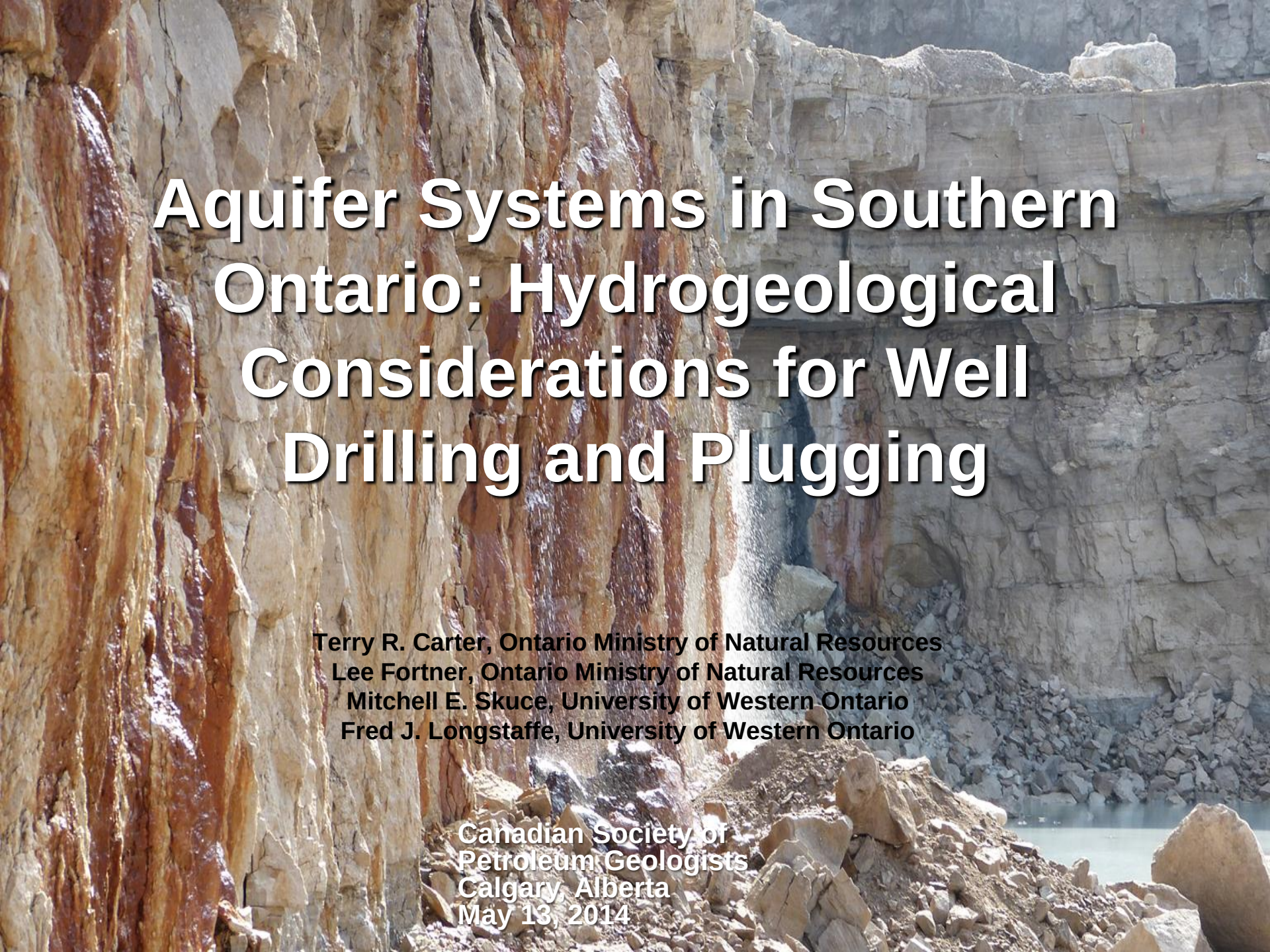


Aquifer Systems in Southern Ontario: Hydrogeological Considerations for Well Drilling and Plugging

Terry R. Carter, Ontario Ministry of Natural Resources
Lee Fortner, Ontario Ministry of Natural Resources
Mitchell E. Skuce, University of Western Ontario
Fred J. Longstaffe, University of Western Ontario

Canadian Society of Petroleum Geologists
Calgary, Alberta
May 13, 2014

Background

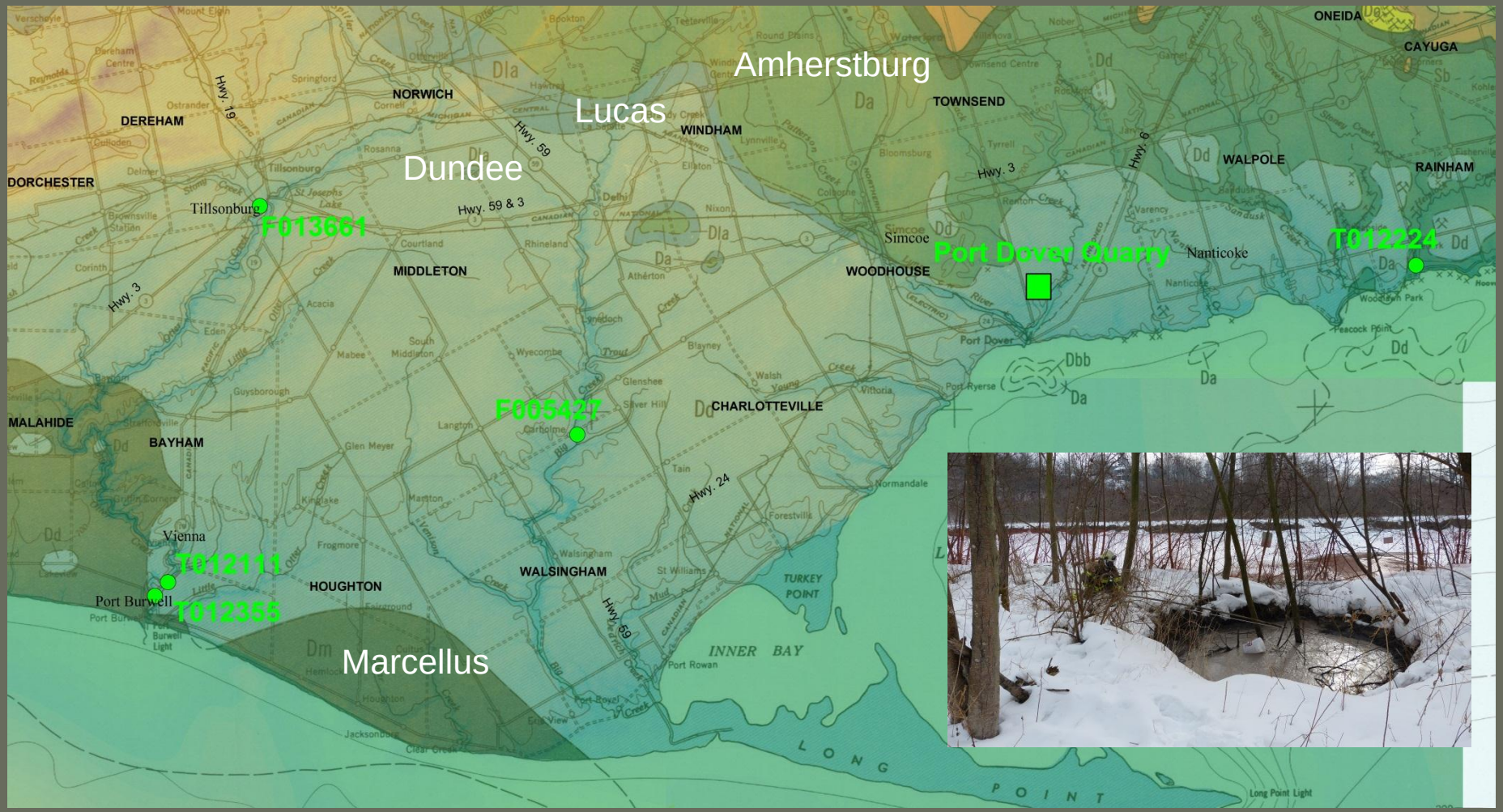
- Ministry of Natural Resources (MNR) regulates oil and gas industry in Ontario
- Oil, Gas and Salt Resources Act requires isolation of potable water aquifers and other porous and permeable intervals during well drilling, construction and plugging to prevent movement and mixing of fluids.
- MNR Abandoned Works Program plugs orphan wells with no identifiable operator other than landowner

- Accurate knowledge of geology and hydrogeology needed by
  - industry to protect environment, design drilling and plugging programs, anticipate drilling hazards
  - MNR – to assess well licence applications, monitor industry compliance, design plugging programs for Abandoned Works wells
  - Map drilling hazards: sulphur water, artesian flow, karst

Steel casing + Sulphur water = Corrosion

Artesian Flow - Sulphur Water

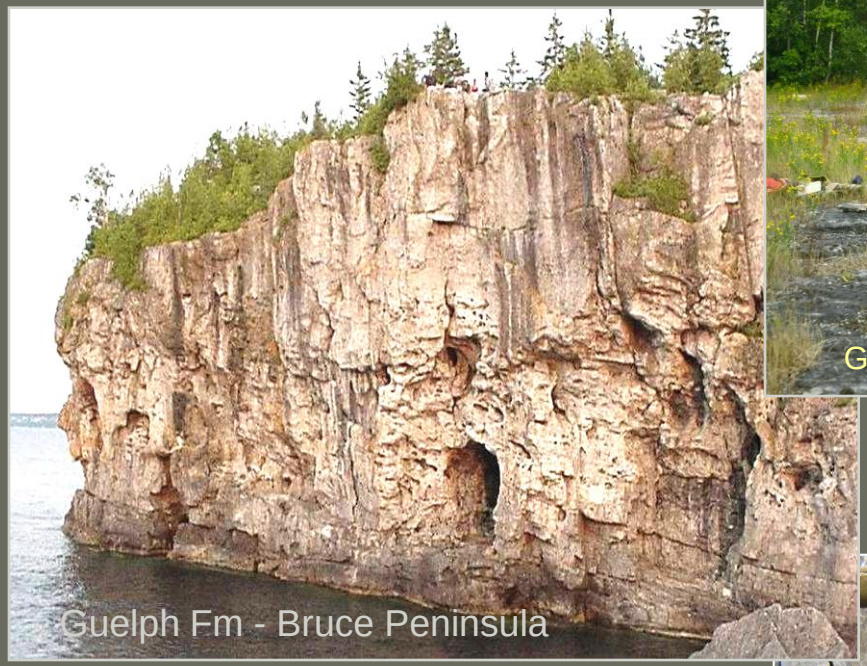
Flowing Sulphur Water in Lucas Formation
Big Otter Ck – Big Ck – Hemlock Ck



