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SURFICIAL GEOLOGY AND LANDSLIDES OF THURSO-RUSSELL MAP-AREA, ONTARIO

N. R. GADD

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SURFICIAL GEOLOGY AND LANDSLIDES OF THURSO-RUSSELL MAP-AREA, ONTARIO 31 G/6E AND 31 G/11E (ONTARIO PORTION)

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SURFICIAL GEOLOGY AND LANDSLIDES OF THURSO-RUSSELL MAP-AREA, ONTARIO

Abstract

A broad area of marine clay plain formed by the Champlain Sea has been modified by fluvial action of the proto-Ottawa River system. Development on a regional scale of braided stream or deltaic deposits left a cover of exceptionally well sorted fine grained sand over the typical sensitive marine clay. These two lithologic units were further incised by fluvial action that developed a number of broad channels between "islands", which are in part rock-defended terraces. Channel bottom sediments of fluvial clay, silt, and sand are identified as being of freshwater origin by the occurrence in them of the pelecypod Lampsilis *sp. at Bear Brook, one mile south of Bourget, Ontario. Radiocarbon dating of a sample of these pelecypods gives a minimum age of 10 200 ± 90 B.P. (GSC-1968) for the main Mer Bleue-Alfred channel of the proto-Ottawa River system. This channel and other abandoned channels are superposed on, or controlled by, the bedrock fault system.*

Large retrogressive landslides are located exclusively along the banks of abandoned post-Champlain Sea drainage channels, and all apparently occurred early in the history of channel development. Recent landslides, such as the May 16, 1971 South Nation River slide, occur in the modern stream where it transects one of the "islands" between abandoned channels. These younger, or modern, slides are deeper but narrower than the earliest retrogressive slides. Modern streams within the abandoned channels produce small rotational bank failures.

Bedrock faulting is thought to have played its most significant role in localizing the postmarine drainage system. Steepening of banks in sensitive clay by river erosion is believed to be the dominant causative factor in landslide development in the map-area. The author presents a working hypothesis to the effect that size and shape parameters of landslides vary through time with the degree of saturation and with the position of the water table within the slide-susceptible exposure. This hypothesis is the subject of continuing research.

Résumé

Le travail fluviatile du réseau hydrographique primitif de l'Outaouais a modifié une grande étendue de la plaine d'argile marine formée par la mer Champlain. On constate une couverture de sable exceptionnellement bien calibré provenant de la formation à l'échelle régionale de dépôts deltaïques ou de chenaux anastomosés qui repose sur l'argile marine sensible typique. Ces deux unités lithologiques ont été, par la suite, entaillées par l'érosion fluviatile qui a creusé de nombreux chenaux assez larges entre des "îles" qui sont, en partie, des terraces protégées par des rochers. Les sédiments déposés au fond des chenaux, constitués de silts et sables fluviatiles, ont été reconnus comme étant des sédiments d'eau douce parce qu'on y a décelé la présence de lamellibranches de l'espèce Lampsilis *à Bear Brook, à un mille au sud de Bourget, en Ontario. La datation isotopique au carbone 14 d'un échantillon de ces lamellibranches révèle que le chenal principal du réseau hydrographique primitif de l'Outaouais, entre la mer Bleue et Alfred, remonte au moins à 10 200 (± 90) B.P. (CGC-1968). Ce chenal, et les autres chenaux aujourd'hui abandonnés, sont superposés au réseau de failles de la roche en place et s'y conforment.*

On trouve le long des rives des chenaux de drainage abandonnés après l'époque de la mer Champlain, et là seulement, d'importants glissements de terrain à action régressive étendue, qui sont tous survenus, semble-t-il, dès le début de la formation des chenaux. Des glissements récents, comme celui de la rivière South Nation, le 16 mai 1971, se produisent dans les cours d'eau actuels, là où celui-ci traverse l'une des "îles" situées entre deux chenaux abandonnés. Ces glissements récents, ou actuels, sont plus profonds mais aussi plus étroits que les glissements à action régressive anciens. Les cours d'eau actuels, coulant dans ces chenaux abandonnés, provoquent des décrochements avec rotation le long des berges.

On pense que les failles de la roche en place ont joué un rôle des plus importants dans la localisation du réseau de drainage après le recul de la mer. La cause prédominante des glissements survenus dans la région étudiée est, croit-on, le fait que, sous l'action de l'érosion fluviatile, les rives, constituées d'argile sensible, ont acquis une pente accusée. L'auteur propose l'hypothèse de travail suivante: les paramètres dimentionnels et géométriques des glissements varient en fonction du temps, selon le degré de saturation et selon la position de la surface piézométrique dans une zone prédisposée aux glissements. Des études se poursuivent actuellement afin de prouver le bien-fondé de cette hypothèse.

