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The enigmatic rings of the James Bay Lowland: a probable geological origin

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Abstract

A survey of airphotos for a large band of Eastern Canada extending from Manitoba to Newfoundland between Lat. 48° N and 52° N has revealed a massive concentration of whitish ring-shaped features, a few tens of metres up to 2 km in diameter, in the organic, black spruce-covered, poorly drained terrain of the James Bay and Hudson Bay Lowland, and on Anticosti Island in the Gulf of Saint Lawrence. The light-coloured tone is related to the more open tree cover and the presence of annular bogs within the rings which contrasts with the surrounding denser tree cover. Ground investigation has shown that the rings coincide with shallow annular depressions in the mineral soil that have been infilled with peat, or covered by shrubs and trees that can tolerate a water table close to the surface. The origin of the rings is considered by some to be the result of biological processes and by others, of geological processes. The radial expansion of a fungus that infects and kills trees thus producing rings in the vegetation, is the basis for the biological hypothesis, while geochemical processes in the soil related to the underlying bedrock geology is the basis for the geological hypothesis. A detailed botanical and dendrochronological investigation carried out in 7 rings in northern Abitibi does not support the radial expansion model and shows that the rings are static features. The rings form a belt extending from north of Lake Nipigon to western Quebec, that closely correlates with the extent of calcareous soils. This, along with the presence of shallow depressions in the calcareous substrate beneath the rings, and the lack of periglacial or geological processes at the surface that could account for the rings, suggest mechanisms acting from below. The depressions may result from carbonate depletion related to geochemical mechanisms in the soil generated at depth in the bedrock geology. Thick, up to 3 m, peat sequences in some annular bogs indicate that the depressions beneath the rings have been formed hundreds, perhaps thousands of years ago, to allow that much peat to accumulate. Thus, the rings have been stationary for long periods of time.

Introduction

Light-coloured circular rings typically ‹300 m but up to 2 km in diameter, are clearly visible on airphotos, in poorly-drained stands of black spruce (*Picea mariana*) in the boreal forest of northwestern Quebec and northern Ontario, as well as on Anticosti Island in the Gulf of Saint Lawrence (**Figure 1**). The features have long been object of curiosity and speculation (Anonymous, 1989a and b). Their origin remains unknown and has intrigued vegetation and earth science specialists since aerial photographs became a common surveying tool. The features have been noted by geologists (e.g. Dean, 1956), some of whom mapped them using a symbol proportional to their actual size (Crosbie, 1980; Paulen and McClenaghan, 1998 a;1998 b). But generally the rings were ignored or not detected by surficial mappers and foresters. We present here the first systematic inventory of the features in an attempt to focus the attention of the geobotanical and geoscience communities on their potential scientific and economic importance. This progress report traces the evolution of research completed toward the objective of determining the origin of the rings, considered by some to be the result of biological and by others, of geological processes. We favour a geolocial/geochemical origin on the basis of the strong negative evidence gathered with respect to biological causes and the positive evidence for geological processes described in this report. Current investigations being carried out in cooperation with the Ontario Geological Survey and the private sector, are directed at a detailed analysis of individual rings.

Previous work

The biological hypothesis

The opinion that the rings result from the radial growth of giant fungi spreading through the root systems of black spruce and other trees has been expressed by several scientists (S. Zoltai, personal communication 1995, R.D.Whitney, personal communication 1994, among others) although no field observations have been presented in support of this interpretation. In the course of an airphoto survey, Mollard (1980) identified about 500 rings in the James Bay Lowland of northern Ontario formed on Holocene marine deposits. He suggedted that the most likely cause of the circular rings is a weakening of the vegetation in the rings by radial growth of a fungus, leading to the development of features similar in appearance, but of larger dimensions than the "fairy rings" commonly observed on lawns. His theory was expressed as follows (Mollard, 1980, plate 12.15): "Beginning from points of infection where a fungus spore germinates, the mycellium grows radially in all directions forming a circular mat. As growth continues, the older portion in the centre dies, and the mat becomes more or less ring-shaped. Advancing under favourable conditions at a rate of up to a metre per year, but normally much less, the rings may continue to grow for 800 years or more. Owing to the depletion of nutrients and food supply within the rings, and also to a slight rise in the water table due to a marked reduction in permeability of the substrate from the packing of the mycellium, black spruce within the rings begin to languish. The black spruce trees become stunted and sparse, less windfirm, and subject to blowdown (windthrow). At the same time, the wetter conditions in the rings favour the growth of tamarack (*Larix laricina*) there. Meanwhile, inside the rings the mycelium dies off, growth conditions return to normal and black spruce trees regenerate. The healthier denser black spruce produce a denser canopy and correspondingly darker tones in the aerial photographs".

Foresters have documented infestations of the fungus *Armillaria ostoyae,* that attacks conifers (Kile et al. 1991). Stands of pines, particularly Scotch pine (*Pinus sylvestris)* are susceptible to the disease in certain parts of Europe. The expression "maladie du rond" - ring disease - (Durrieu and Chaumeton, 1988) is used to describe the circular openings that result from the radial growth of the fungus which kills the pines at the periphery of the circle while regeneration occurs in the inner part of the circle after a few years.

Other hypotheses envisaged by Mollard (1980) but considered unlikely by him, include anthropogenic origin, the eroded outline of buried diamond pipes and clusters of craters from showers of meteorites. Relict permafrost features such as collapsed peat plateaus from which the ice had melted were thought to present outlines similar to the rings when viewed from above. Relict permafrost features were also retained by Mollard as a possible origin.

The geological hypothesis

Less favour has been shown for a geological origin for the rings. Usik (1966), however, described the features, after they were brought to her attention by Dr. A. MacLaren, while she was working with the Geological Survey of Canada (GSC) in the Moose River District of Ontario in 1965. She observed tone and form differences in vegetal cover and showed that the combination of black spruce within the inner circle and outside the ring, and tamarack within the ring produced the circular pattern. Citing advances (Malyuga, 1964) in biogeochemical methods of investigating plant and soil relationships, which provided evidence of increased content of metals in the ash of land plants above ore deposits, biogenic accumulation of metals in the humus layer of soil and changes in the ratio of these metals, Usik proposed that the rings may provide visual evidence of the existence of localized ionic diffusion phenomena above zones of mineralization. Taking into consideration the high ion mobility associated with humic and fulvic acids found in abundance in peat, she felt that the term **dispersion halos** used by Malyuga (1964) to describe such manifestations might apply to the rings.

She observed circular islands entirely composed of vegetation occurring in ponds within organic terrain, a feature also observed by the senior author at several locations in the James Bay Lowland. She proposed further investigation of the rings which would take into account the possibility of biogenesis.

Description

General characteristics of rings viewed from above

It is unlikely that the rings were observed prior to the advent of aerial photography. Most are difficult or impossible to detect from a low-flying aircraft but they can be seen, under good conditions of visibiliy, from a flying height of several hundred metres. The rings are found in low-relief, poorly-drained organic terrain but not within deep bogs. Most are poorly-vegetated annular bogs, some of which are discontinuous, which encircle a better-drained black spruce core and are bordered on the outside by better-drained black spruce cover (the term ring throughout the text refers to the overall circular feature as well as the annular space between the outer and inner circles that define the ring. Where necessary the term annulus is used). The annular bogs are a few metres to several tens of metres wide, although most are less than 20 to 30 m wide. The width of the annulus is not proportional to the overall diameter of the rings; it remains rather constant for all rings, small or large. In other words, the width of the annulus of a ring 200 m in diameter is generally similar to that of a ring 1.5 km in diameter. Black spruce are either absent, sparse or stunted, within the rings, and tamarack or alders (*alnus rugosa*) occur in many rings. The more open ground cover within the rings, due to the wider spacing of the trees, raises the albedo and produces a lighter tone on photographs that contrasts with the darker tone of the inner and outer dense black spruce cover (**Figures 2 and 3 A, B and C**).

