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GEOLOGY, LANDSCAPE DYNAMICS AND LAND-USE OF THE SOUTHERN NIAGARA ESCARPMENT: LANDPLANNING OF A U.N. BIOSPHERE PRESERVE

Simon J. Haynes

Earth Sciences, Brock University, St. Catharines, Ontario, L2S 3A1, Canada

ABSTRACT

Although a U.N. Biosphere Preserve and famous for the magestic Niagara Falls, the southern Niagara Escarpment is a cuesta landscape where landplanning must balance the competing needs of industry, urbanization, agriculture, tourism, outdoor recreation, and nature conservation. To support construction of these major transportation and power geoengineering projects, and industrial/urban development, both the Escarpment dolostones (historically used for hydraulic cement and building stone; now, crushed-stone aggregate) and Quaternary kame deposits (sand and gravel) have experienced major current reserves will be depleted shortly. Three of the abandoned dolostone quarries are now municipal landfills; one of which has leakage problems. Outside the urban centre, recent rural land-use of the southern Niagara Escarpment has changed significantly to take advantage of the unique physical geology: from forest and tender-fruit agriculture, to extensive areas of vinifera vineyards and smaller areas of conservation and parks. This had lead to increased human use of the Biosphere.

RESUMEN

No obstante a la preservación de la biosfera por las Naciones Unidas y a la fama de las majestuosas cataratas, la terraza del Niágara es un paisaje montañoso donde el planeamiento del terreno debe equilibrar las necesidades de la industria, la urbanización, la agricultura y la recreación con la conservación de la naturaleza. Para sustentar la ejecución de grandes proyectos de ingeniería geológica y transportación, tanto las terrazas carbonatadas como las arenas y gravas del Cuaternario han sido muy explotadas. Debido a la degradación del paisaje se ha limitado la expansión de las canteras, y las reservas actuales serán agotadas en breve plazo. Fuera del centro urbano el uso que se da actualmente a las terrazas del Niágara ha cambiado significativamente la geología física: desde bosques y sembrados de árboles frutales, hasta extensas áreas de viñedos, parques y pequeñas áreas de conservación. Esto ha conducido al incremento del uso racional de la biosfera.

INTRODUCTION AND HISTORICAL PERSPECTIVE

The southern Niagara Escarpment is located in the northern part of the Niagara peninsula. This peninsula is bordered by Lake Ontario to the north, Lake Erie to the south and the Niagara River (marking the border with the U.S.A.) to the east (Figure 1). Due to its geographical setting, this region of the Niagara Escarpment has experienced significant urban and industrial expansion, unlike the Escarpment to the north. Also, the climate of this region is considerably warmer than surrounding areas due to the moderating effect on temperatures by the large water masses of lakes Erie and Ontario. This enables natural growth of Carolian plant species that are indigenous to latitudes several hundred kilometres to the south in the United States.

Major settlement of the Niagara peninsula by europeans commenced in the late 18th century, who constructed water-driven mills to support agriculture.

Settlement was mainly below the Escarpment, where the climate cold supports a wide range of crops and soft fruits such as peaches that do not grow elsewhere in central Canada. By 1820, the existing water power of natural creeks was insufficient to meet demands of the mills so proposals were made to build a canal to divert water from the Welland River (Figure 1) over the Escarpment.

This, the first Welland Canal, was constructed with manual labour by a new input of European immigrants in the late 1820's, using wooden locks. The canal was also a convenient way to transport goods over the Escarpment by horse-drawn barges. However, the wooden locks soon deteriorated and canal traffic increased rapidly leading to replacement of the locks by stone (second Welland Canal). This required import of European stone masons and the creation of dolostone, building stone quarries on the Escarpment in the 1840's. By the 1870's immigration building and industrialization had increased so much that a new canal (third Welland canal) was built and extended over the Welland River to Lake Erie to connect shipping with the Upper Great Lakes. This corresponded with the advent of railways.

In 1887, the second Welland canal was reactivated for the first hydroelectric generating station which was used to power the locks of the third canal and an electric tram railway. In 1896, the first major hydroelectric power station in Canada was erected at Decew Falls in St. Catharines (still operating) which enabled the electric railway to be extended over most of the eastern Niagara peninsula; such that by 1911 it was the most extensive electric railway in the world (closed in 1950). Between 1900 and 1911, three large power stations were constructed at Niagara Falls (two still operating). This led to an advance in industrialization, immigration and urbanization and development of the city of Niagara Falls as a major tourist facility for the Niagara Falls and Gorge.

The 1920's were marked by two massive construction projects on the Escarpment: 1. Construction of the Sir Adam Beck No. 1 hydroelectric power station (at the time the world's largest) in the Niagara Gorge (90 m hydraulic head) with a deep 20 km-long canal to draw water from the Welland river, and; 2. Construction of the fourth Welland canal with massive twin flight locks over the Escarpment to take ocean-going vessels to central Canada and the U.S.A. These construction projects required the opening of large crushed dolostone quarries on the Escarpment, and major sand and gravel pits on the Fonthill kame. These projects led directly to major heavy industrialization, particularly the automobile industry. In turn, this led to construction of the Queen Elizabeth Way (QEW), a world famous divided 4-lane highway, from Toronto, to St. Catharines, Niagara Falls and Fort Erie (opposite Buffalo, U.S.A.) that was opening in 1938. All these factors resulted in considerable urbanization of the Escarpment.

