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Quartzose sands in the Lower to Middle Devonian strata of southwestern Ontario: geographic distribution and characterization in drill cuttings and geophysical logs

C.L. Davis

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Publications in this series have not been edited; they are released as submitted by the author.

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List of Acronyms

API American Petroleum Institute Units

CNFD Compensated Neutron Formation Density Log

DT Sonic Log

GIS Geographic Information System

GR Gamma Ray

GRNL Gamma Ray Neutron Log

MNRF Ontario Ministry of Natural Resources and Forestry

NPHI Neutron Porosity Log

OGSR Oil, Gas and Salt Resources Library

OPDS Ontario Petroleum Data System

RHOB Density Log

SONL Sonic Log

1. Abstract

Southern Ontario is underlain by up to 1425 metres of Paleozoic sedimentary rocks unconformably overlying a Precambrian basement complex of metamorphic and igneous rocks. Four distinct quartzose sandstone units occur within the Middle to Lower Devonian succession: the Columbus sand lithofacies of the Lucas Formation, the Sylvania Formation, the Springvale Member of the Bois Blanc Formation, and the Oriskany Formation. All of the sands form continuous to discontinuous beds and lenses within thick accumulations of regional limestones and dolostones. Locally, these sands are significant hosts of groundwater, oil, and/or gas due to their enhanced porosity relative to the confining carbonates.

Information from petroleum wells drilled since the last time these sands were mapped (Bailey and Cochrane, 1985), combined with a comprehensive update of Ontario's petroleum well database, have been used to re-examine the distribution and characterization of these sands. In this study, over 1300 wells containing Devonian-aged strata were examined using binocular microscopy of drill cuttings, geophysical well log analysis, and Geographic Information System (GIS) queries of the Ontario Petroleum Data System (OPDS) petroleum well database. Geographic extents of all four sands have been updated, with sands identified in areas not previously documented. In other cases, stratigraphic assignments were corrected. Petrographic characteristics of the sands, as viewed in cuttings samples, have been documented. Over 800 formation/member top picks have been added or edited, and over 200 picks were identified as erroneous and have been deleted from the petroleum well database. The revised data has been incorporated into an ongoing and broader project to construct a 3D model of the geology and hydrogeology of the Paleozoic bedrock of southern Ontario.

2. Introduction

Much of southwestern Ontario is underlain by marine sedimentary rocks of Devonian age. These bedrock formations rarely outcrop in Ontario, typically remaining hidden beneath unconsolidated Quaternary sediments. The Middle to Lower Devonian succession is dominated by carbonates (limestone and dolostone). Four distinctive quartzose sandstones occur as beds and lenses within these carbonates: the Columbus sand lithofacies of the Lucas Formation, the Sylvania Formation, the Springvale Member of the Bois Blanc Formation, and the Oriskany Formation.

The last comprehensive geologic mapping of the distribution of Devonian sands in southwestern Ontario was completed by Bailey & Cochrane (1985). Subsequent drilling, edits and improvements to the OPDS petroleum well database, new GIS display and query capability, and new regional geological compilations have since become available, highlighting the need to revisit these strata.

The Devonian sands are relatively porous and permeable compared to the enclosing carbonates, and as such have the potential to be valuable hosts of water, oil, and gas in the subsurface. The Columbus sand, specifically, is a significant reservoir rock in several oil pools in southern Ontario (Bailey and Cochrane, 1985). The other sands, although not yet exploited, are candidates for future hydrocarbon production due to their high porosity and thicknesses (Bailey & Cochrane, 1985). These Devonian sands are also locally important components of regional aquifer systems.

The main deliverables of this study, available either in this report or at the Oil, Gas and Salt Resources (OGSR) Library, are:

1) Maps of the geographic extent of each Devonian sand unit.
    a. PDF Format (this report).
    b. Shapefile Format (OGSR Library, www.ogsrlibrary.com).
2) Criteria for identification and characterization of sand units.
    a. Petrographic characteristics based on binocular microscope examination of drill cutting samples (summary in this report).
    b. Petrophysical characteristics based on analysis of geophysical well logs (summary in this report).
3) Database of all 1320+ picks in Microsoft Excel format (www.ogsrlibrary.com), with corresponding edits to the Ontario Petroleum Data System (OPDS) database.
4) Photographs of drill cutting samples from each sand unit (www.ogsrlibrary.com, subset included in report).
5) Geophysical log analyses of each sand unit (subset included in report).
6) Recommendations for future study.

3. Datasets and Methodology

3.1. Drill Cuttings and Geophysical Well Logs

The majority of the analysis in this study is comprised of the examination of drill cutting samples and geophysical well logs. Cuttings are small chips of bedrock created by the process of drilling a borehole or well using either a rotary or cable-tool drill. In Ontario, well operators are legally required to collect samples of cuttings of all bedrock formations penetrated by a petroleum well. Cuttings are typically collected for every 3m (~10ft) interval drilled through the entirety of the well. After collection, these cuttings are sent to the Oil, Gas, and Salt Resources Library (OGSR Library), where they are processed, washed, and placed in small glass or plastic vials for archival storage. The vials are labelled to identify well location and sample depth.

Many wells have accompanying geophysical well logs, which record petrophysical properties of the rock formations penetrated by a well bore (Asquith and Gibson, 1982). Analysis and interpretation of the logs can be used to identify and measure porosity (neutron, density logs) and shaliness/lithology (gamma ray log). The accuracy of depth measurement in properly calibrated geophysical well logs is very high, and is considered the most reliable way to identify geological formation tops in the subsurface, especially when used in combination with drill cuttings and drill core. Some of the applications of well logs include determining unit thicknesses, lithology, correlation between wells, and porosity. A general reference chart for the gamma ray and neutron log expression/characteristics of Paleozoic formations in southern Ontario was created by Beards (1967) and updated by Armstrong and Carter (2010). It should be noted that past studies have had difficulty in the identification of reliable, diagnostic well log signatures for the Devonian sand units (Armstrong & Carter, 2010), and thus all well log signatures in this study have been verified with examination of cuttings or core.

There are hard-copy records for approximately 26,600 wells at the OGSR Library in London, Ontario, with corresponding digital records in the Oracle petroleum well database of the Ontario Petroleum Data System (OPDS). The well records include formation and member top depths and calculated elevations, oil/gas/water intervals, geophysical well logs, and other applicable information. Drill cuttings are available for approximately 13,000 wells, and drill core for over 1,100 wells. This data has been submitted to the Ministry of Natural Resources and Forestry (MNRF) by well operators as a regulatory requirement. The formation top picks made by the operator are retained in the database, but revisions made by geologists of the MNRF, OGS and/or the OGSR Library are separately recorded in OPDS. Revision/verification of the formation top picks for the Lower and Middle Devonian sands are the focus of this study. Public access to this data is at the OGSR Library or its website at www.ogsrlibrary.com.

3.2. Data Accessibility

All data is stored and accessible at the OGSR Library in London, Ontario, or accessible online via subscription to the OGSR Library online database at www.ogsrlibrary.com. Every well analyzed in this study is listed in the Excel spreadsheets and on the OGSR Library website. Utilizing the basic search engine on the Library website, well records can be found by searching for the well reference number (i.e. T002012). Using Advanced Search, wells can also be searched by region, total drilling depth, well type, etc. Most well files include updated formation/member top depths, digital scans of hard-copy files detailing historical well information, and, if applicable, geophysical well logs.

Wells are described with the following convention: Well Reference Number, Well Name, Township, Tract, Lot-Concession (i.e. T006398, Strathburn, Euphemia, 1, 30-X).

3.3. Approach

Starting with data obtained from OPDS, the spatial distribution of wells with recorded formation and member top picks from each of the four Devonian sands were plotted using ArcGIS/Google Earth queries. A formation/member top "pick" is a term used predominantly in the petroleum industry, and refers to the depth below the surface or below the drill rig floor to the top contact of a geologic formation, usually identified via sample cuttings, drill core, or geophysical well logs. Preliminary extent boundaries and 5 km buffer polygons around each sand data point were first created based on previous mapping by Bailey & Cochrane (1985). Sand picks were verified within the previously mapped boundaries to establish a consistent standard for the identification of each respective siliciclastic unit, resulting in a list of parameters that were used to characterize or evaluate each sand formation or member. Drill cuttings and geophysical logs were used to evaluate the validity of the presently known geographic extents. Surrounding wells without recorded Devonian sand picks were then examined to identify any unmapped extensions of the mapped sands. Cuttings and geophysical logs for wells outside of the mapped extent were also examined to eliminate any false picks (misrepresented or incorrectly identified, typographical errors, etc.), and to accurately delineate the boundaries of sand layers and lenses and any unmapped outliers.

For examination of drill cuttings, a 10x/30x binocular microscope was employed, in addition to hydrochloric acid (HCl), Alizarin Red, sample trays, and other sample examination tools commonly used in the petroleum industry (Swanson, 1981). Spatial analysis utilized ArcGIS and Google Earth queries of the OPDS database and Excel spreadsheets

	Columbus Sands	**Sylvania Formation**	**Springvale Member**	**Oriskany Formation**
# of formation/member edits	275	146	162	235
# of eliminated sand picks	52	63	32	51

Table 1: Statistical summary of database edits for each Devonian sand unit examined in this study.

Over 1320 wells were analyzed/reviewed, using both drill cuttings and geophysical well logs. Approximately 820 picks were added or adjusted and approximately 200 picks were eliminated from the existing database (Table 1). Geographic extents of all four Devonian sands have been revised, with variable but significant changes (i.e. elimination of anomalous/outlying picks, addition of new picks) to all sand units. Sample descriptions were enhanced, including the development of a database of sample photos and geophysical well log signatures. OPDS updates included new picks for sands, elimination of old picks, and updated formation/member tops. These updated tops were used to derive new extent maps of the Devonian sands, and for direct input into a 3-D hydrostratigraphic model of southwestern Ontario's subsurface geology.The files supporting this report are accessible at www.ogsrlibrary.com. These files include: Shapefile maps of the four Devonian sands corresponding to the maps seen in this report; an MSExcel spreadsheet including the updated Devonian sand intervals; and drill cutting photos of select sands from this study, contained within a keyhole markup language (.kml) file viewable in Google Earth which is georeferenced to the corresponding wells.

Time and resources did not permit a review of all the available wells. There may be additional occurrences of Devonian sands, probably as isolated outliers, which may remain for delineation in future studies.

4. Geological Setting

Southwestern Ontario lies between the Michigan and Appalachian Basins, and straddles a structural high formed by a combination of the Algonquin and Findlay Arches (Figure 1), which are separated by a structural low called the Chatham Sag. The Michigan and Appalachian basins developed in response to intermittent orogenic and tectonic activity in eastern North America, causing differential uplift and subsidence of the continental crust in eastern North America during Paleozoic time (Johnson et al., 1992; Armstrong & Carter, 2010), with resultant effects on the distribution of Paleozoic sedimentary units. Lying unconformably above the erosional surface of the Precambrian basement complex, up to 1425 m of Paleozoic strata are preserved. This condensed succession of carbonates, evaporites and terrigenous sediments records the changing areal extents of the inland seas of the Appalachian foreland basin and parts of Laurentia craton and subaerial phases on the cratonic region that enabled regional-scale erosion and cannibalization/redistribution of poorly lithified/indurated siliciclastic units across parts of the North American craton. Preserved Paleozoic strata are predominantly marine sedimentary rocks which range in age from Cambrian to Mississippian, with facies that are a reflection of the tropical latitude of Ontario during the Paleozoic Era (Armstrong & Carter, 2010). Appalachian Basin sedimentary strata tend to be more siliciclastic, while Michigan Basin sedimentary strata are dominated by carbonates and evaporites. Generally, the Paleozoic strata dip shallowly at 3 to 6 m/km southwestwards along the Algonquin Arch into the Chatham Sag, and at 3.5 to 12 m/km down arch flanks into the Michigan Basin and Appalachian Basin (Armstrong & Carter, 2010). Most of the Paleozoic bedrock in southwestern Ontario is covered by unconsolidated Quaternary glacial sediments, highlighting the necessity for subsurface analysis.

The Paleozoic strata are cut by a number of normal and strike-slip faults (Brigham and Winder, 1966; Brigham, 1971; Armstrong and Carter, 2010). Salt beds in the underlying Salina Group are often absent near these faults due to post-depositional dissolution. The faults may have acted as conduits for the cross-formational movement of water. The bedrock strata above these zones of salt dissolution often exhibit collapse or subsidence features which created depressions on the paleo-seafloor at different times in the geologic history. These seafloor depressions were sometimes filled with Devonian-aged sands, which were preferentially preserved from the effects of any subsequent erosion.