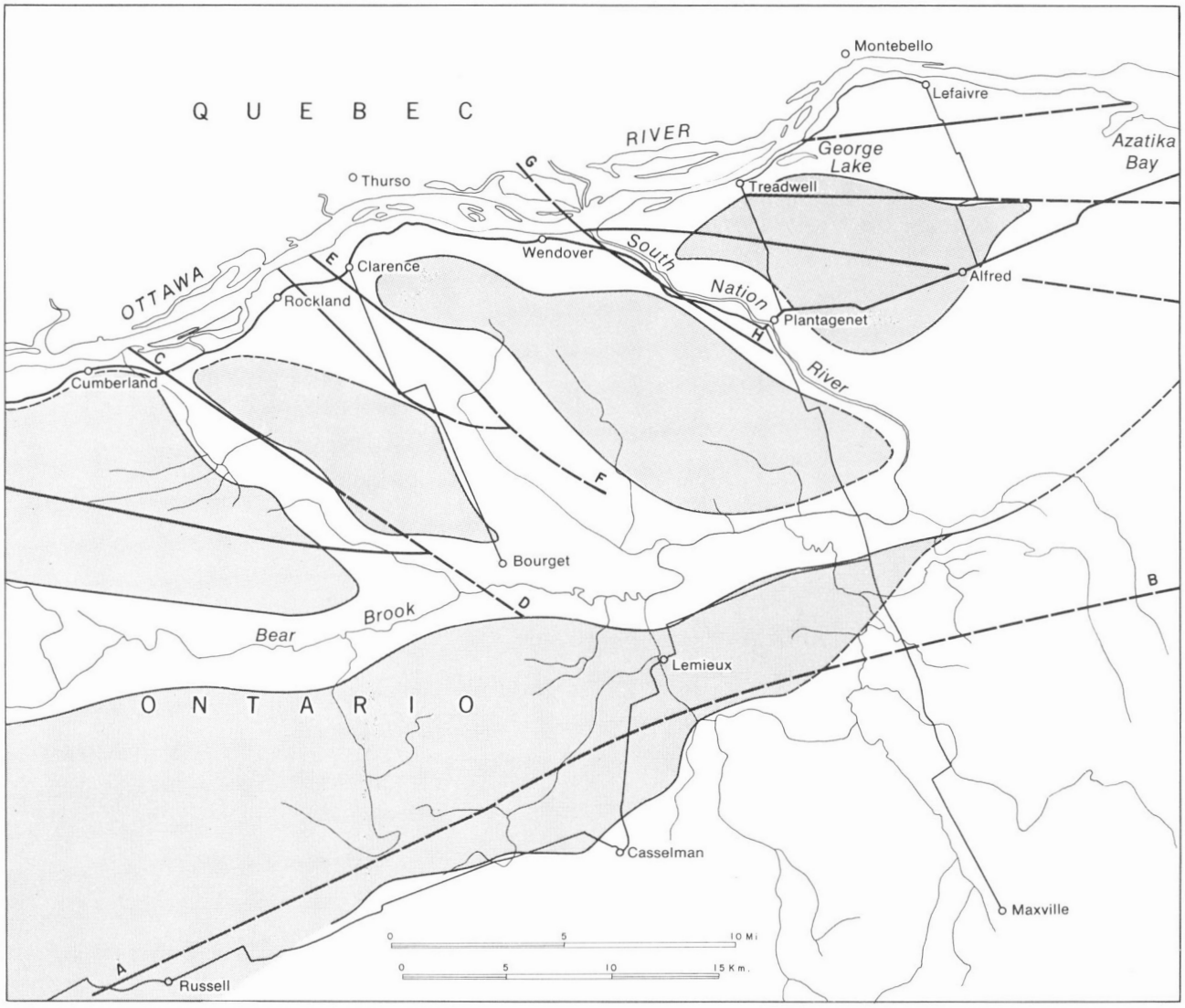

Figure 1. Location of faults (heavy black lines, some lettered AB, CD, EF, GH) in relation to abandoned channels (white) between "islands" or erosional remnants of sand-capped marine clay (stippled). Poorly defined southern limit of channel through Casselman not shown. (Faults after Wilson, 1946, Map 852A).

SURFICIAL GEOLOGY AND LANDSLIDES OF THURSO-RUSSELL MAP-AREA, ONTARIO

INTRODUCTION

The mapping of this area is part of a program of continuing studies of landslides being conducted by the Engineering and Environmental Geology Section, Terrain Sciences Division. This area was selected because of the extensive development of landslide scars. About 11.6 thousand acres (4.6 thousand ha), or nearly 6.5 per cent of the total surface of this map-area, has been involved in landslides. Their ages probably range over the past ten thousand years. The most recent landslide occurred on May 16 and 17, 1971 near the centre of the area on the east bank of South Nation River, about two miles (3 km) upstream from the village of Lemieux. It was a natural geological occurrence rather than a man-made one, and has been described in some detail by various newspaper accounts and in more scientific terms by Eden *et al.* (1971).

