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Preliminary paleomagnetic studies of lake sediments in Eastern Canada
Études paléomagnétiques préliminaires de sédiments lacustres dans l'est du Canada

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Article abstract

Nine lake bottom sediment cores from small lakes in Eastern Canada, three of which were oriented to an azimuth, have been analyzed magnetically in an attempt to delineate the paleomagnetic character of the late-Pleistocene and Holocene sediments as an aid to stratigraphy and chronology. Secular variations are discernable in mineral sediments and in overlying organic sediments when intensities are strong enough to produce reliable results. Where organic content was high and intensities low, erratic results were obtained. Short segments of some cores, involving at most several centimetres, showed negative values for inclination, but whether or not these can be related to magnetic reversals or excursions or are spurious results, cannot be determined at this time.

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PRELIMINARY PALEOMAGNETIC STUDIES OF LAKE SEDIMENTS IN EASTERN CANADA

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ABSTRACT Nine lake bottom sediment cores from small lakes in Eastern Canada, three of which were oriented to an azimuth, have been analyzed magnetically in an attempt to delineate the paleomagnetic character of the late-Pleistocene and Holocene sediments as an aid to stratigraphy and chronology. Secular variations are discernable in mineral sediments and in overlying organic sediments when intensities are strong enough to produce reliable results. Where organic content was high and intensities low, erratic results were obtained. Short segments of some cores, involving at most several centimetres, showed negative values for inclination, but whether or not these can be related to magnetic reversals or excursions or are spurious results, cannot be determined at this time.

RÉSUMÉ *Études paléomagnétiques préliminaires de sédiments lacustres dans l'est du Canada.* Les auteurs ont étudié les propriétés magnétiques de neuf carottes de sédiments, dont trois sont orientées, prélevées au fond de petits lacs de l'est du Canada. Le but de cette étude était de définir les caractéristiques paléomagnétiques des sédiments de la fin du Pléistocène et de l'Holocène, et ce, pour des fins stratigraphiques et chronologiques. Des variations séculaires sont discernables dans les sédiments minéraux qui les recouvrent, quand les intensités sont assez fortes pour donner des résultats valables. Lorsque le contenu organique était élevé et les intensités faibles, les résultats obtenus étaient irréguliers. Des valeurs négatives d'inclinaison ont été obtenues pour des segments, de plusieurs centimètres tout au plus, de certaines carottes. Il est impossible d'affirmer présentement que ces valeurs sont ou ne sont pas en relation avec des inversions ou des excursions du champ magnétique, ou qu'il s'agit de résultats erronés.

РЕЗЮМЕ ПРЕДВАРИТЕЛЬНЫЕ ПАЛЕОКЛИМАТИЧЕСКИЕ ИССЛЕДОВАНИЯ ОСАДКОВ В ОЗЕРАХ ВОСТОЧНОЙ КАНАДЫ. Для исследования были взяты керны из осадков со дна девяти небольших озер в восточной Канаде, причем три из этих кернов были ориентированы по азимуту. В помощь стратиграфии и хронологии, все керны подверглись анализу на магнетизм с целью попытаться установить палеоклиматический характер осадков относящихся к поздне-плейстоценской и Голоценской эрам. Когда сила магнитного поля оказывалась достаточной для того, чтобы получить надежные результаты, оказывалось возможным установить изменения происходившие от века к веку, как в минеральных, так и в лежащих над ними органических осадках. В тех случаях, когда керны содержали большое количество органических осадков, а сила магнитного поля была слабой, полученные результаты носили неопределенный характер. Короткие, не более нескольких сентиметров длинной, сегменты некоторых кернов показывали отрицательный заряд. Однако, до настоящего времени не удалось установить вызвано ли это изменением направления магнитного поля, его сдвигом или объясняется ошибками допущенными при исследовании.

INTRODUCTION

The Brunhes normal epoch, the magnetic epoch which began about 690,000 years ago (OPDYKE, 1972) and was long thought to be of normal polarity throughout, has been shown to contain magnetic events or excursions of various ages. Reported to date are the following events: Biwa II (298,000-292,000 years BP) and Biwa I (186,000-176,000 years BP) events (KAWAI *et al.*, 1972), Blake event (118,000-114,000 years BP) (SMITH and FOSTER, 1969), Lake Mungo event (30,780-28,140 years BP) BARBETTI and McELHINNY, 1972) and the Laschamp event (BONHOMMET and BABKINE, 1967).

The Laschamp event could not be accurately dated when first described, but eventually ^{14}C and K/Ar age determinations placed the end of the event between 8000 and 20,000 years BP and indicated the duration to be not more than 20,000 to 30,000 years (BONHOMMET and ZÄHRINGER, 1969). Subsequently, several investigators have reported magnetic excursions from within the same general time period in sediments of various types from widespread areas of the globe. Those excursions possibly related to the Laschamp event are listed in Table I along with the proposed or determined ages for the phenomenon.

Reports by MÖRNER *et al.* (1971) and MACKARETH (1971) placing the age of an excursion at abour 12,350 years BP and 13,400 years BP respectively, prompted an investigation into the possibility of using the paleomagnetic record preserved in the sediments of small lakes in eastern Canada as a stratigraphic tool for correlation, especially where radiocarbon dates were lacking or where anomalous radiocarbon ages were obtained. To this end, sediments from nine small lake sites were studied, and some of the results comprise this report. Some caution is expressed regarding the paleomagnetic determinations and interpretations of paleomagnetic results.

