SÉQUESTRATION GÉOLOGIQUE DU CO_2
CHAIRE DE RECHERCHE
INRS
Université d'avant-garde

Basin-scale assessment for CO_2 storage prospectivity in the Province of Québec, Canada

Michel Malo and Karine Bédard

6th Trondheim CCS Conference, Norway

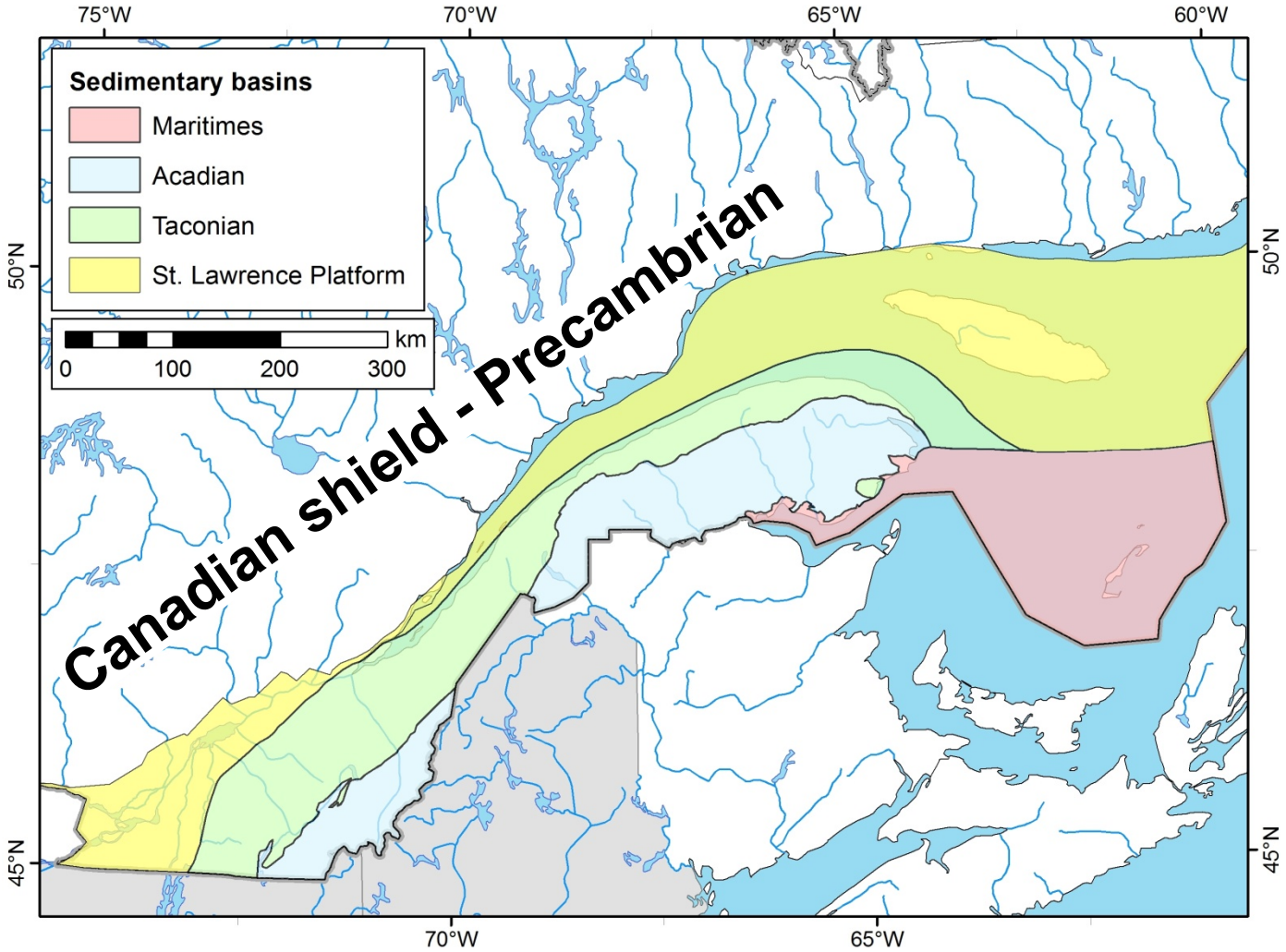
June 15, 2011