The occurrence of landslides apparently is related to geologic history of individual sites, and thus the surficial geology of the map-area was examined in some detail during the 1973 field season in order to evaluate its influence on the nature and distribution of the landslides.

The author was most ably assisted in the field by Richard Hewitt.

GEOLOGICAL HISTORY

Bedrock and its structure

Bedrock geology maps of the area by Wilson (1946) indicate that the area is underlain by Paleozoic sedimentary rocks, dominantly limestone, that are tilted and faulted so that a major downfaulted block, or graben, exists between the north shore of the Ottawa River and a fault, identified as A-B on Figure 1, in the vicinity of Russell, Ontario. The fault is assumed to extend northeasterly, passing between the village of Lemieux and the town of Casselman (Fig. 1). Within the graben block, beds have low-angle dips away from the river towards the south. The exposed edges of the resistant stratigraphic units form escarpments that face northward towards the Ottawa River; thus they form a typical cuesta landform. The block is further disjointed by faults trending southeasterly.

This pattern of faults, scarps, and dipping strata is the fundamental cause of depressions in the bedrock surface, which were reflected in Pleistocene sediments deposited on the surface of the rock, and which in turn controlled the development of now abandoned post-Champlain Sea fluvial drainage. The position of these abandoned channels is marked on the surficial geology map by the distribution of map-units 5 and 6 and on Figure 1. In the resultant pattern the Ottawa River flows easterly in a series of fault depressions along the northern margin of the graben; Bear Brook and a portion of South Nation River (west and east of the town of Bourget, respectively) occupy another depression along the southern part of the tilted block. Two significant faults trending southeasterly between the municipalities of Clarence and Cumberland, and another between Wendover and Plantagent (C-D, E-F, and G-H respectively, Fig. 1), have localized late-glacial cross channels now occupied by the following underfit streams: North Indian Creek, Clarence Creek, and Cobbs Lake Creek, and South Nation River in its lower course including its confluence with the Ottawa River. Another abandoned channel system, less well marked than those mentioned above, trends northeasterly through Casselman parallel to the major fault system and therefore apparently is structurally controlled; it is now occupied in part by Castor River.

As indicated above, the exposed bedrock of the area is of early Paleozoic age, the youngest of which is the Queenston Formation of Upper Richmond Epoch in the Ordovician Period. The great gap in sedimentary record between Ordovician and Pleistocene is a phenomenon of the Ottawa-St. Lawrence Lowland region. Wilson (1946, p. 8) was among the earliest to comment on the "immense interval of unrecorded time [that] elapsed between the withdrawal of the latest Ordovician sea and the beginning of the glacial period". Sedimentary source rocks for glacial materials, therefore, are relatively few.

A small number of bedrock outcrops are shown on the surficial geology map (in pocket); all of these have been recorded on the maps of Wilson (1946, Map 852A) and the reader is referred to that source for specific classification and interpretation of the outcrops. For purposes of this present map, outcrops and thinly veneered bedrock surfaces are classified as bedrock areas and are designated by the map-units "R" and "Ra", respectively.

Bedrock at the surface in the northeast corner of the map-area along the road approximately 1 mile (1.6 km) southeast of Treadwell is limestone, characterized by a solution-pitted surface and by solution expansion of fractures. The latter have produced linear cavities as much as a foot (0.3 m) wide and several feet long and deep. Solution at junctions of intersecting fractures has produced near-vertical tubular cavities of varying size and thus exposures of limestone with solution features, or karst topography. Large closed depressions occur on surfaces of some clay deposits on abandoned river terraces to the west of Treadwell within the map-area, on the terraced area between the village of Lefaivre and Baie des Atocas on the south shore of the Ottawa River in the adjoining Hawkesbury map-sheet (31 G/10W), as well as on the islands or peninsulas in the Ottawa River (31 G/11E) named Petite Presqu'île and Grande Presqu'île. Initially these pitted surfaces were thought to have been produced by collapse of the clay-sand terrace surface materials into solution cavities in the underlying bedrock. Borings made during the 1975 field season,

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however, show that clay deposits near some depressions are thick and bedrock occurs at depths as great as 350 feet (105 m) beneath some depressions. Solution phenomena therefore cannot be as easily invoked as an answer to the question of origin of these unusual pitted terrace surfaces. Although not favoured by the author, Crawford's (1961) identification as an earth-flow phenomenon cannot be discarded as a working hypothesis.

Résumé of glacial history

Within the map-area a single till sheet with minor associated varved silt and some overlying ice-contact sand and gravel represents the Wisconsin (?) glaciation. A thin unit of varves grades upwards into overlying stratified marine clay typical of the region, indicating a similarity in age with the Champlain Sea. By this association and the fact that marine clays of the Ottawa Valley range in age between 10 000 and 12 200 years B.P. (Gadd, in press), it may be assumed that the glacial sediments are at least in part of late Wisconsin age.