Distribution

In Abitibi region

The locations of over 800 rings, varying in diameter from a few tens of metres to nearly 1 km were recorded while mapping surficial deposits in the Quebec portion of northern Abitibi region south of 50° N from 1988 to 1994 (Veillette, Veillette and Pomares, Veillette and Thibaudeau, Paradis, *in prep*.). Most are located north of 49° 30'N (**Figure 4**) and occur in close association with the calcareous glacial deposits transported from the Paleozoic rocks of the Hudson Bay Lowland by late glacial surges (Veillette et al. 1991; Veillette and Smith, 1992). Rings also occur south of that latitude but are less numerous. A few are clearly visible as far south as in the vicinity of lac Sabourin a few kilometres south of Val d'Or (48°N), in low-relief terrain surrounded by peat bogs. These isolated rings can be seen on a commercial flight departing or arriving from the Val d'Or airport on a clear day. Aerial photographs taken within the last few decades would fail to record rings in areas where the original black spruce cover was destroyed by clear cutting for agriculture or logging purposes, or by disturbances due to fire, insect infestations or tree diseases. However, their present distribution in poorly-drained, low-relief sites where black spruce is often of sub-commercial size and drainage problematic for many human activities, may not differ by much from their former distribution. Characteristics readily observable for the Abitibi rings are a water table close to the surface and accumulation of organic material in rings overlying a mineral soil containing a subtantial amount of calcium carbonate, although some rings occur over non calcareous soils. A few are isolated; they generally occur in clusters, such as in the Turgeon, Théo, Angle and Samson Rivers areas (**Figure 4**), with no obvious relationships with the underlying bedrock geology. The largest, about 860 m in diameter, has a surface area of approximately 58 ha, 60% of the rings cover less than 1.6 ha, and 38% less than 1.2 ha.

In eastern Canada between latitudes 48°N and 52°N

Following the initial work in Abitibi where it was observed that the presence of rings is generally associated with thick overburden and clay-rich calcareous till or glaciolacustrine sediments (Veillette and Smith, 1994, and surficial mapping by Veillette and Paradis, see References), the inventory of rings was extended to a large part of eastern Canada. A 2-month survey of airphotos was undertaken in 1994 by the first author to map the extent of the rings from northern Manitoba to the Atlantic coast, including the whole of Newfoundland. In total, about 38 000 airphotos of varying scale, mostly between 1:35 000 and 1:60 000 and covering 95 maps at 1:250 000 scale were examined at the National Airphoto Library in Ottawa for the presence of circular features similar to the rings found in Abitibi and northern Ontario. As little as 8 seconds and sometimes less was sufficient to detect the presence of rings to the naked eye. Complex cases were examined under the stereoscope. Several parameters were recorded, and locations of the observed occurrences were recorded on a map (**Figure 5**). The purpose of the exercise was to establish the distribution of the rings for a large band of the boreal forest (Lat. 48° N to 52° N and Long. 52° W to 96°W) and over a wide variety of bedrock, surficial geology and forest cover conditions. Given the large area covered, the small scale of the photographs used and the speed of the survey, it is probable that many small or poorly-defined rings were missed. However, the inventory provides a reliable estimate of the major concentrations of rings in the area investigated. Generally, the diameters of the rings observed in northern Ontario are similar to those of rings we mapped in northern Abitibi. However, the largest rings (up to 300 ha) occur in northern Ontario. Those of Anticosti Island are comparable in size to the smaller Abitibi rings.

Rings were not found in Newfoundland. Rare circular features similar to those of the James Bay Lowland have been observed in Gaspésie, Quebec, by the senior author. Over 100 rings have been observed in eastern Gaspésie region by S. Fortin (personal communication, 1997). These appear to differ in size and possibly in origin from the

James Bay rings. Rings also occur in the central-western part of Anticosti Island in the Gulf of Saint Lawrence. J.M. Dubois first reported on these (Anonymous,1989a) and in consultation with J.D. Mollard recognized a distinct similarity with the rings of the James Bay Lowland. Similar rings occur in western Canada and in the northern Prairie States (J.D. Mollard, personal communication, 1994).

The results of this survey, together with the more detailed Abitibi survey which includes data on the dimensions and other characteristics of the rings guided the subsequent detailed ground investigation carried out by the second author.

Testing the biological hypothesis

Radial growth, as proposed by Mollard (1980), is an attractive hypothesis for several reasons. Rings occur in a wide variety of sizes, in some cases appear to "bump" into each other (**Figure 3C**), and most convincing, their radial expansion seems to be restricted by bodies of open water. No rings crossed by streams (suggesting that the features predate the streams, or that the expansion of the ring was not impaired by the water body) have been observed. On the other hand, examples of segments of rings present only on one side of a stream have been observed (**Figure 6**). This particular case, given the straight course of the river and the fact that the centre of the circle (obtained by extrapolating the outer circle outline) clearly lies on the same side of the river as the ring, argues for a radial growth from the geometric centre of the ring which was arrested by the river (**Incomplete Type 1 ring**). Similarly, a segment of ring clearly greater than a half-circle is always found on the convex side of a river bend,while a segment of ring less than a half-circle is found on the concave side of the bend (Type 1 ring). These observations fit with the concept of a biological agent spreading radially in the vegetation.

Elsewhere, complete rings seem to have been partially destroyed by a meandering river or by a receding shoreline (**Incomplete Type 2 ring**). Examples of this type of erosion have been observed along rivers and lakes in northern Abitibi. Incomplete rings of the type described in **Figure 6** which have been attributed to arrested growth by a water body (Veillette and Smith, 1992) cannot be distinguished from incomplete rings of Type 2. This illustrates that erroneous conclusions can be reached with regard to the process involved if reasoning is based on image analogy alone. It seems reasonable to conclude from the information at hand, that the formation of Type 1 rings postdates the main drainage system, and Type 2 rings give a relative age for the formation of meanders or the retreat of a shoreline. A detailed study of the evolution of the postglacial drainage system in relation to the distribution of the rings may shed some light on the relationships between bodies of water and rings.

Smith et al. (1992) identified an individual fungus (*Armillaria bulbosa)* in Michigan that occupies at least 15 ha, weighs in excess of 10 000 kg, and has remained genetically stable for more than 1500 years. Growth rate was estimated at ≤ 0.2 m per year. Smith examined several aerial photographs of the Abitibi rings and suggested that the rings may be caused by giant root fungi (M.L. Smith, personal communication 1992). During summer 1992, and using guidelines provided by Dr. Smith, the senior author collected several tissue samples from the base of black spruce specimens showing a variety of stress conditions within one of the rings in the Casa Berardi area of the Abitibi. Cultures performed on these samples in the Department of Botany of the University of Toronto by Dr. Smith proved to be negative for the presence of *Armillaria*. Dr. André Fortin, Director of l'Institut de recherche en biologie végétale de l'Université de Montréal and of the Jardin Botanique de Montréal visited the same ring with the senior author in late summer 1992, collected and analyzed additional tissue samples and found no evidence of fungal infestation in the ring. A poster presented by Veillette and Smith (1992) summarized the results of the investigation at this time.

In addition, no radial growth could be demonstrated by the senior author using large-scale (1:3000) photographic enlargements obtained from aerial photographs (1: 15

840 scale) taken at an interval of 26 years for rings measured in reference to a reliable ground marker (a surveying straight line cut in a dense stand of black spruce and tangent to two rings). It was concluded that the growth is either so slow it cannot be established using aerial photographs (which go back only a few decades), or the rings are static features. Dubois (1994), relying for the most part on the relationships between stream and rings described in Veillette and Smith (1992), proposed a biological (mycological) origin for the rings of Anticosti Island.

Following the failure to demonstrate that the rings result from biological activity in the vegetation cover, a detailed study of the tree and ground covers was planned to determine if the rings are static or dynamic vegetation features. Dr. Yves Bergeron, Director of the Groupe de recherche en écologie forestière (UQAM) visited the site in early summer 1996 and assigned an M.Sc. student to the detailed study of the vegetation within and outside rings. Two seasons of field work and related laboratory analyses directed at the study of 7 rings of average diameter of about 200 m in the Casa Berardi and Selbaie mines area in Abitibi were completed by J.-F. Giroux under the direction of Dr. Yves Bergeron and the senior author. Two important parameters result from this M.Sc. thesis (Giroux, 1998). These are (1) absence of evidence for a radial expansion in the vegetation and (2) the presence of a slight depression in the mineral soil beneath the rings, most pronounced where the accumulation of peat is greatest.

