CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Earth Magnetic Field

Earth magnetic field in the field in front of the Auditorium of Chulalongkorn University has been measured. The signal was recorded on magnetic tape and displayed on a Tektronix oscilloscope. Crude visual estimate of signal-to-noise ratio is 7 : 1 at the start of the decay. Typical signal was photographed by using the Tektronix oscilloscope camera C-27. Typical decay curves of free precession signal of protons in water are shown in Fig.12. Time intervals of 1920 cycles of precession frequency were recorded. Examples of data are presented in table 2 and the reduction of data is shown in tables 3-7. The mean values of precession frequency f and earth magnetic field H_1 and their standard deviation shown in table 3-7 were calculated from each group of data over one period of measurement of approximately 2 min. The plots of the magnetic field on several days of measurement are shown in Figs.13-16. The error bar represents the standard deviation for each group of data. A typical value of total magnetic field at Chulalongkorn University, Bangkok, at 6.02 p.m. on February 18, 1970, was found to be 0.41963 ± 0.00004 gauss. The value of magnetic field obtained is an average over a period of about one second, therefore variations in time shorter than one second can not be measured by this method.

4.2 Field Variation

From Figs.13-16 we can conclude that earth magnetic field varies significantly with time. The variation is the order of a few gammas. The values of the earth magnetic field between 6 p.m. and 7 p.m. are different from day to day.

4.3 Uncertainty of the Field Measurement

One may doubt that the polarizing field will not collapse to zero immediately after switching off the current and this would affect the earth magnetic field measurement. By observation (with Zener diode in switching circuit) of signal output of the amplifier by oscilloscope when switching the current on or off, it is found that there is oscillation which dies out in time about 2 milisecond. The polarizing field then in fact oscillating down to zero in time of the order of 2 milisecond. This left-over polarizing field is avoided in the measurement by starting the measurement of the time interval after the 128^{th} pulse, that is at a time of approximately 70 miliseconds after switching off the polarizing field. Larger fluctuation in the time interval readings are observed when attempt starting before the 128^{th} pulse. By starting the time interval measurement after the 128^{th} pulse, the uncertainty of the field measurement due to the left-over polarizing field is then ignored.

The certainty in frequency measurement (the time interval measurement is to determine the frequency) of an oscillating signal, decaying with characteristic time T_2, is limited by the fact that the decaying signal composes of signal of various

frequencies. The spectrum of frequencies can be found by Fourier transform of the decayiny signal. The Fourier transform[11] of the function $e^{-t/T_2}\sin\omega_o t$ give a distribution of the frequencies peaked at ω_o with half-width $\Delta\omega = \frac{1}{T_2}$ about ω_o. The uncertainty in the frequency measurement of the decaying signal is then $\Delta f = \frac{1}{2\pi T_2}$ Hz. In our case the observed T_2 is about 1 second or greater. Then Δf is approximately equal to 0.16 Hz. This is the uncertainty in frequency 1786 Hz measured which is about 9×10^{-5} out of 1. This factor is much more than the error that could be due to the time base which is about 1×10^{-5} out of 1 or less. The corresponding uncertainty in the magnetic field due to possible error in frequency measurement is 0.00004 gauss from the total field of 0.41963 gauss.

4.4 Possible Future Study

With the improvement, this instrument can be used to observe daily variation in earth's total magnetic field which is of interest. Using the circuits described, a portable instrument can be constructed. It can be carried by hand for ground surveys. Observation of yearly variation of earth magnetic field can also be made by this instrument. It should be interesting to try to see if there is any correlation between the variation of the earth magnetic field and solar activity and the variations of cosmic ray intensity.

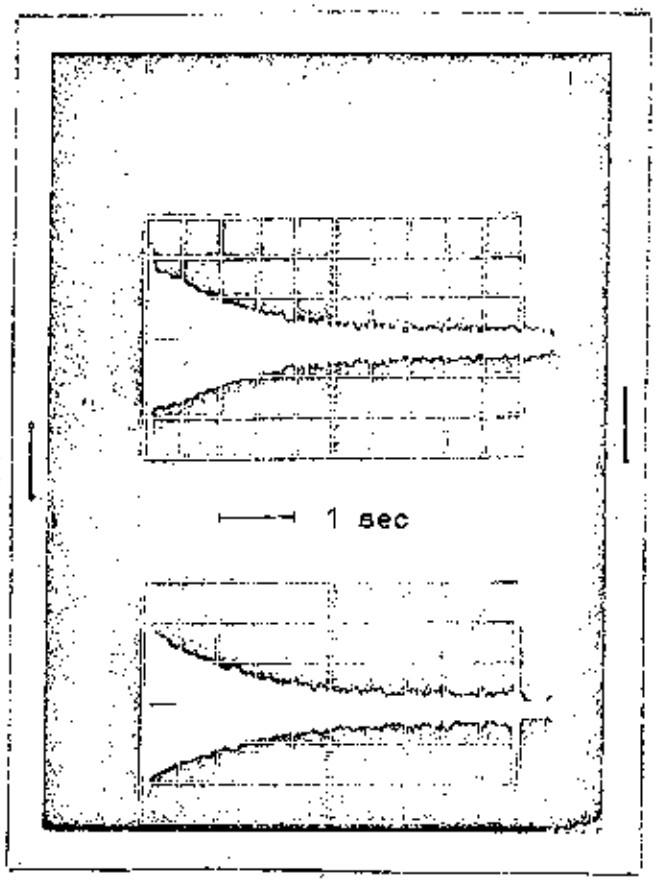


Fig. 12. Decaying free precession signal

(protons in water)