Approximately 12 000 years B.P. the map-area was completely submerged beneath the brackish waters of Champlain Sea. A cover of marine sediment in the form of stratified silt and clay was deposited. As uplift progressed and towards the end of the marine episode, sand encroached on the basin interfingering with the finer sediments until ultimately a major deltaic and braided channel deposit of thick, uniform, fine grained sand lay upon the marine clay surface. It is likely that some of the early channellings in the estuarine or deltaic system scoured the surface of the clay so that in places the contact between clay and sand is erosional and abrupt. As a result there may be isolated channel sections on the surface of the clay that are poorly drained or that drain at depth and in a direction at variance with the slope of the present land surface. As uplift of the region continued, several principal river channels became defined along fault-controlled lines and subsequently became deeply incised in the deltaic sand and the underlying marine clay to depths as great as 100 feet (30 m).

A freshwater clam, identified as *Lampsilis* sp., was found in the sandy facies of the fluvial sediment at Bear Brook, about one mile southeast of Bourget, Ontario, and indicates the freshwater environment of the system that cut these channels. To date the freshwater fossils have been found only in the sandy facies; presumably the silty clay and silty sand couples found in the fine grained channel deposits also were deposited in fresh water. The radiocarbon age of part of the fossil collection taken from the Bear Brook locality is 10 200 ± 90 years B.P. (GSC-1968). This isolated occurrence of freshwater species suggests that the Champlain Sea episode and associated salt-water and brackish-water conditions terminated in the region at least as early as this date. The channel in which the fossils occur may be traced continuously westwards to the Ottawa region, where it is occupied by the peat bog known as Mer Bleue. The association of this channel and its related sediments with a freshwater system has been proposed earlier (Gadd, 1963), and this new evidence adds greater confidence to that interpretation.

Terraces of the abandoned channel systems, raised terraces of the Ottawa River situated below the level of about 250 feet (75 m) a.s.l., and the sediments deposited upon the eroded surface of marine clay and older sediments and bedrock belong to the ancestral Ottawa River drainage system.

In the past ten thousand years major channels have been abandoned and the Ottawa River has been reduced to a single main channel with numerous smaller tributaries, many of which are underfit in the older abandoned channels.

In this area, the development of landslides apparently is related most directly to this latter 10 000-year period of time, during which erosion of the original marine basin sediments has taken place. The relationships are discussed further in this report.

PLEISTOCENE AND YOUNGER SEDIMENTS

Till and reworked glacial debris probably derived from till by wave action in Champlain Sea and/or by other younger weathering processes, are exposed in a few places within the map-area (map-unit 1). The most extensive exposures of these units occur in the northwest part of the area near Clarence, in a few linear areas in the northeast near Centrefield, at Casselman, and near the southern boundary of the map-area between St. Albert and Mayerville. In these places, thin sheets of calcareous sandy grey till are present, but generally they are masked by poorly sorted gravelly glacial debris grading downwards into the typical gravelly to sandy silt till; in places this debris rests directly on the bedrock. The best exposure occurs on the west bank of South Nation River below both the functioning and defunct Casselman dams; here the till is only about 3 feet (1 m) thick. It is overlain by 1 to 2 feet (0.3 to 0.6 m) of thin-bedded, red and grey varved silts that grade upwards into typical banded marine clay. This single exposure of varves in the area is too small a unit to be mappable at any reasonable scale. Its presence here, however, is comparable with the occurrence of post-till varves in the Ottawa area (Gadd, 1963) where the gradational stratigraphic relationship with overlying marine clay is the same as here. The varves are thought to represent freshwater conditions in the region at the end of the last Wisconsin glaciation. The thickness of the unit (1 or 2 ft. (30 to 60 cm)) further indicates a rapid change to the brackish-water conditions typical of Champlain Sea.

In another outcrop of till situated in a road-cut at the top of a bedrock scarp, one mile (1.6 km) southwest of Highway 17 bridge over South Nation River, and north of 'The Rollway', there are several balls of massive, grey clay ranging in size from 3 to 4 inches (7.5 to 10 cm) to 2 feet (60 cm) in diameter. The clay balls may be nonmarine and may come from a preglacial or proglacial deposit, in which case they

represent the initial advance of Wisconsin ice over the Ottawa Valley depression. Another possible explanation is that if the clay balls are presumed to be marine, they may have been caused by ice that advanced some distance into the Champlain Sea; however, if the latter occurred, this is the only evidence of such readvance in the region.