The 1950's and 1960's saw further major construction projects on the Escarpment. Construction of the Sir Adam Beck No. 2 hydroelectric power station in the Niagara Gorge also involved building of two parallel 14 m diameter tunnels, 9 km long, under the city of Niagara Falls (often at a depth of 101 m) to transfer water from the Niagara river, above Niagara Falls.

Three divided 4-lane highways were constructed: 1. over the Escarpment at St. Catharines (Highway 406) to link with Welland; 2. across the Escarpment (Highway 405) to link the QEW highway with the Queenston-Lewiston bridge, and; 3. Highway 58 to link the 406 with Thorold, which required building parallel 2-lane tunnels under the Welland canal. Also, the Welland canal bypass was built to straighten the canal and divert it around the city of Welland.

By the 1970's encroachment of urban and quarry development onto Escarpment lands was causing considerable public concern. This led to the Niagara Escarpment Plan and recognition of the Escarpment as a biosphere that required protection. This resulted in: 1. areas of "Escarpment Natural", being set aside as parks and conservation areas; 2. areas of "Escarpment Protection", where urban construction is restricted; 3. areas of "Escarpment Rural", for agriculture and limited home construction; 4. areas of "Mineral Resource Extraction", which are limited in area, and now the only areas on the Escarpment where crushed stone and sand/gravel may be produced, and; 5. "Urban Areas", that defined the existing urban areas and restricted urban construction within these limits.

The 1980's to present have proven the effectiveness of the Escarpment Plan and designation of the whole of the Niagara Escarpment as a United Nations Biosphere Preserve. However, two factors are creating controversy. Expansion of all the urban centres in Niagara region (away from the Escarpment) has resulted in rapid increase in recreational use of Escarpment Natural and Protection areas by the public, with concerns over the effect of this on the natural habitat. Recognition of the Niagara Region as an internationally-respected wine-producing region has led to major development of Escarpment Protection and Rural areas for vinifera vineyards. Because these vineyards employ major earth-moving to regrade natural slopes and install subdrainage, concern has been expressed over whether this should be allowed in Escarpment Protection areas.

This paper summarizes how the geology of both the bedrock and surficial sediments has governed the landscape dynamics and land-use of the Southern Niagara Escarpment.

GEOLOGY AND PHYSIOGRAPHY

The relation of the geology (bedrock and surficial sediments) to the physiography of the Niagara Escarpment is illustrated in Figure 1. Because a complete discussion is beyond the scope of this article, only a summary of the main features is presented here. The bedrock underlying the plain is the Queenston shale, deposited during the late Ordovician. Overlying this are the south-dipping sediments of the Lower and Middle Silurian that were deposited over a time period of about 25 million years, commencing 438 million years ago, as: sandstones and sandy shales (Whirlpool, Power Glen, Grimsby and Thorold formations); limestones and lime shales (Neagha, Reynales and Irondequoit formations); the Rochester shale, and; the Lockport dolostones that form the brow of the Escarpment. The present physiography of the Escarpment, comprising steep cliffs at Queenston and Grimsby, the large Short Hills reentrant valley, the Fonthill, and the wide terraces between 16 Mile and 30 Mile Creeks, resulted largely from a series of continental ice sheets (glaciations) during the Quaternary, which advanced and retreated over the Niagara Peninsula from about 140,000 to about 10,000 years ago. Each successive glaciation carved the bedrock and laid down glacial till, consisting of rock fragments of both Escarpment bedrock and Precambrian rocks (from north of 45° latitude) in a matrix of clay or sandy silt. During the interglacial periods between glaciations, large lakes (glaciolacustrine) and rivers (glaciofluvial) formed in front of the northward retreating ice sheets.

Because of the erosive power of each of these continental glaciers, much of the earlier glacial tills and interglacial glaciolacustrine (silt and clay) and glaciofluvial (sand and silt) sediments were removed; such that, mainly, only the results of the last glaciation (the Late Wisconsinan) are present.

