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"Instrumentation for wide-frequency-band (0.01 - 100 millihertz) geomagnetic induction work"

Dienstag, den 14.9.1971

Geomagnetic induction work has been carried out in western Canada since 1963, mainly in joint projects between the Earth Physics Branch (formerly Dominion Observatory) in Victoria and the Department of Geophysics at the University of British Columbia. Until recently Askania variographs were the primary instrument used in this work; during the last few years, saturable core (fluxgate) magnetometers were also used to supplement Askania stations; in addition, the University of Alberta group has recently started to use variographs of the GOUGH and REITZEL (1967) type. The westernmost area of this region is characterized by heavy attenuation in ΔZ at shorter periods, and most of the work since 1963 has been concerned with delineation and interpretation of the "low-ΔZ" zone.

Throughout this work we have always been hampered by the limited Z sensitivity of the variographs. Although quite adequate for "normal" Z regions, they simply did not provide enough short-period data with adequate signal-to-noise ratio at the western stations. This is illustrated in Fig. 1, showing the power ratios between Z at a western station and Z at an eastern station. The western attenuation in Z is of the order of 8-12 db for periods of 1000-2000 sec., and even higher for periods below 1000 secs. As long as we were using such surveys primarily for mapping, these data could be used qualitatively; however, as soon as quantitative interpretation in terms of conductivity structure models was attempted, the restricted band-width (of the order of 1 - 1.5 decades) for which valid data were available resulted in models which were far too ambiguous. In order to obtain even remotely non-unique models, considerably broader band-width (>2.5 - 3 decades) would be required, and instrumentation was consequently developed to provide these

