Regional bedrock aquifers and a conceptual groundwater flow model for southern Ontario

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Purpose of Study

- which rocks contain water (aquifers) and oil & gas (reservoirs)
- which rocks are aquitards,
- potable water vs saline and sulfurous water,
- regional flow directions of water,
- areas of artesian flow
- loss of circulation zones
- Do subsurface aquifers and gases have unique geochemical fingerprints?

- Work in progress

Why do we need to know?

- Petroleum Operations Section of Ministry of Natural Resources regulates exploration for and production of oil & natural gas, solution mining of salt, and geological storage of hydrocarbons in province of Ontario and operates Abandoned Works Program to plug orphan wells

- Ontario's Oil, Gas and Salt Resources Act requires isolation of potable water aquifers and other porous and permeable intervals during well drilling, construction and plugging to prevent movement and mixing of fluids.

- Industry needs this data to design drilling programs, MNR for regulatory review and design plugging programs for orphan wells

- All petroleum wells intersect potable water aquifers during drilling.

Steel casing + Sulphur water = Corrosion

Bedrock types in southern Ontario

- Quaternary sediments (10 ka – 1.8 Ma)
  - Unconsolidated glacial sediments
- Paleozoic sedimentary rocks (360-501 Ma)
  - lithified marine sediments deposited during periods of high sea level which flooded most of North America
- Precambrian - (>1 billion yr) deformed crystalline metamorphic rocks of the Grenville Province of the Canadian Shield
- Unconformities – numerous periods of exposure, erosion and karsting. These are key horizons for creation of regional bedrock aquifers

Cross-sectional view: Bedrock types, ages, unconformities

Unconformity – 300 Ma

Drift 10 ka – 1.8 Ma

Paleozoic sedimentary rocks

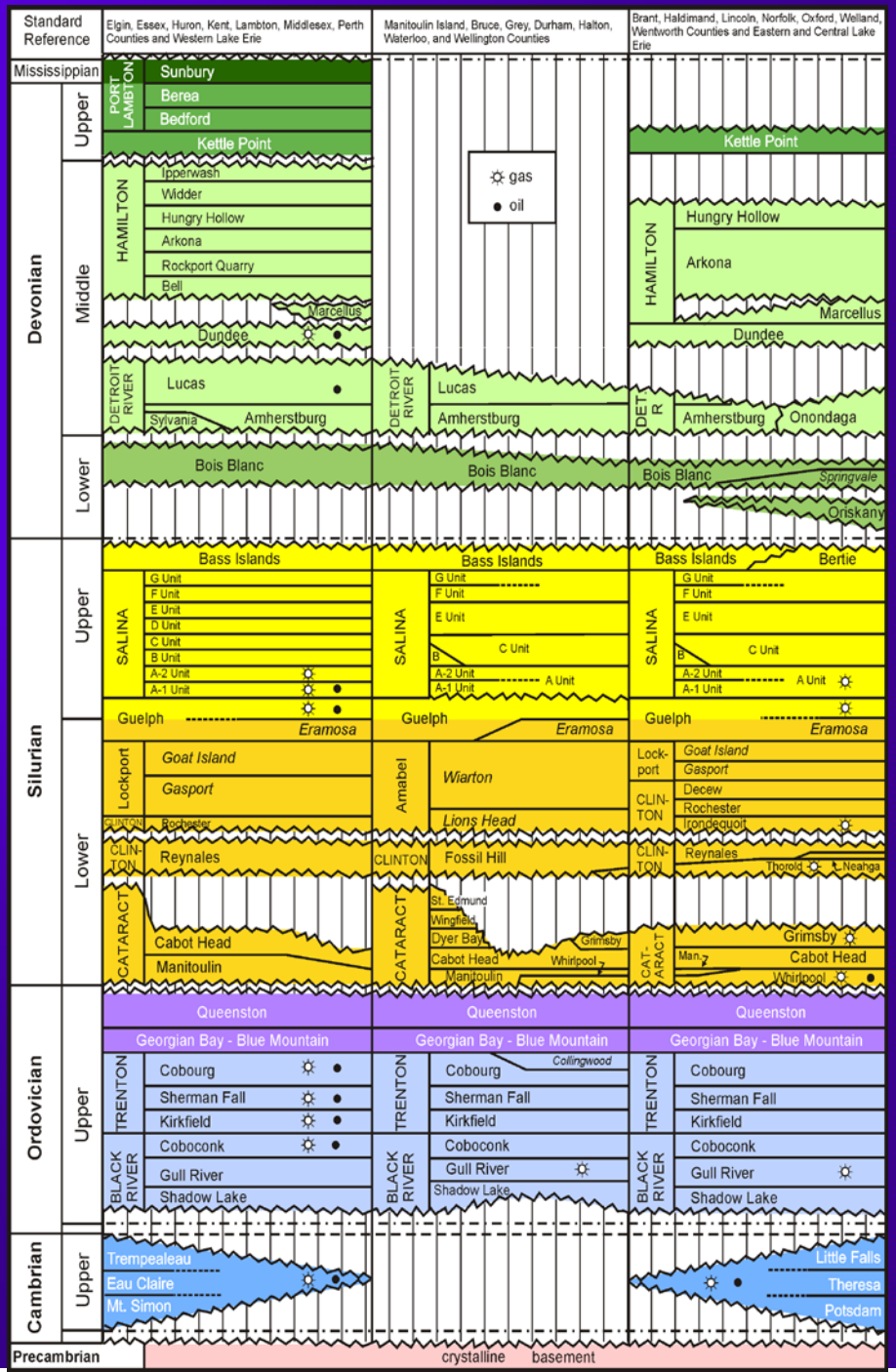
360 – 501 Ma

Unconformity – 500 Ma

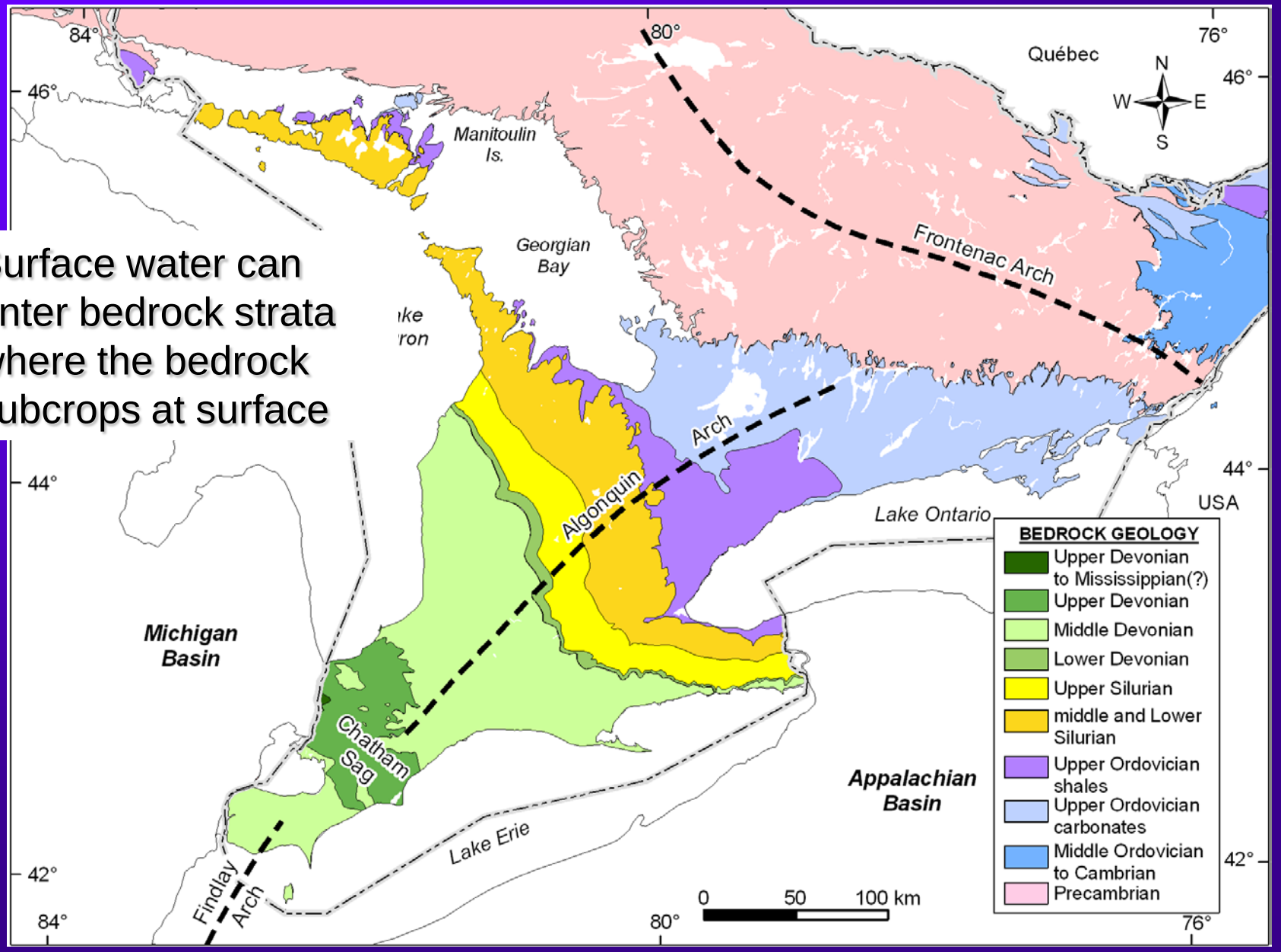
Precambrian >1 Ga

Stratigraphy and Formation Terminolgy

- Numerous disconformities with associated paleokarst
- Regional aquifers closely associated with these zones

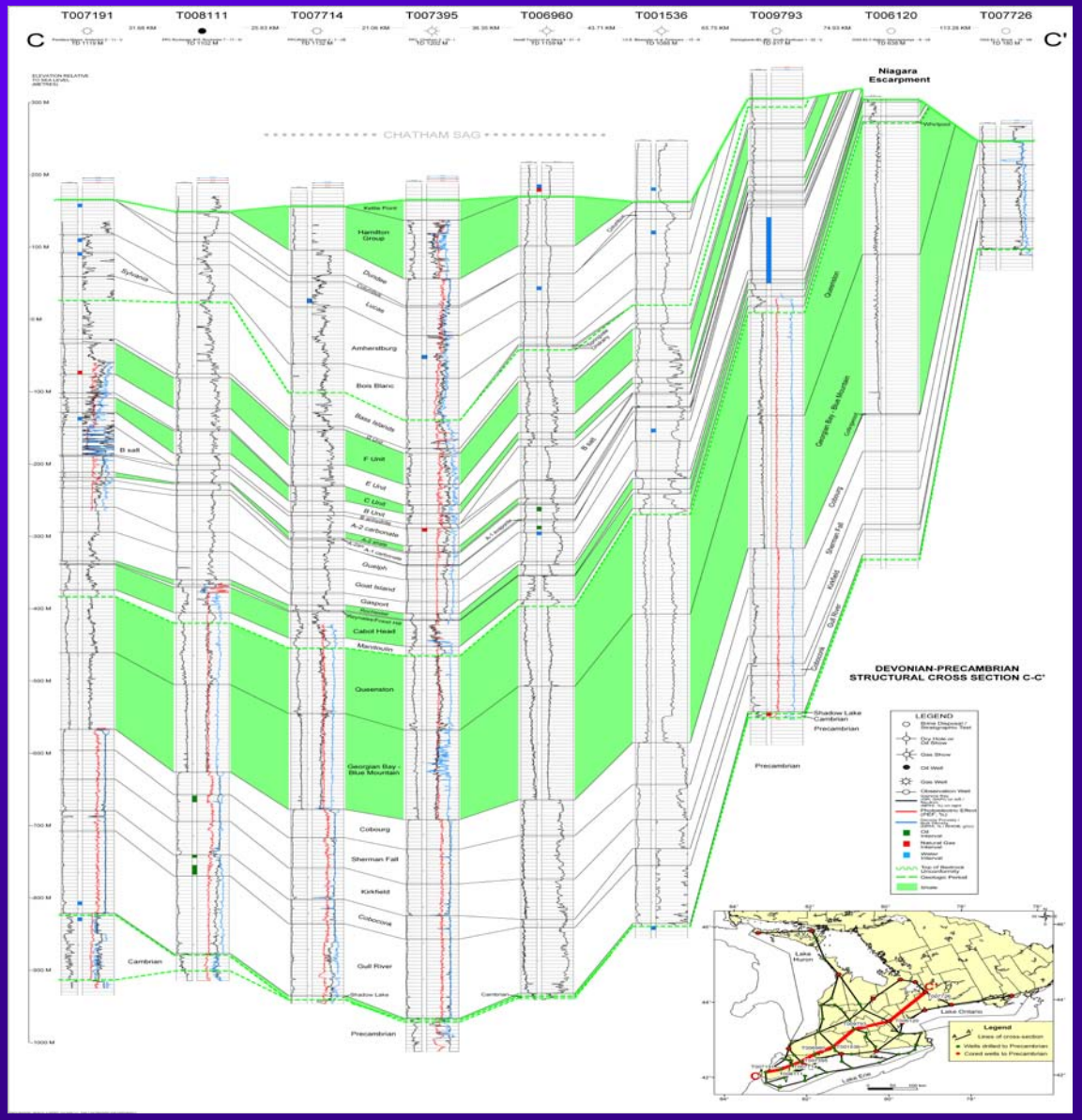


Regional Structures and Bedrock Geology

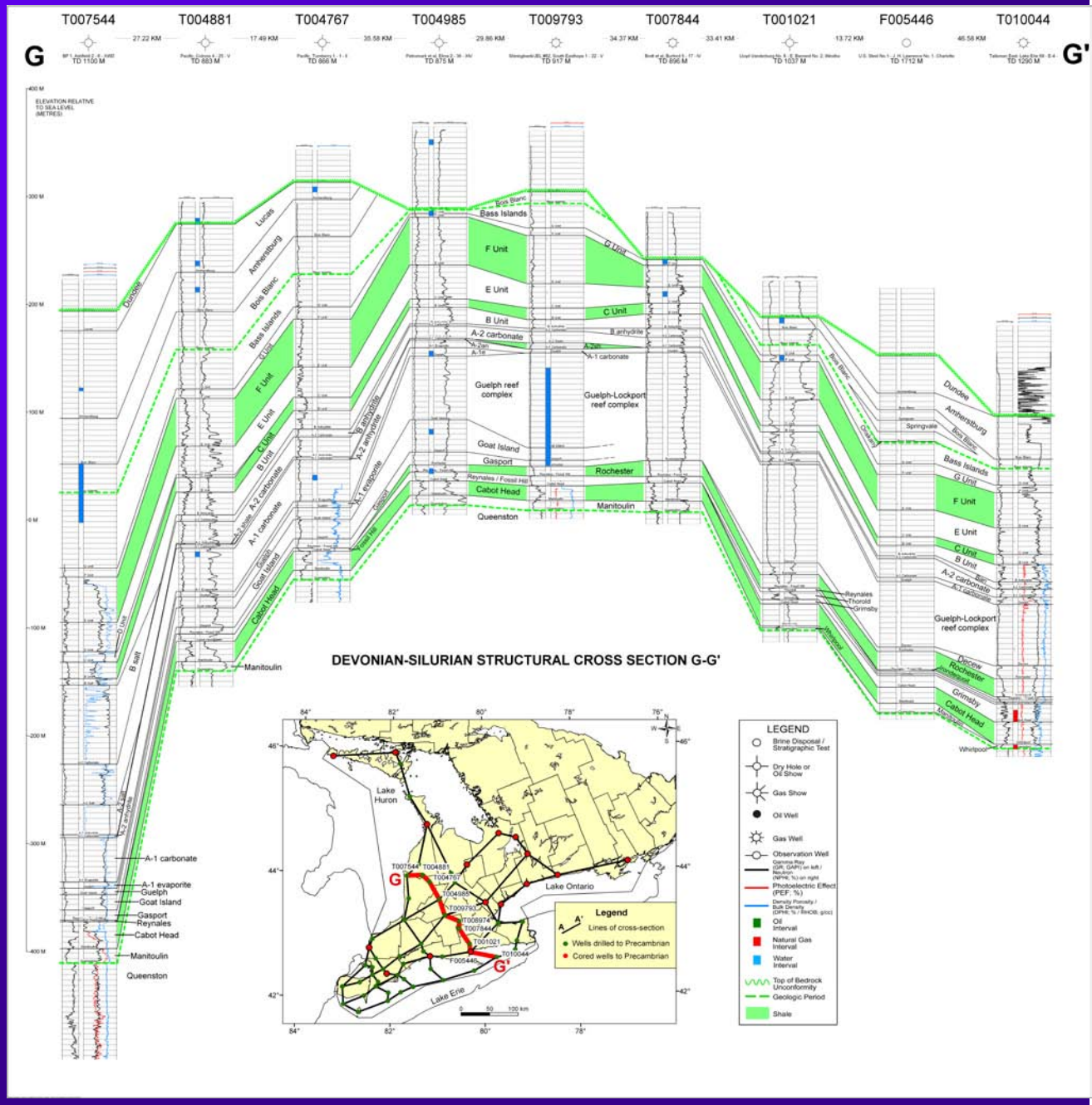


Subsurface Bedrock Structure

- Bounding surfaces for groundwater flow
- Surface water penetration into bedrock at subcrop edges



Subsurface Bedrock Structure



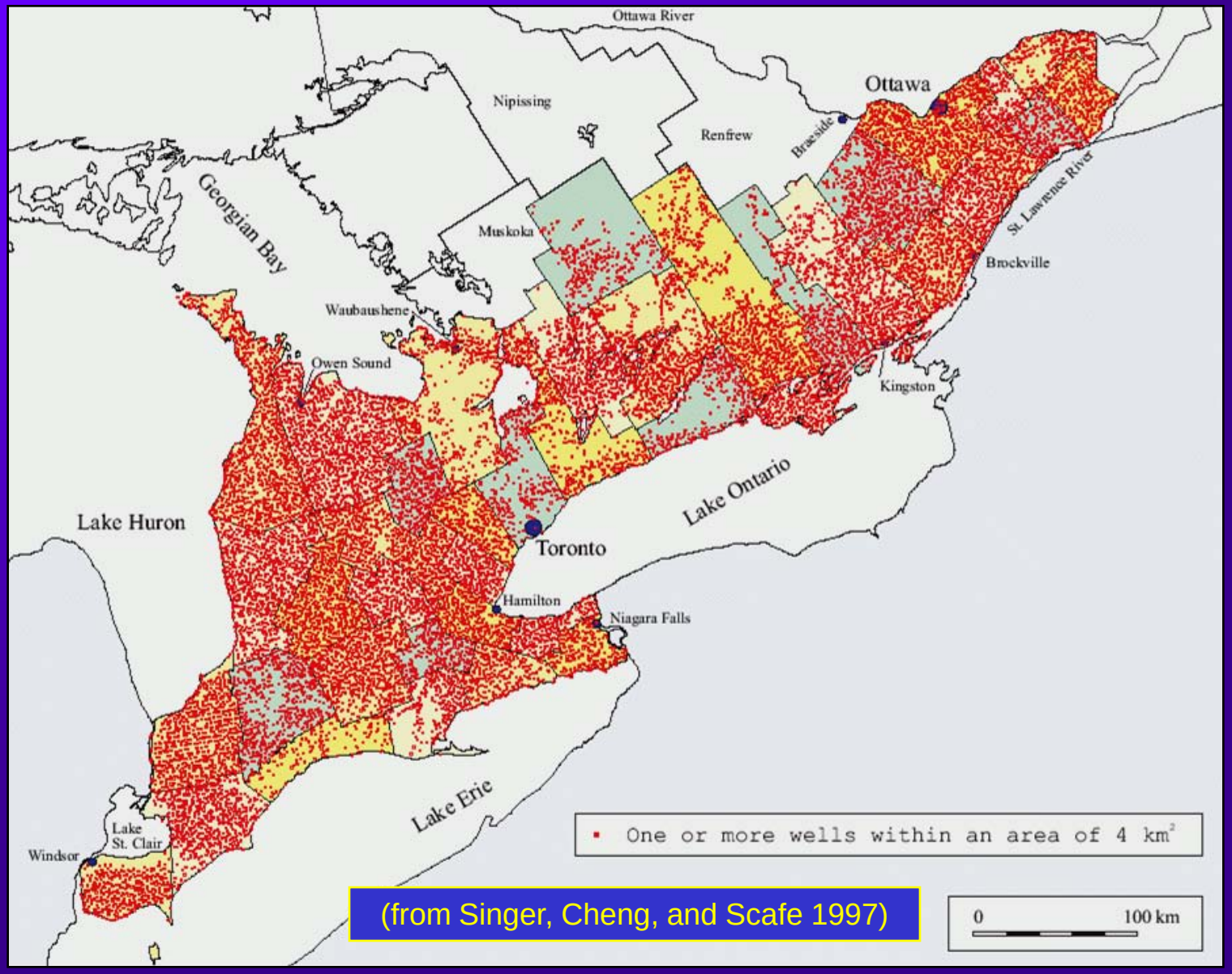
Sources of Information

- Field observations – outcrops, road cuts, quarries
- Drill core and cuttings from petroleum wells
- Geophysical logs
- MOE water well records
- MNR petroleum well records
- Discussions – Frank Brunton, Chris Smart, Theo Beukeboom, Dick Jackson, Jeff Markle, Derek Armstrong