Table 2. Data

February 18, 1970

Time	Time interval of 1920 cycles (ms)	f (Hz)	H_T (Gamma)
18.02	1074.648	1786.632	41963.359
	1074.632	1786.658	41963.970
	1074.640	1786.645	41963.664
	1074.648	1786.632	41963.359
	1074.612	1786.691	41964.745
	1074.623	1786.673	41964.322
	1074.621	1786.676	41964.393
	1074.618	1786.681	41964.510
	1074.606	1786.701	41964.980
	1074.621	1786.676	41964.393
		1786.66±0.03	41964.2 ±0.6
18.05	1074.601	1786.710	41965.191
	1074.592	1786.725	41965.543
	1074.625	1786.670	41964.252
	1074.605	1786.703	41965.027
	1074.636	1786.651	41963.805
	1074.606	1786.701	41964.980
	1074.612	1786.691	41964.745
	1074.606	1786.701	41964.980
	1074.604	1786.705	41965.074
	1074.598	1786.715	41965.309
		1786.70±0.02	41964.9±0.5
18.08	1074.631	1786.660	41964.017
	1074.614	1786.688	41964.674
	1074.635	1786.653	41963.852
	1074.618	1786.681	41964.510
	1074.620	1786.678	41964.440
	1074.591	1786.726	41965.567
	1074.608	1786.698	41964.909
	1074.606	1786.701	41964.980
	1074.608	1786.698	41964.909
	1074.609	1786.696	41964.862
		1786.69±0.02	41964.7±0.6
18.10	1074.595	1786.720	41965.426
	1074.606	1786.701	41964.980
	1074.598	1786.715	41965.309
	1074.606	1786.701	41964.980
	1074.583	1786.740	41965.896
	1074.588	1786.731	41965.684
	1074.611	1786.693	41964.792
	1074.620	1786.678	41964.440
	1074.618	1786.681	41964.510
	1074.576	1786.751	41966.154
		1786.71±0.02	41965.2± 0.6

Time	Time interval of 1920 cycles (ms)	f(Hz)	H_1(Gamma)
18.15	1074.651	1786.626	41963.218
	1074.639	1786.653	41963.852
	1074.635	1786.653	41963.852
	1074.617	1786.683	41964.557
	1074.623	1786.673	41964.322
	1074.619	1786.680	41964.487
	1074.646	1786.635	41963.430
	1074.642	1786.641	41963.571
	1074.617	1786.683	41964.557
	1074.624	1786.671	41964.275
		1786.66 ± 0.02	41964.0 ± 0.5
18.17	1074.646	1786.635	41963.430
	1074.610	1786.695	41964.839
	1074.629	1786.663	41964.087
	1074.628	1786.665	41964.134
	1074.636	1786.651	41963.805
	1074.621	1786.676	41964.393
	1074.619	1786.680	41964.487
	1074.639	1786.646	41963.688
	1074.636	1786.651	41963.805
	1074.624	1786.671	41964.275
		1786.66 ± 0.02	41964.1 ± 0.4
18.21	1074.656	1786.618	41963.030
	1074.650	1786.628	41963.265
	1074.653	1786.623	41963.148
	1074.678	1786.582	41962.185
	1074.623	1786.673	41964.322
	1074.681	1786.577	41962.067
	1074.645	1786.636	41963.453
	1074.653	1786.623	41963.148
	1074.632	1786.658	41963.970
	1074.645	1786.636	41963.453
		1786.63 ± 0.03	$41963.2 \pm .7$

Time	Time interval of 1920 cycles (ms)	f (Hz)	H_1 (Gamma)
18.26	1074.712	1786.525	41960.846
	1074.688	1786.565	41961.785
	1074.689	1786.563	41961.739
	1074.697	1786.550	41961.433
	1074.687	1786.567	41961.832
	1074.684	1786.572	41961.950
	1074.675	1786.587	41962.302
	1074.675	1786.587	41962.302
	1074.685	1786.587	41962.302
	1074.677	1786.583	41962.208
		1786.57 ± 0.02	41961.9 ± 0.5
	Time interval of 896 cycles		
18.31	501.527	1786.544	41961.292
	501.517	1786.580	41962.138
	501.512	1786.597	41962.537
	501.508	1786.612	41962.889
	501.507	1786.613	41962.913
	501.510	1786.604	41962.701
	501.494	1786.661	41964.040
	501.493	1786.665	41964.134
	501.500	1786.640	41963.547
	501.500	1786.640	41963.547
		1786.61 ± 0.04	41963.0 ± 0.9
18.33	501.492	1786.668	41964.205
	501.518	1786.576	41962.044
	501.499	1786.644	41963.641
	501.495	1786.658	41963.970
	501.495	1786.658	41963.970
	501.480	1786.711	41965.215
	501.499	1786.644	41963.641
	501.497	1786.651	41963.805
	501.492	1786.668	41964.205
	501.503	1786.629	41963.289
		1786.65 ± 0.02	41963.8 ± 0.8