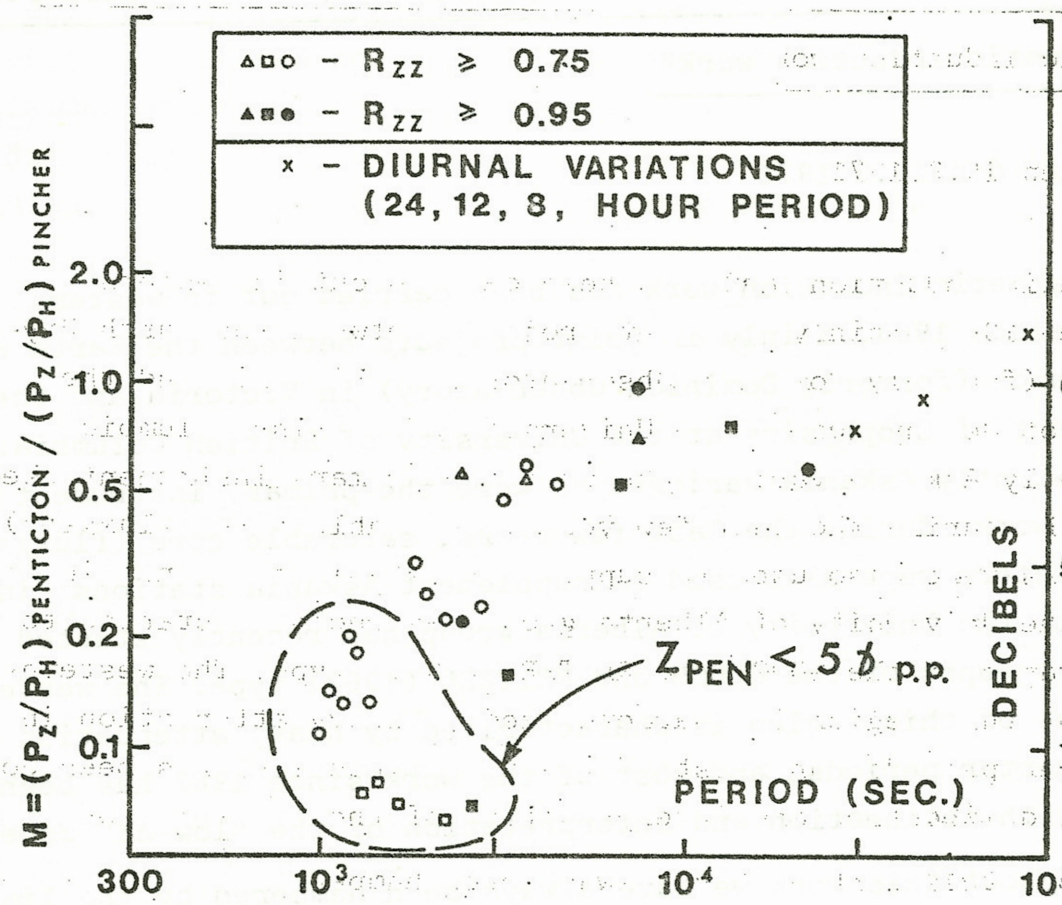

Fig. 1: Power ratios as a function of period for a west/east pair of stations.

short-period data. It should be noted that the low-ΔZ region in question is hardly a "local" feature. In its Canadian section alone the zone is of the order of 750 km wide and at least 1000 km long, and an even larger area in the western U.S.A. presents the same instrumental requirements. Development of instrumentation specifically suited to these requirements is therefore justified, particularly since this region contains a large variety of tectonic features of high interest. Use of this instrumentation is of course not restricted to "low-ΔZ" regions - it is fully flexible for use over a wide range of latitudes and conductivity-structure conditions. It should be emphasized that this development does not involve any revolutionary new discoveries; it is simply a logical assemblage of components which have recently become available.

Since no very short periods (<10 sec.) were to be covered, time-scale resolution presents no problems; in fact even the photographic variographs could readily be adapted for higher resolution. Our Askania variographs have been modified to provide variable chart speeds (20, 30, 60 mm/hr or even higher), and the variographs of GOUGH and REITZEL do already have high time resolution. However, without increased sensitivity the higher chart speeds do not really provide useful short-period information in the "low-ΔZ" region. An examination of Fig.1 shows that straight-forward increases in sensitivity would not solve the problem either: since there is no attenuation at the longer periods, instruments with high-Z sinsitivity would easily go off-scale during even minor disturbances or bays, i.e. any increase in sensitivity must be supported by an increase in dynamic range as well. Also, when running profiles across low-Z/high-Z discontinuities, interchangeable Z variometers with different sensitivities would be required; although technically feasible for both types of variographs, it is