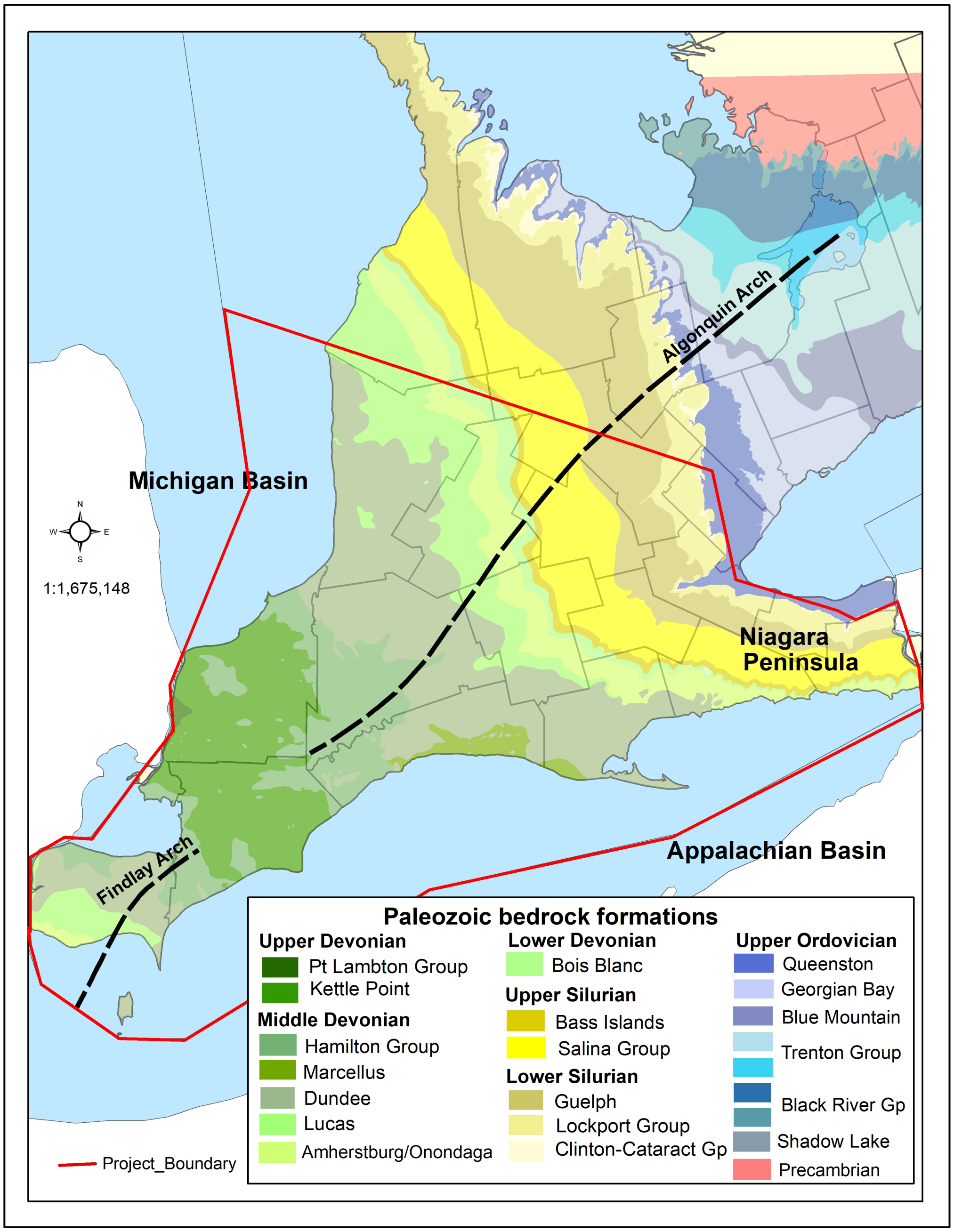

Figure 1: Regional geology of southern Ontario showing the Michigan and Appalachian basins separated by the Algonquin and Findlay arches. The study area is highlighted in red. Adapted from Armstrong and Dodge (2007).

5. Stratigraphic Relationships

The middle to lower Devonian stratigraphy in southwestern Ontario is dominated by carbonates (limestone and dolostone) with lesser shale, mudstone and sandstone (Figure 2). A series of major unconformities in the mid-lower Devonian represent significant time-gaps (Figure 2). The lengthy exposure of these formations led to significant erosion and karst dissolution of the exposed carbonates.

The Upper Silurian in southwestern Ontario is represented by the Salina Group and overlying Bass Islands Formation. The Salina Group is comprised of up to 420 metres of alternating cyclic layers of carbonates, evaporites, and argillaceous carbonates deposited in a slowly subsiding hypersaline sea. The evaporites (halite, anhydrite) of the Salina Group formed as a result of evaporative drawdown of sea-level in a shallow, confined basin during the late Silurian (Sonnenfeld & Al-Aasm, 1991). The variably laminated, argillaceous and bituminous dolostones of the overlying Bass Islands Formation were deposited in an intertidal to supratidal setting (Johnson et al., 1992; Haynes and Parkins, 1992). Thickness of the Bass Islands varies from 10 to 90 metres, with localized thickening to nearly 150 metres. These anomalously thick intervals are interpreted to represent deposition in sea-floor depressions formed by subsidence and collapse over dissolution cavities in salt beds of the underlying Salina Group (Armstrong and Carter, 2010); Sanford, 1969). The Bass Islands produces a relatively flat GR response due to its clean dolostone-mudstone mineralogy. A significant unconformity marks the contact between the Bass Islands Formation and overlying Lower Devonian strata. The Bass Islands surface is very irregular and is characterized by karstic dissolution features.

The Lower Devonian is comprised of the eastward-thinning Bois Blanc Formation, the Springvale Member of the Bois Blanc Formation, and the Oriskany Formation. The Bois Blanc Formation is a thin to medium bedded, fine to medium grained, fossiliferous cherty limestone and dolostone unit deposited during a major marine transgression (Uyeno et al., 1982). It is typically greenish grey to grey-brown, and is rich in rugose and tabulate corals, the stick-like stromatoporoid *Amphipora*, and brachiopods. Chert is often the dominant mineral in the Bois Blanc, locally making up ~90% of the rock volume (Armstrong & Carter, 2010). The Bois Blanc does not have a characteristic GR response. The Oriskany Formation consists of orthoquartzitic sandstone confined to erosional outliers at the unconformity between the Bois Blanc and the underlying Bass Islands Formation. The Springvale Member is a quartzose sand facies within the Bois Blanc Formation.

The Middle Devonian Amherstburg Formation is a poorly defined unit of fine to coarsely crystalline, bituminous, bioclastic, and fossiliferous limestone and dolostone (Armstrong & Carter, 2010). The Amherstburg has no marker beds and is relatively unresponsive on GR logs. In the Niagara Peninsula, the Amherstburg is laterally transitional with cherty fossiliferous limestone of the Onondaga Formation. In the Essex County area, the Amherstburg overlies clean quartz sandstones of the Sylvania Formation, described in more detail below.

The Lucas Formation overlies the Amherstburg Formation. The Lucas Formation is comprised of light grey-brown, fine-crystalline, poorly fossiliferous, thin to medium-bedded to laminated dolostones and limestone, with minor anhydritic and sandy beds (Armstrong & Carter, 2010). Needle-like porosity due to evaporite minerals is locally abundant. Locally, the Lucas contains a sandy lithofacies informally referred to as the "Columbus Sandstone" or "Columbus Sand" (Armstrong and Carter, 2010) by petroleum industry geologists, and formally is referred to as Anderdon member of Lucas Formation as described by Birchard et al. (2004). In this study it is called the Columbus Sand lithofacies of the Lucas Formation, and is described in more detail below.

Disconformably overlying the Lucas Formation are fossiliferous limestones and minor dolostones of the Dundee Formation. The Dundee Formation is grey to tan to brown, medium to thickly bedded, with locally abundant chert. The most identifiable feature of the Dundee Formation is the presence of fossils, including crinoidal debris, brachiopods, corals, and *Tasmanites* (Armstrong &

Carter, 2010). The Dundee Formation has a very low and flat GR response, owing to its clean carbonate mineralogy. The basal portion of the Dundee Formation was deposited during a time of marine transgression, in a shallow lagoon to open carbonate shelf (Hamilton & Coniglio, 1990), in contrast with the restricted marine environment of the underlying Lucas Formation.

Another major unconformity is found at the top of the Dundee Formation, marking the transition to the shales of the Marcellus Formation and siliciclastic-carbonate sequence of the Hamilton Group. This boundary is obvious in logs, as the shaly character of the Hamilton Group and Marcellus Formation produce a high GR response that is highly contrastable to the low GR of the Dundee Formation.

Four distinct quartzose sand units are found within the Middle and Lower Devonian (Fig. 2), all of which are closely associated with significant unconformities. These sands differ in terms of sorting, rounding, grain size, and secondary mineralogy, with abundant quartz sand being their unifying characteristic.

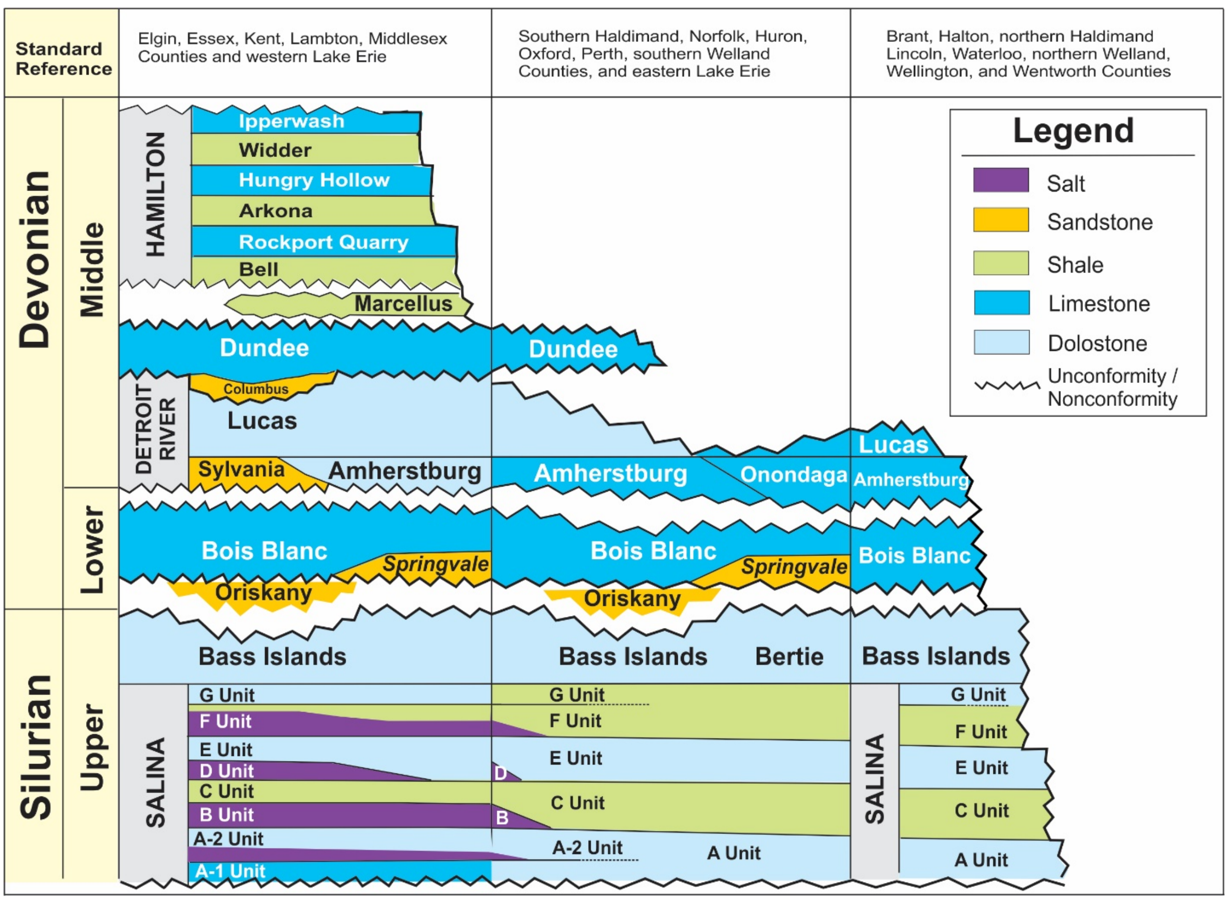

Figure 2: Lithostratigraphy of the Upper Silurian to Middle Devonian strata of southern Ontario, showing Lower Devonian and Middle Devonian sandstones. Adapted from Johnson et al. (1992) and Armstrong & Carter (2010).

Devonian Sand Units

5.1. Oriskany Formation

The Oriskany Formation of Ontario is considered equivalent to the Oriskany Formation in New York and Ohio, as well as the Garden Island Formation in Michigan (Sanford, 1968; Uyeno et al., 1982; Rickard, 1984). In Ontario, it occurs as patchy erosional remnants of a formerly regional sand. The Oriskany Formation lies unconformably over restricted marine dolomites of the underlying Bass Islands Formation and is preferentially preserved in sea-floor depressions created by collapse over dissolution cavities in salt beds of the underlying Salina Group (Bailey and Cochrane, 1985).

The Oriskany Formation is a coarse, well rounded, and poorly sorted quartz sandstone (Reavely & Winder, 1961). It can be distinguished from sandstone of the overlying Springvale by its lack of significant carbonate cement/matrix and lack of glauconite. Its erratic preservation makes it difficult to trace laterally, as significant thicknesses in one well may be neighboured by wells absent of any Oriskany at all. The reference well for the Oriskany Formation is **F005446, U.S. Steel No. 1-J.H. Lawrence No. 1, Charlotteville, 21-I.**

There has been no production of oil or natural gas from the Oriskany Formation in Ontario, but oil staining at Cayuga area quarries may indicate some resource potential (Armstrong & Dodge, 2007). It is a well-known gas producer in the Appalachian Basin to the southeast (Telford & Johnson, 1984). Subcrops of the Oriskany contain fresh water, and sulphurous water may also be present in the subsurface (Armstrong & Carter, 2010).

