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A MAGNETOMETER ARRAY IN GRENVILLE PROVINCE FOR INVESTIGATION OF AN ISLAND-ARC CLOSURE IN S.E. ONTARIO

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ABSTRACT

In October and November 1975 five recording magnetometers were set out in southeastern Ontario to study induction effects in the Grenville between Ottawa and Haliburton. Geological evidence suggests that an ancient (∿ 1250 Ma) continental margin lies within this region. Recordings of variations in X, Y and Z components were obtained at four stations which were compared with Ottawa magnetic observatory. Only small differences in amplitude of corresponding components were observed from one station to another, and major inhomogeneities in the electrical properties of the crust therefore are not evident. While an electrical conductivity anomaly of significant magnitude was not found, there were differences at short periods in the magnetogram traces which are probably related to crustal structure.

Geological and aeromagnetic maps of the region were examined and revealed two large-scale magnetic signatures. These appear as two lineaments of anomalously high total magnetic intensity extending across the Grenville, trending northeasterly.

RESUME

En octobre et novembre 1975, cinq magnétomètres enregistreurs ont été installés dans le sud-est de l'Ontario pour étudier les effets d'induction dans la province géologique Grenville entre Ottawa et Haliburton. L'évidence géologique suggère qu'une marge continentale ancienne (∿ 1250 Ma) existe dans cette région. Des enregistrements des variations des composantes X, Y et Z de quatre stations ont été obtenus et comparés avec les enregistrements de l'observatoire magnétique d'Ottawa. Très peu de différence d'amplitude des

composantes a été observé entre stations et des inhomogénéités majeures des propriétés électriques de la croûte ne sont pas évidentes. Tandis qu'il n'y avait pas d'anomälie de grande partie dans la conductivité électrique, il y avait des différences de courtes périodes sur le magnétogramme ce qui est probablement relié à la structure de la croûte terrestre.

L'étude de cartes géologiques et aéromagnétiques de la région a révélé la présence de deux signatures magnétiques à grande échelle qui traversent la province géologique de Grenville; il s'agit de deux linéaments à intensité magnétique totale anormalement élevée, orientés vers le nord-est.

I INTRODUCTION

Some geological evidence favourable to the existence of a suture in Grenville Province, S.E. Ontario, has been presented by Brown et al., (1975). While its surface expression is now largely obscured, the location is believed to be centred near Lat. 45°N and Long. 77°W, and to contain ancient structural trends in a SW-NE direction. Brown et al. postulate an ensimatic island arc complex generated by subduction of oceanic lithosphere and subsequent continental collision accompanied by ocean closure and joining along a suture. The events presumably began about 1300 Ma ago and continued over an interval of 250 Ma. See Fig. 1 for geological setting.

For a preliminary geophysical investigation of this intriguing and complex region, an array of recording magnetometer stations was established along an east-west arc from Kingston to the Haliburton Highlands. The project was carried out in laboratory and field from September to November 1975.

The purpose of this experiment was to see if any evidence exists for prominent inhomogeneities in the electrical properties of the deep crust in this region which might be associated with an ancient Precambrian tectonic boundary or suture.

II GEOLOGY AND PHYSIOGRAPHY

The possible suture lies within the Frontenac axis of the Grenville Province about 100 km northwest of the St. Lawrence River. All of the recording stations except Ottawa and Kingston are in this region; the two latter points were located in the St. Lawrence Lowlands Platform, close to the physiographic boundary, where the Grenville basement is thinly overlain by

Palaeozoic sediments. In the Frontenac axis, Proterozoic rocks of Aphebian age, granitic intrusions, plutonics and gneisses are covered by Palaeo-helikian pyroclastics and granitic schists derived from sediments. There is considerable variation in the geology at each station in the same geological province, with outcroppings varying in age from 700 to 1400 Ma. A fault extends from near Bancroft in a NE trend line towards the Ottawa River. See Geological Map of Canada, Map 104A GSC, and Geological Map of Ontario, Map 2198, ODM, Toronto. Mineral ages from Grenville Province are discussed by Dence et al. (1971) and petrology of rocks near the 'suture' is described by Sethuraman and Moore (1972). The general geology of the central area is shown in Fig. 2.

III STATION LOCATIONS

The locations chosen and occupied are shown in Table I and in Fig. 1. The average distance between stations is 75 km. These station numbers also appear on the magnetic components on the magnetograms as superior figures, except for Kingston which is identified by superscript 1.

TABLE I

	STATION	LAT.	LONG.	DATA DATES (1975)
1.	Otter Lake	44°48'N	76°09'N	No data
2.	Kingston	44°16'N	76°27'W	Nov.2-4
3.	Big Gull Lake	44°16'N	76°58'W	Nov.2-4
4.	Bancroft (Silent L.)	44°55'N	78°04'W	Nov.2-4
5.	Haliburton West	44°59'N	78°42'W	Nov.2-5
6.	Ottawa Magnetic Observ.	45°24'N	75°33'W	Nov.1-5

Magnetograms from Ottawa Magnetic Observatory were also available for comparison with data from the field stations.

IV INSTRUMENTATION

Five fluxgate magnetometers of the type developed by the Geomagnetism Division were placed in operation at the sites shown in Table I and Fig. 1. These were in operation from Oct. 29-Nov. 20, 1975 but none functioned properly for this length of time. Digital tape cassettes stored the 3-component (X, Y, Z) magnetic variations at a one-minute sampling rate and with a designated accuracy of ± 1 nT.

Lead-acid wet batteries were used to supply power to the magnetometers at three stations; 115 volt A.C. power was available at the others. Lithium cells powered the Datel cassette datalogger. Magnetometer sensitivities for each component were calibrated and set to equal 99.2 ± 0.4 nT/volt before the survey started, and when checked afterwards showed almost no change. WWV radio time signals were used to time the recorders; the probable error of timing over 3 weeks was ± 3 seconds.

During the experiment difficulties arose because the datalogger power supply provided insufficient current to the 'write' head. Many of the traces contained short period noise, sudden jumps, truncated or suppressed signals and other irregular spurious responses. Data from Station No. 2 near Kingston were an exception since the datalogger there had an adequate supply voltage (5 lithium cells as opposed to 4 at other stations). Preliminary tests in the laboratory failed to reveal this deficiency because an electronic power supply was used to run the loggers. However, in the field the cassette recorders did not operate properly for more than a few days simultaneously at all stations.

A severe electrical storm around November 8 knocked out component amplifiers at Stations No. 3 and 5:Big Gull Lake and Haliburton. Laboratory testing later confirmed that two component amplifiers were not functioning properly. Consequently, simultaneous data were obtained for 3 days only and it was difficult to determine whether there were significant differences between stations in short and medium period magnetic field variations. Line voltage fluctuations could also introduce a source of error and Ontario Hydro frequently adjusts power output from 105-120 volts a.c. Serson (1973) has reviewed the instrumentation commonly used in induction studies.

V FIELD SURVEY PROCEDURE

The instruments were set up in secluded locations remote from artificial magnetic disturbance at each site. Two systems of setting up the detector head unit were used: a) an aluminum pipe was placed in a concrete base made on the spot from 'cimex' and water, b) a hole was drilled in bedrock to accomodate the aluminum pipe, with adjustable fittings attached to the 3-component head of the magnetometer. After all the necessary adjustments were made the recorder was started and timed from WWV signals and the unit was left unattended to record for about 3 weeks. Equipment was then retrieved and returned to Blackburn Laboratory.

