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UPPER CAMBRIAN STRATA OF SOUTHWESTERN ONTARIO: SUMMARY OF LITERATURE

By

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REGIONAL TECTONIC AND STRATIGRAPHIC SETTING

Tectonic Setting

According to Sanford *et al.* (1985), the tectonic events in the Appalachian Orogen, epeirogeny on the craton and lower Paleozoic depositional succession of southern Ontario were all controlled by large-scale plate motions, which resulted in periodic rejuvenation of basement blocks on deep-seated fracture systems and subsidence of intervening circular basins. Their Tectonic Cycle I (late Precambrian to late Paleozoic) began with the creation of passive margin conditions, continued with separation during Hadrynian to early Ordovician time, and concluded with active closure and collision during later Paleozoic time. Howell and van der Pluijm (1990) concur with the concept of relating Arch uplift and episodic cratonic basin subsidence to orogenic phases in the Appalachians, and suggest that the pre-Taconian Upper Cambrian/Lower Ordovician stratigraphic sequence accumulated in an elongate NE/SW-trending trough in the location of the later Michigan Basin, possibly as a northern extension of the Reelfoot Rift. Tectonic movements during the Taconic Orogeny at the craton margin were transmitted through the craton by tilting of fault-bounded mega-blocks and expressed as uplift along Arches on dominant NE and NW trends, and as corresponding downwarp of intervening cratonic basins (Sanford *et al.*, 1985).

During the early Palaeozoic the Algonquin Arch was a broad platform between the more rapidly subsiding Michigan Basin to the west and the Allegheny Trough to the east (Bailey and Cochrane, 1984; Sanford *et al.*, 1985). It also separates the northern Bruce basement mega-block (with simple uniform E-W fracture system) from the southern Niagara basement mega-block (with complex multiple sets of fractures cutting it into a maze of smaller blocks) (Sanford *et al.*, 1985). During the Early Ordovician (the earliest phase of the Taconian Orogeny), Arch rejuvenation and fault-bounded uplift induced erosion of previously more extensive Upper Cambrian/Lower Ordovician strata from the crest, resulting in Cambrian erosional edges bounded by fault line scarps and basement blocks along the southern flank of the Algonquin Arch (Bailey and Cochrane, 1984; Sanford *et al.*, 1985). This is the regional-scale, pre-Tippecanoe, or "Knox", Unconformity which truncates all Upper Cambrian strata in southern Ontario, and elsewhere in the northern Appalachians (eg. Fowler *et al.*, 1995) (Fig. 1).

Stratigraphic Setting

The Precambrian surface slopes away from the Shield except for the mildly positive Algonquin Arch, and the Palaeozoic succession of southern Ontario (approximately 1500 m thick) dips away to the south, west and southwest (Roliff, 1954; Sanford and Quillian, 1959). During early Paleozoic time the Precambrian surface was likely similar to its present-day configuration, and irregularities on this surface are reflected far up into the stratigraphy (Sanford and Quillian, 1959). There is commonly development of a widespread regolith zone of highly-weathered granitic detritus mantling the Precambrian surface, known to drillers as "the Arkose" (Bailey and Cochrane, 1984). As the Upper Cambrian sea transgressed from the Appalachian Geosyncline into Quebec, the Ottawa Embayment and through southern Ontario up the flanks of the subdued Algonquin Arch, depositional units thinned, but likely covered the structure, resulting in an overall transgressive succession of marine sandstone and dolomite resting unconformably on basement (Roliff, 1954; Poole *et al.*, 1968). However, these strata, the Sauk Sequence of Sloss (1963), were eroded from the Arch crest during a phase of Early Ordovician uplift (Knox Unconformity) and were subsequently transgressed and overlapped by Middle Ordovician units of the Black River Group (Cohee, 1948; Poole *et al.*, 1968;

