Revised Stratigraphy and Correlations of the Niagaran Provincial Series (Medina, Clinton, and Lockport Groups) in the Type Area of Western New York

U.S. GEOLOGICAL SURVEY BULLETIN 2086

Prepared in cooperation with the U.S. Environmental Protection Agency and the Department of Earth and Environmental Sciences of the University of Rochester

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CONTENTS

FIGURES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Revised Stratigraphy and Correlations of the Niagaran Provincial Series (Medina, Clinton, and Lockport Groups) in the Type Area of Western New York

By Carlton E. Brett[1], Dorothy H. Tepper[2], William M. Goodman[3], Steven T. LoDuca[4], and Bea-Yeh Eckert[5]

ABSTRACT

Recent stratigraphic analysis of the Niagaran Provincial Series (Medina, Clinton, and Lockport Groups) in the classic Niagara region of western New York has helped refine correlations that allow a uniform stratigraphic nomenclature to be applied throughout the region and into southwestern Ontario, Canada. A revision of Niagaran Provincial Series stratigraphic nomenclature is presented that builds on and partly revises the stratigraphic column of Rickard (1975), the most recent correlation of rocks of Silurian age for western New York published by the New York State Geological Survey. Six newly recognized units are established, and 13 are revised—that is, the rank or stratigraphic contacts of previously established units are changed. Six units have been extended geographically into the Niagara region from adjacent areas where they have been previously recognized. The revised nomenclature is intended to apply primarily to Niagara County, N.Y., but is generally applicable within the region between Hamilton, Ont., and Rochester, N.Y.

Development of the revised nomenclature has been facilitated by the availability of nine cores drilled in the Niagara Falls area that permit detailed correlations within the Niagaran Provincial Series. These drill cores were obtained as part of a 1987–91 study of the hydrogeology of the Niagara region by the U.S. Geological Survey in cooperation with the U.S. Environmental Protection Agency.

As established herein, the Medina Group consists of the following seven formations: the Whirlpool Sandstone, the Power Glen Shale, the Devils Hole Sandstone, the Grimsby Formation, the Thorold Sandstone, the Cambria Shale, and the Kodak Sandstone. New formations proposed herein include the Devils Hole Sandstone and the Cambria Shale. In addition, a distinctive, laterally traceable phosphate-pebble bed at the base of the Grimsby Formation is herein formally proposed as the Artpark Phosphate Bed. Stratigraphic contacts of the Power Glen Shale and the Grimsby Formation have been revised. The Thorold Sandstone and the Kodak Sandstone are herein placed in the Medina Group rather than in the Clinton Group.

As established herein, the Clinton Group is divided into the following eight formations: the Neahga Shale, the Reynales Limestone, the Merritton Limestone, the Williamson Shale, the Rockway Dolomite, the Irondequoit Limestone, the Rochester Shale, and the DeCew Dolomite. The Merritton Limestone, the Second Creek Phosphate Bed (at the base of the Williamson Shale), the Williamson Shale, and the Salmon Creek Phosphate Bed (at the base of the Rockway Dolomite) have been extended into the Niagara Falls area from adjacent areas in which they have been previously recognized. Stratigraphic contacts of the Irondequoit Limestone have been revised. The Rockway Dolomite is raised herein to formation rank.

As established herein, the Lockport Group consists of the following four formations: the Gasport Dolomite, the Goat Island Dolomite, the Eramosa Dolomite, and the Guelph Dolomite. The Gasport Dolomite consists of two newly proposed members: a lower dolomitic grainstone designated the Gothic Hill Member, and an upper, argillaceous, locally biohermal, dolomitic wackestone unit termed the Pekin Member. The Goat Island Dolomite contains three newly proposed members: a lower biohermal and grainstone unit designated the Niagara Falls Member; a middle, cherty dolomitic wackestone termed the Ancaster Member (also revised and geographically extended); and an upper,

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argillaceous dolomitic wackestone and shale unit designated the Vinemount Member (also revised and geographically extended). The Eramosa and Guelph Dolomites are not formally divided into members, although several informal units are recognized within each formation and are discussed herein. Stratigraphic contacts of the Gasport Dolomite, Goat Island Dolomite, Eramosa Dolomite, and Guelph Dolomite have been revised.

INTRODUCTION

The Niagaran Provincial Series (Medina, Clinton, and Lockport Groups) of western New York, which has been established as the type area for eastern North America, consists of about 400 ft of dolomite, limestone, shale, and sandstone. These richly fossiliferous rocks were deposited in shallow epeiric seas during the Silurian (439–408 Ma, on the basis of dates from Harland and others, 1982). The Niagaran Provincial Series correlates with the Llandoverian, Wenlockian, and Ludlovian Series of the Welsh Borderland, the European reference section. The Niagaran Series record diverse environments ranging from nonmarine sandstones to deep-water shales and reefal carbonates. This sequence, which was deposited along the northern rim of the Appalachian foreland basin, preserves the record of sediments in an evolving foreland basin (Cheel, 1991). The lateral equivalents of these units crop out along the Niagara Escarpment, which trends east-west from the Rochester, N.Y., area to Hamilton, Ont., Canada. The escarpment continues northwestward across the Bruce Peninsula of Ontario; the Niagaran belt then wraps around the Michigan Basin and extends into Michigan, Wisconsin, Illinois, Indiana, and Ohio.

Although the Niagaran Provincial Series of New York and Ontario has been the focus of several comprehensive stratigraphic analyses, lack of a uniform nomenclature across the international boundary has made precise physical stratigraphic correlation difficult. Resolution of questions related to nomenclature and correlation is timely because recently developed allostratigraphic and geodynamic models require high-resolution data bases. The stratigraphic refinements discussed herein are based on detailed study of cores from nine test holes drilled as part of a study during 1987–91 of the hydrogeology of the Niagara region by the U.S. Geological Survey (USGS) in cooperation with the U.S. Environmental Protection Agency (USEPA). Newly recognized units that are traceable in these cores can also be identified in outcrops in New York and Ontario. Physical traceability of rock units indicates that a uniform stratigraphic nomenclature can be established across the Niagara region, which includes the international boundary. In addition to the inclusion of new units, this revision also resolves conflicts in current stratigraphic nomenclature that arose from miscorrelation of key stratigraphic units. Part of this miscorrelation results from a lack of exposure of some stratigraphic intervals in areas immediately adjacent to the Niagara River Gorge.

The revisions discussed herein comply with the requirements of the North American Stratigraphic Code (NASC) of the North American Commission on Stratigraphic Nomenclature (1983). This study was done in cooperation with the USEPA and the Department of Earth and Environmental Sciences of the University of Rochester. Partial funding was provided by grants from the Petroleum Research Fund of the American Chemical Society (grant 21987–AC8), the Geological Society of America, the New York State Geological Survey, and the Paleontological Society.

PURPOSE AND SCOPE

This report presents a revision of Niagaran Provincial Series stratigraphic nomenclature for the type area of western New York (figs. 1–3). The stratigraphic nomenclature is modified and refined, particularly where the improved stratigraphic data base has provided answers to previously unresolved questions. Changes include proposal of newly recognized units and revision of established units. This study is a preliminary step in revision of the entire Silurian column for New York. To promote use of uniform nomenclature in the Niagara region, where several geologic and hydrogeologic studies are being conducted, the revisions for this area are presented in this report rather than delay publication until statewide revisions are completed.

Changes presented in this report include formal establishment of newly recognized units and revision of previously established units; the revised stratigraphic nomenclature is presented in figure 4. All of the new units and some of the revisions presented herein were informally presented in the following guidebook and journal articles by the authors of this report: Brett and others (1990a,b; 1991); Goodman and Brett (1994); LoDuca and Brett (1991, 1994); and Tepper and others (1990). Duke (1991) also used some of the units informally.

This study builds on and partly revises the stratigraphic column of Rickard (1975), the most recent correlation of rocks of Silurian age for western New York published by the New York State Geological Survey (NYSGS). Niagaran Provincial Series nomenclature for the Niagara region of western New York accepted by the USGS prior to the publication of this report is shown in figure 5. The nomenclature is discussed in detail under the individual unit descriptions.

This study included a detailed literature search and analysis of outcrops and of USGS cores (locations shown in fig. 3). Cores were examined in detail from nine deep test holes drilled as part of the previously mentioned cooperative USGS/USEPA study of the hydrogeology of the Niagara region. Four of the cores extend into the Ordovician Queenston Shale; the remaining five end in the Neahga

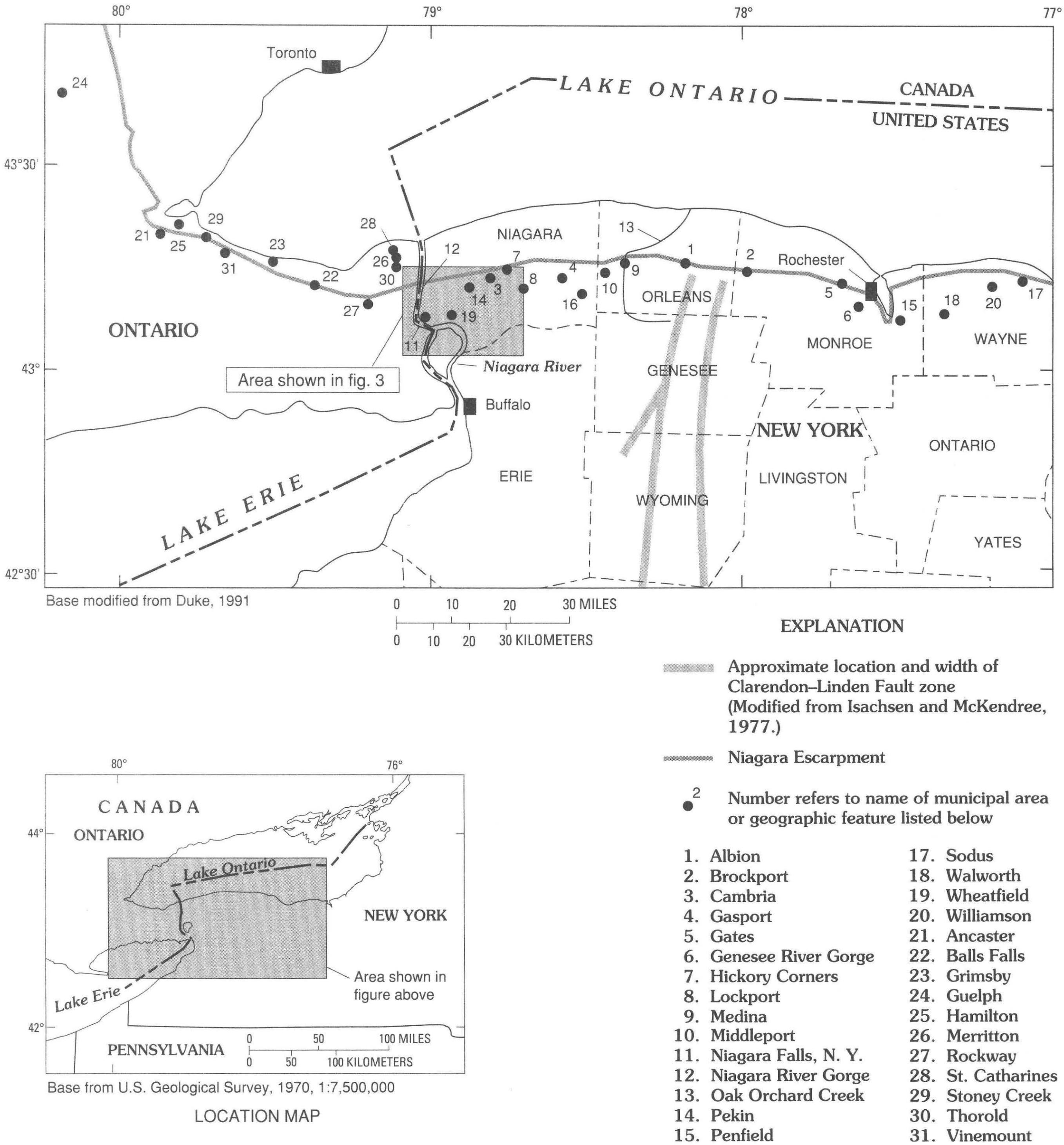


Figure 1. Location of study area and significant geographic features referred to in text.

Shale (Silurian Clinton Group). These cores have provided a continuous, unweathered record to supplement the observations made at outcrops.

The revised nomenclature (fig. 4) applies primarily to Niagara County, N.Y., but is generally applicable to the region between Hamilton, Ont., and Rochester, N.Y. A summary of nomenclature accepted by the Ontario Geological Survey (Johnson and others, 1992) for the equivalent of the Niagaran Provincial Series in the Niagara Peninsula of Ontario is shown in figure 6. North of Hamilton, in the Bruce Peninsula region of Ontario, Niagaran Provincial Series stratigraphic nomenclature is consistent with that of

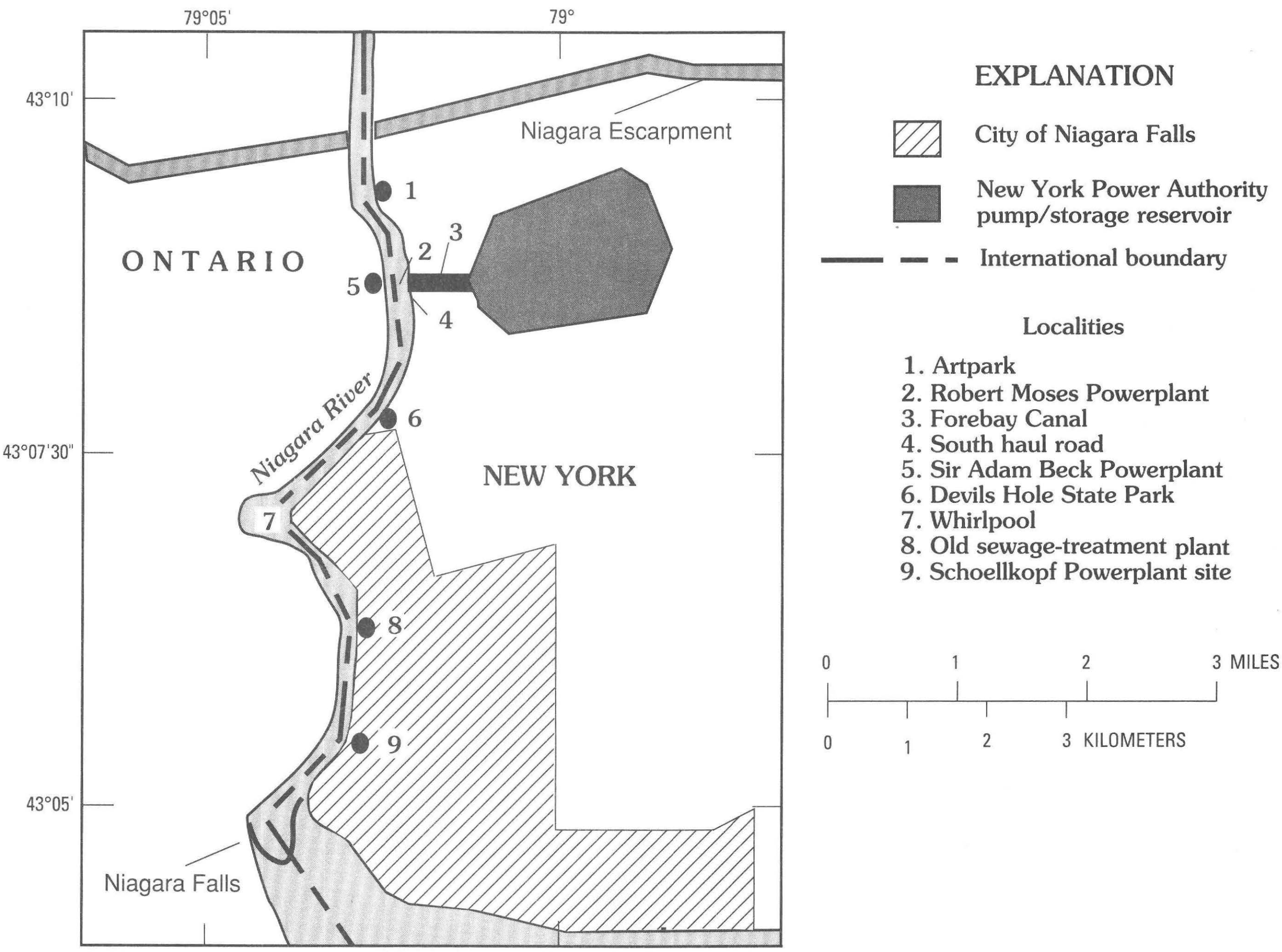


Figure 2. Location of pertinent features in the vicinity of the Niagara River Gorge. Location of area is shown in figure 3. (Modified from Tepper and others, 1990, fig. 1.)

genetically related Michigan Basin strata of Manitoulin Island and northeastern Michigan. East of Rochester, some correlative strata, particularly the Lockport Group, undergo rapid, lateral facies changes that require a stratigraphic nomenclature that emphasizes facies similarities with sections of the Clinton Group type area of east-central New York.

PREVIOUS WORK

The correlation chart of Rickard (1975) is the culmination of about 150 years of research on the Silurian rocks of New York. James Hall (1838, 1839, 1840, 1843) is generally credited with defining key stratigraphic units in western New York, although the pioneering efforts of Hall's mentor, Amos Eaton (1824; 1830a,b; 1832), must be recognized as the starting point in the historical development of Medina, Clinton, and Lockport stratigraphic nomenclature. Hall (1839) proposed a new system of naming rocks on the basis of the geographic name of the type locality; the Rochester Shale and Lockport Limestone were among the first formally named stratigraphic units in North America. Vanuxem (1842) introduced the New York System, in which the Medina Sandstone, Clinton Group, and Niagara Group made up the Ontario Division. Hall (1843) and Emmons (1846) refined Eaton's earlier observations.

The contributions of the pioneering workers in New York were followed by comprehensive refinements published near the turn of the century by Clarke and Schuchert (1899, 1900), Hartnagel (1907, 1912), Kindle and Taylor (1913), Schuchert (1914), and Chadwick (1918). The stratigraphy of the Clinton Group was investigated in detail by Sanford (1935, 1936) and Gillette (1947). Subsequent work on the Silurian stratigraphy of New York includes Fisher's (1953a,b) work on the Clinton Group and the Medina Group (1954, 1966) and his correlation chart of the Silurian rocks of New York (1960), Kilgour's (1963) work on the Clinton Group, Zenger's (1965) work on the

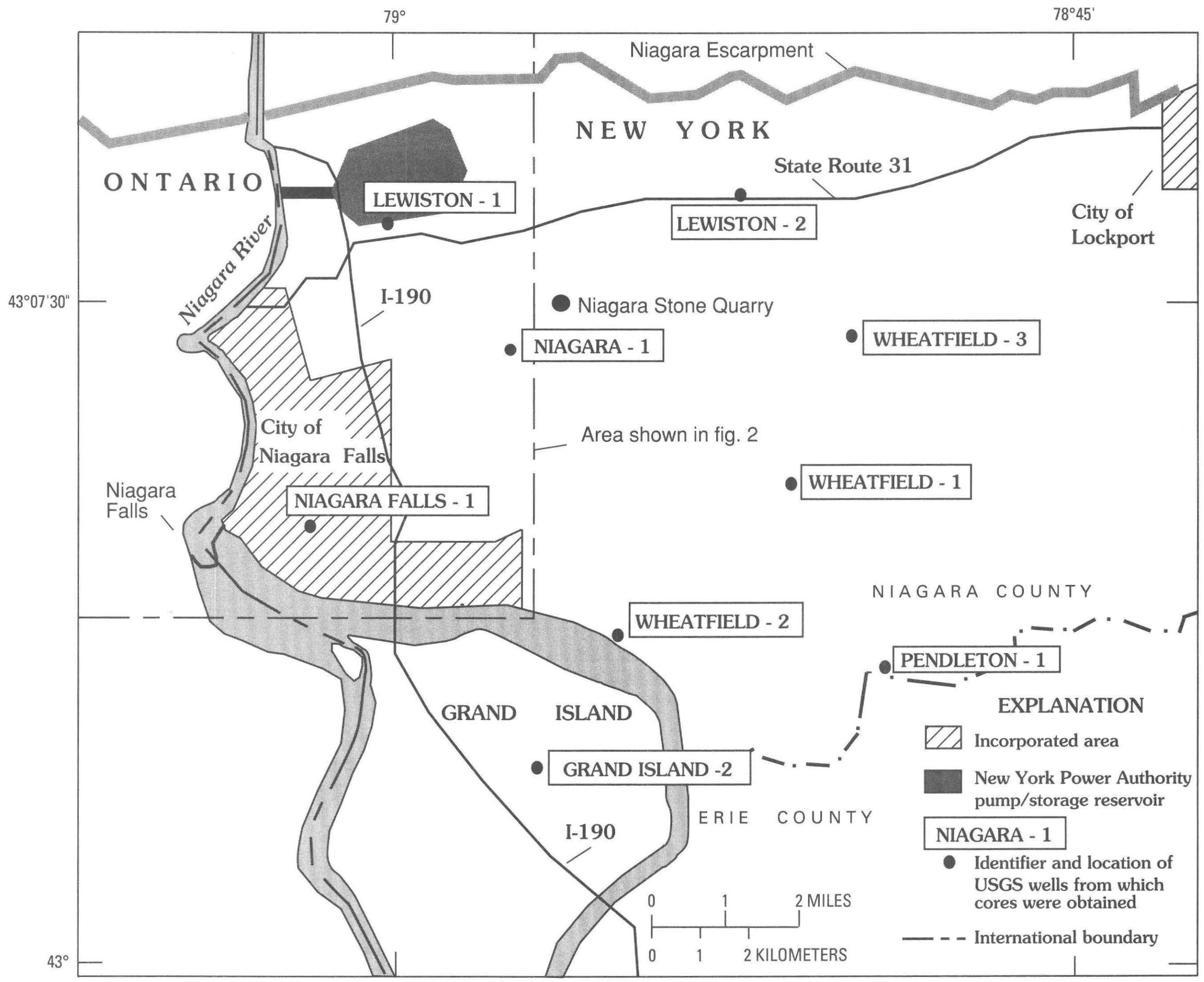
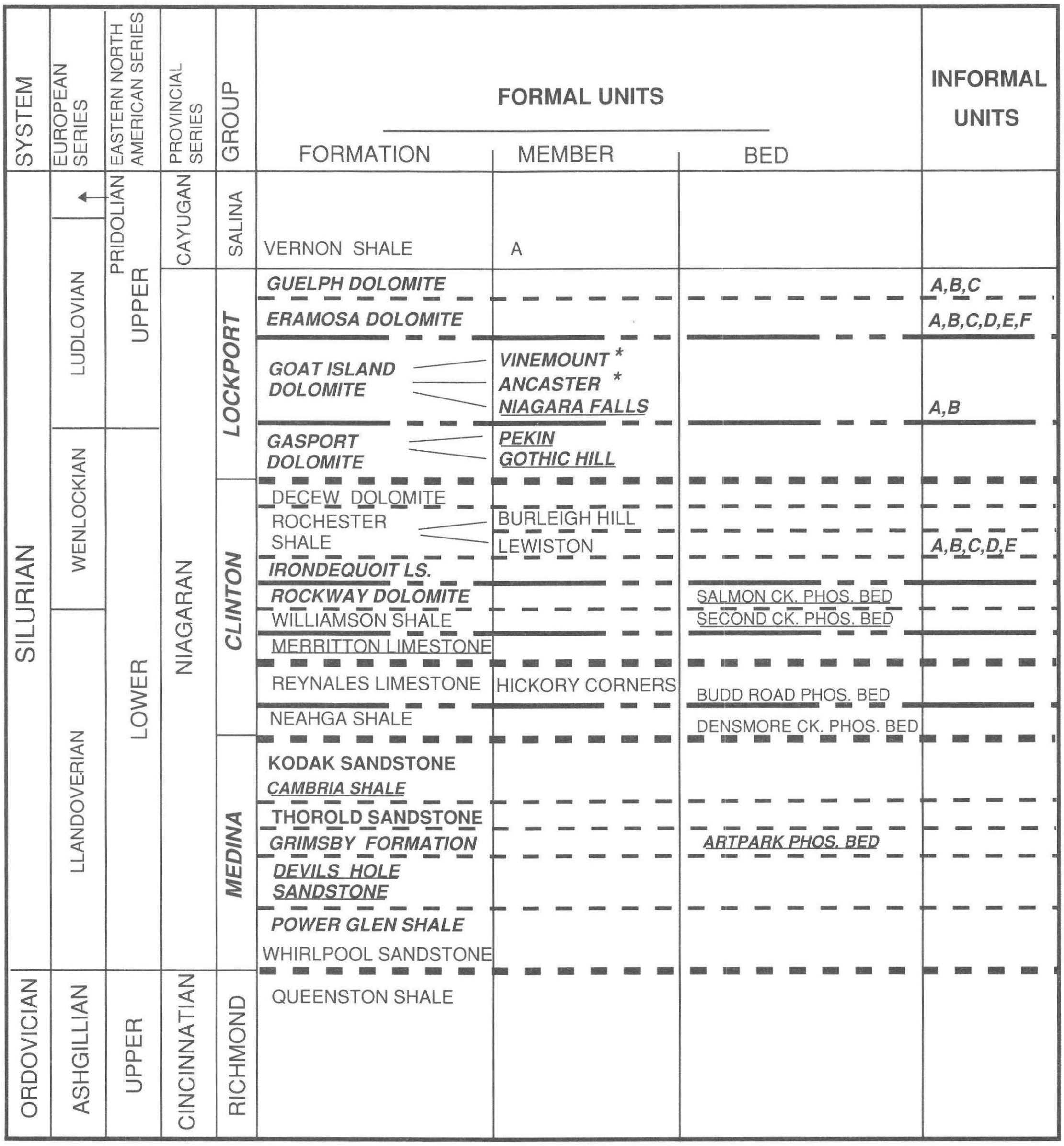


Figure 3. Location of U.S. Geological Survey wells from which cores were obtained. Location of area is shown in figure 1. (Modified from Tepper and others, 1990, fig. 1.)

Lockport Formation, and Rickard's (1975) correlation chart for the entire Silurian section of New York. Martini (1971), Duke (1987a,b), and Duke and Fawcett (1987) provide discussions of the sedimentology and stratigraphy of the Medina Formation. The paleontology and environments of deposition of the Niagaran Provincial Series are discussed in Brett (1981a,b). Brett and others (1990a,b; 1991) and Goodman and Brett (1994) discuss in detail the sequence stratigraphy of the Niagaran Provincial Series and identify six unconformity-bound sequences and several smaller scale disconformity-bound stratal packages that can be correlated into Pennsylvania, Maryland, Ohio, Michigan, and the Bruce Peninsula of Ontario.

Study of the Silurian rocks of Ontario has an equally long history, beginning with the pioneering work of Murray (1845). Early comprehensive stratigraphic treatises were developed by Logan (1863), Bell (1867, 1870), Parks (1913), and Williams (1914a, 1919). More recent syntheses of regional stratigraphy include Bolton's (1957) comprehensive stratigraphy and paleontology of the Niagara Escarpment and subsequent studies by Sanford (1969), Hewitt (1972), Martini (1971, 1974), Telford (1978), and the Ontario Geological Survey (1991).

Many workers have contributed significantly to the interpretation of particular stratigraphic units within the Niagaran Provincial Series. These authors are cited in the appropriate sections. Lukasik's (1988) work on the lithostratigraphy of Silurian rocks in Ohio, Kentucky, and West Virginia was useful in determining regional correlations. References helpful in tracing nomenclatural history include Wilmarth (1938), Keroher and others (1966), Keroher (1970), Berry and Boucot (1970), and Luttrell and others (1981, 1991).



EXPLANATION

– – DIASTEM— Minor discontinuities, including distinct bedding planes and sharp sedimentary contacts, with no evidence of erosional or biostratigraphic gaps

▬ ▪ ▪ MINOR UNCONFORMITY— Disconformities that show evidence of minor erosion and (or) biostratigraphic gaps on the order of a subzone

■ ■ MAJOR UNCONFORMITY— Regionally angular erosional surfaces that may completely bevel one or more underlying stratigraphic units

ITALICIZED AND UNDERLINED = NEW UNIT, PROPOSED HEREIN (FORMAL UNIT)

ITALICIZED ONLY = REVISED HEREIN: CONTACTS OR RANK CHANGED

VERTICAL AND UNDERLINED = EXTENDED GEOGRAPHICALLY

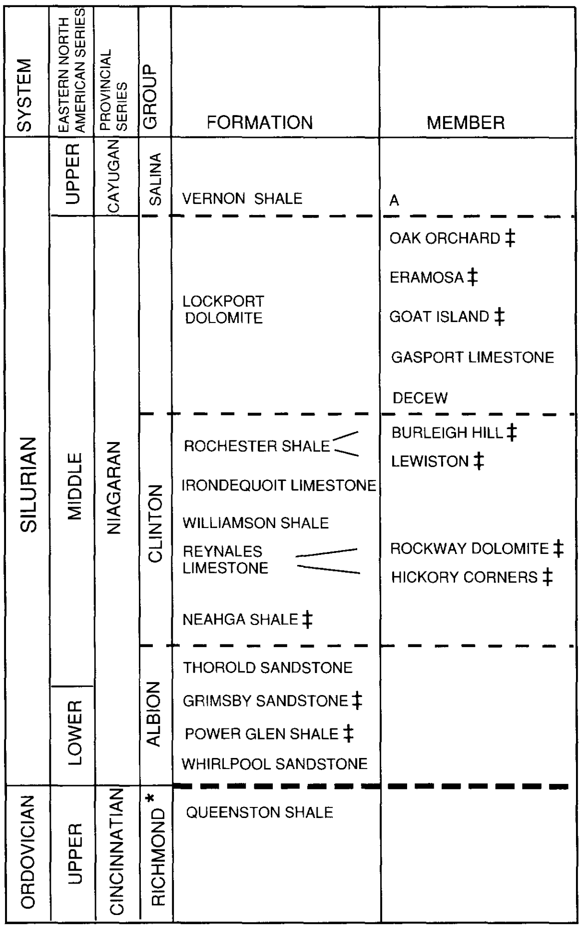
VERTICAL = CHANGE IN GROUP ASSIGNMENT

VERTICAL = NOT REVISED OR OTHERWISE CHANGED

* IN ADDITION TO REVISION HEREIN, THESE UNITS ARE EXTENDED GEOGRAPHICALLY, AND ARE PROPOSED HEREIN AS MEMBERS OF THE GOAT ISLAND DOLOMITE

LS. = Limestone
PHOS. = Phosphate
CK. = Creek

Figure 4. Revised stratigraphic nomenclature for the Niagaran Provincial Series in the Niagara region.



EXPLANATION

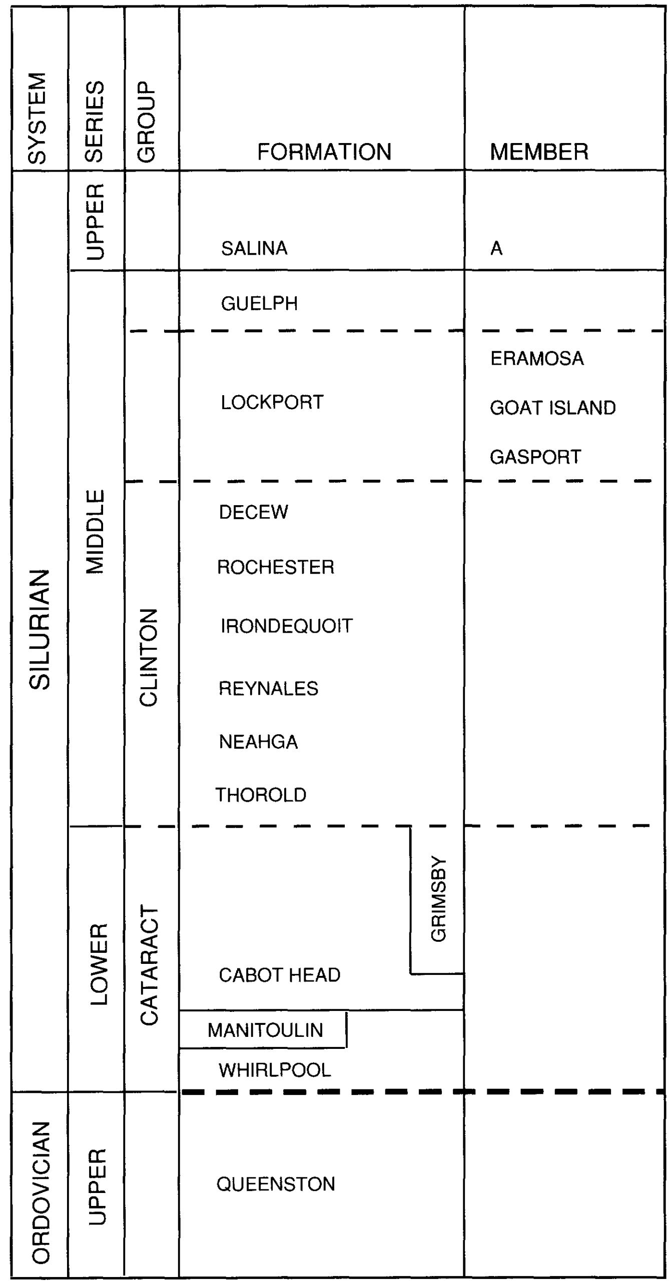
‡ Formation and member names that are not formally accepted by the U.S. Geological Survey (USGS) but are mentioned in some form (for example, they may be shown as formations rather than members as above) in the USGS lexicons of geologic names (Wilmarth, 1938; Keroher and others, 1966; Keroher, 1970; Luttrell and others, 1981; and Luttrell and others, 1991)

* Name formally accepted by USGS for usage in areas other than New York

▬ ▬ Ordovician - Silurian boundary

— — Group boundary

Figure 5. Niagaran Provincial Series nomenclature for the Niagara region of western New York accepted by the U.S. Geological Survey prior to the publication of this report.



EXPLANATION

▬ ▬ Ordovician - Silurian boundary

— — Group boundary

Figure 6. Nomenclature accepted by the Ontario Geological Survey for the equivalent of the Niagaran Provincial Series in the Niagara Peninsula of Ontario. (Modified from Johnson and others, 1992, figs. 20.15, 20.19, 20.24.) (Published with permission from the Ontario Geological Survey.)

ACKNOWLEDGMENTS

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Environmental Conservation), James D. Eckert (Guelph University), Donald Hoskins (Pennsylvania State Geological Survey), Gerard V. Middleton (McMaster University), Mark A. Pearce (United States Gypsum), Lawrence V. Rickard (New York State Geological Survey), Arthur Van Tyne (Van Tyne Consulting), and Donald H. Zenger (Pamona State College).

REVISED STRATIGRAPHY AND CORRELATIONS

During development of Silurian nomenclature in New York, Niagara and Niagaran have been used at the formation, group, and series levels. For example, Niagara Limestone was first introduced by Vanuxem (1839); it is now recognized as the Lockport Dolomite by the USGS. Niagara Group was first introduced by Hall (1842) and included the Rochester Shale and Lockport Limestone; Hall (1867) later included the Guelph Limestone in the Niagara Group. Clarke and Schuchert (1899) modified Niagara Group to include the Clinton beds, Rochester Shale, Lockport Limestone, and the Guelph Dolomite. Prior to this report, the USGS did not assign the Lockport Dolomite (formation), with its five members, to a group but used Clinton Group for the interval above the Thorold Sandstone up to and including the Rochester Shale. Rickard (1975) also included the Thorold Sandstone and the DeCew Dolomite in the Clinton Group. Prior to this report, the USGS used Albion Group for the stratigraphic interval that includes the Whirlpool Sandstone, Power Glen Shale, Grimsby Sandstone, and Thorold Sandstone. This interval, except for the Thorold Sandstone, is shown as the Medina Group on Rickard's (1975) correlation chart. Chamberlain and Salisbury (1906) grouped the New York Silurian formations into the Oswegan Series, Niagaran Series, and Cayugan Series. Fisher (1960) divided the Silurian into two series, the Niagaran and the Cayugan. This usage was accepted by the USGS and by Rickard (1975). The Medina, Clinton, and Lockport Groups were included in the Niagaran Series by Rickard (1975) and that usage is followed herein.

Berry and Boucot (1970) emphasize that the only diagnostic fauna within the New York Silurian is that of the Niagaran Series, which is the only Silurian subdivision that can be demonstrably recognized outside the type area. Because the term Niagaran has become essentially synonymous with Silurian in the western part of North America, Berry and Boucot (1970) suggest that the Series nomenclature of the British Silurian be used for the Silurian of North America. They recommend restriction of the New York Silurian terminology to that area in which the units can be traced on a lithologic and stratigraphic basis. With specific regard to the term Niagaran, they state (p. 15, 16):

> The continued usage of the term "Niagaran" for all of North America has led to its corruption, until now it has become, for all practical purposes, synonymous with "shelly Silurian." It is recommended that the term "Niagaran" be used only as a provincial series term in areas adjacent to western New York where its usage can be justified on a lithologic and stratigraphic basis.*** It is recommended that North Americans discontinue the futile efforts to use the New York section as a standard for purposes of correlation. (Paraphrased from Berry and Boucot (1970) and published with permission of the authors.)

The authors agree with Berry and Boucot (1970) and herein restrict the use of Niagaran Provincial Series to the recommended geographical area. British Series names (Llandoverian, Wenlockian, and Ludlovian) are used throughout the text, however, to assist the reader in correlation of the New York Silurian units with strata elsewhere. Additional information on correlation and ages of selected units is presented in Rickard (1975).

Usage in New York of the term Middle Silurian was abandoned by Rickard (1975), who then divided the Silurian into Lower and Upper Silurian for consistency with European usage. The term Middle Silurian is not used herein for consistency with Rickard (1975) and with international convention. Rickard (1975) placed the Lower and Upper Silurian boundary between the Llandoverian and the Wenlockian Series. Harland and others (1982) have placed this boundary between the Wenlockian and the Ludlovian Series; this placement is used herein.

