MISCELLANEOUS RELEASE—DATA 219

PALEOZOIC GEOLOGY OF SOUTHERN ONTARIO

PROJECT SUMMARY
AND
TECHNICAL DOCUMENT

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Table of Contents

List of Figures

List of Tables

Introduction

The province of Ontario has developed legislation that will see the implementation of Source Water Protection Plans across much of the province. A Technical Experts Committee (TEC) struck by the province in late 2003 identified a number of critical data sets required for source protection planning. One of the geologic data sets identified was a GIS-based Paleozoic bedrock geology map for southern Ontario. In response to this and other demands for readily accessible and easily understood information on the bedrock geology of southern Ontario, the Ontario Geological Survey (OGS) has generated this GIS-based, seamless map of the Paleozoic geology for the region.

Over the past 33 years the Ontario Geological Survey (OGS) has conducted Paleozoic mapping, primarily at a scale of 1:50 000, over most of southern Ontario. This mapping has provided a wealth of information on the stratigraphy, paleontology and potential mineral resources of the Paleozoic bedrock. Over the years, users of these maps have been many and the uses varied. However, with increased usage of digital mapping software, and demand from clients for readily accessible, user-friendly, geology maps the existing map tiles have many limitations for use in the digital world. Generation of this seamless, attributed GIS-based Paleozoic map, for not only source water protection applications but more traditional uses as well, provides users with a flexible, easily used and understood product.

Paleozoic Stratigraphy of Southern Ontario

A stratigraphic chart for the Paleozoic bedrock of southern Ontario is presented in Table 1 and is briefly described in this section. For a more detailed overview, including detailed descriptions of specific units, please see Johnson et al. (1992) or Armstrong and Carter (2006). Other good overviews include Winder and Sanford (1972) and Sanford (1993).

CAMBRIAN

Outcrops of Cambrian rocks are limited in Ontario to the eastern part of the province. Cambrian strata also occur deep in the subsurface of southwestern Ontario. Key references for the Cambrian of Ontario include Sanford and Quillian (1959), Trevail (1990), Bailey (2005).

POTSDAM GROUP

In eastern Ontario Cambrian strata consist of sandstones and conglomerates of the Covey Hill and overlying Nepean Formation, which together form the Potsdam Group (Table 1; Johnson et al. 1992).

Covey Hill Formation: The Covey Hill is characterized by feldspathic conglomerates and impure sandstones. This formation is exposed as small, isolated erosional remnants in fault blocks south of Perth, west of Westport and in the Rockland area, east of Ottawa.

Nepean Formation: The Nepean Formation is dominated by quartzose sandstones with minor conglomerates. In the Kingston area, the Nepean Formation contains a subaerial facies (Wolf and Dalrymple 1984, 1985) with large-scale cross-bedded eolian dunes.

CAMBRIAN UNITS IN THE SUBSURFACE OF SOUTHWESTERN ONTARIO

In the subsurface of southwestern Ontario, Cambrian strata consist of sandstones and dolostones that have been subdivided into 3 formations (Sanford and Quinlan 1959; Trevail 1990) that can be grossly characterized as a basal sandstone-dominated unit, a mixed sandstone-dolostone unit and an upper dolostone-dominated unit. In the western part of this region, Michigan Basin terminology (Mount Simon, Eau Claire and Trempealeau formations) is applied, whereas to the east, Appalachian Basin terms (Potsdam, Theresa and Little Falls formations) are applied (Table 1). These units are discussed more fully in Armstrong and Carter (2006) and Bailey (2005). In New York, Cambrian sandstones previously called the Theresa Sandstone are now called the Galway Formation (*see* Hersi et al. 2003) and the term Theresa Formation is applied to Lower Ordovician sandstones (see below).

ORDOVICIAN

Ordovician strata are widespread in southern Ontario, occurring at or near surface throughout eastern and south-central Ontario and in the subsurface of southwestern Ontario. Key references for the Ordovician of southern Ontario include Sanford (1961), Liberty (1969), Wilson (1946), Williams (1991) and Bernstein (1992).

Lower Ordovician

BEEKMANTOWN GROUP

Lower Ordovician strata are limited in distribution to eastern Ontario, where they consist of, in ascending order, the March and Oxford formations, which together form the Beekmantown Group, (Table 1; Johnson et al. 1992; Williams 1991).

March Formation: The March Formation consists of quartz sandstones, dolomitic sandstones and dolostones. Although previously interpreted to conformably overlie quartz sandstones of the Nepean Formation, recent studies (Dix et al. 2004) show this to be a disconformable contact. Recent workers also correlate much of what has been called the March Formation in Ontario with the Theresa Formation of Quebec and northeastern New York (Bernstein 1992; Hersi et al. 2003).

The grey-weathering dolomitic sandstones and dolostones of the March Formation (=Theresa) disconformably overlie lighter coloured, quartzose sandstones of the Nepean

Formation. This boundary was recently repositioned downward by 1.5 m at the Nepean Formation type section located on Highway 417, west of Ottawa (Dix et al. 2004).

Oxford Formation: The Oxford Formation consists mainly of brown-grey to green-grey, thin- to thick-bedded, very fine- to medium-crystalline dolostone, with local thin glauconitic shale beds, and quartz sandstone and shaly dolostone interbeds becoming more common towards the base (Johnson et al. 1992). Algal laminae and calcite-filled vugs are common (Williams 1991). The Oxford Formation is approximately equivalent to the Beauharnois Formation of Quebec (Globensky 1982) or to the Beauharnois and Carillon formations of Bernstein (1992).

Middle Ordovician

ROCKCLIFFE FORMATION

The Rockcliffe Formation is limited in its distribution to eastern Ontario. It is subdivided into a lower member consisting of light coloured quartz sandstones with interbeds of dark grey to maroon shales, and an upper member consisting of interbedded dark shales, quartz sandstones, shaly bioclastic limestone and silty dolostone (Johnson et al. 1992; Williams 1991). Eastward, towards Quebec, the upper member (also called the St. Martin Member) contains thick cross-bedded crinoidal grainstones. Although these 2 members were identified on some published OGS maps, they are combined for the purpose of this seamless map.

Hersi and Dix (1997) re-assigned the upper member of the Rockcliffe Formation (and some of the overlying Shadow Lake Formation) to a new stratigraphic unit called the Hogs Back Formation. They noted a disconformable contact between the upper (=Hogs Back) and lower members of the Rockcliffe Formation and a sharp but apparently conformable contact of the upper member (=Hogs Back) with the overlying Shadow Lake (or lower Pamelia) Formation.

SIMCOE GROUP

The Simcoe Group consists of 5 units, in ascending order: the Shadow Lake, Gull River, Bobcaygeon, Verulam and Lindsay formations (Table 1; modified from Liberty 1969). The Simcoe Group is equivalent to the Ottawa Group of eastern Ontario (Williams 1991) and to the combined Black River and Trenton groups of the subsurface of southwestern Ontario (Armstrong and Carter 2006). Simcoe Group (and Ottawa Group) rocks outcrop across eastern and south-central Ontario.