Lack of evidence for a radial expansion in the vegetation

The detailed botanical and dendrochronological analyses presented by Giroux (1998) are incompatible with the radial growth model favoured by Mollard (1980) and demonstrated by Durrieu and Chaumeton (1988) for certain conifers. The age distribution, productivity and mortality of black spruce within the 7 rings studied failed to show the gradual increase in age and abundance from the inner boundary of the ring toward the centre of the circle, that is expected in the radial expansion model (Durrieu and Chaumerton,1988). Because ages in excess of 200 years are not exceptional for black spruce, the detailed age profiles constructed by Giroux (1998) across the diameters of the rings, would have been sensitive to the increase in age to be expected toward the centres as regeneration took place. Instead, his study shows that species with affinities for high moisture conditions (*Larix laricina, Alnus rugosa, Kalmia augustifolia*, and several others) are abundant only within the rings, while black spruce and other plant and tree species less tolerant of excessive moisture, thrive in the better-drained core and outside the rings.

An extremely slow rate of growth for the radial expansion of the rings, undetectable with the analytical methods used by Giroux (1998), is most improbable given the growth rates known for a variety of fungi and compiled by him from numerous studies. Fungi which commonly infest conifer forests have growth rates that vary between 0.2 m to 1.3 m per year. Even assuming the lowest rate recorded (0.2 m per year), a distance of 50 m would be covered by the ring during the average life span of a black spruce (250 years in the study area). Inward regeneration from the interior boundary of the ring required by the radial growth model, would then imply that the mean age of the oldest trees should increase over the first 50 m or so toward the centre and become stable at this distance. This evolution would have been detected by Giroux since he laid out 9 (10 m x 10 m), sampling plots along 2 diameters for each of the 7 rings, including one plot at the exterior of the ring. For ground cover plants ‹ 1 m high, samples were taken every 10 m along the 2 diameters. Given the time elapsed since deglaciation of the area, Giroux's results put severe constraints on the biological hypothesis to explain the expansion of rings. For example, assuming that the lowest growth rate known (0.2 m per year, for *Armillaria bulbosa* , Smith et al. 1992), would apply to the largest (2 km in diameter) ring observed in the James Bay Lowland, a period of 5000 years would be required for the fungus to expand along its 1 km radius. Lower growth rates are even less probable given the relatively short postglacial period of the James Bay Lowland. Assuming that the largest rings started to expand immediately following the drainage of glacial lakes Ojibway and Agassiz, about 8000 years ago, the 2 km ring would have been expanding at a mean rate of 0.13 m per year (or 32.5 m during the average life span of a black spruce) – a distance easily detectable by Giroux's analytical methods.

Also, since rings appear to be truncated by streams but not crossed by them, they probably postdate the hydrological network, which implies that an unknown time period must be allocated for the establishement of the hydrological network following the drainage of the glacial lakes. This further restricts the length of the time period available for their expansion.

A depression in the mineral soil beneath rings

In the course of surficial mapping in Abitibi, the senior author observed that the well-vegetated central part of some rings appeared to be elevated compared with the more open annuli. Giroux (1998) demonstrated that the productivity of the black spruce was found to be lower within the ring simply because the water table is generally closer to the surface there than within the centres or outside of the rings. Water ponding and associated peat accumulation in the annulus of rings is in turn caused by the poor drainage induced by depressions in the mineral soil beneath the rings. The depressions were revealed by precision levelling with a theodolite along two transects intersecting at right angle over the diameter and extended beyond the rings for a few tens of metres for each of the 7 rings (Giroux, 1998). The surface elevation was first determined, and from it the elevation of the mineral soil surface was obtained by probing below the organic cover. Gently-sloping depressions in the mineral soil beneath rings, varying in depth between 1 and 2 m below the surrounding nearly flat terrain surface, became obvious when comparing the two levelling profiles. The depressions have in many places, been infilled with peat to the level of the surrounding terrain. The shallow depressions beneath rings explain the widespread occurence of the narrow annular bogs typical of many rings of the James Bay Lowland, as well as the crescent-shaped ponds found in some rings.

These annular depressions cannot be explained by known geomorphological and periglacial processes, yet they are a definite geomorphological feature, the very reason the rings can be seen on airphotos. Fossil pingos, polygonal fossil permafrost terrain, collapsed palsas, iceberg furrows, and dead-ice topography all fail to account for the remarkable and constant circular outline of the few thousand rings that have been observed. The age of the depressions in the James Bay Lowland is bracketed at the older end by the age of the glaciolacustrine sediments into which they formed, which became exposed about 8000 years ago following the drainage of the glacial lakes into Hudson Bay (Veillette, 1994), and at the younger end by the onset of paludification estimated to be around 6000 years BP in Abitibi (Richard, 1980; Y. Bergeron, personal communication 1997; J.J. Veillette, unpublished data). Thick peat, up to 3 m measured in one ring, would normally require hundreds or thousands of years to accumulate. The formation of the depressions may then predate paludification which would push back the age of their formation to the mid-Holocene or earlier. Basal peat and gyttja samples have been collected within rings and submitted for ^{14}C dating. The results are not available at this time.

A correlation between calcareous soils and the presence of rings

The high density band of rings across northern Ontario and western Quebec (**Figure 5**) was superimposed on the bedrock geology (**Figure 7**), the extent of calcareous sediments (**Figure 8**) and the surficial geology (**Figure 9**) in the search for relationships between the geological properties of the substrate and the distribution of the rings. The greatest concentration of rings within the high density band occur in the Hornepayne (42F), Kapuskasing (42G), Smoky Falls (42J), Kenogami River (42K) and

Nakina (42L) map sheets which either overlie the carbonate rocks of the Hudson Bay Platform or are located immediately down-ice from it (**Figure 7**). Rings overlie volcanic, metamorphic and intrusive rocks and do not exhibit any preferential association with any of these rock types at the scale of the survey used here. The number of rings observed to the east and to the south of the Matagami area in Quebec, decreases abruptly (**Figure 8**), this in spite of extensive fine-grained glaciolacustrine deposits in this area. This decrease coincides with a marked drop in the carbonate content of the sediments (generally less than 1%) in eastern Abitibi toward the Chibougamau area (Veillette and McClenaghan, 1996). Between Chibougamau and Newfoundland no rings were observed in the black spruce forest. However, it is significant that rings occur in Anticosti Island, which is underlain by Paleozoic carbonate rocks. There, the cover of sediments over the bedrock is thin.

The strong correlation between the presence of rings and calcareous soil parent materials suggests, given the constraints already described for potential geological and biological processes, that the formation of an annular depression beneath a ring may be related to geological or geochemical processes acting from below such as suggested by Usik (1966). This is plausible if one admits, (1) that there are no biological processes involved and (2) that there is no evidence from our study to support geological or periglacial processes acting from above the sediments, such as fossil permafrost features, eolian action, clusters of craters from showers of meterorites or surface modifications by icebergs. By elimination, one is led to conclude that the shallow depressions may be caused by carbonate depletion in the calcareous sediments beneath the rings. If the depletion of the calcareous parent material is caused by geochemical processes triggered by buried sources in the bedrock below the sediments, it follows that there may not be any surface expression (rings) for the same processes active in areas devoid of a calcareous cover.

The carbonate content of soil samples collected along one radius for each of the 7 rings in the Casa Berardi area by Giroux (1998) tended to be lower for areas beneath the rings than in the central parts of the rings. The results, however, cannot be considered conclusive because the equipment used by Giroux did not allow him to penetrate peat thicknesses in excess of 1.8 m - a serious drawback since thicker peat is present in some of the rings investigated. Difficulties were also encountered in consistently penetrating below the leaching zone (40 to 70 cm) in the harder, better-drained, central parts of the rings to establish valid comparisons between the carbonate content of the substrate beneath rings and in the central parts.