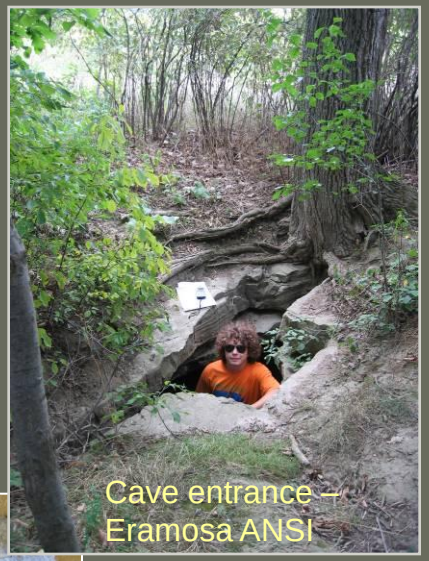
Before

During Plugging

Karst


Guelph Fm - Bruce Peninsula


Grike – Bruce peninsula


Cave entrance – Eramosa ANSI


Guelph Fm – T007290

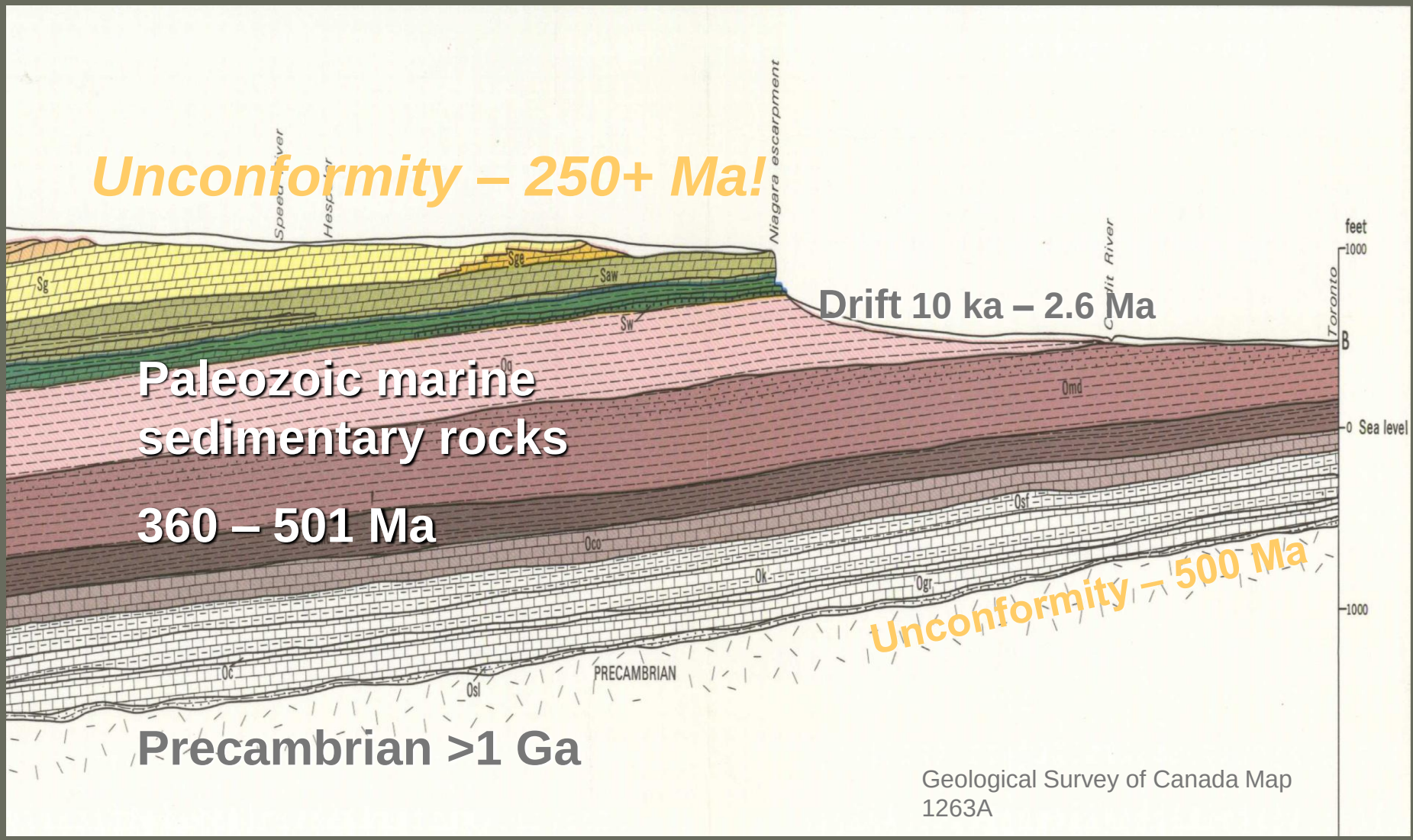
Incompetent Bedrock

Aquifer Mapping & Isotopic Fingerprinting

- In 2009 a project to map regional bedrock aquifers in southern Ontario was initiated by MNR, with focus on the sulphur water zone and potable water
- made possible by improvements to MNR petroleum well database and custom ArcGIS extension – PetroGIS
- QA checks of 35,000 water records, construction of water type maps and static level maps

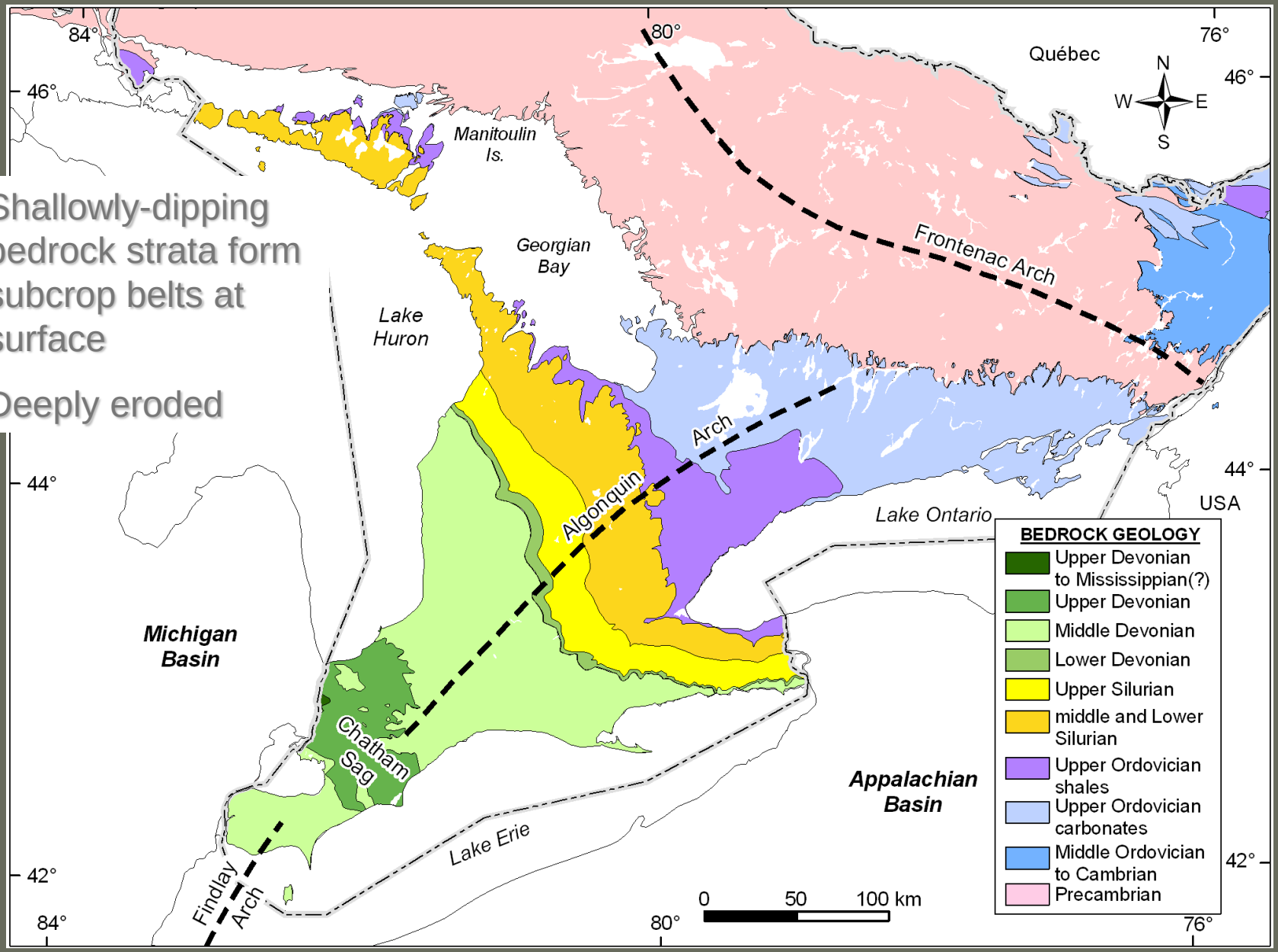
- Project scope expanded in 2011 to acquire isotopic and geochemical fingerprints of formation waters and gases to identify source of leaking fluids at orphan wells and fluid origin
- Joint project with University of Western Ontario
  - Dr. Fred Longstaffe: principal researcher
  - Mitchell Skuce: Formation waters
  - Dr. Joanne Potter: Natural gas

Bedrock Geology



Geological Survey of Canada Map 1263A

Bedrock Geology



Water Types Terminology

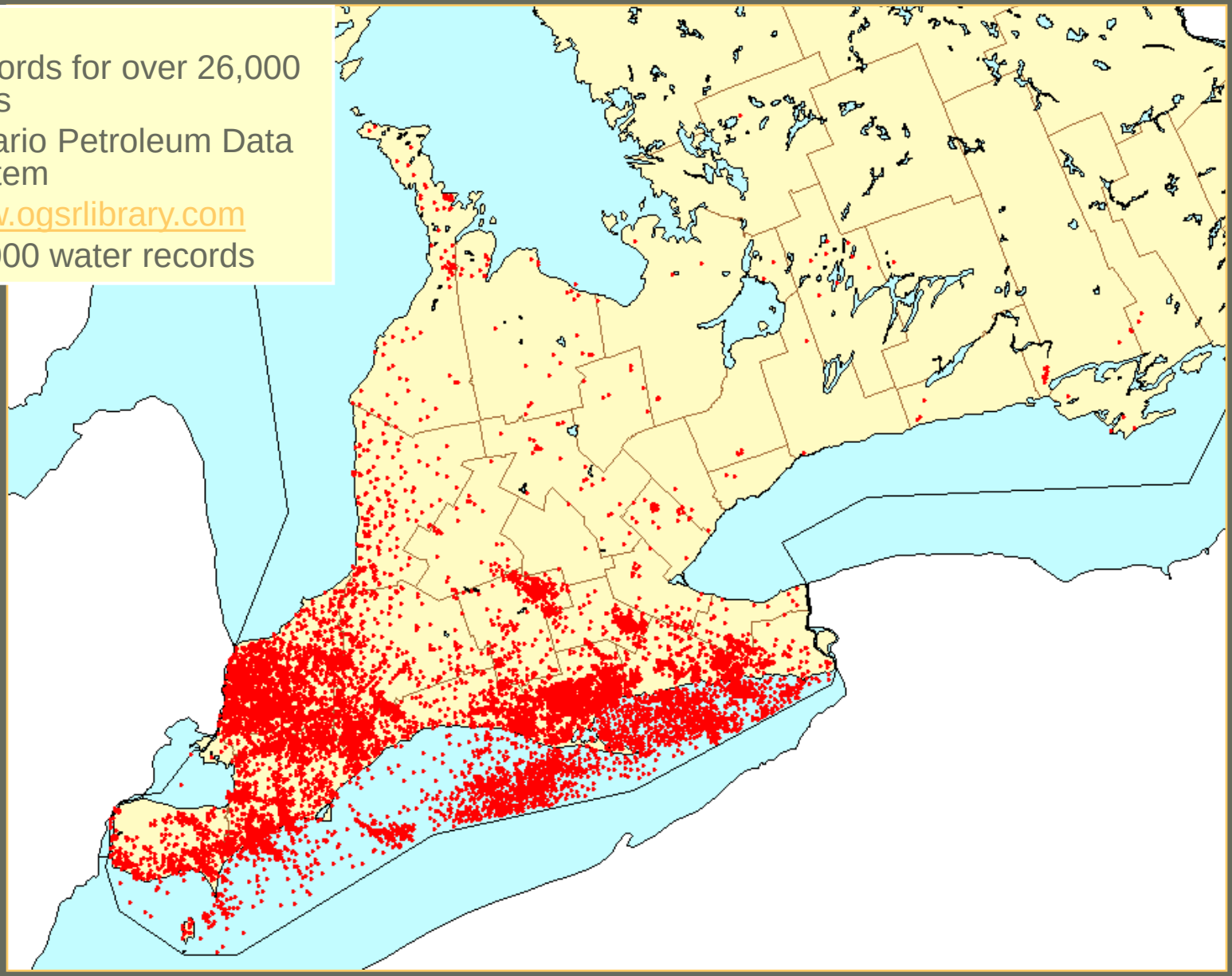
- "Fresh water" – contains less than 1,000 ppm TDS
  - 500 ppm TDS – MOE & Canada Drinking Water Standard
- Brackish – 1,000 to 10,000 ppm TDS
- Saline – 10,000 to 100,000 ppm TDS
- Brine - >100,000 ppm TDS
- Sulphur water – water containing dissolved hydrogen sulfide