Shadow Lake Formation

The Shadow Lake Formation consists of red and green sandy shales, shaly arkosic sandstones and impure silty dolostones. It unconformably overlies the Precambrian basement and disconformably overlies Cambrian or Lower Ordovician units where they are present. Its contact with the underlying Rockcliffe Formation in eastern Ontario has been described as disconformable (Williams 1991; Johnson et al. 1992) or conformable

(Hersi and Dix 1997). Where the Shadow Lake Formation directly overlies Precambrian basement, its thickness is quite variable (from 0 to 15 m) due to the paleotopography of the basement surface.

The Shadow Lake Formation is approximately equivalent to the lower part of the Pamelia Formation (Wilson 1946), a term which continues to be used in eastern Ontario, Quebec and New York State (*see* Hersi and Dix 1999).

Gull River Formation

The Gull River Formation is characterized by very fine-grained (lithographic to sublithographic or micritic), light grey to brown limestones, with variable, yet typically sparse fossil content, and greenish grey, tan-weathering, argillaceous to silty dolostone beds becoming more prevalent towards the base of the formation. Minor shales and thin sandstone beds are locally present. Fossil content is generally higher in the upper part of the formation with locally abundant Tetradium corals, calcite-filled bivalves or large stromatolites.

On OGS maps the Gull River Formation has been variously subdivided into 2 or 3 members. These member subdivisions are retained on a map-by-map basis as sub-units for this project, so only the formation as a whole is seamless from map to map.

Bobcaygeon Formation

The Bobcaygeon Formation is characterized by brown to grey-brown, fossiliferous limestones, with calcarenites (crinoidal grainstones with tabulate corals and stromatoproids) and nodular textures common in the lower part (lower member) and thin shale interbeds or partings and tabular, calcarenitic storm beds more prevalent in the upper parts. The Bobcaygeon Formation is variously subdivided into 2 or 3 informal members. Where the members were mapped, they have been included as sub-units on the seamless map.

In the Lake Simcoe area the Bobcaygeon Formation spans the boundary between the Black Riveran and Trentonian stages, with the boundary located at or near the top of the lower member (Melchin et al. 1994). The lower member is approximately equivalent to the Coboconk Formation and the middle and upper members approximately equivalent to the Kirkfield Formation of the subsurface of southwestern Ontario (Table 1; Armstrong and Carter 2006). Generally the middle and upper members (or upper member where only 2 are mapped) are shalier than the lower member.

Verulam Formation

The Verulam Formation gradationally overlies the Bobcaygeon Formation and consists of interbedded bioclastic to very-fine grained limestone and grey-green calcareous shale. The upper few metres of the Verulam Formation contain more abundant coarse-grained calcarenites (bio- and intraclastic grainstones and rudstones) which are locally mapped as a separate upper member. The Verulam is approximately equivalent to the Sherman Falls

Formation in the subsurface of southwestern Ontario (Table 1; Armstrong and Carter 2006), with the upper member being equivalent to the "Sherman Fall fragmental".

Lindsay Formation

The Lindsay Formation consists mainly of fine- to coarse-grained, fossiliferous, commonly nodular, argillaceous limestone. Over much of its outcrop and subcrop belt the uppermost part of the formation consists of black, organic-rich, fissile (i.e., shaly), very fine-grained limestone called the Collingwood Member (Table 1). In some areas (e.g., Prince Edward County), the remainder of the formation (i.e., its lower member) is subdivided into 2 sub-members. In eastern Ontario the upper member of the Lindsay Formation is called the Eastview Member (Table 1; Johnson et al. 1992). In the subsurface of southwestern Ontario, strata approximately equivalent to the Lindsay are called the Cobourg Formation (Table 1).

Upper Ordovician

BLUE MOUNTAIN FORMATION AND BILLINGS FORMATION

The Blue Mountain Formation consists of dark blue-grey to brown to black shale with thin interbeds of limestone or calcareous siltstone becoming more prevalent upwards. It gradationally overlies the Collingwood Member of the Lindsay Formation or sharply overlies the lower member of the Lindsay where the Collingwood is absent (Table 1). In eastern Ontario the Billings Formation is equivalent to the Blue Mountain (Table 1). Due to their shaly nature both the Blue Mountain and Billings formations are poorly exposed.

GEORGIAN BAY FORMATION AND CARLSBAD FORMATION

The Georgian Bay Formation gradationally overlies the Blue Mountain Formation and consists of interbedded grey-green to dark grey shale and fossiliferous calcareous siltstone to limestone. Non-shale beds are thicker and more laterally continuous than in the underlying Blue Mountain Formation. The equivalent unit in eastern Ontario is the Carlsbad Formation (Table 1).

QUEENSTON FORMATION

The Queenston Formation is characterized by red shale; however, it also contains red siltstone, minor green shale and siltstone, with variable calcareous siltstone to sandstone and limestone interbeds (Johnson et al. 1992). This formation outcrops below the Niagara Escarpment from Niagara Falls to Cabot Head on the Bruce Peninsula. The Queenston Formation gradationally overlies the Georgian Bay Formation and the Carlsbad Formation in eastern Ontario (Table 1).

SILURIAN

Silurian strata are generally well exposed along the Niagara Escarpment. The Silurian Period was traditionally subdivided into Early, Middle and Late epochs; however, recently these have been revised to Early and Late (*see* Norford 1997). The traditional 3-

fold subdivision worked well in Ontario as it roughly corresponded with lithologic groupings: Lower Silurian mixed siliciclastics and carbonates (i.e., the Clinton and Cataract Groups), Middle Silurian carbonates (i.e., the Lockport, Amabel and Guelph formations), and Upper Silurian evaporites, shales and carbonates (i.e., the Salina, Bertie, and Bass Islands formations). Now the Lower to Upper Silurian boundary is thought to be somewhere within the lower Guelph Formation (Norford 1997). Key references for the Silurian of southern Ontario include Sanford (1969b), Bolton (1957) and Brett et al. (1995).

Lower Silurian

CLINTON-CATARACT GROUP

Lower Silurian shale, sandstone and carbonate units occurring along the base of the Niagara Escarpment have been combined into 2 stratigraphic groups, the Clinton and overlying Cataract (Bolton 1957; Johnson et al. 1992). More recent studies have suggested significant revisions to the stratigraphic nomenclature of these units (e.g., Brett et al. 1995). However, for the purpose of this project, and due to the limitations of map scale, all of the units occurring between the Queenston Formation and the Lockport or Amabel formations are grouped into a combined Clinton-Cataract Group. Where specific constituent formations were shown on the original OGS maps they are indicated as "sub-units" in the seamless map.

On the Niagara Peninsula the Clinton-Cataract Group includes, in ascending order: quartz sandstones of the Whirlpool Formation, dolostones of the Manitoulin Formation, grey to red shales of the Cabot Head Formation, red sandstones and shales of the Grimsby Formation, grey-green to white sandstones of the Thorold Formation, dark to green-grey shales of the Neahga Formation, dolostones and argillaceous dolostones of the Reynales Formation, crinoidal limestones of the Irondequoit Formation, grey shales and limestones of the Rochester Formation and argillaceous dolostones of the Decew Formation. Many of these units pinch out or are cut by disconformities to the west and north. Between the Niagara and Bruce peninsulas the Clinton-Cataract Group consists of the Whirlpool, Manitoulin, Cabot Head, and Reynales and/or Fossil Hill formations.

