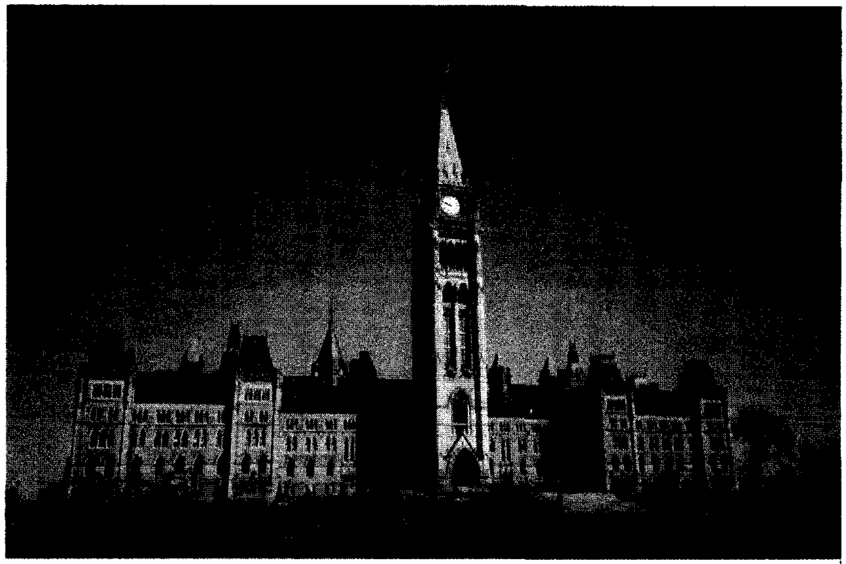
STRATIGRAPHIC AND STRUCTURAL FRAMEWORK OF THE POTSDAM GROUP IN EASTERN ONTARIO, WESTERN QUEBEC AND NORTHERN NEW YORK STATE

by

B.V. Sanford



CANADA'S PARLIAMENT BUILDINGS
CONSTRUCTED FROM SANDSTONE OF THE NEPEAN FORMATION

A thesis submitted to the School Of Graduate Studies

in partial fulfillment of the requirements of the degree of Ph.D. in Earth Sciences

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Stratigraphic and Structural Framework of the Potsdam Group in Eastern Ontario, Western Quebec and Northern New York State

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ABSTRACT

The presence of a major unconformity within the Potsdam Group is an important key to unlocking the geological history of this succession throughout its area of distribution in the Ottawa Embayment and Quebec Basin.

The beds below the unconformity (Abbey Dawn and Covey Hill/Ausable formations) largely of continental origin up to 600 metres thick, is a complex assortment of red and grey quartzite cobble, quartz pebble and quartzarenite deposits of assumed Neoproterozoic to Early Cambrian age. The Covey Hill/Ausable formations have been further divided into four units of wide distribution beginning with the Jericho member of marginal marine origin, confined to the Quebec Basin bordering the Oka-Beauharnois Arch; succeeded and overlapped to the west by Hannawa Falls, Chippewa Bay and Edwardsville members of aeolian, fluvial and possible lacustrine origin. During and immediately following deposition of these members the beds were locally faulted, folded and subjected to a long period of subaerial erosion. This process was likely triggered by a plate tectonic event in progress during Neoproterozoic to early Early Cambrian time, when the continents were in a state of rifting and break-up, followed by the opening of the Iapetus Ocean.

Above the unconformity are the white and grey Nepean and equivalent Cairnside and Keeseville formations up to 110 metres thick composed of quartzarenite and minor quartz pebble conglomerate of Late Cambrian to Early Ordovician age. These formations were deposited on the floor and margins of a seaway that entered the Ottawa Embayment from the east. The highland areas (arches) on all four sides of the embayment provided restricted marine depositional conditions that contributed to the precipitation of minor evaporates, a proliferation of stromatolites and a limited normal marine biota contained within the Nepean sandstone and its stratigraphic equivalents.

Post-Potsdam deformation resulted in the rejuvenation of faults and local folding of Potsdam and younger Paleozoic strata throughout the Ottawa Embayment and Quebec Basin, the timing of which was likely associated with

Taconian and Acadian orogenesis, and by the much later rifting of the North American continent that occurred with the break-up and separation of the continents in the Jurassic and Cretaceous.

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CHAPTER 1

INTRODUCTION

The Potsdam Group, the object of the present study, and its possible stratigraphic equivalents in adjacent regions of the St. Lawrence Platform, are among the oldest non-metamorphosed sedimentary sequences in eastern North America. They are composed largely of sandstone and conglomerate that form the basal stratigraphic units that were deposited along the southeastern margin of the Canadian Shield in eastern Canada and United States, during latest Precambrian to Early Ordovician times.

These sequences, in varying levels of preservation, occur along the entire length and breadth of the St. Lawrence Platform extending from western Newfoundland and Labrador on the east, to Ohio, Michigan and Wisconsin on the west, a distance of 1700 kilometres. Throughout this broad area, the rocks are locally well exposed along the inner margins of the St. Lawrence Platform, and in subsurface have been identified in boreholes and seismic data where they overlie Precambrian basement rocks and are obscured beneath younger Paleozoic cover.

In the Central Division of the St. Lawrence Platform,(Quebec Basin and Ottawa Embayment), the Potsdam Group has been studied in some detail, but little attempt has been made at establishing a consistent stratigraphic framework that links the three principal outcrop belts in New York State, eastern Ontario and western Quebec. In New York, for example, where the Potsdam was first identified by Emmons in 1838, the succession to this day is simply referred to as Potsdam Formation throughout most of the state. Early attempts were made to subdivide the unit in the Lake Champlain region, and these are described in some detail herein under the heading "Summary of previous investigations". The most recent work in this regard was by Fisher (1968), who divided the Potsdam Formation into two units—Ausable and Keeseville members as geological map units—terms that were adopted from previous investigations by Alling (1919) and Emmons (1841), respectively. There is some uncertainty, however, as to whether or not the Ausable and Keeseville formations defined by Fisher (ibid.) are the exact correlatives of the Covey Hill and Cairnside, as is currently in use in the adjacent area of Quebec. Also, the two map units were never systematically extended beyond the limits of the Plattsburgh-Rouses Point area to the westward, bordering the northern margin of the Adirondack Mountains.

Similar classification uncertainties have long prevailed in adjacent areas of Ontario, that largely relate to the original naming and definition of the Nepean Formation by Wilson (1937, 1946). In defining the term, Wilson (ibid.) was apparently unaware of the presence of much older rocks (Covey Hill and equivalent Ausable formations) present beneath the Nepean Formation elsewhere immediately to the south and east of Ottawa, in Ontario, Quebec and adjacent areas of New York State. Thus, her definition of the Nepean at the type section comprised a succession quite different from the rocks she mapped as Nepean elsewhere in eastern Ontario and western Quebec.

This was in part corrected by Williams and Wolf (1982, 1984 b), by the recognition of beds older than the Nepean in the Ottawa Embayment, which were shown on their geological maps as isolated exposures, the authors presumably unaware of their stratigraphic continuity along the eastern margin of the Frontenac Arch extending from the vicinity of Perth to the St. Lawrence River and beyond. To these beds, Williams *et al.,* (ibid.) applied the name Covey Hill Formation, a term borrowed from earlier studies in Quebec by Clark (1966, 1972). The same authors also used the term Potsdam Group, previously defined by Clark (ibid.) to embrace the Covey Hill beds, and the much younger Nepean Formation where the two are juxtaposed.

In Quebec, the term Potsdam Sandstone was used for many years to identify the thick sandstone unit lying at the base of the Paleozoic succession by

Logan (1863) and others. Much later, Clark (1966, 1972) and Globensky (1987) established a very useful classification for their newly defined Potsdam Group, by erecting a two-fold subdivision of units — Covey Hill and Cairnside in that ascending order. So far as is known however, their classification was never tied into the New York section immediately across the border, or into Ontario for that matter, and thus no precise correlations were ever established beyond the jurisdictional boundaries of the province of Quebec.

The published and unpublished database relating to the stratigraphic, sedimentological and petrographic framework of the Potsdam Group is voluminous for all three regions of the present study area, and represents a most valuable resource to say the least. In perusing the literature, however, it is evident that most if not all of the maps, papers and reports published to date are greatly restricted in terms of geographical coverage. This is perhaps in many instances due to constraints placed upon the various authors by state and provincial boundaries that define the political jurisdiction of the state of New York and the provinces of Quebec and Ontario.

Based on the above considerations, the writer has long been cognizant of the need to examine the Potsdam Group in a sufficient level of detail to map and establish accurate regional correlation of rock units, determine facies changes, and establish a structural framework for the Ottawa Embayment and Quebec Basin. Such information is important also to establish more reliable correlation with laterally equivalent stratigraphic sequences that occur elsewhere in the eastern and western extremities of the St. Lawrence Platform.

The writer became involved in such a project in recent years, beginning with the chance finding of an angular unconformity within the Potsdam Group, in a roadcut on the Rideau Ferry Road, approximately eight kilometres southeast of the town of Perth, Ontario (see Figure 1). Here, the sandstone beds beneath the unconformity were observed to be faulted and tilted at a steep angle, and overlain by flat lying sandstone containing a basal quartz pebble conglomerate. The brittle character of the faulting, and intense level of erosion of the lower unit, clearly suggests that the hiatus between the two units must have been

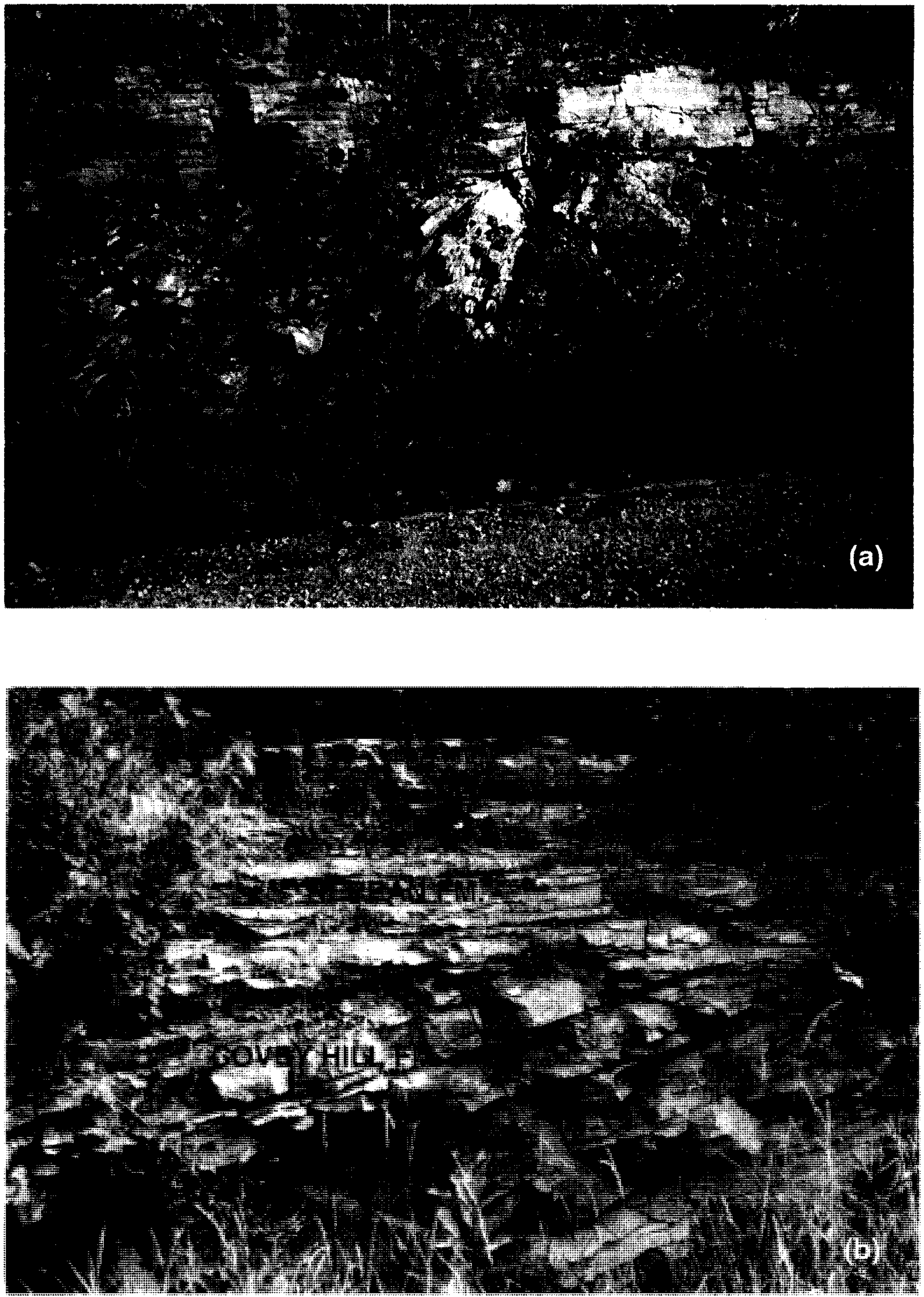


Figure 1: Potsdam Group in roadcut on Rideau Ferry Road, Ontario, at station O-16. (a) Faulted and tilted Covey Hill strata unconformably overlain by flat lying Nepean Formation. (b) Angular unconformity between Covey Hill and Nepean Formation, immediately west of section (a).

substantial. After several visits to the site, the writer could only conclude that a contact of major historical significance between the Covey Hill and Nepean formations had been found, and exposed to very good advantage, at this very accessible locality in eastern Ontario.

Realizing the practical stratigraphic and structural significance of this discovery provided the incentive to look farther afield to determine whether or not similar contact relationships could be found within the Potsdam elsewhere around the margins of the Quebec Basin and Ottawa Embayment. Unconformable contacts at the same stratigraphic horizon were indeed found at many locations in Ontario and adjacent areas of New York State during the course of further investigations in both of these regions. At the same time, a number of additional findings were added to the geological database pertaining to the classification and petrogenesis of the Potsdam Group generally, chief among which are:

(i) the identification of several rock units within the Potsdam Group, some of which had not been previously recognized. These, for the most part have wide stratigraphic continuity that provide an element of consistency to regional correlation, and thus an improvement to the quality of surface and subsurface geological mapping throughout the study area;

(ii) the recognition of lateral and vertical facies changes that point to a variety of depositional and climatic conditions; e.g. aeolian, fluvial and possible lacustrine environments of terrestrial origin in initial phases of deposition; - followed, after a long hiatus, by the deposition of a sequence of marine deposits;

(iii) the identification of water expulsion cones, and vertical columnar structures and their very differing characteristics in terms of origin and development;

(iv) the gross petrographic comparison of rock units, as a possible tool in the reconstruction of depositional environments, and for purposes of regional correlation; and

(v) the identification and documentation of structural deformation (folds and faults) and their relationship to regional tectonics possibly triggered by events centered well beyond the margins of the present study area.

CHAPTER 2

REGIONAL GEOLOGICAL SETTING

The St. Lawrence Platform, as originally defined by Poole *et al.,* (1970) and Sanford (1993 a), is divisible into three major divisions bounded one from the other by south-trending basement arch systems; a Western Division embracing the Michigan and Appalachian basins; a Central Division comprising the Quebec Basin and its western extension the Ottawa Embayment; and an Eastern Division containing the Anticosti Basin.

The Central Division of the Platform, the object of the present study (Figure 2), is in turn divisible into two tectonic elements; (i) the Quebec Basin bounded on the west, north and east by the Oka-Beauharnois, Laurentian and Saguenay arches respectively, and on the south by the Appalachian Orogen; and (ii) the Ottawa Embayment – an appendage of the Quebec Basin, bounded on all four sides by Precambrian highs, namely the Frontenac, Laurentian and Oka-Beauharnois arches on the west, north and east respectively, and the Adirondack Dome on the south. Results of the present study suggest that most, if not all of the arch systems listed above, were structurally positive and active to varying degrees during deposition of the Potsdam Group. This was especially so during its initial (Covey Hill and equivalent Ausable formations) depositional phase. The Appalachian Orogen and Quebec Basin as shown in Figure 2, were of course non-existent as tectonic elements in the Neoproterozoic to Early Ordovician times – that area being the inner segment of a continental shelf lying marginal to a spreading seafloor at the time of Potsdam deposition (Williams *et al.*, 1995; Knight, *et al.*, 1995).

The thick wedge of sandstone and conglomerate that comprise the Potsdam Group was obviously derived directly from Precambrian terranes; partly from basement rocks upon which they lie, and from adjacent areas of the Adirondock Dome and Canadian Shield, the detritus transported into the region

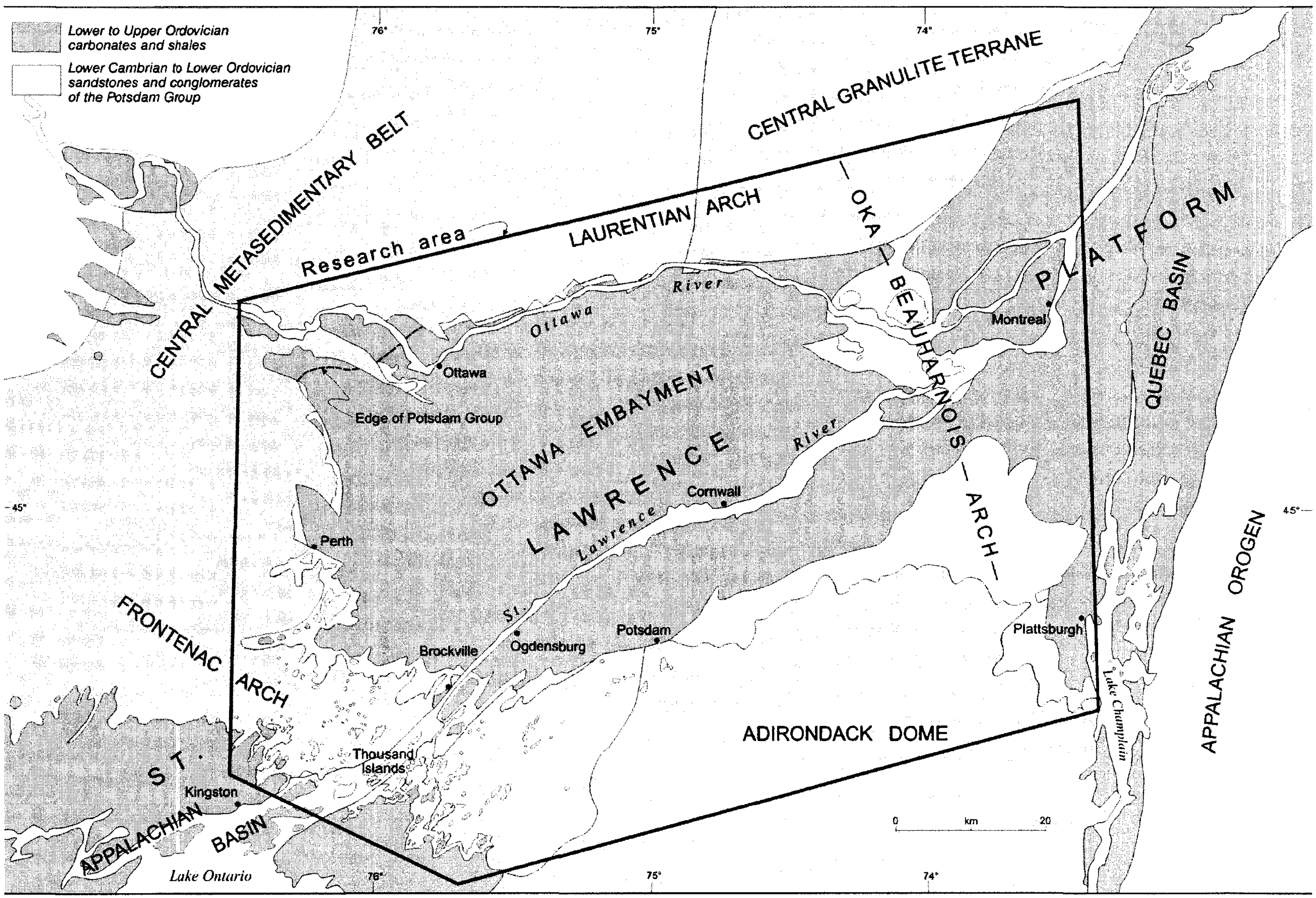


Figure 2 . Index map showing approximate boundaries of research area, and distribution of immediately adjacent geological provinces and tectonic elements.

by fluvial processes. The two principal Precambrian provenance areas for the Potsdam Group as shown in Figure 2, are the Eastern Granulite and Central Metasedimentary subprovinces of the Grenville Province (Baer *et al.*, 1977). The Central Granulite terrane is an igneous and metamorphic belt containing a preponderance of granite and granite-like basement rocks, bordering and underlying a large region of the Quebec Basin, and eastern segment of the Ottawa Embayment. The lower beds of the Potsdam Group in this particular region of the platform thus reflect a provenance consistent with those rocks containing an abundance of quartz and feldspar. The basement rocks of the Central Metasedimentary Belt, on the other hand, contain a variety of metamorphosed sedimentary rocks, chiefly quartzites, which provided the bulk of the detritus for the conglomeratic strata in the Potsdam Group throughout the western part of the Ottawa Embayment, especially in eastern Ontario.

The Potsdam Group, being the oldest of the Paleozoic sedimentary sequences in the Central Division of the platform, form the bedrock surface around the margins of the Quebec Basin and Ottawa Embayment, bordering the Precambrian highland areas (see Figure 3). The beds crop out at surface at numerous localities along the eastern edge of the Frontenac Arch in Ontario, from the vicinity of Ottawa and Gatineau to the St. Lawrence River and beyond into New York State, from whence they continue eastward along the northern margins of the Adirondack Mountains to the vicinity of Lake Champlain. From the northeast extremity of the Adirondacks, the beds form an almost continuous outcrop belt trending north, paralleling the axis of the Oka-Beauharnois Arch. Potsdam strata are locally present at surface along the northern margin of the Ottawa Embayment and Quebec Basin, but for the most part are obscured beneath down-faulted Paleozoic strata bordering the Laurentian Arch. Remnants of Potsdam strata occur sporadically along the axis of the Frontenac Arch, north of the St. Lawrence River in eastern Ontario. They also occur as outliers immediately to the southwest of the arch in the southcentral region of the province. South of the St. Lawrence River in New York, the beds form an almost continuous cover across the southeastern extremity of the Frontenac Arch between the Ottawa Embayment, and the Western Division of the St. Lawrence Platform (Appalachian Basin) to the west. From their exposed edges around the margins of the Ottawa Embayment, Potsdam strata dip basinward into subsurface beneath younger rocks of Ordovician age where they lie on the Precambrian at an elevation of one kilometre below sea-level in the vicinity of Russell, Ontario (Sanford, 1993 b). In the Quebec Basin, Potsdam strata dip generally southward, also beneath Ordovician rocks, where their contact with the Precambrian lies at an elevation in excess of 3 kilometres below sea-level near the Appalachian Structural Front (Sanford, ibid.).

The Potsdam Group and succeeding Ordovician strata contained within the Quebec Basin and Ottawa Embayment are readily divisible into six stratigraphic sequences each bounded by regional unconformities. Sequences I, II and the lower part of Sequence III are represented by the Potsdam Group. Sequence I of assumed Neoproterozoic age, herein newly defined and named Abbey Dawn Formation consists of quartz cobble conglomerate locally exposed along the eastern and western margins of the Frontenac Arch in eastern Ontario; Sequence II, the Covey Hill and equivalent Ausable formations of probable Neoproterozoic to early Early Cambrian age, composed of quartzarenite, quartzite cobble and quartz pebble conglomerate of wide distribution throughout eastern Ontario, western Quebec and northern New York State; and Sequence III, the Nepean and equivalent Cairnside and Keeseville formations of Late Cambrian to early Early Ordovician age, composed of quartzarenite, that give place to carbonate with interbeds of sandstone of the March and equivalent Theresa formations, followed by dolostone of the Oxford and equivalent Beauharnois and Ogdensburg formations, all of Early Ordovician age, in that respective order of succession.

The carbonate beds of Sequence III, and the carbonates, shales and minor sandstones of Sequences IV, V and VI are beyond the scope of the present study. The formations that are included in these sequences are shown on the geological map (see Figure 3), and cross-sections (see Figure 9) however, to enable the reader to obtain a better understanding of the stratigraphic and structural relationships of the Potsdam Group with the remainder of the Ordovician succession throughout the Central Division of the St. Lawrence Platform.

The above identified sequences are intersected by numerous faults, not all of which are shown on the accompanying geological map (Figure 3). Many are most likely very old fracture systems that formed in the Late Proterozoic and were reactivated by the succession of epeirogenic movements associated with plate tectonic events in the Neoproterozoic rifting phase of continental separation (Williams, *et. al.*, 1995), and during the succeeding Taconian and Acadian orogenies in early Middle to Late Ordovician, and upper Middle and Late Devonian times, respectively (Knight, *et al.*, 1995).

CHAPTER 3

SUMMARY OF PREVIOUS INVESTIGATIONS

Geological investigations in eastern North America began on a large scale with the founding of the New York Geological and Natural History Survey in 1836. Its' principal objective at the time was to establish a comprehensive stratigraphic framework for the Paleozoic and Mesozoic sequences that would serve as a standard for the state, as well as elsewhere on an international scale. The New York classification was not universally accepted however, but it did find immediate favor in its' home state of New York, and in adjacent areas of eastern Canada, where many of the terms are still applicable and in common use today.

"Potsdam Sandstone" was one of the early names erected by the New York Geological and Natural History Survey, a term proposed by Ebenezer Emmons in 1838. Its original definition was confined mainly to a redbed sequence of sandstone located at Hannawa Falls in the general vicinity of the city of Potsdam, New York. The redbeds as originally described form merely the basal strata of the Potsdam as it is known today. Shortly thereafter, Emmons (1841) recognized a rock stratigraphic sequence higher in the section in the Lake Champlain area of the state, to which he applied the term "Keeseville Sandstone".

With the founding of the Geological Survey of Canada in 1842, a program for the systematic mapping of Canada was begun. William Logan, the Survey's founder and first director leaned very heavily on the stratigraphic classification established earlier by the New York Geological and Natural History Survey. One of the terms borrowed by Logan was Potsdam Sandstone for rocks of similar age and lithological composition for inclusion on his early published geological maps of immediately adjacent areas in the southern parts of Ontario and Quebec, and for inclusion in his monumental "*Report on the Geology of Canada*" published in 1863.

Following the very early investigations described above, there elapsed a fair interval of time through the latter half of the 19th century, and early 20th century, during which geological investigations within the study area were substantially curtailed; although useful contributions were made from time to time by workers on both sides of the international boundary. This was especially so in New York State, where significant efforts were made by a number of workers to piece together the stratigraphic framework of the Potsdam Sandstone. Some of the more noteworthy of these were the investigations of Cushing (1901; 1908); Van Ingen (1902); Chadwick (1915; 1920), and Alling (1919).

An important step forward in redefining the upper and lower boundaries of the Potsdam was made by Cushing in 1901, by excluding the uppermost interbedded sandstone and dolostone, known as "Passage Beds", a subunit that was long considered a part of the Potsdam by previous workers. In 1908, Cushing proposed the name Theresa Formation for the same beds and that term subsequently gained wide acceptance in New York State.

In 1902, Van Ingen documented a three-fold subdivision of the Potsdam in the Lake Champlain region, that included (i) a lower member of unfossiliferous red and brown sandstone with feldspar clasts; (ii) a middle member of white and yellow sandstone with Climactichnites; and (iii) an upper member of interbedded sandstone and dolomite. The lower member is herein assumed to be the equivalent of Emmons' (1838) basal Potsdam Sandstone (redbeds) of the Hannawa Falls area, and possibly including older redbed shale and siltstone, known to be present in the Plattsburgh area. The middle member would have included Emmons' (1841) Keeseville Sandstone, along with a thick and much older succession of grey sandstone and arkosic conglomerate that are now known to lie unconformably below the Keeseville, herein identified as Chippewa Bay Member of the Ausable Formation. One can readily recognize Van Ingen's upper member in today's terminology as the Theresa Formation.

In 1915, Chadwick established a classification for the Potsdam much like that of Emmons' (1838, 1841) and Van Ingen (1902) reports, embracing the typical red Potsdam Sandstone and Keeseville Sandstone. Perhaps Chadwick's (1920) most significant contribution was the "suggestion" of a possible disconformity between the two units, an interpretation also supported by this writer. However, this disconformity, near the base of the Potsdam, (between the Hannawa Falls and Chippewa Bay members as defined herein) should not be confused with the major unconformity found by the writer much higher in the section, e.g. between the newly defined Ausable and Keeseville formations and equivalent units in Ontario and Quebec as is described elsewhere in this dissertation (see Figure 4).

Perhaps the most significant achievement, since the time of Emmons (1838, 1841) in the construction of a stratigraphic framework for the Potsdam Sandstone, was the introduction of the term "Ausable Member" by Alling in 1919, for the red and grey feldspathic sandstone and pebble conglomerate exposed along the northern margin of the Adirondack Mountains, although its upper and lower boundaries were not well defined.

During the latter half of the 20th century, important contributions to the geology of New York State were made by Fisher 1956, 1962, 1968, 1977 and Fisher *et al.,* (1970), and Rickard (1973). This was particularly so in terms of surface and subsurface mapping, and the establishment of regional correlations and biostratigraphical dating of Cambrian and Ordovician rock units over a wide region of New York State. The identification of an Early Cambrian age for the Ausable Member in the Lake Champlain area of New York State by Fisher (1977) was an important contribution to the geological history of the Potsdam Sandstone in that general region of the state.

Fisher's (1968) stratigraphic studies and mapping of the Plattsburgh – Rouses Point area was a most useful contribution to anyone contemplating field investigations in that region, and elsewhere in New York State, and on the Canadian side of the International boundary. Fisher's (ibid.) division of the Potsdam Formation into Ausable and Keeseville members in accordance with

Alling (1919) and others, should have set the stage for applying that or a similar classification on a systematic basis elsewhere in New York state, but for some unknown reason, it did not.

A number of authors have referred to "upper" and "lower" Potsdam Formation, on an informal basis for sections located here and there along the northern margins of the Adirondack Mountains (e.g. Selleck, 1993), although no one so far as is known, has made note of the presence of the unconformity herein defined that occurs within the Potsdam at many localities in New York State. Thus, the most common practice in that region throughout the years, and still today, is to simply apply the term Potsdam Formation to the undivided stratigraphic succession of sandstone and conglomerate, that lie on the Precambrian, and is succeeded by interbedded dolostone and sandstone of the Theresa Formation.

In Canada, major contributions to the Paleozoic stratigraphy were made during the early and middle years of the 20th century by T.H. Clark, and A.E. Wilson in Quebec and Ontario, respectively. In 1938, T.H. Clark began a comprehensive program of geological mapping of the Quebec Lowlands for the Quebec Department of Mines that continued for more than thirty years. The term Potsdam Sandstone, as originally applied to the basal sandstone in southern Quebec by William Logan, was continued by Clark (1952), the name of which was eventually elevated to Potsdam Group (1966, 1972) and included two major rock units, the Covey Hill and Chateauguay formations in that stratigraphic order of succession. The Chateauguay of Clark, was in turn, divided into Cairnside and Ruisseau Norton members, equivalent to the Nepean and March formations in adjacent regions of Ontario. This classification was revised and greatly improved upon by Globensky (1987) who retained the term Potsdam Group, but restricted its upper limit to include only the Cairnside, raising the latter to formation status. Globinsky (ibid.), in turn, dispensed with the term Ruisseau Norton Member and replaced it with Theresa Formation. It is of interest to note that this change to the definition of the Potsdam was identical to that adopted by Cushing (1901) some 86 years earlier in the state of New York.

Neither Clark nor Globinsky reported a Covey Hill – Cairnside contact anywhere in the field, although the former author provided stratigraphic and structural reasons as to why he believed the two units are bounded by an unconformity.

In Ontario, for a great many years, Alice Wilson (1937, 1946) was the leading authority on matters pertaining to Ordovician stratigraphy, in eastern Ontario. Her original definition of Nepean Formation was long accepted by subsequent workers in the region who failed to recognize the presence of beds (Covey Hill Formation) stratigraphically beneath the Nepean, to the south and east of the type locality.

During more recent research in the Ottawa – St. Lawrence Lowland area, Williams and Wolf (1982, 1984 b) of the Ontario Geological Survey noted the local presence of beds of similar lithological character to the Covey Hill Formation of western Quebec. On the basis of this finding, the same authors reintroduced the term Potsdam Group to embrace the two map units Covey Hill Formation, and a redefined Nepean Formation – a classification presumably compatible to that erected earlier in Quebec by Clark (1966, 1972).

Geological mapping of the Paleozoic terrain in the Kingston area of Ontario was carried out by Baker (1916), during which he identified many sandstone outliers resting directly on the Precambrian which were identified as "Potsdam series". Although the sandstone bodies were mapped as a single unit, it is apparent from his excellent descriptions that two very different rock units are present in the region.

Much later, Liberty (1971), examined parts of the same area mapped by Baker, as well as much of the region to the eastward across the higher structural segments of the Frontenac Arch. He too, established the presence of a large number of sandstone outliers, which were identified as a single unit, Potsdam Formation.

Most of the systematic geological mapping to date in New York State, eastern Ontario and western Quebec was carried out by government agencies, such as the New York State Geological Survey, Geological Survey of Canada, Ontario Geological Survey, and Quebec Department of Mines, now known as Gouvernement du Québec Ministére de l'Energie et des Ressources. In addition, many important investigations relating specifically to the Potsdam Sandstone have been carried out by university faculty members, and by graduate and undergraduate students from time to time, to satisfy partial requirements of Ph.D. M.Sc. or Bachelors level degrees at the various universities scattered throughout the region. The results of some of these have been published in geological journals, although most were never formally released to the public, but can be found for reference purposes in the libraries of the respective universities, and many are contained on microfiche at the library of the Geological Survey of Canada in Ottawa.

Worthy of special mention in the above regard, are the results of research conducted by Lewis (1963), contained in a Ph.D. thesis entitled "*A Paleocurrent Study of the Potsdam Sandstone of New York, Quebec and Ontario.*" This, to the best of the writer's knowledge, is the only research project conducted to date, devoted to such a wide regional area. There are a number of other unpublished theses however, that also contain important information relating to the stratigraphy, sedimentology and petrology of the Potsdam for various restricted regions, including the following: Dobie (2004), Findlay (1968), Jackson (1955), Forsyth (1968), Lewis (1965), Macey (1970), Roliff (1968), Sahakian (1963), Selleck (1975), Sitter (1960) and Waterfall (1968).

In addition to the above, there is a large number of special topic papers, maps and reports relating to the Potsdam Sandstone, that were published by government agencies, research institutions and geological journals that contain a multitude of data such as: Belyea (1952), Bouche *et al.,* (1975), Brand and Rust (1977), Carson (1982), Dix *et al.,* (2004), Donaldson and Munro (2002), Hilowle *et al.,* (2000), Goldring (1931), Grady (2002), Grier (1993), Greggs and Bond (1972), Kirwan (1963), Logan (1851, 1852), MacNaughton *et al.,* (2002), Otvos (1966), Owen (1852), Sanford (1993 a), (1993 b), Sanford and Quillian (1959), Selleck (1978), Wiesut (1961), Wiesut and Clark (1966), Wilson (1956), and Wolf and Dalrymple (1984).

Much useful information pertaining to the Potsdam Group is also to be found in guidebooks that have been prepared for field trips in various segments of the present study area, such as contained in the following abbreviated list: Baird (1972), Clark (1969), Dalrymple and Wolf (1988), Donaldson and Chiarenzelli (2004), Erickson (1993), Erickson and Bjerstedt (1993), Erickson and Fetterman (1993), Hofmann (1972), Liberty (1967), Selleck (1978, 1993), Williams *et al.,* (1992) and Winder and Sanford (1972).

CHAPTER 4

PRESENT INVESTIGATIONS

The field work for the current project began with reconnaissance surveys of the Potsdam Group along the outcrop belt that borders the Precambrian highlands around the margins of the Ottawa Embayment, and in the western part of the Quebec Basin (see Figure 2). The purpose of these initial investigations was to select an area where the Potsdam was best exposed, from which to construct a detailed stratigraphic framework that might serve as a standard for the entire study area.

Very early in the investigation it became apparent that the most complete sections were to be found along the northwest margin of the Adirondack Dome in New York State, where the Potsdam beds cross the southeastern extension of the Frontenac Arch. In Ontario, good sections are exposed along the eastern margin of the Frontenac Arch between Perth and Brockville, and in the Kingston area to the southwest of the arch, bordering the Appalachian Basin. In New York, many of the outcrops can be found along the major highways, such as routes 12, 37, 26 and the many side roads that interconnect with these systems. In Ontario, some of the better sections are in roadcuts on highways 2, 15 and 42, and secondary roads that interconnect the many towns and villages throughout this area.

More than 190 sections were examined in the western region of the study area, which enabled the writer to subdivide the Potsdam into two principal stratigraphic units, the Covey Hill and equivalent Ausable formations, and Nepean and equivalent Keeseville formations [see Figure 6, and Appendix (ii)]. In a few isolated localities on the Ontario side of the St. Lawrence River, a third unit herein thought to be substantially older than Covey Hill was identified and given the name Abbey Dawn Formation (see Figure 4).

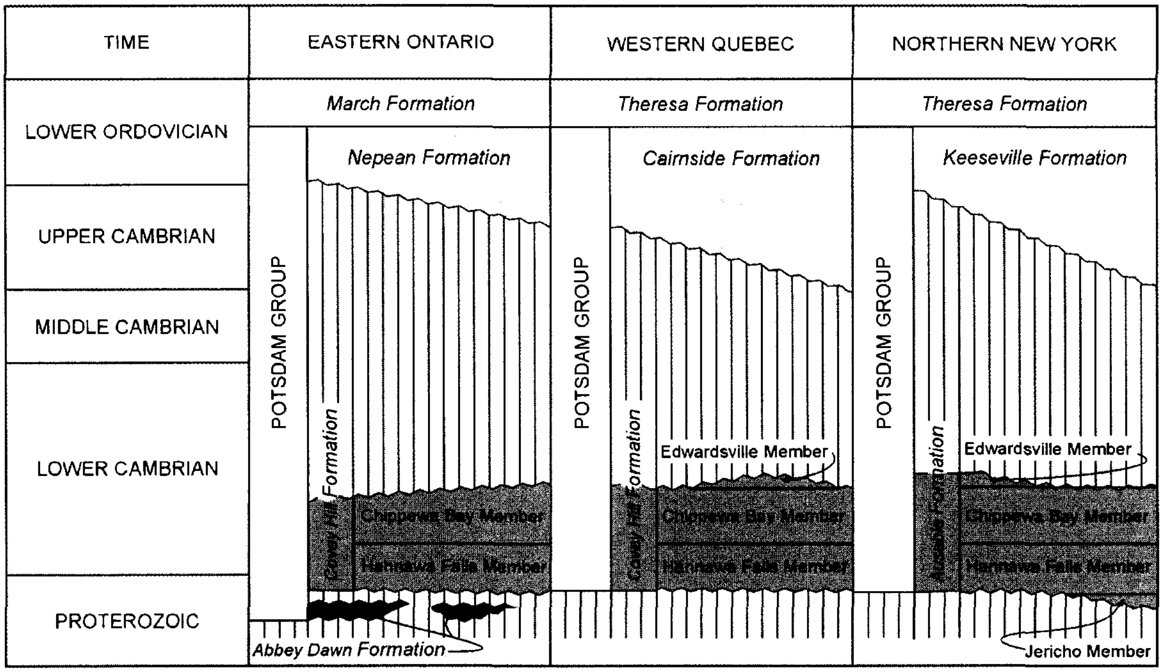


Figure 4. The Potsdam stratigraphic succession in eastern Ontario, western Quebec, and northern New York State.

An additional finding of substantial importance during the early part of the study was the realization that the Covey Hill and equivalent Ausable formations could be further divided into three sub-units, and these are herein named Hannawa Falls, Chippewa Bay and Edwardsville members, in that respective stratigraphic order of succession. The type section for each of these is in New York State, all within a few kilometres of the Thousand Islands region of the St. Lawrence River.

The highly generalized composite stratigraphic framework of the Potsdam Group as pieced together in the western part of the study area is shown in Figure 5. Shown in the same diagram are a succession of vertical bars, illustrating the approximate stratigraphic range of the key sections examined in the field, many of which are photographically illustrated on the pages to follow. In addition to the key sections illustrated in Figure 5, is a complete listing in Appendix (ii) of all of the outcrop sections examined in the field, along with their UTM locations, and the identification of the principal rock units that are exposed at any given field station. The numbered field stations are in turn shown on Figure 6, entitled

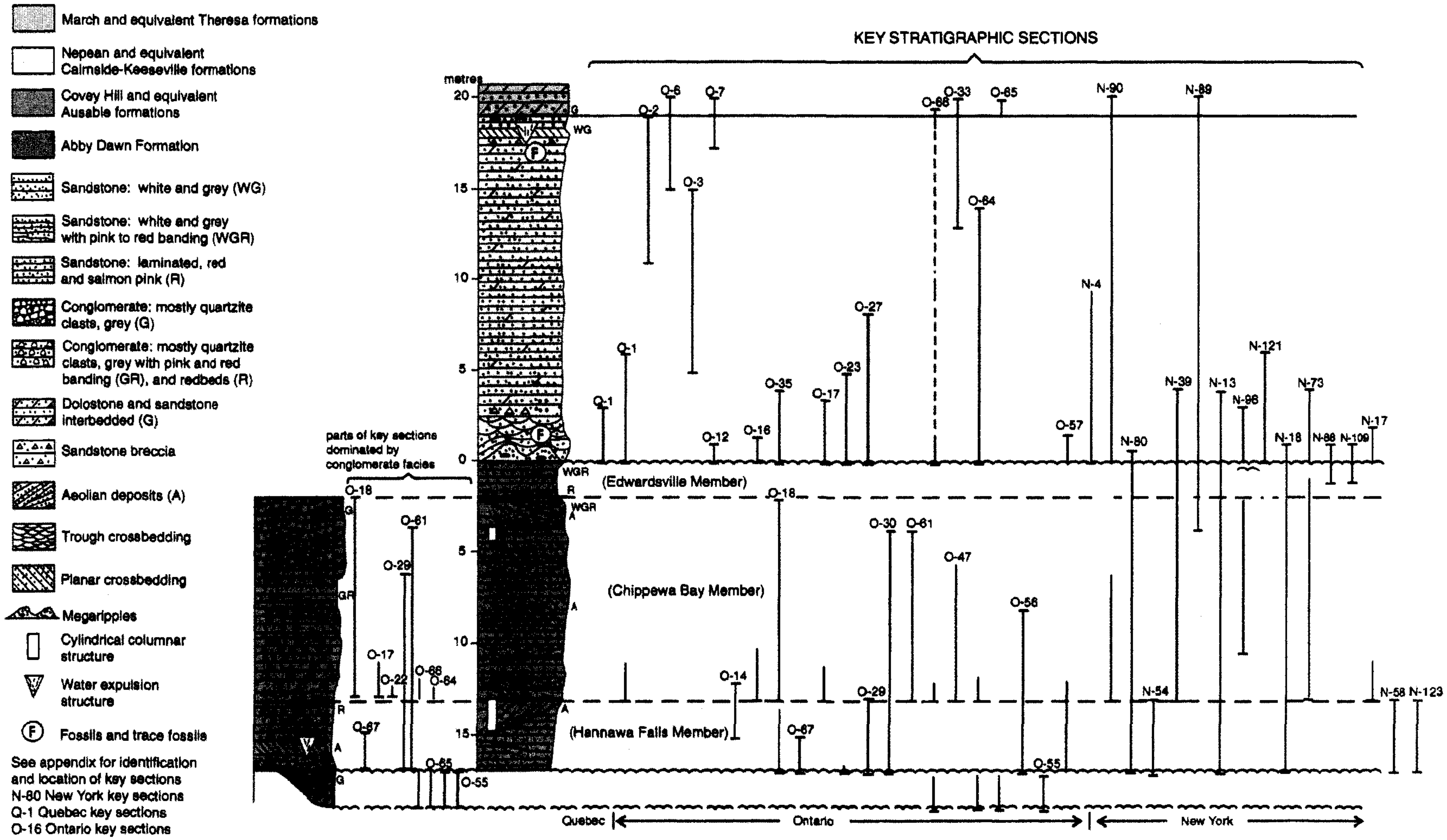


Figure 5. Generalized Potsdam Group succession and vertical stratigraphic range of key sections in the western part of the Ottawa Embayment and adjacent Frontenac Arch.

"Isopachous map showing distribution and thickness of the Potsdam Group, and the location of sections where the rocks are best exposed in eastern Ontario, western Quebec and northern New York State". Because of the high density of stratigraphic control encountered in this area of New York State, field mapping was initially detailed at 1:24,000 scale, and later reduced to 1:250,000 scale (see Figure 3), compatible to the mapping and compilation carried out elsewhere within the study area.

In the eastern sector of the Ottawa Embayment and western part of the Quebec Basin, the Potsdam Group is about 20 times thicker than in the western part of the study area. Outcrops are widely separated and poorly exposed, but, nevertheless more than 110 exposures were located. Only a few of these are considered to be important for piecing together the stratigraphic framework of this eastern region (see Figure 7).

In Quebec, sections were examined on Île Perrôt, and at Saint-Jean Chrysostome, Saint-Pierre (originally known as Cairnside), Havelock, Bridgetown and Covey Hill where a fair level of stratigraphic control had been reported earlier by Clark (1966) and Globensky (1987). Undoubtedly, the more complete sections observed by the writer were located on Île Perrôt, and the hillside that rises steeply in elevation (250m) above the village of Covey Hill, and reaches its summit in the vicinity of the Canada-United States International boundary. In the immediately adjacent areas of New York State, stratigraphic data were gleaned primarily from key sections located in the Chateaugay River Gorge and roadcuts on autoroutes 87, 22, 9, 11, 190 and the many sideroads and stream systems that intersect the region.

In piecing together a stratigraphic framework for the eastern sector of the Ottawa Embayment (see Figure 7), the writer drew heavily on what had been previously observed during the examination of sections in the Thousand Island region of New York and Ontario. Very important in this regard was the recognition of the Covey Hill and equivalent Ausable sub-units – Hannawa Falls, Chippewa Bay and Edwardsville members in this eastern region of the study area. Providing an additional level of stratigraphic control in this extreme northeastern sector of the Potsdam outcrop belt is the presence of what may be a thin deltaic marine facies of maroon, brick red and pink sandstone and conglomerate, siltstone and shale, with interbeds of dolomitic limestone and dolostone, that were named Jericho Member by J. L. Wallach Geosciences Inc. and MIR Teledetection Inc. (2004). These beds rest directly on the Precambrian and are succeeded by the Hannawa Falls, both members of which are herein included in the Ausable Formation.

Palocurrent direction studies of the Potsdam Group are based mainly on crossbed measurements from 13 localities in widely separated parts of the study area. The principal purpose of this endeavour was to determine the paleocurrent directions in the Covey Hill and the much younger Nepean Formation in Ontario, and their equivalents in Quebec and New York State. The locations where measurements were taken were too few to establish a basin-wide flow pattern, but the information retrieved should prove useful as applied to any future paleocurrent analysis of the Potsdam Group.

The principal rock units of the Potsdam Group were also sampled at selected localities for the preparation of thin-sections which have provided useful petrographic information that aid in the reconstruction of depositional environments, and processes of diagenesis. Such information also provides a potential tool for local and regional correlation of rock units.

In addition to field investigations, the writer compiled and examined all readily available borehole subsurface data, diamond drill cores, well history reports, etc., for the preparation of the geological map (see Figure 3), cross-sections (see Figure 9), Potsdam isopach map (see Figure 6), and subsurface stratigraphic sections (see Figure 8).

During the course of present investigations, the writer also perused much of the published and unpublished data relating to the Potsdam Group, and younger Ordovician rocks of eastern Ontario, western Quebec and northern New York State. Some of these data were most helpful in the construction of a geological map (see Figure 3), of the region, albeit with substantial modifications of previous mapping of the Potsdam Group, and certain other parts of the

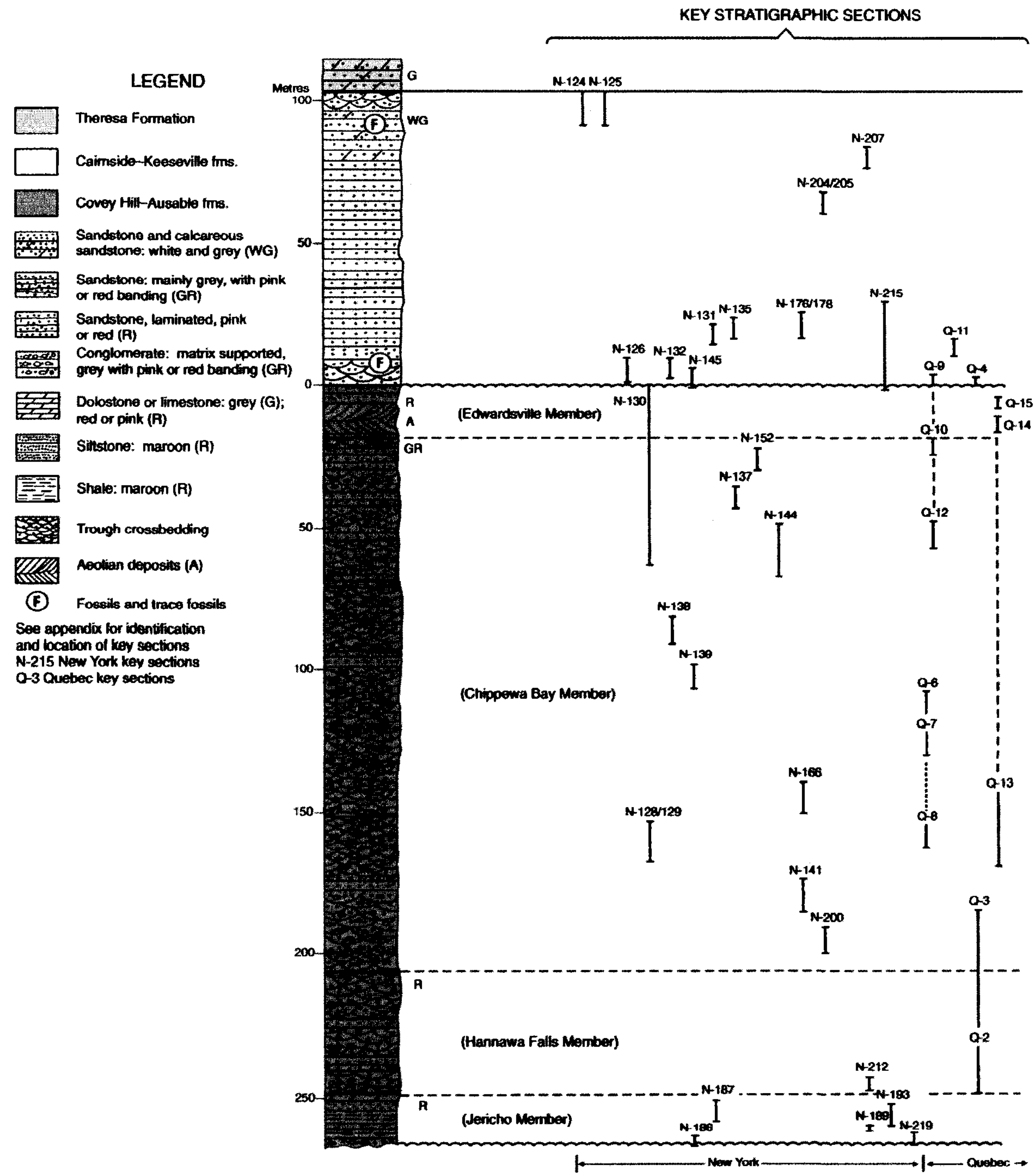


Figure 7. Generalized Potsdam Group succession and vertical stratigraphic range of key sections in the eastern part of the Ottawa Embayment and adjacent margin of the Quebec Basin.

succession, particularly in Ontario and New York State. Most of the remaining contents of the dissertation however, are based on the writer's current geological research conducted in the field, from firsthand observations and interpretation of the many stratigraphic sections that are exposed throughout the study area – as listed in the Appendix herein.

CHAPTER 5

STRATIGRAPHIC FRAMEWORK

POTSDAM GROUP

Definition and Thickness

The Potsdam Group as defined herein, comprises a thick succession of sandstone and conglomerate that directly overlie Precambrian basement rocks throughout the Quebec Basin and Ottawa Embayment (<u>see</u> Figure 3). They, in turn, are succeeded by interbedded dolostone and sandstone of the Theresa Formation in New York State and Quebec, and by the equivalent March Formation in eastern Ontario.

The basal contact of the Potsdam Group with the Precambrian was found at 11 locations, all within the western part of the study area as listed in the following table.

Locality *	Station	Beds lying on PreC
Lac Beauchamp, Que.	Q-1	Cairnside
Highway 15, Elgin, Ont.	O-23	Covey Hill
Abbey Dawn Road, Ont.	O-55	Abbey Dawn
Highway 2, Gananoque, Ont.	O-51	Nepean
Highway 401, Butternut Bay, Ont.	O-65	Abbey Dawn
Highway 15, Jones Falls, Ont.	O-27	Covey Hill/Nepean

Lynhurst, Ont.	O-43	Covey Hill
Sloan Quarry, near Sunbury, Ont.	O-57	Covey Hill
Route 12, Goose Bay, N.Y.	N-54	Ausable
Route 12, Alexandria Bay, N.Y.	N-13	Ausable
Theresa, N.Y.	N-18	Ausable

*Precise UTM locations recorded in Appendix.

Table 1: Potsdam Group – Precambrian contact, eastern Ontario and northern New York State.

In addition to the above, there are many localities in Ontario and New York where the Potsdam – Precambrian contact is obscured by only a few centimeters of Quaternary sediments.

The Potsdam contact with the succeeding Theresa Formation in New York State and Quebec, and with the equivalent March Formation in eastern Ontario, is mostly conformable but everywhere abrupt. Some of the best exposures of this contact are located as follows: (i) on a sideroad immediately west of Almonte, Ontario, at station O-9; (ii) Highway 416, Ottawa, Ontario, at station O-6; (iii) Hawthorne Road, Ottawa, at station O-7; (iv) Highway 15 near Elgin at station O-24; (v) Highway 42, near Philipsville at station O-33; and (vi) Route 12, near Blind Bay, New York where the contact is exposed at two locations in close proximity to one another, at stations N-89 and N-90 (see Figure 6).

For the purpose of this dissertation, the status of the term Potsdam Formation, as it is presently known in New York, is raised to Potsdam Group, to be consistent with the definition of its equivalents in adjacent areas of Ontario and Quebec (see Figure 4).

The terms Ausable and Keeseville members of the Potsdam long ago introduced into the literature by Emmons, 1841, Alling, 1919, and more recently by Fisher, 1968, for the Plattsburgh Rouses Point area of northeastern New York State are retained, but redefined as formations. During the course of the present investigation, the writer has applied the above terminology to similar rock units where these are exposed along the northern margins of the Adirondack Mountains, extending from Lake Champlain to the Thousand Islands region of the state (see figures 2 and 3). In the process, the stratigraphic boundaries of the Ausable and Keeseville formations are standardized so as to be consistent with the Covey Hill and Cairnside formations in Quebec, and the equivalent Covey Hill and Nepean formations in eastern Ontario (see Figure 4).

To further fulfill the requirements of the present study, the Potsdam is enlarged to encompass a relatively thin unit of quartzite cobble and boulder conglomerate, herein newly defined and named Abbey Dawn Formation. These beds form a basal unit of the Potsdam Group, and thus everywhere rest unconformably on Precambrian crystalline rocks, where they are preserved at four isolated localities in eastern Ontario. They are then unconformably overlain with rocks of different ages, ranging from Cambrian to late Middle Ordovician.

The Potsdam Group where mapped at surface and in subsurface (see figures 3, 6, 8 and 9), is a wedge-shaped body of sandstone and conglomerate whose thickness varies from 20 metres along the eastern margin of the Frontenac Arch, to about 700 metres at the eastern extremity of the Ottawa Embayment. Bordering the Oka-Beauharnois Arch to the east, the Potsdam exceeds 500 metres thick, from whence it thins to 360 metres or less, as the beds are traced into the deeper segments of the Quebec Basin (see Figure 6).

The isopach map of the Potsdam Group shown in Figure 6, and those illustrating the thickness of the Covey Hill and Nepean formations, and their equivalents (see figures 12 and 62), can only be considered approximate in terms of accuracy. This is due mainly to the relatively few deep boreholes that have been completed to date throughout the region. The procedure otherwise taken in the construction of the isopach maps was essentially as follows: (i) to obtain rough estimates of the thicknesses of the Potsdam Group and formations, along the basin margins, by the examination of the some 300 sections at the locations shown in Figure 6; (ii) to obtain thicknesses of the same units from the 14 boreholes that in one place or another penetrated the Potsdam Group in subsurface (see Figure 8); and finally (iii) the construction of five regional intersecting sections across the basin (see Figure 9), calibrated by the surface and subsurface information obtained from sources (i) and (ii) above; the cross-sections ultimately providing the point-by-point data sets along the lines of sections, used to construct the isopachous diagrams.

The detailed classification of the Potsdam Group in the three principal geographical regions of the study area is shown in Figure 4. The unconformable contact between the Covey Hill and Nepean formations and their equivalents, represents a major break in deposition that was found by the writer at 21 specific locations in the field. Nine of these are in Ontario, mostly along the eastern margin of the Frontenac Arch, and the remaining 12, in immediately adjacent areas of New York, in the general vicinity of the Thousand Islands region. Most of the contacts are abrupt, although structurally concordant, but several are marked by a profound angular unconformity between the two units (see Table 2).