A second look at the geological hypothesis

The serious constraints imposed on the fungus hypothesis and on the geological and geomorphological causes just mentioned narrow the focus of research. In spite of the initial attractiveness of the biological hypothesis, the lack of evolution in the vegetation cover and the presence of a depression beneath the rings warrant a closer look at geological processes acting from below to explain the origin of the rings. Two small rings in Abitibi observed only on airphotos, appear to rest on bedrock with a thin, patchy cover of sandy non-calcareous till. Morris (1994) observed circular features, some of them similar to those described here on the limestone floor of quarries and in fields in southern Ontario, which he tentatively attributed to hydrocarbon seepage from below.

The geochemical processes of ion migration through glacial sediments from buried sources suggested by Usik (1966), or similar processes not yet well understood, now appear more attractive. Smee (1979) estimated that elements related to base metal mineralization would take up to 8000 years to diffuse through 5 m of fine-grained glaciolacustrine sediments. Assuming the rings are the result of bedrock anomalies associated with mineralization and covered with thick sediments, geochemical diffusion would need to be more rapid than 5 m per 8000 years because some overlie glacial deposits several tens of metres thick in many parts of the James Bay Lowland. Hamilton (1998) has developed a model for electrochemical mass-transport in soils based on the premise that an upward increasing redox gradient exists in most geological materials. Electronic conductors such as graphite or metallic sulphides in bedrock can provide a short-circuit route across this redox field between reducing agents abundant at depth and oxidising agents abundant at the surface. This consumes oxidizing agents in surficial materials above the conductor and is postulated to result in the propagation of a negative redox anisotropy to ground surface. The model is currently being applied to rings by Hamilton.

The characteristic of the rings and their distribution in Abitibi and elsewhere were discussed with P. Keating, R. Dumont and C. Dunn of the GSC. Keating and Dumont have plotted the locations of 540 rings on high resolution magnetic maps of northern Abitibi in order to test for a correlation to features detected by aeromagnetic surveys. The results of this work, still in progress, by Keating and Dumont will be made available at a later time.

Discussion

No evidence was found to support the hypothesis that the James Bay Lowland rings result from biological processes. The hypothesis rests almost entirely on the image analogy with the smaller fairy rings observed on lawns and had never been seriously challenged prior to this study. We have demonstrated that the rings are visible on aerial photographs because vegetation associated with a water table close to the surface (such as alders or tamarack), and bogs, have developed over annular depressions in the mineral soil beneath rings producing a tone contrast with the surrounding darker tree cover of better-drained soils. The depressions and the perfect circular outline of the rings cannot be explained by known periglacial or geological processes. This eliminates late deglaciation or early postglacial processes that would result in modifications of the soil surface caused by the action of permafrost, gouging by icebergs or deflation by wind. The infilling of the annular depressions in the calcareous substrate by peat, up to 3 m in places, required a high water table and a reasonably long period of accumulation which is here tentatively assigned to the mid-Holocene paludification period in Abitibi (pending ^{14}C ages on gyttja and basal peat sample collected in some rings). Thick peat implies that the depressions were formed several hundreds of years ago, possibly thousands, and that the rings occupy the same position today as they did then.

Thick peat layers in the depressions therefore argue against the radial growth hypothesis in the vegetation which is rendered even less tenable by the constraints imposed on it by the known rates of growth of fungi that commonly infest conifer forests. The age distribution, productivity and mortality of black spruce and other trees and plants for the 7 rings studied by Giroux (1998) in Abitibi failed to show the dynamic evolution in the vegetation expected from a radial expansion in the tree and ground covers.

The possibility that the rings are fossil biological features, i.e., they expanded radially for an unknown period of time during the Holocene and then became stable, appears remote because this model does not explain the formation of an annular depression in the mineral substrate beneath the rings.

We are therefore led to look for a geological cause for the rings other than those examined in this study which are all associated with processes acting at the surface of the sediments. The presence of a shallow depression in the mineral soil beneath the ring, and the strong correlation between the distribution of the rings and a calcareous substrate (soil or bedrock) in Eastern Canada, points toward a mechanism acting from below. Since leaching of carbonate due to percolation of water from above is unlikely to have occurred only in the rings, depletion of carbonates beneath the rings triggered by processes at depth, is a more probable cause.

The precise nature of the processes responsible for the formation of the rings remains unknown. We have, however, shown that the radial expansion model upon which rests the biological hypothesis cannot be verified using well-proven botanical and dendrochronological methods. On the other hand, geomorphological and geological data and observations seriously hint at geological causes originating from below. It is hoped that this report will stimulate interest in the search for the mechanisms at work.

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Figure 8 Extent of calcareous sediments in northwestern Quebec and northern Ontario. Adapted from Sado and Carswell (1987), and Veillette and McClenaghan (1996).

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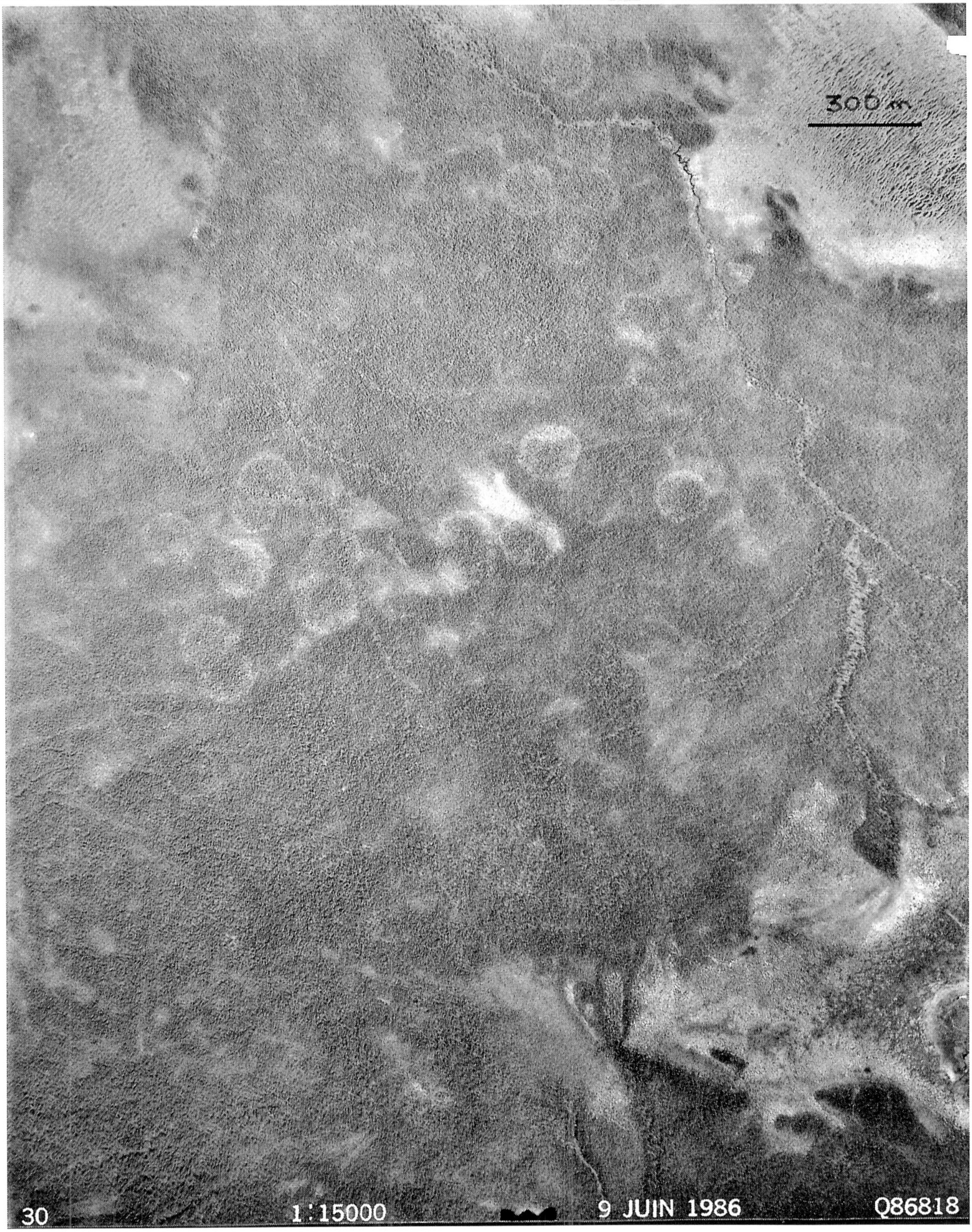