On the Bruce Peninsula and Manitoulin Island the Clinton-Cataract Group includes, in ascending order: the Manitoulin, Cabot Head, Dyer Bay, Wingfield, St. Edmund and Fossil Hill formations. The units between the Cabot Head and Fossil Hill formations are progressively truncated by a sub-Fossil Hill Formation disconformity southward on the Bruce Peninsula (Armstrong and Goodman 1990).

LOCKPORT FORMATION

The Lockport Formation is essentially restricted in the outcrop belt to the Niagara Peninsula, where it has been subdivided into 3 members: in ascending order, they are the Gasport, Goat Island, and Eramosa members (Table 1). The first 2 members are commonly combined on OGS maps. An additional "un-named" member, informally known as the Vinemount shale beds, is locally developed above the Goat Island Member and is combined with the lower 2 members on OGS maps. Assignment of the Eramosa Member to the Lockport Formation (Bolton 1957) is presently under review by the OGS. Some workers have suggested re-assigning it to the overlying Guelph Formation (e.g., Armstrong 1993; Armstrong and Goodman 1990) or elevating it to formational status (e.g., Brett et al. 1995, Brunton et al. 2005). For the purpose of this report the stratigraphic position of the Eramosa Member is left as it was originally mapped: member of the Lockport Formation on the Niagara Peninsula; member of the Amabel Formation from Burlington to the Guelph area; and member of the Guelph Formation on the Bruce Peninsula.

The Gasport Member is characterized by thick-bedded, blue-grey, crinoidal, limestones to dolostones. The Goat Island Member consists mainly of light brown, locally cherty, thin- to medium-bedded dolostones. The Vinemount shale beds (= “un-named” member) consist of argillaceous dolostones and shale. The Eramosa Member in the Niagara Peninsula area is characterized by thin- to thick-bedded, bituminous, locally laminated, dark brown dolostones.

AMABEL FORMATION

The Amabel Formation is characterized by white to blue-grey, thick- to massive-bedded, dolostones, which form the white cliffs of the Niagara Escarpment north from the Dundas-Burlington area to Manitoulin Island. The light coloured, massive-bedded dolostones of the Amabel include crinoidal grainstones and fossiliferous biohermal facies. South of the Guelph area, bituminous thin-bedded dolostones overlying the light coloured massive dolostones, have been mapped as the Eramosa Member of the Amabel Formation (see discussion above). The remainder of the Amabel Formation in this area has not been subdivided. In the Bruce Peninsula area, the Amabel Formation is subdivided into the Lions Head and Wiarton/Colpoy Bay members (e.g., Armstrong 1993). The Lions Head Member consists of thin- to medium-bedded, grey to grey-brown, fine-crystalline dolostones. The overlying Wiarton/Colpoy Bay Member (previously Wiarton and Colpoy Bay members of Liberty and Bolton 1971) is similar to the unsubdivided Amabel Formation of the Burlington to Guelph area. As described above, bituminous dolostones of the Eramosa Member, previously assigned to the Amabel Formation on the Bruce Peninsula, have been mapped as a unit within the overlying Guelph Formation (e.g., Armstrong 1993).

On Manitoulin Island, OGS geologists mapped the Amabel Formation using a lithofacies-based technique, so the stratigraphic subdivisions recognized elsewhere in this formation were not portrayed there (e.g., Johnson and Telford 1985). The lithofacies are portrayed on the seamless map as sub-units of the Amabel Formation.

The Amabel Formation is thought to be approximately equivalent to the Lockport Formation and the upper units of the Clinton Group (*see* Armstrong and Carter 2006). On the seamless map the Amabel and Lockport formations are portrayed as equivalent units.

Upper Silurian

GUELPH FORMATION

The Guelph Formation is characterized by tan to brown, medium- to very thick-bedded, fine- to medium-crystalline, sucrosic dolostones. Its outcrop-subcrop belt runs parallel to and west or south of the Niagara Escarpment. It is generally not well exposed, except on the Bruce Peninsula and at a few localities in the Guelph-Cambridge area. Various depositional facies (e.g., barrier complex, patch reef belt, etc.) have been mapped in the subsurface of southwestern Ontario (e.g., Sanford 1969b) where this unit hosts significant oil and gas reservoirs. OGS mapping on the Bruce Peninsula (e.g., Armstrong 1993) subdivided the Guelph into a number of lithofacies which are portrayed in the seamless map as sub-units. Two of these lithofacies represent the represent the Eramosa Member in this region.

SALINA FORMATION

The Salina Formation consists of thin-bedded, argillaceous dolostones and shales, with beds and nodules of gypsum in the near-surface and thick salt beds in the deep subsurface (Armstrong and Carter 2006; Sanford 1977; Carter 1987). The unit is very poorly exposed due to its shale content and the high solubility of its evaporite minerals. Its distribution is largely based on subsurface records.

BERTIE FORMATION

The Bertie Formation consists of a variety of brown to grey, argillaceous, laminated, bituminous and burrowed dolostones. The Bertie has been subdivided into 5 members, but these are not shown on OGS maps. The Bertie has been mapped on the Niagara Peninsula from Fort Erie to north of Simcoe where it was interpreted to grade laterally into the Bass Islands Formation. Haynes and Parkins (1992), however, report that the Bertie Formation is progressively cut by the Bass Islands Formation from Dunnville to Hagersville. Both the Bertie and Bass Islands occupy the same stratigraphic position, above the Salina and beneath Devonian strata, so they have been portrayed as equivalent units on this map.

BASS ISLANDS FORMATION

The Bass Islands Formation consists of dark brown to light grey-tan, very fine- to fine-crystalline, variably laminated, mottled, argillaceous or bituminous, very fine- to fine-crystalline and sucrosic dolostones (Armstrong and Carter 2006). As discussed above, the relationship between the Bass Islands and Bertie formations is complex: although the Bass Islands appears to be younger, at least in part, than the Bertie, both of these units are reported to conformably overlie the Salina Formation. The Bass Islands Formation is poorly exposed west of Hagersville, occurring in a narrow belt that extends to MacGregor Point on Lake Huron.

DEVONIAN

Devonian strata underlie most of southwestern Ontario; however, they are mostly covered beneath Quaternary sediments. The Lower and Middle Devonian units are dominated by limestones and dolostones, whereas, Upper Devonian strata are dominated by shales. Key references for the Devonian stratigraphy of southern Ontario include Birchard et al. (2004), Rickard (1984), Uyeno et al. (1982) and Sanford (1968).

Lower Devonian

ORISKANY FORMATION

The oldest Devonian strata preserved in southern Ontario are the grey to yellowish white, coarse-grained, thick- to massive-bedded, calcareous quartzose sandstones of the Oriskany Formation (Armstrong and Carter 2006; Uyeno et al. 1982). This unit has a very limited distribution, with outcrops known only in the Cayuga to Hagersville area, Haldimand County. This is because the Oriskany is bounded above and below by disconformities (the basal disconformity marks the boundary between the Silurian and Devonian) and so only erosional remnants of this unit have been preserved.

BOIS BLANC FORMATION

The Oriskany Formation is disconformably overlain by the grey to brown, very cherty, fossiliferous, argillaceous limestones and dolostones of the Bois Blanc Formation (Uyeno et al. 1982). Thin beds of glauconitic quartz sandstone that occur near the base of the Bois Blanc are assigned to the Springvale Member (this member is not shown on OGS maps). The Bois Blanc Formation outcrops and subcrops in a narrow belt from Fort Erie on the Niagara River to MacGregor Point on Lake Huron. North of Norfolk County outcrops of this unit are sparse.