5.2. Springvale Member (Bois Blanc Formation)

The Springvale Member of the Bois Blanc Formation occurs either as interbeds or as the basal unit of the Bois Blanc Formation, lying unconformably above the Bass Islands Formation, and locally immediately over quartzose sandstone of the Oriskany Formation. The Springvale consists of white to green-brown (often glauconitic) quartzitic sandstones and minor sandy carbonates (Armstrong & Carter, 2010). The unit is present throughout most of southern Ontario, thickening towards the east and into Salina dissolution/collapse depressions. Springvale sandstone has historically been confused with Oriskany Formation sandstone. It has been proposed that the Springvale may actually be Oriskany Formation sands reworked during basal Bois Blanc transgression (Abel & Heyman, 1981; Telford & Johnson, 1984). Part of the confusion between Springvale and Oriskany was discussed by Bailey & Cochrane (1985), who noted that the two units are often in reservoir continuity.

The reference well for the Springvale Formation in southern Ontario is **T006045, Harwich, 1, 25-IECR,** which hosts sandstone bed intervals up to 1.5m thick in the basal 27m of the Bois Blanc Formation.

5.3. Sylvania Formation

The Middle Devonian Sylvania Formation disconformably overlies the Bois Blanc Formation and is gradationally overlain by the Amherstburg Formation (Armstrong and Carter, 2010). The typically pure white, friable Sylvania sandstone is very easily distinguishable in cuttings, core, and well logs. It is the basal unit of Detroit River Group in western Essex County (Reavely & Winder, 1961; Fagerstrom, 1971; Johnson et al., 1992; Russell, 1993).

The Sylvania Formation is named after outcrops found near Sylvania, Ohio (Winder, 1961), and is interpreted to be a continuous stratigraphic equivalent to its counterpart across the international boundary. There is a general thinning northeastward of Sylvania Formation sandstones into Ontario, before completely pinching out in western Essex County (Russell, 1993). Sylvania sandstone does not outcrop in Ontario, and is therefore only known from well records and samples (Russell, 1993). The frosting of quartz grains and high quartz percent support an interpretation that Sylvania sands are aeolian in origin. Further analysis, including the presence of marine fossils, indicate that the unit is more likely a combination of wind-blown sands that were later reworked in some form of beach environment (shallow marine) (Russell, 1993). This suggests an external source for the initial quartz grains. The Sylvania Formation's stratigraphic placement lying unconformably on Silurian and Devonian rocks indicates that it is likely the initial deposit of a transgressive sea (Russell, 1993).

These orthoquartzitic sandstones **(Reference well T007191, Pembina Maxus, Anderdon, 2, 11-V)** have not produced any oil or natural gas in Ontario. They do, however, act as a locally significant aquifer, hosting sulphurous or salty water (Armstrong and Carter, 2010), and are a source of high purity glass sand in Ontario and Ohio (Heinrich, 1979).

5.4. Columbus Sand Lithofacies, Lucas Formation

The Columbus sands generally occur in the uppermost Lucas Formation, at the contact with overlying limestones of the Dundee Formation. Previous studies have cautiously described Columbus as an interval unit lying above the Lucas, or the Amherstburg in areas beyond the pinchout edge of the Lucas, and below the Dundee Formation (Bailey & Cochrane, 1985), but it is generally considered to be a lithofacies within the Lucas Formation (Armstrong & Carter, 2010). The Columbus Sand is named after the Columbus Limestone in Ohio (Armstrong & Carter, 2010), however there is no definitive evidence of a stratigraphic correlation, and this study does not attempt to resolve this issue.

The Columbus consists primarily of sandy limestone to limy sandstone. The Columbus sands subcrop in parts of Essex County and on Pelee Island (Lake Erie) (Reavely & Winder, 1961). Columbus sands are more extensive than the other Devonian sands, and the most significant thicknesses may be related to Salina salt dissolution-collapse features (Bailey & Cochrane, 1985).

Hamilton (1991) identified a variety of sandy facies within both the Dundee and Lucas Formation. At the Rodney Oil Pool dolomitized siliciclastic sand-rich lime grainstones occur at the base of the Dundee Formation, and are immediately overlain by lime wackestone to packstone and mudstone facies of the Dundee (Hamilton, 1991). Quartzose sandstones were also documented at the top of the Lucas or interbedded in the top 10-15m of the Lucas (Hamilton, 1991).

Historically, natural gas was present in the Columbus (and Lucas Formation) and was produced into the late 1800s. Production of oil from the Columbus is still ongoing in Ontario, with a relatively large potential oil resource, despite continuous production. There is no previously documented reference well for the Columbus Sand in Ontario.

6. Results: Distribution and Characterization of Devonian Sands in Southwestern Ontario

The subsurface distribution of the four Devonian sands has been mapped in this study. Characterization of the sands has been made from examination of drill cuttings and interpretation of geophysical logs, in particular gamma ray logs. "Sands," in this report, refer to sandstones with a significant proportion of sand-sized clastic quartz. The "sands" variably occur as discrete loose grains of quartz or as well-cemented sandstone, usually with a carbonate cement.

6.1. Oriskany Formation

Sample Description

Oriskany Formation sands vary from calcareous quartz sandstones to quartz arenites. Figure 3 shows the subsurface distribution of the Oriskany Formation (blue) in southwestern Ontario. In drill cuttings, these sands typically appear yellow-white to light grey in colour, are variably fossiliferous, and are thick to massive bedded. They are often very distinguishable from the surrounding strata due to their pure sandy presence in sample vials and well logs. Quartz grains can range in size from upper fine to upper coarse (0.177-1.00mm), or very coarse sands (>1mm), but regionally most Oriskany sands are medium to coarse-grained (0.350-1.00mm). There is generally no carbonate cement in the cuttings samples, however sometimes light dustings of calcite/dolomite cement are found accompanying the quartz grains. Quartz grains are subrounded to well-rounded and sorting is variable but typically moderately sorted (Fig. 4, 5). Glauconite is never found in the Oriskany, which is a distinguishing attribute used to help differentiate between the Oriskany Formation and the overlying Springvale Member sands. The main accessory mineral found in the Oriskany is dolomite/calcite, of which there are typically low amounts.

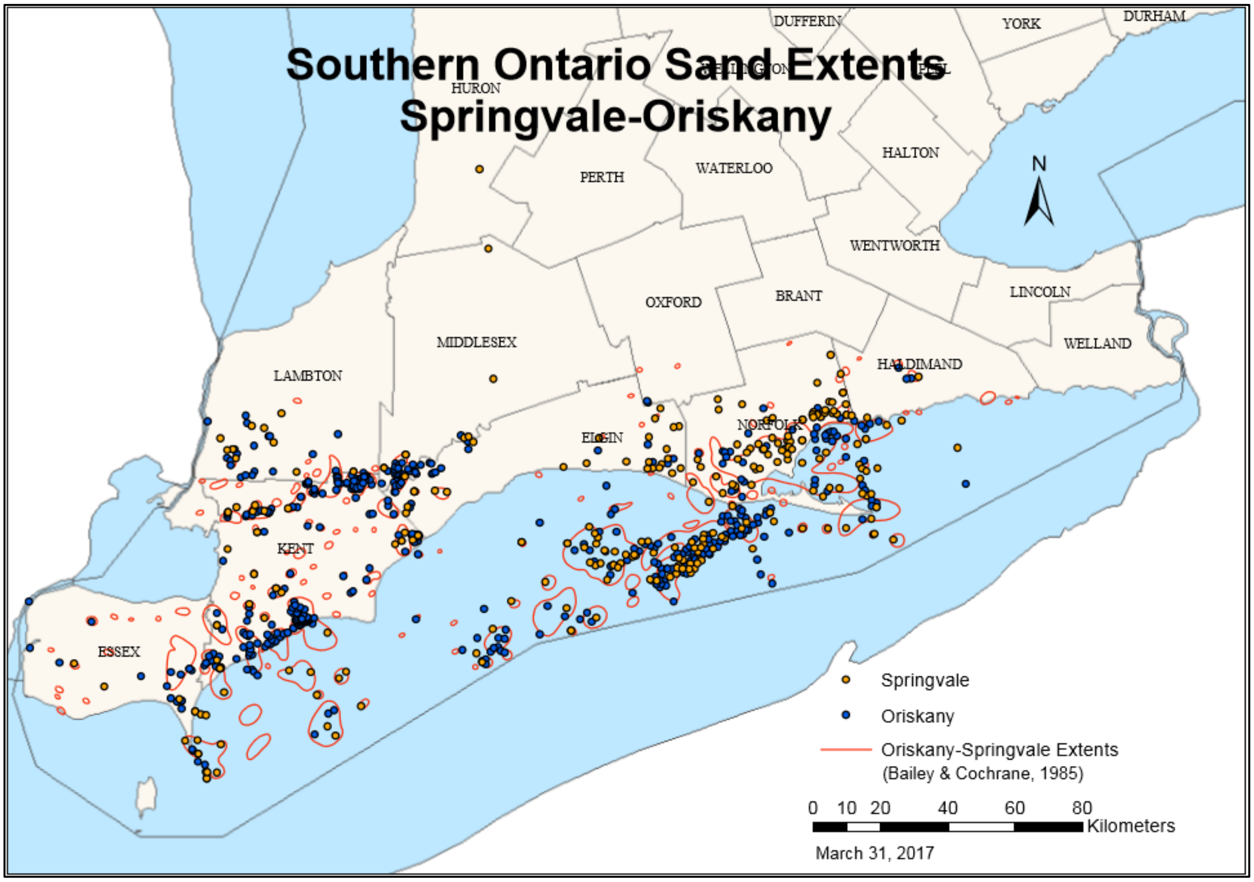

Figure 3: Map showing petroleum wells where Springvale and Oriskany sands are present, compared with previously mapped extent (1 km buffered red lines; Bailey & Cochrane, 1985).

Figure 4: F005526, Place Ryerse No. 7, Lake Erie, 47-E. Oriskany Formation. 82.9m depth. 10x photograph of typical medium quartz sand (+minor carbonate) of the Oriskany Formation.

Figure 5: T007168, Cons et al 34150, Mersea, 2, 20-VII. Oriskany Formation. 165m depth. 30x photograph of medium to coarse quartz sand (+minor carbonate) of Oriskany Formation.

Log Interpretation

Provided with a high-quality geophysical log, and thicknesses of 2 to 3 metres or greater, the majority of Oriskany Formation sands should be identifiable in a log pattern. The signature is an abrupt negative GR shift below the flat GR of the Bois Blanc and above the flat GR of the Bass Islands (Figs. 6, 7). This abrupt shift is due to unconformable contacts between each of these units. When possible, GR should be used to help identify Oriskany in logs, and to confirm observations in drill cuttings. There is also typically a corresponding shift on the neutron log that can be used in tandem with the GR to identify Oriskany units. Correspondence between logs and samples is typically very good.

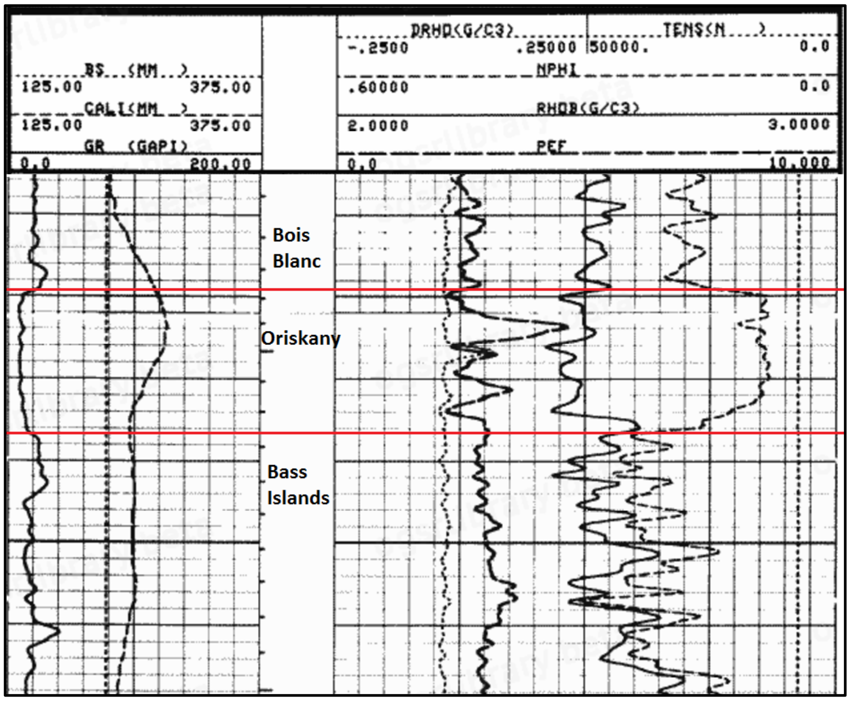

Figure 6: T007168, Cons et al 34150, Mersea, 2, 20-VII. CNFD log (GR left; RHOB right). An abrupt negative GR shift corresponds to the Oriskany interval in samples.