Bailey and Cochrane, 1984) (Fig. 1). At the crest of the Algonquin Arch, Middle Ordovician rocks rest directly on Precambrian basement (Cohee, 1948; Roliff, 1954) (Fig. 2). Currently, Upper Cambrian strata comprise about 1% of the Palaeozoic rock volume and occur over only about 50% of the area of southwestern Ontario (Sanford and Quillian, 1959). These strata range 0-60 m thick over an area of about 25000 sq. km, where preserved beneath Middle Ordovician carbonates, and are thickest in the Lake Huron and Lake Erie areas in the far western and southern parts of the province (Roliff, 1954). The entire Upper Cambrian section, representing the only preserved portion of the Sauk Sequence in southwestern Ontario, thins by both onlap and erosion onto both flanks of the Algonquin Arch (Bailey and Cochrane, 1984) (Fig. 2). The Middle Ordovician overlaps progressively older Cambrian units toward the crest of the Arch, generally comprising arkosic sandstones and sandy mudstones near the base (Shadow Lake Formation) and sandy dolostones toward the top (Gull River Formation) (Roliff, 1954). In many older wells, a unit referred to as "Basal Beds" is logged overlying basement, which may be uppermost Upper Cambrian in age, or may be the basal Middle Ordovician Shadow Lake Formation (Roliff, 1954; Bailey and Cochrane, 1984).

JACOBSVILLE FORMATION

Distribution

The term Jacobsville Formation is used in the Manitoulin Island region of Ontario to denote the oldest Paleozoic rocks unconformably overlying basement (Liberty, 1955; Liberty and Bolton, 1971). The type area is in northern Michigan where there are up to 460 m of Dreisbachian (early Late Cambrian) age red arkose and conglomerate (Cohee, 1948), but the sediments so designated in Ontario may not be precisely equivalent (Liberty, 1955). The unit is present in outcrop near Sault Ste. Marie (Liberty and Bolton, 1971) and in several reference wells in the Bruce Peninsula where it likely has a very limited distribution depending on paleotopography on the Precambrian surface (Liberty, 1955; Liberty and Bolton, 1971). It is up to 14 m thick, resting unconformably on Precambrian. It is typically erosionally truncated by Middle Ordovician units, although stratigraphically it is overlain by the Mount Simon sandstone (Roliff, 1954; Winder, 1961). The Jacobsville Formation is presumed to be Upper Cambrian in age, although it is unfossiliferous, and could be older because relationships to other units are unclear (Liberty, 1955).

Lithology

The unit comprises red, brown or purple, fine grained sandstone of uniform aspect wherever present (Liberty, 1955). Minor conglomerate and coarse grained arkose are commonly recorded at the base (Winder, 1961; Liberty and Bolton, 1971) and minor sandy shale beds occur (Liberty and Bolton, 1971).

POTSDAM (MOUNT SIMON) FORMATION

Distribution

At the base of the Phanerozoic section of southwestern Ontario are up to 50 m of white to greenish or locally reddish orthoquartzitic sandstone, overlapped by Ordovician units, which is traditionally referred to the Potsdam Formation in the southeast, and the Mount Simon Formation in the northwest (Poole *et al.*, 1968).

The Potsdam was named by Emmons (1838) with a type locality in New York, but an Ontario type locality was designated near Kingston, and even Logan recognized the extension of this unit to the southern side of the Frontenac Axis (Winder, 1961). Sanford and Quillian (1959) used this name for basal quartzose sandstone, with a basal boulder conglomerate, unconformably overlying basement east of 81° W longitude (ie. east of London). They recognized a lower white unit and upper red unit, possibly separated by an unconformity in the Kingston area, with the upper portion conformable with the overlying Middle Ordovician Black River limestone (Winder, 1961).

The Mount Simon was named by Walcott for sandstones lying on basement in Wisconsin and was traced into southwestern Ontario by Cohee (1948) and Roliff (1954), where Liberty (1955) designated a reference well near Simcoe (U.S. Steel #1, Norfolk Co., Charlotteville Twp, 21-I). Sanford and Quillian (1959) applied the name to all basal white to grey quartzose sandstone west of 81° W longitude (ie. west of London), and suggested equivalence to Potsdam to the east. The Mount Simon rests unconformably on Precambrian basement (never on Jacobsville), is overlain by the Eau Claire or overlapped by the Middle Ordovician, and is presumed (but not proven) to be of Upper Cambrian age (Cohee, 1948; Roliff, 1954; Liberty, 1955).

The erosionally truncated edges of the Potsdam (Mount Simon) rim the Algonquin Arch in the subsurface from Manitoulin Island, down the western shore of Lake Huron, and around the northern shore of Lake Erie, and therefore the unit underlies much of southwestern Ontario (Liberty, 1955; Winder, 1961). It is thickest and deepest at the International Boundary (thickening into the U.S.) and thins inland through the adjacent counties to subcrop beneath the sub-Middle Ordovician unconformity (Cohee, 1948; Liberty and Bolton, 1971).