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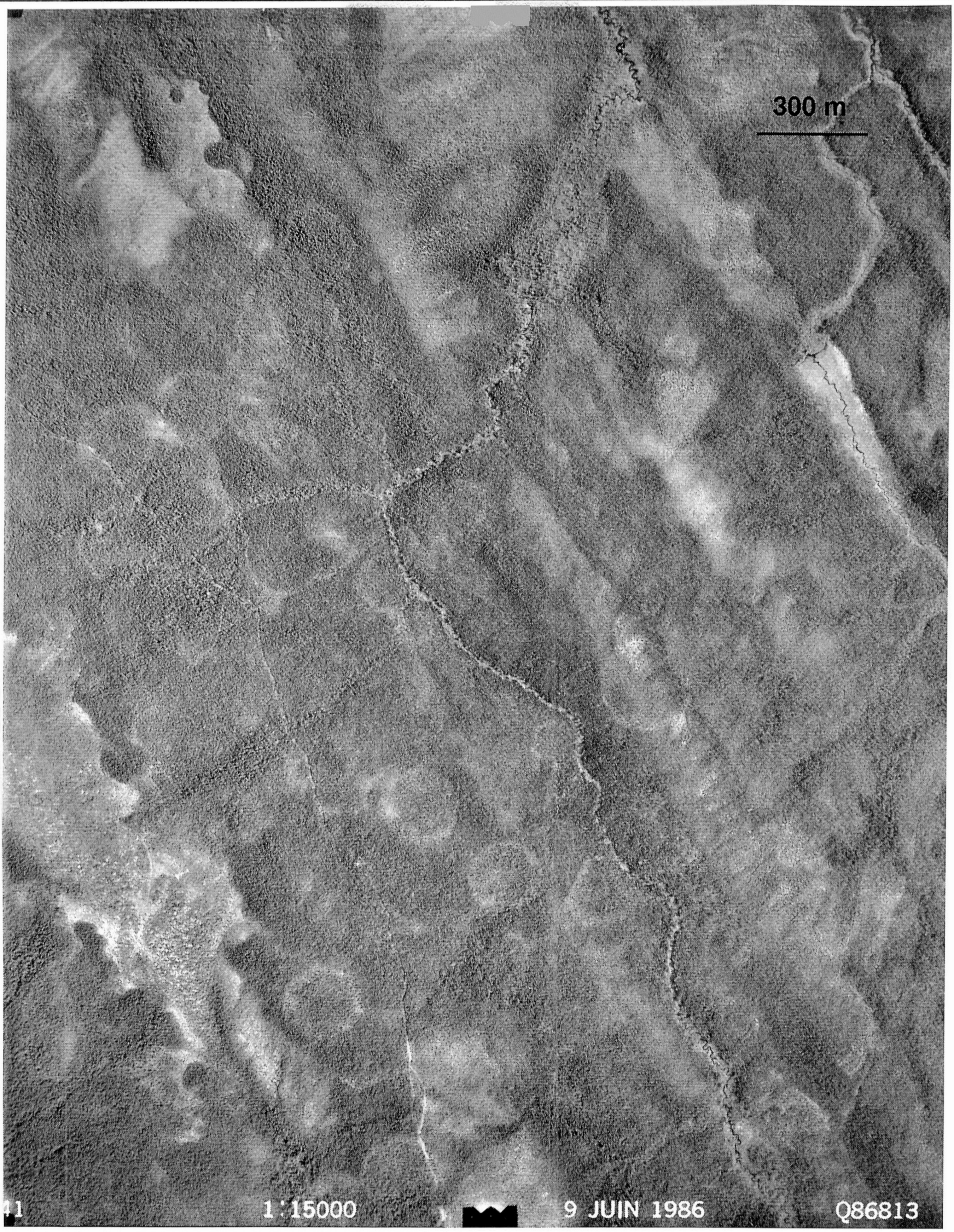

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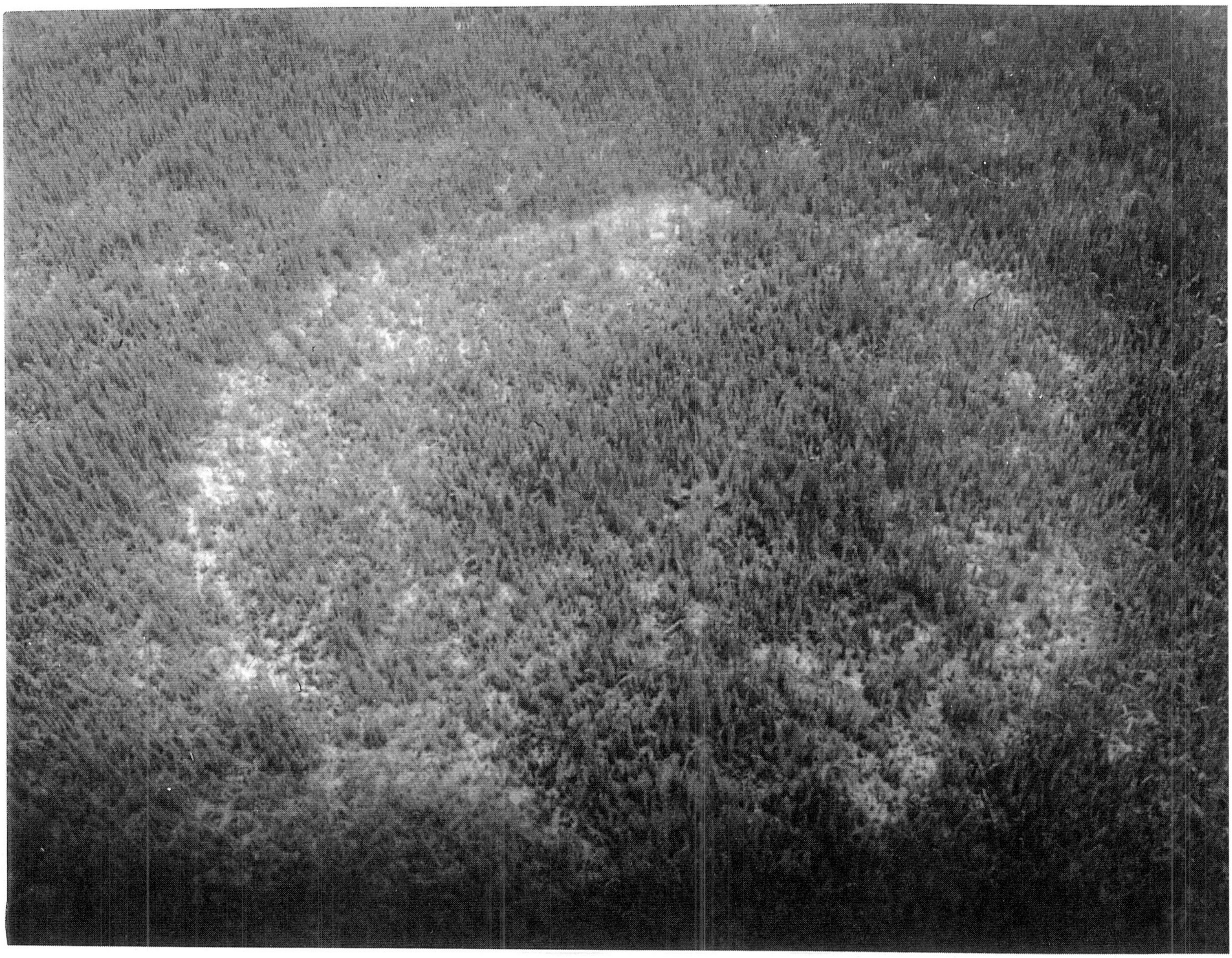

