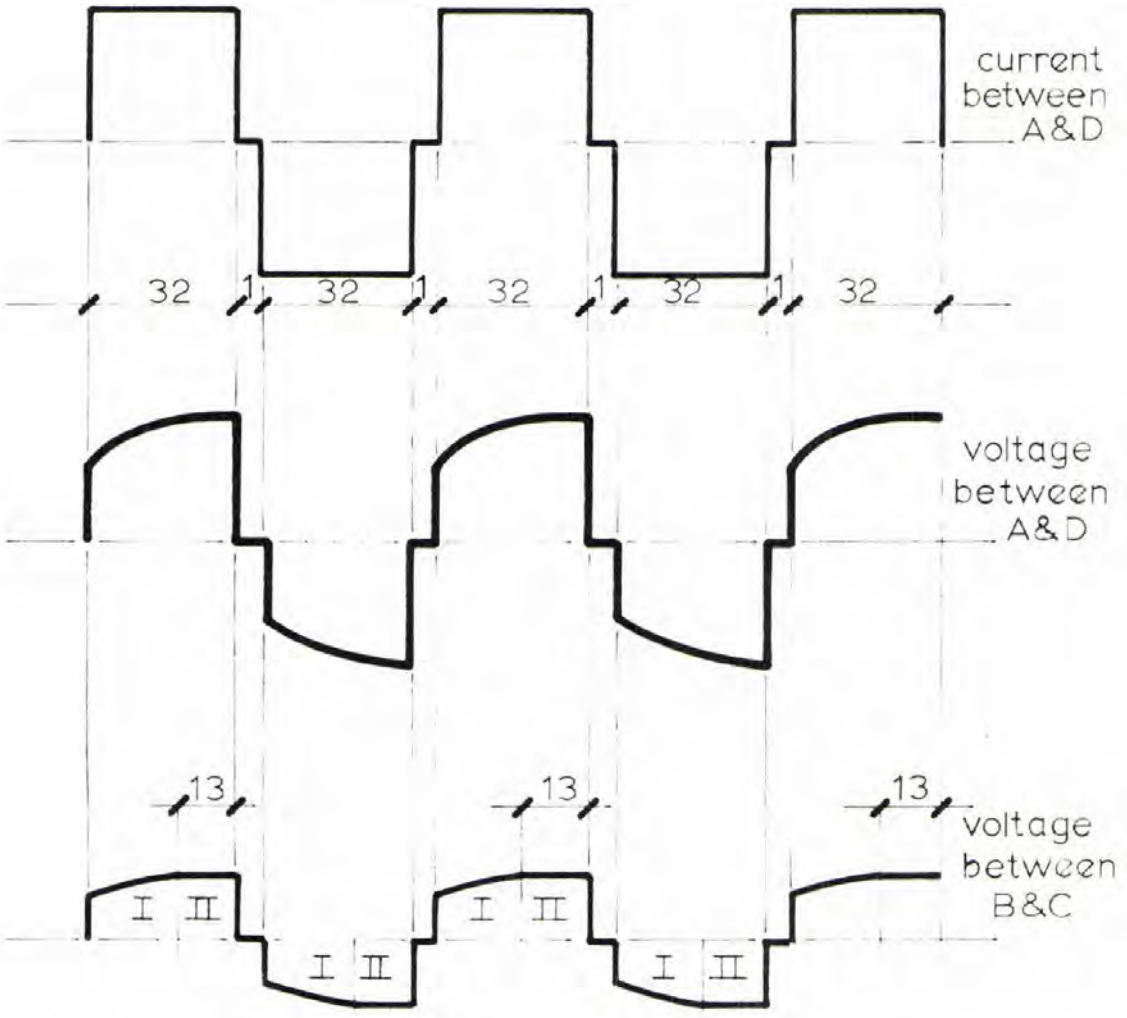

FIG. B.2 WAVE-FORMS ACROSS PAIRS OF ELECTRODES OF THE RESISTIVITY CELL

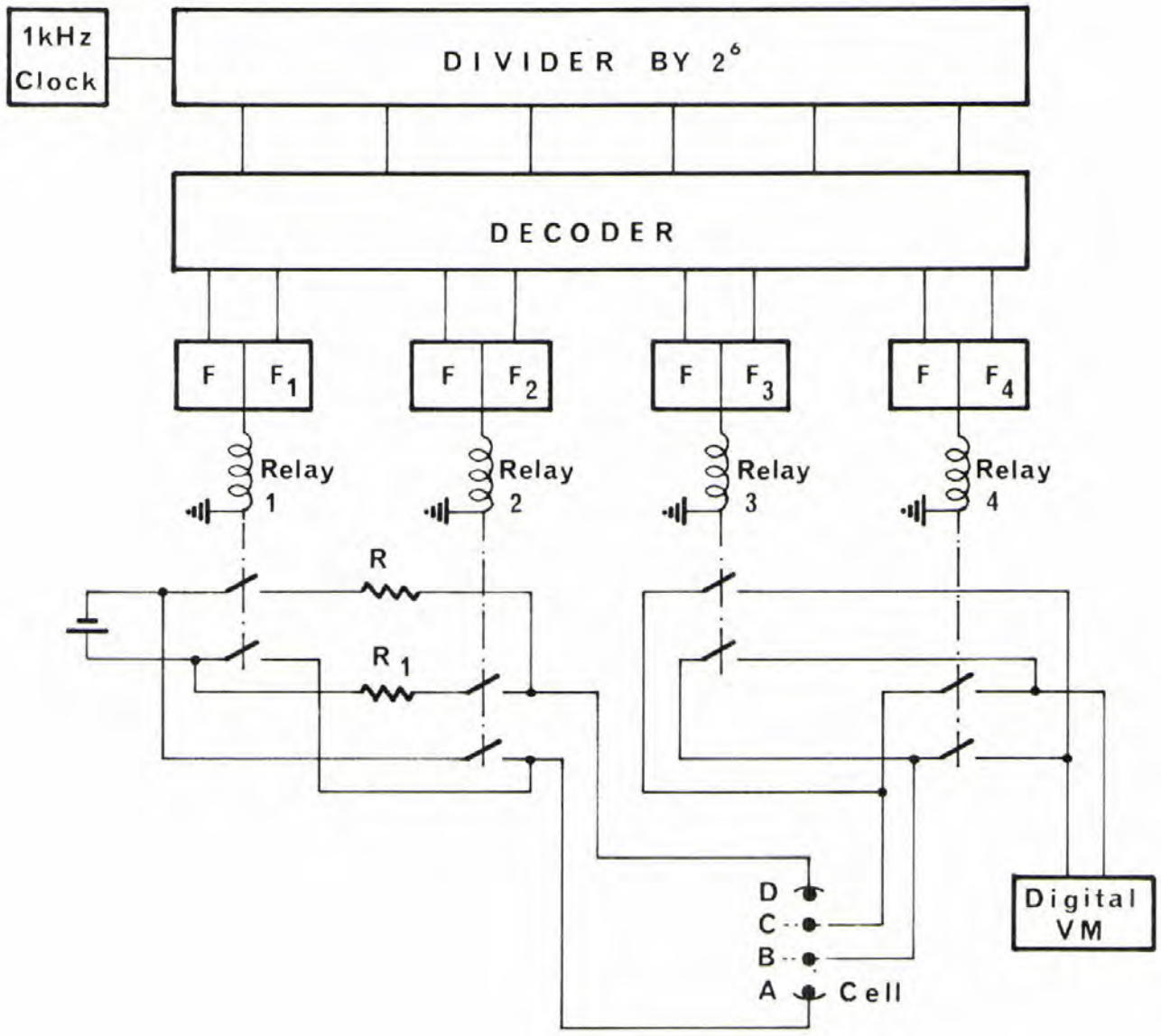

FIG. B.3 ELECTRONICS OF THE ELECTRICAL RESISTIVITY MEASURER

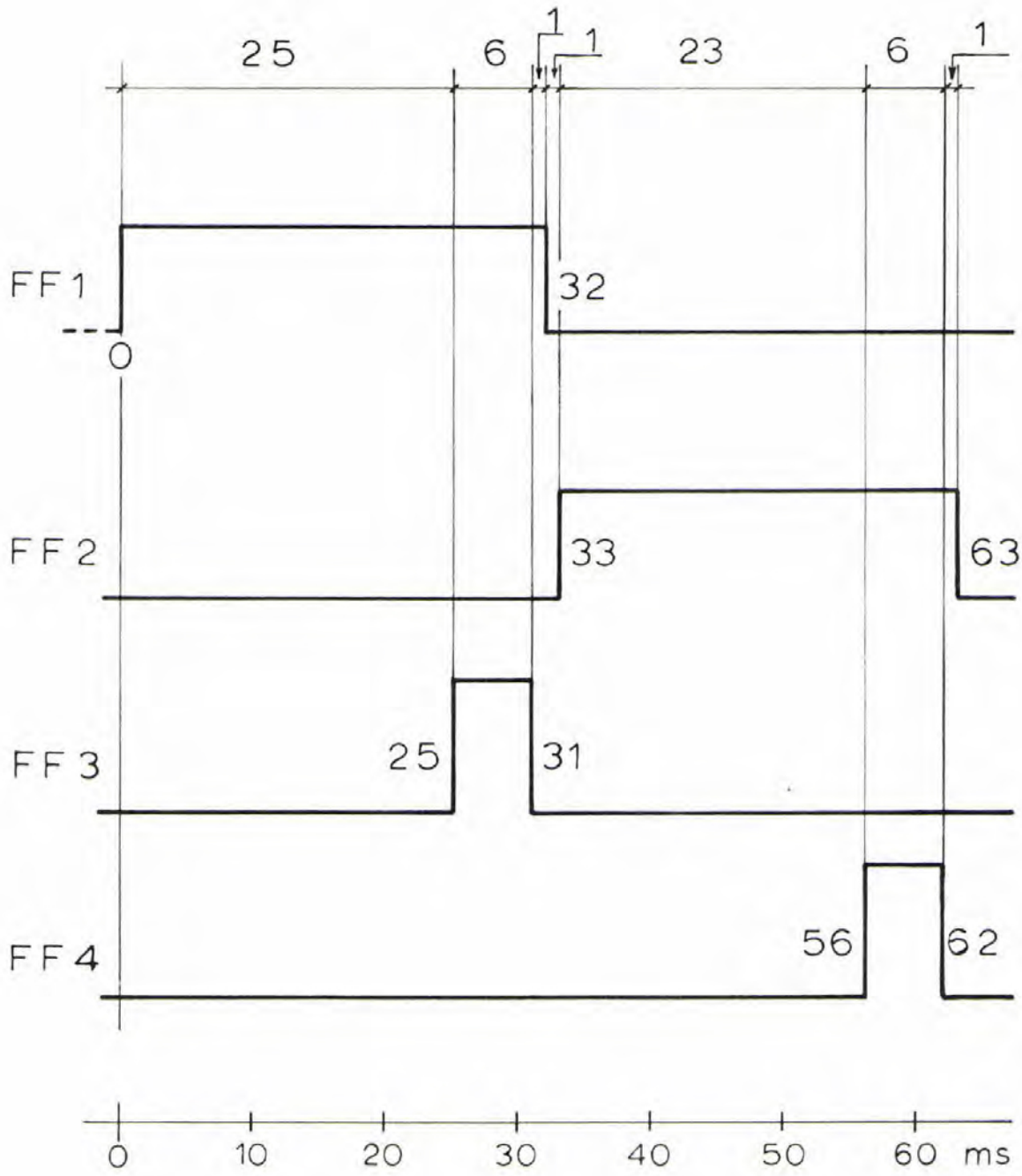

FIG. B.4 TIMING OF THE FLIP-FLOPS IN THE ELECTRICAL RESISTIVITY MEASURER

REFERENCES

1. A. Kermabon, P. Blavier, U. Cortis, H. Delauze, "The Sphincter Corer: a wide-diameter corer with water-tight core catcher", Marine Geology 4, 1966, pp. 149-162.

2. M.J. Hvorslev, "Sub-surface Exploration and Sampling of Soils for Civil Engineering Purposes", U.S. Army, Corps Engns, Waterways Expt: Sta., Wicksburg, Miss., 1949, 521 pp.

3. E.L. Hamilton, "Sediment Sound Velocity Measurements made in situ from Bathyscaphe TRIESTE", Journal of Geophysical Research, Vol. 68, No. 21, November 1963.

4. G.E. Archie, "The Electrical Resistivity Log as an aid in determining some Reservoir characteristics", Transactions of the American Institute of mining and metallurgical Engineers, Vol. 146, 1942.

5. B. Kullenberg, "On the Salinity of the Water contained in Marine Sediments", Göteborg. Zungl. Vetenskaps och Vitterhets - samhalles Handlingat, 1952.

6. C.M. Hubbard, "The design and construction of piezo-ceramic stack assemblies", ARL Teddington N72/L.

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