Sources of Information

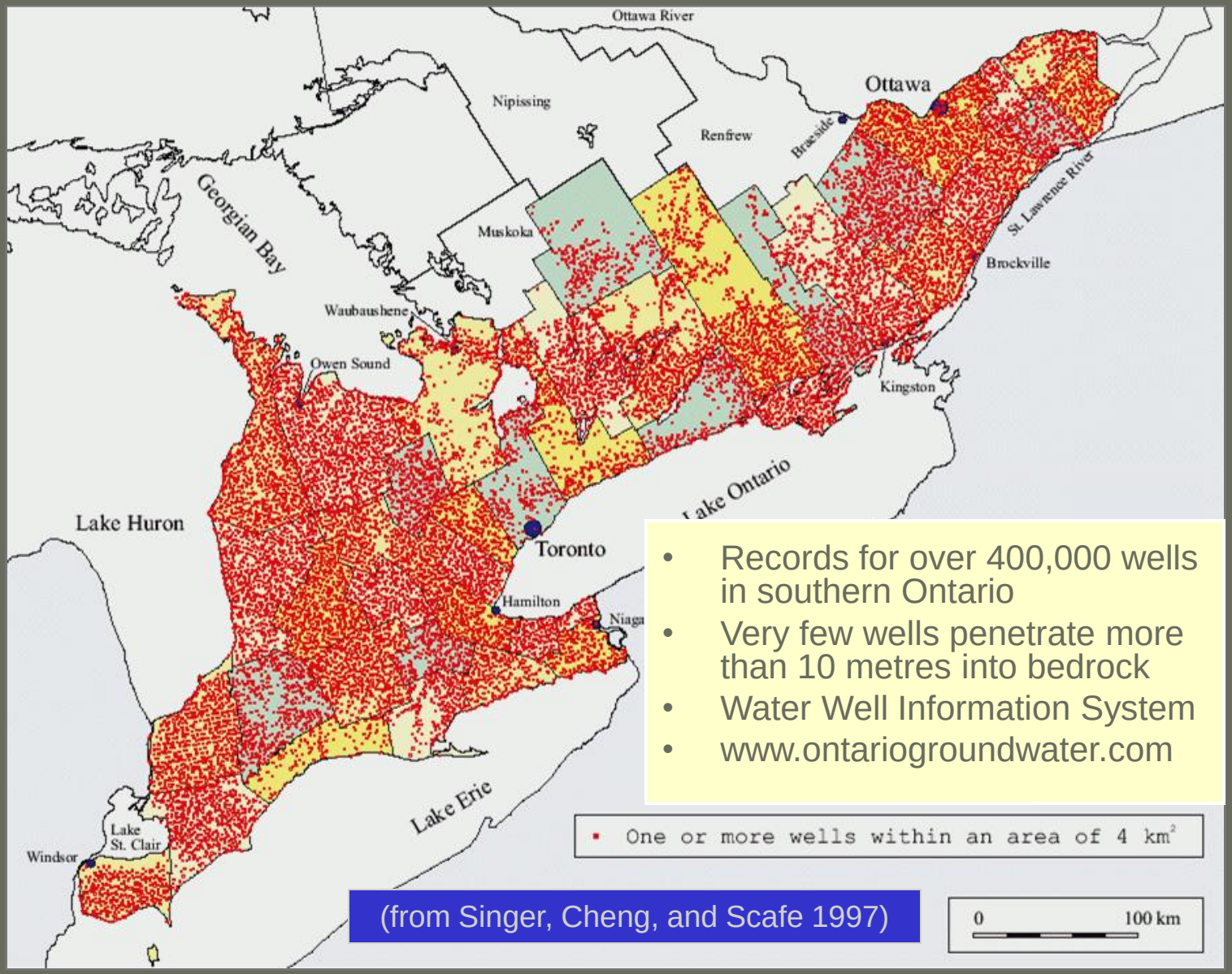
- Outcrops, road cuts, quarries
- New Isotopic and hydrogeochemical data from 130 water samples
- MOE water well records (drift and very shallow bedrock)
- MNR petroleum well records: www.ogsrlibrary.com
- Ontario Geological Survey
- Hobbs et al (2011), Dollar (1988), Weaver (1994), Armstrong and Carter (2010), Hamilton (2010), MacRitchie et al (1994), Singer et (1997), Lazorek and Carter (2008), Skuce (2014), Sharpe et al (2014), Carter (2012), others
- Acknowledgements – Lee Fortner, Frank Brunton, Chris Smart, Theo Beukeboom, Dick Jackson, Jeff Markle, Derek Armstrong, Dave Sharpe, Scott MacRitchie, Mitchell Skuce, Fred Longstaffe, Candace Freckelton, Jonathon Sykes, Jordan Clark and others

Petroleum Well Records - MNR

- Records for over 26,000 wells
- Ontario Petroleum Data System
- www.ogsrlibrary.com
- 35,000 water records



Water well records - MOE



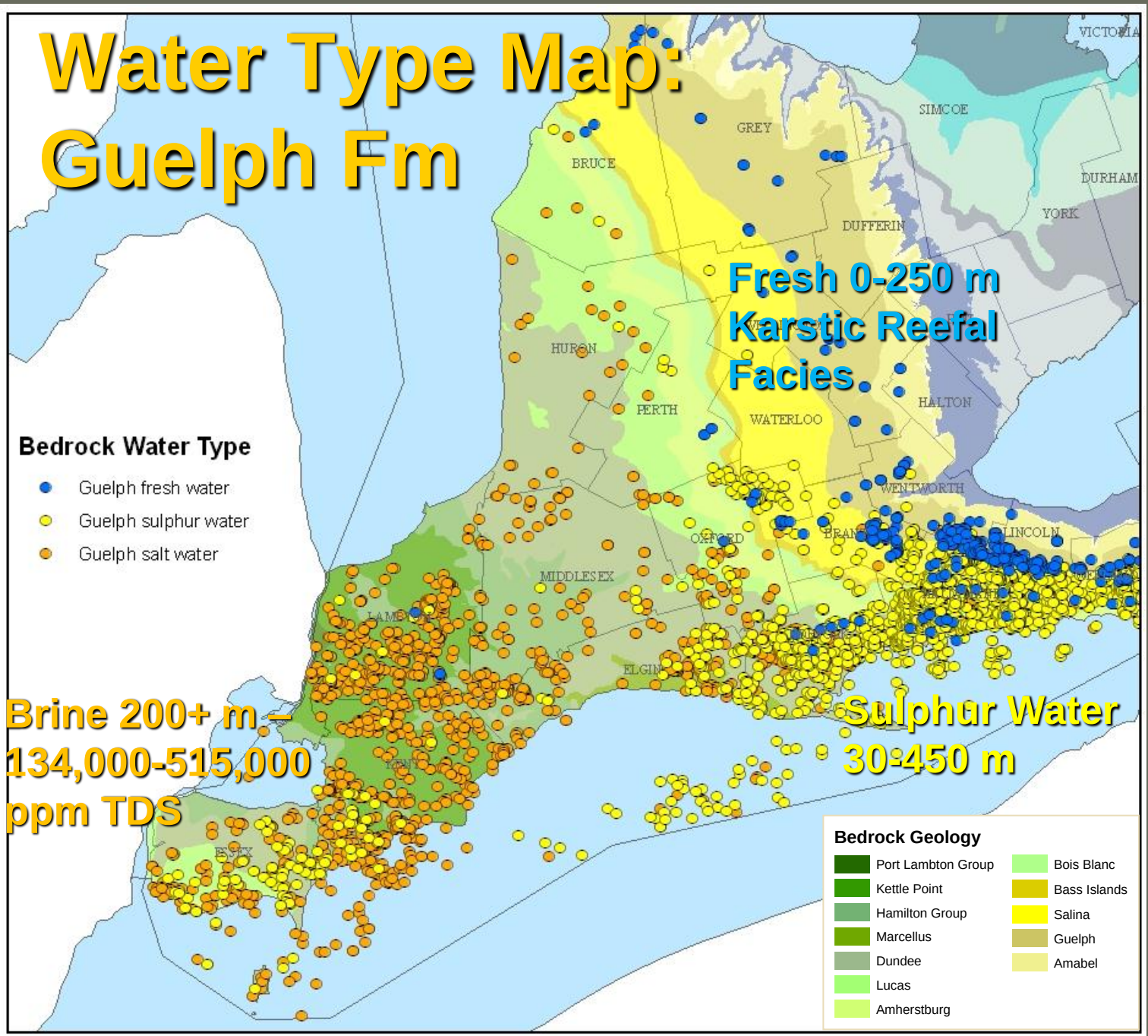
- Records for over 400,000 wells in southern Ontario
- Very few wells penetrate more than 10 metres into bedrock
- Water Well Information System
- www.ontariogroundwater.com

(from Singer, Cheng, and Scafe 1997)

Aquifer Mapping by Water Type

- 35,000 water records in petroleum well database
- Water type as recorded by driller for petroleum wells *drilled by cable tool method* & plotted by formation
  - Fresh water (FRE)
  - Sulphur water (SUL)
  - Brine (SAL)

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

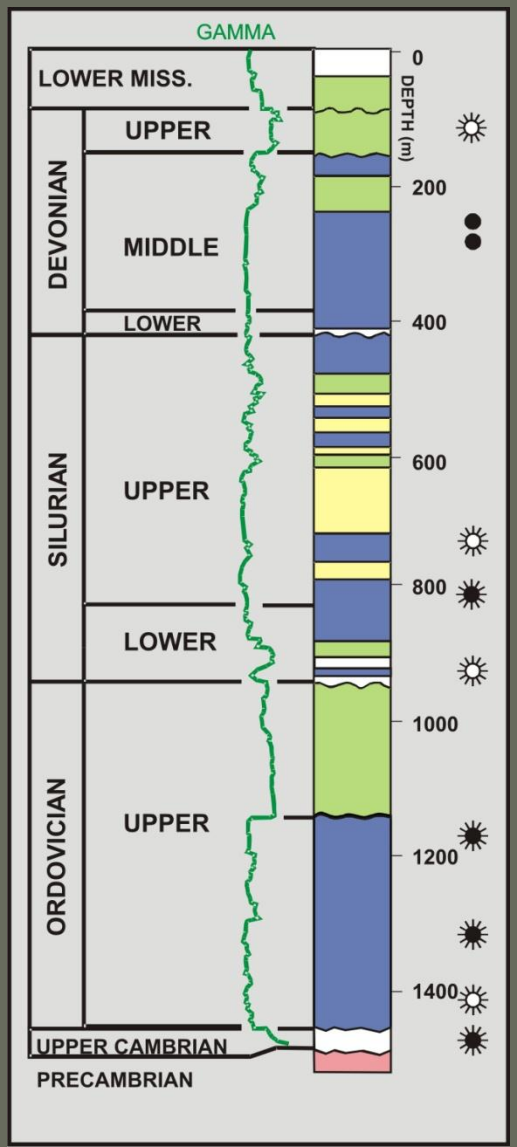

Water Type Map:
Guelph Fm
Fresh 0-250 m
Karstic Reefal
Facies
Brine 200+ m –
134,000-515,000
ppm TDS
Sulphur Water
30-450 m
Bedrock Water Type
Guelph fresh water
Guelph sulphur water
Guelph salt water
Bedrock Geology
Port Lambton Group
Kettle Point
Hamilton Group
Marcellus
Dundee
Lucas
Amherstburg
Bois Blanc
Bass Islands
Salina
Guelph
Amabel
SIMCOE
GREY
BRUCE
DURHAM
YORK
DUFFERIN
HURON
PERTH
WATERLOO
HALTON
WENTWORTH
OXFORD
MIDDLESEX
ELGIN
ESSEX