Centre - Eau Terre Environnement

INRS
Université d'avant-garde

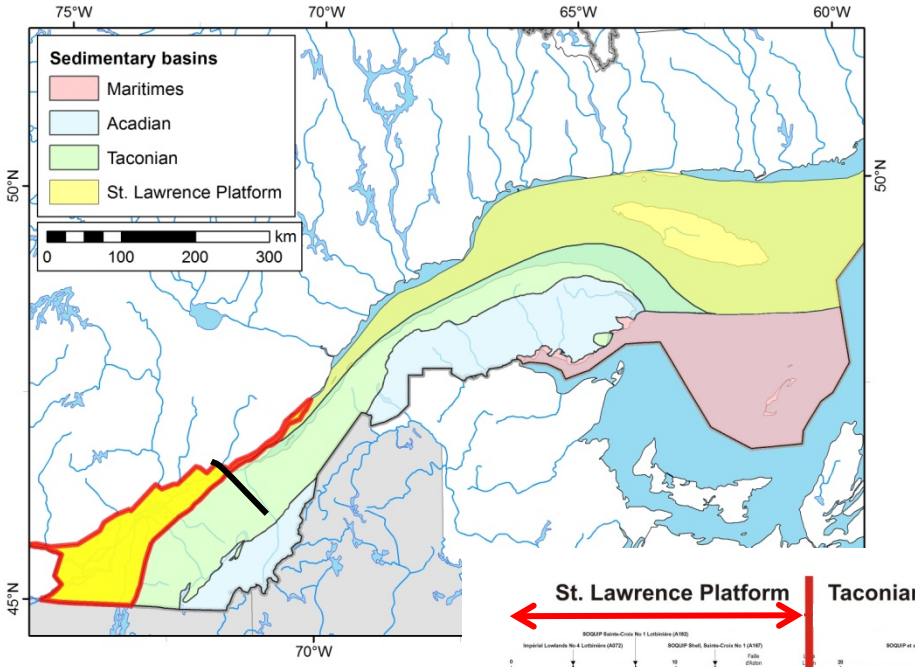
The Province of Québec in Canada

Paleozoic sedimentary basins in Québec

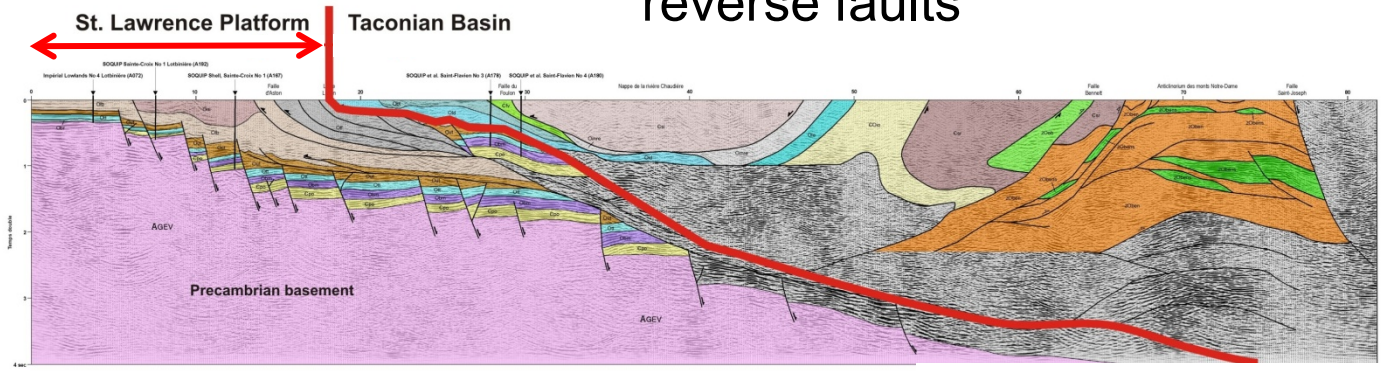


St. Lawrence platform basin

St. Lawrence Lowlands sub-basin (Cambrian to Upper Ordovician)