METHODS

The first cores used in this study had been collected for pollen studies and, therefore, were not oriented. Also, the one metre core increments had been cut into 50 cm lengths for ease of storage which meant that not only were each metre increment not oriented relative to each other, but each half-metre was not oriented relative to the other half as well. Hence declination could not be determined with any degree of confidence. Attempts at trying to obtain a relative orientation for the whole core by matching up the declination at the top of a segment with the declination at the base of the overlying segment proved too confusing and unreliable to be worthwhile. Eventually several cores were recovered specifically for magnetic study, and these were oriented with respect to an azimuth using the sun. As each metre increment was taken during the coring procedure, the sampler was oriented relative to the sun and the time of day was recorded. Knowing the date, correct local time and latitude and longitude, the sun's true bearing could be determined later using sun tables.

All cores were obtained with a Livingstone piston corer with a 3.8 cm inside diameter core tube. Increments 2.4 cm long were cut from the core and were pared down to fit the magnetometer sample holder. Measurements of the natural remanent magnetization were made on a digital spinner magnetometer. Samples were then demagnetized in a 100 oersted alternating magnetic field to remove any unstable component of

TABLE I

Paleomagnetic excursions possibly correlative with the Laschamp Event.
Excursions paléomagnétiques en corrélation possible avec l'événement de Laschamp.

Locality	Age (BP)	Dating method	Reference
Laschamp, France	>7000 – 9000	^{14}C	BONHOMMET and BABKINE, 1967.
Laschamp, France	<20,000	K/Ar	BONHOMMET and ZAHRINGER, 1969.
Gothenburg, Sweden	>12,350	^{14}C	MÖRNER *et al.*, 1971; MÖRNER and LANSER, 1974.
Lake Windermere, U.K.	13,400 ± 400	^{14}C	MACKERETH, 1971.
Mediterranean and Pacific	7000	Fauna	WOLLIN *et al.*, 1971.
Gulf of Mexico	12,500 – 17,000	Fauna	CLARK and KENNETT, 1973.
Lake Biwa, Japan	17,600 – 18,700	^{14}C	NAKAJIMA *et al.*, 1971.
Gulf of Mexico	17,000 ± 1500	Fauna	FREED and HEALY, 1974.
North Atlantic	>12,350	Fauna	MÖRNER and LANSER, 1975.
Blekinge, Sweden	12,077 – 12,103 ± 150	Varves	NÖEL and TARLING, 1975.
Lake Erie, Canada	>8000 – <14,000	Pollen	CREER *et al.*, 1976a.
Imuruk Lake, Alaska	17,000 – 18,000	Pollen	NOLTIMIER and COLINVAUX, 1976.
Lake Michigan, U.S.A.	8000 – 10,000	?	DODSON *et al.*, 1976.
Lake Ontario, Canada	>12,500	Pollen	ANDERSON *et al.* 1976

magnetization. The 100 oersted demagnetizing field was found to be suitable for most sediments after stability index measurements were carried out on test samples from each core. For this test, samples were subjected to partial alternating demagnetizing fields up to 1,000 oersteds measured at 100 oersted intervals. Erratic stability index measurements were obtained for sediments with high organic content and low intensity. When this type of sediment was encountered, analysis was discontinued.

RESULTS

The first core analyzed magnetically was from Basswood Road Lake in New Brunswick (Fig. 1). This core, which was primarily collected for pollen analysis, was not oriented and had been cut into half-metre increments. The core showed 0.5 m of organic clay and grey clay below the organic sediments which has a basal radiocarbon date of 12,600 ± 270 years BP (GSC-1067; MOTT, 1975). Gyttja, another clay layer, and more gyttja occur above as shown in the stratigraphic column in Figure 2.

The magnetic inclination (Fig. 2) fluctuates between 40° and 70° for most of the core except for the basal clay. At the top of the clay, three samples have negative inclinations with one completely reversed. Below this values are positive but fluctuate widely between 10° and 70°. Is this the Gothenburg "flip" which is reported to have ended at 12,350 years BP (MÖRNER and LANSER, 1974)? Although the time interval involved at Basswood Road appears to be rather short the possibility of correlation still exists. Unfortunately, the sampling did not penetrate deeper and duplicate cores were not obtained. Hopefully, an opportunity to revisit this site will come in the near future.