The revised stratigraphic nomenclature is presented in figure 4. Stratigraphic units are identified in figure 4 and in the text as belonging to one of the following five categories: (1) new unit, proposed herein; (2) revised herein (stratigraphic contacts or rank of unit changed); (3) geographic extension of unit previously recognized outside Niagara County; (4) change in group assignment; and (5) not revised herein (no change to unit as defined by previous workers). As required in the NASC (North American Commission on Stratigraphic Nomenclature, 1983, p. 859), lithic terms have been added to each of the previously established names of the four marker beds in the Clinton Group. A summary of revisions or other modifications is provided, as appropriate, at the end of the discussion for each unit.

Many stratigraphic units in figure 4 are shown as separated by diastems or by minor or major unconformities. Diastems are minor discontinuities, including distinct bedding planes and sharp sedimentary contacts with no evidence of erosion or biostratigraphic gaps. Minor and major unconformities shown in figure 4, in contrast, represent gaps estimated to encompass tens of thousands to millions of years. Minor unconformities are disconformities that show evidence of minor erosion and (or) biostratigraphic gaps on the scale of a subzone. These surfaces do not substantially truncate regional stratigraphic units but they are sharp and indicate (1) local removal of up to a few feet of underlying beds, (2) minor channeling, and (3) clasts eroded from adjacent beds. Major unconformities, which include most stratigraphic sequence boundaries (as defined by Brett and others, 1990a), are regionally angular erosion surfaces that can completely bevel one or more underlying stratigraphic units. Typically, hiatuses spanning one or more biostratigraphic zones are evident in areas where the unconformity is most pronounced.

The relation between Rickard's (1975) chronostratigraphic units and the revised units for the Medina, Clinton, and Lockport Groups is shown in figures 8, 14, and 22. Although all of the group names remain the same as in Rickard (1975), the contacts of the Medina, Clinton, and Lockport Groups are revised. Changes at the formation level include (1) use of Canadian stratigraphic nomenclature (for example, Guelph Dolomite) to establish uniformity across the international border; (2) geographical extension of two formations (Merritton Limestone and Williamson Shale) that had been previously recognized beyond Niagara County but have now been recognized as actually extending into Niagara County; (3) proposal of two new formations (Devils Hole Sandstone and Cambria Shale); and (4) the rank or stratigraphic contacts of eight formations have been revised. In addition to these changes at the formation level, several new members are proposed and two are revised and extended geographically. Some new informal units are included in the revised column. Of particular importance to regional stratigraphic correlations are four distinctive, laterally traceable, phosphate-pebble horizons that are herein given formal bed-level status. Phosphate-pebble beds are particularly useful for stratigraphic correlation because they formed over large areas of the sea floor during periods of extremely slow deposition or nondeposition. Phosphate precipitates on the sea floor as nodules, crusts, or infilling of shells, and these precipitates are often reworked by storm-related depositional processes that produce widespread marker beds.

The following principles have been consistently applied in the revisions herein: (1) definition of stratigraphic units is based on the type sections or localities; (2) when possible, names in long-standing use are retained with appropriate revisions or redefinitions instead of being replaced with new stratigraphic names; (3) when names for stratigraphic intervals are duplicated, the more recently proposed name is abandoned in favor of the earlier proposed term; and (4) a stratigraphic name for an interval is applied uniformly over the entire region over which that interval, as defined by general lithology and bounding contacts, can be recognized; that is, the same name is used despite (a) local facies changes and (b) crossing of geopolitical boundaries such as the U.S.–Canadian border. Strict application of these principles has led to some changes in usage of names.

To resolve conflicts in the present stratigraphic nomenclature that have been caused by miscorrelation of units between New York and Ontario, particularly in the Lockport Group, the contacts between units with Canadian type sections or localities have been shifted considerably for consistency with Canadian usage. Thus, for example, the name Eramosa Dolomite is applied herein to a different interval of the Lockport Group than that recognized in earlier reports (for example, Zenger, 1965; Rickard, 1975). This shift is warranted because recent work demonstrates that the Eramosa interval, as defined along the Eramosa River area in Guelph, Ont., has previously been miscorrelated in the Niagara region with a lower, argillaceous interval herein termed the Vinemount Member (also informally defined in Ontario as the Vinemount Shale) of the Goat Island Dolomite. In turn, the name Eramosa replaces the term "Oak Orchard," which must be abandoned because strata of the interval in question are not exposed at the type locality on Oak Orchard Creek in Medina, N.Y. Likewise, modifications in the previously applied definitions of the Grimsby Formation and Thorold Sandstone result in improved characterization of the units as exposed at their respective type sections.

The NASC specifies that proposed stratigraphic units be identified as either allostratigraphic or lithostratigraphic units. In many ways, traditional Silurian units of formation- or member-level qualify as allostratigraphic units although they might have been originally defined as lithostratigraphic units. For example, the Neahga Shale is defined as a gray to green shale overlying the Thorold Sandstone and underlying the Reynales Limestone (Sanford, 1935). The original definition of the Neahga Shale is based on both its lithologic character and stratigraphic position; however, the nature of its disconformable contacts also qualifies it as an allostratigraphic unit. The internal characteristics of the formation change slightly, but not significantly. Consequently, the Neahga is a legitimately mappable lithologic unit with bounding discontinuities marked by mappable phosphate-pebble beds.

Supporting the allostratigraphic nature of stratigraphic units within the Niagaran Provincial Series is the elimination of the concept of laterally extensive, diachronous, transgressive, sheet sandstones. The Thorold-Kodak sandstone sheet, traditionally considered to be a laterally continuous, diachronous unit, actually represents two discrete, closely isochronous sandstone bodies at different stratigraphic levels (Duke and others, 1987). The revised units that result from recently improved correlations are lithostratigraphic in the sense that they remain mappable lithologic units, but they also have allostratigraphic significance because of their high degree of isochroneity; generally sharp, disconformable boundaries; and their relation to allocyclic sedimentary patterns. A major consequence of the revisions presented herein has been the elimination of lithostratigraphic units with grossly diachronous boundaries.

The following discussion of stratigraphic revisions begins at the base of the Silurian column with the Medina Group and proceeds upward through the Clinton Group and the Lockport Group. Names for all of the new units proposed herein have been formally reserved through the Geologic Names Committee of the USGS. All revisions have been made in accordance with the NASC. Because the NASC does not allow use of the "submember" category, units that would be of this rank are treated as informal units and have been given alphanumeric designations. Informal units are discussed under the appropriate "member" categories.

The use of quotes for stratigraphic nomenclature in this report is restricted to units that have been misidentified or abandoned. If stratigraphic nomenclature for a unit has changed over time, the term for the unit is shown, with capitalization, as given in whatever reference is cited rather than according to the most recent nomenclature. For example, Second Creek Bed was formally named by Linn and Brett (1988) and in all references to their work, the bed is termed Second Creek Bed rather than Second Creek Phosphate Bed, as it has been renamed herein.

As has been previously discussed, this study builds on and partly revises the stratigraphic column of Rickard (1975), the most recent correlation of rocks of Silurian age for western New York to be published by the NYSGS. Units that are established in the nomenclature of the NYSGS but that have not been previously accepted by the USGS or are not proposed herein are footnoted where first mentioned in the text. Nomenclature different than that accepted by USGS in Pennsylvania is also footnoted where first used in the text. Several stratigraphic names that have been used informally in Ontario but were not previously used in New York have been proposed as formal names in this report—first usage of these terms in the text is also footnoted. There are no footnotes concerning any other usage of Canadian terms because neither the USGS nor the NYSGS has jurisdiction over usage of these terms.

A discussion of "first usage of nomenclature" is provided for each unit that is not revised or otherwise changed herein, or has been geographically extended herein, or has had a group assignment changed herein. For units that are revised herein, a section on "brief history of nomenclature" is included. A "background" discussion of nomenclature is provided for those units that are newly proposed herein.

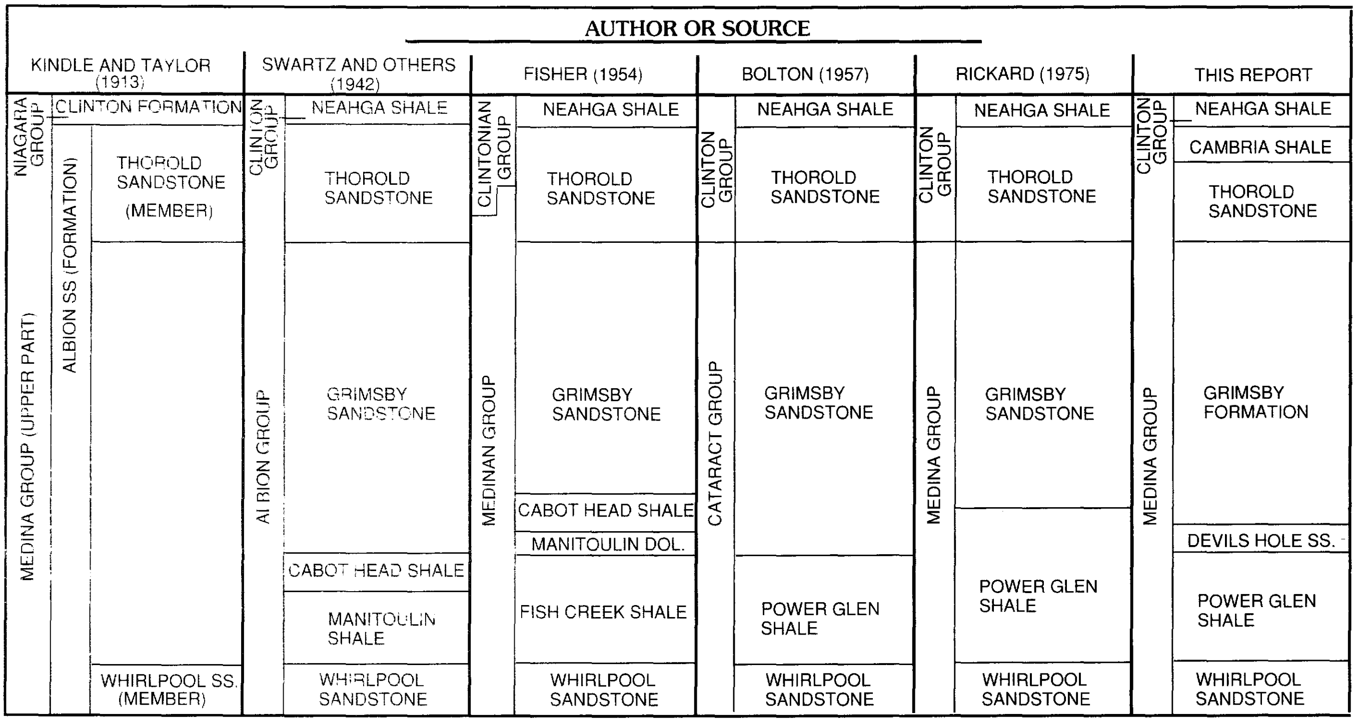
MEDINA GROUP (revised herein)

As revised herein, the Medina Group consists of 80–115 ft of white, green, and red, barren to moderately fossiliferous sandstone, siltstone, and shale. Carbonates are conspicuously absent east of Hamilton, Ont., and the amount of carbonate cement is minimal (Fisher, 1966). The Medina Group is the principal reservoir for natural gas in western New York. The type locality for the Medina Group is along Oak Orchard Creek in the Village of Medina, Orleans County, N.Y. Excellent reference sections crop out at the Genesee and Niagara River Gorges and at DeCew Falls, Ont.

The history of nomenclature of what is now termed the Medina Group, beginning with Conrad (1837) and ending with Bolton (1953), is presented in Fisher (1954); Bolton (1957, table 2) presents a detailed summary of this nomenclature for 1910–53. A historical summary of nomenclature of the Medina Group in the Niagara region is shown in figure 7. Early investigators of the Medina include Conrad (1837); Vanuxem (1840, first usage of Medina; 1842); Hall (1840, 1843); Gilbert (1899); Luther (1899); Fairchild (1901); Grabau (1901, 1905, 1908, 1909, 1913); Kindle and Taylor (1913); Kindle (1914); Schuchert (1914); Chadwick (1918, 1935); Williams (1919); Goldring (1931); and Swartz and others (1942). More recent workers include Fisher (1954, 1960); Bolton (1957); Martini (1971, 1974); Rickard (1975); Duke (1987a,b; 1991); Duke and Fawcett (1987); and Duke, Fawcett, and Brusse (1991).

To date, no consensus has been reached regarding the stratigraphic rank of the Medina sequence. The term Medina Group is used by the NYSGS; prior to this report, the same strata were designated Albion Group by the USGS, and termed the Cataract Group in Ontario by Bolton (1957). The Medina was referred to as a formation as early as Vanuxem (1840) and Hall (1840), both of whom used Medina Sandstone to refer to the interval including the Queenston Shale to the base of the Thorold Sandstone. The Medina has been referred to as a formation as late as Duke (1987a), who included the following members in the Niagara River Gorge area: Whirlpool, Cabot Head, Grimsby, Thorold, and Neahga. Conversely, it was given group rank by Fisher (1954) (fig. 7) and is considered a group by the NYSGS (Rickard, 1975) (figs. 7, 8). The Medina is herein considered a group (figs. 7, 8) because at least two scales of units are traceable within the traditional, formally recognized subdivisions of the Medina (for example, Grimsby Formation).

As defined herein, the base of the Medina Group is placed at the contact between the Whirlpool Sandstone and the Ordovician Queenston Shale; this contact is known as the Cherokee discontinuity (named by Dennison and Head, 1975), which separates the Ordovician from the Silurian Systems. It is a nearly planar surface that slopes gently northwestward, and it is described by Middleton (1987) and Brett and others (1990b). The disconformity is of unknown duration in the Niagara region (Rutka and others,1991). At this unconformity across western and central New York, Lower Silurian formations assigned to the Medina Group progressively onlap the eroded Queenston surface eastward. Between Hamilton, Ont., and Medina, N.Y. (fig. 1), the Whirlpool Sandstone forms the base of the Medina Group, and the lower contact of the Medina Group is placed between the Queenston Shale and the overlying Whirlpool Sandstone. East of Medina, the basal units (Whirlpool Sandstone and Power Glen Shale) become condensed and their remnants have been mapped as basal units of the Grimsby Formation. At Rochester, N.Y., the basal units



EXPLANATION
SS. = Sandstone
DOL. = Dolomite

Figure 7. Historical summary of Medina Group nomenclature in the Niagara region.

pinch out, and the lower boundary of the Medina Group is placed at the contact between the Queenston Shale and the equivalent of the Devils Hole Sandstone that has been assigned previously to the Grimsby Formation.

The stratigraphic placement of the Medina-Clinton Group contact has been controversial (fig. 7). On the basis of evidence of erosion at the Grimsby-Thorold contact in the Niagara River Gorge, several previous workers (for example, Bolton [1957] and Rickard [1975]) have suggested that the Thorold Sandstone and younger strata be included in the Clinton Group. Other stratigraphers (for example, Swartz and others [1942]), however, have placed the Medina Group contact at the top of the Thorold Sandstone in the Niagara area. Duke (1987a) used the relative predominance of siliciclastic beds over carbonate beds as a criterion and proposed that the Medina Group contact be placed at the contact between the Neahga Shale and the overlying Reynales Limestone.

The Thorold Sandstone, Cambria Shale, and Kodak Sandstone are herein considered part of the Medina Group, and the upper contact of the Medina Group is herein revised to be at the unconformable contact between the Kodak Sandstone and the Densmore Creek Phosphate Bed of the overlying Neahga Shale (fig. 8). The Medina Group contact is informally placed at this contact by Brett and others (1991), Duke (1991), and LoDuca and Brett (1994). These authors recognize that the Thorold and Kodak are distinct sandstone intervals separated by the Cambria Shale, and that the Thorold interval can be traced below the Cambria Shale between Niagara County and the Rochester, N.Y., area. The Thorold-Cambria-Kodak succession appears to be relatively conformable.

These three units are progressively truncated along the low-angle regional unconformity that is marked by the Densmore Creek Phosphate Bed. Although the presence of phosphate pebbles at the Kodak Sandstone-Maplewood Shale[6] contact was noted as early as Hall (1843), the traceability of this phosphate bed was not fully appreciated until recently. Fisher (1953b) recognized the potential for tracing phosphate beds in the Clinton Group, but the stratigraphic complexity of the uppermost part of the Medina Group led to miscorrelation of phosphate horizons. The availability of the USGS cores has facilitated accurate correlations of phosphate horizons above the Kodak Sandstone and within higher units that are herein assigned to the lower part of the Clinton Group. Because the contact is an unconformity,

[6]Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

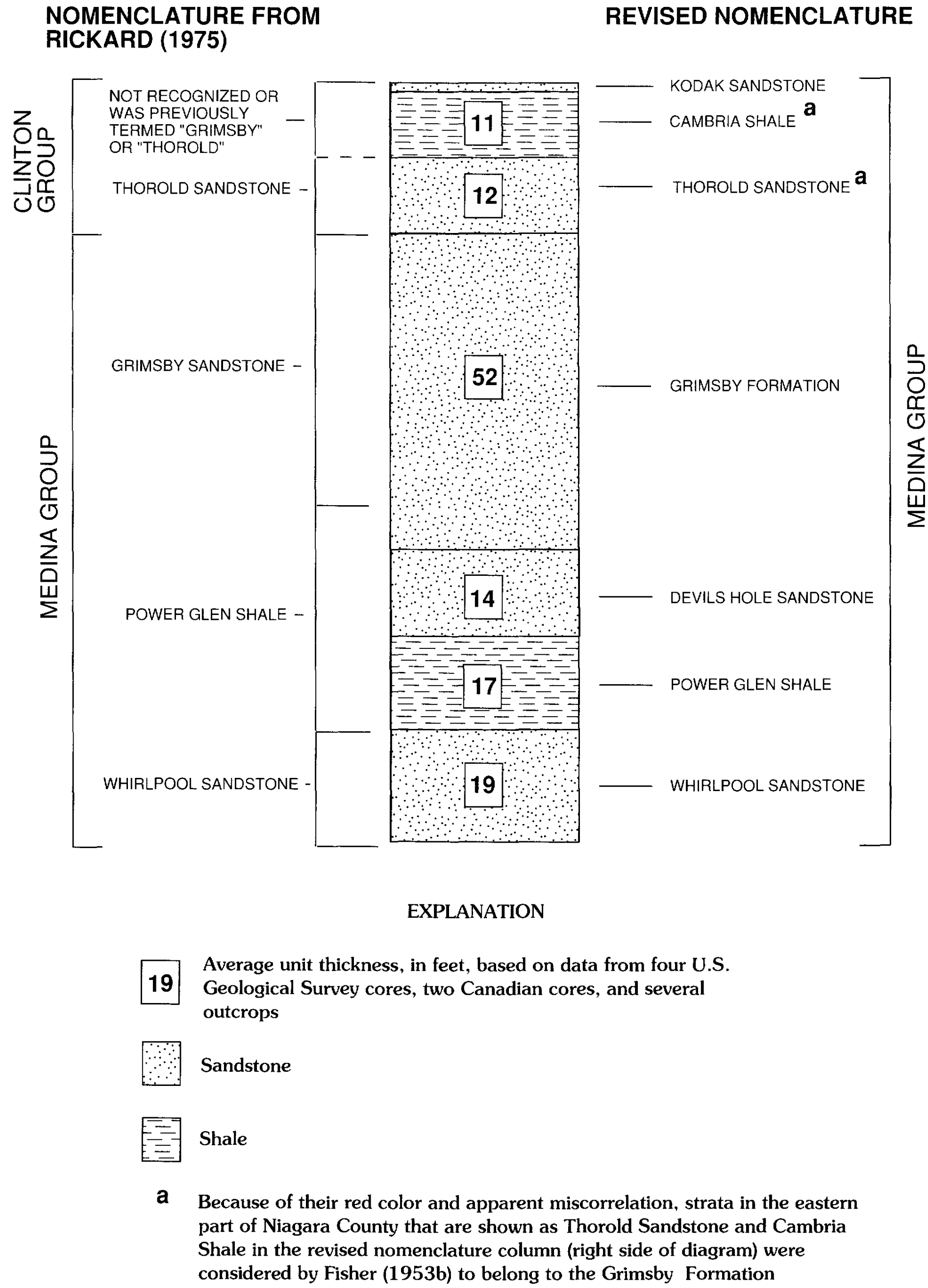


Figure 8. Stratigraphic nomenclature from Rickard (1975) and revised nomenclature for the Medina Group in the Niagara region. Formation contacts and lithologic shading of units are based on the revised nomenclature.

different formations are juxtaposed along it. From Niagara County westward to St. Catharines, Ont., the Thorold Sandstone directly underlies the basal Clinton unconformity that is marked by the Densmore Creek Phosphate Bed. Eastward from Niagara County, the Cambria Shale and the Kodak Sandstone form the section between the Thorold and the basal Clinton unconformity.

The Medina Group sediments were deposited in deltaic and shallow marine environments, which are described in detail in Martini (1971), Duke (1991), and Duke and others (1991). According to Brett and Calkin (1987), the sequence from the Whirlpool Sandstone through the Grimsby Formation records an Early Silurian marine transgression over the eroded Queenston deposits, followed by regression resulting from active progradation of the Medina fringe delta.

Conflicts in the current lithostratigraphic divisions of the Medina Group are discussed by Duke (1987a) and Duke and others (1991), who note that previously established

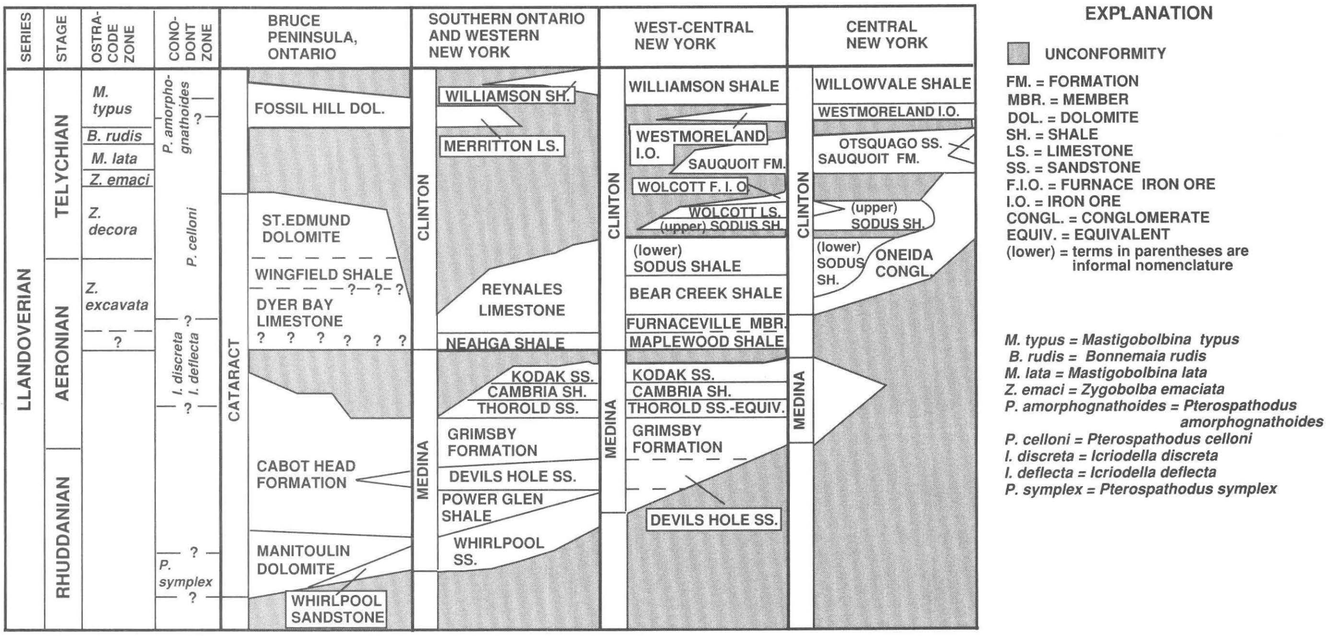


Figure 9. Stratigraphic correlations for the Medina Group and lower part of the Clinton Group in parts of Ontario and New York. (Modified from Brett and others, 1991, fig. 5.)

formations have been defined on the basis of regional color variation. These authors emphasize that these regional patterns of color variation do not necessarily match lithologic correlations and attribute the color variation in the Medina to patterns of secondary diagenetic reduction of strata that were oxidized when deposited.

As defined herein, the Medina Group consists of the following seven formations (fig. 8), in ascending order: the Whirlpool Sandstone, the Power Glen Shale, the Devils Hole Sandstone, the Grimsby Formation, the Thorold Sandstone, the Cambria Shale, and the Kodak Sandstone. New formations proposed herein (fig. 4) include the Devils Hole Sandstone and the Cambria Shale. In addition, a distinctive, laterally traceable phosphate-pebble bed at the base of the Grimsby Formation is herein formally proposed as the Artpark Phosphate Bed (fig. 4). Stratigraphic contacts of the Power Glen Shale and the Grimsby Formation are revised (fig. 4). The stratigraphic units of the Medina Group are described in the following sections.

A comparison of stratigraphic nomenclature from Rickard (1975) with revised nomenclature for the Medina Group is shown in figure 8. Stratigraphic correlations for the Medina Group are shown in figure 9, and a geologic section showing stratigraphic relations in the Medina Group with regional correlations between Hamilton, Ont., and Rochester, N.Y., is shown in figure 10. A descriptive stratigraphic column for the Medina Group at the Niagara River Gorge near Lewiston, N.Y., is presented in figure 11, and natural-gamma logs and stratigraphic correlations for units within the Medina Group are shown in figure 12.

Summary of Revisions: Rickard (1975) included only the Whirlpool Sandstone, Power Glen Shale, and the Grimsby Sandstone in the Medina Group. The contact between the Medina and Clinton Groups has been shifted formally herein from the contact between the Grimsby Formation and the Thorold Sandstone to the major unconformity between the Kodak Sandstone and the Densmore Creek Phosphate Bed, at the base of the Neahga Shale. New formations proposed herein include the Devils Hole Sandstone and the Cambria Shale. The Artpark Phosphate Bed is introduced at the base of the Grimsby Formation. Stratigraphic contacts of the Power Glen Shale and the Grimsby Formation have been revised. The Thorold Sandstone and the Kodak Sandstone are herein included in the Medina Group rather than in the Clinton Group.

WHIRLPOOL SANDSTONE
(not revised or otherwise changed herein)

First Usage of Nomenclature: First used by Grabau (1909) for the white quartzose sandstone, which is 25 ft thick at its exposure in the Whirlpool in Niagara River Gorge (fig. 2). It was defined as the basal bed of the Upper Medina (later named Albion Sandstone); overlain by red, green, and gray sandstones and shale; and underlain by the Queenston Shale of the Richmond Group.

Type Locality: Exposures along the Canadian side of the Whirlpool and extending downstream to Lewiston, Niagara River Gorge (Niagara Falls quadrangle) (Grabau, 1909).

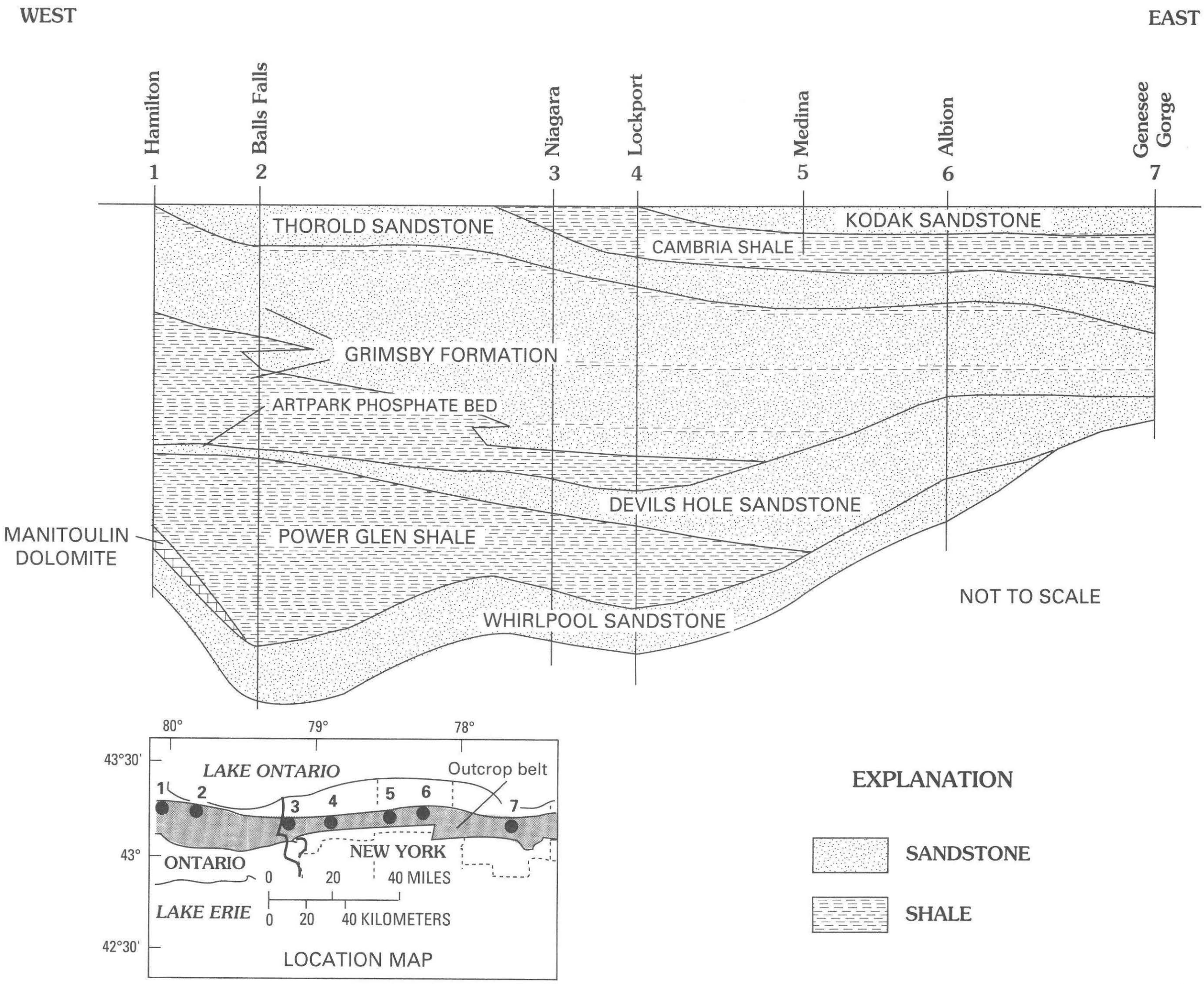


Figure 10. Diagrammatic stratigraphic relations in the Medina Group, with regional correlations between Hamilton, Ont., and the Genesee River Gorge at Rochester, N.Y. Length of vertical line at each locality indicates units observed in the field or in drill cores. (Modified from Brett and others, 1991, fig. 7.)

Reference Sections: DeCew Falls, Ont.; Route 403 roadcut, Hamilton, Ont.; Lockport, N.Y., at railroad overpass on Niagara Street.

Thickness: In the Niagara River Gorge, the thickness of the Whirlpool Sandstone ranges from 18 to 28 ft (Bolton, 1957). In the USGS cores, the thickness ranges from 20.5 to 23.6 ft.

Lithologic Description: In the Niagara region (fig. 11), the Whirlpool Sandstone is a light-gray to white, medium- to coarse-grained (0.004–0.028 in., according to Middleton, 1987), trough cross-bedded, quartzose sandstone with thin, dark-gray to greenish-gray shale clasts and interbeds. It has been classified by Rutka and others (1991) as a subarkose to quartz arenite. The contacts of shale interbeds and between laminae in trough cross sets are commonly microstylolitic. The Whirlpool Sandstone contains floral microfossils (Gray and Boucot, 1971). According to Middleton and others (1987), a transgressive surface separates the nonmarine, braided fluvial environments of the lower part of the Whirlpool from the marine nearshore, wave-affected environment of the upper part of the Whirlpool. This bounding transgressive surface is sharp and is defined by the presence of either a shale clast lag deposit, the first appearance of symmetrical ripples, or more regularly interbedded shale (Rutka and others, 1991). Middleton and others (1987) and Rutka and others (1991) describe the paleontology, environments of deposition, and regional correlations of the Whirlpool and discuss facies within the lower and upper units of the Whirlpool. The lower part of the Whirlpool is characterized by medium- to fine-grained sandstone with large-scale, northwestward dipping trough cross bedding (Brett and others, 1990a) and by large-scale tabular and festoon cross bedding and channels up to 300 ft across (Brett and Calkin, 1987). The lower unit typically comprises two-thirds of the total

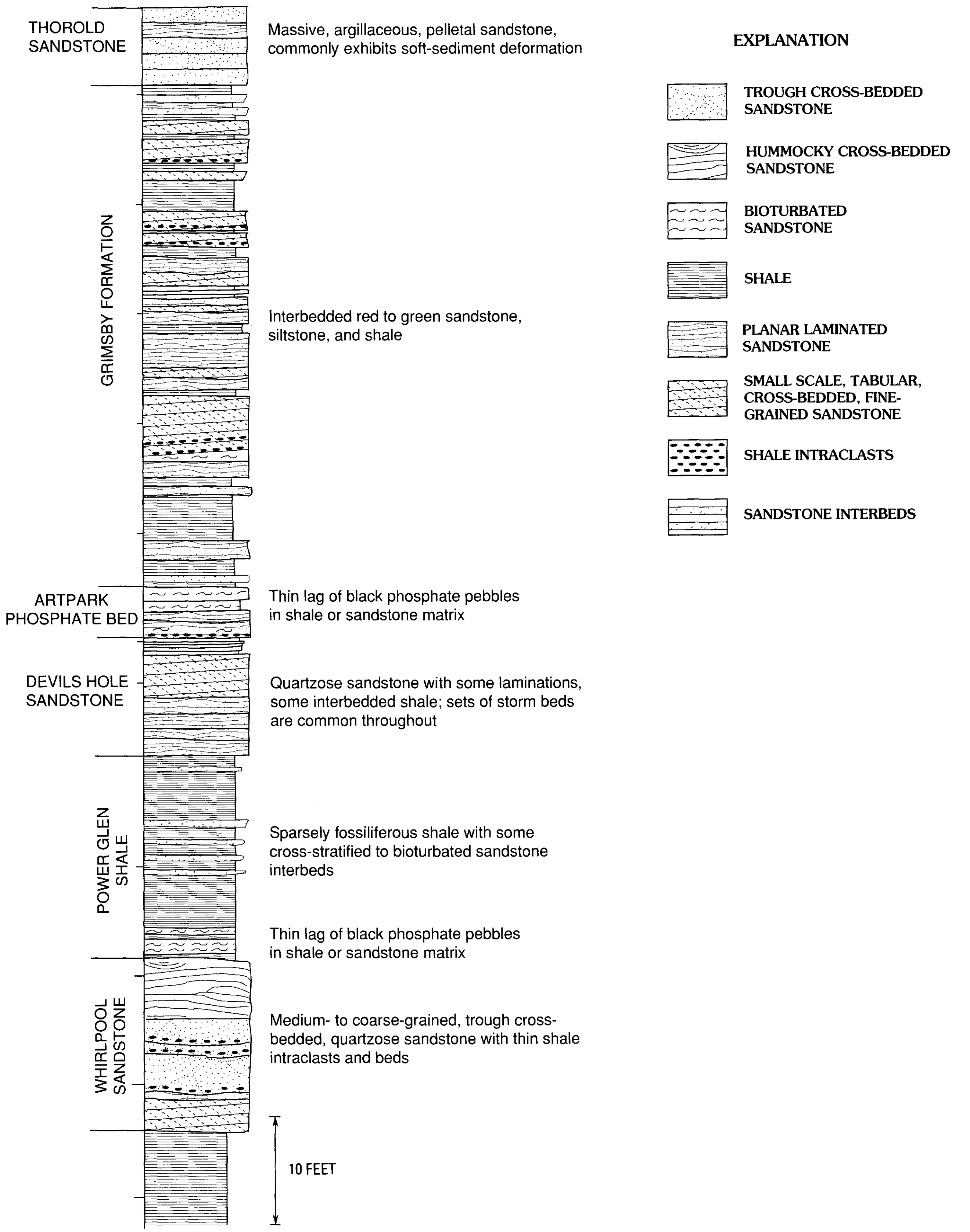


Figure 11. Descriptive stratigraphic column for the Medina Group at the Niagara River Gorge near Lewiston, N.Y. The uppermost Medina units, the Cambria Shale and the Kodak Sandstone, are missing as a result of erosion beneath the basal Clinton unconformity. (Modified from Brett and others, 1991, fig. 6.)