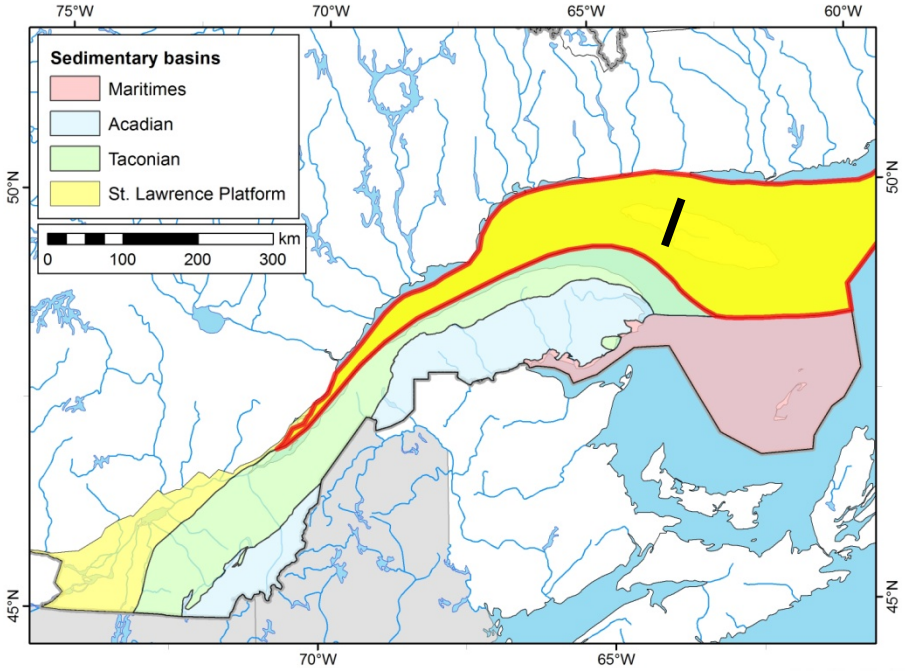
- Complete plateform sequence
- From the base to the top:
  - Basal sandstone, dolomite, carbonate, shale and turbidite of the foreland basin
- Limited faulting
  - Synsedimentary normal faults re-activated as high-angle reverse faults



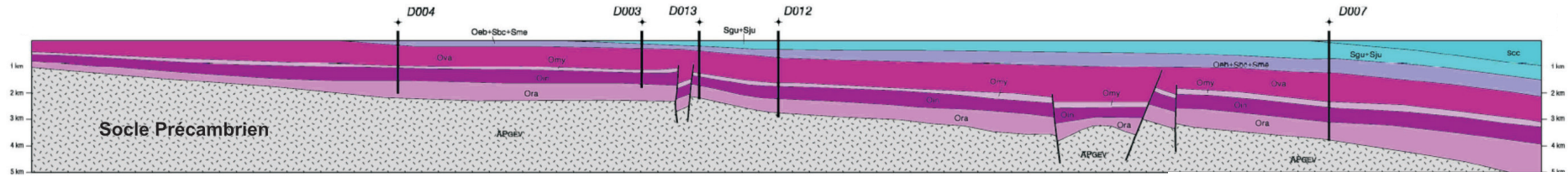
Modified from Castonguay et al. 2004

St. Lawrence platform basin

Anticosti sub-basin (Lower Ordovician to Lower Silurian)