Aquifers by Water Type & Depth

Fresh

Sulphur Water

Brine



Shallow Aquifers

0-250 m

Lucas & Dundee formations
Bass Islands Formation

30-450 m

200+ m

Guelph Formation

Cambrian

OIL
GAS
OIL & GAS

SANDSTONE
SHALE
CARBONATE
SALT
METAMORPHIC

Aquifer Systems – southern Ontario

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

- Intermediate Regime
  4. Sulphur Water Aquifer System

- Deep Regime
  5. Brine Aquifer System

Shallow Aquifers

1. Overburden Aquifer System

- Fresh water in unconsolidated Recent sediments, and glacial sediments
- Tens of metres overburden thickness, max 260 m in moraines and bedrock valleys
- Complex aquifers of local extent, principal source of potable groundwater in southern Ontario

Shallow Aquifers

2. Interface/Contact Aquifer System

- Regional fresh water aquifer at interface between porous & permeable surficial sediments and less porous & permeable Paleozoic bedrock
  - Includes uppermost few metres of bedrock which is usually jointed, weathered, porous
- Most extensive, continuous, fresh water aquifer in southern Ontario
- Ca-HCO3, Ca-SO4
- pH 6.2 to 8.8 (measured in field)
- 0-9000 TDS, avg 731, median 494 (calculated from Hamilton, 2011)
- NOTE: fresh water only penetrates a few metres into bedrock unless the bedrock is karsted or fractured

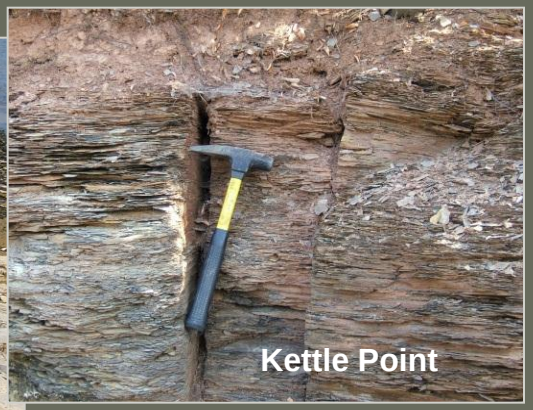
Shallow Regime

Contact Aquifer

Contact aquifer

Joints at bedrock surface


Kettle Point shales, L. Huron

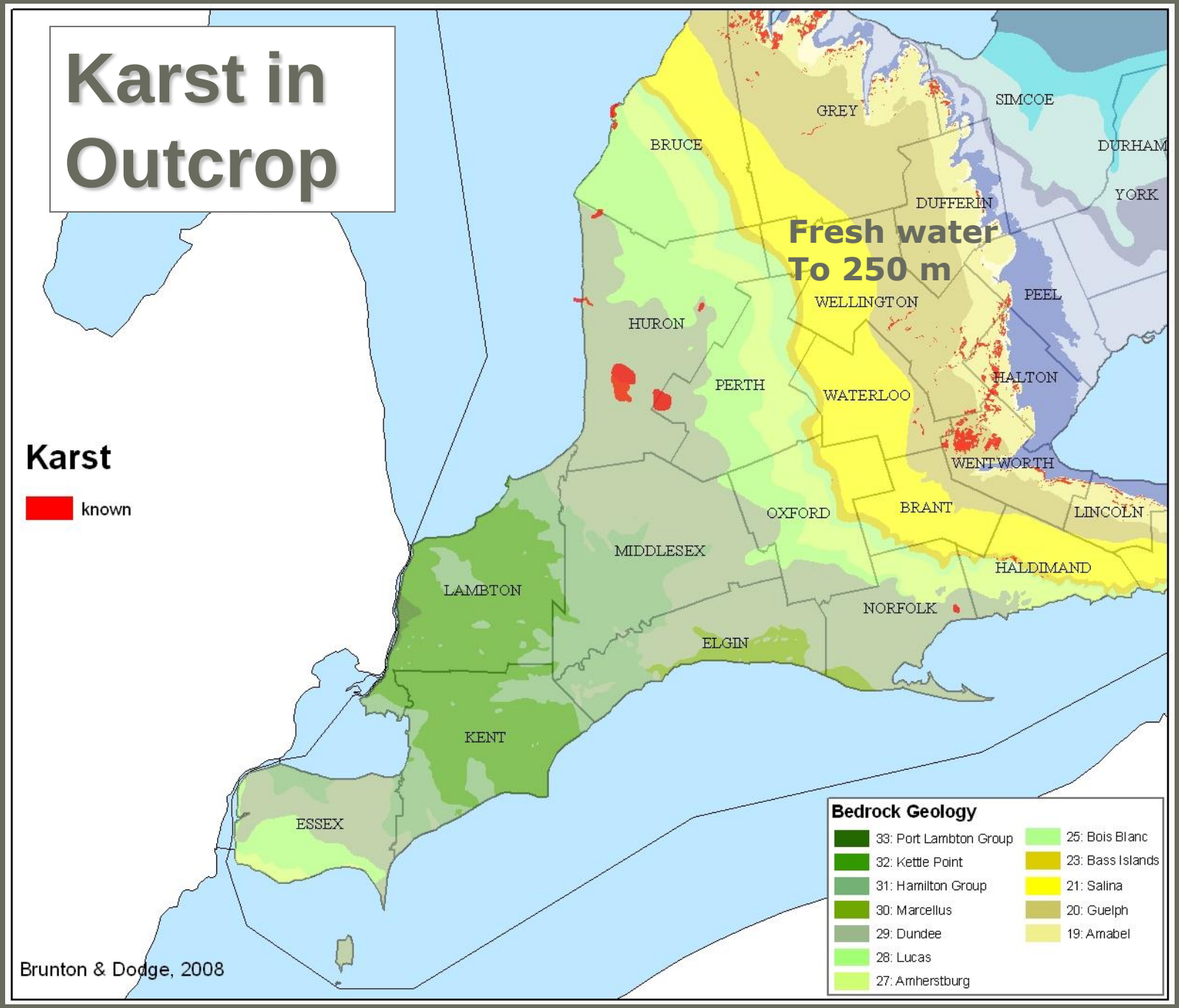

Kettle Point


Whirlpool Formation, Niagara River

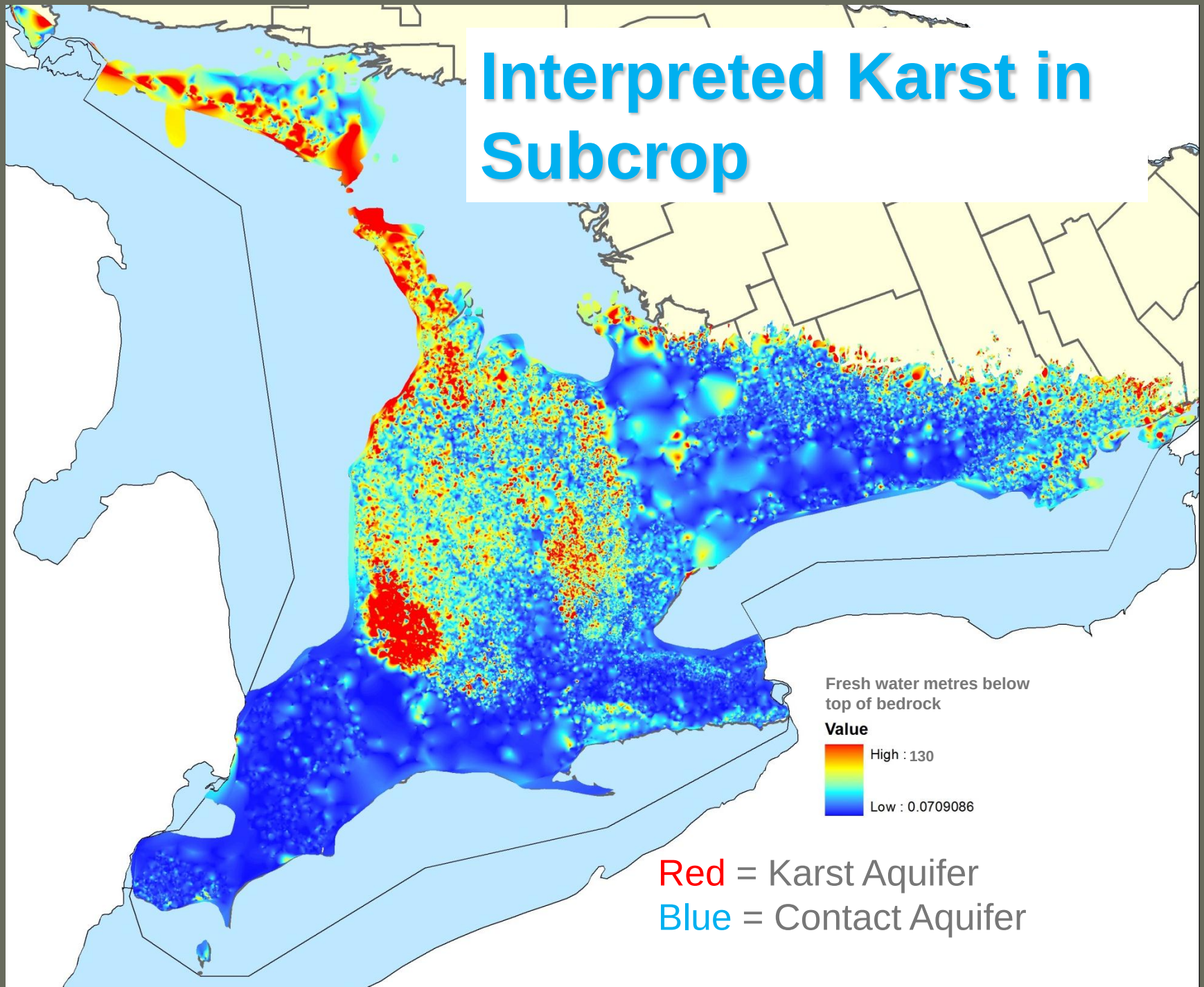

Goat Island-Gasport (Amabel) dolostone, Bruce peninsula

3. Karst Aquifer System

- Fresh water aquifers in karst-influenced carbonate and evaporite bedrock near present day surface
- Local extent, complex, within outcropping bedrock or beneath shallow drift
- Extend as deep as 250 metres below surface