Middle Devonian

ONONDAGA FORMATION

The Onondaga Formation consists of a range of rock types including variably cherty, fossiliferous, or argillaceous limestones, with locally developed bioherms and minor shales. It has been subdivided into 3 members: in ascending order, the Edgecliffe, Clarence and Moorehouse members (Uyeno et al. 1982). The Onondaga Formation and its members have been mapped in the southern Niagara Peninsula area as far west as Norfolk County. The 3 members are shown as sub-units in the seamless map. The Onondaga Formation in Ontario is considered to be approximately equivalent to the Detroit River Group (Johnson et al. 1992). On the seamless map it is portrayed as equivalent to the Amherstburg Formation. Younger Onondaga Formation strata in New York are considered equivalent to the Dundee Formation (Rickard 1984; Uyeno et al. 1982).

DETROIT RIVER GROUP

The Detroit River Group consists of limestones, dolostones and minor sandstones that outcrop (very poorly) and subcrop (beneath Quaternary cover) in a belt from northern Norfolk County to southern Bruce County. It also occurs, again mostly in subcrop, in the extreme southwest of the Province in Essex County. The Detroit River Group consists of 3 formations: in ascending order, the Sylvania, Amherstburg and Lucas formations (Table 1). The Sylvania Formation consists of quartzitic sandstone and is only known in Ontario in the subsurface of Essex, Kent and Lambton counties (Sanford 1968; Telford and Russell 1981).

Amherstburg Formation: The Amherstburg Formation consists of tan to grey-brown to dark brown, fine- to coarse-grained, bituminous, commonly cherty, fossiliferous limestones and dolostones (Armstrong and Carter 2006). In Bruce and Huron counties, the Amherstburg Formation contains abundant stromatoporoid-dominated, limestone bioherms that have been mapped as the “Formosa Reef Limestone” (Uyeno et al. 1982). The Formosa Reef Limestone is portrayed as a sub-unit in the seamless map. Where the Amherstburg Formation is cherty it is difficult to distinguish from the underlying Bois Blanc Formation.

Lucas Formation: Sharply, but conformably overlying the Amherstburg Formation are limestones, dolostones, anhydritic beds and local sandy limestones of the Lucas Formation. Uyeno et al. (1982) subdivided the Lucas Formation into 3 lithologically based units: the Lucas Formation undifferentiated, the Anderdon Member limestone and the Anderdon Member sandy limestone. The undifferentiated Lucas consists of thin- to medium-bedded, light to grey-brown, fine-crystalline, poorly fossiliferous dolostone and limestone with stromatolitic laminations. The Anderdon Member consists mainly of light to dark grey-brown, thin- to medium-bedded, fine-grained, sparsely fossiliferous limestone, alternating with coarse-grained bioclastic limestone. Locally, the Anderdon contains medium- to massive-bedded, medium- to coarse-grained, fossiliferous sandy limestones. These members and facies are not portrayed on OGS maps or on the seamless map. Recent work by Birchard et al. (2004) provides a more detailed description of the Lucas Formation and its stratigraphic relationships.

DUNDEE FORMATION

The limestones of the Dundee Formation disconformably overlie the Lucas Formation. The Dundee Formation subcrops, and rarely outcrops, over a broad belt extending from Norfolk and Elgin counties on Lake Erie to Huron County on Lake Huron. It also subcrops to the southwest in Essex County. The Dundee Formation consists of grey to tan to brown, fossiliferous, medium- to thick-bedded limestones and minor dolostones, with bituminous partings, oil staining, and locally abundant chert nodules (Johnson et al. 1992). Its sharp, disconformable basal contact with the laminated limestone of the Lucas Formation is clearly exposed in the St. Marys Quarry (Armstrong and Carter 2006).

MARCELLUS FORMATION

The Marcellus Formation is not exposed at surface in Ontario. It subcrops beneath Quaternary sediments along the north shore of central Lake Erie and extends into the subsurface beneath the lake. It consists of black, organic-rich shale with interbeds of grey shale and impure carbonates (Johnson et al. 1992; Johnson et al. 1989).

HAMILTON GROUP

The Hamilton Group is a calcareous shale-dominated unit with relatively thin carbonate-dominated intervals. It is subdivided into 6 formations: in ascending order, the Bell, Rockport Quarry, Arkona, Hungry Hollow, Widder and Ipperwash formations (Table 1; Uyeno et al. 1982). The Rockport Quarry, Hungry Hollow and Ipperwash formations contain more limestone beds than the other formations. The Hamilton Group is very poorly exposed in a belt from southern Lake Huron to western Lake Erie. Three of its constituent units are well exposed at the Rock Glen Conservation Area near Arkona (*see* Armstrong and Carter 2006).

Upper Devonian

KETTLE POINT FORMATION

The Kettle Point Formation consists of brown to black, laminated, organic-rich shales and siltstones with minor green, bioturbated shales and siltstones and carbonate concretions in the lower part. It disconformably overlies units of the Hamilton Group. Only one outcrop is known, at Kettle Point on the shore of Lake Huron.

PORT LAMBTON GROUP

The youngest Paleozoic unit in southern Ontario is the Port Lambton Group. It is of Upper Devonian to possibly Lower Mississippian age and consists of, in ascending order: grey shales of the Bedford Formation, grey sandstones, shales and minor siltstones of the Berea Formation and black shales of the Sunbury Formation (Table 1; Johnson et al. 1992). The Port Lambton Group is not exposed in Ontario, but mapped in western Lambton County based on subsurface data.

Data Sources

OGS PALEOZOIC BEDROCK GEOLOGY MAPS

The seamless map project covers all of southern Ontario underlain by Paleozoic age bedrock, excluding Cockburn and St. Joseph islands. The OGS has published a total of 56 1:50 000 scale maps covering 82 complete or partial National Topographic System (NTS) map sheets in the project area (Figure 1). These original maps are individually available from the OGS in digital format. Two regions in southern Ontario (labelled “m2544” on Figure 1), covering approximately 41 NTS sheets, do not have detailed map coverage due to the thick cover of glacial drift that exists in these regions. Currently, the only available digital bedrock map for these thick-drift areas is the Geology of Ontario (GoO) Bedrock Geology of Ontario, Southern Sheet (OGS Map 2544), published at a scale of 1:1 000 000 (OGS 1991). This map was used as a base in thick-drift areas, with revisions made using other data sources from those listed below.

OTHER BEDROCK GEOLOGY MAPS

Geological Survey of Canada Maps

Regional scale bedrock geology maps published by the Geological Survey of Canada were used in attempting to resolve "boundary fault" issues along the margins of thick-drift areas. These maps include Figure 1 (back pocket) in Uyeno et al. (1982), maps by Sanford (1969a) and those published in association with GSC papers by Liberty and Bolton (1971) and Liberty (1969).