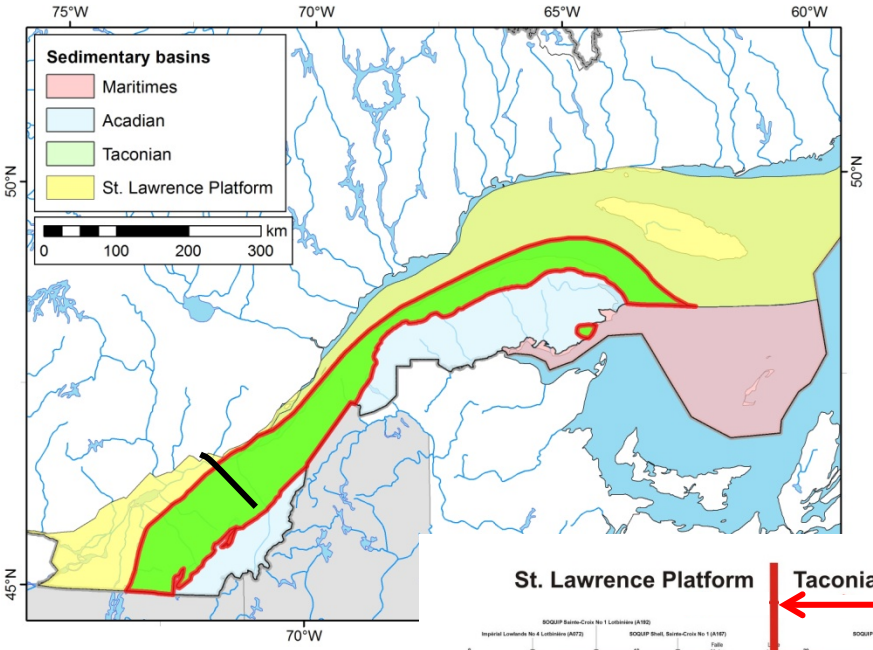


- Carbonate platform
- Limited faulting
  - syn-sedimentary normal faults

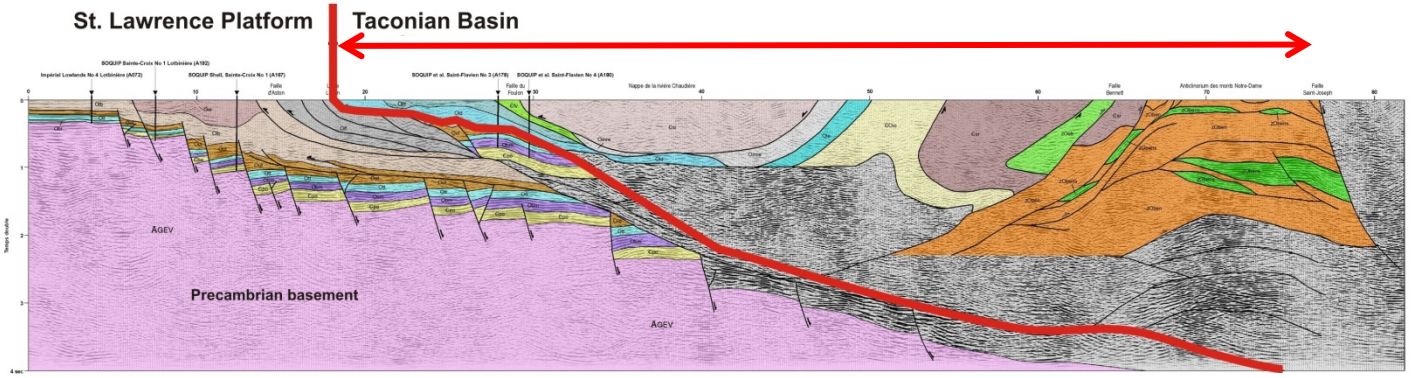


Modified from Castonguay et al. 2005

Taconian basin (Cambrian to Upper Ordovician)

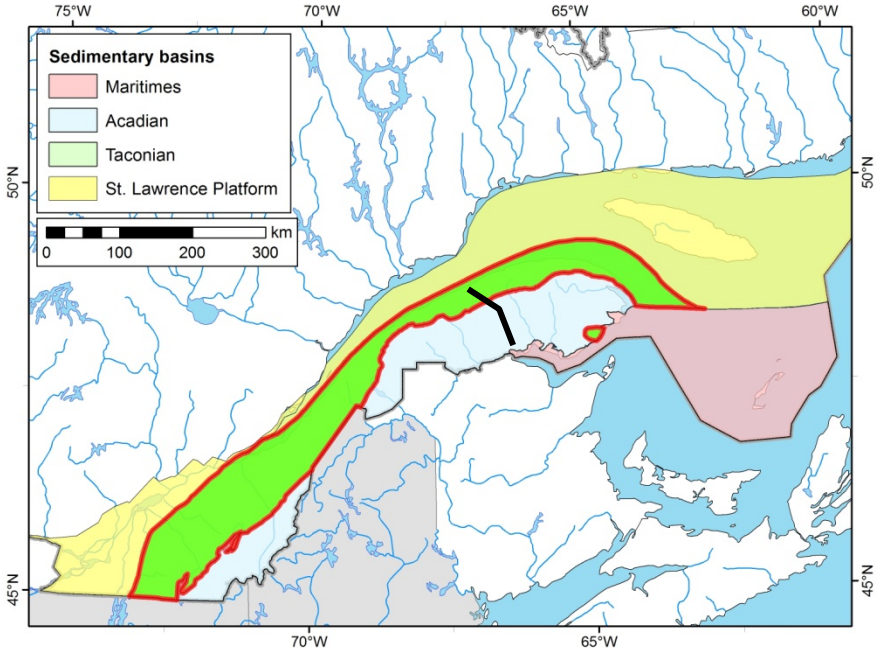


- Cambrian-Ordovician rocks of the Laurentian passive margin and Ordovician rocks of the Iapetus oceanic domain
- Highly faulted and folded during the Mid-Ordovician Taconian orogeny and superimposed Mid–Devonian Acadian orogeny