Little Lake, a second site in the same area of New Brunswick (Fig. 1), has pebbly sand below organic sediment with basal clay partings. The basal date of 16,500 ± 370 years BP (GSC-1063) was shown by pollen analysis to be anomalous and roughly correlative with the 12,600 years BP date at Basswood Road Lake

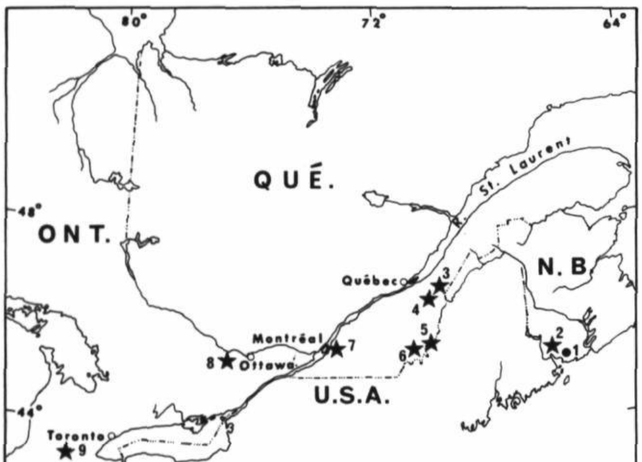

FIGURE 1. Map showing location of sampling sites. Stars indicate when magnetic profiles is included in report. Dot indicates when magnetic profile is not included. 1) Little Lake, N.B.; 2) Basswood Road Lake, N.B.; 3) Lac Colin, Qué.; 4) Petit Lac Terrien, Qué.; 5) Unknown Pond, Maine; 6) Lac aux Araignées, Qué.; 7) Lac des Bouleaux, Qué.; 8) Clayton Lake, Ont.; 9) Maplehurst Lake, Ont.

Carte de localisation des sites échantillonnés. Étoiles: profils magnétiques décrits dans le texte; point: profil magnétique non inclus.

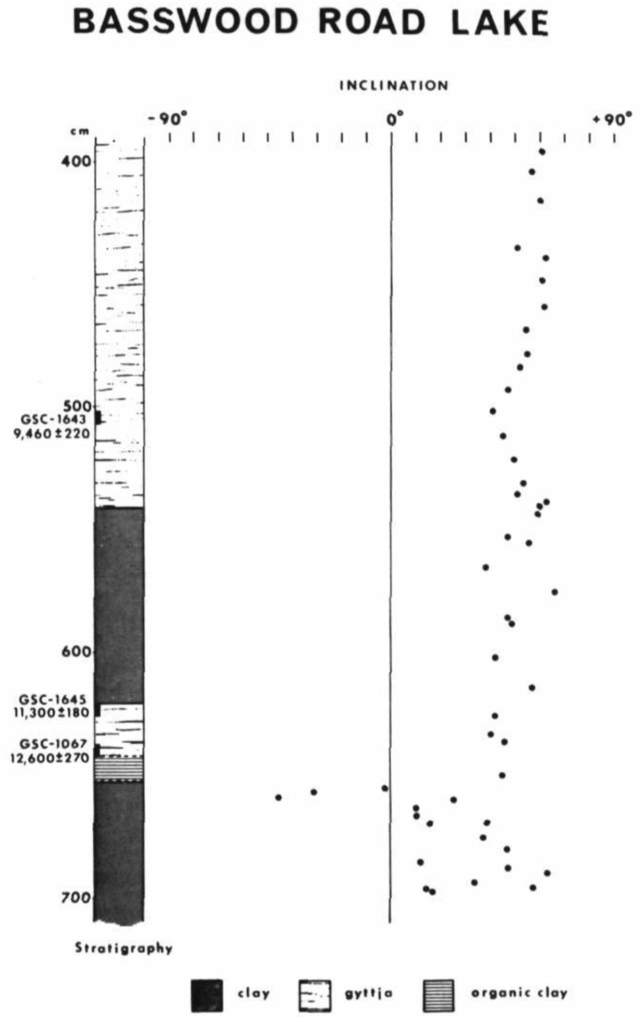

FIGURE 2. Stratigraphy, radiocarbon dates and magnetic inclination profile for Basswood Road Lake, New Brunswick.

Stratigraphie, dates au radiocarbone et profil de l'inclinaison magnétique du lac Basswood Road, Nouveau-Brunswick.

(MOTT, 1975). The basal pebbly sand should then be about the same age as the basal clay at Basswood Road Lake. The magnetic inclination plot does not show any negative readings but the angle varies between 3° and 80° and resembles the part of the Basswood Road Lake profile below the negative inclination peak. However, the pebbles in the sand may have exerted a strong influence on the readings, and since they may not have been oriented to the magnetic direction existing at the time of deposition, the results may not be reliable.

Since the New Brunswick cores showed such promising magnetic records which could be interpreted, other cores, collected for palynological studies, were also analyzed magnetically. A core from Maplehurst Lake in southern Ontario (Fig. 1) revealed almost 1.5 m of fine sand and silt, and silty clay underlying organic sediment. The basal organic sediment was radiocarbon-dated at 12,500 ± 180 years BP (GSC-1156), which is well within the age range of the possible excursion in New Brunswick. The upper part of the magnetic profile has inclinations ranging between 40° and 80°, but in the lower part they fluctuate widely with one negative reading of -5° (Fig. 3). Unfortunately, the core did not extend deeper.