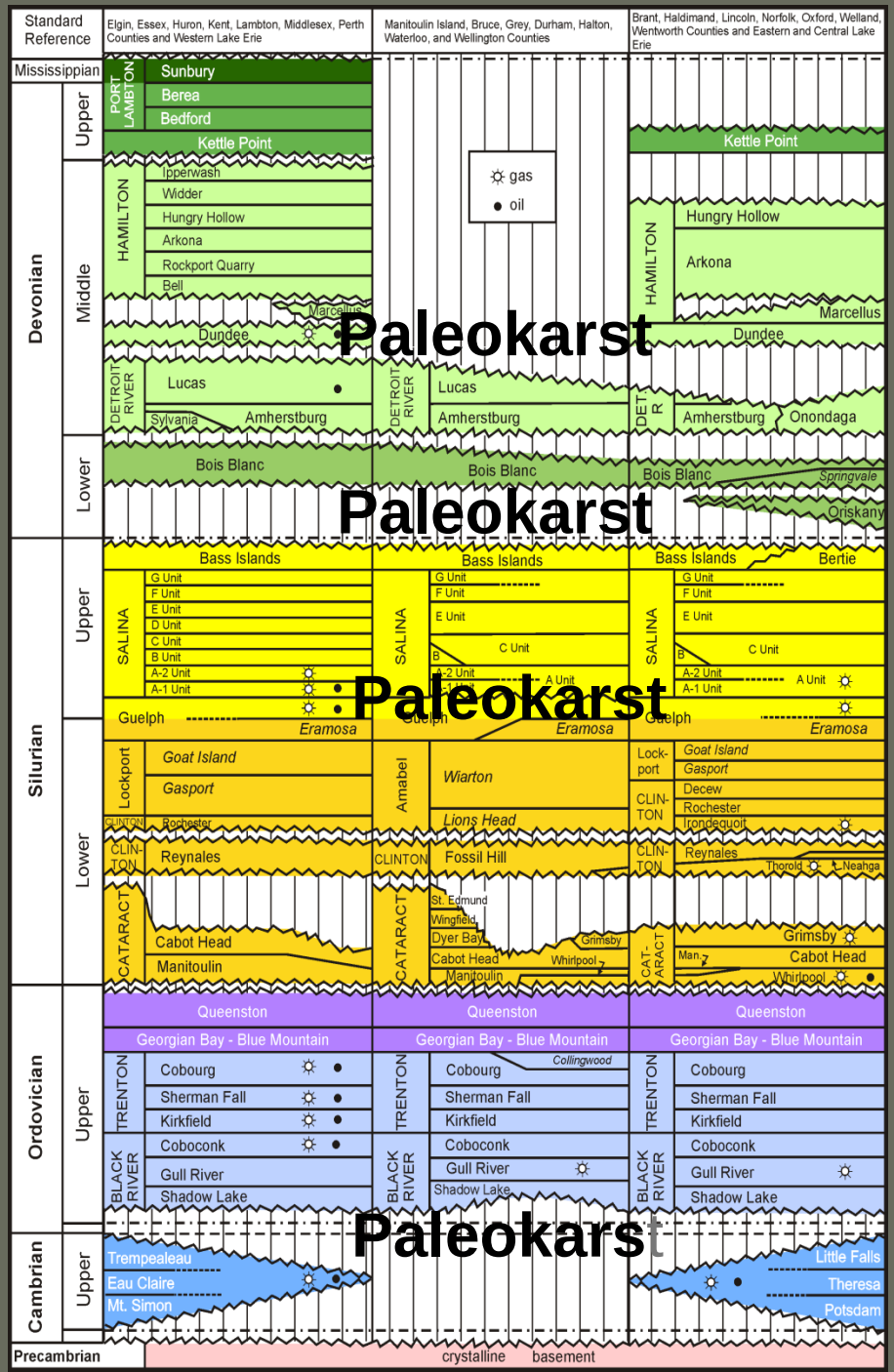

Karst in Outcrop
Fresh water To 250 m
Karst
known
GREY
SIMCOE
BRUCE
DURHAM
YORK
DUFFERIN
PEEL
WELLINGTON
HURON
PERTH
WATERLOO
HALTON
WENTWORTH
OXFORD
BRANT
LINCOLN
MIDDLESEX
HALDIMAND
LAMBTON
NORFOLK
ELGIN
KENT
ESSEX
Bedrock Geology
33: Port Lambton Group
32: Kettle Point
31: Hamilton Group
30: Marcellus
29: Dundee
28: Lucas
27: Amherstburg
25: Bois Blanc
23: Bass Islands
21: Salina
20: Guelph
19: Amabel
Brunton & Dodge, 2008

Interpreted Karst in Subcrop



Intermediate to Deep Regime

- All regional aquifers associated with paleokarst at unconformities
- Thin, regional extent
- Most deep bedrock formations are aquitards

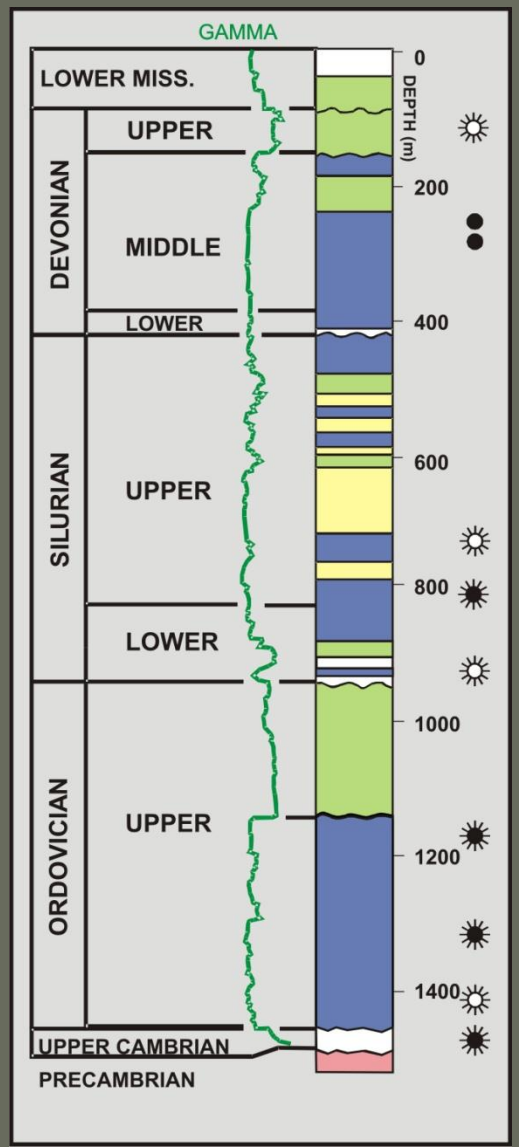


Intermediate Regime

4. Sulphur Water Aquifer System

- Confined to unconfined aquifers of brackish to saline sulphur water separated by thick aquitards
- Anoxic conditions
- Moderate salinities – 563 to 43,600 mg/l TDS
- pH 7.24 to 11.7
- Oxygen/hydrogen isotopes indicate water is meteoric- both modern and Pleistocene
- Na-Ca-Cl, Ca-Na-SO4