Oil, Gas and Salt Resources Library

- The Library is a resource centre for study of subsurface geology and oil, gas, salt and underground hydrocarbon storage resources of Ontario
- Public access to petroleum well data collected by Ministry of Natural Resources under authority of Oil, Gas and Salt Resources Act

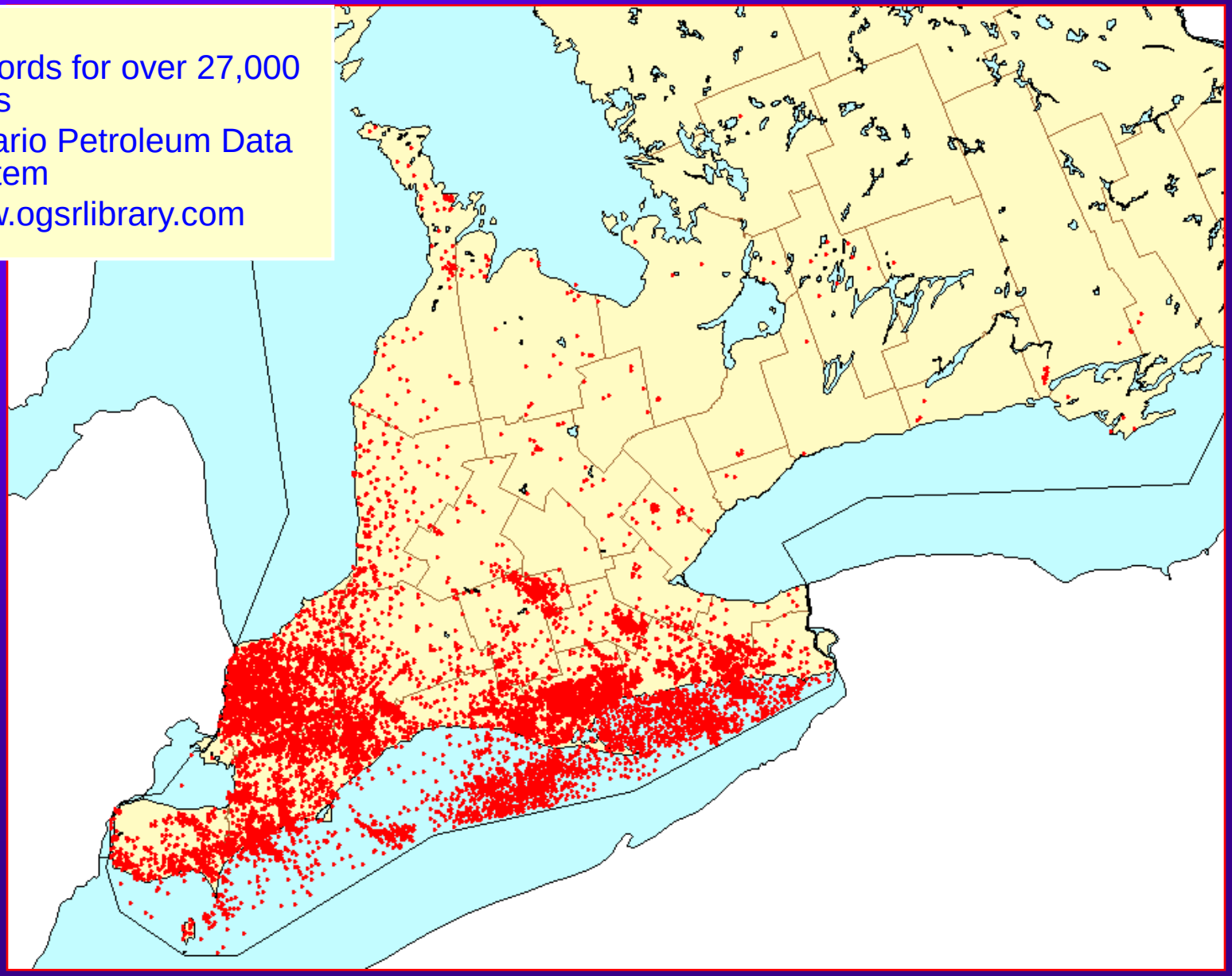
Water well records - MOE



(from Singer, Cheng, and Scafe 1997)

Petroleum Well Records - MNR

- Records for over 27,000 wells
- Ontario Petroleum Data System
- www.ogsrlibrary.com



Aquifer Systems – southern Ontario

- Shallow (Fresh Water) Aquifers
  1. Overburden Aquifer System
  2. Interface Aquifer System
  3. Karst Aquifer System

- Deep (Saline) Aquifers
  4. Bedrock Saline Aquifer System

Shallow Aquifer Systems

1. Overburden Aquifer System

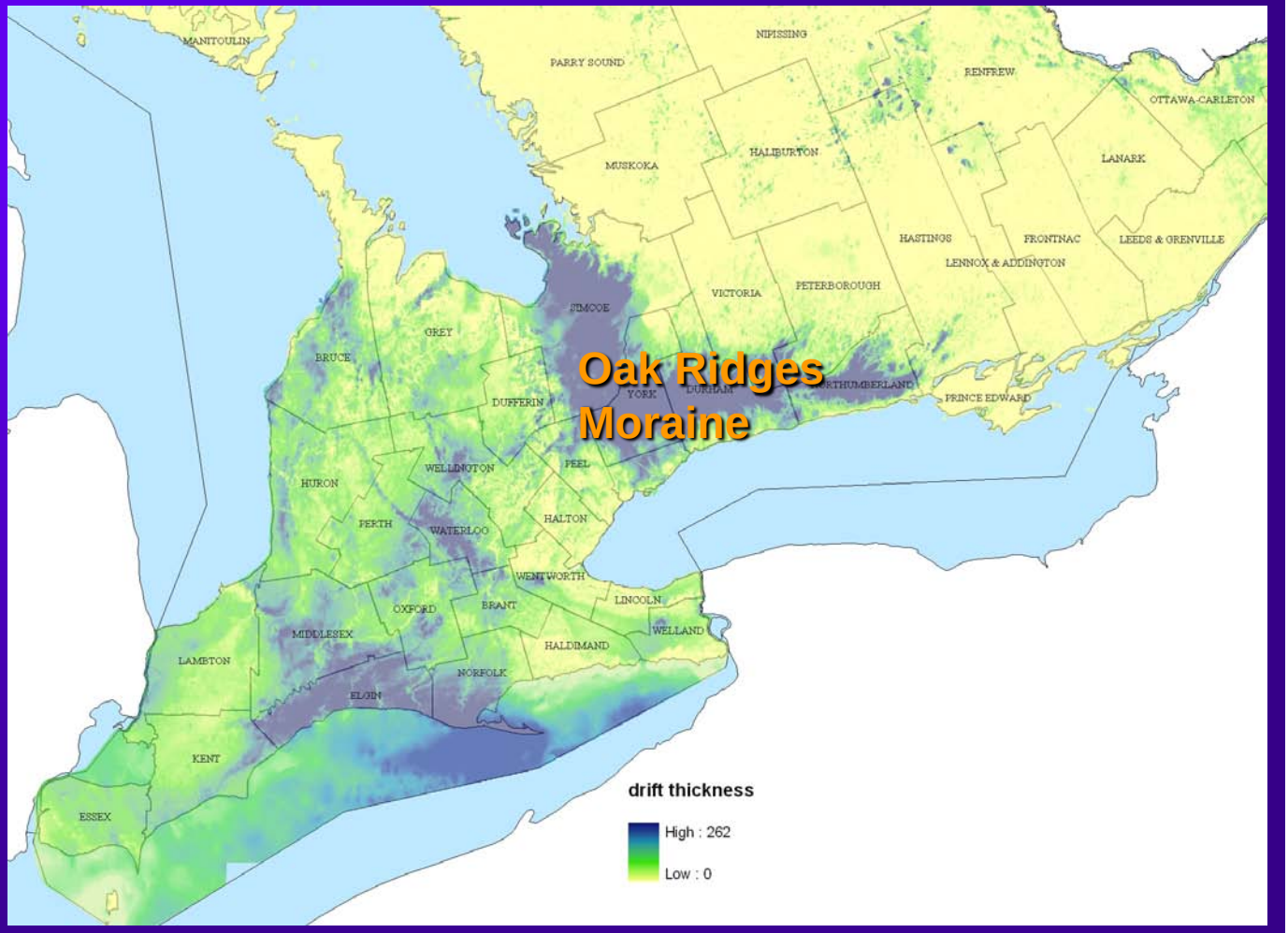
- Fresh water in unconsolidated Recent sediments, and glacial sediments
- Complex, local extent, principal source of potable groundwater for domestic water wells in southern Ontario
- Bedrock forms lower bounding surface

Overburden Aquifers: Drift Thickness

- glacial and Recent sediments tens of metres or more in thickness – "sponge" that soaks up rainfall and releases it slowly to surface water courses

-Thickened drift in bedrock valleys and glacial moraines

-Areas of thick drift (Oak Ridges) are important aquifers.



Shallow Aquifers

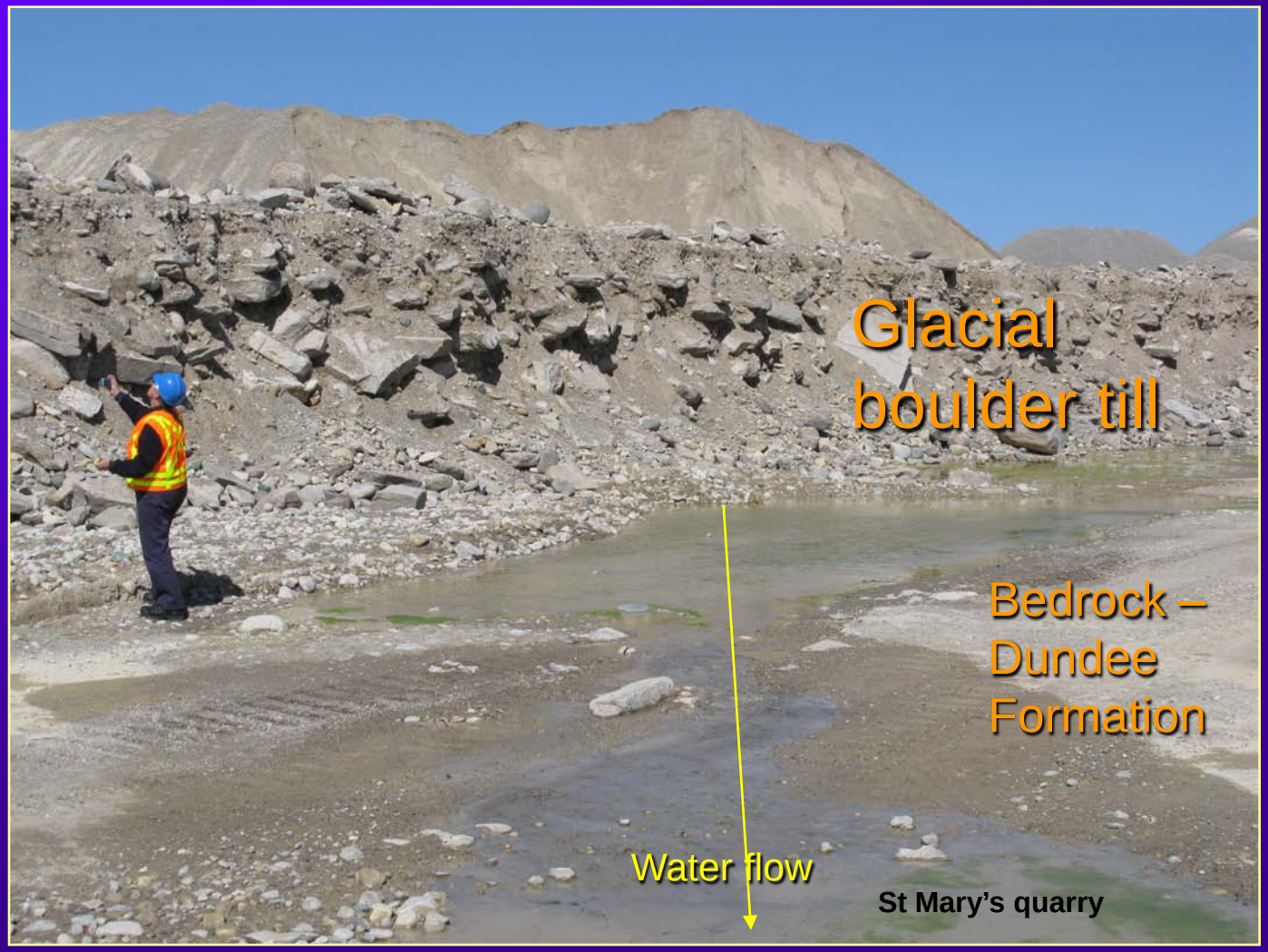
2. Interface/Contact Aquifer System

- Regional fresh water aquifer at Interface between surficial sediments and Paleozoic bedrock - uppermost few metres of bedrock is jointed, weathered, porous
- Most extensive, continuous, fresh water aquifer in southern Ontario
- Local water quality issues directly related to bedrock composition

- NOTE: fresh water only penetrates a few metres into bedrock unless the bedrock is karsted or faulted/fractured

Shallow Aquifers

Contact Aquifer



Contact aquifer

Joints at bedrock surface

Kettle Point shales, L. Huron

Kettle Point

Whirlpool Formation, Niagara River

Goat Island-Gasport (Amabel) dolostone, Bruce peninsula

Bedrock Topography and Bedrock Valleys

- lower bounding surface for "contact aquifer"

-Regional flow down slope and in bedrock valleys

-Valleys correspond to subcrop belts of easily eroded shale bedrock and/or evaporites