Notable exceptions are: the valleys buried by glaciation (Figure 1), particularly the Short Hills valley, which was formed as a pre-Late Wisconsinan river gorge complete with a buried waterfall similar to the present Niagara Falls, and; the upper Escarpment terrace (Irondequoit Terrace, Figure 1), which is over a kilometre wide in the Vineland area, that resulted probably from a combination of ice carving by older glaciers and shore erosion by earlier lakes. As the Late Wisconsinan ice retreated, it laid down a series of Halton till moraines on top and below the Escarpment, as well as the glaciofluvial sands and gravels of the Fonthill and Niagara Falls kames. As ice retreated north of the Escarpment, a series of lakes formed between the ice and the Escarpment, with deposition of glaciolacustrine clays and silt over the Halton till on the Irondequoit terraces. As the ice retreated north of Toronto, a large lake (Lake Iroquois) formed in front of it about 12,000 years ago. The shore bluff of Lake Iroquois forms a prominent ridge of beach deposits that marks the true geological base of the Niagara Escarpment. Above this shore bluff, a prominent terrace (Bell Terrace), marks the lower of the Lake Iroquois Bench terraces. Below the Lake Iroquois shore bluff, lake deposits of stratified sand, silt and clay were deposited in Lake Iroquois (Lake Iroquois Plain lacustrine deposits).

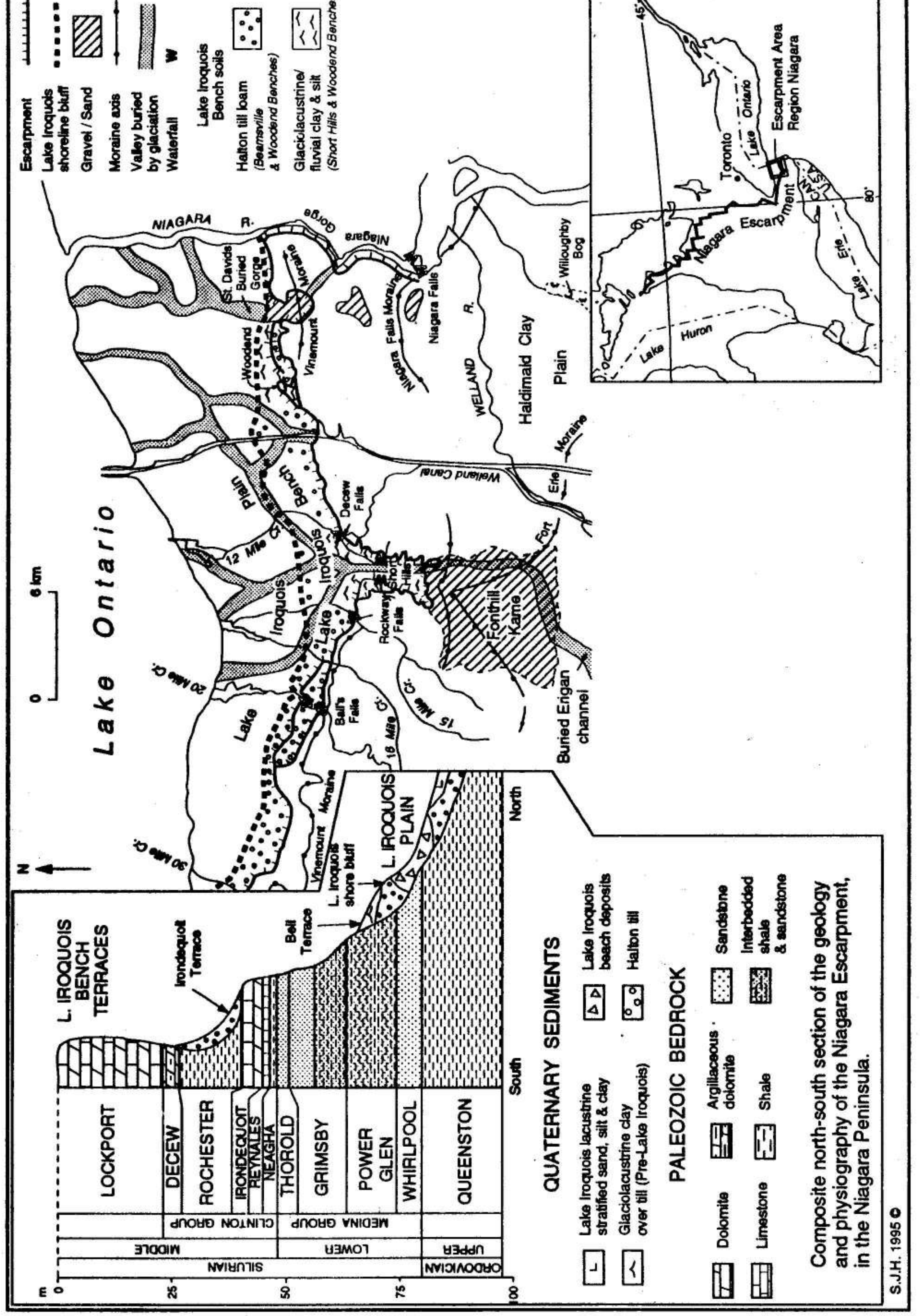

FIGURE 1. Major geologic and physiographic features of the Niagara Escarpment area, Region Niagara.

Because the exact nature and age of the pro-glacial lakes that formed terraces below the brow of the Escarpment (before the Lake Iroquois shore bluff) are unknown, and may represent higher levels of Lake Iroquois, they are collectively referred to by this author as, "Lake Iroquois Bench Terraces".