At many locations, particularly on the Ontario side of the St. Lawrence River along the axis and bordering the Frontenac Arch, much, if not all of the upper Covey Hill Formation was removed by erosion prior to deposition of the Nepean Formation. This is further confirmation that the hiatus between the two formations was of long duration, as implied in Figure 4.

Inconsistency in the use of stratigraphic nomenclature in New York, Ontario and Quebec as it applies to the Potsdam Group has long been a major detriment in sorting out the stratigraphic framework from one jurisdiction to another, and without such basic information as stratigraphic control, regional sedimentological and structural studies are of limited value. It is partly for this reason, along with the need for a basin analysis of the Ottawa Embayment in general, that the writer embarked on the present investigation.

The following section describes the succession of rock units that comprise the Potsdam Group, which includes: (i) the Abbey Dawn Formation; (ii) Covey Hill and equivalent Ausable formations and their contained subunits: Jericho, Hannawa Falls, Chippewa Bay and Edwardsville members; and (iii) Nepean and equivalent Cairnside and Keeseville formations, in that respective order of succession.

The formal introduction of the new terms *Abbey Dawn Formation*, *Jericho*, *Hannawa Falls*, *Chippewa Bay*, *Edwardsville members*, along with the redefinition of *Potsdam Group*, *Ausable* and *Keesville formations*, are contained in Sanford (in press), and thus applied in a formal sense in the present dissertation.

ABBEY DAWN FORMATION

Definition

The term Abbey Dawn Formation is herein proposed for conglomerate that forms a basal unit of the Potsdam Group, exposed locally on opposite margins of the Frontenac Arch, at four principal localities in eastern Ontario. On the west side of the arch the beds are exposed at a single station [see Figure 10 (a) and (b)] herein defined as the type locality. Here they lie directly on highly deformed Precambrian quartzites of the Grenville Province (Central Metasedimentary Belt), and are unconformably succeeded by limestone of late Middle Ordovician age.

On the eastern margin of the Frontenac Arch, similar, if not identical conglomerate facies crop out at three locations, either resting on or in close proximity to Precambrian quartzite and granite. Because the Abbey Dawn Formation was deposited at differing levels of elevation on a highly irregular basement surface, it is succeeded regionally by Paleozoic rocks of differing stratigraphic levels that range in age from probable Early Cambrian (Covey Hill Formation) through Early Ordovician (March Formation) to late Middle Ordovician (Gull River Formation). Because of the general overall appearance of the formation, in terms of lithology, weathering characteristics, and sharp angular unconformity with younger formations as referred to above, strata of the Abbey Dawn Formation are assumed to be substantially older than any of the succeeding Potsdam units of the Covey Hill or Nepean formations.

The type section of the formation is located approximately eight kilometres due east of Kingston, Ontario, at station O-55 in a roadcut on Abbey Dawn Road, one half kilometre north of where it intersects Highway 2 (see figures 3, 6 and 10).

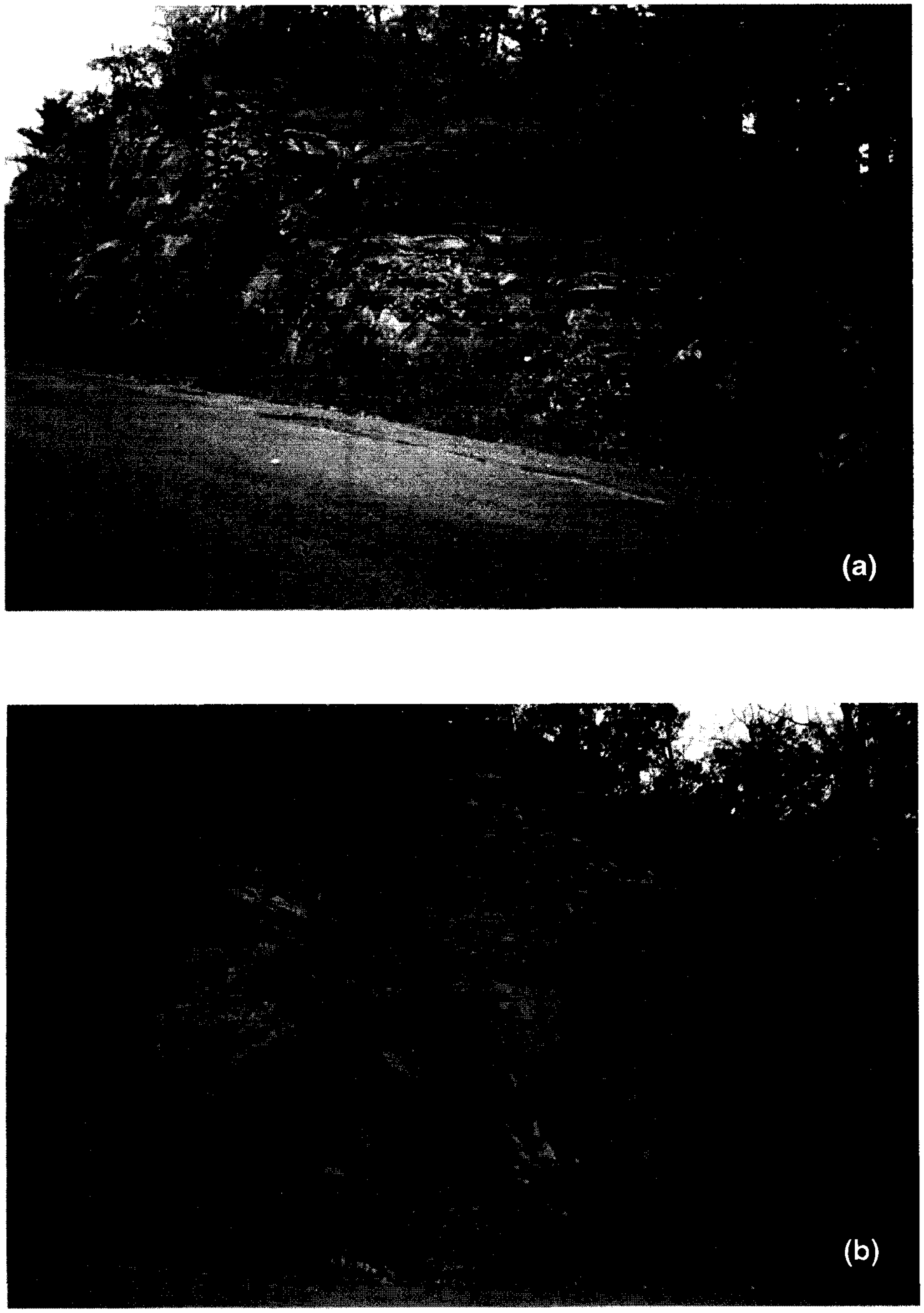


Figure 10: Late Proterozoic (?) Abbey Dawn Formation in roadcut on Abbey Dawn Road, north of Highway 2, Ontario at station O-55. (a) Quartzite cobble and boulder conglomerate dipping south off Precambrian quartzite ridge, unconformably overlapped by late Middle Ordovician Gull River limestone. (b) Close-up view of quartzite cobble and boulder conglomerate.

Distribution and Thickness

The exposed surface distribution of the Abbey Dawn Formation, is limited to four isolated geographical localities as follows: (i) the type locality as defined above (station O-55), where the deposits, up to two metres thick blanket the south side of a very steeply sloping Precambrian ridge; (ii) Lyn Valley Conservation Area (station O-64), located at the eastern edge of the village of Lyn, six kilometers due west of the city of Brockville, Ontario, where 1.8 metres of section are exposed; (see Figure 28); (iii) roadcut, five kilometers southeast of the village of Athens, Ontario (station O-66) where 5.3 metres of conglomerate are exposed and tilted northward; and (iv) roadcut on both east and west lanes of Highway 401 (station O-65) near Butternut Bay, Ontario, where the conglomerate is 3.7 metres in thickness (see Figure 11).

There are undoubtedly many other occurrences of Abbey Dawn conglomerate present here and there that are either obscured beneath Quaternary deposits, or younger Paleozoic rocks in subsurface regions of the Ottawa Embayment and Quebec Basin. If so, their most likely distribution would be along the margins of the Frontenac, Laurentian and Oka-Beauharnois arches or Adirondack Dome, where tectonic movements were probably the most intensive during the closing phase of the Proterozoic period. In fact, the coarse cobble and boulder conglomerate and breccia that locally occur at the base of the Potsdam Group in the Canton, Hannawa Falls, Allens Falls and Nicholville areas of New York State, as described and illustrated by Reed (1934), Chadwick (1920), Postel *et al.,* (1959) and Krynine (1948), appear to be identical to the Abbey Dawn Formation of eastern Ontario.

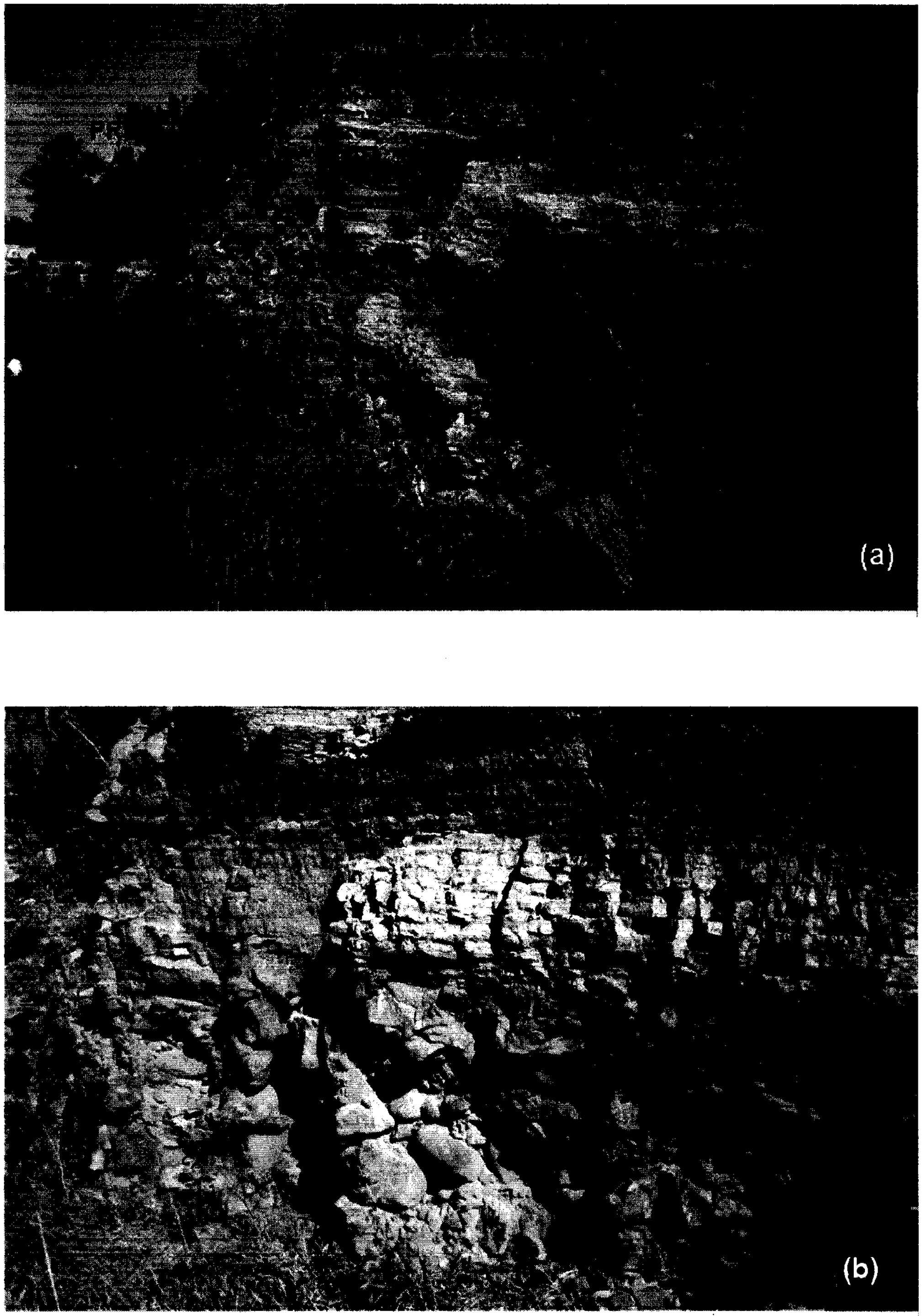


Figure 11: Abbey Dawn Formation in roadcut on Highway 401, Ontario, at station O-65. (a) Quartzite cobble and boulder conglomerate lying on Precambrian granite gneiss, and unconformably succeeded by dolostones and sandstones of the March Formation. (b) Close-up view of cobble and boulder conglomerate.

Lithology and Stratigraphic Relationships

The Abbey Dawn Formation is remarkably similar from place to place with regard to lithological composition, weathering characteristics and general lack of bedding. For the most part, the formation consists of poorly-sorted cobble and boulder conglomerate, comprised mainly > 98% of grey and blue grey quartzite clasts that vary from angular to subrounded. Few granite clasts were observed at any of the exposures despite the widespread distribution of granite throughout the region, and the fact that at two localities (stations O-65 and O-66) the Abbey Dawn overlies directly basement rocks composed of granite gneiss.

Despite the similarities of lithological composition throughout its area of distribution, there are substantial differences in clast-size distribution of the framework within the Abbey Dawn Formation at any given outcrop, and from one exposure to another. At the type section (station O-55), clast sizes vary from two to 20 cm. in diameter. Where exposed on Highway 401, (station 0-65), slabs of quartzite up to 60 cm. long are present at the base of the formation, and decrease upward in diameter to 15 cm. at the top of the exposure. At the Lyn Valley Conservation Area (station O-64), many of the cobbles and boulders that apparently lie directly on Precambrian quartzites, are angular, whereas elsewhere they are substantially more rounded.

The Abbey Dawn Formation everywhere rests on Precambrian rocks of the Central Metasedimentary Belt of the Grenville Province. At the type locality (station O-55), the contact is marked by an angular unconformity (see Figure 10). The basal contact of the formation can also be seen at station O-65 on Highway 401, where strata rest with abrupt and unconformable contact on Precambrian granite gneiss. Elsewhere, near Athens (station O-66), and at Lyn Valley Conservation Area (station O-64), the basal contact is not exposed, but in both instances the beds undoubtedly lie unconformably on Precambrian granite and quartzite respectively, within a covered interval of a few centimeters.

Rocks stratigraphically succeeding the Abbey Dawn Formation consist of sandstone and minor conglomerate, dolostone and limestone that range in age from probable Early Cambrian to late Middle Ordovician, in all instances likely representing a hiatus of considerable magnitude. At the type section (station O-55), the conglomerate is succeeded by Gull River limestone of late Middle Ordovician age, the boundary between the two bounded by an angular unconformity (see Figure 10). Where the Gull River Formation onlaps and eventually overlaps the truncated edges of the Abbey Dawn Formation, thin stringers of reworked pebble conglomerate derived from the deposits below intertongue with the overlying limestone along the contact interface.

On the eastern margin of the Frontenac Arch, five kilometers southeast of the village of Athens, Ontario (Station O-66), Abbey Dawn conglomerate is unconformably succeeded by a thin veneer of Covey Hill sandstone containing quartzite pebbles and cobbles that were presumably derived, at least in part, from the underlying conglomerate.

At the Lyn Valley Conservation Area, (station O-64), the sharply angular conglomerate of the Abbey Dawn Formation is unconformably succeeded by sandstone containing well rounded cobbles and boulders of the Chippewa Bay Member of the Covey Hill Formation (see Figure 28), a sequence largely identical to the stratigraphic succession described above in the vicinity of the village of Athens, Ontario.

On Highway 401, near Butternut Bay (station O-65), the Abbey Dawn conglomerate is overlain by interbedded dolostone and sandstone of the Lower Ordovician March Formation. Here too, the contact is abrupt and unconformable (see Figure 11).

Petrogenesis

During the Neoproterozoic and Early Cambrian, somewhere within the range of 550 – 615 Ma, the eastern margin of the North American continent was undergoing intensive deformation triggered by the rifting and opening of an ancestral Iapetus Ocean (Williams and Hiscox, 1968, Williams *et al.*, 1995). This process apparently led to widespread rejuvenation of the major arch systems, and the corresponding deposition of sandstone and conglomerate throughout the eastern part of the North American continent, including the Central Division (present area of study) of the St. Lawrence Platform.

The Frontenac Arch, along with the several other northwest-southeast trending arch systems that separate the basinal areas along the St. Lawrence Platform would have more than likely been involved in such epeirogeny. The rejuvenation of these features would have been the mechanisms required to produce the conglomerates of the Abbey Dawn Formation, as well as the release of the enormous volumes of sand and gravel deposits contained in the succeeding Covey Hill and equivalent Ausable formations that accumulated in the Central Division of the St. Lawrence Platform, in Neoproterozoic to Early Cambrian time.

Reasons for the preponderance of quartzite detritus, and the corresponding paucity of granite rock fragments is open to speculation. One possible explanation, is that granite clasts were probably abundant during the initial phase of Abbey Dawn deposition, and were removed in large part by physical and chemical weathering of the feldspars during transport and diagenesis.

The general lack of sand-size matrix in the Abbey Dawn conglomerate would suggest that the framework clasts were transported relatively short distances from the provenance areas. The angularity of many of the cobbles, boulders and blocks would also support such a hypothesis.

The direction of transport can only be determined at two of the four localities. On Abbey Dawn Road, the conglomerate clasts were obviously transported to the south probably as flow debris, down a steep slope, away from a vertical dipping east-west trending Precambrian quartzite ridge. On Highway 401, near Butternut Bay, the orientation of the imbrication of some of the larger blocks at the base of the formation indicate an eastward paleocurrent direction of 080°. In both instances the coarse detritus was probably transported by rapid flowing fluvial systems, that may have been induced by flash-flooding conditions during periods of exceptional heavy rainfall.

Age and Regional Correlation

The precise age of the Abbey Dawn Formation is unknown. One can only thus speculate as to its age by lithological comparison with rocks deposited elsewhere in the St. Lawrence Platform, and by its inferred association with rifting that began along the eastern margin of the North American continent during the final stages of the Proterozoic. (Williams *et al.*, 1995)

There would appear to be some similarity in lithology and processes of deposition between the Abbey Dawn Formation as described above and the Double Mer conglomerate of the Lake Melville region of southern Labrador, (Gower, 1986); Stevenson, l967, 1970 and Grant 1975) and the Bateau Formation in the Strait of Belle Isle region of Newfoundland and Labrador (Williams *et al.,* 1995). The late Proterozoic age of the Bateau and overlying volcanics of the Lighthouse Cove formations are well documented, based on their stratigraphic position beneath younger Lower Cambrian sequences. Neoproterozoic mafic dyke swarms and the emplacement of anorogenic plutons in the Lake Melville region and in western Newfoundland, that range between 550 and 620 Ma, and Long Range dykes provide further documentation as to the likely age of the rifting process (Williams *et al.*, ibid.), (see Figure 59).

In Quebec and Ontario, pluton emplacement and dyke swarms of ages similar to those of the Newfoundland and Labrador occurrences, indicate those regions were under a similar extensional stress regime, at the end of the Proterozoic and beginning of Paleozoic time (Easton, 1992). The deposition of the Abbey Dawn Formation thus was quite probably a product of the initial phase of this widespread tectonic event.

COVEY HILL AND EQUIVALENT AUSABLE FORMATIONS

Definition

The Covey Hill Formation in Quebec and Ontario, and its stratigraphic equivalent Ausable Formation in New York State, the latter herein redefined, comprise red, pink and grey, to locally white sandstone and conglomerate that are largely of non-marine origin. These deposits accumulated in a variety of dominant aeolian and fluvial depositional environments that when coupled with alternating arid to humid climatic conditions, and intense rift-induced tectonic movements, produced a complex variety of facies relationships that prevailed throughout a long period of Neoproterozoic to early Early Cambrian time.

Except for the two known locations in eastern Ontario, where the Covey Hill rests on the Abbey Dawn Formation, these same beds and the equivalent Ausable Formation elsewhere rest on metamorphic rocks of the Grenville Province. They are everywhere in turn succeeded by sandstone of the Nepean Formation in Ontario, and equivalent Cairnside and Keeseville formations in adjacent areas of Quebec and New York respectively.

The preponderance of well-exposed stratigraphic sections in the western extremity of the study area is directly attributable to the relatively thin units and erosional conditions that prevailed in the general vicinity of the Frontenac Arch. The relatively thin Covey Hill and succeeding Nepean strata and their equivalents, that once completely blanketed the region, were greatly reduced in areal extent through geological time, by erosion along the axis and marginal areas of the arch bordering the Ottawa Embayment to the east, and bordering area of the Appalachian Basin to the west. Along the erosional edges of the parent bodies of the Covey Hill and its Ausable equivalent, and the numerous outliers that occur beyond their boundaries, the beds have weathered to form low but prominent escarpments, in which each of the rock units and their contacts are well exposed on both sides of the international boundary (see Figure 3).

Thus, to establish a standard reference section for these lower strata of the Potsdam Group, the logical place to begin the initial investigation was the Thousand Islands region and immediately adjacent area of New York, and areas to the north in eastern Ontario, particularly along the eastern margin of the Frontenac Arch. In each of these two regions, criteria were quickly established for separating the Covey Hill and equivalent Ausable formations from the Nepean and equivalent Keeseville, and in many places this was accomplished by simply searching out the unconformity in the field between the two principal stratigraphic units, all 21 of the known locations of which are identified in the following table (see Figure 6).

Location (Ontario) **	**Station**
Rideau Ferry Road	O-16*.
Highway 15 at Otter Lake	O-17*
Highway 15 at Elgin	O-23
Highway 42 at Delta	O-35*
Rockland	O-1
5 km. S.E. of Athens	O-66
Highway 15 near Jones Falls	O-27*
Sloan Quarry, near Sunbury	O-57
Lyn Valley Conservation Area	O-64

Location (New York)**	Station
Near Chippewa Bay	N-88
Near Chippewa Bay	N-91
Route 26, near Chippewa Bay	N-17
Theresa	N-18
Route 12, near Alexandria Bay	N-13
Redwood	N-39*
Route 37, near South Hammond	N-73
Route 12, near Duck Cove	N-80*
Blind Bay Road, off Route 12	N-89
Blind Bay Road, at Pleasant Valley Rd.	N-90
Black Lake Road, near Hammond	N-96
Black Lake Road, near Edwardsville	N-109

* denotes an angular unconformity
** precise UTM locations recorded in Appendix (ii).

Table 2: Unconformable contacts between Nepean (Keeseville) and Covey Hill (Ausable) formations in eastern Ontario and northern New York State.

The term Covey Hill Formation as herein adopted for Quebec and eastern Ontario, is precisely as defined by Clark (1966, 1972), and Globensky (1987). There is some uncertainty however, as to the definition of the Ausable Formation in the adjacent area of New York as originally introduced to the literature by Alling (1919), and later adopted by Fisher (1968). For the purpose of this dissertation, the upper boundary of both the Covey Hill and equivalent Ausable formations is the unconformity discussed above. The base of the two formations is their contact with the Precambrian, as illustrated in Figure 4, except for the two locations (stations O-64 and O-66 described earlier), where the Covey Hill lies directly on the Abbey Dawn Formation.

The three-fold subdivision of the Covey Hill (Ausable) succession in the western part of the study area (see figures 4 and 5), that can be readily identified in the field, provides a greater level of stratigraphic control for purposes of regional correlation and the dating of geological events generally, than would have otherwise been possible by the mere identification of the upper and lower boundaries of the formation. The units identified, and herein named in ascending stratigraphic order, Hannawa Falls, Chippewa Bay and Edwardsville members have remarkable regional stratigraphic continuity, not only in the western sector of the study area, but also to the east, where they have been identified in exposures along the northern margins of the Adirondack Mountains, and into the adjoining areas of Quebec along the axis of the Oka-Beauharnois Arch (see Figure 3).

In addition to the widespread recognition of the above members in the field around the margins of the Ottawa Embayment and Quebec Basin, identical units can also be readily identified in subsurface, as shown in the borehole sections and cross-sections (see figures 8 and 9), particularly the Hannawa Falls and Chippewa Bay members that have the more consistent distribution throughout the study area.

During the course of field investigations it became evident, that a very long period of geological time had elapsed between deposition of the Covey Hill (Ausable) and the succeeding Nepean and equivalent Keeseville and Cairnside formations. There are thus many localities where the upper beds of the Covey Hill have been removed by erosion, and some instances where the formation was completely eroded. This is particularly so along the axis and western margins of the Frontenac Arch in Ontario, where only remnants of the Covey Hill are still preserved.

In addition to the erosional removal of the upper beds of the Covey Hill (e.g. Edwardsville and Chippewa Bay) are areas where the lower beds (Hannawa Falls Member) are absent due to non-deposition. This can be seen in localities underlain by the Precambrian Central Metasedimentary Belt, where the tightly folded rocks form ridges and valleys upon which the Covey Hill (Ausable) sandstone and/or conglomerate were originally deposited. In those areas where the Hannawa Falls Member is missing, it is assumed to have been due to significant topographical relief on some of the Precambrian ridges or possible block faulted structures that were likely emergent during the deposition of these lower beds.

The stratigraphic succession of the Covey Hill (Ausable) as established along the western margin of the Ottawa Embayment, is duplicated to large extent along the northeastern margins of the Adirondack Mountains and in adjacent areas of Quebec, although the rock units are many orders of magnitude thicker in the latter regions. Poor exposures and cover by Quaternary deposits, has hampered stratigraphic analysis and determination of unit thicknesses in this part of the study area (see Figure 7).

In addition to the stratigraphic and sedimentological information derived from the recognition of the Hannawa Falls, Chippewa Bay and Edwardsville members in the eastern region of the study area, important information is also obtained from the presence of a highly variable pre-Hannawa Falls redbed sequence of probable marine origin in the Jericho area of northeastern New York State. The latter beds lie directly on the Precambrian, and in turn are overlain by redbeds of the Hannawa Falls member of the Ausable Formation. Because of its probable conformable relationship with the overlying Hannawa Falls beds of the Ausable Formation in New York, and with the Covey Hill where identified at the base of the Quonto-St. Vincent de Paul No.1 borehole in Quebec (see Figure 8), the Jericho is included herein as the lower member of those two equivalent formations in this western part of the Quebec Basin.

Distribution and Thickness

The Covey Hill (Ausable) formations are broadly distributed throughout the Ottawa Embayment and Quebec Basin, as shown in figures 3 and 12. In the Thousand Islands and nearby areas of New York State, the Ausable Formation blankets a substantial part of the southern extension of the Frontenac Arch where it has a maximum thickness of about 10 metres. From the axis of the arch the beds dip into subsurface beneath the Keeseville and Theresa formations towards the northeast and southwest into the Ottawa Embayment and Appalachian Basin respectively.

North of the St. Lawrence River in Ontario, Covey Hill strata are absent along the axis of the Frontenac Arch, presumably having been removed by erosion, prior to the deposition of the Nepean Formation. Its surface distribution along the eastern margin of the arch however, is fairly consistent in a narrow belt extending from the village of Lyn, northwestward to the town of Perth (see Figure 3), from whence it dips eastward beneath younger Ordovician rocks, into the Ottawa Embayment. Because of the highly irregular configuration of the Precambrian basement along the eastern margin of the arch, the Covey Hill varies substantially in thickness from a few centimetres to a maximum of about 12 metres. Between Perth and an arbitrary point between Gatineau, Quebec, and Rockland, Ontario, the northeast trending eroded edge of the Covey Hill in subsurface is stratigraphically overlapped to the northwest by the Nepean Formation (see figures 3 and 12).

On the western margin of the Frontenac Arch in central Ontario, about 6 metres of Covey Hill strata are preserved in a large outlier, along with a few small erosional remnants near the village of Sunbury, approximately 16 kilometres northeast of the city of Kingston. Covey Hill beds are also preserved as a small remnant on the eastern outskirts of the city of Gananoque, in what is perceived as a downfaulted block. These beds lying high on the western flank of the Frontenac Arch, and the larger outlier located near Sunbury are important

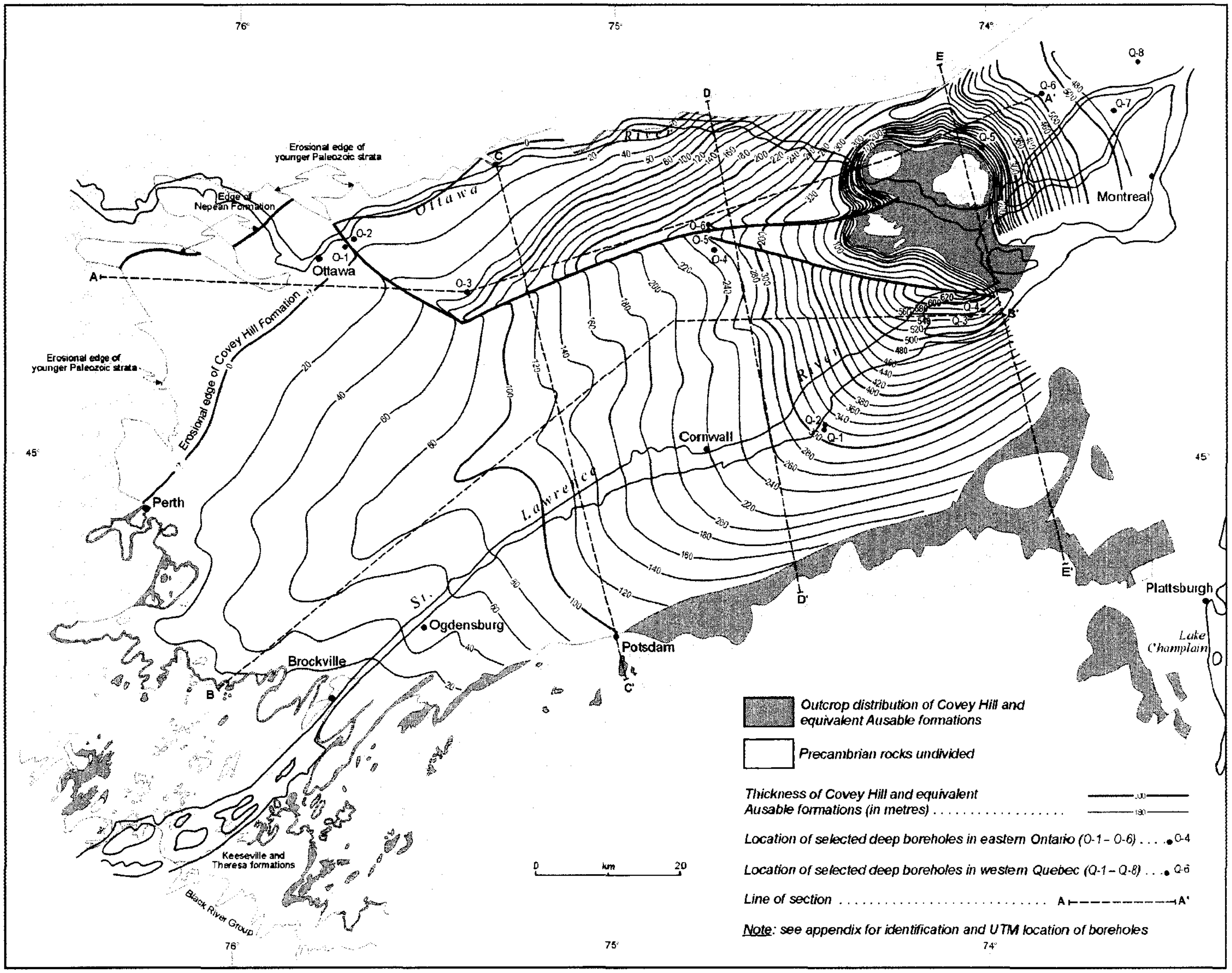


Figure 12. Isopachous map showing distribution and thickness of the Covey Hill and equivalent Ausable formations in eastern Ontario, western Quebec and northern New York State.

occurrences in terms of reconstructing the original distribution of these strata elsewhere to the westward along the St. Lawrence Platform.

For more than 150 kilometres along the northern margin of the Ottawa Embayment, extending from the vicinity of Masson, Quebec to Montreal and beyond, the Covey Hill Formation is largely obscured beneath downfaulted Paleozoic strata bordering the Laurentian Arch, with two possible exceptions; (i) Rockland, Ontario, station 0-1; where two metres of Covey Hill overlain by the Nepean Formation were identified; and (ii) Papineauville area of Quebec, where Covey Hill beds are assumed to be present in a tilted fault block similar to the Rockland structure (see Figure 3), although its presence at the latter locality has not been firmly established.

From the Thousand Islands and adjacent area of New York State, strata of the Ausable Formation continue along the northern margins of the Adirondack Mountains, either as outliers, or in a continuous outcrop belt to the vicinity of Lake Champlain. There is no way of accurately determining the thickness of the strata along this belt except for information contained in the intersecting cross-sections (see Figure 9) across the Ottawa Embayment transposed onto the Covey Hill isopachous map (see Figure 12). These imply a progressive thickening from 10 metres in the Thousand Islands to 250 metres or more approaching the Oka-Beauharnois Arch. A similar thickness in the adjacent area of Covey Hill, Quebec can be assumed from the north-facing block-faulted structure that has been uplifted along the Stockwell Fault, just north of the international boundary exposing the Covey Hill intermittently through an interval of at least 200 metres of vertical relief (see cross section E-E' of Figure 9). The presence of Keeseville or equivalent Cairnside at the summit of this structure at an altitude of 200 metres above its elevation to the north of the fault, would clearly indicate the time of faulting to be post-Keeseville age.

For a short distance north of the Stockwell Fault, Covey Hill strata follow the axis of the Oka-Beauharnois Arch, from whence they disappear from surface into the Valleyfield Trough (new name) to lie beneath younger rocks of the Cairnside and succeeding Theresa formations. North of the trough, they again rise to surface in the vicinity of Île Perrôt from whence they form a halo around the Precambrian inliers of the Oka, Rigaud and Saint-Andre Est mountains, a highland area representing the more prominent northernmost extension of the Oka-Beauharnois Arch. Where the Covey Hill is best exposed in this region of the arch, (western end of Île Perrôt at stations Q-2 and Q-3), the formation by direct measurement is at least 30.5 metres thick, with neither the base, or the top of the formation exposed.

In subsurface of the Ottawa Embayment, the Covey Hill and equivalent Ausable formations form a wedge of sandstone and conglomerate varying in thickness from <10 metres bordering the Frontenac Arch, to 620 metres in the deepest part of the Valleyfield Trough, along the northern margin of a down-faulted block bounded by the Sainte-Justine Fault (see figures 9 and 12). Its thickness in the latter region is based on data from the St. Lawrence River No.1 borehole (see Figure 8), that did not reach the base of the Covey Hill, extrapolated into a probable deeper segment of the Ottawa Embayment, along the down-dropped side of the fault.

Along the northeast margin of the Oka-Beauharnois Arch, the Covey Hill is probably in excess of 500 metres thick based on an extrapolation from the Mallet Test Hole No.1, from whence the beds thin eastward towards the deeper part of the Quebec Basin, as noted by its thickness (360 m) in the Quonto-Mascouche No. 1 borehole (see Figure 8).

Some anomalous thickening of the Covey Hill Formation evidently occurred within the confines of a large down-faulted block that occupies the northern part of the Ottawa Embayment (see Figure 12). The beds contained within the structure dip to the south from their northern erosional edge and thicken to >300 metres within the boundaries of the Gloucester and Russell-Riguad fault systems. These strata appear to have a very different structural style from those located to the west and south. One must assume therefore that this very large graben initially formed very early in the depositional history of the Potsdam Group, an event in all likelihood triggered by late Precambrian to early Early Cambrian rifting.

Lithology and Stratigraphic Relationships

The Jericho, Hannawa Falls, Chippewa Bay and Edwardsville members are very important elements in the chronological reconstruction of geological events that took place during deposition of the Covey Hill (Ausable) formations. The lower two units, Jericho and Hannawa Falls members are the most readily identifiable, both in the field and in subsurface. Both are redbed sequences, although lithologically distinct, obviously due to significant differences inherent to their environments of deposition.

The third successive unit from base, the Chippewa Bay Member is typically the youngest unit of the Covey Hill (Ausable) preserved in the field and in subsurface due to the widespread erosion of much of the overlying Edwardsville Member. The Chippewa Bay Member is more consistently distributed throughout the study area, due to its greater thickness, and resistance to weathering. Where the Chippewa Bay Member lies immediately subjacent to the Nepean or its equivalent Keeseville and Cairnside formations however, it may be difficult to separate these, due to similarities of color and lithological composition. This similarity is the probable reason why the Potsdam of New York, and the Nepean of Ontario have been mapped and described as a single stratigraphic unit for so many years. However, once the subtle differences between the Chippewa Bay and Nepean and equivalent Keeseville are established, along with the recognition of the fact that the two are everywhere bounded by an unconformity, mapping of the respective units can become a routine process. In the few localities of New York State where the Edwardsville Member is preserved (e.g. station N-80), its unconformable boundary with the overlying Keeseville where exposed, is readily recognizable in the field (see Figure 65).

Jericho Member

The Jericho Member of the Ausable Formation is a redbed sequence that is confined to the Quebec Basin, its western depositional edge presumably bounded by the Oka-Beauharnois Arch (see Figure 2). Exposures are apparently confined to a single locality in the Jericho area of New York State, approximately 20 kilometres west of Plattsburgh, at stations N-186, N-187, N-188, N-189, N-191, N-193, N-194 and N-219 (see Appendix for precise locations). Because of the very thin intervals of strata exposed (few centimeters to 2 metres) at any given station, it is difficult to piece together the precise stratigraphic order of the individual stratal units that comprise the member. As far as is possible to determine, the succession begins with a layer of deep red shaley, sandy and feldspathic dolostone and conglomerate, best exposed at station N-193, followed by layers of pink sandy dolostone, (station 194), and greyish-pink dolomitic limestone at station N-191 succeeded by maroon shales and siltstones at station N-187 [see Figures 13 (a) and (b)]. The precise thickness of the Jericho Member at the type locality is also difficult to determine, but a rough estimate of 15-20 metres may be realistic as shown in the composite stratigraphic column of Figure 7.

In the Quonto – St. Vincent de Paul No.1 borehole completed in an adjacent area of Quebec, 34 metres of Jericho strata were penetrated at the base of the Covey Hill Formation. The lower half of the member consists of dark red and brown conglomerate and sandstone, and the upper half of maroon shale and siltstone (see Figure 8). Elongated clasts of maroon shale, typical of the upper strata of the Jericho, were observed near the base of the Hannawa Falls Member of the Covey Hill Formation at station Q-2, on Île Perrôt, [see Figure 40 (a)] indicating the probable presence of those beds in subsurface in that general vicinity of the Quebec Basin.

Brief mention of the redbeds exposed in the vicinity of Jericho was made by Fisher (1968), who suggested their correlation with redbeds exposed approximately 100 kilometres westward at Nicholville by Postel *et al.*, (1959) and Allens Falls by Krynine (1948) near Potsdam. The Jericho beds exposed to the east of the Oka-Beauharnois Arch of possible deltaic marine origin, are considered to be older than the beds exposed at Nicholville and Allens Falls, the later of which are included in the Hannawa Falls Member of the Ausable Formation (see Figure 4).

In contrast to the Jericho, the succeeding units of the Ausable and equivalent Covey Hill formations, the Hannawa Falls, Chippewa Bay and Edwardsville members of non-marine origin, are widely distributed throughout the Quebec Basin and Ottawa Embayment. All three units are exposed within the study area, but it is extremely rare for all three to be preserved at any given locality. The exception to this can be seen at Theresa, station N-18 and in an outlier a short distance east of Alexandria Bay, (station N-13), both located in the general vicinity of the Thousand Islands in New York State, and herein identified as reference sections for the Ausable Formation [see Figure 14 (a) and (b)]. At both locations, the Ausable Formation rests unconformably on the Precambrian, and is succeeded unconformably by the Keeseville Formation. Between the two unconformities at station N-13 are the intervening units of the Hannawa Falls, Chippewa Bay and Edwardsville members, all very well exposed. At station N-18, only the Hannawa Falls and Chippewa Bay members appear to be represented. Station N-13 near Alexandria Bay is a road-cut on Route 12, and is the more accessible of the two reference sections, and the one most recommended for close-up examination of the lithology and contact relationships between the succession of rock units.

Figure 13: Basal unit of Ausable Formation (Jericho Member) in the Lake Champlain region of New York State. (a) Maroon shale and siltstone in stream cut at station N-187. (b) Thin unit of pink and red sandy dolostone at station 191, typical of the marine carbonate interbedded with the shale/siltstone facies of the Jericho Member.

Hannawa Falls Member

The type locality for the Hannawa Falls Member is station N-123, close to Potsdam, New York, the original type area for the Potsdam Sandstone named by Emmons, (1838). At this locality, the Hannawa Falls Member of the Ausable Formation, as herein proposed, is a relatively thin veneer (6.4 m thick) of cross-bedded fine to medium grained red quartzarenite, preserved as a tiny outlier about seven square kilometres in areal extent. The inclination of the cross-stratification up to 30^0 to the southwest, suggests the mode of transport to this site from the northeast was more than likely by aeolian processes (see Figure 15).

Thinly laminated quartzarenite of the Hannawa Falls Member, is preserved as outliers at numerous localities in the surrounding Potsdam and Canton areas, and extend to the southwest along the margin of the Adirondack Mountains, to the vicinity of Theresa, and most of these are also interpreted to be of aeolian origin. Some are contained in block-faulted structures, such as illustrated and described in the Chapter Structural Framework of the Potsdam Group, in Figure 85 (a) and (c), at stations N-120 and N-122, and elsewhere along the foothills belt.

In contrast to the type section of the Hannawa Falls in New York State, and perhaps one or two other localities, (e. g. stations N-56 and N-58) where the redbeds (dunes) are steeply inclined and likely the product of aeolian grainflow deposition, are the more common occurrences of thinly laminated, relatively flat lying quartzarenite containing climbing wind ripple cross-stratification. The latter deposits are present at the base of the two reference sections at Theresa and near Alexandria Bay, stations N-18 and N-13 respectively [see figures 14 (a) and (b)], and in roadcuts along Route 12 at stations N-53, N-54 and N-55 (see Figure 16). Hannawa Falls strata are also present beneath the Chippewa Bay Member at station N-80, but are here largely obscured beneath sediments of Quaternary age.

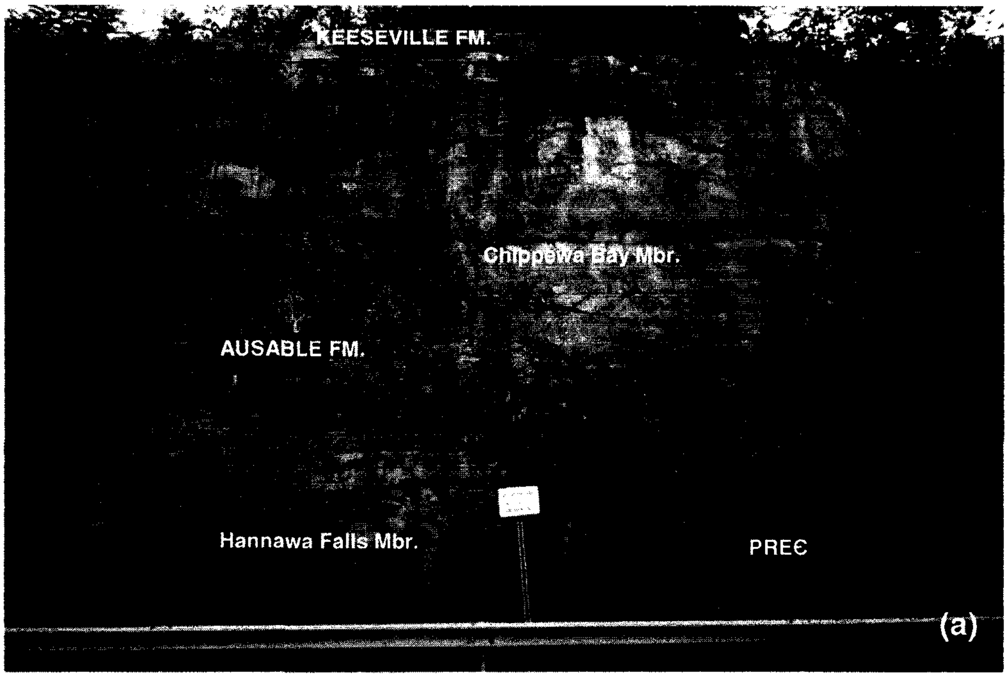


Figure 14: Reference section for the Ausable Formation in the Thousand Islands region of New York State. In both areas, the formation rests on Precambrian metamorphic rocks, and is unconformably succeeded by the Keeseville Formation. (a) Cliff section in the town of Theresa at station N-18. (Note – the prominent bounding surfaces within the Ausable Formation at this location). (b) Roadcut on Route 12 near Alexandria Bay at station N-13. (Note the presence of the Hannawa Falls, Chippewa Bay and Edwardsville members).

Figure 15: Hannawa Falls Member of the Ausable Formation 6.4 metres thick consisting of cross-stratified aeolian deposits at the type locality in New York State, station N-123. Also the type locality for the Potsdam Sandstone, where it was originally identified and named by Emmons in 1838 (Beds are quartzarenite containing well sorted and well rounded grains).

Figure 16: Ausable Formation (Hannawa Falls Member) containing climbing wind ripple cross-stratification in a roadcut on Route 12 near Goose Bay, New York State at station N-54.

Throughout the above mentioned areas, the Hannawa Falls varies from two metres to six or more metres in thickness, and there are areas where the member is absent either due to non-deposition over highs on the Precambrian basement surface, or removal by erosion following its deposition. In some areas, all of the members of the Ausable Formation are absent, such as Wellesley Island and to the south of the islands along the St. Lawrence River, where the formation is stratigraphically overlapped by the Keeseville Formation, the latter of which lie directly on the Precambrian (see Figure 3).

One of the more noteworthy characteristics of the Hannawa Falls Member on the New York side of the St. Lawrence River is the fine grained character of the quartzarenite, and the general lack of gravel detritus, even at the base of the unit such as at station N-54, where it lies directly on the Precambrian (see Figure 89).

On the Ontario side of the St. Lawrence River the Hannawa Falls Member, and indeed all of the Covey Hill strata are absent over the higher structural elements of the Frontenac Arch. Thus, in this region, the surface distribution of the formation is confined mainly to a narrow belt along the eastern margin of the arch extending from the vicinity of Brockville to Perth. However, the Hannawa Falls Member was nowhere observed in the field between Brockville and the town of Delta. Whether the beds are absent throughout this distance (35 km), or simply obscured beneath Quaternary sediments is unknown. The first occurrence of the Hannawa Falls Member along this segment of the arch is a roadcut on Highway 42, at the northern outskirts of the town of Delta at station O-35. Here, 4.5 metres of fine grained, dark reddish-brown quartzarenite are present, with their base not exposed (see Figure 17). The gently folded beds are succeeded by the Nepean Formation, separated by an angular unconformity. The absence of younger Covey Hill strata (e.g. Chippewa Bay Member) at this locality is likely due to the removal of the latter by erosion, during the hiatus that prevailed throughout this region and elsewhere prior to deposition of the Nepean Formation.

Figure 17: Covey Hill Formation (Hannawa Falls Member) dark red quartzarenite, 4.5 metres thick in a roadcut on Highway 42 near the northern town limit of Delta, Ontario at station O-35. (Note – Nepean in background, overlying the Covey Hill with angular unconformity).

The next occurrence of Hannawa Falls strata along the highly irregular outcrop belt is at station O-30, 4.5 km. southeast of Elgin. The beds exposed here, upwards to 5 metres thick consisting of pink, thinly laminated quartzarenite (<u>see</u> Figure 18), lie in a block-faulted structure along a prominent northeast-trending escarpment of Covey Hill sandstone. The lower contact of the Hannawa Falls with the Precambrian is not exposed, but can be placed within an interval of a few centimetres. Its upper boundary with the Chippewa Bay Member is abrupt, and may thus represent a disconformity.

Farther to the west at Jones Falls, good exposures of Hannawa Falls strata can be seen at stations O-28 and O-29. The more complete of the two, (station O-28) is in excess of 10 metres thick and consists of flat lying brick-red, thinly laminated quartzarenite with well rounded quartz cobbles dispersed in a medium to coarse grained sandstone matrix in the lower part of the section, becoming more numerous at base. A more accessible section is located at

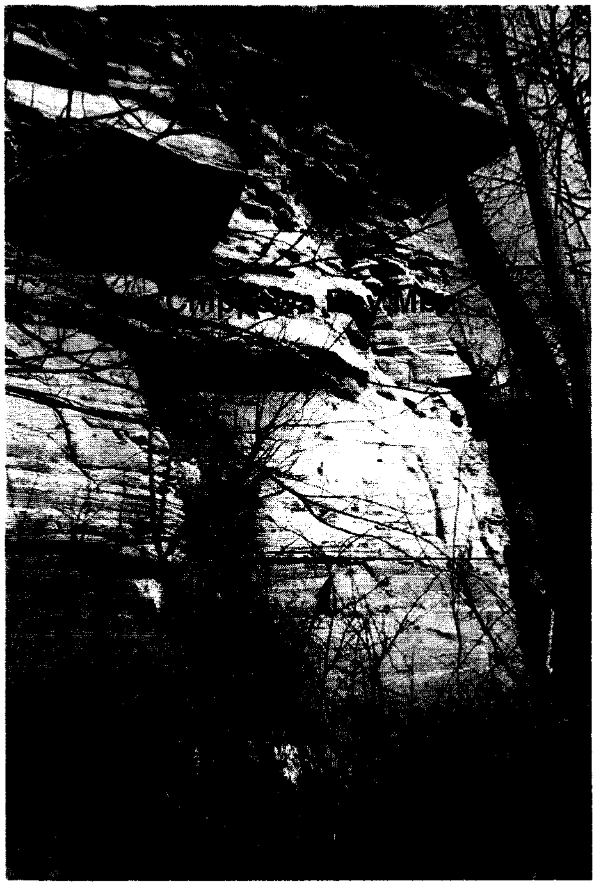


Figure 18: Down-faulted block of Covey Hill Formation (Hannawa Falls and Chippewa Bay members), 4.5 kilometres southeast of Elgin, Ontario, at station O-30. (Note – abrupt, possible disconformity between the two units, marked by arrow).

station O-29 on the Jones Falls sideroad 2.5 kilometres west of Highway 15, where about 6 metres of brick-red quartzarenite are exposed in a low escarpment [see Figure 19 (a)].

Flat lying laminated aeolian beds containing quartz cobbles at base, are interrupted part way up the section by a steeply inclined interval of crossbedded strata, approximately one metre thick, dipping at 30° to the north. Prominently displayed at the same location and visible in Figure 19 (a), is a water expulsion structure that apparently formed very early in the history of Hannawa Falls deposition. Features showing what once were the upward and lateral branching routes of the escaping fluids through the soft sediment layers, and the collapse of the sediment back into the cavity are remarkably well preserved at this location.

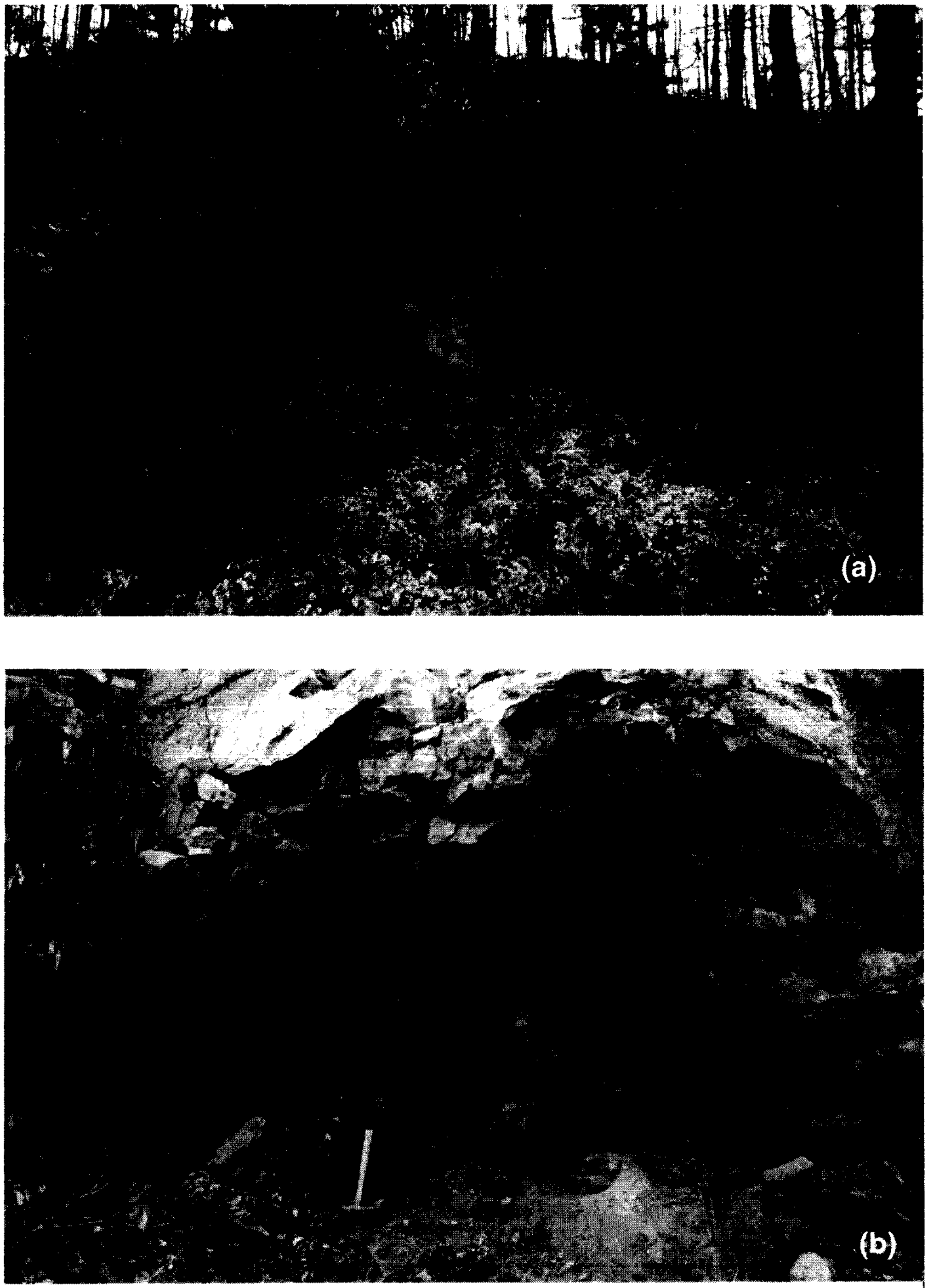


Figure 19: Covey Hill Formation (Hannawa Falls Member) near Jones Falls, Ontario. (a) Six metre escarpment section at station O-29. (Note – water expulsion structure intersecting maroon, thinly laminated aeolian deposits). (b) Small remnant of Hannawa Falls Member of similar lithology to (a) Preserved between Precambrian basement rocks and Nepean Formation, 5.5 kilometres north of Jones Falls side road on Highway 15, Ontario, at station O-27.

Approximately 5.5 km north of Jones Falls sideroad on Highway 15, at station O-27, a unique occurrence of Hannawa Falls Member is preserved as a small remnant (pod), of dark red conglomeratic and shaley sandstone 85 centimetres thick, lying on the Precambrian and unconformably overlain by the Nepean Formation [see Figure 19 (b)]. The presence of this tiny remnant, and thin stringers of red sandstone extending along the contact to the south, identical to the much thicker succession of Hannawa Falls Member, located a mere 6 km. distance to the south at Jones Falls, clearly illustrates the degree of uplift and erosion, occurring, either during, or immediately following the deposition of the Covey Hill Formation in this region of the Frontenac Arch. Similar evidence for tectonism occurs to the north at Elgin, on Highway 15 at station 23, where only a thin remnant (45 centimetres) of dark grey shaley sandstone and pink conglomeratic sandstone of the Hannawa Falls is preserved between the Precambrian basement and overlying Nepean Formation (see Figure 20). Twenty kilometers to the west, remnants of deep red sandy and shaley quartzite conglomerate of the Hannawa Falls largely identical to the Jones Falls section are present in the Salem and Fermoy areas, near the town of Westport, at stations O-67 and O-68, where the beds are 3 and 2 metres thick respectively.

A somewhat more spectacular occurrence of the Hannawa Falls Member is exposed on the Rideau Ferry Road, between Lombardy and Perth. At station O-14, near the intersection of Otty Lake Road and Rideau Ferry Road, 2.4 metres of finely laminated pink and red quartzarenite, with its base not exposed contained in a graben, is succeeded by light grey and pinkish grey sandstone of the Chippewa Bay Member (see Figure 21). The contact between the two members is abrupt and quite possibly disconformable, as it appears to be elsewhere, where the two members are juxtaposed. The Hannawa Falls Member at this locality is a fine-to-medium-grained quartzarenite containing climbing wind ripple cross-stratification. This occurrence is the most northern exposure of this unit in eastern Ontario. From this general region, the Covey Hill Formation is stratigraphically overlapped to the north by the Nepean Formation.