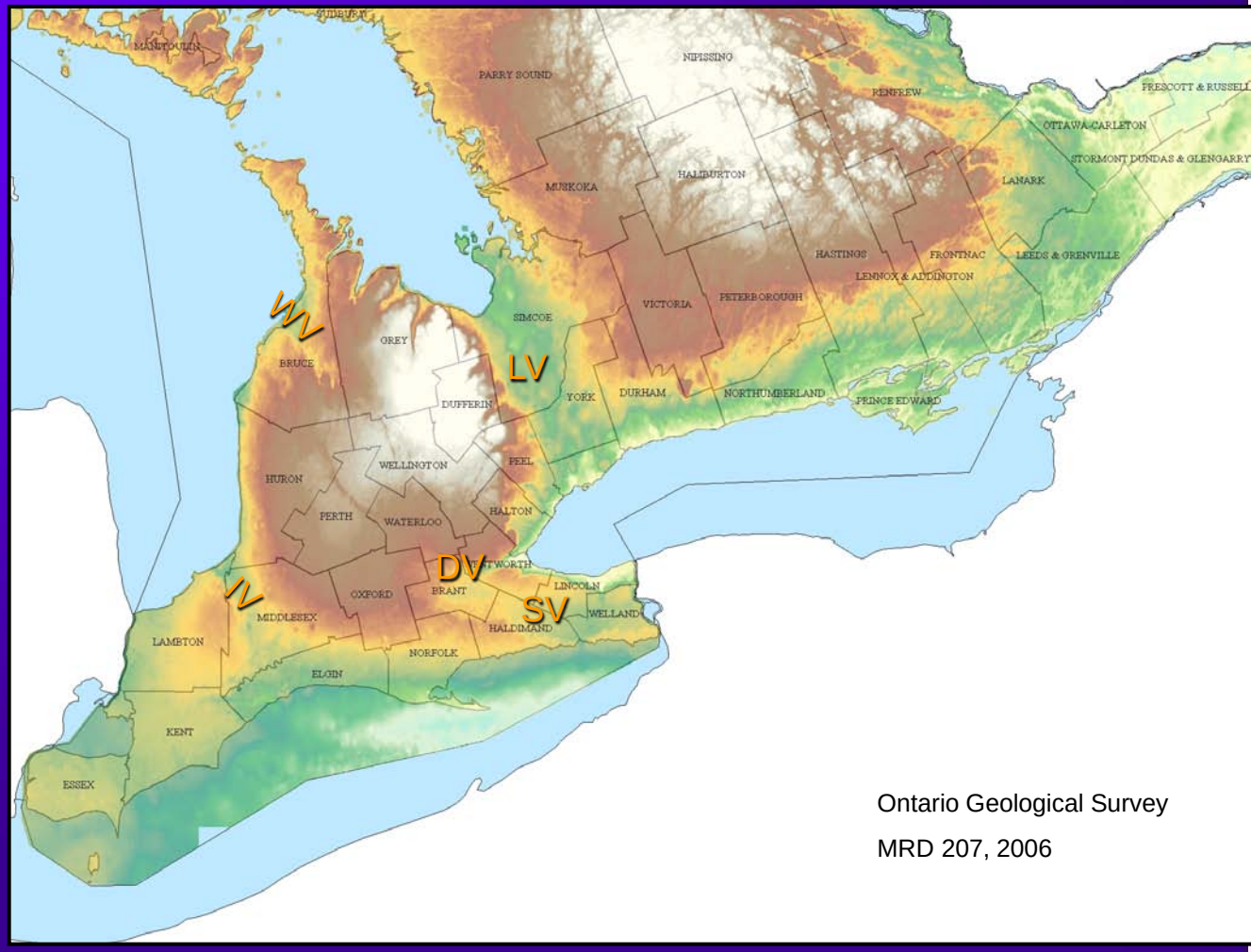
-WV:Walkerton Valley

-SV:Salina Valley

-LV:Laurentian Valley

-IV:Ipperwash Valley

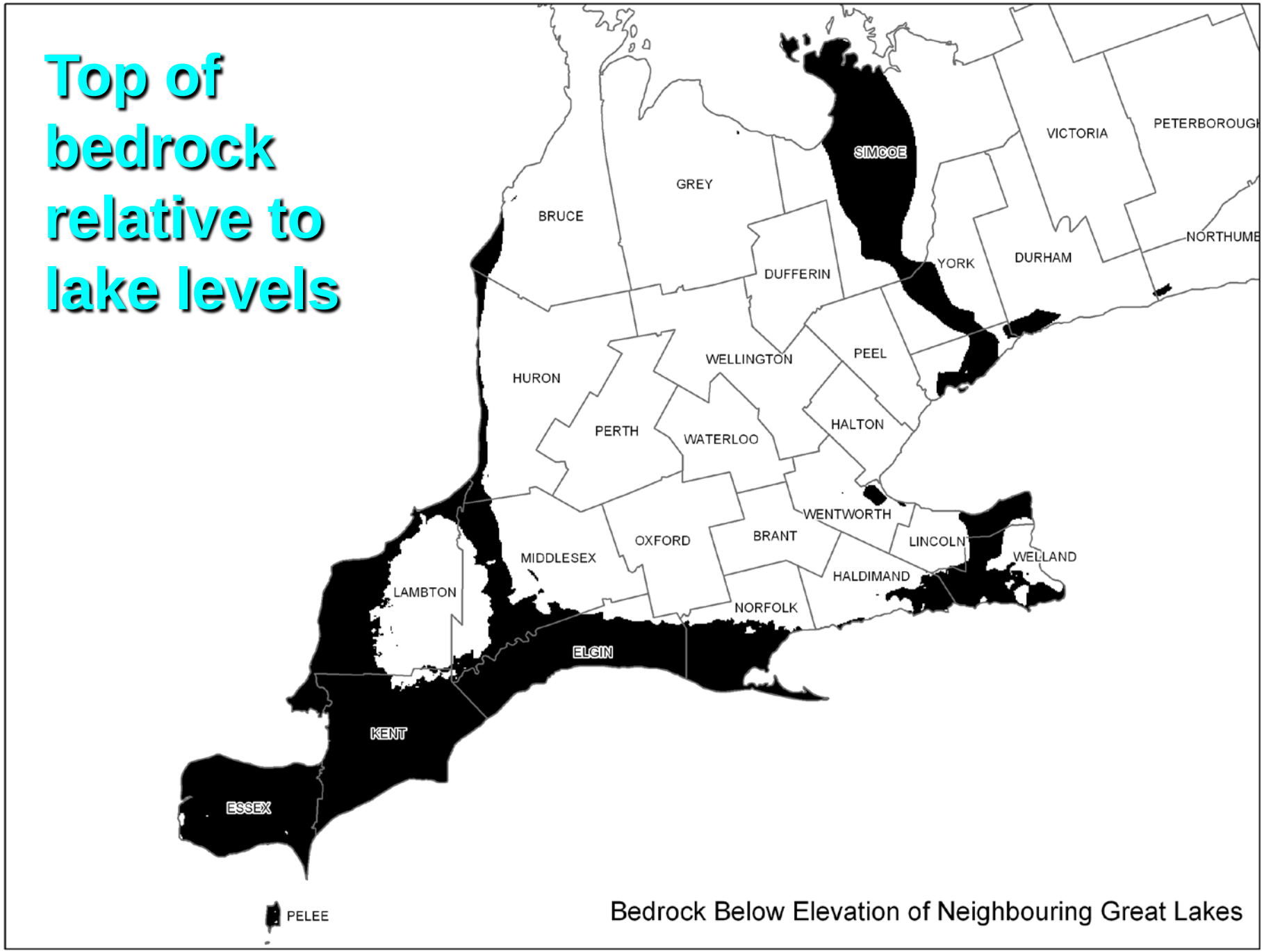
-DV:Dundas Valley



Ontario Geological Survey

MRD 207, 2006

Top of bedrock relative to lake levels



Bedrock Below Elevation of Neighbouring Great Lakes

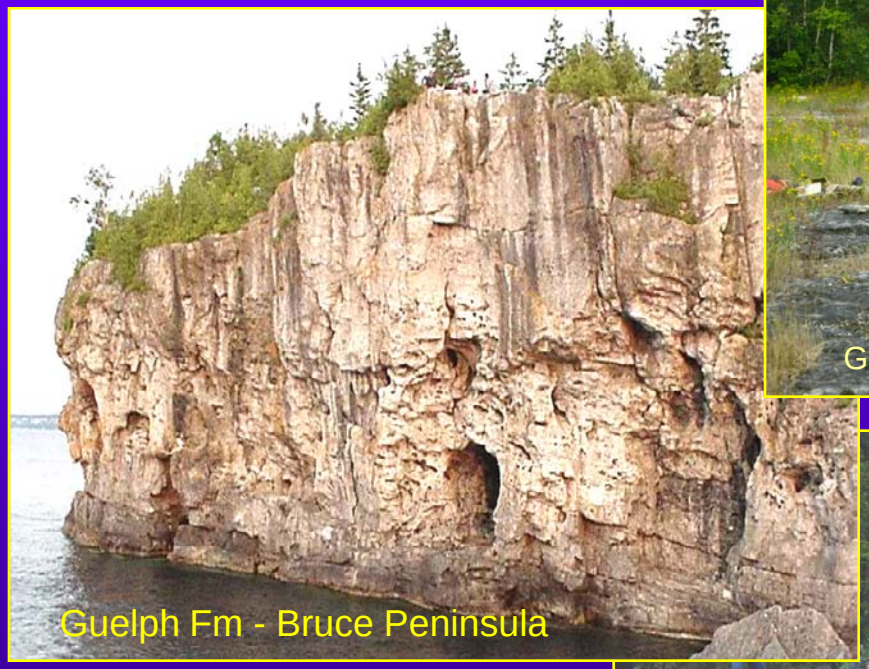
Shallow Aquifers

3. Karst Aquifer System

- fresh water aquifers in shallow, karst-influenced carbonate bedrock
- local extent, complex, outcropping bedrock or beneath shallow drift
- Extend up to 200 metres into bedrock

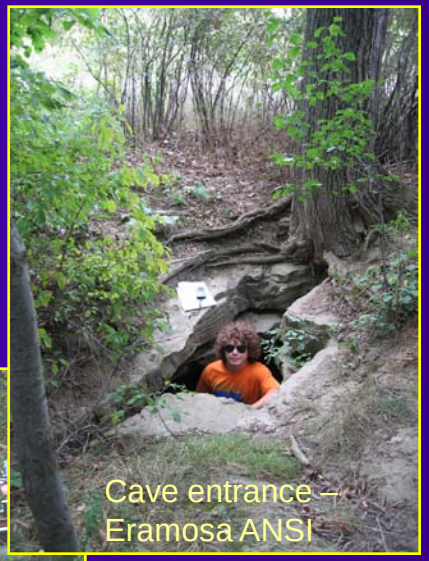
Shallow Aquifers:

Modern Karst



Guelph Fm - Bruce Peninsula

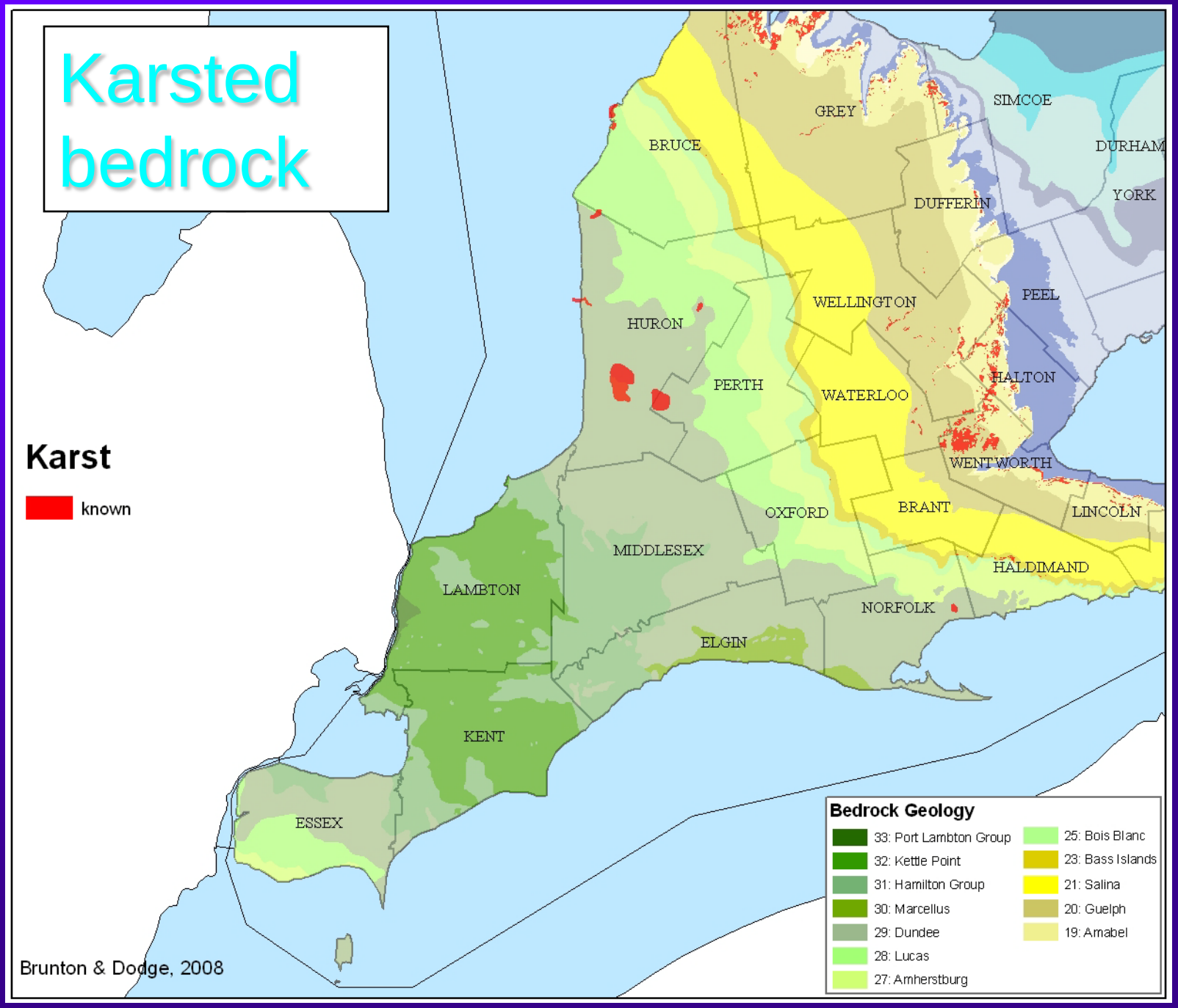
Grike – Bruce peninsula



Cave entrance – Eramosa ANSI

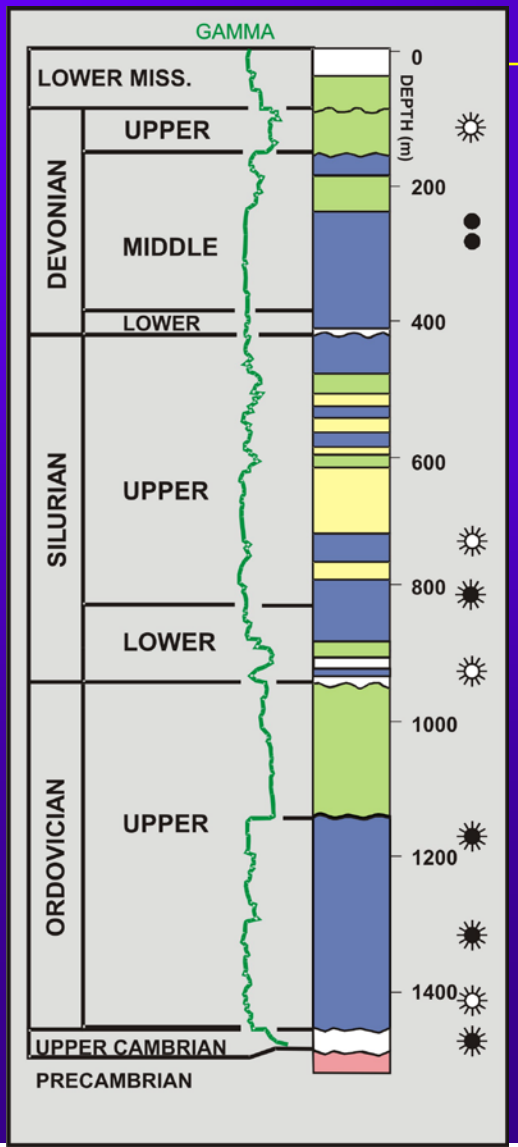
Modern karst surface, NY

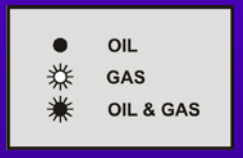
Karsted bedrock

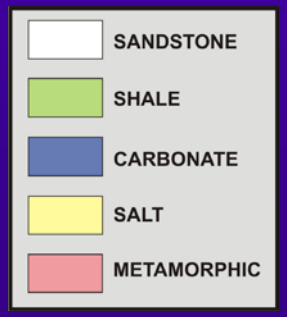


Deep Aquifers

4. Bedrock Saline Aquifer System







Shallow Aquifers

Lucas & Dundee formations

Bass Islands Formation

Guelph Formation

Cambrian

Bedrock Saline Aquifers

Deep Aquifers

Bedrock Saline Aquifer System

- Porous rocks in deep subsurface contain saline/sulphurous “formation” water or hydrocarbons confined/separated by impermeable rocks
- Extreme salinities – from 140,000 to 391,000 mg/l TDS
  - (Soy sauce contains 140-180,000 mg/l)
- large areal extent due to the persistence of the bounding bedrock layers and/or associated paleokarst
- hydraulic communication with shallow aquifers and surface water at subcrop edge

Mapping: Deep Bedrock Aquifers

- Water type intersected in petroleum wells plotted by formation
  - Fresh water (FRE)
  - Sulphur water (SUL)
  - Salt water (SAL)

Formation top & Water interval data

CTY: Lambton **TWP:** Moore **TRACT** 6 **LOT** 1 **CON:** II
WELL NAME: Lang & Vye Plum Creek, Moore 6 - 1 - II **WELL ID:** T008201 **CLASS:** NPW
OPERATOR: 839058 Ontario Inc. **TARGET:** SAL **STATUS:** DH - ABD

DRILLING DATA
CONTRACTOR: 839058 Ontario Inc.
RIG TYPE: ☐ CABLE ☐ ROTARY
GRND ELEV: 191
KB ELEV: 192.10 **DRILLER TD:** 644.50
TVD: 644.50 **PBTD:** **PBTVD:**

DATES
LICENCE ISSUED: Aug 12, 1994
SPUD DATE: Aug 14, 1994
TD DATE: Mar 10, 1995
COMPLETE DATE:
WORKOVER DATE:
PLUG DATE: Oct 20, 1995

COORDINATES
N/S BOUND. 710.6m S
E/W BOUND: 391m W
NAD 83
SURF LAT: 42° 46' 48.300 " N
SURF LONG: 82° 14' 39.100 " W
BOT LAT: 42° 46' 48.300 " N
BOT LONG: 82° 14' 39.100 " W

SAMPLES
TOP: 0.00
BOT: 643.00
TRAY: 10586/87

PERIOD	FORMATION	TOP	TVD	ELEV
QUATERNARY	Drift			
	Top of Bedrock	20.00	20.00	172.10
DEVONIAN	Port Lambton Group			
	Kettle Point	20.00	20.00	172.10
	Hamilton Group	36.00	36.00	156.10
	Marcellus			
	Dundee	117.50	117.50	74.60
	Columbus			
	Lucas	147.00	147.00	45.10
	Amherstburg	209.00	209.00	-16.90
	Bois Blanc	269.00	269.00	-76.90
	Springvale			
	Oriskany			
SILURIAN	Bass Islands/Bertie	293.00	293.00	-100.90
	G Unit	338.00	338.00	-145.90
	F Unit	347.00	347.00	-154.90
	F Salt			
	E Unit	387.00	387.00	-194.90
	D Unit	411.00	411.00	-218.90
	C Unit	422.00	422.00	-229.90
	B Unit	440.00	440.00	-247.90
	B Salt	448.00	448.00	-255.90
	B Anhydrite			
	A-2 Carbonate	526.00	526.00	-333.90
	A-2 Shale			
	A-2 Salt	571.00	571.00	-378.90
	A-2 Anhydrite	593.00	593.00	-400.90
	A-1 Carbonate	595.00	595.00	-402.90
	A-1 Evaporite	635.00	635.00	-442.90
	Guelph	639.00	639.00	-446.90
	Goat Island			
	Gasport			
	Decew			
	Rochester			
	Irondequoit			
	Reynales/Fossil Hill			
	Thorold			
	Grimsby			
	Cabot Head			
	Manitoulin			
	Whirlpool			
ORDOVICIAN	Queenston			
	Georgian Bay-Blue Mountain			
	Collingwood			
	Cobourg			
	Sherman Fall			
	Kirkfield			
	Coboconk			
	Gull River			
	Shadow Lake			
CAMBRIAN	Cambrian			
PRECAMBRIAN	Precambrian			
Geology by:	MNR			

COMPLETION DATA
GAS: $10^3 m^3/d$ 0.00
OIL: m^3/d 0.00 **Perforated:** ☐
SIP: kPag 0.00 **Open Hole:** ☐
FORMATION:
INTERVALS: Prim T B 2nd T B 3rd T B
REMARKS:

INITAL GAS

INTERVAL	FLOW 1000 m3/d	SIP kPag	Anal	Analysis Formation

INITIAL OIL

INTERVAL	FLOW m3/d	API	Anal	Analysis Formation

INITIAL WATER

INTERVAL	STATIC LEVEL	TYPE	Anal	Analysis Formation
141 -	36.00	Sulphur	N	Lucas
20 -	11.00	Fresh	N	Kettle Point

CASING AND TUBING

DIAM.	WEIGHT	SET DEPTH	HOW SET	RECOV.
273.05	60.00	21	Shoe	
218.95	36.00	117	Cement	
178.05	29.00	348	Cement	