Lac des Bouleaux on Mont Bruno near Montréal, Québec (Fig. 1), was another site that appeared promising. Two radiocarbon dates were obtained on a core from the lake; 13,000 ± 290 years BP (GSC-1344; LOWDON and BLAKE, 1973) from the basal organic sediment overlying 50 cm of coarsely laminated silty clay, and 12,400 ± 170 years BP (GSC-1803; LOWDON and BLAKE, 1975) from immediately above. The magnetic inclination wavers around 60° throughout the silty clay, but in the organic sediment it becomes erratic with one sample having a negative value (Fig. 4). At first glance it would appear that a small excursion might have been recorded for the same time period found previously in the other cores. However, since this site is below the limit of the Champlain Sea on Mont Bruno, it is impossible for this site to be as old as the dates indicate. A radiocarbon date of 11,000 ± 350 years BP (Gif-401; LASALLE, 1966) on marine shells from a gravel pit at the west end of Lac des Bouleaux indicates that the lake could not have been isolated from the sea prior to that time. Also, a subsequent palynological study (Mott, unpubl.) showed that the basal organic sediment contains abundant spruce pollen. The spruce pollen zone in this area dates between about 10,000 and 11,000 years BP (TERASMAE and LASALLE,

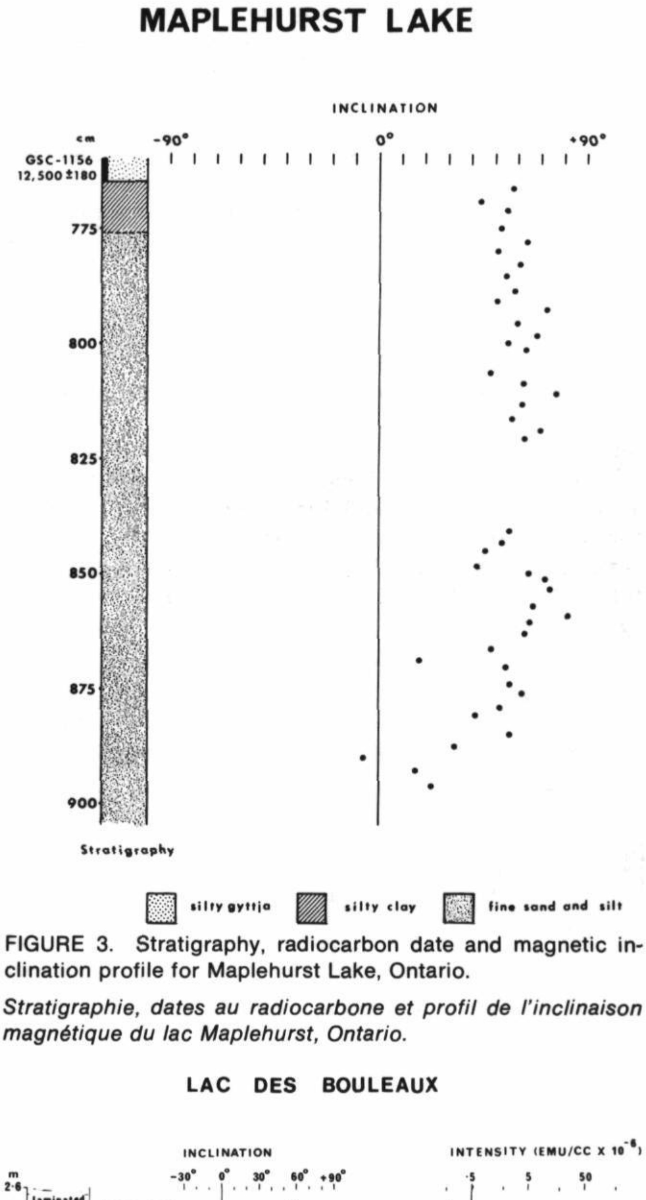

FIGURE 3. Stratigraphy, radiocarbon date and magnetic inclination profile for Maplehurst Lake, Ontario.

Stratigraphie, dates au radiocarbone et profil de l'inclinaison magnétique du lac Maplehurst, Ontario.

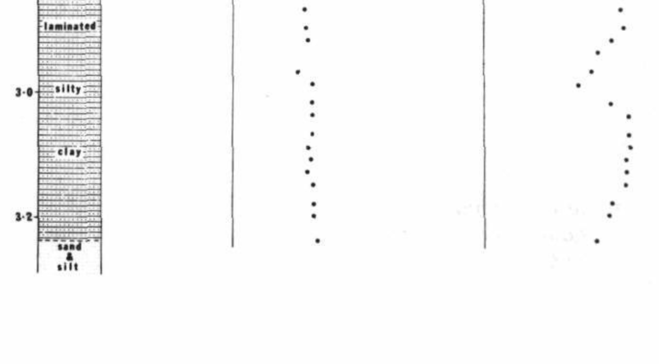

FIGURE 4. Stratigraphy, radiocarbon dates and magnetic inclination and intensity profiles for Lac des Bouleaux, Québec.

Stratigraphie, dates au radiocarbone et profils de l'inclinaison et de l'intensité magnétiques du lac des Bouleaux, Québec.

1968). Thus, the anomalous readings do not fall within the age range of the possible excursion found in the New Brunswick cores. We believe that the results shown here do not constitute an excursion but are spurious results caused by the weak magnetic intensity of the organic sediment being dominated, perhaps, by coarse mineral particles.