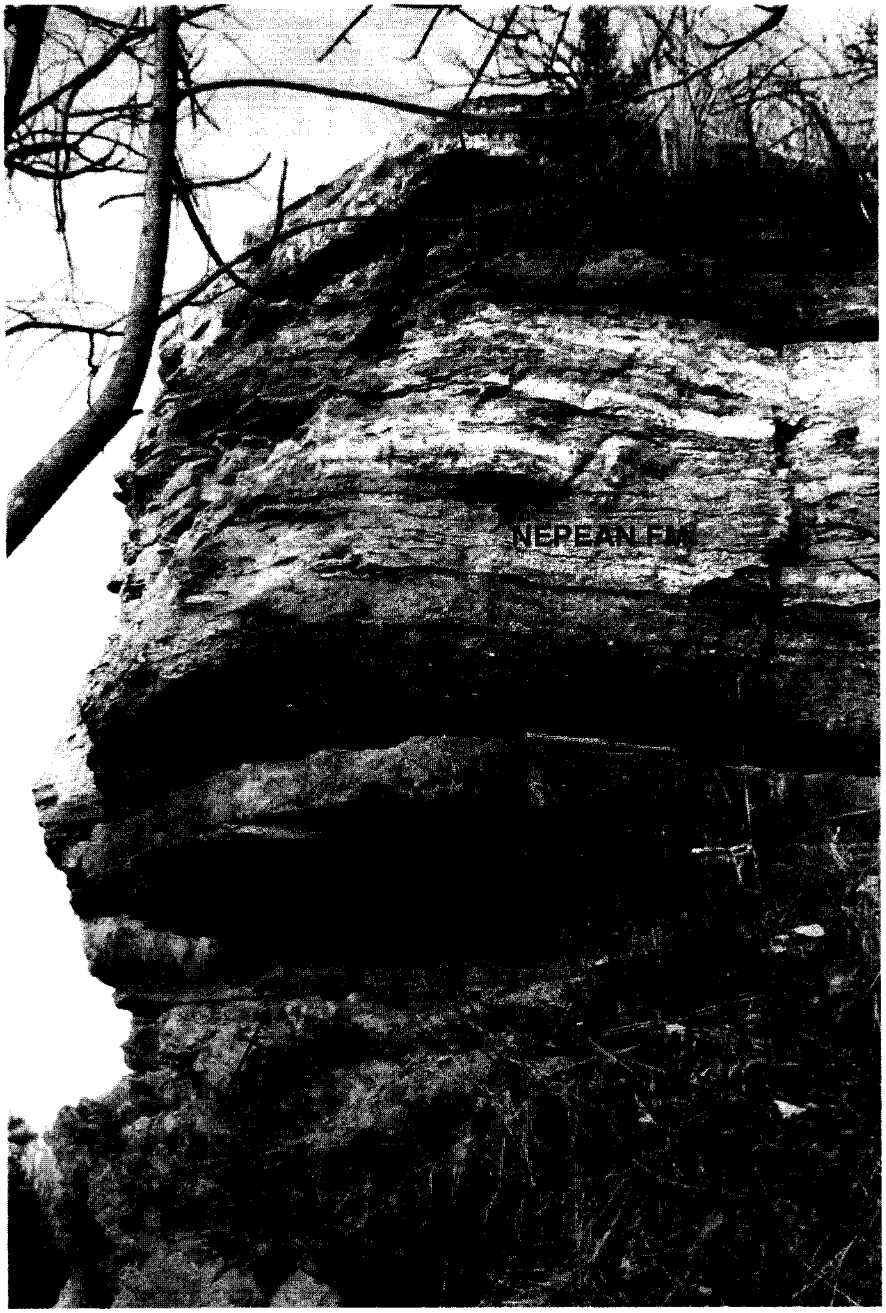


Figure 20: Thin remnant of Covey Hill Formation (Hannawa Falls Member) resting on Precambrian metavolcanic rocks, and succeeded unconformably by Nepean Formation, Highway 15 at Elgin, Ontario at station O-23. (Note – quartz pebble conglomerate at base of Nepean, above hammer).

Figure 21: Covey Hill Formation in roadcut on Rideau Ferry Road at intersection with Otty Lake Road, Ontario, at station O-14. (Note the sharp disconformable (?) contact marked by arrow, between salmon pink finely laminated beds of the Hannawa Falls Member, and overlying more massive pinkish-grey sandstone of the Chippewa Bay Member).

On the western flank of the Frontenac Arch in Ontario, the red quartzarenite of the Hannawa Falls Member of the Covey Hill Formation is contained in a large outlier near the village of Sunbury, approximately 16 kilometres northeast of Kingston (see Figure 3). The beds here, are approximately 5.5 metres thick, where they are best exposed in the Norman Sloan quarry, on the north bank of the Cataraqui River at station O-57 [see Figure 22 (a)]. The beds lie directly on the Precambrian, where they contain a thin quartzite conglomerate at base, and are succeeded by a thin remnant of Chippewa Bay strata with major erosional disconformity. Within the confines of the quarry the beds are aeolian in origin, as interpreted by Wolf and Dalrymple (1984), Cole (1999), and MacNaughton *et al.*, (2002). Within the Hannawa Falls is a one metre thick matrix supported quartzite cobble conglomerate presumably the remnants of a stream system that temporarily interrupted the aeolian

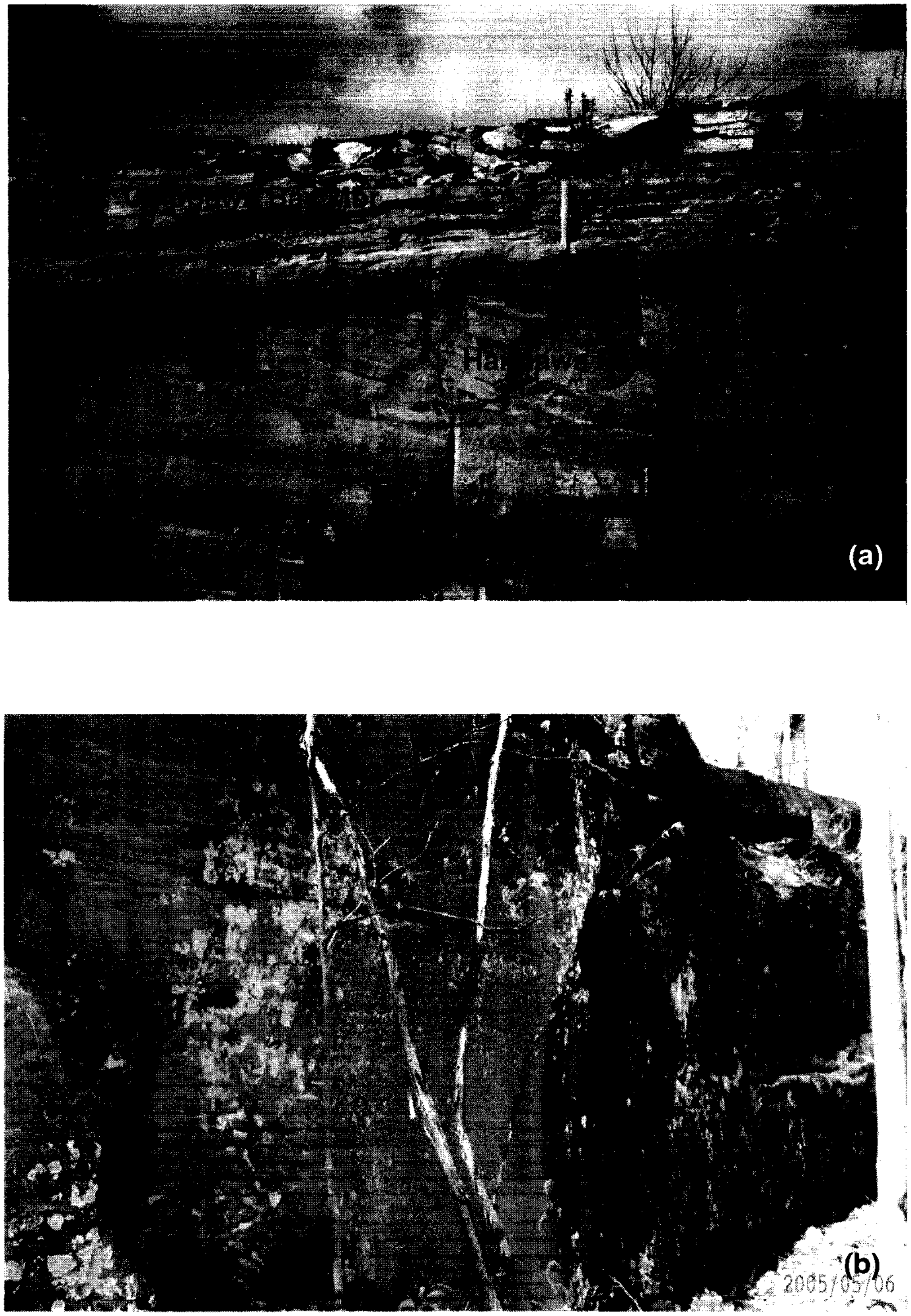


Figure 22: Covey Hill sandstones (Hannawa Falls Member), 4.6 metres of section exposed in large outlier near Sunbury, Ontario. (a) South dipping pink and red sandstone of aeolian origin in the Sloan quarry at station O-57. (b) Flat lying dark reddish-brown thinly laminated sandstone of assumed aeolian origin, two kilometres west of section (a) at station O-59.

depositonal process. The crossbeds below the conglomerate dip in a southwest direction (250°), and above the conglomerate in a south to southeast direction beneath the Cataraqui River. Immediately to the north of the quarry workings, on the same property, the steeply dipping aeolian deposits give place laterally to relatively flat lying dark reddish-brown quartzarenite containing climbing wind ripple structures.

A steeply dipping redbed sequence, of the Hannawa Falls Member, with neither the base or top exposed, forms a low escarpment along the south bank of the Cataraqui River on the William Hughes property at station O-56 [see Figure 47 (a)]. This site is well known as the "Park of Pillars", containing vertical columnar structures as described by Baker (1916); Hawley and Hart (1934); Winder and Sanford (1972), and others. The beds exposed here are deep red, thinly laminated quartzarenite, that dip south, and are thus apparently a continuation of the uppermost aeolian bedset exposed on the opposite side of the river in the Sloan quarry.

Approximately three kilometers west of the Cataraqui River, two additional exposures of the Hannawa Falls Member were discovered at stations O-58 and O-59, that are 1.5m and 4.6m in thickness, respectively. Beds contained in these two outcrops [see Figure 22(b)] are lithologically similar to the sections described above – consisting of dark reddish brown, finely laminated quartzarenite, that is flat lying and assumed to be of aeolian origin (climbing wind ripples). Desiccation polygons were noted on the upper surface of the outcrop at station O-59, which indicate this part of the succession may have been of interdunal origin.

From the type locality at Hannawa Falls near Potsdam, New York, the beds are continuous to the east along the northern margins of the Adirondack mountains, although they are only locally exposed in this general region. Short distances east of Potsdam, New York at Allens Falls and Nicholville, the Hannawa Falls Member is present in re-entrant depressions on the Precambrian surface along the Potsdam Group contact, where they emerge from beneath the Chippewa Bay Member of the Ausable Formation. In both areas, the beds are composed of coarse arkosic conglomerate with sandstone interbeds, of assumed fluvial origin. These occurrences are described in some detail by Krynine (1948), and Postel *et al.,* (1959). East of Nicholville, the topographical expression of the northern margin of the Adirondack Mountains progressively rises in elevation, and it may be thus possible that the Hannawa Falls member is stratigraphically overlapped throughout much if not all of this area by the younger and perhaps more broadly distributed beds of the Chippewa Bay Member. The Hannawa Falls Member was identified with certainty in the Lake Champlain area at only one locality, near Laphams Mills in an uplifted block-faulted structure oriented to the north-northwest that transects Interstate 87, at station N-212 (see Figure 23).

Figure 23: Ausable Formation (Hannawa Falls Member) exposed on Interstate 87 near Laphams Mills, New York at station N-212, (Beds here of alluvial origin, contain quartz-feldspar pebble conglomerate and are characterized by a preponderance of small scale trough crossbedding.

Here 2.1 metres of strata comprised of red, coarse grained feldspathic quartz pebble conglomerate and feldspathic arenite, are exposed at this locality.

In the adjacent area of Quebec, the Hannawa Falls Member of the Covey Hill Formation is also apparently restricted in outcrop distribution to a single locality confined to the western end of Île Perrôt. Here, at station Q-2, (see Figure 24), some 20 metres of Hannawa Falls strata lie at the base of a prominent northeast oriented escarpment and are abruptly succeeded higher in section by slightly more massive grey beds of the Chippewa Bay Member. The fine to medium grained strata are red to dark reddish-brown in color and trough cross-stratified.

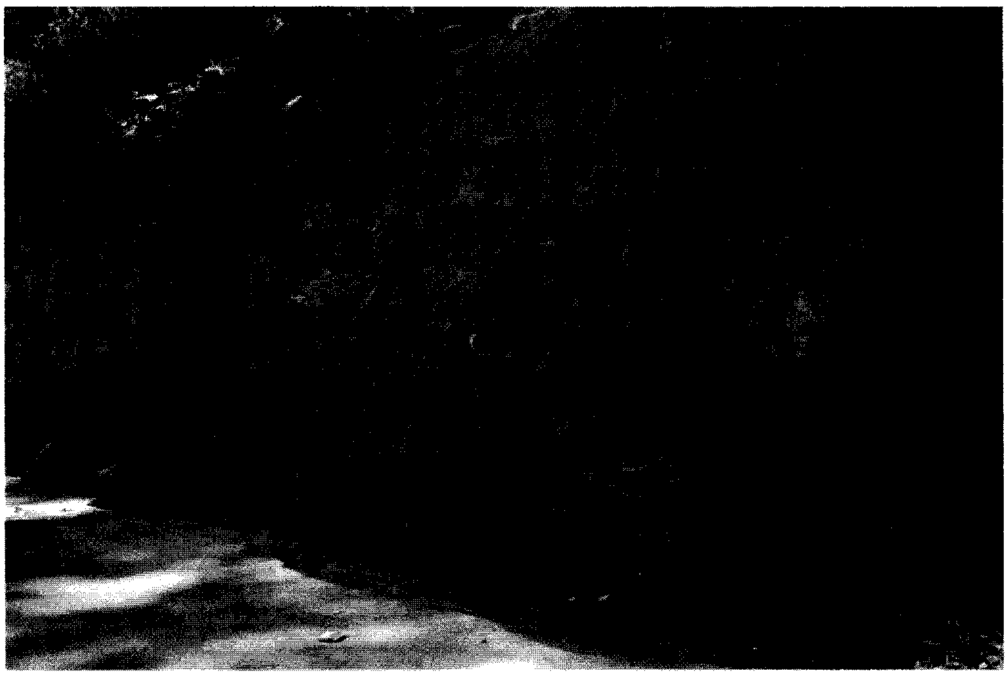


Figure 24: Covey Hill Formation (Hannawa Falls Member) comprised of dark reddish brown arkosic sandstone exposed on grounds of shopping mall at western end of Ile Perrôt, Quebec, at station Q-2.

In addition to the relatively broad distribution of the Hannawa Falls Member at surface around the margins of the Ottawa Embayment and Quebec Basin, is its equally consistent presence in subsurface throughout the study area, as illustrated in figures 8 and 9. Also consistent in subsurface is its distinctive salmon pink to dark reddish-brown color as it is traced from the vicinity of Ottawa, eastward to the Montreal region and beyond. In the western extremity of the Ottawa Embayment, the member is largely quartzarenite, which gradually grades to feldspathic arenite in an eastward direction containing abundant quartz-feldspar pebble conglomerate approaching the Oka-Beauharnois Arch (see Figure 9). Where boreholes have penetrated basement, or were terminated at depths near to basement along the downdropped side of the Gloucester and Russell-Rigaud fault systems, large blocks of Precambrian basement were sometimes encountered that greatly impeded the drilling process. These are assumed to have become dislodged from the upthrown side of the fault systems, from whence they had toppled into the graben, either prior to, or during the initial depositional phase of the Hannawa Falls Member.

Precise thicknesses of the Hannawa Falls from west to east in subsurface is difficult to determine, because most of the boreholes drilled in the Ottawa Embayment were terminated within that unit, but some data are available (see Table 3). However, the following are thicknesses arrived at for the eight cored boreholes for which good records are available, the + designation referring to the thickness of the Hannawa Falls penetrated without having reached basement.

Borehole	**Thickness**	**Borehole**	**Thickness**
GSC Lebreton No. 1	7.6 m	St. Lawrence No. 1	171.3+m
GSC Russell No. 1	47.6 m	Mallet Test No.1	152+m
GSC McCrimmon No.1	33.6m+	Quonto-St.Vincent de Paul No. 1	91.1m
Imperial Laggan No.1	42.7m+	Quonto-Mascouche	199m

Table 3: Thickness of Hannawa Falls Member in subsurface.

Chippewa Bay Member

The Chippewa Bay Member of the Ausable and equivalent Covey Hill formations overlie the Hannawa Falls Member with abrupt contact and stratigraphically overlaps that unit at various localities to rest directly on the Precambrian. This is apparently so on a regional scale, along the northeastern margin of the Adirondack Mountains in New York State, and bordering areas of the Oka-Beauharnois Arch, where the Precambrian basement rocks are of high relief. Similarly, the Chippewa Bay would appear to overlap the Hannawa Falls at various localities along the eastern margin of the Frontenac Arch, and particularly so in eastern Ontario, bordering the Thousand Islands region of the St. Lawrence River, where tectonic activity was the most intense during late Precambrian to Early Cambrian time. Similar relations between the two units can also be seen on a more local scale in both Ontario and New York, where Hannawa Falls strata are absent due to non-deposition over Precambrian topographic highs, ridges and possible block-faulted structures in which case they are stratigraphically overlapped by the Chippewa Bay Member.

The Chippewa Bay is succeeded by the Edwardsville Member with abrupt contact, the latter unit having very limited distribution in parts of New York State and Quebec. Elsewhere throughout the Ottawa Embayment and western Quebec Basin, the Chippewa Bay is overlain unconformably by the Nepean Formation in Ontario and its equivalent (Cairnside and Keeseville formations) in Quebec and New York, respectively.

The Chippewa Bay Member is named for the classic section exposed on Route 12 at station 80, a short distance west of the village of Chippewa Bay, and the indentation of the St. Lawrence River, also bearing that name (see Figure 25). The beds, some six metres thick at this locality, consist of greyish-green, and pinkish-grey quartzarenite, that rest on the Hannawa Falls, (the contact is obscured by Quaternary deposits), and are succeeded with sharp possible disconformable contact (marked with arrow) by sandstone of the Edwardsville

Figure 25: Ausable Formation (Chippewa Bay and Edwardsville members) in roadcut on Route 12 near Duck Cove, New York, at station N-80, contact between grey-green sandstone of the Chippewa Bay Member and red, thinly laminated beds of overlying Edwardsville Member is shown by arrow in upper part of photo. (Note deep weathering of strata behind 1.5 metre pole).

Member. Similar beds can also be seen in both of the reference sections [stations N-18 and N-13, see Figure 14, (a) and (b) respectively] where the entire unit and its contact relationships are well preserved. At station N-18, within the townsite of Theresa, approximately ten metres of grey and pinkish-grey quartzarenite of the Chippewa Bay Member rests on the Hannawa Falls with sharp angular unconformity. At this location, its upper contact with the Keeseville Formation is somewhat uncertain because of the inaccessibility of that uppermost part of the succession. Three prominent bounding surfaces are displayed within the section, the lower of which coincides with the contact between the Hannawa Falls and Chippewa Bay members and the others about mid-way up the Chippewa Bay Member. To account for the lower of these, e.g. at the top of the Hannawa Falls Member, one might suspect minor folding to form a gentle syncline, (see Figure 14 a) followed by a period of subaerial erosion.

For the others higher in section, cut and fill processes might be a possible explanation, although there is evidence in the form of drag folding to suggest that horizontal dislocation may have occurred along one or more of these bounding surfaces as well (J. L. Wallach, personal communication).

At the second reference section, located on Route 12, at station N-13 (see Figure 14 b) a short distance to the east of Alexandria Bay, 9 metres of pink and grey quartzarenite of the Chippewa Bay are well exposed, along with their lower and upper contacts with the Hannawa Falls and Edwardsville Members respectively. At this roadcut, a prominent discoloration of the weathered surface of the member is evident. This is presumably due to the bleaching of iron-oxide pigment from the parent rock by the natural migration of groundwater, along bedding planes and through the interstices of the rock unit. A close examination of the beds at this locality, as well as many of the other Chippewa Bay sections throughout the study area, might lead one to the conclusion that the entire unit was originally deposited as a redbed sequence, and was subsequently bleached during early diagenesis, and is perhaps still undergoing this process today.

In much of the western part of the Ottawa Embayment the Chippewa Bay Member is parallel bedded quartzarenite, except in a few localities in the Thousand Islands area of New York State, where the strata have undergone intensive scouring, presumably by fluvial abrasion and/or wave action that has produced hummocky bedforms such as the section located at station N-15 shown in Figure 26, near Theresa. Such abrasional processes produced abundant large scale trough crossbedding, which is also a common characteristic of this unit elsewhere to the eastward in northeastern New York State and adjacent Covey Hill and Île Perrôt areas of Quebec.

Chippewa Bay quartzarenite facies similar to that of the Thousand Islands area of New York can be traced across the St. Lawrence River into eastern Ontario. One such occurrence is a tiny outlier in a roadcut on Highway 2 at station O-52, about one kilometre east of Gananoque. The beds here (see Figure 27) are preserved in a downfaulted block, and the outlier itself is in turn intersected by a normal fault down to the west. The beds at this station are 5.5

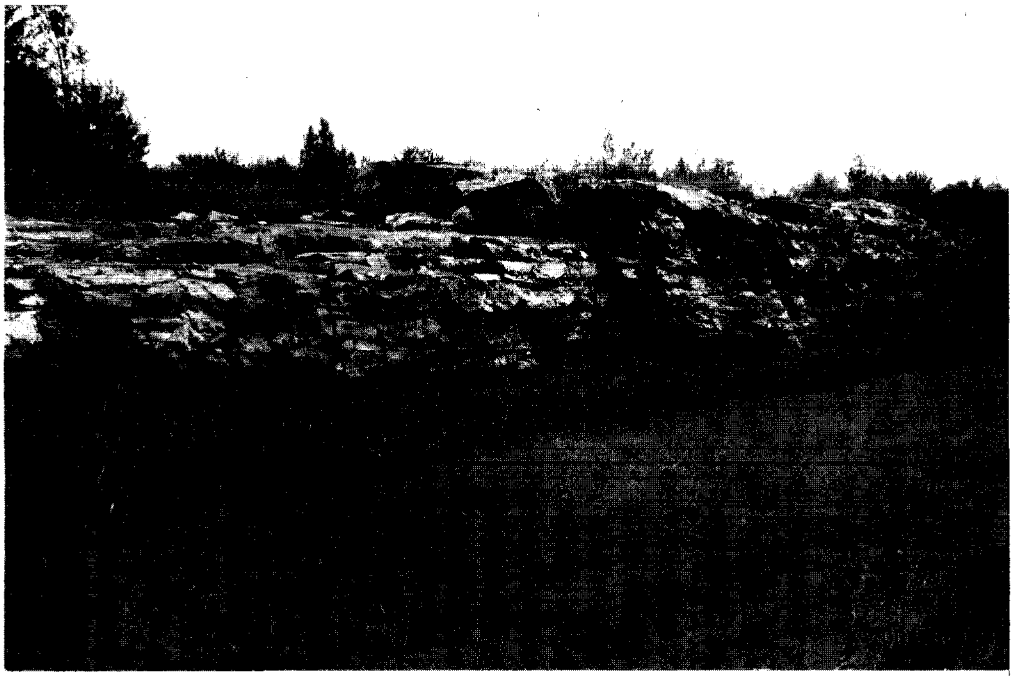


Figure 26: Hummocky trough crossbedded sandstone of the Ausable Formation (Chippewa Bay Member), at station N-15.

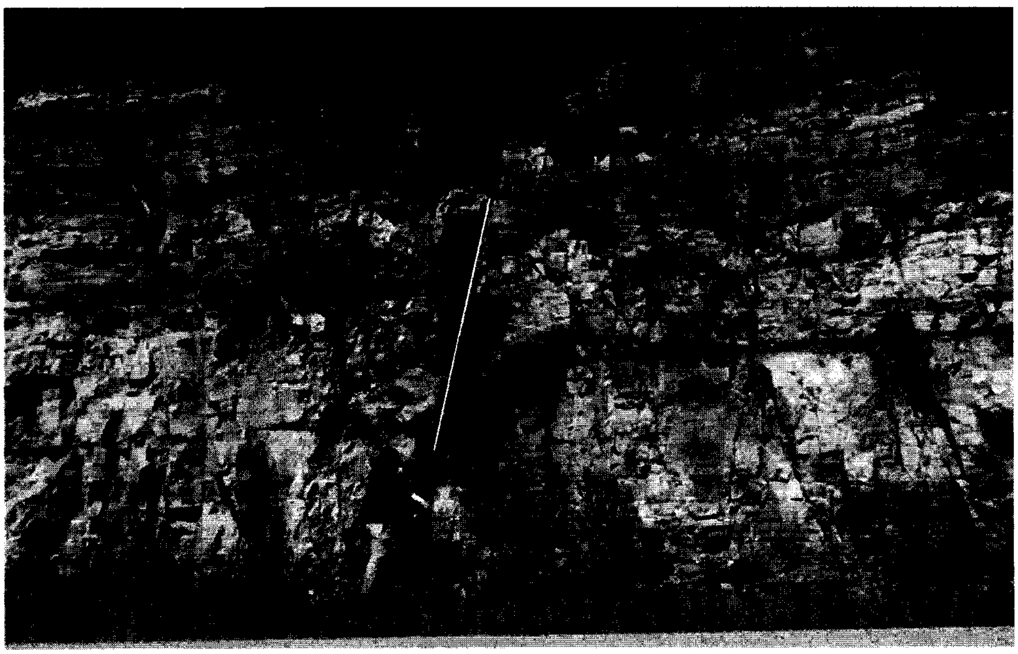


Figure 27: Outlier of Covey Hill (Chippewa Bay Member) one kilometre east of Gananoque on Highway 2 at station O-52. (White line denotes normal fault, down to left).

metres thick and are pinkish-grey, and intensely trough cross-stratified. The lower contact with the Precambrian is not exposed, but quartzite cobbles in some of the lower beds indicate the contact is probably in close proximity. Outliers in immediately surrounding areas are all Nepean Formation. This would suggest that the Covey Hill (Chippewa Bay Member), once blanketed this segment (western margin) of the arch, and was removed, for the most part, prior to the deposition of the Nepean. The one other occurrence of Chippewa Bay Member is on the west side of the Frontenac Arch, in the Sloan quarry at station O-57 [see figures 22 and 48 (b)]. The beds where exposed in the upper northeast wall of the quarry consist of yellow, fine to medium grained quartzarenite containing a thin quartzite cobble basal conglomerate with angular consolidated clasts of red sandstone derived from the underlying Hannawa Falls Member. Associated with these basal stream-bed deposits is a preponderance of asymmetrical ripples that are exposed on blocks removed from the quarry face.

On the exact opposite side of the Frontenac Arch to the northeast, are two thin exposures of Chippewa Bay Member, both less than a metre thick, consisting of grey quartzarenite containing quartzite cobbles and boulders. One is located at the Lyn Valley Conservation Area, on the outskirts of the village of Lyn at station O-63 (see Figure 28). The other is 11 kilometres to the west on a county road five kilometres southeast of Athens, at station O-66. At both localities, the Hannawa Falls Member is missing, and the Chippewa Bay rests unconformably on the Abbey Dawn Formation, and is in turn unconformably succeeded by the Nepean Formation.

From the general vicinity of the town of Athens, northwestward to Otter Lake, on Highway 15, the Chippewa Bay Member comprises a very complex assortment of quartz cobble and boulder conglomerate intermixed with quartzarenite deposits. Throughout much of this region, conglomerate is the dominant facies, although quartzarenite of likely aeolian origin with no conglomeratic component occurs in a few intervening locations.

Perhaps one of the more spectacular sections of quartzite cobble and boulder conglomerate to be seen anywhere in this region is exposed in an outlier

Figure 28: Covey Hill Formation (Chippewa Bay Member) unconformably overlying Abbey Dawn Formation, and in turn unconformably overlain by Nepean Formation, at Lyn Valley Conservation Area, station O-64.

on the southwest shore of Charleston Lake (Charleston Lake Provincial Park). At station O-61 [see Figure 29 (a)], upwards to 8 metres of coarse clast supported cobble quartzite conglomerate, containing thin stringers of pinkish-grey coarse grained sandstone are present near the entrance to the park. At a nearby location of the same outlier, station O-60, Figure 29 (b), the quartz cobbles are interbedded with massive beds and lenses of grey and greyish-green coarse grained sandstone. The conglomerate and sandstone at this locality appear to have been transported in a southeast direction from a northeast trending fault scarp. Some evidence for a possible fault in this area can be seen on satellite imagery in the form of a major lineament that intersects Charleston Lake at this approximate locality, as shown in Figure 3.

Somewhat thinner conglomeratic units than the above were mapped in nearby areas bordering Charleston Lake at two localities: (i) on a county road about 0.25 kilometres north of Lynhurst, at station O-43 (see Figure 30) where

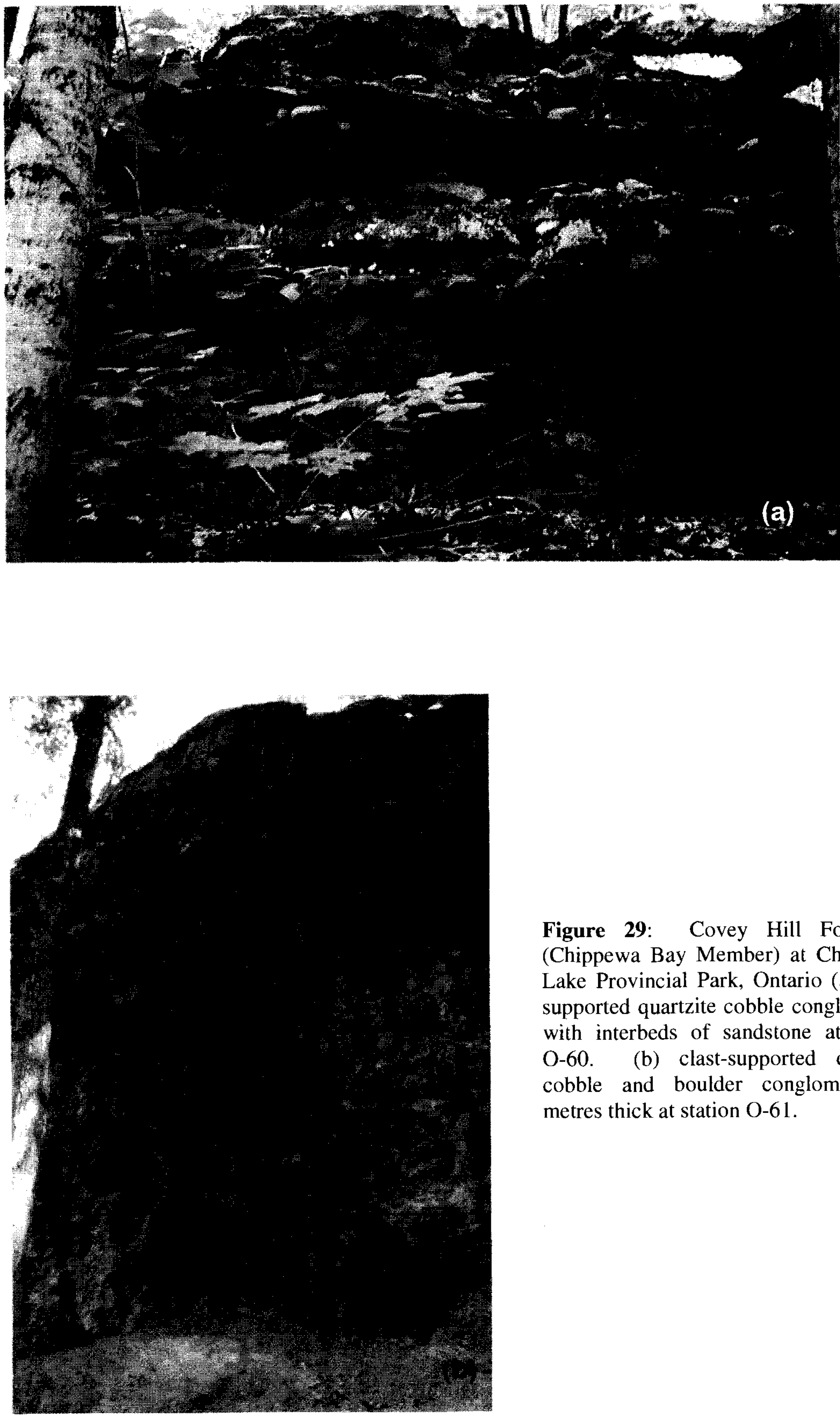


Figure 29: Covey Hill Formation (Chippewa Bay Member) at Charleston Lake Provincial Park, Ontario (a) clast-supported quartzite cobble conglomerate with interbeds of sandstone at station O-60. (b) clast-supported quartzite cobble and boulder conglomerate 8 metres thick at station O-61.

Figure 30: Covey Hill quartzite cobble conglomerate 1.2m thick (Chippewa Bay Member) near village of Lyndhurst, Ontario at station O-43 lying on Precambrian coarsely crystalline limestone (marble).

1.2 metres of quartzite conglomerate, with minor feldspar clasts, rests unconformably on Precambrian coarsely crystalline limestone (marble); and (ii) on Slack Road leading south from the village of Charleston Lake to cottages on the lake (station O-46), where about one metre of clast-supported quartzite conglomerate is overlain by 30 centimetres of coarse-grained, pinkish-grey sandstone. The latter strata are highly irregular, due to the very intense trough cross-stratification of the beds.

One of the better exposures of Chippewa Bay conglomerate and sandstone is contained in an abandoned quarry five kilometres west of Highway 15 at Briton Bay, station O-18, Figure 31, (a) and (b). Here, the stratal succession is up to 10 metres thick and is readily divisible into alternating units of sandstone and conglomerate. Conglomerate clasts are mainly quartzite pebbles and cobbles, in addition to an abundance of weathered feldspar clasts. The sandstone interbeds are weathered to a drab olive green color due to their probable chlorite content, a characteristic that is not only common to this outcrop, but to a great many of the other Chippewa Bay exposures throughout the western and eastern parts of the Ottawa Embayment.

On the south wall of the quarry, the remains of major river channels having intersected the Chippewa Bay member during its deposition is well displayed. Two major cut and fill structures are exposed, the upper superimposed upon, and slightly overlapping the lower, at a later period of geological time. (see Figure 31 (a)). Another cut and fill structure slightly higher in section can be seen in Figure 31 (b) (to the immediate right of man), where a channel has intersected a successively higher lithic unit of the Chippewa Bay Member. The sand and coarse gravel that formed the successive layers of sandstone and conglomerate at this site were likely derived from the Rideau Lakes Fault immediately to the north, that trends northeasterly through the Rideau Lakes. (see Figure 3).

A remnant of the conglomerate facies described above is exposed a short distance to the north of Briton Bay, in a deep ditch on the west side of Highway 15 at the Twin Pines Camp Grounds at station O-17 (see Figure 32). At this locality strata are 2.1 metres thick, and consist of pinkish grey, wellrounded to subrounded quartzite clasts dispersed in a matrix of coarse sandstone. Subtle bedding in the conglomerate dips to the south (to left in photo), whereas the overlying Nepean is clearly inclined to the north (to the right in photo), the bounding surface between the two thus constituting an angular unconformity.

Somewhat beyond the periphery of the conglomerate belt are two excellent exposures of Chippewa Bay quartzarenite, both within a few kilometres of the town of Elgin. One of these is located 4.5 kilometres east-southeast of Elgin, in a down-faulted block at station O-30 (see Figure 18). Here, 5-7 metres of thinly laminated pinkish-grey quartzarenite rests abruptly and possibly disconformably on redbeds of the Hannawa Falls (the latter described in a previous section). The relatively flat lying beds contain two intervals, each at least one metre thick of east-dipping strata of probable aeolian origin. Near the top of the unit, is a vertical cylindrical column similar, albeit much smaller, than

Figure 31: Covey Hill (Chippewa Bay Member) in Briton Bay quarry at station O-18, (a) 12 metre section of grey-green feldspathic sandstone and interbedded quartzite pebble conglomerate, capped by quartzite cobble conglomerate. Note the presence of major stream channel cut and fill structures. (b) Channel fill deposits of sandstone and pebble conglomerate in lower center and right of photo, overlain by quartzite cobble conglomerate with minor abandoned channels shown in upper-center and right of photo.

those occurring on the William Hughes property on the south bank of the Cataraqui River, near the village of Sunbury.

Four and a half kilometres to the southwest of Elgin, on a sideroad leading to Davis Lock on the Rideau Canal, another occurrence of Chippewa Bay Member is contained in a broad syncline (<u>see</u> Figure 33). The slightly irregular

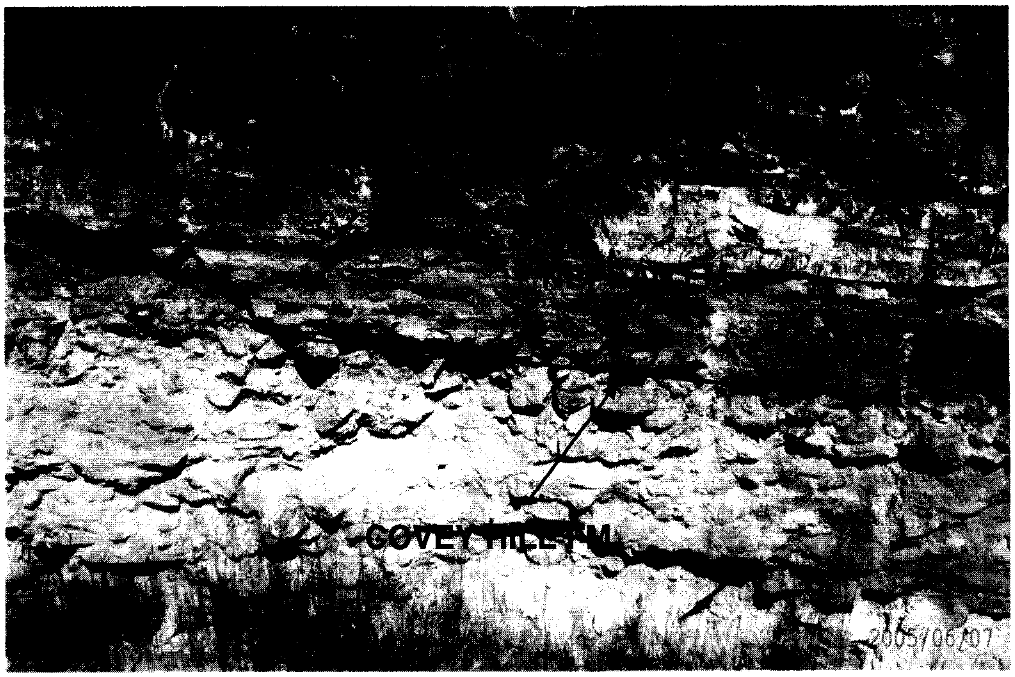


Figure 32: Covey Hill Formation (Chippewa Bay Member) consisting of quartz cobble and boulder conglomerate with sandstone matrix, overlain with angular unconformity by basal conglomerate and sandstone of the Nepean Formation, Highway 15, Ontario, at station O-17. (Note compass for scale immediately below the contact).

beds are 2.7 metres thick and consist of pinkish-grey and yellowish-orange, fine- to medium-grained quartzarenite. It is not known whether these beds lie directly on the Precambrian, or if a thin layer of Hannawa Falls separates the two, as no rock unit contacts are exposed at this locality. A very short distance to the east at Elgin (station O-20) and again at Delta (station O-17), Chippewa Bay strata are absent between the Hannawa Falls Member of the Covey Hill and the

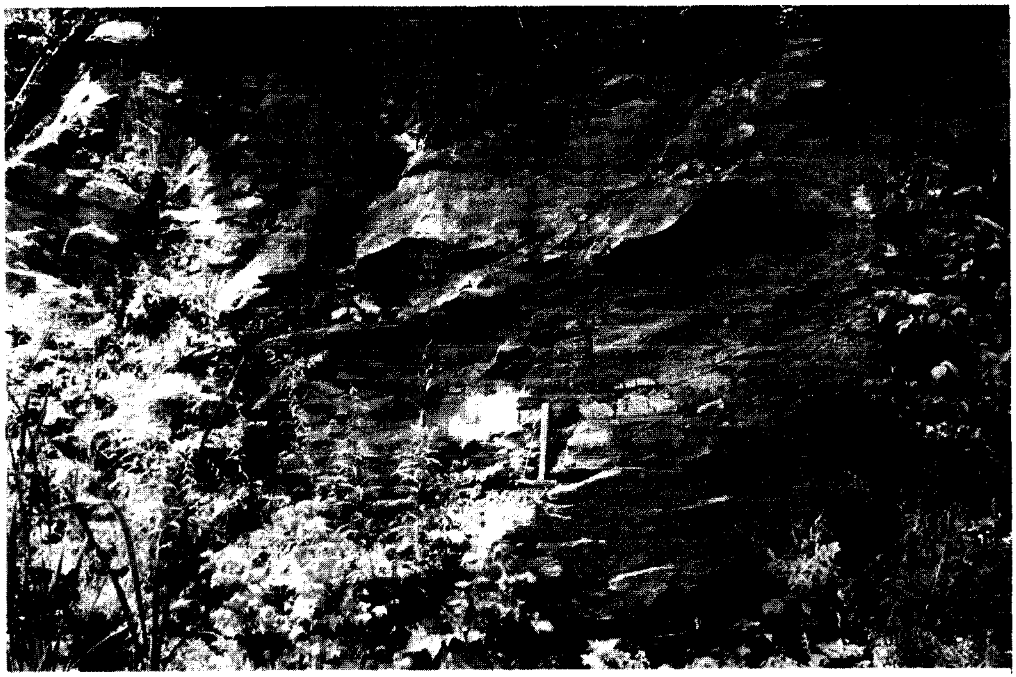


Figure 33: Covey Hill sandstone (Chippewa Bay Member) near Davis Lock on the Rideau Canal, Ontario, at station O-47. (Note the minor folding of the Covey Hill at this locality).

overlying Nepean. Its absence in these localities is likely attributable to erosion, prior to deposition of the latter formation.

Thin remnants of Chippewa Bay sandstone are present on the Rideau Ferry Road at stations O-14 and O-16. At station O-14 where the member overlies the Hannawa Falls with abrupt contact (see Figure 21), the beds are less than a metre thick, and consist of massive light pinkish-grey quartzarenite, in sharp contrast to the thinly laminated redbeds of the Hannawa Falls Member upon which they rest. At station O-16, near Rideau Ferry, at least five metres of grey and red-stained, medium grained quartzarenite of the Chippewa Bay Member is cut by a normal fault, from whence the beds dip steeply to the west [see Figure 1, (a) and (b)]. Following deformation, the strata were bevelled by erosion, before deposition of the overlying Nepean Formation.

From the Rideau Ferry Road northwestward to the vicinity of Pakenham, Ontario, the Covey Hill Formation is absent due to erosion, and is thus stratigraphically overlapped by the Nepean Formation (see Figure 3).

The northern most exposure of Covey Hill Formation in the western part of the Ottawa Embayment is located at Rockland, Ontario, near the boat launch to the Ottawa River at station O-1. The beds of Chippewa Bay Member (1.5 metres thick), are pinkish grey and thickly bedded near their base, becoming more thinly bedded and laminated in its upper part (see Figure 75). The contact of the Chippewa Bay with the underlying Precambrian marble present in this general area, is not exposed, but is likely no more than a few centimetres below the base of the section at this site. Its upper contact with the Nepean is placed at the base of the cross-stratified dunes shown in Figure 75, the latter containing a bed of limestone of assumed marine origin. It is not known whether this member of the Covey Hill is exposed elsewhere along the Paleozoic – Precambrian contact between Rockland, Ontario and points eastward.

Between Black Lake and Malone bordering the Adirondack Mountains in New York, no traces of the Chippewa Bay Member were observed by the writer (see Figure 3). It is undoubtedly present beneath Quaternary deposits, at least from the Potsdam area eastward to the vicinity of Belmont Center, where in the latter area a short distance east of Malone thin exposures of grey- and red-banded quartzarenite of the Chippewa Bay Member are present at stations N-128 and N-129.

To the immediate east of the latter outcrops, in the Chateaugay River gorge, where the Pulp Mill Road crosses the river at station N-130, an estimated 12 metres of section are exposed. Strata near the base of the gorge, which were inaccessible to the writer, consist of grey quartzarenite (see Figure 34), that are assumed to be Chippewa Bay Member of the Ausable Formation, overlain near the top of the gorge by the Edwardsville Member.

Farther east in New York approaching the Oka Beauharnois Arch, are several exposures of the Chippewa Bay Member, most of which are not more than a few centimetres to one or two metres thick. The most noteworthy are two

Figure 34: View to the southeast showing Ausable Formation (Chippewa Bay Member), in Chateaugay River gorge at station O-130. (Note north-dipping beds intersected by north trending normal faults that are parallel to the flow of the river.

outcrop sections located on Route 190, about a kilometre west of Ellenburg Centre at stations N-138 and N-139 (see Figure 6). Station N-139, the more conglomeratic of the two [see Figure 35 (a)] is a two-metre thick section, consisting of grey and pink quartz-feldspar conglomerate. The feldspars, mostly of sand-size, are decayed to kaolinite [see Figure 35 (b)]. The Chippewa Bay Member at this locality consists of trough cross-stratified strata. As a consequence, the beds have a highly irregular appearance that was formed by the scouring and depositional processes of braided stream systems that transected the area during the Early Cambrian period. In this general area of New York State, sandstone and pebble conglomerate of the Chippewa Bay Member are in sharp contrast to uniformly bedded sandstone equivalents exposed elsewhere along the northern margin of the Adirondack Mountains. A major facies change from aeolian to fluvial origin can thus be assumed to have occurred at some point immediately to the west of station N-139 (see Figure 50).

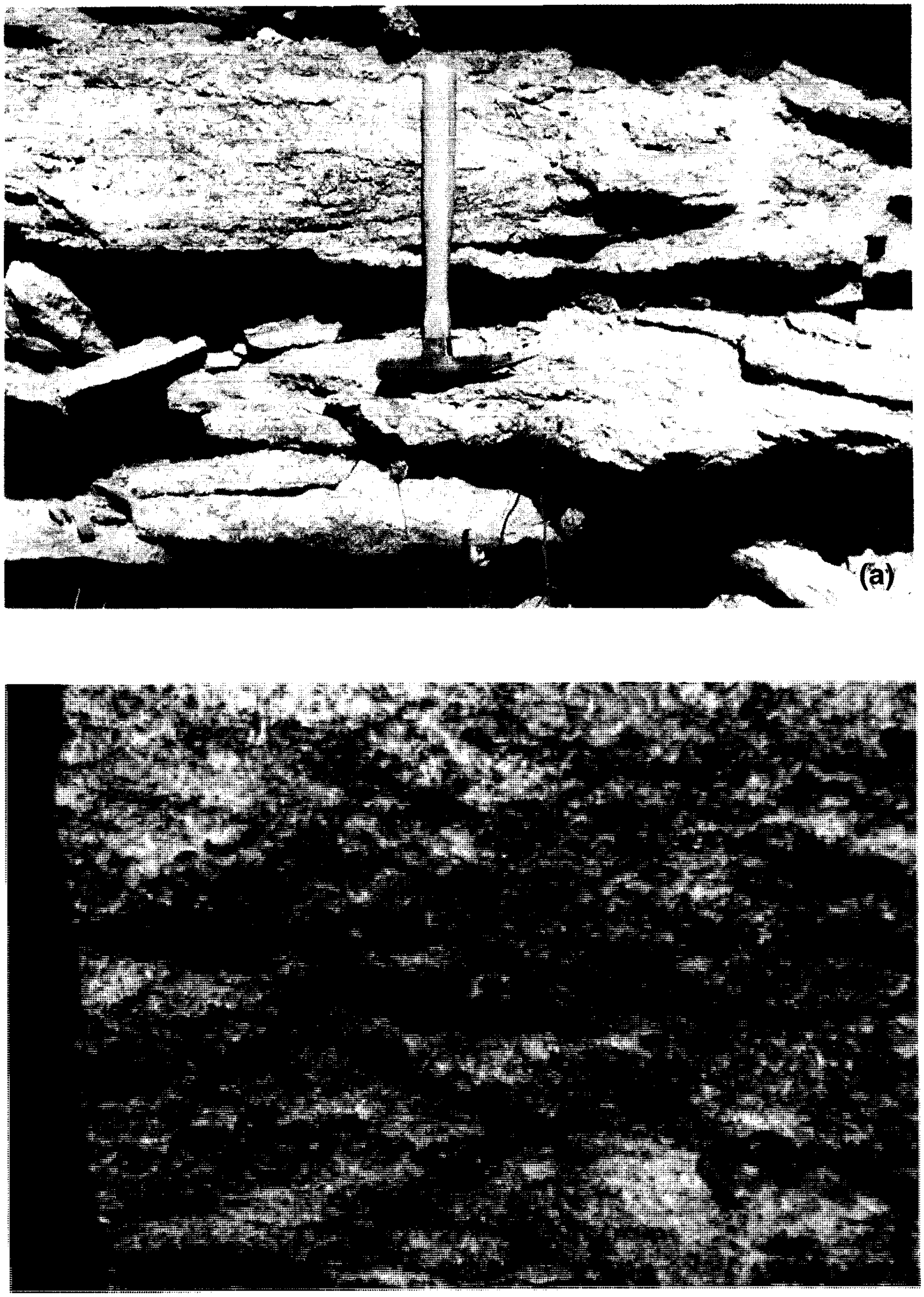


Figure 35: Ausable Formation (Chippewa Bay Member) near Ellenburg, New York at station N-138. (a) Coarse grained, pink and grey sandstone with abundant clasts of quartz-feldspar pebble conglomerate. (b) Close-up, of pink and red quartz pebble clasts, and yellow to white feldspar, the latter mostly decayed to kaolinite.

The conglomeratic content of the Chippewa Bay Member varies substantially from place to place in this general region of New York State, and there are a number of localities where this unit can be classified as a feldspathic arenite to quartzarenite depending on the presence or absence of feldspar clasts. However, the red to pink banding so characteristic of the Ausable and equivalent Covey Hill is almost always present in this region of the state, which serves to differentiate these beds from the sometimes lithologically similar, Keeseville Formation.

In the immediately adjacent regions of Quebec, the Chippewa Bay Member of the Covey Hill Formation is exposed at several localities near the village of Covey Hill, and in the ditches of the roads that climb the steep incline above the type locality. Undoubtedly the most continuous section anywhere exposed is part way up the incline at station Q-13 (see Figure 36) where 21

Figure 36: Ditch section, showing a typical exposure of Covey Hill Formation (Chippewa Bay Member) along roadway leading to the summit of the high hill above the village of Covey Hill, Quebec, at station Q-6. Here, and elsewhere, in this region, the beds are grey-green and locally pink, conglomeratic, and intensely trough cross-stratified.

metres of intensely trough cross-stratified strata were measured. The beds, dipping at 5° to the north are primarily greenish-grey coarse-grained sandstone, containing interbeds of quartz-feldspar pebble conglomerate throughout.

Thirty-seven kilometres north of the above described section, the Covey Hill (Chippewa Bay Member) rises to surface from beneath the Valleyfield Trough where it is exposed near the top of a low escarpment at the western end of Île Perrôt. Approximately nine metres of Chippewa Bay strata are exposed at station Q-2 (see Figure 37), in a major roadcut on Don Quichotte Boulevard. The beds comprise mostly grey, medium to coarse-grained sandstone, with characteristic pink and red banding throughout. Interbeds of quartz-feldspar pebble conglomerate are also common throughout the member, as is well-developed large-scale trough cross-stratification, as described in later pages of the present text. The unit for most part, is thinly bedded, but contained in thick massive layers that weather dark reddish-brown.

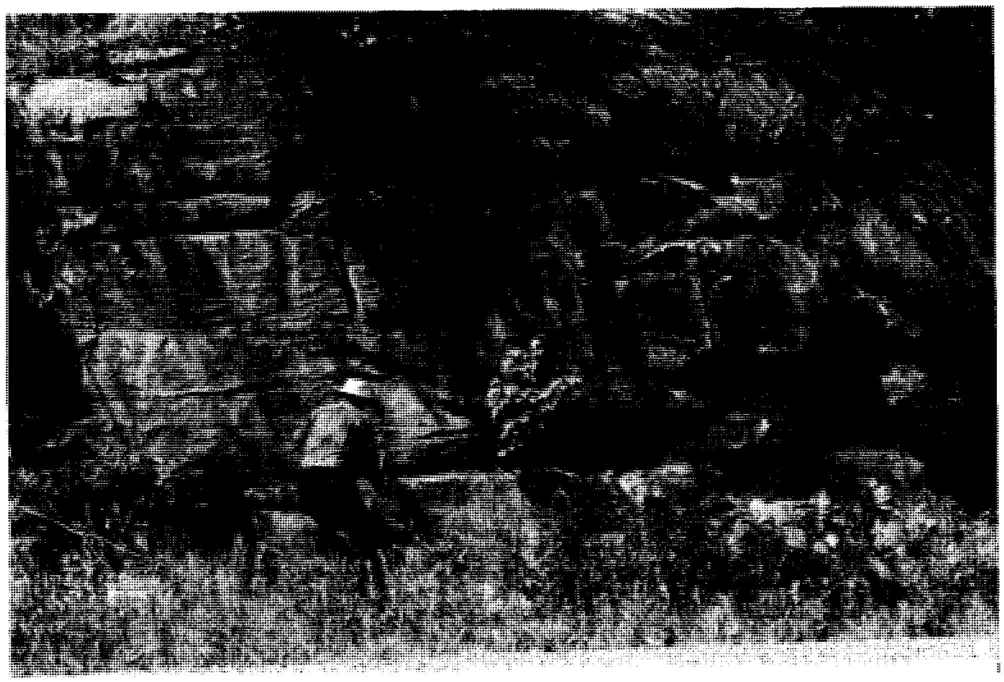


Figure 37: Covey Hill Formation (Chippewa Bay Member) on Ile Perrôt, Quebec at station Q-3. Beds are grey and pink sandstone with intervals of quartz-feldspar pebble conglomerate. (Dune large scale cross stratification is common).

The Chippewa Bay Member can be readily identified in the diamond-drill cored boreholes completed to date in the Ottawa Embayment and western part of the Quebec Basin (see Figure 8). In the western part of the Ottawa Embayment the beds are primarily pinkish-grey, quartzarenite, as first encountered in the GSC Russell No.1 borehole, giving place in an eastward direction to light grey and cream-colored quartz-feldspar conglomerate with sandstone interbeds in the GSC McCrimmon No.1 borehole, with similar conglomerate facies contained in each of the Imperial Laggan No.1 and St. Lawrence River No.1 boreholes. On the northeastern margin of the Oka-Beauharnois Arch, (Quebec Basin), quartzarenite is the more abundant facies, with the quartz-feldspar conglomerate mainly confined to interbeds here and there within the Chippewa Bay Member (see Figure 9, section A-A[1]).

In most of the boreholes, beginning with GSC McCrimmon No.1, much kaolinite is dispersed throughout the interstices of the sandstone and conglomerate, particularly in the drill core that are located in closer proximity to the Oka-Beauharnois Arch (see Figure 8). The Chippewa Bay Member increases in thickness from west to east across the Ottawa Embayment to reach its maximum around the margins of the topographically higher segments of the Oka-Beauharnois Arch, as shown in the following table.

Borehole	Thickness	Borehole	Thickness
Dominion Observatory No.1	0.0 m	St. Lawrence River No. 1	324.0 m
GSC Lebreton No.1	0.0 m	Mallet Test Hole No. 1	322.5 m
GSC Russell, No. 1	11.6 m	Quonto–St. Vincent de Paul No. 1	338.0 m
GSC McCrimmon No. 1	156.4 m	Quonto – Mascouche No.1	196.0 m
Imperial Laggan No. 1	182.3 m		

Table 4: Thickness of Chippewa Bay Member in subsurface (see Figure 8 and Appendix ii, for location).