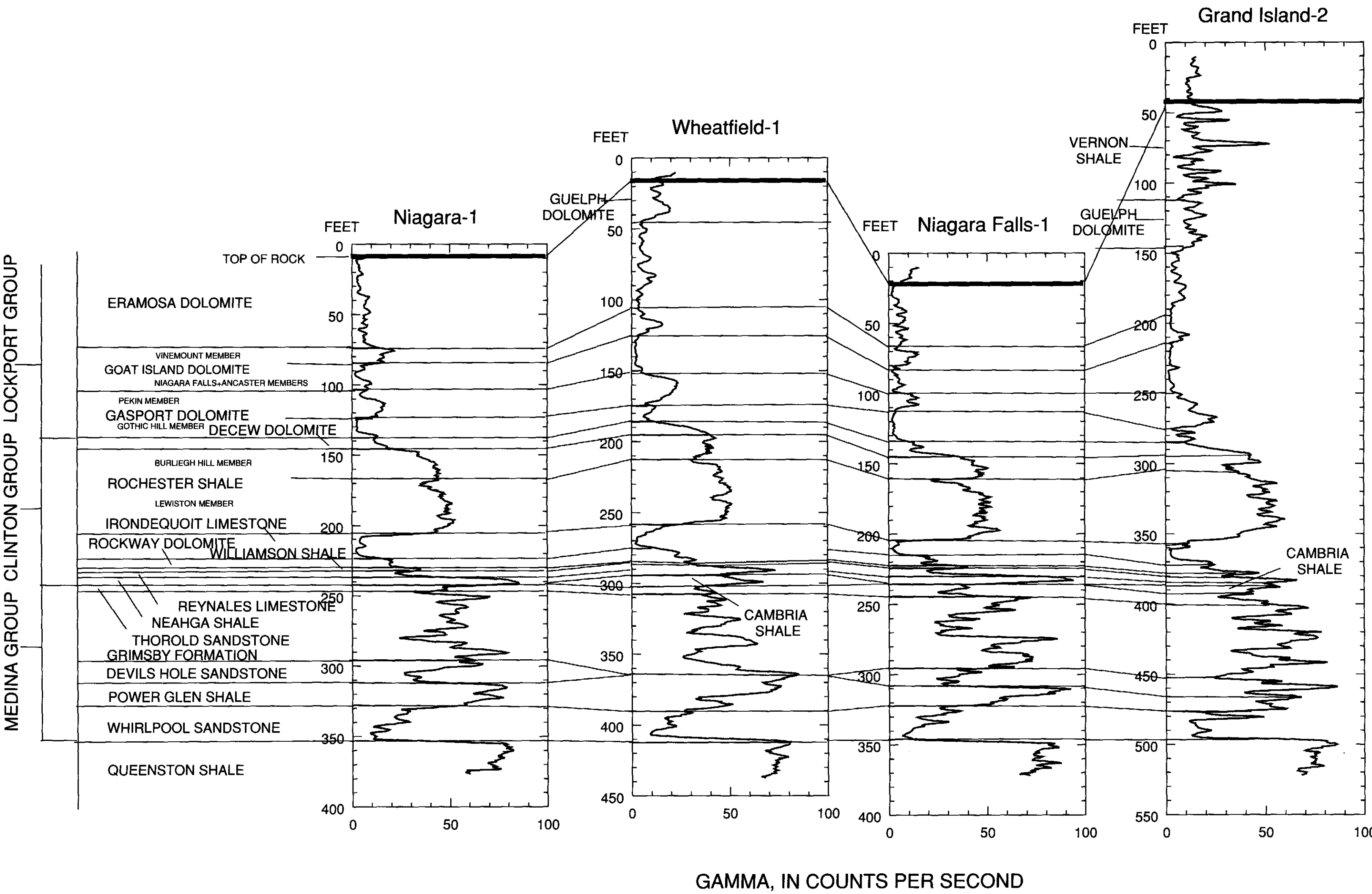


Figure 12. Natural-gamma logs and stratigraphic correlations from U.S. Geological Survey Queenston cores (locations shown in fig. 3). Depths shown are depths below land surface, in feet. The common datum on the logs is the contact between the Queenston Shale and the Whirlpool Sandstone.

formation thickness in outcrop, rarely contains shale interbeds, and is coarser grained and more massively bedded than the upper unit (Rutka and others, 1991). The upper unit is characterized by hummocky cross stratification, oscillation ripples, sparse fossils, and greater abundance of shale interbeds than the lower part of the Whirlpool (Brett and others, 1990a). Seyler (1982) suggests a nearshore, probably beach or shoreface, environment for this upper unit.

Camerate crinoids (*Ptychocrinus*) in the Niagara River Gorge at Lewiston and pelecypods at Balls Falls (fig.1) have been observed in the upper part of the Whirlpool (J.D. Eckert, University of Guelph, oral commun., 1992). Ostracodes, linguloid brachiopods, and trilobites have been found in the upper 3–6 ft of the Whirlpool. The Whirlpool fauna is probably the oldest known North American assemblage of Silurian fossils (Kilgour and Liberty, 1981).

Contacts: The Whirlpool Sandstone unconformably overlies the Upper Ordovician Queenston Shale. The basal contact of the Whirlpool Sandstone is sharp and planar nearly everywhere and contains abundant green shale rip-up clasts and impressions of desiccation cracks from the top of the Queenston (Brett and Calkin, 1987). The typically green color of the contact with the Queenston Shale indicates reducing processes. In the Niagara region, a thin bed containing fossil grains and phosphatic nodules is locally present at the contact between the Whirlpool Sandstone and the overlying Power Glen Shale (Brett and others, 1991). In other areas, the contact of the Whirlpool with the overlying Power Glen Shale is gradational over a few feet of interbedded sandstones and shales. In the Hamilton region, the upper beds of the Whirlpool grade laterally into carbonates of the Manitoulin Dolomite.

Regional Correlations: Regional stratigraphic correlations and relations for the Whirlpool Sandstone are shown in figures 9 and 10, respectively. The Whirlpool Sandstone is mappable as far west as Hamilton, Ont., where it begins to undergo facies changes. North of Hamilton, it grades into carbonate facies of the Manitoulin Dolomite. To the east, near Medina, N.Y., the overlying Power Glen Shale pinches out, and the Whirlpool is overlain by the Devils Hole Sandstone; however, the Whirlpool has not previously been formally recognized as a separate unit there and has instead been mapped as a lowermost unit of the Grimsby Formation. In cores from the Albion area, in Orleans County, N.Y., a carbonate- and pyrite-enriched zone in the cross-bedded sandstone sequence appears to mark the boundary between the Whirlpool and Devils Hole Sandstones. The sandstones equivalent to the Whirlpool could thus be distinguished from the sandstones equivalent to the Devils Hole in eastern Orleans County; however, between Albion and Rochester, the Whirlpool Sandstone apparently pinches out (figs. 9, 10). The Clarendon-Linden Fault is between Albion and Rochester and could play a role in the pinchout of the Whirlpool Sandstone, but the precise relation between the fault and the Whirlpool Sandstone remains to be defined.

Age: Because the Whirlpool Sandstone does not contain any diagnostic macrofossils, its age cannot be established through biostratigraphic zonation. Floral microfossils could enable precise dating if a Silurian acritarch zonation can be established. Physical stratigraphic tracing of the Whirlpool Sandstone into fossiliferous carbonates of the Manitoulin Dolomite indicates an early Llandoverian age.

Summary of Revisions or Changes: Not revised or otherwise changed herein.

POWER GLEN SHALE
(revised herein)

Brief History of Nomenclature: Bolton (1953) proposed the name Power Glen Formation for the 48 ft of shales with interbedded sandstones and limestones between the Whirlpool Sandstone and the Grimsby Formation at DeCew Falls, Ont. The Power Glen was considered by Bolton (1957) (fig. 7) to be correlative to the Manitoulin Dolomite and, at least, to the lower part of the Cabot Head Formation. This interval was assigned by Fisher (1954) to the Fish Creek Shale, Manitoulin Dolomite, and Cabot Head Shale. Fisher (1966) states that this tripartite division is not traceable beyond the Niagara River Gorge and suggests use of Bolton's name Power Glen for the non-red argillaceous facies of the Medina Group. The name Power Glen is used on Rickard's (1975) correlation chart; the interval he identified as Power Glen has been divided herein into the Power Glen Shale, the Devils Hole Sandstone, and the basal beds of the Grimsby Formation (fig. 8). The formal revisions to the Power Glen Shale made herein have been informally introduced by Brett and others (1990a,b; 1991).

Type Section: DeCew Falls, Ont. (Fonthill, 30M/3c, Canadian National Topographic Survey (NTS)) (Bolton, 1953).

Reference Sections: Niagara River Gorge; railroad cut on Niagara Street, Lockport, N.Y.; cut in Niagara Escarpment at Ontario Hydro (DeCew Falls) generating station (Power Glen) just west of St. Catharines, Ont.

Thickness: Where well exposed in outcrop, the thickness of the Power Glen Shale ranges from 20.0 to 27.5 ft. In the USGS cores, it ranges from 11.3 to 25.3 ft, with a mean thickness of 16.8 ft.

Lithologic Description: In the Niagara region (fig. 11), the Power Glen Shale is a marine shale that is sparsely fossiliferous, dark-gray to green-gray with light-gray to bluegray, hummocky cross-stratified to bioturbated, quartzose sandstone interbeds. The sandstone interbeds are commonly prominent in the upper third of the formation. The Power Glen can also contain interbeds of dolomite, calcareous siltstone, and sandy limestone (Kilgour and Liberty, 1981).

Contacts: As stated in the section on the Whirlpool-Sandstone, the contact of the Power Glen Shale with the underlying Whirlpool Sandstone is typically gradational over 1–3 ft of interbedded hummocky sandstone and shale. At some localities, however, a thin phosphatic horizon is present at the boundary between sandstone-dominated and shale-dominated intervals. The upper contact is placed at the relatively sharp contact between the gray shale of the Power Glen and the overlying white to pink Devils Hole Sandstone. This contact can be transitional, however, where the uppermost interval of the Power Glen locally contains abundant sandstone interbeds.

Regional Correlations: Regional stratigraphic correlations and relations for the Power Glen Shale are shown in figures 9 and 10, respectively. East of Lockport, N.Y., the Power Glen thins rapidly and pinches out between Medina and Albion, in Orleans County. In a drill core from Middleport, in eastern Niagara County, the Power Glen interval consists of about 6 ft of maroon to gray shale with thin sandstone interbeds. West of DeCew Falls, Ont., the Power Glen grades laterally into the lower part of the Cabot Head Formation.

Age: Bolton (1957) emphasized the similarities between the fauna of the Power Glen Shale and that of the Manitoulin Dolomite of the Bruce Peninsula region. This fauna, dominated by the bryozoan *Helopora fragilis*, is characteristic of the lower part of the Llandoverian Series (Rhuddanian).

Summary of Revisions: The interval considered as Power Glen by Rickard (1975) has been divided herein into the Power Glen Shale, the Devils Hole Sandstone, and the basal beds of the Grimsby Formation. The lower contact of the Power Glen is not revised herein. The upper contact is herein revised to be with the Devils Hole Sandstone, a new unit proposed herein, rather than with the Grimsby Formation. In the Niagara area, the Devils Hole Sandstone and about 3–6 ft of overlying green shale that are herein assigned to the Grimsby were formerly included within the Power Glen. Where the lateral equivalents of the Devils Hole and the overlying shales are red, as at Lockport, they were formerly included in the Grimsby Formation.

DEVILS HOLE SANDSTONE
(new unit, proposed herein)

Background: The Devils Hole Sandstone is formally proposed herein as a new formation. From Lockport eastward, this interval had previously been recognized as part of the Grimsby Sandstone (Brett and others, 1990b). West of Lockport, where the Devils Hole is white, it had been included in the Power Glen Formation (Bolton, 1957). Rickard (1975) considered the Devils Hole interval as part of the Power Glen Shale (fig. 7). Brett and others (1990a,b; 1991) referred to this unit as an unnamed sandstone and correlated it with the middle unit of the Cabot Head Shale in Ontario (Brett and others, 1990b). Duke (1991) informally named this unit the Devil's Hole Sandstone and correlated it with the Ball's Falls Formation, a thin interval of dolomitic shale and dolostone that is treated herein as a facies of the Devils Hole.

Duke (1987a) and Duke and others (1991) demonstrated that the color range from pinkish to pale gray in sandstones of the Medina Group was probably the result of late diagenetic alteration. Where the sandstones are overlain by reddish, oxidized shale and sandstone, they are red or pink, but where they are overlain by gray marine shale, they are pale gray or white. Duke (1987a) noted that the sandstones are otherwise lithologically similar and that if the stratigraphy had been defined without regard to color, these sandstones would most likely have been considered the same unit, as they are herein.

This observation applies to the Devils Hole Sandstone as well as to the Power Glen Shale, the Thorold Sandstone, and the Grimsby Formation. The Devils Hole is clearly distinct from the Grimsby Formation although both are reddish in some areas. The Devils Hole is sharply separated from the Grimsby by a thin, condensed interval rich in phosphatic or hematitic clasts in nearly all sections (except the Niagara Falls-1 core, in which the Devils Hole is absent). The Devils Hole could be included as a member of the Power Glen Shale, but in most outcrops, it is sharply set off from the Power Glen by a sharp to slightly erosional basal contact. In addition, the Devils Hole can be recognized in sections in western Niagara County and Orleans County where the typical gray shale facies of the Power Glen Shale is lacking.

Type Section: Roadcut along the east side of Niagara River Gorge on the south haul road to the Robert Moses Powerplant, 0.4 mi north of Devils Hole State Park; town of Lewiston, Niagara County, N.Y. (Lewiston quadrangle).

Reference Sections: North end of Niagara River Gorge at Artpark; outcrop at DeCew Falls hydroelectric plant in St. Catharines, Ont.; roadcut at W. Jackson Street beneath Somerset Railroad viaduct, city of Lockport, Niagara County, N.Y.

Thickness: The Devils Hole Sandstone is 14.9 ft thick in the Grand Island-2 core; 13.5 ft thick in the Niagara Falls-1 core; 13.1 ft thick in the Niagara-1 core, and is missing in the Wheatfield-1 core. This absence is anomalous because the sandstone appears in all outcrops and is consistent in thickness (13–15 ft) in cores and outcrops. The Devils Hole was probably deposited in the Wheatfield-1 area but could have been removed in a local erosional channel formed prior to deposition of the Artpark Phosphate Bed.

Lithologic Description: At its type section, the Devils Hole Sandstone is a well-sorted, white to very pale pink, slightly dolomitic, medium- to fine-grained quartz arenite with some horizontal to hummocky cross lamination and minor interbeds of greenish-gray shale. It is similar in facies to the upper unit of the Whirlpool Sandstone (Brett and others, 1991). At the north end of Niagara River Gorge (fig. 11) and in outcrops near St. Catharines, Ont., the upper half of the formation consists of pale yellowish-gray, sandy dolostone or dolomitic sandstone with scattered small phosphatic nodules and fossil steinkerns; this facies, which was erroneously referred to as "Manitoulin Dolomite" by Fisher (1954), grades into the informally named Ball's Falls Formation of Duke (1991), which is at the top rather than the base of the Power Glen Shale. In eastern Niagara County (for example, in the Lockport area), the Devils Hole is represented by massive, mottled pink and pale gray sandstone with partings and rip-up clasts of red shale. It is barren to sparsely fossiliferous in most sections, although it can contain nautiloids and *Planolites* burrows. In the northern part of Niagara River Gorge, it contains abundant *Helopora* bryozoans and phosphatic steinkerns of small gastropods and bellerophontids. Shell fragments of lingulid brachiopods are present in outcrops in the Lockport, N.Y., area.

Balls Falls facies: The Ball's Falls Formation that was informally named in Duke (1991) is herein considered an informal facies, pending further detailed study. The Balls Falls facies consists of thin beds of dolomitic sandstone, fine-grained dolomite, and interbedded gray to red shale. Locally, the sandstone beds are hematitic and stand out as deep-red beds in otherwise greenish-gray Power Glen Shale and basal Grimsby (Cabot Head) Formation. The hematized beds are typically quite fossiliferous. The dominant faunal element is the branching bryozoan *Helopora.*

Condensed eastern sandstone facies: The apparent eastern equivalents of the Devils Hole Sandstone in the Rochester area consist of laminated, porous, calcareous, oolitic, and arkosic sandstone. At the Genesee River Gorge, the condensed unit immediately overlies the Cherokee discontinuity and provides an excellent stratigraphic marker bed. Fossils are rare in this unit, although isolated crinoid ossicles have been observed in thin sections.

Contacts: In the Niagara region, the Devils Hole Sandstone has a sharp contact with the underlying dark-gray shales of the Power Glen. In Orleans County, the pink, massive Devils Hole Sandstone directly overlies the Whirlpool Sandstone, and the cryptic contact is marked by a pyritic, calcareous interval in the quartz arenites. In the Rochester area, the basal contact of the equivalent of the Devils Hole coincides with the basal Silurian Cherokee discontinuity. The Devils Hole is locally shaly in its uppermost 1–2 ft. At the north end of Niagara River Gorge, it is thin and is overlain by the Artpark Phosphate Bed of the Grimsby Formation. To the south, in drill cores from Niagara Falls, the Devils Hole is overlain by or is amalgamated with a thin phosphatic or hematitic bed (Brett and others, 1991). Throughout the Orleans-Monroe County area, the upper contact is gradational with the basal argillaceous facies of the Grimsby Formation.

Regional Correlations: Regional stratigraphic correlations and relations for the Devils Hole Sandstone are shown in figures 9 and 10, respectively. From St. Catharines westward to Hamilton, Ont., the typical dolomitic sandstones of the Devils Hole are thin and discontinuous, and phosphatic or hematitic sandy dolomites are persistent. Duke (1991) referred to this facies as the Ball's Falls Formation (informal usage). The typical Devils Hole sandstone and dolomitic facies interfinger in the northern Niagara River Gorge area. East of Niagara County, the Devils Hole appears to grade into massive, pink, mottled sandstones that have been quarried for building stones at Hulberton and Albion.

Age: Early Llandoverian (Rhuddanian).

Summary of Revisions or Changes: The Devils Hole Sandstone is proposed herein as a new formation. From Lockport eastward, this interval had previously been recognized as part of the Grimsby Sandstone (Brett and others, 1990b). West of Lockport, where the sandstone is white, it had been included in the Power Glen Formation (Bolton, 1957). Rickard (1975) considered the Devils Hole interval as part of the Power Glen Shale. The basal contact is with the Power Glen Shale; the upper contact is with the Artpark Phosphate Bed of the Grimsby Formation.

GRIMSBY FORMATION
(revised herein)

Brief History of Nomenclature: The name Grimsby Formation was first proposed by Williams (1914a,b). He stated that it consists of 6 ft of gray shale underlain by thickly bedded, mottled red and green sandstone that is 12 ft thick at the type section but is 50 ft thick in the Niagara River Gorge. He defined it as overlain by the Thorold Sandstone and underlain by the Cabot Head Shale. Gillette (1940) and Fisher (1954) (fig. 7) used the name Grimsby to refer to the entire Lower Silurian sequence of red shales and sandstones below the Clinton Group. Fisher (1954) placed the Grimsby Formation at the top of the Medina Group and suggested that the Grimsby-Thorold contact should be considered the boundary between the Medina and Clinton Groups. Fisher's (1954) correlation chart shows the lower contact of the Grimsby to be with the Cabot Head Shale and its upper contact to be with the Thorold Sandstone in the Niagara River Gorge, but shows the Grimsby in Lockport as unconformably overlain by the Neahga Shale and underlain by the Fish Creek Shale. Liberty and Bolton (1956) use the term Grimsby Formation in Ontario to include the interval above the Power Glen or Cabot Head Shale and below the Thorold Sandstone. The Grimsby is also shown between the Power Glen and the Thorold on Rickard's (1975) correlation chart (figs. 7, 8). The Grimsby as defined herein includes all of the Grimsby as defined by Rickard (1975) and the upper part of the section that he recognized as the Power Glen (fig. 8). The formal revisions to the Grimsby made herein have been informally introduced by Brett and others (1990a,b; 1991).

The authors prefer the use of Grimsby Formation to Grimsby Sandstone because this unit is heterolithic (fig. 10). For example, at the type section, the Grimsby is a mixture of sandstone and shale. Shale facies are more prominent in the Niagara River Gorge and in Ontario sections than in western New York.

Type Section: Exposures along east side of gorge at Forty Mile Creek at Grimsby, Ont. (Grimsby, 30M/4h, Canadian NTS) (Williams, 1919).

Reference Sections: Niagara River Gorge; Somerset Railroad cut at Lockport, N.Y.; gorge of Oak Orchard Creek at Medina, N.Y.; gorge of Sandy Creek at Albion, N.Y.; Genesee River Gorge in Rochester, N.Y.

Thickness: In the Niagara region, the thickness of the Grimsby Formation, as revised herein, ranges from 56 to 72 ft in outcrop. In the USGS cores, however, it ranges from 49.3 to 55.7 ft, with a mean thickness of 51.8 ft. The Grimsby is considerably thinner (29.5 ft) at the Genesee River Gorge and ranges from 53.5 to 57 ft in the Hamilton, Ont., area.

Lithologic Description: The Grimsby Formation consists of an interbedded sequence of red and green sandstones, siltstones, and shales (fig. 11). It comprises an overall shallowing upward sequence that represents progradation of shallow, marine tidal flat sands over marine muds (Martini, 1971; Duke and Fawcett, 1987). The Grimsby sequence tends to be most argillaceous at its base. Its contact with the underlying Devils Hole Sandstone is marked by the Artpark Phosphate Bed (discussed in next section). The matrix of the Artpark Phosphate Bed and the basal 5–10 ft of the Grimsby typically consist of intensely burrowed greenish-gray to maroon shale. Fossils common in this basal argillaceous zone include pelecypods, cephalopods, ostracodes, bryozoans, linguloid brachiopods, and occasional rhynchonellid brachiopods.

The remainder of the Grimsby succession consists of red and white mottled, fine- to medium-grained sandstone and conglomerate interbedded with shale; the ratio of sandstone to shale increases upward to the contact with the Thorold Sandstone. Shale interbeds are typically dusky maroon. Coarsening- and thickening-upward successions on the scale of 3–4 ft in the Grimsby at Niagara River Gorge have been mapped by Duke and Fawcett (1987). Such cycles can be capped by thin phosphatic lag deposits or can be partly or completely cut out by localized sandstone-filled channels.

Sandstone beds, which are pinkish-red and commonly contain light-green reduction spots, are also characterized by Liesegang banding. Sandstone interbeds contain diverse primary sedimentary structures. Beds near the base of the Grimsby sequence are thinner than elsewhere and display hummocky cross stratification. Higher in the section, planar and low-angle trough cross stratification become increasingly common. Basal shale-clast conglomerates, interference and oscillation ripple marks, gutter casts, load casts, and ball and pillow structures are abundant in the upper sandstone beds. Locally, the upper beds of the Grimsby are also bioturbated. Common trace fossils include *Arthrophycus*, *Daedalus*, and *Skolithos*.

Contacts: The sharp basal contact of the Grimsby Formation is with the Devils Hole Sandstone. As stated previously, the Artpark Phosphate Bed commonly overlies this contact. The lower contact of the Grimsby was previously drawn at a color change between greenish-gray shales assigned to the Power Glen and red shales assigned to the Grimsby. Duke (1987a) and Duke and others (1991) demonstrated, however, that this color-based contact (also applied to the Power Glen Shale, Devil's Hole Sandstone, and Thorold Sandstone) is not an appropriate horizon at which to place the contact because it reflects secondary diagenetic reduction of strata rather than a true lithologic boundary between traceable units. In the Niagara region, the upper contact with the Thorold Sandstone is a sharp but conformable surface, and the basal bed of the Thorold Sandstone locally contains clasts of underlying Grimsby units. Farther to the west, near the Grimsby type section, the Thorold Sandstone and other overlying units are absent and the upper contact of the Grimsby is with the Merritton Limestone.

Regional Correlations: Regional stratigraphic correlations and relations for the Grimsby Formation are shown in figures 9 and 10, respectively. As defined herein, the Grimsby Formation is a laterally extensive unit that can be traced at least from Rochester, N.Y., to Hamilton, Ont. In the Rochester area, it is considerably sandier than at the type section. West of the type section, the Grimsby becomes fine grained, particularly in its lower part. As the unit is traced westward, a green coloration becomes increasingly dominant. Green shale replaces red shale and sandstone from the base of the unit upward.

Age: Although none of the taxa in the fossiliferous Grimsby are diagnostic biostratigraphic markers, Bolton (1957) emphasized the similarities with the early Llandoverian fauna of the Brassfield Limestone of the midcontinent. The Grimsby is herein considered to be early Llandoverian (latest Rhuddanian to earliest Aeronian).

Summary of Revisions: The Grimsby Formation as defined herein includes all of the Grimsby and the upper part of the Power Glen as recognized by Rickard (1975). The basal contact of the Grimsby is herein revised to be the lower contact of the Artpark Phosphate Bed with the underlying Devils Hole Sandstone or, if the Devils Hole is missing, with the underlying Power Glen Shale. As such, greenish shales overlying the Artpark Phosphate Bed in some sections that were formerly assigned to the Power Glen are herein included within the Grimsby. The upper contact of the Grimsby is not revised herein.

ARTPARK PHOSPHATE BED
(new unit, proposed herein)

Background: The Artpark Phosphate Bed is formally proposed herein as a new bed at the base of the Grimsby Formation. The term was first used informally by Brett and others (1990a,b; 1991) for the thin, phosphatic and (or) hematitic, sandy dolostone that overlies the Devils Hole Sandstone.

Type Section: Small bluff at north end of Niagara River Gorge, 0.25 mi south of Artpark State Park, Lewiston, N.Y. (Lewiston quadrangle).

Reference Sections: Somerset Railroad viaduct cut at West Jackson Street, Lockport, N.Y.; Balls Falls on Twenty Mile Creek at Jordan, Ont.

Thickness: The Artpark Phosphate Bed is 4.9 ft thick at the type section, but its thickness ranges from 0.1 ft to 6 ft.

Lithologic Description: At its type section (fig. 11), the Artpark Phosphate Bed is a phosphatic sandy dolomite. Observations of the four USGS Queenston cores indicate substantial facies variation within the Artpark Phosphate Bed. Phosphate pebbles in the USGS Niagara-1 and Niagara Falls-1 cores are disseminated through several feet of a light gray to white, fine-grained, dolomitic sandstone or sandy dolomite overlying the Devils Hole Sandstone. In contrast, in the USGS Grand Island-2 and Wheatfield-1 cores, the Artpark Phosphate Bed is a thin lag deposit of black pebbles in a gray or red shale matrix, completely devoid of sand. In spite of its local variations, the Artpark Phosphate Bed can be traced between the various cores and outcrops in the Niagara region.

Contacts: Both the upper and lower contacts of the Artpark Phosphate Bed are sharp and well defined at most localities; near Artpark, however, the contact with the underlying Devils Hole Sandstone is more diffuse due to bioturbation and mixing processes.

Regional Correlations: Regional stratigraphic correlations and relations for the Artpark Phosphate Bed are shown in figures 9 and 10, respectively. In the Niagara region, the Artpark Phosphate Bed lies slightly below the color change that was used by previous authors to define the Power Glen Shale-Grimsby Formation contact. This color change is diachronous; its position relative to the Artpark Phosphate Bed east of Niagara Falls differs from that to the west.

To the east, near Medina, N.Y., the Power Glen Shale is missing as a result of truncation beneath the Devils Hole Sandstone. In Orleans County, the position of the Artpark Phosphate Bed is marked by the base of a shale intraclast zone in channel sandstones that have been mapped as Grimsby Formation.

Westward from the Niagara region, the red coloration of facies of the Grimsby occurs at progressively higher stratigraphic intervals. The presence of the Artpark Phosphate Bed within the Cabot Head Formation of the Hamilton area illustrates that the Cabot Head Formation as defined by Bolton (1957) is correlative, in part, to both the Power Glen Shale and the lower part of the Grimsby Formation at Niagara. In the Jordan to Hamilton, Ont., area, the Artpark Phosphate Bed becomes hematitic and contains abundant trepostome bryozoa.

Age: Although the Artpark Phosphate Bed is locally fossiliferous, none of its taxa have biostratigraphic significance. Like other units in the Medina Group, its fauna is similar to the early Llandoverian fauna of the Brassfield Limestone. The age of the Artpark Phosphate Bed, therefore, is probably late Rhuddanian to early Aeronian.

Summary of Revisions or Changes: The laterally extensive Artpark Phosphate Bed is formally proposed herein as a new unit at the base of the Grimsby Formation.

THOROLD SANDSTONE
(group assignment changed herein)

First Usage of Nomenclature: Originally called Thorold Quartzite by Grabau (1913), on the basis of an exposure on the Welland Canal at Thorold, Ont. Grabau (1913) stated that the Thorold Quartzite was underlain by the Medina red sandstones and overlain by the Sodus Shale, which he included in the Medina Group. The formation is a quartzite at the type locality (Williams, 1919), but in New York and in most places in Ontario, it is a sandstone (Gillette, 1947).

Type Section: Exposure on the Welland Canal at Thorold, Ont. (St. Catharines, 30M/3g, Canadian NTS) (Grabau, 1913).

Reference Sections: Jolly Cut, Hamilton, Ont.; Niagara River Gorge; railroad cut at Lockport, N.Y.; Genesee River Gorge in Rochester, N.Y.

Thickness: The thickness of the Thorold Sandstone ranges from about 4.5 to 10 ft in outcrop. In the USGS cores, the thickness ranges from 6.9 to 9.5 ft.

Lithologic Description: As defined herein, the Thorold Sandstone consists of two laterally correlative facies. To the east, between Rochester and Lockport, N.Y., it is a mottled pink to red, cross-bedded, channel sandstone with abundant *Daedalus* trace fossils. In the Niagara region (fig. 11) and westward, the Thorold is a light-gray to white, massive, argillaceous, pelletal sandstone that commonly exhibits soft-sediment deformation. It is typically interbedded with thin, green, silty shales. The shale content gradually increases toward the top of the unit. Although the Thorold is largely nonfossiliferous in the study area, a few fragments of linguloid brachiopods were reported from the Hamilton area by Bolton (1957).

Contacts: The lower contact of the Thorold Sandstone with the Grimsby Formation is sharp but nearly conformable. This basal contact has been variably interpreted as either conformable (Duke, 1991) or unconformable (Gillette, 1947), and these interpretations have served as a basis for previous inclusion of the Thorold within either the Medina or Clinton Group. As interpreted in this report, the Thorold Sandstone is related to the Medina Group in terms of its depositional history; evidence for this interpretation is presented below.

Various stratigraphic units overlie the Thorold Sandstone as a result of the low-angle, regional unconformity immediately above it. Between Rochester and Niagara Falls, N.Y., the Thorold is sharply but conformably overlain by the Cambria Shale (see next section) of the Medina Group. Between Niagara Falls and Hamilton, Ont., the Thorold typically is unconformably overlain by the phosphatic to calcareous Densmore Creek Phosphate Bed of the Neahga Shale (see discussion below) of the Clinton Group. At outcrops in the Hamilton area, the Thorold Sandstone has apparently been truncated beneath this erosional surface. Upper beds of greenish shale and sandstone previously assigned to the Thorold have been reassigned to the upper beds of the Grimsby (Duke, 1987a). The light coloration of these beds is due to secondary reduction (Duke, 1987a). Where the Thorold is overlain by the Neahga Shale, the sandstone typically is white; where overlain by the reddish Cambria Shale, the sandstone tends to be pink or red.

Regional Correlations: Regional stratigraphic correlations and relations for the Thorold Sandstone are shown in figures 9 and 10, respectively. Lateral equivalency of the Thorold and Kodak Sandstones has been assumed since the work of Eaton (1824) and Hall (1843), although Kilgour (1963) expressed some doubt as to their correlation. Recent mapping of the Densmore Creek Phosphate Bed and detailed correlation of intraformational Grimsby units by Fawcett and others (1988) indicates that the Kodak Sandstone of the Rochester area occupies a higher stratigraphic position than the Thorold Sandstone of the Niagara region, and that these units do not form a continuous sandstone sheet. The Thorold and Kodak Sandstones are separated by a fossiliferous, red, interbedded shale, siltstone, and thin bedded sandstone unit herein named the Cambria Shale.

Age: On the basis of the presumed correlation with the Kodak Sandstone, Rickard (1975) placed the Thorold Sandstone in the lower Llandoverian (Aeronian B_3). Revised correlations indicate that the Thorold Sandstone is slightly older but probably still Aeronian.

Summary of Changes: The Thorold Sandstone as shown on Rickard's (1975) correlation chart has been herein divided into the Thorold Sandstone and a new unit (proposed herein), the Cambria Shale. The Thorold Sandstone is herein placed in the Medina Group rather than in the Clinton Group.

CAMBRIA SHALE
(new unit, proposed herein)

Background: Rickard (1975) considered the strata herein assigned to the newly proposed Cambria Shale as the upper part of the Thorold Sandstone (figs. 7, 8). The interval that is assigned to the Cambria Shale was first referred to as an unnamed shale by Brett and others (1990a,b) and (informally) referred to as the Cambria Shale by Brett and others (1991). Because the strata are red, the Cambria Shale had previously been considered in places to be part of the Grimsby Sandstone by Fisher (1953a,b). Similarly, in areas where the Thorold Sandstone is pink, it was also considered part of the Grimsby. Correlation of the Thorold into the Rochester area demonstrates that the shales of the Cambria are separated from the true Grimsby by the intervening *Daedalus*-bearing Thorold Sandstone.

The position of the Cambria Shale between the underlying Thorold Sandstone and the overlying Kodak Sandstone justifies designation of these red shales as a distinct formation. The Cambria could be designated as a member of either the overlying Kodak or the underlying Thorold but it is separated by relatively sharp contacts from both units. In addition, because the Cambria is missing at the type section of the Thorold in Ontario, it cannot be appropriately included as a member of the Thorold Sandstone.

Type Section: Outcrop beneath and immediately north of the overpass of Lower Mountain Road over Lockport Junction Road (Routes 93 and 270) in the village of Hickory Corners, town of Cambria, Niagara County, N.Y. (Cambria quadrangle). The upper contact of the Cambria Shale is unconformable with the Neahga Shale at this outcrop.

Reference Sections: Railroad overpass on Niagara St. in Lockport, N.Y.; Genesee River Gorge in Rochester, N.Y.

Thickness: The thickness of the Cambria Shale ranges from a featheredge in the north end of the Niagara River Gorge to as much as 13.5 ft at the southernmost and easternmost parts of the Genesee River Gorge. It ranges in thickness from 5.1 to 8.9 ft in the Grand Island-2 and Wheatfield-1 cores, respectively, the southernmost of the four USGS cores that penetrated the entire Medina section. The Cambria is not present in the other two USGS cores (Niagara-1 and Niagara Falls-1).

Lithologic Description: The Cambria Shale is a red to reddish-green, sparsely fossiliferous, interbedded sequence of shale, siltstone, and fine-grained sandstone. It is divisible into lower and upper shales separated by a middle sandstone interval. This internal stratigraphy is most apparent at the Genesee River Gorge in Rochester. The upper and lower shales contain abundant leperditiid ostracodes on bedding planes. The medial sandstone consists of a mottled red and green, bioturbated, argillaceous sandstone, with thin shale interbeds. *Daedalus* trace fossils dominate the fabric of the sandstone. *Rusophycus* also is found on the bottoms of sandstone beds in the Genesee River Gorge sections.

This tripartite stratigraphy is less apparent at sections in Orleans and Niagara Counties than in the Genesee River Gorge. Thin siltstone and sandstone interbeds occur virtually throughout the interval. In western sections, caliche horizons and desiccation cracks are common, as are ostracodes and bivalves.

Contacts: The Cambria Shale has a sharp contact with the underlying Thorold Sandstone. The stratigraphic position of its upper contact varies as a result of the low-angle, regional unconformity at the top of the Medina Group. Between Rochester and Lockport, N.Y., the Cambria Shale is sharply but conformably overlain by the Kodak

Sandstone. West of Lockport, N.Y., the Kodak Sandstone is absent, and the Cambria is in sharp, unconformable contact with the overlying Densmore Creek Phosphate Bed (LoDuca and Brett, 1994) of the Neahga Shale (Clinton Group). The Cambria becomes dark green near its upper contact with the Neahga, apparently because of diagenetic reduction of iron. In Ontario, the Cambria Shale is erosionally truncated beneath the unconformity that marks the boundary between the Medina and Clinton Groups.

Regional Correlations: Regional stratigraphic correlations and relations for the Cambria Shale are shown in figures 9 and 10, respectively. The Cambria Shale extends from Niagara Falls to at least as far east as Webster, in Monroe County, N.Y. It is fossiliferous throughout its extent and generally coarsens eastward.

Age: The Cambria Shale is of early Llandoverian age, on the basis of the Aeronian (B_3) age of the overlying Kodak Sandstone.

Summary of Revisions or Changes: The Cambria Shale is a new formation, proposed herein. Rickard (1975) considered strata assigned herein to the Cambria Shale as the upper part of the Thorold Sandstone in western sections and as part of the Grimsby Sandstone at Rochester. Fisher (1953b) considered the strata assigned herein to the Cambria Shale in places to be part of the Grimsby Formation. The Cambria Shale displays a sharp basal contact with the Thorold Sandstone. The stratigraphic position of the upper contact of the Cambria varies as a result of the low-angle, regional unconformity at the top of the Medina Group.

KODAK SANDSTONE
(group assignment changed herein)

First Usage of Nomenclature: First used by Chadwick (1935) as Kodak Sandstone to replace what was formerly called Thorold Sandstone, but was determined by Chadwick to be younger than the true Thorold of Niagara River Gorge, and equivalent to units of the Clinton Group in age.

Type Section: In lower Genesee River Gorge from the lower falls to Kodak Park, Seth Green Drive (Rochester West quadrangle) (Chadwick, 1935).

Reference Section: Oak Orchard Creek, Village of Medina, Orleans County, N.Y.

Thickness: The reported thickness of the Kodak Sandstone varies widely because its lower contact with the Cambria Shale is locally difficult to establish based on criteria other than color. At Rochester, the Kodak is 5 ft thick; at Albion, it is as much as 11 ft thick in cores; and at Lockport, it is only a few inches thick.

Lithologic Description: The Kodak Sandstone is a medium-gray to white, argillaceous, quartzose sandstone. In places, it contains abundant *Daedalus* trace fossils. Where primary bedding structures are preserved, a rhythmic alternation of sandy and shaly interbeds is apparent.

Contacts: As stated above, the basal contact of the Kodak Sandstone with the underlying Cambria Shale has locally been masked by intense bioturbation. Both units contain abundant trace-fossil assemblages. In areas where bioturbation has not obliterated primary sedimentary fabric, however, the contact typically appears to be sharp because of diagenetic color change. In cores, structures resembling iron stromatolites are common and suggest a minor disconformity at the base of the Kodak. A major unconformity is present at the contact of the Kodak Sandstone with the overlying Densmore Creek Phosphate Bed of the Neahga Shale.

Regional Correlations: Regional stratigraphic correlations and relations for the Kodak Sandstone are shown in figures 9 and 10, respectively. The Kodak Sandstone is preserved between Webster and Lockport, N.Y. Between the cities of Niagara Falls and Hamilton, Ont., no stratigraphic equivalents to the Kodak Sandstone are known; instead, the time interval spanning deposition of the Cambria and Kodak is represented by the unconformity between the Thorold Sandstone and the Neahga Shale.