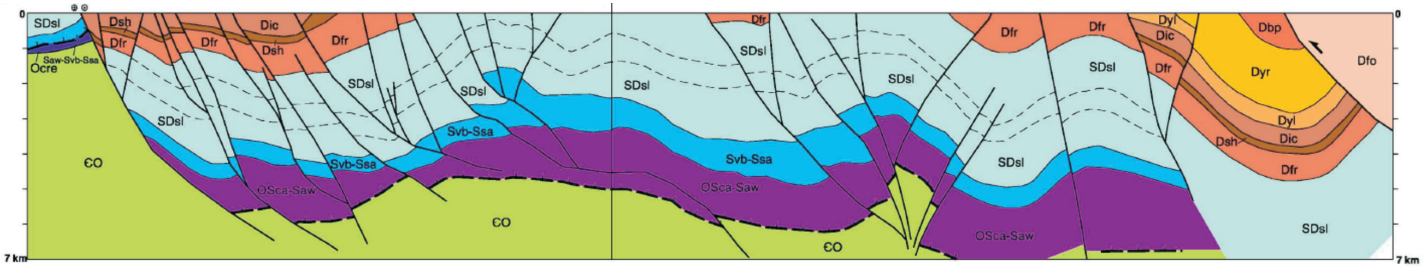


Modified from Castonguay et al. 2004

Acadian basin (Upper Ordovician to Lower Devonian

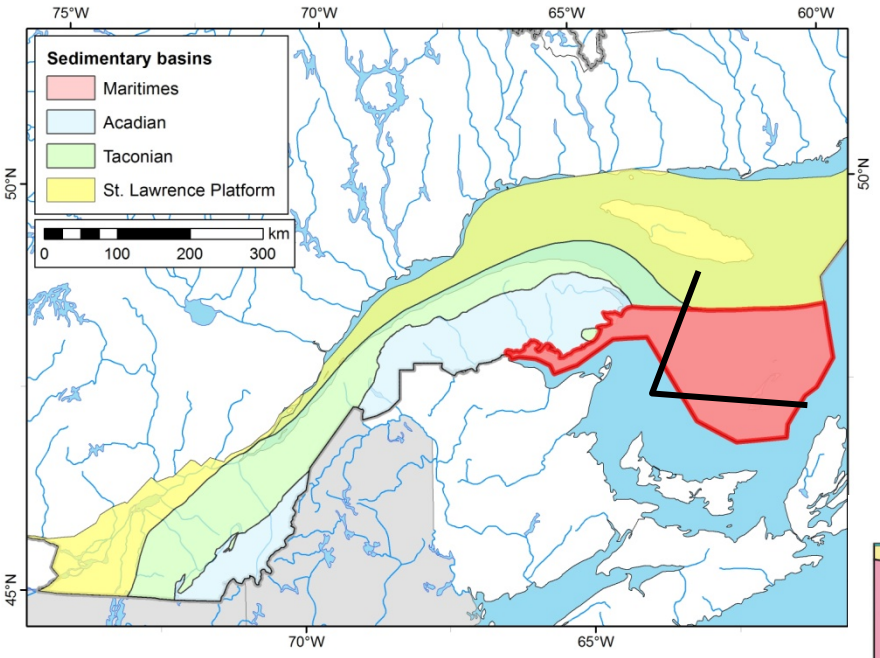


- Successor basin after the Taconian orogeny
- Moderate to extensive faulting and folding during the Mid-Devonian Acadian orogeny