VI ANALYSIS OF RESULTS

For processing of the data a number of computer techniques were used. First the data from cassettes were read out onto disc format memory storage on the minicomputer at Blackburn Laboratory. They were plotted with a scale factor of 6 nT/mm. Plots of data for X, Y and Z components are shown in Figs. 3-11, in order, top to bottom, Kingston, Gull L., Silent L., Haliburton, Ottawa. From the 3 week period three days were selected as being sufficiently coherent and accurate for intercomparisons. The Ottawa Magnetic Observatory higher sensitivity magnetograms were selected and adjusted to the same scale factor as the Datel plots.

The data were examined for periods of 5-30, 30-60 and 60-120 minutes duration. An inspection of the profiles at Bancroft (Silent Lake Park) vs. Kingston and Ottawa impresses one with the remarkably close correlation in morphology and amplitude of magnetic bays and short-term disturbances. Of course, they are all near the same geomagnetic latitude and have closely similar geological environments. However, if the earth's crust were more highly electrically conductive near the 'suture' it should affect the temporal geomagnetic variations nearby, see Edwards and Greenhouse (1975) and Niblett et al. (1974). Since there does not appear to be any major suppression or enhancement of the variations of vertical field (and other elements) one can infer broadly that the electrical properties in the crust and upper mantle are fairly uniform over this region.

Since insufficient data are available for the usual statistical approach we have selected several significant magnetic events for the above periods at the main 'control' station - Ottawa Observatory. These are summarized in Table II, with the corresponding values at the other stations . Lilley (1975) has described methods of interpretation of observed magnetic field variations which are similar to the approach used here.

Looking at the long period disturbances (> 60 minutes) with highest amplitudes (Table II) one again finds that the stations are all quite similar. The mean of the amplitudes of measured events over the five stations is 68.1 nT and the variance at individual stations is insignificant except possibly at Kingston, where there is a suggestion of consistently lower long-period amplitudes.

VII DISCUSSION

In examining a total of 14 events which occurred over 3 days one finds a consistently higher amplitude of Z response, for all periods, at Ottawa Magnetic Observatory, possibly because it has the highest magnetic latitude of the 5 stations. At longer periods (>60 mins) the difference is slight for all stations except Kingston which displays about 15% less response in amplitude. For shorter periods the reduction in amplitude, relative to Ottawa, varies from 8-20%. At Station 3 - Gull Lake - there is some indication of suppression of Z fields but more data are required for a quantitative analysis. At Station 5 - Haliburton - there is unusual enhancement of the response in X to a long period (240 min.) disturbance for which there seems to be no explanation apart from instrumental drift.

It is difficult to infer from these few data any clear induction signature which might be associated with an old plate boundary - e.g. the tectonic edge of Grenvillian orogeny. On the other hand there does seem to be some gravitational evidence for a cryptic suture or some unusual feature, as discussed by Baer et al. (1974). Bouguer gravity anomaly maps compiled by the Earth Physics Branch (EPB) show a minor 'high' (relative to surroundings) in the 'suture' area, trending SW-NE, see Gravity Map References (1955, 1971) also Gibb and Thomas (1976).

The aeromagnetic maps of the Geological Survey of Canada, (GSC, 1962) have been examined and compared with the geological maps of the region, Ontario Department of Mines (1964). The parts of the southern Grenville being examined here underwent orogeny from Middle to Late Precambrian (1300-1050 Ma) during which time the metasediments and metavolcanics were folded and reworked and plutonic rocks appeared. This is a major depositional zone with accumulations as great as 7 km (Sethuraman and Moore, 1973).

Along the central portion of the 'suture', Fig. 1, there are bands of amphibolites and similar rocks alternating with outcrops of granites, quartzite and paragneiss. Near Big Gull Lake (named Clarendon L. on some maps) there are two bands of basic volcanics about one km wide and twenty km long at the surface (line A-B Fig. 1). Contours of total magnetic intensity surrounding these bands have maximum lateral gradients across them of about 100 nT/km. On the other hand there are very low gradients (10 nT/km) over the grey granites of the Northbrook pluton, adjacent to the volcanics (line C-D, Fig. 1). Refer also to Fig. 2 for detail in this area.

Over the Elzevir batholith (E, Fig. 1) about 25 km west of station 3 there are very low gradients; the Elzevir granite is similar to the Northbrook type.

Very large positive anomalies occur over the Mount Moriah (3000 nT) and Skootamata Lake (1200 nT) syenite bodies (M and S, Fig. 1). Other lesser but still appreciable anomalies follow the Fernleigh-Clyde fault (F-X, Fig. 1) which is flanked by amphibolites on the south and quartz diorites and mafics on the north side. Linear magnetic contours extend along most of the length of this fault trending northeasterly. The lateral gradients are about 500 nT/km. The strong variability in the magnetic field here is in marked contrast to the smoothness over the Northbrook pluton and Elzevir batholith.

To the south, the Robertson Lake shear zone (R-L, Fig. 1) coincides with a magnetic lineament about 30 km long, trending northeast, with gradients in F of about 400 nT/km across the zone.

In summary we find generally low magnetic relief over plutonic rocks but the syenite extrusions are highly magnetic; there is moderate to high relief over the metasediments and metavolcanics. There is no clear magnetic correlation consistently related to rock types at the surface, probably because of the elaborate Grenvillian orogeny which has resulted in a wide range of physical properties here. Where the plutonics occur they mask the magnetic intensity of the underlying rocks which are probably more highly magnetized.

Referring to the Great Lakes-Ontario aeromagnetic map (GSC, 1962 b) one observes several remarkable magnetic signatures. There is an oval-shaped area 20 km west of station 3 of nearly zero magnetic relief. It extends about 25 km east-west between the Mount Moriah and Skootamata Lake anomalies (M-S, Fig. 1) and about 40 km north-south centered on the Elzevir batholith (E).

In contrast to this there is a magnetically high linear extending from the southwest end of the suture (Lat. 44°N, Long. 78°W) in a northeasterly direction for about 100 km across the Grenville to the oval area described above, where there is a hiatus. About 40 km northeast of this area, near X on the F-X line, there is an indistinct but apparent continuation of this high along the suture line, trending northeasterly towards the Ottawa River. Is this the surficial magnetic signature of the suture? Possibly, but it is not unique, since there is a similar high magnetic linear about 60 km to the west, trending northeast (roughly parallel) following the Bancroft fault (Fig. 1). Positive anomalies here are of the same order of magnitude ($\sim$300 nT) above ambient total field. There also appear to be flanking lows ($\sim$200nT below normal) along the easterly salients of both positive linears. Perhaps these two outstanding magnetic signatures mark the boundaries of a Grenville suture.

Considering again the minor suppression of shorter periods of the Z magnetic variations at Station 3 and the reasons for it, we can now suggest from the aeromagnetic and geological data that it might be genetically related to the unusually low magnetic relief in the western environs of Big Gull Lake. This Grenville suture, if extant, is well named cryptic!

Further magnetovariational surveys could include several stations in a north-south array across the suture zone. A second array outside the zone should operate simultaneously. Higher sampling rates are advisable.

The use of magnetotelluric instrumentation would enable one to secure information from greater depths, probably from beneath the earth's crust, believed to be about 39 km thick here.

VIII ACKNOWLEDGEMENTS

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Dr. M.D. Thomas, Gravity and Geodynamics Division, has reviewed the manuscript and offered helpful advice. Dr. R. Kurtz has loaned computer programs and helped adapt the sub-routines to this problem. E.I. Loomer supplied the AMOS traces from Ottawa magnetic observatory. Dr. P.H. Serson approved the project and has added useful editorial comments. The authors are grateful to personnel in the Drafting Section, the Photo Unit and the word processing office, EPB. Dr. P.H. Thompson, of the Geological Survey of Canada, kindly supplied a detailed geological map of the area.