Sulphur Water Aquifers



Lucas & Dundee

Bass Islands

Guelph

30-450 m

Sulphur Water

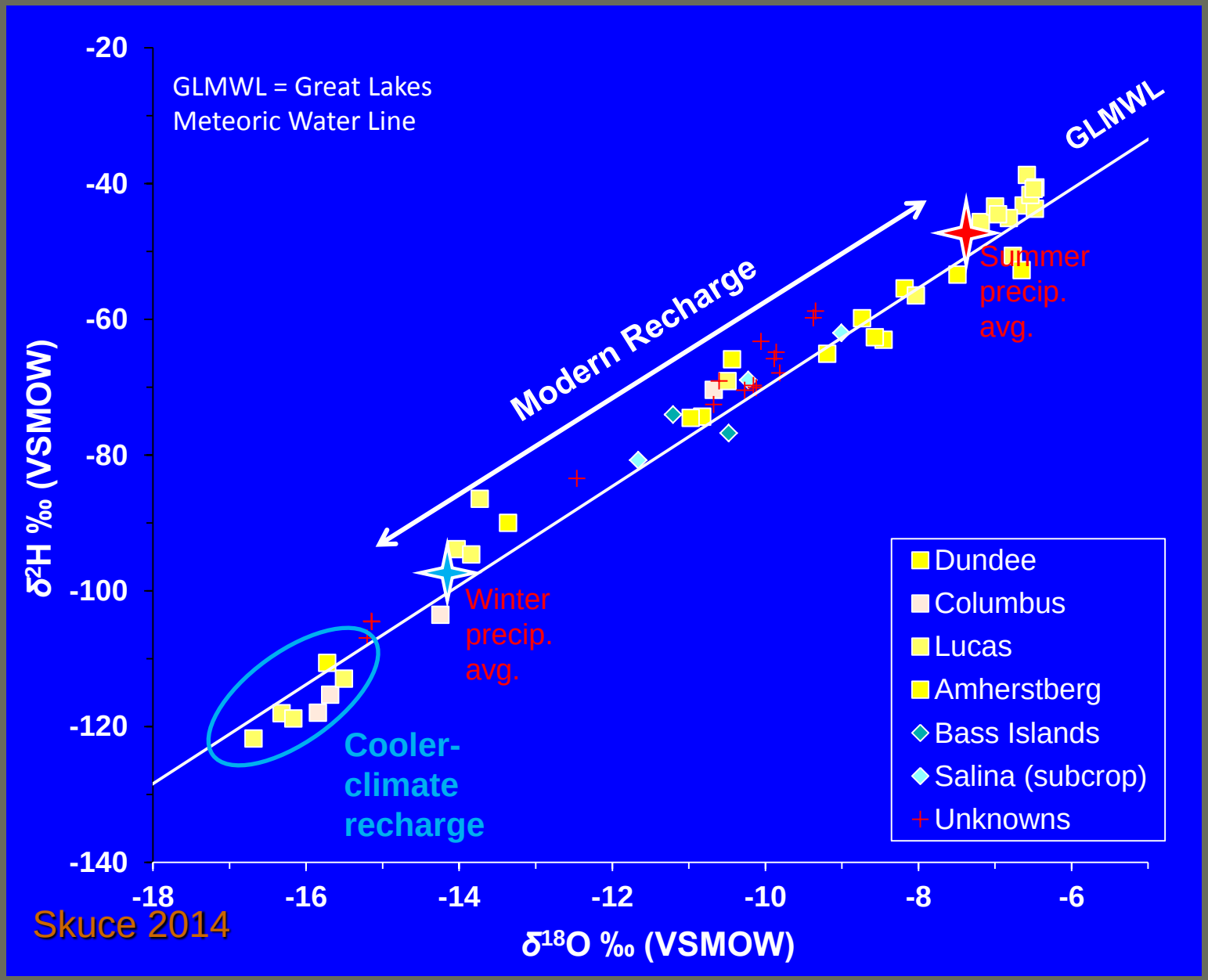
OIL
GAS
OIL & GAS

SANDSTONE
SHALE
CARBONATE
SALT
METAMORPHIC

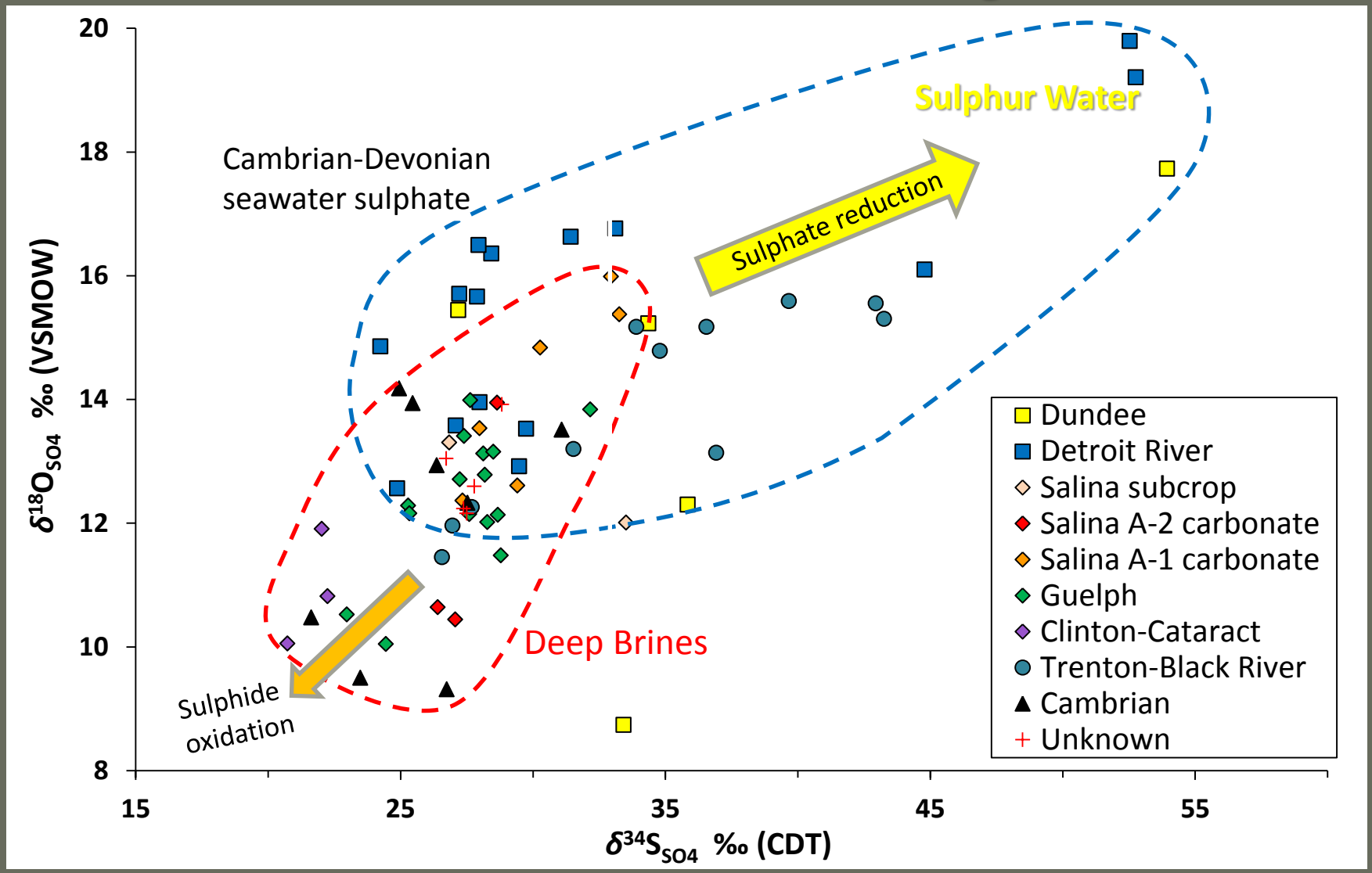
Lucas Sulphur Water Discharge
Port Dover Quarry

Lucas Sulphur Water Discharge: MacGregor Quarry

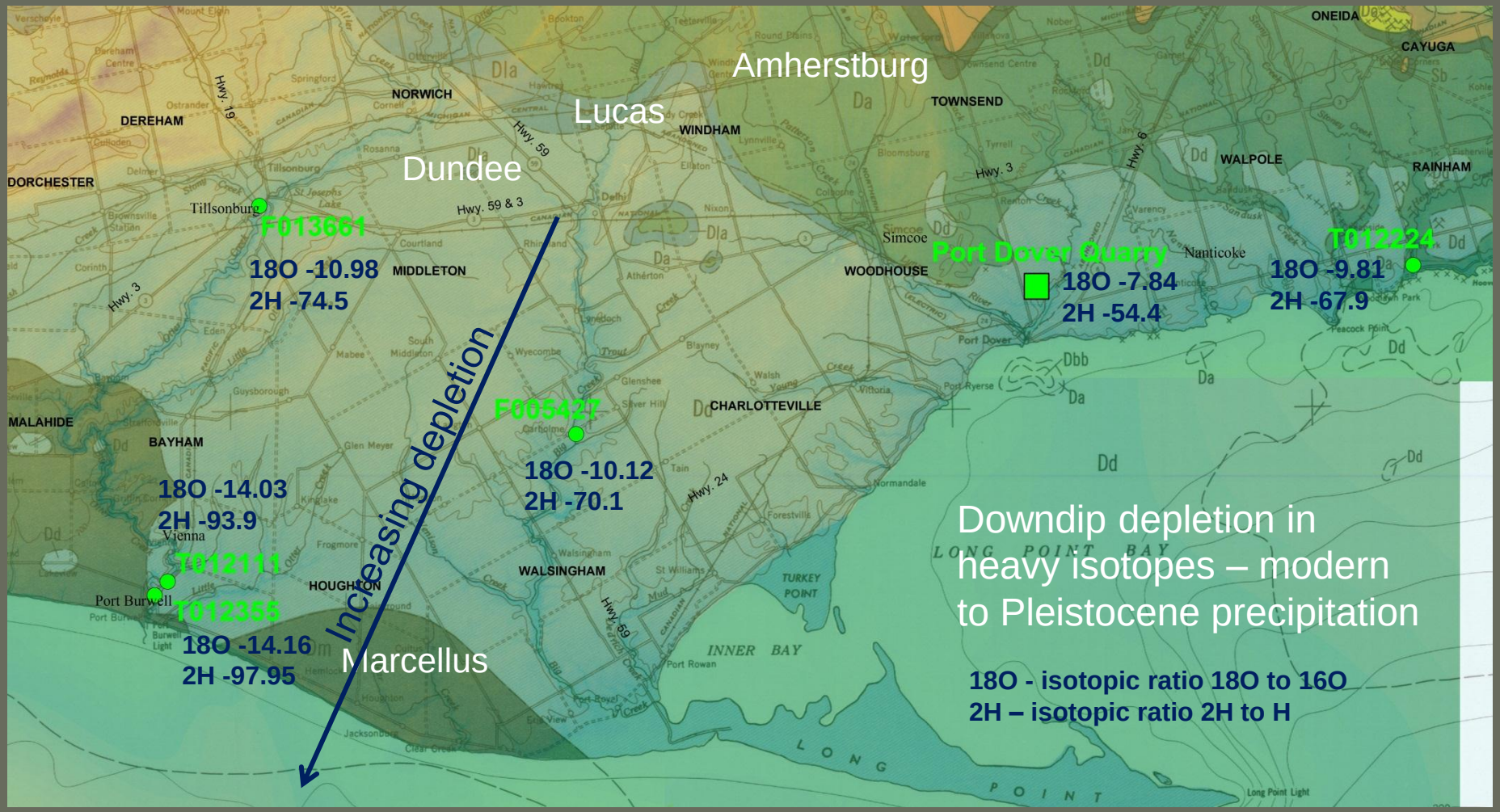
Isotopic Ratios – Sulphur Water



Sulphate Isotopes – evidence of microbial activity



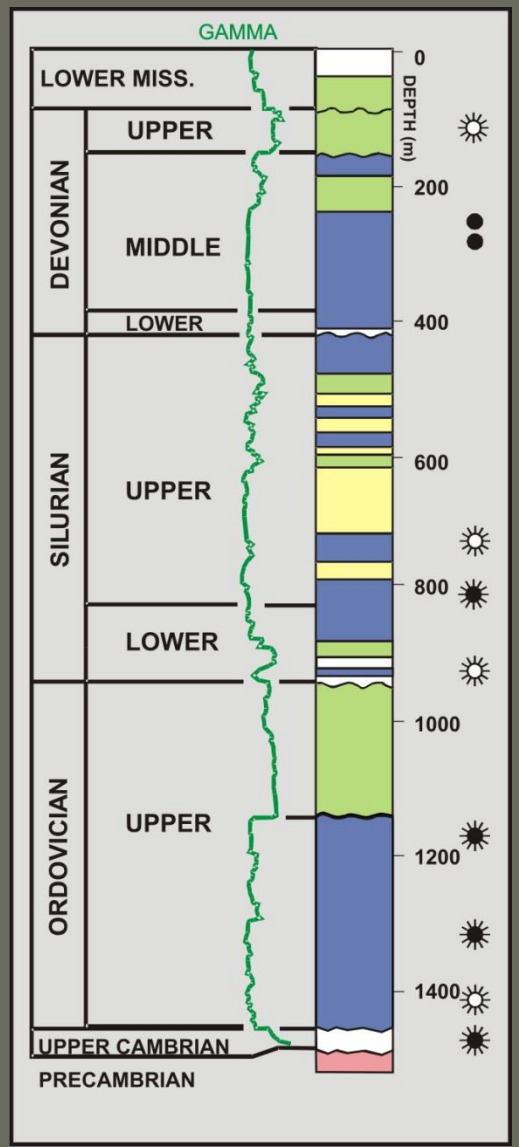
Deep incursion of Pleistocene Water

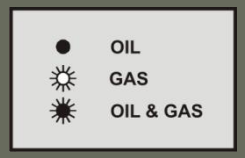


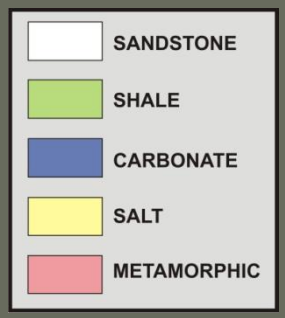
5. Deep Brine System

- Hydrocarbon reservoirs and thin confined regional brine aquifers, separated by thick aquitards
- No flow
- Anoxic
- Extreme salinities – 134,000 to 515,000 mg/l TDS (Soy sauce contains 140-180,000 mg/l)
- Na-Ca-Cl, Ca-Na-Cl
- Laboratory-measured pH 3 to 7
- Isotopic compositions indicate water is evaporatively concentrated seawater 300+ million years old (Skuce, 2014, NWMO, 2011)