Time	Time interval of 1920 cycles (ms)	f (Hz)	H_1 (Gamma)
18.37	501.534	1786.519	41960.705
	501.516	1786.583	41962.208
	501.513	1786.594	41962.467
	501.515	1786.587	41962.302
	501.516	1786.583	41962.208
	501.515	1786.587	41962.302
	501.526	1786.547	41961.363
	501.522	1786.562	41961.715
	501.512	1786.597	41962.537
	501.502	1786.634	41963.406
		1786.58 ± 0.03	41962.1 ± 0.7
18.39	501.501	1786.636	41963.453
	501.505	1786.622	41963.124
	501.512	1786.597	41962.537
	501.514	1786.590	41962.373
	501.523	1786.558	41961.621
	501.504	1786.626	41963.218
	501.516	1786.583	41962.208
	501.530	1786.533	41961.034
	501.531	1786.530	41960.963
	501.531	1786.530	41960.963
		1786.58 ± 0.04	41962.2 ± 0.9
18.41	501.527	1786.544	41961.292
	501.521	1786.565	41961.785
	501.537	1786.508	41960.447
	501.520	1786.569	41961.879
	501.517	1786.580	41962.138
	501.524	1786.554	41961.527
	501.517	1786.580	41962.138
	501.527	1786.544	41961.292
	501.516	1786.583	41962.208
	501.532	1786.526	41960.869
		1786.55 ± 0.02	41962.2 ± 0.9

Time	Time interval of 1920 cycles (ms)	f (Hz)	H_1 (Gamma)
18.48	501.550	1786.462	41959.366
	501.534	1786.519	41960.705
	501.537	1786.508	41960.447
	501.537	1786.508	41960.447
	501.513	1786.594	41962.467
	501.512	1786.597	41962.537
	501.529	1786.537	41961.128
	501.520	1786.569	41961.879
	501.523	1786.558	41961.621
	501.521	1786.565	41961.785
		1786.54 $\pm$0.04	41961.2 $\pm$ 1.0

Data

February 19, 1970

Time	Time interval of 896 cycles (ms)	f (Hz)	H_1 (Gamma)
18.20	501.515	1786.587	41962.302
	501.516	1786.583	41962.208
	501.509	1786.608	41962.795
	501.508	1786.612	41962.889
	501.508	1786.612	41962.889
	501.508	1786.612	41962.889
	501.505	1786.622	41963.124
	501.496	1786.654	41963.877
	501.495	1786.658	41963.970
	501.504	1786.626	41963.218
		1786.62±0.02	41963.0±0.6
18.22	501.508	1786.612	41962.889
	501.491	1786.672	41964.299
	501.481	1786.708	41965.144

Time	Time interval of 896 cycles (ms)	f(Hz)	H_1 (Gamma)
	501.484	1786.697	41964.886
	501.499	1786.644	41963.641
	501.497	1786.651	41963.805
	501.489	1786.679	41964.463
	501.501	1786.636	41963.453
	501.495	1786.658	41963.970
	501.494	1786.661	41964.040
		1786.66±0.03	41964.1±0.7
18.27	501.505	1786.622	41963.124
	501.506	1786.619	41963.054
	501.506	1786.619	41963.054
	501.503	1786.630	41963.312
	501.508	1786.612	41962.889
	501.498	1786.647	41963.711
	501.499	1786.644	41963.641
	501.492	1786.668	41964.205
	501.501	1786.636	41963.453
	501.509	1786.608	41962.795
		1786.63±0.02	41963.3±0.4
18.29	501.502	1786.634	41963.406
	501.511	1786.601	41962.631
	501.496	1786.654	41963.876
	501.507	1786.615	41962.960
	501.506	1786.619	41963.054
	501.508	1786.612	41962.889
	501.500	1786.640	41963.547
	501.506	1786.619	41963.054
	501.498	1786.647	41963.711
	501.507	1786.615	41962.960
		1786.63±0.01	41963.2±0.4
18.34	501.523	1786.558	41961.621
	501.522	1786.562	41961.715
	501.511	1786.601	41962.631
	501.503	1786.629	41963.289
	501.502	1786.633	41963.383
	501.506	1786.619	41963.054
	501.500	1786.640	41963.547
	501.505	1786.622	41963.124
	501.508	1786.612	41962.889
	501.501	1786.636	41963.453
		1786.61±0.03	41962.9±0.7
18.37	501.518	1786.576	41962.044
	501.513	1786.594	41962.467
	501.523	1786.558	41961.622
	501.519	1786.572	41961.950
	501.523	1786.558	41961.622

Time	Time interval of 896 cycles (ms)	f(Hz)	H_1(Gamma)
	501.517	1786.580	41962.138
	501.509	1786.608	41962.795
	501.525	1786.551	41961.457
	501.505	1786.622	41963.124
	501.523	1786.558	41961.622
		1786.58±0.02	41962.1±0.6
	Time interval of 1920 cycles		
18.42	1074.783	1786.407	41958.074
	1074.786	1786.402	41957.957
	1074.763	1786.440	41958.850
	1074.753	1786.457	41959.249
	1074.741	1786.477	41959.719
	1074.747	1786.467	41959.484
	1074.750	1786.462	41959.366
	1074.732	1786.492	41960.071
	1074.774	1786.422	41958.427
	1074.767	1786.434	41958.709
		1786.45±0.03	41959.0±0.7
18.44	1074.754	1786.455	41959.202
	1074.768	1786.432	41958.662
	1074.740	1786.478	41959.742
	1074.728	1786.498	41960.212
	1074.737	1786.484	41959.883
	1074.735	1786.487	41959.953
	1074.739	1786.480	41959.789
	1074.734	1786.488	41959.977
	1074.751	1786.460	41959.319
	1074.749	1786.464	41959.414
		1786.47±0.02	41959.6±0.5
18.48	1074.755	1786.454	41959.178
	1074.749	1786.464	41959.413
	1074.761	1786.444	41958.944
	1074.725	1786.504	41960.353
	1074.778	1786.415	41968.262
	1074.756	1786.452	41959.131
	1074.748	1786.465	41959.437
	1074.751	1786.460	41959.319
	1074.735	1786.487	41959.953
	1074.737	1786.484	41959.883
		1786.46±0.02	41959.4±0.6