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APPENDIX

Operational times, Suture experiment, 1975.

Stn. 1	Otter Lake-no data (Casette inoperative)
Stn. 2	Kingston-October 24, 2015 UT, started.
	All cassette tape used - ran 45 days
	Off time Dec. 10, 1800 U.T.
Stn. 3	Gull Lake-Start Oct. 29, 1859 UT
	Gull Lake, Off Nov. 20, 1842 UT
Stn. 4	Bancroft-Silent Lake Provincial Park
	Start Oct. 29 1502 UT
	Off Nov. 20 1842 UT
Stn. 5	Haliburton Start Oct. 29 1240 UT
	Tape jammed about Nov. 9, Off Nov. 20.
Stn. 6	Blackburn Observatory-continuous operation (AMOS) X,Y,Z.

TABLE II

MEAN AMPLITUDES OF FOURTEEN EVENTS

VERTICAL MAGNETIC INTENSITY (nT)

NOV. 2, 3, 4, 1975

Station	Periods		
	(5-30 min.)	(30-60 min.)	(60-120 min.)
Kingston	48.1	79.0	60.0
Gull Lake	50.1	-	70.0
Bancroft	56.6	89.3	68.7
Haliburton	54.2	87.3	70.7
Ottawa	64.2	96.0	71.0

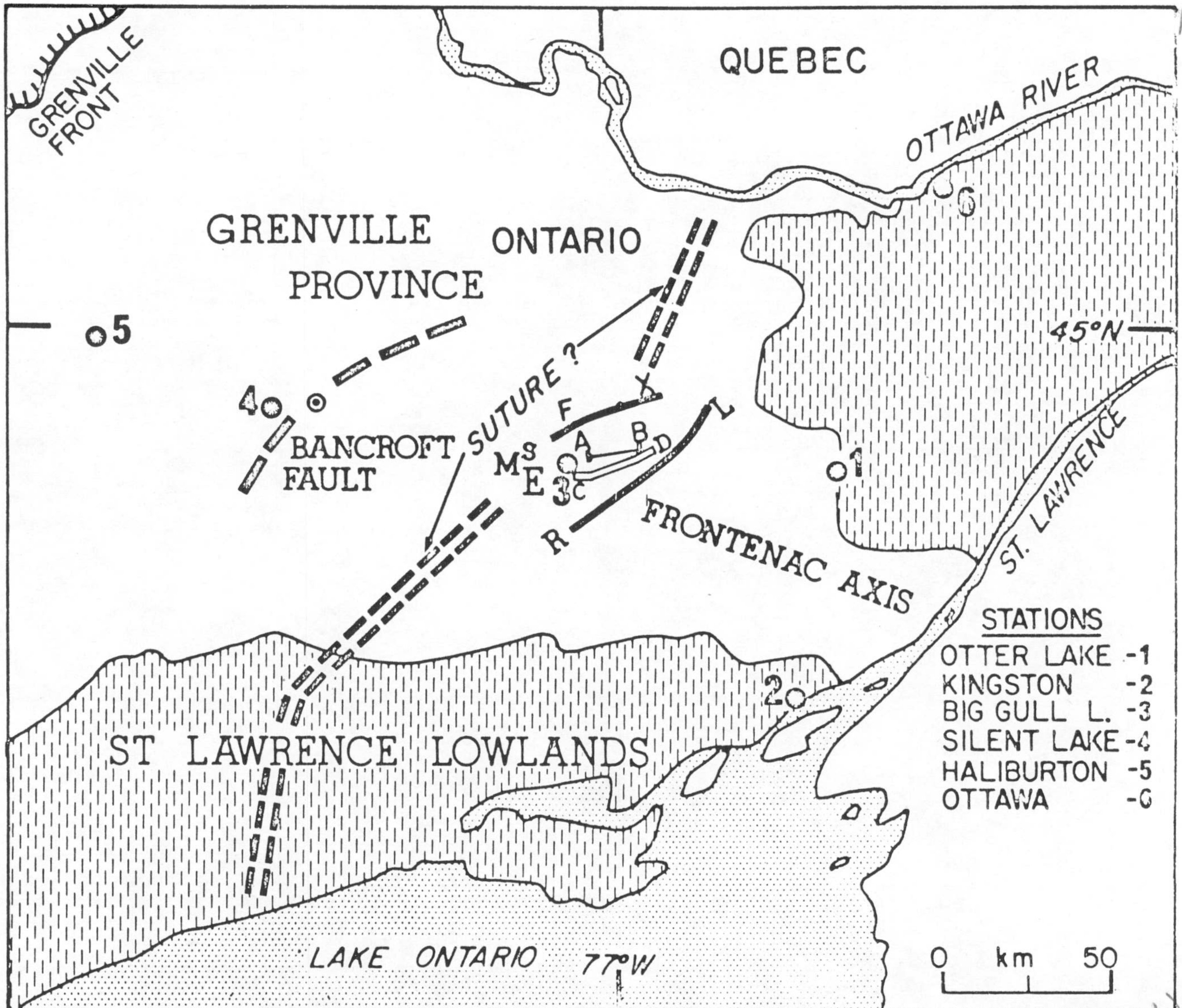

Figure 1: Area of investigation, showing geological province boundaries and location of stations. A-B denotes narrow mafic bands, C-D is the Northbrook pluton, M is the Mount Moriah syenite, S is Skootamata L., E the Elzevir batholith. R-L is Robertson Lake shear zone. F-X is Fernleigh-Clyde fault.