Deep Saline Aquifers







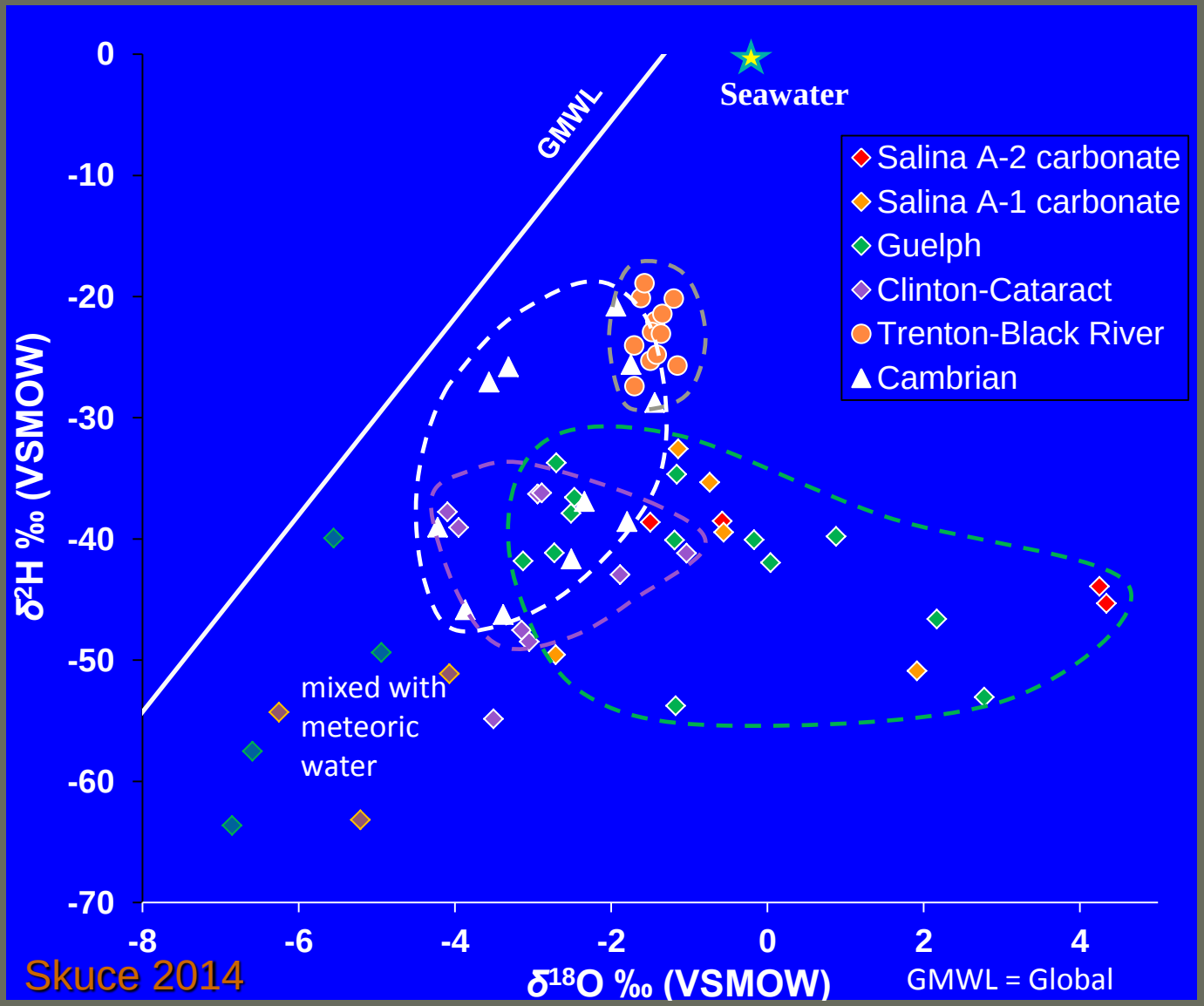
Bass Islands–Bois Blanc

Guelph Formation

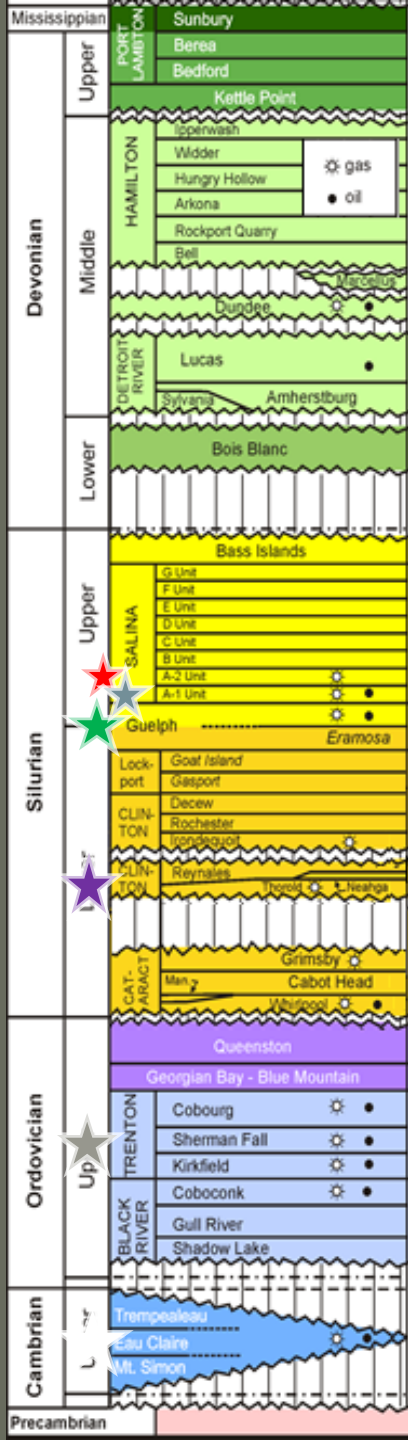
200+ m

Cambrian

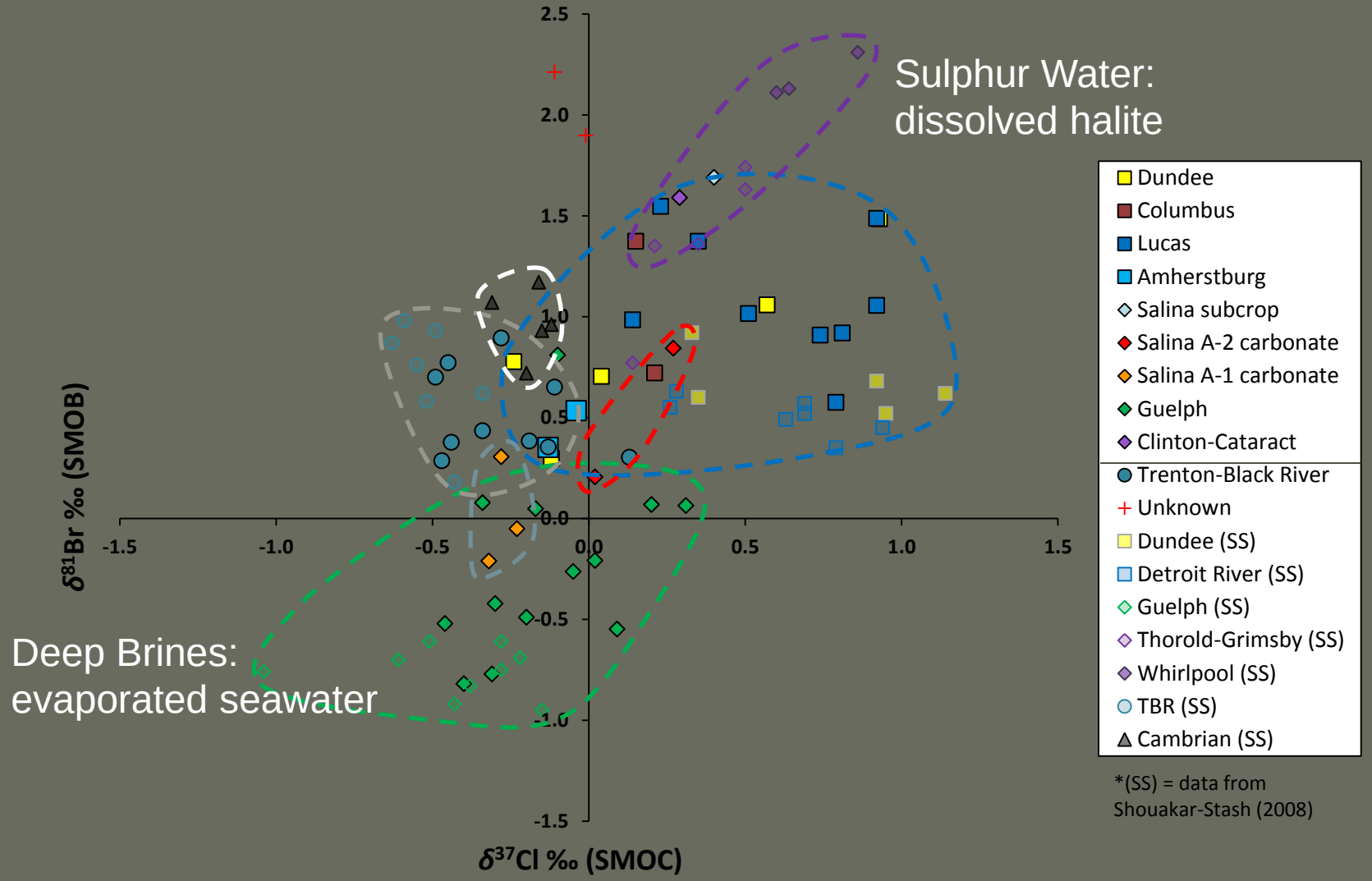
Isotopic Ratios - Deep Brine



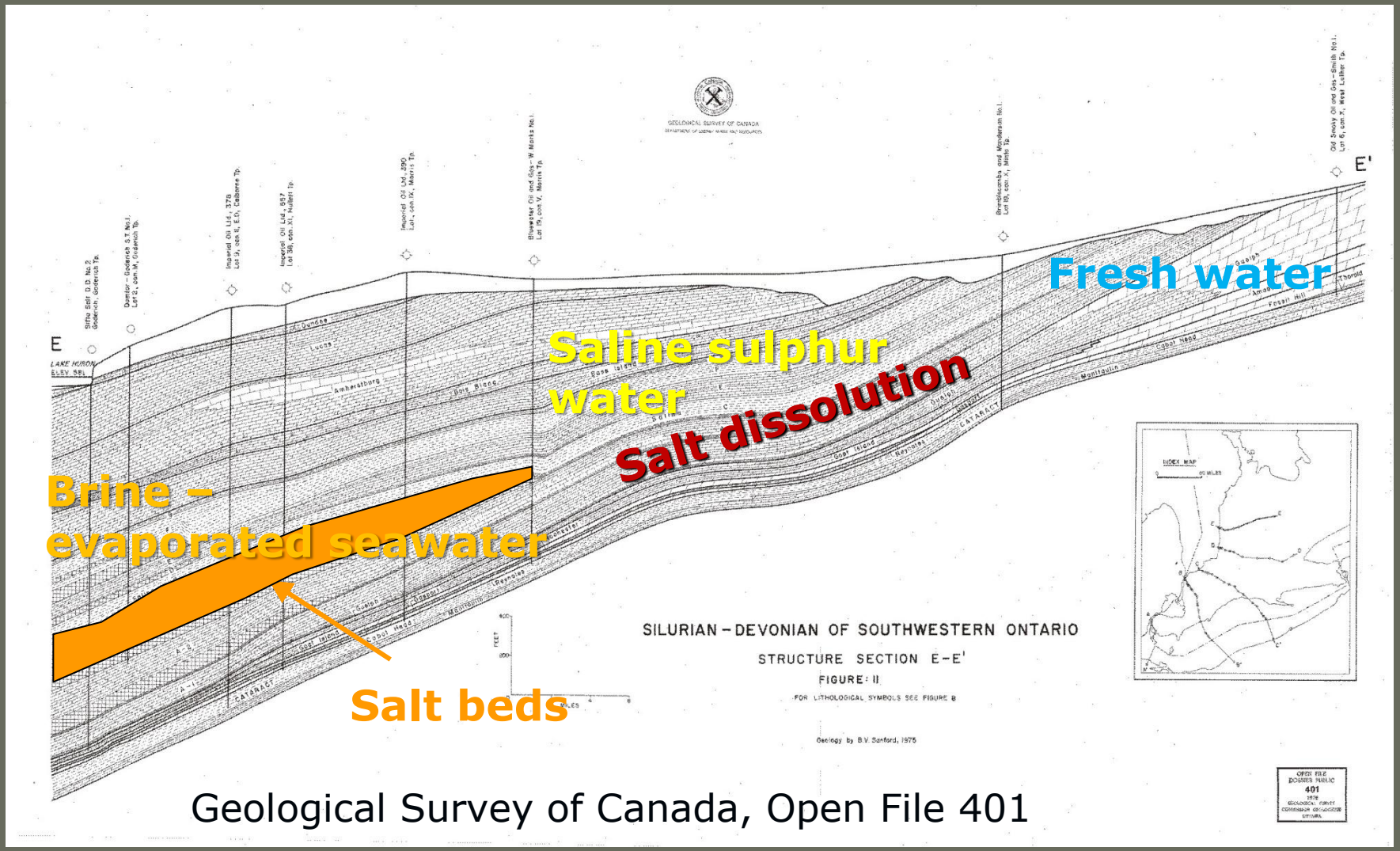
GMWL = Global Meteoric Water Line



Cl and Br isotopes – origin of dissolved salt

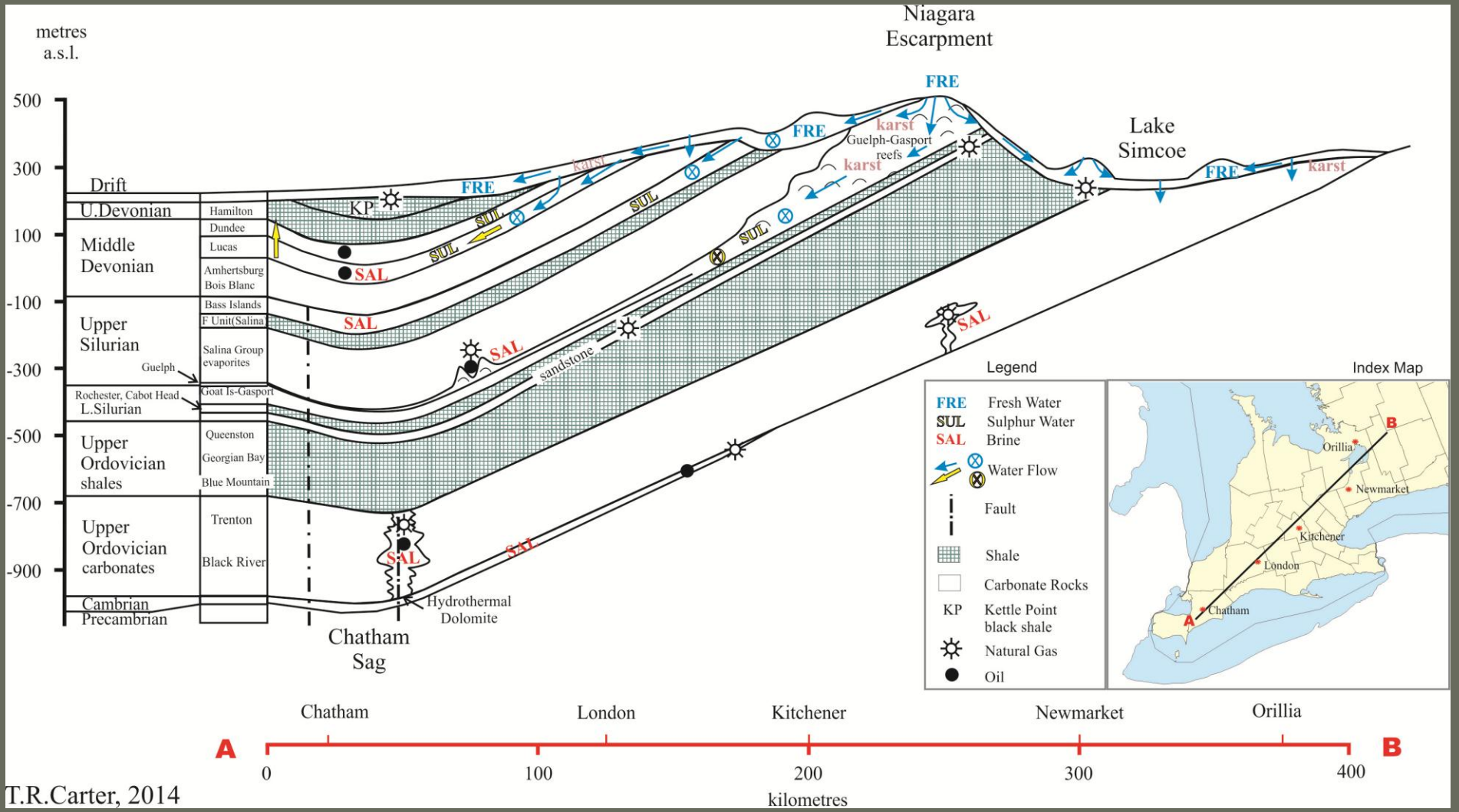


Origin of Dissolved Salt



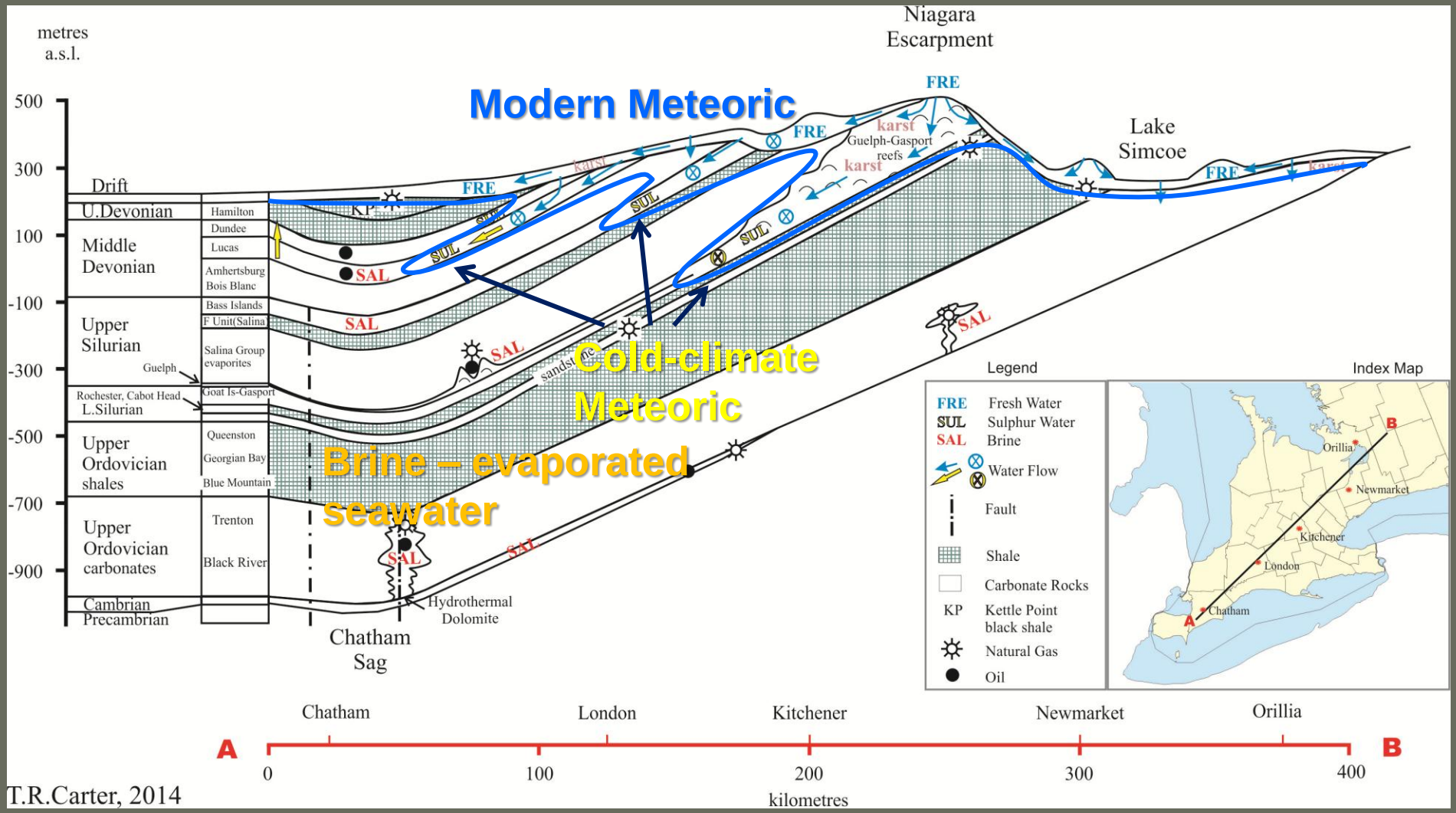
Geological Survey of Canada, Open File 401

Geological Groundwater Model – before isotope data



T.R.Carter, 2014

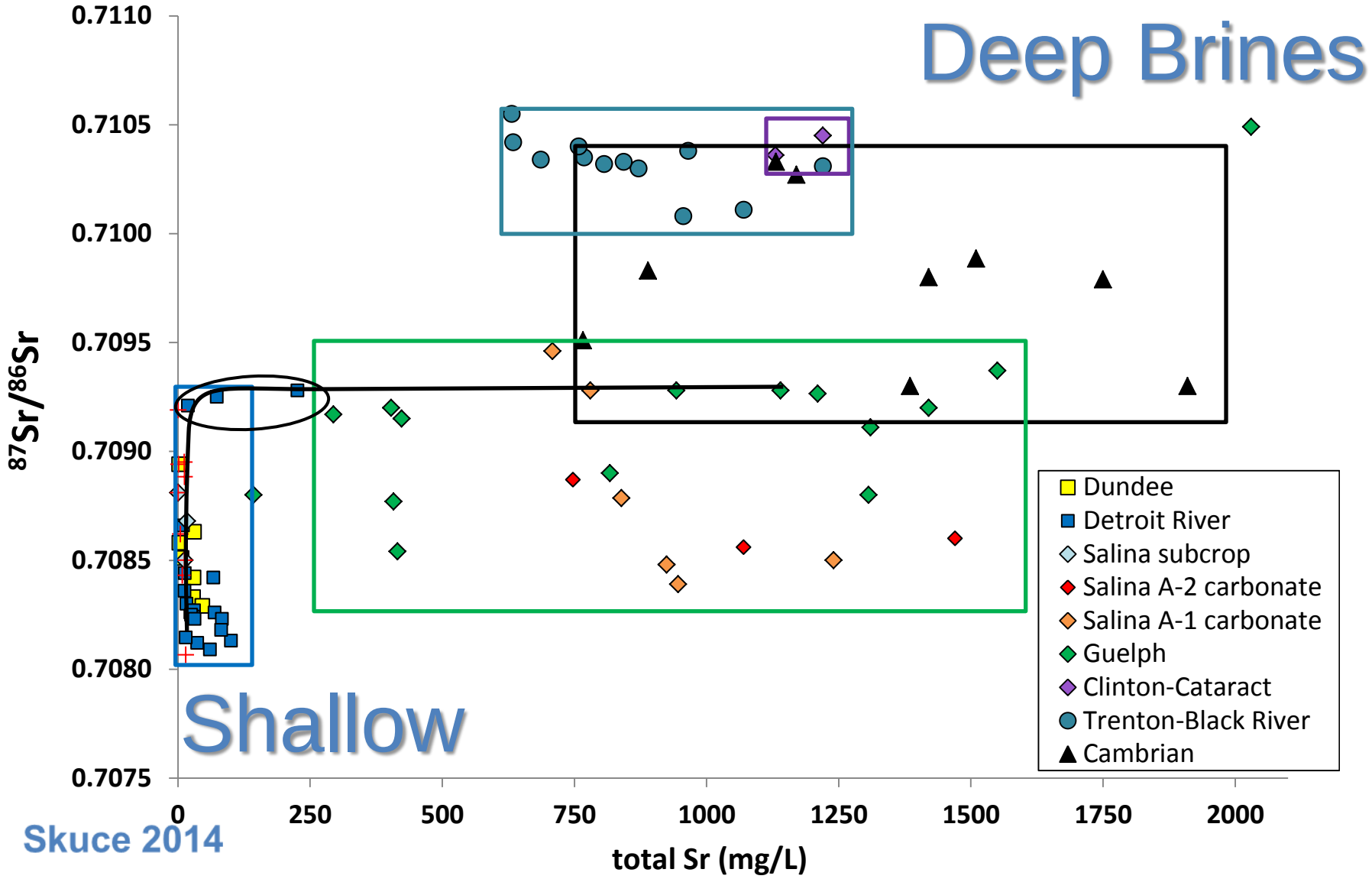
Geological Groundwater Model - with isotope data



Considerations for Drilling and Plugging

- Vertical zonation of water type – must be isolated from each other
  - Shallow fresh water - meteoric
  - Intermediate sulphurous saline water – meteoric with dissolved salt from bedrock
  - Deep brine – evaporatively concentrated seawater
- Fresh water up to 130 metres below top of bedrock in karst regions
- Regional fresh water aquifer at interface between drift and bedrock
- Hazards
  - Artesian sulphur water flow in valleys north of Lake Erie
  - Regional sulphur water zone at 30 to 450 metres
  - Locally incompetent bedrock in Lucas
  - Loss of circulation in shallow karst

Strontium Isotopes



Skuce 2014