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THE COLLECTION OF SOIL TEMPERATURE DATA IN INTENSIVE STUDIES OF ECOSYSTEMS

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13. SUMMARY

a. The operation and the routine use of a Limpet Logger and a Grant Recorder and the various possible types of power supply are described and discussed. A suitable design for a power-pack is given.

b. The selection of a recording site, and installation of the instruments and probes, including methods of protecting, joining and labelling probe leads, are described.

c. Calibration of the instruments and probes is described. The stability of the instruments and possible sources of error in recording are indicated.

d. Various methods of converting the recorded data into a computer-compatible form are described. Their relative costs and accuracies are assessed.

e. Overall costs of using the equipment are assessed.

f. Advantages and disadvantages of using a strip-chart recorder are examined in comparison with use of a magnetic or paper tape recorder.

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Fraser, A. I. (1968). Recording some aspects of a forest environment. In Wadsworth, R. M. (Ed). The measurement of Environmental Factors in Terrestrial Ecology (Symp. Brit. Ecol. Soc. Reading 1967), 235-242. Blackwell Scientific Publications, Oxford and Edinburgh.

CONTENTS

1. INTRODUCTION

The main aim of this paper is to describe and discuss some methods of collecting detailed soil temperature data and converting them into a computer-compatible form. The methods were those used in Merlewood project 301/12 which is part of the intensive study of energy flow and nutrient circulation in a whole ecosystem on the Meathop Wood IBP site, near Grange-over-Sands. I have chosen to deal with my subject in some detail intentionally so as to give the reader an adequate background to the problems which arose and to the solutions to the problems.

Soil temperature data were required in the Meathop project for three main reasons:

a. To facilitate the setting up of laboratory experiments at temperatures close to mean field temperatures.

b. To allow metabolic data collected at various temperatures in the laboratory to be corrected for the difference between these temperatures and field temperature.

c. To allow comparisons of temperature or metabolic data to be made

   (i) within the site spatially or temporally and
   (ii) between Meathop and other sites.

2. SELECTION OF EQUIPMENT

In 1964-65, when the research was being planned, the equipment which was required had to be relatively inexpensive and had to possess certain characteristics:

a. The ability to record from 10-30 points continuously or at frequent intervals during each day, to cover the possible need for detailed temperature data in soil and plant physiological studies, and to facilitate accurate estimation of temperature mean and range on a daily, weekly, monthly and yearly basis.

b. The ability to operate satisfactorily from batteries in the absence of a mains electricity supply.

c. The ability to perform satisfactorily under field conditions when unattended for at least a week.

d. Of a design such that the general performance, including accuracy of recording, could be checked easily in the field.

In 1965 three types of recorder appeared to satisfy the above conditions:

(i) A 50-channel Westinghouse data-logger (Table 1) which had a punched paper tape output and which cost about £2500 or £50 per channel. This seemed to be a well-tested logger, and it had been chosen by the Forestry Commission for meteorological recording after examination of various logging systems, but it appeared to be too large and expensive for our temperature recording requirements. However, bearing in mind that it has performed satisfactorily for the Commission since about 1965 and that it has several advantages over other systems (Fraser, 1968 and 1969) it might have been a better choice than the equipment which we finally selected, particularly if it had been used to record data from all the meteorological equipment on the Meathop site.

(ii) A 10-probe D-Mac Limpet Logger (Table 1) which cost about £330 including 10 temperature probes with long leads and appropriate input boards. Calibration equipment and probably a second Logger would have been needed to cover all our requirements and inclusion of this equipment would have increased the total cost to £910 and cost per probe from £33 to £45.5. In the D-Mac Logger, data are recorded on magnetic tape and can be fed directly into a computer using a suitable interface, or, punched automatically on to paper tape for computer input. Early versions of the Logger were known to be unreliable in operation but an improved version became available in about 1965 when we were choosing equipment.

(iii) A Grant strip-chart Temperature Recorder (Table 1) which cost about £310, including 24 temperature probes with long leads, i.e. £13 per recording point. This was considerably cheaper than the other two systems but the running costs were likely to be greater than those for the data loggers because of the labour involved in converting the recorded data into a computer-compatible form. Like the Westinghouse assembly the Grant required to be housed in a well-insulated weatherproof shelter. It was known to be a fairly reliable instrument on evidence gathered from several users.

Ultimately, for Meathop, one Limpet Logger and one 24-point Grant Recorder were acquired with the intention of using the Logger for routine soil temperature recording over several years and the Grant as a reserve instrument and for recording temperature in special projects. On the basis of our experience with the instruments at Meathop, a 30-point Grant Recorder was purchased subsequently for use on the Moor House IBP site in the Northern Pennines.

3. THE LIMPET LOGGER

a. Outline description

The D-Mac temperature recording system consisted of up to 10 probes linked to a specially designed magnetic tape recorder which was enclosed in a heavy metal waterproof box. The probes available in 1965 were ach about 6 cm long and 1.5 cm in diameter and consisted of a transistor embedded in Araldite. The Mark II probes, which we tried to use after poor performance by the larger probes, were also cylindrical, 5.0 cm x 0.65 cm, and each consisted of a diode enclosed in a sealed stainless steel tube. Both types of probes had time constants* of about 3 minutes.

The recorder had several main parts:

(i) A precision clock powered by a 1.5 volt battery
(ii) A main control unit incorporating a power stabilizer, electronics controlling the sequence of operations and an analogue-to-digital converter
(iii) A channel selector
(iv) A magnetic tape-deck
(v) An internal power supply or terminals for an external supply (see Section 5 below).

b. Operation

Recording was initiated by the electromechanical clock. This switched on the power to the tape-deck motor and to the main control unit where the voltage was stabilized and applied to the sequence controller, the analogue-to-digital converter and the probes. The input voltage from the probes varied with temperature and was converted into pulse form by the analogue-to-digital converter and then recorded on the already moving magnetic tape. The analogue voltage input from each probe was sampled in turn via the channel selector, then power to the various parts of the Logger was switched off by the control unit.

4. THE GRANT RECORDER

a. Outline description

The Grant temperature recording system consisted of up to 24 or 30 probes linked to a modified Rustrak-type miniature Recorder. Each of the probes used at Meathop consisted of a thermistor bead mounted inside a stainless steel tube (length 13 cm, diameter 0.5 cm). Similar probes of about half this size were used at Moor House. Both probes had time constants of about 20-30 seconds, but other sizes and shapes of probes with different electrical characteristics are available.

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* A time constant is the time required for an electrical quantity, e.g. voltage or resistance, to rise to 63.2% of its final value or to fall to 36.8% of its initial value.

The Recorder contained a control unit which, in some instruments, is attached to the back of the Recorder, or, in others, housed in a separate die-cast box. This unit comprised an electric clock, a 5.4 volt battery or terminals for a *stepped-down mains power supply (Section 5), a multipoint* rotary switch and associated motor, input sockets for the probes, the circuitry necessary for calibration checks, an ON/OFF switch and a selector switch for choosing continuous or intermittent recording.

b. Operation

If the controls were set for intermittent recording, such as the hourly recording used *on the IBP sites, a cam on the* clock operated a switch which switched on the motors driving the strip-chart recorder and the rotary switch. A constant voltage of about 5.4 volts was applied to each thermistor in turn through the rotary switch and the current flowing through the thermistor was indicated by the galvanometer on the recorder. This current depended on the resistance of the thermistor, which in turn depended on the probe temperature.

While each thermistor circuit was complete, the loosely-pivoted needle of the galvanometer was pushed several times on to the moving pressure-sensitive strip-chart by a chopper-bar; thus a trace was produced from a series of scratches on the paper. In more modern Grant Recorders, short gaps between successive traces are produced by intermittent action of the chopper-bar. This facilitates identification of individual traces during chart reading. In the current studies, dummy probes, i.e. plugs containing very high resistances, were used to produce a gap between almost identical traces on the charts.

If the Grant was switched for continuous running, then the rotary switch operated continuously and, immediately after one recording cycle was finished, another began.