Time	Time interval of 1920 cycles (ms)	f(Hz)	H_f(Gamma)
18.50	1074.752	1786.459	41959.296
	1074.747	1786.467	41959.484
	1074.762	1786.442	41958.897
	1074.755	1786.454	41959.178
	1074.746	1786.469	41959.531
	1074.755	1786.454	41959.178
	1074.757	1786.450	41959.084
	1074.780	1786.412	41958.192
	1074.765	1786.437	41958.779
	1074.767	1786.434	41958.709
		1786.45±0.02	41959.0±0.4

Table 3. Reduction of data

February 16, 1970

Local time (Bangkok)	Precession frequency (Hz)	Earth's total magnetic field (Gamma)
18.04	1786.84 ± 0.06	41968.2 ± 1.3
18.10	1786.87 ± 0.02	41969.0 ± 0.3
18.14	1786.89 ± 0.04	41969.4 ± 0.8
18.29	1786.92 ± 0.04	41970.1 ± 0.8
18.34	1786.93 ± 0.03	41970.4 ± 0.7
18.38	1787.02 ± 0.05	41972.2 ± 1.3
18.41	1787.02 ± 0.03	41972.4 ± 0.6
18.45	1787.03 ± 0.01	41972.7 ± 0.4
18.47	1786.95 ± 0.03	41970.9 ± 0.6
18.51	1786.97 ± 0.02	41971.2 ± 0.5

Table 4. Reduction of data

February 17, 1970

Local time (Bangkok)	Precession frequency (Hz)	Earth's total magnetic field (Gamma)
18.08	1786.68 ± 0.02	41964.4 ± 0.5
18.10	1786.75 ± 0.03	41966.1 ± 1.2
18.13	1786.73 ± 0.02	41965.6 ± 0.4
18.16	1786.73 ± 0.03	41965.6 ± 0.8
18.20	1786.72 ± 0.03	41965.4 ± 0.8
18.23	1786.72 ± 0.02	41965.4 ± 0.5
18.28	1786.70 ± 0.03	41964.9 ± 0.7
18.32	1786.69 ± 0.02	41964.7 ± 0.4
18.36	1786.69 ± 0.03	41964.7 ± 0.7
18.40	1786.71 ± 0.02	41965.1 ± 0.5
18.44	1786.72 ± 0.04	41965.4 ± 1.0
18.47	1786.78 ± 0.03	41966.8 ± 0.7
18.51	1786.79 ± 0.04	41967.1 ± 0.9
18.54	1786.81 ± 0.03	41967.6 ± 0.6

Table 5. Reduction of data

February 18, 1970

Local time (Bangkok)	Precession frequency (Hz)	Earth's total magnetic field (Gamma)
18.03	1786.66 ± 0.03	41964.2 ± 0.6
18.06	1786.70 ± 0.02	41964.9 ± 0.5
18.09	1786.69 ± 0.02	41964.7 ± 0.6
18.11	1786.71 ± 0.02	41965.2 ± 0.6
18.16	1786.66 ± 0.02	41964.0 ± 0.5
18.18	1786.66 ± 0.02	41964.1 ± 0.4
18.22	1786.63 ± 0.03	41963.2 ± 0.7
18.27	1786.57 ± 0.02	41961.9 ± 0.5
18.31	1786.61 ± 0.04	41963.0 ± 0.9
18.34	1786.65 ± 0.02	41963.8 ± 0.8
18.38	1786.58 ± 0.03	41962.1 ± 0.7
18.40	1786.58 ± 0.04	41962.2 ± 0.9
18.42	1786.55 ± 0.02	41962.2 ± 0.9
18.49	1786.54 ± 0.04	41961.2 ± 1.0

Table 6. Reduction of data

February 19, 1970

Local time (Bangkok)	Precession frequency (Hz)	Earth's total magnetic field (Gamma)
18.21	1786.62 ± 0.02	41963.0 ± 0.6
18.23	1786.66 ± 0.03	41964.1 ± 0.7
18.28	1786.63 ± 0.02	41963.3 ± 0.4
18.30	1786.63 ± 0.01	41963.2 ± 0.4
18.35	1786.61 ± 0.03	41962.9 ± 0.7
18.38	1786.58 ± 0.02	41962.1 ± 0.6
18.43	1786.45 ± 0.03	41959.0 ± 0.7
18.45	1786.47 ± 0.02	41959.6 ± 0.5
18.49	1786.46 ± 0.02	41959.4 ± 0.6
18.51	1786.45 ± 0.02	41959.0 ± 0.4