The most prominent terraces being: 1. the Irondequoit Terrace developed by erosion of the soft Rochester shale overlying the resistant Irondequoit limestone, and; 2. the Bell Terrace formed by erosion of the Halton Hill that was deposited over the Whirlpool sandstone at the base of the Escarpment.

The kame deposits of sand and gravel overlying sandy silt, form hills, particularly the large Fonthill kame (Figure 1) that forms a prominent hill about 75 m higher than the top of the Escarpment. This appears to have formed by glaciofluvial outflow from a wedge of ice, left in the Short Hills gorge of the pre-Late Wisconsinan Erigan river channel, during retreat of the Late Wisconsinan ice sheet. Also, sand and gravel deposits were deposited in the pre-Lake Wisconsinan St. Davids buried gorge (the ancestral Niagara River) during, or shortly after, formation of the Late Wisconsinan Vinemount Moraine (Figure 1). This Vinemount Moraine forms a low ridge of till that is present in much of the region, immediately south of the bedrock scarp of the Escarpment (Figure 1).

URBAN CENTRES, PARKLANDS AND VINEYARDS

Figure 2 gives the location of existing urban built-up areas, major parklands and the principal estate vinifera vineyards in the Southern Niagara Escarpment region. Within the Escarpment area proper (between the Escarpment brow and the Lake Iroquois shoreline bluff; Figures. 1 and 2), urban development comprises the cities of St. Catharines and Thorold; other towns and cities lie outside this area. This Escarpment area is the site of principal conservation area parks and the only Provincial park in the region (the Short Hills Park).

These parklands are Escarpment Natural areas and many are sited about picturesque waterfalls, over the Lockport dolostone and/or the Irondequoit limestone, that have undercut the softer Rochester and Power Glen shales underlying the resistant carbonates. The lands immediately bordering the Niagara Gorge and Falls form a continuous park (the Niagara Parkway) that constitutes Canada's foremost tourist attraction to view the falls and the complete geological sequence of the bedrock from the Lockport carbonates to the Queenston shale (Figure 2). At Ball's Falls, a third, small, waterfall has formed over the resistant Whirlpool sandstone.

The vinifera vineyards of the Escarpment are all located on the Lake Iroquois Bench Terraces (Figure 2). Most are on the lower Bell Terrace, but in the Vineland area the Irondequoit Terrace is very wide (Figure 2) and utilized extensively for vinifera vineyards. In general, vinifera grapes prefer poor soils to produce quality wines. Many of the vinifera vineyards are located on till soils. However, the vineyards of the Woodend area are on till and glaciolacustrine clay and silt, and those at the mouth of the Short Hills reentrant valley are on glaciolacustrine clay (Figure 2). Vineyards on the Lake Iroquois Plain north of Lake Iroquois shore bluff are located on a till ridge overlain by thin Lake Iroquois lacustrine sand, silt and clay. Worldwide, many famous vineyards are on gravel soils, so the till and clay soil vineyards of Niagara are unusual. However, it is the combination of these unusual soils and climate that give Niagara wines their distinctive character and particularly the, "ice wines", increasing medal-winning international recognition.

MAJOR TRANSPORTATION ROUTES

The relation of current major road, rail and canal transportation routes to the geology of the Southern Niagara Escarpment is illustrated in Figure 3. Because the Escarpment is generally steep, with only a narrow Irondequoit terrace east of 16 Mile Creek, civil engineering has made excellent use of the limited access to climb the Escarpment. The Short Hills reentrant valley was proposed as a possible route for the first Welland Canal as the climb over the Escarpment is the most gentle here. Why this route was rejected is not known, but may have been due to concerns about water draining away from the floor of the canal through the thick porous sequence of glaciofluvial sands and sandy silts prevalent in the upper part of the valley. Fortunately, this picturesque valley was not chosen for rail and major highway routes because when these were constructed, they were sited to link Toronto with the U.S.A., via the urban centres of St. Catharines and Niagara Falls.

The first (1829, 39 locks) and second (1845; 27 locks) Welland canals used 12 Mile from Lake Ontario to the Lake Iroquois shore bluff. They crossed the Bell Terrace of the Lake Iroquois Bench to the Escarpment, about 0,5 km east of the present Highway 406, where they utilised a narrow Irondequoit Terrace to a subdued Lockport scarp. The third canal (1887; 26 electric-powered locks) used the same Lake Ontario entrance at 12 Mile Creek but traversed diagonally southeast to the buried valley reentrant into the Escarpment used by the present canal. The 4th Welland canal (Figure 3), which opened in 1932, uses seven massive concrete locks, 262 m long, 24,4 m wide and about 14 m deep to climb the 100 m difference in elevation between Lakes Ontario and Erie over the Escarpment. Lock 1 is located near the entrance to Lake Ontario. Lock 2 is about halfway across the Lake Iroquois Plain. Lock 3 is at the Lake Iroquois shore bluff, which here is a large sand bar (the Homer Bar). Lock 4 to 7 are continuous over the Escarpment and are double locks (twin flight locks) to enable ships to pass in both directions at the same time. This was made possible by the fact that the small buried valley reentrant used by the modern canal does not continue over the Escarpment (Figure 3), such that the weight of each of the twin locks is supported directly by a floor of bedrock into which the locks were blasted as sunken steps.