5. POWER SUPPLIES

The choice of source of power was conditioned by the availability of particular sources on the site, the voltage required, the variability in voltage tolerated by each recording instrument and the effect of temperature on the instruments and their power source.

a. Batteries

From April 1966, when recording first began, until May 1967, mains electricity was unavailable on the site and both instruments were battery-powered. Batteries were obtained either from ITT Electronic Services or Mallory Batteries Ltd. (Table 1).

(i) Limpet Logger

A constant voltage was unnecessary for this instrument as the built-in voltage stabilizer will stabilize voltages varying between 11.0 and 14.0 volts. 13.5 volt batteries, each composed of three 4.5 volt carbon-zinc radio batteries in series (Ever-Ready AD28 or equivalent), were mainly used for our Logger. D-Mac do not recommend these batteries for use below 0°C but our Logger recorded data at temperatures down to -3°C whilst it was powered by them. A manganese-alkaline battery, the Mallory SKB1141 consisting of nine Mn1300 cells, was recommended for use at low temperatures and it performed satisfactorily under these conditions. However, it was expensive, costing 5-9 times as much as a comparable carbon-zinc battery, but it had a longer shelf-life and larger capacity than the latter. Sutton and Rorison (1970) used a Deac (Table 1) chargeable nickel-cadmium accumulator successfully in their Logger. This is suitable for all the temperatures normally encountered in the field down to -20°C.

(ii) Grant Recorder

A constant voltage is essential for this instrument. As supplied in 1965 our Recorder was powered by a 5.4 volt mercury battery (Grant OR4) composed of four Mallory ZM12 or RM12R cells each supplying about 1.35 volts.

Initial laboratory tests with the Recorder running at temperatures ranging from about -9°C to 15°C indicated that if OR4 batteries were used near to or below 0°C, the recorded temperature and the battery voltage under load changed during each recording cycle (Table 2). Below 0°C the voltage change could be as high as 0.6 volts with one OR4 battery or 0.25 volts if two OR4's in parallel were used to reduce the current drain per battery. Use of a mercury battery composed of four Mallory RM1450R cells, specially designed for use at low temperatures, reduced the voltage change to about 0.16 volts at -8°C. Even for temperatures above 0°C, use of this battery minimized the variation in temperature recorded during a recording cycle (Table 2). Although the low-temperature batteries cost more than the OR4's, they had a greater capacity so the overall cost per day of use was about the same for both batteries. Because of these considerations, our Recorder was powered by a composite RM1450R battery during the whole of its first year of operation. On the Moor House site a Recorder using low-temperature batteries has performed satisfactorily under Pennine moorland conditions at ambient temperatures as low as -7°C (O. W. Heal, personal communication).

Grants now offer a range of alternative power supplies, including Deac accumulators and various high- and low-temperature mercury batteries with a shelf-life of two years or more at room temperature. They also supply Recorders suitable for various mains power supplies.

b. Mains

In May 1967, a 240 volt 50 cycles A.C. power supply became available at Meathop and this was rectified and stepped down for the instruments using a power-pack (Fig. 1) designed with the help of Mr. W. H. Moore (Freshwater Biological Association), constructed by Mr. J. Heath (Biological Records Centre, The Nature Conservancy, Monks Wood Experimental Station) and modified later by Mr. F. Broomfield (Grange-over-Sands). Electrical components were obtained mainly from ITT or Radiospares Ltd. (Table 1). The pack had three characteristics which made it particularly suitable for our purposes:

(i) The A.C. mains ripple on the rectified supply was reduced to well within the limits specified for the Logger.

(ii) If the mains supply failed, a stand-by 12.5 volt accumulator, consisting of two Lucas SCZ7E accumulators in series, was automatically brought into use.

(iii) The output voltages were adjustable so that about 11.5-14.0 volts off-load or 11.0-12.5 volts on-load was available for the Logger and a constant 5.75 volts, on and off load, for the Grant. A voltage slightly lower than 5.75 volts was preferred for the latter but the choice of voltage was limited by the availability of a suitable zener diode for the power pack. Because of the use of 5.75 volts rather than a 5.4 volt supply it was necessary to keep the Recorder at 13°-15°C (Section 6a), otherwise the limit of adjustment on the upper calibrating potentiometer (Section 7a (i)) was reached.

In 1968, after faults on the Logger had led to faults in the power-pack and an interruption of the power supply to both Grant and Logger, the latter was linked directly to the stand-by accumulators of the power-pack. This arrangement seemed to be satisfactory, but the accumulators needed recharging every 1-3 weeks.

6. INSTALLATION AND MAINTENANCE OF THE INSTRUMENTS

a. Selection of the recording site and installation of the instruments

The ecosystem studies at Meathop were centred on one particular hectare of deciduous woodland and work was carried out either on this hectare or on adjacent comparable areas.

As a first step towards choosing a recording site, the variability of soil temperature across the hectare was examined by installing 23 Grant probes horizontally at the base of the litter layer at points selected randomly from a grid of 30 permanent sampling points used for various purposes (Fig. 2). Recording began in April and continued until June 1966. Daily mean temperatures at each sampling point were calculated from hourly readings for the two or three days in each month on which the temperature range on the site was greatest (Table 3a).

It appeared likely that maintenance of temperature probes on the hectare would cause considerable site disturbance so the possibility of recording on an adjacent area was tested. Six probes were removed from the hectare and placed at the base of the litter layer on a small adjacent area (Fig. 2) in late June 1966. The remaining 17 probes gave an adequate estimate of soil temperature on the hectare (Table 3a). Soil temperature measured on the small area in July 1966 gave an accurate estimate of the soil temperature on the hectare (Table 3b) so Logger and Grant probes were installed horizontally in stacks in the soil (Table 4) on the small area (Fig. 2), and routine soil temperature recording began. One of the initial aims was to compare the performance of the two instruments, so some Logger and some Grant probes were placed alongside each other (Table 4). This comparison had to be curtailed because of poor performance by the Logger.

From April until December 1966, the recording instruments were kept in an insulated metal box placed on the soil surface in a well shaded place in the Wood. In December 1966, the instruments were transferred to more favourable conditions in a newly-built field laboratory. This was heated to maintain a temperature of >5°C. In spite of this and the provision of a stable stepped-down mains power supply (Section 5b above), it became difficult to maintain the Grant Recorder on calibration so in January 1969 it was placed in a polythene and wooden-frame tent in the field laboratory. The tent was heated by an electric light bulb controlled by a cheap bimetallic thermostat. Maintenance of a suitable environment for the Logger presented no major problems.

b. Probe leads

(i) Protection

The probes were up to 100 m from the instrument box or field laboratory so a considerable amount of cable was exposed to possible hazards (Fig. 2). The main bundles of leads were held together with PVC adhesive tape and suspended from a wire supported 30-50 cm above the soil surface. These leads were undamaged after use for four and a half years except for slight gnawing of the insulation by small mammals in the area where the cables ran along the soil surface and into the soil.

Other cables, running to a second recording area 100 m from the main site, were tied singly to wooden posts and suspended about 50 cm above the ground. These cables were cut frequently in one small area of the wood, probably by jays. The cutting ceased when the cables were laid on the soil surface and covered with planks or roofing tiles, but, again, small mammals caused some damage to the insulation.

At Moor House, Grant cables placed inside a split plastic hosepipe were adequately protected against sheep and small mammals but indification of individual cables was difficult when the need for checking arose. Suspension of cables from posts was eventually used and this was satisfactory except that some chafing of cable insulation on the posts occurred when the cables were moved by strong winds (O. W. Heal, personal communication).

(ii) Junctions

Junctions should be avoided in the field if possible as they are always a potential source of trouble. However, at Meathop, they were necessary where a cable was seriously damaged, and also 2-3 m from a probe where cables were longer than a few metres. The latter arrangement enabled us to test the long lead or the probe plus short lead separately, if a fault arose in a probe circuit. If a fault was detected in a long lead, and if a rapid inspection failed to reveal the cause of the trouble, the cheapest solution was inevitably to use a substitute cable. When a break occurred in the insulation, moisture seeped rapidly into the cable. The affected length was usually removed if about 0.5 m of cable on each side of the break was cut out before the cable was rejoined.