Bedrock Maps in Aggregate Resources Inventory Papers

The OGS produces Aggregate Resources Inventory Papers (ARIPs) and associated maps for Ontario. Most ARIPs include a map of bedrock aggregate resources that is based on a published bedrock geology map for the inventory area. In the area between Meaford and Owen Sound there are no published bedrock maps, so the bedrock resources maps for the ARIPs in this area were used for the seamless map. These ARIP maps were based on bedrock information derived from Quaternary geology maps by B.H. Feenstra (Feenstra, unpublished; Feenstra 1994). Some of the contacts were subsequently revised based on field investigations (see below).

OTHER DATA SOURCES

Additional data sources included water well records, petroleum exploration well records and OGS Miscellaneous Release—Data (MRD) 207, an updated digital topographic map of the bedrock surface for southern Ontario (Gao et al. 2006). Petroleum exploration well data was accessed through the Ministry of Natural Resources' (MNR) Ontario Petroleum Data System (OPDS) database. The new bedrock topographic map for southern Ontario (MRD 207) was generated utilizing bedrock top elevation data from the OPDS, the Ministry of the Environment's extensive water well database and other subsurface data sources (*see* Gao et al. 2006).

In the Kitchener–Waterloo–Cambridge area, subsurface data from MRD 205 (Bajc and Hunter 2006) and unpublished borehole data from the Regional Municipality of Waterloo were used to help resolve "boundary fault" issues for this project.

FIELD INVESTIGATIONS

Field investigations for this project were conducted mainly during the 2006 field season. They focused on areas in southern Ontario covered by 1:50 000 scale Paleozoic geology maps published by the OGS (Figure 1), which not coincidentally, cover areas where bedrock is exposed or are covered by relatively thin drift, including most of eastern Ontario; the Middle Ordovician outcrop belt from the Kingston area to Georgian Bay; the Upper Ordovician to Silurian outcrop belt along the Niagara Escarpment, from the Niagara Peninsula to Manitoulin Island; and the small Silurian–Devonian outcrop belt on the south side of the Niagara Peninsula. In addition, efforts were made to examine the few scattered outcrops and quarries representative of Devonian and Upper Silurian strata which underlie most of southwestern Ontario.

Revisions to Pre-Existing Maps

This seamless bedrock map provides a more accurate and larger scale representation of the Paleozoic geology of southern Ontario than the 1:1 000 000 scale Geology of Ontario map (OGS 1991). The seamless map is more suitable for local geological investigations, while providing province-wide geological context.

In generating the seamless map, the intention was to essentially stitch together existing 1:50 000 scale OGS maps (or other maps if no 1:50 000 scale coverage was available). Re-mapping and major revisions to map sheets were only done where serious errors or omissions were discovered or where new published interpretations were readily available (see below).

Aside from scale and level of detail, one significant difference between the seamless map and the GoO map is that the seamless map only includes faults that appear on 1:50 000 scale OGS maps (or working maps by D.A. Williams for eastern Ontario, as discussed below). Most of the faults plotted on GoO map (OGS 1991) west of Kingston indicate faulting of the Precambrian basement with uncertain or no known effect on the overlying Paleozoic strata. These faults are not included in the seamless map. Future work should address the structural geology of the Paleozoic bedrock in southern Ontario.

During the course of generating the seamless map numerous, mostly small, off-sets of unit contacts between map sheets, or “boundary faults” (i.e., not real faults) were corrected. Revisions were primarily based on field-based investigation and interpretation. A few map sheets required more extensive revisions for various reasons that are discussed below. The level of revision and methods employed for each map sheet are present in the following sections and highlighted in the map index attribute table in the field labeled “revisions”. A complete list of OGS 1:50 000 maps used in this project is provided in Table 2.

EASTERN ONTARIO

Eastern Ontario is covered by 20, 1:50 000 scale Paleozoic geology maps (Figure 1). The most recent mapping by the OGS in eastern Ontario was carried out in the early 1980s by D.A. Williams and R.R. Wolf (*see* Figure 1 and Table 2). These geologists were involved in mapping all except 3 map sheets, the Brockville–Mallorytown, Merrickville and Kemptville map sheets (maps P.2495, P.2494 and P.2493), which were mapped by D.M. Carson (Carson 1982c, 1982b, 1982a, respectively). Significant “boundary faults” exist between the Carson maps and those of the surrounding Williams and Wolf maps. Subsequent mapping by D.A. Williams resolved these "boundary faults", as shown in page-size compilation maps in Williams (1991) and Johnson et al. (1992). Williams' revised and unpublished working maps (at 1:50 000 scale) were obtained for this project and were digitized for inclusion in the seamless map. The resulting seamless map coverage over eastern Ontario represents minor to moderate revisions for most of the map sheets and major revisions of maps P.2495, P.2494 and P.2493 (*see* Figure 1), based on data from these unpublished maps.

SOUTH-CENTRAL ONTARIO OUTCROP BELT

Cambrian (in the east) to Middle Ordovician strata are exposed in south-central Ontario in a belt that extends from the Kingston–Gananoque area to northern Lake Simcoe and then to southern Georgian Bay. It is bound to the north by the Paleozoic–Precambrian unconformity and is covered to the southwest by thick glacial drift. This outcrop belt is covered by 12, 1:50 000 OGS Paleozoic bedrock map sheets (Figure 1). Eight of these, from the Peterborough–Campbellford map sheet east, were most recently mapped by D.M. Carson in the early 1980s (*see* Figure 1 and Table 2). The 3 westernmost maps (Fenelon Falls, Orillia and Penetanguishene map sheets) were mapped by D.K. Armstrong and assistants in the early 1990s. Field work for this project found that map "boundary faults" at the formation level are generally minor and could be readily resolved. At the sub-formation level (i.e., members), lateral facies changes within the Middle Ordovician Bobcaygeon and Gull River formations, and differing interpretations, resulted in the variable subdivision of these formations (e.g., 3 members on one map sheet versus 2 members on another) such that they could not be easily correlated from map to map.

The situation is similar for the Lindsay Formation in the Prince Edward County area which Carson (1981) subdivided into 2 members, both of which make up the lower member of the Lindsay Formation as per Johnson et al. (1992).

Significant errors known to exist on the published Gananoque–Wolfe Island map sheet (P.2496, Carson 1982d) were corrected in the seamless map using the unpublished working maps of D.A. Williams, previous mapping of the area by Liberty (1971) and field investigations for this project.

SOUTH-CENTRAL ONTARIO THICK-DRIFT AREA

South and west of the Middle Ordovician outcrop belt, glacial drift thickens rapidly and there are no 1:50 000 scale bedrock maps published by the OGS (Figure 1). Regional scale maps for this area, including OGS (1991), Liberty (1969) and Sanford (1969a), were largely based on available subsurface data such as sparse petroleum exploration wells and water well records. In the creation of MRD 207, Gao et al. (2006) utilized newer available data (e.g., Fligg and Rodrigues 1983) and techniques to generate a more refined version of the bedrock topography in this area. Examination of this map suggests further revisions to unit contacts are required. Some revisions were made, mostly to address “boundary faults” with adjacent maps. This area requires further mapping using new subsurface data and maps.