LOGGING RECORD

INTERVAL	TYPE	COMPANY

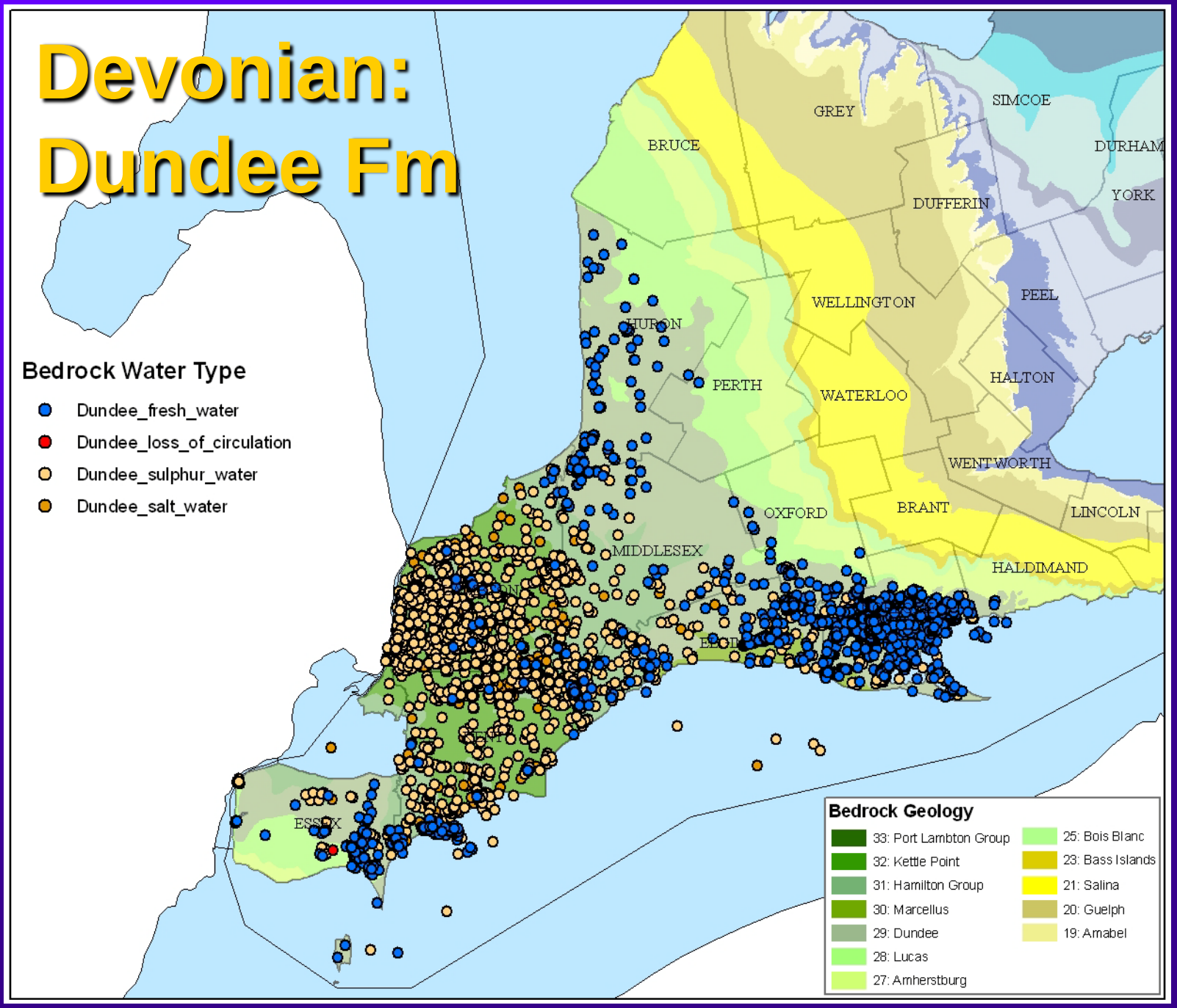
CORING RECORD

INTERVAL	LOCATION	NO.	Anal

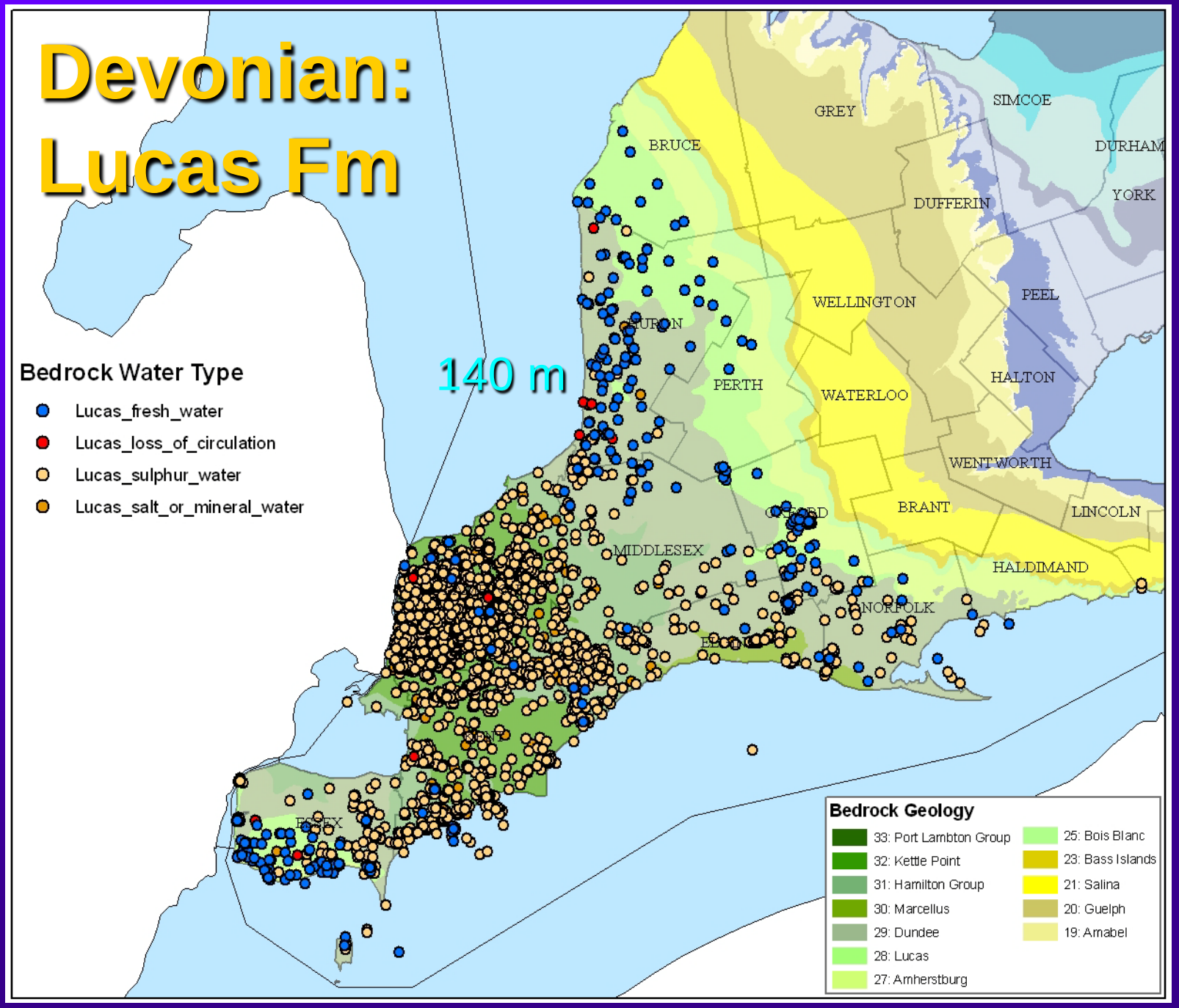
INITIAL WATER

INTERVAL	STATIC LEVEL	TYPE	Anal	Analysis Formation
141 -	36.00	Sulphur	N	Lucas
20 -	11.00	Fresh	N	Kettle Point

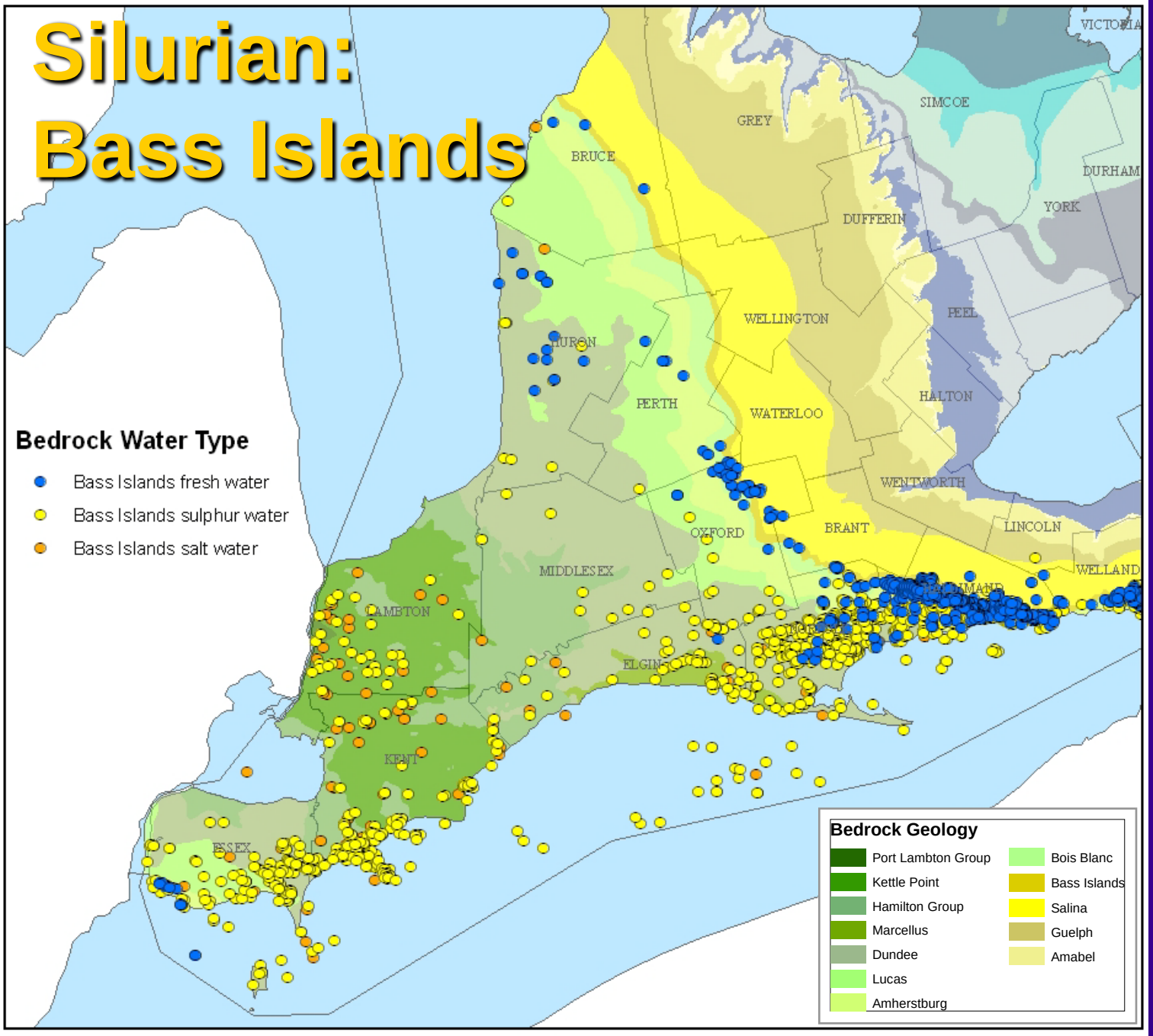
Devonian: Dundee Fm



Devonian: Lucas Fm

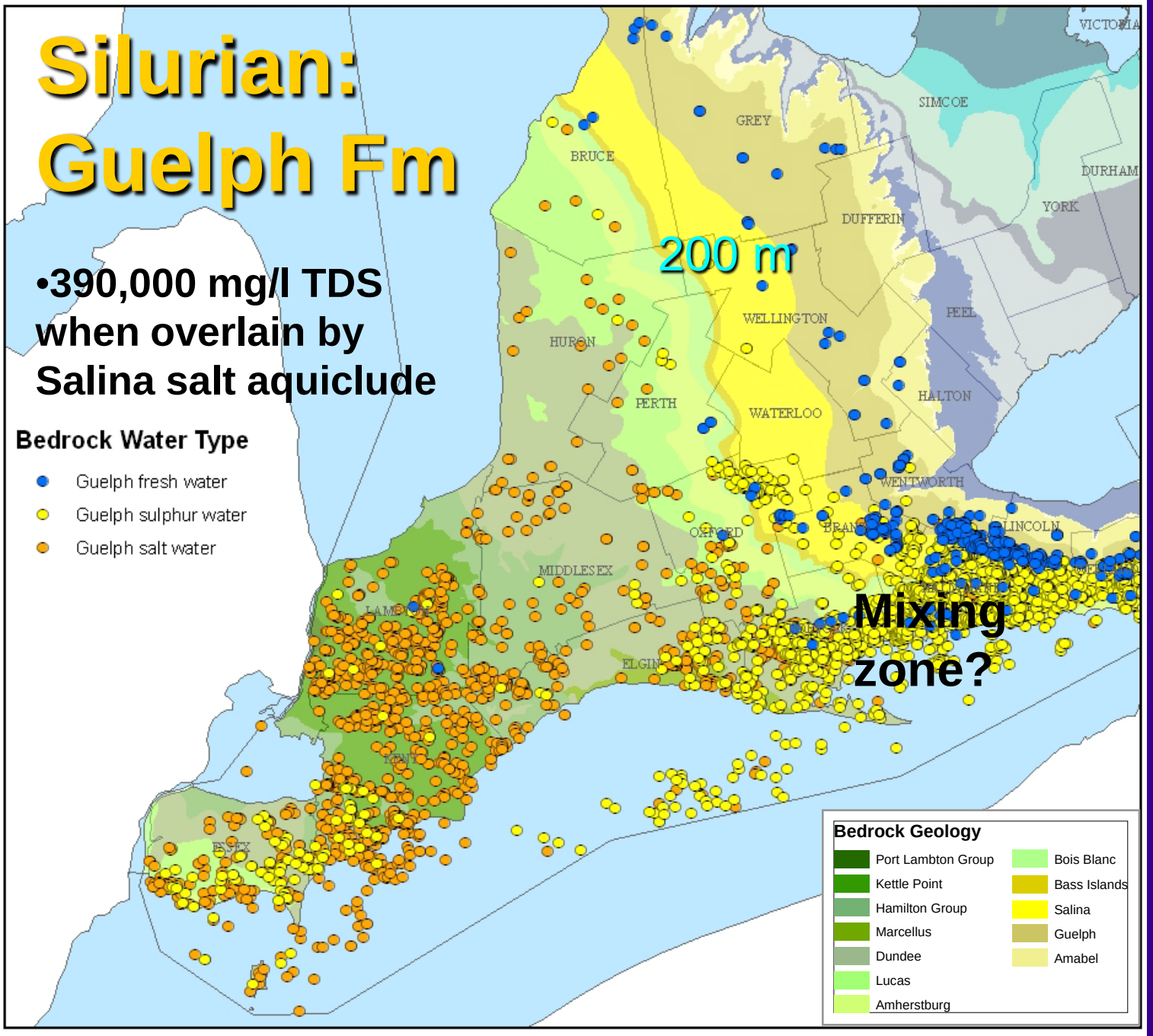


Silurian: Bass Islands

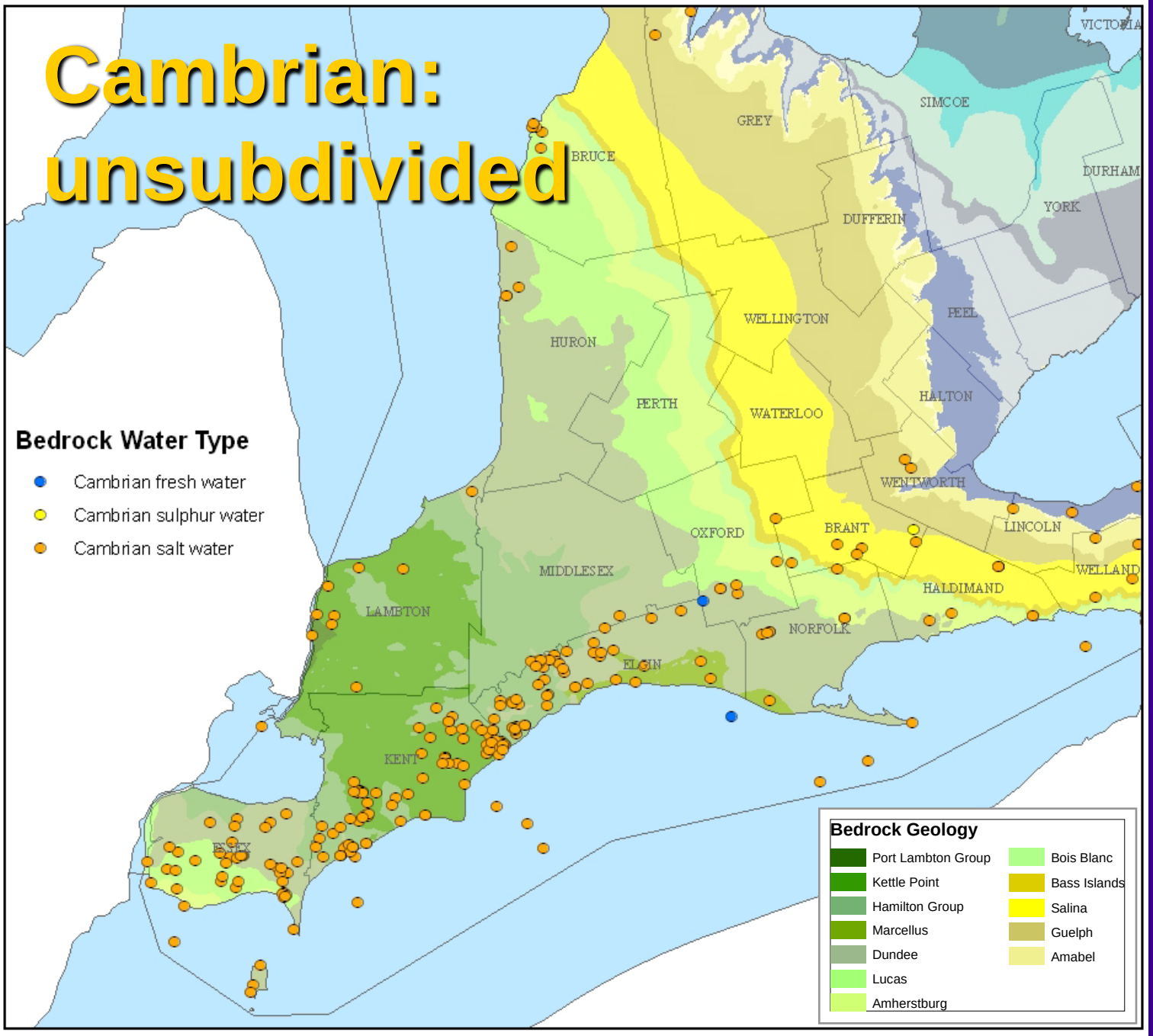


Silurian: Guelph Fm

- 390,000 mg/l TDS when overlain by Salina salt aquiclude



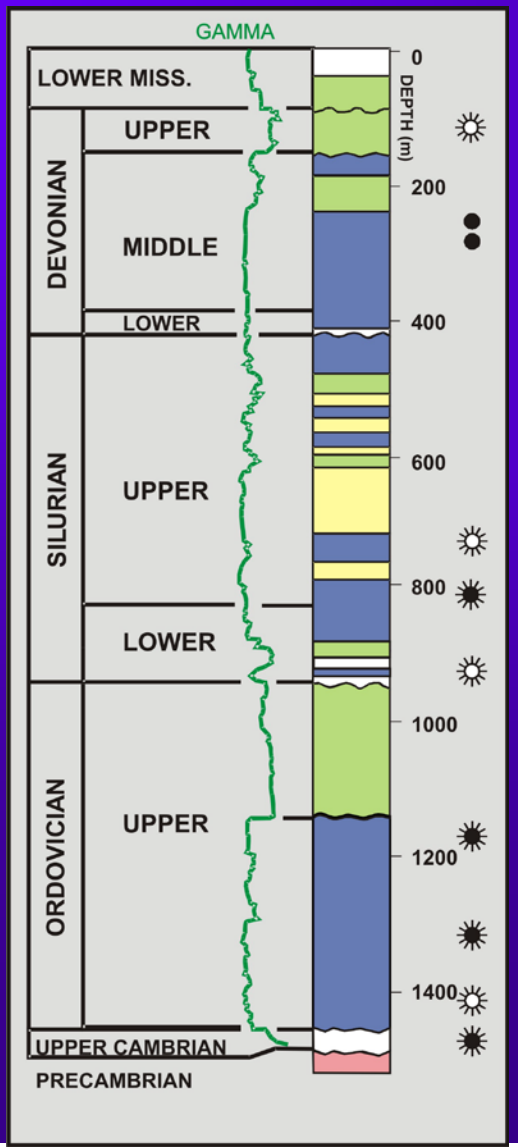
Cambrian: unsubdivided

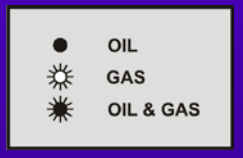


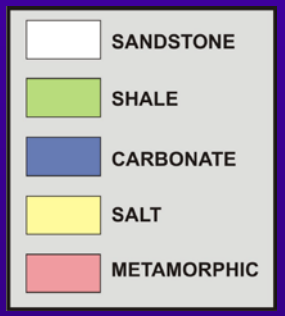
Mapping: Deep Bedrock Aquitards

- Water type intersected in each well plotted by formation
  - Fresh water (FRE)
  - Sulphur water (SUL)
  - Salt water (SAL)