Three types of junction were used successfully (Fig. 3a, b and c). Typical examples of these were completely dry after 1 year (a), 1-3 years (b) and 1-1.5 years (c) of use. Extra protection was provided by inverting a metal biscuit tin, a plastic box or a concrete roofing tile over each junction. Junction type d (Fig. 3) was successful for only a few months. The small amounts of moisture, which gradually leaked into the plastic tube, led to corrosion of the plugs and metal tubular connectors and eventually to a significant change in their electrical resistance.

(iii) Labelling

Individual cables should be labelled so that they can be identified easily when cable faults occur. If cables are more than a few metres in length it may be necessary to label each cable at several points. It is particularly useful to have a label on each cable near to the recording instrument, on either side of a junction, inside junction boxes and near to the probes. Dymo plastic labels (Table 1) will last for several years on cables, if the two ends of each label are stapled together with an office stapler.

c. Routine maintenance

Keeping of an instrument log-book, which was taken into the field every time we inspected the instruments, has proved invaluable.

During the first eighteen months of the project a standard series of checks on instrument performance was developed and notes on the diagnosis of faults were written. The former were designed particularly to reveal faults which might otherwise have been overlooked, e.g. calibration drift, and to facilitate interpretation of the recorded data. The diagnostic notes included a list of the main faults which occurred, together with their symptoms. Copies of both the check-list and the notes provided a useful supplement to the manufacturers' handbooks and they were always available in the field laboratory. They reminded trained staff of their duties and were particularly useful when new staff had to assume responsibility for the instruments.

7. CALIBRATION OF THE INSTRUMENTS

a. Methods

Two types of calibration were used:

(i) Calibration without the probes

This involved checking and adjusting the recording instrument so that it recorded accurately when a standard electrical analogue of temperature was fed into it. This analogue was normally produced externally for the Logger and internally for the Grant.

For the Logger, this calibration involved adjustment of the analogue-to-digital converter and it should not be required when D-Mac probes and circuitry are being used. We never attempted it. Calibration of the Grant Recorder changes with temperature and/or with changes in the power supply voltage (Section 7b (ii)). Re-calibration was therefore carried out at least once per week at two reference points using the two built-in rotary potentiometers. Suitably positioned points may be chosen when the Grant is being ordered.

(ii) Calibration with the probes

This involved comparison of the temperature recorded by the Logger or Grant with that indicated by an accurate thermometer, followed by adjustment of the calibration (the Logger) or correction for calibration error (the Grant). For laboratory calibration, a bundle of probes was suspended in a vigorously stirred water-bath so that the probe tips were as near as possible to and at the same level as a mercury-in-glass thermometer (10 cm immersion, range -5°-+40°C, graduated in 0.1°C and calibrated by the National Physical Laboratory to the nearest 0.05°C). The water-bath temperature was controlled to within ± 0.25°C, but calibration was attempted only when the temperature was stable to within ± 0.1°C.

For field calibration, either the probes and thermometer were placed in water in a thermos flask, the contents being shaken gently and continuously, or the thermometer was placed alongside a probe in the soil. Field calibrations were carried out only when the ambient temperature was virtually constant. In field and laboratory calibrations a reading from a probe under test was always compared with the mean of thermometer readings taken before and after the probe reading.

For the Logger, calibration (ii) involved adjustment of resistors on the input boards until the probes under test were on calibration at two points, one at each end of the measureable temperature range. The digital reading from each probe, i.e. the reading which would normally be recorded on magnetic tape, was indicated on the visual display unit of a D-Mac portable calibrator.

The Grant probes are carefully matched with each other and with the Recorder by the manufacturers but changes in their calibration may occur and if necessary these would have to be corrected during data processing.

b. Changes in the accuracy of recording

(i) Limpet Logger

Factors such as changes in ambient temperature or power supply voltage did not appear to affect the calibration of the Logger but such effects may have been obscured by the many instrument faults which occurred.

The Logger transistor and diode probes were on calibration to within ± 1 digit on the portable calibrator (± 0.5°C) at all points in the measureable temperature range (-10°-40°C) immediately after calibration. Both types of probe, or their associated circuitry, were unstable in routine use, wandering off calibration 0.5-2.0°C within a few days or weeks after calibration. This and other instrument malfunctions caused us to stop using the Logger and led other workers, e.g. Sutton and Rorison (1970), to use alternative types of temperature-measuring probes and circuits with the Logger.

(ii) Grant Recorder

The accuracy of the temperatures recorded on the Grant depended on the magnitude of four types of error, the first two being associated with probe characteristics, the second two with the characteristics of the Recorder when it was operating with the probes:

1. The range of variation in the temperatures recorded from different probes, when the latter were all at the same temperature, was approximately ± 0.3°C in both 1965 and 1970.

2. The drift in calibration of individual probes between purchase of the equipment and the end of recording (1965-1970) ranged from 0 to -0.3°C for recorded temperatures of 0°-20°C. These slight changes were probably associated with changes in thermistor resistance with age (see, for example, Mortimer and Moore, 1953), or changes in the resistance of probe lead connections.

3. The temperature indicated by the Recorder deviated from the ambient temperature experienced by the probe in a characteristic way which was related to the characteristics of the electrical components in the instrument (Fig. 4). According to its specification the Grant ought to record within ± 1°C. These limits were achieved over a recorded temperature range of about -5° to +40°C when the Recorder was on calibration at its two fixed reference points, 15° and 35°C.

4. Because the Recorder components were sensitive to ambient temperature changes, internal calibration of the instrument at the two reference points varied ± 1°C independently of the temperature experienced by the probes.

If the errors indicated in 1-4 above were additive, then the maximum deviations of recorded temperatures from true temperatures would be -2.6° and $+2.3^{\circ}C$ for individual temperature recordings on the chart. In practice, recorded temperatures were not corrected for the variations between probes (1) and drift in probe calibration (2) because these errors were so small and were compensated for partly by use of replicate probes at the same soil depth. No correction was made for the variation in the internal calibration of the Recorder (4) but this error was minimized by checking and adjusting the Recorder at least once per week (Section 6c above) and by keeping it at a fairly high and constant temperature (Section 5b and 6a above).

All recorded data were corrected for error (3) using a computer program developed by D. K. Lindley (Systems Section, Merlewood). This used the relationship

$$T = 0.372449 + 1.18680t - 0.0254072t^2 + 0.0010620t^3 - 0.0000206803t^4 + 0.000000185889t^5,$$

where T and t are respectively the corrected and the recorded temperature. Coefficients correct to a large number of decimal places were essential to avoid errors of $>1^{\circ}-2^{\circ}C$ in the corrected data.

8. TRANSFERENCE OF THE RECORDED DATA TO A COMPUTER

a. Data collected on magnetic tape

There are several ways of handling data in this form. They may be read directly into a computer from tape using a suitable interface; this approach has been used at the Institute of Hydrology at Wallingford. Alternatively, they may be punched on to paper tape, printed out, or displayed in digital code on a visual display unit for checking purposes. Suitable equipment, e.g. the D-Mac automatic translator with visual display only, cost basically about £1000, a tape-punch or typewriter being optional extras costing £350 or more.

Sutton and Rorison (1970) are successfully using a translation system for Logger tapes which involves feeding the output from a modified D-Mac portable translator through a special adapter unit into a Solartron Data Logger (Table 1). The electrical output from the latter drives a tape-punch and an electric typewriter. One advantage of this system is that the digitally coded information on magnetic tape is converted into temperature values and the output consists of simultaneously produced paper tape and a print-out for checking purposes.

To extract the data from the Meathop Logger tapes, we used the D-Mac translation service which produced a paper tape punched in a specified code, e.g. ASCII eight-track or Ferranti Mercury five-track code. This service was rather slow but it was relatively cheap and in our experience the output was acceptable for many purposes. It was always in the digital code used on the Logger magnetic tape but a computer program for conversion of the data into temperature form could easily be written.

b. Data on strip-charts

If £2000 or more is available, a commercially manufactured trace-reader or pencil-follower may be bought to convert data on strip-charts into a computer-compatible form (see equipment by D-Mac Ltd. and Normalair-Garrett Ltd. (Table 1)). For most of the Meathop data several less sophisticated methods of extracting the data were used:

(i) Manual method

This involved placing each chart on a simple stand made of Tufnol, brass and white metals (Fig. 5), reading off each temperature to the nearest 0.5°C and writing it down on a printed form, then later, punching the data on to paper tape. The printed form was arranged so that each row contained all the data collected from different probes on a particular hour of a particular day. Each column contained all the hourly data collected from one probe in one day. Columns were numbered 1-24 and a space was available at the head of each column for insertion of depth of probe in the soil. Hours of the day were printed at the side of the form and there were two rows of 'boxes' for daily total and mean temperatures per probe at the foot of the form. 'Boxes' were available at the head of the form for insertion of information on the instrument in use, the site, date and day number.