Lithology

The Potsdam (Mount Simon) comprises light grey to white, well sorted, friable, medium to coarse sandstone with minor thin beds of brown fine crystalline sandy dolostone and minor shale increasing toward the top (Cohee, 1948; Roliff, 1954; Liberty, 1955). A thin arkosic sandstone commonly occurs at the base, overlying Precambrian basement (Sanford and Quillian, 1959). Quartz grains are subangular to subrounded, with rounding and frosting increasing upward, and trace glauconite is ubiquitous (Roliff, 1954; Sanford and Quillian, 1959; Liberty and Bolton, 1971).

THERESA (EAU CLAIRE) FORMATION

Distribution

Stratigraphically overlying the Potsdam (Mount Simon) Formation through part of southwestern Ontario are up to 75 m of dolostone and sandy dolostone truncated and overlapped by Middle Ordovician units (Roliff, 1954). These rocks overlap the Potsdam (Mount Simon) toward the Algonquin Arch to lie unconformably on Precambrian basement (Poole *et al.*,1968). The Theresa Formation was designated at a type locality in New York and Sanford and Quillian (1959) suggested the name only be used east of 81° W longitude (ie. east of London). It is present in the subsurface in the Niagara Peninsula/Lake Ontario area, thinning to a subcrop truncation edge to the west (Sanford and Quillian, 1959).

The Eau Claire Formation, a Michigan Basin sandstone and lesser dolostone unit, was traced into southwestern Ontario by Cohee (1948) and Roliff (1954), and Sanford and Quillian (1959) suggested the name only be used west of 81° W longitude (ie. west of London). It is present as a thin wedge in the subsurface of the Lake Huron/Bruce Peninsula, and Lambton/Essex/Kent Co./ Lake Erie areas where it overlaps the Mount Simon and thins to a subcrop truncation edge toward the

Algonquin Arch (Cohee, 1948; Sanford and Quillian, 1959; Liberty and Bolton, 1971). The Theresa and Eau Clair are considered as approximately equivalent (Winder, 1961), although no proven ages exist (Liberty and Bolton, 1971.)

Lithology

The Theresa (Eau Claire) Formation comprises grey to pinkish grey, fine to medium crystalline dolostone, sandy dolostone, argillaceous dolostone, and fine to coarse sandstone (Cohee, 1948; Roliff, 1954; Sanford and Quillian, 1959). Where resting on basement, there may be a basal, reddish arkosic sandstone (Sanford and Quillian, 1959; Liberty and Bolton, 1971). The proportion of dolostone increases upward and may be glauconitic near the top, especially to the west (Sanford and Quillian, 1959; Winder, 1961). Quartz grains are rounded and frosted (Sanford and Quillian, 1959; Liberty and Bolton, 1971).

LITTLE FALLS (TREMPELEAU) FORMATION

These units represent the youngest Upper Cambrian rocks in the area, but occur only under Lakes Erie and Huron near the International Boundary, wedging out toward land (Sanford and Quillian, 1959; Poole *et al.*, 1968). The Little Falls occurs in only one well in Lake Erie and is about 30 m thick (Poole *et al.*, 1968). The units overlie, and may overlap, the Theresa (Eau Claire). The lithology is a distinctive buff grey, fine to medium crystalline dolostone, locally sandy (Sanford and Quillian, 1959).

BASAL SANDSTONE/GRANITE WASH PROBLEM

From the basinal flanks, toward the crest of the Arch, the above stratigraphic units are less distinct and transgressive winnowing apparently produced thin sandy shoreward equivalents of all the units (Bailey and Cochrane, 1984). Sandstones of this type, of Theresa (Eau Claire) age, are finer grained and better sorted than those of Potsdam (Mount Simon) or earlier vintage, but can result in difficult correlation problems (Bailey and Cochrane, 1984). In addition, on the crestal areas of the Arch, isolated patches of sandstone of unknown (Upper Cambrian, Lower Ordovician or Middle Ordovician) age occur, and can be very porous and prospective (Bailey and Cochrane, 1984).