Edwardsville Member

Completing the Ausable succession in New York State is a thin quartzarenite unit that locally succeeds the Chippewa Bay with sharp contact, herein named the Edwardsville Member. The type section is located at station N-109 on Black Lake Road, about one kilometre east of the village of Edwardsville. Here, the beds consist of light pink quartzarenite, slightly less that one metre in thickness, that are unconformably overlain by the Keeseville Formation (see Figure 38). Elsewhere in the Thousand Islands region of New York the beds

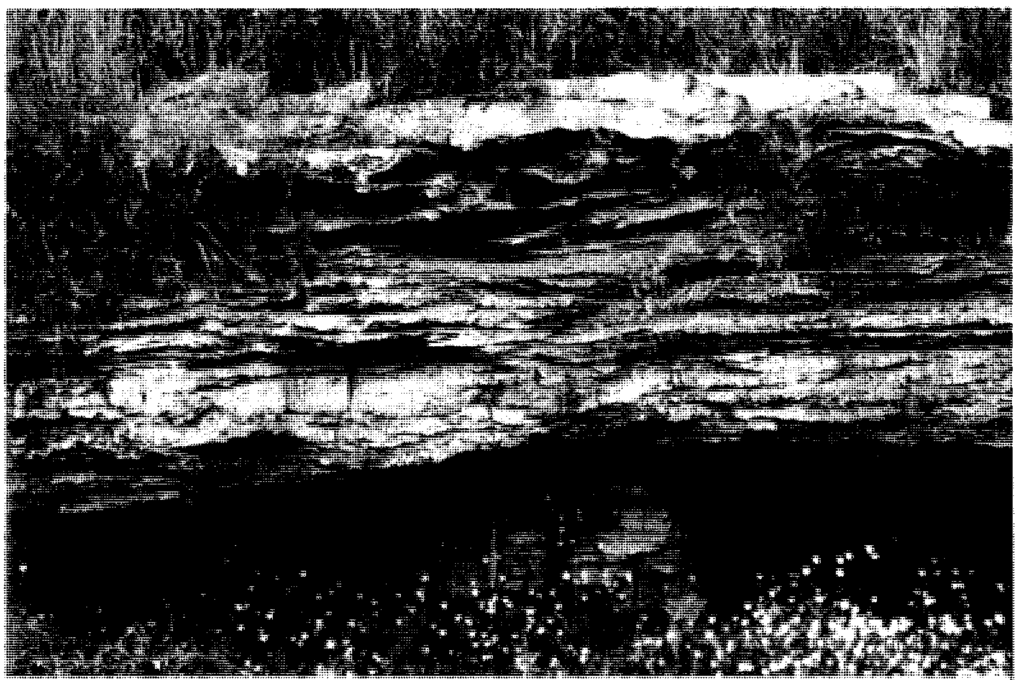


Figure 38: Ausable Formation (Edwardsville Member), overlain unconformably by the Keeseville Formation, on Black Lake Road near Edwardsville, New York at station N-109. (Note the cross-stratification throughout the Keeseville Formation).

have sporadic distribution, having been removed mainly by erosion prior to Keeseville deposition. However, they are particularly well developed at station

N-80, on Route 12, (see Figure 27), where the member can be readily divided into two units, a lower very conspicuous succession of red, thinly laminated strata, one metre in thickness, overlain by pink, thinly bedded quartzarenite, two metres in thickness. A few metres to the east of station N-80, at the same exposure on Route 12, the upper beds of the Edwardsville are overlain by fossiliferous sandstone of the Keeseville Formation with slight angular unconformity [see Figure 65 (b)]. A similar occurrence of Edwardsville Member as described above is present in the reference section located near Alexandria Bay on Route 12 at station N-13, [see Figure 14 (a)], where beds of largely identical composition, color and thickness as at station N-80 are succeeded unconformably by the Keeseville Formation. The Edwardsville Member is apparently absent at the other reference section within the town limits of Theresa at station N-18 [see Figure 14 (b)], where the Keeseville rests unconformably on the Chippewa Bay Member.

Despite the sporadic presence of the Edwardsville Member in the Thousand Islands region of New York State, the unit is apparently nowhere present on the opposite side of the St. Lawrence River in eastern Ontario. Its absence in the latter area is either attributable to non-deposition, or to erosion as a result of the more intensive tectonic movements that were apparently in progress throughout the Ottawa Embayment immediately following the Covey Hill period of deposition.

There is no trace of the Edwardsville Member of the Ausable Formation along the northern margins of the Adirondack Mountains between Black Lake and the vicinity of Chateaugay in northern New York State, perhaps due to burial beneath Quaternary deposits. In the latter locality, however, the member is exposed in the Chateaugay River gorge, where Pulp Mill Road crosses the river at station N-130. On the west bank of the river, a short distance downstream from the bridge, the Edwardsville beds immediately above water level [see Figure 39 (a)], dip at about 17° to the east, and these in turn are overlain by crossbedded strata dipping at 8° to the west-southwest. Both sets are assumed to be of aeolian origin, particularly the lower beds, as suggested by their curved

Figure 39: Ausable Formation (Edwardsville Member) all of assumed aeolian origin exposed in the upper Chateaugay River gorge, New York at station N-130. (a) East-dipping beds, just above water level, in turn overlain by west dipping strata. (b) Pink, thinly laminated and flat lying beds immediately overlying the strata illustrated in photo (a).

and steeply dipping foresets. Overlying these deposits are three metres of flat-lying thinly laminated, pink, fine-grained quartzarenite [see Figure 39 (b)], that is lithologically similar to the Edwardsville Member present to the west in the Thousand Islands region. A few metres to the west of the above exposure is an outcropping of white massive bedded sandstone, 1.5 metres thick, at a slightly higher topographical level, that is herein classified as Keeseville Formation, its lower contact with the Ausable Formation not exposed. A short distance downstream, the Ausable – Keeseville contact crosses the river, at which point the latter formation forms the bedrock surface, dipping northward into the Ottawa Embayment (see Geological map, Figure 3).

Twenty-five kilometres to the northeast of Chateaugay, New York, and in adjacent areas of Quebec, are two thin exposures of Edwardsville Member located at the very summit of the high hill that rises above the Quebec Lowland, approximately two kilometres north of the International boundary at station Q-14 and Q-15. The stratigraphically lower of the two (Q-14) is light greenish-grey and red stained finely laminated quartzarenite. At the slightly higher elevation (Q-15), the beds are deep red, and trough crossbedded. These two outcrops are undoubtedly the youngest strata of the Covey Hill yet found in Quebec, which are assumed also to be equivalent to the beds classified as Edwardsville Member in the Chateaugay River gorge, and points to the west in the Thousand Islands region of New York,

Following deposition of the Ausable and equivalent Covey Hill formations, it is proposed that these units were exposed for an extended period (see Figure 4) during which substantial volumes of sandstone and/or conglomerate, were removed by erosion. This was particularly so along the axis and margins of the Frontenac Arch in eastern Ontario, and to a very large extent completely around the outer margins of the Ottawa Embayment and Quebec Basin. Along with the processes of erosion, there was intense deformation from place to place in the form of faulting and folding of the Covey Hill and equivalent Ausable strata, that left a highly irregular surface upon which the succeeding Nepean and equivalent

Cairnside and Keeseville formations were deposited during the Late Cambrian and Early Ordovician.

Where the Ausable Formation forms the bedrock surface around the northern margin of the Adirondack Mountains the beds locally display unique weathering characteristics, quite unlike the Nepean and equivalent Keeseville, or any of the other succeeding formations of Ordovician age. In fact, their very highly irregular surface, (mound-like topographical expression) likely the product of structural deformation closely resembles Precambrian surface terrains of many parts of the Canadian Shield. Some of the Ausable outcrops would have thus been overlooked during the course of current field investigation, had such well-rounded dome-shaped exposures not been searched out and examined in closer detail.

Sedimentary Structures

With the exception of Lewis (1963), very little attention has been given in the past to research on a regional scale relating to the reconstruction of paleocurrent flow directions in the Potsdam Group. Sedimentary structures, particularly crossbedding, a necessary component of such research, abound in the Covey Hill and equivalent Ausable formations, the single most prominent of features being trough crossbedded structures. These occur in great abundance in the alluvial deposits of the Covey Hill Formation on Île Perrôt and Covey Hill areas of Quebec, and in the equivalent Ausable Formation where exposed on Interstate 87, and Route 190 in the adjacent area of New York State. Although substantially fewer in number in the western part of the Ottawa Embayment in New York and eastern Ontario, they are in sufficient numbers to establish reliable wind and water sediment transport directions on a broad scale in that region as well.

During the course of present investigations in the Ottawa Embayment and adjacent region of the Quebec Basin, time and resources did not permit comprehensive paleocurrent analysis of each of the stratigraphic units contained in the Potsdam Group. Long cognizant however of the importance of paleocurrent studies relating to sedimentary basin evolution, an effort was made to revisit a few of the sites for closer examination, where crossbedding had been previously noted to be well developed. The crossbedding measurements thus obtained on a reconnaissance scale were far too few to obtain a basinwide understanding of paleocurrent flow directions. Those that were obtained however, serve to provide a means of comparing paleocurrent directions in the Covey Hill and equivalent Ausable Formation, with the Nepean Formation and its equivalents, the two sequences representing very different environments of deposition (e.g. wind versus water transport). The measurements shown in Table 5, for the Covey Hill and equivalent Ausable formations, and illustrated in Figure 50 (identified by red arrows) as they relate to measurements in the latter formations, are discussed in further detail in a later section of this dissertation.

Locality	Station	Number of Readings	Average paleocurrent flow direction
Gananoque, Ont.	O-52	50	300°
Briton Bay, Ont.	O-18	16	021°
Ile Perrôt, Que.	Q-2/Q-3	37	056° / 129°
Alexandria Bay, N.Y.	N-13	50	163°
Ellenburg, N.Y.	N-139	23	139°

Table 5: Paleocurrent flow directions in Covey Hill (Ausable) Formation at selected locations in eastern Ontario, western Quebec and northern New York State.

Some good examples of trough crossbedding in the Covey Hill and equivalent Ausable formations are shown in figures 40 to 45 inclusive. The ripple trough cross-stratified beds of Figure 40 (a), occur in basal strata of the Covey Hill Formation (Hannawa Falls Member), at the base of a low escarpment near the western end of Île Perrôt at station Q-2. The narrow width of the troughs (see hammer for scale) is typical also of those found at the one other exposure of Hannawa Falls in an adjacent area of New York State on Interstate 87 near Laphams Mills at station N-212. Higher in the Covey Hill succession (Chippewa Bay Member) on Île Perrôt at station Q-3 [see Figure 40 (b)], trough cross-stratified beds crop out. Hofmann (1972) reports troughs in these same beds up to 15 metres wide.

Well developed trough cross-stratification in Ausable strata (Chippewa Bay Member) is also exposed on Route 190 at station N-139 near Ellenburg Centre New York, (see Figure 41). This station is a classic site for the study of trough cross-stratification and alluvial sedimentation processes, and should thus be a destination for anyone involved in such studies of the Potsdam Group in this region of the state. Paleocurrent flow directions as recorded in the eastern part of the study area (east of the Oka-Beauharnois Arch) although widely divergent from place to place, have an average eastward component into the Quebec Basin.

Far to the west in the Thousand Islands and Black Lake regions of New York, dune trough cross-stratification is developed in the Chippewa Bay Member at several locations. In the Hammond area at station N-96 (see Figure 42) on the northeast side of the Frontenac Arch, trough cross-stratification in hummocky sandstones of the Ausable Formation of possible fluvial origin (Chippewa Bay Member) have apparent flow directions to the northeast, into the Ottawa Embayment, whereas farther to the west in the Alexandria Bay area, bordering the Frontenac Arch to the west, measured flow directions are to the southeast. In the latter area – the highly random paleocurrent direction opposite to what one might expect is probably due to the variable configuration of the paleoslope, as a

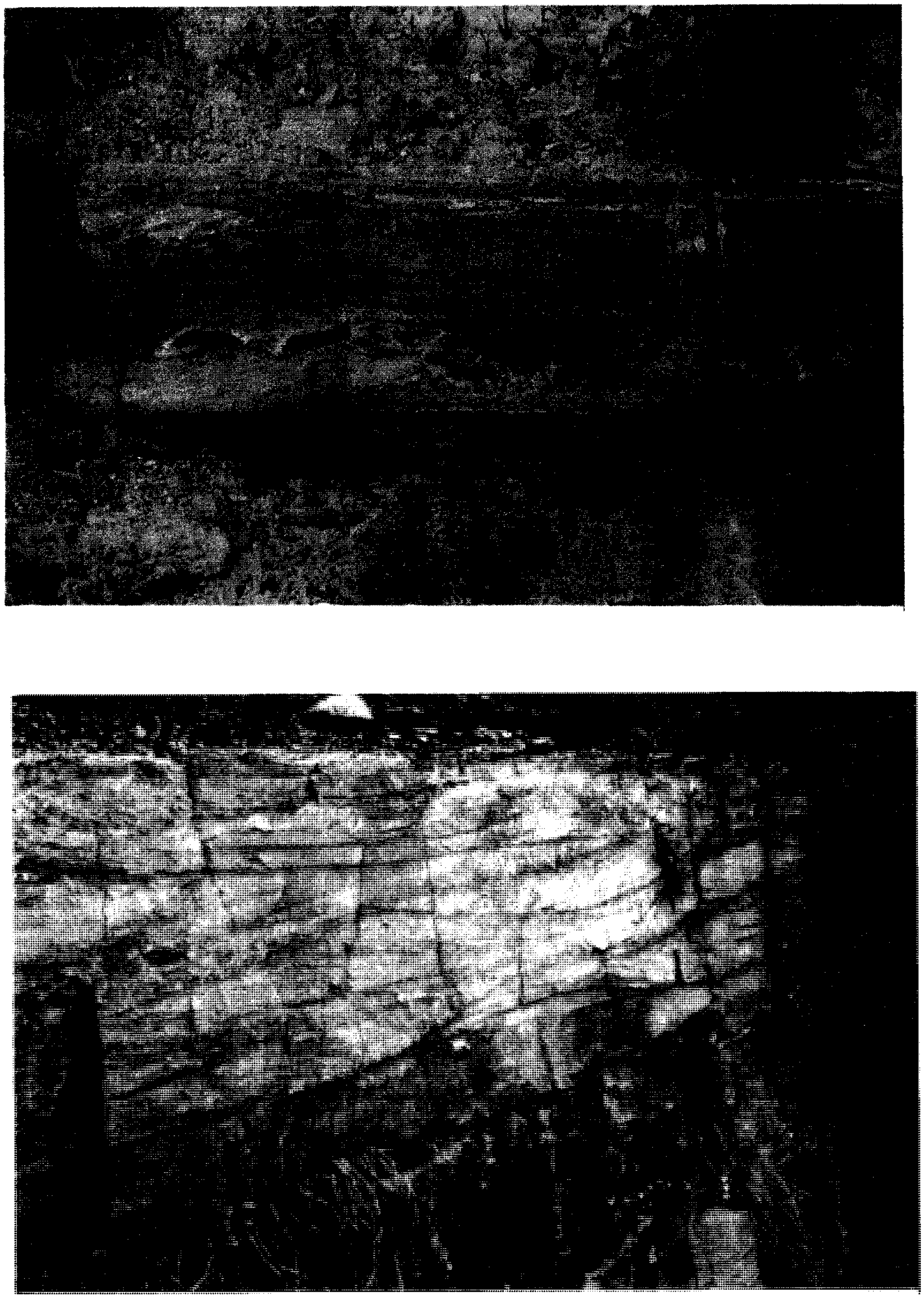


Figure 40: Cross–stratification in Covey Hill Formation near western extremity of Île Perrôt, Quebec. (a) Small scale ripple cross-lamination in Hannawa Falls Member, near its base at station Q-2. Note maroon shale fragments derived from subjacent Jericho Member, the latter possibly present in subsurface, at or near this locality. (b) Small to medium scale dune trough cross-stratification in overlying Chippewa Bay Member at station Q-3.

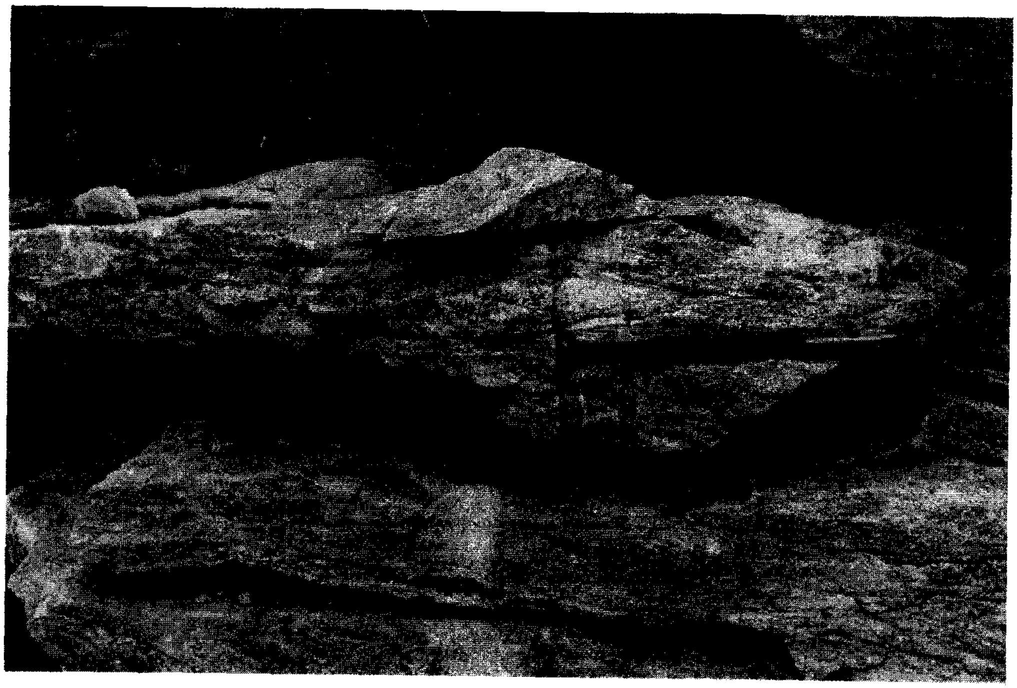


Figure 41: Dune trough cross-stratification in Ausable Formation (Chippewa Bay Member) in roadcut on Route 190 near Ellenburg, New York, at station N-138.

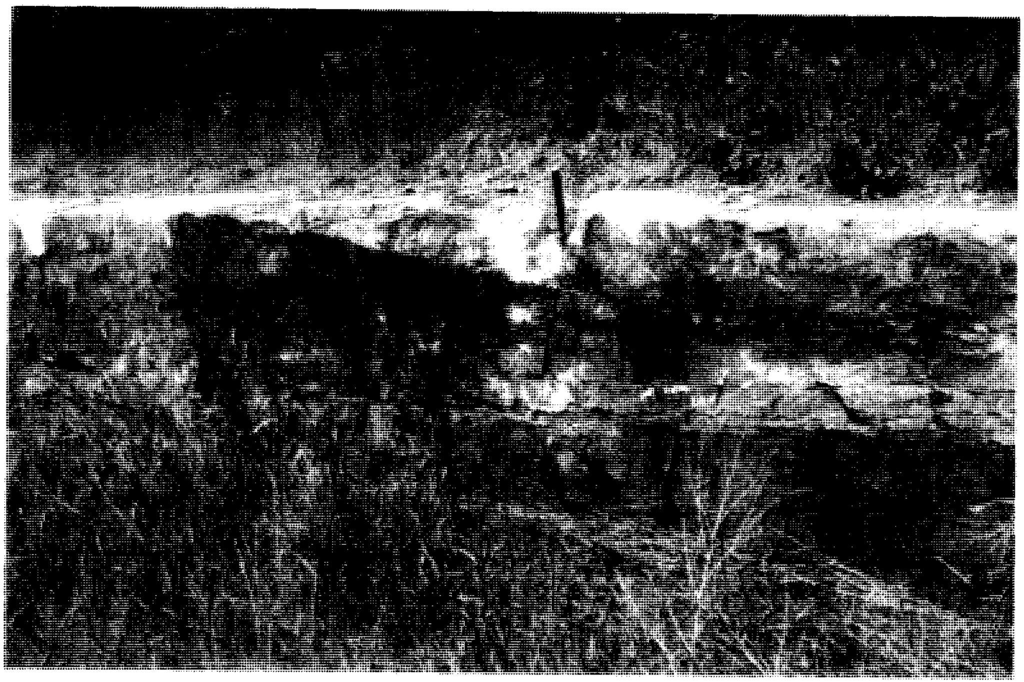


Figure 42: Dune trough cross-stratification in Ausable Formation (Chippewa Bay Member) in roadcut on Black Lake Road, near Hammond, New York, at station N-96.

result of uplift and block faulting of various isolated segments of the Frontenac Arch during the Early Cambrian.

In the adjacent area of eastern Ontario, dune trough cross-stratification in aeolian deposits of the Chippewa Bay Member of the Covey Hill Formation is well developed in a down-faulted block near Gananoque at station O-52 (see Figure 43) that indicate an average flow direction of 300°. Well developed dune

Figure 43: Dune trough cross-stratification in isolated remnant (down-faulted block) of Covey Hill Formation (Chippewa Bay Member) in roadcut on Highway 2, near Gananoque, Ontario, at station O-52.

trough cross-stratification was also found in abundance in the Chippewa Bay Member, also of aeolian origin, 4.5 kilometres southeast of Elgin, Ontario at station O-30, (see Figure 44). Precise flow directions were unattainable here, but an approximate orientation to the southeast, into the Ottawa Embayment is probably a fair estimate of the direction of transport.

At Briton Bay quarry, described earlier, on the south shore of the Rideau Lakes at station O-18, are two cut and fill structures, one superimposed on the other, oriented in a north-northeast direction (021°), the remains of river channels

Figure 44: Trough cross–stratification in Covey Hill Formation (Chippewa Bay Member) 4.5 kilometres southeast of Elgin, Ontario, at station O-30.

that transected the region during the Covey Hill (Chippewa Bay Member) depositional period. Only the northeast margin of the channels are intact, showing the steeply dipping sandstone and pebble conglomerate that were once part of the bedload being swept along by the current of the river as it flowed northeastward into the Ottawa Embayment (see Figure 32). Imbrication and other textural variations in the quartzite cobble conglomerate are commonly displayed in the uppermost lithic unit of the Briton quarry, as illustrated in Figure 45.

In contrast to the abundance of trough crossbedding in the Covey Hill and equivalent Ausable formations, asymmetrical ripple markings were rarely noted. There are probably many occurrences where these were overlooked, due mainly to the fact that most of the sections examined in the field are vertical roadcuts, where such small scale features are more difficult to identify.

Large scale cross-lamination formed by scouring and stratigraphic onlap are particularly well developed in the Hannawa Falls Member of the Ausable

Figure 45: Imbricated clasts of quartzite cobble conglomerate in Covey Hill Formation (Chippewa Bay Member), Briton Bay quarry, Ontario, at station O-18.

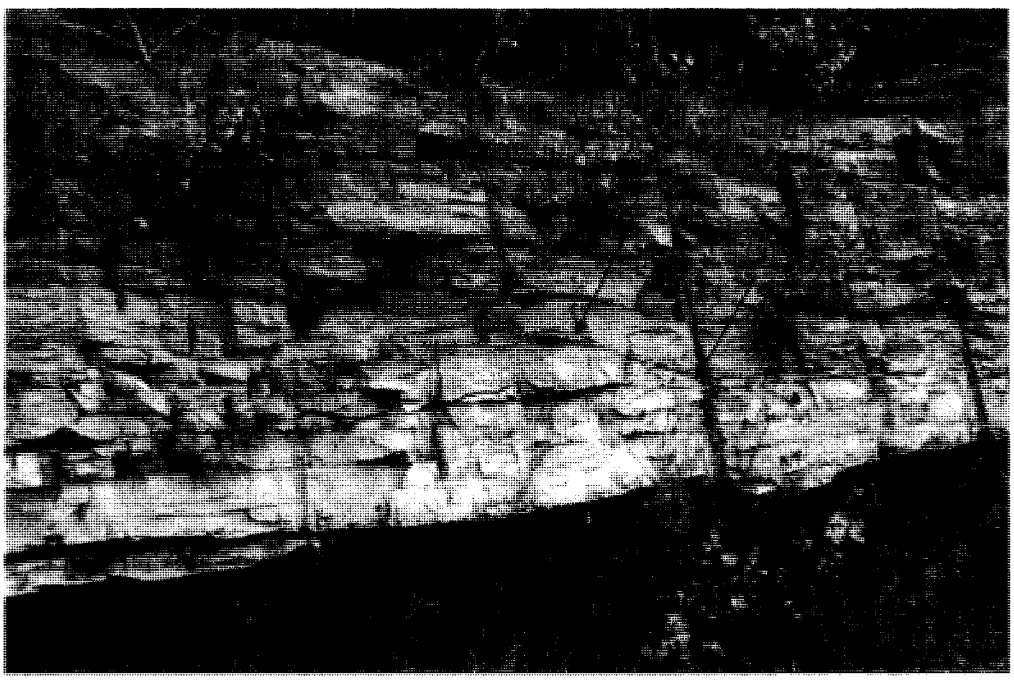


Figure 46: Cross-lamination formed by scouring and stratigraphic onlap near base of Ausable Formation (Hannawa Falls Member), on Route 12, New York, at station N-54. Arrows point to scoured surface. (Note bleaching of lower beds of formation, immediately above its contact with Precambrian).

Formation in the Thousand Islands region of New York with perhaps one of the better examples observed at station N-54 (see Figure 46).

Crossbedded aeolian deposits are important components of all three members of the Covey Hill and equivalent Ausable formations in widely separated parts of the study area. The more readily recognizable occurrences (aeolian cross-stratification) with dips up to 30° are contained in the Hannawa Falls Member in the following locations in Ontario and New York State as recorded in Table 6 (the thickness and transport directions are approximate).

Location (stations)	Thickness	Paleoflow direction
Edwardsville Member		
Chateaugay River, N.Y. N-130	1-2 m	090°E and 260°W
Covey Hill, Que. Q-15	10 cm +	100° E
Chippewa Bay Member		
Elgin, Ont. O-30	2 m	135° SE
Goose Bay, N.Y. N-53	1 m	220° SW
Hannawa Falls Member		
Sunbury, Ont. O-56 and O-57	5m	250° SW and 180° S
Jones Falls, Ont. O-29	1 m	360° N
Redwood, N.Y. N-58	4-5 m	225° SW
Hannawa Falls, N.Y. N-123	4 m	225° SW

Table 6: Paleoflow directions of aeolian dunes in Covey Hill (Ausable) formations in eastern Ontario, western Quebec and northern New York State.

In the succeeding Chippewa Bay Member of the Covey Hill and equivalent Ausable formations, similar aeolian grainflow cross-stratified deposits were identified at two locations; near Elgin, Ontario at station O-30 where two intervals about one metre in thickness each, dip 16° to the southeast and on Route 12, New York at station N-53, where the unit less than a metre in thickness, dips 10° to the southwest.. The latter occurrence extends along Route 12 for upwards of a kilometre.

Beds that are herein interpreted to be of similar aeolian origin were identified by the writer in the upper beds exposed in the Chateaugay River gorge at station N-130. Two sets of crossbeds contained in the Edwardsville Member of the Ausable Formation are exposed here, one resting upon the other dipping in opposite directions. The lower set is dipping at 17° to the east, the other set at 8° to the west [see Figure 39 (a)].

At the crest of the high promontory that rises above Covey Hill, immediately north of the International boundary in Quebec at station Q-15, is a pavement exposure, consisting of dark red quartzarenite of the Edwardsville Member. Only a few centimetres of very thin laminated strata are exposed, and these are contained in a single set of trough crossbeds that dip at low angle to the east (100°). These could be either fluvial or aeolian origin, but because of the nearby occurrence of aeolian deposits in the Chateaugay River gorge, the latter interpretation of their origin is the more likely.

Numerous occurrences of climbing wind ripple deposits were noted in all three members of the Covey Hill and equivalent Ausable formations throughout the western part of the study area. Apparent direction of transport of these beds is often difficult to obtain in the field, and no attempt to measure these on a systematic basis was made.

Although water expulsion structures probably occur in Covey Hill and Ausable formations at numerous localities throughout the study area, only one such feature was identified and documented during the present study. It is located on the Jones Falls Road, 2.5 kilometres west of Highway 15, at station O-29 (see Figure 19). It appears to have formed as a major eruption of formation fluids that traversed upward through the section in a radiating pattern, and thence collapsed back into the cavity created by the eruption. Similar concave upward cone shaped structures occur in similar age rocks at or near station N-58, on Stine Road, 3.5 kilometres northeast of Redwood, New York. These were identified and described in some detail by Dietrich (1953).

Perhaps the more exotic of sedimentary structures are the cylindrical columns that are contained in the aeolian beds of the Hannawa Falls Member of the Covey Hill Formation, on the William Hughes property at station O-56 [see Figure 47 (a)]. These can be viewed in cross-section at this location along with the inner concentric banding of one of the columns [see Figure 47 (b)]. On the opposite side of the Cataraqui River in the Sloan quarry at station O-57, the top of what may be an unexhumed column is well displayed in plan view [see Figure 48 (a)].

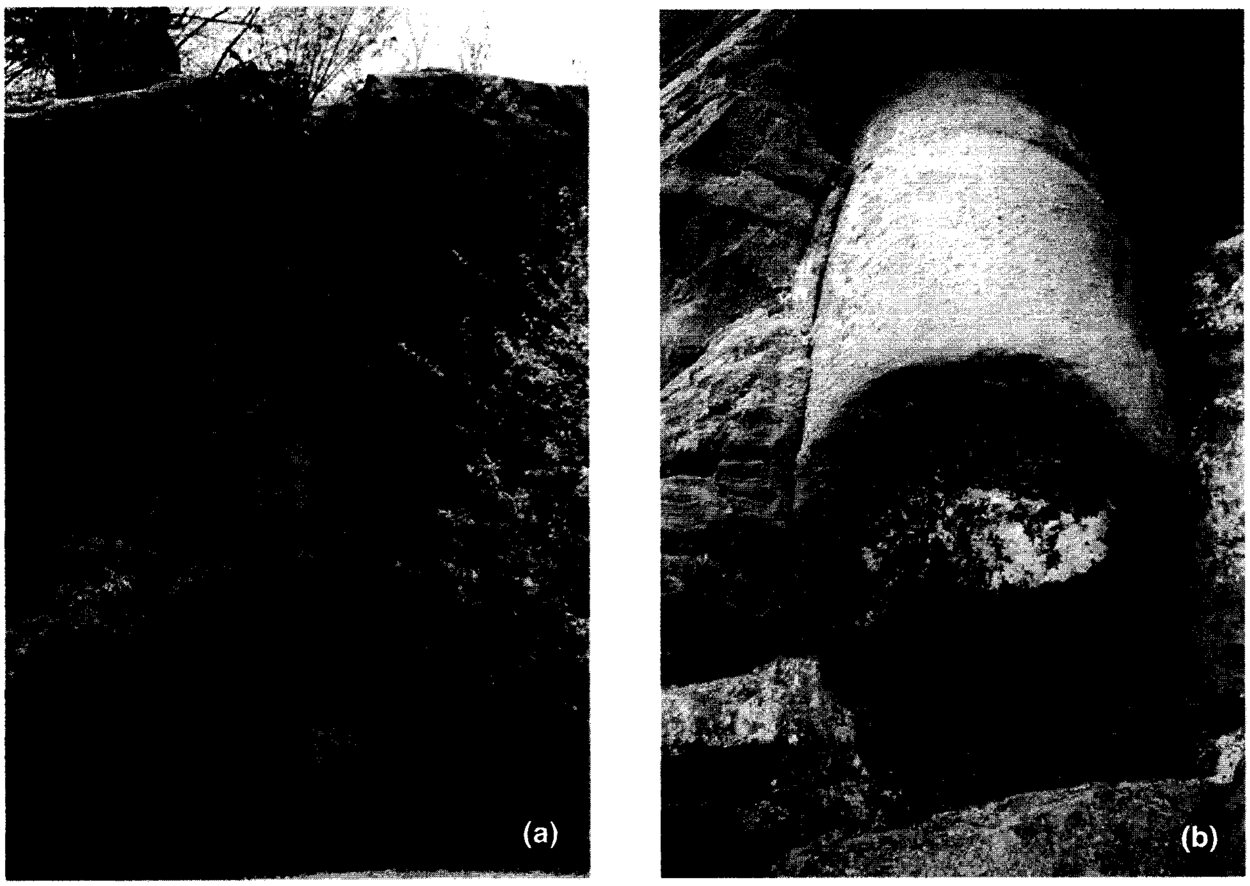


Figure 47: Cylindrical columnar structure formed in aeolian sandstone of the Covey Hill Formation (Hannawa Falls Member). (a) "Park of Pillars", on south shore of Cataraqui River (Rideau Canal), at station O-56. (b) Cross-sectional view of internal structure of a column, showing concentric layering of the sandstone.

The origin of these structures has been the subject of speculation for a great many years, and the controversy will likely never be settled, until such time as one of the columns can be dismantled at its base, to determine whether it originated from the bottom or the top. Discussion relating to the description and origin of the columns located on the William Hughes property and elsewhere are contained in Baker (1916), Dietrich (1953), Donaldson and Chiarenzelli (2004), Gruhman and Peterson (1992), Hawley and Hart (1934), and Miser (1935). Some of the theories that have been put forward for their origin, by the above authors and others as paraphrased from Winder and Sanford (1972) are: (i) fossil tree trunks (an interpretation not to be taken seriously); (ii) excavation of potholes and later infilling by sand; (iii) concretions; (iv) collapse or local slumping of sand into cavities in underlying Precambrian marble; and (v) structures formed by dewatering processes.

From the writer's perspective the more logical explanation for the origin of the columns is item (ii) above, as there appears to be a fair amount of evidence to support the concept that they were drilled from the top down by rotating quartzite cobbles in vortices on the floor of stream systems, much like the motion of a diamond bit drilling into bedrock. Some of the supporting evidence is as follows:

(i) Potholes that formed in Quaternary and more recent times are well documented in the literature. Some are in the process of forming today in the bottom of fast moving stream systems, cutting perfect cylinders into the bedrock formations, one of the better examples being "Jacob's Well", located in Ausable Chasm in northeastern New York State. This particular feature approximately six metres in depth and 1.6 metres in diameter, is similar in dimensions to the cylindrical columns located on the William Hughes property at field station O-56.Therefore the technique is a well known and valid process that must be taken into consideration;

(ii) The columns on the Hughes property (station O-56), and in the adjacent Sloan quarry (station O-57), are contained in the Hannawa Falls Member of the Covey Hill Formation [see Figure 47 (a)]. The unit in this locality is a redbed sequence of aeolian deposits that was deposited under extreme arid conditions; totally unlike the immediately overlying beds of the Chippewa Bay Member, containing fluvial, aeolian and possible lacustrine deposits representative of a far more humid climatic regime. The major change in climate that is likely to have taken place between the deposition of the Hannawa Falls and Chippewa Bay members could not have happened abruptly. The evidence here and elsewhere throughout the study area is that a substantial period of time may have elapsed following the deposition of the Hannawa Falls, that enabled the latter to have become sufficiently consolidated to withstand the drilling process;

(iii) A good example of the "tools" that may have drilled the cylinders in the Hannawa Falls are shown in the overturned block of Chippewa Bay Member [see Figure 48 (b)]. These are quartzite pebbles and cobbles that lie at the base of the Chippewa Bay Member just above the contact of the two members where the drilling began [see contact at hammer in Figure 48 (b)];

(iv) When the current velocity of the stream systems could no longer sustain the drilling process beyond a certain depth (i.e. 5-6? metres) the cylinder would gradually begin to fill with sand. This would likely have been a mixture of the red Hannawa Falls, and yellowish-grey Chippewa Bay, and that appears to be what is contained within the columns;

(v) The introduction of the sand into the cylinder would have been rotational due to the continuing helical motion of the stream bottom current, as shown by the concentric layering along the inner walls of the cylinder, and at the surface expression of the column, as shown in Figure 47 (a) and Figure 48 (a), respectively; and finally,

(vi) Cylindrical columns located at or near station N-58 on Stine Road, near Redwood, New York are contained in a stratigraphic framework largely identical to station O-56 and O-57 described above, e.g. aeolian strata abruptly succeeded by fluvial deposits. This would suggest that the two

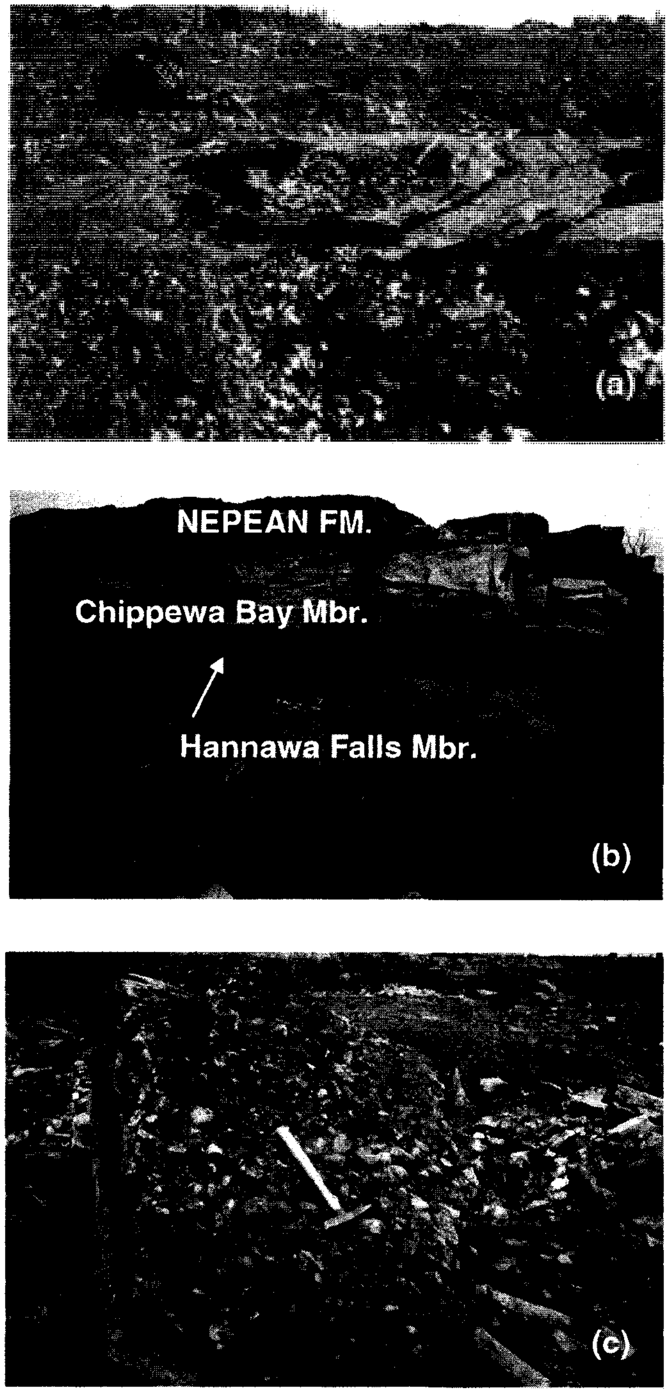


Figure 48: Evidence for assuming the presence of a cylindrical column in Sloan quarry on the north shore of the Cataraqui River at station O-57. (a) View of assumed top and concluding phase of column (note concentric banding, marking the final infilling process (?) of the underlying structure). (b) Aeolian sandstone of the Hannawa Falls Member, below hammer, overlain unconformably by stream-bed deposits of the Chippewa Bay Member. Head of hammer marks the horizon where drilling of the nearby cylinder, shown in (a) above, is believed to have begun. (c) Overturned block of Chippewa Bay Member showing the basal quartzite cobble conglomerate – the latter being the presumed source of the rotating tools for the drilling of the cylinder.

occurrences may have been triggered by a similar, if not identical geological process.

The columns near Redwood, New York are described by Dietrich (1953), who attributed their origin to slumping into - "cavities formed in the underlying Precambrian marble, during or after deposition of the Potsdam sand".

A similar, but much smaller columnar structure than those described above was found at station O-30 approximately 4.5 kilometres southeast of Elgin, Ontario [see Figure 49 (a) plan view, and (b) partial cross-section view]. It too presumably formed by a current induced drilling process from top downward, triggered by the onset of fluvial conditions that prevailed for a brief period between episodes of aeolian deposition below and above.

Various other interpretations for the origin of columnar structures and empty cylinders that occur in the Potsdam Group within the present study area can be found in papers contained in the References of this dissertation.

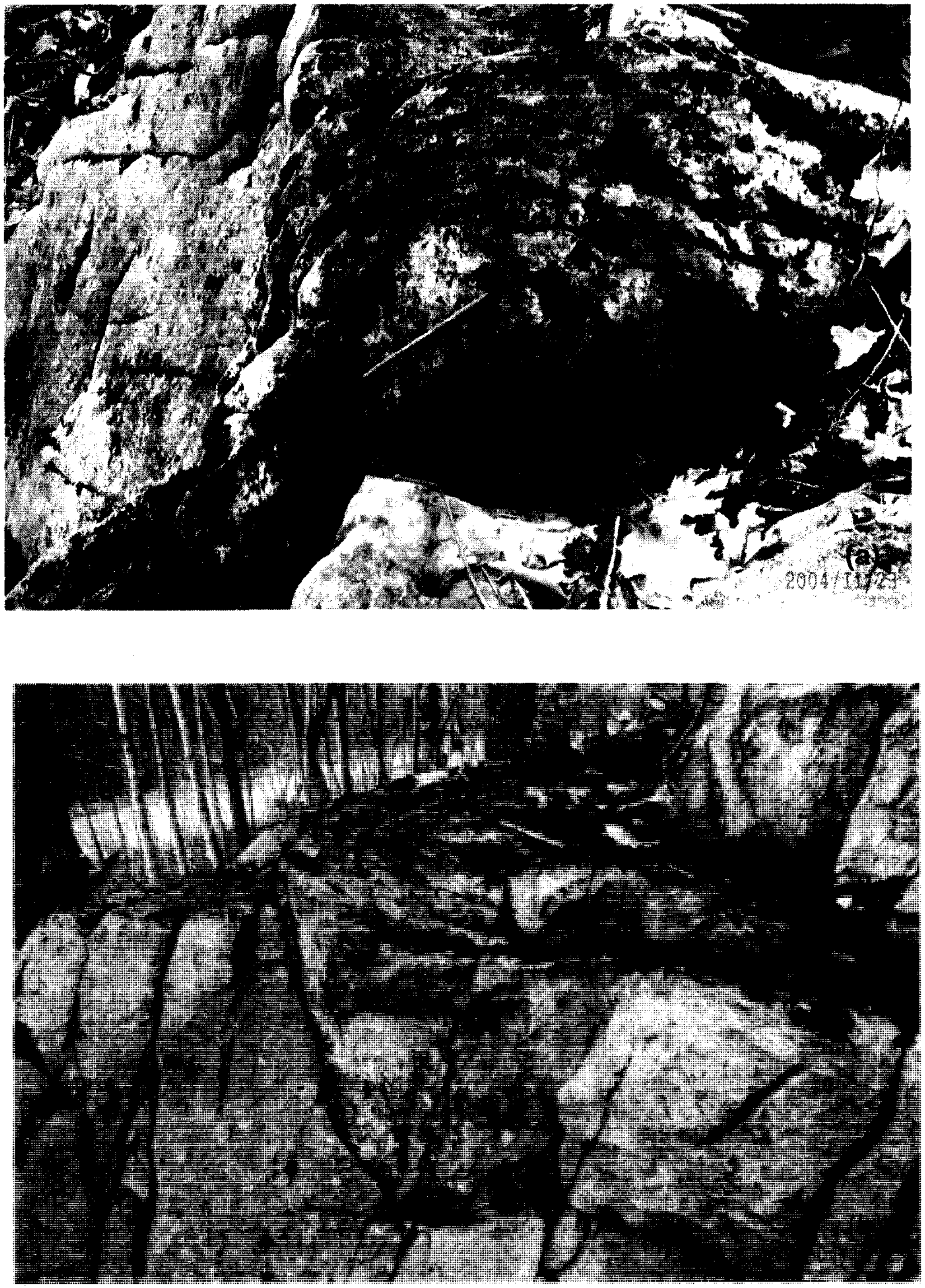


Figure 49: Miniature cylindrical column in the Covey Hill Formation (Chippewa Bay Member) 4.5 kilometres southeast of Elgin, Ontario, at station O-30. (a) Plan view of small columnar structure. (b) Partially exposed cross-sectional view of column.

Petrogenesis

During the initial phases of Potsdam deposition (latest Proterozoic to early Early Cambrian), the structural configuration of the principal tectonic elements bordering and underlying the Ottawa Embayment, and immediately adjacent areas are assumed to have had some general similarity to that of today. The Adirondack Dome was probably an upland area, but only mildly active, as evidenced by the preponderance of fine detritus (sandstone versus conglomerate) that was being transported by the river systems flowing northward into the Ottawa Embayment.

The Frontenac Arch on the other hand, was likely both a prominent physiographic element, and tectonically active during the early Potsdam (Covey Hill and equivalent Ausable) depositional period. This was particularly so along the segment of the arch in eastern Ontario, immediately to the north of what is now the St. Lawrence River. Faulting along the eastern margin of this region of the arch is inferred to have been particularly intensive, resulting in the dispersal of sand and gravel eastward into the Ottawa Embayment. Quartzite cobble conglomerates locally dominated depositional processes along the uplifted margins of the Precambrian, particularly the northeast-trending fault system that transects the Rideau Lakes and the many other faults of dominant northeast orientation that occur in this general region of eastern Ontario. While the gravels (conglomerates) were accumulating along the Frontenac Arch, the sand-size detritus are assumed to have been transported by stream systems eastward into the Ottawa Embayment where they likely accumulated in a lacustine environment of deposition (see Figure 50), and were later reworked and dispersed by aeolian processes.

On the opposite side of the Frontenac Arch, similar processes presumably were underway with sand and gravel being transported into the central and southwestern parts of Ontario by fluvial and aeolian processes. However, much of the history relating to the transport and deposition of Late Precambrian to

Early Cambrian sediments into these regions was long lost by processes of subaerial erosion, during the long hiatus following early Potsdam deposition.

The Laurentian Arch, that extends along the southern margin of the Canadian Shield was also a major tectonic element during the initial phase of Potsdam deposition. Uplift of the arch, perhaps beginning as early as latest Proterozoic or Early Cambrian at the latest, in conjunction with rifting processes in progress at the time, would have been the mechanism that dislodged a large rectangular basement block, that tilted southward, down to basin, that occupies the northern part of the Ottawa Embayment (see Figure 3). This provided an elongated east-west trending receptacle for the accumulation of slightly anomalous thicknesses of sand and gravel into its southern confines, as documented by borehole drilling in this part of the study area (see figures 8 and 12).

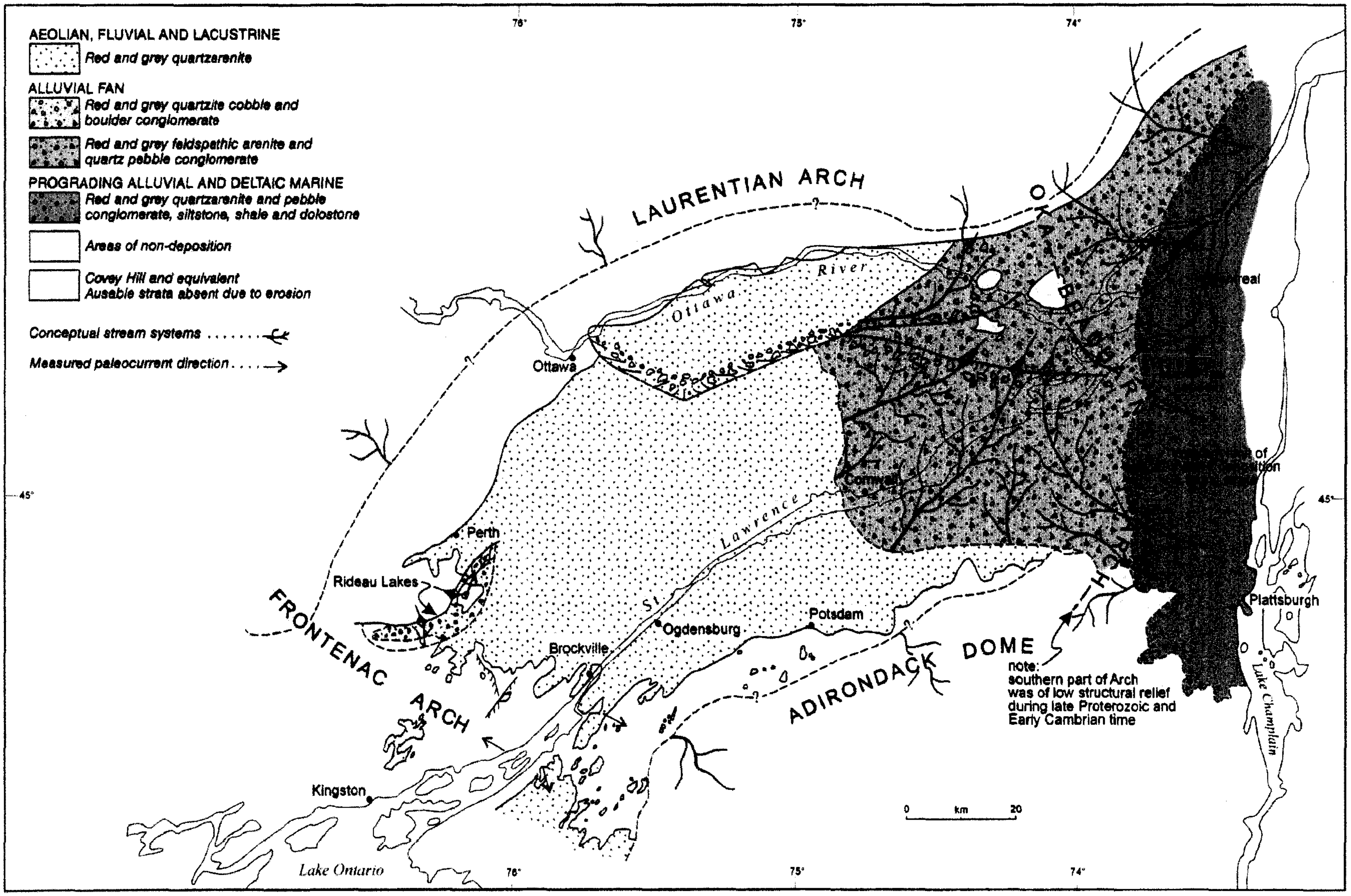


Figure 50. Depositional environments and facies distribution of Covey Hill and equivalent Ausable formations.

The most intensive basement movements anywhere within this overall region evidently occurred during the same period along the Oka-Beauharnois Arch, particularly its more northern segment, now known as the Oka, Rigaud and Saint-Andre-Est mountain regions of Quebec. Major uplift of this segment of the arch resulted in the dispersal of enormous volumes of sand and gravel by alluvial processes, both to the west, south and east into the Ottawa Embayment, and Quebec Basin, respectively (see figures 8, 9 and 50). The high promontory to the south that towers above the Ottawa-Quebec Lowland in the vicinity of Covey Hill was not present during the Early Cambrian. It came into being at a much later period of geological time coincident with uplift of the northeastern region of the Adirondack Mountains. Thus, the source of the thick Covey Hill and equivalent Ausable alluvial sequences of 250 metres or more, in the Covey Hill region of Quebec and adjacent New York, and upwards to 600 metres in the Valleyfield Trough, was probably the mountainous region of the Oka-Beauharnois Arch to the north, more so than the Adirondacks, as implied by the isopach map of those formations illustrated in Figure 12.

At some point in Early Cambrian time, presumably for reasons relating to the cessation of continental rifting processes, Potsdam (Covey Hill and equivalent Ausable) deposition ceased. The ensuing hiatus was, apparently long term, resulting in the erosion of substantial thicknesses of Covey Hill and equivalent Ausable formations. In some regions, including the Ontario axial segment of the Frontenac Arch, and the Waverly extension of the Laurentian Arch that extended into the southwestern part of Ontario, the Covey Hill was removed almost entirely (except for a few outliers here and there) by erosion prior to deposition of the Nepean Formation (see Figure 59).

With the possible exception of the Jericho Member, that was presumably deposited along the inner continental shelf in a marginal marine environment, each of the successive members of the Covey Hill and equivalent Ausable formations are assumed to be of non-marine origin, and there are several lines of evidence to support such an assumption as follows:

(i) the absence of marine fossils and trace fossils throughout the succession, except for arthropod trackways that locally occur near its base in aeolian deposits of the Hannawa Falls Member. Arthropods survive in marine or fresh water environments and evidence of their presence in the Sunbury area of Ontario (station O-56) in those strata prove only that they had migrated a very long distance (a minimum of 200 kilometres) from the nearest seaway, and had become firmly adapted to a continental environment of existence;

(ii) lithological characteristics, and bedform structures that are more likely to be associated with aeolian environments of deposition, e.g. the very uniform thinly laminated beds of the Hannawa Falls (see figures 15 and 21), Chippewa Bay (see Figure 64) and Edwardsville (see Figure 25); and the deposits of sandstone and conglomerate deposited marginal to the Frontenac and Oka-Beauharnois arches, that contain trough cross-stratified sandstone and conglomerate [(see figures 31 and 40 (b)] that are interpreted to be of fluvial origin; and

(iii) the preponderance of aeolian deposits throughout the Covey Hill and equivalent Ausable formations, that point to an ephemeral nature of the stream and lake systems through various periods of Early Cambrian time; and

(iv) the local occurrences of columnar structures that are inferred to have formed as potholes on the bed of fast moving stream systems, during Hannawa Falls and Chippewa Bay deposition.

The definition of each of the rock units comprising the Hannawa Falls, Chippewa Bay and Edwardsville members of the Covey Hill and equivalent Ausable formations is based to some degree on factors relating to lithology and bedding characteristics, but with the principal emphasis on their identification in the field and subsurface, based on color, and iron oxide content. Although the color of a rock unit is not universally attributable to climatic conditions, the distinctive red stained coloration of the Hannawa Falls and Edwardsville members, and the equally distinctive grey and greenish-grey color of the intervening Chippewa Bay member were indeed most likely controlled by climatic conditions that prevailed during those depositional periods. Thus, in the long distance correlation of the rock units from place to place across the Ottawa Embayment and Quebec Basin, there is some additional benefit to be had in the knowledge that the sharp climatic boundaries, where these occur, can be used as " time stratigraphic" indicators, as well.

The lower of the units, the Hannawa Falls redbeds, most likely represents a period of extremely arid conditions due to low rainfall and low water table that enabled the iron oxide to become fixed within the interstices of the sandstone and/or conglomerate, during an early stage of diagenesis. In general, these beds contain substantially lesser volumes of conglomerate than the succeeding Chippewa Bay, and this was presumably at least in part due to the more placid ephemeral stream systems that during periods of arid climatic conditions were unable to sustain the transport of coarse bedload deposits into the basinal regimes. The presence of dust rims that surround the individual sand grains of the Hannawa Falls Member, that are locked into the system by quartz cementation provide an unique tool in the local and regional correlation of these beds from place to place (see Figure 51). The photomicrographs illustrate the well rounded and well sorted framework of the Hannawa Falls Member at the type section. These beds of aeolian origin, consisting of grainflow cross-stratified dunes appear to contain higher concentrations of iron oxide than can be seen to occur in the more common climbing wind ripple structures contained elsewhere in the Hannawa Falls Member. Nevertheless, a good comparison can be drawn between the two types of deposit as exposed at the type section of the Hannawa Falls in New York (station N-123), and strata exposed 100 kilometres distant near Jones Falls, Ontario (station O-27) as indicated by the photomicrographs shown in Figure 52. The similarity between the two areas in terms of the presence of iron oxide dust rims, grain size, texture and presence of quartz overgrowths is compelling.

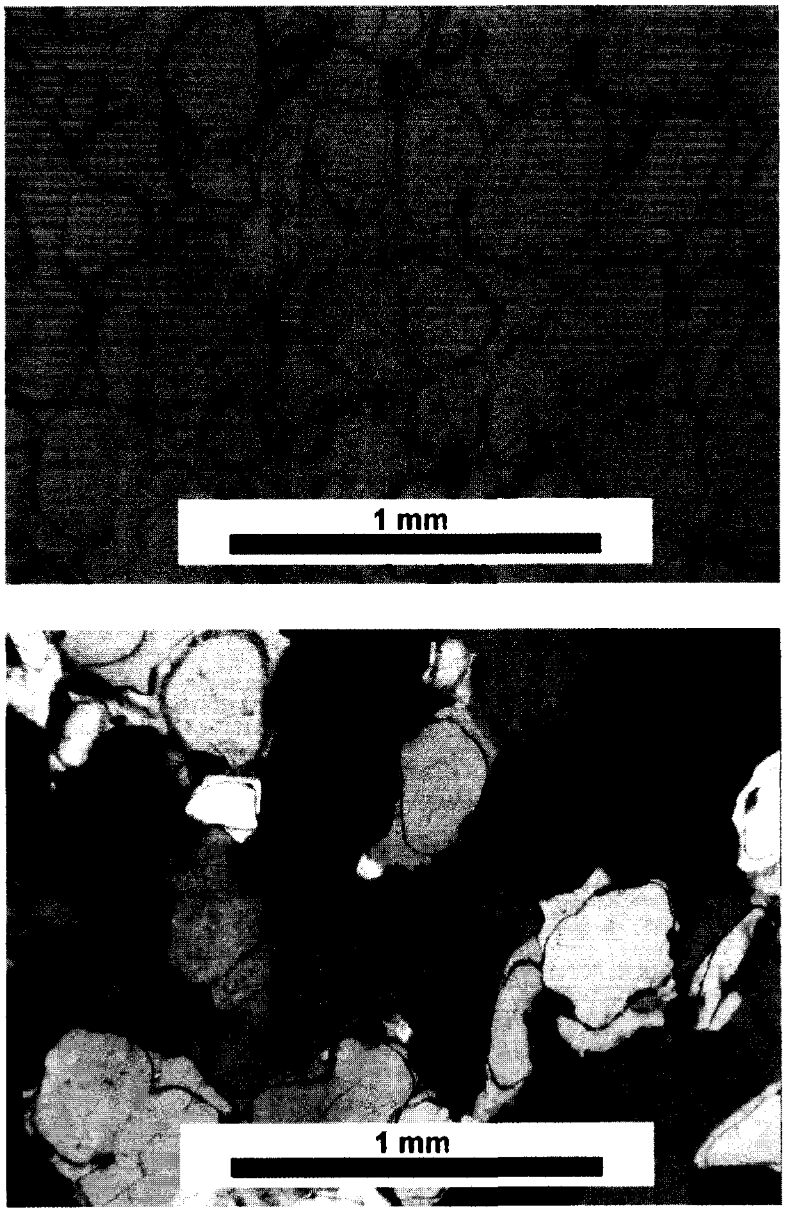


Figure 51: Photomicrographs of the Ausable Formation (Hannawa Falls Member), from the type section at station N-123. (Note red dust rims sealed in place by quartz overgrowths).