Reading off the data from the charts was very tedious and expensive so we attempted to improve our technique in several ways (Table 5). Of these, reading off and simultaneously punching the data was the most rapid and cheapest approach. Editing of the paper tapes produced by this method is relatively easy if a standard, clearly defined tape format is adopted.

(ii) Use of a commercial data processing service

Strip-charts can be read satisfactorily commerically but the cost is high even when a special low-price contract is arranged for the work (Table 5). We used the firm now known as the C. I. Data Centre Ltd., (Table 1), and obtained satisfactory tapes and print-outs of data collected over eighteen weeks.

(iii) Use of a custom-built chart-reader

This instrument, costing approximately £1300, with a punched-tape output (Fig. 6) was acquired by the Chemical Section at Merlewood primarily for the reading of charts approximately 25 cm (10") in width. It can be used to read off Grant data rapidly and cheaply (Table 5), but, instrument or operator errors are less easily detected with this approach than with (i) above because of the absence of a print-out at the time of punching. The reader can discriminate between two points on the chart c. 0.25 mm apart which is equivalent to 0.25°C on a Grant chart with a 50°C span. Lack of reproducibility due to errors associated with factors such as parallax or lateral movement of the chart could add another 0.25°C to the error. Scaling values, indicating the digital readings for the left- and right-hand sides of the chart scale, have to be inserted on the tape to allow conversion of digital units to °C. This insertion and the conversion itself introduces another possible error of about 0.25°C. It therefore appears that temperature data produced by this type of chart-reading followed by computer data processing will have an error of >0.5° <1.0°C in addition to recording errors.

On the basis of the figures in Table 5, use of the Merlewood chart-reader or manual reading plus simultaneous punching are clearly the best methods of extracting data from the Grant charts, but recording on magnetic tape followed by automatic data processing is cheaper.

9. OVERALL COSTS OF COLLECTING SOIL TEMPERATURE DATA

In Tables 5 and 6, I have attempted to cost the collection of temperature data at Meathop on the basis of the actual costs incurred for the Grant Recorder and the costs that would have been incurred for the Logger if the latter had performed satisfactorily. All the costs are based on prices and salaries for the 1966-69 period, but the figures can be scaled up to 1973 values using a multiplying factor in the range 1.5 to 2.0. Table 6 should be easily understood if the associated notes are studies. We did not develop and use the cheapest methods of extracting the data from the Grant charts until towards the end of the work, but it should be stressed that, of all the methods we used, the cheapest were the most unpleasant and difficult methods for the worker. The main conclusions from these analyses of times and costs are indicated in Sections 10 and 11 below.

10. PARTICULAR ADVANTAGES AND DISADVANTAGES OF USING A MINIATURE STRIP-CHART RECORDER FOR TEMPERATURE DATA CAPTURE

a. Advantages

(i) Simplicity of design compared with that of, say, a Limpet Logger, so maintenance is relatively easy without the aid of a trained electronics technician.

(ii) Coupled with (i) is reliability. Once we had identified and solved the problems related to the effect of temperature on our Grant Recorder, we found that it was very reliable.

(iii) The recording of data on to a strip-chart provides a permanent record of those data, and, as the data are potentially immediately available at the time of recording, identification and correction of instrument faults is facilitated. On the Grant, for example, we found that the trace for a probe whose lead contained a slightly wet junction had a characteristic feathered appearance. This symptom would not have been detected on a magnetic tape recorder without the use of a special probe calibration instrument.

(iv) A strip-chart record is extremely useful when a scientist wishes to record information more or less continuously and where his main interest lies in certain types of values, e.g. maxima or minima or, in the case of soil temperature, say the number of days on which the temperature exceeds a certain value. Such information can be extracted very rapidly from a strip-chart — probably more rapidly than by using a computer with a magnetic tape or punched tape record bearing in mind the time needed for checking and editing computer inputs and outputs.

(v) Low initial cost. In the mid-1960s a 24-point Grant Recorder cost about a third of the price of two 10-channel Loggers plus calibration equipment (Table 6).

b. Disadvantages

(i) The overall size of the recorder limits the size of the chart which can be used and this affects the resolution, accuracy and precision of the whole recording assembly. The use of very sensitive transducers becomes a luxury if the characteristics of the recorder limit the performance of the whole assembly.

In some miniature strip-chart recorders part of the temperature range which the recorder can measure can be expanded to cover a full chart-width and hence the resolution may be improved. However, use of this facility with hourly recording would require more sophisticated electrical circuitry which could reduce the instrument's reliability and which would increase costs.

(ii) Data on a strip-chart are not in an easily manageable form. To convert them to a computer-compatible form or even a form useable with a desk calculator is tedious, time-consuming and expensive (Tables 5 and 6).

11. CONCLUSIONS

a. The Limpet Logger (1965 vintage, modernized in 1968) was a most unsatisfactory instrument for recording temperature largely because of the instability of the D-Mac temperature-measuring system. The latter may have been improved since 1968. Sutton and Rorison (1970) describe an alternative system for the Logger and this is apparently a great improvement on the D-Mac version. Use of an improved Logger would be a cheaper and more efficient way of collecting temperature data than use of a Grant Recorder.

b. The Grant Recorder (1965 vintage) was a very reliable instrument for recording temperature. It produced an instantly visible and permanent record of the data being collected but it had two main disadvantages in use:

(i) It was very sensitive to small changes in power supply voltage and in ambient temperature.

(ii) Conversion of data on strip-charts into a computer-compatible form was laborious and expensive.

c. Temperatures can be recorded on the Grant and extracted from the strip-charts with an accuracy of better than ± 3.5°C (range) using a chart-reader with a punched-tape output or by reading off the data and simultaneously punching them on paper tape. By correcting for instrument error, the accuracy can be improved to better than ± 2.5°C. This value includes a maximum error of ± 1.0°C associated with the reading off and punching of data and ± 1.5°C associated with variation between probes and drift in the calibration of the probes and the Recorder.

d. The main advantages to be gained by using a magnetic or paper tape recorder are avoidance of tedious work during initial data handling and facilitation and acceleration of data processing. There seems to be no significant financial advantage (Tables 5 and 6).

Fraser, A. I. (1969). The uses of automatic data-loggers in forest research. J. Roy. Stat. Soc. Series C. (Applied Statistics) 18(1), 78-81.

Mortimer, C. H. and Moore, W. H. (1953). The use of thermistors for the measurement of lake temperatures. Mitt. int. Verein. theor. angew. Limnol. 2, 1-42.

Sutton, F. and Rorison, I. H. (1970). The modification of a data logger for the recording of temperatures in the field, using thermistor sensors. J. appl.Ecol. 7, 321-329.

Table 1.

Main suppliers of equipment, materials and service

C. I. Data Centre Ltd., Wellington House, Station Road, Aldershot, Hants.

Deac (Great Britain) Ltd., Hermitage Street, Crewkerne, Somerset.

D-Mac Ltd., Queen Elizabeth Avenue, Hillington, Glasgow, S.W. 2.

Dymo Ltd., Astronaut House, Hounslow Road, Feltham, Middlesex.

A. C. Farnell Ltd., Industrial Division, 81 Kirkstall Road, Leeds 3.

Grant Instruments (Development) Ltd., Toft, Cambridge.

ITT Electronic Services, Edinburgh Way, Harlow, Essex.

Mallory Batteries Ltd., Gatwick Road, Crawley, Sussex.

Normalair-Garrett Ltd., Industrial Electronics Division, Yeovil, Somerset.

Radiospares, P.O. Box 427, 13-17 Epworth Street, London, E.C. 2.