Unfortunately, groundwater flow through the bedrock has caused collapse of theconcrete side of one of these locks. All four canals followed the same route south of the trace of the Niagara Falls moraine because, although this moraine is only a low ridge here, its elevation necessitated a "deep cut". This presented major geoengineering problems for the first canal in that the glacial till is unstable and the sides of the cut were subject to collapse as the cut was deepened; this required considerable cutting back of the canal banks to achieve a stable slope.

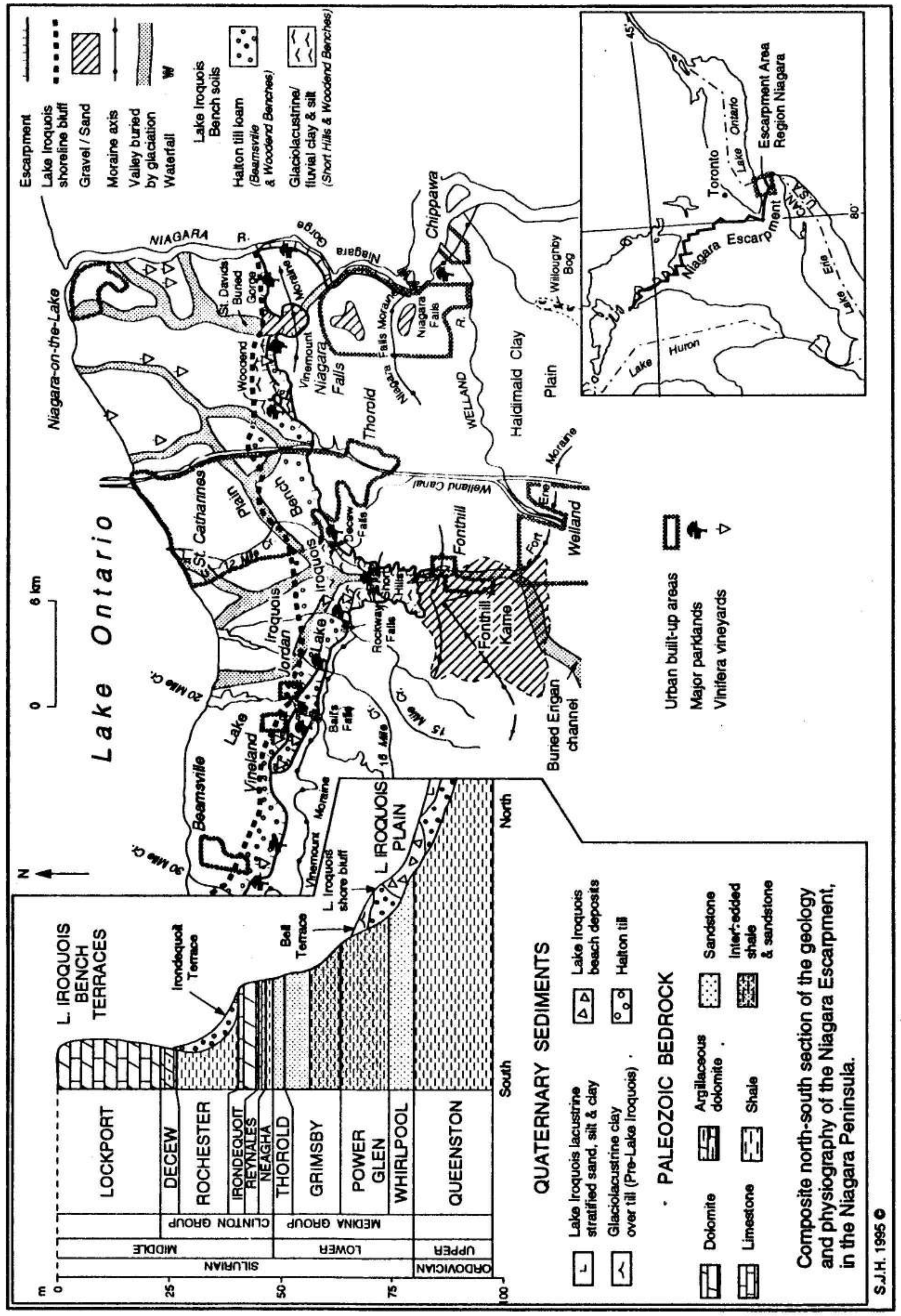

FIGURE 2. Relation of urban centres, parklands and vinifera vineyards to the geology and physiography of the southern Niagara Escarpment.