Ice-contact sediments (map-unit 2) related to retreat of the ice margin constitute fluvially stratified sands and gravels, including cobble and boulder gravel, having a wide range both in size of materials and in degree of sorting. Steep dips of beds are common, and rapid changes in direction and volume of flow are recorded in the sediments. Only three bodies of such material are mapped in the area: one east and one southeast of Casselman, and another parallel to the township road approximately one mile (1.6 km) northwest of St. Pascal (de Baylon). All three bodies are overlain by fossiliferous marine clay; the presence of the more southerly two is indicated only by a minor hummock or ridge 5 to 10 feet (1.5 to 3 m) in height and an anomalous occurrence of pebbles and boulders at the surface of the clay. The unit near St. Pascal has been nearly circumscribed by landslide scars so that it now stands as a linear ridge nearly 50 feet (15 m) high. This form may reflect its origin as an esker segment. All these have been exploited by quarrying as local sources of gravel.

Marine clay (map-unit 3) underlies most of the map-area although it is exposed at the surface only in the extreme southeast corner of the map-area where it overlies ice-contact deposits and till and underlies the extensive Moose Creek Bog (map-unit 7). Elsewhere marine clay underlies an extensive channel sand unit (map-unit 4) and younger fluvial deposits (map-units 5 and 6).

As mentioned above, the contact of the marine clay with underlying glacial varves is gradational and the lower part of the marine clay map-unit is thin bedded with regular varve-like alternations of fine and coarse silt. Colour banding – reddish brown fine grained, and brownish grey to grey coarse grained strata – is also a common characteristic of the two bodies of sediment. Generally, it is possible, however, to note the disappearance of graded bedding, present in varves but not in the marine sediment, as a criterion for distinguishing marine from freshwater units. Typically the thickness of beds increases upwards in the body of marine sediment and diminishes again towards its upper surface. The thin upper beds of marine clay commonly are interbedded with fine grey sand and in places have red-grey colour banding similar to that in the lower portion of the unit.

Marine sediments in the map-area commonly contain few fossils; *Portlandia arctica* is characteristic of the more massive beds, and assemblages including *Portlandia arctica, Macoma balthica,* and *Hiatella arctica* are more representative of the sandy facies that probably represents a late shallow phase of the marine basin development (fossils of both deep-water and shallow-water environments were found in different slump blocks within the scar of the 1971 South Nation River landslide). Many large slides have occurred within this material in the map-area (*see* map in pocket). A discussion of the geological controls on location, size, and frequency of landslides is given in later paragraphs (*see* section on Time).

The most widespread lithologic unit is deltaic and fluviatile sand (map-unit 4) that overlies marine clay in all landslide sites in the area. The nature of the contact between marine clay and this overlying sand unit is not well known because there are few clean exposures. It appears, however, that in a few places the sand has a gradational relationship, interfingering with upper units of marine clay; in most other places the contact is a sharp break between clay and sand, and apparently is erosional. This erosional relationship, cross-bedding and channel structures within the sand, and the presence of a number of abandoned channels on the surface of the sand unit indicate that the younger sand unit is of deltaic or fluvial origin.

No fossils are clearly associated with this sand unit, although small numbers of shells of *Macoma* sp. and *Hiatella* sp. were found in sand interfingering with marine clay at the head of the scar of the 1971 South Nation River landslide. These occurred, however, as single valves and disoriented pairs and may have been exotics. Nearly two hundred shallow auger borings in the sand unit (map-unit 4) exposed no fossil remains.

This paucity or lack of marine shells may be taken as negative evidence in favour of an estuarine or freshwater environment of deposition for the sand. Further support of this hypothesis is given by the shape of the surface of the deposit in relation to its present distribution. The deltaic or fluvial sand is now separated into "islands" by broad channels that were part of a major proto-Ottawa River system presently carrying underfit streams. It is notable that each of these "islands" has a high point on the north or northwest and a gradual or low-angle surface slope towards south and southeast. In other words these islands have a surface gradient that slopes downwards in the direction of flow of the abandoned channel systems surrounding them. The island block occupying the north-central part of the map-area is defined along its northern boundary by cuesta scarps and could be described as constituting a rock-defended terrace. In this case the portion of the sand unit above the scarp in the northwest corner of the map-area, near Clarence, has a surface elevation in excess of 300 feet (90 m) a.s.l. From that point to the terraced slipoff slope east of Pendleton, the surface of the sand unit declines gradually to below 200 feet (60 m) a.s.l. It is apparent in this case that some part of the sand was being deposited or reworked during incision of the abandoned channel system into both the sand and the subjacent marine clay. The sand is, therefore, at least in part fluvial and possibly also belongs to a freshwater environment of deposition such as delta or braided river channels; it is doubtful if true saline or brackish-water conditions existed during deposition of map-unit 4.

Sediments that are confined to the abandoned channel systems and are distributed on the raised terraces of the Ottawa River (map-units 5 and 6) are fine and coarse facies (respectively) of river sediment. The finer facies (map-unit 5) is widely distributed and is characterized by laminated or at least colour-banded silt and/or clay. Regular alternations of fine grained grey to brownish grey coarse silt and brownish grey to brick-red silt and clay of from one quarter inch (0.6 cm) to several inches in thickness are found in most of the exposures, particularly those occurring in the valley floor and in flat terraces.