Table 7. Reduction of data

February 23, 1970

Local time (Bangkok)	Precession frequency (Hz)	Earth's total magnetic field (Gamma)
19.23	1787.34 ± 0.03	41979.9 ± 0.8
19.25	1787.41 ± 0.03	41981.6 ± 0.7
19.29	1787.43 ± 0.04	41982.1 ± 0.8
19.31	1787.46 ± 0.01	41982.8 ± 0.3
19.35	1787.44 ± 0.04	41982.4 ± 0.9
19.37	1787.45 ± 0.03	41982.6 ± 0.7
19.42	1787.45 ± 0.03	41982.7 ± 0.6
19.44	1787.47 ± 0.04	41983.2 ± 0.9
19.48	1787.46 ± 0.03	41982.8 ± 0.7
19.50	1787.44 ± 0.03	41982.3 ± 0.7
19.55	1787.40 ± 0.03	41981.3 ± 0.5
19.57	1787.40 ± 0.03	41981.4 ± 0.5

February 16, 1970

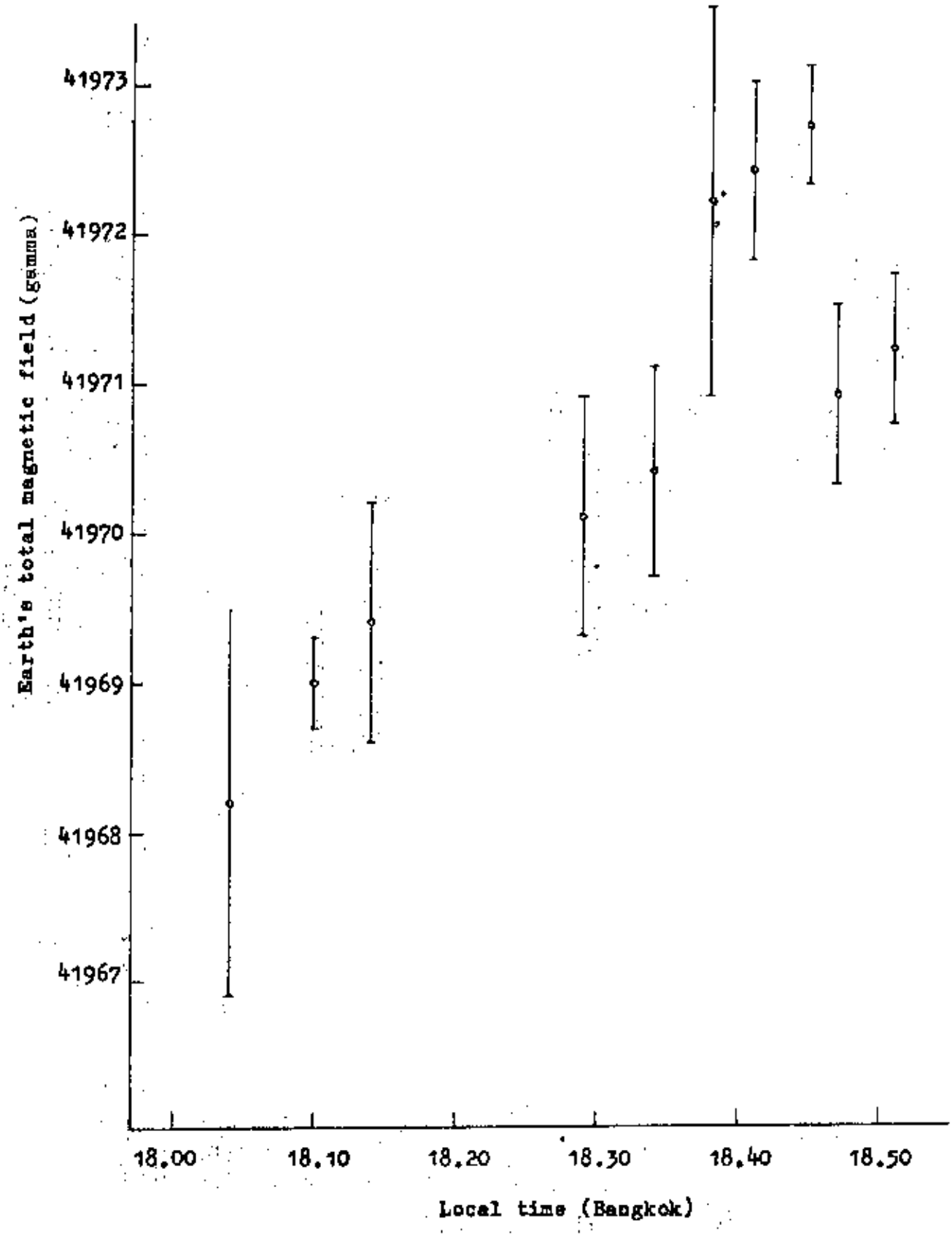


Fig. 13 Variation in earth's total magnetic field.