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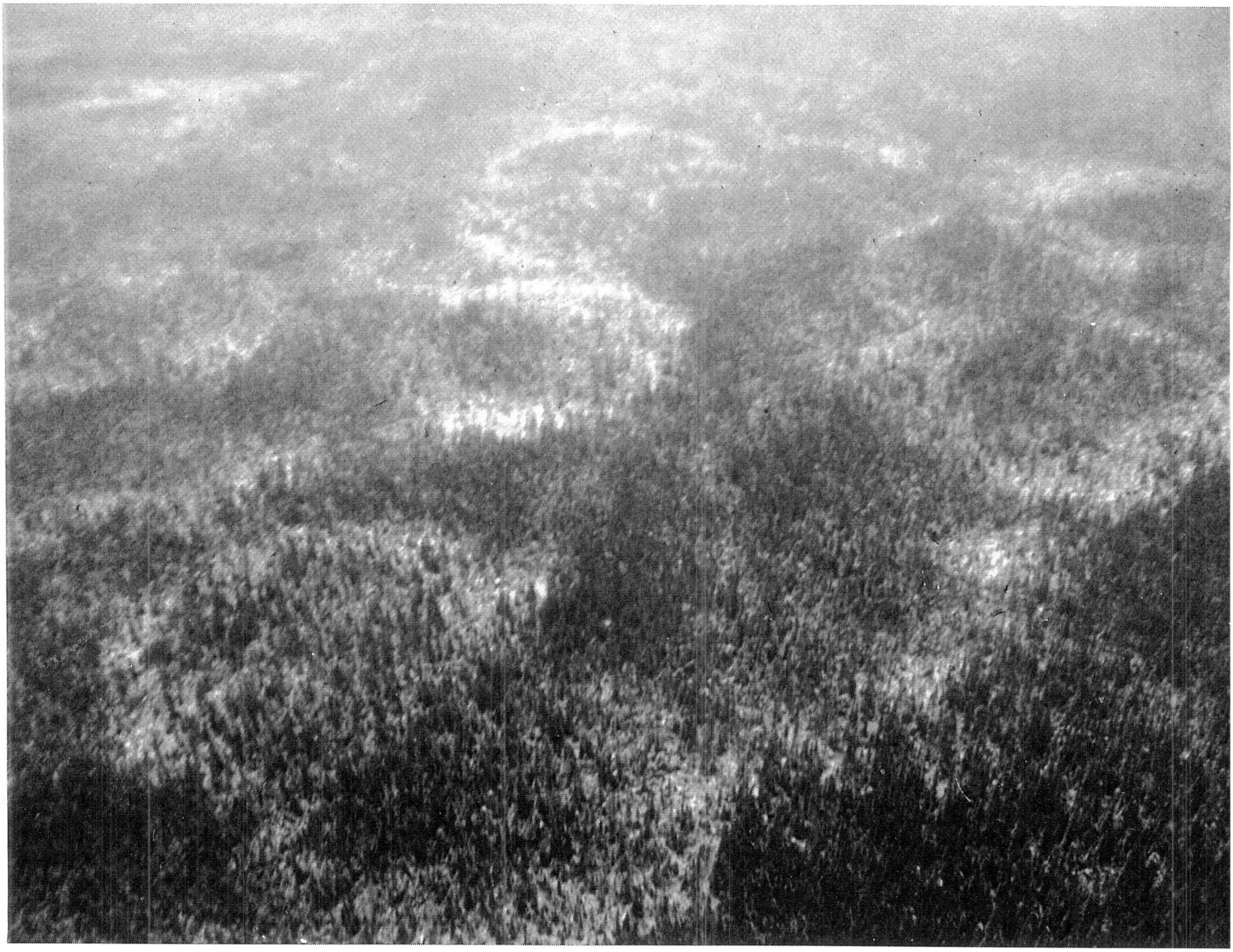

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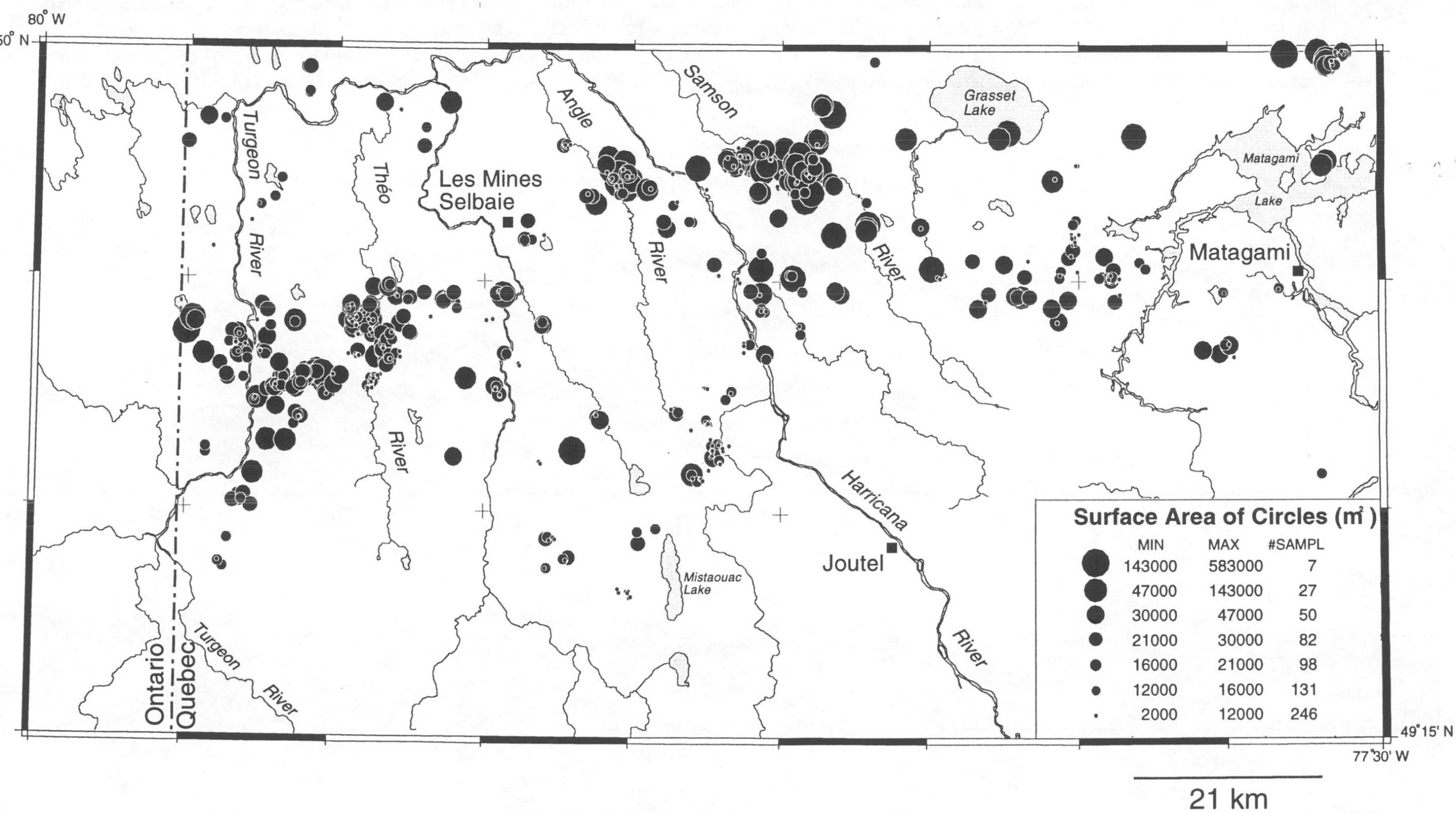