HYDROCARBON POTENTIAL OF UPPER CAMBRIAN ROCKS

Exploration History

The Upper Cambrian units of southwestern Ontario have proven oil and gas reserves (about 13% of Ontario gas; Powell *et al.*, 1984), and represents the last "frontier in conventional hydrocarbon exploration in the province (Sanford, 1989, *pers. comm.*). In addition, these units have currently un-evaluated capacity for salt water injection, gas storage and toxic waste disposal (Sanford, 1989, *pers. comm.*). All hydrocarbon reservoirs discovered to date occur in dolostones Theresa) and dolomitic sandstone (Potsdam) units near the updip truncated erosional edge of Cambrian strata along the southern flank of the Algonquin Arch (Powell *et al.*, 1984) (Fig. 2). The Cambro-Ordovician succession of southwestern Ontario is thermally marginally mature (C.A.I.=2-2.5, ie. 60-90 burial temperature) (Legall *et al.*, 1981; Barker and Pollack, 1984). Cambrian oils were sourced from the upper Ordovician Collingwood marine shale (Powell *et al.*, 1984), whereas there is no presently known source for Cambrian gas (Barker and Pollack, 1984).

In southwestern Ontario, oil was first discovered in Cambrian rocks at Romney in 1923, downdip of the erosional edge in porosity/permeability pinchouts in interbedded dolostone and sandstone of the Theresa Formation (Poole *et al.*, 1968). Gas was first discovered at Electric in 1948, with initial flows of 600 Mcf/d from Potsdam (Mount Simon) sandstones (Roliff, 1954). Discovery of oil at the erosional truncation edge of the Potsdam in 1960 at Gobles initiated a round of deep drilling in southwestern Ontario which resulted in further discoveries (Poole *et al.*, 1968). Attention was again focused on the deep Ordovician and Cambrian targets during the 1980's, particularly in Kent, Elgin and Sussex Counties, and the adjoining offshore areas of Lake Erie. This has again resulted in a number of new oil and gas discoveries and field extensions. Presently, Cambrian oil pools average 1.57 million barrels reserves, 23% recovery factor, 1803 acres area, producing from reservoirs with about 10 % porosity and 45 md permeability (Daily Oil Bulletin, June 4, 1986).

Traps and Reservoirs

Structural, stratigraphic, erosional truncation and porosity/permeability pinchout mechanisms all play parts in trapping oil and gas in Cambrian units (Bailey and Cochrane, 1984; Powell *et al.*, 1984; Barker and Pollack, 1984). For all play types, the untested areas are large, and potential is significant (Bailey and Cochrane, 1984).

Porous Cambrian units pinch out updip against the Precambrian surface and are top-sealed by the overlapping Shadow Lake Formation, such as at Gobles and Innerkip (Bailey and Cochrane, 1984). Structurally-based mechanisms related to basement block faulting appear to be the main controlling factors (Roliff, 1954; Bailey and Cochrane, 1984; Sanford *et al.*, 1985; Sanford, 1989, *pers. comm.*).

For most Cambrian fields, the main traps involve basement tilt-fault blocks of various scales formed in the Early Ordovician rejuvenation of the Algonquin Arch, and reactivated in Late Ordovician, Silurian and Devonian times (Bailey and Cochrane, 1984; Sanford *et al.*, 1985). For example, the Clearville Field traps oil in Upper Cambrian sandstone and dolostone at the northern uplifted side of a triangular-shaped block and is sealed by juxtaposition against Middle Ordovician limestone (Sanford *et al.*, 1985). Some blocks may have been active during deposition, and erosional paleotopography at the overlying unconformity surface may have created stratigraphic traps as noted in northwestern Pennsylvania (Pees and Fox, 1990).

In Ohio and New York Cambrian sandstones have porosities averaging 8-12 % (up to 15%), isolated rich source rock intervals (T.O.C. 3.6-4.8 % in the oil window) and pool reserves averaging 300-400 MMcf/well (ranging 75 MMcf/well to 1Bcf/ well) (Petzet, 1991; Robinson, 1991).