hardly a practical solution. It is clear therefore that we would require variable sensitivities as well as higher dynamic range. We have consequently had to turn to electronic systems, with some regret, since it meant losing the thermal stability which permitted data collection at the diurnal periodicities; we feel that the resulting loss of about 1/2 decade at the long-period end is more than compensated for by the addition of about 2.5 decades to the short-period end.

In any case we are still planning to supplement our profiles with Askania stations at selected sites in order to obtain the diurnal data.

Development of these broad-band systems was made possible by two recent technical advances and by one "administrative" stroke of luck:

a) Commercial availability of a transistorized three-component saturable-core magnetometer, at modest cost (about 3000). This instrument (Trigg et al, 1971) is a transistorized version of the tube-type "IGY" design of SERSON (1957). Its DC power consumption is low enough (~5 Watt) to permit battery-powered mobile operation.

b) Design of an automatic zero suppression circuit by TRIGG(1970); this circuit applies a baseline shift whenever the output signal of the magnetometer reaches a preset limiting value. Since the circuit can "step" 7 times in each direction it provides a large improvement in dynamic range; for example a total range of 1600 gamma-to-peak can be handled even though the recording device operates at a full-scale range of only 200 gamma.

c) It was found that the seismic research groups at the participating organizations were in possession of a number of slow-speed FM tape recorders (Geotech type 17373 or Precision Instruments type PI-5100). These were in intensive use for relatively short periods of time, but could be applied to geomagnetic use during the rest of the year. Since the recording device represents the most expensive single item in these systems, such "free" availability permitted the building up of systems for multi-station use without impossible financial strain.