The phosphate-pebble horizon at the base of the Neahga-Maplewood Shale sequence has been designated the Densmore Creek Phosphate Bed (LoDuca and Brett, 1994). In the Rochester area, the Densmore Creek Phosphate Bed is at the boundary between the Kodak Sandstone and the Maplewood Shale. As the phosphate bed is traced toward the Niagara region, however, the uppermost part of the Medina Group units becomes progressively beveled. The Kodak Sandstone underlies the Densmore Creek Phosphate Bed as far west as Lockport, but just west of Lockport, the Densmore Creek Phosphate Bed separates the Cambria Shale from the Neahga Shale, and no Kodak Sandstone is present. In the Niagara River Gorge, the Densmore Creek Phosphate Bed is at the contact between the Thorold Sandstone and the Neahga Shale, and both the Cambria Shale and the Kodak Sandstone are missing.

As discussed previously, phosphate-pebble beds can be useful in locating stratigraphic breaks. In the preceding discussion, the Medina-Clinton Group contact is placed at the low-angle, regional unconformity overlain by the Densmore Creek Phosphate Bed. The Maplewood and Neahga Shales mark a basal Clinton transgression over an eroded surface at the top of the Medina Group. The presence of the Densmore Creek Phosphate Bed above the Kodak Sandstone at Rochester conclusively places the Kodak within the Medina Group. Gillette (1947) reported poorly preserved specimens of *Zygobolba prolixa* and *Zygobolba curta* in the Thorold in Oswego County, in beds that would now be considered Kodak (J.M. Berdan, U.S. Geological Survey, written commun., 1992). This is important because it could provide a younger age for the top of the Medina Group than previously suspected.

Age: On the basis of ostracodes, the Kodak Sandstone is of early Llandoverian age (probably Aeronian [B_3]) (Gillette, 1947; Berry and Boucot, 1970).

Summary of Changes: The Kodak is herein separated from the Thorold by the Cambria Shale, in contrast to Rickard's correlation chart (1975), where the Thorold and Kodak are shown as coextensive units. In addition, the Kodak Sandstone is herein placed in the Medina Group rather than in the Clinton Group.

CLINTON GROUP
(revised herein)

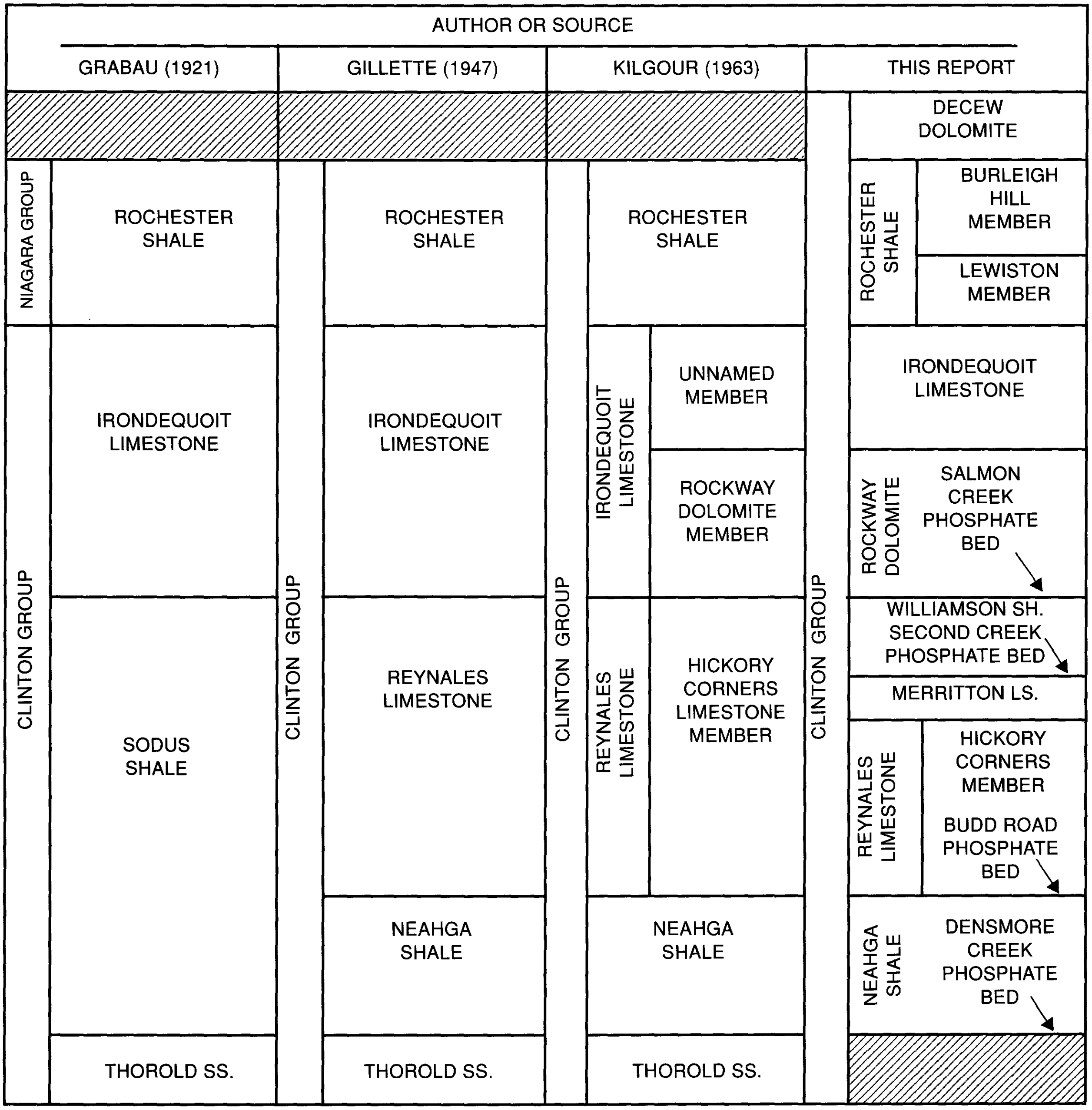
In the Niagara region, the Clinton Group consists of about 100–110 ft of thin- to medium-bedded shale, limestone, and dolomite. It includes the Rochester Shale, one of the oldest formally designated stratigraphic units in North America (Hall, 1839). The type area of the Clinton Group is near the town of Clinton in central New York. The name Clinton Group was first proposed by Vanuxem (1839) and was established by Vanuxem (1842) as the Clinton Group of the Ontario Division of the New York System. Vanuxem's Clinton Group included what is now called the Thorold Sandstone up to the base of the Rochester Shale. James Hall (1843) accepted Vanuxem's Clinton Group and described the lithology and paleontology of this interval (Hall, 1852). Since that time, many workers, including Hartnagel (1907), Newland and Hartnagel (1908), Kindle and Taylor (1913), Schuchert (1914), Chadwick (1918), Grabau (1921), Ulrich and Bassler (1923), Sanford (1933, 1935, 1936), Gillette (1947), Fisher (1953b, 1960), Bolton (1957), Kilgour (1963, 1966), Zenger (1971), Lin and Brett (1988), LoDuca (1988), Brett and others (1990a,b; 1991), and LoDuca and Brett (1994) have revised and refined the internal stratigraphy. Gillette (1947), Bolton (1957), and Kilgour (1963) provide detailed reviews of Clinton nomenclature. A historical summary of nomenclature for the Clinton Group of the Niagara region is presented in figure 13.

As defined herein, the base of the Clinton Group is placed at the base of the Neahga Shale, at an unconformity marked by the Densmore Creek Phosphate Bed (LoDuca and Brett, 1994). Traditionally, the lower contact of the Clinton Group had been placed at the base of the Thorold Sandstone (fig. 13). The Thorold Sandstone, however, and units that overlie it locally, including the Cambria Shale and Kodak Sandstone (described previously), lie beneath a regional angular unconformity overlain by the Densmore Creek Phosphate Bed at the base of the Neahga Shale. The Medina units are progressively truncated westward. The unconformity at the base of the Neahga provides a conclusive physical basis for definition of the Medina-Clinton Group contact. The interval below the Neahga Shale is therefore removed from the Clinton Group and assigned to the underlying Medina Group. A complete discussion is given in LoDuca and Brett (1994). The upper contact of the Clinton Group is placed at the sharp, erosional, regionally unconformable contact between the DeCew Dolomite and the overlying Gasport Dolomite of the Lockport Group. In the past, the DeCew has been included either as the uppermost unit of the Clinton Group (Bolton, 1957) or as the lowermost unit of the Lockport Group (Gillette, 1947; Zenger, 1965). Because the DeCew appears nearly conformable and gradational with the upper part of the Rochester Shale at most localities and is truncated by an unconformity at the base of the Gasport in western New York and Ontario, it is herein placed in the Clinton Group (fig. 13).

Within the Niagara region, the Clinton Group includes the following eight formations, in ascending order: the Neahga Shale; the Reynales Limestone (Hickory Corners Member); the Merritton Limestone; the Williamson Shale; the Rockway Dolomite; the Irondequoit Limestone; the Rochester Shale, including the Lewiston and Burleigh Hill Members; and the DeCew Dolomite. The Merritton Limestone, the Second Creek Phosphate Bed, the Williamson Shale, and the Salmon Creek Phosphate Bed are herein extended into the Niagara Falls area for the first time (fig. 4). Stratigraphic contacts of the Irondequoit Limestone have been revised (fig. 4). The Rockway Dolomite is raised herein to formation rank (fig. 4). A comparison of stratigraphic nomenclature from Rickard (1975) with revised nomenclature for the Clinton Group is shown in figure 14.

Although Gillette (1947) designated Lower, Middle, and Upper portions of the Clinton Group on the basis of discontinuities in ostracode biostratigraphy, his subdivisions will not be used herein; however, informal reference will be made to the lower, middle, and upper parts of the Clinton. In the Niagara region, the lower part of the Clinton Group includes the Neahga Shale and the Reynales Limestone (Hickory Corners Member) (fig. 9). The upper part of the Clinton Group within this region includes the Merritton Limestone, Williamson Shale, Rockway Dolomite, Irondequoit Limestone, Rochester Shale, and the DeCew Dolomite (figs. 9, 15). A major regional angular unconformity at the base of the Merritton Limestone in Ontario and the Williamson Shale in New York (fig. 9) separates the lower and upper parts of the Clinton Group. In the Niagara region, the unconformity separating the lower and upper parts of the Clinton has truncated the entire middle part as well as the upper beds of the lower part of the Clinton. Strata in the lower part of the Clinton Group are quite thin as a result of erosional truncation, which continues westward into Ontario to the extent that no strata from this interval are preserved between St. Catharines and Hamilton, Ont.

In west-central New York, additional units are present between the Reynales Limestone and the overlying equivalent of the Williamson, the Willowvale Shale (fig. 9). These units, which include the lower and upper parts of the Sodus Shale and the Wolcott Limestone, are progressively truncated westward beneath a major unconformity at the base of the Williamson Shale. In the Niagara region, this unconformity is marked in cores and field exposures by a phosphate-pebble horizon named the Second Creek Phosphate Bed

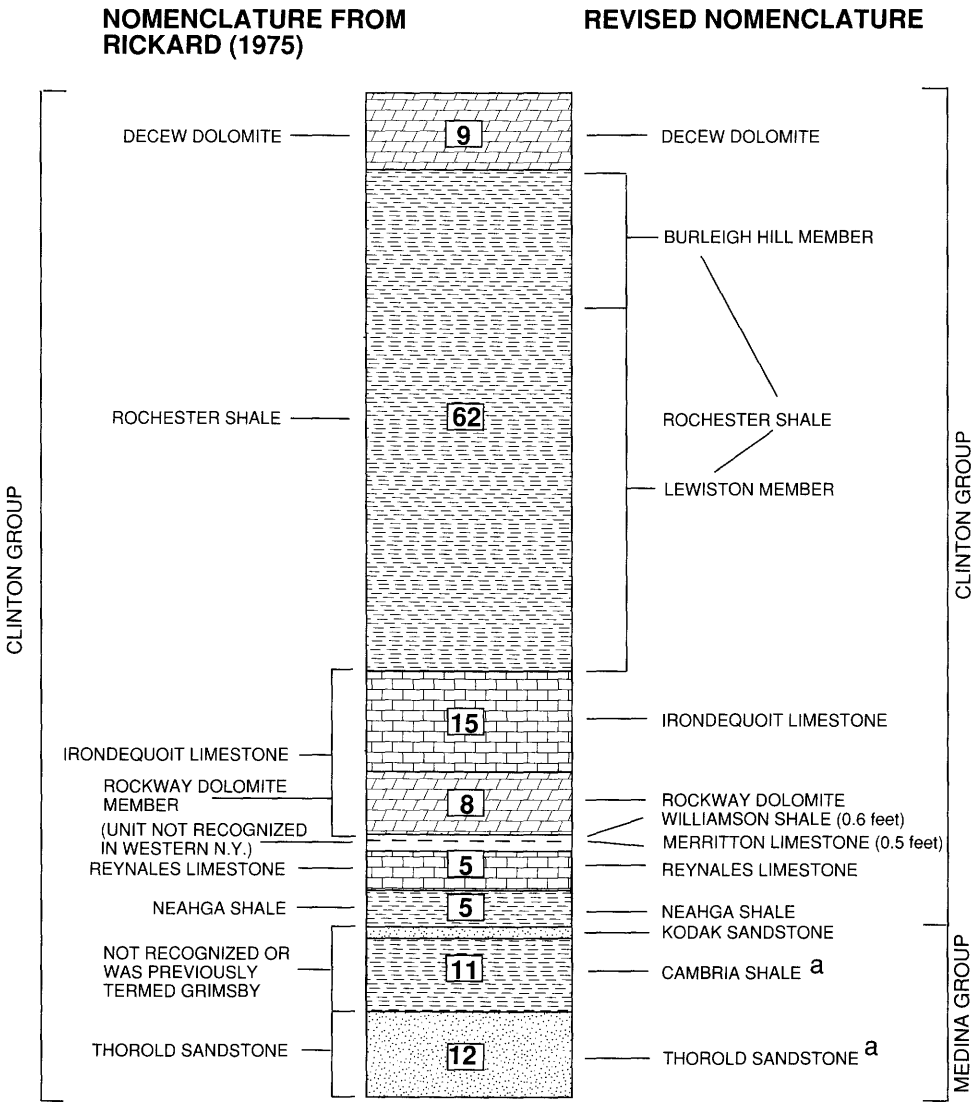


EXPLANATION

[hatched box] = Unit not recognized by author in equivalent stratigraphic position
SS. = Sandstone
LS. = Limestone
SH. = Shale

Figure 13. Historical summary of Clinton Group nomenclature in the Niagara region.

(Lin and Brett, 1988). In the Clinton type area near Utica, N.Y., lower units of the Clinton are either absent as a result of depositional pinchout (Reynales and lower part of the Sodus) or have changed facies (upper part of the Sodus and Wolcott) into a thin conglomerate and sandstone unit known as the Oneida Conglomerate (fig. 9). In addition, a green



EXPLANATION

[12] Average unit thickness, in feet, based on data from nine U.S. Geological Survey cores, two Canadian cores, and several outcrops

Sandstone

Dolomite

Shale

Limestone

a Because of their red color and apparent miscorrelation, strata in the eastern part of Niagara County that are shown as Thorold Sandstone and Cambria Shale in the revised nomenclature column (right side of diagram) were considered by Fisher (1953b) to belong to the Grimsby Formation

Figure 14. Stratigraphic nomenclature from Rickard (1975) and revised nomenclature for the Clinton Group in the Niagara region. Formation contacts and lithologic shading of units are based on the revised nomenclature.

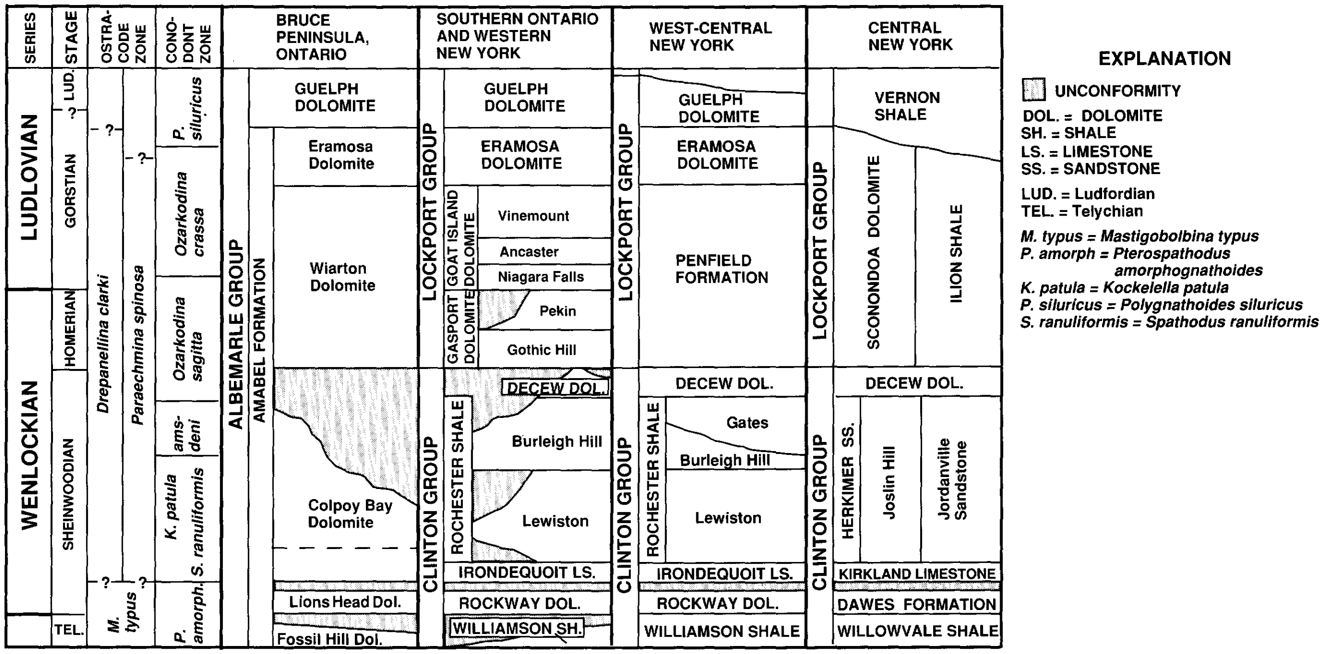


Figure 15. Stratigraphic correlations for the upper part of the Clinton Group and the Lockport Group in parts of Ontario and New York. Formation names are shown in uppercase and member names are shown in upper- and lowercase. (Modified from Brett and others, 1991, fig. 9.)

shale and sandstone unit up to 100 ft thick, the Sauquoit Formation[7], is present between the Oneida and the overlying Willowvale Shale[8] of the upper part of the Clinton (lateral equivalent of the Williamson Shale [Eckert and Brett, 1989]) (fig. 9). The Sauquoit is absent in western New York as a result of erosional beveling.

Correlation charts for the lower and upper parts of the Clinton Group are shown in figures 9 and 15, respectively. Geologic sections showing stratigraphic relations with regional correlations for the lower part of the Clinton Group in western New York are shown in figure 16 and for the upper part of the Clinton Group in figure 17. Descriptive stratigraphic columns for the lower part of the Clinton Group are presented in figure 18 and for the upper part of the Clinton Group in figure 19. Natural-gamma logs and stratigraphic correlations for units within the Clinton Group are presented in figures 12 and 20.

Summary of Revisions: The Densmore Creek Phosphate Bed of the Neahga Shale is designated herein as the basal unit of the Clinton Group. The contact between the DeCew Dolomite and the Gothic Hill Member of the Gasport Dolomite is designated herein as the upper contact of the Clinton Group. The Merritton Limestone, the Williamson Shale and its Second Creek Phosphate Bed, and the Salmon Creek Phosphate Bed of the Rockway Dolomite have been extended into the Niagara Falls area from areas where they were previously recognized. Stratigraphic contacts for the Irondequoit Limestone have been revised. The Rockway Dolomite is raised herein to formation rank.

NEAHGA SHALE
(not revised or otherwise changed herein)

First Usage of Nomenclature: Sanford (1933) proposed the name Neahga Shale for the green shale of the lower part of the Clinton Group in the Niagara River Gorge (Neahga is the Native American name for the Niagara River). In 1935, he referred to the same interval as the Neahga Formation, and stated that it is underlain by the Thorold Sandstone and overlain by the Reynales Limestone. Sanford (1935) correlated the Neahga with the Maplewood Shale, stating that they occupy the same stratigraphic position and are of about the same age.

Type Locality: Niagara River Gorge section south of Artpark, Lewiston, N.Y. (Lewiston quadrangle) (Sanford, 1935, p. 170–174).

Reference Sections: Along railroad track north of the junction of the tracks and Niagara Road immediately west of Lockport, N.Y.; roadcut along Budd Road 1.3 mi west of Hickory Corners, N.Y.; cliff in the east wall of Niagara River Gorge about 0.3 mi north of Robert Moses Powerplant and 1.4 mi south of Artpark, in Lewiston, N.Y.; railroad cut along Welland Canal, St. Catharines, Ont.

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[7]Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

[8]Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

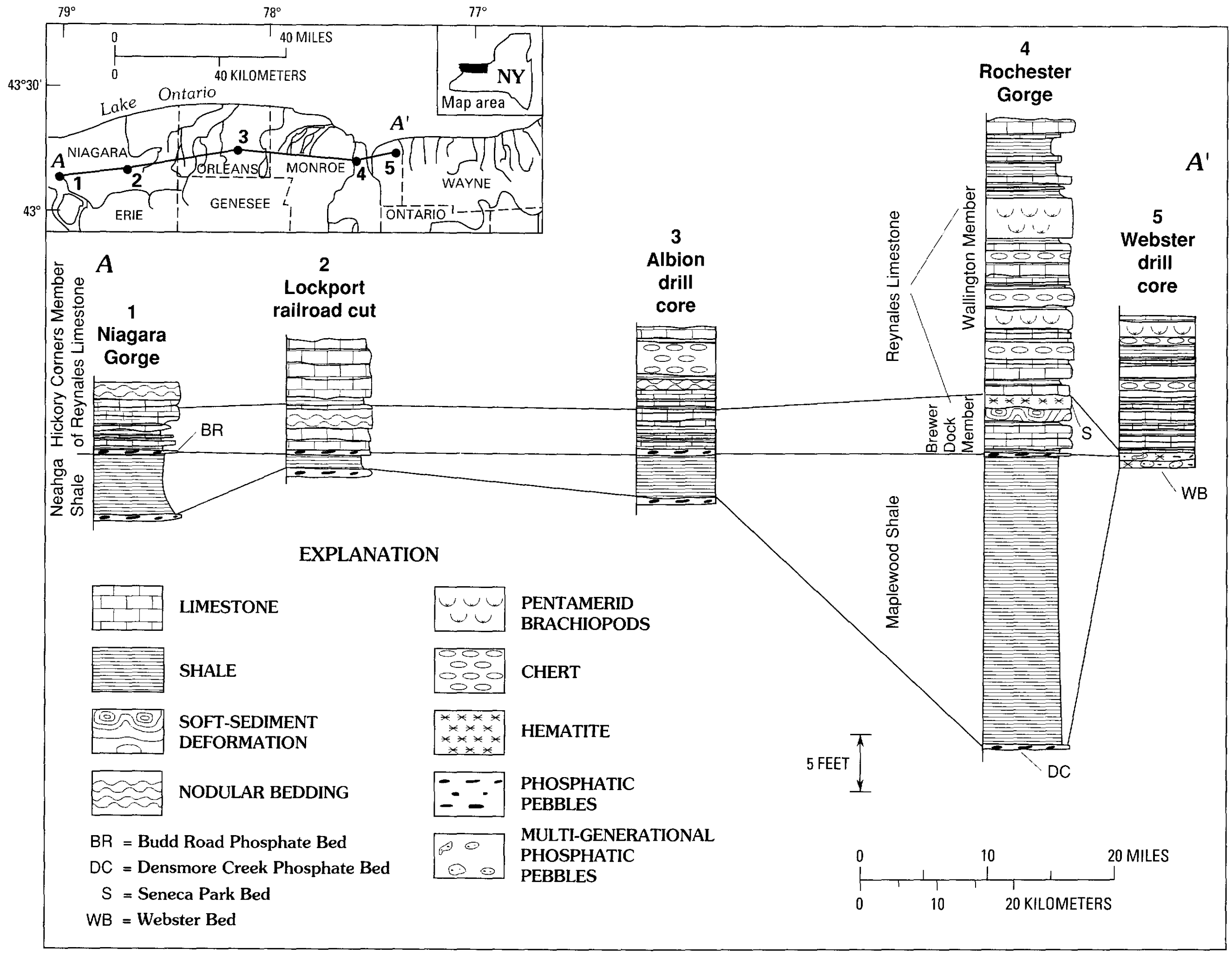

Figure 16. Generalized stratigraphic relations in the lower part of the Clinton Group in western New York. Top of columns represents top of bedrock in all sections except at Rochester Gorge. Datum is the base of the Reynales Limestone. (Modified from LoDuca and Brett, 1994, figs. 1, 10.)

Thickness: In the Niagara region, the Neahga Shale ranges in thickness from 2 to 6 ft. It is 6 ft thick at the type section, less than 2 ft thick at Lockport, N.Y., and 2.5 ft thick at St. Catharines, Ont.

Lithologic Description: The Neahga Shale is green to gray, slightly silty, slightly calcareous, soft, and highly fissile (fig. 18). The basal bed of the Neahga is the Densmore Creek Phosphate Bed, which overlies the regional unconformity between the Medina and Clinton Groups. In the Niagara region, this bed consists of phosphate nodules, pebbles, and cobbles incorporated into a dolomitic sandstone matrix. Macrofossils within the Neahga are scarce and consist primarily of linguloid brachiopods. A complete faunal list is given in Fisher (1953a,b). Acritarch assemblages in the Neahga Shale have been studied by Fisher (1953a) and Cramer and Diez de Cramer (1970) and by Gray and Boucot (1971, 1972).

Contacts: The basal bed of the Neahga Shale is the Densmore Creek Phosphate Bed, which overlies the regional unconformity between the Medina and Clinton Groups. This unconformity truncates successively older units westward. The upper contact is sharp and unconformably overlain by the Budd Road Phosphate Bed of the Hickory Corners Member of the Reynales Limestone.

Regional Correlations: The Neahga has been traced westward to St. Catharines, Ont., and eastward to the Rochester, N.Y., area, where it is referred to as the Maplewood Shale (figs. 9, 16). Beyond Rochester, the unit pinches out rapidly and is absent east of Webster, N.Y. (LoDuca and Brett, 1994).

Age: Gillette (1947) reported *Zygobolba excavata* in the Neahga Shale. According to LoDuca and Brett (1994), the age of the Neahga is late Aeronian (Llandoverian B_2 to C_1).

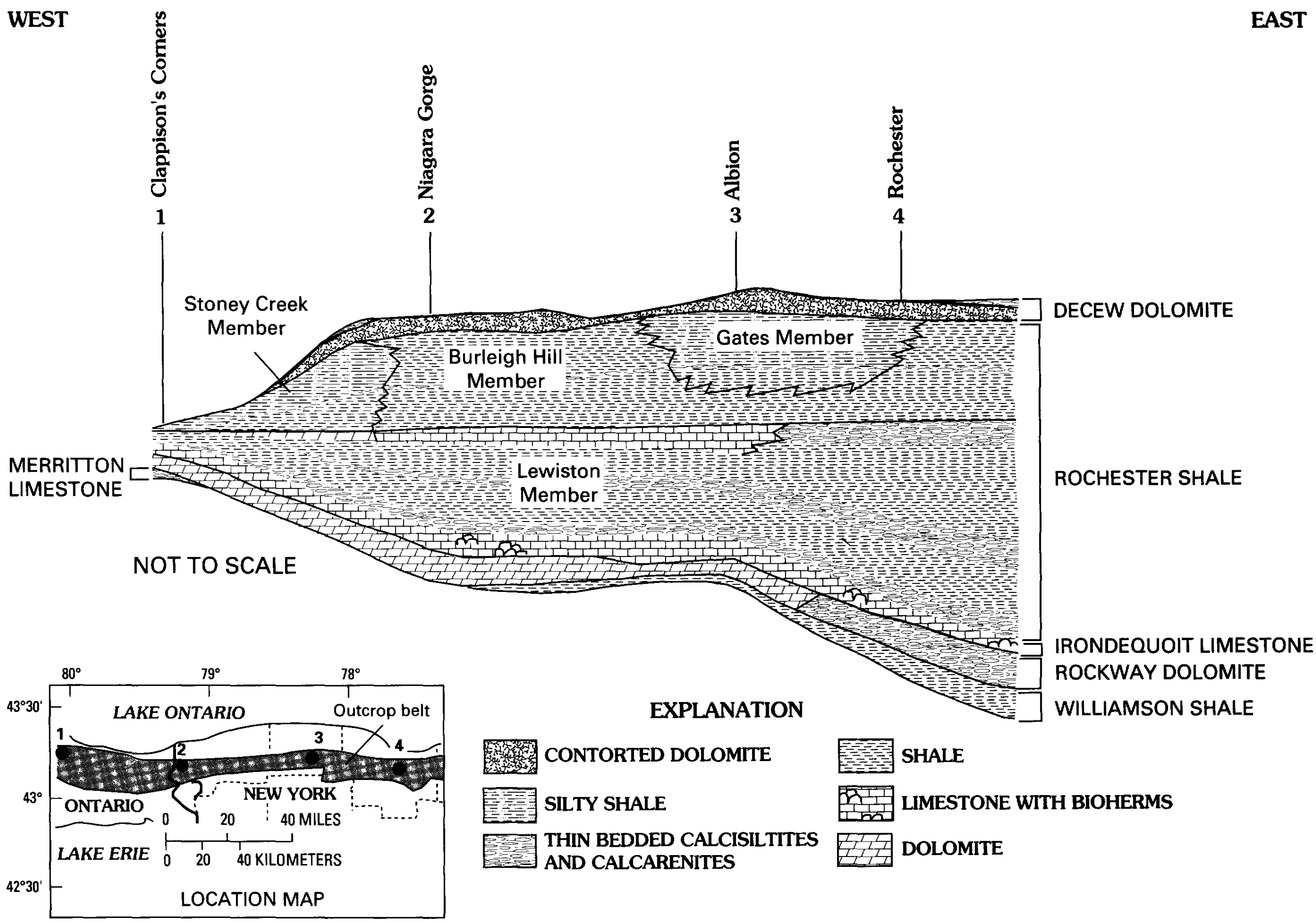

Figure 17. Diagrammatic stratigraphic relations in the upper part of the Clinton Group, with regional correlations between Clappison's Corners, Ont., and Rochester, N.Y. Reference datum is the contact between the Lewiston and Burleigh Hill Members of the Rochester Shale.

Summary of Revisions or Changes: Not revised or otherwise changed herein.

DENSMORE CREEK PHOSPHATE BED
(not revised or otherwise changed herein other than minor modification of unit name)

First Usage of Nomenclature: The Densmore Creek Phosphate Bed of the Neahga Shale is first mentioned informally in Brett and others (1990a,b; 1991) where it is described as a thin, multigenerational phosphatic lag deposit that overlies a minor erosional surface that separates the Medina from the Clinton Group. The unit is formally named the Densmore Creek Bed in LoDuca and Brett (1994) but is herein termed the Densmore Creek Phosphate Bed.

Type Section: Exposure on Densmore Creek about 0.1 mi east of Densmore Road bridge in the town of Irondequoit, Monroe County, N.Y. (Rochester East quadrangle) (LoDuca and Brett, 1994).

Reference Sections: Genesee River Gorge section in Rochester, N.Y.; railroad cut north of the intersection of Niagara Road and railroad tracks west of Lockport, N.Y.; roadcut along Budd Road, 1.3 mi west of Hickory Corners, N.Y.; Niagara River Gorge section south of Artpark, Lewiston, N.Y.; Merritton railroad cut at Thorold, Ont.

Thickness: The Densmore Creek Phosphate Bed ranges in thickness from less than 1 in. to over 6 in. In the Niagara region, it is typically 2–4 in. thick.

Lithologic Description: The Densmore Creek Phosphate Bed is composed of phosphate pebbles and cobbles, some more than 4 in. in diameter, in a dolomitic shale matrix (fig. 18*B*). In exposures near Hickory Corners and Lockport, the upper part of the bed is crowded with *Hyattidina congesta* brachiopods. Bryozoans and phosphate-coated gastropods are also locally abundant (Fisher, 1953b; LoDuca and Brett, 1994). A detailed discussion of the Densmore Creek Bed is provided by LoDuca and Brett (1994), who describe this unit as a phosphatic, calcareous sandstone that is ubiquitous at the base of the Neahga Shale.

Contacts: The Densmore Creek Phosphate Bed directly overlies and marks a regional unconformity that truncates successively older units to the west and is designated herein as the lowest unit of the Clinton Group.

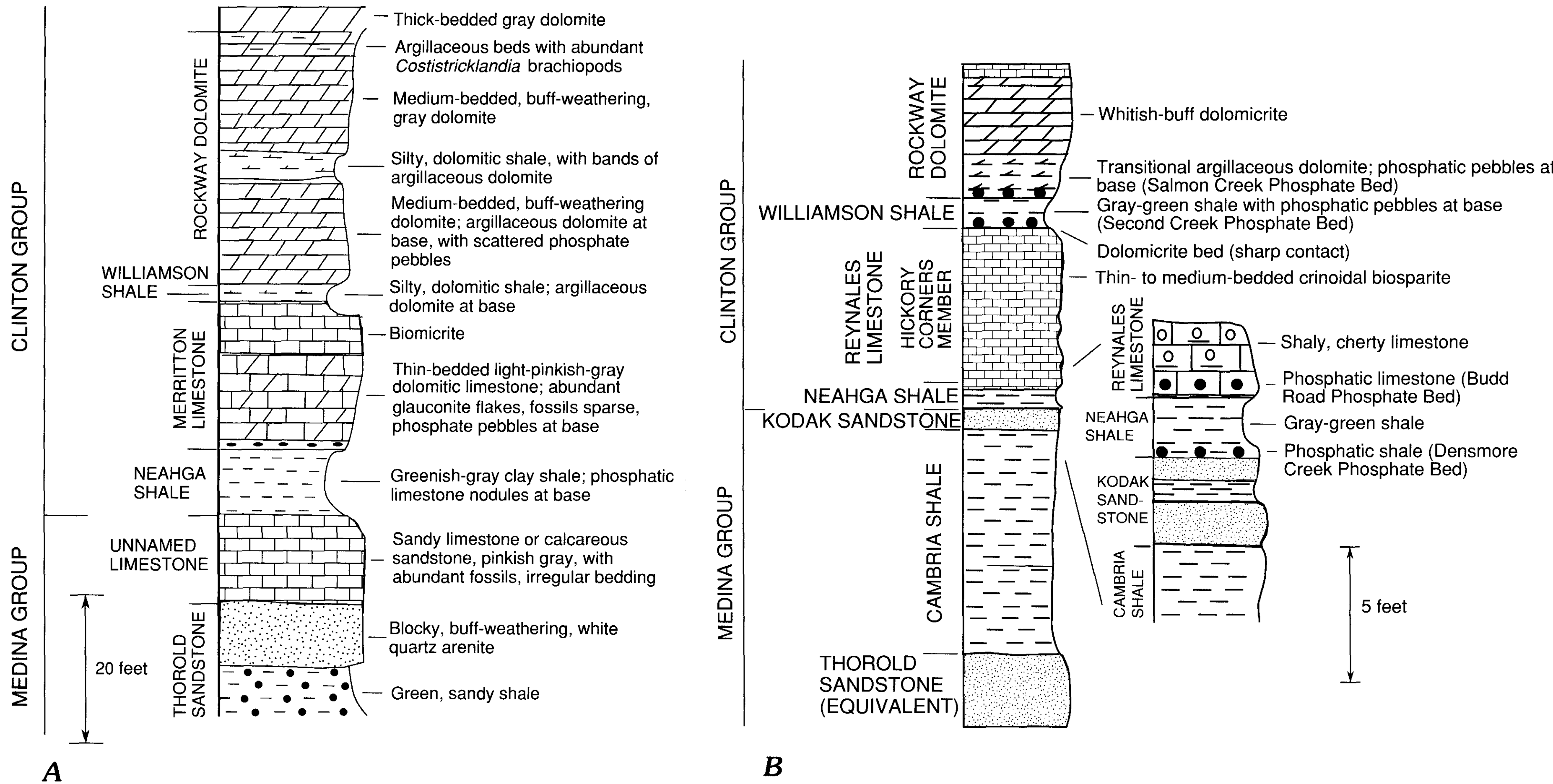

Figure 18. Descriptive stratigraphic column for the upper part of the Medina Group and the lower and basal upper parts of the Clinton Group at (*A*) the railroad cut section in Merritton, Ont., and (*B*) the Somerset Railroad cut in Lockport, N.Y. (Modified from Brett and others, 1991, fig. 11.)

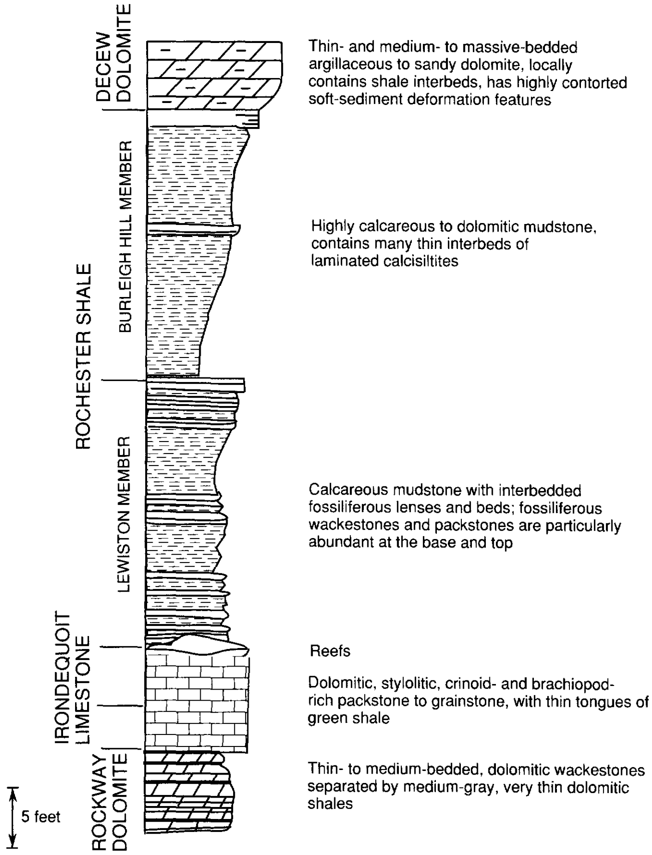

Figure 19. Descriptive stratigraphic column for the upper part of the Clinton Group at Niagara River Gorge near Lewiston, N.Y. (Modified from Brett and others, 1991, fig. 13.)