A correlation between low magnetic intensity and erratic inclination determination can be seen in the plot from Unknown Pond located on the Maine side of the Québec-Maine border east of Lac Mégantic, Québec (Fig. 1). Most of the inclination measurements range between 35° and 70° in the basal silty clay (Fig. 5). In the overlying organic sediment the intensity drops off sharply and the magnetic inclination fluctuates widely with many negative values appearing. The two radiocarbon dates have been shown to be anomalously old (MOTT, 1977), with the result that the magnetic profile for the lower organic sediment cannot be correlated with a possible excursion in the 12,350 years BP range.

The magnetic profiles discussed above involve only the basal organic and underlying inorganic sediments of the cores because the magnetic intensity of the upper organic sediments was found to be too weak to provide reliable results. However, seven metres of core from Lac aux Araignées located near Lac Mégantic, Québec (Fig. 1), produced reliable results (Fig. 6) from the organic sediments as well. This is a much larger lake than the previous lakes and the mineral content of the sediments is much higher. From the basal clay upward through the organic clay, where a date of 10,700 ± 310 years BP (GSC-1353; MOTT and FOSTER, 1973) was obtained, and continuing upward through the silty gyttja into gyttja, the magnetic inclination varies between 30° and 70°. Intensity gradually diminishes upward with increasing organic content, and in the upper part of the profile, wider fluctuations in inclination appear. It may be possible with more work, to correlate the oscillations in the angle of inclination with other sites, as has been attempted with declination in Great Lakes cores (CREER *et al.*, 1976a and b; ANDERSON *et al.*, 1976).

The results outlined above have been obtained from cores collected for purposes other than paleomagnetic studies. It was decided that properly oriented cores should be obtained so that the magnetic declination could also be used to characterize the sediments. Toward this end, three sites were cored, two in Québec (Petit Lac Terrien and Lac Colin), and one in Ontario (Clayton Lake).

Petit Lac Terrien is a small lake situated about 6 km northeast of St-Nazaire-de-Buckland, Québec (Fig. 1). A radiocarbon date of 12,640 ± 190 years BP (GSC-312; DYCK *et al*, 1966) was obtained from the base of a core collected several years ago. Pollen analysis showed the date to be from the herb pollen zone (MOTT, 1977) indicating an old date should be expected, but carbonates in the sediment cast some doubt on the validity of the date. Additional evidence that would corroborate or reject the date would be useful. It was hoped that the paleomagnetic record would provide such evidence; hence two oriented cores were collected at the site. Almost 6 m of gyttja overlie 30 cm of laminated silty gyttja and 5 cm of moss. Below this, to a depth of 680 cm, is silty clay with some organics overlying grey, inorganic clay.

UNKNOWN POND

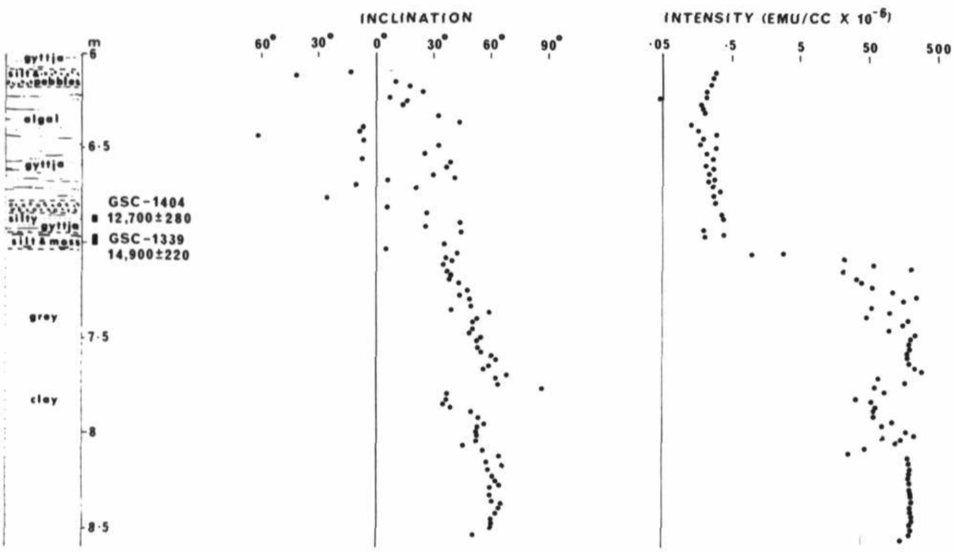

FIGURE 5. Stratigraphy, radiocarbon dates and magnetic inclination and intensity profiles for Unknown Pond, Maine.

Stratigraphie, dates au radiocarbone et profils de l'inclinaison et de l'intensité magnétiques du Unknown Pond, Maine.

Various problems were encountered with measuring the magnetic character of the two cores because of the very low magnetic intensity which fluctuated around 0.8×10^{-6} gauss for most of the mineral sediment, and less for the organic sediments. Although the cores were oriented, the declination measurements were too erratic to warrant including in Figure 7. The sediment below 6 m depth from the first core (shown to the left of the stratigraphic column in Fig. 7) shows a wide range of positive inclination values, whereas above 6 m, several negative inclination readings were obtained. It was realized that because the magnetic intensity of the sediment was so low, magnetic contamination of the plastic sediment holder was causing the negative values. Consequently, the results obtained for this part of the core are unreliable. The magnetic inclination for the second core, shown to the right of the stratigraphic column, is entirely different from the first core in that there is more scatter and negative values are common throughout the basal clays. No explanation for this difference is apparent. Had the second core been the only one measured, it might have been assumed that the values were reliable and recorded an excursion in the 12,600 years BP range. Obviously, more than one core should be analyzed whenever possible, care should be taken to eliminate contamination, and only sediments with strong remanent magnetism should be used.