A block diagram of the circuitry used for GDS work is shown in Figure 2. In order to reach very short periods (5-10 sec.), the fluxgate outputs are split into two bands:

A) the long-period band, using the "scale expanders", provides an effective dynamic range of over 70 db (1600 gamma full-scale, with noise level under 0.5 gamma peak-to-peak in a low-pass frequency-restricted band).

B) short-period band: by inserting band-pass filters to attenuate the large-amplitude long-period fluctuations, additional amplifi-

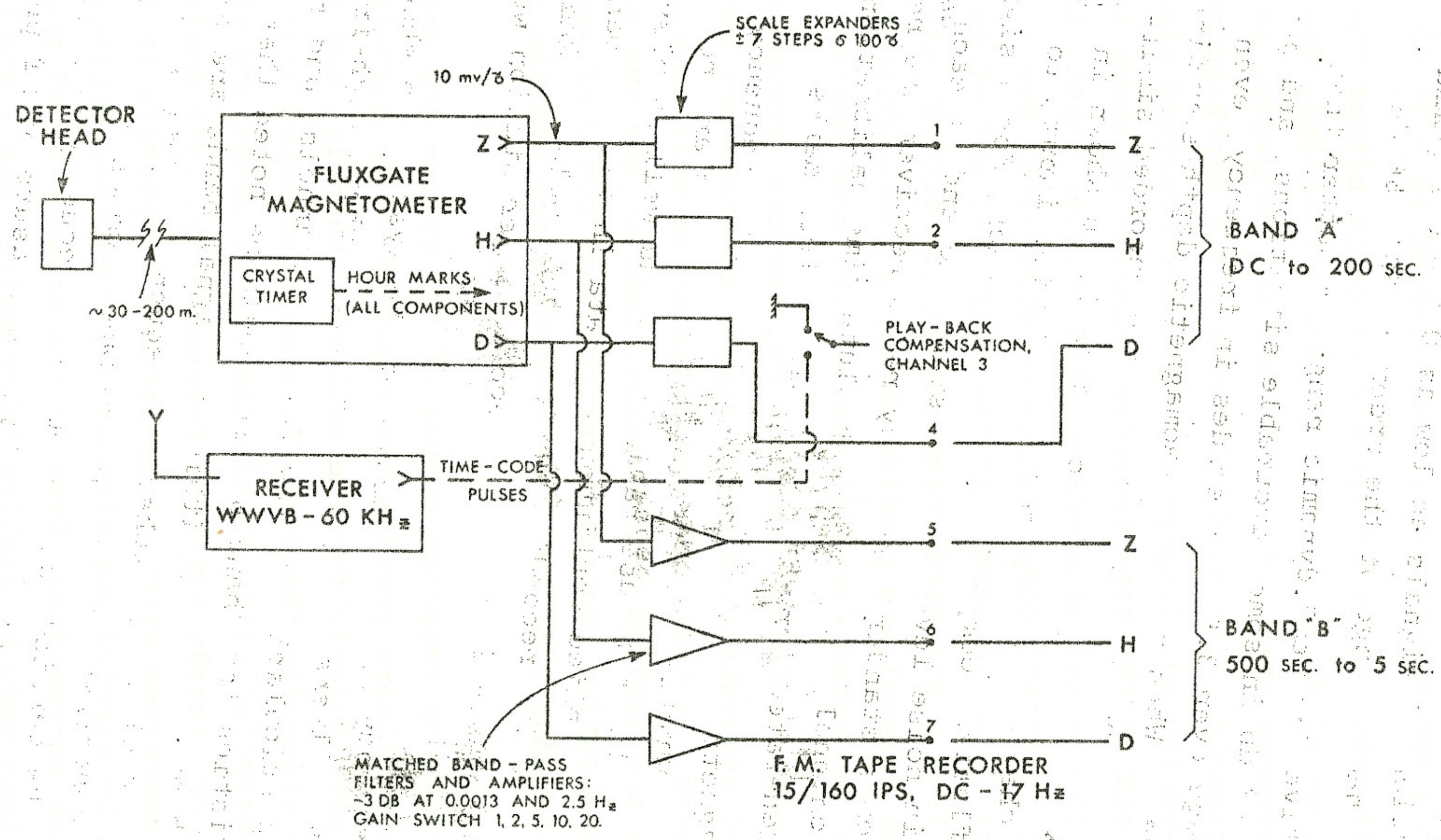

Fig. 2: Block diagram of instrumentation, conneted for geomagnetic depth sounding (GDS) use.

cation can be introduced to provide even higher sensitivity for short-period fluctuations (<100 sec. in particular). Depending on gain settings, resolution of signals as low as 0.1 - 0.2 gamma can be achieved, with a dynamic range of the order of 50 - 56 db.

The overall effective "system" dynamic range is better than 78 db, reaching over 82 db in some favourable situations, and permits effective coverage over 3.5 - 4 decades in frequency, even with "low - ΔZ" signals. When used for geomagnetic depth-sounding (GDS), the short-period and long-period data are recorded simultaneously, using six of the tape recorder channels as shown in Fig. 2. The seventh channel is operated with shorted input, to provide automatic "flutter" compensation on play-back, for a significant improvement in noise level; at the start and end of each tape, time marks from a standard-frequency radio receiver are recorded on the same channel, to provide absolute time-calibration of the internally-generated (crystal-controlled) hour marks.

When used for magneto-telluric (MT) work, the two frequency bands are recorded separately, since 5 signal channels are required for each band. In that case radio timing as well as playback compensation are applied continuously. Data in the two bands is recorded in consecutive recording periods, but could of course be recorded simultaneously if two tape recorders per station were available.

The overall frequency response curves of the system are shown in Figure 3. Active filters provide the required sharp high-frequency cut-offs, particularly for the telluric channels, and the low-cut characteristics for "band B". It should be noted that frequency response characteristics within the signal bands are either rigourously flat, or closely matched. Consequently, data analysis (which is always concerned with ratios between components in this type of work) can be carried out without any frequency-dependent instrument-response corrections. Even in the measure of MT phase shifts no corrections need be applied in practice: the E and H response curves deviate from perfect match only at the high-frequency limits of the bands, and it has been our experience that valid phase data is seldom obtained near this limit.