LIST OF FIGURES

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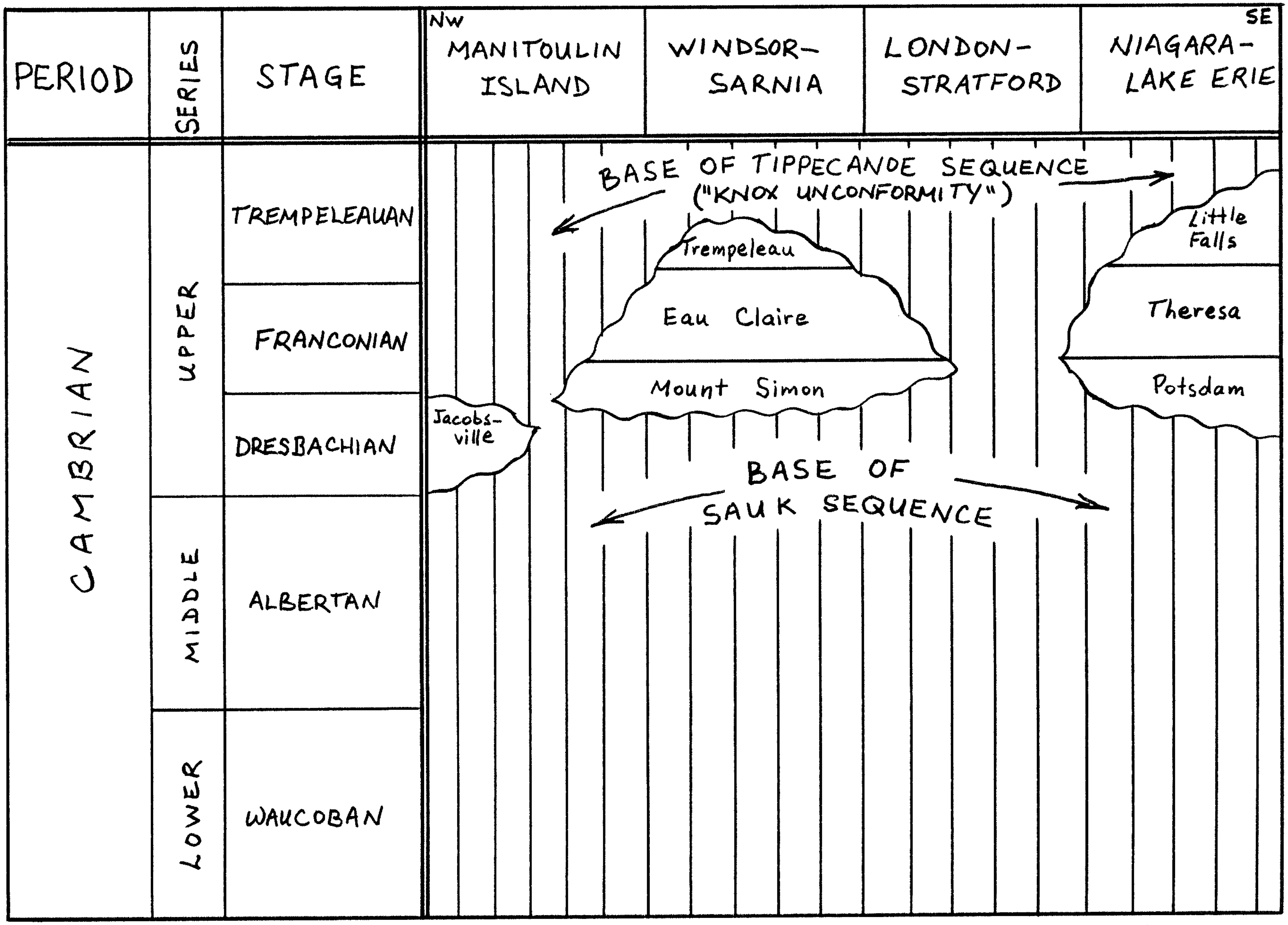
PERIOD
SERIES
STAGE
NW
MANITOULIN ISLAND
WINDSOR-SARNIA
LONDON-STRATFORD
NIAGARA-LAKE ERIE
SE
CAMBRIAN
UPPER
MIDDLE
LOWER
TREMPELEAUAN
FRANCONIAN
DRESBACHIAN
ALBERTAN
WAUCOBAN
BASE OF TIPPECANOE SEQUENCE
("KNOX UNCONFORMITY")
Trempeleau
Eau Claire
Mount Simon
Little Falls
Theresa
Potsdam
Jacobs-ville
BASE OF SAUK SEQUENCE

FIGURE 1.