A 2 m interval of an oriented core from Lac Colin, Québec (Fig. 1) was analyzed for remanent magnetism, and the results are shown in Figure 8 along with the stratigraphy and radiocarbon dates. Laminated silty clay is overlain by laminated black and grey clay with some organic content, laminated silty gyttja, and laminated black and brown gyttja. Two radiocarbon dates were obtained; one from the black and grey clay is 11,100 ± 180 years BP (GSC-2282), and the second,

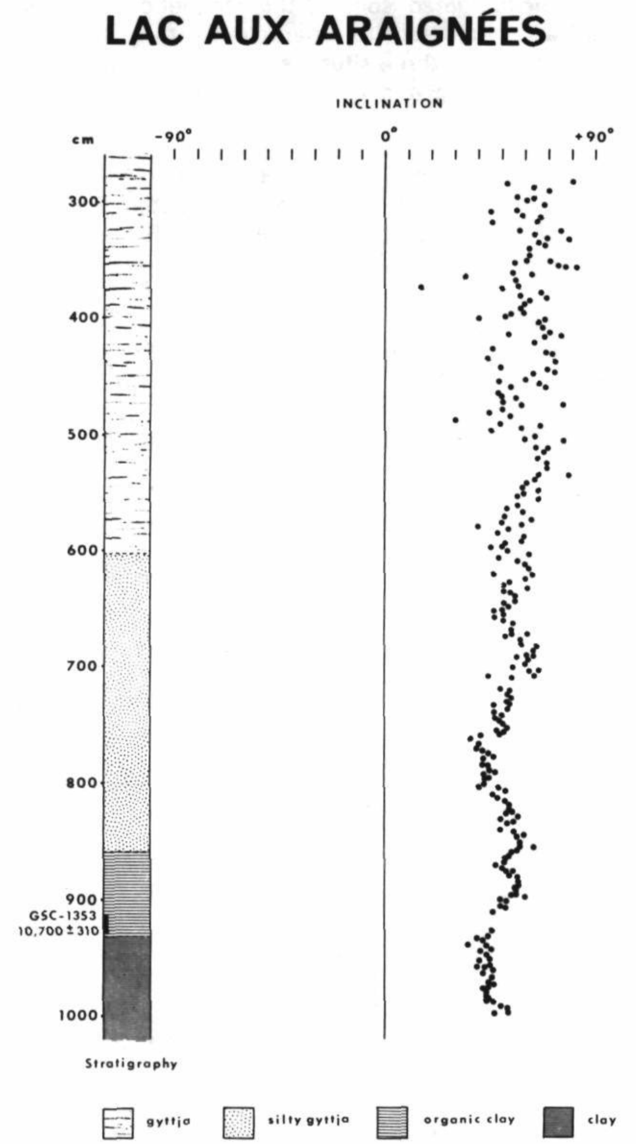

FIGURE 6. Stratigraphy, radiocarbon date and magnetic inclination profile for Lac aux Araignées, Québec.

Stratigraphie, dates au radiocarbone et profil de l'inclinaison magnétique du lac aux Araignées, Québec.

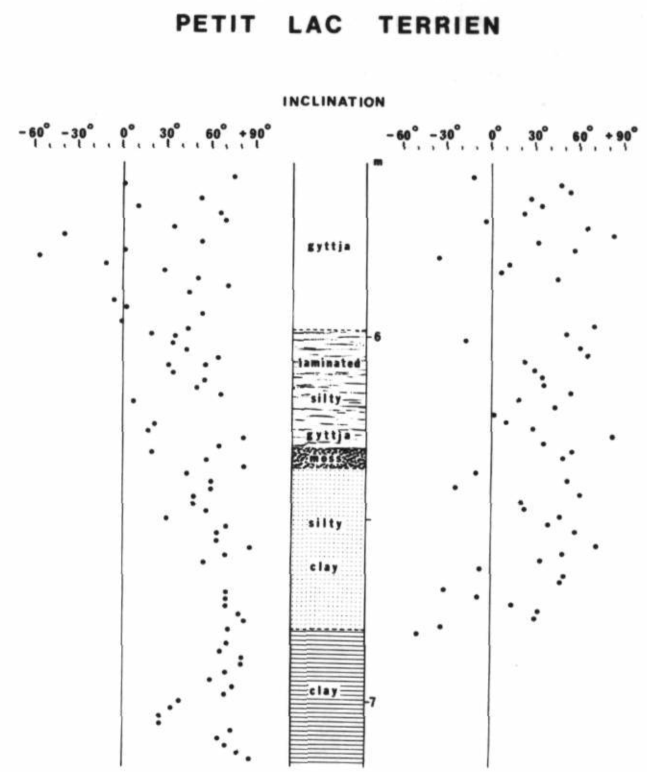

FIGURE 7. Stratigraphy and magnetic inclination for two separate cores from Petit Lac Terrien, Québec.