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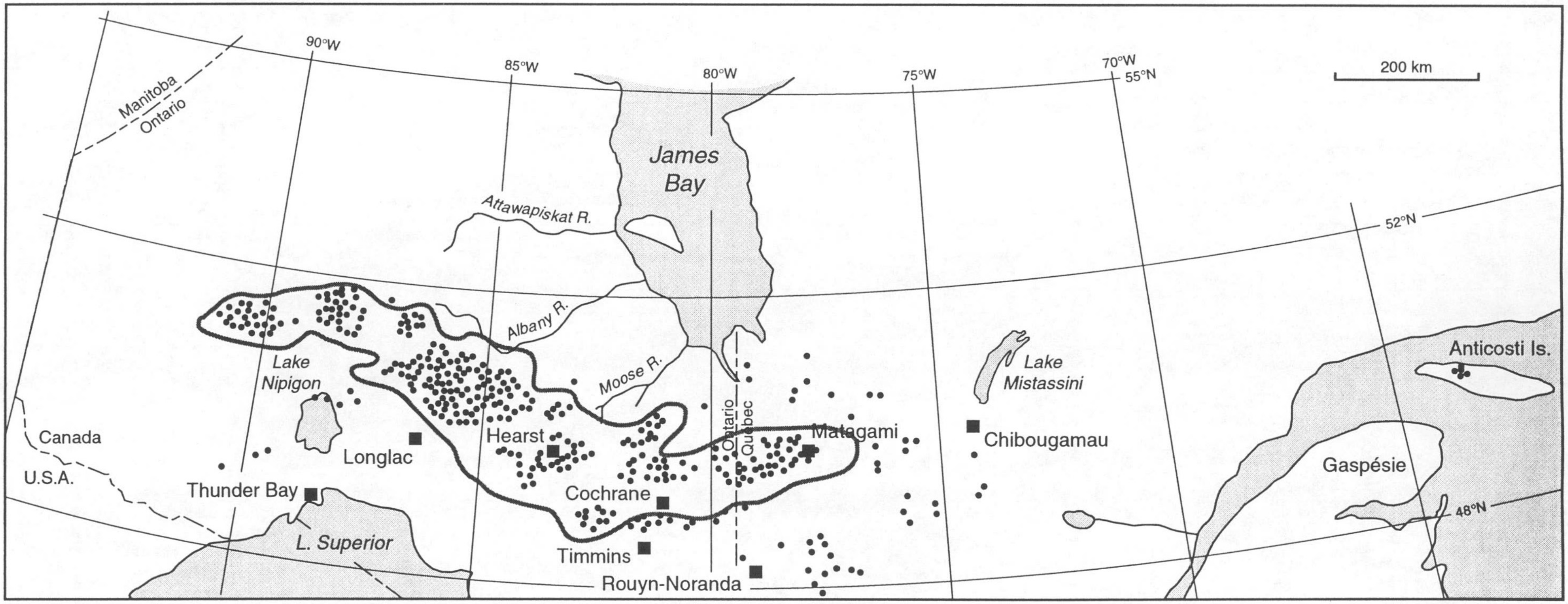

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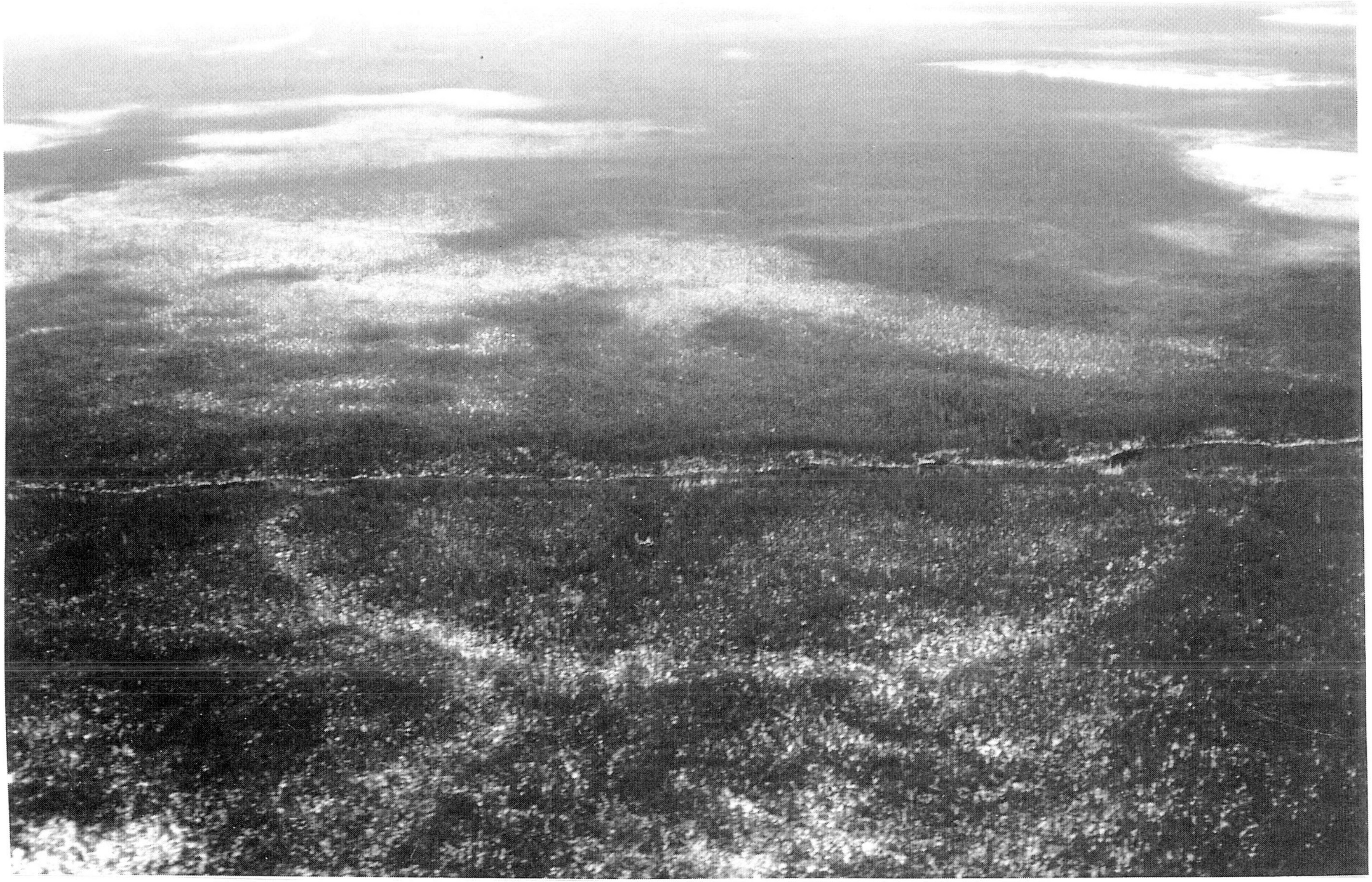

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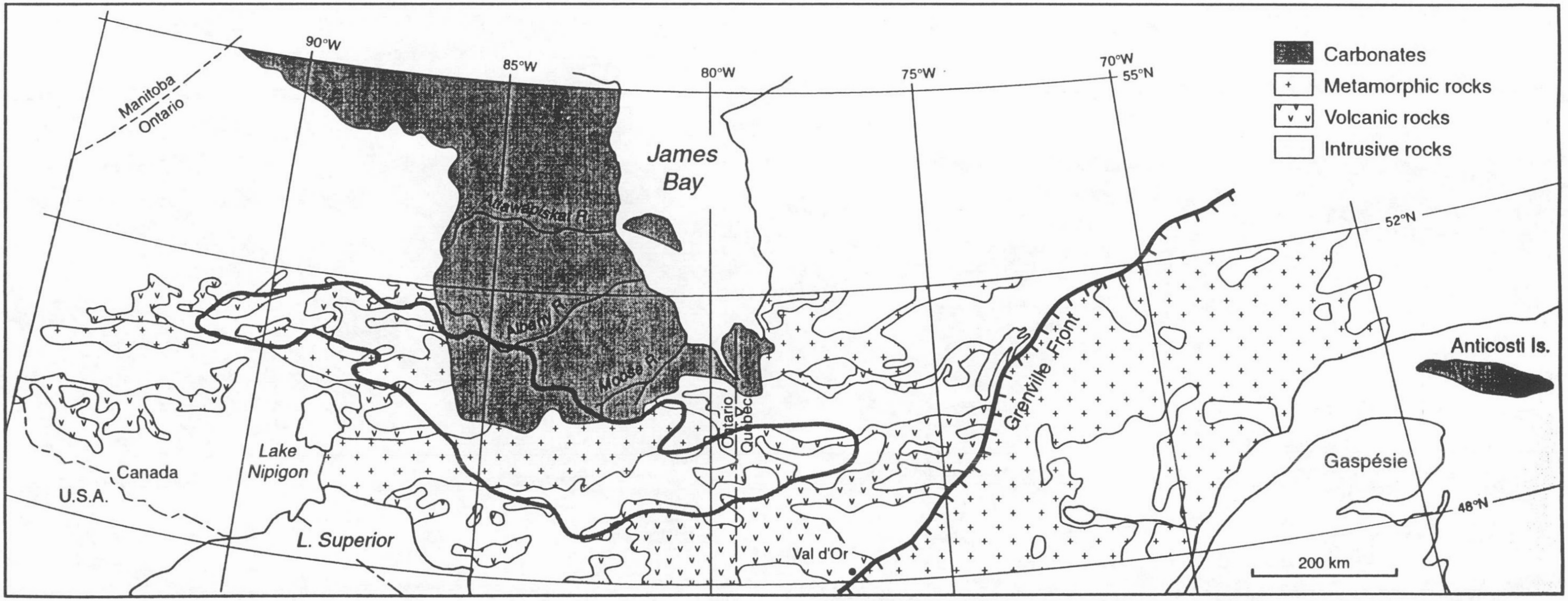