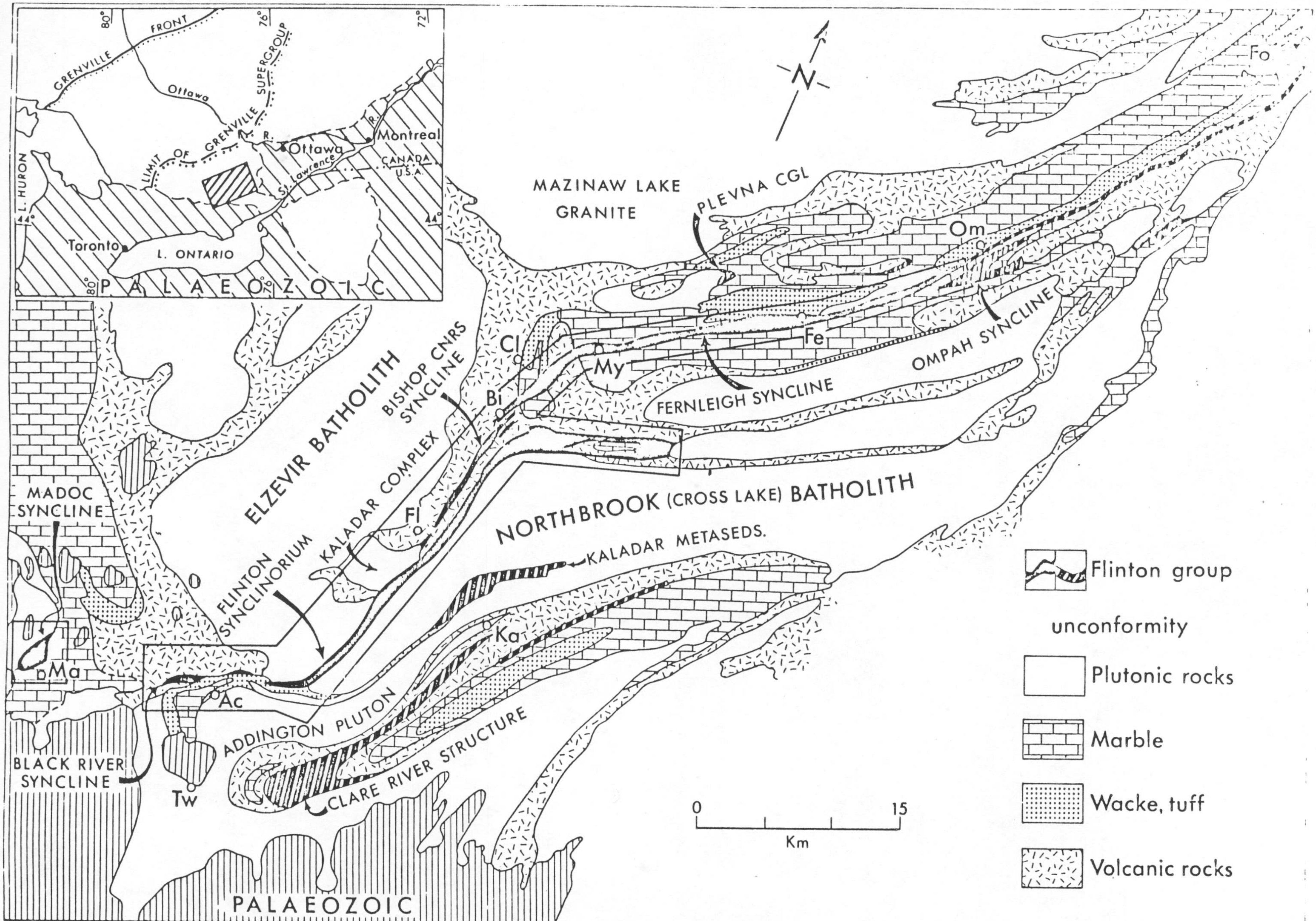

Figure 2: General geology of the central area of investigation. Northbrook Batholith is referred to as Northbrook pluton in the text. Place names Fe = Fernleigh, Cl = Cloyne, Om - Ompah, TW = Tweed.

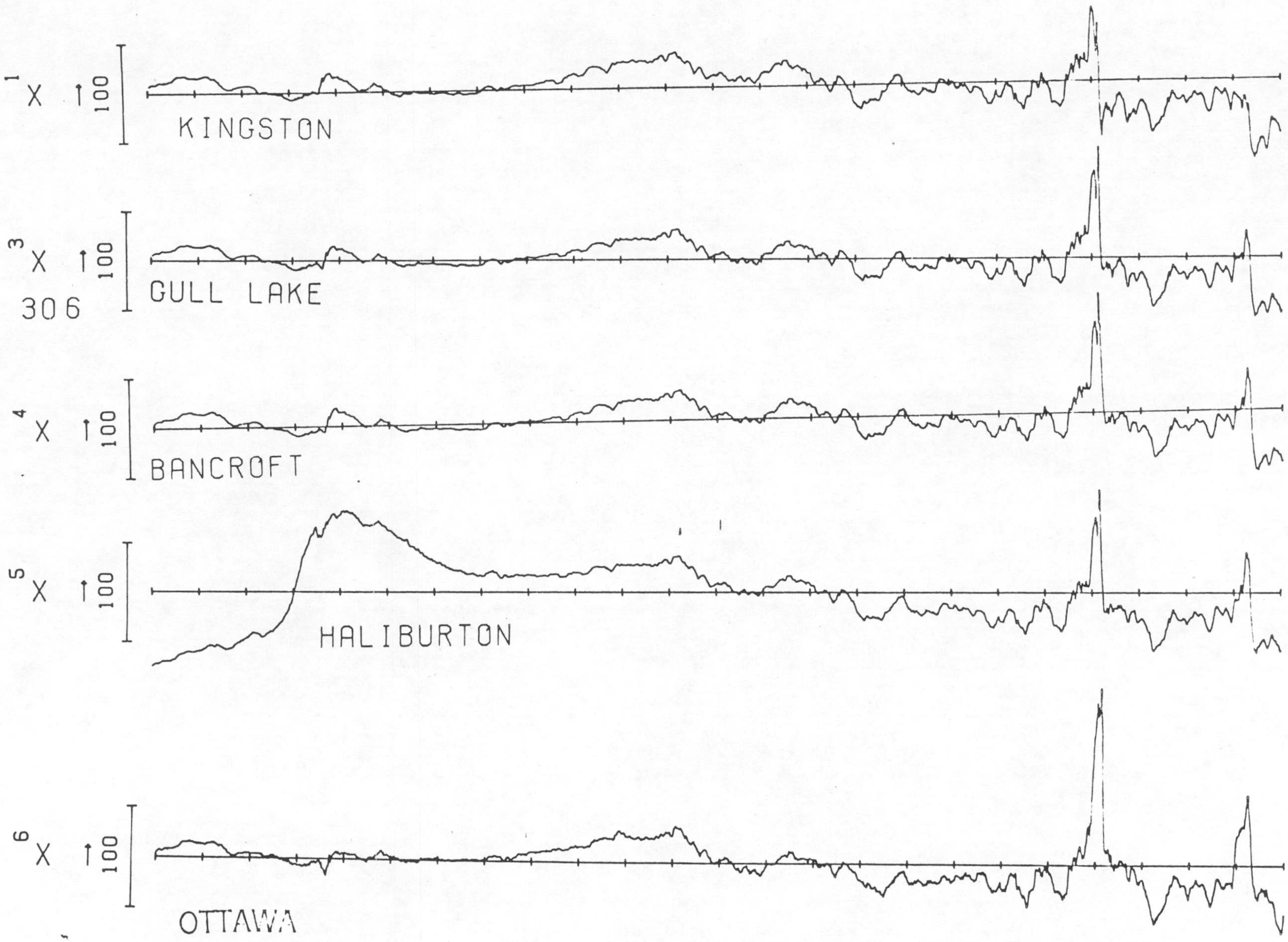

Figure 3: Magnetograms, North component (X=H.cos D) Day 306. Scale bar = 100 nT.