Stratigraphie et profils de l'inclinaison magnétique de deux carottes différentes du Petit Lac Terrien, Québec.

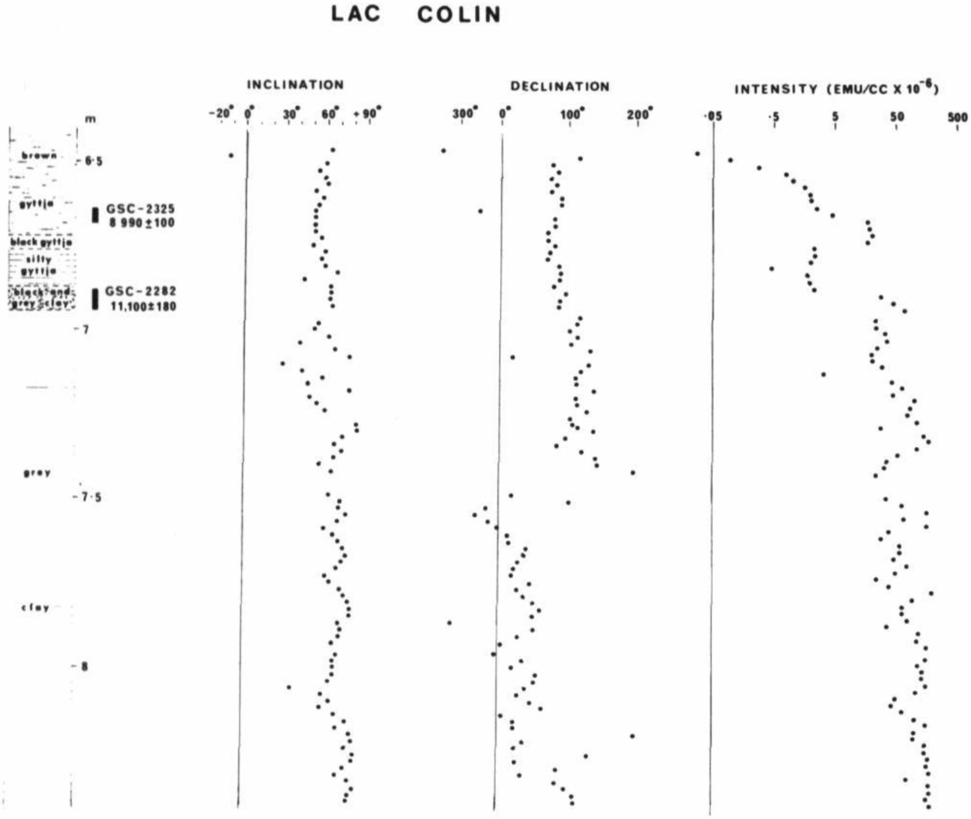

FIGURE 8. Stratigraphy, radiocarbon dates and magnetic inclination, declination and intensity profiles for Lac Colin, Québec.

Stratigraphie, dates au radiocarbone et profils de l'inclinaison, de la déclinaison et de l'intensité magnétiques du lac Colin, Québec.

from the base of the brown laminated gyttja, is 8990 ± 100 years BP (GSC-2325; MOTT, 1977).

The magnetic intensity is fairly strong throughout except near the upper part of the profile where it drops off sharply when the sediment becomes highly organic. The magnetic inclination shows some variation and the angle decreases slightly towards the top of the profile. It fluctuates more widely towards the top of the laminated grey clay but smooths out again in the organic sediment. One negative value is obtained near the top of the profile, but since the intensity is very low at this point, the negative reading may be spurious. The angle of declination is about 100° at the base of the profile and gradually swings to less than 0° at a depth of 750 cm where a discontinuity occurs, and the declination angle above the break is 100° again. This break in the declination profile occurs at the boundary between two 1 m core segments and might possibly result from an error in orientation at the time of sampling.

Another example is the Clayton Lake site located about 50 km southwest of Ottawa, Ontario (Fig. 1). Clayton Lake is situated at or just below the marine limit for the southern side of the Champlain Sea. Four metres of laminated and faintly laminated clay overlain by silty clay with minor organics and silty gyttja were analyzed (Fig. 9). No radiocarbon dates are available

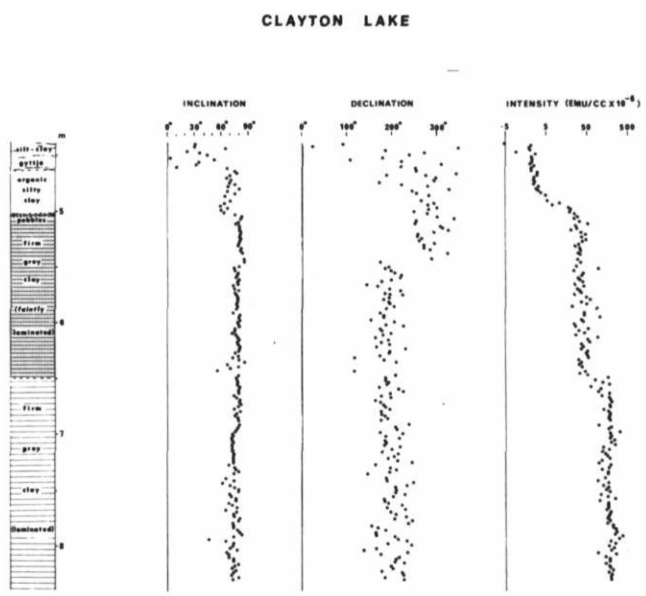

FIGURE 9. Stratigraphy and magnetic inclination, declination and intensity profiles for Clayton Lake, Ontario.