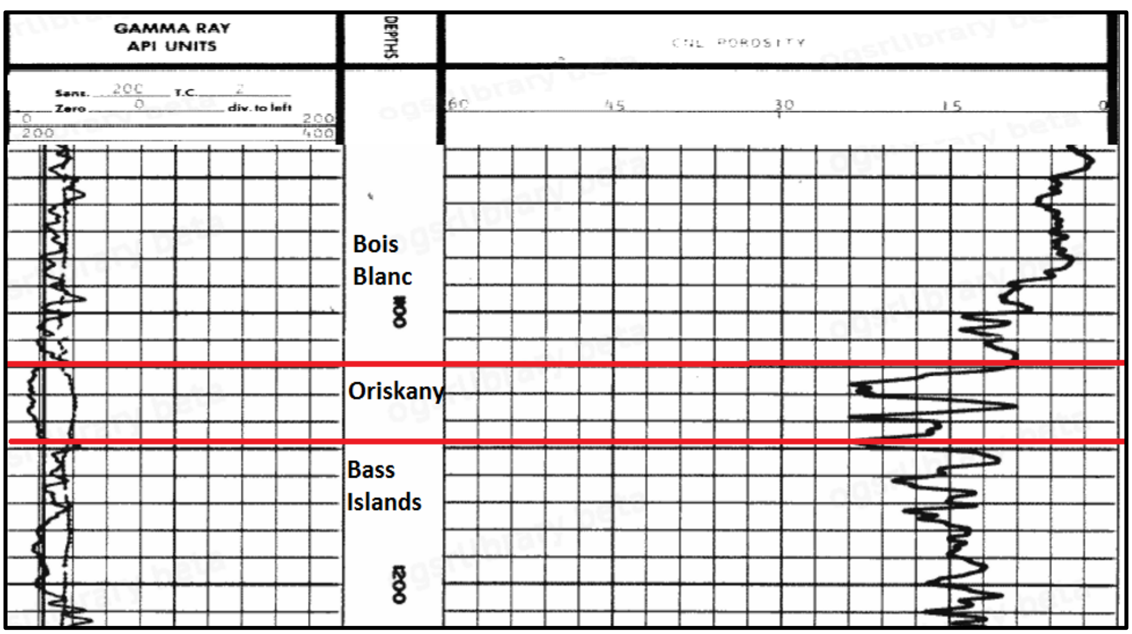

Figure 7: T004725, Consumers' 13512, Lake Erie, 220-X. Oriskany Formation. CNFD log (GR left; NPHI right). Upper and lower contacts of Oriskany are abrupt GR shifts, indicating unconformable upper and lower contacts.

Regional Extent

Oriskany is common on the Appalachian Basin side of the Algonquin Arch and within the Chatham Sag (Fig. 1, Fig. 3). Because of its relationship to Salina collapse units it has a very discontinuous distribution, typically occurring in thick ‘pockets’, and is completely absent from large areas. This makes this unit somewhat difficult to map regionally. This preferential preservation across large areas indicates that Oriskany may have originally been much more extensive than its current preserved extent.

An example of the local thickness variation is well F001225 and the nearby well F001176. These wells are within 3 km of each other, and F001225 displays ~10m of Oriskany, while the adjacent well at the extent of this erosional ‘patch’ displays only trace Oriskany.

Common Misidentification

In general, thick intervals of Oriskany Formation are relatively easy to identify in cuttings, even without the use of a microscope. If less than 1 to 2 metres in thickness, it could be blended in with other units and be less identifiable without the use of a microscope or well logs.

Perhaps the primary reason that Oriskany has not been identified in modern maps is because many old scans have identified these units as “Springvale,” which was subsequently dropped during transfer to Form 7’s. An exploration tip for Oriskany is to look at old scans (especially in Lake Erie area) and try to find mention of Springvale or Oriskany “at base of Bois Blanc.” Occasionally, in looking at the logs and/or samples, it is simple to identify Oriskany units after this. In some rare cases, shale incorporated into the sandy Oriskany layers act to increase GR response and lead to potential mischaracterization as Springvale in logs.

Regional Variation

Petrographically, the Oriskany sand is fairly consistent across its mapped extent in southwestern Ontario. The morphology of quartz grains doesn’t have significant regional variation. The main regional variation in Oriskany is unit thickness, although it could be argued that these changes are actually locally constrained, as the thickness of the Oriskany unit is mostly tied to the amount and timing of Salina collapse and the depth of the resulting depression on the Devonian sea floor.

Picking Protocol

Sample: Distinguishing Oriskany sand versus Springvale sand in cuttings can be difficult, especially when they are in direct contact. Oriskany is distinguished by its generally coarser grain size, lack of glauconite, and typical lack of carbonate cement. Well logs can also be very helpful based on differentiation in GR signatures. If there is no Springvale present at all, then Oriskany is easily identified as a clean quartz sand at the contact between the Bois Blanc and Bass Islands Formation. Both bounding formations (Bois Blanc and Bass Islands) have no clastic quartz component, so any sand in this interval can be attributed to either Springvale or Oriskany.

Log: It is important to note that identifying Oriskany simply based on well logs may cause issues, as Springvale and Oriskany can provide very similar well log signatures. For example, in the case of the thick, minor glauconite, and clean Springvale sands common beneath Lake Erie, well log signatures often were misinterpreted as Oriskany sands. When present, Oriskany should have a clean and consistently low GR reading, displayed as a sharp negative shift on the GR log. The Oriskany Formation top pick is generally made at the inflection point.

Future Work

One area that warrants further study is north of London, as Springvale units have now been found in Huron County, suggesting Oriskany could also be present. The most likely area where additional Oriskany sands occur is in areas where the underlying F-Salt has been dissolved away subsequent to deposition.

6.2. Springvale Member, Bois Blanc Formation

Sample Description

In this study, Springvale sand ranges from quartzose, consolidated to unconsolidated sandstone (+/- glauconite) occurring as the basal (or near basal) unit or as interbeds in the lower Bois Blanc Formation to glauconitic, calcitic sands occurring either as the basal (or near basal) unit or as interbed(s) in the lower Bois Blanc Formation. These two end-member Springvale sands are typically not gradational, but also do not necessarily have specific regional constraints. The cleaner, more quartz-rich sand appears to be mostly restricted to the eastern Lake Erie area. Springvale Member sands can often be distinguished from Oriskany Formation sands because of Bois Blanc Formation cherts or limestone below the sand unit and above the Bass Islands Formation contact. Bois Blanc cherts often interfinger with the sand intervals, and cherty fragments are often found together with the sand. Glauconite is variably present in the Springvale unit, and can be used as a distinguishing feature when identifying this unit. The presence of glauconite distinguishes Springvale from any other unit, however in some cases, basal Bois Blanc may also be glauconitic when no sand is present. This is informally known as “Springvale Equivalent,” but is not recognized as a distinct member or formation. Green staining and accessory pyrite is variably present in Springvale sands. Where Springvale sandstone is in contact with Oriskany sandstone, the transition can be difficult to identify, which is why in previous studies the two sands are mapped as one (Bailey and Cochrane, 1985). Figure 3 shows the subsurface distribution of both the Springvale Member (orange).

Most Springvale quartz grains are fine to medium grained (0.125-0.500mm), variably frosted and typically well rounded. The dark green specks are glauconite, found within quartz cemented by dolomitic cement (Fig. 8).

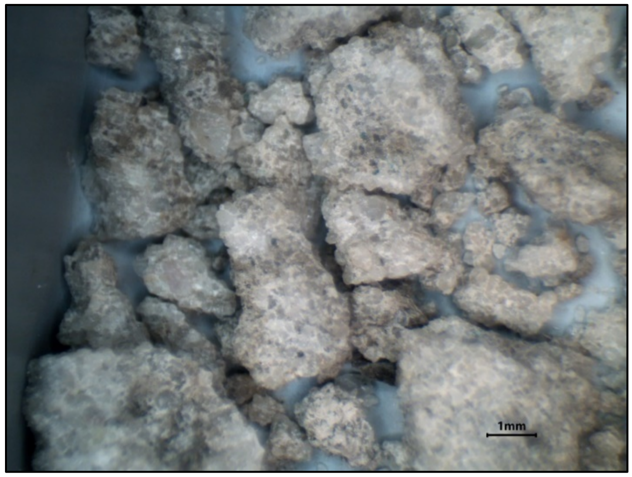

Figure 8: T002803, Consumers' Amoco 13102, Lake Erie offshore, 96-D. Springvale Member. 175.26m depth. 10x photograph of typical Springvale sand; cemented (calcite/dolomite) fine to medium quartz sand with glauconite (green).

Another end-member example of Springvale is shown below (Fig. 9). This end-member type of Springvale is disaggregated (loose) sand, variably dolomitic, with sparse glauconite. The main features that permit distinction from an Oriskany Formation sand is the finer (typically medium grained) quartz, location/depth of the sand, and underlying units.

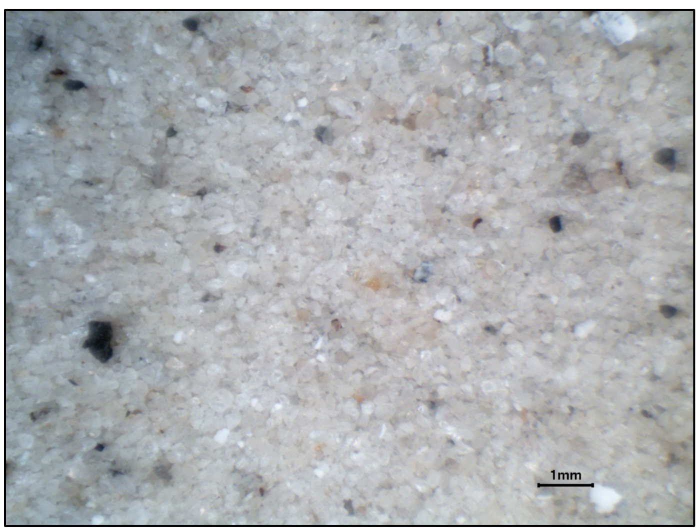

Figure 9: T006477, Consumers 13858, Lake Erie 122-R-, Lake Erie, 122, R. 243m depth. 10x photograph of variably dolomitic, quartzose Springvale sand, often misinterpreted to be Oriskany, found in the eastern Lake Erie area. Minor chert fragments are found in this unit.

Log Interpretation

The GR log interpretation of the Springvale Member is largely dependent on the carbonate content and the presence and abundance of glauconite. When present, radioactive glauconite will create a positive GR shift, occasionally even greater than the flat GR response of the surrounding limestones and dolostones of the Bois Blanc and Bass Islands Formations. When glauconite is not present, or is present in very low abundances, the GR log of Springvale may be displayed as a negative shift in GR, similar to the clean sands of Oriskany or Sylvania.

In an ideal case, Springvale GR should be higher than Oriskany, due to its glauconitic (radioactive) nature, and they can be differentiated on this basis (see Fig. 10). Here, the two units are separated by a cherty layer of Bois Blanc. In the case of clean Springvale sand (which is quite common in the eastern Lake Erie area), the flat, low GR reading is very easily confused with Oriskany. An example of a basal bed of glauconitic Springvale overlying Bass Islands is shown in Fig. 11. Note the higher GR signature due to the glauconitic nature of this sample. An example of an interbed of Springvale, bounded below by Bois Blanc, is shown in Fig. 12.

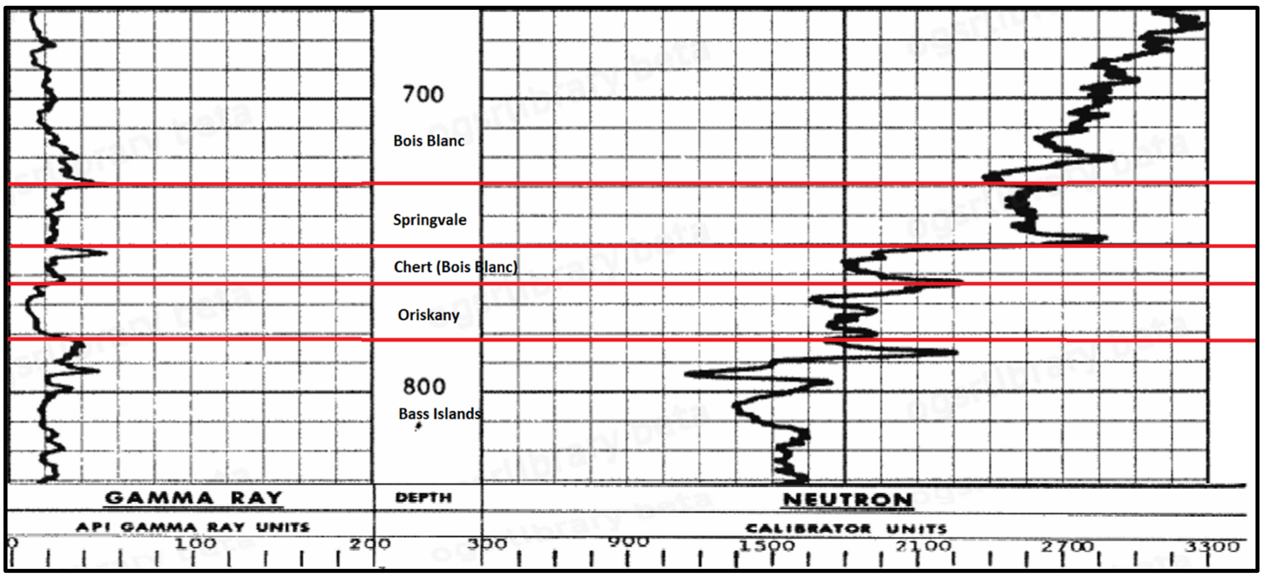

Figure 10: T003653, Consumers' 13237, Lake Erie, 123-F. Springvale Member. GRNL log (GR left, Neutron right). An ideal case (above) of two distinct sand units separated by chert (Bois Blanc). Springvale has a slightly higher GR reading (due to glauconite) than Oriskany.