Regional Aquitards







Kettle Point
Hamilton

Salina F Unit

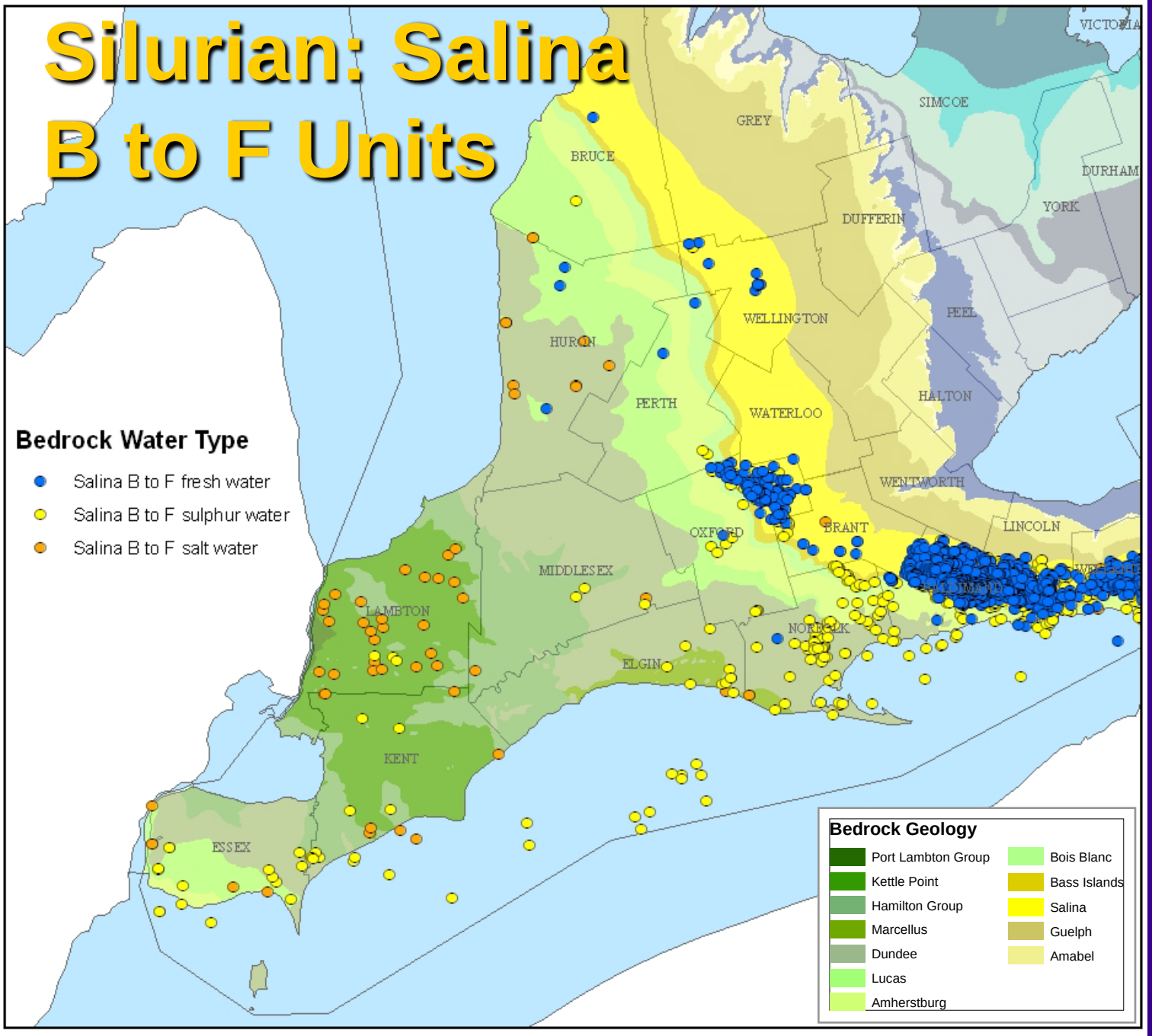
Salina Aquiclude

Rochester

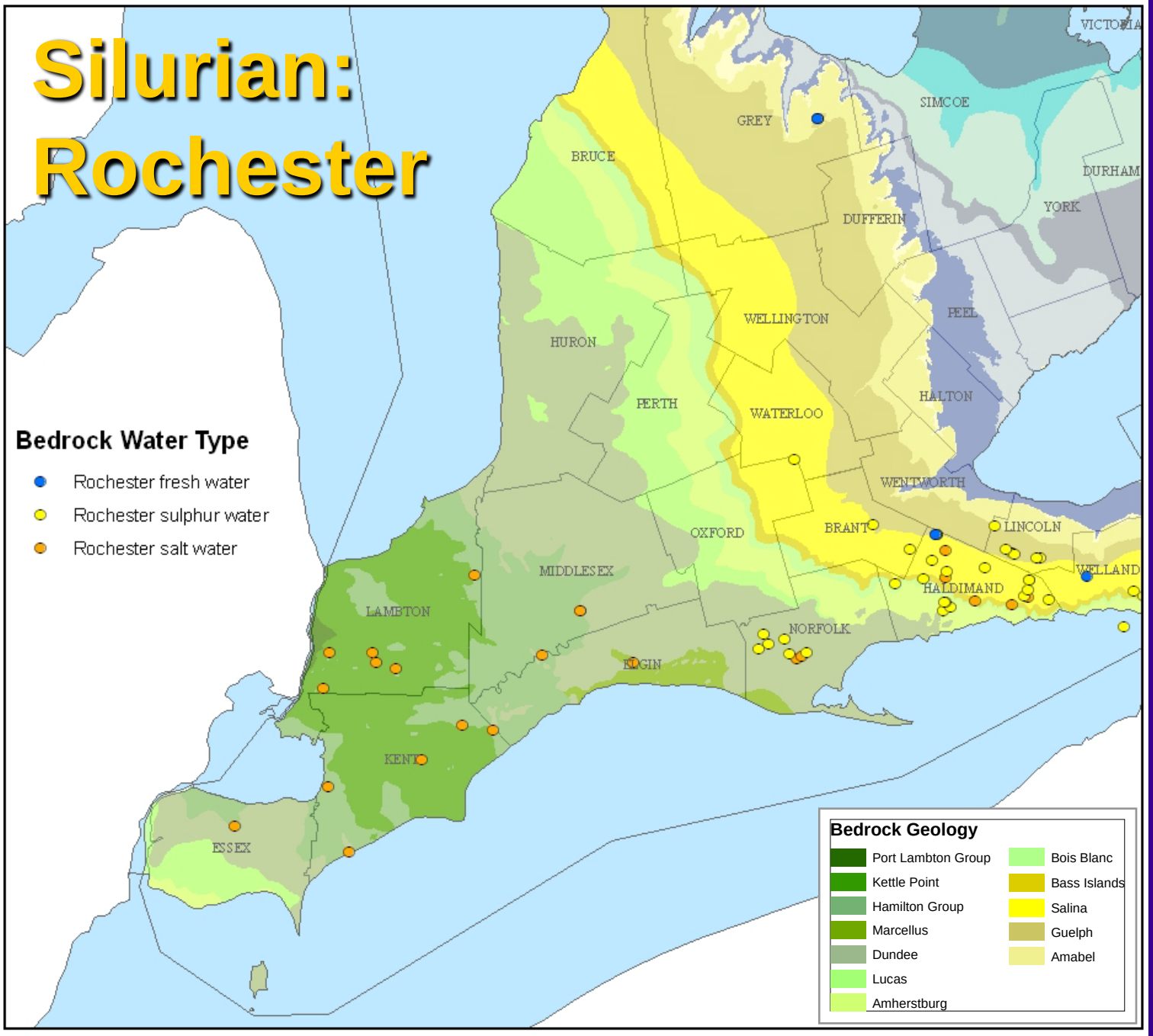
Ordovician shale

Trenton-Black River

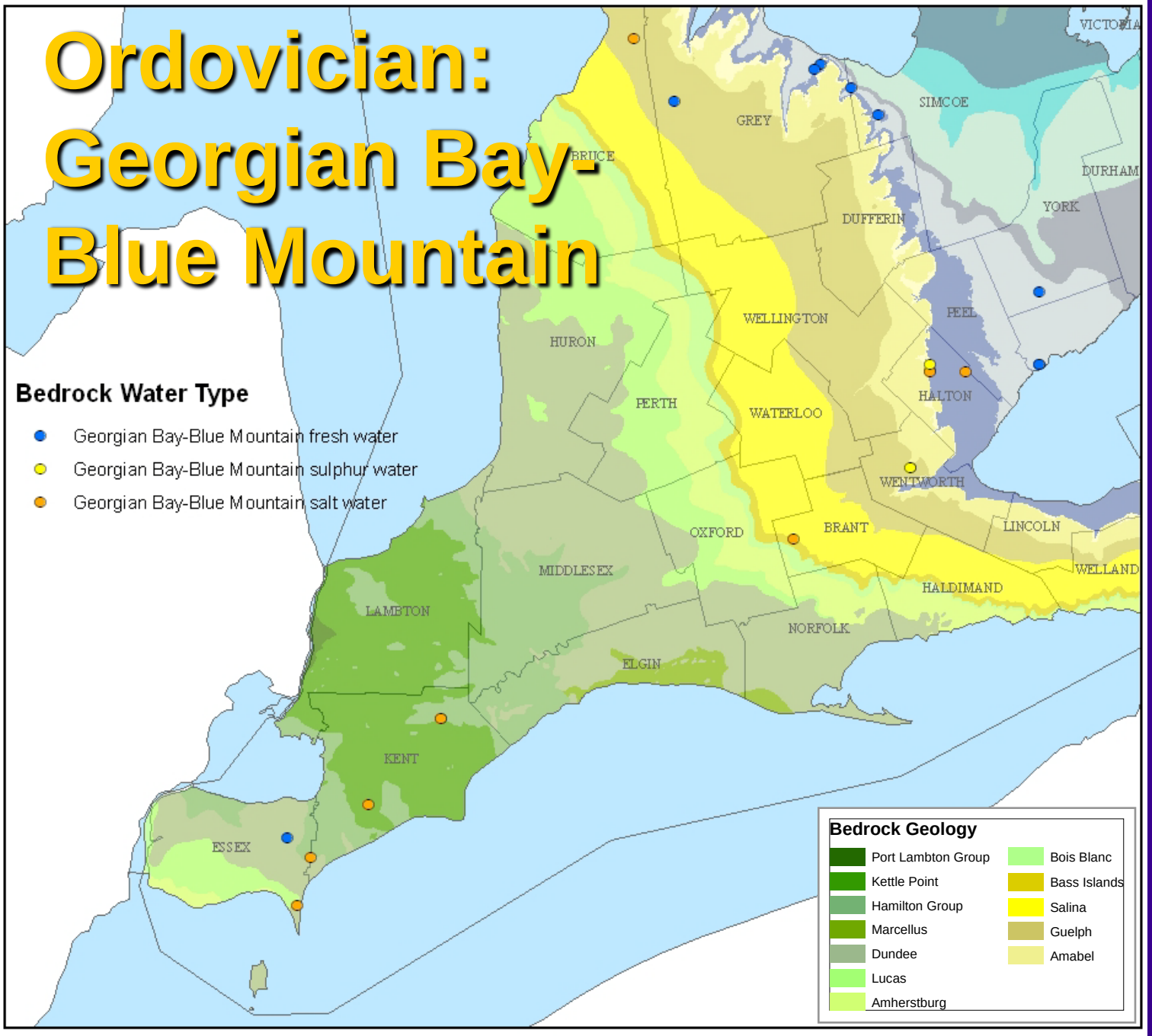
Silurian: Salina B to F Units



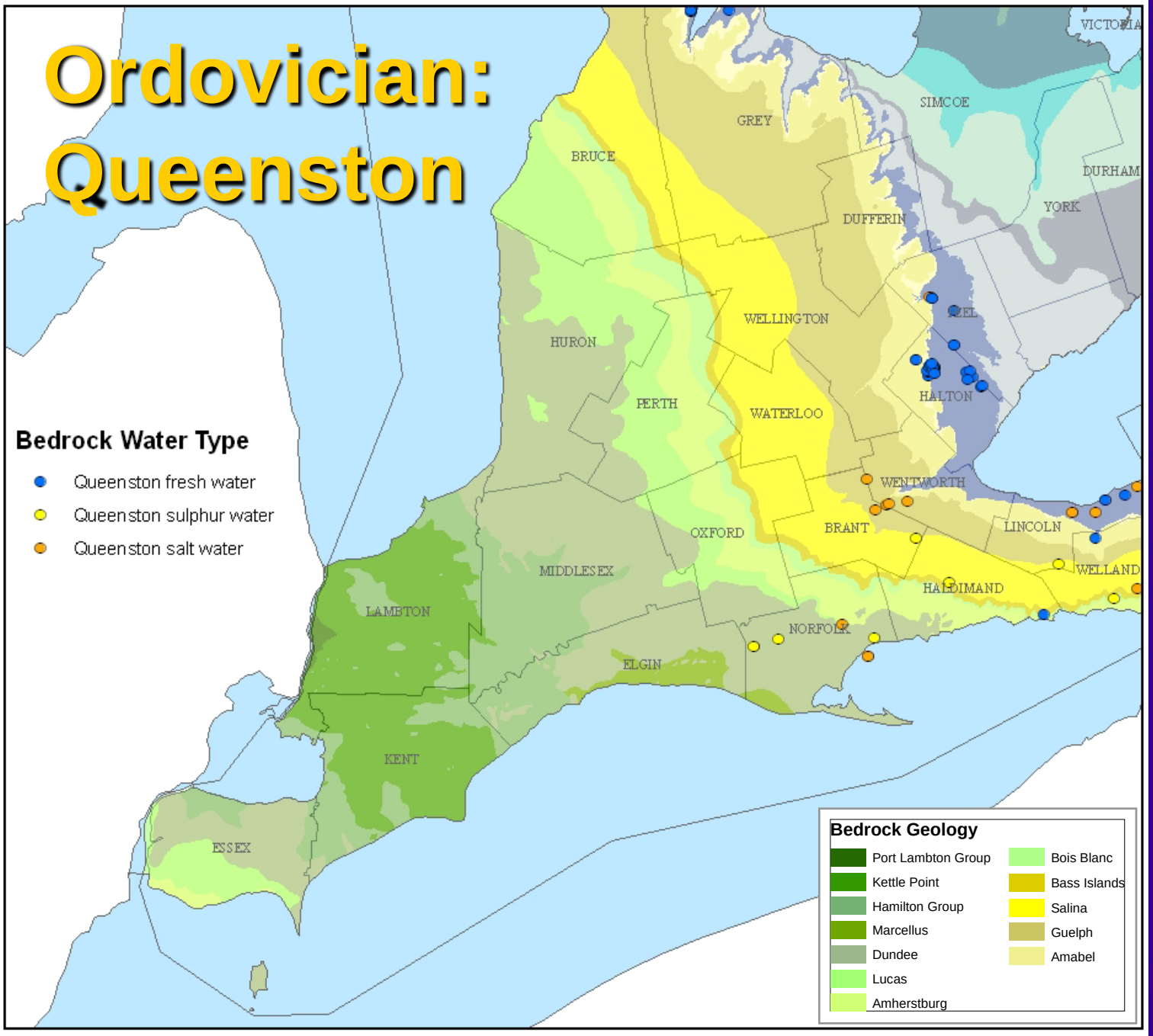
Silurian: Rochester



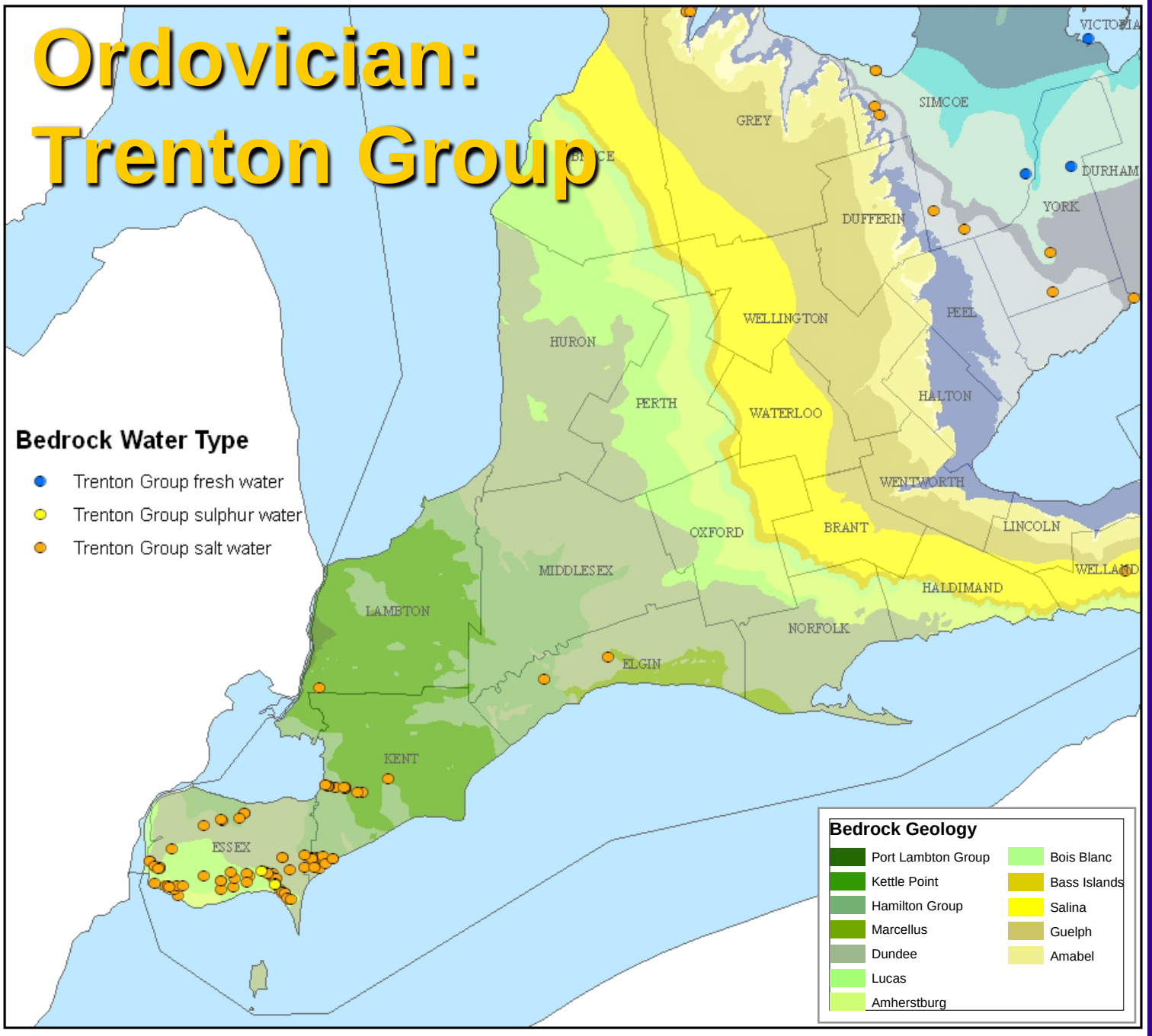
Ordovician: Georgian Bay-Blue Mountain



Ordovician: Queenston

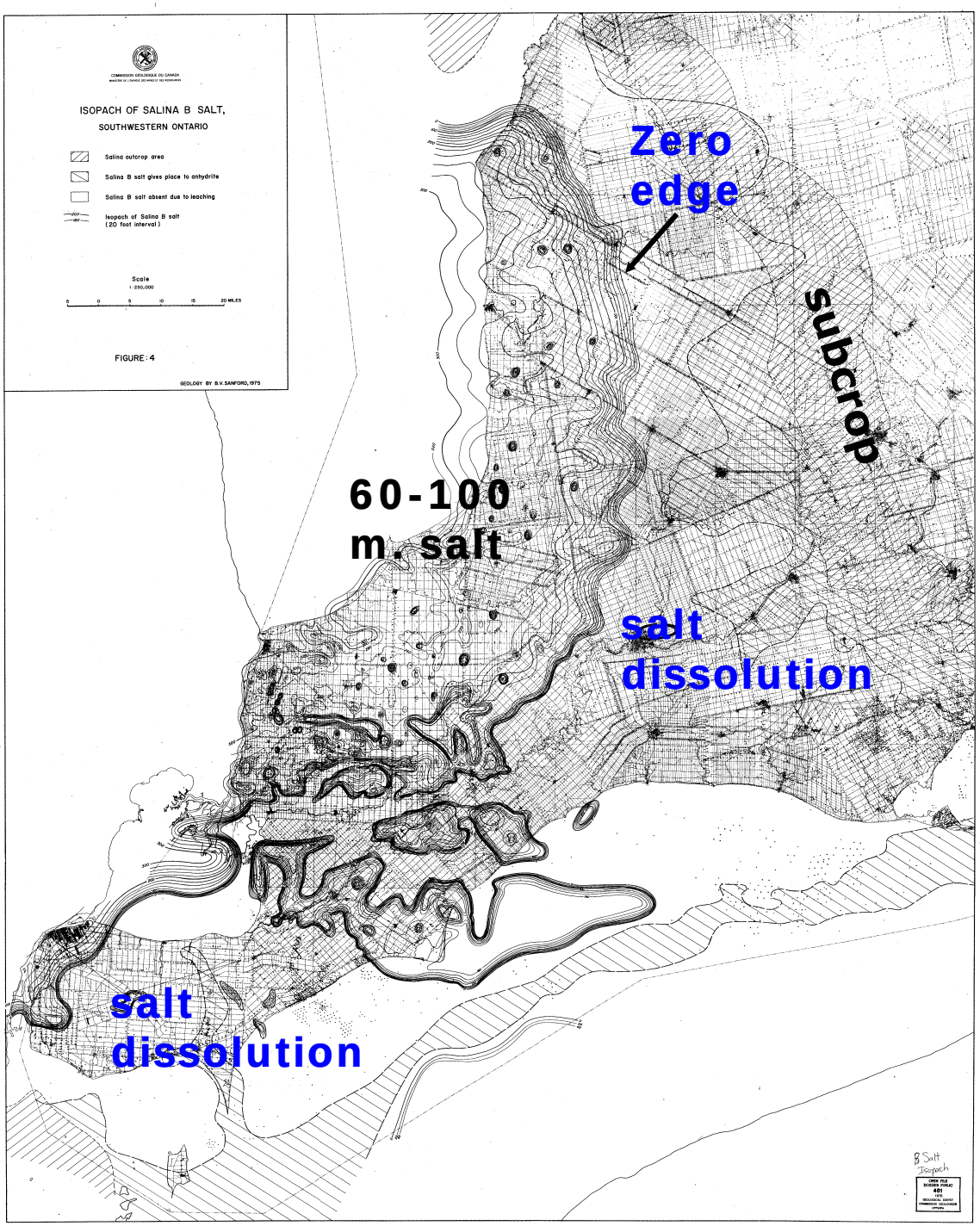


Ordovician: Trenton Group



Why are Deep Aquifers so Salty?

- Salina Group salt beds exhibit evidence of dissolution
- "fresh" water has penetrated the salt from subcrop or through faults subsequent to deposition and burial
- dissolved salt may be the source of sodium and chlorides in the saline aquifers

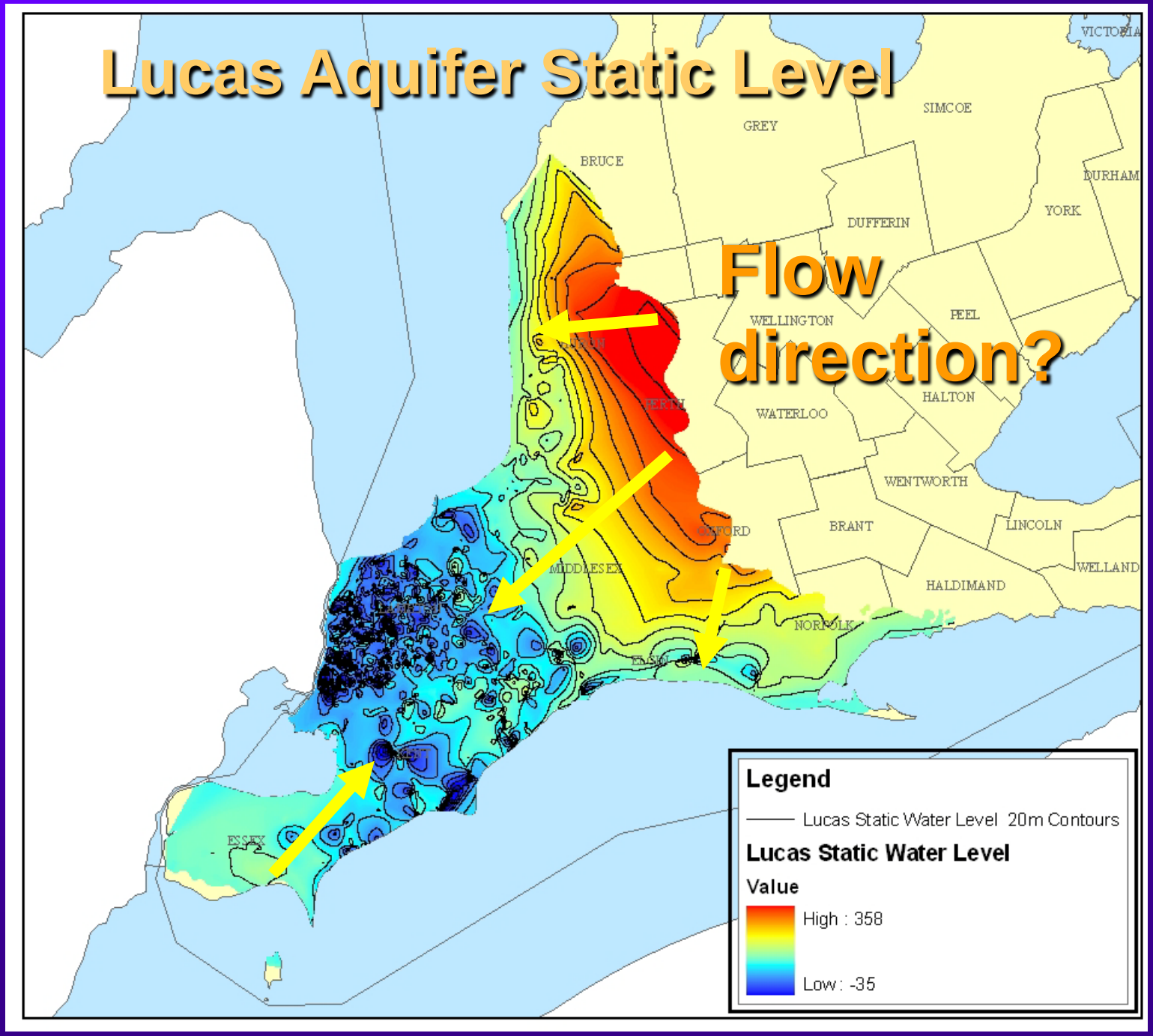


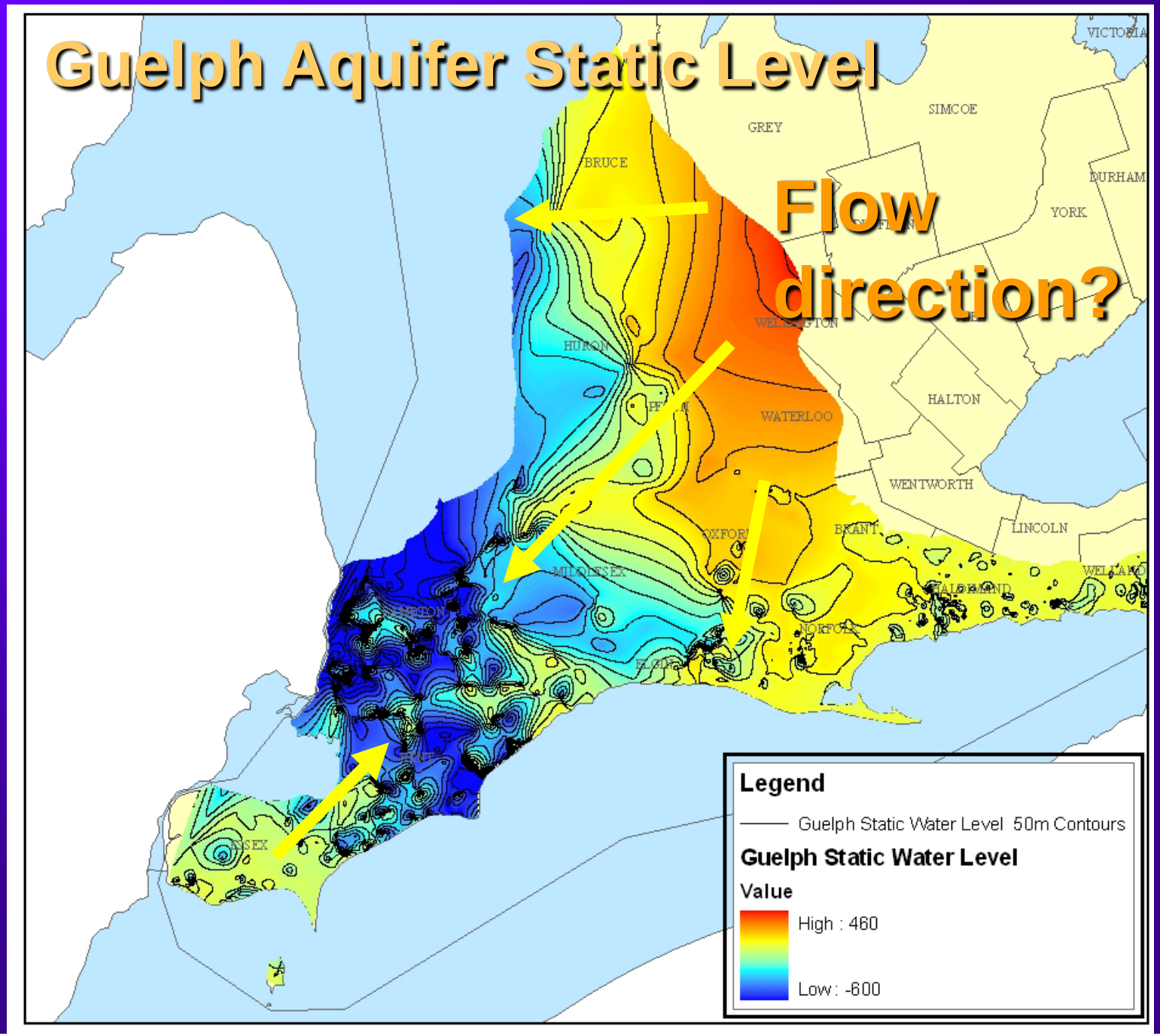
Salt-encrusted Core – Guelph Saline Aquifer

Mapping of Static Level – Potentiometric Surface?

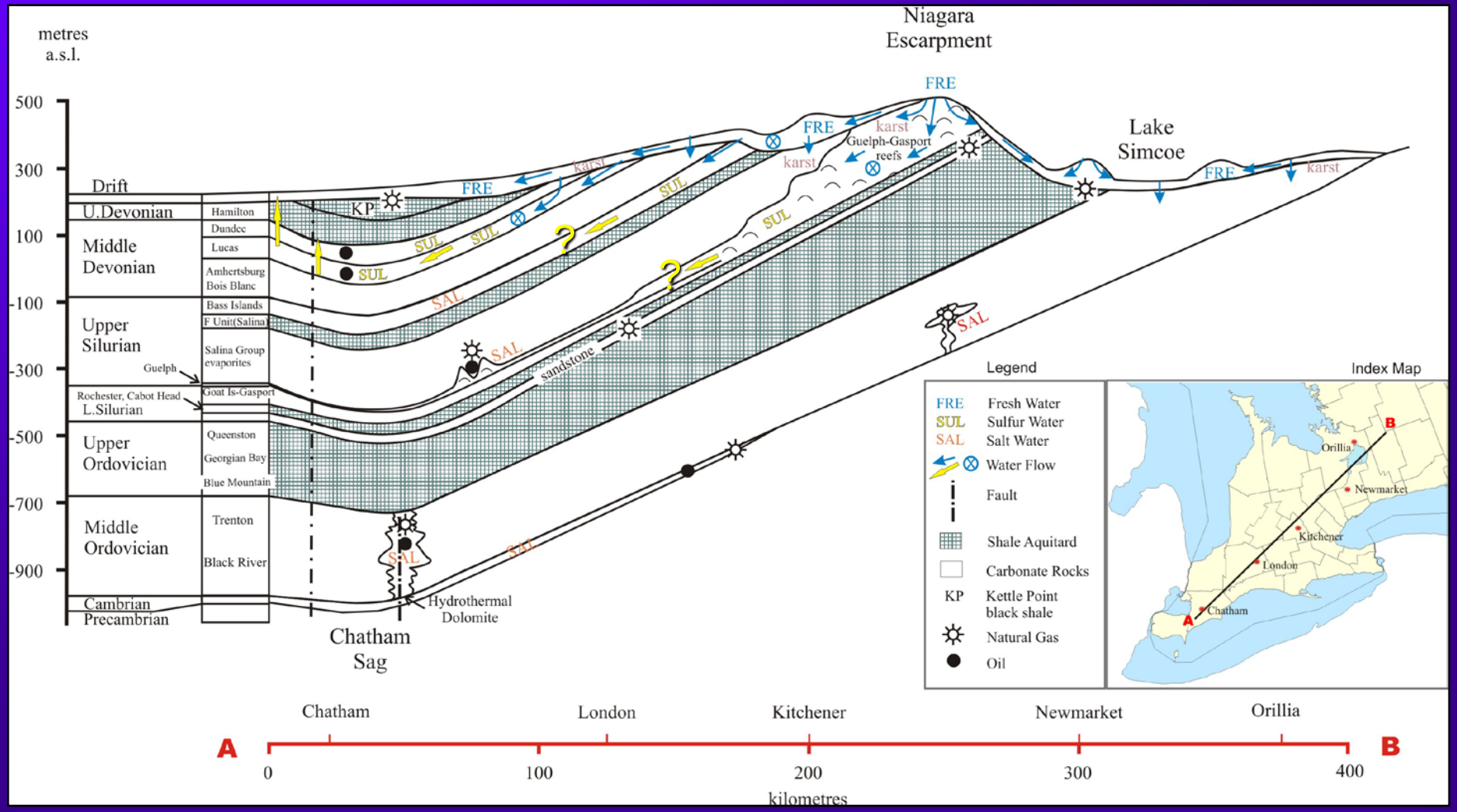