Regional Correlations: The Densmore Creek Phosphate Bed has been traced west to St. Catharines, Ont., and east to beyond Rochester, N.Y., where it becomes hematitic and forms the basal part of the Webster Bed[9] (fig. 16). The Webster Bed is formally named in LoDuca and Brett (1994).

Age: The age of the Densmore Creek Phosphate Bed is estimated to be Llandoverian (B_2 to C_1) (LoDuca and Brett, 1994).

Summary of Revisions or Changes: Not revised or otherwise changed herein other than minor modification of the name Densmore Creek Bed as formally named in LoDuca and Brett (1994) to Densmore Creek Phosphate Bed.

REYNALES LIMESTONE
(not revised or otherwise changed herein)

First Usage of Nomenclature: This unit was originally named the *Pentamerus* Limestone by Hall (1843) because exposures in Rochester contain an abundance of the brachiopod *Pentamerus oblongus.* Chadwick (1918) introduced the term Reynales Limestone Member (of the Clinton Formation) for the same fossiliferous limestone exposed beneath the Sodus Shale at Rochester, Lockport, and Niagara. He stated that the Reynales is overlain by the Sodus Shale and is, therefore, older than the Wolcott Limestone, with which the Reynales had been previously correlated by Hartnagel (1907).

Type Locality: Reynales Basin, 8 mi east of Lockport, Niagara County, N.Y. (Gasport quadrangle) (Chadwick, 1918). Gillette (1947) designated an exposure on Johnson Creek (Jeddo Creek) in Middleport, N.Y., as the type locality.

Reference Sections: Along tracks south of the intersection of railroad tracks and Niagara Road west of Lockport, N.Y.; Niagara River Gorge section south of Artpark, Lewiston, N.Y.; along haul road to the Sir Adam Beck Powerplant on the Canadian side of the Niagara River Gorge.

Thickness: The Reynales Limestone ranges in thickness from 0 to 12 ft in the Niagara region.

Lithologic Description: In the Niagara region, the Reynales Limestone is represented only by the Hickory Corners Member, which consists of a fossiliferous gray to pink limestone with shale partings (fig. 18*B*). A detailed description is given in the following section. Paxton (1985) provided a detailed description and interpretation of the petrology of the Reynales.

Contacts: The Reynales Limestone is underlain unconformably by the Neahga Shale. The upper contact of the Reynales is also unconformable and is marked by the contact with the Merritton Limestone or with the base of the Second Creek Phosphate Bed of the Williamson Shale.

Regional Correlations: The type facies of the Reynales in Niagara County is somewhat different from the facies characteristic of the Reynales in the Genesee River Gorge region and elsewhere east of Monroe County. At the Genesee River Gorge in Rochester, the Reynales is about 20 ft thick and is divided into two members (Brewer Dock and Wallington Members), which are discussed in detail in LoDuca and Brett (1994). Regional stratigraphic correlations and relations for the Reynales Limestone are shown in figures 9 and 16, respectively. The Reynales Limestone extends eastward to the Martville, N.Y., area, where it becomes shaly and is referred to as the Bear Creek Shale[10] (Gillette, 1947). West of the Niagara region, the Reynales is truncated abruptly and is not present in Ontario west of the Niagara River Gorge section, although clasts of limestone and chert within the Merritton Limestone at Thorold could represent eroded fragments. The name "Reynales" is applied, although incorrectly, in Canada to refer collectively

[9] Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

[10] Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

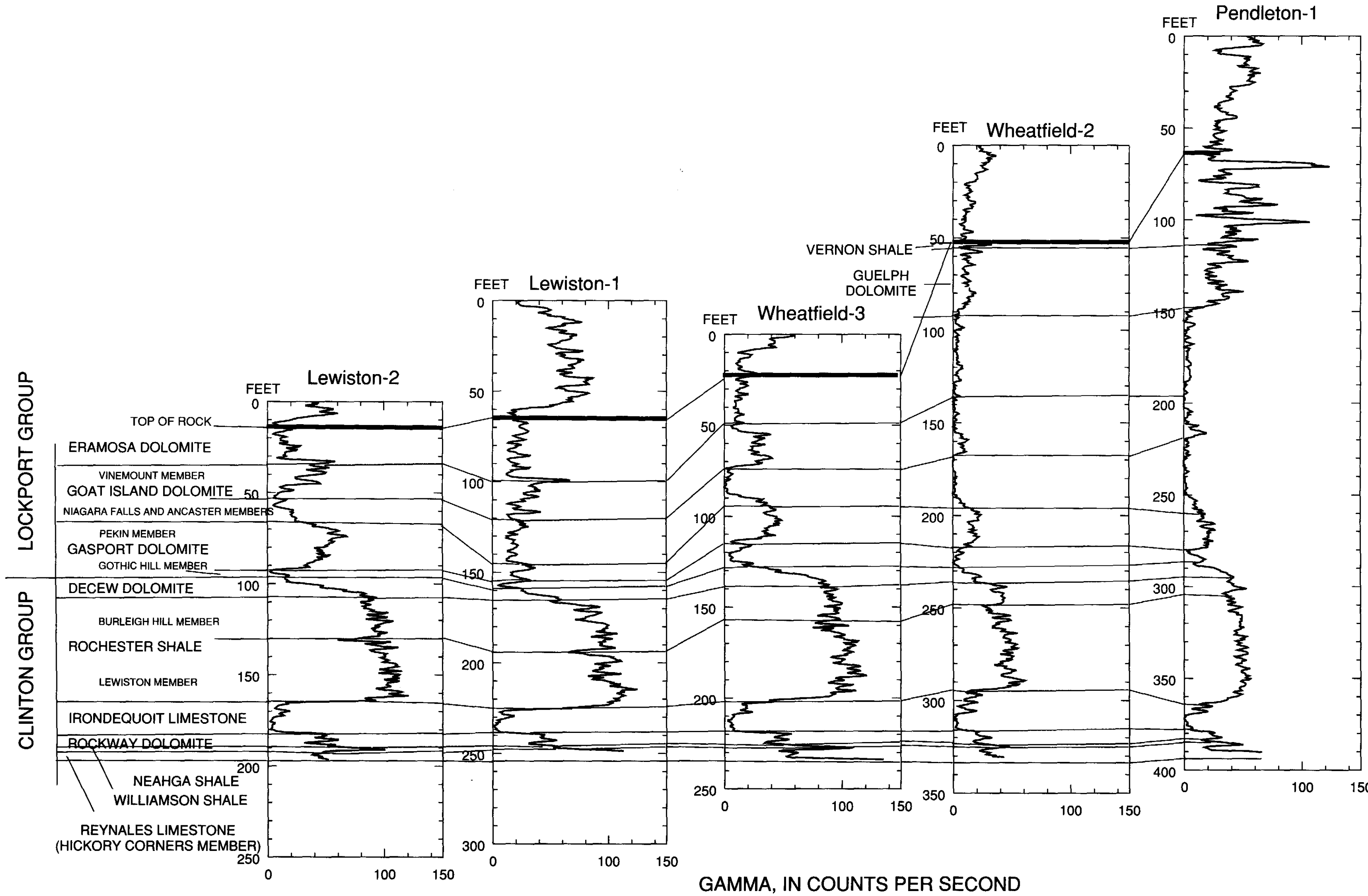

Figure 20. Natural-gamma logs and stratigraphic correlations from U.S. Geological Survey Neahga cores (locations shown in fig. 3). Depths shown are depths below land surface, in feet. The common datum on the logs is the contact between the Rockway Dolomite and the Irondequoit Limestone.

to two discrete units that are markedly younger than the Reynales of western New York—the Merritton Limestone and the Rockway Member of the Irondequoit Limestone. The age of the Merritton is Llandoverian C_5; the age of the Rockway is Llandoverian C_6 to early Wenlockian. At the type locality, however, the Reynales is Llandoverian C_2. In addition, strata referred to as Reynales in Canada are *above* the Second Creek Phosphate Bed, whereas Reynales strata at the type locality in western New York clearly are *below* this phosphate bed. Thus, both physical and biostratigraphic criteria indicate that the term Reynales should no longer be applied to any strata in Canada other than those exposed in the Canadian face of the Niagara River Gorge.

Age: The debate on the age of the Reynales is summarized in LoDuca and Brett (1994), who indicate that the lowest beds of the Reynales could be of Llandoverian C_2 age and that the remainder of the Reynales Limestone is probably also C_2. Based on ostracodes and conodonts, Maxwell and Over (1994) suggest that the entire Reynales is of C_{1-2} (Aeronian) age.

Summary of Revisions or Changes: Not revised or otherwise changed herein.

HICKORY CORNERS MEMBER
(not revised or otherwise changed herein)

First Usage of Nomenclature: The Hickory Corners Limestone Member of the Reynales Limestone was introduced by Kilgour (1963) (fig. 13), who stated that the unit overlies the Neahga Shale and underlies the Rockway Dolomite Member of the Irondequoit Limestone, which was also introduced by Kilgour (1963) (fig. 13).

Type Locality: Roadcut along Budd Road, 0.1 mi north of intersection of Budd Road and Lower Mountain Road, 1.3 mi west of village of Hickory Corners, town of Cambria, Niagara County, N.Y. (Cambria quadrangle) (Kilgour, 1963). The Hickory Corners Member is 9 ft thick at the type locality (Kilgour, 1963).

Reference Sections: Along tracks south of the intersection of railroad tracks and Niagara Road immediately west of Lockport, N.Y.; Niagara River Gorge section south of Artpark, Lewiston, N.Y.; along haul road to the Sir Adam Beck Powerplant on the Canadian side of the Niagara River Gorge.

Thickness: The Hickory Corners Member of the Reynales Limestone ranges in thickness from 0 to 12 ft in the Niagara region. At Middleport, N.Y., it is about 8 ft thick; in the Niagara River Gorge, it thins (as a result of erosional truncation) to about 5 ft thick. The Hickory Corners has not been observed in Ontario west of the Niagara River Gorge.

Lithologic Description: The Hickory Corners Member is a thin- to medium-bedded, gray to pink, nodular, locally fossiliferous, dolomitic limestone with thin shale partings (fig. 18*B*), and chert is common near the top. A widely traceable phosphate horizon, the Budd Road Phosphate Bed, forms the base of this unit (see next section). Characteristic fossils within the Hickory Corners Member include the brachiopods *Hyattidina* and *Eocoelia*, crinoid columnals, and abundant trepostome bryozoa. Detailed lithologic descriptions are found in Kilgour (1963, 1966), Brett and Calkin (1987), and LoDuca and Brett (1994).

Contacts: The Hickory Corners Member of the Reynales Limestone unconformably overlies the Neahga Shale; the surface of this unconformity is overlain by the Budd Road Phosphate Bed (discussed in the following section). The upper contact of the Hickory Corners is also unconformable and is overlain by the Merritton Limestone or, where the Merritton is absent, by the Second Creek Phosphate Bed of the Williamson Shale.

Regional Correlations: Regional stratigraphic correlations and relations for the Reynales (Hickory Corners Member) are shown in figures 9 and 16, respectively. In the Rochester, N.Y., area, the Hickory Corners Member correlates with the Brewer Dock Member[11] of the Reynales Limestone. The Hickory Corners probably also correlates with the basal part of the overlying Wallington Member[12], although this relation is difficult to ascertain because the intervening hematite bed that is the primary basis for subdivision of the Reynales in the Rochester area is not present in the Niagara region. These correlations are discussed in more detail in LoDuca and Brett (1994). The equivalent of the hematite bed of the Rochester Gorge could be represented at Lockport by an 8-in. grainstone bed that lies about 4 ft above the base of the Hickory Corners Member. The 2 ft of Hickory Corners strata exposed above the grainstone bed in Lockport are more massive than the underlying beds and contain abundant chert; this interval most likely represents the equivalent of the lower part of the Wallington Member of the Rochester area (LoDuca and Brett, 1994). This ambiguity in correlation with the Rochester section led Kilgour (1963) to designate strata of the Reynales Limestone exposed in the Niagara region as a separate member. West of the Niagara region, the Hickory Corners Member is truncated abruptly and has not been observed in Ontario beyond the Niagara River Gorge section.

Age: The age of the Hickory Corners Member is Aeronian. LoDuca and Brett (1994) provide a complete discussion of the age of this unit.

Summary of Revisions or Changes: Not revised or otherwise changed herein.

BUDD ROAD PHOSPHATE BED
(not revised or otherwise changed herein other than minor modification of unit name)

First Usage of Nomenclature: The Budd Road Bed of the Reynales Limestone is first mentioned informally in

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[11] Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

[12] Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

Brett and others (1990b, 1991), where it is described as a thin, phosphate-rich limestone bed. The unit is formally named the Budd Road Bed in LoDuca and Brett (1994) but is herein termed the Budd Road Phosphate Bed.

Type Section: Exposure on Budd Road, 0.1 mi north of intersection of Budd Road and Lower Mountain Road, 1.3 mi west of village of Hickory Corners, town of Cambria, Niagara County, N.Y. (Cambria quadrangle) (LoDuca and Brett, 1994).

Reference Sections: Along railroad tracks north of the junction between tracks and Niagara Road on the west side of Lockport, N.Y.; Niagara River Gorge south of Artpark in Lewiston, N.Y.

Thickness: The Budd Road Phosphate Bed is a thin but persistent unit that ranges in thickness from 1 to 4 in.

Lithologic Description: The Budd Road Phosphate Bed overlies a minor unconformity at the base of the Hickory Corners Member of the Reynales Limestone and consists of phosphate pebbles (1/8–1/4 in. in diameter) in a silty limestone matrix (fig. 18*B*). Phosphate pebbles within the Budd Road Phosphate Bed are typically smaller than those in the Densmore Creek Phosphate Bed of the Neahga Shale. A more complete discussion of this unit is provided in LoDuca and Brett (1994).

Contacts: The base of the Budd Road Phosphate Bed marks a minor unconformity between the Neahga or Maplewood Shale and the overlying Reynales Limestone.

Regional Correlations: Regional stratigraphic relations for the Budd Road Phosphate Bed are shown in figure 16. The Budd Road Phosphate Bed extends from Cambria westward to the Niagara River Gorge and eastward to the Rochester area, beyond which it becomes hematitic and forms the lower part of the Furnaceville Member[13] of the Reynales (LoDuca, 1988; LoDuca and Brett, 1994).

Age: Middle Llandoverian; Aeronian (C_1 or C_2): *Distamodas kentuckiensis* Zone (Kleffner, 1991).

Summary of Revisions or Changes: Not revised or otherwise changed herein, other than minor modification of the name Budd Road Bed as formally named in LoDuca and Brett (1994) to Budd Road Phosphate Bed.

MERRITTON LIMESTONE
(geographic extension herein)

First Usage of Nomenclature: Kilgour (1963) first introduced this unit as the Merritton Limestone Member of the Reynales Limestone and traced it across the Niagara Peninsula from Thorold westward to Georgetown, Ont. He noted a considerable unconformity at the base of the Merritton but pointed out that the disconformity at the top of the Merritton is not as marked as that at the base (Kilgour, 1963). In Ontario, the Merritton has commonly been considered as part of the Reynales. It is shown as a formation-rank unit, however, on Rickard's (1975) correlation chart, although it is not extended from Ontario into western New York. Brett and others (1991) state that the Merritton is clearly distinct from the Reynales and consider it a separate formation.

Type Section: Cut along Canadian National Railroad, immediately west of Lock 5 on the Welland Canal near the village of Merritton, Ont. (St. Catharines, 30M/3g, Canadian NTS) (Kilgour, 1963).

Reference Sections: Fifteen Mile Creek, Rockway, Ont.; roadcut on Victoria Avenue near Vineland and south of Jordan, Ont.; roadcut along Highway 20 in the town of Stoney Creek, Ont.; roadcut along south side of Highway 403 along Niagara Escarpment northeast of Mohawk Road exit, town of Ancaster, Ont.

Thickness: In outcrop, the thickness of the Merritton averages about 2.5 ft and is greatest in the Niagara Peninsula at Fifteen Mile Creek (Rockway, Ont.), where it reaches 3.5 ft. A greenish, argillaceous dolomite about 0.5 ft thick in the Niagara Falls-1 core and the Grand Island-2 core might represent the eastern feather-edge of the Merritton.

Lithologic Description: At the type section (fig. 18*A*), and particularly near Hamilton, Ont., the Merritton contains three beds of subequal thickness (0.8–1.0 ft) that consist of light greenish-gray, buff-weathering dolomitic to argillaceous limestone with thin shale partings. A black, phosphate-stained hardground typically separates the lower and middle beds. The limestone contains abundant bright-green glauconite and pyrite, particularly in the basal 6-in. bed, which also contains sand-and gravel-sized phosphate nodules and chert pebbles. The lower two carbonate beds in the Merritton Limestone are fine-grained wackestone; the upper bed is typically coarser than the lower beds and contains an abundance of the brachiopod *Pentameroides subrectus* and crinoidal debris. Other brachiopods, including *Coolinia*, *Atrypa*, *Dalejina*, and *Leptaena*, and corals, such as *Favosites* and *Enterolasma*, are found at the Merritton type section. The lower beds are extensively bioturbated; glauconite can be concentrated in large *Planolites* burrows.

Contacts: The basal contact of the Merritton is sharp and coincides with the major regional, angular unconformity that separates the lower and upper parts of the Clinton Group. The unconformity is overlain by a thin calcareous bed containing granules of phosphate and glauconite and small chert clasts. At the Merritton type section, the upper contact of the Merritton is also a sharp erosion surface that truncates *Pentameroides* brachiopods that are in their original life positions. The upper contact of the Merritton is also coated with black phosphatic material, and the overlying brownish- to greenish-gray shale of the Williamson and (or) Rockway Dolomite contains phosphatic pebbles.

[13]Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

Regional Correlations: Kilgour (1963) originally defined the Merritton as a member of the Reynales Limestone but noted the sharp basal contact and chert pebbles within the Merritton that were derived from erosion of the Hickory Corners Member of the Reynales. The presence of this erosional unconformity indicates that the Merritton is distinct from the Reynales. This is discussed in the preceding section and in LoDuca and Brett (1994). Regional correlation indicates that the erosion surface that underlies the Merritton is coextensive with the major unconformity that underlies the Second Creek Phosphate Bed of the Williamson Shale farther east (Lin and Brett, 1988). In the Hamilton, Ont., area, the Sauquoit Shale, Wolcott Furnace Iron Ore,[14] Wolcott Limestone, Sodus Shale, and the Reynales Limestone have been removed by erosion at this unconformity (Lin and Brett, 1988; Brett and others, 1990a,b). Indeed, this regional pattern of progressive downcutting continues westward; Kilgour (1963) recognized that the erosion surface beneath the Merritton Limestone truncates the Neahga Shale and, ultimately, the Thorold Sandstone westward in Ontario. The Merritton Limestone, therefore, should not be considered a member of the Reynales Limestone because it *overlies* the regionally angular unconformity that truncates the Reynales. Instead, the Merritton is associated with the stratigraphic succession that overlies this major unconformity and is similar in age to the lower parts of the Williamson Shale and Willowvale Shale and the underlying Westmoreland Iron Ore[15] in the type area of the Clinton of central New York.

These stratigraphic correlations are supported by both brachiopod and conodont biostratigraphic data. The Merritton contains abundant *Pentameroides subrectus*, a brachiopod known only from late Telychian (Llandoverian C_5), whereas the Reynales at the type section contains *Pentamerus oblongus*, known from strata as old as Aeronian (Llandoverian C_1 or C_2) (Johnston and Colville, 1982). New conodont evidence also suggests a probable late Telychian (late Llandoverian C_5) age for the Merritton; this suggests correlation with the Westmoreland Iron Ore, which lies immediately below the Williamson Shale in east-central New York (Mark Kleffner, Ohio State University, oral commun., 1990). The Merritton is disconformably overlain by a thin, greenish- to brownish-gray phosphatic shale that yields a distinctive acritarch assemblage typical of the Williamson Shale to the east, which is discussed in the following section.

[14]Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

[15]Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

For the reasons outlined above, the Merritton Limestone has been removed from the Reynales Limestone and has been assigned to a formation rank (Brett and others, 1991). An alternative interpretation would be to make the Merritton a member of the Williamson Shale, but this is not favored because a slight disconformity is present between the Merritton and the overlying, thin, shale tongue equivalent to the Williamson. The phosphatic zone at the contact between these units probably correlates with the Second Creek Phosphate Bed.

West of the type section, the Merritton Limestone can be traced with certainty to the Hamilton area, where it is completely dolomitized. Kilgour (1963) reported that the Merritton is absent at Limehouse, Ont.; however, reexamination of this locality indicates that the typical, tripartite carbonate sequence of the Merritton is present, although difficult to distinguish from the overlying Rockway Dolomite. Northwest of this area, near Orangeville, the Merritton appears to grade into coral-bearing carbonates mapped by Bolton (1957) as the Fossil Hill Formation. The Fossil Hill also overlies a regionally angular unconformity on the Bruce Peninsula (Brett and others, 1990a) and is approximately of late Telychian (Llandoverian C_5 or C_6) age.

East of the type section, the Merritton is not present in outcrops and has not been recognized (except for a possible 2- to 3-in. limestone remnant) in the Niagara River Gorge. As noted above, however, a featheredge of the unit is probably present in two of the USGS drill cores (Niagara Falls-1 and Grand Island-2). The unconformity between the Merritton and the tongue of the Williamson Shale apparently truncates the Merritton eastward within the approximately 10-mi distance between the type area and the vicinity of the Niagara River Gorge. This pinchout could also be interpreted as depositional.

Age: The Merritton is of late Telychian (Llandoverian C_5) age, as indicated by *Pentameroides* brachiopods and conodont species typical of the upper *celloni* Zone (Berry and Boucot, 1970; Mark Kleffner, Ohio State University, oral commun., 1991).

Summary of Change: Rickard (1975) does not extend the Merritton Limestone from Ontario into western New York. The Merritton Limestone is herein geographically extended (tentatively) from Thorold, Ont., where it was traced by Kilgour (1963), into the southern Niagara County subsurface.

WILLIAMSON SHALE
(geographic extension herein)

First Usage of Nomenclature: Hartnagel (1907) proposed the term Williamson Shale for the Second Clinton Shale designated by Hall (1843). The Williamson Shale, as used by Hartnagel in the Rochester area, included what are now referred to as the Williamson and the juxtaposed lower part of the Sodus Shale. Hartnagel (1907) stated that the

Williamson Shale is underlain by the Wolcott Limestone and overlain by the Irondequoit Limestone.

Type Section: Exposures at Salmon Creek, about 160 ft south of Route 104, town of Williamson, Wayne County, N.Y. (Williamson quadrangle) (Hartnagel, 1907).

Reference Sections: Browncroft Creek, in east Rochester, N.Y.; Genesee River Gorge, also in Rochester.

Thickness: The Williamson Shale ranges from a featheredge in Niagara County to a maximum thickness of 78.5 ft at Lakeport, Oneida County, N.Y.

Lithologic Description: The Williamson Shale is a greenish-gray to black, fissile to platy, graptolite-bearing shale (fig. 18*B*). At its base is a thin (0.75 to 8 in.) quartz and phosphate-pebble bed designated the Second Creek Bed by Linand Brett (1988) (geographical extension herein). Fossil assemblages in the Williamson Shale are discussed in Lin and Brett (1988).

Contacts: Both the lower and upper contacts of the Williamson Shale are sharp and unconformable (Lin and Brett, 1988). The lower contact is marked by the Second Creek Phosphate Bed, a major regional angular unconformity that overlies various formations in the lower to middle parts of the Clinton. The upper contact with the Rockway Dolomite is sharp and disconformable and is marked by a quartz and phosphate-pebble bed designated the Salmon Creek Bed by Lin and Brett (1988); this bed is discussed in the following section on the Rockway Dolomite.

Regional Correlations: Regional stratigraphic correlations and relations of the Williamson Shale are shown in figures 9, 15, and 17. East of the study area, the Williamson Shale thickens to a maximum of 65 ft near Oneida Lake, then thins and grades laterally into the Willowvale Shale of the Clinton type area, near Utica, N.Y. The Williamson is the westward stratigraphic equivalent of the Willowvale Shale—both are bounded by the same biostratigraphically dated discontinuity surfaces (Lin and Brett, 1988). Westward across the study area, the Williamson thins and the shale ultimately pinches out between Lockport and St. Catharines, Ont. In the Niagara County area, the Williamson is exceptionally thin and is confined to the basal Second Creek Phosphate Bed and a few inches of greenish shale. In the Hamilton, Ont., region, thin remnants of the Williamson locally overlie the Merritton Limestone.

Age: The Williamson Shale is of latest Llandoverian, late Telychian (C_6) age on the basis of the rugose coral *Palaeocyclus*, monograptid graptolites (Ruedemann, 1947; Berry and Boucot, 1970), *Pterospathodus amorphognathoides* Zone conodonts, and *Mastigobolbina typus* Zone ostracodes (Ulrich and Bassler, 1923; Gillette, 1947; Rickard, 1975; Lin and Brett, 1988).

Summary of Changes: Rickard's (1975) correlation chart shows the Williamson Shale extending as far west as the Albion, N.Y., area. Lin and Brett (1988) recognized the Williamson Shale as far west as Lockport, N.Y. It is herein geographically extended westward to the Niagara Falls area, where a thin erosional remnant has been observed in the USGS cores. The Second Creek Phosphate Bed of the Williamson apparently also extends into Ontario.

SECOND CREEK PHOSPHATE BED
(geographic extension, minor modification of unit name herein)

First Usage of Nomenclature: The basal phosphatic-quartz pebble bed of the Williamson Shale was designated the Second Creek Bed by Lin and Brett (1988). It is a thin but widespread bed. Lin and Brett (1988) present evidence that the Second Creek is laterally equivalent to the Westmoreland Iron Ore at the base of the Willowvale Shale. The Second Creek Bed overlies a major regional angular unconformity; it truncates over 150 ft of shales, carbonates, and hematite beds that are exposed in west-central New York, and bevels progressively lower stratigraphic units to the west (Brett and others, 1991). The bed is herein termed the Second Creek Phosphate Bed.

Type Section: Exposures on Second Creek, near Red Mill Road, north of Alton, Wayne County, N.Y. (Rose quadrangle) (Lin and Brett, 1988).

Reference Sections: Genesee River Gorge in Rochester, N.Y.; railroad cut at Lockport, N.Y.; Niagara River Gorge.

Thickness: The Second Creek Phosphate Bed ranges from 0.1 to 0.7 ft thick. At the type section, the bed ranges from 0.1 to 0.25 ft thick. In the USGS cores, the Second Creek Phosphate Bed is thin (0.1–0.2 ft) but distinctive.

Lithologic Description: The Second Creek Phosphate Bed is a thin but laterally persistent quartzose and phosphatic granule-to-pebble-sized conglomeratic-lag deposit (fig. 18*B*). The bed can be pyritic, locally calcareous, and fossiliferous, with abundant *Eoplectodonta* brachiopods (Lin and Brett, 1988). The Second Creek Phosphate Bed represents relict sediments reworked during a widespread (late Llandoverian, C_6) marine transgression (Lin and Brett, 1988).

Contacts: The lower contact is sharp and erosional, particularly where the Second Creek Phosphate Bed directly overlies a broad, regional, low-angle unconformity. In Ontario, where the Merritton Limestone is above this same unconformity, the Second Creek Phosphate Bed seems to disconformably overlie the Merritton. The upper contact of the Second Creek Phosphate Bed is gradational where the green shales of the Williamson overlie the bed, but where the shales are absent, the contact with the overlying Rockway Dolomite is unconformable.

Regional Correlations: At the type section, the Second Creek Phosphate Bed lies at the unconformable contact between the Wolcott Furnace Iron Ore and the overlying shales of the Williamson (Lin and Brett, 1988). Farther east in the Clinton type area, the sequence becomes increasingly conformable, and the Second Creek Phosphate Bed lies at the paraconformable contact between the Willowvale Shale (lateral equivalent of the Williamson) and the Westmoreland Iron Ore.

Westward from the Clinton type area, the appearance of successively older stratigraphic units beneath the Second Creek Phosphate Bed illustrates that the bed marks a significant, low-angle, regional unconformity that increases in magnitude from east to west (Lin and Brett, 1988). For example, at Rochester, the Second Creek Phosphate Bed immediately overlies the Sodus Shale, whereas in the Niagara River Gorge, it overlies the Reynales Limestone. The pattern of northwestward overstep is reversed in the Bruce Peninsula of Ontario; a succession of beds emerges below the lower contact of the Fossil Hill to the northwest and these strata are laterally continuous between the western flank of the Appalachian Basin and the southeastern flank of the Michigan Basin. From St. Catharines to Hamilton, Ont.,the Second Creek Phosphate Bed lies at the upper contact of the Merritton Limestone. North of Hamilton, it most likely would be present at the top of the Fossil Hill Limestone.

Age: The Second Creek Phosphate Bed lies above the *Pentameroides*-bearing Merritton Limestone, which has been considered to be of Llandoverian late C_5 to C_6 age. Conodont assemblages confirm a Llandoverian C_6 age (Lin and Brett, 1988).

Summary of Change: Lin and Brett (1988) recognized the Second Creek Bed as far west as Lockport, N.Y. It is herein geographically extended westward to at least the St. Catharines area. It has been recognized in the USGS cores, in the Niagara River Gorge, and in outcrops in the Niagara Peninsula of Ontario. A minor modification of the name has been made from Second Creek Bed as formally named by Lin and Brett (1988) to Second Creek Phosphate Bed.

ROCKWAY DOLOMITE
(revised herein)

Brief History of Nomenclature: The Rockway Dolomite Member of the Irondequoit Limestone was named by Kilgour (1963) (fig. 13), who assigned it to the Irondequoit on the basis of his interpretation of fossil content and stratigraphic relations. It had previously been considered the upper part of the Reynales Formation. Kilgour (1963) stated that at the type locality, the Rockway disconformably overlies the Merritton Limestone Member of the Reynales; between Middleport, N.Y., and the Niagara River Gorge, the Rockway overlies the Hickory Corners Limestone Member of the Reynales.

Discussion of Change in Rank: Although Kilgour (1963) removed the Rockway Dolomite from the Reynales Formation, the Ontario Geological Survey has continued to map the Rockway, together with the underlying Merritton, as Reynales. Neither of these units belongs with the Reynales Limestone, however, because they overlie the major sequence boundary that, in turn, overlies and locally truncates the Reynales. In southern Ontario, where the type sections are located, the Merritton and Rockway are lithologically distinctive—the former is more calcareous, glauconitic, and fossiliferous, and the latter is dolomitic, pyritic, and only sparsely fossiliferous. The distinct lithofacies of these units warrant their rank as formations as opposed to their incorporation as members into the much older Reynales Limestone. In addition, a very thin, brownish phosphatic shale between the two units at the Merritton type section may represent the featheredge of an intervening unit; therefore, the Williamson Shale (see discussion under Williamson Shale and Merritton Limestone), the Merritton, and the Rockway cannot be construed as contiguous members of a single formation.

Formation rank for the Rockway Dolomite, therefore, is proposed herein. Kilgour (1963) designated the Rockway as a member of the Irondequoit Formation, recognizing that the argillaceous dolomicrites and the overlying crinoidal grainstones that had previously been designated as Irondequoit were similar in age—approximately early Wenlockian. The dolomicrites and grainstones, however, belong to different (although successive) conodont zones; the dolomicrites of the Rockway contain a fauna typical of the *Pterospathodus amorphognathoides* Zone, whereas most, if not all, of the grainstone of the Irondequoit is in the *Kockelella ranuliformis* Zone (Kleffner, 1991). Rickard (1975) also shows the Rockway as a member of the Irondequoit in the Niagara area.

The Rockway Dolomite always appears to be separated from the overlying crinoidal packstones and grainstones of the Irondequoit Limestone by a sharp, disconformable contact. In the Niagara region, this contact is typically an irregular surface at the top of the highest dolomicrite bed of the Rockway. This uppermost bed of the Rockway is welded to the base of the overlying grainstones. Clasts of the Rockway Dolomite in the basal grainstone of the Irondequoit indicate a period of erosion between deposition of these two units. Regional correlation of this contact indicates that it is an extensive disconformity that corresponds to the contact between the Dawes Formation[16] and the overlying crinoidal, hematitic Kirkland Limestone[17] in the Clinton type area and to the contact between the Rose Hill Shale[18] and the Keefer Sandstone in central Pennsylvania (Brett and others, 1990a). The greatest amount of erosion of the Rockway observed in the Niagara region is in eastern Niagara County and in Orleans County, where the upper half of the Rockway is truncated by the unconformity below the Irondequoit

[16]Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

[17]Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

[18]Designated "Rose Hill Formation" by the U.S. Geological Survey.

quoit. At the Irondequoit type locality (near Rochester), the Rockway-Irondequoit contact shows little or no evidence of erosion but is sharp and is at least a diastem. A disconformity is therefore recognized between the Rockway Dolomite and the Irondequoit Limestone (Brett and others, 1990a), and these units are consequently considered to be discrete formations. The Rockway Dolomite is herein elevated to formation rank, and the Irondequoit is reestablished herein to its previous usage (for example, Gillette, 1947) and is restricted to the massive packstone and grainstone lithology in the Niagara area.

Type Locality: Gorge at Fifteen Mile Creek at Rockway, Ont. (Fonthill, 30M/3c, Canadian NTS) (Kilgour, 1963).

Reference Sections: Genesee River Gorge in Rochester, N.Y.; Niagara River Gorge; Route 403 roadcuts in Hamilton, Ont.

Thickness: At the type locality, the Rockway is 12 ft thick. In the USGS cores, its thickness ranges from 6.6 to 9.2 ft.

Lithologic Description: In Niagara County, the lithology of the Rockway closely resembles that at its type locality in that it consists of medium gray, pale buff-weathering, thin- to medium-bedded, dolomitic wackestones separated by medium-gray, very thin dolomitic shales (figs. 18*B*, 19). The dolomitic shale interbeds thicken eastward from Niagara County. In cores, much of the rock appears burrow-mottled, and the trace fossils *Chondrites* and *Planolites* are observed on some bedding planes. Minor amounts of pyrite are associated with the burrows.

In the Niagara River Gorge and throughout the Niagara region, the Rockway contains a distinctive succession of beds. A lower shale-rich zone about 1 ft thick at the base grades upward into medium-bedded dolomite. A thick, blocky bed of dolomitic wackestone typically is present about 3 ft above the base of the unit and is, in turn, overlain by a succession of thin to medium beds and an upper shaly zone up to 6 in. thick. The uppermost bed is a thin (2–6 in.) dolomicrite bed that is typically welded to the base of the overlying Irondequoit Limestone. The upper contact of this bed is irregular and darkly stained in some outcrops.

In most of southwestern Ontario and western New York, the Rockway Dolomite is barren to sparsely fossiliferous. The observed macrofauna consists of a few taxa. Between St. Catharines and Hamilton, Ont., poorly preserved molds of the brachiopod *Costistricklandia* and rare *Favosites* corals are found on bedding planes low in the Rockway. At the Niagara River Gorge, nautiloids, gastropods, and dendroid graptolites occur sporadically. Scattered pelmatozoan ossicles and brachiopod valves are evident in the USGS cores.

Contacts: Both the lower and upper contacts of the Rockway Dolomite are sharp and disconformable. The Rockway appears to onlap progressively older units across the Niagara region of Ontario. Inspection of the USGS cores has shown that a thin tongue of greenish-gray phosphatic shale (beneath the Rockway) extends into the Niagara area; this indicates that at least the Second Creek Phosphate Bed of the Williamson Shale extends as far west as the Niagara River Gorge. At Niagara River Gorge, the disconformable contact between this green shale and the overlying Rockway is marked by an interval of argillaceous dolomite up to 1.5 ft thick that contains scattered phosphate and quartz grains. This rather diffuse zone probably correlates with the more compact phosphate and quartz granule bed designated the Salmon Creek Bed by Lin and Brett (1988). Near St. Catharines, Ont., the Rockway disconformably overlies the Merritton Limestone. The contact between these units is a phosphatic hardground that probably correlates with the amalgamated Second Creek Phosphate Bed and Salmon Creek Phosphate Bed. The upper contact of the Rockway with the Irondequoit represents at least a minor unconformity. In addition, the grain size changes abruptly from the very fine-grained dolomite of the Rockway to the medium- to coarse-crystalline limestone of the Irondequoit.

Regional Correlations: Regional stratigraphic correlations and relations of the Rockway Dolomite are shown in figures 15 and 17, respectively. The Rockway becomes increasingly shaly east of the study area. At the Genesee River Gorge in Rochester, N.Y., the Rockway is about 50 percent green shale and is interbedded with thin limestones (wackestones). In Madison County, the Rockway and its distinctive basal bed can be traced directly into dolomitic sandstones and shales of the Dawes Formation of the Clinton type area. Rhythmic carbonate-shale and sandstone-shale bedding patterns in the Rockway have facilitated correlations between the Rockway and the Dawes Formation across New York. Northwest of the study area, the Rockway Dolomite appears to grade laterally into beds assigned to the Lions Head Member of the Amabel Formation at the north tributary of the Nottasawaga River near Orangeville, Ont.

Age: The Rockway Dolomite is assigned to the upper *Pterospathodus amorphognathoides* conodont Zone (Rexroad and Rickard, 1965; Kleffner, 1991) and is therefore earliest Wenlockian in age.

Summary of Revision: The Rockway Dolomite is herein raised in rank from a member of the Irondequoit Limestone, as originally proposed by Kilgour (1963) and as shown in Rickard (1975), to formation status. It is recognized as separated from the Irondequoit Limestone by a disconformity (Brett and others, 1990a). In most of New York, it is underlain at a minor disconformity by the Williamson Shale, but in parts of Niagara County where the Williamson is extremely thin, the Rockway may directly overlie the Second Creek Phosphate Bed of the Williamson.