NIAGARA ESCARPMENT

The Upper Ordovician to Silurian outcrop belt extends along the Niagara Escarpment from the Niagara Peninsula to the Bruce Peninsula (the Escarpment extends on to Manitoulin Island but is discussed below). The Niagara Escarpment area is covered by 15, 1:50 000 scale OGS bedrock maps (*see* Figure 1 and Table 2): 10 maps along the Escarpment from Collingwood to Niagara Falls by P.G. Telford, B.A. Liberty, I.J. Bond and B.H. Feenstra in the mid-1970s; 2 maps in the Brantford–Cambridge area by P.G. Telford in the 1970s; and 3 maps on the Bruce Peninsula by D.K. Armstrong and assistants made in the late 1980s. There are no Paleozoic bedrock maps published by the OGS for the section of the Niagara Escarpment between Collingwood and Owen Sound.

The Niagara Escarpment area includes units deposited in the Appalachian Basin and their correlative units in the Michigan Basin (*see* Johnson et al. 1992), and as such, there is considerable lateral lithologic and stratigraphic variability. Much of this variability occurs in relatively thin units that comprise the Clinton and Cataract groups and occur in a narrow outcrop belt at the base of the Niagara Escarpment.

There were relatively few “boundary faults” among the map sheets in this area. Field work focused on refining the mapping of contacts in the Meaford to Owen Sound area, where no published 1:50 000 bedrock mapping exists. Field work was also required to refine mapping of Clinton and Cataract group units on the 3 Bruce Peninsula area maps.

“Boundary faults” between maps P.3191 and OFM 198 in the Stokes Bay area on the Bruce Peninsula were resolved by field investigation. The southwest corner of map P.3236, in the vicinity of Southhampton was revised based on the map by Uyeno et al. (1982).

Some unit contacts were revised in the western Dundas Valley area (southeast and northeast corners of map sheets P.1983 and P1984, respectively) based on consideration of the new bedrock topography map in MRD 207.

A “boundary fault” involving the contact between the Guelph and Salina formations at the intersection of maps P.1983, Map 2342 and Map 2544, in the Kitchener–Waterloo–Cambridge area, was resolved using subsurface data from MRD 205 (Bajc and Hunter 2006) and the Regional Municipality of Waterloo.

Significant “boundary faults” exist between map P.1984 and Map 2544 in the vicinity of the intersection among Brant, Oxford and Norfolk counties. Contacts among the Salina, Bass Islands, Bois Blanc and Amherstburg/Onondaga formations were all revised using Uyeno et al. (1982), the new bedrock topography map from MRD 207 and subsurface information from MNR’s OPDS.

MANITOULIN ISLAND

Middle Ordovician to Silurian strata are well exposed on Manitoulin Island and islands immediately to the north. The 6, 1:50 000 scale OGS maps covering Manitoulin Island were all done by M.D. Johnson and P.G. Telford in the early to middle 1980s (see Figure 1 and Table 2), so there were only a few minor "boundary faults" to correct.

SOUTHERN NIAGARA PENINSULA AREA

The southern Niagara Peninsula area extending from Fort Erie west to Simcoe is underlain by Upper Silurian to Middle Devonian age units, and is covered by 3, 1:50 000 OGS maps completed by P.G. Telford and assistants (e.g., Telford and Tarrant 1975) in the 1970s (*see* Figure 1 and Table 2). Although no "boundary faults" occur among these maps, some do occur with the adjacent Map 2544 in northern Norfolk County. These were resolved using Uyeno et al. (1982), the bedrock topography map from MRD 207 and subsurface information from MNR's OPDS.

SOUTHWESTERN ONTARIO THICK-DRIFT AREA

Southwestern Ontario is underlain by poorly exposed Devonian strata covered by thick glacial drift. Only 1, 1:50 000 Paleozoic map, P.2396 in the Windsor–Essex area, has been published by the OGS within this area. Regional scale maps covering this area were published by the GSC (e.g., Uyeno et al. 1982; Liberty and Bolton 1971; Sanford 1969a) using the available sparse but significant outcrop and quarry exposures and subsurface data sources such as petroleum exploration drilling records. Some of these outcrops and quarries were examined during the field work for this project.

"Boundary faults" between OGS Map 2544 (OGS 1991) and adjacent 1:50 000 scale maps of the Niagara Escarpment area exist near Southhampton, Kitchener–Waterloo and near the intersection of Norfolk, Brant and Oxford counties. These were resolved using the map by Uyeno et al. (1982), the new bedrock topography map in MRD 207 and available new subsurface data (as discussed above).

Comparison of the new bedrock topography map with the present bedrock geology map coverage for southwestern Ontario suggests other revisions may be required. This will be the focus of future work by the OGS.

Coverages and Attributes

In addition to a base map layer, the project consists of 5 ArcInfo® coverages or layers: paleo_poly.pat, paleo_poly.aat, paleo_fault, paleo_point, paleo_photo and paleo_index. Paleo_poly.pat contains the Paleozoic bedrock unit polygons. The map units are stratigraphic formations or in some cases groups as indicated in the project legend. Paleo_poly.aat contains the geologic contact lines between unit polygons. Faulted contacts are indicated by different line types. Paleo_fault contains fault lines with level of confidence indicated as per original map. These may also be boundary of unit polygon (i.e., coincident with a Paleo_poly.aat line) or may cross-cut unit polygons. Paleo_point contains outcrops, quarries and drill hole locations digitized directly from original maps. Paleo_photo contains information and representative photographs of all of the outcropping Paleozoic bedrock units on the map. Paleo_index contains references to all published OGS Paleozoic maps. Please refer to the "readme" document on the CD-ROM for technical details on these ArcInfo® coverages (layers), attributes and general CD-ROM content and functionality.

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Telford, P.G. and Tarrant, G.A. 1975. Paleozoic geology of the Welland-Fort Erie area, southern Ontario; Ontario Division of Mines, Preliminary Map P.989, scale 1:50 000.

Williams, D.A., Rae, A.M., and Wolf, R.R. 1984. Paleozoic geology of the Ottawa area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2716, scale 1:50 000.

Williams, D.A., Rae, A.M., and Wolf, R.R. 1985. Paleozoic geology of the Russell-Thurso area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2717, scale 1:50 000.

Williams, D.A., Rae, A.M., and Wolf, R.R. 1985. Paleozoic geology of the Hawkesbury-Lachute area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2718, scale 1:50 000.

Williams, D.A., Rae, A.M., and Wolf, R.R. 1985. Paleozoic geology of the Alexandria-Vaudreuil area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2719, scale 1:50 000.

Williams, D.A., and Wolf, R.R. 1984. Paleozoic geology of the Westport area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2723, scale 1:50 000.

Williams, D.A., and Wolf, R.R. 1984. Paleozoic geology of the Perth area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2724, scale 1:50 000.

Williams, D.A., and Wolf, R.R. 1984. Paleozoic geology of the Carleton Place area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2725, scale 1:50 000.

Williams, D.A., Wolf, R.R., and Carson, D.M. 1985. Paleozoic geology of the Cornwall-Huntingdon area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2720, scale 1:50 000.

Williams, D.A., Wolf, R.R., and Carson, D.M. 1985. Paleozoic geology of the Winchester area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2721, scale 1:50 000.

Williams, D.A., Wolf, R.R., and Carson, D.M. 1985. Paleozoic geology of the Morrisburg area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2722, scale 1:50 000.

Williams, D.A., Wolf, R.R., and Rae, A.M. 1984. Paleozoic geology of the Arnprior-Quyon area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2726, scale 1:50 000.

Figure 1: Index of Paleozoic maps published by the OGS for southern Ontario.