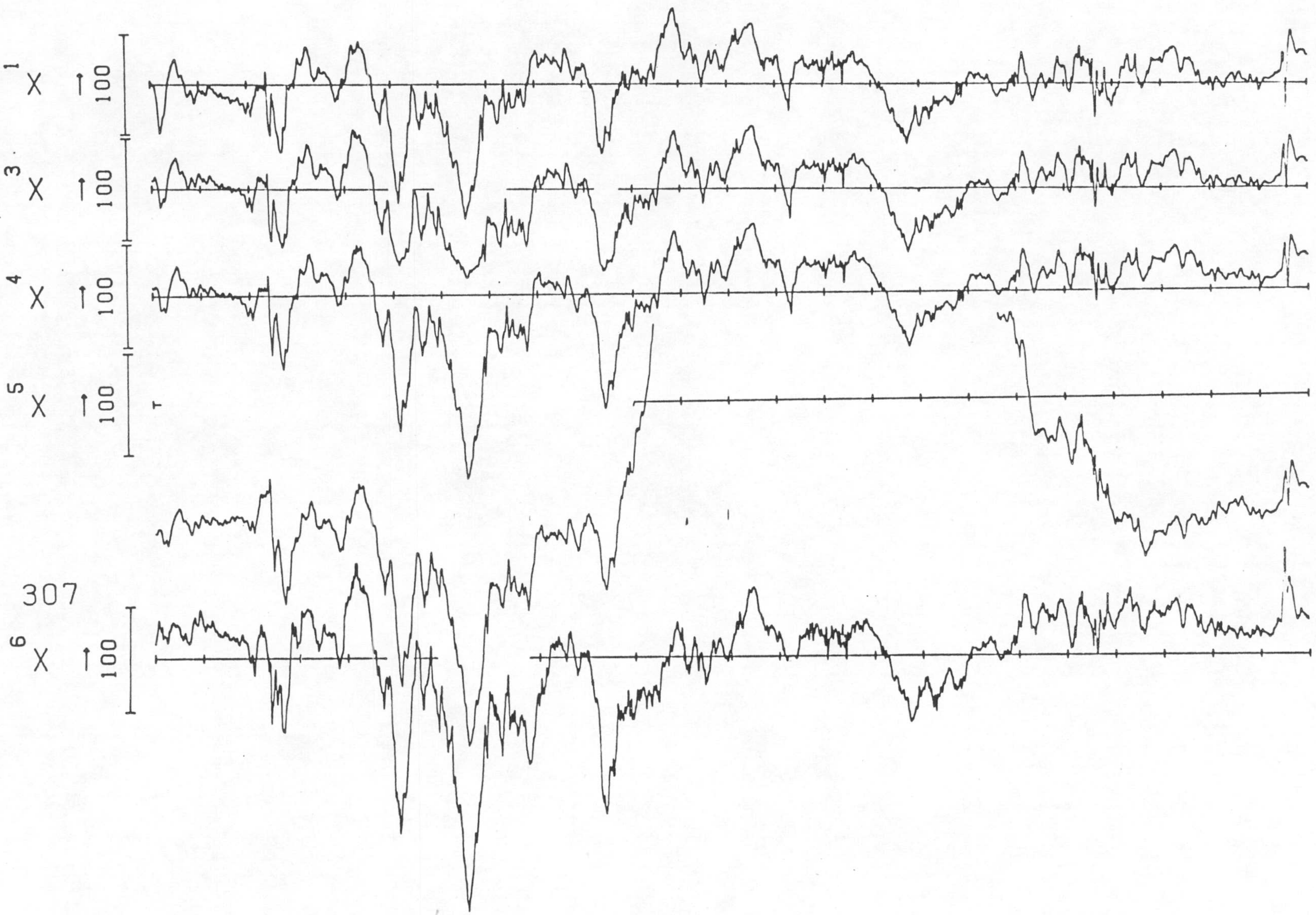

Figure 4: North component (X=H. cos D) Day 307. Scale bar = 100 nT.

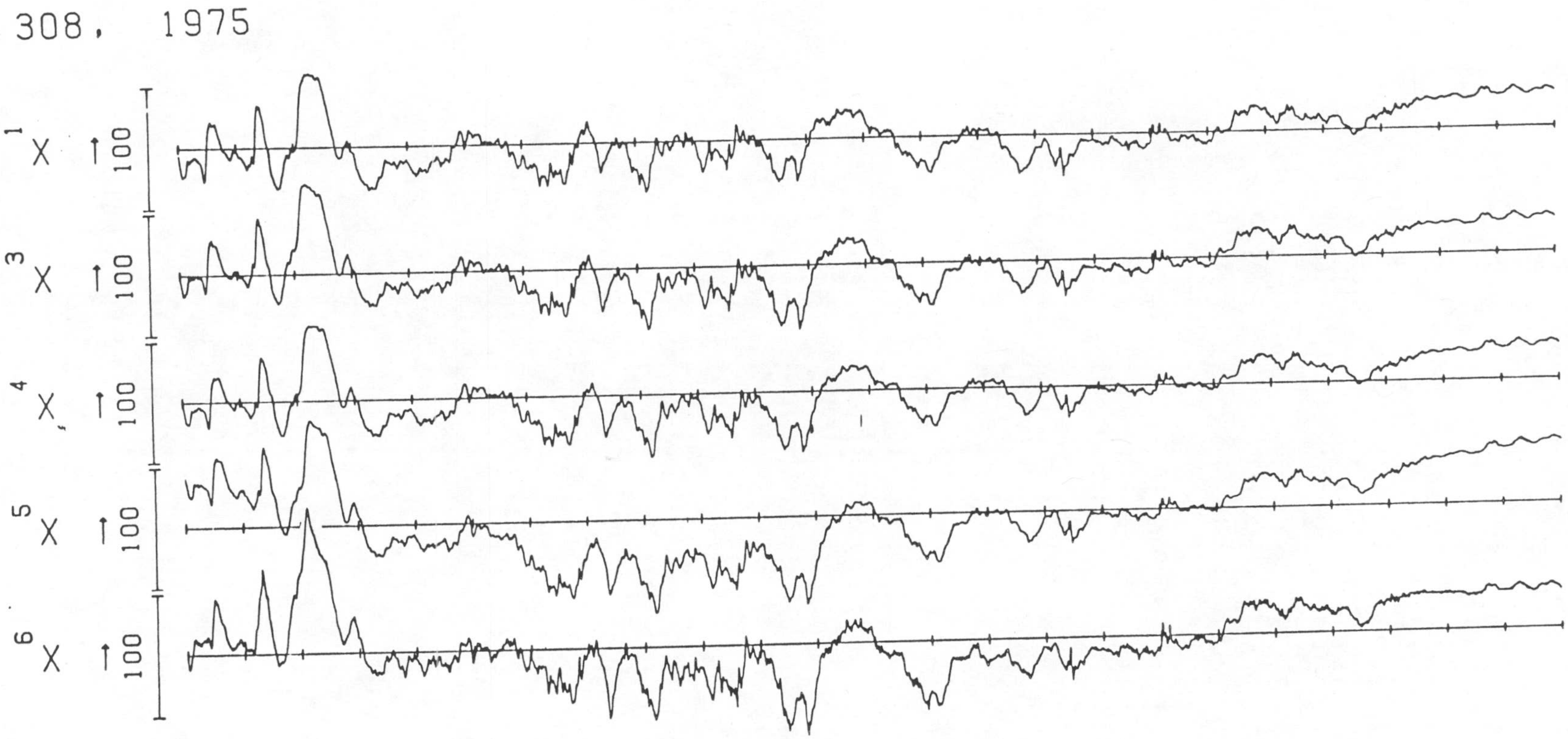

Figure 5. North component (X=H). cos D) Day 308. Scale bar = 100 nT.