SALMON CREEK PHOSPHATE BED
(geographic extension, minor modification of unit name herein)

First Usage of Nomenclature: The Salmon Creek Bed was named by Lin and Brett (1988). It is best developed at the type section of the Williamson Shale. Lin and Brett (1988) assigned the Salmon Creek Bed to the base of the Rockway Member (herein considered the Rockway Dolomite, a formation-level unit) of the Irondequoit Limestone. It probably correlates with the conglomeratic basal bed of the Dawes Formation in the type area of the Clinton Group (Lin and Brett, 1988). The Salmon Creek Bed was traced by Lin and Brett (1988) from its easternmost exposure at Second Creek to west of Lockport, N.Y. The bed is herein termed the Salmon Creek Phosphate Bed.

Type Section: Exposures at Salmon Creek, about 160 ft south of Route 104, town of Williamson, Wayne County, N.Y. (Williamson quadrangle) (Lin and Brett, 1988).

Reference Sections: Genesee River Gorge in Rochester, N.Y.; Lockport Glen railroad cut in Lockport, N.Y.

Thickness: The Salmon Creek Phosphate Bed ranges from 0.25 to 0.5 ft in thickness.

Lithologic Description: The Salmon Creek Phosphate Bed is a buff-weathering, light greenish-gray, pyritic, bioturbated dolomicrite that contains small pebbles of quartz and phosphate (fig. 18*B*).

Contacts: The lower contact with the Williamson Shale is sharp and disconformable. The upper contact with the Rockway Dolomite is more gradational and apparently conformable.

Regional Correlations: To the east, the Salmon Creek Phosphate Bed can be traced into the basal hematitic ore bed of the Dawes Formation in the Clinton type area (Lin and Brett, 1988; Brett and others, 1990a). To the west, in the Niagara region of Ontario, the Williamson Shale appears to pinch out; as a result, the Second Creek Phosphate Bed merges with the Salmon Creek Phosphate Bed to form a complex phosphatic zone at the top of the Merritton Limestone.

Age: The Salmon Creek Phosphate Bed is of latest Llandoverian age (Telychian C_6) to earliest Wenlockian, on the basis of upper *Pterospathodus amorphognathoides* Zone conodonts and *Mastigobolbina typus* Zone ostracodes.

Summary of Change: Lin and Brett (1988) recognized the Salmon Creek Bed as far west as Lockport, N.Y. It is herein geographically extended westward to the Niagara Falls area, where it has been recognized in the USGS cores. A minor modification of the name has been made from Salmon Creek Bed as formally named by Lin and Brett (1988) to Salmon Creek Phosphate Bed.

IRONDEQUOIT LIMESTONE
(revised herein)

Brief History of Nomenclature: Hartnagel (1907) named the Irondequoit Limestone Member of the Clinton Formation for the town of Irondequoit, just north of Rochester, in Monroe County, N.Y. He defined the Irondequoit as the top member of the Clinton Formation in the Rochester and Ontario Beach quadrangles and stated that it is underlain by the Williamson Shale and overlain by the Rochester Shale. Chadwick (1908) classified the Irondequoit as the basal member of the Rochester Shale, on the basis of faunal similarities. Hartnagel (1912) excluded the Irondequoit from the Rochester Shale and traced the Irondequoit to the Niagara River. Ulrich and Bassler (1923) and Goldring (1931) placed the Irondequoit between the Williamson Shale and the Rochester Shale. Although Gillette (1947) restricted the term Irondequoit to the massive packstone and grainstone found in the Niagara area, Kilgour (1963) designated the underlying Rockway Dolomite as a member of the Irondequoit Formation (fig. 13). Rickard (1975) considered the Rockway to be a member of the Irondequoit in the Niagara region (fig. 14). The Rockway Dolomite is herein elevated to formation rank, and the Irondequoit is reestablished to its previous usage (Gillette, 1947), which is restricted to the massive packstone and grainstone (fig. 14). See "Discussion of Change in Rank" in the preceding section on the Rockway Dolomite.

Type Locality: None is specifically given but the unit was probably named for exposures in tributaries of Irondequoit Creek, in the town of Webster, Monroe County, N.Y. (Rochester East quadrangle) (Hartnagel, 1907).

Reference Sections: Irondequoit Creek in Webster, N.Y.; Genesee River Gorge in Rochester, N.Y.; Niagara River Gorge; Route 403 roadcuts in Hamilton, Ont.

Thickness: In the USGS cores, the thickness of the Irondequoit Limestone ranges from 11.5 to 22.4 ft and generally increases southward. The maximum observed thickness is 22.4 ft in the USGS Wheatfield-2 core; the minimum is less than 5 ft near Albion, Orleans County, N.Y.

Lithologic Description: In Niagara County, the Irondequoit Limestone is a thick- to massive-bedded, medium greenish-gray to pinkish-gray, buff-weathering, dolomitic, crinoidal- and brachiopod-rich packstone to grainstone (fig. 19). Laterally persistent stylolitic surfaces are prominent within the unit. The Irondequoit contains pink calcite crystals and pyrite, gypsum, and pyrolusite (Kilgour and Liberty, 1981). The lower 1–2 ft are typically altered to aphanitic dolomite. Upper beds of the Irondequoit consist of medium- to massive-bedded crinoidal limestone. Thin tongues of green shale, commonly with small (less than 1/3 in.) micritic intraclasts, are common. The brachiopods *Atrypa* and *Whitfieldella* and the rugose coral *Enterolasma* are commonly observed in core and outcrop.

Toward the top of the Irondequoit, thin greenish shale layers become increasingly numerous, and the upper 1–2 ft is an argillaceous, brachiopod-rich packstone. A distinctive green shale and an overlying grainstone rich in the brachiopod *Whitfieldella* are present about 10 ft above the base of the Irondequoit in the USGS Grand Island-2 core. This interval appears to correlate with a *Whitfieldella*-rich marker bed that is traceable eastward to Wayne County.

Small bioherms (3–10 ft across and up to 6.5 ft high) are common in the upper beds of the Irondequoit. These bioherms are sparsely fossiliferous, pale greenish-gray, nonbedded micrite masses that commonly contain internal crinkly surfaces and partings associated with microstylolites. The mounds consist partly of foliose fistuliporoid bryozoans and locally contain pockets filled with trilobite and nautiloid material. These bioherms have been described in detail by Sarle (1901) and by Hewitt and Cuffey (1985).

Contacts: At the lower contact, a dark-stained erosional surface separates coarse crinoidal packstones of the Irondequoit from a thin dolomitic wackestone bed of the underlying Rockway Dolomite. This stained contact is pronounced everywhere in the study area. In the Hamilton, Ont., area, it is so distinctive that many workers (for example, Bolton, 1957) have perceived it as the significant stratigraphic break between the lower and upper parts of the Clinton Group and used it as the boundary between the "Reynales" as defined in Ontario (actually the Rockway Dolomite) and the Irondequoit Limestone. Although the surface underwent relatively little erosion, the relatively deep-water shales and dolomites of the Rockway change abruptly to the shallow, crinoidal grainstones of the Irondequoit (Brett and others, 1990b).

A transitional interval of argillaceous, shelly limestone that ranges from a few inches to a few feet thick is typically found at the contact of the Irondequoit with the overlying Rochester Shale. The Irondequoit-Rochester contact is apparently conformable in the Niagara region but becomes disconformable in the Hamilton, Ont., region.

Regional Correlations: Regional stratigraphic correlations and relations for the Irondequoit Limestone are shown in figures 15 and 17, respectively. The Irondequoit Limestone grades eastward from massive grainstones at Niagara River Gorge to thin- and medium-bedded wackestones and packstones and thin shales in Monroe County. At the Genesee River Gorge in Rochester, N.Y., the Irondequoit consists of interbedded, thin- to medium-bedded, dolomitic wackestones and packstones with abundant thin shale partings and micritic bioherms. The Irondequoit extends eastward from the Rochester area to the Clinton type area, where it grades laterally into the Kirkland Limestone (Brett and others, 1990a). To the northwest, in the Bruce Peninsula region, the Irondequoit grades into the lower part of the Colpoy Bay Member of the Amabel Formation (Bolton, 1957).

Age: The Irondequoit Limestone contains *Mastigobolbina typus* Zone ostracodes and *Kockelella ranuliformis* Zone conodonts (Swartz, 1923; Gillette, 1947; Kleffner, 1991). The presence of these conodonts and ostracodes indicates that the Irondequoit is of earliest Wenlockian (early Sheinwoodian) age.

Summary of Revision: The unit that Kilgour (1963) and Rickard (1975) considered to be the Rockway Member of the Irondequoit Limestone is herein removed from the Irondequoit and raised to formation rank and is termed the Rockway Dolomite. This reestablishes previous usage (Gillette, 1947) of the Irondequoit, and restricts it in the Niagara area to the massive packstone and grainstone.

ROCHESTER SHALE
(not revised or otherwise changed herein)

First Usage of Nomenclature: The Rochester Shale was named by James Hall (1839), probably for exposures in the Genesee River Gorge near Rochester, N.Y., of calcareous shales underlying the Lockport Limestone and the overlying green shale and iron ore. It was the first formally designated stratigraphic unit in North America. Hall (1842, 1843) proposed the Niagara Group, which included the Rochester Shale and Lockport Limestone. In 1843, Hall abandoned the term Rochester Shale and replaced it with Niagara Shale. When Clarke and Schuchert (1899) introduced the Niagaran Period or Group to include the Clinton beds, Rochester Shale, Lockport Limestone, and the Guelph Dolomite, they revived the term Rochester Shale with its original meaning and subsequent workers have accepted this name.

Type Locality: As originally designated by Hall (1839), the type locality is near Rochester, N.Y., probably in the Genesee River Gorge, Monroe County, N.Y. (Rochester East and West quadrangles).

Reference Sections: The Rochester Shale is exposed in many creek sections along the Niagara Escarpment, although relatively few complete exposures are known. Exposures in cliffs of the Niagara River Gorge near Lewiston, both north and south of the Robert Moses Powerplant (south haul road), and sections at DeCew Falls, near St. Catharines, Ont., are the best local reference sections for the entire formation (Bolton, 1957; Brett, 1983a,b).

Thickness: The Rochester Shale ranges from 1.5 to more than 120 ft thick. In the Niagara region, it ranges from 58 to 65 ft thick, with an average thickness of about 60 ft.

Lithologic Description: The Rochester Shale consists of medium-dark gray to black calcareous mudstone with thin interbeds of calcareous to dolomitic calcisiltite (pelletal grainstone) and calcarenite (fossil packstone and grainstone) (figs. 17, 19). Carbonate interbeds are particularly concentrated near the base, middle, and upper third of the formation. The Rochester has been divided into the Lewiston and Burleigh Hill Members in the Niagara region

(Brett, 1983a,b). The division was made at the top of a series of skeletal packstones to grainstones that are typically rich in bryozoans and (or) brachiopod-shell fragments. The altitude of this unit above the lower contact increases steadily southward as the amount of section between the bryozoan-rich packstone interval and the lower contact of the formation increases (Brett, 1983a,b). This generalization has been confirmed through examination of the USGS cores. Lithologic subdivisions (informal units A–E) of the Lewiston Member as originally proposed by Brett (1983a,b) have been modified slightly, as discussed below. Facies are traceable without substantial change in fossil content or lithology from east to west for distances exceeding 95 mi, but abrupt lateral facies changes occur along short (3–8 mi) north-south distances (for example, along the Niagara River Gorge); this suggests that the facies belts are elongated east-west, parallel to both a northern paleoshoreline and to the present outcrop belt along the Niagara Escarpment (Brett, 1983a,b).

Contacts: In western New York, the basal contact with the Irondequoit Limestone is gradational over intervals ranging from several inches to 2 ft. In Ontario, this contact becomes increasingly sharp and disconformable westward.

Regional Correlations: Regional stratigraphic correlations and relations for the Rochester Shale are shown in figures 15 and 17, respectively. The Rochester Shale is exposed from Waterdown (north of Hamilton, Ont.) eastward to the area of Verona, in Oneida County, N.Y. Shale of the same name and approximately the same age is exposed in the central Appalachians from Pennsylvania to northern Virginia. East of Verona, N.Y., the Rochester Shale becomes sufficiently arenaceous that strata equivalent to the Rochester are assigned to the Herkimer Sandstone[19].

Age: Early to middle Wenlockian, as indicated by *Paraechmina spinosa* Zone ostracodes (Berdan and Zenger, 1965), and by conodonts of the *Kockelella ranuliformis* and *Ozarkodina sagitta* Zones (Kleffner, 1991).

Summary of Revisions or Changes: Not revised or otherwise changed herein except for minor refinement of informal subdivisions of the Lewiston Member.

LEWISTON MEMBER
(not revised or otherwise changed herein)

First Usage of Nomenclature: The term Lewiston Member of the Rochester Shale was introduced by Brett (1983a,b) to designate the shales and fossiliferous limestones of the lower unit of the Rochester Shale from Hamilton, Ont., to west-central New York. The Lewiston is typified by bryozoan- and brachiopod-rich mudstones and thin limestones at the base and top (units A, B, D, E), which are separated by an interval of sparsely fossiliferous shales and calcisiltites (unit C) (Brett, 1983b).

Type Section: Cliff in the east wall of Niagara River Gorge about 0.3 mi north of Robert Moses Powerplant and 1.4 mi south of Artpark, in Lewiston, Niagara County, N.Y. (Lewiston quadrangle) (Brett, 1983b).

Reference Sections: South haul road (access for Robert Moses Powerplant) in the Niagara River Gorge; site of the old Schoellkopf Powerplant in the east wall of the gorge; partial sections at Lockport Gulf (Eighteen Mile Creek gully) and along a tributary of Jeddo Creek in Middleport, N.Y. (Brett, 1983a,b).

Thickness: The Lewiston Member thickens regularly and rapidly southward along the Niagara River Gorge. The member is about 26–30 ft thick in the north end of the Niagara River Gorge at Lewiston, but more than 45 ft thick in the gorge near Niagara Falls. It is 38 ft thick in the USGS Niagara–1 core, 43 ft thick in the USGS Niagara Falls–1 core, and 55 ft thick in the USGS Grand Island–2 core. Most of this thickening involves a middle interval of sparsely fossiliferous shale that has been informally designated unit C by Brett (1983b).

Lithologic Description: The Lewiston Member consists of medium- to dark-gray, calcareous mudstone with interbedded fossiliferous lenses and beds (figs. 17, 19). Fossiliferous wackestones and packstones are particularly abundant in the lowermost and uppermost parts of the unit. Several traceable units can be recognized within the Lewiston Member at most localities; these intervals have been designated informally as units A through E by Brett (1983b) and are described below.

UNIT A

This unit consists of highly fossiliferous, typically brachiopod-rich, argillaceous limestone (packstone to grainstone) and very calcareous shale. Unit A forms a transition from the underlying Irondequoit Limestone in the Niagara region. In some sections this interval is marked at its top by a relatively compact shell-rich limestone band overlain by less fossiliferous mudstone. Unit A is thin; it is only 1–2 ft thick in the USGS cores.

UNIT B

Unit B is characterized by calcareous mudstone interbedded with lenses (biostromes) of ramose bryozoans and brachiopods. Its facies range from argillaceous wackestone to packstone. The rhombiferan *Caryocrinites* and the coronoid (Brett and others, 1983) *Stephanocrinus* are common in unit B. The contact between unit B and unit C marks a relatively abrupt decrease in fossil content; the mudstones of unit C are only sparsely fossiliferous. Unit B ranges in thickness from about 12 ft in the north Niagara River Gorge to about 27 ft in the USGS Grand Island–2 core. On the

[19] Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

basis of detailed examination of the USGS cores, unit B is subdivided (informally) into lower and upper bryozoan biostromal units (B–1, B–3) that are separated by an interval of relatively sparsely fossiliferous mudstone (B–2). The B–2 interval is quite thin in northern areas (1–2 ft thick in the northern Niagara River Gorge) but thickens to the south (7.5 ft thick in the USGS Grand Island–2 core). The upper bryozoan biostromal unit, B–3, becomes sparsely fossiliferous and is indistinct in the USGS Grand Island–2 core. It appears to grade into the sparsely fossiliferous unit C.

UNIT C

This unit is a sparsely fossiliferous zone characterized by thin shell pavements, thin laminated calcisiltites, and a lack of bryozoan lenses. The thickness of this interval ranges from about 4 ft in the north to more than 25 ft in the USGS Grand Island–2 core. It displays major southward thickening that could be partly due to loss of resolution of the B–3 unit.

UNIT D

The lithology of this unit is variable, but it is easily recognized in the northern end of the Niagara River Gorge as a bryozoan- and brachiopod-rich facies resembling unit B. The northern facies is replaced south of the Whirlpool area in the Niagara River Gorge by a 3–4-ft-thick interval of laminated and typically contorted dolomitic calcisiltites that closely resemble the DeCew Dolomite (discussed below). In outcrop, this interval weathers as a series of resistant bands with low-angle, hummocky cross stratification and soft-sediment deformation structures. These beds are overlain by a few feet of calcareous mudstone containing thin, shell- and bryozoan-rich bands. The thickness of unit D ranges from about 10 ft in the north end of the Niagara River Gorge to about 3 ft near Grand Island. This trend of northward thickening is opposite to that of unit C, into which unit D probably grades to the south.

UNIT E

This unit is a thin but widespread interval containing calcareous, fossil-rich shales and interbeds up to 5 in. thick of bryozoan- and brachiopod-rich calcarenite. Although this interval is thin, it is recognizable in all USGS cores and crops out in the Niagara region. Above the top surface of unit E, there is generally a sharp change into barren shales that characterize the overlying Burleigh Hill Member. The unit E packstone to grainstone interval is as much as 4 ft thick at the Niagara Escarpment but is only 1 ft thick in the Wheatfield-Grand Island area.

Contacts: The contact of the Lewiston Member with the underlying Irondequoit Limestone is gradational in the Niagara region; unit A represents the transition beds. The upper contact of the Lewiston Member is drawn at the typically distinct top of the uppermost thick grainstone-packstone bed of unit E. At some localities, this bed is pyrite coated and might reflect a minor discontinuity. At a few localities, however, the few inches of mudstone above the last substantial unit E bed contain one or two thin shell pavements that might represent a thin, transitional interval from unit E into the overlying Burleigh Hill Member.

Regional Correlations: Regional stratigraphic correlations and relations for the Lewiston Member are shown in figures 15 and 17, respectively. Regional correlations of the Lewiston Member have been established by Brett (1983a,b). The Lewiston Member can be recognized from at least the Sodus area of central New York westward to the Hamilton, Ont., area. Probable correlatives have been identified in the Rochester Shale of Pennsylvania, Maryland, and West Virginia (Brett and others, 1990a). The key carbonate interval that marks the top of the Lewiston Member, unit E, is apparently correlative with a zone of calcareous sandstones and sandy hematitic limestones in the Herkimer Sandstone of east-central New York.

The Lewiston is everywhere underlain by the Irondequoit Limestone and is bounded above by a sharp contact between a thin (0.7–4.0 ft) interval of bryozoan- and brachiopod-rich wackestone to packstone (unit E), and the overlying sparsely fossiliferous Burleigh Hill Member. As a result of basal onlap of beds onto the Irondequoit, depositional pinchout, and probable truncation at the top, the Lewiston Member generally thins to the northwest. Its maximum thickness ranges from 90 ft in the Sodus-Wolcott area; more than 70 ft near Rochester; about 40 ft near Albion; 35 ft in northern Niagara County; 20 ft near Stoney Creek, Ont.; and about 10 ft or less at Hamilton, Ont. In addition to thinning westward, the unit also thins abruptly northward; its thickness is about 54 ft in the Grand Island-2 core, 46 ft in the Wheatfield–1 core, 40 ft near Niagara Falls, and 30 ft at Lewiston. Most of this change is due to the northward thinning of the middle, sparsely fossiliferous shale intervals (units B–2 and C).

The lowest interval of the Rochester Shale in the Niagara region, unit A of Brett (1983a), is a 1–2-ft-thick transitional, brachiopod- and pelmatozoan-rich argillaceous packstone to calcareous shale. This interval thins to the west and is absent west of St. Catharines; to the east, it thickens slightly to about 4 ft near Rochester.

The lower 10–17 ft (unit B) are highly fossiliferous at almost all outcrops between Grimsby, Ont., and Rochester, N.Y. In the Niagara Peninsula of Ontario, as well as Niagara and Orleans Counties in New York, this interval is typified by ramose bryozoan colonies; eastward, near Rochester, the fauna becomes increasingly dominated by brachiopods. The proportion of sparsely fossiliferous shales in unit B increases markedly to the south and east of Niagara River Gorge; as the upper biostromal beds (informal unit B–3) become thinner and sparsely fossiliferous, this interval appears to merge with unit C, which ranges from sparsely fossiliferous to nearly barren. It typically contains thin, laminated calcisiltite beds that decrease in number to the south.

Dramatic regional changes occur in the fossil content of units D and E. These units are highly fossiliferous and contain thin, bryozoan-rich limestones in sections along the Niagara Escarpment from Grimsby, Ont., east to near Medina, N.Y., but the fossil content decreases rapidly to the south and east. Unit D becomes sparsely fossiliferous and contains thick, laminated calcisiltite beds. This interval is well developed near the south end of Niagara River Gorge, where it contains several thick to massive ledges of dolomitic calcisiltite. These beds, which are apparently confined to broad channellike areas, resemble the DeCew Dolomite and show similar soft-sediment deformation. Unit E, the limestone that caps the Lewiston Member, thins southward and eastward from about 3 to 5 ft of bryozoan- and crinoid-rich pack- and grainstone to a bed less than 6 in. thick composed of compact fossil packstone. In Ontario, this interval displays a sharp to erosional base and becomes a thin, compact, and commonly heavily mineralized bed of crinoidal grainstone resembling the Gasport Dolomite. To the east, only a single, thin, crinoid- and brachiopod-rich packstone bed persists as a continuous unit to Brockport; near Rochester, it is lenticular and locally absent.

Age: The Lewiston Member is early to middle Wenlockian (Sheinwoodian), on the basis of *Paraechmina spinosa* Zone ostracodes (Berdan and Zenger, 1965) and *Kockelella ranuliformis* Zone conodonts (Kleffner, 1991).

Summary of Revisions or Changes: Not revised or otherwise changed herein except for minor refinement of informal subdivisions of the Lewiston Member. These include subdivision of unit B into intervals B–1, B–2, and B–3. Minor changes are also made in the definition of the upper and lower boundaries of unit D.

BURLEIGH HILL MEMBER
(not revised or otherwise changed herein)

First Usage of Nomenclature: The term Burleigh Hill Member was introduced by Brett (1983a,b) for the upper member of the Rochester Shale in the Niagara region, between Grimsby, Ont., and the Monroe County, N.Y., area. The Burleigh Hill consists of sparsely fossiliferous, calcareous to dolomitic shale.

Type Section: Roadcut in Niagara Escarpment (locally called Burleigh Hill) along Burleigh Hill Drive, in Thorold, Ont. (St. Catharines, 30M/3g, Canadian NTS) (Brett, 1983b).

Reference Sections: Many creeks and rivers that cut through the Niagara Escarpment, such as the Niagara River and the Genesee River, expose at least the upper part of the Burleigh Hill Member. The Burleigh Hill is exposed at DeCew Falls on Twelve Mile Creek and is exposed in its entirety along the cliffs adjacent to the Robert Moses Powerplant on the east side of Niagara River Gorge. An outcrop on Gasport Road in the town of Gasport, Niagara County, N.Y., also exposes the entire member.

Thickness: The Burleigh Hill Member is about 30 ft thick in the north end of the Niagara River Gorge and includes transitional dolomitic beds toward its top. It thins toward the south, in contrast to the Lewiston Member (Brett, 1983b). The Burleigh Hill is 23 ft thick in the USGS Niagara-1 core, 16.5 ft thick in the USGS Wheatfield–1 core, and only 10.4 ft thick in the USGS Grand Island–2 core.

Lithologic Description: The Burleigh Hill Member consists of rather uniform dark- to medium-gray, pale- and platy-weathering, highly calcareous to dolomitic mudstone (figs. 17, 19). It contains abundant thin interbeds of medium gray, pale-buff weathering, laminated calcisiltites (pelletal grainstones) that become thicker (2–4 in.) and more closely spaced in the upper 5–10 ft of the unit. The Burleigh Hill becomes increasingly calcareous to dolomitic upward and grades into argillaceous limestone and dolomite near the top (Brett, 1983b). In contrast to the Lewiston Member, the Burleigh Hill contains a sparse fossil assemblage of low diversity but locally contains scattered *Dalmanites* and *Trimerus* trilobites, *Coolinia* and *Resserella* brachiopods, and the bivalve *Cornellites* (Brett, 1983b). A few thin (1–2 in.) coquinites rich in crinoids, ostracodes, and trilobites are common in the upper few feet of the Burleigh Hill. A thin but persistent marker bed about 15 ft below the contact with the DeCew Dolomite at the north end of Niagara River Gorge locally contains an abundance of the brachiopod *Dalejina*. This bed has been traced eastward from St. Catharines, Ont., to the Sodus, N.Y., area.

Contacts: The lower contact of the Burleigh Hill Member is typically sharp and is at the top of the last thick bryozoan- and brachiopod-rich packstone (or grainstone) of unit E of the Lewiston Member. The upper contact with the DeCew Dolomite is sharp but probably conformable in outcrops at the north end of the Niagara River Gorge and gradational at most localities along the Niagara Escarpment. In contrast, the contact is sharp and erosional in the southern Niagara River Gorge near Niagara Falls (see discussion below of DeCew Dolomite). Nonetheless, this contact is difficult to locate precisely in most of the USGS cores because the Burleigh Hill Member and the DeCew Dolomite are similar in grain size, texture, and color.

Regional Correlations: Regional stratigraphic correlations and relations for the Burleigh Hill Member are shown in figures 15 and 17, respectively. The Burleigh Hill Member is traceable westward to near Stoney Creek, Ont., where it grades into argillaceous dolomites and dolomitic shales of the Stoney Creek Member (introduced by Brett, 1983a,b). The Burleigh Hill Member is traceable eastward toward the

Brockport, N.Y., area, where the upper part of the member is replaced by the Gates Dolomite[20].

Age: The Burleigh Hill contains the boundary between the *Kockelella ranuliformis* and *Ozarkodina sagitta* conodont Zones (Kleffner, 1991). The unit therefore straddles the middle Wenlockian Sheinwoodian-Homerian Stage boundary.

Summary of Revisions or Changes: Not revised or otherwise changed herein.

DECEW DOLOMITE
(not revised or otherwise changed herein)

First Usage of Nomenclature: The term DeCew Limestone was introduced by Williams (1914a,b) for the 8.5-ft-thick, fine-grained, dark-gray, argillaceous limestone overlying the Rochester Shale and underlying the Lockport Dolomite at DeCew Falls on Twelve Mile Creek, near St. Catharines, Ont. Williams (1914a) suggested that the DeCew represents reworked Rochester Shale to which lime has been added. He considered the DeCew a transitional unit between the Rochester Shale and the Lockport but thought it was more closely related to the overlying carbonates and included it (Williams, 1919) as the basal bed of his Lockport Member of the Niagara Formation in the Niagara Peninsula.

Type Section: DeCew Falls on Twelve Mile Creek, western St. Catharines, Ont. (Fonthill, 30M/3c, Canadian NTS) (Williams, 1914a).

Reference Sections: Several excellent sections of DeCew Dolomite are exposed along the Niagara River Gorge, especially at the south haul road (access to Robert Moses Powerplant), at the adjacent Devils Hole State Park, and at the abandoned Niagara Falls sewage-treatment plant. Other good exposures are at Lockport Junction Road (Route 429) west of Lockport, N.Y., and at the Burleigh Hill Drive roadcut in Thorold, Ont.

Thickness: Outcrops of the DeCew Dolomite in the Niagara region range in thickness from about 8 to 12 ft. In the Gasport area of Niagara County, however, the DeCew is unusually thin and locally absent. In the USGS cores, it ranges in thickness from 4.5 to 11.8 ft. The considerable variation in thickness of the DeCew in the Niagara Peninsula of Ontario could be partly the result of erosion (Bolton, 1957).

Lithologic Description: The DeCew Dolomite consists of variably bedded, dark-gray to olive-gray, argillaceous to sandy, fine-grained dolomite that locally contains shaly partings and interbeds up to a few inches thick (figs. 17, 19). A middle bed of dolomitic shale up to 3 ft thick is present in the southern Niagara River Gorge. The DeCew weathers to a distinctive light olive gray. Stringers of crinoid ossicles are present locally near the base of the unit. Zones of intraformational conglomerate and planar to hummocky cross lamination are typical. The most distinctive feature of the DeCew is pervasive soft-sediment deformation features (possibly enterolithic), which include flame structures and overturned and isoclinal folds. Contorted bedding is seen in nearly all outcrops of the DeCew and is visible (although subtle) in the USGS cores. Solution cavities have formed in several outcrops along the Niagara River Gorge, particularly at Devils Hole State Park.

The DeCew Dolomite is barren in many sections except for crinoidal stringers and scattered ossicles. *Planolites* and *Chondrites* burrows are prominent at some levels. Lingulid brachiopods and trilobites have also been observed but are rare.

Contacts: As noted above (see discussion of the Burleigh Hill Member of the Rochester Shale), the base of the DeCew Dolomite appears gradational at most outcrops along the Niagara Escarpment and is difficult to distinguish in all the USGS cores. In contrast, the base of the DeCew is sharp at the southern end of the Niagara River Gorge, where it shows channellike scours up to 3 ft across and 1–2 ft in relief that have been cut into the underlying Rochester Shale. The upper contact with the Gasport Dolomite is sharp nearly everywhere in the Niagara region (except in the USGS Niagara Falls–1 core). In many areas the uppermost bed of the DeCew, which is a few inches thick, is a laminated, greenish-gray calcisiltite or dolosiltite. The Gasport Dolomite has a sharp and commonly stylolitic contact with this bed and the basal Gasport contains clasts of it. Bolton (1957) speculated that the thin, greenish-gray clay bands that separate the DeCew from the overlying Gasport could be due partly to seepage along this pronounced surface. Whether this surface underwent major erosion is uncertain. This unconformity cuts out the DeCew entirely near Hamilton, Ont., however, and further truncates the upper beds of the Rochester Shale northwest of that area (Brett and others, 1991). To the east, a fossiliferous shale (Glenmark Member[21] of the DeCew [Brett and others, 1990a]) is juxtaposed between beds equivalent to the basal DeCew and to the Gasport.

Regional Correlations: Regional stratigraphic correlations and relations for the DeCew Dolomite are shown in figures 15 and 17, respectively. The DeCew Dolomite is distinctive in outcrop and is traceable from near Stoney Creek, Ont., eastward at least to the vicinity of Penfield, N.Y. It appears to be thin or absent, however, near Gasport (Niagara County) and Fancher (Orleans County), N.Y.

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[20] Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

[21] Usage of the New York State Geological Survey; nomenclature not formally accepted by the U.S. Geological Survey.

AUTHOR OR SOURCE									
BOLTON (1957)			ZENGER (1965)		RICKARD (1975)		THIS REPORT		
ALBEMARLE GROUP		GUELPH FORMATION	LOCKPORT FORMATION	OAK ORCHARD MEMBER	LOCKPORT GROUP	GUELPH DOLOMITE	LOCKPORT GROUP		GUELPH DOLOMITE
	LOCKPORT FORMATION	ERAMOSA MEMBER							ERAMOSA DOLOMITE
				ERAMOSA MEMBER		ERAMOSA FORMATION		GOAT ISLAND DOLOMITE	VINEMOUNT MEMBER
		GOAT ISLAND MEMBER		GOAT ISLAND MEMBER		GOAT ISLAND FORMATION			ANCASTER MEMBER
									NIAGARA FALLS MEMBER
		GASPORT MEMBER		GASPORT MEMBER		GASPORT FORMATION		GASPORT DOLOMITE	PEKIN MEMBER
									GOTHIC HILL MEMBER

Figure 21. Historical summary of Lockport Group nomenclature in the Niagara region.

Age: Middle Wenlockian: *sagitta* Zone conodonts were obtained from the DeCew by Rexroad and Rickard (1965); included in *Ozarkodina sagitta* Zone by Kleffner (1991).

Summary of Revisions or Changes: Not revised or otherwise changed herein.

LOCKPORT GROUP
(revised herein)

As defined herein, the Lockport Group in the Niagara region consists of about 160–175 ft of massive- to medium-bedded, argillaceous dolomite with minor amounts of dolomitic limestone and shale. The outcrop belt of the Lockport Group in New York extends from Niagara Falls 200 mi east to Ilion, where it pinches out (Zenger, 1965). Because the carbonates of the Lockport Group are more resistant to weathering than the rocks of the Medina and Clinton Groups, they form the most prominent part of the Niagara Escarpment. Hall (1839) designated the Lockport, N.Y., area as the type locality for this group, but the best reference outcrop section is the more recently excavated Niagara Stone Quarry in the town of Niagara, N.Y. No field exposures display the entire Lockport Group succession, but three of the USGS cores (Grand Island–2, Pendleton–1, and Wheatfield–2) include the entire Lockport section.

The Lockport carbonates have long been collectively treated as a formation, beginning with Hall (1839) and have continued to be considered a formation as recently as Zenger (1965). A historical summary of nomenclature for the Lockport Group is shown in figure 21. A comprehensive summary of the nomenclature is presented in Bolton (1957) and in Zenger (1965). The internal stratigraphy and paleontology of the Lockport Group has been refined and revised by many workers, including Hall (1839, 1840, 1843, 1852), Vanuxem (1839, 1842), Logan (1863), Arey (1892), Clarke and Schuchert (1899), Grabau (1901), Clarke and Ruedemann (1903), Hartnagel (1907), Kindle and Taylor (1913), Chadwick (1917), Ulrich and Bassler (1923), Goldring (1931), Howell and Sanford (1947), Fisher (1954, 1960), Bolton (1957), Zenger (1962, 1965), Crowley (1973), Rickard (1975), and LoDuca and Brett (1991).

As previously defined in New York, the Lockport interval either was assigned no formal group designation (Zenger, 1965), or the name Lockport was used for both the formation and the group, in violation of the NASC. The Lockport is considered a group in Berry and Boucot (1970) but divisions such as the Gasport are given only member status, leaving open the question of the proper stratigraphic rank. The NYSGS considers the Lockport to have group status (Fisher, 1960; Rickard, 1975) and to include all units between the Clinton and Salina Groups. The Lockport is also given group status herein for the following reasons. Several subdivisions of the Lockport that were formally termed members (for example, Gasport, Goat Island) contain consistently recognizable, widely traceable internal units. These internal units would be termed beds under the constraints of the NASC. Raising major Lockport units to formation status resolves the problem because these smaller units can then be termed members. The thicknesses of the formations of the Lockport Group are mappable on 1:24,000-scale quadrangle sheets (except where the Lockport crops out on the nearly vertical Niagara Escarpment). Although the term group could be considered inappropriate for such a lithologically consistent package as the Lockport, its thickness is comparable to those of the Medina and Clinton Groups and of other somewhat uniform carbonate sequences (for example, Helderberg Group) in New York that have been given group status.

As defined herein, the base of the Lockport Group is sharply marked at the abrupt unconformity at the base of the Gasport Dolomite. In most outcrops and USGS cores, this contact between the DeCew Dolomite (of the Clinton Group) and the massive crinoidal grainstones of the Gothic Hill Member of the Gasport Dolomite can be located without ambiguity. This contact is similar to that between the Rockway Dolomite and the Irondequoit Limestone but it is a more extensive and more regionally eroded angular unconformity (Brett and others, 1991). This contact is sharp and commonly stylolitic in the Niagara region. To the west, this unconformity truncates the DeCew near Hamilton, Ont., and the upper beds of the Rochester Shale are cut out northwest of that area (Brett and others, 1991).

The upper contact of the Lockport Group is gradational, with an interfingering of lithologies typical of the upper part of the Guelph Dolomite with the greenish and black shales of the overlying Vernon Shale (lowest unit of the Salina Group). This interval, observed in the USGS Grand Island–2, Pendleton–1, and Wheatfield–1 cores, is termed the transition zone, which is herein recognized as unit C of the Guelph Dolomite. It is unclear whether these transition beds were included by Rickard (1975) (or by Zenger, 1965) in the uppermost part of the Lockport Group or in the lowermost part of the Salina Group (fig. 22). Inclusion of this transition zone herein adds 22–29 ft to the overall thickness of the Lockport Group. The authors arbitrarily place the Lockport-Salina contact, which does not crop out anywhere in the study area, at the first thick (greater than 1 in.) black shale interbed. This bed might not be stratigraphically equivalent in all sections, however.

As revised herein, the Lockport Group consists of the following four formations: the Gasport Dolomite, Goat Island Dolomite, Eramosa Dolomite, and Guelph Dolomite. The Eramosa Dolomite includes the lower and middle parts of the unit previously designated the "Oak Orchard Member"[22] by Zenger (1965), and the Guelph Dolomite includes the upper part of Zenger's "Oak Orchard Member." The name "Oak Orchard" is not used in this report because little or none of the interval generally ascribed to the "Oak

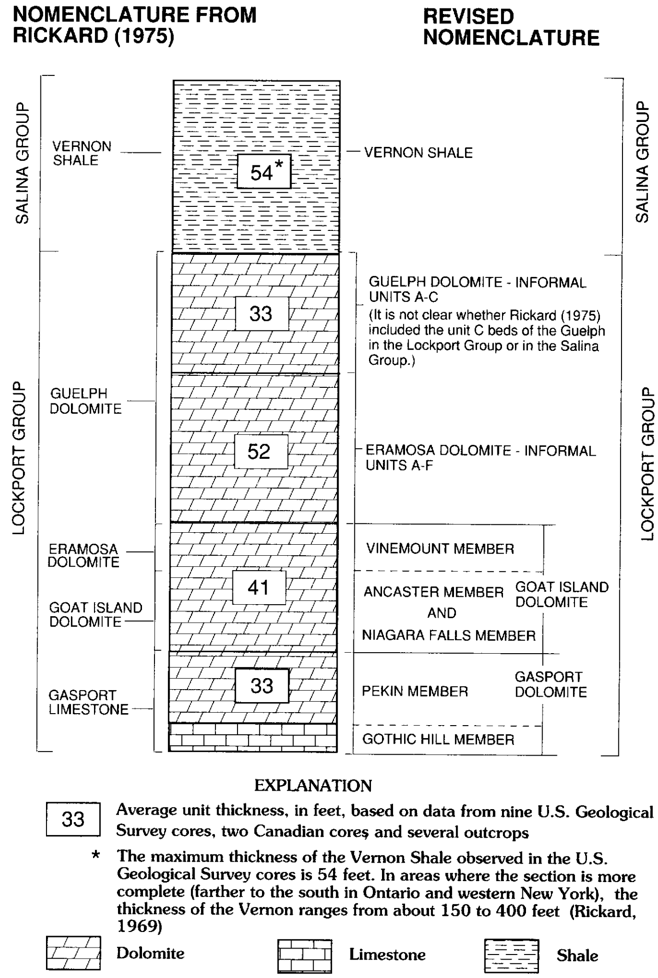

Figure 22. Stratigraphic nomenclature from Rickard (1975) and revised nomenclature for the Lockport Group in the Niagara region. Formation contacts and lithologic shading of units are based on the revised nomenclature.