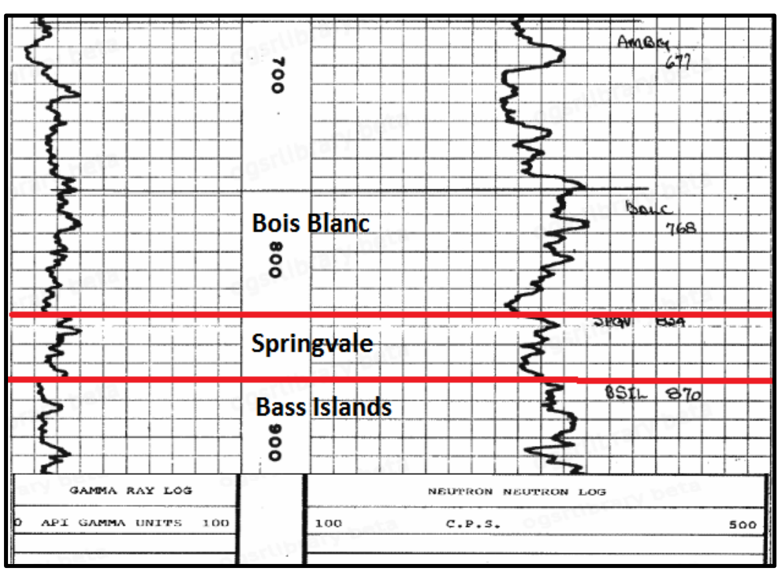

Figure 11: T003900, Brett Lowrie, Dawn, 1, 15-VII. Springvale Member. GRNL log (GR left; neutron right). Basal Springvale Member between Bois Blanc Formation and Bass Islands Formation, showing a relatively high, flat GR reading as compared to surrounding formations. This higher reading is likely related to presence of glauconite in Springvale in this well.

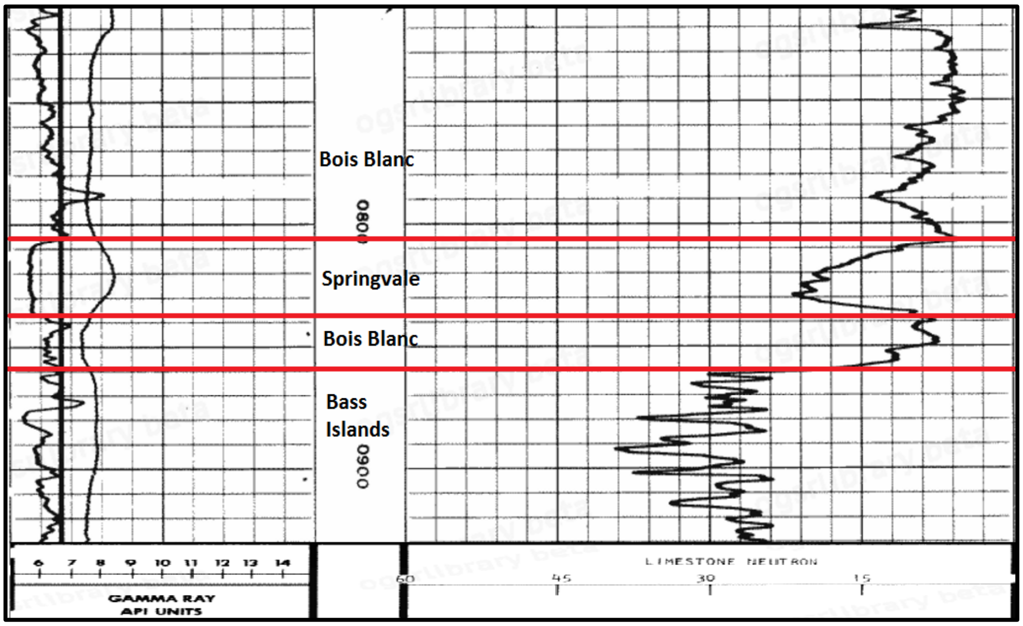

Figure 12: T004429, Consumers' 13405, Lake Erie, 120-Y. CNFD log (GR left; neutron right). 'Clean,' non-glauconitic Springvale interbed near the base of Bois Blanc.

Regional Extent

Springvale sandstone is thought to represent the "reworking" of Oriskany sands and subsequent re-deposition, and therefore it is understandable that Springvale would be less abundant than the already structurally controlled and relatively sparse Oriskany. Springvale sands have more or less the same distribution as the Oriskany, and are often found directly overlying Oriskany sands, appearing as essentially continuous units. Springvale sands stretch across southwestern Ontario from Essex to Haldimand County. A number of significant outliers (i.e. Biddulph, T002351), in Middlesex and Oxford counties were checked and confirmed, indicating Springvale preservation may be much more extensive than previously thought.

Common Misidentification

Springvale sands are frequently confused with Oriskany in the petroleum well records. These challenges can be overcome by a combination of viewing both samples and logs.

The main criteria used to distinguish between these units includes:

1. **Grain size.** Oriskany Formation sands are typically upper medium to coarse grained sand, while Springvale sands are typically fine to upper medium grained.

2. **Depth.** Oriskany sands always directly overly Bass Islands Formation. On the other hand, Springvale often occurs as interbeds in the Bois Blanc, underlain by more Bois Blanc Formation or Bois Blanc chert units before the transition to Bass Islands.
3. **Chert.** Abundant white chert fragments of the Bois Blanc will often be found within the Springvale Sand, due to Springvale's interbedded nature.

Regional Variation

Regionally, there is a general thickening eastward of the Springvale Member, however, thicknesses of Springvale appear to be mostly locally controlled. In eastern Lake Erie especially, Springvale sands are thick (often >10m), and typically unconsolidated, fine to medium-grained quartzose sandstones. This is quite different than further west where the Springvale is generally thinner and comprised of aggregated (calcite-cemented) glauconitic calcitic sands.

Picking Protocol

Sample: The top of Springvale Member sands is generally easy to pick, as it occurs at the first occurrence of quartz sand below the top of the Bois Blanc Formation. However, one difficulty is that Springvale often forms as interbeds in the Bois Blanc at different stratigraphic levels, meaning that this isn't always a cohesive unit. For mapping purposes, all strata below the uppermost sand and above the base of the lowermost sand are grouped as Springvale sands, rather than Bois Blanc Formation.

Log: As mentioned previously, Springvale log patterns differ considerably depending upon the amount of glauconite (radioactive-high GR), and cleanliness of sand (i.e. carbonate percentage). In the case of clean, quartzose Springvale, it should be picked at the inflection point of the corresponding negative GR shift. When the Springvale unit is high in glauconite and/or carbonate, there may be a positive increase in GR.

Future Work

Springvale Member sands are much more regionally extensive than previously mapped. Additional areas of sand not mapped in this study may occur above salt dissolution and collapse features.

Additional work could be performed on dividing and correcting Oriskany Formation and Springvale Member picks in OPDS. A large number of checked wells in the current study turned out to be Springvale, when listed as Oriskany, or vice versa. The progress made in this study has further developed the petrographic and petrophysical methods which can be used to distinguish these units.

6.3. Sylvania Formation

Sample Description

The Sylvania Formation is a clean, well sorted, pure quartz arenite present only in Essex County. This sand unit ranges up to over 30m in thickness in SW Ontario. Generally, the sands are brownish grey to pure white, high purity (95% or more quartz), very well rounded and sorted, pitted/frosted, and typically brownish grey to pure white (dependent upon variable carbonate content). In some cases, variable dolomite percentage, locally up to 20%, leads to lower quartz purity and loosely binds quartz grains together. Quartz grain size is variable, from fine to coarse grained. The most common grain size is medium grained sand (0.250-0.500mm). The lower contact of Sylvania is a sharp discontinuity with the Bois Blanc Formation. A rare zone of interbedded sandy and cherty dolostone beds has been documented at the base of the Sylvania (Russell, 1993), but was not documented in this study. The top contact can be somewhat gradational, marked by a typical increase of dolomite percent at the expense of sand upward into the Amherstburg Formation. Figure 13 shows the extent of the Sylvania sands in Ontario.

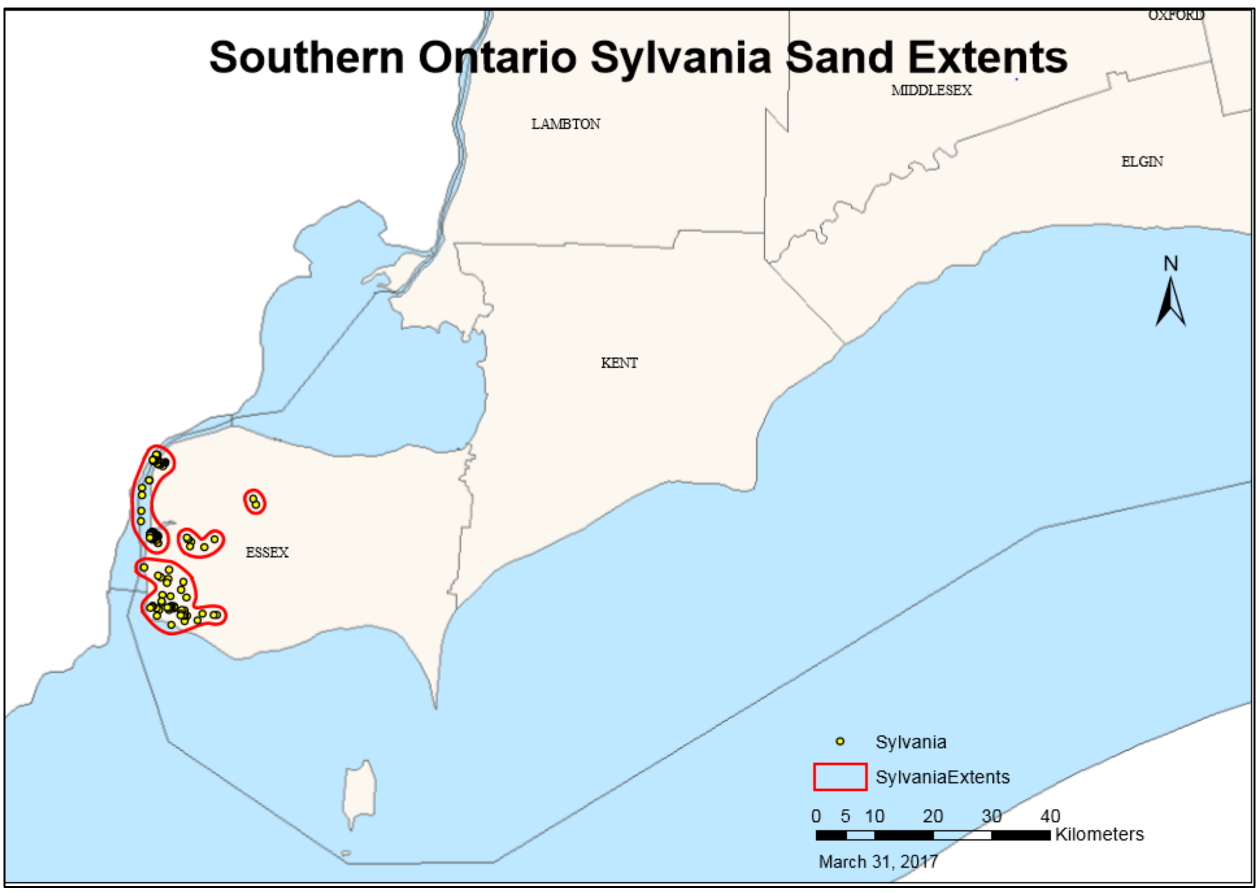

Figure 13: Map showing petroleum wells where Sylvania Formation sand is present. Red lines indicate previously mapped extent of Sylvania Formation (1.5 km buffered lines, Bailey and Cochrane, 1985).

Some of the morphological variation in Sylvania Formation sands are shown in the figures below (Figs. 14, 15). This variation is usually grain size and percent dolomite.