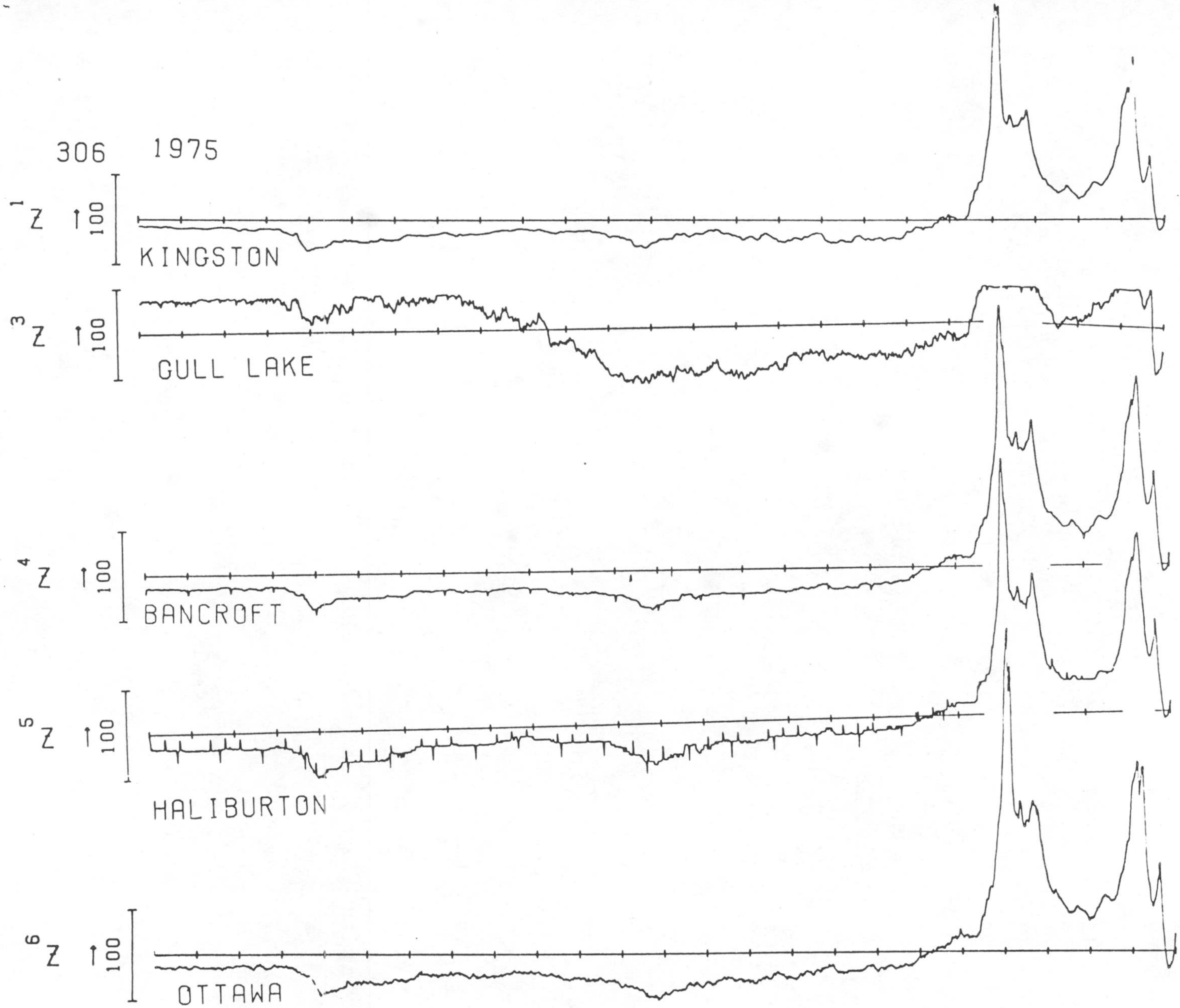

Figure 6: Vertical field component (Z=H. tan I) Day 306. Scale bar = 100 nT, increasing upwards.

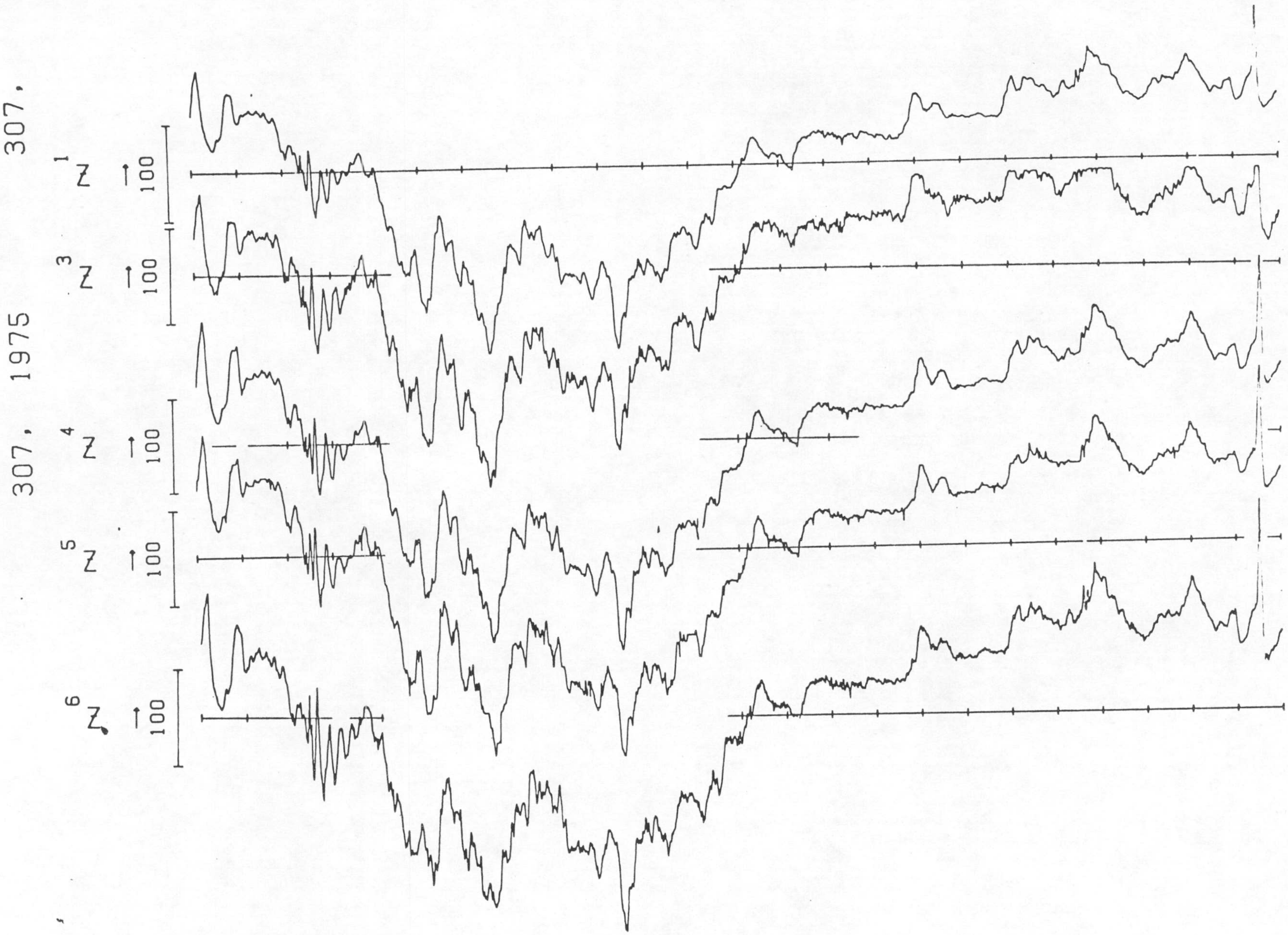

Figure 7: Vertical field component (Z=H. tan I) Day 307. Scale bar = 100 nT.