Near the margins of the channels and in shoreward positions along terraces the clay is commonly interbedded with fine silt and sand; in places the sequence becomes progressively more sandy upwards until it is entirely of stratified sand. A gradational relationship exists between map-unit 6 and unit 5. There is a marked and characteristic pattern to the stratification of this shoreward silt-sand facies of map-unit 6. Each bed comprises a lower unit of fine silt and clay (in this area commonly of brick-red colour) that grades upwards into coarse silt (grey-brown to grey) that, in turn, grades upwards into fine sand (grey to buff in colour). Repetition of this sequence in thick deposits, commonly with sand content increasing upwards from unit to unit, indicates rhythmic or cyclic deposition – perhaps on an annual cycle. The puzzling feature of these units is the gradation upwards of increasing grain size indicating increasing energy in the environment of deposition during the accumulation of each rhythmic succession. The author suggests an annual event beginning with bankfull or flood conditions in the spring of the year providing fine sediment nearshore during a short-term, deep-water phase with gradual increase in the energy level as water surfaces drop to normal levels providing shallower water and higher energy in the form of both current and wave action that would carry and deposit progressively coarser sediment in the shore environment. The best exposures of this unusual rhythmite are found near an overpass on Highway 417 where it crosses Prescott and Russell County Road No. 3 about three miles west of Casselman, Ontario.

The sand unit (map-unit 6) occurs chiefly as bars and spits in the channels, and minor deltas, bars, and beaches along their margins. The sand is medium to fine grained and has some disseminated organic matter as well as characteristically bronzed mica flakes (probably indicative of oxidation).

Fossils of singular interest were collected in a grey sand and silty sand unit (included in map-unit 6) overlying rhythmically bedded sand-silt-clay deposits (map-unit 5) on the south bank of Bear Brook at 0.7 mile (1.1 km) southeast of Bourget, Ontario. These were exposed in the summer of 1973 during construction of approaches of a new bridge over Bear Brook. Individual valves and complete specimens of freshwater clams, some well preserved and with the periostracum attached, were identified as *Lampsilis* sp. by Arthur Clarke of the National Museum of Natural Sciences (W. Blake, Jr., 1974, pers. comm.). Radiocarbon dating in the radiometric laboratories of the Geological Survey of Canada gave an age of 10 200 ± 90 years B. P. (GSC-1968) for representative specimens from this collection of shells (dated material was not identified before analysis, but is assumed by the author to be *Lampsilis* sp.).

The presence of these fossils in the channel deposits sheds new light on a long-standing question. Antevs (1925) identified a two-clay system, older Champlain Sea clays and younger "upper clay" identified as marine sediment of the "Ottawa Sea". Gadd (1961, 1963) has previously inferred from other evidence that similar channel and terrace sediments, thought to be equivalent to Antevs' second marine sequence, were in fact of freshwater origin and has offered fluvial or lacustrine origin as an alternative working hypothesis. The occurrence of *Lampsilis* sp. is the first clear evidence that sediments in the post-Champlain Sea abandoned channels of the Ottawa Valley are of freshwater origin.

Bog deposits (map-unit 7) composed of peat and muck varying up to several feet in thickness are shown in only three places within the map-area. Moose Creek Bog, part of which occupies the southeast corner of the map-area, overlies poorly drained marine clay deposits occupying the north side of the drainage divide between the Ottawa and St. Lawrence River drainage basins. The other two smaller and shallower peat bogs occupy parts of abandoned channels in map-unit 5 near Cobbs Lake Creek and South Nation River in the vicinity of Bourget and Pendleton, respectively. Thin, discontinuous units of peat bog exist on the uplifted, poorly drained surfaces of saturated sand (map-unit 4), but generally are too small to be identified on the map.

Modern alluvium in shore deposits, such as that present at the mouth of South Nation River, in the spit enclosing Cunningham Bay, and in linear islands in Ottawa River, has been included in map-unit 6 as being of common origin, even though these modern units are several thousand years younger than their uplifted counterparts that constitute the bulk of map-unit 6.

GEOLOGICAL CONTROLS ON OCCURRENCE OF LANDSLIDES

The comments and interpretations that follow relate to observations made within the map-area during one field season (1973) and are preliminary in nature. The purpose of this section is to direct attention to some areas of study that may contribute to a greater understanding of the geology of landslides in sensitive clays of the Ottawa-St. Lawrence basin.

Bedrock and geomorphic controls

As described previously there is direct correspondence between the position of significant faults in the bedrock of the region and of post-Champlain Sea river channels. Also, all of the largest landslides of the area are localized along these channels, which are mostly now abandoned, and smaller though significant

slides are distributed along a stretch of the modern South Nation River which may not be fault controlled. In both cases steep banks of marine clay were exposed by river erosion, but probably a small difference in the history of development explains the differences in size and frequency of landslides represented by the relative acreages. Of a total of approximately 11 640 acres of landslide terrain in the area, 11 160 acres are associated with the fault-controlled abandoned channel system, whereas only about 480 acres are associated with the modern stream.