The Solartron Electronic Group Ltd., Farnborough, Hants.

Westinghouse Brake and Signal Co. Ltd., Automation Division, New Road, Chippenham, Wilts.

Table 2.

Change in the temperature recorded during a recording cycle when the Grant Recorder was kept at various temperatures.

Ambient temperature of Recorder and one probe °C	Range of temperature recorded by the probe during one recording cycle °C	Batteries used
14.7	0.3	One OR4
4.5	0.5	One OR4
0.4	1.2	One OR4
- 7.7	2.6	One OR4
- 9.0	0.8	Two OR4s in parallel
- 9.0	0.2	One RM1450R assembly
> 0.0	< 0.1	

Table 3.

Variation in temperature at the base of the L/F layer on the Meathop Wood IBP site:

a) across the type hectare,

b) between the type hectare and a small adjacent area (Fig. 2).

The two mean temperatures given for each day were not significantly different from each other (P >0.25)

a)

Date	Daily mean temperature (°C) on the type hectare with S.E.	
	23 probes	17 probes
8.4.66	6.50 ± 0.040	6.48 ± 0.045
9.4.66	6.62 ± 0.027	6.62 ± 0.032
10.4.66	7.08 ± 0.039	7.09 ± 0.044
7.5.66	8.73 ± 0.075	8.72 ± 0.072
8.5.66	8.33 ± 0.034	8.35 ± 0.027
9.5.66	9.29 ± 0.108	9.28 ± 0.094
12.6.66	14.78 ± 0.050	14.82 ± 0.057
13.6.66	14.46 ± 0.051	14.49 ± 0.061

b)

Date	Daily mean temperature (°C) with S.E.	
	Type hectare 17 probes	Small adjacent area 6 probes
8-9.7.66	15.10 ± 0.111	15.17 ± 0.112

Table 4.

Arrangement of the temperature probes in the soil profile on the small area alongside the type hectare at Meathop.

Station	Depth of probe in soil (cm)	Type of probe
1	0, 5, 10, 20, 30, 50	Grant
2	0, 5, 10, 20, 30, 50	Grant
3	0, 5	Grant
	0, 5, 10, 20, 50	Logger
4	0, 5	Grant
	0, 5, 10, 20, 50	Logger

O cm = Base of L/F layer or top of mineral soil

Table 5.

Approximate time taken and costs for extraction of temperature data from Grant charts and Limpet Logger magnetic tapes, costs based on 1966-69 values.

Method of extraction	Minutes per 1000 data			£ Cost
	Reading	Punching	Reading and Punching	
GRANT				
1. Reading and writing down on standard forms, then punching	200	80	280	1.75*
2. Reading and simultaneous punching	-	-	80	0.50*
3. As 2. but using a commercial data handling service	-	-	0 at the Research Station	3.90+
4. As 2. but using Nature Conservancy chart reader	-	-	80	0.50*
LOGGER				
5. Machine translation by D-Mac Ltd.	-	-	0 at the Research Station	0.20+

* Figures based on junior staff salary of £780 per year or c. £3 per working day; depreciation on equipment, maintenance of equipment, other running costs and overheads are not included but cost of checking and editing tapes prior to computer input is included.

\+ All costs and a profit margin included.

Table 6.

Overall costs[1] of using either a Grant Recorder (20 probes) or two Limpet Loggers (2 x 10 probes) to collect 524,160 hourly temperature data over three years. (see additional notes on next page).

		Recorder	2 Loggers and portable calibrator
a)	Initial cost including probes and leads[2]	310	910
b)	Depreciation on capital invested in equipment[3]	93	273
c)	Running costs including expendables staff time for maintenance of overheads[4]	644	648
d)	Data extraction	1013[5]	241[6]
	Totals (b + c + d)	1750	1162
	Data extraction using cheapest method throughout	339	241
	Revised totals	1076	1162
	Cost per 1000 data	2.05	2.22

Notes on Table 6

1. All costs are based on 1966-69 figures. Multiply figures by 1.5 to 2.0 to obtain comparable 1973 values.

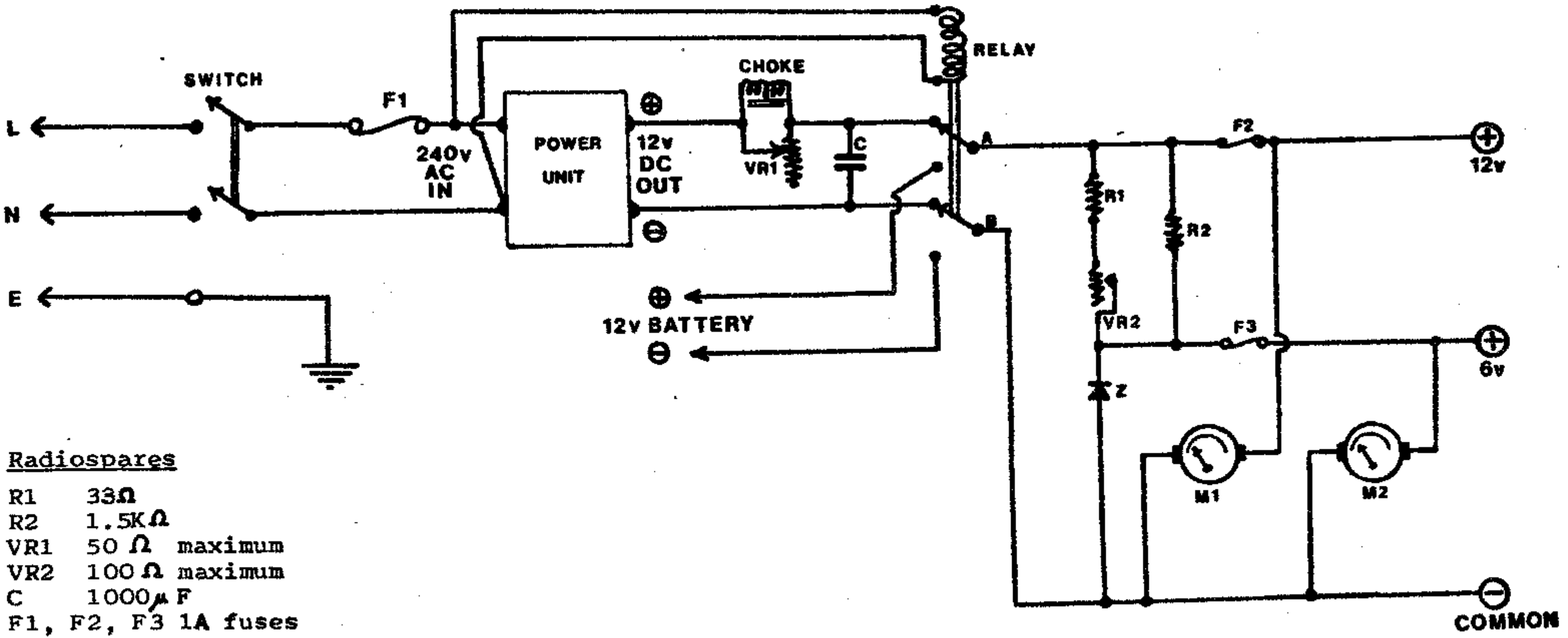
2. 1965-66 prices.

3. 10% of initial price, per year.

4. Includes one day per week of one A.S.O.'s time (£468 where salary = £780 per annum or £3 per working day) + a proportion of Soil Ecology Section overheads (£95 = 0.204 x salary cost) including part of the cost of Station administrative staff, post, general stationery, telephones, rates, electricity, fuel for heating + batteries or cost of a power-pack (£45) + one strip-chart per three weeks (£26) for Grant or 4 magnetic tapes per year for Logger (£30) + sundries, including special stationery, part of cost of Avominor, etc. (say £10).

5. Based on data given in Table 5 where 50% of the data was extracted using method 1 (£458), 38% with 2 (£100) and 12% with 3 (£225) + a proportion of Soil Ecology Section overheads (£230 = 0.293 x salary cost) including the overheads given in 3 above and a proportion of the Section computing costs.

6. Includes charge for D-Mac translation service (£112) + staff time for checking and editing tapes prior to computer input (£100) + overheads on staff salary as in 4 (£29).