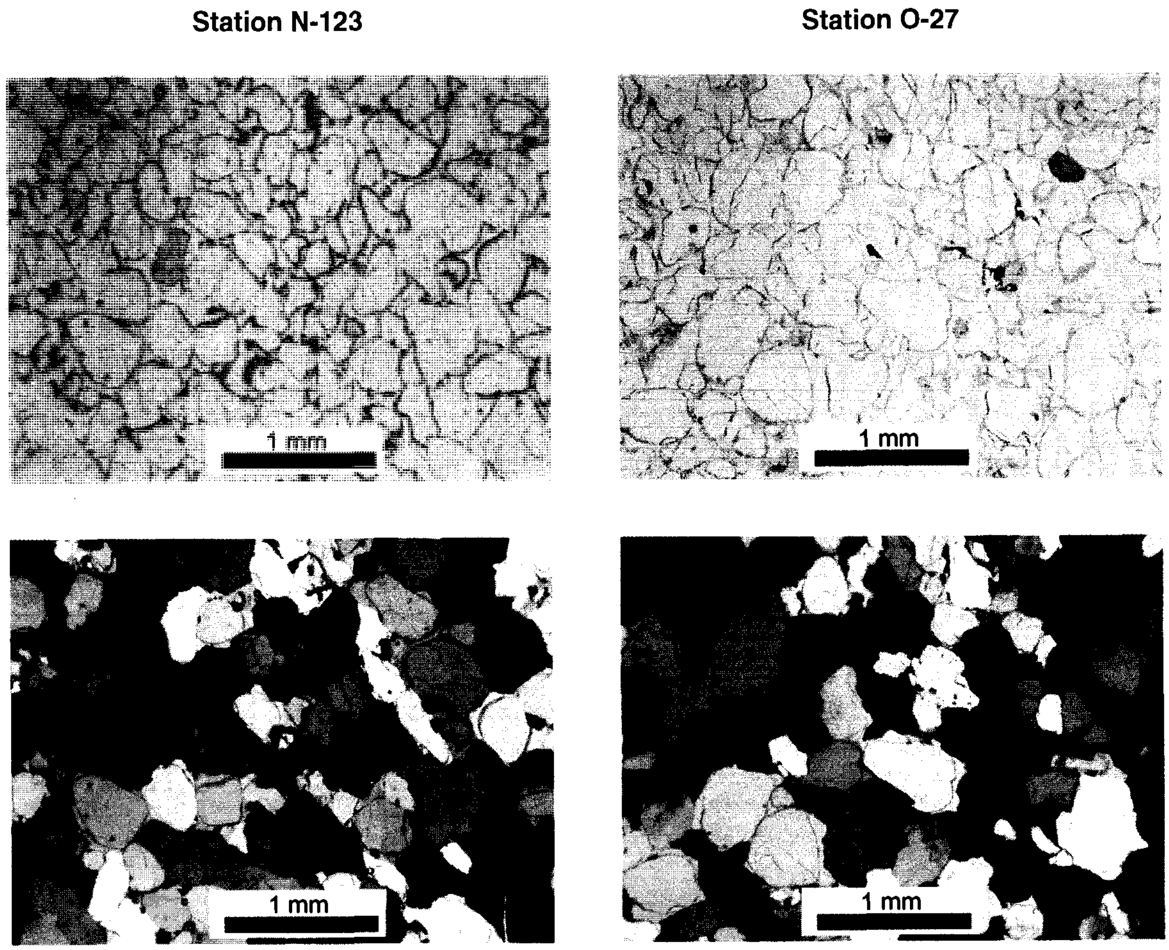


Figure 52: Photomicrographs illustrating the petrographic similarity of Hannawa Falls Member in Ausable and equivalent Covey Hill formations at stations N-123 and O-27 respectively. (Note the presence of dust rims and quartz overgrowths at both stations).

At an exposure of the Hannawa Falls member on Rideau Ferry Road, Ontario at station O-14, are pink, thinly laminated quartzarenite beds, (shown earlier in Figure 21). In thin section (see Figure 53), the detritus can be seen to consist of subrounded, very fine and well sorted quartz grains. The origin of the detritus is somewhat problematic, but is herein assumed to be the fines of a point bar, transported by aeolian processes, and redeposited as climbing wind ripple structures. The well defined outlines of the individual grains shown here, (in plane light) are due to the high concentrations of iron oxide. That this particular

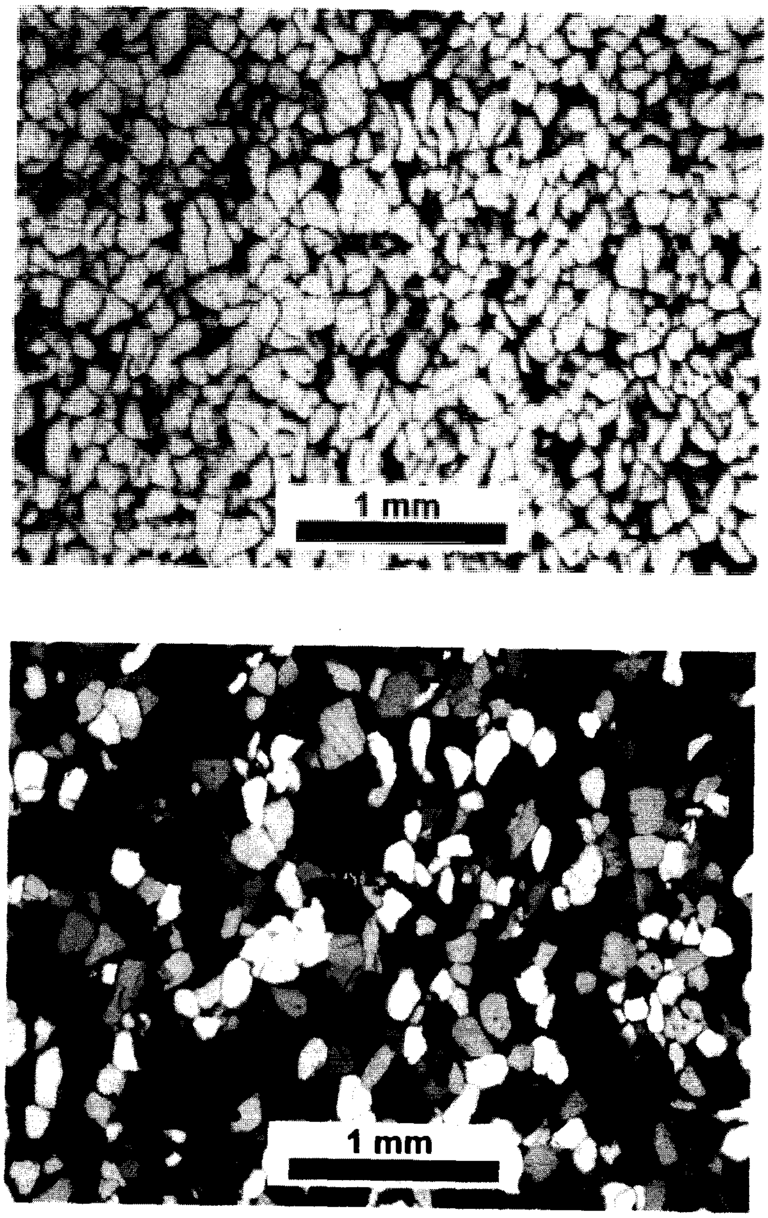


Figure 53: Photomicrographs of the Covey Hill Formation (Hannawa Falls Member) at station O-14. (Note the presence of red dust rims surrounding the sand grains and dispersed throughout the interstices of the sandstone).

exposure is a part of the Hannawa Falls depositional event, as are each of the above described photomicrographic examples, there can be little doubt.

When the above described photomicrographs are in turn compared to the same stratigraphic interval at the opposite extremity of the study area near Lake Champlain (station N-212), some significant differences emerge with regard to sphericity, grain size, sorting, and classification of the rock type (see Figure 54). In the latter area, the feldspathic arenite and quartz conglomerate are of assumed alluvial origin, in sharp contrast to the aeolian quartzarenite of stations N-123 and O-29, described above. Nevertheless, the presence of iron oxide dust rims around the grains, locked into place by quartz overgrowths, would clearly suggest that the strata were deposited during the same arid climatic conditions, and were thus in all probability, a part of the same depositional sequence. (note the large fragment of microcline in Figure 54).

In contrast to the arid conditions that prevailed during Hannawa Falls deposition, the Chippewa Bay beds are the product of a more humid environment, in which the stream systems were capable of transporting much larger volumes of both fine and coarse bedload detritus into the Ottawa Embayment and Quebec Basin (see Figure 50). The coarse cobble and boulder conglomerate deposited in the Rideau Lakes and Charleston Lake areas of eastern Ontario described earlier, were deposited during this interval. At the same time, the finer constituents presumably derived from a similar source (Frontenac Arch, and to a lesser extent the Adirondack Dome) were likely carried into the western part of the Ottawa Embayment by fluvial systems, where they were redistributed over and over by aeolian processes.

There were undoubtedly significant volumes of iron compounds carried into the basinal areas by stream systems during the Chippewa Bay depositional period. The consistent pink and red remnants of iron oxide that still remain in these strata interbanded with the grey sandstone and conglomerate would suggest that the entire unit may have been originally deposited as a redbed sequence. The diagnostic red dust rims that surround the individual quartz grains and feldspar clasts (where the latter are present), in the Hannawa Falls

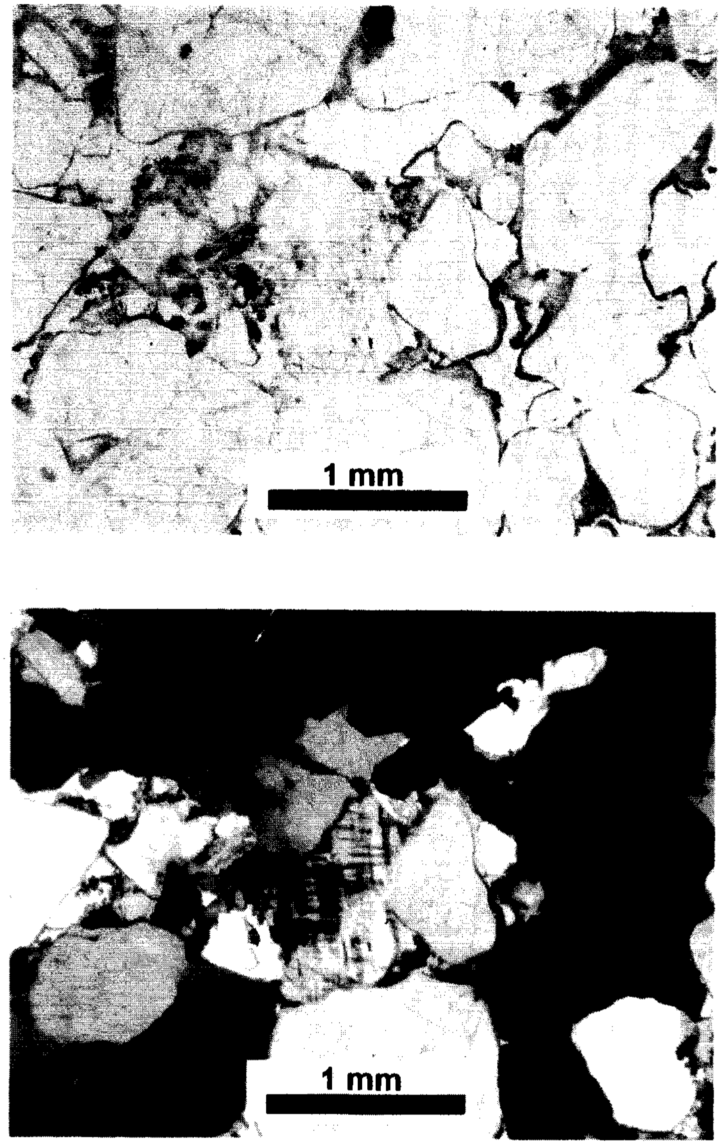


Figure 54: Photomicrographs of the Ausable Formation (Hannawa Falls Member) at station N-212. (Note the coarse texture of the framework, and the presence of feldspar (microcline), and red dust rims surrounding the sand and pebble size grains).

Member, are by no means as well developed in the Chippewa Bay Member. They were presumably washed away (bleached) in large part by the interstitial movement of water soon after their deposition as a result of the more humid conditions prevailing at that time.

There are a number of locations however, where the outline of the individual grains of the Chippewa Bay Member appears to be enhanced to some significant degree by iron oxide staining, sealed in place by quartz overgrowths such as illustrated in the thin section (plane light) photomicrograph of Figure 55, cut from the type section at station N-80. The purpose of thin sectioning here and elsewhere in this particular stratigraphic interval, in the absence of any other criteria, was to find a means of establishing local and regional correlation within the Chippewa Bay, thus to distinguish it from the succeeding Keeseville and equivalent Nepean and Cairnside formations (i.e. see Figure 81), in those few regions where the two formations appear to be lithologically similar. In most instances this technique can be seen to work very well, but there are others in which it may not.

The stratigraphic intervals where this technique may not be conclusive are the zones where large volumes of fluids likely moved interstitially through the Covey Hill and equivalent Ausable formations over very long periods of time, thus removing any traces whatever of iron-oxides. This would be most likely in the lowermost part of the sequence immediately above its unconformable contact with the Precambrian, as shown at station 54 (see Figure 46), and along its upper boundaries, where in contact with the Nepean or equivalent Cairnside and Keeseville formations. Deeply weathered zones that are not uncommon in Covey Hill and equivalent Ausable formations were also conduits for the transport of large volumes of fluids that would in all probability remove or reduce any remaining iron oxide residue that might have been otherwise present in those strata.

There are a few localities in the eastern part of the study area in northeastern New York State and adjacent areas of Quebec, where the use of thin sections would be beneficial in the identification of the Chippewa Bay

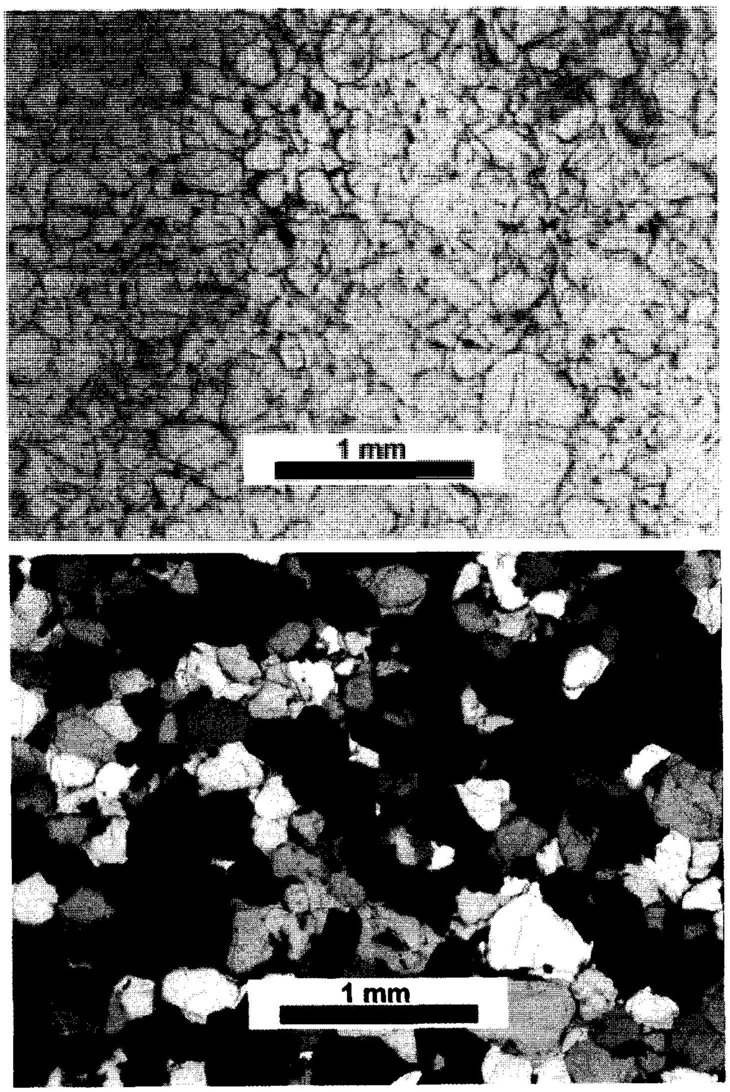


Figure 55: Photomicrographs of the Ausable Formation (Chippewa Bay Member) at station N-80. (Note the traces of red iron oxide residue dispersed throughout the interstices of the sandstone).

Member of the Ausable (Covey Hill) formations whether or not they contain iron oxide residue. Generally, the poorly sorted and arkosic (feldspathic) character of the Chippewa Bay can be identified from a hand specimen in the field. If and when some difficulty in correlation arises, however, a thin section, such as illustrated in the photomicrographs of Figure 56 from a sample taken at station N-152 in New York State, would clearly identify the arkosic rock unit as Ausable Formation. (Note the presence here of the large feldspar (microcline) clast, similar to that identified in Figure 53 sampled from the Hannawa Falls Member at station N-212).

The pink to red coloration of the Edwardsville Member of the Ausable and equivalent Covey Hill formations, where these beds are locally identified in New York and Quebec, are lithologically similar to the more broadly distributed Hannawa Falls Member. The thinly laminated Edwardsville strata, also of probable aeolian origin, are in sharp contrast to the grey Chippewa Bay strata upon which they rest with abrupt and possible disconformable contact, such as at station N-80 (see Figure 25). This major change in color may represent a corresponding change of climatic conditions from a period of high humidity (Chippewa Bay Member) to a period of elevated arid conditions, during the depositional period of the Edwardsville Member.

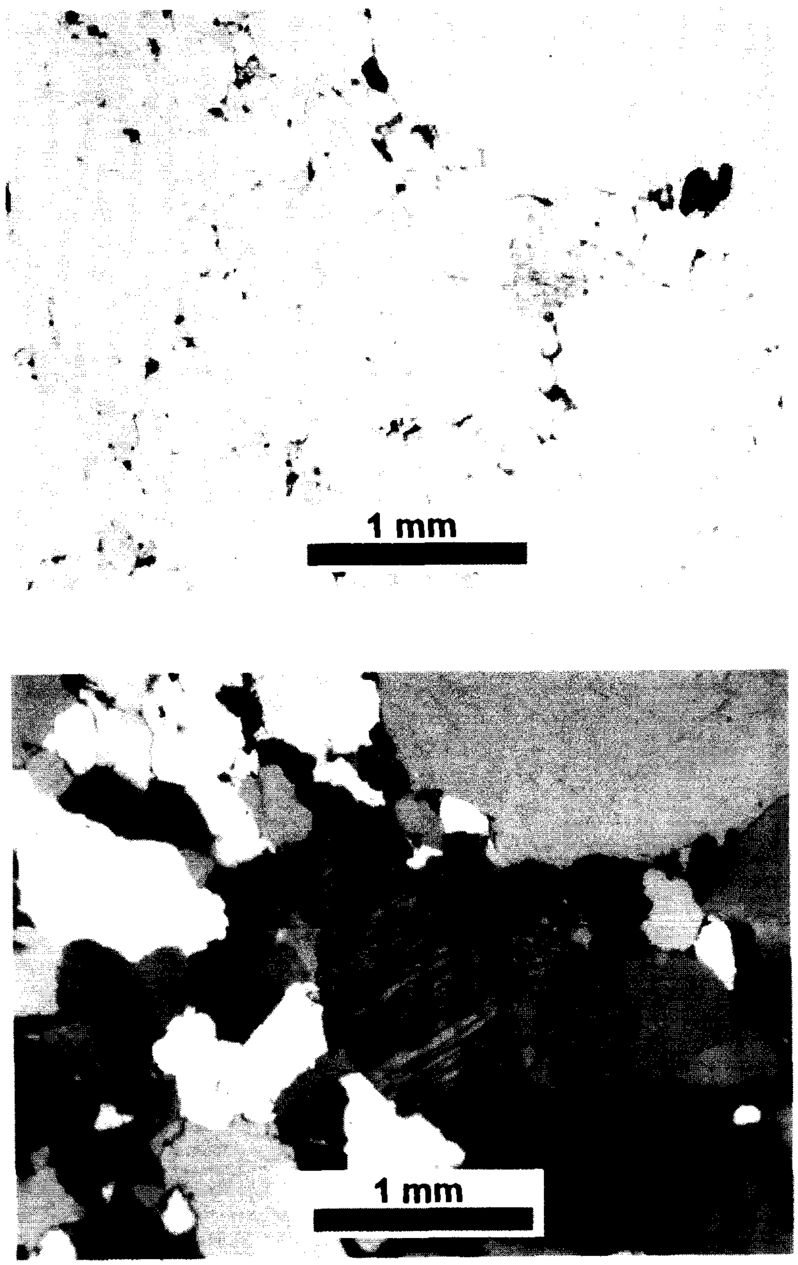


Figure 56: Photomicrographs of the Ausable Formation (Chippewa Bay Member) at station N-152. (Note the traces of iron oxide staining and course texture of the framework and the precence of feldspar (microcline).

Age and Regional Correlation

The age of the Covey Hill and equivalent Ausable formations is uncertain. Some of the comments with regard to the possible age of the Abbey Dawn Formation contained in a previous section of the present dissertation, applies in a general way to these beds as well, as they were likely deposited soon thereafter, presumably triggered by the same tectonic event. The Jericho Member that forms the basal unit of the Ausable Formation in the Lake Champlain region appears to have no stratigraphic equivalent to the west of its outcrop belt, and could conceivably be Neoproterozoic age. The absence of marine fossils or trace fossils in the dolomitic limestone and sandy dolostone of that unit, would support a possible latest Precambrian age for these strata. If such is the case, it would imply a pre-Early Cambrian opening of the Iapetus Ocean which is not in serious conflict with the findings of Williams *et al.,* (1995) and Knight *et al.,* (1995).

Covey Hill and equivalent Ausable units stratigraphically higher than the Jericho are also devoid of marine fossils within the confines of the Ottawa Embayment. However the presence of the arthropod *Protichnites* sp., trackways in terrestrial deposits of the Hannawa Falls Member near the base of the Covey Hill at station O-57 (see Figure 57) clearly indicate that the beds in which they are contained are not older than Early Cambrian age.

The regional tectonics that triggered and accompanied the deposition of the Covey Hill and equivalent Ausable formations, may be linked to rifting that began in Neoproterozoic to Early Cambrian time at the eastern extremity of the St. Lawrence Platform, as documented and summarized by Williams *et al.,* (1995), and others. The radiometric dates of 564 to 573 shown by Williams *et al.,* (ibid) and Easton (1992), for the emplacement of some of the mafic dykes and anorogenic plutons in southern Quebec and eastern Ontario would imply an extensional stress regime at or near the beginning of the Paleozoic , e.g. Early Cambrian time.

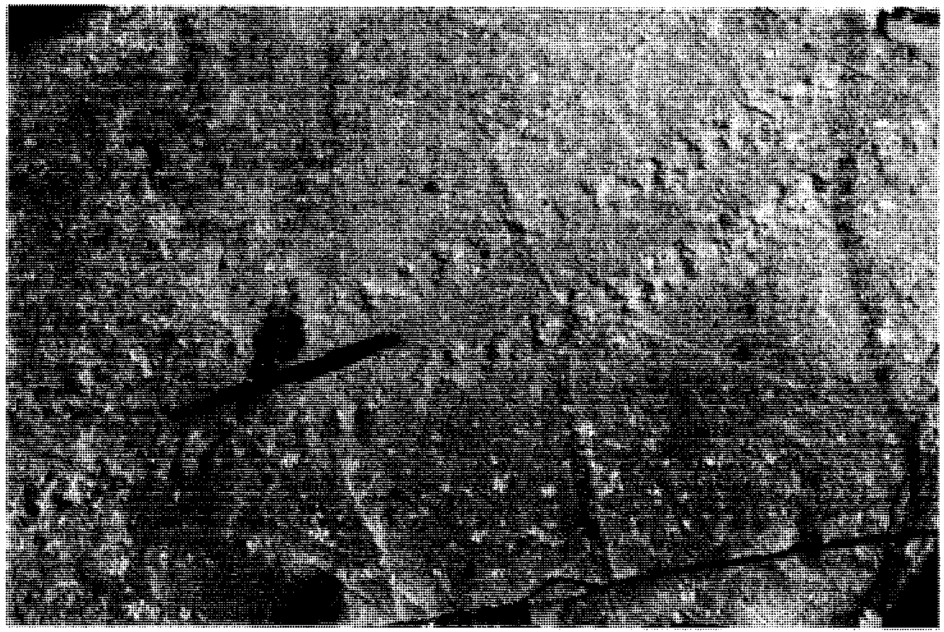


Figure 57: Trace fossil trackway of arthropod *Protichnites* sp. in aeolian sandstone of the Hannawa Falls Member of the Covey Hill Formation, Sloan Quarry, Ontario at station O-57.

In addition to the timing of tectonic events as established by radiometric dating along the eastern segment of the St. Lawrence Platform is the close lithological similarity of the Covey Hill and equivalent Ausable formations to the Double Mer and Bradore formations of southeast Labrador and western Newfoundland, the latter unit of which can be dated on the basis of its stratigraphic position beneath fossiliferous strata (Forteau Formation) of known Early Cambrian age (Williams *et al.*, 1995). Some of the red and grey sandstone and conglomerate of alluvial origin that were deposited in proximity to the Oka-Beauharnois Arch in Quebec and adjacent area of northeastern New York State are very similar indeed to the red and grey sandstone and conglomerate of the Bradore and Double Mer formations of western Newfoundland and the Lake Melville area of Labrador respectively, as described by Stevenson (1967; 1970), Gower (1986), and Cumming (1983). Unless there is some evidence to the contrary concerning the correlation of these basal Paleozoic strata, it is here concluded that they are all part of the same depositional sequence, and are thus stratigraphically equivalent (see Figure 58). The Covey Hill and equivalent

Ausable formations also have a number of lithological characteristics in common with the pre-Upper Cambrian Jacobsville and Middle Run formations of Michigan and Ohio respectively, both occurrences contained in the Western Division of the St. Lawrence Platform. The latter units have been dated Grenvillian to Early and Middle Cambrian, with the most recent emphasis placed on their association with the much older Grenvillian Orogeny (Santos *et al.*, 2002). The two formations consisting largely of redbed lithic arenite of alluvial origin occupy a similar stratigraphic position, unconformably overlying Precambrian metamorphic basement, and in turn succeeded by marine quartzarenite of Middle to Late Cambrian age. The Jacobsville, where exposed along the south shore of Lake Superior in the Northern Peninsula of Michigan was mapped in detail by Hamblin (1958), during which the beds were classified as "Lower to Middle Cambrian age". Hamblin (ibid.), provided very good evidence for excluding the Jacobsville from the Precambrian Keweenawan, on the basis of its provenance and direction of transport and he assigned to it a much younger age as noted above than had any of the previous workers in that northern region of Michigan.

The Middle Run Formation, known only from subsurface investigations in northwestern Ohio and adjacent states has been studied in various levels of detail by Dean and Baranoski (2002); Santos *et al.,* (2002); Drahovzal *et al.,* (1992); Drahovzal (1997); Benjamin *et al.,* (1997); Potter (1996); and Shrake *et al.,* (1990). Most of the above authors favor a Precambrian age for the formation, but a precise date has not yet been firmly established. Santos *et al.,* (2002), have documented a mainly Grenvillian source for the Middle Run, based on the dating of detrital zircons, but this procedure proves only that the formation is likely younger than the Grenville, but how much younger is open to speculation. Benjamin *et al.,* (1997), suggested an Eocambrian to Early Cambrian age, and that assumed designation is the one most favored by the writer, in that it supports the assumption of a single depositional event the length and breadth of the St. Lawrence Platform in response to intense rifting processes that are known to have been active at that time (Williams *et al.,* (1995).

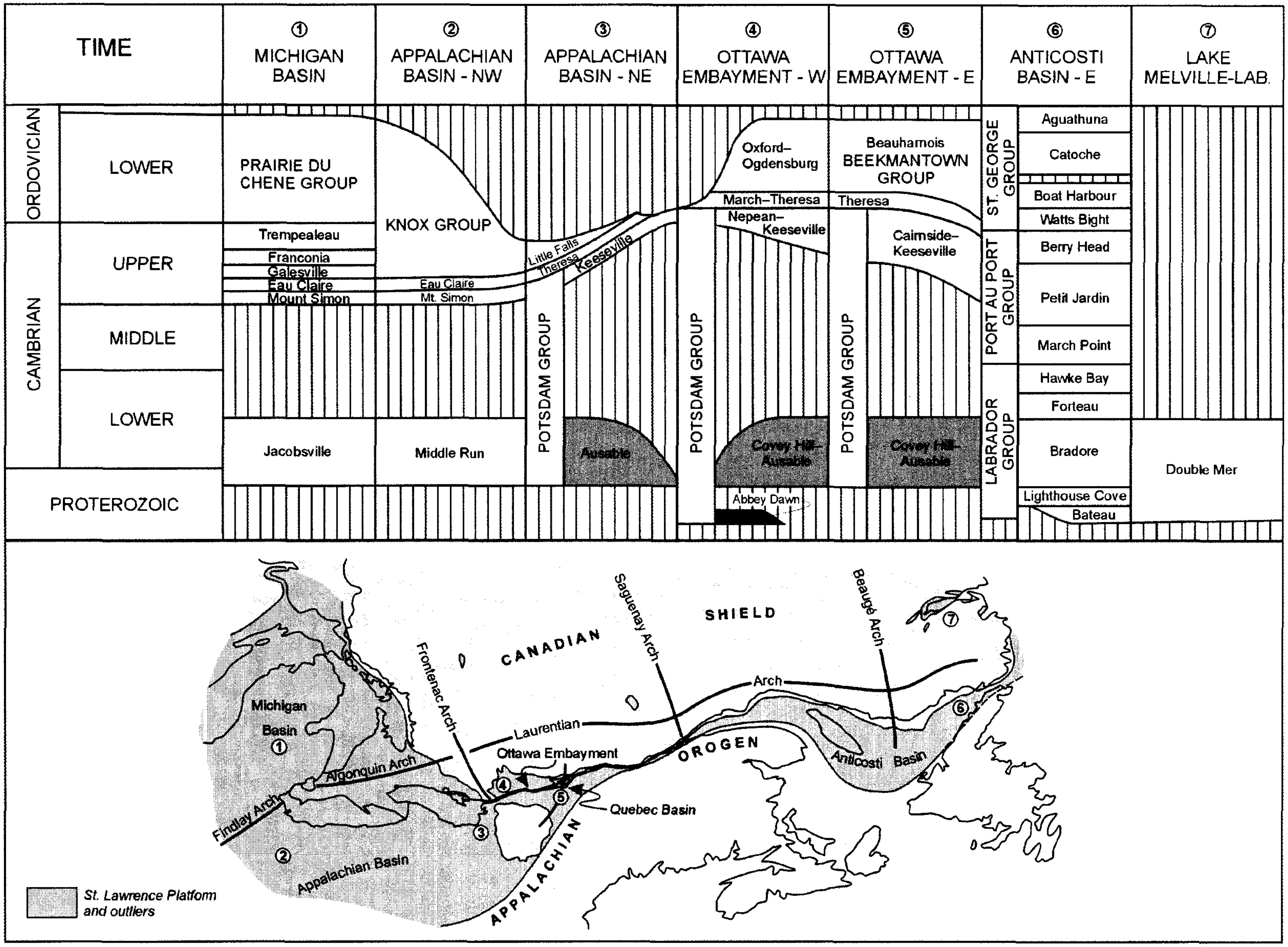


Figure 58. The Potsdam Group in the Ottawa Embayment and Quebec Basin, and its possible stratigraphic relationship to strata of latest Proterozoic to Early Ordovician age in adjacent regions of the St. Lawrence Platform.

Midway between the type sections of the Middle Run and Jacobsville formations is the McClure-Sparks No. 1 deep borehole completed in the approximate structural center of the Michigan Basin (Brown *et al.,* 1982). A stratigraphic log of the lowermost sedimentary strata penetrated in this borehole between the approximate depths of 3677 and 4971 metres (obtained through the courtesy of D. Michael Bricker of the Michigan Geological Survey) is a redbed sequence of strata not unlike the Jacobsville of northern Michigan and the Middle Run of northwestern Ohio. This would strongly suggest that the basal redbeds of those two formations may well be a horizontally continuous stratigraphic sequence throughout this region of the Michigan and Appalachian basins in subsurface, as originally speculated by Cohee (1945).

The original deposition of the Potsdam Group in the Quebec Basin and Ottawa Embayment as established in this dissertation extended well beyond the margins of the Frontenac Arch to the west, through central and southwestern Ontario. Major uplift of the Laurentian Arch and its western extension, the Waverly Arch, resulted in the erosion of much of the Covey Hill Formation, and only remnants of that formation were locally preserved (see Figure 59). The tiny remnant of Covey Hill near Gananoque at station O-52, and the large outlier near Sunbury at stations O-56 and O-57, are two such remnants. Others have been recorded farther to the west by the writer during previous investigations, at the village of Burnt River near Coboconk, Ontario, and in boreholes drilled by Imperial Oil Enterprises in the Niagara Peninsula of Ontario. Jacobsville sandstone (Covey Hill equivalent) was reported in boreholes drilled along the south shore of Georgian Bay by Roliff (1954), and on Cockburn Island, near the western extremity of Manitoulin Island, by Cohee (1945).

The presence of scattered outliers throughout central and southwestern Ontario, coupled by the remarkable lithological similiarity of certain of the rock strata extending from western Newfoundland and Labrador, to Quebec Basin and Ottawa Embayment and beyond to Michigan and Ohio, strongly suggests that these respective stratigraphic sequences may have been once interconnected, and thus stratigraphically equivalent as implied in Figure 58.

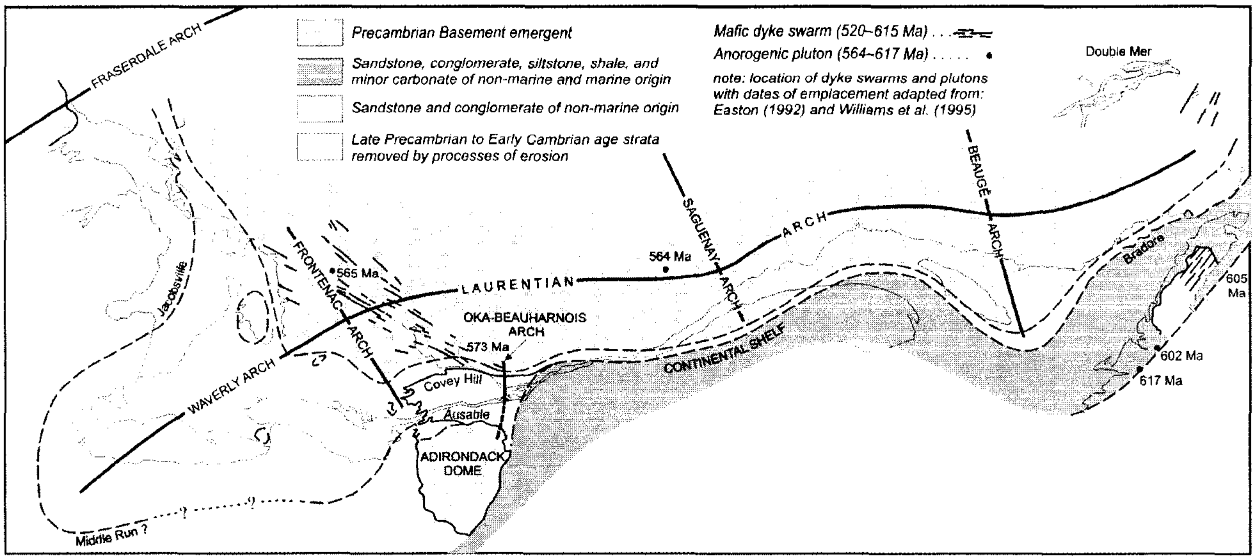


Figure 59. Paleogeography of Neoproterozoic to Early Cambrian sequence.

NEPEAN AND EQUIVALENT CAIRNSIDE AND KEESEVILLE FORMATONS

Definition

The Nepean Formation in Ontario, and its stratigraphic equivalents Cairnside and Keeseville formations in Quebec and New York State respectively, are composed of white and light grey quartzarenite that vary from Late Cambrian to Early Ordovician age. The beds are mostly of marine origin, and form the youngest rock unit of the Potsdam Group in the Quebec Basin and Ottawa Embayment. Throughout much of the study area, the beds rest unconformably on substantially older strata of the Potsdam Group, one or another of the three members (Hannawa Falls, Chippewa Bay or Edwardsville) that comprise the Covey Hill and equivalent Ausable formations. Such stratigraphic relationships are largely continuous across the southern extension of the Frontenac Arch in New York State, as shown in Figure 3; although the areal distribution of the Keeseville and Ausable formations on the western side of the arch beneath younger rocks of the Theresa Formation is obscure, due to the absence of any known deep borehole data in that region. Quite different conditions however, prevail north of the St. Lawrence River in Ontario, where the Nepean can be seen to overlap the Covey Hill and lie directly on the Precambrian, only remnants of which are preserved locally across the higher structural segments of the Frontenac Arch.

One such exposure (outlier) among many others, where the Nepean has overlapped the Covey Hill to rest directly on the Precambrian is located near Gananoque, Ontario, at station O-51 [see Figure 60 (a)]. Some 40 kilometers to the east of Gananoque, near Hammond, New York, at station N-96, is a section showing the Nepean equivalent – the Keeseville Formation resting

Figure 60: Nepean Sandstone in eastern Ontario, and equivalent Keeseville strata in northern New York State, illustrating the lithological similarity of the two units throughout the western part of the Ottawa Embayment. (a) Nepean Formation, on Precambrian rocks in roadcut on Highway 2 near Gananoque, Ontario, at station O-51. (b) Keeseville Formation, lying unconformably on Ausable Formation (Chippewa Bay Member) on Black Lake Road near Hammond, New York, at station N-95.

unconformably on the Ausable Formation (Covey Hill equivalent), the two units combined, commonly referred to as Potsdam Formation in this part of the state [see Figure 60 (b)]. In addition to the remarkable lithological similarity of the Nepean and Keeseville as displayed in the two field photos, such a comparison should also put to rest the long held misconception that the Nepean, as originally defined by Wilson (1946), in the Ottawa region is stratigraphically equivalent to the "Potsdam Formation" of New York State.

Throughout the Ottawa Embayment and Quebec Basin, the Nepean is succeeded, usually with abrupt contact, by interbedded dolostone and sandstone of the March Formation in Ontario, and in Quebec and New York by a similar lithology of the equivalent Theresa Formation.

In the western part of the study area, some 41 key sections have been identified where the Potsdam Group strata are best exposed. These are identified in Figure 5, and their precise locations are recorded in the Appendix herein. At several localities, both in Ontario and New York, either the lower or upper contact of the Nepean or Keeseville with older and younger rocks respectively are exposed. Nowhere in Ontario to the writer's knowledge is the Nepean exposed in its entirety, although there are a number of locations where it is nearly so. In New York State on the other hand, the Keeseville can be viewed from bottom to top at two closely spaced locations, exposing both its lower contact with the Ausable Formation, and its upper boundary with the Theresa Formation. These are located near Blind Bay just off Route 12 at stations N-89 and N-90 [see Figure 61 (a) and (b)], both of which are herein designated as reference sections.

Throughout the eastern part of the Ottawa Embayment and western part of the Quebec basin, the Keeseville and Cairnside are for the most part poorly exposed much like the underlying Ausable and equivalent Covey Hill formations. Stratigraphic relationships of the former strata with older and younger units in this eastern region are also poorly known, due to the fact that their contacts are everywhere obscured beneath Quaternary surficial deposits. Nevertheless, some success was had in viewing a significant part of the Keeseville and

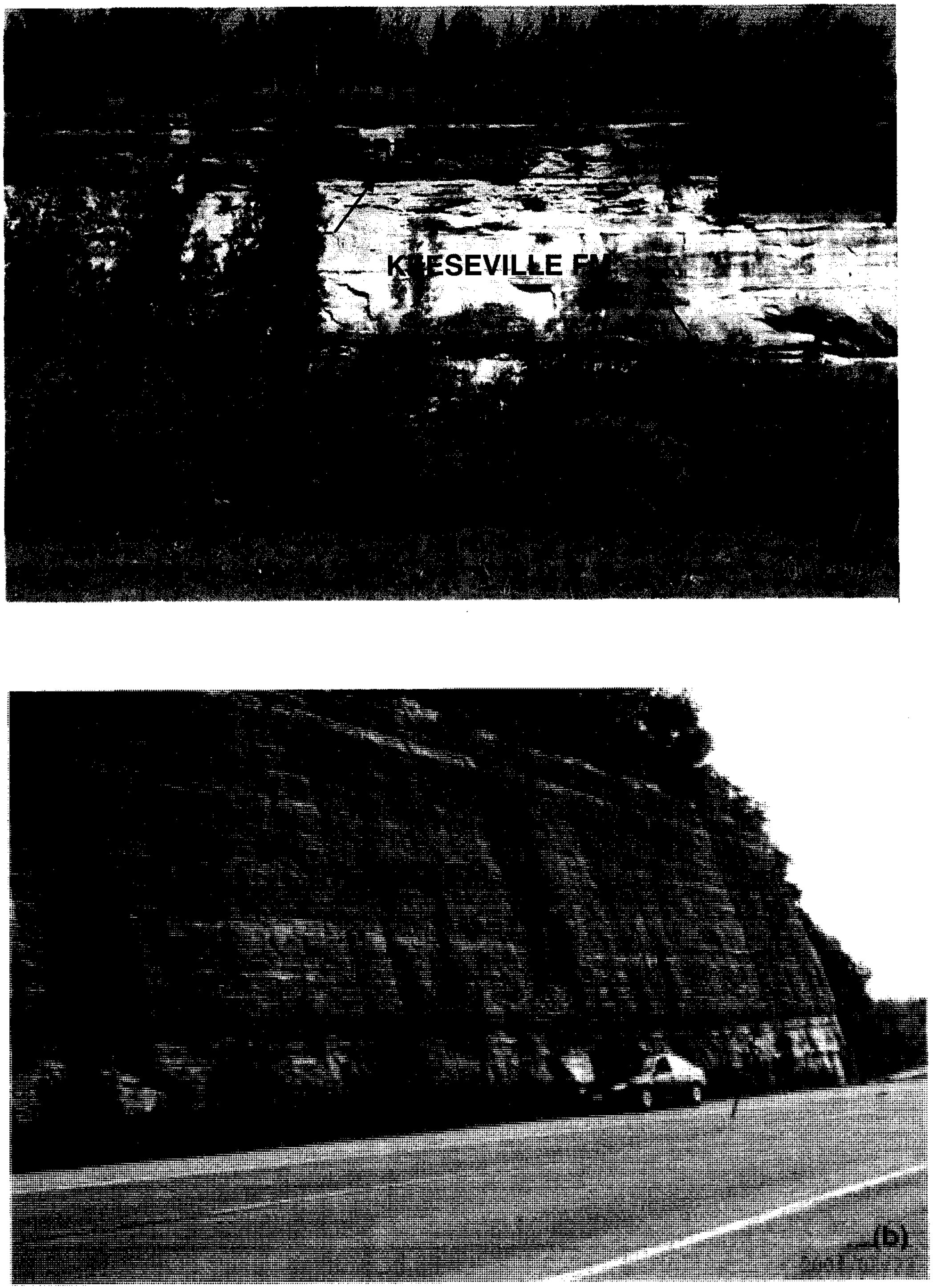


Figure 61: Ausable – Keeseville – Theresa succession in the Blind Bay area of northern New York. (a) View from Pleasant Valley Road near its intersection with Route 12 at station N-89. Here, a complete section of Keeseville (8.8 m) is exposed, lying unconformably on the Ausable Formation (Chippewa Bay Member) and is succeeded conformably by the Theresa Formation. (Note megaripplies at the base of the Keeseville). (b) Keeseville/Theresa contact in nearby road cut on Route 12, at station N-89.

Cairnside composite succession (see Figure 7), to establish, if nothing more than the remarkable lithological uniformity of these strata from place to place within this part of the study area. With the exception of Chateaugay River Gorge (station N-130) and Ausable Chasm (station N-215) there are very few exposures of Keeseville and equivalent Cairnside formations that would rate being referred to as key sections.

Perhaps some of the more useful information to be had with regard to establishing a clearcut definition of the Nepean and equivalent Cairnside and Keeseville formations was gleaned from the cored boreholes completed to date in the western part of the Quebec Basin and Ottawa Embayment. Their remarkable uniform lithological characteristics in terms of composition and color are such that they are readily recognizable in subsurface, and can thus be traced from borehole to borehole, as shown in the detailed logs (see Figure 8), and cross-sections (see Figure 9).

Distribution and Thickness

The Nepean and equivalent Cairnside and Keeseville formations have wide distribution in the Quebec Basin and Ottawa Embayment, as shown in Figures 3 and 9. Throughout most of this area, their outcrop belt essentially parallels that of the underlying Covey Hill and Ausable formations, except in the northwestern part of the Ottawa Embayment where the latter units were removed by erosion soon following their deposition; in which case the Nepean and Keeseville can be seen to rest directly on the Precambrian. Stratigraphic overlap is particularly evident in the west and northwestern part of the Ottawa Embayment, particularly to the west of a northeast imaginary line drawn from the vicinity of Perth to the Gloucester Fault just south of Ottawa, where the Nepean overlaps the eroded edge of the Covey Hill. From this line, the Nepean continues to the northwest where it eventually pinches out in the vicinity of Pakenham (see figures 3 and 62).

Similar conditions occur locally immediately south of the St. Lawrence River in New York State beginning in the Wellesley Island area, and extending for some distance to the southwest, where the Keeseville has also overlapped the Ausable Formation to lie directly on the Precambrian. From the above findings it is evident that the Nepean and Keeseville formations once formed a continuous blanket deposit across the Frontenac arch and extended into the central part of Ontario, along with successively younger Ordovician formations much of which has long since been removed by erosion.

In the Thousand Islands region of New York State, a precise thickness of 8.8 metres for the Keeseville was obtained where the formation is completely exposed at a single locality on a sideroad off Route 12 leading to Blind Bay at station N-90, and in a nearby section near the intersection of Route 12 and Pleasant Valley Road at station N-89 [see Figure 61 (a)]. Similar thicknesses or possibly even less may prevail to the southwest, where the Keeseville Formation crosses the higher structural axis of the Frontenac Arch extension.

In Ontario, the Nepean Formation forms an almost continuous outcrop belt from Brockville to Pakenham along the eastern margin of the Frontenac Arch. Immediately to the west of Brockville the formation is at least 15 metres thick at the Lyn Valley Conservation Area at station O-64. From here it thickens northward along the outcrop belt bordering the Frontenac Arch to 30.5 metres near the town of Athens at station O-66. From Athens north to Ottawa, partially exposed sections of one to five metres are the more common thicknesses recorded for the Nepean along the outcrop belt. On the west side of the Gloucester Fault, where the latter passes through Ottawa in the Dow's Lake region, the Nepean is 30.9 metres thick as recorded by the writer in the Dominion Observatory No.1 borehole (see Figure 8).

Sandstone of the Cairnside and equivalent Nepean Formation contained, mostly in a series of tilted fault blocks have been mapped eastward along the northern margin of the Ottawa Embayment from the city of Gatineau to the vicinity of Montebello, Quebec (Wilson, 1946; Baird, 1972). East of Montebello the beds are obscured beneath younger rocks along the downdropped side of the Lachute Fault (see Figure 3).

Along the southwest and south side of the Ottawa Embayment bordering the Adirondack Mountains, extending from Black Lake to the vicinity of Potsdam, New York, the Keeseville is locally exposed, but for the most part is obscured beneath downfaulted strata of the Theresa Formation (see Figure 3). It again rises to surface at Brasher Falls, where two or three metres of section are exposed, and from whence it forms a continuous outcrop belt throughout the remaining distance to the type locality at Keeseville, New York, near the shore of Lake Champlain.

The precise thickness of the Keeseville, and equivalent Cairnside where applicable, is not precisely known along this stretch of terrain, but based on the isopachs of Figure 62, a progressive eastward thickening can be seen to prevail from 8.8 metres at Blind Bay (station N-90) to more than 80 metres where it approaches the southern extension of the Oka-Beauharnois Arch in the vicinity of Chateaugay, New York.

High above the Quebec Lowland, mostly contained on the New York side of the international boundary, is an isolated outlier of Keeseville Formation (see figures 3 and 8 – section E-E'). Its' presence in this region at an altitude in excess of 200 metres above its elevation north of the Stockwell Fault, would clearly imply major uplift of this segment of the Oka-Beauharnois Arch at some point in time subsequent to its' period of deposition.

A short distance north of the Stockwell Fault, the Cairnside dips beneath younger rocks of the Theresa Formation along the axis of the Valleyfield Trough. North of the trough the beds again rise to surface to form a halo-like surface expression around the Oka, Rigaud and Saint-Andrea-Est mountains, the latter of which form the most northern and prominent part of the Oka-Beauharnois Arch.

Thicknesses of the Keeseville and Cairnside formations along the axis of the Oka-Beauharnois Arch area in New York and Quebec are unknown due to

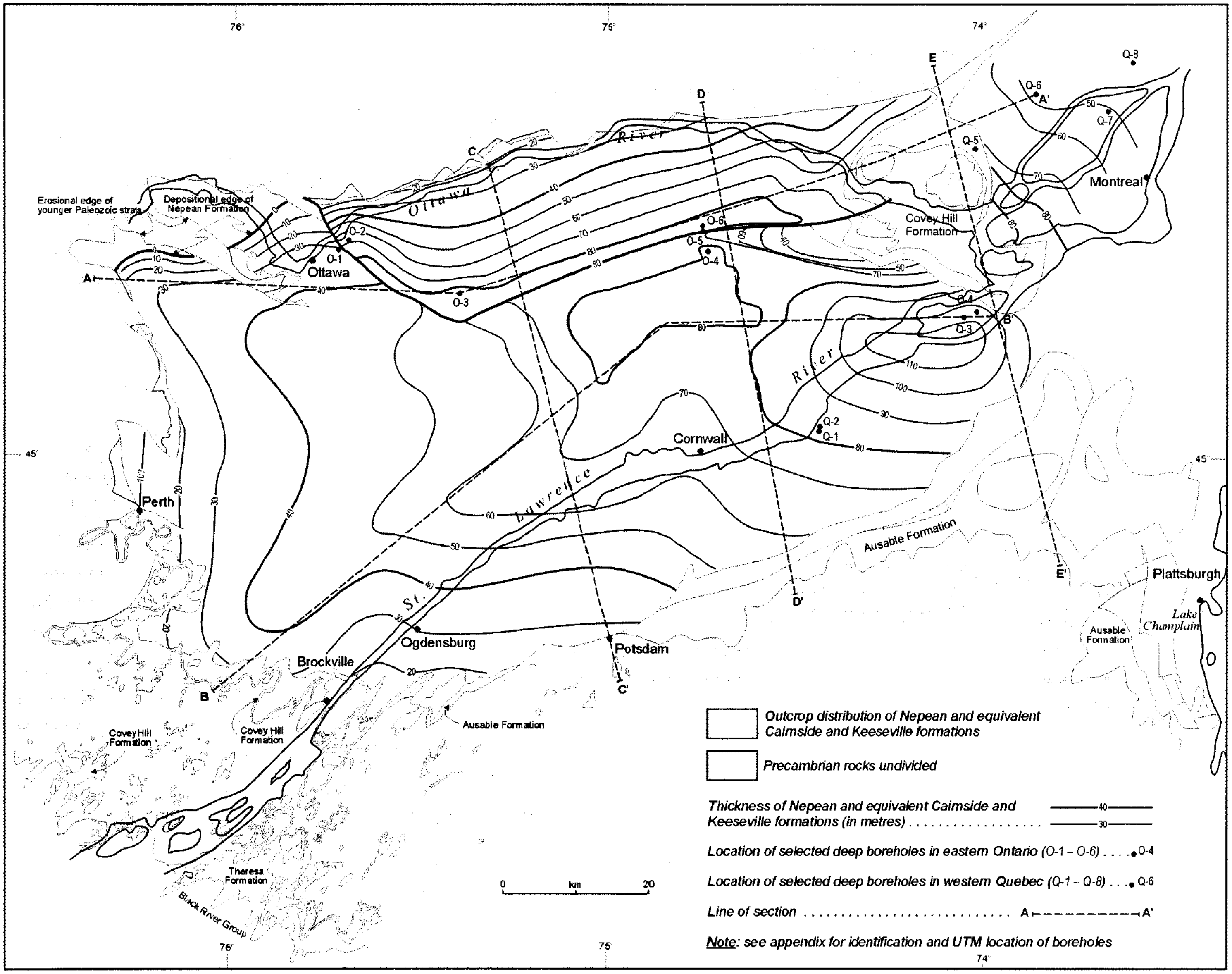


Figure 62. Isopachous map showing distribution and thickness of the Nepean and equivalent Cairnside and Keeseville formations in eastern Ontario, western Quebec and northern New York State.

the relatively thin exposures of those formations in surface outcrops in either of those areas. On the northeast side of the arch in New York State bordering Lake Champlain, the precise thickness of the Keeseville is also imprecisely known. Fisher (1968) reported a thickness of 455+ feet (139 metres) for the Potsdam sandstone exposed in the Ausable Chasm. It is not completely clear whether Fisher (ibid.) intended the 455+ feet to include only the Keeseville Formation, or whether it also included some of the underlying strata of the Ausable Formation.

In the subsurface regions of the Ottawa Embayment, the Nepean and equivalent formations thicken progressively in an eastward direction from a minimum known thickness of 30.9 metres in the Ottawa area to a maximum of 110 metres in the extreme eastern end of the Ottawa Embayment (see Figure 62). Based on the isopachs,, one can conclude that the Ottawa Embayment was in all likelihood an enclosed basin bounded by arch systems during deposition of the Nepean and equivalent Cairnside and Keeseville formations. On the east side of the Oka-Beauharnois Arch, the Cairnside thins substantially into the Quebec Basin, as shown in Table 7 and Figure 62.

As during the preceding Covey Hill depositional period, anomalous thickening of the Nepean Formation appears to have prevailed within the confines of the downfaulted block that occupies the northern part of the Ottawa Embayment. From its northern eroded edge, the Nepean thickens to more than 80 metres in the lower structural segment of the half-graben, that is bounded on the west and south by the Gloucester and Russell-Rigaud faults, respectively. That this structure was in place in the beginning of the Nepean depositional period can best be demonstrated by comparing the difference in thickness of the formation on opposite sides of those major fault systems. This can be done with some degree of accuracy in the Ottawa area, where the Dominion Observatory No.1 borehole on the west side of the Gloucester Fault penetrated 30.9 metres of Nepean, whereas less than one kilometre to the east on the downdropped side of the fault, 70.3 metres is recorded in the GSC LeBreton No.1 borehole. A similar comparison can be drawn at the eastern end of the Russell-Rigaud Fault near the village of McCrimmon, where a similar discrepancy in the thickness of the

Nepean can be established by comparing the 65.8 metres of Nepean in the GSC McCrimmon No.1 borehole with the 84.3 metres encountered in the nearby Consumers No.12023 borehole, drilled on the downdropped side of the fault.

The thickness of the Nepean and equivalent Cairnside formations in the succession of boreholes extending across the northern part of the Ottawa Embayment and into the Quebec Basin are listed in the following table.

Borehole	Thickness	Borehole	Thickness
Dominion Observatory No.1	30.9 m	St. Lawrence River No.1	107.3 m
GSC Lebreton No.1	70.3 m	Gastem - Dundee No.1	82.6 m
GSC Russell No.1	84.5 m	Gastem - Dundee No.2	75.5 m
GSC McCrimmon No.1	65.8 m	Mallet Test No.1	43 m
Imperial Laggan No.1	85.1 m	Quonto - St. Vincent de Paul	52 m
Consumers Gas 12023	84.3 m	Quonto - Mascouche	49 m

Table 7: Thickness of Nepean (Cairnside) Formation in subsurface

Lithology and Stratigraphic Relationships

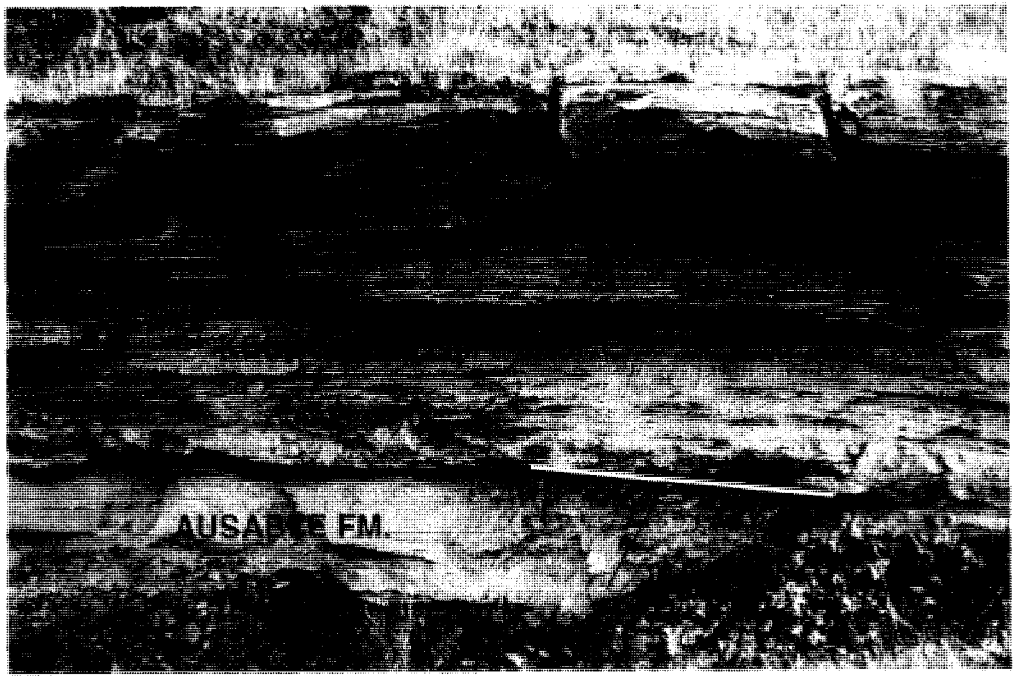
The Nepean and its Keeseville and Cairnside equivalents have remarkable lithological similarity throughout the length and breadth of the Ottawa Embayment, and western part of the Quebec Basin. The beds are mostly white, cream and light grey color, that weather medium to dark grey, and locally brick red, the latter a surficial discoloration more common to the lower beds of the

Nepean in parts of eastern Ontario and adjacent areas of New York State. The beds, largely composed of quartzarenite, commonly contain a basal conglomerate comprising quartz pebble and/or quartzite cobble clasts.