February 17, 1970

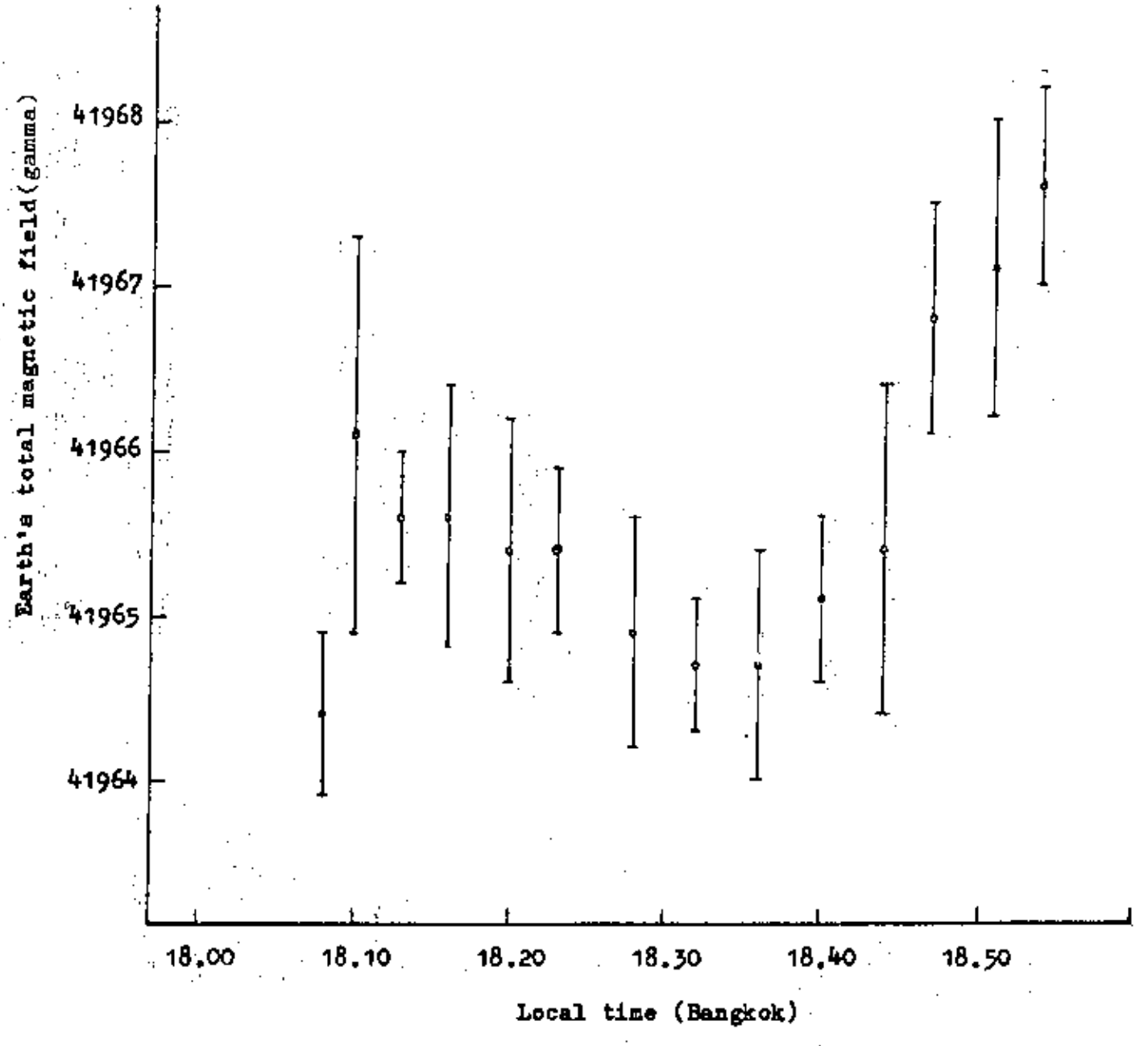


Fig. 14 Variation in earth's total magnetic field.