Log Interpretation

When viewed relative to its bounding formations, the Sylvania Formation displays a very obvious gamma ray signature. The negative shift in GR is typical of the lower clay content in clean sandstones as compared to the bounding dolostones and limestones of the Lucas and Bois Blanc. This signature is essentially the same as the Oriskany signature, a reflection of the similarity in the sand type and purity between the two units. The primary difference between Oriskany signature and Sylvania signature is the occasional slight gradational nature of the Sylvania top with the base of the Amherstburg. This makes the Sylvania top slightly more difficult to pick, however tops were generally picked at the inflection point. In most cases, a shift in the neutron log can be seen as well which matches the GR kick. This neutron shift corresponds to a general increase in porosity in the Sylvania Formation sands from the less porous overlying Lucas/Amherstburg dolostones and underlying Bois Blanc limestones. Sylvania sands are often quite thick, so the GR kick used to identify these sands is typically obvious. There is usually very good correspondence between logs and samples for Sylvania sands. When possible, Sylvania should be confirmed with logs, and the GR log should be used to provide very precise top and bottom depths.

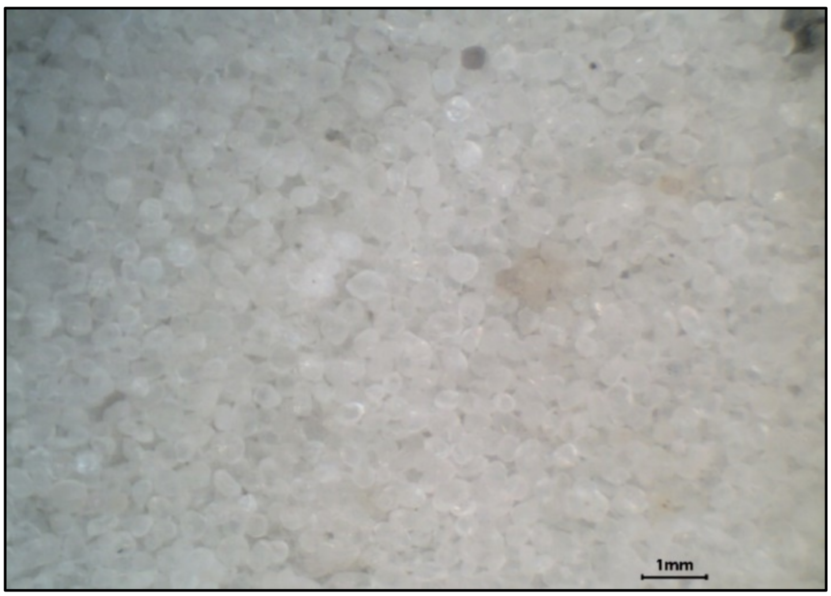

Figure 14: T007135, Cansalt DDH 2, Sandwich West, Fighting Island. Sylvania Formation. 99.9m depth. 10x photograph of pure, white quartz arenite (medium grained, 0.250-0.500mm) with very well rounded and sorted, variably frosted quartz grains of the Sylvania Formation with little to no dolomite cement.

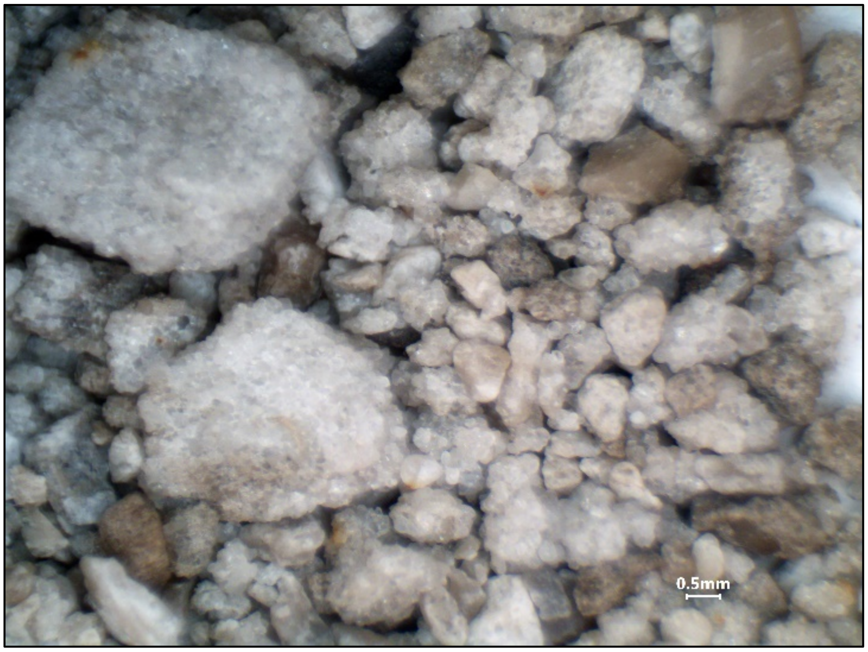

Figure 15: T007123, Pembina, Sandwich South, 1, 9-XIII. Sylvania Formation. 140m depth. 10x photograph of a variation of Sylvania (with increased dolomitic component), and aggregated (loosely cemented) finer-grained (<0.250mm) quartz grains.

Three typical GRNL logs for Sylvania are shown below (Figs. 16, 17, 18):

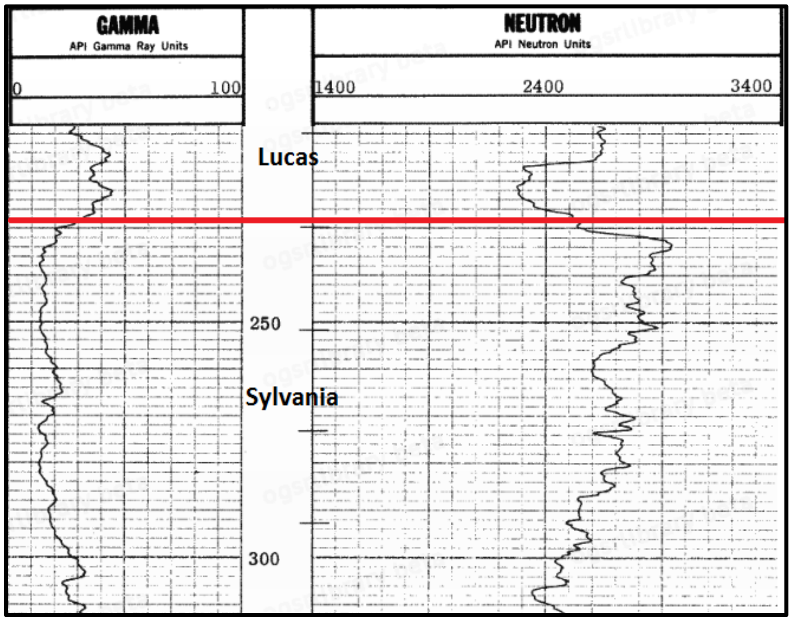

Figure 16: T008709, D5, Essex, Anderdon, unknown, 33-I. Sylvania Formation. GRNL log (GR left; Neutron right). A positive shift on the neutron log matches a negative shift in the GR log; both characteristic of porous, clean sand units.

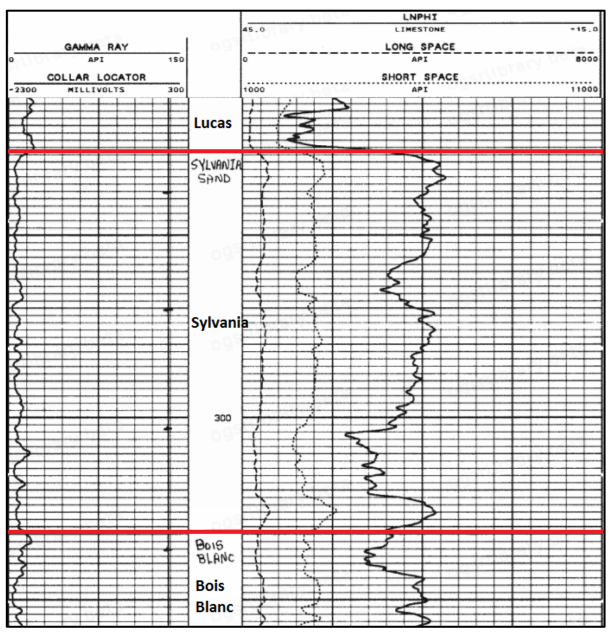

Figure 17: F007645, Brine Well D-7, Anderdon, unknown, 33-I. Sylvania Formation. CNFD log (GR left; NPHI right). A negative GR shift is seen accompanying a positive neutron shift, reflecting the true, pure sandy nature of Sylvania in this well. GR shift is not as pronounced here as in other wells.

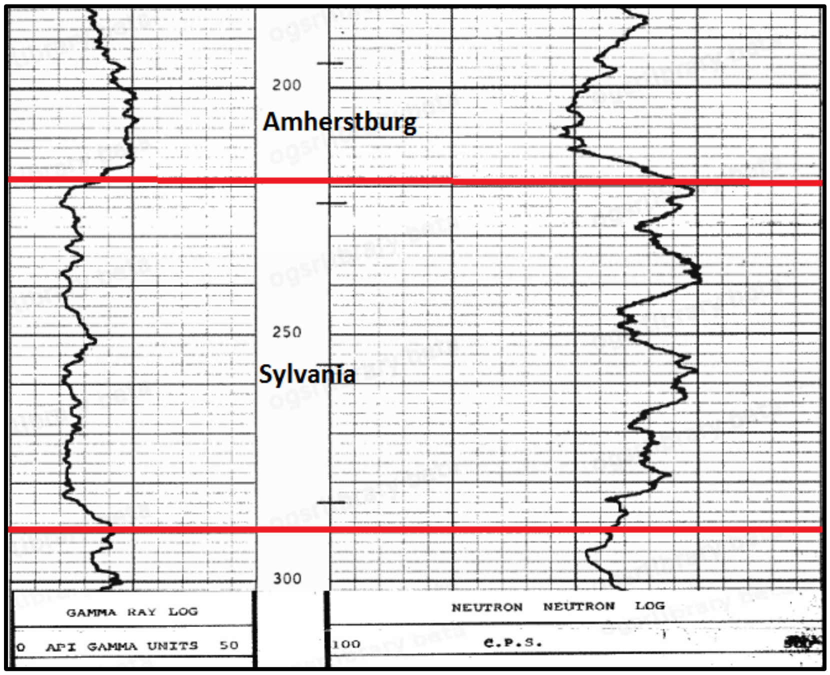

Figure 18: T003680, Allied Chemical E-6, Anderdon, unknown, 34-I. Sylvania Formation. GRNL log (GR left, neutron right). A positive shift on the neutron log matches a negative shift in the GR log; both characteristic of porous, clean sand units.

Regional Extent

This study eliminated false or incorrect Sylvania Formation top picks scattered across southwestern Ontario, and confirmed the known distribution exclusively in western Essex County, as documented by Armstrong and Carter (2010).

The apparent low abundance of Sylvania picks in western Essex County (Figure 13) is not representative of the true Sylvania presence/extent, but rather a reflection of the low abundance of drilled wells in this area. Most wells analyzed in western Essex had significant thicknesses of Sylvania sands, indicating a contiguous formation, thinning towards the east. There is a sharp and clear erosional edge of Sylvania, wedging out before the eastern side of Essex County.

Common Misidentification

Past studies (Russell, 1993) have indicated that Sylvania Formation is only present in Essex County. Operating on this assumption, all Sylvania picks in the OPDS database outside of Essex County were treated as suspect. Upon analysis, many of these units hosted no sand whatsoever, and were treated as data entry errors. Some of these sands were actually Columbus or Oriskany sands that had been improperly logged. As noted by Russell (1993), this may occur if the difficult transition between Dundee and Lucas is not recorded, as the next sandy facies down-well (Springvale or Oriskany) may be identified incorrectly as Sylvania.

Regional Variation

Sylvania Formation is not very extensive, and thus there is very little regional variation in Ontario. The main difference regionally is the westward thickening of Sylvania (basin ward) away from the eastern margin, and across the international boundary. Sylvania sands in Michigan and Ohio are much more extensive, and record significant variation.

Picking Protocol

Sample: In drill cuttings, the Sylvania Formation is easily identified by the appearance of white to greyish brown quartz sand. In contrast to the overlying clean dolostones of the Lucas or Amherstburg Formation, the first occurrence of quartz grains can be definitively considered as the top of the Sylvania Formation sands. These sands are typically coarse and pure enough that they are usually quite visibly identifiable, even when present in considerably small proportions in vials.

Log: Picking the Sylvania Formation with logs is fairly reliable. The pronounced and consistent shift in GR and neutron is often unmistakable. As mentioned previously, the occasionally gradational contact with the overlying Amherstburg Formation means that the log pattern for Sylvania may often be more gradational than some of the other unconformity-bounded units (i.e. Oriskany). The formation top is picked at the GR inflection point leading into the low and consistent/pure GR sand signature. Neutron logs also often reflect the increase in porosity within the Sylvania Formation as compared to surrounding dolostones and limestones.

Future Work

This project has constrained the geographic extent of Sylvania Formation sands very well in southern Ontario, and the formation top data recorded in OPDS is accurate and consistent.

6.4. Columbus Sand

Columbus Sand vs Columbus Equivalent

Two sand “facies” have been identified and are separately described. The Columbus Sand is a quartzose sandstone, whereas the Columbus Equivalent is a diagenetic carbonate clast-dominated facies spatially associated with the Columbus Sand.