- Static level data for water intervals reported by driller and recorded in OPDS
- Plot by formation, grid and contour using ArcGIS
- Interpret flow direction
- NOTE – not corrected for water density so apparent flow directions must be confirmed

Lucas Aquifer Static Level




Guelph Aquifer Static Level
Flow direction?
VICTORIA
SIMCOE
GREY
BRUCE
DURHAM
YORK
WELLINGTON
HURON
HALTON
WATERLOO
WENTWORTH
LINCOLN
BRANT
MIDDLESEX
NORFOLK
ESSEX
Legend
Guelph Static Water Level 50m Contours
Guelph Static Water Level
Value
High : 460
Low : -600

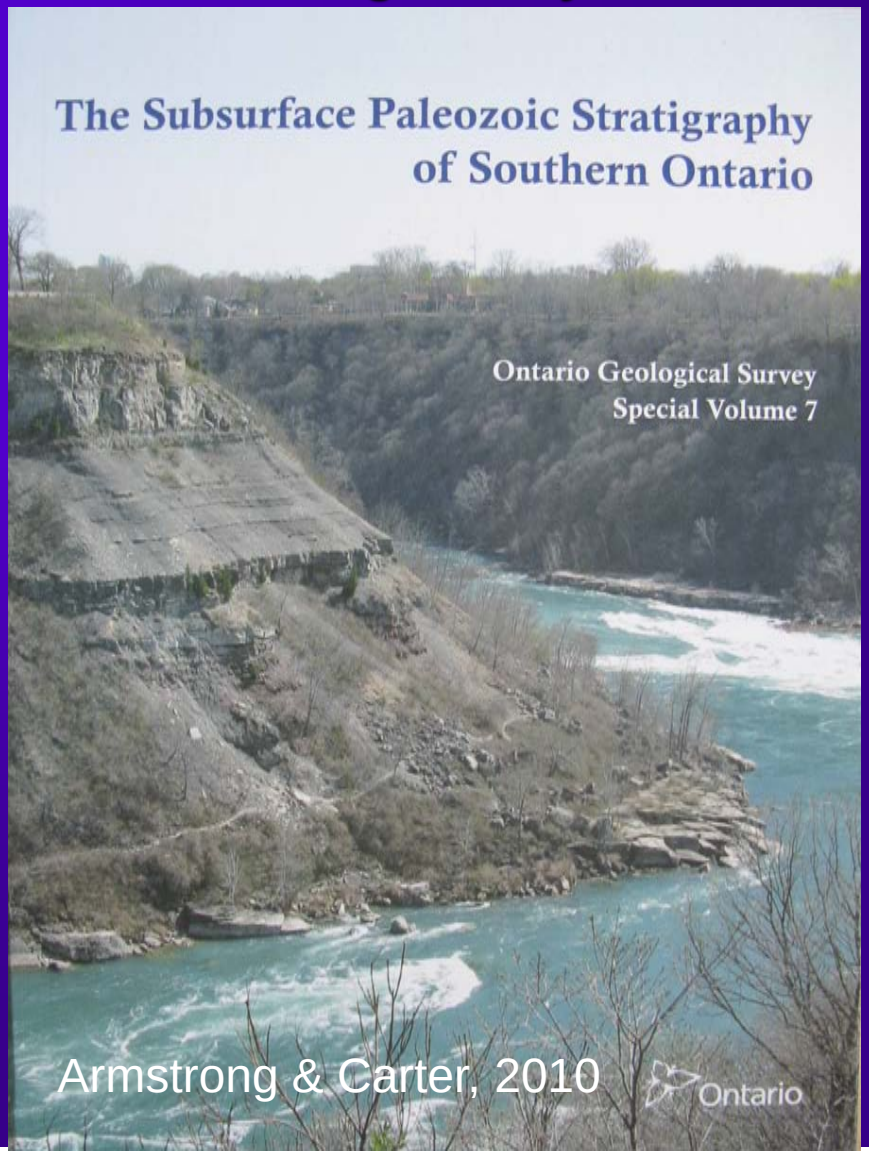
Conceptual Groundwater Model for Southern Ontario



Additional Reading

www.ogsrlibrary.com

- Collaboration between MNR, MNDMF, Geological Survey of Canada and Oil, Gas and Salt Resources Library
- Reference volume and practical guide
- Standards for identifying formations and formation contacts
- Formation descriptions
- Bibliography
- Regional cross-sections
- Oil, gas and water in subsurface formations




Questions?