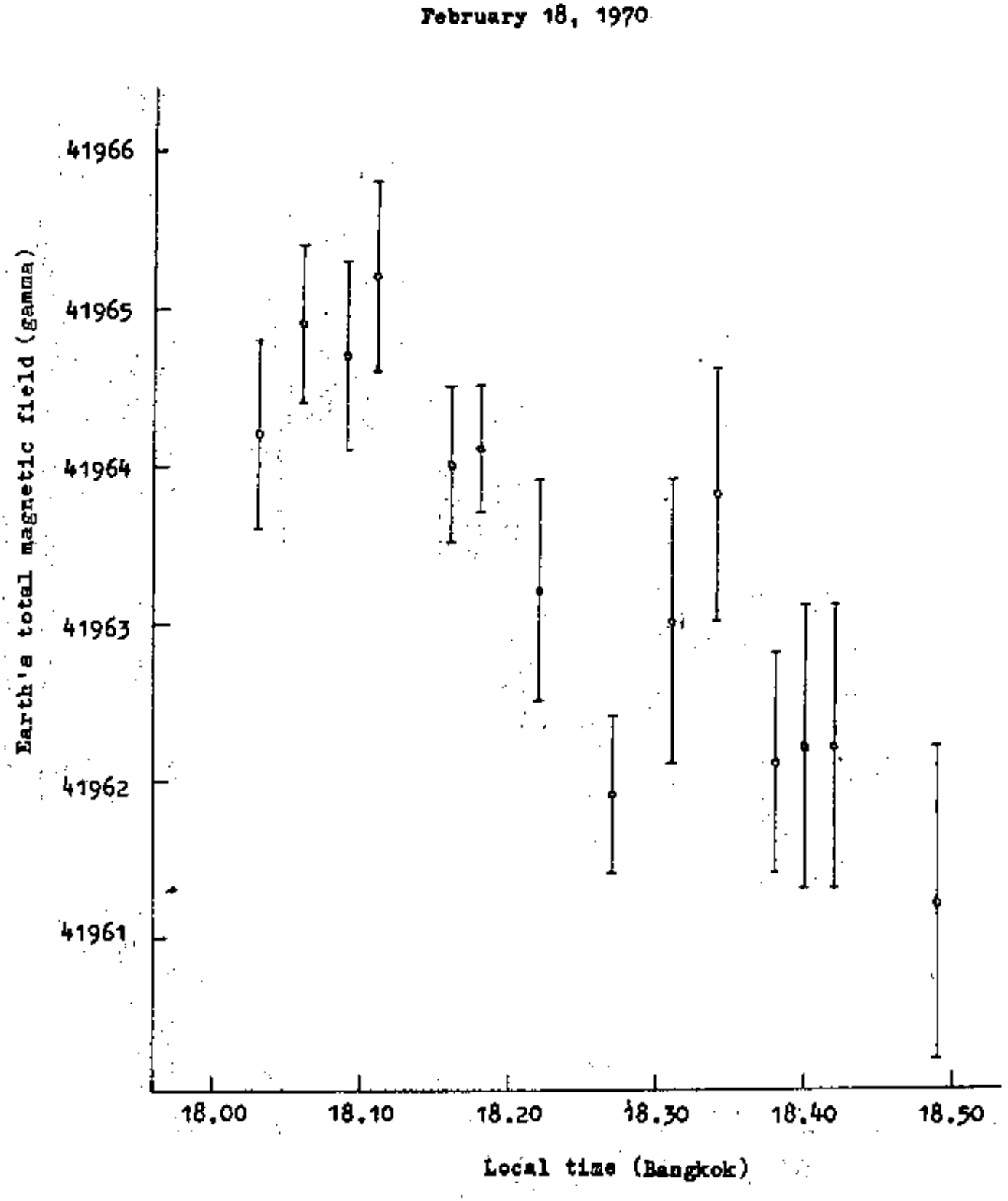


Fig. 15 Variation in earth's total magnetic field

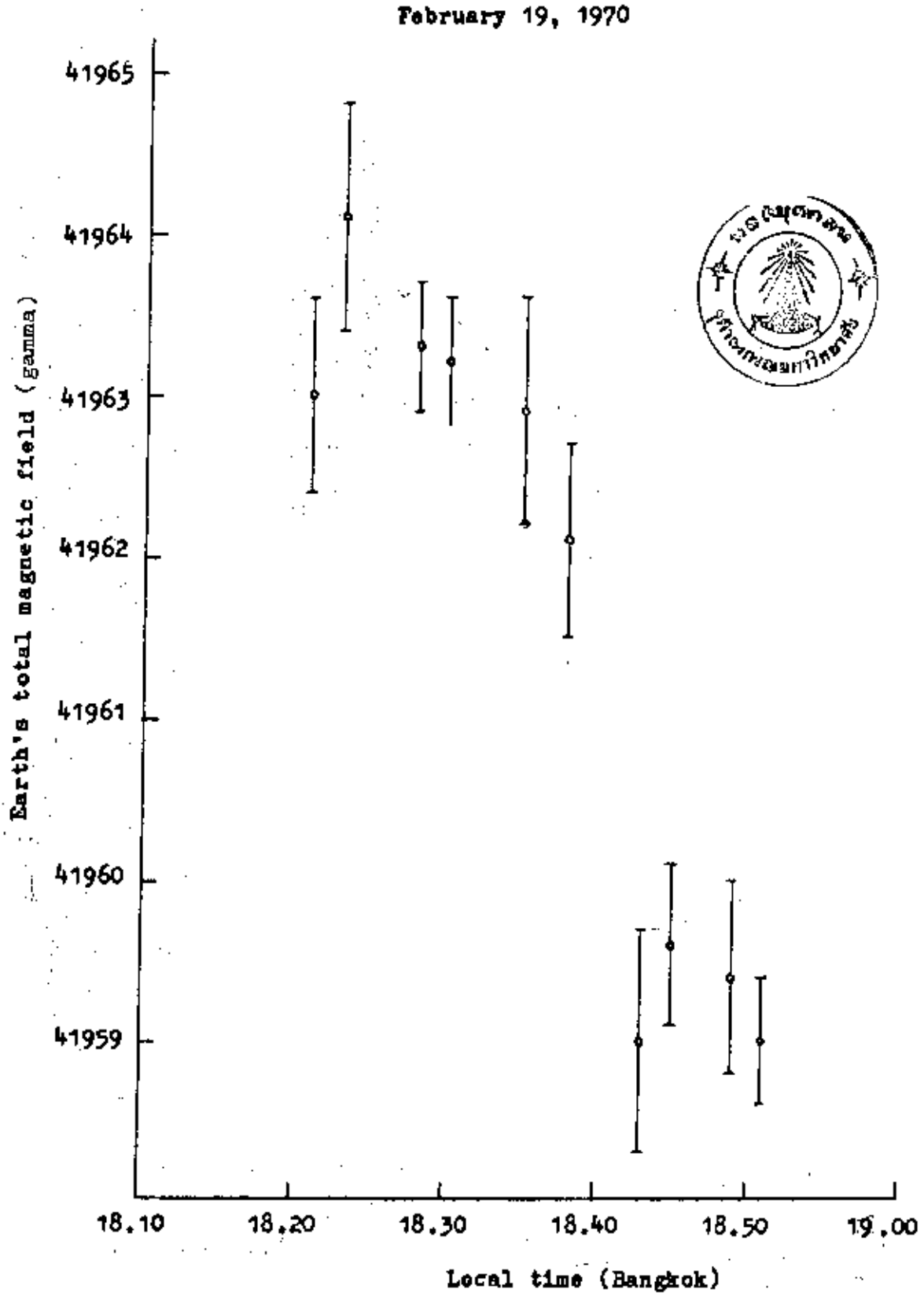
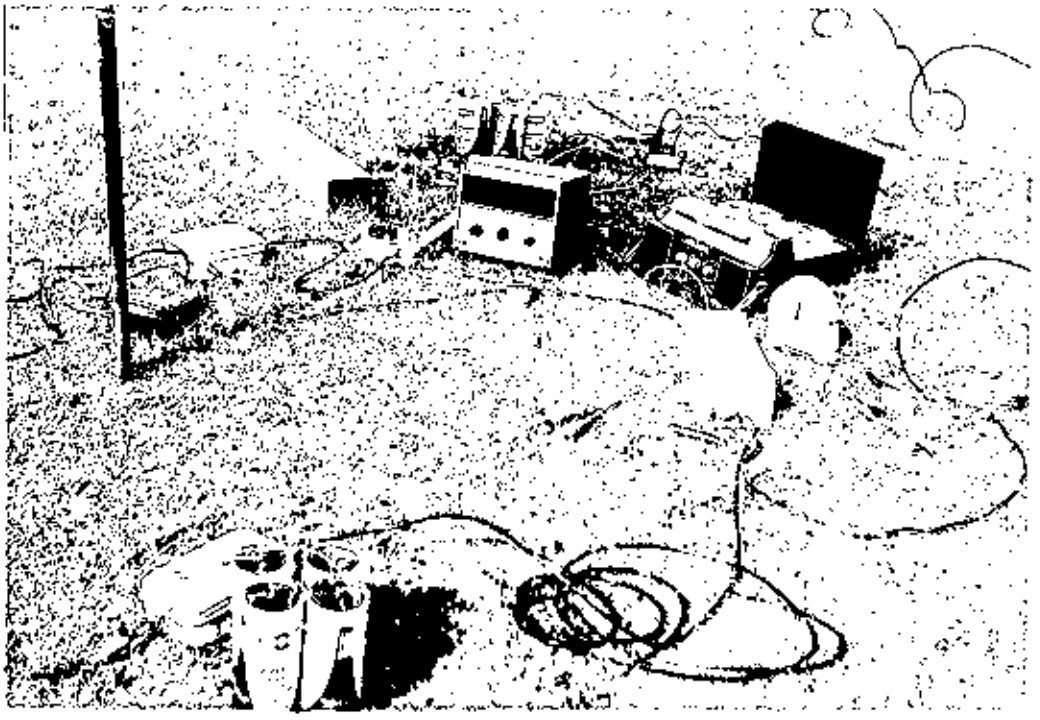