The fault system (Fig. 1) that predates Pleistocene glaciation of the region provided zones of weakness along which glacial erosion scoured and broadened linear depressions, only partly filled them with glacial debris, and allowed for localized deposition of thick deposits of marine clay at the bottom of Champlain Sea. It is postulated that the surface of the marine clay retained fault-controlled depressions. Thus the fault system was the fundamental factor determining the pattern of postmarine surface drainage streams. Incision of the streams was rapid because of the great accumulation of fine, soft sediment in the preglacial channels; because of high susceptibility of this material to mass wastage by mudflow, the new fluvial channels widened very rapidly. Smaller and somewhat younger tributary streams, such as the sector of South Nation River between Casselman and Lemieux, however, developed on broad flat islands of the dissected flood plain, perhaps as tributaries of the broader channels; they had a smaller initial gradient, relatively coarse material in their beds, and a short time interval in which to develop.

Thus the modern channels are narrower than the early ones and although some are now incised more deeply than the abandoned channels, they have a smaller capacity for slide debris. This may be a limiting factor in the control of size of flow slides for it seems axiomatic that retrogression of a flow slide or earthflow is limited by the capacity of the basin or valley into which it flows. The relative lengths (measured at right angles to the original bank where first failure occurred) of landslide scars in the two slide zones under comparison seem to support this concept but may also relate to other factors. South Nation River valley with bank heights of about 75 to 100 feet (23 to 30 m) and a valley width of about 0.25 mile (400 m) has a maximum slide scar length of about 0.4 mile (630 m) but an average length of less than 0.25 mile (400 m). Slide scars on the 2- to 3-mile (3- to 5-km) wide channel through St. Pascal have retrogressed from banks 25 to 50 feet (8 to 15 m) high for more than a mile; indeed, the nearly 3-mile (5-km) wide surface of a narrow portion of the interfluve "island" lying between Clarence Creek and Wendover has been destroyed almost completely by the coalescence of slides that flowed more than a mile both northeast and southwest through initial failures in slopes of adjacent channels.

Time

The degree of retrogression is much greater in early slides that occurred along now abandoned channels than that in modern channels, even though the initial bank heights of the older slides were much lower. Modern stream banks are stable at much greater heights. The writer assumes that because of the age difference of ten thousand years and because of the related drop in sea level and general water table in that period, clay deposits have become better drained, more resistant, and therefore less susceptible to liquefaction. As a result modern landslides are deeper and narrower than earlier ones. The size-shape parameters of landslides have changed through time, mainly due to dewatering of the sediments.

Another relative time sequence is apparent, but as yet no dates have been ascertained. In the Clarence Creek-Cobbs Lake Creek abandoned channel the more northerly sets of landslide scars virtually are devoid of flow aprons, suggesting that the aprons have been removed by river erosion which produced the scarp now truncating this group of slides. Farther south in the same channel, large flow aprons have been preserved in the channel floor adjacent to the scars from which they flowed. Airphotos show that flow patterns are continuous from the scar to the apron although in places the line of the original bank is visible through the apron of flow debris. This second group of slides with aprons apparently is younger than the group whose aprons have been removed. As a general rule the headwalls of these major scars are vegetated, smooth, and apparently inactive although a few have produced small slumps and flows where streams and springs presently are active. Thus the presence of active agents of erosion becomes an additional time-dependent factor in landslide development. It may be said that along abandoned channel slopes, although the potential for retrogressive flow slides is high, it is not being activated to any significant degree by modern stream or other erosion. On the other hand South Nation River with its shallow, flood-prone channel is now actively eroding its banks and is responsible for several large landslides, some of which have occurred within the recollection of many local residents. The most recent one occurred in May 1971 (Eden *et al.*, 1971) and involved nearly 50 acres of farmland; the slide blocked the South Nation River over a total distance of nearly two miles, including about one-half mile (0.8 km) of debris-choked channel upstream from the slide scar.

Marine vs. freshwater sediment

Where preserved in a moist or saturated state within the area, marine clay (map-unit 3) commonly has an unconfined compressive strength, as measured by a pocket penetrometer, of less than 1.0 ton per square foot; readings of 0.25 to 0.5 ton per square foot are common and liquefaction of clay on a power auger or a hand auger occurred in places where highly saturated material was encountered. Commonly in this

area marine clay is overlain by saturated sand (map-unit 4) and therefore is in a highly saturated state, susceptible to liquefaction. The freshwater silt-clay, map-unit 5 (so-called by association with sand (map-unit 6) that contains freshwater clams at one locality) typically has relatively higher unconfined compressive strength ranging from about 1.0 to 3.5 tons per square foot with a few occurrences of moist clay with strength as low as 0.5 (in one place even 0.2) ton per square foot.