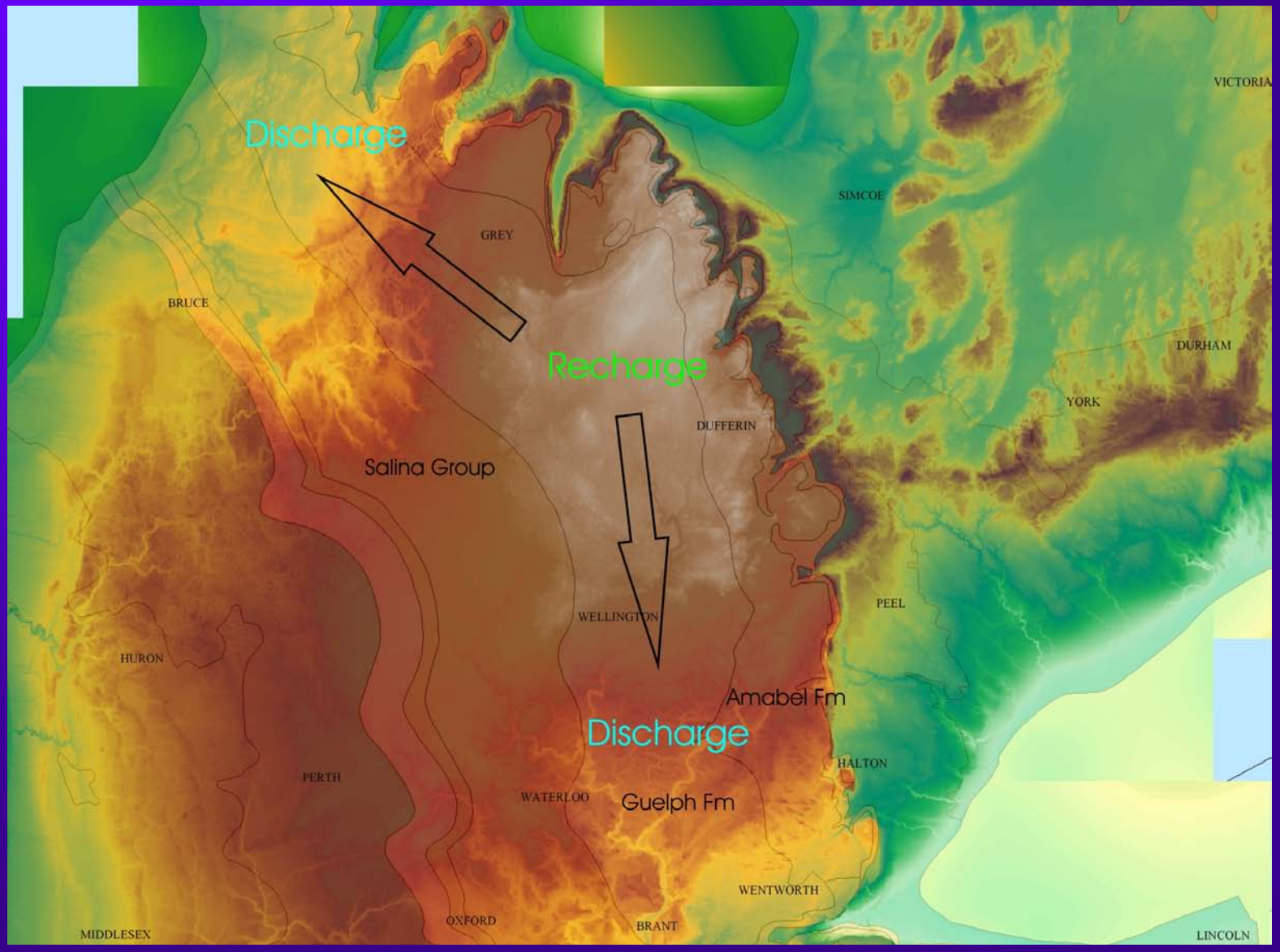
Geological Controls on Groundwater Flow

- Subsurface groundwater flow
  - bounding surfaces are formed by rock strata of contrasting porosity and permeability (aquitards)
  - Faults, fractures enhance lateral flow or allow flow across bounding surfaces
  - Buoyancy – fresh water floats on top of saline water

Groundwater Chemistry/Quality

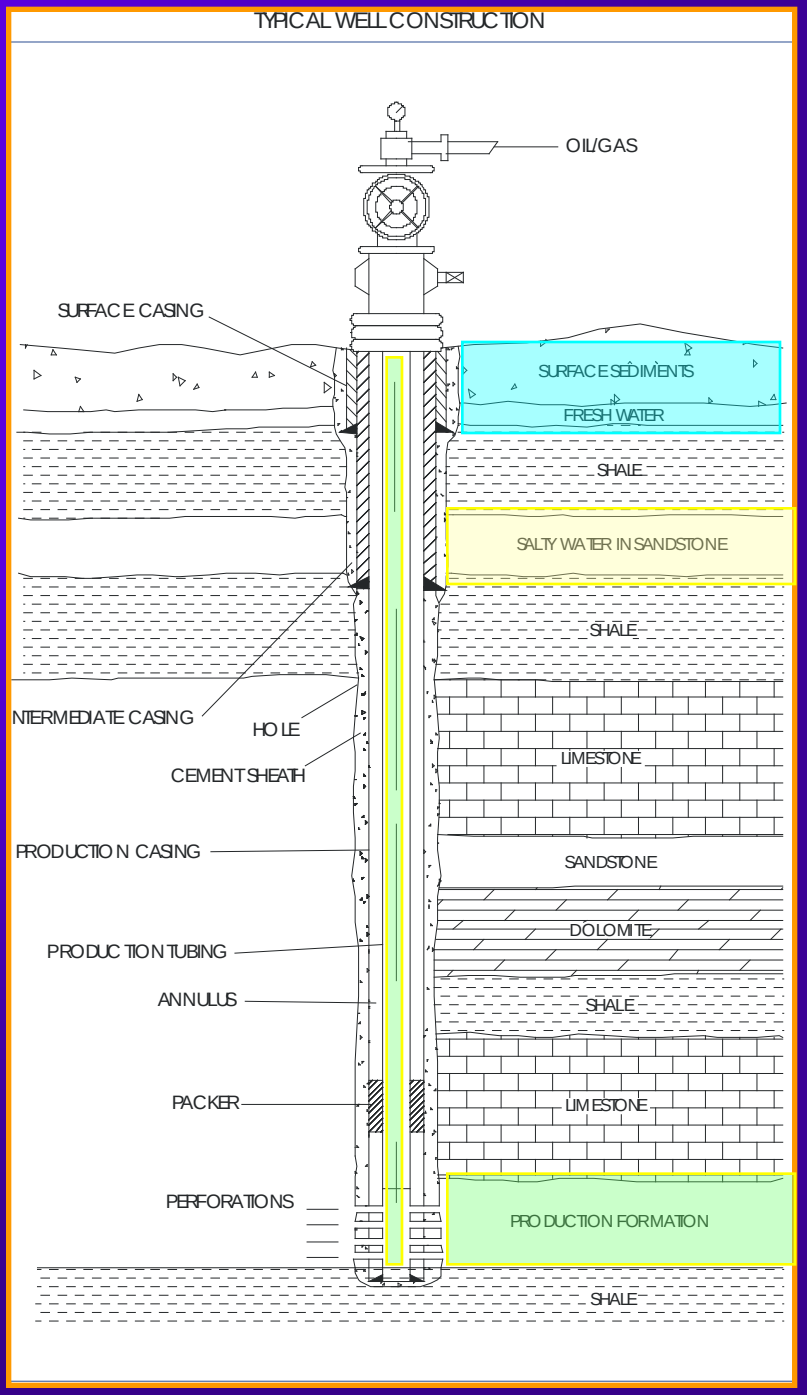
- dissolved compounds in Ontario bedrock aquifers:
  - Methane in rocks with high organic content
  - Radon in rocks enriched in uranium
  - chlorides of Na, Mg, Ca;
  - Ca/Mg sulfate, Ca/Mg carbonate
  - Pb, F, As, etc

Guelph-Amabel Bedrock Aquifer – Conceptual Water Flow



Drilling Program

- Regulatory requirement in Ontario for petroleum wells
- Cemented casings to protect potable water aquifers and prevent mixing and movement of subsurface fluids
- Identify geological strata, oil/gas/water intervals and pressures, sulphur water, geological hazards

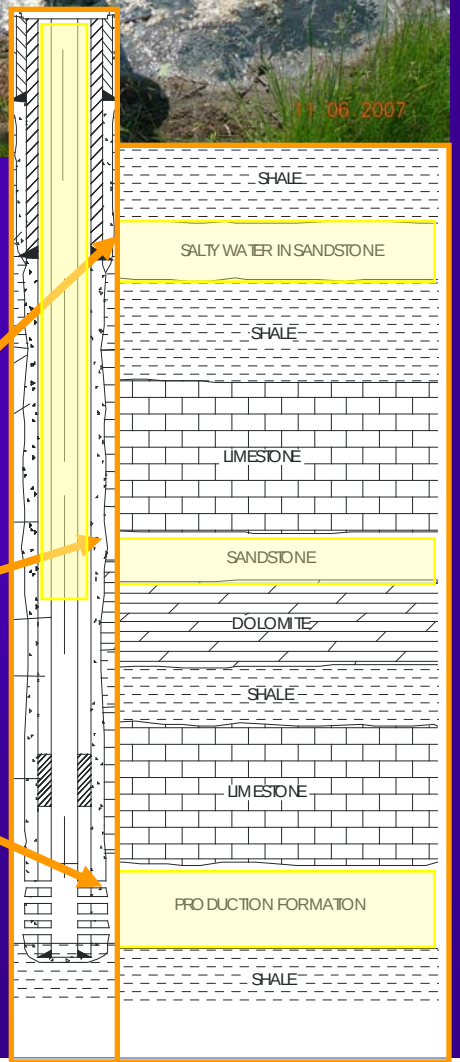


Fresh water aquifers

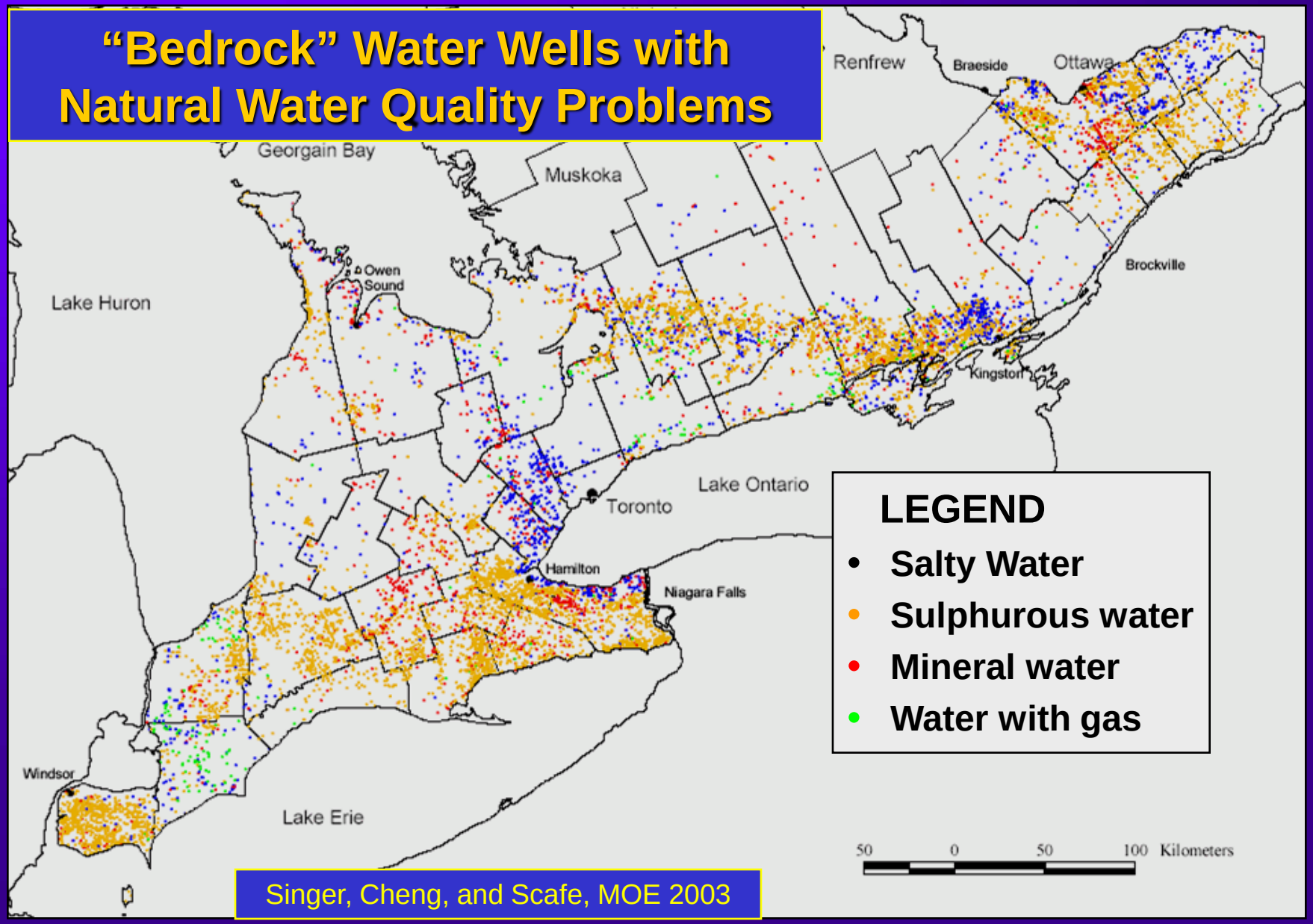
Deep aquifers and/or oil & gas in bedrock

Abandoned Works/ Well Plugging

- Which formations contain sulfur water/oil/gas?
- Which formations are competent for setting of plugs?
- Where has casing corrosion occured?