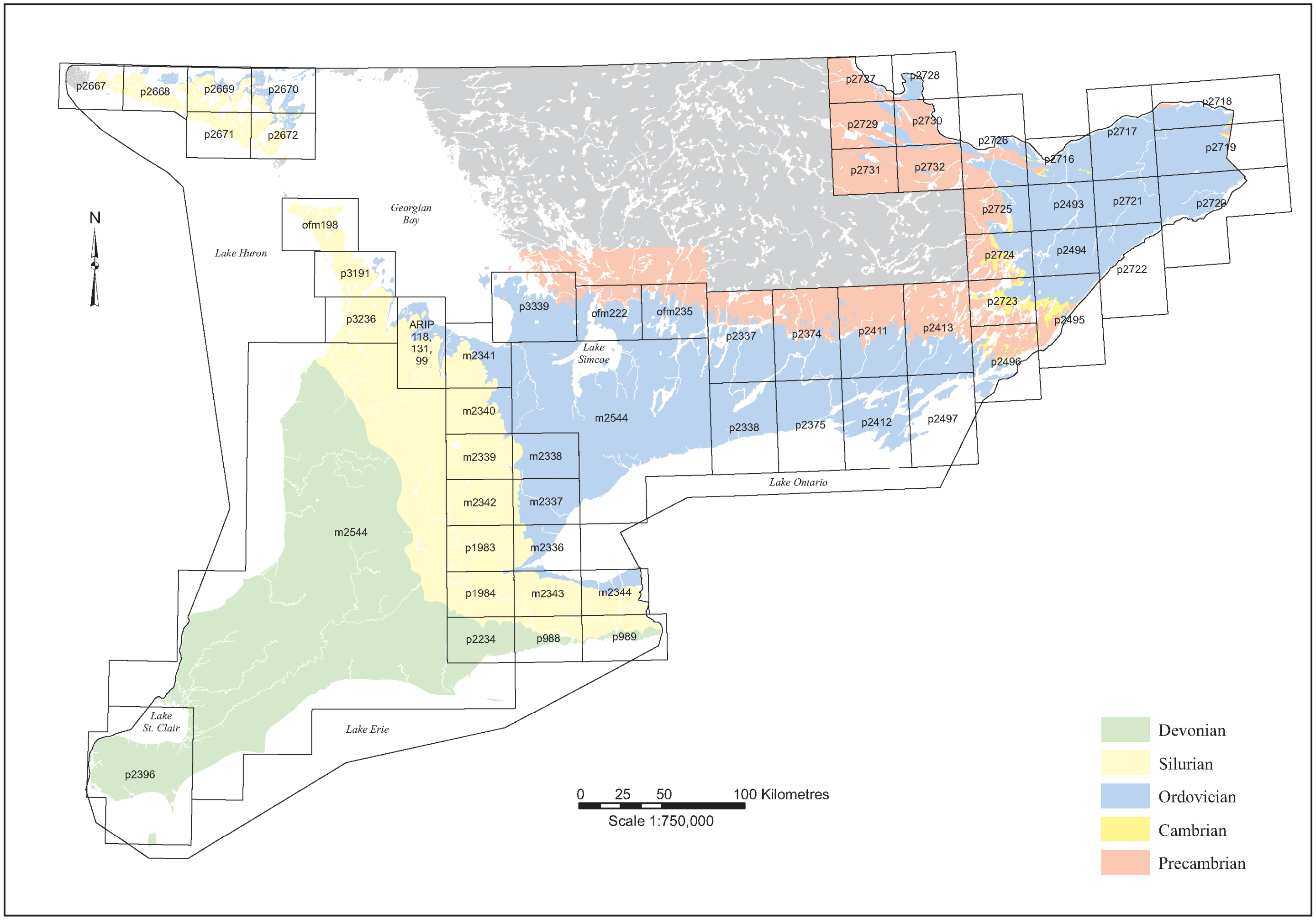

Table 1: Paleozoic Stratigraphy of Southern Ontario

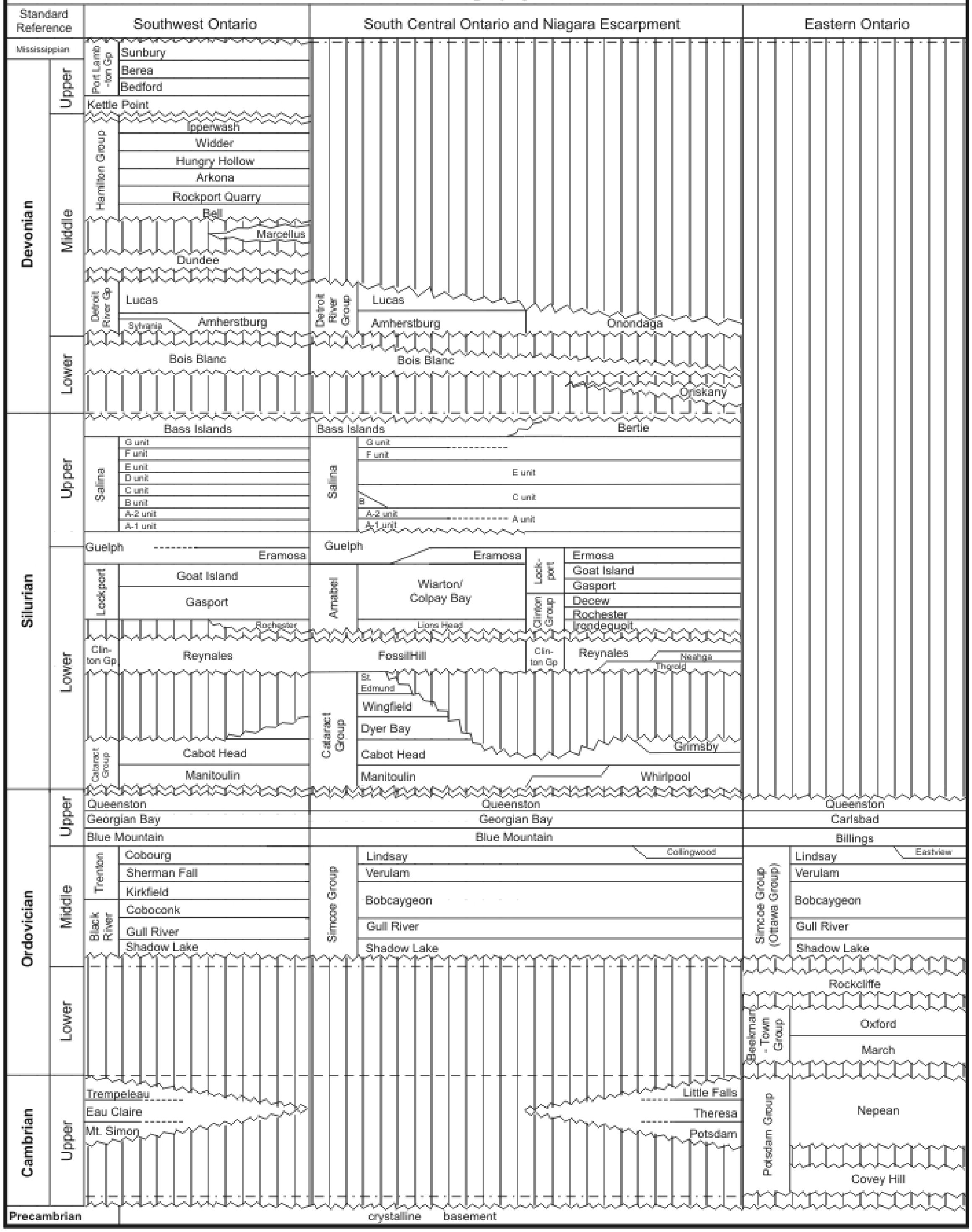

Table 2: List of OGS Paleozoic bedrock maps for southern Ontario (see bibliography for detailed references).