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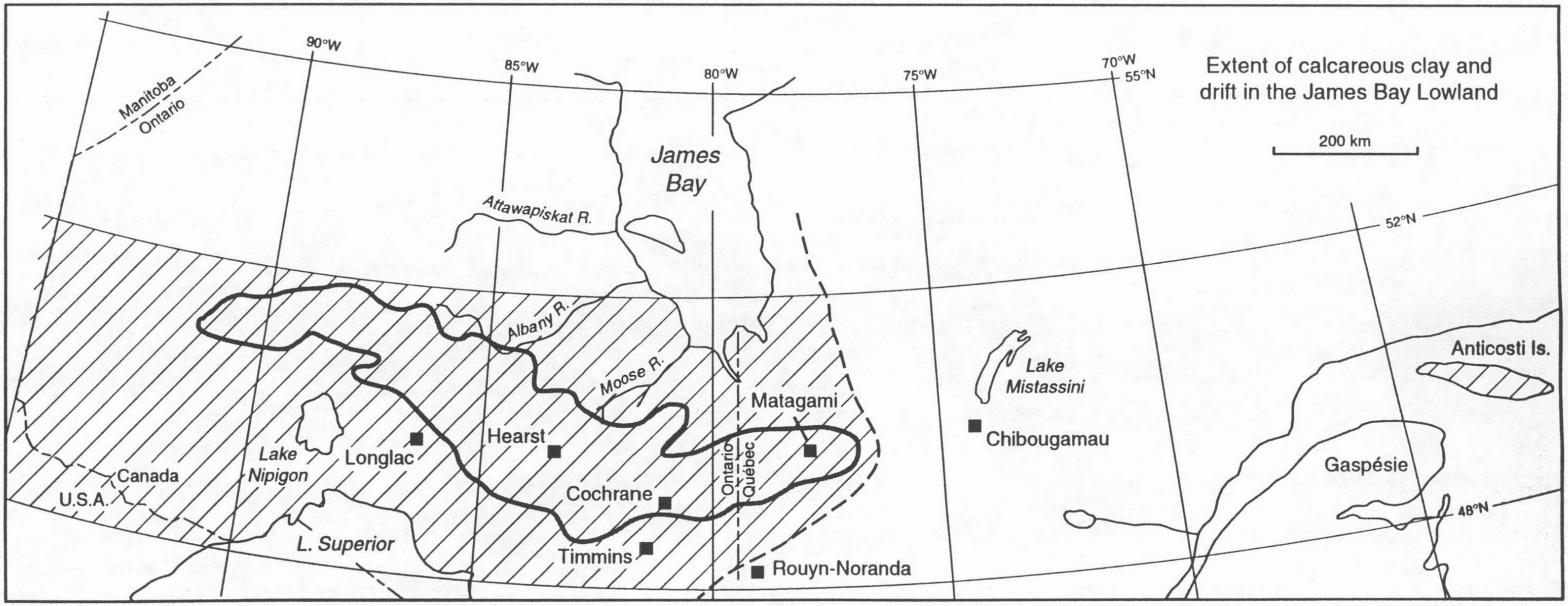

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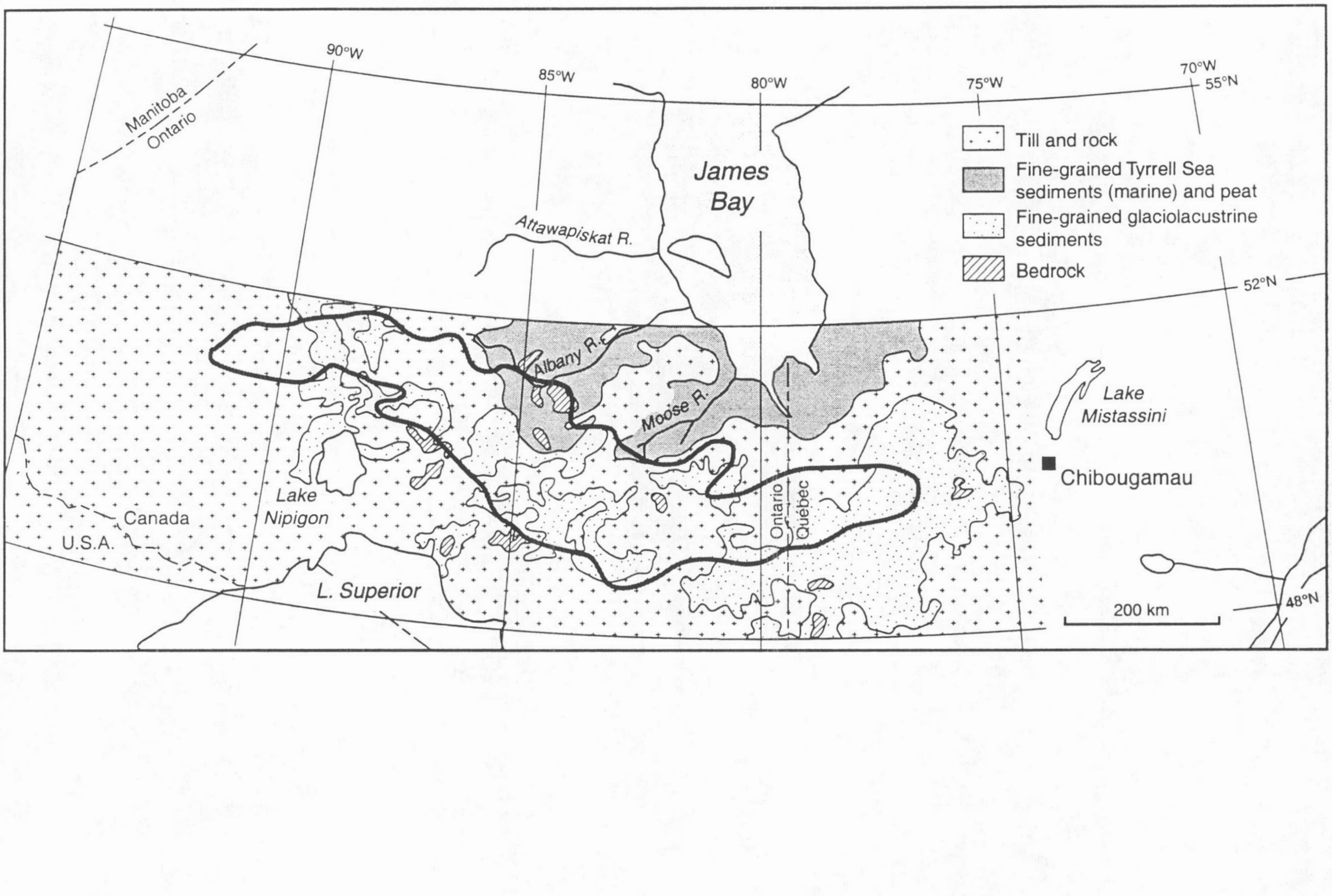

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