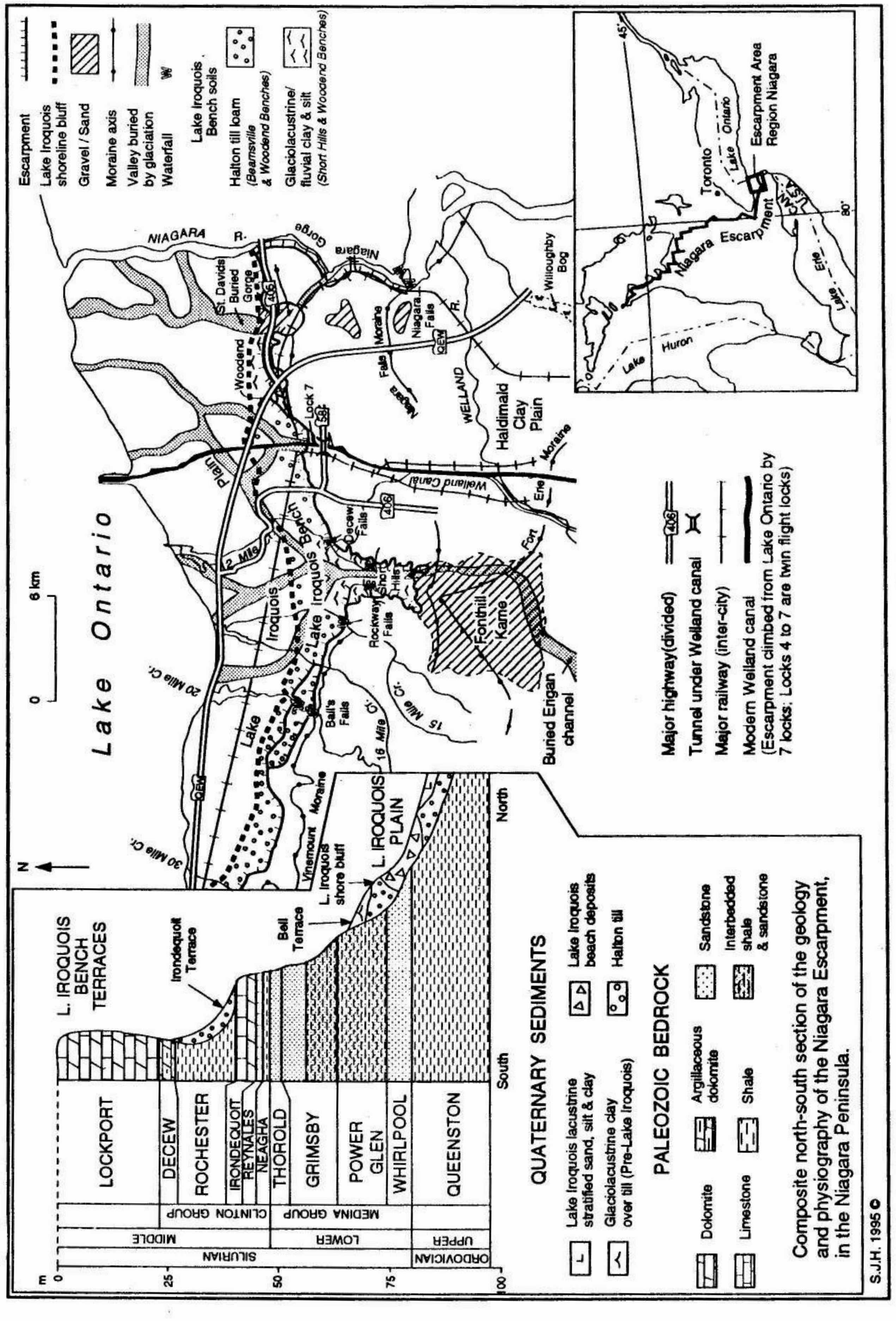

FIGURE 3. Relation of current major road, rail and canal transportation routes to the geology and physiography of the southern Niagara Escarpment.

The railway from Toronto to Niagara Falls and the U.S.A. (Figure 3) crosses the Lake Iroquois shore bluff by a cutting. Then, it climbs the Escarpment firstly, by means of a cutting through the glaciolacustrine sediments between the Escarpment and the bedrock outlier at Woodend. From here, it climbs diagonally across an Irondequoit terrace to a small reentrant in the Lockport scarp which it traverses by a shallow cutting. Then, it skirts the southern margin of the upper part of the buried St. David Gorge.

At the base of the Escarpment, another rail line to Thorold and Welland uses a cutting through a ledge of Grimsby-Thorold-Neagha-Reynales-Irondequoit to mount a small Irondequoit terrace. From here it uses the same reentrant as the modern Welland canal by means of a cutting through glacial till and the underlying, soft, Rochester shale.

The QEW highway crosses the Escarpment diagonally by using a broad Irondequoit terrace and a southeastward reentrant into the Lockport scarp immediately east of Woodend (Figure 3). Although cutting and regrading of till and glaciolacustrine sediments was needed, no rock cuts were required. From the QEW, Highway 405 leaves eastward, diagonally across the same broad Irondequoit terrace to cross the Lockport scarp by means of a cutting into the sand and gravel filled reentrant, above the St. Davids Buried Gorge (Figure 3).