<u>Radiospares</u>

R1	33Ω
R2	1.5KΩ
VR1	50 Ω maximum
VR2	100 Ω maximum
C	1000μF

F1, F2, F3 1A fuses

Choke: "Midget" 60mH, 500mA, 6Ω

<u>ITT</u>

Z	Zener diode Z2A56F, 5.6V, 1W
M1	Shinohara MR38, 12V DC, 0-20V
M2	Shinohara MR38, 6V DC, 0-12V

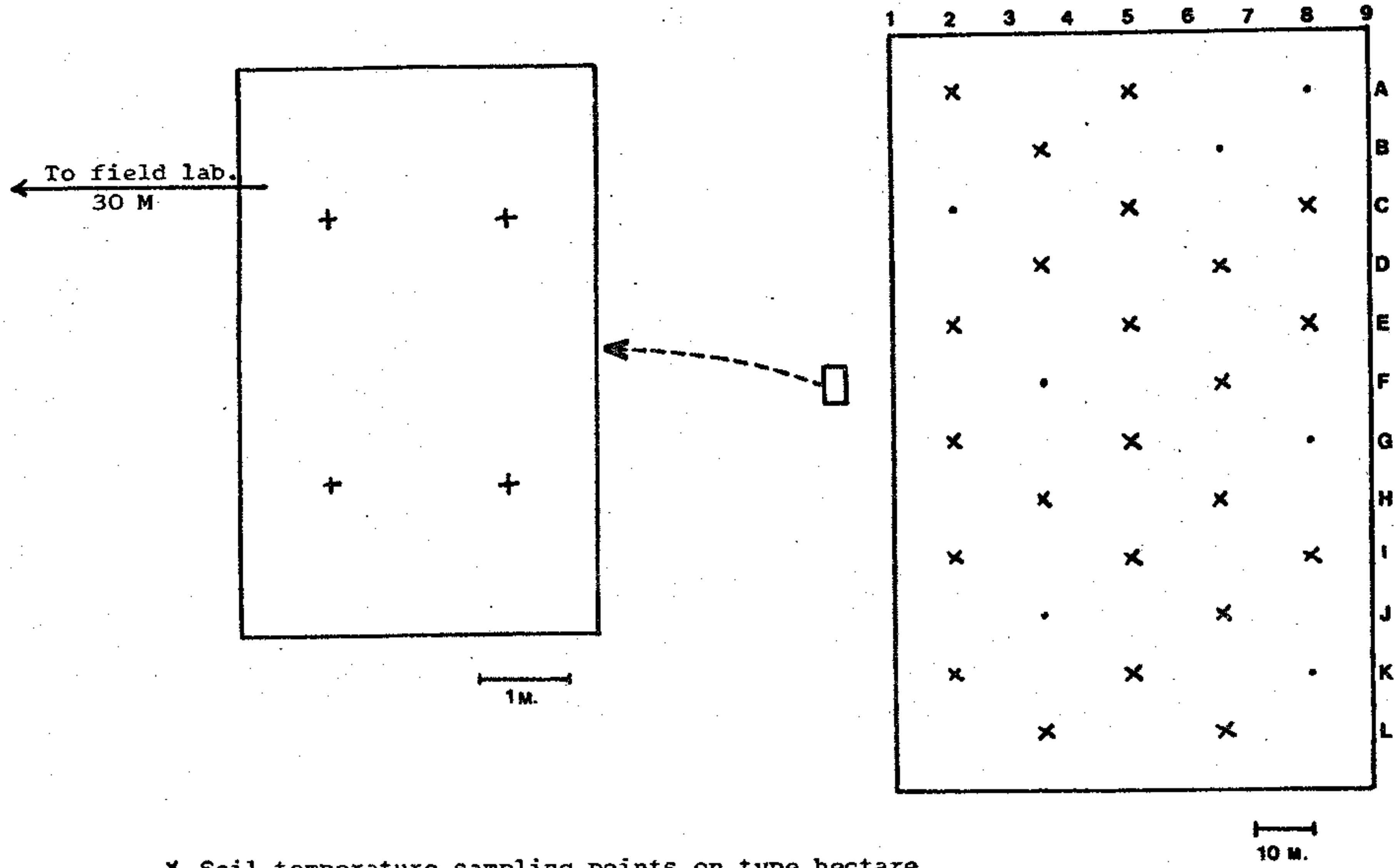
Relay: Keyswitch MK2P, 230V, 50c/s AC
Power Unit: Newmarket FC106, 12V, 500 mA DC

Figure 1. Electrical circuit of power pack

Notes for Figure 1

The circuit diagram shows the relay in the operated position. When the mains supply is switched off, the relay switches input terminals A and B over to a 12 V battery supply.

The choke is shunted by variable resistance VR1 set to approximately 2Ω to prevent excessive voltage drop under heavy load when the Grant clock is first switched on. Condenser C1 reduces the mains ripple produced when a DC supply is produced from AC. Resistors, R1, R2 and VR2 combine to give a normal working resistance of about 72Ω. When starting the Grant clock it is necessary to reduce this combined resistance (to not less than 33Ω), using variable resistor VR2. When the clock has started, VR2 should be altered to its initial setting.