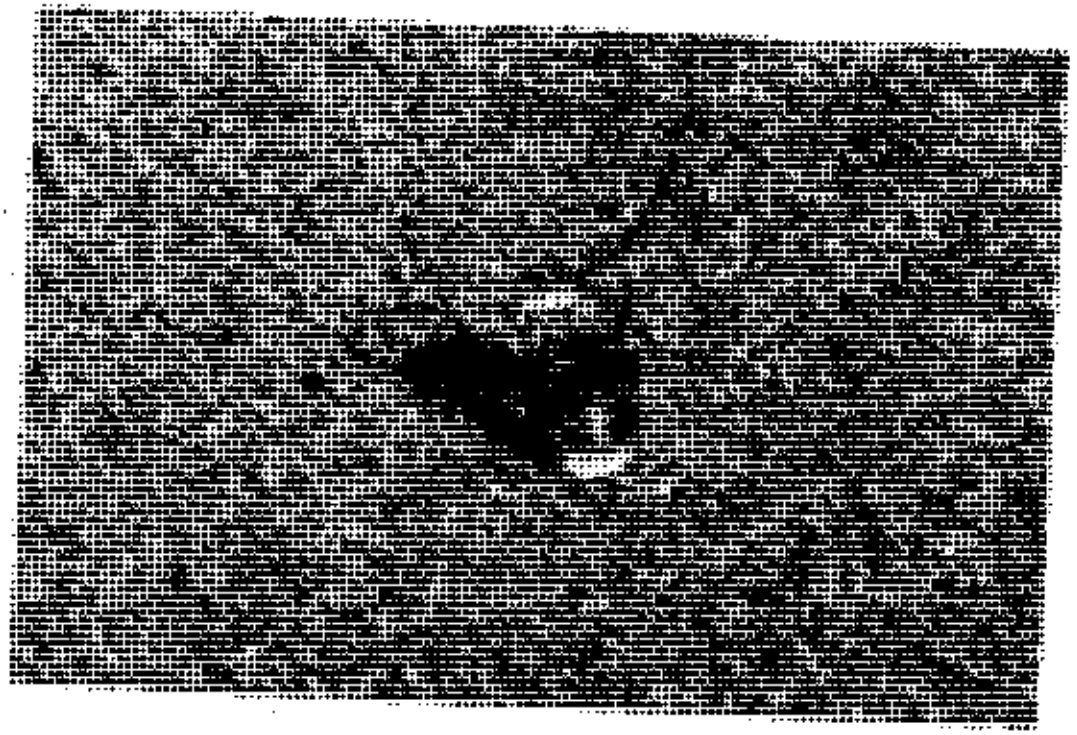


Fig. 16 Variation in earth's total magnetic field.



a. The apparatus.



b. Coil orientation.

Fig. THE PHOTOGRAPHS OF APPARATUS