In contrast, the more modern Highway 406 (Figure 3) required extensive removal of bedrock as a side cut into Rochester shale and a parallel cut into Lockport dolostone. This material was employed to build a long ramp (about 1-1/2 km) from the Bell terrace to the top of the Irondequoit ledge. Highway 58 is located on top of the Lockport scarp, but its access and exit ramps with Highway 406 require single-lane rock cuts through the dolostone. It then crosses the Welland canal by means of two parallel tunnels cut into the Lockport dolostone. Because tunnel walls of dolostone were required to support the weight of the canal, the location of the tunnel was limited by the fact that the canal reentrant is immediately north, while thick clays (Haldimand Clay Plain) with swamps, which would create water problems for a tunnel, lie to the south.

EXTRACTIVE MINERAL AND LANDFILL SITES

Locations of the sites of extractive mineral resources and landfills within the Escarpment Plan Area are presented in Figure 4. The extractive mineral sites include: 1. the presently-producing, crushed stone aggregate quarries in Lockport dolostone (3 active); 2. the major past and present sand and gravel pits (2; only one on the Fonthill kame is now active); 3. the principal, now-abandoned, building stone quarries in the Lockport dolostone (3), Irondequoit limestone (1) and Grimsby sandstone (1); 4. historical lime or hydraulic cement works in Lockport dolostone and Decew argillaceous dolomite (3), and; 5. landfill sites in abandoned Lockport stone and/or crushed stone quarries (3).

The crushed stone quarries are sited in locations where thick sequences of Lockport dolostone are overlain by a thin veneer of glacial sediments. The Lockport comprises three members. The lower Gasport Member is a dense crinoidal packstone, thin-bedded at the base and thick-bedded above. The middle Goat Island Member is a massive, thick-bedded, micritic dolostone with large vugs lined with secondary carbonate and sulphate crystals. The upper Eramosa Member is a dense, wavy-bedded, petroliferous algal boundstone with infilled vugs of cabonates, sulphates and sulphides (pyrite, marasite, galena and sphalerite); chert nodules are common, in places forming layers. Generally, the amount of chert increases westward. Petrographically, the Lockport Formation displays rapid local variation of the calcite/dolomite ratio from limestone to dolomite, but, as dolomite is present normally, dolostone is the preferred rock classification. The geotechnical test classification of aggregate is good and suitable for all construction purposes. However, the amount of chert must be monitored as it is alkali-reactive with Portland cement, which may cause concrete to fail. Some quarries extract the underlying Decew argillaceous dolomite that was deposited as a mudstone displaying prominent slump structures. However, the clay content of this rock makes it softer and unsuitable for high-grade concrete specifications, although suitable for granular road base.

Use of the Lockport dolostone as building stone was restricted to the dense Gasport Member. This grey stone was used first to build houses on the Escarpment, but the principal quarrying was to produce the stone locks of the second and third Welland canals. In the 1840's, a secondary monument and tombstone industry was created when rope saws were introduced to the quarries for stone cutting. The Grimsby sandstone is a red, cross-bedded sandstone that breaks into tabular sheets. This characteristic was employed by early settlers for building and tombstones. From about the middle 19th century to the 1920's, an unusually thick sequence of thicker-bedded Grimsby sandstone was quarried at Woodend (Figure 4), as a particularly attractive building stone for several large churches and municipal buildings in Thorold and St. Catharines. Overlying the Grimsby at Woodend, the light grey, medium-bedded, crinoidal Irondequoit limestone was quarried (Figure 4). Although some of this stone may have been used for canal locks, it was used as a cornerstone for the walls of buildings made primarily of Grimsby sandstone to give resistance to weathering, as well as aesthetic colour balance.

Historical, 19th century, lime and hydraulic cement works are known at three locations (Figure 4) from the presence of lime kilns and man-made caves into the lower Gasport Member and/or underlying Decew Formation. The Decew argillaceous dolomite is a natural hydraulic cement whose use for mortar and concrete was introduced in the second half of the 19th century; lime being used for mortar, beforehand. With the acceptance of Portland cement as a superior product for mortar and concrete in the late 19th century, the workings were disbanded.

Commencing in the middle 19th century, the red Queenston shale supported a major manufacture of brick for building construction. Although some of the early Queenston quarries may have been located on the banks of the rivers cutting the Lake Iroquois Bench, the larger, later, works (now abandoned) were all located on the Lake Iroquois Plain away from the Escarpment.