× Soil temperature sampling points on type hectare

• Other permanent sampling points

+ Soil temperature sampling points on area adjacent to type hectare

Figure 2. Arrangement of soil temperature sampling areas at Meathop

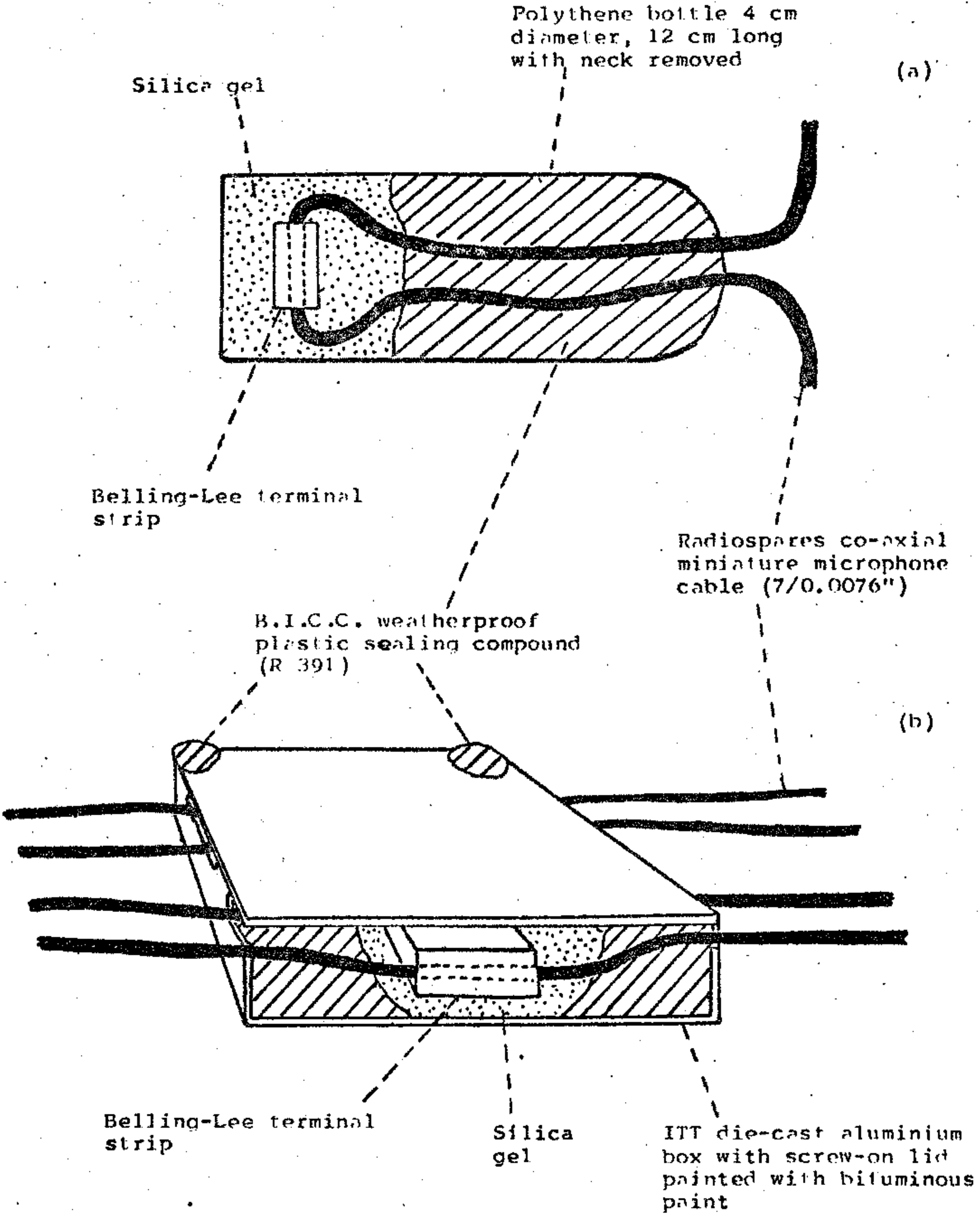


Figure 3. Types of cable junction for field use.
(a) and (b) for Grant cables

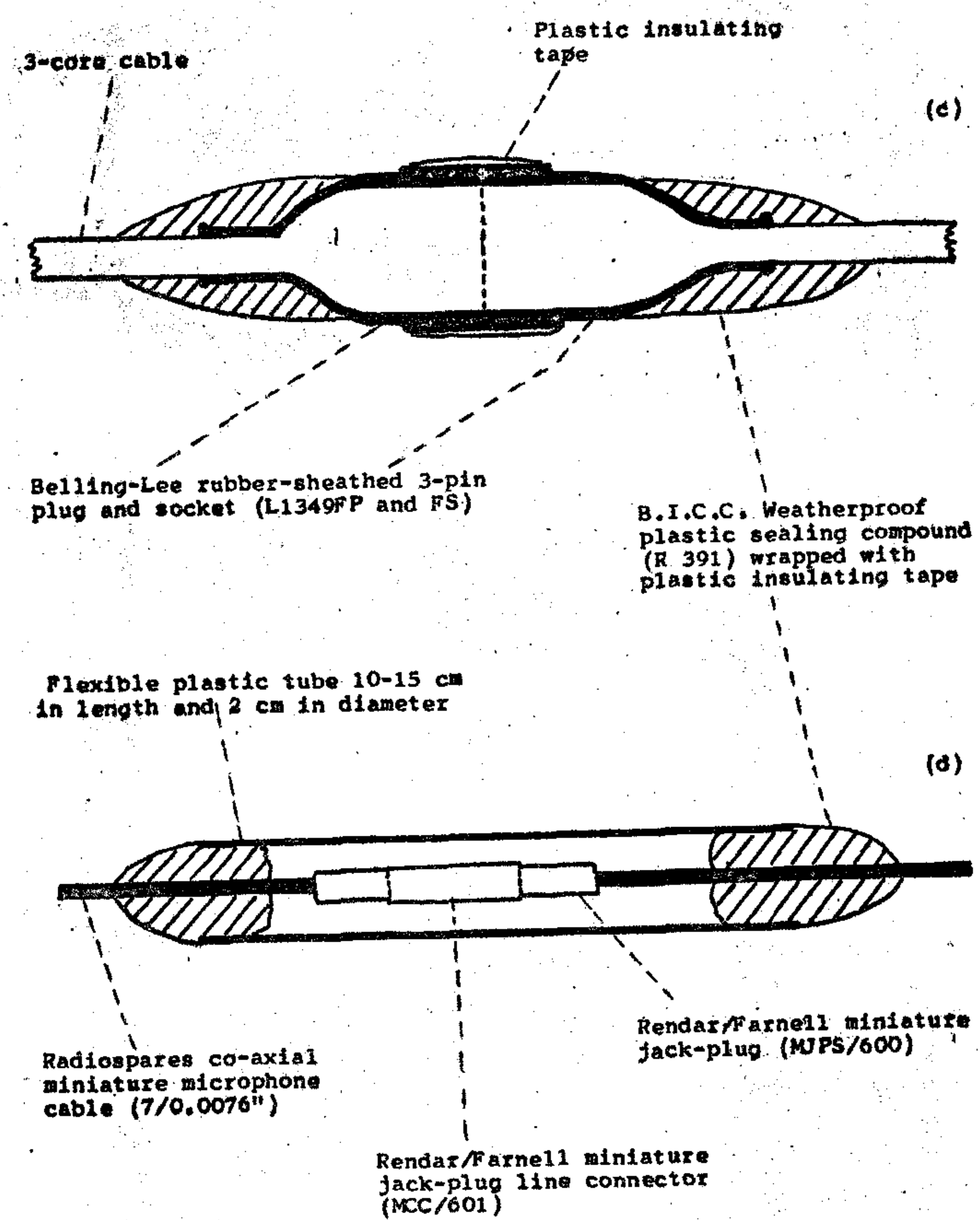


Figure 3 (continued). Types of cable junction for field use:

(c) Logger cables

(d) Grant cables. One example of an unsatisfactory junction for comparison with (a)-(c)

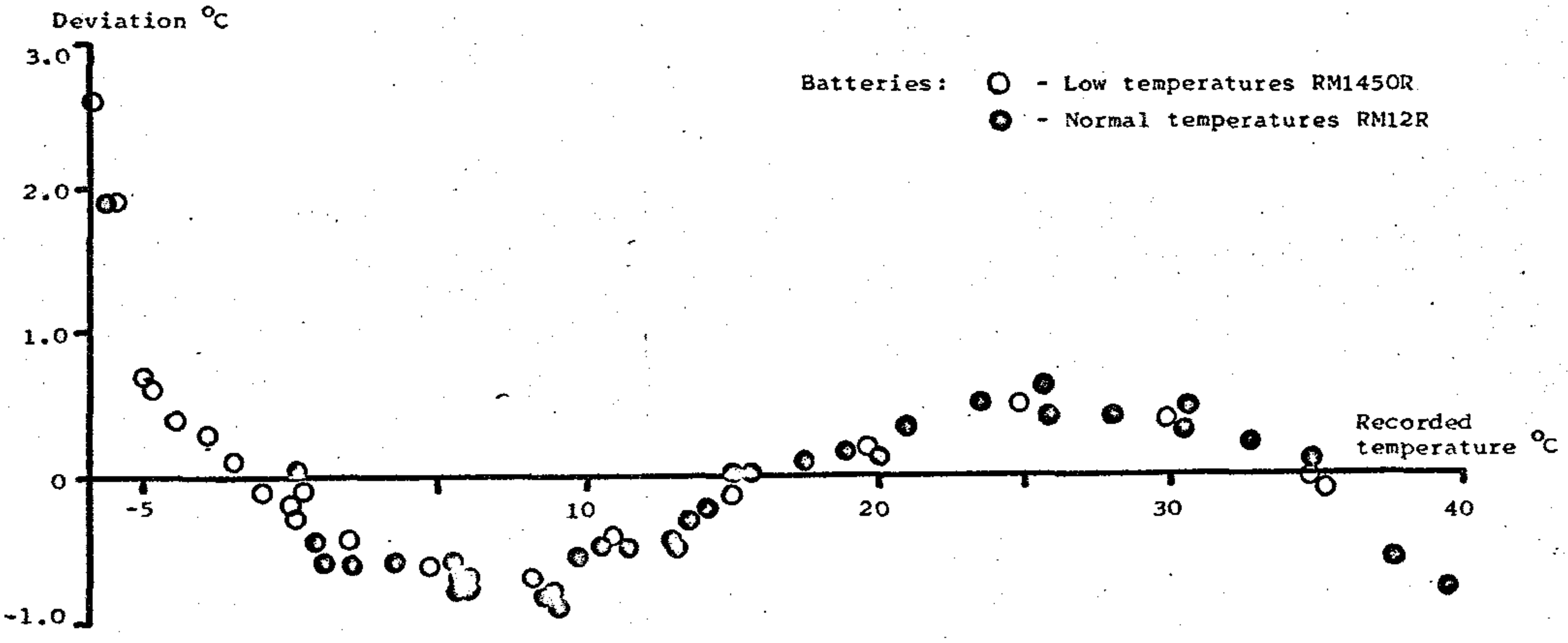


Fig. 4. Grant recorder - deviation of the recorded temperature from the true temperature