Map #'s	Authors, Year of Publication, and Map Name
M2336	Liberty, B.A., Bond, I.J. and Telford P.G. 1976. Paleozoic geology of the Hamilton area.
M2337	Bond, I.J., Liberty, B.A. and Telford, P.G. 1976. Paleozoic geology of the Brampton area.
M2338	Bond, I.J. and Telford, P.G. 1976. Paleozoic geology of the Bolton area.
M2339	Liberty, B.A., Bond, I.J. and Telford P.G. 1976. Paleozoic geology of the Orangeville area.
M2340	Liberty, B.A., Bond, I.J. and Telford P.G. 1976. Paleozoic geology of the Dundalk area.
M2341	Telford, P.G. 1976. Paleozoic geology of the Collingwood-Nottawasaga area.
M2342	Telford, P.G. 1976. Paleozoic geology of the Guelph area.
M2343	Liberty, B.A., Feenstra, B.H. and Telford, P.G. 1976. Paleozoic geology of the Grimsby area.
M2344	Liberty, B.A., Feenstra, B.H. and Telford, P.G. 1976. Paleozoic geology of the Niagara area.
M2544	Ontario Geological Survey 1991. Bedrock geology of Ontario, southern sheet.
OFM198	Armstrong, D.K. and Dubord, M.P. 1992. Paleozoic geology of the northern Bruce Peninsula area.
OFM222	Armstrong, D.K. and Anastas, A.S. 1993. Paleozoic geology of the Orillia area.
OFM235	Armstrong, D.K. and Rhéaume, P. 1993. Paleozoic geology of the Fenelon Falls area.
P1983	Telford, P.G. 1979. Paleozoic geology of the Cambridge area.
P1984	Telford, P.G. 1979. Paleozoic geology of the Brantford area.
P2234	Telford, P.G. and Hamblin, A.P. 1980. Paleozoic geology of the Simcoe area.
P2337	Carson, D.M. 1980. Paleozoic geology of the Burleigh Falls-Peterborough area.
P2338	Carson, D.M. 1980. Paleozoic geology of the Rice Lake-Port Hope area.
P2374	Carson, D.M. 1980. Paleozoic geology of the Bannockburn-Campbellford area.
P2375	Carson, D.M. 1980. Paleozoic geology of the Trenton-Consecon area.
P2396	Telford, P.G. and Russell, D.J. 1981. Paleozoic geology of the Windsor-Essex and Pelee Island Area.
P2411	Carson, D.M. 1981. Paleozoic geology of the Kaladar-Tweed area.
P2412	Carson, D.M. 1981. Paleozoic geology of the Belleville-Willington area.
P2413	Carson, D.M. 1981. Paleozoic geology of the Tichborne-Sydenham area.
P2493	Carson, D.M. 1982. Paleozoic geology of the Kemptville area.
P2494	Carson, D.M. 1982. Paleozoic geology of the Merrickville area.
P2495	Carson, D.M. 1982. Paleozoic geology of the Brockville-Mallorytown area.
P2496	Carson, D.M. 1982. Paleozoic geology of the Gananoque-Wolfe Island area.
P2497	Carson, D.M. 1982. Paleozoic geology of the Bath-Yorkshire Island area.

P2667 Johnson, M.D. and Telford, P.G. 1985. Paleozoic geology of the Meldrum Bay area, District of Manitoulin.
P2668 Johnson, M.D. and Telford, P.G. 1985. Paleozoic geology of the Silver Water area, District of Manitoulin.
P2669 Johnson, M.D. and Telford, P.G. 1985. Paleozoic geology of the Kagawong area, District of Manitoulin.
P2670 Johnson, M.D. and Telford, P.G. 1985. Paleozoic geology of the Little Current area, District of Manitoulin.
P2671 Johnson, M.D. and Telford, P.G. 1985. Paleozoic geology of the Providence Bay area, District of Manitoulin.
P2672 Johnson, M.D. and Telford, P.G. 1985. Paleozoic geology of the Manitowaning area, District of Manitoulin.
P2716 Williams, D.A., Rae, A.M., and Wolf, R.R. 1984. Paleozoic geology of the Ottawa area.
P2717 Williams, D.A., Rae, A.M., and Wolf, R.R. 1985. Paleozoic geology of the Russell-Thurso area.
P2718 Williams, D.A., Rae, A.M., and Wolf, R.R. 1985. Paleozoic geology of the Hawkesbury-Lachute area.
P2719 Williams, D.A., Rae, A.M., and Wolf, R.R. 1985. Paleozoic geology of the Alexandria-Vaudreuil area.
P2720 Williams, D.A., Wolf, R.R., and Carson, D.M. 1985. Paleozoic geology of the Cornwall-Huntingdon area.
P2721 Williams, D.A., Wolf, R.R., and Carson, D.M. 1985. Paleozoic geology of the Winchester area.
P2722 Williams, D.A., Wolf, R.R., and Carson, D.M. 1985. Paleozoic geology of the Morrisburg area.
P2723 Williams, D.A., and Wolf, R.R. 1984. Paleozoic geology of the Westport area.
P2724 Williams, D.A., and Wolf, R.R. 1984. Paleozoic geology of the Perth area.
P2725 Williams, D.A., and Wolf, R.R. 1984. Paleozoic geology of the Carleton Place area.
P2726 Williams, D.A., Wolf, R.R., and Rae, A.M. 1984. Paleozoic geology of the Arnprior-Quyon area.
P2727 Russell, D.J., and Williams, D.A. 1985. Paleozoic geology of the Pembroke area.
P2728 Russell, D.J., and Williams, D.A. 1985. Paleozoic geology of the Fort Coulonge area.
P2729 Russell, D.J., and Williams, D.A. 1985. Paleozoic geology of the Golden Lake area.
P2730 Russell, D.J., and Williams, D.A. 1985. Paleozoic geology of the Cobden area.
P2731 Russell, D.J., and Williams, D.A. 1985. Paleozoic geology of the Brudenell area.
P2732 Russell, D.J., and Williams, D.A. 1985. Paleozoic geology of the Renfrew area.
P3191 Armstrong, D.K. 1993. Paleozoic geology of the central Bruce Peninsula area.
P3236 Armstrong, D.K. 1993. Paleozoic geology of the southern Bruce Peninsula area.
P3339 Armstrong, D.K. and Rhéaume, P. 1995. Paleozoic geology of the Penetanguishene-Elmvale area.
P988 Telford, P.G. and Tarrant, G.A. 1975. Paleozoic geology of Dunnville area.
P989 Telford, P.G. and Tarrant, G.A. 1975. Paleozoic geology of the Welland-Fort Erie area.