Orchard Member" (Zenger, 1965) is present at the type locality along Oak Orchard Creek in Orleans County, N.Y. In addition, the term "Oak Orchard" overlaps in usage with the Canadian terms Eramosa and Guelph.

Stratigraphic contacts have been revised for the Gasport Dolomite, Goat Island Dolomite, Eramosa Dolomite, and Guelph Dolomite. The Gasport Dolomite consists of two newly proposed members—a lower grainstone unit termed the Gothic Hill Member and an upper, argillaceous, fine-grained carbonate termed the Pekin Member (fig. 4). The Goat Island Dolomite contains three newly proposed members: a lower biohermal grainstone unit termed the Niagara Falls Member (with two informal units); a middle, cherty, fine-grained dolomite termed the Ancaster Member

[22]Recognized as "Oak Orchard Dolomite" by the New York State Geological Survey; this nomenclature is not formally accepted by the U.S. Geological Survey.

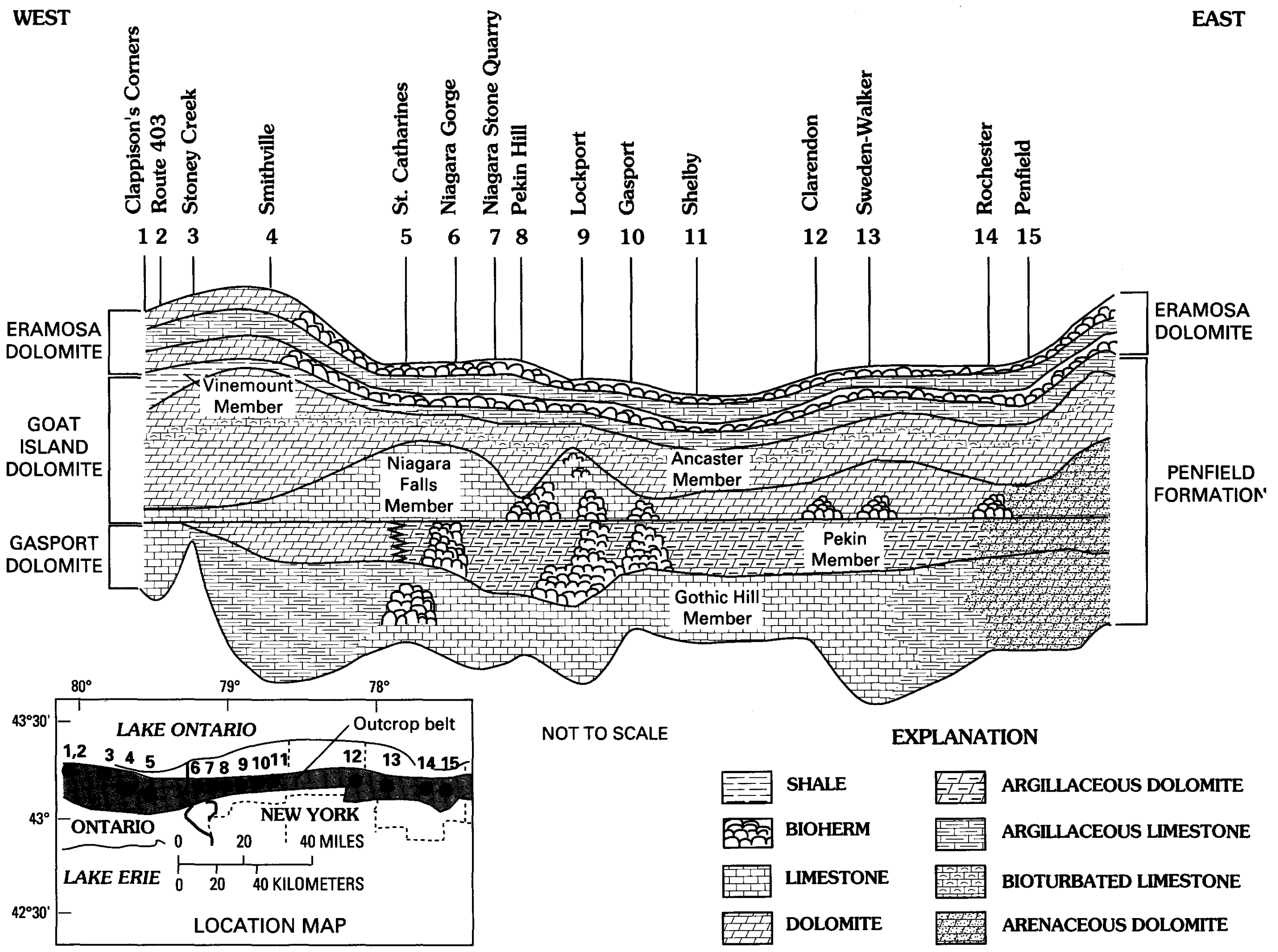

Figure 23. Diagrammatic stratigraphic relations in the Lockport Group, with regional correlations between Clappison's Corners, Ont., and Penfield, N.Y. Reference datum is the contact between the Gasport Dolomite and the Goat Island Dolomite.

(name used informally in Ontario); and an upper, argillaceous, fine-grained dolomite and shale unit termed the Vinemount (name used informally in Ontario) Member (fig. 4). The Vinemount Member was formerly miscorrelated with the Eramosa Member as defined by Zenger (1965). The Eramosa and Guelph Dolomites are not formally subdivided although several informal units are recognized herein within each formation. The relation between stratigraphic nomenclature from Rickard (1975) and the revised nomenclature for the Lockport Group is shown in figure 22.

These revised stratigraphic units are described in the following sections. A stratigraphic correlation chart for the Lockport Group is shown in figure 15. A geologic section for the Lockport Group, with regional correlations between Clappison's Corners, Ont., and Penfield (Wayne County), N.Y., is shown in figure 23. A descriptive stratigraphic column for the Lockport Group is shown in figure 24. Natural-gamma logs and stratigraphic correlations for units within the Lockport Group are presented in figures 12 and 20.

Summary of Revisions: Lockport Group as used herein refers to the stratigraphic interval identified as Lockport Group on Rickard's (1975) correlation chart (fig. 22) in that it also encompasses all units between the Clinton and Salina Groups. It is unclear, however, whether the transition beds that are herein recognized as unit C of the Guelph were included by Rickard (1975) (or by Zenger, 1965) in the uppermost part of the Lockport Group or in the lowermost part of the Salina Group. The authors arbitrarily place the Lockport-Salina contact, which does not crop out anywhere in the study area, at the first thick (greater than 1 in.) black shale interbed. The contact between the DeCew Dolomite and the Gothic Hill Member of the Gasport Dolomite is designated herein as the basal contact of the Lockport Group. Stratigraphic contacts have been revised for the Gasport Dolomite, Goat Island Dolomite, Eramosa Dolomite, and Guelph Dolomite. These major subdivisions of the Lockport Group were previously referred to as members of the Lockport Formation by Zenger (1965) but are treated herein

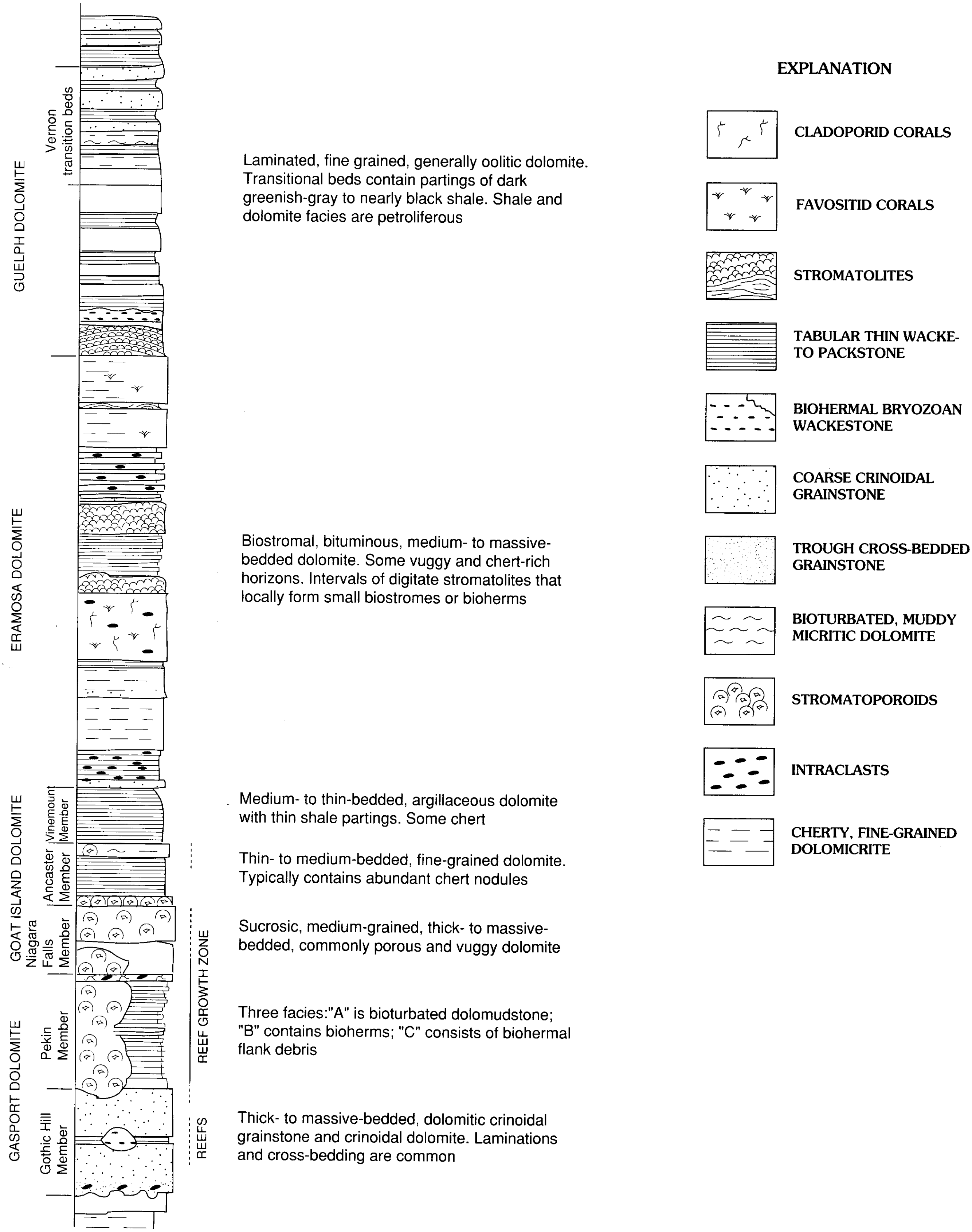

Figure 24. Descriptive stratigraphic column for the Lockport Group. Composite section for Niagara County is shown. (Modified from Brett and others, 1991, fig. 15.)

as formations within the Lockport Group, in accordance with the usage of Rickard (1975).

The Gasport Dolomite is divided into two new members, the Gothic Hill Member and the overlying Pekin Member. The term Goat Island Dolomite is retained but the Goat Island is herein split into three new members: the Niagara Falls Member, the Ancaster Member (also revised and extended geographically), and the Vinemount Member (also revised and extended geographically). The latter unit was previously miscorrelated with the Eramosa Member of Zenger (1965). The Eramosa Dolomite as defined herein includes parts of the unit termed the "Oak Orchard Member" by Zenger (1965). The term "Oak Orchard" is not used in Rickard's (1975) correlation chart for western New York; Guelph is used instead. The authors are in agreement with this usage; the name "Oak Orchard" is not used in the present work because little or none of the interval previously assigned to the Oak Orchard Member (Zenger, 1965) is present at the type locality along Oak Orchard Creek in Orleans County, N.Y. The Guelph Dolomite as defined herein is the uppermost formation of the Lockport Group and includes strata previously considered as the upper part of the Oak Orchard Member of Zenger (1965).

GASPORT DOLOMITE
(revised herein)

Brief History of Nomenclature: The Gasport Limestone Member of the Lockport Dolomite was named by Kindle and Taylor (1913) for exposures near Gasport, Niagara County, N.Y. This interval had previously been referred to as the Encrinital Limestone by Hall (1843) and as the Crinoidal Limestone by Grabau (1901). Howell and Sanford (1947) regarded the DeCew Waterlime Member rather than the Gasport as the basal member of the Lockport Formation. Fisher (1960) stated that the Gasport is the basal formation in the Lockport Group and that it underlies the Goat Island Limestone and overlies the DeCew Dolomite. Zenger (1965) referred to the Gasport Member of the Lockport Formation. The Gasport is given formation-level status in Rickard's (1975) correlation chart (fig. 21), although he refers to it with two lithologic modifiers, as the Gasport limestone and dolomite. The Gasport is herein referred to as the Gasport Dolomite. The formal revisions to the Gasport Dolomite made herein have been informally introduced by the authors (Brett and others, 1990a,b, 1991; Tepper and others, 1990; and LoDuca and Brett, 1991).

Type Locality: Unspecified exposures near Gasport, Niagara County, N.Y. (Kindle and Taylor, 1913) (Gasport quadrangle).

Reference Sections: Many sections along the Niagara River Gorge; Niagara Stone Quarry, town of Niagara, N.Y.; Route 429 roadcut in Pekin, N.Y.; roadcut on Townline Road at the Lockport-Cambria, N.Y., town line; Frontier Stone Quarry, Lockport, N.Y.; and Frontier Stone Quarry, immediately south of Route 31, village of Gasport, town of Royalton, Niagara County, N.Y. (Gasport quadrangle).

Thickness: The Gasport Dolomite ranges in thickness from a minimum of 19.5 ft in the USGS Lewiston-1 core to a maximum of 37.2 ft in the USGS Wheatfield-2 core, where much of the unit consists of dark-gray, argillaceous dolomite and shale. The average thickness of the unit in the USGS cores is 33.8 ft. Local biohermal buildups cause the thickness of this unit to vary considerably. Both members of the Gasport typically decrease in thickness to the west along the Niagara Escarpment (Brett and others, 1991).

Lithologic Description: The Gasport Dolomite consists of two members named herein: the Gothic Hill Member, a light pinkish-gray, crinoidal- and brachiopod-rich dolograinstone to dolopackstone; and the Pekin Member, a dark olive-gray, argillaceous, fine- to medium-grained dolomicrite that grades laterally into bioherms and flanking dolorudites (figs. 23, 24). These members of the Gasport are described in detail below. The occurrence of patch reefs in the Gasport is discussed in detail by Crowley (1973) and in Crowley and Poore (1974).

Contacts: As noted above, the basal contact of the Gothic Hill Member with the underlying DeCew Dolomite is generally sharp and locally erosional. At many localities along the outcrop belt between Brockport, N.Y., and Hamilton, Ont., the contact is sharp and commonly stylolitic, and the lowest foot of the Gothic Hill Member contains rip-up clasts of DeCew Dolomite. At sections from Brockport eastward, however, the contact is typically gradational and contains fine-grained sandy dolomite of the DeCew interbedded with crinoidal sandy dolomite of the lower part of the Gothic Hill.

The contact of the Gasport with the overlying Goat Island Dolomite is also typically sharp, stylolitic, and probably erosional in many sections. At some localities, the pale-buff grainstones of the lower part of the Goat Island rest abruptly on dark-gray, tabular to biostromal beds of the upper part of the Pekin Member. The Wenlockian-Ludlovian boundary is placed at or slightly above the Gasport-Goat Island contact by LoDuca and Brett (1991).

Regional Correlations: The Gasport caps the Niagara Escarpment in western New York. It can be traced as a distinct unit for 110 mi along the escarpment from just west of Hamilton, Ont., to Brockport, N.Y. (figs. 15, 23) (Crowley, 1973). The Gasport Dolomite is recognizable westward to near Dundas, Ont. With the truncation of the Rochester Shale beneath the sub-Gasport unconformity at Waterdown, Ont., the massive crinoidal dolomite of the Gasport directly overlies the lithologically similar Irondequoit Limestone. The unconformity between these units is typically obscure and they are not differentiated northwest of this area. The term Amabel Formation is used in Ontario for the resulting massive dolograinstone unit. The beds equivalent to the Gasport on the Bruce Peninsula have been identified as belonging to the Wiarton Member of the Amabel (Bolton, 1957).

From Hamilton, Ont., eastward to near Clarendon, N.Y., the lower part of the Gasport (Gothic Hill Member) is traceable as a distinct crinoidal grainstone. The upper part of the Gasport (Pekin Member) is a distinctly more argillaceous, dark-gray, thinly bedded dolomite that is thin to absent near Hamilton, Ont. Near Stoney Creek, virtually the entire Gasport is missing; its absence could be attributed to erosion prior to deposition of the Goat Island Dolomite.

Age: The Gasport Dolomite is of latest Wenlockian age, as indicated by the presence of *Ozarkodina sagitta* Zone conodonts (Rexroad and Rickard, 1965; LoDuca and Brett, 1991).

Summary of Revisions: The Gasport Dolomite is herein divided into two new members, the Gothic Hill Member and the overlying Pekin Member. The Gasport as defined herein includes the "crinoidal," "small bioherms," and "dark, bedded" facies of Zenger (1965), and the "crinoid-bar," "reef," and "interreef" facies identified by Crowley (1973). The upper contact of the Gasport Dolomite is revised herein. The "stromatoporoid-cap" facies of Crowley is considered herein as part of the Niagara Falls Member of the Goat Island rather than as part of the Gasport because it is separated from the Gasport by a minor unconformity at many localities.

GOTHIC HILL MEMBER
(new unit, proposed herein)

Background: The term Gothic Hill was first informally introduced by the authors (Brett and others, 1990a,b, 1991; Tepper and others, 1990; LoDuca and Brett, 1991). It is formally proposed as a new unit herein. Zenger (1965) informally recognized this unit as the "crinoidal" facies and classified it as a calcirudite or dolorudite because it contained abundant, coarse-grained crinoid and brachiopod fragments. This unit also corresponds to the "crinoidal-bar" facies of Crowley (1973), who states that it is the most widespread facies of the Gasport between Hamilton, Ont., and Brockport, N.Y.

Type Locality: Roadcut along the northeast-facing Niagara Escarpment on Gothic Hill Road, about 0.1 mi south of the intersection of Lower Mountain Road and Gothic Hill Road, about 2 mi west of the city of Lockport, Niagara County, N.Y. (Lockport quadrangle).

Reference Sections: Excellent reference sections are exposed in the Niagara Stone Quarry, Niagara; the Niagara River Gorge; the Frontier Stone quarries at Lockport and Gasport; and the roadcut on Townline Road at the Lockport-Cambria, N.Y., town line.

Thickness: The Gothic Hill Member ranges in thickness from 3 ft in the USGS Lewiston-1 core to over 21 ft at the Lockport Junction roadcut; its average thickness is about 15 ft. The thickness of this unit varies considerably depending on local biohermal buildups.

Lithologic Description: The Gothic Hill Member, which is similar to the Irondequoit Limestone in terms of lithology and fauna, consists of thick- to massive-bedded, dark olive-gray to light-pink, dolomitic limestone (primarily crinoidal grainstone and crinoidal dolomite) and weathers to a light olive-gray (figs. 23, 24). Laminations and cross bedding are common within the unit; trough cross-stratification and possible bimodal ("herringbone") cross-stratification are particularly well developed at the northern end of the Niagara River Gorge. The Gothic Hill Member corresponds to the "crinoidal-bar" facies of Crowley (1973). Near St. Catharines, Ont., and Lockport, N.Y., the Gothic Hill Member contains small bioherms composed of crinkly weathering, pale-gray to greenish-gray micrite with abundant crustose fistuliporoid and ramose bryozoans; alveolitid, favositid, and colonial rugosan corals; and pelmatozoan holdfasts (Zenger, 1965; Crowley, 1973; Brett, 1985).

The Gothic Hill Member can be subdivided into three parts: (1) a basal crinoidal- and brachiopod-rich grainstone that typically contains dolomicrite clasts, especially near the bottom of the unit; (2) a middle zone, generally 1–2 ft thick, of thinner bedded, more argillaceous, and darker gray dolomite that locally contains small bioherms; and (3) an upper, coarse grainstone unit that typically forms about one-third of the total thickness of the Gothic Hill. Large bioherms that extend upward into the overlying Pekin Member commonly originate near the top of the upper grainstone unit.

Contacts: The lower contact between the massive crinoidal grainstones of the Gothic Hill Member and the DeCew Dolomite is sharp, commonly stylolitic, and erosional nearly everywhere in the Niagara region. In most outcrops and in the USGS cores, this contact can be located without ambiguity. It is similar to the contact between the Rockway Dolomite and the Irondequoit Limestone but is more extensive and more regionally eroded (Brett and others, 1991). In many areas, the uppermost bed of the DeCew is a few inches thick and is a laminated, greenish-stained calcisiltite or dolosiltite. The Gothic Hill has a sharp and commonly stylolitic contact with this bed and contains clasts of it. Bolton (1957) noted thin, greenish-gray clay bands that he speculated could be due partly to seepage along the pronounced surface that separates the DeCew from the overlying Gasport. Whether this surface underwent major erosion is uncertain. To the west, however, this unconformity cuts out the DeCew entirely near Hamilton, Ont., and further truncates the upper beds of the Rochester Shale northwest of that area (Brett and others, 1991). To the east, a fossiliferous shale (Glenmark Member of the DeCew; Brett and others, 1990a) is juxtaposed between beds equivalent to the basal DeCew and to the Gasport. The upper contact of the Gothic Hill Member with the Pekin Member is conformable but relatively sharp, although it can be gradational over several inches. Pronounced changes in color, grain size, and bedding style are typical from the pinkish, coarse-grained, thick- to massive-bedded Gothic Hill Member to the dark-gray or black, fine-grained, thin- to medium-bedded Pekin Member.

Regional Correlations: According to Crowley (1973), the Gothic Hill Member is laterally continuous with, and lithologically similar to, the crinoid-rich Wiarton Member of the Amabel Formation west of Hamilton, Ont. The typical facies of the Gothic Hill Member is recognized from Hamilton, Ont., eastward to McCargo Lake, near Fancher, N.Y. (figs. 15, 23). The unit generally thins to the northwest near Hamilton and, at East Stoney Creek roadcut, it is nearly absent as a result of truncation beneath the Goat Island Dolomite. At most localities, the Gothic Hill is readily recognizable as a pinkish-gray, massive crinoidal grainstone, although in a few outcrops near St. Catharines and in the USGS Lewiston–1 core, the interval consists of finer-grained dolopackstone or wackestone with interbedded shales, which could represent infilling of local minor depressions or intershoal areas. To the east, in eastern Orleans County, N.Y., a relatively abrupt change occurs in the 2.5 mi between McCargo Lake and the Genesee-Le Roy Stone Quarry at Clarendon. At McCargo Lake, the Gothic Hill Member is represented by about 10 ft of coarse, stromatoporoid- and coral-bearing dolopackstones and grainstones. In contrast, this interval at the Genesee-Le Roy Stone Quarry is represented by about 12 ft of interbedded laminated and bioturbated crinoidal dolowackestone resembling the DeCew Dolomite, and by thin beds of crinoidal grainstones. In eastern Monroe County, this facies grades into the laminated sandy dolomites and dolomitic sandstones of the lower part of the Penfield Member[23] of the Lockport Formation (Zenger, 1965). To the south, as indicated in the USGS Grand Island-2 core, the grainstones are thin and grade into interbedded packstones and wackestones.

Age: Late Wenlockian; *Ozarkodina sagitta* conodont Zone (Rexroad and Rickard, 1965; LoDuca and Brett, 1991; Kleffner, 1991).

Summary of Revision or Change: The Gothic Hill Member is a new unit, proposed herein. It is the lowermost member of the Gasport Dolomite and is underlain by the DeCew Dolomite and overlain by the Pekin Member of the Gasport.

[23]Rickard (1975) considers the Penfield to be a formation-level unit although he refers to it as the Penfield sandstone and dolomite. Because the lithology of this unit is mixed, the authors will herein refer to it as the Penfield Formation. This nomenclature is not formally accepted by the U.S. Geological Survey.

PEKIN MEMBER
(new unit, proposed herein)

Background: The term Pekin Member was first informally introduced by the authors (Brett and others, 1990a,b, 1991; Tepper and others, 1990; LoDuca and Brett, 1991). It is formally proposed as a new unit herein. The Pekin Member includes both the "small bioherms" facies and the "dark, bedded" facies informally recognized by Zenger (1965). The "dark, bedded" facies grade laterally into the "small bioherms" facies (Zenger, 1965). Between the margins of some bioherms and the "dark, bedded" facies, Zenger (1965) observed dark dolomitic layers that contain a profusion of coral and stromatoporoid fragments, which represent flanking debris. These dark beds south of Gasport were referred to as the "Gasport shaly channel" by Ruedemann (1925). The "small bioherms" and "dark, bedded" facies of Zenger were referred to as the "reef" and "interreef facies" respectively, by Crowley (1973).

Type Section: Roadcuts on Route 429 at the overpass of Upper Mountain Road, village of Pekin, Niagara County, N.Y. (Ransomville quadrangle). This exposure was described in detail by Crowley and Poore (1974).

Reference Sections: Excellent reference sections are exposed in the Niagara Stone Quarry in Niagara, N.Y.; the southern Niagara River Gorge; and the Frontier Stone quarries at Lockport and Gasport, N.Y.

Thickness: The Pekin Member, like the underlying Gothic Hill Member, is highly variable in thickness, partly as a result of local biohermal buildups. The interval attains a maximum thickness of about 33 ft in the USGS Lewiston-2 core but thins considerably northward. The Pekin averages about 23 ft in thickness in the USGS cores.

Lithologic Description: The reef-bearing Pekin Member is an argillaceous, dark-gray, fine-grained, thin- to medium-bedded dolomicrite (figs. 23, 24). Bioherms locally extend from the top of the grainstones of the Gothic Hill up into the Pekin or from the Pekin itself up into the overlying Goat Island. The Pekin Member consists of three distinct facies assemblages. Facies assemblage A, which is predominant, consists of nonreefal deposits that accumulated east and west of a region containing many bioherms (fig. 23). To the west, facies assemblage A is a medium- to dark-gray, thin- to medium-bedded and slightly nodular, bioturbated dolomudstone to slightly fossiliferous dolowackestone with scattered crinoid ossicles and small rugose corals (*Enterolasma*). To the east, facies assemblage A consists primarily of argillaceous to arenaceous dolomite. Facies assemblage B consists of coral-stromatoporoid framestones forming bioherms up to 20 ft high. The dominant facies consist of pale-buff to greenish-gray, crinkly-weathering micrite with abundant tabulates (*Favosites, Heliolites, Halysites*), colonial rugosans (*Diplophyllum*), and stromatoporoid heads. Facies assemblage C is a dark-gray, coarse, rubbly dolorudite composed of fragments of corals and stromatoporoids in a dark micritic matrix and represents biohermal flank debris. Facies assemblage C contains small-scale, localized halos of abraded reefal material. The dolorudite facies typically extend only a few yards laterally from the bioherms.

Contacts: The lower contact of the Pekin Member with the Gothic Hill Member can be gradational over several inches. Although the upper contact with the Niagara Falls Member of the Goat Island locally appears gradational, it is sharp to gently undulatory in the northern and western parts of the study area. Even in the USGS cores in which the contact is obscure, clusters of celestite crystals in vugs at the top of the Pekin Member suggest possible early diagenetic alteration of this contact. In some areas, the Pekin is truncated beneath the undulatory base of the Niagara Falls Member. At the type locality in Pekin, N.Y., for example, the upper contact with the Goat Island is highly irregular, with as much as 10 ft of relief. This contact appears channelized, and the Pekin Member is completely truncated in parts of the outcrop (Brett and others, 1990b).

Regional Correlations: The Pekin Member is recognized from the Niagara River Gorge eastward to Brockport, N.Y. (figs. 15, 23). In southern Niagara County, as at Lockport, Gasport (in most places), and eastward at least as far as Oak Orchard Creek, the Pekin Member is well developed and ranges from 15 to more than 30 ft thick. East of Brockport, the Pekin Member grades into the laminated sandy dolomites and dolomitic sandstones of the Penfield Formation. West of the Niagara River Gorge, the Pekin Member is partly to completely truncated by an erosional surface beneath the Goat Island Dolomite. At the Highway 403 roadcut near Hamilton, Ont., and at the Highway 20 roadcut in Stoney Creek, Ont., only a thin remnant of the Pekin crops out, which consists of a few inches of shale and argillaceous dolomite. Small (3–5-ft diameter, 1–2-ft high) bioherms with corals and bryozoans protrude upward into this unit. East of Stoney Creek, Ont., the Pekin is apparently missing, as is most of the Gasport, but the Pekin reappears as a thin interval in the Vinemount Quarry.

About 10 ft of dark-gray argillaceous dolomite apparently representing the Pekin Member overlies grainstones of the Gothic Hill in drill cores from Smithville, Ont., southeast of Grimsby, but the Pekin appears to be absent in sections from St. Catharines eastward to the northern end of the Niagara River Gorge. Along the south haul road immediately south of the Robert Moses Powerplant in Lewiston, N.Y., about 7 ft of typically argillaceous dolomite of the Pekin Member underlies the undulatory base of the Niagara Falls Member of the Goat Island Dolomite. In cliffs just north of the powerplant and less than 1 mi north of the outcrop on the south haul road, however, the Pekin is absent, and the basal vuggy bed of the Goat Island, again with a distinctly undulatory basal contact, rests directly on grainstone of the Gothic Hill. Similarly, in parts of the type-section roadcut at Pekin Hill on Route 429 in Pekin, N.Y., the Pekin ranges up to 15 ft thick, but at the southern end of this roadcut, it appears to be completely truncated beneath biohermal beds of the Niagara Falls Member of the Goat Island Dolomite. A similar undulatory contact between the Pekin Member and the Niagara Falls Member is observed at the Frontier Stone Quarry in Gasport.

Age: The Pekin Member is late Wenlockian (Homerian) because it is within the *Ozarkodina sagitta* conodont Zone (Rexroad and Rickard, 1965; LoDuca and Brett, 1991; Kleffner, 1991).

Summary of Revision or Change: The Pekin Member is a new unit, proposed herein, as the upper member of the Gasport Dolomite. It is underlain by the Gothic Hill Member and is overlain by the Goat Island Dolomite.

GOAT ISLAND DOLOMITE
(revised herein)

Brief History of Nomenclature: The Goat Island Dolomite was originally named the Suspension Bridge Dolomite Member of the Lockport Dolomite by Cumings (1939), who defined it as the middle member of the Lockport, overlying the Gasport Dolomite Member and underlying the Eramosa Dolomite Member. Because the name Suspension Bridge was preoccupied (used for a Lower Ordovician formation in New Brunswick), the term was replaced by Goat Island Member of the Lockport Formation by Howell and Sanford (1947). This unit is named for Goat Island, the small island on the brink of Niagara Falls. Bolton (1957) retained the term Goat Island Member of the Lockport Formation in southern Ontario (fig. 21). The same unit was referred to as the Goat Island Member of the Lockport Formation by Zenger (1965) but is considered a formation-level unit by Rickard (1975) (fig. 21). The interval identified herein as the Goat Island Dolomite corresponds to Rickard's (1975) Goat Island and Eramosa intervals (fig. 22). The formal stratigraphic revisions of the Goat Island Dolomite made herein have previously been informally introduced by the authors (Brett and others, 1990a,b, 1991; Tepper and others, 1990; LoDuca and Brett, 1991).

Type Locality: Cliffs on the north escarpment of Goat Island, slightly below the level of the brink of Niagara Falls and between the American and Horseshoe Falls (Niagara Falls quadrangle) (Howell and Sanford, 1947). This type section is poor because it is largely inaccessible.

Reference Sections: Access road for the Sir Adam Beck Powerplant at Queenston, Ont.; south haul road for the Robert Moses Powerplant, Lewiston, N.Y. (designated as the primary reference section by Zenger, 1965); Niagara Stone Quarry, Niagara, N.Y.; Frontier Stone Quarry, Lockport, N.Y.

Thickness: The Goat Island Dolomite has a minimum thickness of 26 ft in the USGS Lewiston–2 core and reaches a maximum thickness of 55.9 ft in the USGS Wheatfield-2 core. It averages about 42 ft in thickness in the nine USGS cores.

Lithologic Description: The lithology of the Goat Island Dolomite is highly variable (figs. 23, 24), but in general, the unit is finer grained and thinner bedded than the Gothic Hill Member of the Gasport Dolomite. The Goat Island Dolomite is divided into three distinct members that are discussed in the next sections: (1) the Niagara Falls Member, a gray to buff, biohermal grainstone; (2) the Ancaster Member[24], a buff, thin-bedded, fine-grained, chert-rich dolomite; and (3) the Vinemount[25] Member, a light to dark gray, thin-bedded, shaly dolomite with some chert.

Contacts: The Niagara Falls Member of the Goat Island Dolomite is underlain by the Pekin Member of the Gasport Dolomite. The Pekin is locally truncated beneath the undulatory base of the Niagara Falls Member. The upper contact of the Vinemount Member of the Goat Island with the Eramosa Dolomite is typically sharp, although fine-grained, argillaceous dolomite resembling the Vinemount lithology is locally present as thin beds in the Eramosa Dolomite.

Regional Correlations: The Goat Island Dolomite has been traced from outcrops northwest of Hamilton, Ont., to Brockport, N.Y. (figs. 15, 23). East of Brockport, the Goat Island appears to be represented by a medium- to thick-bedded interval of relatively fine-grained, sandy dolomite in the upper part of the Penfield Formation.

Age: The Goat Island Dolomite is probably of latest Wenlockian to earliest Ludlovian age (LoDuca and Brett, 1991); see "Age" discussion in next section. The Goat Island spans the uppermost part of the *Ozarkodina sagitta* Zone, and the *Ozarkodina crassa* and *Ancoradella ploeckensis* conodont Zones.

Summary of Revision: The interval identified herein as the Goat Island Dolomite corresponds to Rickard's (1975) Goat Island and Eramosa intervals. The term Goat Island is retained but the upper and lower contacts have been revised. The Goat Island is herein split into three new members, which are discussed in the following sections: (1) the Niagara Falls Member; (2) the Ancaster Member (also revised and extended geographically); and (3) the Vinemount Member (also revised and extended geographically).

[24]Name used in Ontario and not previously formally used in New York; named formally herein.

[25]Name used informally in Ontario and not previously formally used in New York; named formally herein.

NIAGARA FALLS MEMBER
(new unit, proposed herein)

Background: The term Niagara Falls Member was first informally introduced by the authors (Brett and others, 1990a,b, 1991; Tepper and others, 1990; LoDuca and Brett, 1991) and is formally proposed as a new unit herein. This unit includes the "stromatoporoid-cap" facies of Crowley (1973) that he considered to be part of the Gasport although Zenger (1965) assigned it to part of the Goat Island.

Type Section: Outcrop at old sewage-pumping station on the east wall of Niagara River Gorge, west of the intersection of Ashland Avenue and the Robert Moses Parkway, city of Niagara Falls, N.Y. (Niagara Falls quadrangle).

Reference Sections: Niagara River Gorge at various locations, including Goat Island slightly below the caprock of Niagara Falls; Niagara Stone Quarry in Niagara, N.Y.; Frontier Stone quarries at Lockport and Gasport, N.Y.

Thickness: The thickness of the Niagara Falls Member ranges from less than 3 ft at the north end of the Niagara River Gorge to more than 15 ft at the Frontier Stone Quarry in Lockport, N.Y.

Lithologic Description: In the Niagara River Gorge, the Niagara Falls Member is a prominent light-olive to brownish-gray, sucrosic, medium-grained, thick- to massive-bedded, commonly porous and vuggy dolomite (figs. 23, 24). The vugs commonly are filled with sphalerite, gypsum, calcite, and dolomite crystals. Some of these mineral-filled vugs are found in coral and stromatoporoid heads (Brett and Calkin, 1987). The Niagara Falls Member weathers to very light gray (whitish) and is a conspicuous unit near the top of Niagara River Gorge. In the Niagara region, the Niagara Falls Member is similar to the Gothic Hill Member of the Gasport because it locally consists of very coarse, pinkish-gray, crinoidal grainstone with bioherms containing stromatoporoids and favositid and cladoporid corals (Tepper and others, 1990). The small patch reefs of the Niagara Falls Member grade laterally into extensive nonreef areas, where the contact between the Niagara Falls Member and the underlying Pekin is typically obscure (Tepper and others, 1990). From the type locality eastward to Brockport, the Niagara Falls Member typically is biostromal and is characterized by an abundance of stromatoporoids. This interval was referred to as the "stromatoporoid cap facies" by Crowley (1973), although he assigned it to the Gasport Dolomite rather than to the Goat Island Dolomite. East of the Niagara River Gorge, two distinct lithologic units that are informally termed units A and B and are of subequal thickness form the Niagara Falls Member.