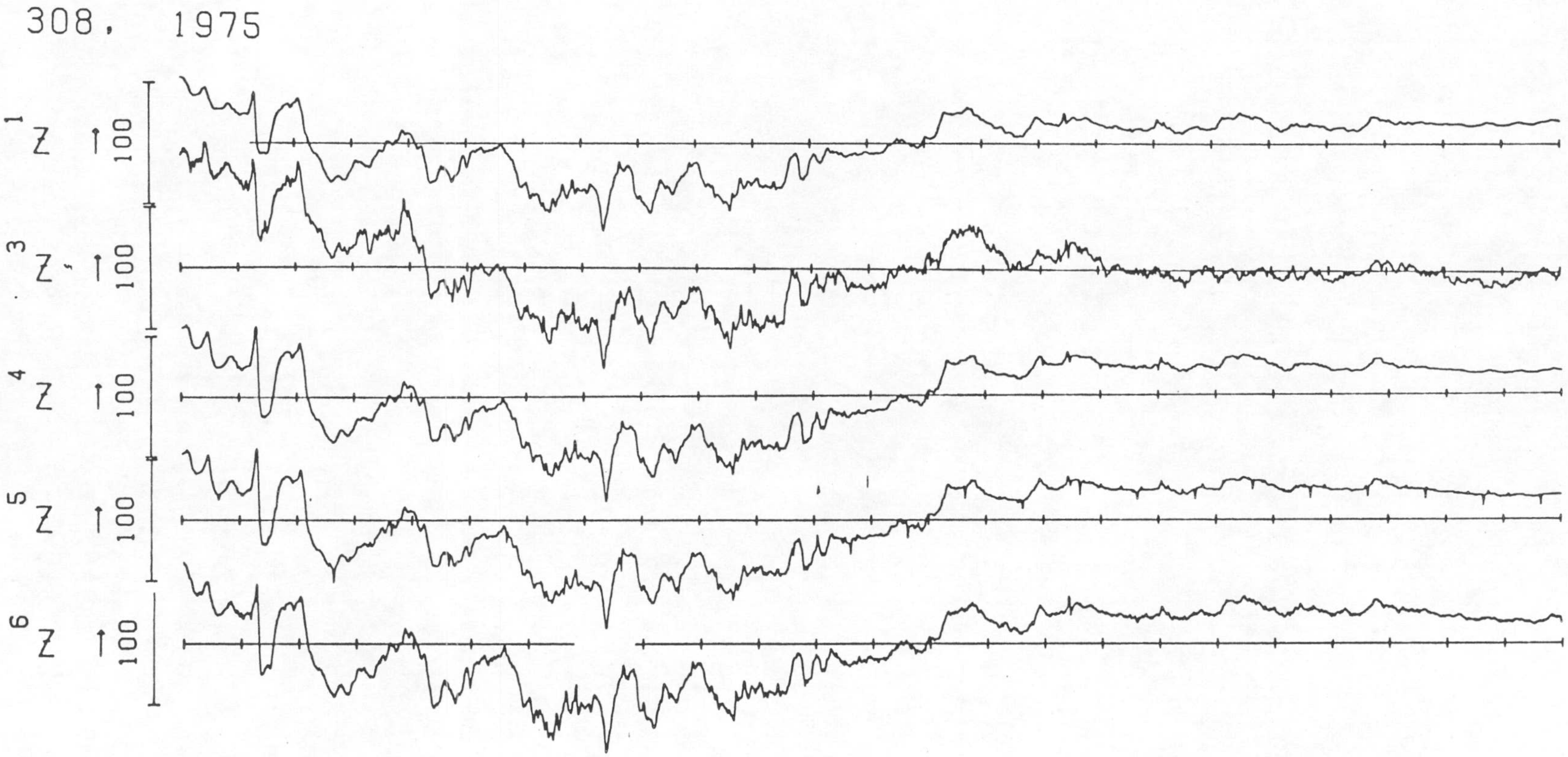

Figure 8. Vertical field component (Z=H. tan I) Day 308. Scale bar = 100 nT.

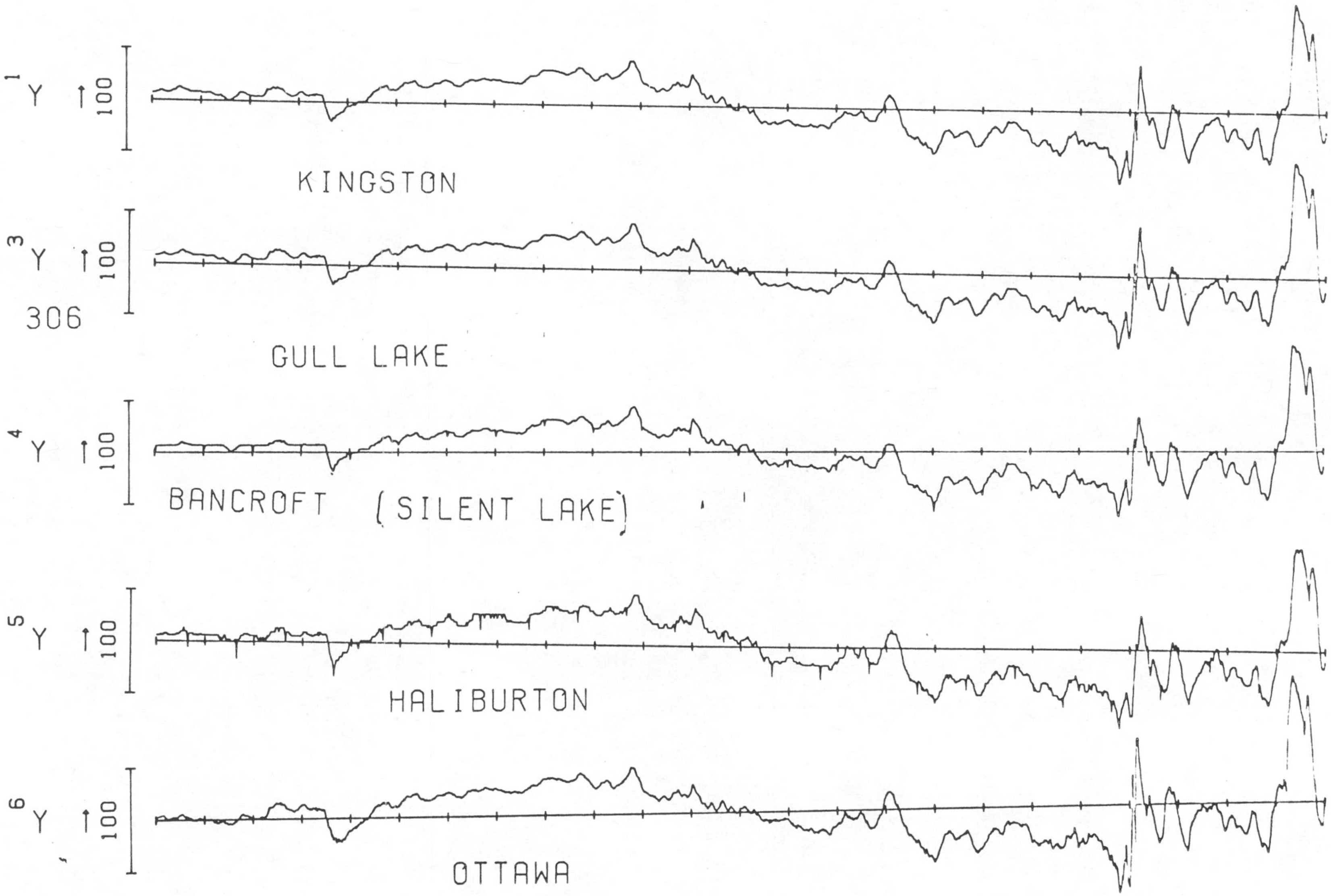

Figure 9: East component (Y=H. sin D) Day 306. Scale bar = 100 nT, increasing upwards.