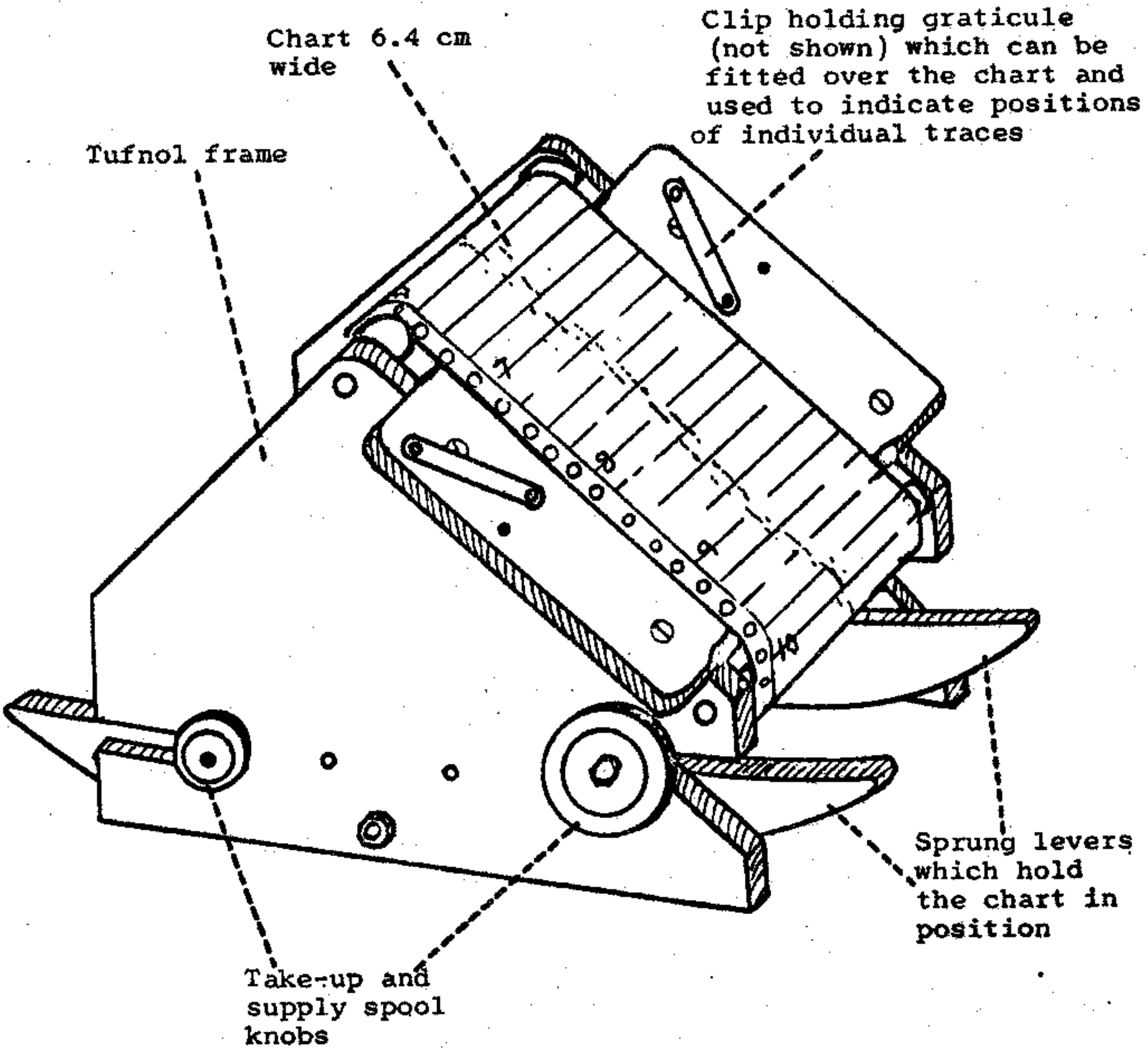


Figure 5. Chart reading stand for Grant charts

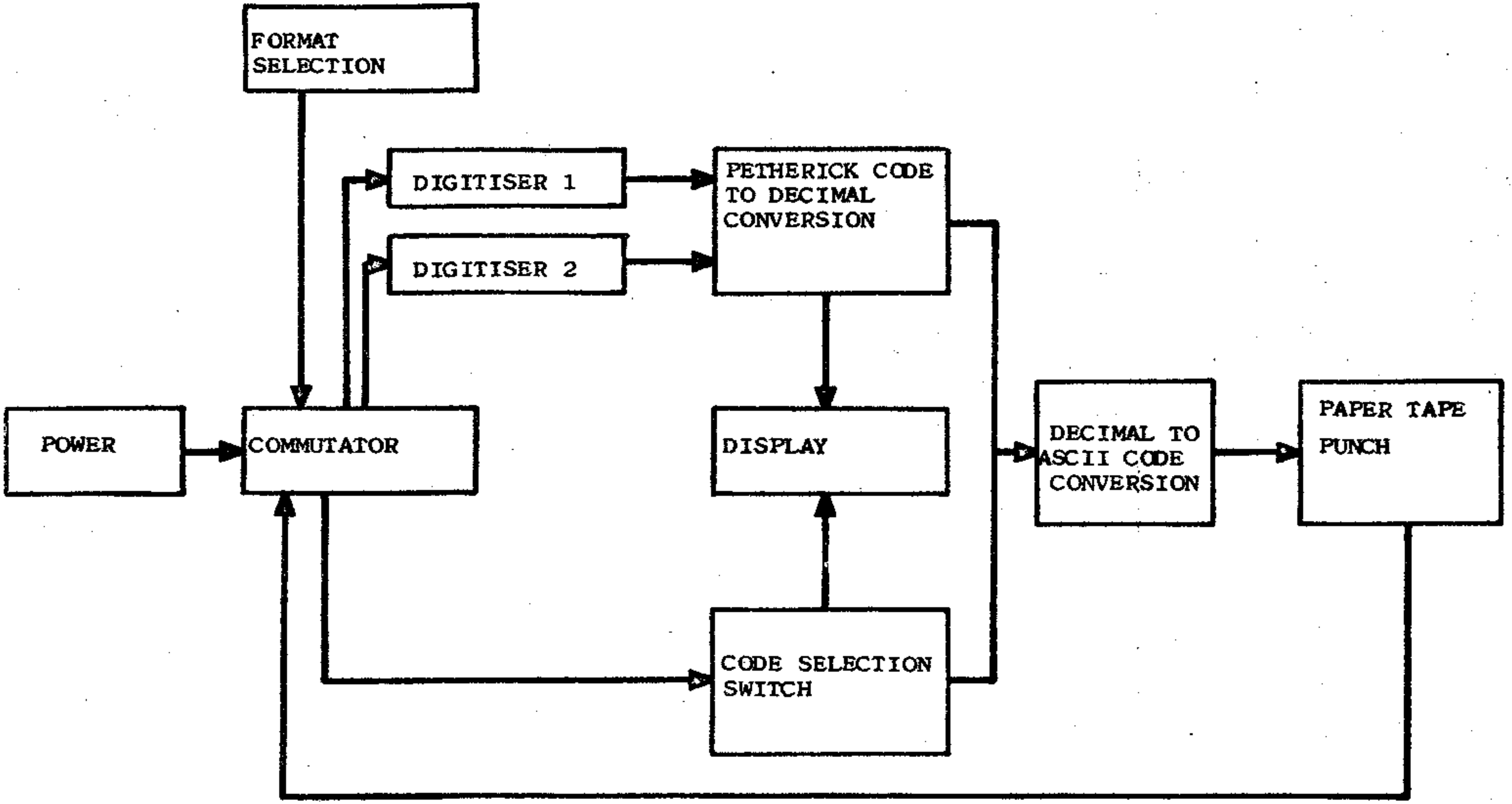


Figure 6.   Main units and controls of Merlewood chart reader