UNIT A

The base of unit A can be sharp and form an irregular contact with the underlying Pekin Member of the Gasport Dolomite. At the Route 429 roadcut at Pekin Hill, local channels of the Niagara Falls Member cut through at least 6–7 ft of the Pekin Member. These channeled areas are infilled with a stromatoporoid-rich micritic bioherm that Crowley and Poore (1974) referred to as the "Pekin reef" of the Gasport Formation. The relation of this channel-fill to adjacent facies is complex, but the bioherm clearly rests unconformably atop the Gasport strata (Brett and others, 1990b).

Unit A of the Niagara Falls Member consists of two locally developed facies. One facies consists of pale pinkish-gray to olive-gray, crinoidal, dolopackstone and grainstone that weather to a very light gray color. Stromatoporoids and cladoporid corals are abundant, and small, low (up to 7 ft high) bioherms are locally present that consist of pale micrite with abundant rugose and tabulate corals, pelmatozoan holdfasts, and stromatoporoids. The crinoidal grainstone is closely associated with the bioherms and could represent a halo of debris around them. The other facies of unit A is best developed at the northern end of the Niagara River Gorge and in the adjacent Queenston-St. Catharines area. It consists of thin- to thick-bedded, pale-olive-gray, fine-grained dolowackestone and is extremely vuggy, with yellowish dolomite and sphalerite crystals lining the vugs.

A thin, argillaceous dolomite bed immediately overlies unit A at several localities (for example, Lockport, Clarendon, Brockport) and contains a distinctive *Medusaegraptus* and dendroid graptolite fauna (LoDuca, 1990; LoDuca and Brett, 1991).

UNIT B

The upper interval of the Niagara Falls Member, unit B, is a dark-gray to pale-pinkish-gray massive dolorudite that typically contains a profusion of stromatoporoid heads and favositids. Brett and others (1990b) describe the outcrop of unit B at the Niagara Stone Quarry in Niagara, N.Y., although they refer to what is termed unit B herein as the Niagara Falls C unit.

Contacts: The basal contact of the Niagara Falls Member with the underlying Pekin Member of the Gasport Dolomite is commonly sharp and locally erosional. The upper contact of the Niagara Falls Member is marked by an abrupt change to pale olive-gray, thin-bedded, fine-grained cherty dolomite of the Ancaster Member (new unit, proposed herein), which weathers to light tan. This contact is generally sharp but conformable.

Regional Correlations: The Niagara Falls Member has been traced from Brockport, N.Y., westward to Hamilton, Ont. (figs. 15, 23). West of Hamilton, the Niagara Falls Member grades into the massive carbonates of the Amabel Formation; to the east, it grades into the sandy dolomites of the Penfield Formation. The Niagara Falls Member is a stromatoporoid- and cladoporid-rich packstone and crinoidal grainstone at the southeastern rim of the Frontier Dolomite Quarry in Gasport. At Oak Orchard Creek, the correlative interval is represented by a 3-ft-thick, reddish, hematitic crinoidal packstone (Zenger, 1965). The Niagara Falls Member is represented by a complex interval exposed in the Genesee-Le Roy Stone Quarry at Clarendon. On the southeastern wall of the quarry, the Niagara Falls Member consists of two massive grainstone beds, each about 8 ft thick, split by the *Medusaegraptus*-bearing argillaceous dolomite. In contrast, the northern face of the same quarry displays only a single 8-ft-thick crinoidal grainstone bed. At the Iroquois Stone Quarry (Sweden-Walker Quarry) in Brockport, a 5–6-ft-thick crinoidal grainstone with small coral-stromatoporoid bioherms represents the Niagara Falls Member.

Age: Latest Wenlockian to early Ludlovian; contains the *Ozarkodina sagitta*/*Ozarkodina crassa* conodont Zonal boundary (LoDuca and Brett, 1991).

Summary of Revision: The Niagara Falls Member is a new unit, proposed herein as the lowermost member of the Goat Island Dolomite. Two informal units of the Niagara Falls, units A and B, are introduced herein.

ANCASTER MEMBER
(revised herein and geographic extension)

Brief History of Nomenclature: Nowlan (1935) considered the Eramosa to be a formation in the Lockport Group and included within it the entire section above the Gasport Dolomite and below the Guelph Dolomite. Shaw (1937) recognized two members, the Ancaster and Speedwell, and stated that the Ancaster Member comprised the lower, chert-rich part of the "expanded" Eramosa Formation. Cumings (1939) redefined Eramosa in its original, restricted sense and substituted the name Suspension Bridge for the interval that overlies the Gasport and underlies the Eramosa. Because the term Suspension Bridge was preoccupied, Howell and Sanford (1947) changed the name to Goat Island. The term Ancaster has been used informally in Ontario by Bolton (1957), who stated that the beds immediately above the Gasport at the base of the Goat Island contain plentiful chert nodules and lenses and are consistent throughout the Niagara Peninsula, and he referred to them as the Ancaster chert beds. These chert beds are traceable from Clappison's Corners roadcut east to DeCew Falls; the concentration of chert is greatest in the Hamilton, Ont., area and decreases eastward (Bolton, 1957). Zenger (1965) notes that the lower strata of the Goat Island in the Niagara Peninsula of Ontario are characterized by an abundance of chert nodules and are referred to informally as the Ancaster chert beds. Although he comments that the cherty beds in the lower part of the Goat Island at Albion are probably equivalent to the Ancaster chert beds of Ontario, he does not further discuss their occurrence in western New York. Sanford (1969) informally divides the Goat Island into two members, a lower cherty member termed Ancaster and an upper member, similar to the Ancaster but containing little or no chert. The term Ancaster Member has been used informally by the authors (Brett and others, 1990a,b, 1991; Tepper and others, 1990; LoDuca and Brett, 1991). The Ancaster Member of the Goat Island Dolomite is proposed herein as a formal unit and is geographically extended into the study area from the Niagara Peninsula of Ontario (fig. 4).

Type Locality: Highway 403 roadcut, town of Ancaster, Ont. (Dundas, 30M/5d, Canadian NTS) (Bolton, 1957).

Reference Sections: North end of the Niagara River Gorge; Niagara Stone Quarry, Niagara, N.Y.; Genesee-Le Roy Quarry, Clarendon, N.Y.

Thickness: The Ancaster Member, like the Niagara Falls Member below it, is variable in thickness, and these two units appear to have a compensatory thickening/thinning relation (that is, where the Ancaster is thick, the Niagara Falls is thin, and vice versa). The Ancaster Member ranges in thickness from a minimum of 2 ft at the south end of the Niagara River Gorge to a maximum of 25 ft at the type locality. It thins rapidly in areas where the Niagara Falls Member is a thick, massive grainstone. The unit averages about 12 ft in thickness.

Lithologic Description: The middle part of the Goat Island, herein formally termed the Ancaster Member, is a medium ash-gray, thin- to medium-bedded, fine-grained dolomite (figs. 23, 24). The unit weathers to light tan and typically contains abundant nodules (up to 5 in. across) of distinctive pale, cream-colored chert. The chert nodules commonly contain better preserved original sedimentary fabrics than do the surrounding dolomites and frequently incorporate well-preserved silicified fossils, including the rugose coral *Enterolasma*; the brachiopods *Stegerhynchus*, *Leptaena*, and *Howellella*; gastropods; and, rarely, trilobites. The Ancaster Member is generally cherty throughout its lateral extent, although at the Niagara Stone Quarry in Niagara, N.Y., chert is rather scarce and is absent at the Frontier Stone Quarry in Lockport, N.Y. At several field exposures, a thin, laterally continuous cherty band about 5 ft above the base of the unit contains a profusion of *Whitfieldella* brachiopod valves. The upper 1–2 ft of the Ancaster Member are typically biostromal and contain abundant *Whitfieldella*, corals, and small stromatoporoids.

Contacts: As noted above, the basal contact of the Ancaster Member with the Niagara Falls Member is generally sharp but conformable. Color and texture typically change from dark gray and medium grained below this boundary to pale buff and finer grained above it.

The upper contact of the Ancaster Member with the Vinemount Member is typically sharp, though conformable. A shaly interval with a ground-water seepage zone is recognized at this contact in many outcrops. In the USGS cores, an abrupt upward change to a darker gray and finer grain size is discernible at this contact. As noted above, one or more beds of coarse crinoidal debris are typically observed near the top of the Ancaster Member.

Regional Correlations: Regional stratigraphic correlations and relations for the Ancaster Member are shown in figures 15 and 23, respectively. The Ancaster Member has been traced from Hamilton, Ont., east to Clarendon, N.Y. West of Hamilton, it grades into the massive carbonates of the Amabel Formation, and east of Clarendon, it merges with the thinly bedded, sandy dolomite facies of the Penfield Formation. Although cherty facies appear in the northern and southern extremes of the Niagara River Gorge, the Ancaster Member is largely absent from gorge sections in which a massive Niagara Falls Member occupies most of the thickness of the Goat Island. In contrast, the Ancaster Member, with well-developed chert beds, is predominant in the Niagara Stone Quarry, which is only 2–3 mi east of the Niagara River Gorge sections in which the Ancaster is absent. In drill cores from a hazardous-waste-disposal site in Niagara Falls (near the intersection of Pine Avenue and Packard Road), the cherty facies is largely replaced by dark, argillaceous dolomite. This lateral facies change suggests that a narrow, troughlike depression could have been present in central Niagara County during deposition of the lower part of the Goat Island. In all outcrop sections northeast of this area (Pekin roadcut, Lockport Quarry, Oak Orchard Creek, Clarendon Quarry), a relatively uniform interval of fine-grained, brownish-gray, and generally cherty Ancaster Member overlies grainstones of the Niagara Falls Member. At Oak Orchard Creek, an interval of more than 7 ft of brownish-gray, thinly bedded dolomite with abundant elongate, white chert nodules was misidentified by Zenger (1965, p. 174) as the "Oak Orchard Member" (herein termed Eramosa Dolomite). Zenger notes (p. 67) that the presence of chert nodules is atypical for the "Oak Orchard Member." The anomaly is resolved if this unit at Oak Orchard Creek is recognized as the Ancaster Member of the Goat Island instead of the "Oak Orchard Member." The easternmost exposure of typical Ancaster facies crops out at the Genesee-Le Roy Stone Quarry, 15 mi east of Oak Orchard Creek. This outcrop consists of a 15-ft-thick, thinly bedded, brownish-gray cherty dolomite that closely resembles the outcrop at Oak Orchard Creek.

Age: Early Ludlovian, above the top of the *Ozarkodina sagitta* Zone conodonts.

Summary of Revisions or Changes: The term Ancaster was previously used (beginning with Shaw, 1937) as an informal name for thinly bedded dolomite with distinctive white chert nodules found near Hamilton, Ont. The Ancaster Member is herein defined as a formal unit of the Goat Island Dolomite and is geographically extended eastward to Clarendon, N.Y., from the Niagara Peninsula of Ontario.

VINEMOUNT MEMBER
(revised herein and geographic extension)

Brief History of Nomenclature: Hewitt (1960) was first to make informal reference to the Vinemount shale beds, a section of argillaceous dolomite with abundant shale partings that is 17 ft thick in the Armstrong Brothers Company Limited Vinemount Quarry, in Vinemount, Saltfleet Township, Ont. In the Hamilton, Ont., area, Telford and others (1975) considered this shaly dolomite interval as a distinct mappable unit but referred to it only as an unnamed member. On a map of the Paleozoic geology of the Grimsby, Ont., area by Liberty and others (1976a), the Lockport Formation consists of four members: Gasport Member, Goat Island Member, unnamed member, and Eramosa Member. This unnamed member is identified as argillaceous dolostone and shale of the Vinemount shale beds. On a geologic section across the Niagara Peninsula in Ontario, Telford (1978) shows the Vinemount shale beds pinching out between Hamilton and Niagara Falls. The Vinemount shale beds are referred to as an informal member of the Lockport Formation in Derry Michener Booth and Wahl and Ontario Geological Survey (1989). The stratigraphic interval herein termed the Vinemount Member of the Goat Island Dolomite is the same as that assigned to the Eramosa Dolomite on Rickard's (1975) correlation chart. The term Vinemount Member has been used informally by the authors (Brett and others, 1990a,b, 1991; Tepper and others, 1990; LoDuca and Brett, 1991). The Vinemount Member of the Goat Island Dolomite is proposed herein as a formal unit and is geographically extended into the study area from the Niagara Peninsula of Ontario (fig. 4).

Type Section: Vinemount Quarry, north of Green Mountain Road, in Vinemount, Saltfleet Township, Ont. (Winona, 30M/4g, Canadian NTS).

Reference Sections: Niagara River Gorge; Niagara Stone Quarry, Niagara, N.Y.; Frontier Stone Quarry, Lockport, N.Y.

Thickness: The Vinemount Member in the Niagara region is relatively uniform in thickness—about 17 ft in outcrops, 20 ft in the USGS Grand Island-2 core, and 19 ft in the Wheatfield-1 core. It is anomalously thin (10 ft) in the USGS Niagara-1 core and near Niagara Falls, Ont. (9 ft). At the type section at the Vinemount Quarry near Vinemount, Ont., it is about 18 ft thick.

Lithologic Description: In the Niagara region, the Vinemount Member consists of light- to dark-gray, medium- to thin-bedded, very fine-grained, argillaceous dolomite with thin shale partings (figs. 23, 24). The Vinemount is commonly bituminous and yields a petroliferous odor from fresh surfaces. It locally contains vugs lined with gypsum, sphalerite, calcite, dolomite, fluorite, and galena. Pyrite is locally disseminated throughout this unit. White to bluish-gray chert, typically with a distinctly banded or wood-grained appearance, is found in the upper 5 ft of the unit in several of the USGS cores, and near the base of the Vinemount Member along the south haul road in Niagara River Gorge. On both sides of the gorge near Niagara Falls, the Vinemount consists of about 7 ft of thin-bedded, brownish-gray dolomite with alternating bands (up to 6 in. thick) of bluish-gray chert. Fossils are sparse in the Vinemount Member but include small rhynchonellid brachiopods, gastropods, nautiloids (large *Dawsonoceras*), and small rugose corals. Favositids and stromatoporoids generally are lacking. Farther west, at the type section near Vinemount, Ont., the unit becomes increasingly argillaceous and consists mainly of dark-gray, unfossiliferous shale and highly argillaceous dolomite.

Contacts: At many localities, the contact of the Vinemount Member with the underlying Ancaster Member is conformable but abrupt and is typically demarcated by a 1–2-in. layer of black shale. In some sections within the Niagara Falls area, however, this contact is gradational and difficult to establish. The contact of the Vinemount Member with the overlying Eramosa Dolomite appears gradational in areas where fine-grained argillaceous dolomites of the Vinemount are interfingered with cleaner carbonates over an interval of several feet. In other areas, however, this contact is sharp between the thin-bedded argillaceous dolomites and shales of the Vinemount and the massive, biostromal, vuggy dolomite of the basal Eramosa beds.

Regional Correlations: Regional stratigraphic correlations and relations for the Vinemount Member are shown in figures 15 and 23, respectively. The Vinemount Member has been traced westward from Orleans County, N.Y., to the Steetly quarries near Dundas, Ont. West of Hamilton, Ont., it grades into the massive carbonates of the Amabel Formation. The Vinemount extends eastward at least to Orleans County, N.Y. At Oak Orchard Creek, the Vinemount is represented by the uppermost 4–5 ft of dark brownish-gray, carbonaceous dolomite assigned by Zenger (1965, p. 174) to the "Oak Orchard Member" (unit 12). This unit is the source of the upper Guelph fauna or upper Shelby beds of Clarke and Ruedemann (1903). This unit, however, is actually lower in the section than the interval previously referred to as the "Oak Orchard Member" in the Niagara region. At the Genesee-Le Roy Stone Quarry in eastern Orleans County, the Vinemount consists of about 10 ft of thin-bedded, slightly cherty, fossiliferous gray dolomite. The basal contact is gradational with the underlying cherty Ancaster Member, but the upper contact with the overlying massive lower unit of the Eramosa Dolomite is sharp. Correlation of the Vinemount Member east of Orleans County is difficult, primarily because outcrops are sparse, but this interval probably correlates with an upper fossiliferous interval of the Penfield Formation that is well exposed on roadcuts along Route I–490 near the town of Gates, west of Rochester, N.Y. If this interval is correlative, then the Vinemount is much more widely traceable than previously suspected.

Age: Early Ludlovian.

Summary of Revisions or Changes: The stratigraphic interval herein termed the Vinemount Member is the same as that assigned to the Eramosa Dolomite on Rickard's (1975) correlation chart. The Vinemount Member of the Goat Island Dolomite is herein made a formal unit. It is geographically extended eastward to at least Orleans County, N.Y., from the Niagara Peninsula of Ontario, where it has been considered an unnamed member of the Lockport Formation.

ERAMOSA DOLOMITE
(revised herein)

Brief History of Nomenclature: Williams (1915) proposed the term Eramosa Member for the bituminous dolomites at the top of the Lockport Formation on the Eramosa River between Rockwood and Guelph, Ont. Williams (1919) considered the Eramosa to be conformably overlain by the Guelph Dolomite, which he treated as a separate formation, and underlain by an unnamed dolomite that separated the Eramosa from the Gasport Member. Nowlan (1935) and Shaw (1937) redefined the Eramosa to include the entire section between the Gasport and the Guelph. Cumings (1939) recognized the Eramosa as the uppermost member of the Lockport Dolomite and stated that it is underlain by the Suspension Bridge Member (a name he introduced) and overlain by the Guelph Dolomite. Howell and Sanford (1947) stated that the Eramosa Member overlies the Goat Island Member (a name they introduced) and underlies the Oak Orchard Member (a name they introduced). Bolton (1957) included the bituminous dolomites of Williams (1915) and thin, nonbituminous horizons at or near the top of the Amabel Formation (lateral equivalent of the Lockport Formation) in his Eramosa Member (fig. 21). Zenger (1965) considered the Eramosa a member of the Lockport Formation (fig. 21), overlain by the Oak Orchard Dolomite and underlain by the Goat Island Dolomite, and extending only as far east as the Tonawanda-Lockport area of New York. The Eramosa Dolomite is considered a formation-level unit on Rickard's (1975) correlation chart; it is underlain by the Goat Island Dolomite and overlain by the Guelph Dolomite (figs. 21, 22). The Eramosa Dolomite, as revised herein, corresponds with the lower and middle sections of the Guelph Dolomite as shown on Rickard's (1975) correlation chart (fig. 22). The term Eramosa Dolomite as revised herein has been informally introduced by the authors (Brett and others, 1990a,b, 1991; Tepper and others, 1990; LoDuca and Brett, 1991). It is formally revised herein.

Type Locality: Banks of the Eramosa River between Rockwood and Guelph, Ont. (Guelph-Rockwood, 40P/9b, Canadian NTS), Williams (1915).

Reference Sections: Niagara River Gorge, old sewage-treatment plant access road in Niagara Falls, N.Y.; south haul road (access to Robert Moses Powerplant); Niagara Stone Quarry in Niagara, N.Y.; and the Vinemount Stone Quarry in Vinemount, Ont.

Thickness: The thickness of the Eramosa Dolomite in the Niagara Falls, N.Y., area ranges from about 38 ft to slightly over 50 ft.

Lithologic Description: As originally defined by Williams (1915), the Eramosa Dolomite included at least 50 ft of upper beds of the Lockport in southern Ontario. At its type locality, the Eramosa consists of thick- to thin-bedded, dark-brownish-gray, bituminous dolomite that emits a petroliferous odor. Some horizons contain small white chert nodules.

As defined herein, the Eramosa Dolomite is separate from, and immediately overlies, beds in western New York designated as "Eramosa" by Zenger (1965) that are regarded herein as the Vinemount Member, the uppermost member of the Goat Island Dolomite. The Eramosa Dolomite of western New York, as defined herein, consists of about 50 ft of biostromal, bituminous, medium- to massive-bedded, brownish weathering dolomites (figs. 23, 24) that have previously been assigned to the lower part of the Oak Orchard Member (Zenger, 1965). As noted above, little or none of this unit is present along Oak Orchard Creek; therefore, the name "Oak Orchard" is formally abandoned herein. Because part of the interval formerly named "Oak Orchard" is laterally continuous with the Eramosa Dolomite in Ontario, the term Eramosa Dolomite is herein applied, although the Eramosa facies typically found in western New York differ somewhat from those in Ontario. The eastern facies of the Eramosa Dolomite is characterized by massive, pale-brownish-weathering, vuggy, commonly biostromal dolomite with some intervals of sparsely fossiliferous, medium bedded, flaggy-weathering, brownish-gray, bituminous dolomite and intervals of digitate stromatolites that locally form small biostromes or bioherms. This interval, including several traceable subdivisions, is overlain by a thin, persistent band of light-gray stromatolitic dolomite that forms the base of the Guelph Dolomite, as recognized herein. Equivalence of the Eramosa Dolomite, as revised herein, with Canadian units has been supported by lateral correlations of cores and outcrops between the Niagara and Guelph, Ont., areas. Six major units are recognizable rather consistently in the Niagara region and are designated herein as informal units A through F, as described below.

UNIT A

The basal Eramosa, unit A, is a rather uniform, 7–8-ft-thick, massive, biostromal dolomite. It is characterized by thickets of the ramose tabulate coral *Cladopora*, which are commonly packed together with favositids and (rarely) stromatoporoids in a dark-brownish-gray dolomitic matrix. In some areas, white chert nodules are abundant, particularly in the lower part of this unit. Weathered blocks of this interval are massive and have a distinctive pitted appearance. Although unit A is quite vuggy, it is highly resistant and tends to form overhangs in outcrop.

UNIT B

Unit B is relatively uniform; it is fine grained, sparsely fossiliferous, and bituminous. It is rarely slightly argillaceous and vuggy. It weathers medium bedded to flaggy and tends to form a slight reentrant in cliff profiles. This interval ranges in thickness from about 13 ft to more than 20 ft.

UNIT C

Unit C is a recurrent *Cladopora*-rich biostromal interval (as in unit A) in some localities, but elsewhere it is characterized by distinctive bunlike masses of digitate stromatolites up to 5 ft thick that are sometimes associated with favositid corals. The rock tends to be massive- or thick-bedded, brownish-weathering, saccharoidal dolomite with abundant large vugs, many of which occupy fossil voids. The vugs are typically lined with sphalerite, galena, fluorite, calcite, or dolomite. The variation in the thickness of unit C primarily reflects the distribution of algal buildups.

UNIT D

In outcrop, a flaggy-weathering zone in the lower part of this unit typically forms a reentrant. In outcrop, unit D is a tripartite interval consisting of lower and upper flaggy-weathering, dark-brownish-gray, nonfossiliferous, saccharoidal dolomites that commonly are separated by a somewhat more massive 3–4-ft-thick bed that is locally packed with a distinctive branching form of *Favosites*. This interval, which averages 16.8 ft thick in the USGS cores, is sharply overlain by unit E.

UNIT E

Unit E consists of a regionally widespread, 1–2-ft-thick marker bed of light-gray, laminar, stromatolitic dolomite.

UNIT F

Unit F is a medium-grained, olive-gray dolomite that locally contains scattered oolites and *Favosites*. It averages 7.4 ft thick in the USGS drill cores. Because it resembles unit D, it is included within the Eramosa.

Contacts: The basal contact of the Eramosa Dolomite with the underlying Vinemount Member of the Goat Island Dolomite is relatively sharp in most weathered exposures; locally the contact is gently undulatory. In Niagara County, the contact is at the top of a 1–2-ft-thick bed of crinoid-rich, coarse-grained dolomite at the top of the Vinemount Member. The upper contact of the Eramosa Dolomite with the basal stromatolite marker bed of the overlying Guelph Dolomite is sharp.

Regional Correlations: Regional stratigraphic correlations and relations of the Eramosa Dolomite are shown in figures 15 and 23, respectively. The Eramosa Dolomite is traceable in cores westward to Guelph, Ont. At the Vinemount Quarry near Stoney Creek, Ont., the lower part of the unit is well exposed. No complete exposures of the Eramosa (as defined herein) crop out between Stoney Creek and the Niagara River. In Niagara County, the Eramosa is partly exposed along the Niagara River, and all units are exposed in the Niagara Stone Quarry.

To the east, the Eramosa Dolomite is poorly exposed but the massive basal biostromal beds (4–6 ft thick) crop out in the Clarendon Quarry and along Route I-490 near the junction with Route 531. The basal biostromal beds are present in exposures along Allens Creek near Rochester, N.Y., and at the top of the Penfield Quarry in Rochester.

Age: Ludlovian (Berry and Boucot, 1970, p. 181; LoDuca and Brett, 1991), on the basis of *Ancyrodella ploeckensis* and *Polygnathoides siluricus* Zone conodonts (LoDuca and Brett, 1991; Kleffner, 1991).

Summary of Revisions: The upper and lower contacts of the Eramosa Dolomite have been revised to include about 50 ft of strata that were previously assigned to the lower part of the "Oak Orchard Member" as defined by Zenger (1965) and shown as belonging to the Guelph Dolomite by Rickard (1975). The Eramosa Dolomite, as defined herein, is separate from and directly overlies beds in western New York previously designated as Eramosa by Zenger (1965), and regarded herein as the Vinemount Member of the Goat Island. This revision allows uniformity of nomenclature across the border with Ontario. Six informal units of the Eramosa, units A through F, have been introduced herein.

GUELPH DOLOMITE
(revised herein)

Brief History of Nomenclature: The Guelph Formation was originally designated by Logan (1863); he did not specify a precise type section although he stated that the Guelph was developed in the area of Guelph and Galt, Ont. He also stated that the Guelph Formation appears to be absent in New York. Although Hall (1867) considered the Galt or Guelph Limestone of Canada to be above the Niagara Limestone of Niagara Falls, he included the Galt or Guelph in the Niagara Group. Arey (1892) discovered strata of the Guelph Formation in Rochester, N.Y., where 4 ft of it overlie typical Niagara Limestone. Clarke and Schuchert (1899) included the Guelph Dolomite in the Niagaran but excluded it from the Lockport Dolomite. Clarke and Ruedemann (1903) recognized strata containing two invasions of Guelph fauna into New York as the Upper and Lower Shelby Dolomite. Kindle and Taylor (1913), in their folio on the Niagara quadrangle, recognized Guelph fauna in the upper part of the Lockport Dolomite, which they considered a formation-level unit. Schuchert (1914) observed the precursors of the Guelph fauna in the highest beds of the Lockport Dolomite in Niagara River Gorge. Ulrich and Bassler (1923) included the rocks containing the Guelph fauna in the Lockport Dolomite. Zenger (1965) stated that the "Oak Orchard Member" of the Lockport Formation extends westward into Ontario, where it is called the Guelph Formation. He emphasized that east of Hamilton, in the Niagara Peninsula of Ontario, the Guelph is closer lithologically to the "Oak Orchard" than to the buff, saccharoidal dolomite of the true Guelph. The Guelph is shown on Rickard's (1975) correlation chart as the westward lateral equivalent of the "Oak Orchard Dolomite." The Guelph as revised herein encompasses only the upper part of the stratigraphic interval referred to as the Guelph Dolomite on Rickard's (1975) correlation chart (fig. 22). The term Guelph Dolomite, as formally revised herein, has previously been introduced informally by the authors (Brett and others, 1990a,b, 1991; Tepper and others, 1990; LoDuca and Brett, 1991). Discussions of the Guelph in Ontario are provided by Williams (1919), Shaw (1937), Caley (1940, 1941), Bolton and Liberty (1955), Bolton (1957), and Sanford (1969). The Guelph Formation, which overlies the Eramosa Member of the Lockport Formation, is poorly exposed in the Niagara Peninsula of Ontario (Liberty and others, 1976a,b). The Guelph is described in its type area by Telford (1976).

Type Locality: The name Guelph was first proposed by Logan (1863). Although the Guelph Dolomite is an accepted unit in Canadian literature, the precise type section is not specified.

Reference Sections: The lower beds and the contact with the underlying Eramosa Dolomite are well exposed in the old Penitentiary Quarry near Speedwell Station, 0.5 mi northeast of Guelph (Guelph-Rockwood, 40P/9b, Canadian NTS). Upper parts of the succession are exposed along the Eramosa River at Elora Gorge, north of Guelph (Guelph-Rockwood, 40P/9b, Canadian NTS). Reference sections for the eastern facies of the Guelph in the Niagara River Gorge area include cuts along the east access road to the Robert Moses Powerplant, just west of Military Road, near the Route I-190 underpass in Lewiston, N.Y.

Thickness: The Guelph Dolomite in Ontario probably forms a "great lentil thinning to the southwest toward the Niagara River and to the northwest at Manitoulin Island" (Sanford, 1972). In the intervening region (for example, near Guelph) it attains an unknown thickness, estimated to be between 200 and 300 ft. Only a thin wedge of the Guelph, previously identified as upper beds of the Oak Orchard Member by Zenger (1965), extends into Niagara County; the upper part is replaced by the Vernon Shale.

Guelph strata are nowhere exposed in entirety, but the complete thickness of the unit as defined herein is present in the following USGS cores: Grand Island-2, where it is 37.2 ft thick, including transitional beds into the Vernon Shale; and in the Pendleton-1 core, where it is 35.9 ft thick, including the transition beds.

Lithologic Description: In Niagara County, the Guelph is medium-gray to dark-gray, light-gray to tan weathering, laminated, fine-grained, commonly oolitic dolomite (figs. 23, 24). It is divided herein into three informal units: A, B, and C. The upper transitional beds (herein designated as informal unit C) contain partings of dark greenish-gray to nearly black shale; the shale content increases upward toward the top of the formation. The shale and dolomite facies are petroliferous. The Guelph in Niagara County, N.Y., is sparsely fossiliferous, except for stromatolites. Favositids, small *Whitfieldella* and *Howellella* brachiopods, and possible ostracodes have been identified.

UNIT A

Unit A consists of very light gray, fine-grained, stromatolitic dolomite and is marked by a distinctive and apparently continuous biostromal bed of LLH–SH type stromatolites (based on classification scheme of Logan and others, 1964). These stromatolites form large rounded mounds up to 10 ft across. Lower parts of the stromatolites are laterally linked; laminae are subhorizontal but are gently convex upward with wavy surfaces. Upper (and outer) parts of the mounds display a digitate fabric (0.75–1.25 in. across) and contain columnar stromatolites up to 6 in. high, with dolomicrite and flat-edgewise dolomicrite clasts in narrow interstices. The stromatolites are capped by thrombolites, which can be surrounded by fossil debris, typically *Whitfieldella* and ostracodes. Unit A can be locally oolitic. Part of this interval (6–7 ft) is exposed along the east access road to the Robert Moses Powerplant, just west of Military Road, near the Route I–190 underpass in Lewiston, N.Y. The thickness of unit A in the USGS cores averages 4.0 ft.

UNIT B

Unit B is a 4–6-ft-thick interval of contorted, dark-gray, laminated, oolitic dolomite with partings of black shale. This interval appears to represent stromatolitic sediment that has undergone soft-sediment deformation. The middle beds of this unit are more uniform, medium bluish-gray, oolitic dolomite with thin, dark, shaly partings and beds of small (1–2 in.) intraclasts of dolomicrite. The beds show flaggy weathering in outcrop.

UNIT C

Unit C, at the top of the Guelph Dolomite, forms a transition zone between lithologies typical of the Guelph and those of the overlying Vernon Shale of the Salina Group. Unit C averages 28 ft thick and is similar to unit B but contains minute (1/32–1/8 in.) pits or vugs that apparently are remnant from dissolved evaporite crystals. Unit C also contains many interbedded zones up to several inches thick of fine-grained, olive-gray to greenish-gray, argillaceous dolomite and thin, black or dark-gray, shaly partings. Although the latter closely resemble the dominant lithologies of the overlying Vernon Shale, the predominance of medium-gray oolitic dolomite justifies placement of this transition zone with the underlying Lockport Group.

Contacts: The lower boundary of the Guelph Dolomite with the Eramosa Dolomite is placed at the sharp base of the thick laminar stromatolite zone (unit A). This interval normally lies 7–9 ft above unit E, a thin stromatolite bed of the Eramosa Dolomite. In addition to field and core relations, the basal stromatolitic marker horizon of the Guelph has a distinctive signature (an abrupt positive deflection) on natural-gamma logs (figs. 12, 20). The upper boundary of the Guelph Dolomite in Niagara County is indistinct and difficult to place as a result of the gradual upward transition into the Vernon Shale. The authors have arbitrarily placed the boundary at the base of the first black shale bed that is greater than 1 in. thick, but emphasize that this stratigraphic horizon might not be equivalent in all sections. As such, the Guelph Dolomite contains a higher proportion of gray dolomite than dolomitic shale. In the overlying Vernon Shale, the proportions are more equal.

Regional Correlations: Regional stratigraphic correlations for the Guelph Dolomite are shown in figure 15. The thin tongue of rock herein tentatively assigned to the Guelph Dolomite is atypical of the unit as exposed in Ontario but is apparently the lateral equivalent of it, as indicated by transitional facies at intermediate localities near Hamilton, Ont. The beds herein assigned to the eastern facies of the Guelph Dolomite were previously assigned to the upper part of the "Oak Orchard Member" by Zenger (1965). The basal stromatolite beds are distinctive and traceable into the more typical Guelph facies of Ontario. The thick stromatolitic bed (unit A) is a distinctive marker and is present in all of the USGS cores. Unit A is traceable westward into Canada (Robert Blair, Golder Associates, written commun., 1988). This stromatolitic zone appears in outcrop in a section near the base of the Guelph Dolomite on Highway 403 at Hamilton, Ont. This outcrop and intervening cores appear to establish the continuity of the stromatolitic facies at the base of the Guelph Dolomite west to Hamilton, where it is developed in typical Guelph facies (very light tan-weathering, saccharoidal dolomites). To the north, near Guelph Township, however, the basal layer loses its stromatolitic character and, instead, contains biostromes of small, branching favositids that closely resemble those seen in the upper part of the Eramosa in Niagara County. The Guelph Dolomite therefore appears to grade into more open marine facies to the northwest.

Age: Late Ludlovian, on the basis of *Polygnathoides siluricus* Zone conodonts (Berry and Boucot, 1970; Kleffner, 1991; LoDuca and Brett, 1991).

Summary of Revisions: The lower contact of the Guelph Dolomite is revised herein to be at the base of a thick, regionally extensive stromatolite bed (informal unit A of the Guelph). In Niagara County, the Guelph as revised herein includes about 35 ft of strata previously included in the upper part of the Oak Orchard Member as defined by Zenger (1965), and only the upper part of the stratigraphic interval referred to as the Guelph Dolomite on Rickard's (1975) correlation chart. This revision allows uniformity of nomenclature across the border with Ontario. Three informal units of the Guelph, units A through C, are introduced herein.

SUMMARY AND CONCLUSIONS

A revised stratigraphic nomenclature for the Niagaran Provincial Series has been developed that establishes uniform nomenclature across the Niagara region. This revised nomenclature is primarily intended to apply to the type area in western New York but is applicable to the adjacent regions between Hamilton, Ont., and Rochester, N.Y.

This study builds upon and partly revises the stratigraphic column of Rickard (1975), the most recent correlation of rocks of Silurian age for western New York to be published by the New York State Geological Survey. Changes include establishment of 6 new units, revision of 13 units, and geographical extension of 6 units. Although all of the group names have remained the same, the boundaries of the Medina, Clinton, and Lockport Groups have been revised. Changes at the formation level include use of Canadian nomenclature (for example, Guelph Dolomite) to establish uniformity across the international border; geographical extensions of two formations (Merritton Limestone and Williamson Shale) that had previously been recognized beyond Niagara County but have now been recognized as actually extending into Niagara County; and proposal of two new formations (Devils Hole Sandstone and Cambria Shale). The rank or stratigraphic contacts of eight formations have been revised. In addition to these changes at the formation level, three new members are proposed and two are revised, extended geographically, and proposed as members of the Goat Island Dolomite. Of particular importance to regional correlations are four distinctive, laterally traceable, phosphate-pebble horizons, which are given formal bed-level status. Some new informal units are included in the revised column.

Names for all of the newly established units have been formally reserved through the Geologic Names Committee of the U.S. Geological Survey, and all revisions have been made in accordance with the North American Stratigraphic Code.

As revised herein, the Medina Group consists of the following seven formations, in ascending order: the Whirlpool Sandstone, the Power Glen Shale, the Devils Hole Sandstone, the Grimsby Formation, the Thorold Sandstone, the Cambria Shale, and the Kodak Sandstone. New formations proposed herein include the Devils Hole Sandstone and the Cambria Shale. In addition, a newly recognized distinctive, laterally traceable phosphate-pebble bed at the base of the Grimsby Formation is herein formally proposed as the Artpark Phosphate Bed. Stratigraphic contacts of the Power Glen Shale and the Grimsby Formation have been revised. The Thorold Sandstone and the Kodak Sandstone are herein included in the Medina Group rather than in the Clinton Group.

The Clinton Group has been divided into the following eight formations: the Neahga Shale, the Reynales Limestone, the Merritton Limestone, the Williamson Shale, the Rockway Dolomite, the Irondequoit Limestone, the Rochester Shale, and the DeCew Dolomite. The Merritton Limestone, the Second Creek Phosphate Bed, the Williamson Shale, and the Salmon Creek Phosphate Bed have been extended into the Niagara Falls area from areas to the east in which they were previously recognized. Stratigraphic contacts of the Irondequoit Limestone have been revised. The Rockway is raised herein to formation rank.

As revised herein, the Lockport Group consists of the following four formations: the Gasport Dolomite, the Goat Island Dolomite, the Eramosa Dolomite, and the Guelph Dolomite. The Gasport Dolomite consists of two newly proposed members: a lower grainstone termed the Gothic Hill Member and an upper, argillaceous, wackestone termed the Pekin Member. The Goat Island Dolomite contains three newly proposed members: a lower biohermal and grainstone unit termed the Niagara Falls Member; a middle, cherty, wackestone termed the Ancaster Member (also revised and geographically extended); and an upper, argillaceous, wackestone and shale unit termed the Vinemount Member (also revised and geographically extended). The Eramosa and Guelph Dolomites are not formally subdivided, although several informal units are recognized herein within each formation. Stratigraphic contacts of the Gasport Dolomite, Goat Island Dolomite, Eramosa Dolomite, and Guelph Dolomite have been revised.

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