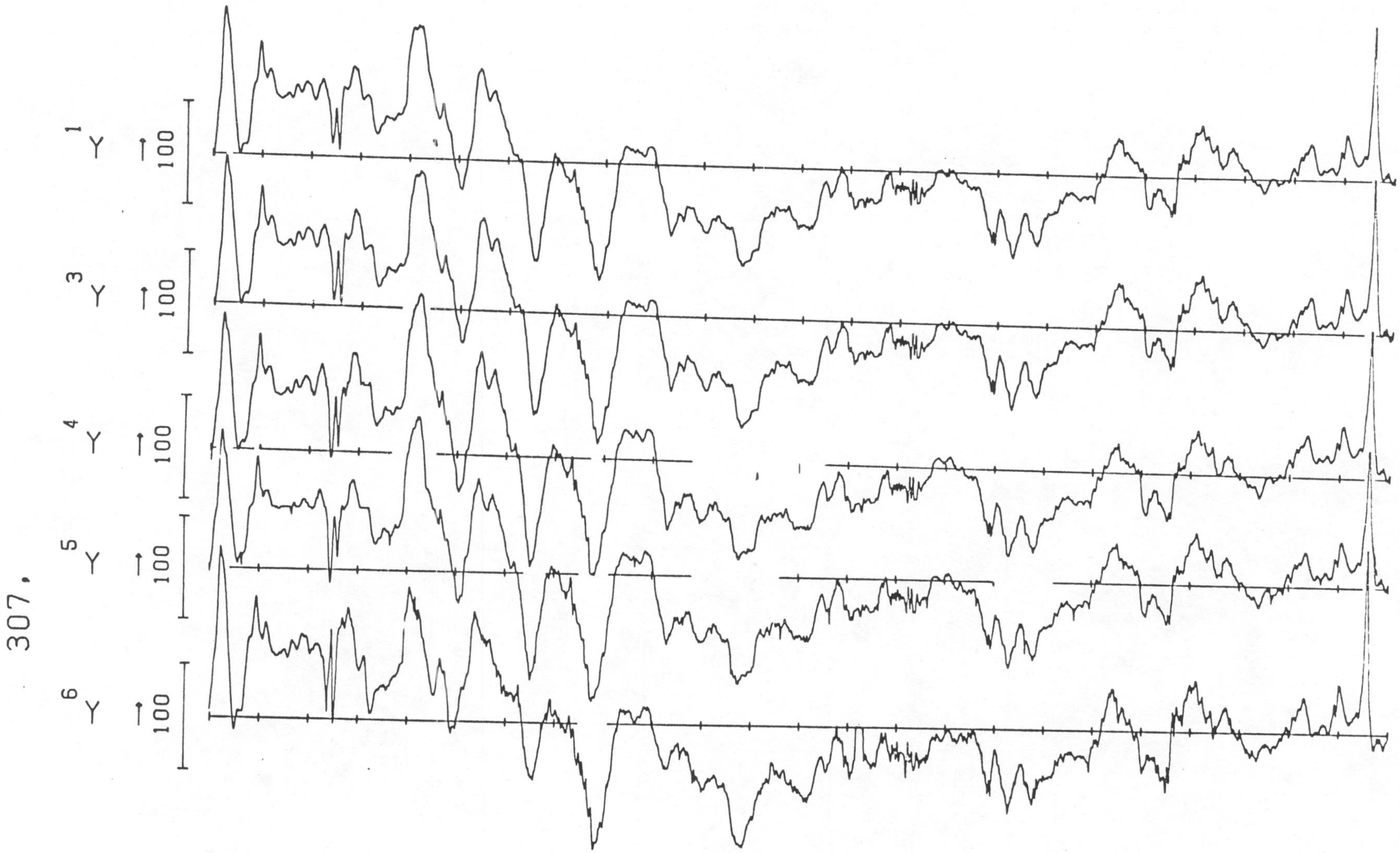

Figure 10: East component (Y=H. sin D.) Day 307. Scale bar = 100 nT.

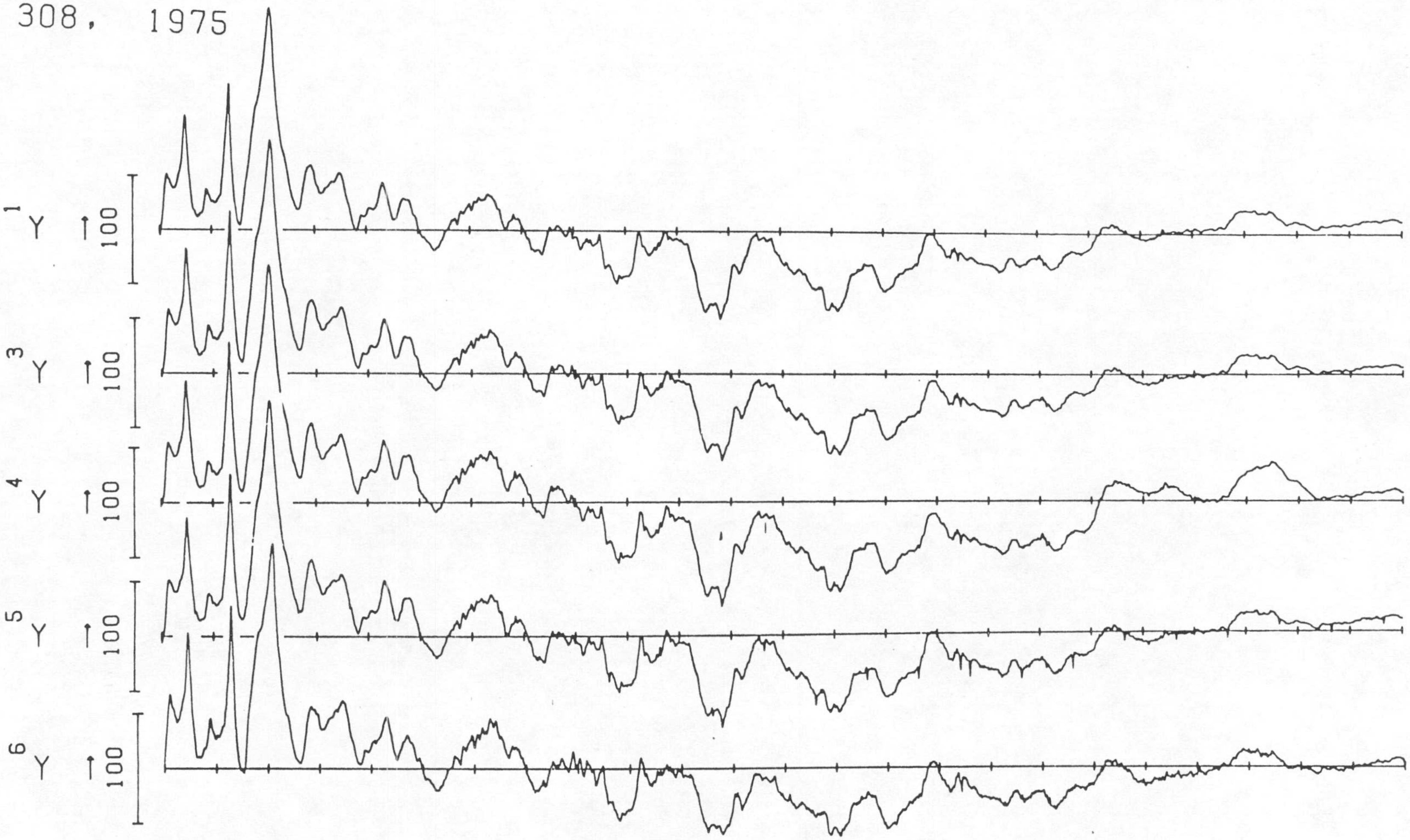

Figure 11: East component (Y=H. sin D.) Day 308. Scale bar = 100 nT.