Sample Description

The Columbus Sand (Figs. 19, 20, 21) ranges from sandy limestones to limy sandstones to almost pure quartz sand, and is typically thick to massive bedded. Quartz grains are variably frosted and moderately to well sorted. Quartz is most often found ‘floating’ in a calcitic or dolomitic matrix. Average quartz grain size in these aggregates is ~fine (0.125-0.25 mm), but quartz grains up to lower medium grained (0.250-0.350mm) are common when present as disaggregated quartz (Fig. 20, 21). The percentage of quartz varies considerably, even in adjacent wells. An example is the Rodney Pool, where producing intervals are quartz-dominated in some wells, and carbonate-dominated in adjacent wells.

The distribution of the Columbus Sand (and Columbus Equivalent; Fig. 19) determined in this study is compared to previous mapping by Bailey and Cochrane (1985).

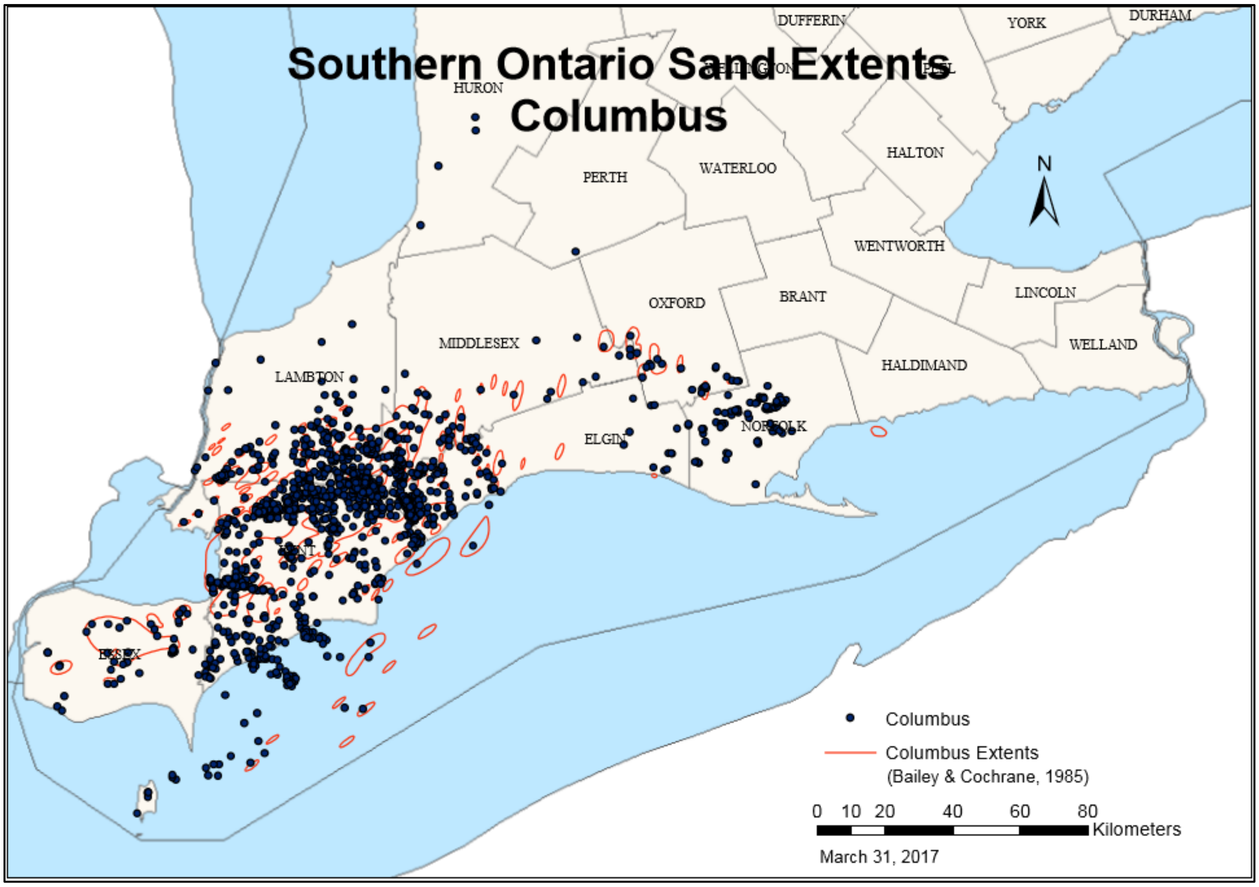

Figure 19: Map displaying petroleum wells where Columbus Sand is present (including Columbus Equivalent), compared to previously mapped extent boundaries (1 km buffered red lines; Bailey & Cochrane, 1985).

Figure 20: F001709, Ajax Oil and Gas Co. Ltd. No. 12 -R.W. Johnston No. 2, Dover, 3-III. Columbus, 130.45m depth. 10x photograph of loose quartz of Columbus and some aggregated (cemented) quartz grains.

Figure 21: T001348, B.A. Moravian I.R. 25, Orford, 2, 25. Columbus, 140.8m depth. 10x photograph of uncemented quartz sand grains within sandy limestone.

Log Interpretation

Columbus Sand well log patterns are typically not as pronounced as some of the other cleaner quartz sands (i.e. Sylvania Formation, Oriskany Formation). For this reason, included below are a number of different log signatures (Fig. 22, 23) that could be attributed to Columbus Sand. Red lines indicate formation/member tops picks. A slight to pronounced negative GR shift can sometimes be seen where the Columbus is dominated by quartz sand, compared to the clean Dundee Formation limestone. In the case of carbonate-cemented Columbus with lesser quartz (dominant type), well log signatures may be less pronounced compared to the carbonates of the Dundee and Lucas formations and are unreliable. Ideally, neutron logs should display a positive shift in the sandy Columbus domain as well, a reflection of the increased porosity of the sand as compared to the less porous dolostones and limestones of the bounding formations.

Log signatures should only be used in combination with examination of drill cuttings or core to identify Columbus sands.

Regional Extent

The Columbus Sand is the most regionally extensive of the Devonian sands, occurring everywhere from Essex County to Norfolk County (Fig. 19). Columbus sand outliers occur in Huron County, much further north than previously predicted or documented. The thickest units of Columbus appear to fill in depressions in the underlying Devonian units created during Salina salt dissolution and subsidence (Bailey & Cochrane, 1985).

Common Misidentification

The most common misidentification of Columbus is when it is confused for Columbus Equivalent or Dundee Formation. This misidentification is likely due to the tendency to group carbonate and quartz sands together in the past. It is suggested that Columbus in general should be subdivided into the classic Columbus quartzose sand (clastic quartz+/-carbonate cement), and the Columbus Equivalent (dolomite grains hosted in dolomitic cement) described in the following section.

Another common misidentification is a less common sand interval within the Lucas, rather than at or near the contact with the overlying Dundee Formation. These stratigraphically lower sands are uncommon and may be of a different origin. They are not included as either “Columbus sand” or “Columbus Equivalent” in this study and are not separately recorded in the petroleum well database.

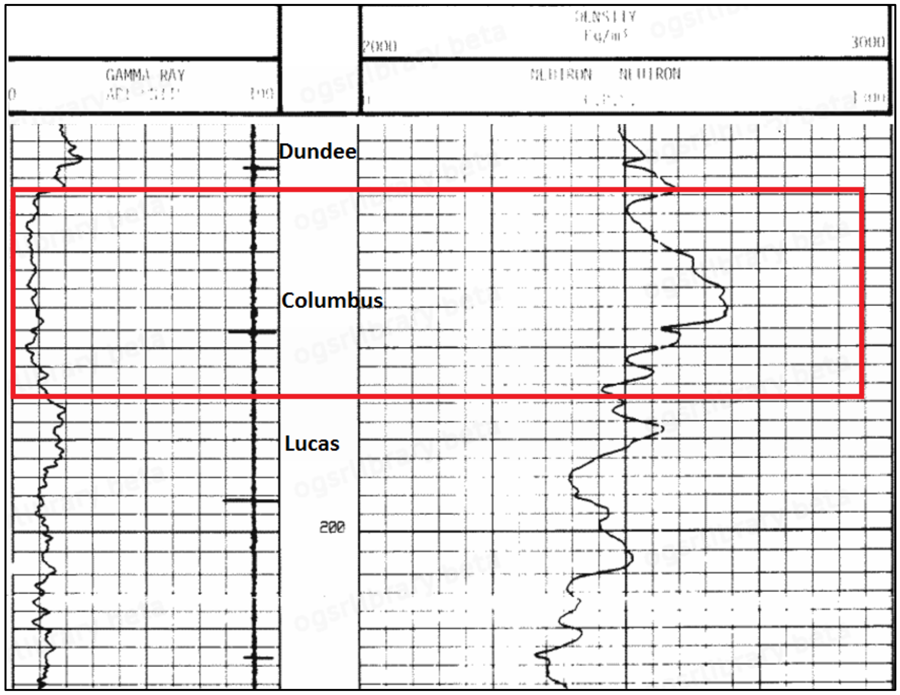

Figure 22: T007013, Twin Star #2, Camden, 6, 10-X. Columbus. GRNL (Gamma Ray, left; Neutron, right) log showing contrast between limestone of Dundee and slightly lower GR (API) response of Columbus sandy limestone. Neutron log (right) shows increased porosity in sandy Columbus section.

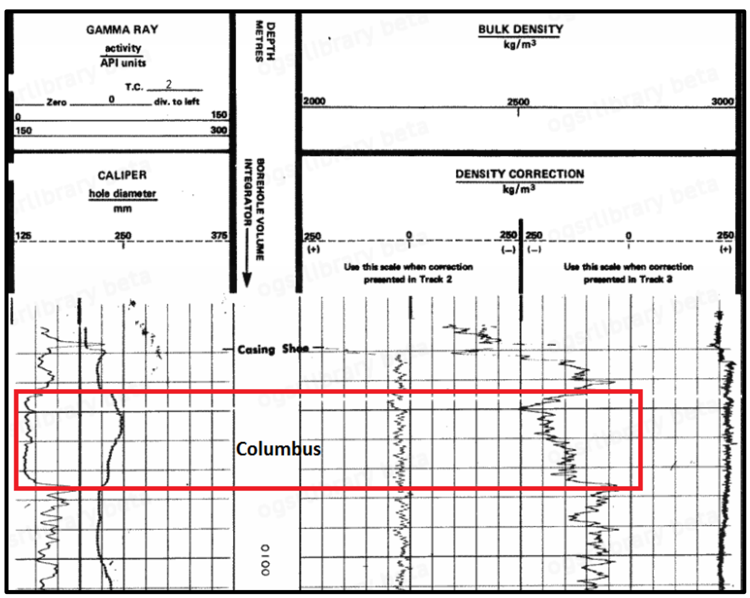

Figure 23: T005794, CS et al., Dereham, 1, 27-VII. Columbus. CNFD (Gamma Ray, left; Density, right) log showing an example of a Columbus log pattern that is relatively easy to pick. A relatively sharp GR decrease, combined with a decrease in density, are characteristic of these sandy intervals.

Regional Variation

The Columbus Sand displays considerable variation in morphology, grain size, rounding etc. of quartz grains, and transition into Columbus Equivalent facies. These changes can occur in adjacent wells, where clastic quartz sands of the Columbus grade into clastic carbonate sands of the Equivalent facies, hence the need for further mapping and characterization focused on the Columbus interval.

Picking Protocol

Sample: In cuttings, the top of the Columbus Sand can be difficult to pick. This difficulty lies primarily in the gradational way in which this sand *appears* to present itself. Although the upper contact is unconformable, there is often a gradational sequence from Dundee and Columbus "Equivalent" into quartzose Columbus Sand. For this reason, these units were divided, and the first occurrence of actual quartz sand in a carbonate matrix or pure quartz sand (above the Lucas Formation) is considered as the top of the Columbus Sand.

Log: In some cases, the top of the Columbus Sand is easier to identify using geophysical logs than using cuttings, but logs alone are not consistent, and should only be used in tandem with drill cuttings or drill core analysis. A negative GR shift from the overlying Dundee limestones often identifies the Columbus sands, followed by an increase in GR intensity back into the underlying Lucas or Amherstburg Formation dolostones. These relatively sharp boundaries in the logs are related to the unconformable boundaries of the Columbus Sand. Although neutron and density logs can be helpful with Columbus identification, log picks are most consistently made at the inflection point on GR logs for both the top and bottom of the Columbus. Log picks should be confirmed with samples, and vice versa.

6.5. Columbus Equivalent (Lucas Formation)

The Columbus Equivalent is a granular carbonate facies that occurs together with typical Columbus quartzose sands. Currently, these two facies are mapped together, and for the purposes of this project, both are considered together, as "Columbus sands." This project has, however, illustrated the need to properly differentiate between these units, and suggests how these units should be divided. Hamilton (1991) has interpreted the Columbus Equivalent as preferential dolomitization of the precursor limestones in proximity to beds of quartzose sand of the Columbus Sand, and credits it with forming the bulk of the oil reservoir at the Rodney Oil Pool.

Sample Description

Columbus Equivalent is comprised of fine-grained rhombs of crystalline dolomite 0.1-0.25 mm in size supported by a very fine-grained carbonate (typically dolomitic) matrix (Fig. 24). The granular nature gives a clastic appearance which with only cursory examination is easily mistaken for Columbus Sand, but careful examination at higher magnifications can help display the angularity of the dolomite grains as compared to the rounded, quartz clasts in the Columbus Sand.