Where the complete section of Keeseville formation is exposed at stations N-89 and N-90 near Blind Bay, New York, it is composed of white and light grey quartzarenite [see figures 61 (a) and 63 (a) and (b)]. Where these beds unconformably overlie the Ausable Formation, the basal strata of the Keeseville shown to the right of the photo [see Figure 61 (a)] are medium–scale cross-stratified and similar to those noted at several locations elsewhere at the base of the Keeseville and equivalent Nepean in New York and Ontario respectively. The upper contact of the Keeseville with the Theresa as exposed on Route 12, a few metres to the west of the above described section [see Figure 61 (b)] well illustrates the sharp, but apparently conformable boundary between the two formations at this location.

A short distance to the northwest of station N-89, is the other complete section of the Keeseville Formation exposed on a short side road off Route 12 leading to Blind Bay, identified as station N-90 [see Figure 63 (a) and (b)]. At this location, a quartzite pebble and cobble conglomerate at the base of the formation unconformably overlies the Chippewa Bay Member of the Ausable Formation. This 30cm thick trough crossbedded conglomerate is succeeded with abrupt contact by finely laminated quartzarenite that is highly bioturbated as shown in Figure 63 (b).

The sharp break in sedimentation processes between the basal conglomerate, and the overlying laminated beds could conceivably imply that the former were deposited in a fluvial environment at some point in time preceding the marine invasion of the Keeseville sea. There are other areas both in Ontario and New York where a thin conglomerate unit, basal and structurally concordant with the Nepean and equivalent Keeseville, that appear to have been deposited prior to the marine deposition of those formations. The most notable of these in Ontario is located on Highway 15, at station O-17 (see Figure 32).



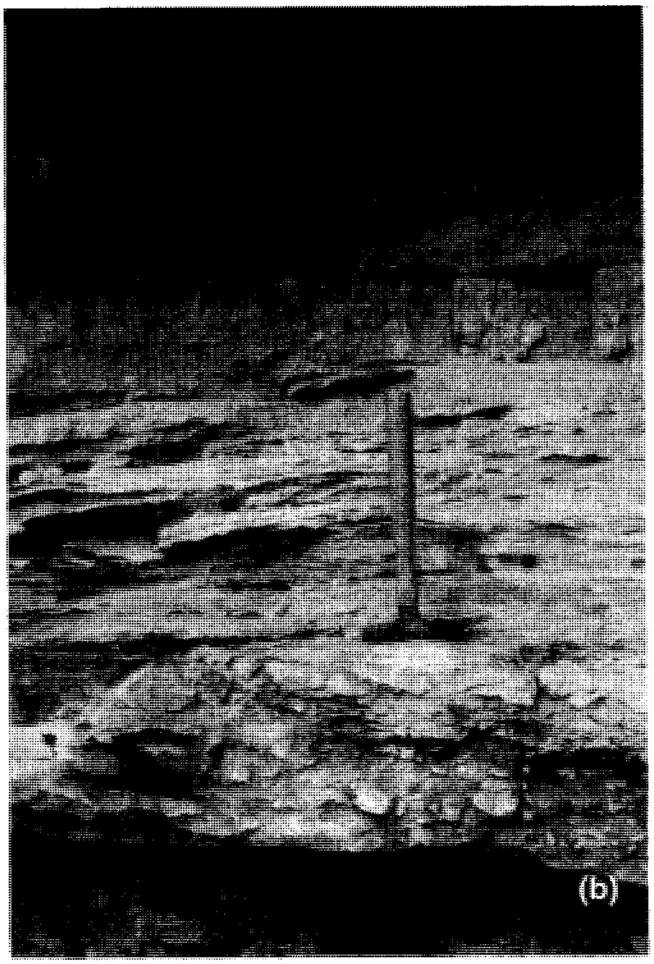


Figure 63: Grey and white, thinly bedded Keeseville Formation, resting on Ausable Formation (Chippewa Bay Member) near Blind Bay, New York, at station N-90. (a) Unconformable contact between Ausable Formation (Chippewa Bay Member) and Keeseville identified by head of hammer. (b) Close-up of Keeseville Formation, showing trough crossbedded quartzite cobble conglomerate and breccia at base of formation, and intense vertical bioturbation above the hammer handle.

Many good exposures of Keeseville sandstone occur elsewhere throughout the Thousand Islands region and general vicinity of New York State. At 12 of these locations, the formation was observed to lie with unconformable contact on the Ausable Formation. These are listed in Table 2 of a previous section under the heading of Covey Hill and Equivalent Ausable Formations.

A good example of the unconformable relationships that prevail between the Keeseville and Ausable formations in this region of the state, can be seen about one kilometre west of Redwood, at station N-39 [see Figure 64 (a) and (b)]. Here, the Chippewa bay Member of the Ausable Formation is assumed to have been deformed prior to deposition of the Keeseville, and the flat lying strata of the latter are thus in angular discordance with the beds below the unconformity. Approximately three metres of Keeseville light grey quartzarenite are exposed at this locality, in sharp contrast to the 20+ metres of the underlying Ausable beds that are exposed along the steep incline of the road to the right of the photo. The origin of the pea-size spherical and elliptical cavities at the base of the Keeseville as shown in Figure 64 (b) is not fully understood. They may have originally formed as tiny algal and/or calcite accretionary nodules (pisoliths?) that were removed by dissolution at a later period of geological time.

Throughout most of the study area the Nepean and its equivalents unconformably overlie the Chippewa Bay Member of the Ausable (Covey Hill), and at three locations at least in Ontario the Hannawa Falls Member. At several localities in the Thousand Islands region of New York, fossiliferous strata of the Keeseville lie on stratigraphically higher beds of the Ausable Formation, namely the Edwardsville Member, at stations N-13, N-109, N-88 and N-80. One of the better examples is the reference section at station N-13 located near Alexandria Bay, where the Keeseville, slightly less than two metres in thickness can be readily distinguished from the Edwardsville Member as noted by its slightly darker colored weathering characteristics shown in Figure 65(a). The contact can also be readily noted by its irregular character, and by the presence here and there of thin planar crossbeds at the base of the Keeseville that dip in an eastward direction. Fossil remains are abundant in the Keeseville at this locality,

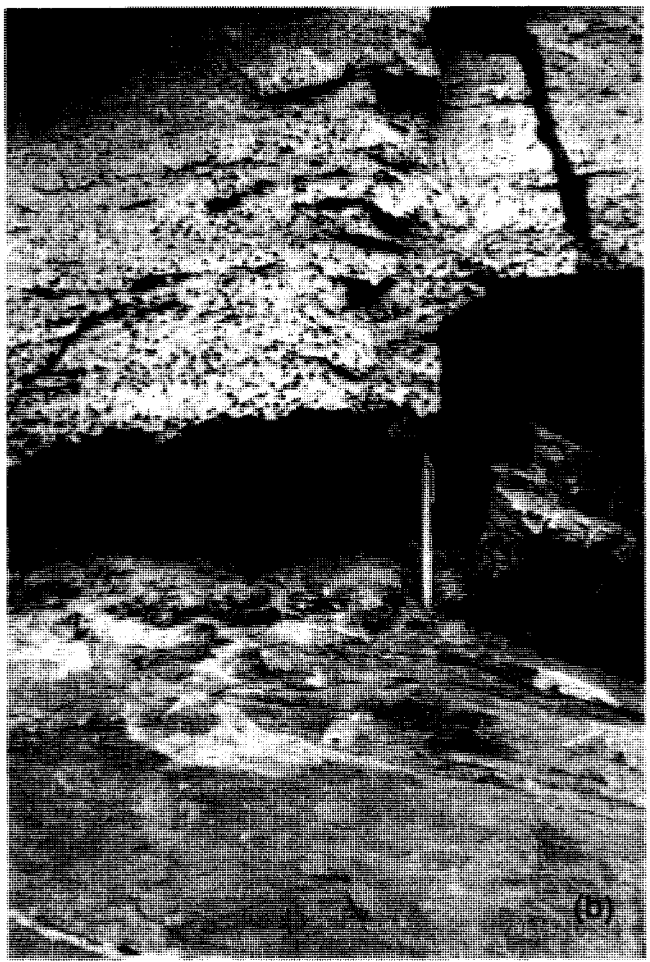


Figure 64: Ausable – Keeseville contact, one kilometre west of Redwood, New York at station N-39. (a) Sharp boundary between the two formations marked by angular uconformity. (b) Close-up of contact, showing vast differences in physical appearance of the two rock units. (Note the pea-size spherical and elliptical cavities at the base of the Keeseville Formation, possibly of algal and/or calcite accretionary origin).

although they are poorly preserved, and unidentifiable, due to intense abrasion of the latter by wave action.

A similar unconformable relationship between the Keeseville and Edwardsville Member of the Ausable Formation was noted in a roadcut on Route 12, near Duck Cove at station N-80. The excellent section of Ausable strata exposed at this site, described earlier (see Figure 25) is succeeded by the Keeseville Formation, at the eastern end of the roadcut, as shown in Figure 65 (b). The Ausable strata are tilted slightly to the northeast, and thus appear to be in minor angular discordance with the overlying Keeseville. The Keeseville is intensely bioturbated at this station, and elsewhere in this particular region of the study area.

Farther to the south of the above described exposures, where Interstate 81 crosses Wellesley Island, New York at station N-4, is an excellent section of Keeseville Formation [see Figure 66 (a) and (b)]. Neither the lower or upper contact with older and younger rocks is exposed here, although it can be readily assumed that the formation at this station rests directly on granitic rocks of the Grenville Province. The lower 1.8 metres are coarse quartzite cobble conglomerate containing interlayers of light grey kaolinite [see Figure 66(a)]. These are succeeded by 4 to 5 meters of thin uniformly bedded quartzarenite, white to light grey and yellowish-orange in color, containing a few quartz pebbles and quartzite cobbles in their lower part [see Figure 66(b)]. A few tens of metres to the north at this same exposure, the beds are intensely trough crossbedded with average paleocurrent direction toward the southwest at 232°.

In Ontario, good exposures of the Nepean Formation were noted along the east side of the Frontenac Arch, extending from Brockville to Ottawa, as well as at isolated locations along the axis of the arch, and locally to the west of the Frontenac Arch. In at least nine of these locations, the Nepean unconformably overlies the Covey Hill Formation. (see Table 2).

In addition to the above recorded stations where the Nepean - Covey Hill contact is well displayed, are two locations where the Nepean can be seen to

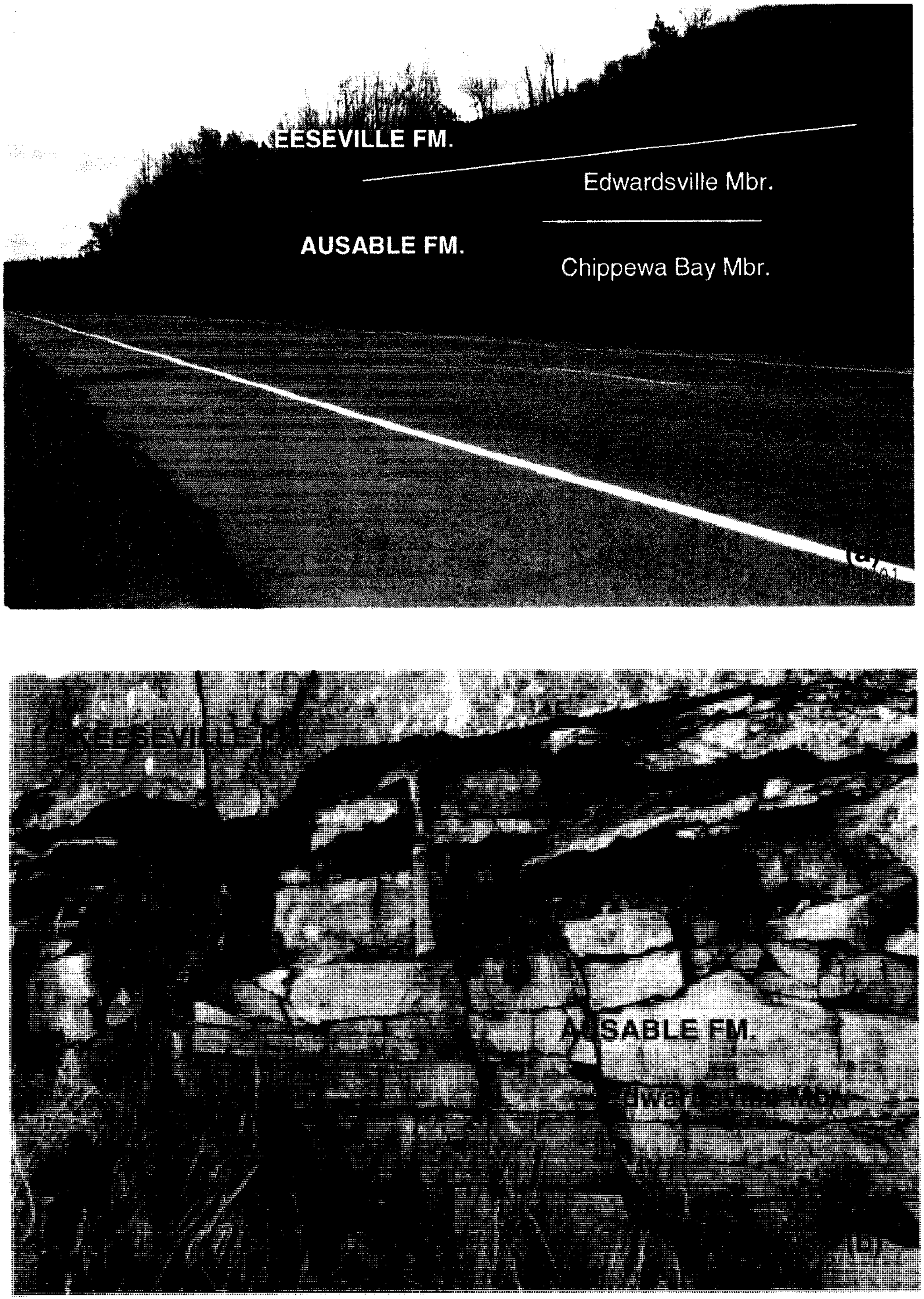


Figure 65: Keeseville Formation resting with unconformable contact on Ausable Formation at reference section on Route 12, New York State. (a) Darker grey beds at top of section is the Keeseville resting on grey and pink Edwardsville Member of the Ausable Formation at station N-13. (b) Grey sandstone of the Keeseville (above hammer) resting with slight angular discordance on thinner beds of the Edwardsville Member of the Ausable Formation at station N-80.

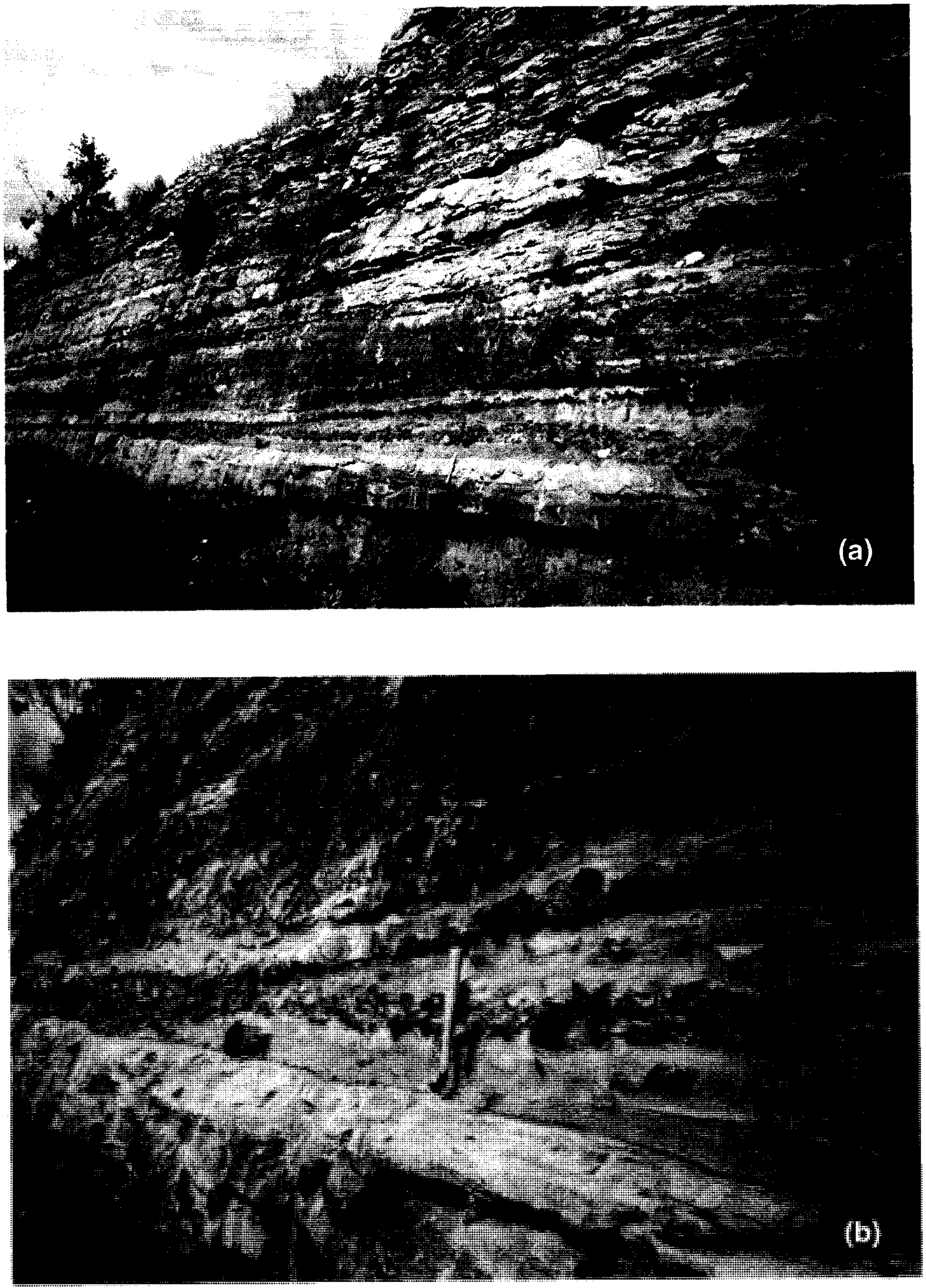


Figure 66: Keeseville Formation in a roadcut exposed on Interstate 81, Wellesley Island, New York at station N-4. (a) Nearly complete section of Keeseville sandstone preserved in block-faulted structure containing thick basal quartzite conglomerate. (b) Close-up of basal quartzite cobble and boulder conglomerate. (Note light grey layers composed largely of decayed feldspar [kaolinite]).

rest directly on the Precambrian. These widely separated exposures are at stations located near Gananoque at O-51, and at Lac Beauchamp in Gatineau, Quebec at Q-1. There are other locations where the basal contact with the Precambrian is obscured by only a few centimetres, notably on the shore of Mississippi Lake at station O-10.

One of the more complete sections of Nepean is exposed in a cliff section at the Lyn Valley Conservation Area, on the eastern outskirts of the village of Lyn at station O-64. The basal unit of the formation exposed near the entrance to the park resting unconformably on the Covey Hill is composed of brown sandy limestone, one metre thick, containing large, well-rounded quartzite cobbles at its base (see Figure 28). A few metres laterally, is the remainder of the formation, 15 metres of white quartzarenite that are contained in thick massive layers, as shown in Figure 67.

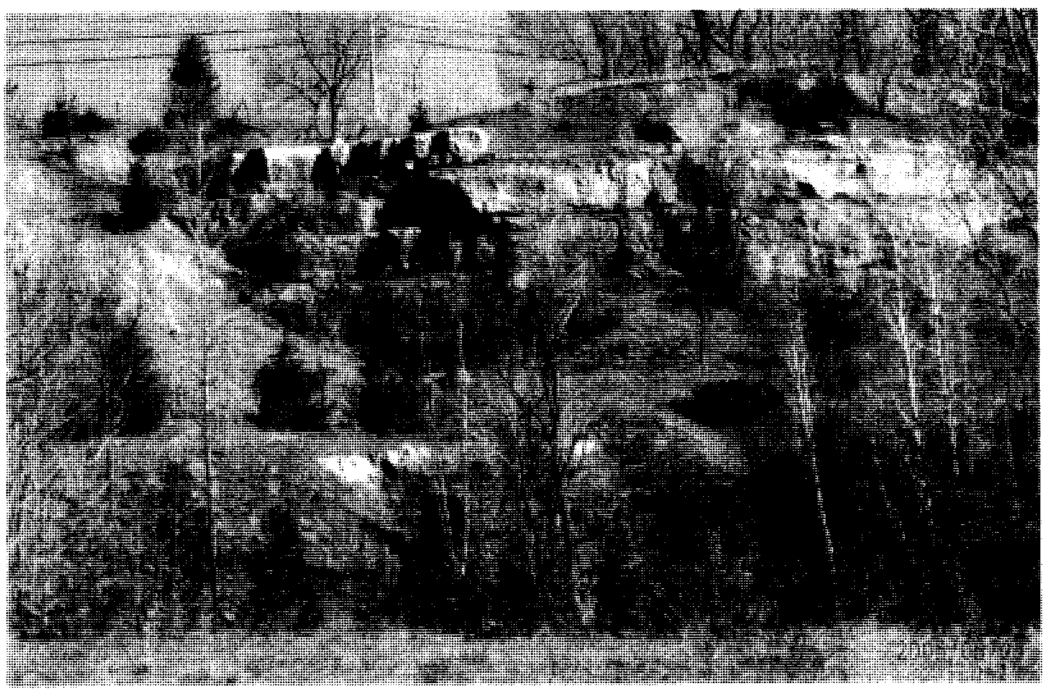


Figure 67: 15 metre cliff section of Nepean sandstone exposed at Lyn Valley Conservation Area, Lyn, Ontario at station O-64.

In some contrast to the clean sandstone of high-energy-marine origin exposed at Lyn, is a roadcut on Highway 42, near Philipsville at station O-33, where the Nepean would appear to have been deposited in a more distal part of the Ottawa Embayment (see Figure 68). The thin, uniform grey beds of the Nepean, 4.5 metres thick, are here overlain with sharp contact by the March Formation. The slight angle of discordance observed in the upper right of the photo between the Nepean and March suggests a minor hiatus in deposition between the two formations.

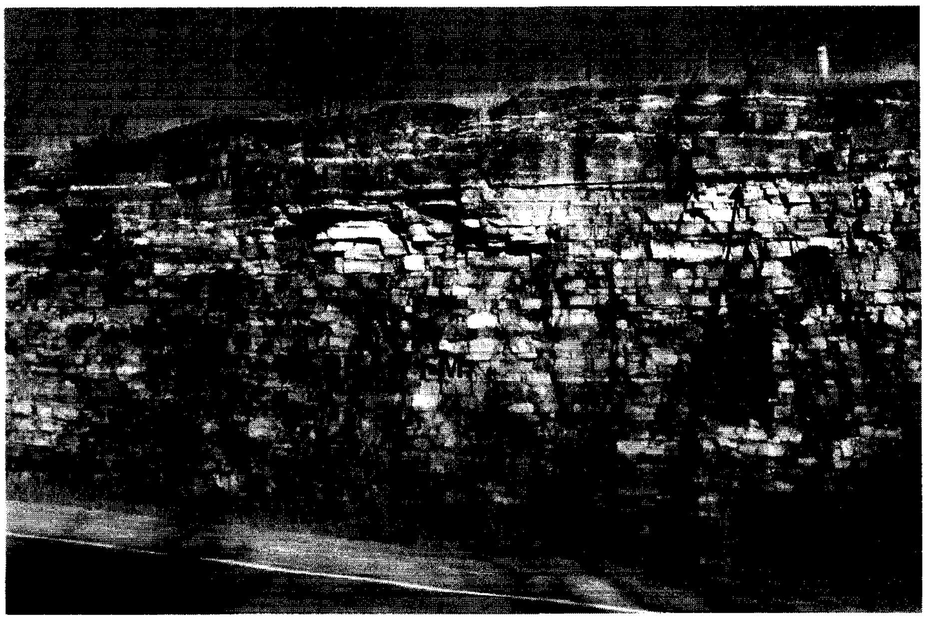


Figure 68: Thin, uniformly bedded Nepean sandstone overlain with sharp contact by the March Formation, marked by arrow, in roadcut on Highway 42, at station O-33.

There are many other good exposures of Nepean elsewhere along highways 15 and 42 in Ontario that are too numerous to describe or illustrate herein. Many of these are listed in the Appendix of the present dissertation, the location of which may prove to be of some value to workers who may wish to pursue further research on the Potsdam Group in this region. However, one would be remiss to not include the well known stratigraphic section on Highway 15 at Elgin (station O-23) in any regional discussion of the Nepean Formation. For many years, it was the only known exposure of the Paleozoic – Precambrian boundary, and was thus a popular field trip stop. The oldest Paleozoic beds at this location were long thought to be Nepean Formation resting on steeply dipping Precambrian metavolcanic rocks. What makes the section even of more historical interest, is the presence of a thin remnant of Lower Cambrian Covey Hill Formation preserved between the Precambrian and Upper Cambrian to Lower Ordovician Nepean Formation, and there are thus two unconformities to be seen at this site, instead of one (see Figure 20). The base of the Nepean here exposed is marked by the geological hammer, above which is a thin shaley and sandy quartz pebble conglomerate 20 centimetres thick, succeeded by pink, greenish-grey to white quartzarenite, two metres in thickness.

Farther to the north on Highway 15, the Nepean is again exposed at station O-17 (see Figure 32), where it rests with angular unconformity on coarse cobble and boulder conglomerate of the Chippewa Bay Member of the Covey Hill. The basal 0.5 metres of the Nepean at this site is composed of well rounded quartz cobbles that were likely derived from the underlying Covey Hill. Overlying the conglomerate with abrupt contact is white, thinly bedded bioturbated quartzarenite three to four metres thick that is intensely iron oxide stained along fractures.

Perhaps the most impressive of any of the Nepean exposures in this general area of Ontario and elsewhere are stations O-16 on the Rideau Ferry Road between Perth and Lombardy, and station O-35 at Delta, Ontario (see Figures 1 and 17). The spectacular nature of both these outcrops is largely because of the readily apparent angular discordance between the Nepean and the underlying fractured and folded beds of the Covey Hill Formation. However, the beds beneath the unconformity at these two locations are quite different in terms of lithology and age, with strata at station O-35 near Delta (Hannawa Falls Member) having undergone substantially greater intensity and depth of erosion than noted elsewhere within the study area. The Nepean strata at this station is medium to dark grey argillaceous sandstone containing an abundance of quartzite cobbles. In contrast, the Nepean Formation at station O-16 is a clean white and light grey quartzarenite containing a thin pebble conglomerate where the basal strata of the formation overlies the flatly bevelled erosional surface of the Chippewa Bay Member of the Covey Hill Formation.

From the Perth area, the Nepean outcrop belt continues northward to the vicinity of Pakenham, the latter area presumably representing the most northwestern depositional edge of the formation. Along much of this outcrop belt, the Nepean can be seen in the ditches of some of the roads that intersect the region, and locally occurring in roadcuts up to two metres in thickness. Where the base of the Nepean is exposed on the shore of Mississippi Lake near Carleton Place at station O-10, the lower 20 cm of the formation is composed of nodular bedded limestone. Overlying these with abrupt contact are bioturbated pinkish-white and grey brecciated sandstone about one metre thick (see Figure 69). Precambrian quartzite is present immediately below the hammer, and this

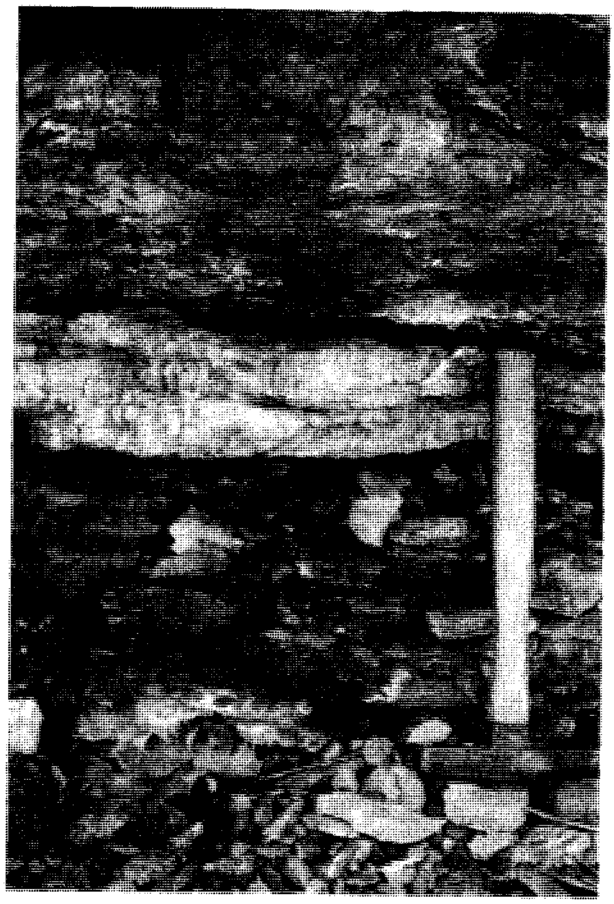


Figure 69: Nepean Formation at Mississippi Lake, Ontario, at station O-10. (Note nodular limestone beds at base of formation).

contact relationship precludes the possibility of any remnants of Covey Hill Formation being present beneath the Nepean in this general locality of the study area.

From Carleton Place, the Nepean outcrop belt continues to the north, where it is exposed at two localities on a southwest oriented sideroad, about one kilometre west of Almonte at stations O-8 and O-9. At station O-8, about two metres of white and light grey quartzarenite is exposed, and at station O-9, the Nepean sandstone is overlain by dolostone and sandy dolostone of the March Formation. The contact is abrupt, as it appears to be at most other locations in eastern Ontario and adjacent areas of New York State, where observed during the course of the present investigation.

On the west side of Ottawa, in what were once the cities of Nepean and Kanata, excellent roadcut exposures of the Nepean Formation can be observed along both lanes of Highways 417 and 416. The Nepean Formation was originally named by Wilson (1937, 1946) for the sandstone exposed in Nepean Township, "where the large quarries lie from which the stone was taken for the Parliament Building of Canada, and for many other large buildings". One may assume from this that her type section was the Campbell Quarry located near Bells Corners. Greggs and Bond (1972) in the belief that "these (Campbell) quarries are now filled in and little outcrop is visible", set about to establish a "Principal Reference Section for the Nepean Formation" on the north side of Highway 417, in the approximate vicinity of the writer's station O-2, as shown in Figure 70.

The type section, as so designated on Highway 417, approximately seven metres in thickness, is composed of white to cream colored quartzarenite in thin relatively uniform beds, that weather light grey to yellowish-orange. Thin yellowish-orange calcitic to dolomitic sandstone interbeds occur here and there in the middle to upper beds, increasing near the top of the section. Greggs and Bond (1972) did not identify any of the carbonate interbeds at the top of the section as March Formation having assumed that unit was absent due to erosion

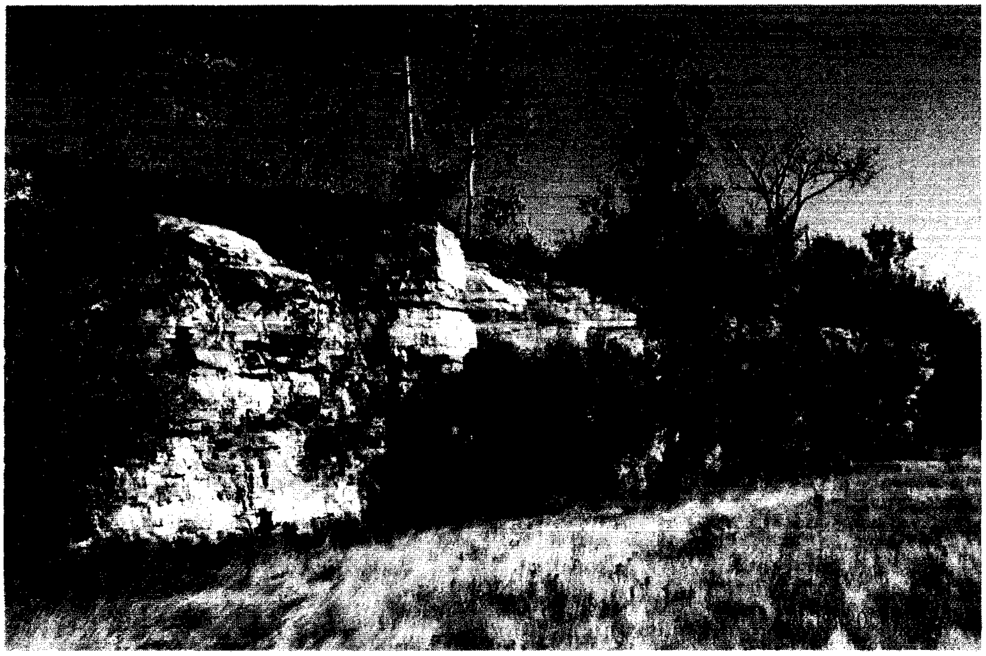


Figure 70: Principal Reference section for the Nepean Formation, as adopted by Greggs and Bond (1972) on Highway 417, Ontario, at station O-2. Beds are composed of quartzarenite with thin calcareous interbeds, typical of the Nepean and equivalent Keeseville and Cairnside formations throughout the study area.

along with upwards to “three metres” of the uppermost beds of the Nepean Formation.

In a later study of the same general stratigraphic succession, Brand and Rust (1977) identified a thin layer of sandstone with minor carbonate at the very top of the section as March Formation, as did Williams *et al.,* (1984) during the course of geological mapping for the Ontario Geological Survey. In a more recent paper, Dix *et al.,* (2004) lowered the Nepean – Theresa (March) boundary 1.5 metres below that interpreted by Brand and Rust (1977), to coincide with an irregular surface within the sandstone which they interpreted to be an unconformity.

During the examination of the same exposure on Highway 417, the writer was unable to find a stratigraphic horizon anywhere within the succession that would be of any value in terms of defining the Nepean – March contact, or that would have any practical application elsewhere beyond the present limits of this particular outcrop belt. Instead, the more logical alternative may be to classify the entire type section as Nepean Formation, as did Greggs and Bond (1972), and turn one's attention to the Nepean – March contact where it is exposed to far better advantage on Highway 416, at station O-6 (see Figure 71). From the

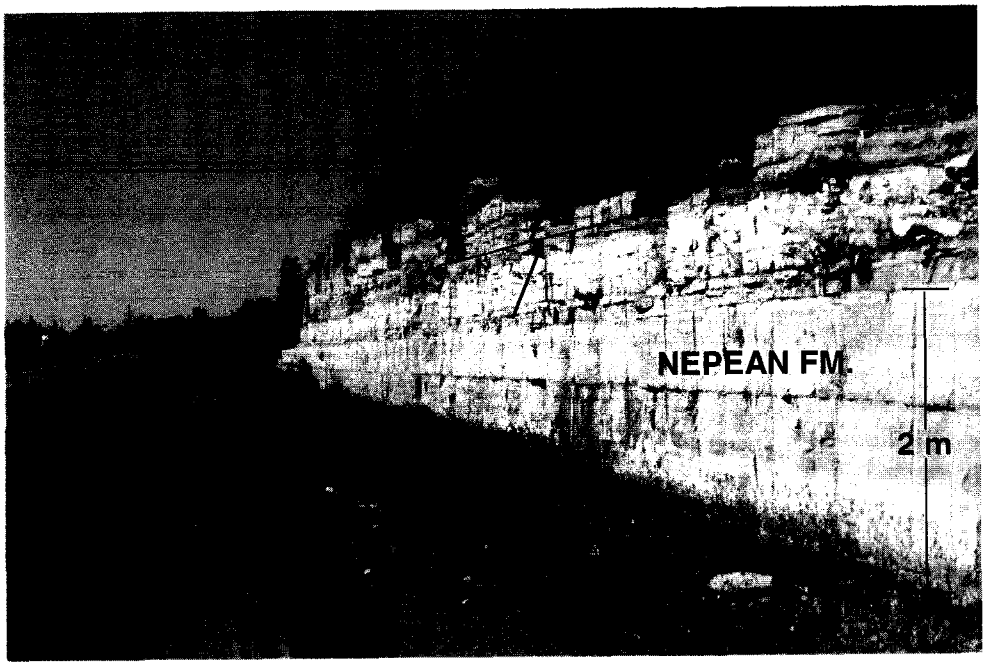


Figure 71: Nepean sandstone conformably overlain by dolostone of the March Formation, marked by arrow, in roadcut on Highway 416, Ontario, at station O-6. (Note the presence of a thin carbonate layer within the Nepean, approximately two metres above the base of the section).

writer's perspective, the definition of the Nepean – March boundary at the first appearance of a carbonate interbed, as long ago proposed by Wilson (1946) and others, is impractical. A far more simple and effective method of establishing this boundary throughout the Ottawa Embayment and Quebec Basin both at surface and in subsurface, is where the Nepean sandstone with minor carbonate interbeds give place vertically to dominant carbonate, with minor sandstone interbeds or lenses, as shown in figures 61 (b), 68 and 71.

To set the record straight with regard to the Campbell Quarry, it can be said that the workings are still intact, as they were during the professional years of Alice Wilson, thanks to the efforts of the Government of Canada. However, the grounds are not freely accessible to the general public, and there was thus a need on the part of Greggs and Bond (ibid.), to establish a new type section for this very important sedimentary succession. The Nepean beds exposed in the long abandoned Campbell Quarry at station O-3, is a classic section with much historical significance. An estimated 11 metres of strata are exposed at two levels (benches), consisting of white and light grey, thin to thick, uniformly bedded quartzarenite, that weathers grey to faintly pink and yellowish-green (see Figure 72). Neither the lower or the upper contact with the Precambrian basement and March Formation are exposed here, although the base of the

Figure 72: Campbell Quarry, near Bells Corner, Ottawa, at station O-3. Photo shows the lower of two benches where the Nepean sandstone was quarried for the construction of the Canadian Parliament Buildings, Victoria Memorial Museum, and other large buildings in Ottawa.

lower level of the quarry cannot be too far above the Precambrian surface at this locality. The Campbell Quarry as presently preserved by Canada Natural Resources, is much the same as it was more than 50 years ago when Alice Wilson used it as a field trip destination to show her Geological Survey of Canada colleagues (the writer included), and her "Carleton College" paleontology class, where the building materials for the Parliament Buildings, Victoria Memorial Museum and other large government buildings originated.

A short distance to the southwest of the type section, as defined by Greggs and Bond (ibid.), are excellent exposures of Nepean at the Terry Fox on-ramp to Highway 417 at station O-4 (see Figure 73), and in the nearby Kanata Centrum Shopping Plaza at station O-5. The strata are thin to thick bedded, consisting of white and cream-colored quartzarenite. The upper beds exposed at station O-4, contain a stromatolite biostrome, pseudomorphs of gypsum and desiccation markings suggestive of hyper saline intertidal to supratidal (sabkha), environments of deposition (Hilowle *et al.,* 2000). Aeolian deposits near the base of the Nepean have also been identified and described in this region of Ottawa. (Dobie, 2004). Deformation in the form of faulting, and the presence of ball and pillow structures, can locally be seen to occur slightly higher in section at station O-5 (see Figure 87).

On the north side of the Ottawa River in the city of Gatineau at Lac Beauchamp recreational area, station Q-1, thick massive beds of the Cairnside (Nepean) Formation, form the three to four metre high walls of an abandoned quarry. The beds sit directly on the Precambrian with unconformable contact exposed [see Figure 74(a)], the lower strata here and there containing large cobbles and boulders of quartzite. According to Hilowle *et al.,* (ibid.), the individual bedsets in this section are subaqueous dunes that "represent high-energy sedimentation in a subtidal marine environment". The sandstone is clean and nearly white in color and weathered dark grey to black, and dark reddish-brown in places. Trough crossbedding is abundant throughout the succession, from which two principal paleocurrent flow directions can be established at 024° and 122°. Stylolite seams are rarely seen in the Potsdam Group, but occur in

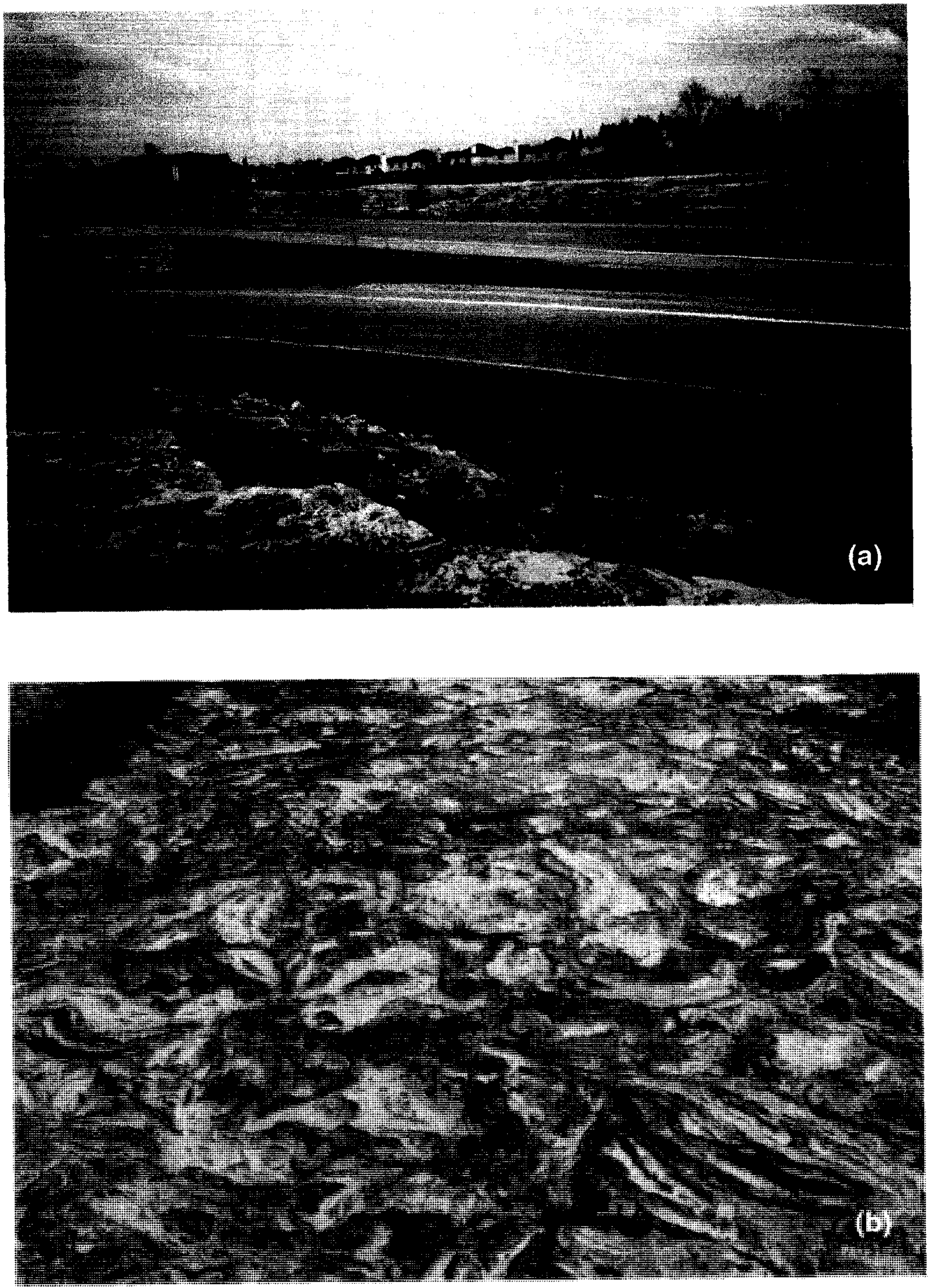


Figure 73: (a) Nepean sandstone exposed at Terry Fox Interchange on Highway 417, Ottawa, Ontario, at station O-4. (b) Surface layer of stromatolite biostrome exposed in lower left of photo (a) above.

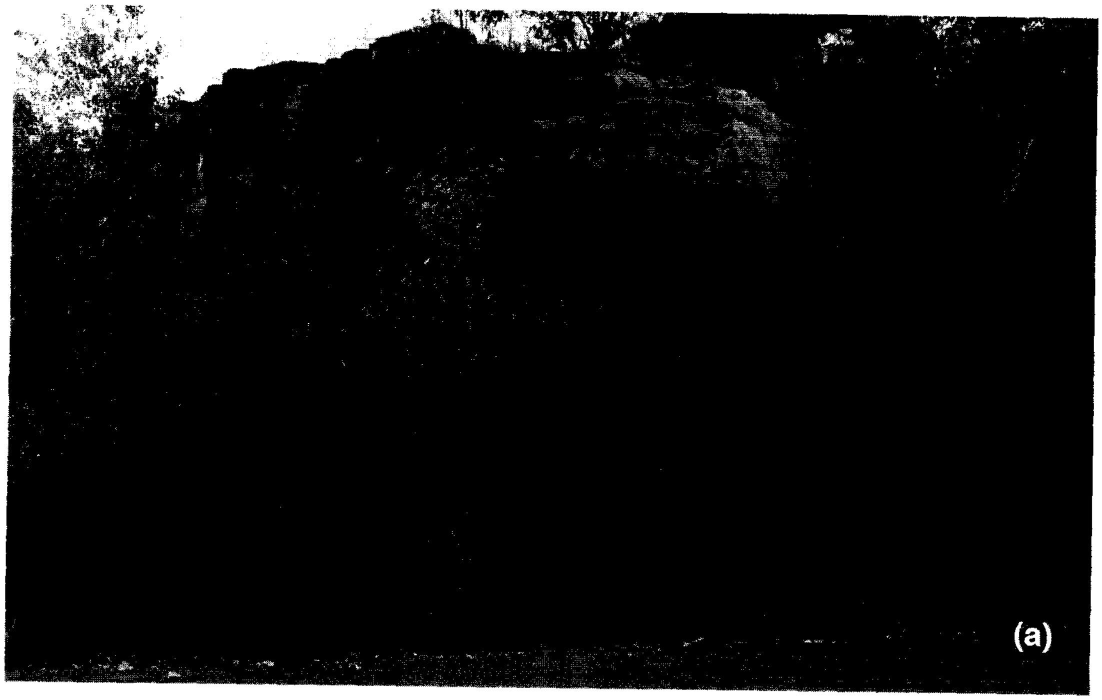


Figure 74: (a) Cairnside (Nepean) sandstone resting unconformably on Precambrian basement at Lac Beauchamp, Gatineau, Quebec, at station Q-1. (b) Transverse asymmetrical megaripples at the base of Cairnside on floor of abandoned quarry, a few metres south of photo (a). (Paleocurrent direction from right to left of photo).

great abundance at the Lac Beauchamp location, mainly along the bedding planes throughout the succession. Asymmetrical transverse megaripples in red stained quartzarenite occur at the base of the Cairnside (Nepean) Formation near the southern extremity of the abandoned quarry. The trend of the megaripple axes is east-southeast, with a corresponding paleoflow direction of 020°, their internal dune cross-stratification from right to left of photo in Figure 74(b). These structures show a configuration similar to dune cross-stratification seen elsewhere at the base of the Nepean and equivalent Keeseville formations at Rockland, Ontario (station O-1, see Figure 75), Lyn Valley Conservation Area, Ontario (station O-64, see Figure 28) and Blind Bay area of New York [station N-89, see Figure 61 (a)].

The upper contact of the Cairnside (Nepean) with the overlying Theresa (March) is not exposed in the park area, but the latter formation can be seen in outcrop immediately to the east of the park entrance on the north side of Maloney Boulevard. This would suggest that the very thin unit of Cairnside as exposed in the walls of the quarry may be very near to that of its original depositional thickness. Nepean sandstone, similar in appearance to the Cairnside (Nepean) described above, is exposed in a roadcut and quarries on Hawthorne Road at station O-7. The thick massive beds of high energy marine origin are presumably dunes similar to the Lac Beauchamp deposits that were deposited in very shallow marine conditions that prevailed along the upthrown side of the Gloucester Fault, the latter assumed to have been structurally high during the Nepean depositional period. Trough crossbedding is abundant in these beds, that show average palocurrent flow direction to the east at 087°. The upper boundary of the Nepean where overlain by the March Formation is abrupt and placed at the base of a thin unit of brown sandy dolomitic limestone. Immediately below the contact are small scale planar crossbeds (15 cm. thick), the foresets of which dip south-southeast presumably indicative of a temporary retreat of the Nepean sea in that direction prior to March deposition.

In contrast to the exposures in Ottawa and Gatineau where the Nepean Formation lies directly on the Precambrian crystalline rocks, is an isolated outcrop at Rockland, Ontario, at station O-1, in which the Covey Hill separates it and the Precambrian (see Figure 75). The lower 10 to 15 centimetres of the Nepean that lies on the Covey Hill is composed of black finely crystalline limestone that grades upward to grey, calcareous sandstone.

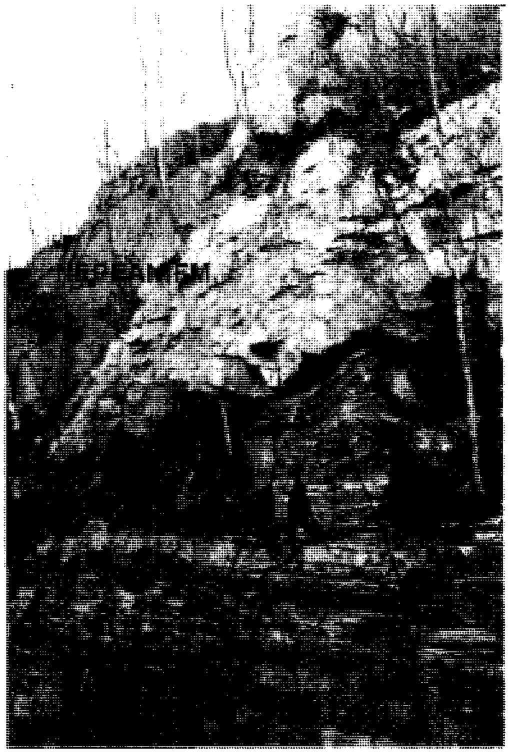


Figure 75: Nepean sandstone unconformably overlying Covey Hill Formation (Chippewa Bay Member) fronting Ottawa River at Rockland, Ontario, at station O-1. (Note large scale asymmetrical cross-stratification at base of Nepean. Paleocurrent direction from left to right of photo).

Near the crest of large scale ripples are imbricated rip-up sandstone clasts indicative of paleoflow to the north – from left to right in the field photo. The lower contact of these beds is abrupt, and presumably unconformable with the underlying Covey Hill. Their upper contact with the white and light grey Nepean quartzarenite, containing numerous pea-size spherical cavities, is also sharp, and may be disconformable.

On the southwest side of the Frontenac Arch in the Sloan Quarry located near Sunbury, Ontario (station O-57), an erosional remnant of grey bioturbated quartzarenite of the Nepean can be seen to rest unconformably on yellow, uniformly bedded sandstone of the Chippewa Bay Member of the Covey Hill (see

Figure 76). This is the only site in this part of central Ontario, to the writer's knowledge, where the above described stratigraphic relationships can be observed in outcrop. Elsewhere in this region, the Nepean rests directly on the Precambrian. From a paleogeographical viewpoint, the above described occurrence is important in that it proves beyond a reasonable doubt that Covey Hill strata were once widespread throughout southcentral and southwestern Ontario in pre-Nepean times, and were removed on a broad regional scale by erosion during the long hiatus that prevailed following its deposition.

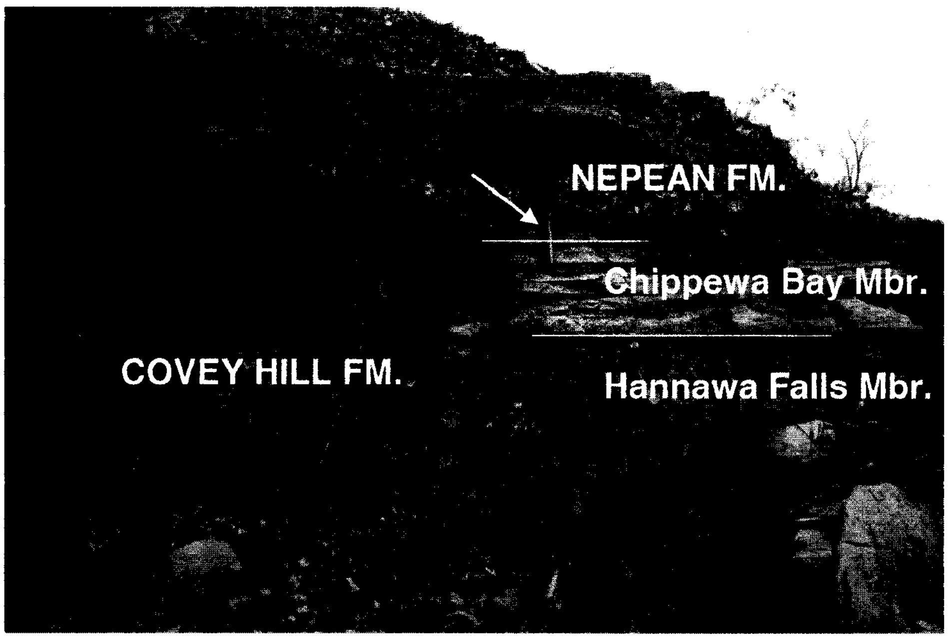


Figure 76: Nepean Formation resting with unconformable contact on Covey Hill Formation (Chippewa Bay Member) above base of hammer handle, in Norman Sloan quarry near Sunbury, Ontario, at station O-57.

Along the northern margin of the Adirondack Mountains, between Rensselaer Falls and the vicinity of Potsdam, the Keeseville Formation is apparently obscured beneath downfaulted Theresa strata. From the latter area eastward, the beds form a continuous outcrop belt to the vicinity of Plattsburgh on Lake Champlain. The first occurrence of Keeseville is at Brasher Falls, station N-124, where about two metres or less of sandstone are exposed on the floor and walls of the St. Regis River. From this point eastward to Chateaugay, outcrops are widely separated, occurring on the Salmon River at station N-125, and again near Burke, station N-126.

At Chateaugay River, station N-130 where it is crossed by Pulp Mill Road, a few metres west of the bridge and higher on the river bank is a 1.5 metre exposure of Keeseville Formation consisting of white massive bedded quartzarenite. Its' basal contact with the Ausable Formation (Edwardsville Member see Figure 40 (a) and (b) present in the upper walls of the gorge (described in an earlier section) is not exposed. However, based on the substantial differences in lithology and color of the two units, the contact is undoubtedly abrupt and unconformable. A thicker section of Keeseville, not examined by the writer, is apparently located a short distance downstream where fossil collections were made by Fisher (1968). East of Chateaugay, the frequency of Keeseville exposures greatly increase in number throughout the remaining distance to Lake Champlain. Most of these are not more than one or two metres thick, and are of uniform lithological composition, such as shown in figures 78 (c) and (d).

Where the Keeseville outcrop belt crosses into Quebec along the southern margin of the Valleyfield Trough (see Figure 3) the beds are known as Cairnside Formation (Globinsky, 1987), although the tiny community from which the type section was originally named is now known as Saint-Pierre. At this locality the beds are widely exposed, but nowhere were they observed to be more than one to two metres thick.

At the type section of the Keeseville Formation, a thick succession of uniformly bedded white and light grey quartzarenite is exposed along the vertical walls of the Ausable Chasm. The beds as viewed from the Route 9 bridge at station N-215 where it crosses the Ausable River is shown in Figure 77. The total thickness of beds exposed between the viewing platform (shown in upper middle of photo) and the river is approximately 30 metres, although the actual thickness of the formation at this locality may be up to twice or even three times

Figure 77: Keeseville Formation viewed from bridge where Route 9 crosses Ausable Chasm, New York, at station N-215. Approximately 30 metres of uniformly bedded Keeseville strata are exposed at this location.

that number, based on its thickness recorded in boreholes northeast of the Oka-Beauharnois Arch in adjacent areas of Quebec.