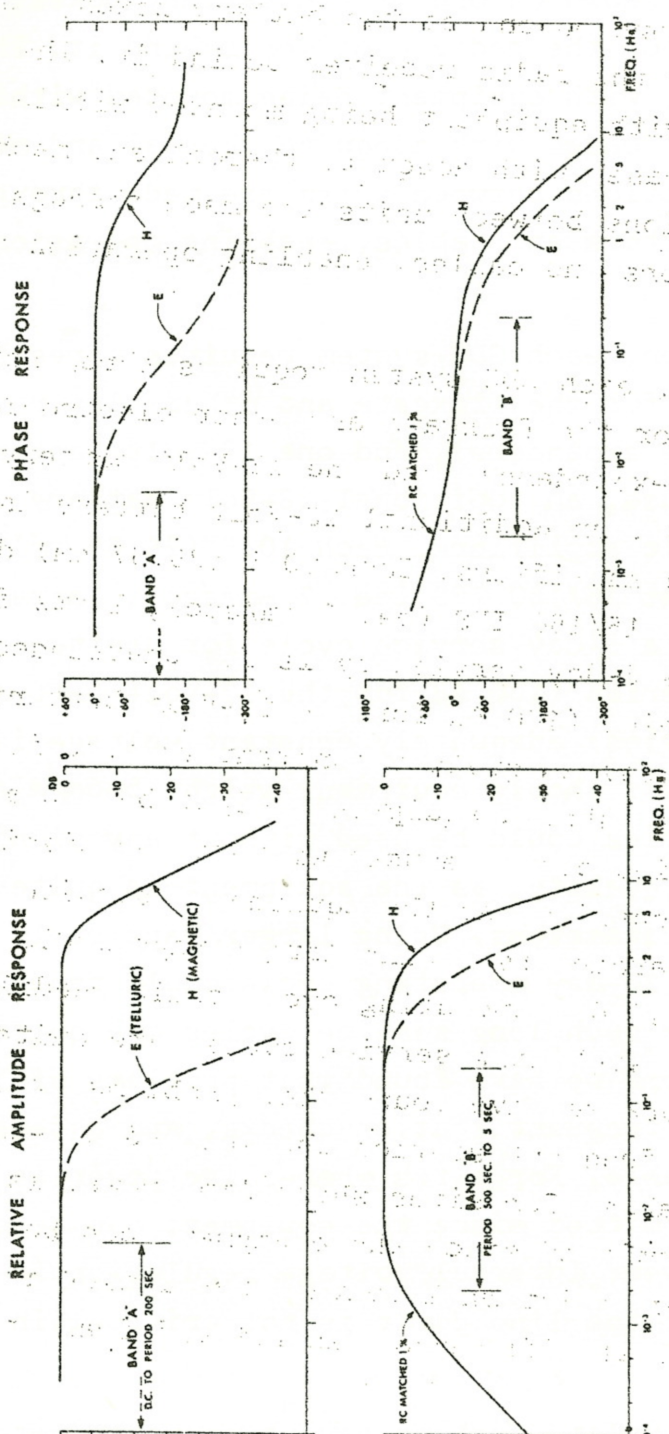

Fig. 3: Overall system frequency response curves.

A photograph of the GDS system is shown in Figure 4 (for MT work a second enclosure is added, containing the two telluric amplifiers). The transit case contains (from top to bottom) the fluxgate instrument, a switching and control unit, and the standard time receiver. The tape recorder is shown in front; the fluxgate detector head is shown on one of the battery boxes, and the ferrite core antenna for the radio receiver behind it. The system is fully weatherproof, with equipment being mounted within waterproof aluminum transit cases with adequate thermal and mechanical protection; all connections between units are made through external water-proof connectors and cables, enabling operation with all lids closed.

In mobile operation, each GDS system requires three batteries: two 18-Volt batteries for the fluxgate and other electronic circuitry (filters, scale expanders), and one 12-Volt battery for the tape recorder. In MT use, an additional 18-Volt battery is required for the telluric amplifiers. Each 10.5"(26.67 cm) diameter tape reel, recording at 15/160 IPS (ca. 2 mm/sec), lasts for over 120 hours, permitting a 5-day service cycle for unattended stations. Using heavy-duty batteries (100 AH for the 12-Volt batteries, 45 AH for the 18-Volt batteries) adequately constant voltage is maintained for these 5 days; should equipment weight become a critical factor, smaller batteries could be used without any significant deterioration in data quality, as the equipment is quite insensitive to power supply parameters. Using larger tape reels (14", ie. 35.56 cm diameter), a 10-day operating cycle could readily be achieved; for GDS work such long service cycles are quite practicable, but for MT work we have found that problems of line breakage require more frequent station checks, and a 5-day cycle was found to be desirable. For sites where line power is available, the batteries can be omitted since the equipment can be operated directly from line power; internal voltage regulation is provided, so that the quality of the line power is not critical in either voltage or frequency.