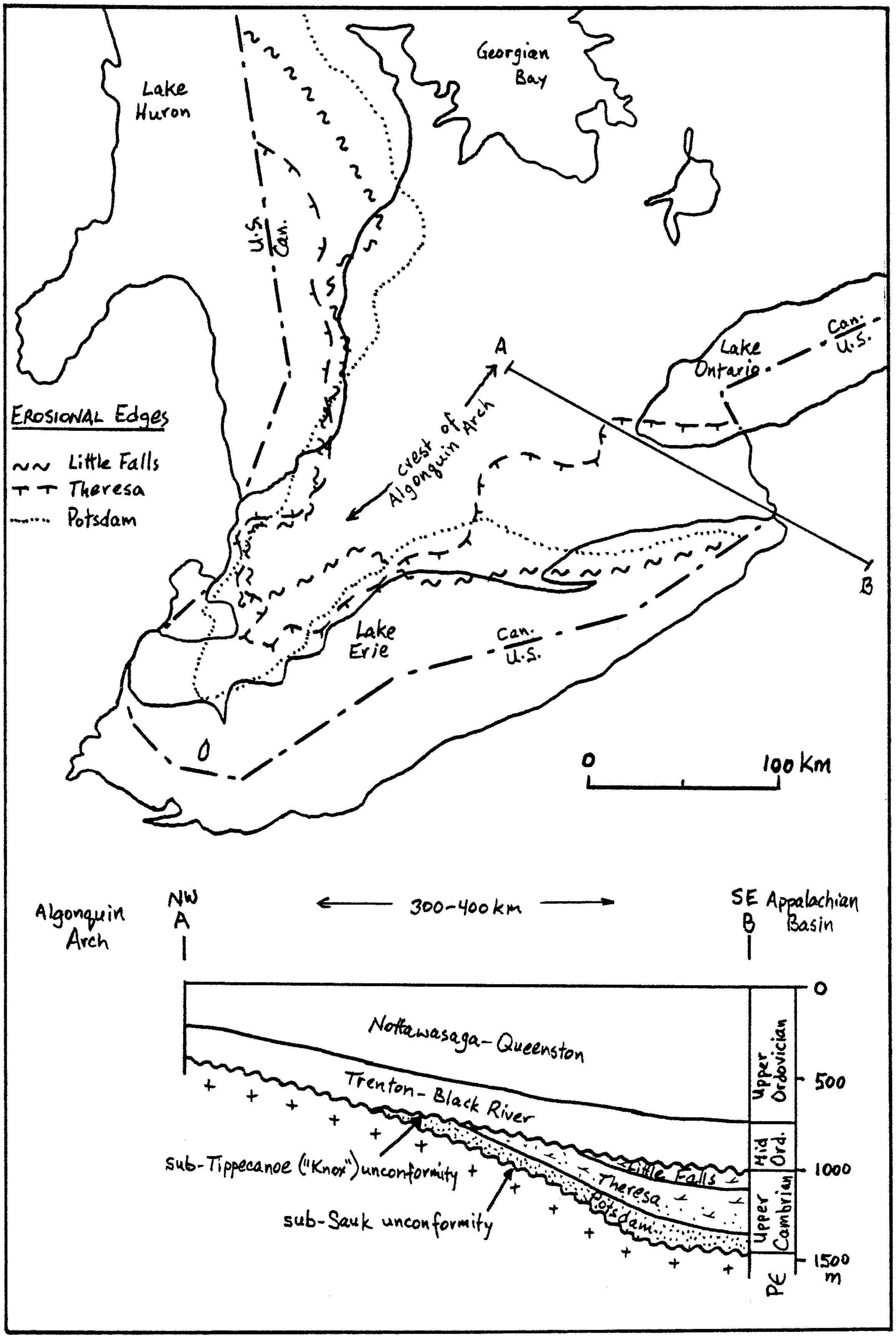
Georgian Bay
Lake Huron
U.S.
Can.
Lake Ontario
Can.
U.S.
A
B
EROSIONAL Edges
Little Falls
Theresa
Potsdam
crest of Algonquin Arch
Lake Erie
Can.
U.S.
0
100 Km
Algonquin Arch
NW
A
300-400 km
SE
B
Appalachian Basin
Nottawasaga-Queenston
Trenton-Black River
Little Falls
Theresa
Potsdam
sub-Tippecanoe ("Knox") unconformity
sub-Sauk unconformity
Upper Ordovician
Mid Ord.
Upper Cambrian
PC
0
500
1000
1500 m

FIGURE 2.