The lithological composition of the Nepean, and equivalent Cairnside and Keeseville formations where identified in boreholes in the Ottawa Embayment and western part of the Quebec Basin, is essentially identical to that observed in the many exposures examined in the field (see Figure 8). Strata are composed of white, cream or light grey quartzarenite throughout their area of distribution in subsurface, which in some instances contain quartz pebbles at their base, and sometimes higher in the formation. Argillaceous to shaley beds, occur locally but make up little of the stratigraphic section. Thin layers of gypsum interbedded with the sandstone occur throughout the upper half of the Nepean in the Imperial Laggan No.1 borehole. The presence also of brecciated intervals in the GSC LeBreton No. 1 borehole, and some brecciation also in GSC Russell No.1 may be suggestive of halite deposition, and subsequent removal by dissolution at some time during or soon after Nepean deposition. The presence also of thin igneous sills of assumed Early Cretaceous Age (Monteregian origin) was also noted in the St. Lawrence River No.1, and Quonto–St. Vincent de Paul boreholes as shown in Figure 8.

With the exception of the Dominion Observatory No.1 borehole, where the Nepean rests directly on the Precambrian, in all other boreholes, the Nepean or its equivalent Cairnside rests on the Covey Hill Formation, the positioning of the contact in diamond drill cores being a relatively straightforward process. Similarly, the Nepean or Cairnside contact with the overlying March and equivalent Theresa is everywhere abrupt when selected at a stratigraphic horizon where the overlying carbonate and sandy carbonate forms the dominant lithology of the formation.

Sedimentary Structures

The most common bedforms observed by the writer in the Nepean and equivalent Cairnside and Keeseville formations are small to medium scale cross-stratified structures. The most common form (>95%) is trough cross-stratified and cross-laminated sets, with rare planar crossbedded sets. In contrast to the Covey Hill and equivalent Ausable formations however, where trough cross-stratification is confined mainly to fluvial deposits, and were thus more numerous in the eastern part of the study area, they appear to be equally abundant everywhere in the Nepean and its stratigraphic equivalents, where the latter are exposed around the margins of the Ottawa Embayment and Quebec Basin (see Figure 78).

In the selection of sites for measuring crossbed orientations, in the Nepean and its equivalents, the principal objective was to compare flow directions with the Covey Hill and equivalent Ausable Formations at selected sites, and if possible to compare these findings with those obtained by Lewis (1963), the latter containing the only systematic crossbedding data published to date on the Potsdam Group in eastern Ontario, western Quebec and New York

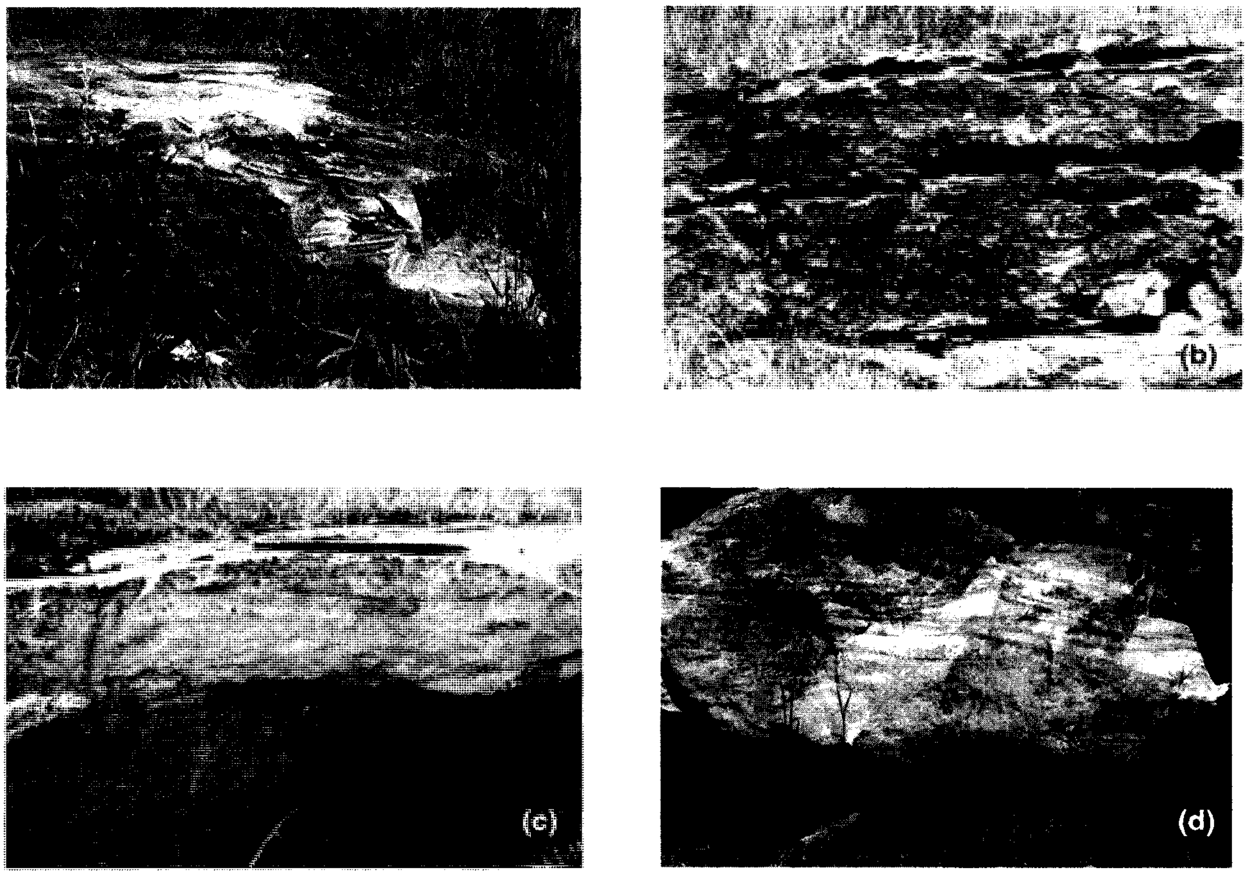


Figure 78: Dominant bedforms in Nepean and equivalent Keeseville and Cairnside formations are small-and medium-scale trough cross-stratification, some typical examples shown as follows: (a) Route 37, near Hammond, New York, at station N-78. (b) Highway 2, west of Gananoque, Ontario, at station O-53. (c) Route 190, near Ellenburg, New York, at station N-163, and (d) Route 9, near Chazy, New York at station N-210.

State. Sites were selected at widely separated localities, and at random, provided they contained well defined crossbeds - in each case trough cross-stratification. These are listed in Table 8 and shown in Figure 80, by red arrows at the respective locations where the readings were taken.

Locality	Station	Number of Readings	Average Paleocurrent Flow Direction
Clayton, N.Y.	N-1	20	166°
Wellesley Island, N.Y.	N-3	40	232°
South Hammond, N.Y.	N-73	1	218°
Hammond, N.Y.	N-78	3	199°
Ellenburg, N.Y.	N-140	30	013°
Chazy, N.Y.	N-210	26	091°
Lac Beauchamp, Que.	Q-1	26	024°/122°
Rideau Ferry, Ont.	O-15	40	065°
Hawthorne Rd., Ont.	O-7	36	087°
Gananoque, Ont.	O-53	16	144°

Table 8: Paleocurrent flow direction in Nepean and equivalent Cairnside, Keeseville formations in eastern Ontario, western Quebec and northern New York State.

The number of stations listed in Table 8 are obviously too few to reconstruct an accurate overview of paleocurrent flow directions throughout the study area. However the data plotted in Figure 80 show a highly generalized model of possible paleocurrent directions that may have been in place as the seaway flooded into the Ottawa Embayment, at least during its initial transgression.

To obtain readings that can be best used as examples to draw comparisons of paleoflow direction between the Nepean and Covey Hill and their equivalents, two areas were selected at opposite ends of the study area. One of these was located near Ellenburg, New York, and the other near Gananoque, Ontario, both areas containing an abundance of well-defined trough cross-stratified structures. In the eastern part of the study area near Ellenberg, at stations N-139 and N-140, separate and very different crossbedding measurements were recorded for the Ausable and Keeseville formations, containing paleocurrent flow directions of 139° and 013° respectively. The 139° measurement for the Ausable Formation is very close to the flow directions mapped by Lewis (1963), and one can only conclude from this that most of his measurements in this particular region were taken in Ausable bedrock terrains.

In the western part of the study area near Gananoque, Ontario, at stations O-52 and O-53, neither of the cross-stratification measurements of 307° and 144° for the Covey Hill and Nepean respectively are compatible with one another, or with Lewis (ibid.), yet when the two directions are averaged, the resulting vector of 225° is identical to the paleocurrent directions compiled by that author for this particular location. When Lewis (ibid.) carried out his research on crossbedding in New York, Ontario and Quebec, the Potsdam Formation was everywhere considered a single and continuous stratigraphic unit. It may have thus been possible that his "mean vector cross-bedding azimuth" calculations involved the averaging of two distinct populations of crossbeds in this particular region of his study area and it is only natural that his results would reflect that interpretation.

Crossbedding measurements if systematically recorded in the Nepean and equivalent formations would be most useful to establish marine current flow directions as the Upper Cambrian to Lower Ordovician sea moved into the

Ottawa Embayment from the Quebec Basin. The orientation of crossbedding in the aeolian deposits of the Covey Hill and equivalent Ausable formations on the other hand would likely show inconsistent wind transport directions that in one place or another would point to all degrees of azimuth. Any future paleocurrent research should therefore pay careful attention to the stratigraphic framework established in this investigation and record the crossbedding measurements separately for each of the two depositional sequences.

Examples of trough cross-stratification in the Keeseville Formation at Chazy (station N-210), Ellenburg (station N-140), and Hammond (N-78) all in New York State, are shown in Figure 78. One of the better examples of trough crossbedding in the Nepean Formation in eastern Ontario was recorded near Gananoque, also shown in Figure 78.

Perhaps one of the better examples of planar crossbedding was recorded on Black Lake Road at station N-116 (see Figure 79), which at the same location can be seen to be intersected by water expulsion structures, this being the only locality where the latter features were observed to be contained in the Keeseville or equivalent formations indentified in the field.

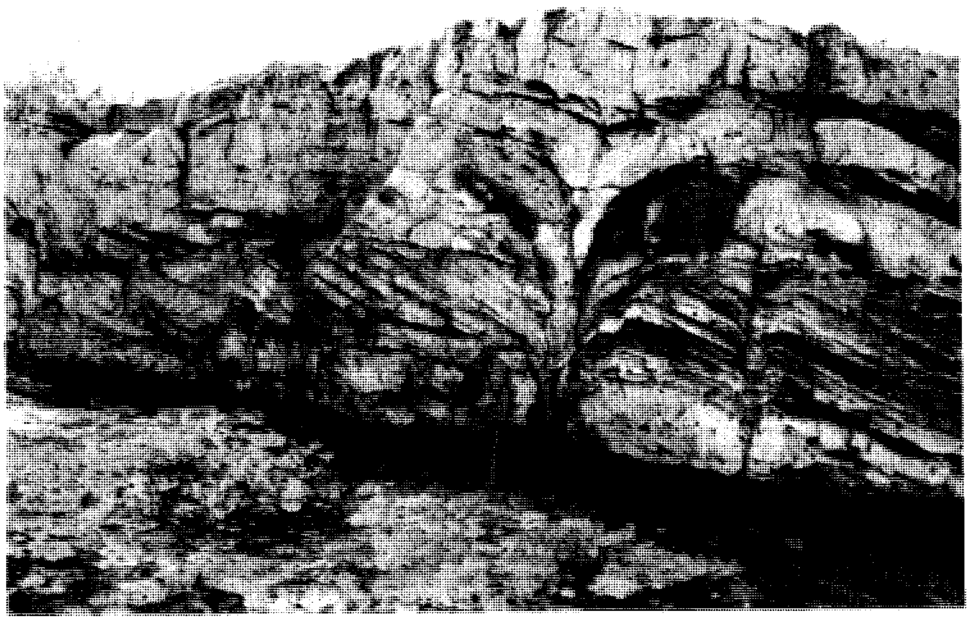


Figure 79: Planar crossbedding in upper Keeseville Formation, bordering the north shore of Black Lake, New York, at station N-116. (Note water expulsion structures).

Cylindrical structures such as formed in the Covey Hill and equivalent Ausable formations described in a previous section, are features that would not have likely formed during the marine deposition of the Nepean and Keeseville formations. However, such a well preserved, now empty cylinder in the Nepean Formation, can be observed in a roadcut on Highway 15, near the Jones Falls side road, at station O-27. The structure was probably formed by the same process, as those described earlier in the Covey Hill Formation on the William Hughes property at station O-56, but in all likelihood during the Quaternary period by a glacial outwash stream system, during which it was filled with sand and gravel, that was long since removed by erosion. The base of the cylinder is still intact at this location where it terminated within the Nepean Formation. The remnants of a similar empty cylinder of probable Quaternary age intersects Covey Hill strata at Charleston Lake, Ontario, (station 0-60), and is described in detail by Donaldson and Chiarenzelli (2004).

The bedsets contained in the Nepean and equivalent formations are of highly variable thickness, and this is a distinguishing characteristic of this upper unit of the Potsdam Group. At certain localities, notably at Blind Bay, New York at station N-90, beds are less than a centimetre thick [see Figure 63 (a)], whereas in some other regions they may be more than a metre thick, i.e. Lac Beauchamp, Quebec at station Q-1, [see Figure 74 (a)], and on Hawthorne road in Ottawa at station O-7. Such major differences in thickness of bedsets were apparently controlled by local and regional differences in paleogeography. The thicker sets would have been controlled in large part by major channel systems, under high energy depositonal conditions, and the thinner sets confined to the more common inter-channel areas where sediment was transported by wind and lower energy tidal currents.

There are undoubtedly numerous other areas bordering the basinal regimes where thickly layered intervals of quartzarenites are present, in either the Nepean, Keeseville or Cairnside formations, that originated by a similar process as cited above. Elsewhere, the Nepean and equivalents are more thinly bedded as they are traced into the distal areas of the Ottawa Embayment and Quebec Basin.

Petrogenesis

Marine depositional processes that began at the eastern end of the St. Lawrence Platform (Williams, *et at.*, 1995) at the onset of seafloor spreading in the Neoproterozoic and Early Cambrian, progressively spread north and westward onto the craton into the southern part of what is now the Quebec, Appalachian and Michigan basins in the Late Cambrian. From the Quebec Basin, the sea is assumed to have entered the Ottawa Embayment, initially through the Valleyfield Trough, (identified in Figure 3), which was a much wider geographical feature than it is today. From there it transgressed westward across the much older and partially eroded Covey Hill and Ausable terrains, eventually reaching the eastern margin of the Frontenac Arch in the initial Tremadoc Stage of the Early Ordovician (see figures 4 and 80).

In the western segment of the St. Lawrence Platform, the seaway advancing from the south across what is now the Appalachian basin, was presumably also time-transgressive as it approached the Frontenac Arch from the south and west. Thus the two bodies of water probably coelesced across the Frontenac Arch at some point in early Early Ordovician time to form a continuous seaway, the entire length and breadth of the St. Lawrence Platform.

Although the Nepean and equivalent Cairnside and Keeseville formations are by tradition considered part of the Potsdam Group, they have also, been long interpreted as a basal transgressive unit of the Beekmantown Group, which grades upward into the March and equivalent Theresa formations, and Oxford and equivalent Beauharnois and Odgensburg formations. (e.g. Wilson 1946). On the other hand, the interpretation of a regional unconformity at the boundary of the Cairnside Formation (Potsdam Group) and Theresa Formation

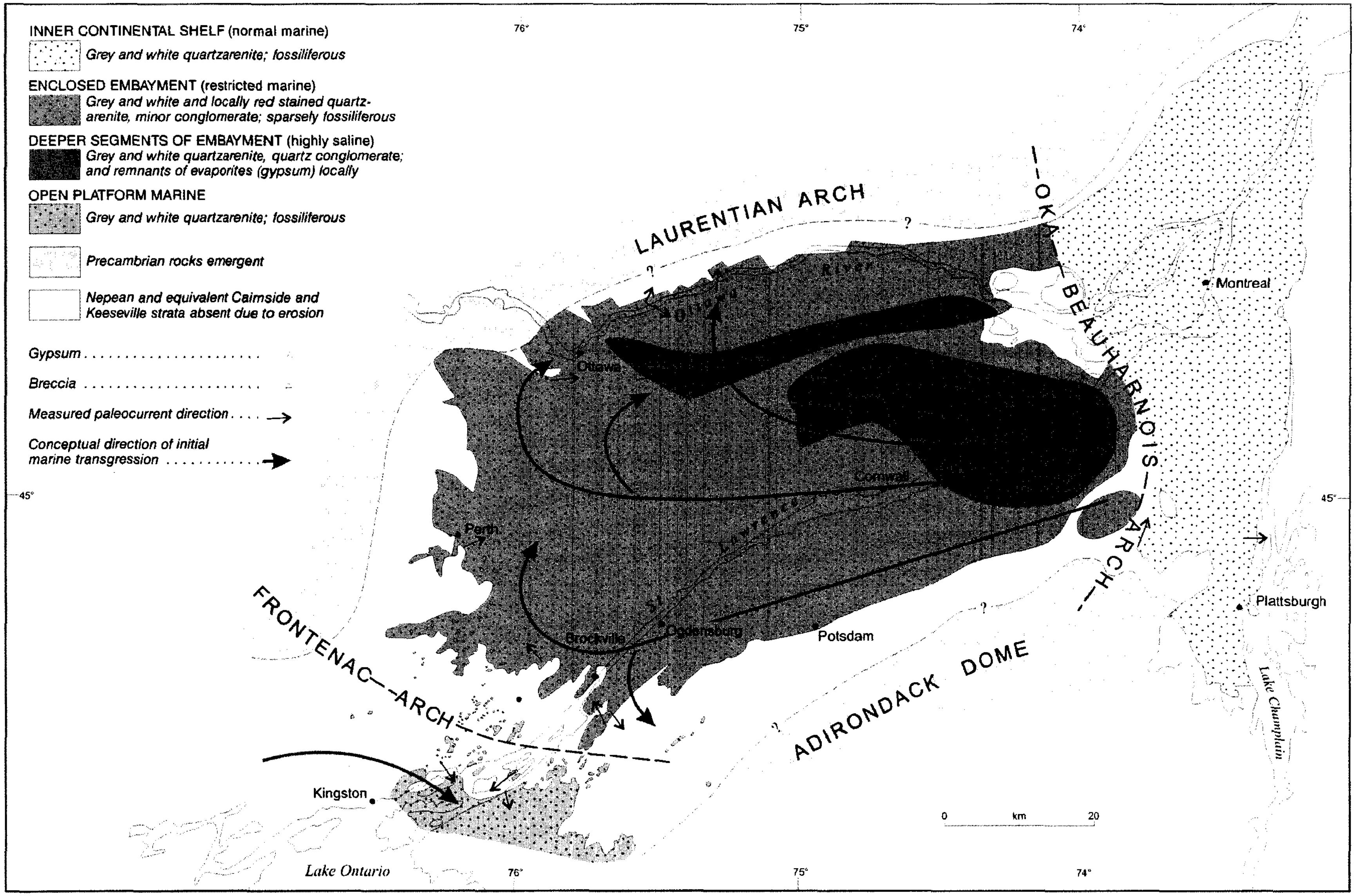


Figure 80. Depositional environments and facies distribution of Nepean and equivalent Cairnside and Keeseville formations.

(Beekmantown Group) in the Quebec Reentrant by Salad Hersi *et al.*, (2002), would clearly suggest that the contact between these two units was not a gradational process as long assumed.

The Precambrian terranes bordering the Ottawa Embayment and Quebec Basin during Late Cambrian and Early Ordovician time were positive physiographic elements, similar in some respects to those that prevailed during the Early Cambrian, as discussed in a previous section. However, the intense structural movements that accompanied the earlier Potsdam events were substantially reduced in the Late Cambrian to Early Ordovician, due to the much subdued intensity of tectonic events in progress in these later times, along the eastern margin of the North American continent. There is a great deal of uncertainty as to the cause or causes that may have triggered the substantial rise of sea-level that led to the marine transgression of such a broad region of the craton in the Late Cambrian and Early Ordovician. One might assume that the thickening and widening of the continental shelves (Knight, *et al.,* 1995), along with some tectonic adjustment that affected the volume of the oceans on a global scale, may have been the principal causes of the rise in sea-level that occurred at this particular period of geological time.

During the Late Cambrian, the Adirondack Dome was presumably a positive element and emergent, but mildly tectonic, except perhaps for the northeastern region of New York where substantial thicknesses of sand were apparently transported into the Quebec Basin, in a north-northeast and east direction, off the southern extremity of the Oka-Beauharnois Arch (Fisher, 1968). The Frontenac Arch was also a positive structural element during the Late Cambrian to Early Ordovician as evidenced by the substantial thinning of the Nepean and equivalent Keeseville along its higher structural axis that separates the Ottawa Embayment on the east, from what is now the Appalachian Basin to the west.

Throughout the western part of the Ottawa Embayment, the Nepean and Keeseville quartzarenite would appear to be of coarser texture than the subjacent Covey Hill and Ausable, as observed in hand specimens and thin-sections. This implies derivation of the detritus directly from Precambrian provenance areas, rather than second cycle origin. An exception to this may be the conglomerate that occurs at the base of the Nepean at two localities on Highway 15 in Ontario at stations O-17 and O-27, (see figures 32 and 19). In both of these areas, coarse quartzite cobble conglomerate occurs in the Covey Hill, and may well be the second cycle origin of the quartzite conglomerate found locally in the lower part of the Nepean Formation. Sand deposited in the northwestern part of the Ottawa Embayment was presumably derived from the Laurentian Arch bordering the Canadian Shield, although little is known about the Cairnside (Nepean) Formation in the region east of Gatineau, Quebec, where the beds are largely obscured by domestic and commercial development, or are otherwise buried beneath downfaulted blocks of younger Ordovician strata.

The principal source of much of the Nepean and equivalent Cairnside and Keeseville detritus deposited in the eastern and central parts of the Ottawa Embayment and adjacent Quebec Basin was presumably the northern segment of the Oka-Beauharnois Arch. The significant thicknesses of sand that accumulated to the west, south and east of this major structural feature would suggest it may have been undergoing tectonic rejuvenation throughout Late Cambrian and possibly early Early Ordovician time. The Cairnside sand derived from this segment of the arch may be of second cycle origin, having possibly been derived from the thick wedge of Covey Hill strata that was deposited around the margins of the Oka, Rigaud and Saint-Andre-Est mountains during Early Cambrian time.

U – Pb isotopic analyses of detrital zircons extracted from the Potsdam Sandstone in the Ausable Chasm in northeastern New York State by Gaudette *et al.*, (1981), yielded age dates corresponding to the Superior and Grenville provinces of the Canadian Shield. Zircons of Grenvillian age could have been derived from a wide spectrum of locations of the Adirondack Dome and/or immediately adjacent area of the Canadian Shield to the north. Whether or not the zircons of Archean age on the other hand were derived from pre-Grenvillian age rocks preserved in the Adirondack Mountains as suggested by Gaudette *et.*

al., (ibid.) or were transported southward into the area by stream systems that had their headwaters located far to the north in the Superior Province is unknown.

The presence of Precambrian highs on all four sides of the Ottawa Embayment provided sufficient enclosure for the concentration of higher than normal salinities during deposition of the Nepean and equivalent formations. The highly generalized facies map in Figure 80 shows the areas where salinities would have more than likely been significantly higher than normal, in which evaporites could conceivably have been deposited. Imperial Laggan No. 1 borehole (see Figure 8) encountered numerous gypsum interbeds throughout the upper half of the Nepean Formation, indicating hyper-saturation of the depositional medium in the eastern, deeper parts of the Ottawa Embayment. Fairly intensive brecciation in GSC-LeBreton No.1 borehole, and to a lesser extent in GSC-Russell No.1 borehole, might also suggest the initial presence of minor halite in those areas, with subsequent dissolution and collapse.

Additional evidence of highly saline conditions throughout the Ottawa Embayment is the widespread paucity of normal marine fossils, except for trace fossils that have been noted here and there. The presence also of stromatolites that can survive and even thrive in hypersaline conditions is one of the better indicators of evaporitic conditions. These occur in great numbers in the Kanata region of Ottawa, on Highway 17, at Terry Fox Interchange, where they reach biostromal proportions at station O-2 [see Figure 73 (b)], and in various areas of New York State, notably near Chapel Corners, where numerous solitary stromatolites were observed at station N-66, and elsewhere.

On the western margin of the Frontenac Arch in Ontario and New York State, where more normal open platform marine conditions prevailed, fossils appear to be present in the Keeseville and equivalent Nepean formations in greater numbers and diversity. Similarly, on the east side of the Oka-Beauharnois Arch bordering what was once an open marine continental shelf, extensive fossil collections were made by Van Ingen (1901) and Fisher (1968).

In a previous section of the present dissertation, photomicrographs of Covey Hill and equivalent Ausable sandstone were introduced to show the presence of iron oxide dust rims surrounding the individual sand grains that are locked into the system by quartz overgrowths and cementing material. It was also pointed out that the Nepean and its equivalents generally lack this characteristic, and the differences between the two units can thus be recognized by comparing photomicrographs of the two stratigraphic units. Such a test was conducted on thin sections cut from the Covey Hill and Nepean Formations, that lie below and above the unconformity respectively, on Rideau Ferry Road at station O-16 [see Figures 81 (a) and (b)]. At this station, the two formations are bounded by an angular unconformity, so there is no question as to where to place the contact. However, at this locality the Chippewa Bay Member of the Covey Hill Formation is of very similar lithology to the overlying Nepean, and had there not been structural discordance between the two, some difficulty may have been had in distinguishing a contact at this locality. The photomicrographs on the other hand show significant petrological differences. Below the unconformity, [see Figure 81 (a)], the individual grains of the Covey Hill, as shown in plane light are readily identifiable by red dust rims, whereas above the unconformity [see Figure 81 (b)] the individual grains of the Nepean lack the red coloration around their rims, and their outline are thus barely perceptible in plane light in the photomicrograph. A second point of interest in comparing the two thin sections from below and above the unconformity is that the Nepean Formation having been deposited in a higher energy marine environment is of slightly coarser texture, which might suggest that the sands were likely of primary origin, at this particular site, and thus derived directly from a Precambrian provenance area beyond the margins of the Ottawa Embayment.

Another petrological characteristic of the Nepean and its equivalents throughout much of the study area is the haphazard interlaying of fine and coarse sandstone. This is commonly seen in outcrop and in subsurface, where the normally fine to medium grained quartzarenite contain intermittent layers of very coarse sand to granule or fine quartz-pebble conglomerate. One example of

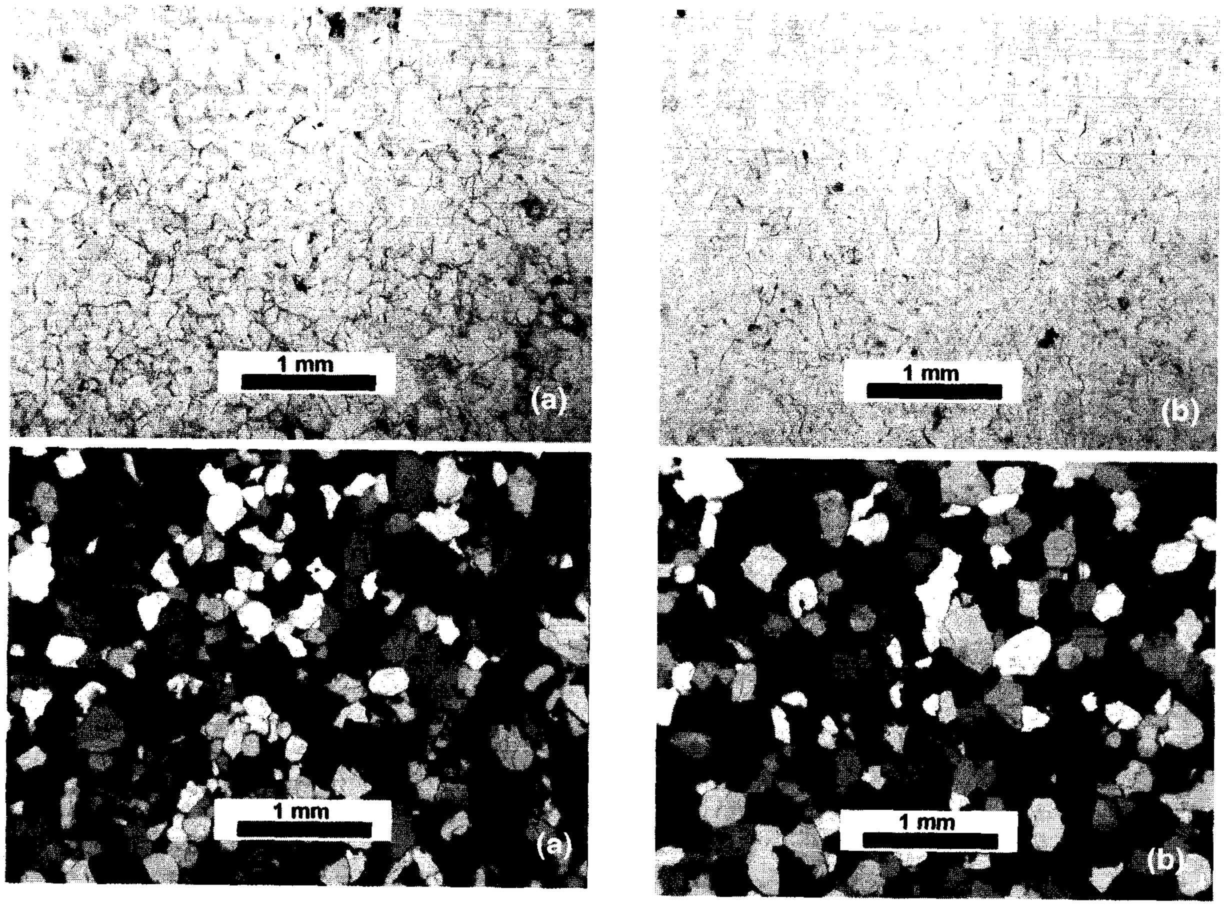


Figure 81: Photomicrographs of Potsdam sandstone near Rideau Ferry, Ontario, at station O-16. (a) Fine to medium grained sandstone of the Covey Hill Formation (Chippewa Bay Member), beneath angular unconformity, (b) Medium grained sandstone of the Nepean Formation, above the unconformity. [Note the well-defined outline of sand grains in plane light in (a), and lack of definition in plane light (b)].

such a boundary between fine and coarse sandstone layers in the Keeseville Formation can be seen in a photomicrograph representative of station N-81 near Hammond, New York (see Figure 82).

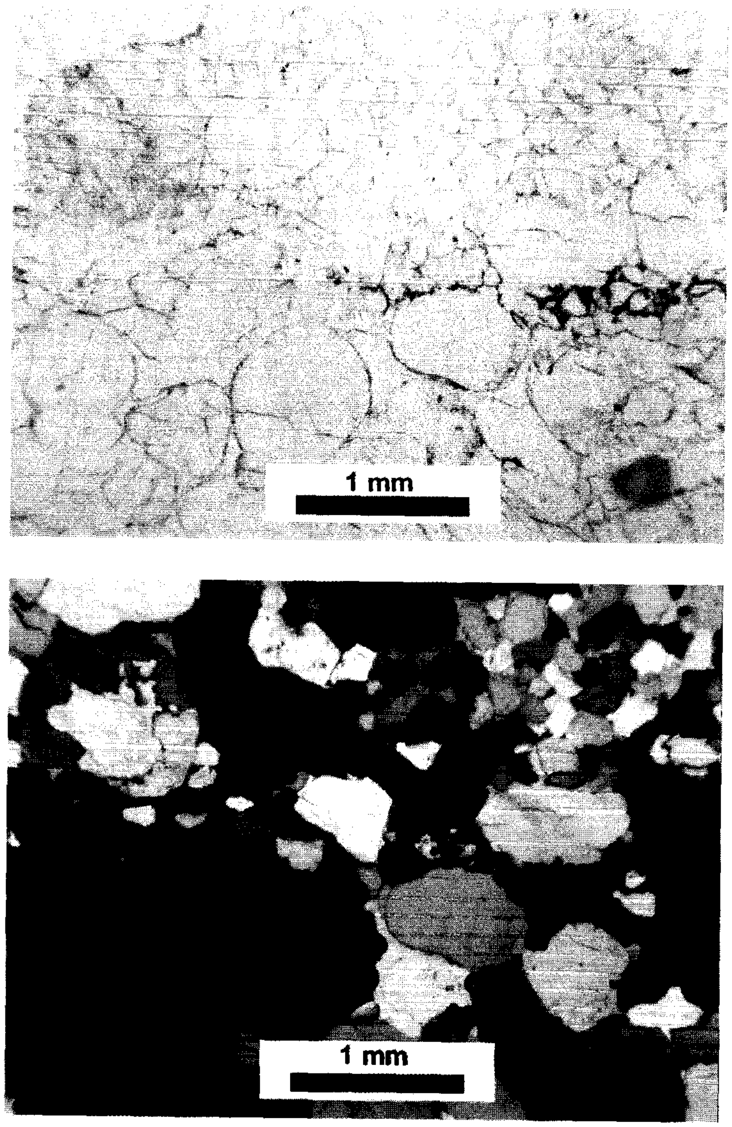


Figure 82: Photomicrographs of Keeseville sandstone near Chippewa Bay, New York, at station N-81, showing abrupt change from fine to very coarse grain sizes, typical of the Keeseville and equivalent Nepean in this part of the study area.

Age and Regional Correlation

Fisher (1968), in his report on *the "Geology of the Plattsburgh and Rouses Point, New York-Vermont Quadrangles*", dates the Keeseville Member as Dresbachian (early Late Cambrian) based on the presence of triolobites *Komaspidella seelyi* and *Lonchocephalus minutus* that were collected in Ausable Chasm "about 120 feet (36.6 m) from the lowest beds", along with "the probable mollusk, *Hyolithes* and the inarticulate brachiopods, *Lingulella* and *Obolella*".

Farther to the west in Chateaugay River Gorge, Fisher (ibid.), dated "the Potsdam (Keeseville Member) later Late Cambrian (Trempealeau), yielding the trilobites *Prosaukia* and *Ptychaspis*). Fisher (ibid), goes on to state that "In St. Lawrence County (north and west of the Adirondack Mountains) diagnostic trilobites have not been reported, but in view of the progressive northwestward chronologic transgression, the Potsdam (Keeseville) is likely Early Canadian".

In adjacent areas of Quebec, Clark (1966, 1972) reported the presence of *Lingulepis acuminata* in the Cairnside Member of the Chateauguay Formation, along with a number of trace fossils including *Climachichnites wilsoni, Protichnites* sp., *Arenicolites* sp., *Skolithos* sp., and *Pyrichnites* sp. The Cairnside Formation, as it is now known, has been traditionally dated as Late Cambrian (Clark, 1966, 1972); and Globinsky (1987), although none of the fossils described by the above authors appear to be diagnostic of either Cambrian or Ordovician age.

At the western end of the Ottawa Embayment, Wilson (1946) dated the Nepean Formation as Early Ordovician, mainly on the basis of it being a part of a continuing depositional sequence, "grading from sandstone (Nepean) into interbedded sandstone and dolomite (March), and then into dolomite (Oxford)", the latter formations long thought to be Early Ordovician age, based on the presence of *Ophileta compacta, Ecciomphalus calciferous* and other Lower Ordovician forms. The only marine fossil indigenous to the Nepean, with the exception of trace fossils and stromatolites in eastern Ontario is *Lingulella* *accuminata*, which according to Wilson (1946) "has been cited from New York, Vermont, Wisconsin, Minnesota and Tennessee from both the Cambrian and Lower Ordovician".

In adjacent areas of New York State, fossils appear to be locally abundant, although they were mostly destroyed by abrasion during depositional processes. At one location on the west side of the Frontenac Arch extension near Redwood, New York at station N-42, an Echinoderm colony was noted, and photos of which were tentatively described by Jean Dougherty (personal communication) of the Geological Survey of Canada as reminiscent of *Pleurocystites* sp. Elsewhere in New York State and eastern Ontario stromatolites were noted in fair numbers along with small flat coiled gastropods, and many trace fossils, including *Climachichnites* sp., possible *Locheia* sp., *Diplocraterion* sp., *Arenicolites* sp., and *Rosselia* sp. none of which have any particular value in terms of biostratigraphical zonation.

The first major breakthrough in the dating of the Nepean type section, in the western part of the Ottawa Embayment at station O-2 on Highway 417, was by Brand and Rust (1977), who recovered conodonts of early Arenigian age from three zones in the upper part of the succession. Two of these zones were in beds near the top of a unit classified as Nepean Formation, and the third from the very top of the section that they referred to as March Formation. Beds lower in the section were barren of conodont fauna, and were classified as Tremadocian (Lower Ordovician), as originally assumed by Wilson (1946), and Greggs and Bond (1972), the latter of whom considered the entire section to be Nepean and of Tremadocian age.

During the course of more recent investigations of the same section discussed above, Godfrey Nowlan of the Geological Survey of Canada (in Dix *et al.,* (2004) recovered conodonts from two intervals which he dated as Tremadocian to Arenigian , which were from strata that were identified by Dix *et al.,* (ibid.) as Theresa (March) Formation. Based on the findings of the current investigation, the writer could find no basis for the identification of March Formation at this location, and thus the entire section is herein classified as

Nepean Formation, and assumed to be of Early Ordovician age in accordance with Greggs and Bond (1972), and the more recent dating by Godfrey Nowlan in Dix *et al.,* (ibid.).

In New York State, where the Keeseville Formation overlies the southern extension of the Frontenac Arch it thins to 8.8 metres or less, and appears to be in conformable contact with the overlying Theresa Formation. So far as is known, these upper Keeseville beds have not been dated, but one can reasonably conclude that they too are mostly Early Ordovician age, (see figures 58 and 83).

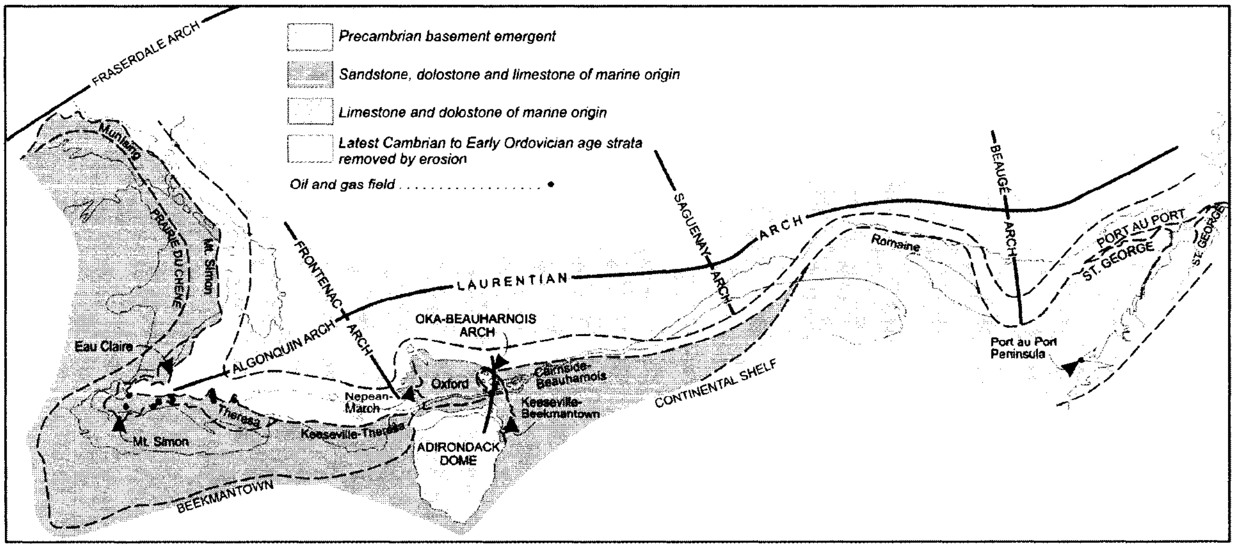


Figure 83 . Paleogeography of Late Cambrian to Early Ordovician sequence

The Cairnside and equivalent Keesville formations in the western part of Quebec Basin dated Late Cambrian by Fisher (1968; 1977) are in all probability equivalents of the carbonate rocks of the Petit Jardin and Berry Head formations of Dresbachian, Franconian and Trempealeauan age in western Newfoundland at the eastern extremity of the St. Lawrence Platform (Knight *et al.,* 1995). They are in turn presumably correlative to the Upper Cambrian sandstone and carbonate rocks of the Mount Simon, Eau Claire, Galesville, Franconia and

Trempealeau formations, in that respective stratigraphic order of succession, in the Michigan Basin.

The slightly younger (Early Ordovician) Nepean and equivalent Keeseville formations, where these have transgressed through time in those areas approaching and overlying the Frontenac Arch, are likely equivalent to the lower St. George Group (Watts Bight) of western Newfoundland (Knight *et al.,* 1955). They are likely also equivalent to the lower Prairie du Chene Group (Oneota Formation) in the Michigan Basin and adjacent area of Wisconsin, at the opposite extremity of the St. Lawrence Platform (Smith *et al.*, 1993).

CHAPTER 6

STRUCTURAL FRAMEWORK OF THE POTSDAM GROUP

The Canadian Shield, composed largely of Precambrian igneous and metamorphosed terranes, forms the bedrock surface throughout a wide region of eastern and northern Canada (Wheeler, *et al.,* 1997), and is everywhere continuous in subsurface beneath the Phanerozoic sedimentary terrains of the Arctic, Interior, Hudson and St. Lawrence platforms. Ingrained in the structural framework of the Canadian Shield and its extensions, are a series of northeast- and northwest-trending orthogonal arch systems, which previously were identified and defined by Sanford, *et al.,* (1985), Sanford, (1987), and Sanford and Grant (1990, 1998). These major tectonic elements, some of which extend for several thousand kilometres across the North American continent (Sanford, *et al.,* 1985) were described in greater detail by Card, *et al.,* (1997), along with new insights into the history of their probable inception, and the triggering mechanisms that likely gave rise to episodes of rejuvenation and uplift during the Proterozoic and Phanerozoic. The arch systems as they relate to inception and development of the foreland basins of the St. Lawrence Platform are discussed in Sanford (1993 a, 1998 a).

Although major deformation of the southern margin of the St. Lawrence Platform is known to have accompanied the emplacement of allochthons during Taconian and Acadian orogenesis (Williams, *et al.,* 1995; Knight, *et al.,* (1993), the more intensive periods of epeirogeny affecting broad regions of the North American craton occurred as a result of three specific plate-tectonic related events, as discussed by Card, *et al.,* (1997): (i) the initial rifting and separation of the continents, and opening of the ancestral Iapetus Ocean, during the Late Proterozoic and Early Cambrian, (ii) an event of uncertain origin (possible continental collision?) that abruptly altered the broad transgression of the seaways across the Canadian craton at the close of the Early Silurian and continuing through the Late Silurian, and (iii) a second period of crustal extension related to continental breakup in the Jurassic and Cretaceous.

The first of these events in the Late Proterozoic to Early Cambrian affected a large area of the southern Canadian Shield, extending from western Newfoundland and southeast Labrador (Williams, *et al.*, 1995), to the Great Lakes region of Canada and United States (Sanford 1993 a and b). Affects of rifting is recorded along the Laurentian Arch (see Figure 59), where it bordered the St. Lawrence Platform in southern Quebec and southeastern Ontario to the vicinity of Georgian Bay (Lake Huron). In the latter area it merged with the Waverly Arch curving to the southwest and extending across southwestern Ontario and into northwestern Ohio.

Intersecting the Laurentian Arch at right angles is a series of southeast-trending arches, which from east to west are the Beaugé, Saguenay, Oka-Beauharnois and Frontenac arches, all of which were positive tectonic elements from late Precambrian to Early Cambrian (Sanford, 1993 a). The mostly non-marine sandstone and conglomerate that were deposited at that time within the St. Lawrence Platform, make up the lower strata of the Labrador Group in the east (Bateau, Lighthouse Cove and Bradore formations and Double Mer Formation, the lower part of the Potsdam (Abbey Dawn and Covey Hill and equivalent Ausable formations) in the Quebec Basin and Ottawa Embayment, and possibly the Jacobsville and Middle Run formations in the Michigan and Appalachian basins, respectively, in the western part of the platform. Structural rejuvenation of the Grenville structural front that curves sharply to the south near the eastern extremity of Manitoulin Island and passes through eastern Michigan and across western Ohio (Benjamin, *et al.,* 1997), and the broadly distributed Grenville basement rocks exposed in this general region, would most likely have provided a major sediment source for the latter formations.

Most of the deformation that accompanied Neoproterozoic to Early Cambrian deposition in the Central Division of the Platform as determined during the present investigation, appears to have been a consequence of normal faulting and local thrust faulting. In many places the beds are gently folded, but whether or not such deformation was due to regional stresses or was activated during the process of fault-block rotation or a combination of these processes is not readily known. Such deformation is quite well displayed throughout the present study area, and particularly so along the eastern margin of the Frontenac Arch in Ontario, and the Frontenac Arch extension in New York State. Here fractures can be readily recognized on satellite imagery (Sanford, *et al.,* 1985), dominant to the northeast. A second less common set is oriented to the southeast; followed by the least common set that trends E-W and is confined largely to the Ottawa-Bonnechere Graben, at the northern part of the Frontenac Arch (Card, *et al.,* 1997) and in the Montreal area (see Figure 3).

Major northeast oriented structures that involve Covey Hill and equivalent Ausable formations, which clearly pre-date the Nepean and equivalent Keeseville formation, appear to have been related to the rejuvenation of these fracture sets, and are present at stations O-14, O-16, O-17, O-27, O-35 and O-52 in Ontario, and at stations N-39, N-80 and N-26 in New York State.

The first and perhaps the most spectacular of such deformation is recorded at station O-16, where the Chippewa Bay Member of the Covey Hill was uplifted along a normal fault oriented at 050°. The uplift was at least five metres, and likely much more, in as much as the Covey Hill was substantially bevelled by erosion prior to the deposition of the Nepean Formation (see Figure 1). On the upthrown side of the fault are large blocks of quartzite conglomerate representing the basal strata of the formation. Along the downdropped side of the fault, grey and reddish stained sandstone of the Covey Hill is steeply dipping to the west, gradually decreasing to nearly horizontal near the western end of the outcrop. The time of faulting was obviously post-Covey Hill, judging by the brittle nature of the fracturing, but prior to the deposition of the Nepean, the latter of which is flat lying and resting on the Covey Hill with angular unconformity.

Approximately 2.5 kilometres to the west of the aforementioned structure, remnants of the Hannawa Falls and Chippewa Bay members of the Covey Hill are preserved in a graben at station O-14 (see Figure 21). The outcrop is bounded both on the west and east by Precambrian rocks, and the strata between form a well-defined syncline, its axis oriented at 050°. The present exposure presumably represents only a part of the original graben, its eastern half apparently having been removed by erosion. At the base of the Covey Hill Formation at its preserved eastern margin is a tightly folded anticlinal structure (see Figure 84). This is assumed to have formed by compression as a result of

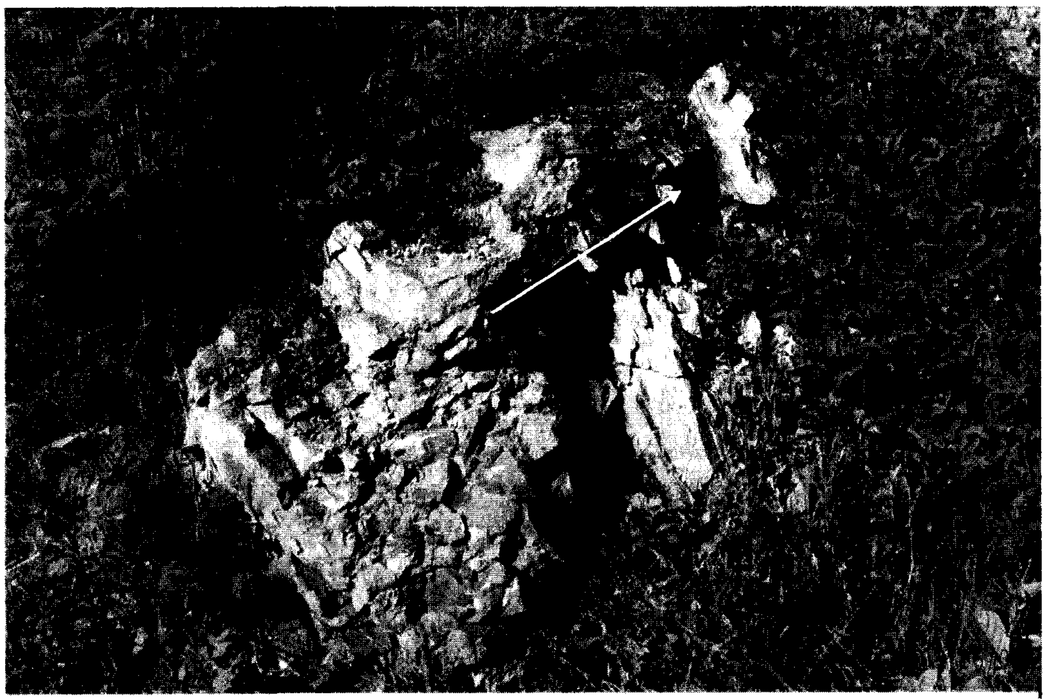


Figure 84: Tightly folded basal strata of Covey Hill Formation on Rideau Ferry Road at intersection with Otty Lake Road, Ontario at station O-14. (Arrow defines axis of structure).

the horizontal shortening of the Hannawa Falls Member as the beds were squeezed between the two parallel faults as they collapsed into the confines of the graben. The well preserved stratification in the tightly folded structure suggests that the deformation may have taken place prior to the complete lithification of the Hannawa Falls Member. The age of the folding at station 0-14 would thus appear to predate the faulting and tilting of the younger Chippewa Bay Member of the Covey Hill Formation located a short distance to the east, at station 0-16 (see Figure 1). One might further conclude from the above comparison of the two stations that the structural deformation of the Covey Hill may have been an ongoing process in this part of eastern Ontario at least, throughout the depositional phases of the Lower Cambrian.

Evidence of pre-Nepean folding can also be observed in a roadcut on Highway 42 at the northern town limits of Delta, Ontario, at station O-35, where again, the basal strata of the Covey Hill Formation (Hannawa Falls Member) is folded and succeeded with angular unconformity by flat lying strata of the Nepean. The axis of the fold is also 050°, coincident to the axis of the folding and fracturing of the Covey Hill at the two previous sections discussed. This section is similar in some respects to station O-16, except that the sharply upturned edges of the Covey Hill beds beneath the angular unconformity form a highly irregular surface beneath the Nepean, particularly along the northern margin of the syncline. Here, a major depression on the surface of the Covey Hill was initially filled with pebbly sandstone and quartzite cobble conglomerate of the Nepean, the latter onlapping and progressively overlapping the higher structural segments of the Covey Hill Formation to the south (see Figure 17).

Pre-Nepean deformation of Covey Hill strata most likely occurred at an isolated locality on Highway 2 near Gananoque, Ontario at station O-52 (see Figure 27). A tiny remnant of Chippewa Bay strata of the Covey Hill Formation is preserved in a possible down-faulted block in an area where Nepean outliers normally overlie the Precambrian surface. A southeast-trending lineament separating these beds from the nearest Nepean outlier to the east, in addition to a normal fault with the same orientation, that cuts Covey Hill strata, is sufficient evidence to suspect structural movement of these beds prior to deposition of the Nepean, in this western part of the Frontenac Arch.

In adjacent areas of New York State, there are many areas where Ausable strata have been subjected to faulting and consequent rigid block rotation, resulting in gentle to steep inclination of the strata. At some of these locations, the deformation can be seen to pre-date deposition of the Keeseville Formation, such as at stations N-40 and N-80 [see figures 64 and 65 (b)]. There are a number of locations where deformation is believed to have also pre-dated Keeseville deposition, but in the absence of the latter, the age of faulting is uncertain. Three such structures are shown in Figure 85 (a), (b) and (c). Section (a) is the Hannawa Falls Member of the Ausable Formation near Pope Mills at station N-120; section (b) Hannawa Falls and Chippewa Bay members, near Six Berry Lake at station N-33; and section (c) an isolated outlier of Hannawa Falls member, 12 kilometres north of Gouverneur at station N-122.

Evidence of pre-Keeseville thrust faulting can be seen in at least two localities in New York State, at stations N-40 and N-26 [see figures 86 (a) and (b)]. Section (a) shows Chippewa Bay beds of the Ausable Formation cut by what would appear to be a low-angle thrust fault oriented at 325° dipping to the northeast, superimposed on which is a major anticline, its axis of similar trend to the thrust. A few hundred metres to the east of this structure, the irregular surface of the Ausable Formation is overlain with angular unconformity by the Keeseville Formation (see Figure 64).

High angle thrust faulting can also be seen to have occurred below an unconformity within the Ausable Formation (Chippewa Bay Member) at station N-26 (see Figure 86 (b). The lateral and upward movement of the beds below the unconformity along the thrusts, and compensating vertical dislocation of the upper beds, have combined to form the prominent monoclinal structure shown to the left of the hammer. Here, the thrusts strike 050°, dipping 063° to the southeast.

Major deformation, mostly expressed as faulting prior to Nepean and equivalent formations, can be assumed to have occurred at many other widely separated parts of the study area. This is particularly so along the northern segment of the Oka-Beauharnois Arch in the Oka-Rigaud-Saint-André Est mountains region of Quebec. The stratigraphic sections of Covey Hill Formation exposed on the western part of Île Perrôt described earlier, some 30.5 metres thick, are succeeded on the eastern end of the island by the Cairnside

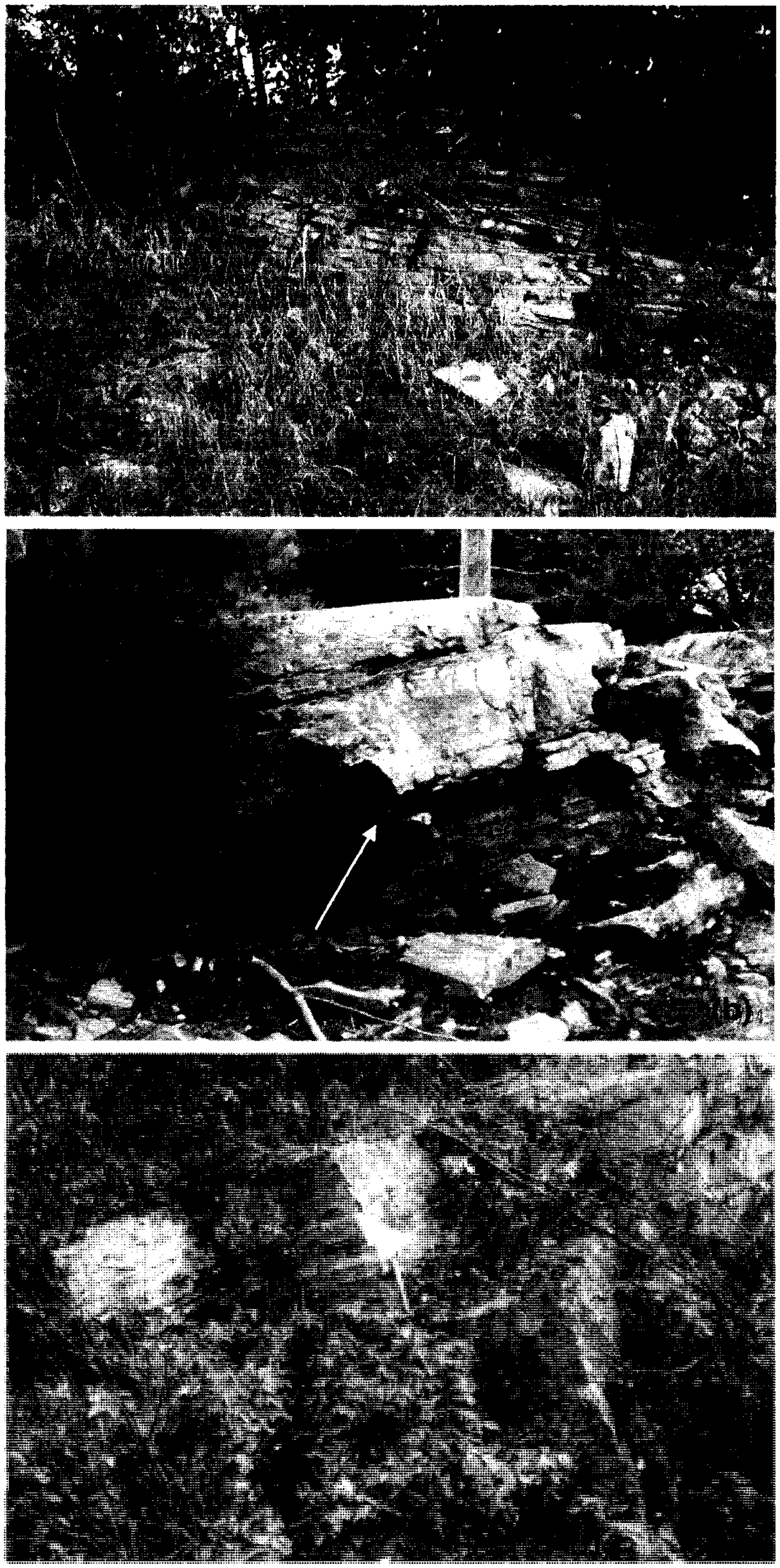


Figure 85: Block faulting and tilting of the Ausable Formation assumed to have occurred prior to deposition of the Keesevile Formation in New York State: (a) Hannawa Falls Member near Pope Mills at station N-120. (b) Hannawa Falls and Chippewa Bay members near Six Berry Lake at station N-33, and (c) An isolated outlier of Hannawa Falls Member, 12 kilometres north of Gouverneur, at station N-122.