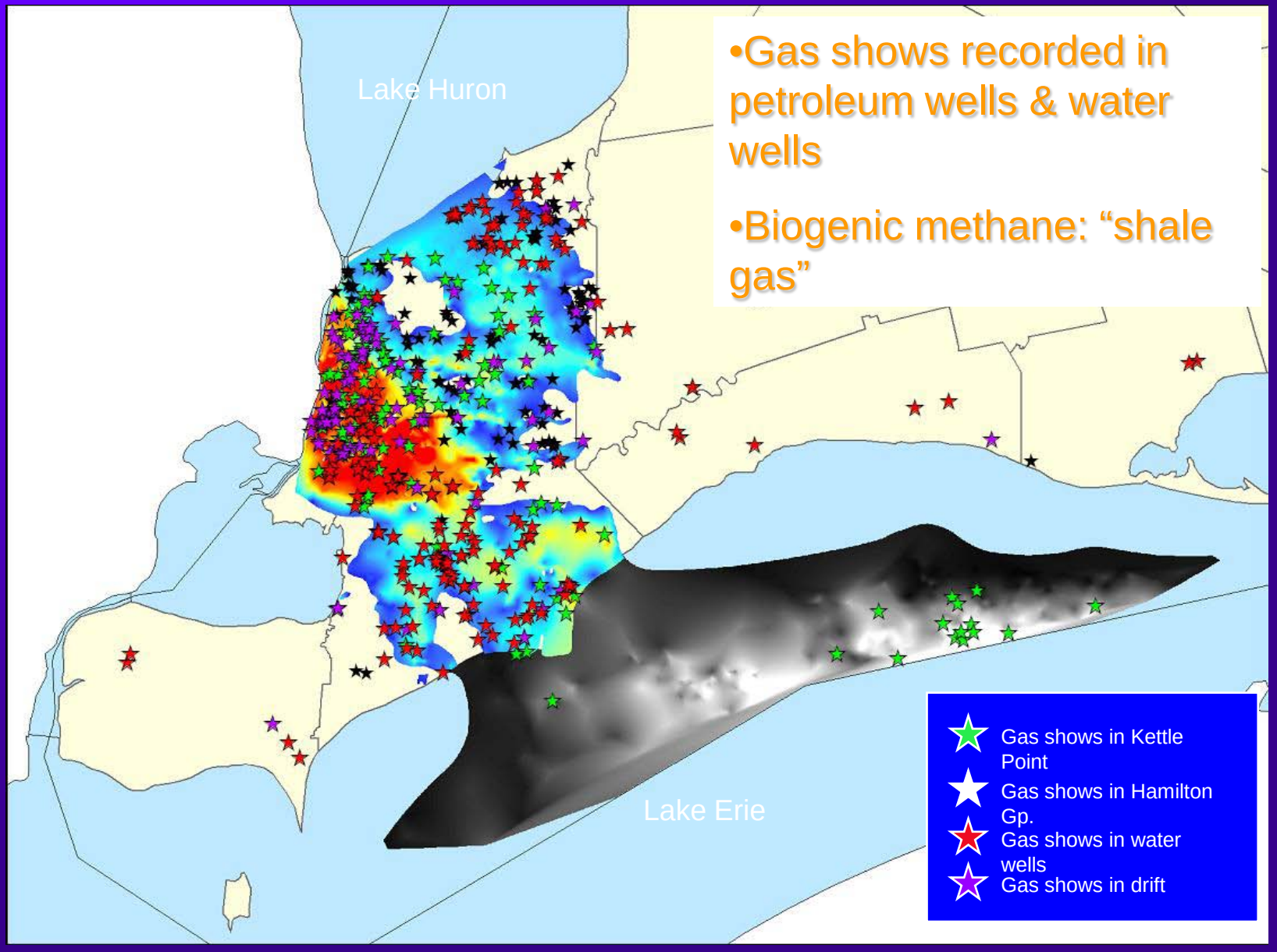


“Bedrock” Water Wells with Natural Water Quality Problems

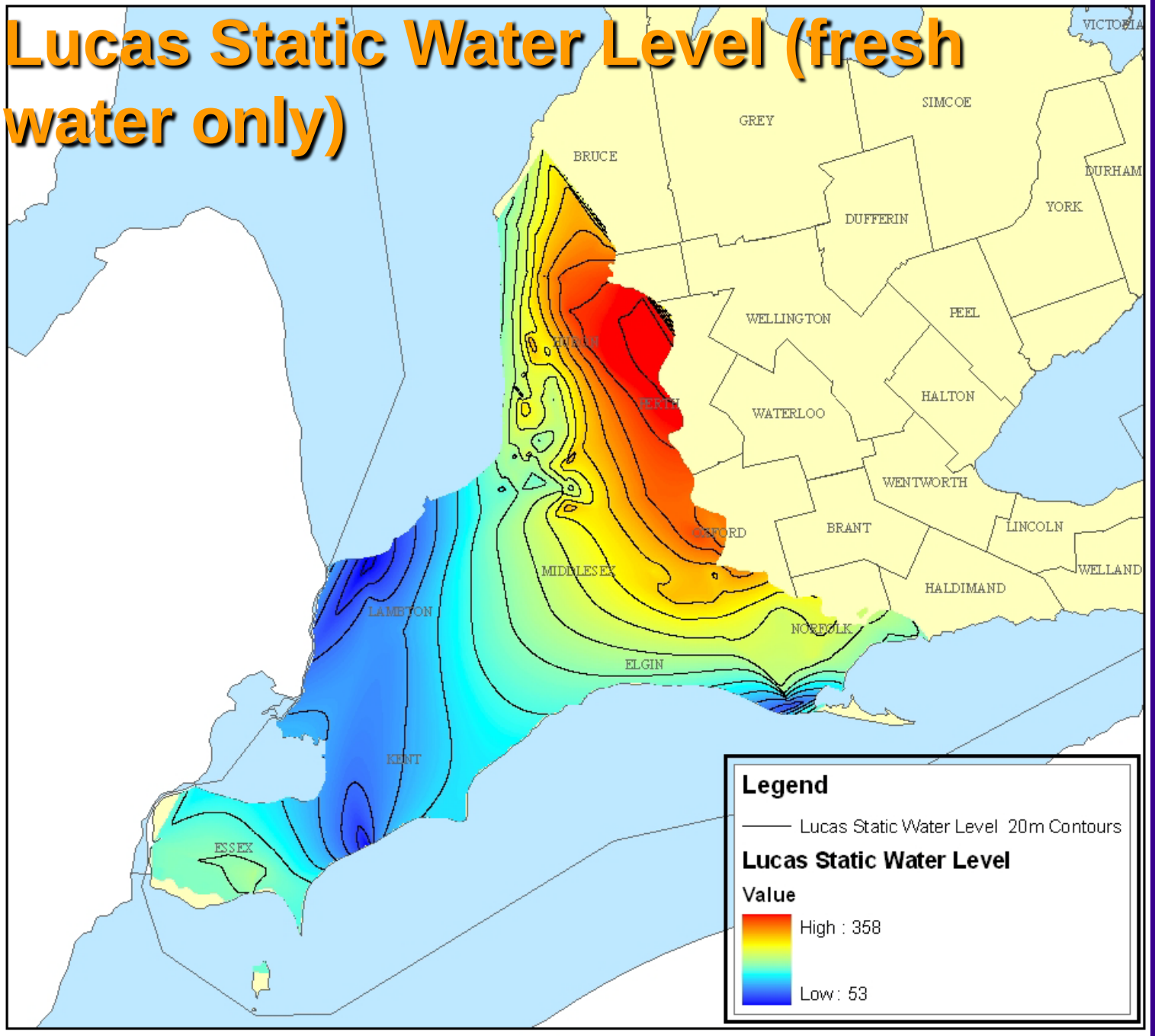


Singer, Cheng, and Scafe, MOE 2003

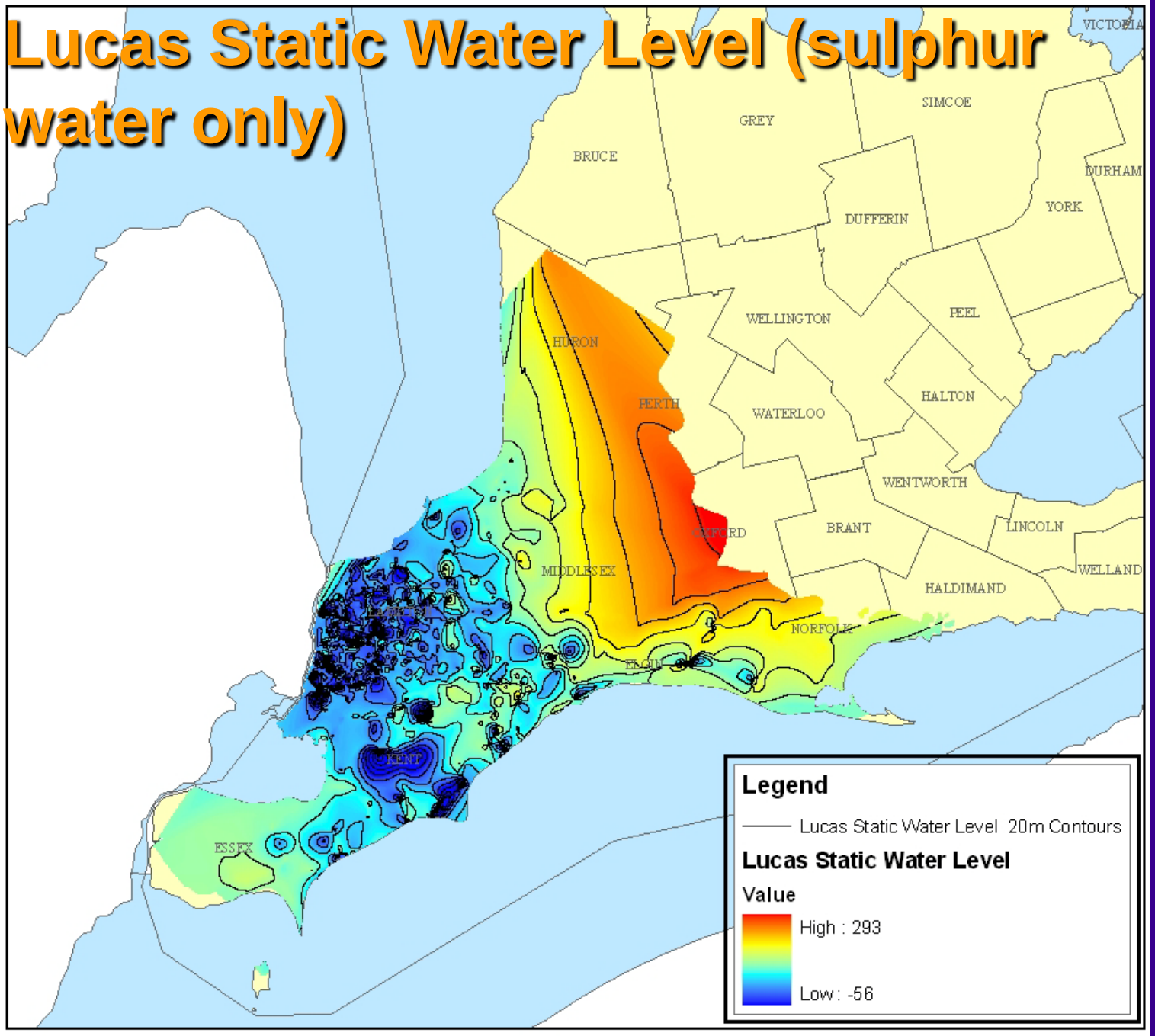
Methane in Contact Aquifer



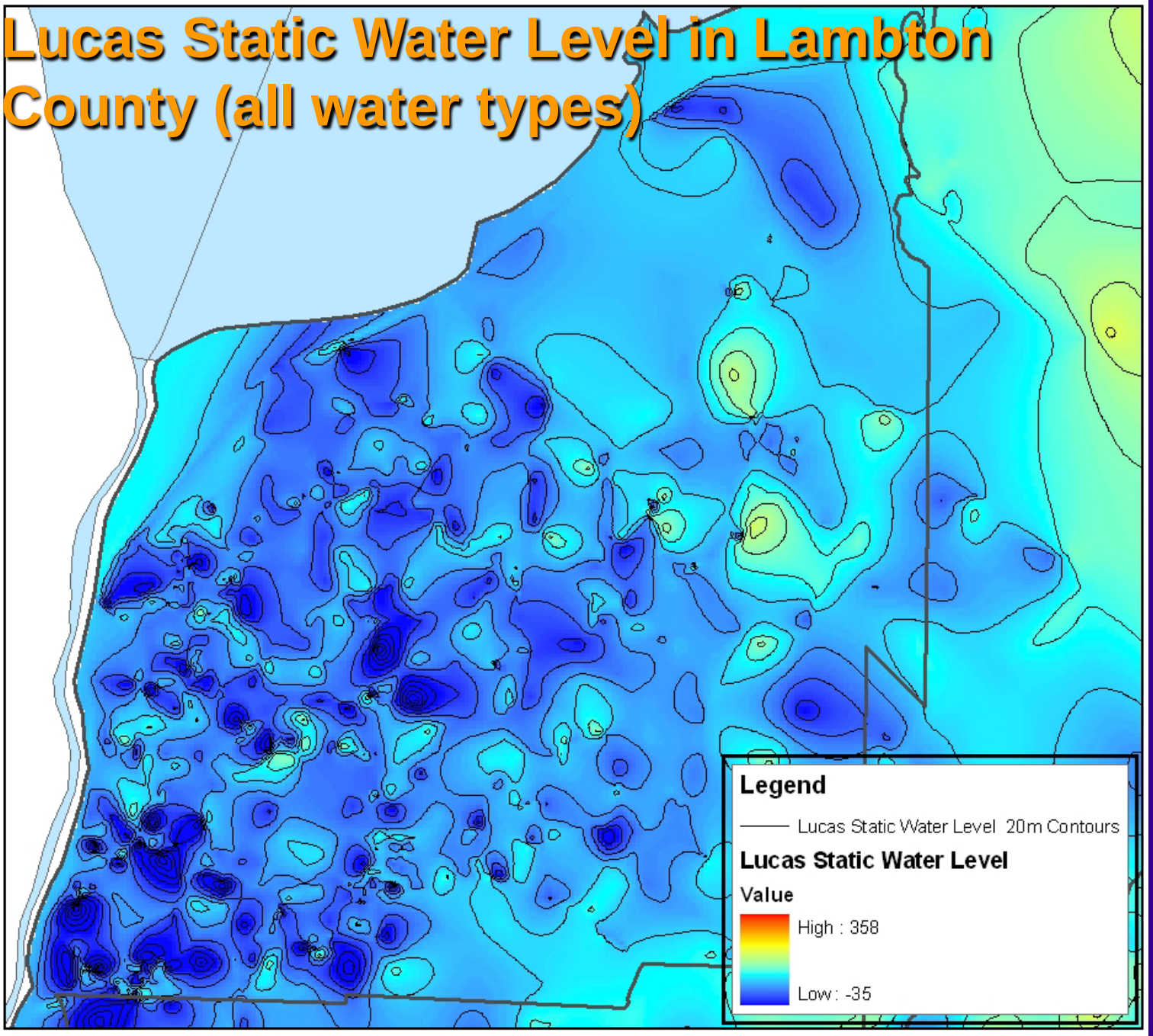
Lucas Static Water Level (fresh water only)



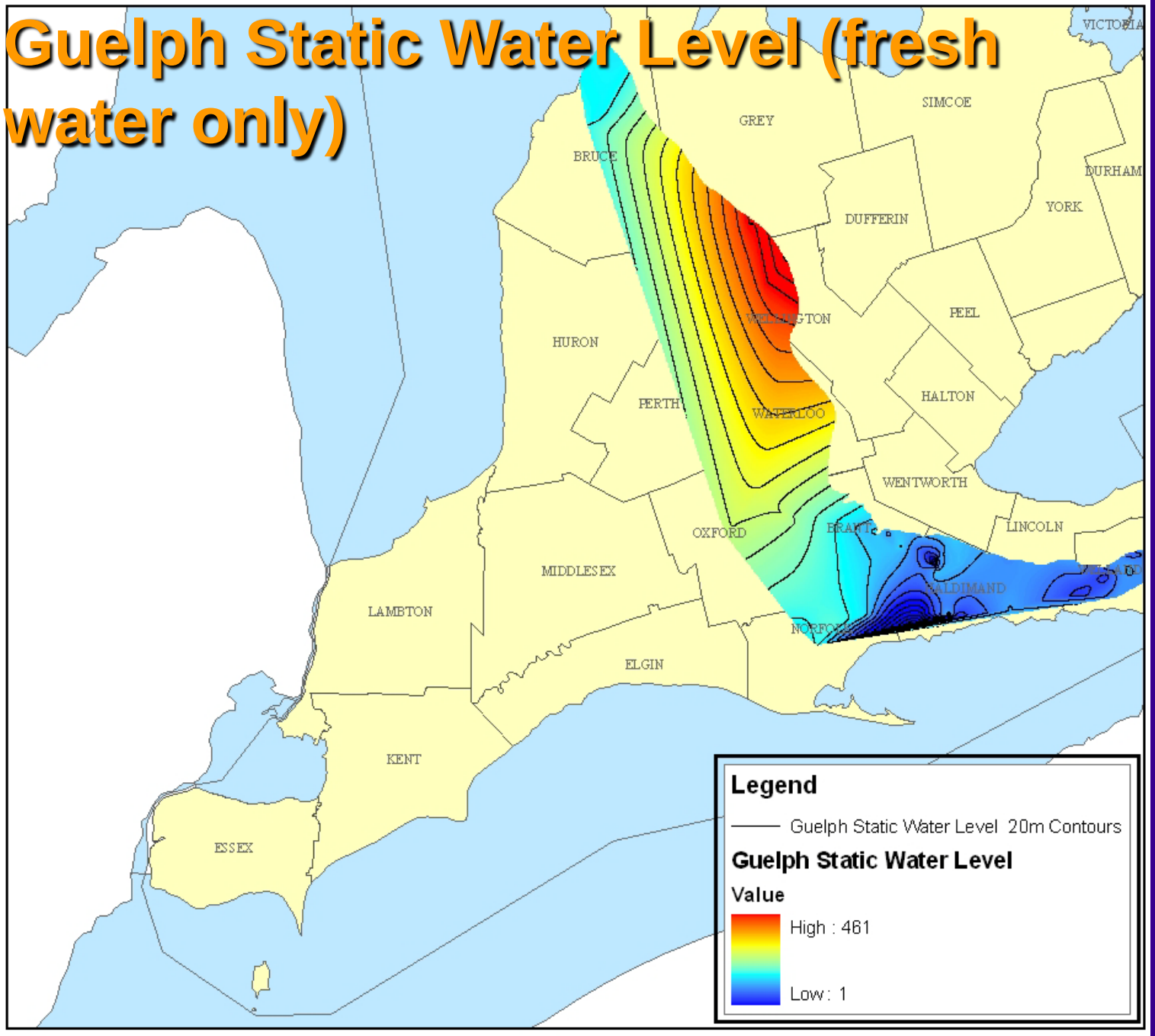
Lucas Static Water Level (sulphur water only)



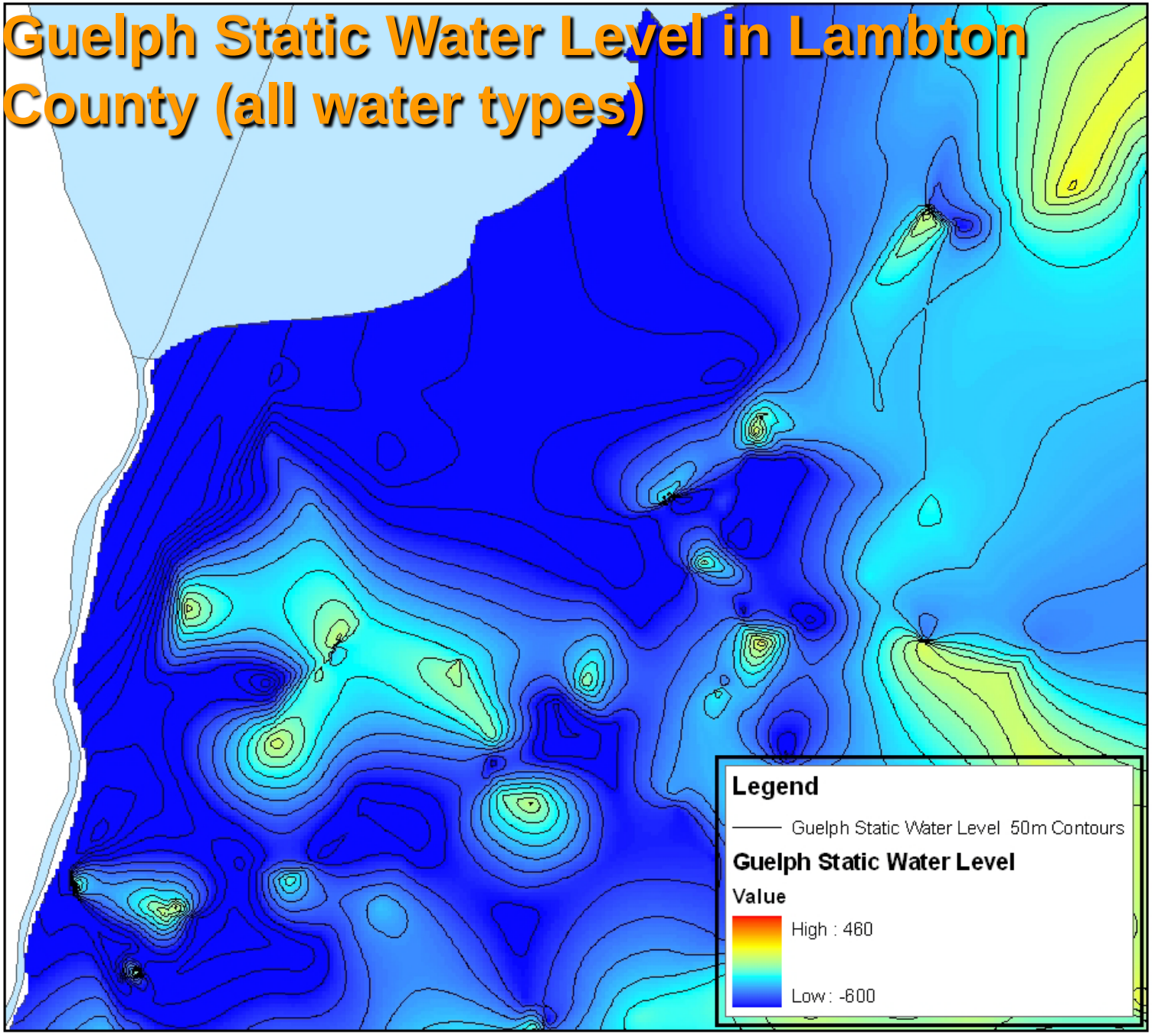
Lucas Static Water Level in Lambton County (all water types)



Guelph Static Water Level (fresh water only)



Guelph Static Water Level in Lambton County (all water types)



Guelph Static Water Level (no fresh water)