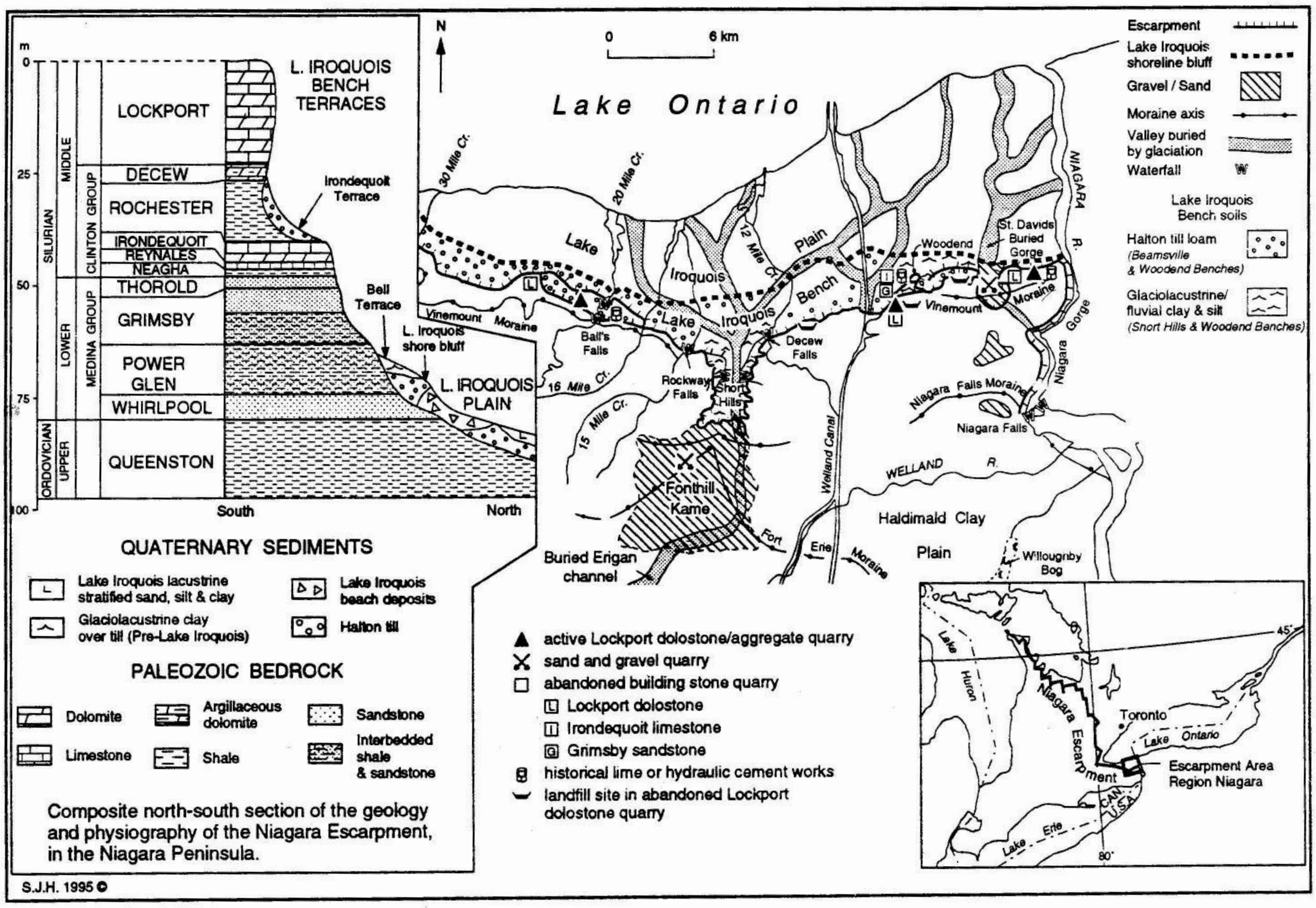

FIGURE 4. Location of major crushed stone, sand and gravel and abandoned building stone quarries, historic lime and hydraulic cement works, and landfill sites on the southern Niagara Escarpment.

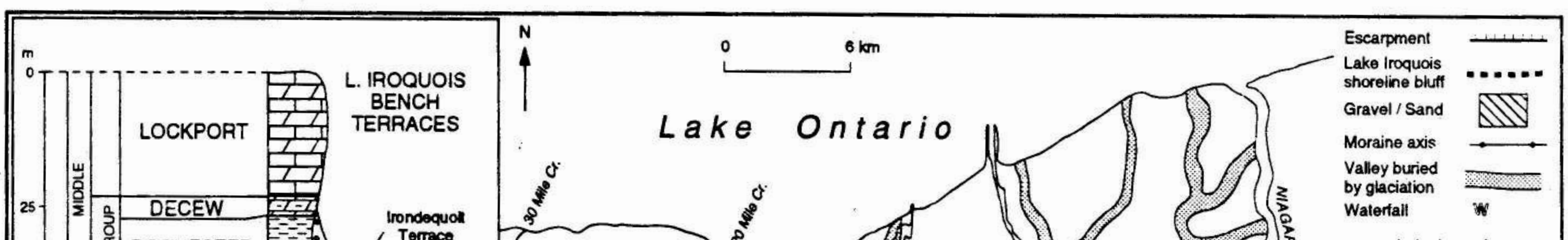

FIGURE 5. Relation of hydroelectric power stations, reservoirs, canals and tunnels and water treatment plants to the geology and physiography of the southern Niagara Escarpment.