Stratigraphie, dates au radiocarbone et profils de l'inclinaison, de la déclinaison et de l'intensité magnétiques du lac Clayton, Ontario.

for this site, but preliminary pollen analysis revealed a spruce peak at the base of the organic, silty clays. In the Ottawa area the spruce maximum is dated at about 10,000 years BP (Mott, unpubl.).

Changes in the magnetic intensity of this core seem to correspond directly to changes in sediment type. A sharp drop in the intensity plot occurs at the contact between the basal laminated grey clay and the overlying faintly laminated grey clay, and a second decline occurs at the contact between the latter and the overlying organic sediments. The angle of magnetic inclination varies between 75° and 90° in the inorganic sediments, fluctuates between 70° and 90° throughout the silty organic clay and becomes highly scattered in the silty gyttja, probably because of the lower intensity. The declination angle fluctuates around 200° below 540 cm. Above this depth, the angle is much higher, but here again, the break seems to relate to the contact between two core segments. Why there is a shift of about 90° in the declination in both the Lac Colin and Clayton Lake cores corresponding to core breaks, when care was taken to orient both cores, is a puzzle. However, the fact that both shifts occur at the contacts of core increments is too coincidental to account for in any other way than a problem with correct orientation at the time of coring.

DISCUSSION

The various examples of anomalous behaviour noted in the above profiles indicate that considerable caution should be exercised in accepting paleomagnetic results at face value, especially when only single cores from a site are used. VEROSUB (1975) has previously expressed this caution and has documented how spurious results can be obtained using an actual case. Using folds in varved sediments from a site in New England he has shown how results from such a situation, if cored by a piston sampler, could be erroneously interpreted as a paleomagnetic excursion. Although the results obtained from Basswood Road and Maplehurst Lakes appear to be valid, without replicate cores to verify the internal consistency of the results for each basin, caution should be exerted in interpreting a paleomagnetic excursion. The Petit Lac Terrien results point this out only too forcefully.

The intensity of the remanent magnetism is another possible source of anomalous paleomagnetic behaviour. The Unknown Pond, Lac des Bouleaux, Lac Colin and Clayton Lake cores show that with weak intensities, spurious readings for both inclination and declination can be obtained. Possible explanations for these anomalous readings are: the occurrence of sporadic magnetic mineral grains which dominate the magnetic character, slight movement of the magnetic mineral grains within the loose organic matrix during analysis and diagenetic changes in the sediment following deposition.

When a coring device that retrieves a core in increments is used, some discrepancy in the paleomagnetic signature between one increment and the next may be encountered even when attempts are made to orient the increments to some given azimuth. This is obviously the case in both the Lac Colin and Clayton Lake cores where a shift in the angle of declination was encountered at core breaks. Thus any anomalous magnetic behaviour at such points in a core should be regarded as suspect.

On the positive side, however, some aspects of the paleomagnetic record could prove useful for stratigraphic correlation purposes. Where the age of the sediment is within the appropriate time range, a magnetic excursion, if not a true reversal, may be encountered. This may be the case at Basswood Road and Maplehurst Lakes, but more work is required to corroborate this evidence. Secular variations in the geomagnetic record may be useful if swings can be correlated from site so site. An example of this variation can be seen in the inclination record for Lac aux Araignées. Variations in declination may be even more useful as definite cyclical patterns seem to be emerging from studies by various authors (CREER, 1974; CREER and KOPPER, 1976; CREER *et al.*, 1976a and b). Intensity may prove to be a useful tool to detect changes in sediment lithology. This can be readily seen in the Clayton Lake profile where only a faint change in the visibility of laminations is apparent, but a sharp change is apparent in the intensity plot. Hence, changes which may not be visible in the sediments themselves may be visible in the intensity measurements.

CONCLUSIONS

The data presented here do not confirm the existence of a paleomagnetic event correlative with the Laschamp Event in its broadest sense (BONHOMMET and ZÄHRINGER, 1969). If anything, the results show an absence of any magnetic character that could be interpreted as a polarity event or excursion younger than about 12,500 years BP. Two sites show deviations that might be correlated with Mörner's Gothenburg "flip" and accompanying excursion, but the lack of corroborative evidence from replicate cores precludes any positive conclusion. Apparent from the above examples is the fact that great care is required in determining the paleomagnetic character of sediments from small lake sites, and that because of possible spurious data, extreme caution should be exerted in interpretation. The concern of VEROSUB (1975), and the requirements that internal, spatial and temporal consistency in replicate cores from each of several areas be fulfilled before paleomagnetic phenomena are used as magnetostratigraphic horizons, cannot be too strongly reiterated.

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