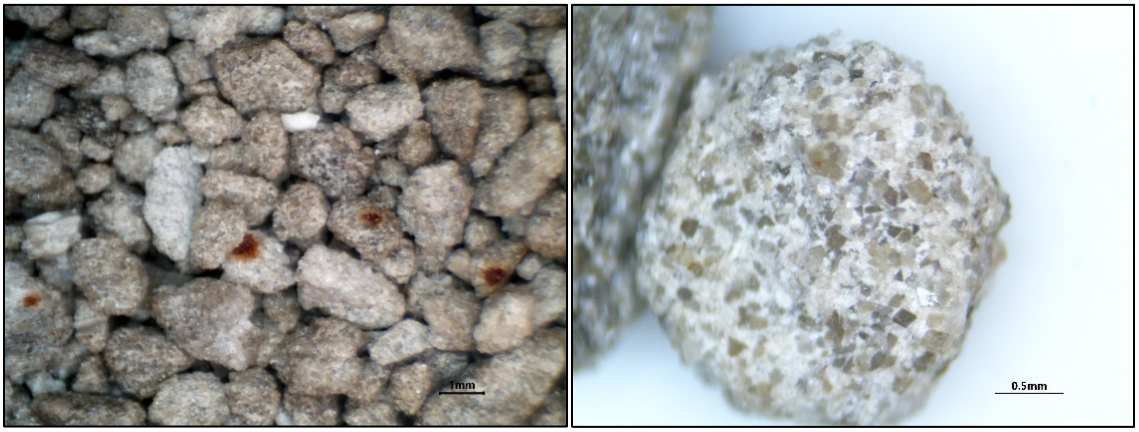

Figure 24: T002115, Tobacco Rd. No. 7-A. Herman No. 1, Orford, 52-STR. 168.25m depth. 10x (left) and 30x (right) photograph of Columbus Equivalent (dolomite grains hosted in dolomitic cement) facies commonly misinterpreted as Columbus quartzose sand.

Log Interpretation

The log patterns for Columbus Equivalent are by far the most difficult to interpret and understand. No examples of Columbus Equivalent log signatures are provided in this report as there is no diagnostic signature.

Regional Extent

Observations of the Columbus Equivalent facies were reported throughout southern Ontario wherever the Columbus Sand was present.

Common Misidentification

Prior to the recognition of Columbus Sand and Columbus Equivalent, Columbus Equivalent has often been misidentified in petroleum well records as Columbus Sand. Columbus Sand is defined where there is a quartz sand component, and thus, Columbus Equivalent should not, in the future, be considered a part of the Columbus Sand. Columbus Equivalent tops are also often misinterpreted to be somewhere within the Dundee, as there is a common transition from regional Dundee→ basal Dundee packstones and grainstones→Columbus Equivalent, where the basal Dundee grainstones may resemble the granular dolomites of the Columbus Equivalent.

Picking Protocol

Samples: Columbus Equivalent can be difficult to pick in samples. At first glance, this unit appears more gradational, with a gradual upwards transition into basal Dundee grainstones. It is suggested that "Columbus Equivalent" should be picked as the first occurrence of very fine to fine grained dolomite rhombs hosted in carbonate matrix. Dolomite rhombs do not occur in the basal Dundee.

Log: The reliability of logs for picking Columbus Equivalent is low. Occasionally, a GR and neutron or density change can be observed between Dundee and Lucas, however these changes are not pronounced and should only be used to help with observations from drill cuttings.

Columbus Issues and Future Work

The Columbus Equivalent is spatially associated with the clastic quartzose sands of the Columbus Sand, but its petrographic characteristics as observed in cuttings is more consistent with a diagenetic origin, rather than a clastic origin, in agreement with Hamilton (1991). This is an important distinction and needs to be understood for proper interpretation of reservoir development in these strata and design of secondary recovery projects. The Columbus Equivalent has some of the best porosity in the Rodney Oil Pool (Hamilton, 1991).

New Columbus picks made in and around the Huron Shores area indicates that the Columbus Sand is much more extensive than previously thought. Much like Oriskany, this may be due to preferential preservation in salt dissolution-collapse features. In this case, one potential way to explore for more Columbus Sand would be to query OPDS for wells where Salina salt beds have been dissolved away.

Lastly, the stratigraphic issues discussed in this study present an emerging modelling problem that may have implications for the placement of formation tops in this zone (i.e. Lucas, Columbus Sand). Further discussion and investigation is required in order to assign member or formation status to the Columbus Sand. The Columbus Equivalent is not a stratigraphic unit.

Dundee-Columbus-Lucas Transition Zone

Much of the difficulty in addressing the Columbus sands stems from the often gradational and complicated interrelationship at the Dundee Formation-Columbus-Lucas Formation transition. A general sequence from bottom-up that can be observed in many wells intersecting this interval is described below:

1) *Sandstone beds within Lucas Formation:* Calcareous quartzose sands occasionally occur as interbeds within the upper the Lucas Formation. These sands are very similar to the quartzose sand of the Columbus Sand, which generally occurs at the contact between the Dundee and Lucas.
2) *Lucas Formation:* The generally accepted top of the Lucas Formation in Ontario is described as dominantly dolostones, with lesser limestones, anhydritic beds and local sandy limestones (Armstrong & Carter, 2010). The sometimes-confusing Dundee-Lucas transition has often been missed or incorrectly picked. Previous studies have considered Columbus to be a lithofacies at the top of the Lucas Formation (i.e. picked with the same formation top), causing issues for modelling and geological conceptualization. See the Lucas Formation reference well T006045, OGS 82-2 Chatham, Harwich, 1, 25-I.E.C.R in Armstrong and Carter (2010).
3) *Columbus Sand and Columbus Equivalent:* The Columbus Sand and Columbus Equivalent usually occur together. The Columbus Sand is a quartzose sandstone with dolomite cement and

the Columbus Equivalent is a granular dolostone comprised of crystalline rhombs in a very fine-grained dolomite matrix, interpreted to be diagenetic in origin.

4) *Basal Dundee Formation bioclastic grainstones:* The basal Dundee in the vicinity of the Rodney Oil Pool is comprised of bioclastic lime packstones and grainstones. This facies is often confused with and hard to distinguish from the Columbus Equivalent, largely a result of the clastic nature of both facies.
5) *Dundee Formation:* Comprised mostly of limestones and minor dolostones, the typical Dundee Formation is relatively clean, providing a distinct low GR as compared to the overlying shales of the Hamilton Group or Marcellus Formations. Generally abundant algal cysts *(Tasmanites)* are diagnostic of the basal Dundee Formation and can be used to distinguish the basal Dundee from the top of the underlying Lucas Formation dolomite and the sands of the Columbus. Dundee Formation reference well T006045, O.G.S.-82-2 Chatham, Harwich, 1, 25-I.E.C.R (Armstrong and Carter, 2010).

7. Summary and Conclusions

The mapping of these four Devonian sand units has added considerable knowledge about the complicated nature of sand units in Ontario. This study has provided many new potential project ideas that include:

1. Detailed mapping of Columbus Sand vs. Columbus 'Equivalent'.
2. Columbus mapping and quantification of dolomite cement percentage in sands.
3. More extensive sand mapping throughout SW Ontario, up to at least central Huron County, where new sand picks have been made recently (i.e. Columbus, Springvale).

This project has:

- provided data on petrography and petrophysical character to establish protocols for consistent identification in cuttings samples and geophysical logs;
- improved accuracy of mapping of sand distribution and added data points in areas where units were not previously mapped (due to new drilling or missed picks);
- eliminated incorrect picks and adjusted formation/member tops; and
- found sand outliers up to 60-80 km from their respective main sand bodies.

From a statistical perspective, samples and logs for over 1300 wells were analyzed, approximately 820 new or revised sand picks were made, and over 200 incorrect sand picks were eliminated from the petroleum well records of the Ontario Petroleum Data System.

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9. References

Abel, K. D. and Heyman, L., 1981. The Oriskany Sandstone in the subsurface of Pennsylvania: Pennsylvania Geological Survey, 4th ser. *Mineral Resources Report*, *81*(9).

Armstrong, D. K. and Carter, T.R., 2010. The subsurface Paleozoic stratigraphy of southern Ontario. Ontario Geological Survey, Special Volume no. 7, 301p.

Armstrong, D. K. and Dodge, J.E.P., 2007. Paleozoic geology of southern Ontario. Ontario Geological Survey, Miscellaneous Release—Data, 219. Retrieved May 1, 2017 from http ://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/R105/R105.pdf.

Asquith, G. and Gibson, C., 1982. Basic well log analysis for geologists. American Association of Petroleum Geologists, Methods in Exploration Series, no.2, 216 p.

Bailey, B. and Cochrane, R.O., 1985. Evaluation of the conventional and potential oil and gas reserves of the Devonian of Ontario. Ontario Geological Survey, Open File Report, 5555.

Beards, R.J., 1967. Guide to the subsurface Palaeozoic stratigraphy of southern Ontario. Ontario Department of Energy Resources Management, Paper 67-2, 19p. Retrieved April 25, 2017 from: http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/OGP67-02/OGP67-02.pdf.

Birchard, M.C., Rutka, M.A., and Brunton, F.R., 2004. Lithofacies and geochemistry of the Lucas Formation in the subsurface of southwestern Ontario: A high-purity limestone and potential high-purity dolostone resource. Ontario Geological Survey, Open File Report 6137, 180 p.

Brigham, R.J., 1971. Structural geology of southwestern Ontario and southeastern Michigan. Ontario Department of Mines and Northern Affairs, Petroleum Resources Section, Paper 71-2, 110p. Retrieved April 2, 2017 from http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/OGP71-02/OGP71-02.pdf.

Brigham, R.J. and Winder, C.G.,1966. Structural geology of Paleozoic sediments in southwestern Ontario. Proceedings, Ontario Petroleum Institute, 5th Annual Conference, London, Ontario, v.5, Technical Paper 13, 21p.

Fagerstrom, J.A., 1971. Brachiopods of the Detroit River Group (Devonian) from southwestern Ontario and adjacent areas of Michigan and Ohio. Geological Survey of Canada, Bulletin 204.

Hamilton, G.D., 1991. Styles of reservoir development in middle Devonian carbonates of southwestern Ontario (M.Sc. Thesis). University of Waterloo, Ontario, Canada.

Hamilton, G.D. and Coniglio, M., 1990. Diagenetic history of dolomitized Ordovician and Devonian oil and gas reservoirs in southwestern Ontario; Part A, Styles of reservoir development in the Middle Devonian of southwestern Ontario. Ontario Geological Survey Miscellaneous Paper Report 150, 115-130.

Haynes, S.J. and Parkins, W.G., 1992. Stratigraphy of the Cayugan Series: Lithofacies of the Bertie and Bass Islands formations, Onondaga Escarpment; in Geoscience Research Grant Program, Summary of Research 1991-1992. Ontario Geological Survey, Miscellaneous Paper 159, p.22-37.

Heinrich, E.W., 1979. Economic geology of the sand and sandstone resources of Michigan;.*State of Michigan, Department of Natural Resources, Geological Survey Division,* 31p. Retrieved April 24, 2017 from http://www.michigan.gov/documents/deq/GIMDL-RI21_216264_7.pdf.

Johnson, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G., and Rutka, M.A., 1992. Paleozoic and Mesozoic geology of Ontario. Geology of Ontario, Ontario Geological Survey, Special Volume 4 (Part 2), p.907-1008.

Reavely, G.H. and Winder, C.G., 1961. The Sylvania Sandstone in southwestern Ontario. The Canadian Mining and Metallurgy Bulletin, 64, 109-112.

Rickard, L.V., 1984. Correlation of the subsurface Lower and Middle Devonian of the Lake Erie region. Geological Society of America, Bulletin 95, 814-828.

Russell, D.J., 1993. *Role of the Sylvania Formation* in *sinkhole* development, Essex County; Ontario. Ontario Geological Survey, Open File Report 5861, 122p.

Sanford, B.V., 1968. Devonian of Ontario and Michigan; *in* International Symposium of the Devonian System, Alberta Society of Petroleum Geologists, 1, 973-999.

Sanford, B.V., 1969. Geology, Toronto-Windsor area, Ontario; Geological Survey of Canada, Map 1263A, scale 1:250 000.

Sonnenfeld, P. and I. Al-Aasm. 1991. The Salina evaporites in the Michigan Basin. Geological Society of America Special Paper 256, 139-153.

Swanson, R.G., 1981. Sample examination manual. American Association of Petroleum Geologists, Methods in Exploration Series, no.1, 35 p.

Telford, P.G. and Johnson, M.D., 1984. Paleozoic stratigraphy of southwestern Ontario. Geological Association of Canada-Mineralogical Association of Canada, Joint Annual Meeting, London, Ontario, Field Trip Guidebook no. 1, 45p.

Uyeno, T.T., Telford, P.G., and Sanford, B.V., 1982. Devonian conodonts and stratigraphy of southwestern Ontario. Geological Survey of Canada, Bulletin 332, 55p.

Winder, C.G., 1961. Lexicon of Paleozoic names in southwestern Ontario. University of Toronto Press.