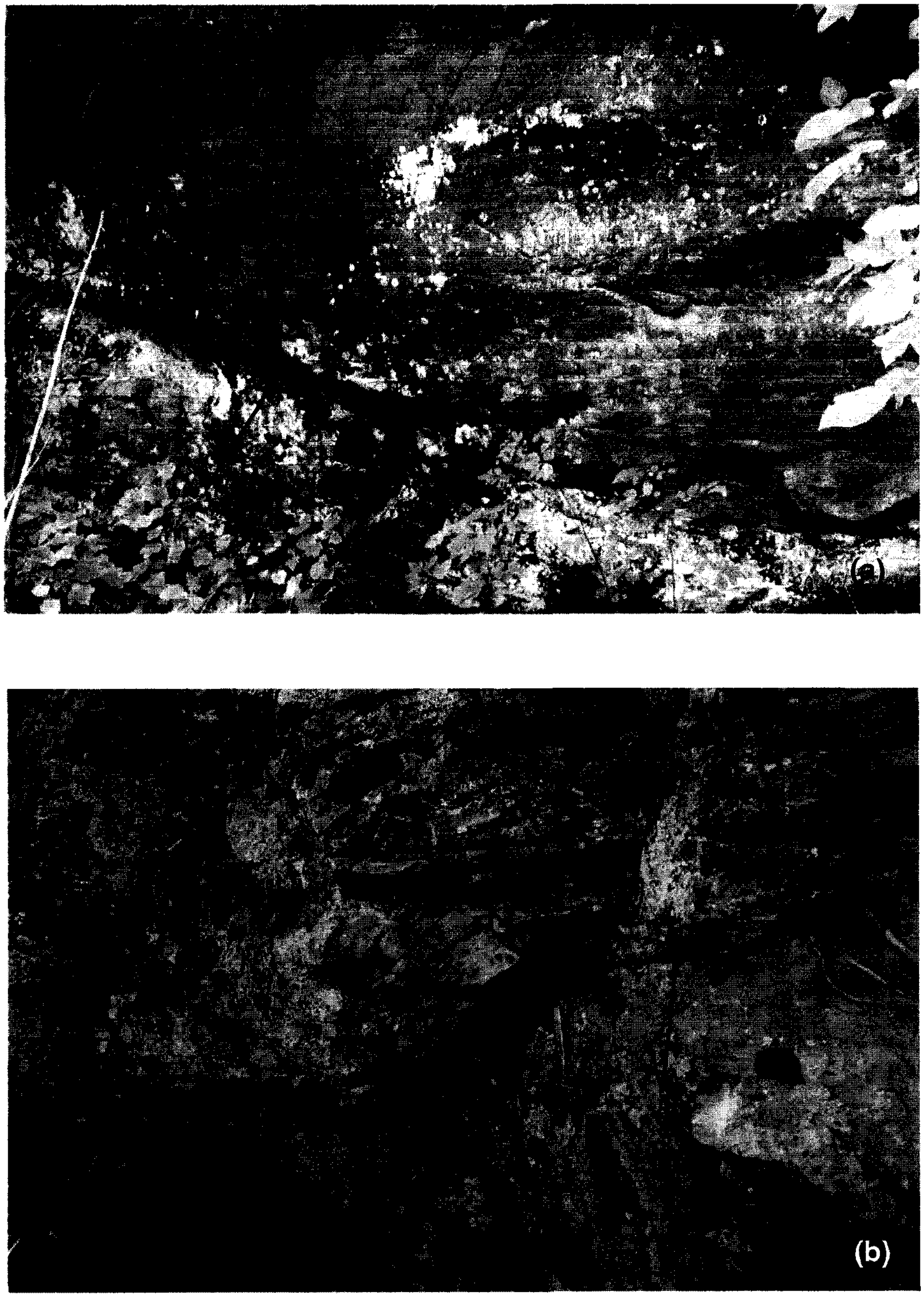


Figure 86: Pre-Keeseville thrust faulting in Ausable Formation. (a) Possible low angle thrust fault intersecting Chippewa Bay member, one kilometre west of Redwood, New York, at station N-40. (b) High angle thrust faulting within the Ausable Formation below an unconformity, and compensating vertical normal fault movements in the upper beds, having combined to form the monoclinal structure to the left of the hammer handle, near Theresa, New York, at station N-26. Arrows denote unconformity.

Formation, which would serve to confirm the presence of a thin remnant of Covey Hill on this more northern segment of the arch. A short distance to the southwest of Île Perrôt is the location of the St. Lawrence River No. 1 borehole, which penetrated 496 metres of Covey Hill strata without having reached the Precambrian basement (see Figure 8). A further observation is that the basal dark reddish-brown beds of the Hannawa Falls member exposed at the western end of Île Perrôt are lithologically similar to the basal strata of the Hannawa Falls Member that lie in subsurface near the base of the St. Lawrence River No. 1 borehole. This suggests that the east-southeast trending Sainte-Justine Fault, shown in Figure 3, was active during or immediately following Covey Hill deposition, its northern side moving up relative to the deeper Valleyfield Trough to the south. Following uplift of the northern segment of the arch, most of the Covey Hill was presumably eroded prior to deposition of the Cairnside Formation in the Île Perrôt region of the Oka-Beauharnois Arch.

In addition to the very intensive and widespread deformation of the Covey Hill and equivalent Ausable formations during and immediately following their deposition, as documented above, is the fracturing and folding of the succeeding beds of the Potsdam Group that took place at later periods of geological time. At many localities throughout the study area, the Potsdam Group and younger Ordovician formations are intersected by normal faults, as shown on the geological map, (see Figure 3), and there are undoubtedly many more, as postulated by Williams and Wolf (1982, 1984 a and b); Williams *et al.*, (1984, 1985 and 1992).

Perhaps one of the best examples of intensive and widespread post-Potsdam uplift occurred along the southern margin of the Valleyfield Trough south of Montreal, the latter having been a much broader feature during Potsdam deposition than it is today, (see Figure 3). Uplift along the Stockwell Fault, and its southeast and southwest extensions in adjacent areas of New York State, is indicated by a thick Covey Hill succession that occurs 200 metres or more above its counterpart in the Quebec lowland, which is there capped by the Cairnside and equivalent Keeseville formations, as illustrated in figures 3 and 9, section E-E'.

Judging by the numerous faults that intersect the entire Paleozoic succession, there was undoubtedly significant tectonic activity throughout the eastern part of the Ottawa Embayment, and western part of the Quebec Basin following deposition of the Potsdam Group. The age of the faulting has not been established, but there may well have been repeated movements during successive periods ranging from late Early Ordovician, early Middle to Late Ordovician, Early to Late Silurian, Late Middle to Late Devonian and Jurassic to Cretaceous – periods of tectonic activity previously documented throughout the length and breadth of the St. Lawrence Platform (Sanford, 1993 a and b).

Mapping of the faults that intersect the Potsdam Group and younger Ordovician rocks shown in Figure 3 were in large part based on topographic lineaments, changes in the structural attitude of the beds, and the presence of rock units of differing lithologies and/or ages that lie in juxtaposition to one another, and only in rare instances, such as shown at the Kanata Centrum Shopping Plaza at station O-5 9 (see Figure 87 a and b), are faults actually seen in the field intersecting the rock strata. At this locality, the faults shown in (a) oriented at 090°, are presumably splays emanating from the nearby Hazeldean Fault shown in Figure 3. The yellowish-orange deposits of goethite, where observed along the fracture surfaces (Figures 87 a and b) were presumably precipitated from iron rich hydrothermal fluids that exploited the fracture network. Detailed descriptions of this and nearby exposures of the Nepean Formation are contained in Dobie (2004).

Folds in the Nepean and equivalent formations can be observed at widely separated parts of the study area, but rarely are they as well developed, as in the vicinity of station O-27, (see Figure 88). There the fold axes, which trend at 066°, perpendicular to Highway 15, extend south for almost a kilometre to where the Nepean beds eventually onlap a Precambrian ridge.

Drag folds were observed in the Precambrian where overlain by the Ausable Formation at two locations in the western part of the Ottawa Embayment

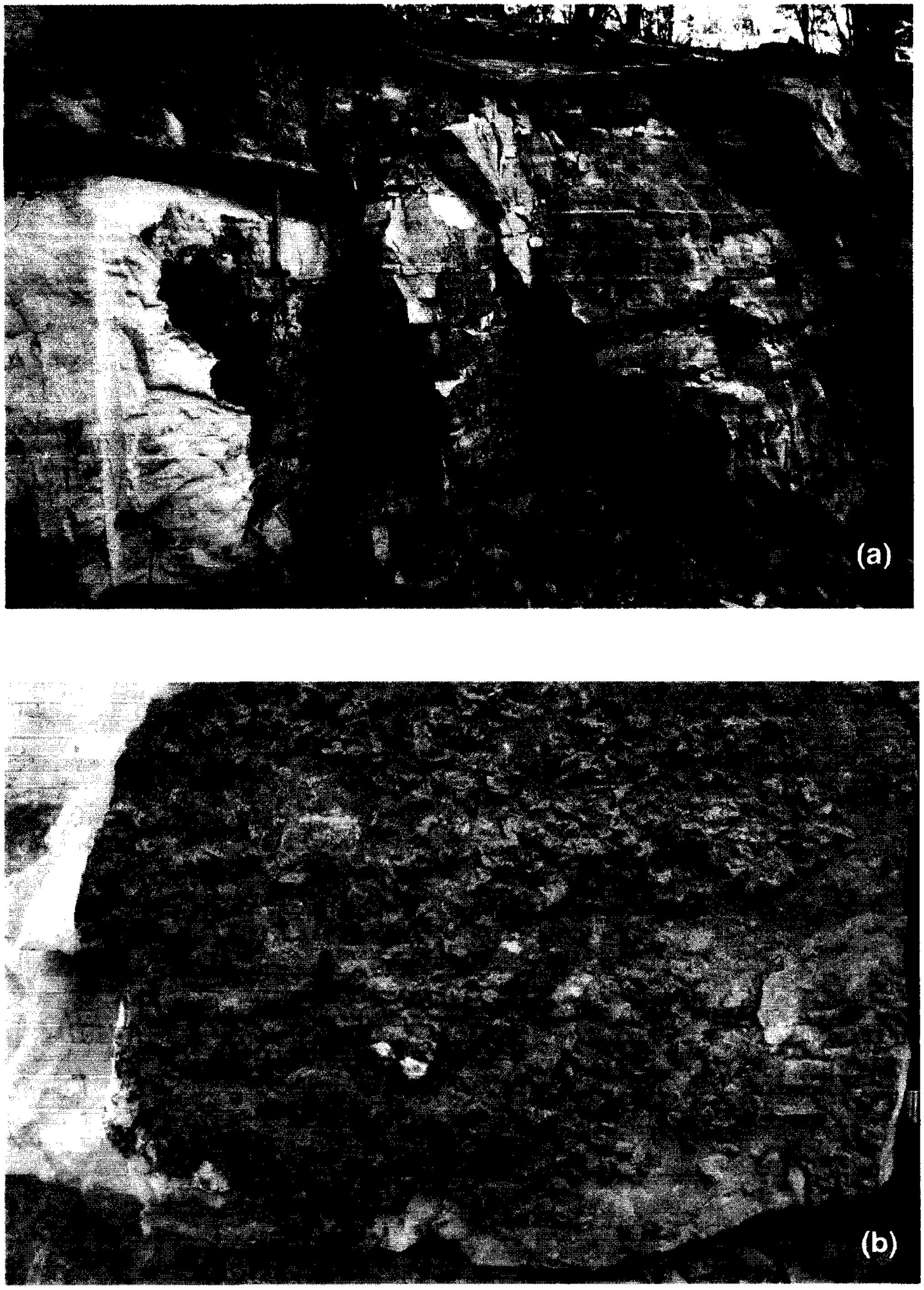


Figure 87: Normal faults intersecting Nepean strata in Kanata Centrum Shopping Mall, Ottawa, Ontario, at station O-5. These are presumably splays emanating from the nearby Hazeldean Fault shown in Figure 3. Yellowish orange deposits of goethite that can be seen in (a) to have formed along each of the fracture surfaces, and shown in close detail in photo (b), are assumed to have formed by hydrothermal fluids moving along the fractures.

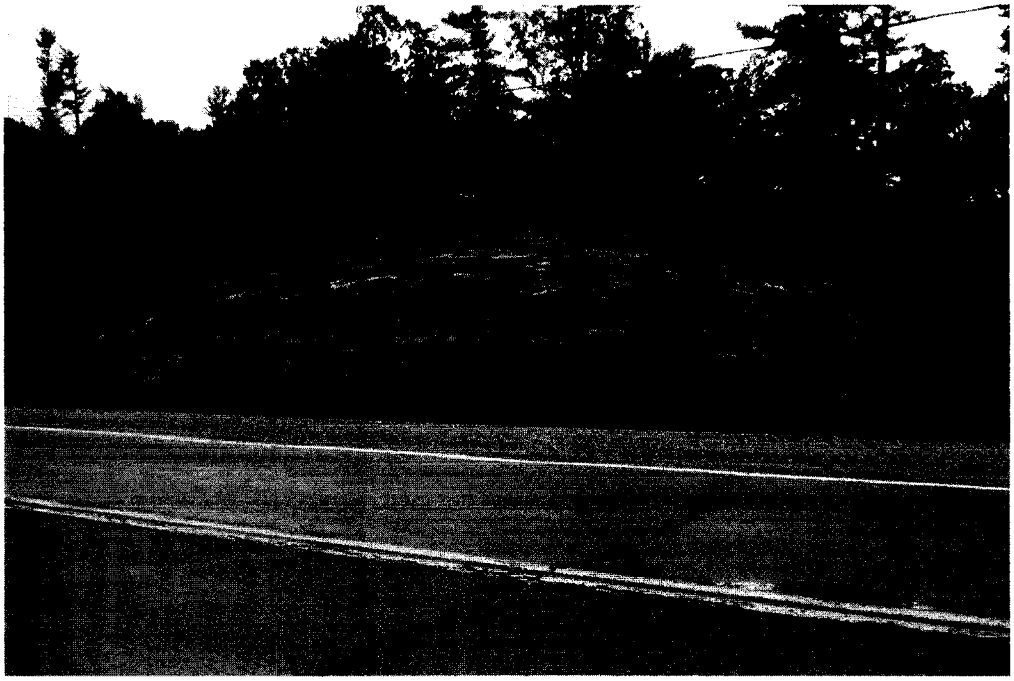


Figure 88: Folded Nepean strata on Highway 15 Ontario, near station O-27.

on Route 12 in New York State, (stations N-13 and N-54 respectively). At both locations the drag fold axes trend north-northeast (030°); asymmetry of the folds indicate tectonic transport of the Ausable towards the west-northwest relative to the underlying basement (see Figure 89).

The horizontal transport of the Potsdam Group across the basement surface in a west-northwest direction can be attributed to high regional stress fields associated with Taconian and/or Acadian orogenesis in progress from early Middle Ordovician to Late Devonian. A high angle thrust intersecting the Keeseville Formation at an outlier in the Rock Island Road region of New York State at station N-121 striking at 270°, was likely associated with the same compressional events that triggered movements along the basement surface farther westward, as described above.

Brecciation of the basal strata of the Keeseville Formation occurred in a wide area bordering the St. Lawrence River in New York, shortly following deposition, an example of which is shown at station N-87 near Chippewa Bay in Figure 90. The tectonism that triggered the brecciation may have been a

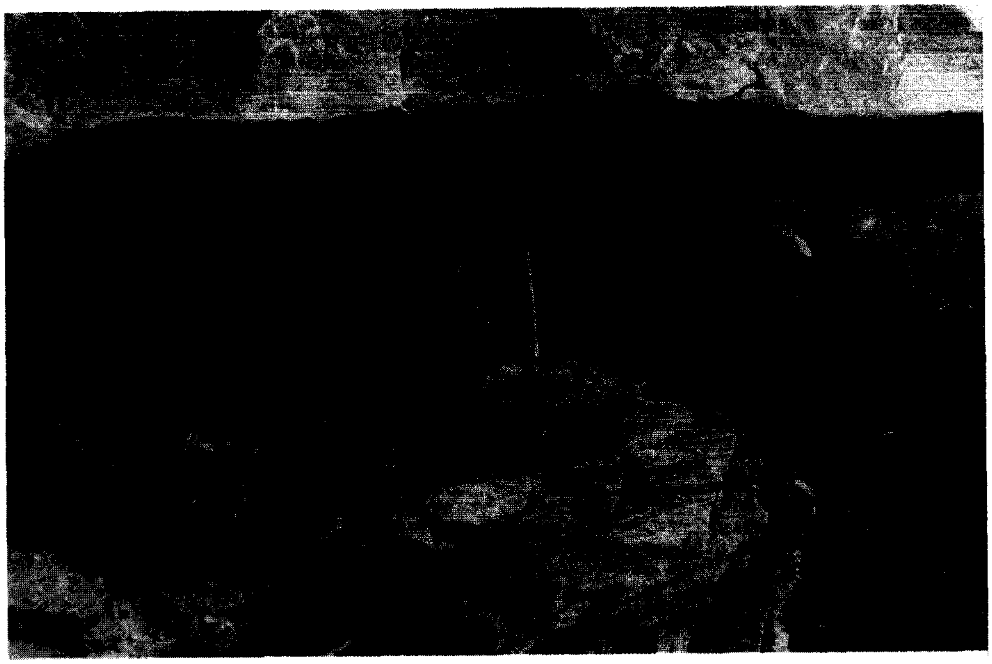


Figure 89: Unconformable contact between Precambrian and overlying Hannawa Falls Member of the Ausable Formation near Goose Bay, New York, on Route 12, at station N-54. Note the presence of drag folds in the Precambrian metagranites as a result of lateral movement of the overlying Ausable Formation across its surface in a west-northwest direction.

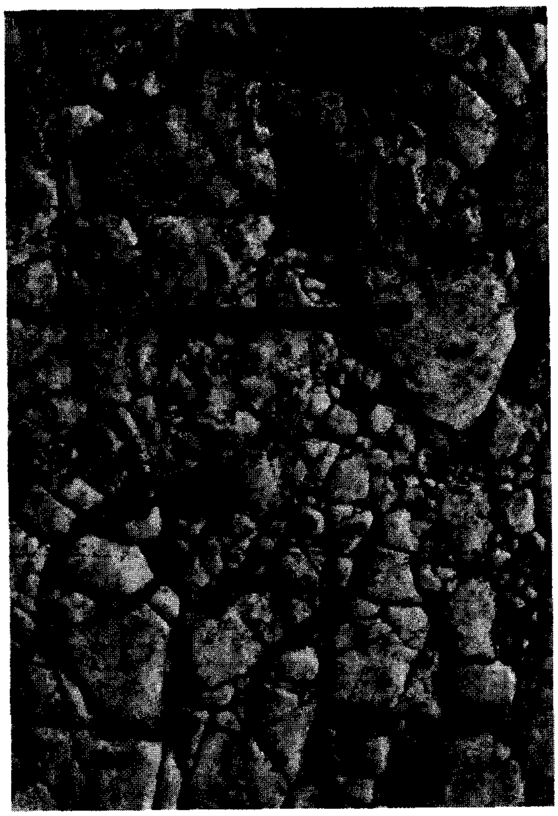


Figure 90: Intraformational breccia in basal Keeseville sandstone near Chippewa Bay, New York, at station N-87

rejuvenation of the St. Lawrence River Fault (see Figure 3), an event possibly coincident with the initiation of Keeseville deposition, and outpouring of quartzite conglomerate at that point in time on Wellesley Island, as noted at station N-4 [see Figure 66 (a)].

Much emphasis on the part of past workers, i.e. Kumarapeli and Saul (1966) has been placed on the significance of anorgenic plate motions such as the rifting processes induced during the Mesozoic Era, with regard to deformation of the St. Lawrence Platform. Undoubtedly some imprint of this event was registered on this region in terms of further rejuvenation of fracture systems, and dyke and pluton emplacement. However, from previous investigations of the St. Lawrence, Arctic and Hudson platforms the writer has determined that by far the more intensive epeirogeny during the Phanerozoic began at the close of the Early Silurian and continued into the Late Silurian. This event radically changed the pattern of seaways that had previously inundated most of the Canadian Shield, and gave rise to the rapid and deep subsidence of the cratonic and foreland basins during this period, i.e. Michigan and Hudson Bay basins. What effects these processes may have had on the Central Division of the St. Lawrence Platform is not clear. However, the very fact that Silurian rocks are nowhere present in the Ottawa Embayment or the Quebec Basin may be because this area was in a state of uplift and undergoing major epeirogeny during that period and as a consequence Silurian strata were never deposited or were thin and quickly eroded. Intense deformation of Silurian rocks in the Gaspé Peninsula as recorded by Bourque *et al.*, (2001), Malo (2001), and to a lesser extent in the Appalachian Basin by Ettensohn and Brett (2002) indicate the broad regional extent of tectonism in progress during that period of geological time. The writer thus believes that much of the post-Potsdam deformation of this region may have been of Early to Late Silurian age, and related to the continental-wide event which may have been triggered by continental collision and final closing of a the Iapetus Ocean during an early phase of the Acadian Orogeny.

CHAPTER 7

SUMMARY AND CONCLUSIONS

During the course of the present investigation of the Potsdam Group, a number of new observations and interpretations have been made. The most significant of these are summarized in their order of importance as they relate to the reconstruction of the geological history of the Potsdam Group:

1. ***The recognition and documentation of a regional unconformity within the Potsdam Group that can be used on a wide regional scale in Ontario and New York State as a stratigraphic marker to separate the Covey Hill and equivalent Ausable formations from the succeeding Nepean and equivalent Keeseville formations***; following the discovery of the unconformity on the Rideau Ferry Road in Ontario, twenty additional locations were found in Ontario and New York where the units are separated by an unconformity, and at six of these by an angular unconformity. It was also noted that at each of these locations the rocks beneath the unconformity are largely of terrestrial origin, and those above are marine and marginal-marine. During the long hiatus that prevailed between the two units, the Covey Hill and equivalent Ausable formations were subjected to intense deformation and erosion, especially along the axis of the Frontenac Arch on the Ontario side of the St. Lawrence River where these strata have been completely eroded.

2. ***The identification of several new rock units within the Potsdam Group based on the lithology, color and environment of deposition***; this includes the recognition of a quartzite cobble and boulder conglomerate at the base of the Potsdam in Ontario herein named Abbey Dawn Formation, that is of probable Neoproterozoic age. Identified also

within the possible Late Proterozoic to Early Cambrian strata of the Covey Hill and equivalent Ausable formations are in ascending stratigraphic order, the Jericho, Hannawa Falls, Chippewa Bay and Edwardsville members. These units have wide areal continuity that provides a high level of confidence with regard to local and regional correlation throughout the Ottawa Embayment and Quebec Basin, and with equivalent stratigraphic sequences in opposite extremities of the St. Lawrence Platform.

3. ***The recognition of lateral and vertical facies changes contained within the Covey Hill and equivalent Ausable formations, that point to a variety of depositional conditions mainly of terrestrial origin***; these were in large part controlled by long periods of arid climatic conditions, and an intervening period of high humidity, coupled with intense tectonic activity. The Covey Hill and equivalent Ausable formations were presumably deposited as a redbed sequence. The Jericho, Hannawa Falls and Edwardsville retained much of their red and pink coloration as a result of arid conditions during deposition and subsequent diagenetic alteration. The Chippewa Bay Member, on the other hand, was intensely leached during early burial. This difference in early diagenetic processes was likely related to more humid environmental conditions, plus increased subsurface fluid flow. Throughout the western part of the Ottawa Embayment, Covey Hill and equivalent Ausable deposition may have been largely lacustrine initially, which were ephemeral during arid periods, thence giving rise to widespread units dominated by aeolian deposition, except for patches of quartzite pebble and boulder conglomerate in the Rideau Lakes area that was transported eastward off the Frontenac Arch. To the east, bordering the Oka-Beauharnois Arch thick sequences of quartz-feldspar pebble conglomerate and feldspathic arenite were transported into the Ottawa Embayment and Quebec Basin by a major network of braided stream systems.

4. ***The recognition of the Nepean and its equivalents at surface and in subsurface throughout the Ottawa Embayment as a highly saline basin of deposition***; upon entering the Ottawa Embayment from the eastward, the Late Cambrian to Early Ordovician seaway, bounded on four sides by Precambrian highland areas, became highly saline probably at a very early stage, and becoming progressively more so throughout the depositional period of the Nepean and its equivalents. This is suggested by the paucity of normal marine faunas within the confines of the Embayment and by the presence of gypsum interbeds in distal segments of the basin, coupled with the presence of stromatolites of local biostromal proportions, and brecciation of Nepean beds that may be due to the dissolution of evaporites and collapse of the overlying strata. Both to the west of the Frontenac Arch, and to the east of the Oka-Beauharnois Arch, there is a greater abundance and diversity of marine organisms, suggesting more open marine conditions in these regions during deposition of the Nepean and its equivalents.

5. ***The identification of water expulsion cones and vertical columnar structures, and their very differing characteristics in terms of origin and development***; water expulsion structures noted during the present study are cone shaped features, tiny at their base where the fluids emerge from the stratified deposits, and wide at the top, where the channels through the soft sediment branched outward and upward that carried sediment in its path, the latter of which collapsed back into the cavity, in random order. Such features are not abundant in the Potsdam Group, and only two were observed, one at Jones Falls, Ontario, intersecting the Hannawa Falls member of the Covey Hill, and the other at Black Lake, New York in the Keeseville Formation. The configuration of the columnar structures, on the other hand, consist of perfectly uniform vertical columns, 0.5 to 1.0 metres or more in diameter that are concentrically banded throughout. These features are herein believed to have formed by a simple drilling process in a stream bed where a rapidly moving current set

the rotating mechanism (quartzite cobbles) in motion, to bore a vertical cylinder, up to five metres in depth. When the rotating current could no longer sustain the drilling process, the cylinder was filled with sand in a similar rotating manner forming concentric layering parallel to the configuration of the cylinder.

The columns are well displayed in cross-section on the William Hughes property on the shore of the Cataraqui River (Rideau Canal). Examples of quartzite cobbles that would have been required to complete the drilling process are contained in outcrop in the Norman Sloan quarry on the opposite bank of the river, along with the surface plan view of a column, showing the concentric layering of the sand as it may have been deposited during the final infilling process of the cylinder.

A similar, but much smaller column was found on the east side of the Frontenac Arch in the Chippewa Bay Member of the Covey Hill Formation at an isolated outcrop near Elgin, Ontario. Cylinders were also found at two other localities where their contents have been removed by erosion, one located in Covey Hill strata at Charleston Lake Provincial park, and the other in the Nepean Formation near Jones Falls, both in Ontario. They are both of probable Quaternary origin, having formed on the bed of glacial outwash stream systems, during a period of receding glaciation.

6. ***The gross petrographic comparison of rock units, as a possible tool in the reconstruction of depositional environments, and for purposes of local and regional correlation***; although lithological differences, and the presence of an unconformity, are usually sufficient criteria for separating the Covey Hill and Nepean formations and their equivalents from place to place, there are instances where it is difficult to differentiate between the two stratal units where the Nepean or its equivalent Keeseville rest directly on the lithologically similar Chippewa Bay Member of the Covey Hill or its equivalent Ausable Formation. Invariably, the Covey Hill and equivalent Ausable formations contain red iron oxide dust

rim coatings around the framework sand grains that are overgrown by quartz precipitated during burial diagenesis. Even in the highly leached strata of the Chippewa Bay, framework grains contain microscopic remnants of red oxide rims that is in sharp contrast to the overlying Nepean or its Keeseville equivalent, where hematite rims are absent.

7. ***The identification and documentation of structural deformation (folds and faults) and its relationship to regional tectonics centred well beyond the margins of the study area, during and subsequent to Potsdam deposition***; the documentation of folding and faulting of the Covey Hill and equivalent Ausable formations clearly indicate intense deformation that predates Nepean and its equivalents at a number of locations in eastern Ontario and adjacent areas of New York State. The presence of dyke swarms and plutons of anorogenic origin in Precambrian terranes immediately to the north of the study area, would suggest that the timing of the early Potsdam deformation was coeval with plate tectonic events in progress during the Neoproterozoic and Early Cambrian, when the continents were in a state of rifting and break-up, followed by the opening of the Iapetus Ocean..

   Post-Nepean and equivalent Keeseville and Cairnside deformation, resulting in both folding and faulting, was widespread throughout the study area, the timing of which is uncertain. One can only conclude that the deformation was in part due to widespread epeirogeny in progress in the Canadian craton related to Taconian and Acadian orogenesis in progress from early Middle Ordovician to Late Devonian, and perhaps also to a large degree by the rifting and separation of the continents that occurred during the Jurassic and Cretaceous.

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Appendix (i)

Location of Boreholes

Ontario	Location	Thickness of Potsdam
O-1 Dominion Observatory No. 1	443950E; 5026500N	31m
O-2 GSC Lebreton No. 1	445500E; 5028100N	78m
O-3 GSC Russell No. 1	469150E; 5017450N	144m
O-4 Imperial Oil Ltd., Laggan No.1	521325E; 5026350N	310+m
O-5 GSC McCrimmon No. 1	520250E; 5030200N	256+m
O-6 Consumers Gas 12023	520333E; 5030981N	339m

Quebec	Location	Thickness of Potsdam
Q-1 Gastem – Dundee No. 1	544391E; 4989999N	166+m
Q-2 Gastem – Dundee No. 2	544254E; 4990442N	97+m
Q-3 Montreal No. 1	577490E; 5014092N	439+m
Q-4 St. Lawrence River No. 1	577025E; 5013642N	603+m
Q-5 Oka No. 8	577150E; 5047500N	320+m
Q-6 Mallet Test No. 1	590508E; 5057823N	519+m
Q-7 Quonto International – St. Vincent de Paul No. 1	604418E; 5055374N	516m
Q-8 Quonto International - Mascouche No. 1	610070E; 5066362N	365m

Appendix (ii)

Location of Field Stations

Ontario				
Sta.no	Area	1:250,000 map sheet	UTM location	Rocks exposed
O-1*	Rockland	Ottawa 31G	476500E; 5041500N	Covey Hill/Nepean
O-2*	Ottawa	Ottawa 31G	432050E; 5019700N	Nepean
O-3*	Ottawa	Ottawa 31G	432100E; 5018900N	Nepean
O-4	Ottawa	Ottawa 31G	428410E; 5017535N	Nepean
O-5	Ottawa	Ottawa 31G	428532E; 5017954N	Nepean
O-6*	Ottawa	Ottawa 31G	437841E; 5016272N	Nepean/March
O-7*	Ottawa	Ottawa 31G	456144E; 5017333N	Nepean/March
O-8	Almonte	Pembrooke 31F	404546E; 5007349N	Nepean
O-9	Almonte	Pembrooke 31F	404625E; 5007425N	Nepean/March
O-10	Mississippi Lake	Pembrooke 31F	408250E; 4995900N	Nepean
O-11	Mississippi Lake	Pembrooke 31F	402823E; 4985611N	Nepean/March
O-12*	Mississippi Lake	Pembrooke 31F	406721E; 4987232N	PreC/Nepean
O-13	Mississippi Lake	Pembrooke 31F	406324E; 4985609N	Nepean/March
O-14*	Rideau Ferry	Kingston 31C	405884E; 4967820N	Covey Hill
O-15	Rideau Ferry	Kingston 31C	405560E; 4969200N	Nepean
O-16*	Rideau Ferry	Kingston 31C	408423E; 4967610N	Covey Hill/Nepean
O-17*	Otter Lake	Kingston 31C	412659E; 4959755N	Covey Hill/Nepean
O-18*	Briton Bay	Kingston 31C	406309E; 4958089N	Covey Hill
O-19	Briton Bay	Kingston 31C	407450E; 4955000N	Covey Hill
O-20	Portland	Kingston 31C	408050E; 4952939N	Nepean
O-21	Crosby	Kingston 31C	400635E; 4942884N	Nepean
O-22*	Crosby	Kingston 31C	400801E; 4942483N	Nepean
O-23*	Elgin	Kingston 31C	402834E; 4940012N	PreC/Covey Hill/Nepean
O-24	Elgin	Kingston 31C	403630E; 4939348N	Nepean/March
O-25	Elgin	Kingston 31C	404200E; 4938450N	Nepean
O-26	Elgin	Kingston 31C	404100E; 4936450N	Nepean
O-27*	Jones Falls	Kingston 31C	404090E; 4934500N	PreC/Covey Hill/Nepean
O-28	Jones Falls	Kingston 31C	401924E; 4933165N	Covey Hill
O-29*	Jones Falls	Kingston 31C	401956E; 4932350N	Covey Hill
O-30*	Elgin	Kingston 31C	406002E; 4936441N	Covey Hill
O-31	Elgin	Kingston 31C	406186E; 4938443N	Nepean
O-32	Elgin	Kingston 31C	405450E; 4943000N	Nepean
O-33*	Philipsville	Kingston 31C	409459E; 4943600N	Nepean/March
O-34	Philipsville	Kingston 31C	410200E; 4926500N	Covey Hill
O-35*	Delta	Kingston 31C	410302E; 4942614N	Covey Hill/Nepean
O-36	Delta	Kingston 31C	410906E; 4941216N	Nepean
O-37	Delta	Kingston 31C	412637E; 4939140N	Covey Hill
O-38	Delta	Kingston 31C	413074E; 4938852N	Nepean
O-39	Charleston Lake	Kingston 31C	418470E; 4937296N	Nepean

O-40	Charleston Lake	Kingston 31C	416993E; 4937131N	Nepean
O-41	Charleston Lake	Kingston 31C	415940E; 4937026N	Nepean
O-42	Lyndhurst	Kingston 31C	411789E; 4935700N	Nepean
O-43	Lyndhurst	Kingston 31C	411723E; 4935120N	Covey Hill
O-44	Lyndhurst	Kingston 31C	411073E; 4934054N	Nepean
O-45	Charleston Lake	Kingston 31C	419521E; 4936705N	Covey Hill
O-46	Charleston Lake	Kingston 31C	419020E; 4934942N	Nepean (?)
O-47*	Davis Lock	Kingston 31C	397051E; 4936100N	Covey Hill
O-48	Lansdowne	Ogdensburg 31B	420310E; 4916935N	Nepean
O-49	Lansdowne	Kingston 31C	418837E; 4918914N	Nepean
O-50	Lansdowne	Kingston 31C	414065E; 4918878N	Nepean
O-51	Gananoque	Kingston 31C	409935E; 4911053N	PreC/Nepean
O-52	Gananoque	Kingston 31C	409758E; 4910883N	Covey Hill
O-53	Gananoque	Kingston 31C	400334E; 4907867N	Nepean
O-54	Ganonoque	Kingston 31C	394883E; 4905508N	Nepean
O-55*	Kingston	Kingston 31C	389600E; 4902020N	PreC/Abbey Dawn/ Gull River
O-56*	Sunbury	Kingston 31C	389520E; 4912016N	Covey Hill
O-57*	Sunbury	Kingston 31C	390789E; 4912949N	PreC/Covey Hill/Nepean
O-58	Sunbury	Kingston 31C	387666E; 4914267N	Covey Hill
O-59	Sunbury	Kingston 31C	388789E; 4915324N	Covey Hill
O-60	Charleston Lake	Kingston 31C	418797E; 4929750N	Covey Hill
O-61*	Charleston Lake	Kingston 31C	417600E; 4928400N	Covey Hill
O-62	Lyn	Ogdensburg 31B	437243E; 4936854N	Nepean
O-63	Lyn	Ogdensburg 31B	437740E; 4935927N	Nepean
O-64*	Lyn	Ogdensburg 31B	438347E; 4936282N	PreC/Abbey Dawn/ Covey Hill/Nepean
O-65*	Butternut Bay	Odgensburg 31B	436810E; 4929860N	PreC/Abbey Dawn/March
O-66*	Athens	Odgensburg 31B	427442E; 4937404N	Abbey Dawn/ Covey Hill/Nepean
O-67*	Salem	Kingston 31E	383200E; 4945200N	Covey Hill
O-68	Fermoy	Kingston 31E	381500E; 4945750N	Covey Hill

Quebec				
Sta.no	**Area**	**1:250,000 map sheet**	**UTM location**	**Rocks exposed**
Q-1*	Gatineau	Ottawa 31G	451415E; 5037084N	PreC/Cairnside
Q-2*	Ile Perrôt	Montreal	581310E; 5026470N	Covey Hill
Q-3*	Ile Perrôt	Montreal	581570E; 5026290N	Covey Hill
Q-4*	Ile Perrôt	Montreal	589550E; 5023950N	Cairnside (Nepean)
Q-5*	Covey Hill	Montreal	596274E; 4988706N	Covey Hill
Q-6*	Covey Hill	Montreal	591518E; 4987409N	Covey Hill
Q-7*	Covey Hill	Montreal	594549E; 4985743N	Covey Hill
Q-8*	Covey Hill	Montreal	597199E; 4985419N	Covey Hill
Q-9*	Saint Pierre	Montreal	587545E; 4996190N	Cairnside
Q-10*	Saint Pierre	Montreal	591017E; 4995515N	Covey Hill

Q-11*	Bridgetown	Montreal	582697E; 4986664N	Cairnside
Q-12*	Saint-Jean Chrysostone	Montreal	597337E; 4994954N	Covey Hill
Q-13*	Covey Hill	Montreal	591513E; 4987598N	Covey Hill
Q-14*	Covey Hill	Montreal	592857E; 4985700N	Covey Hill
Q-15*	Covey Hill	Montreal	594549E; 4985748N	Covey Hill

New York				
Sta.no	**Quadrangle**	**1:250,000 map sheet**	**UTM location**	**Rocks exposed**
N-1	Clayton	Kingston 31C	413205E; 4898240N	Keeseville
N-2	Thousand Is. Park	Kingston 31C	419304E; 4907018N	Keeseville
N-3	Alexandria Bay	Ogdensburg 31B	420556E; 4905987N	Keeseville
N-4	Thousand Is. Park	Kingston 31C	419488E; 4907450N	Keeseville
N-5	Alexandria Bay	Ogdensburg 31B	420262E; 4902815N	Keeseville
N-6	Alexandria Bay	Ogdensburg 31B	422933E; 4900909N	Keeseville
N-7	Alexandria Bay	Ogdensburg 31B	425754E; 4904193N	Ausable
N-8	Alexandria Bay	Ogdensburg 31B	428739E; 4905147N	Ausable
N-9	Alexandria Bay	Ogdensburg 31B	428935E; 4905017N	Ausable
N-10	Alexandria Bay	Ogdensburg 31B	428384E; 4907702N	Keeseville
N-11	Alexandria Bay	Ogdensburg 31B	427991E; 4907977N	Keeseville
N-12	Alexandria Bay	Ogdensburg 31B	428485E; 4910354N	Keeseville
N-13*	Alexandria Bay	Ogdensburg 31B	430059E; 4910604N	PreC/Ausable/Keeseville
N-14	Alexandria Bay	Ogdensburg 31B	430118E; 4910676N	Ausable
N-15	Theresa	Ogdensburg 31B	434505E; 4895625N	Ausable
N-16	Theresa	Ogdensburg 31B	433836E; 4895550N	Keeseville
N-17*	Theresa	Ogdensburg 31B	434488E; 4897850N	Ausable/Keeseville
N-18*	Theresa	Ogdensburg 31B	436714E; 4896198N	PreC/Ausable/Keeseville
N-19	Theresa	Ogdensburg 31B	436921E; 4895947N	Ausable
N-20	Theresa	Ogdensburg 31B	437978E; 4895623N	Ausble
N-21	Theresa	Ogdensburg 31B	438215E; 4895477N	Ausable
N-22	Theresa	Ogdensburg 31B	439458E; 4897770N	Ausable
N-23	Theresa	Ogdensburg 31B	434704E; 4899215N	Keeseville
N-24	Theresa	Ogdensburg 31B	434755E; 4899329N	Keeseville
N-25	Theresa	Ogdensburg 31B	436162E; 4899223N	Ausable
N-26	Theresa	Ogdensburg 31B	436256E; 4899636N	Ausable
N-27	Redwood	Ogdensburg 31B	436411E; 4900145N	Keeseville
N-28	Redwood	Ogdensburg 31B	436662E; 4901203N	Ausable
N-29	Redwood	Ogdensburg 31B	435984E; 4901647N	Keeseville
N-30	Redwood	Ogdensburg 31B	435725E; 4901811N	Keeseville
N-31	Redwood	Ogdensburg 31B	436926E; 4901307N	Ausable
N-32	Redwood	Ogdensburg 31B	437705E; 4901711N	Ausable
N-33	Redwood	Ogdensburg 31B	437829E; 4901779N	Ausable
N-34	Redwood	Ogdensburg 31B	438035E; 4901897N	Ausable

N-35	Redwood	Ogdensburg 31B	438709E; 4902532N	Ausable
N-36	Redwood	Ogdensburg 31B	439147E; 4903800N	Ausable
N-37	Redwood	Ogdensburg 31B	436930E; 4904803N	Keeseville
N-38	Redwood	Ogdensburg 31B	435946E; 4905890N	Keeseville
N-39*	Redwood	Ogdensburg 31B	435146E; 4905627N	Ausable/Keeseville
N-40	Redwood	Ogdensburg 31B	435066E; 4905605N	Ausable
N-41	Redwood	Ogdensburg 31B	431709E; 4905645N	Keeseville
N-42	Redwood	Ogdensburg 31B	435912E; 4906623N	Keeseville
N-43	Redwood	Ogdensburg 31B	435923E; 4906911N	Ausable
N-44	Redwood	Ogdensburg 31B	436197E; 4904606N	Keeseville
N-45	Redwood	Ogdensburg 31B	433100E; 4906750N	Keeseville
N-46	Redwood	Ogdensburg 31B	433389E; 4906856N	Keeseville
N-47	Redwood	Ogdensburg 31B	433151E; 4907815N	Keeseville
N-48	Redwood	Ogdensburg 31B	433450E; 4908167N	Keeseville
N-49	Redwood	Ogdensburg 31B	433645E; 4908566N	Ausable
N-50	Redwood	Ogdensburg 31B	433612E; 4908694N	Keeseville
N-51	Redwood	Ogdensburg 31B	433597E; 4908778N	Keeseville
N-52	Redwood	Ogdensburg 31B	433586E; 4909113N	Keeseville
N-53	Redwood	Ogdensburg 31B	432072E; 4912176N	Ausable
N-54*	Redwood	Ogdensburg 31B	433061E; 4913021N	Ausable
N-55	Redwood	Ogdensburg 31B	433135E; 4913112N	Ausable
N-56	Redwood	Ogdensburg 31B	437279E; 4908026N	Ausable
N-57	Redwood	Ogdensburg 31B	437437E; 4908477N	Ausable
N-58*	Redwood	Ogdensburg 31B	437087E; 4908957N	Ausable
N-59	Redwood	Ogdensburg 31B	435716E; 4910730N	Ausable
N-60	Redwood	Ogdensburg 31B	435692E; 4911863N	Ausable
N-61	Redwood	Ogdensburg 31B	435928E; 4912880N	Ausable
N-62	Redwood	Ogdensburg 31B	436180E; 4913100N	Keeseville
N-63	Redwood	Ogdensburg 31B	431971E; 4902089N	Keeseville
N-64	Redwood	Ogdensburg 31B	433098E; 4910209N	Keeseville
N-65	Muskellunge Lake	Ogdensburg 31B	440275E; 4905331N	Keeseville
N-66	Muskellunge Lake	Ogdensburg 31B	440604E; 4905628N	Keeseville
N-67	Muskellunge Lake	Ogdensburg 31B	440712E; 4905786N	Ausable
N-68	Muskellunge Lake	Ogdensburg 31B	441080E; 4906012N	Ausable
N-69	Muskellunge Lake	Ogdensburg 31B	440454E; 4906588N	Keeseville
N-70	Muskellunge Lake	Ogdensburg 31B	440538E; 4906968N	Keeseville
N-71	Muskellunge Lake	Ogdensburg 31B	440748E; 4906166N	Ausable
N-72	Chippewa Bay	Ogdensburg 31B	439850E; 4914411N	Ausable
N-73*	Hammond	Ogdensburg 31B	440606E; 4915124N	Ausable/Keeseville
N-74	Hammond	Ogdensburg 31B	441971E; 4916836N	Ausable
N-75	Hammond	Ogdensburg 31B	442480E; 4917865N	Ausable
N-76	Hammond	Ogdensburg 31B	443393E; 4918878N	Ausable
N-77	Hammond	Ogdensburg 31B	443719E; 4919166N	Ausable
N-78	Hammond	Ogdensburg 31B	443794E; 4919361N	Keeseville
N-79	Hammond	Ogdensburg 31B	444462E; 4916673N	Ausable
N-80*	Chippewa Bay	Ogdensburg 31B	437384E; 4917814N	Ausable/Keeseville
N-81	Chippewa Bay	Ogdensburg 31B	437890E; 4918254N	Keeseville
N-82	Chippewa Bay	Ogdensburg 31B	438149E; 4918634N	Keeseville
N-83	Chippewa Bay	Ogdensburg 31B	438480E; 4918955N	Keeseville

N-84	Chippewa Bay	Ogdensburg 31B	438315E; 4919418N	Ausable
N-85	Chippewa Bay	Ogdensburg 31B	438570E; 4919804N	Ausable
N-86	Chippewa Bay	Ogdensburg 31B	438934E; 4919411N	Keeseville
N-87	Chippewa Bay	Ogdensburg 31B	439209E; 4919663N	Keeseville
N-88*	Chippewa Bay	Ogdensburg 31B	439278E; 4919731N	Ausable/Keeseville
N-89*	Chippewa Bay	Ogdensburg 31B	439288E; 4924031N	Ausable/Keeseville/ Theresa
N-90*	Chippewa Bay	Ogdensburg 31B	438760E; 4925121N	Theresa/Keeseville/ Ausable
N-91	Hammond	Ogdensburg 31B	440433E; 4921840N	Ausable/Keeseville
N-92	Hammond	Ogdensburg 31B	440539E; 4922566N	Ausable
N-93	Hammond	Ogdensburg 31B	440530E; 4922668N	Ausable
N-94	Hammond	Ogdensburg 31B	442006E; 4924341N	Ausable
N-95	Hammond	Ogdensburg 31B	445882E; 4922357N	Ausable
N-96*	Hammond	Ogdensburg 31B	446373E; 4922953N	Ausable/Keeseville
N-97	Hammond	Ogdensburg 31B	446578E; 4923110N	Keeseville
N-98	Hammond	Ogdensburg 31B	447499E; 4924216N	Ausable
N-99	Hammond	Ogdensburg 31B	446402E; 4926357N	Keeseville
N-100	Hammond	Ogdensburg 31B	446662E; 4926671N	Keeseville
M-101	Hammond	Ogdensburg 31B	445788E; 4927349N	Keeseville
N-102	Morristown	Ogdensburg 31B	440406E; 4929246N	Keeseville
N-103	Morristown	Ogdensburg 31B	445809E; 4934582N	Keeseville
N-104	Morristown	Ogdensburg 31B	446606E; 4935379N	Keeseville
N-105	Morristown	Ogdensburg 31B	448359E; 4928892N	Keeseville
N-106	Morristown	Ogdensburg 31B	450050E; 4928069N	Keeseville
N-107	Morristown	Ogdensburg 31B	450218E; 4927773N	Ausable
N-108	Edwardsville	Ogdensburg 31B	452619E; 4930495N	Keeseville
N-109*	Edwardsville	Ogdensburg 31B	453297E; 4930718N	Ausable/Keeseville
N-110	Edwardsville	Ogdensburg 31B	450697E; 4933896N	Keeseville
N-111	Edwardsville	Ogdensburg 31B	450876E; 4934094N	Keeseville
N-112	Edwardsville	Ogdensburg 31B	451129E; 4934422N	Keeseville
N-113	Edwardsville	Ogdensburg 31B	451726E; 4934628N	Keeseville
N-114	Edwardsville	Ogdensburg 31B	451519E; 4935293N	Keeseville
N-115	Edwardsville	Ogdensburg 31B	455999E; 4933455N	Keeseville
N-116	Edwardsville	Ogdensburg 31B	456995E; 4934122N	Keeseville
N-117	Edwardsville	Ogdensburg 31B	458036E; 4934915N	Keeseville
N-118	Edwardsville	Ogdensburg 31B	459204E; 4935637N	Ausable
N-119	Pope Mills	Ogdensburg 31B	456417E; 4926460N	Ausable
N-120	Pope Mills	Ogdensburg 31B	456703E; 4926599N	Ausable
N-121*	Richville	Ogdensburg 31B	463926E; 4915442N	Keeseville
N-122	Richville	Ogdensburg 31B	463682E; 4922324N	Ausable
N-123*	Hannawa Falls	Ogdensburg 31B	502050E; 4941190N	Ausable
N-124*	Brasher Falls	Ogdensburg 31B	517980E; 4968500N	Keeseville
N-125*	Constable	Ogdensburg 31B	553696E; 4971879N	Keeseville
N-126*	Burke	Ogdensburg 31B	565430E; 4972473N	Keeseville
N-127	Burke	Ogdensburg 31B	565785E; 4971310N	Keeseville
N-128*	Chasm Falls	Ogdensburg 31B	566954E; 4967703N	Ausable
N-129*	Chasm Falls	Ogdensburg 31B	567998E; 4968956N	Ausable
N-130*	Chateaguay	Ogdensburg 31B	571974E; 4972971N	Ausable/Keeseville

N-131*	Chateaguay	Ogdensburg 31B	578785E; 4976078N	Keeseville
N-132*	Chateaguay	Ogdensburg 31B	578778E; 4979604N	Keeseville
N-133	Churubusco	Lake Champlain	582737E; 4981990N	Keeseville
N-134	Churubusco	Lake Champlain	583518E; 4983199N	Keeseville
N-135*	Churubusco	Lake Champlain	584315E; 4977184N	Keeseville
N-136	Churubusco	Lake Champlain	581184E; 4976195N	Keeseville
N-137*	Churubusco	Lake Champlain	581656E; 4971344N	Ausable
N-138*	Churubusco	Lake Champlain	585876E; 4970137N	Ausable
N-139*	Churubusco	Lake Champlain	585348E; 4970049N	Ausable
N-140	Churubusco	Lake Champlain	587600E; 4968450N	Ausable
N-141*	Ellenburg Mtn.	Lake Champlain	593181E; 4965010N	Ausable
N-142	Ellenburg Depot	Lake Champlain	590072E; 4969810N	Ausable
N-143	Ellenburg Depot	Lake Champlain	589017E; 4970697N	Ausable
N-144*	Ellenburg Depot	Lake Champlain	589064E; 4972032N	Ausable
N-145*	Ellenburg Depot	Lake Champlain	589743E; 4979189N	Keeseville
N-146	Ellenburg Depot	Lake Champlain	591428E; 4979433N	Keeseville
N-147	Ellenburg Depot	Lake Champlain	590915E; 4979343N	Keeseville
N-148	Ellenburg Depot	Lake Champlain	596610E; 4982047N	Keeseville
N-149	Ellenburg Depot	Lake Champlain	598309E; 4983144N	Keeseville
N-150	Ellenburg Depot	Lake Champlain	598066E; 4981369N	Keeseville
N-151	Ellenburg Depot	Lake Champlain	595774E; 4980909N	Keeseville
N-152*	Ellenburg Depot	Lake Champlain	594209E; 4979592N	Ausable
N-153	Ellenburg Depot	Lake Champlain	597236E; 4979213N	Keeseville
N-154	Altona	Lake Champlain	599401E; 4979574N	Keeseville
N-155	Ellenburg Depot	Lake Champlain	595555E; 4977612N	Keeseville
N-156	Ellenburg Depot	Lake Champlain	594556E;4978002N	Keeseville
N-157	Ellenburg Depot	Lake Champlain	594450E; 4977900N	Keeseville
N-158	Ellenburg Depot	Lake Champlain	593135E; 4976775N	Keeseville
N-159	Ellenburg Depot	Lake Champlain	595059E; 4974729N	Keeseville
N-160	Altona	Lake Champlain	599432E; 4975691N	Keeseville
N-161	Altona	Lake Champlain	599828E; 4974794N	Keeseville
N-162	Ellenburg Depot	Lake Champlain	596210E; 4973222N	Keeseville
N-163	Ellenburg Depot	Lake Champlain	593907E; 4971267N	Keeseville
N-164	Ellenburg Depot	Lake Champlain	594489E; 4970981N	Keeseville
N-165	Ellenburg Depot	Lake Champlain	595811E; 4969857N	Keeseville
N-166*	Ellenburg Mtn.	Lake Champlain	596018E; 4968465N	Keeseville
N-167	Jericho	Lake Champlain	599273E; 4962400N	Ausable
N-168	Jericho	Lake Champlain	599369E; 4962704N	Ausable
N-169	Jerricho	Lake Champlain	601528E; 4968118N	Keeseville
N-170	Altona	Lake Champlain	602060E; 4971946N	Keeseville
N-171	Altona	Lake Champlain	602346E; 4973096N	Keeseville
N-172	Altona	Lake Champlain	604900E; 4972691N	Keeseville
N-173	Jericho	Lake Champlain	605432E; 4969668N	Keeseville
N-174	Altona	Lake Champlain	607122E; 4970443N	Keeseville
N-175	Altona	Lake Champlain	606129E; 4970511N	Keeseville
N-176*	Altona	Lake Champlain	606954E; 4971427N	Keeseville
N-177	Altona	Lake Champlain	607553E; 4975171N	Keeseville
N-178*	Altona	Lake Champlain	607489E; 4975630N	Keeseville
N-179	Altona	Lake Champlain	607190E; 4978930N	Keeseville

N-180	Mooers	Lake Champlain	610124E; 4978132N	Keeseville
N-181	Mooers	Lake Champlain	612041E; 4979382N	Keeseville
N-182	Mooers	Lake Champlain	613126E; 4979347N	Keeseville
N-183	Mooers	Lake Champlain	612853E; 4976017N	Keeseville
N-184	Jericho	Lake Champlain	606289E; 4965515N	Ausable
N-185	Jericho	Lake Champlain	607555E; 4965482N	Ausable
N-186*	Jericho	Lake Champlain	604306E; 4964042N	Ausable
N-187*	Jericho	Lake Champlain	605142E; 4962498N	Ausable
N-188	Jericho	Lake Champlain	606978E; 4960323N	Ausable
N-189*	West Chazy	Lake Champlain	608938E; 4957860N	Ausable
N-190	Morrisonville	Lake Champlain	609246E; 4951133N	Keeseville
N-191	West Chazy	Lake Champlain	611762E; 4962600N	Ausable
N-192	West Chazy	Lake Champlain	612700E; 4963200N	Keeseville
N-193*	West Chazy	Lake Champlain	613796E; 4964152N	Ausable
N-194	West Chazy	Lake Champlain	614374E; 4964172N	Ausable
N-195	West Chazy	Lake Champlain	611737E; 4963573N	Ausable
N-196	West Chazy	Lake Champlain	610304E; 4963728N	Ausable
N-197	West Chazy	Lake Champlain	609699E; 4964098N	Ausable
N-198	West Chazy	Lake Champlain	616944E; 4968144N	Ausable
N-199	West Chazy	Lake Champlain	616369E; 4968938N	Ausable
N-200*	West Chazy	Lake Champlain	615750E; 4968866N	Ausable
N-201	West Chazy	Lake Champlain	614318E; 4968853N	Ausable
N-202	West Chazy	Lake Champlain	614200E; 497000N	Ausable
N-203	West Chazy	Lake Champlain	615550E; 4977500N	Ausable
N-204*	Mooers	Lake Champlain	614909E; 4972049N	Keeseville
N-205*	Mooers	Lake Champlain	618328E; 4972073N	Keeseville
N-206	Champlain	Lake Champlain	622187E; 4979788N	Keeseville
N-207*	Champlain	Lake Champlain	622809E; 4979680N	Keeseville
N-208	Champlain	Lake Champlain	624093E; 4977938N	Keeseville
N-209	Champlain	Lake Champlain	623165E; 4976259N	Keeseville
N-210	Champlain	Lake Champlain	623409E; 4972324N	Keeseville
N-211	Morrisonville	Lake Champlain	614416E; 4942797N	Keeseville
N-212*	Keeseville	Lake Champlain	619272E; 4939112N	Ausable
N-213	Keeseville	Lake Champlain	622365E; 4931219N	Keeseville
N-214	Keeseville	Lake Champlain	622110E; 4931262N	Keeseville
N-215*	Keeseville	Lake Champlain	621058E; 4929472N	Keeseville
N-216	Mooers	Lake Champlain	615414E; 4981345N	Keeseville
N-217	Champlain	Lake Champlain	618515E; 4982820N	Keeseville
N-218	Ellenburg Depot	Lake Champlain	595590E; 4981707N	Ausable
N-219*	West Chazy	Lake Champlain	613202E; 4964127N	Ausable

- Denotes key sections

Appendix (iii)

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Figure 3: Map - Geology eastern Ontario, western Quebec and northern New York State.

Figure 6: Isopachous map showing distribution and thickness of the Potsdam Group and the locations of sections where the rocks are best exposed in eastern Ontario, western Quebec, and northern New York State.

Figure 8: The Potsdam Group stratigraphic succession as interpreted from diamond drill core recovered from deep boreholes drilled in eastern Ontario and western Quebec.

Figure 9: Stratigraphic – structural sections across Ottawa Embayment and western segment of the Quebec Basin.