It is not surprising, therefore, that the majority of landslides in the area, mostly of the flow slide or earthflow type, occur in marine clay which is saturated, soft, sensitive, and stands in steep slopes of 50 feet (15 m) or more in height. Only two slides (probably flow slides) of a size large enough to be shown on the map (northwest corner of map near the banks of Ottawa River) are present in the freshwater clay which generally has much greater strength. Commonly, mass wastage of the freshwater clay occurs as small bank failures only, or flow slides involving very little liquefaction of the sediment.

No doubt most of the silt-clay sized sediment deposited in the freshwater channel environment (map-unit 5) is a secondary sediment derived in great part from the erosion, mainly by mass wastage, of the original marine clay. Among other things, it remains to be investigated whether there is a basic structural difference between these clays (e.g. flocculated or 'ped' structure in marine clay vs. granular structure in freshwater clay) that has a bearing on the relative frequency of landslides in the two sediments.

Groundwater hydrology

Because saturation and high pore-water pressures in clays are principal factors in the landslide mechanism, a study of groundwater hydrology in the area is considered to be an important part of any investigation of landslide susceptibility. Although this aspect remains to be studied in detail within the map-area, a few related general comments may be of some value here.

In addition to the other factors already mentioned, the greatest number of landslides in this area have occurred where there is a general, relatively thick cover of sand. The dissected fluvial and deltaic sands of map-unit 4 have low surface gradients and have a very high water table – generally less than 9 feet (2.7 m) below the surface and commonly 1 to 4 feet (0.3 to 1.2 m) below the surface. In most observed occurrences, underlying marine clay of map-unit 3 is saturated and very soft (< 1.0 ton per square foot). By contrast, much of the surface of map-unit 5, freshwater silt-clay, is virtually bare, having little or no sand cover; the freshwater silt-clay is considerably more resistant (u.c.s. > 1.0 tons per square foot) than the marine clay except where it is overlain by sand or where drainage is obstructed. It seems evident therefore that the groundwater regime is very much affected by the presence or absence of a sand cover. Given similar clays of low permeability, the one without sand cover will have the higher runoff rate and the lower amount of recharge. In fact the recharge would be limited and seasonal. The areas with sand cover, on the other hand, would have low runoff and a high level of recharge on a year-round basis. Perhaps this factor is at least as important as any other in the localization of slide phenomena in the marine clay of the area.

If thoroughly air dried, both marine and freshwater clays have unconfined compressive strengths greater than the capacity of the pocket penetrometer (i.e., > 4.5 tons per square foot). Exposed clay surfaces of both types therefore will have similar, if not identical, strength characteristics. A comparison of strength characteristics of the two types of clay under a range of hydrologic conditions is projected in order to compare the effect of environment of deposition as distinguishable from the present environment. Further comparative studies of mineralogy, structure, and bonding or cementation of the sediments also are suggested and projected.

CONCLUSIONS

(1) The presence of a fault system in the bedrock of this area controls the preglacial channels, the thick accumulation of marine clay, the post-Champlain Sea drainage systems, and thus the concentrations of major landslides.

(2) This report records the first discovery of freshwater clams, *Lampsilis* sp., in fluvial sediments occupying channels cut in Champlain Sea clay. Radiocarbon dating of the shell material indicates an early development (10 200 ± 90 years B.P., GSC-1968) of a freshwater fluvial system, the proto-Ottawa River system.

(3) Marine clays generally have low strength and have been involved in numerous, large flow-type landslides, whereas the freshwater clays have relatively higher strength and have produced mainly small bank failures or gravity slides.

(4) Within a channel system the relative age of slides or groups of slides may be assessed by the presence or absence of debris aprons on the floor of the adjacent abandoned channel; most younger slides have the apron of debris preserved, whereas older slides have their aprons removed by stream erosion in the channel.

(5) High landslide potential is correlated with a high level of saturation of the clay which, it is postulated, may be related to the presence of sand cover over the marine clay.

(6) The slides formed along abandoned channels near Clarence Creek are much larger than a younger group of slides along the Casselman-Lemieux sector of South Nation River, including the South Nation River landslide of May 16-17, 1971. Time-controlled factors such as drainage may be as important as valley width in regulating the relative amount of retrogression in those two groups of landslides.

(7) Retrogression and liquefaction are restricted to the marine clay banks. Along South Nation River there are contrasting landslide patterns. Above Lemieux where the valley intersects marine clay, retrogressive

flow slides are common whereas below Lemieux where the valley intersects freshwater channel sediments, small bank failures are the characteristic landslide form.

(8) The contrast in landslide frequency and type between marine and freshwater sediments to a significant degree is probably due to a fundamental physical or chemical difference in the sediments.

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