At present four complete systems have been constructed (two each by the University of B.C. and by Victoria Magnetic Observatory). Two of the systems have been field tested earlier this

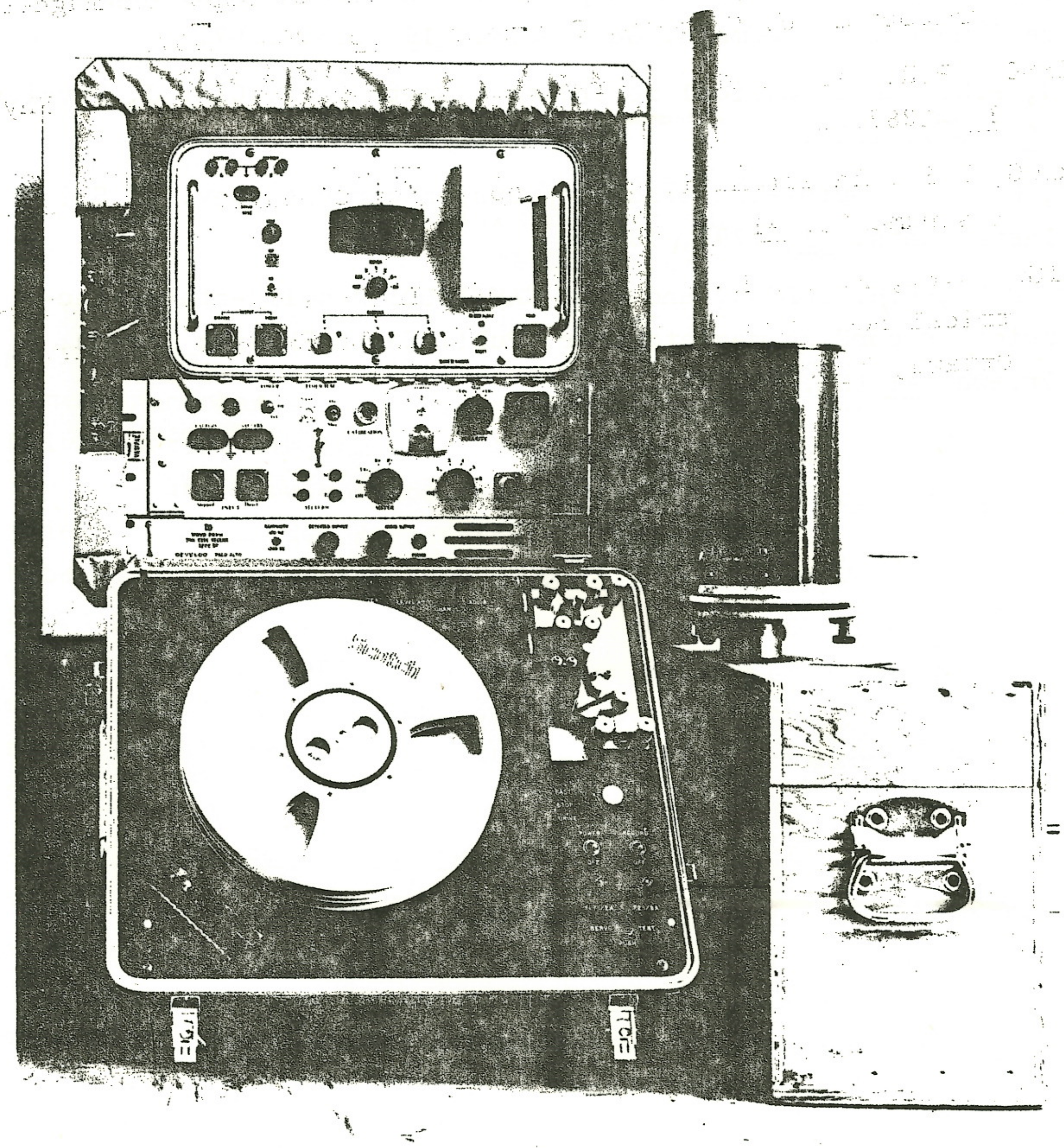

Fig. 4: Photograph of GDS system.

summer, with satisfactory results. All four are currently in use on a new profile.

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