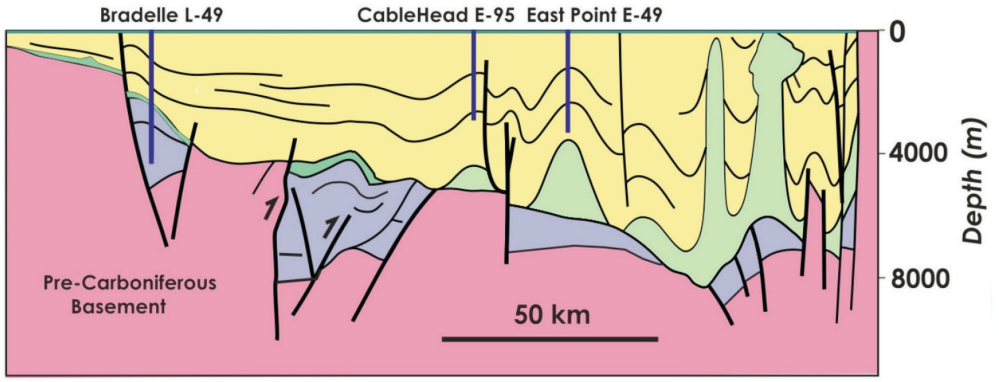


Modified from Castonguay et al. 2004

Maritimes basin (Upper Devonian to Permian)



- Successor basin after the Taconian and Acadian orogenies
- Salt domes and coal meaures
- Limited extensional and strike-slip faulting



Modified from Lavoie et al. 2009

Methodology for screening and ranking of sedimentary basins

adapted from Bachu (2003) and Kaldi and Gibson-Poole (2008)

- **15 criteria**
  - 10 geological
  - 5 pratical
- **Some criteria are not assessed – hydrogeology, pressure regime**
- **Allow objective comparison between basins**

Geological criteria

	Classes				
	1	**2**	**3**	**4**	**5**
Seismicity (tectonic setting)	Very high (e.g.: subduction zones)	High (e.g.: syn-rift)	Intermediate (e.g.: foreland)	Low (e.g.: marge passive)	Very low (e.g.: craton)
Size	Very small (<1,000 km^2)	Small (1,000-5,000 km^2)	Medium (5,000-25,000 km^2)	Large (25,000-50,000 km^2)	Very large (>50,000 km^2)
Depth	Very shallow (<300 m)	Shallow (300-800 m)	Deep (>3,500 m)	Intermediate (800-3,500 m)	
Deformation (faults & fractures)	Extensive	Moderate	Limited		
Reservoir- seal pairs	Poor	Intermediate	Excellent		
Geothermal	Warm basin (>40°C/km)	Moderate (30-40°C/km)	Cold basin (<30°C/km)		
Hydrocarbon potential	None	Small	Medium	Large	Giant
Evaporites	None	Domes	Beds		
Coal	None	Very shallow (<300m)	Deep (>800m)	Shallow (300-800m)	
Maturity	Unexplored	Exploration	Developing	Mature	Super mature

Practical criteria

	Classes				
	1	**2**	**3**	**4**	**5**
On/Off shore	Deep offshore	Shallow offshore	Onshore		
Climate	Arctic	Sub-arctic	Desert	Tropical	Temperate
Accessibility	Inaccessible	Difficult	Acceptable	Easy	
Infrastructure	None	Minor	Moderate	Extensive	
Major CO_2 sources	None	Few	Moderate	Significant	Many

Numerical values for each criteria and classes and weights assigned to the criteria

$$\sum_{1}^{15} w_i = 1$$

		$j=1$	$j=2$	$j=3$	$j=4$	$j=5$	Weight W_i
$i=1$	Seismicity (tectonic setting)	1	3	7	15	15	0.10
$i=2$	Size	1	3	5	8	10	0.06
$i=3$	Depth	1	2	6	10		0.10
$i=4$	Deformation (faults & fractures)	1	4	10			0.09
$i=5$	Reservoir- seal pairs	1	4	10			0.10
$i=6$	Geothermal	1	4	10			0.08
$i=7$	Hydrocarbon potential	1	3	7	14	21	0.04
$i=8$	Evaporites	1	2	3			0.01
$i=9$	Coal	1	2	5			0.04
$i=10$	Maturity	1	2	4	8	10	0.08
$i=11$	On/Off shore	1	5	10	15		0.11
$i=12$	Climate	1	2	4	7	10	0.04
$i=13$	Accessibility	1	3	6	10		0.04
$i=14$	Infrastructure	1	3	7	10		0.05
$i=15$	Major CO_2 sources	1	3	7	11	15	0.06

Basin suitability evaluation method

- **Each class (*j*) from each criterion (*i*) has a *score***
  - $F_{i,j}$

- ***Normalized score* for each criterion**
  - P_i^k
  - Class 1 = 0
  - Class n = 1

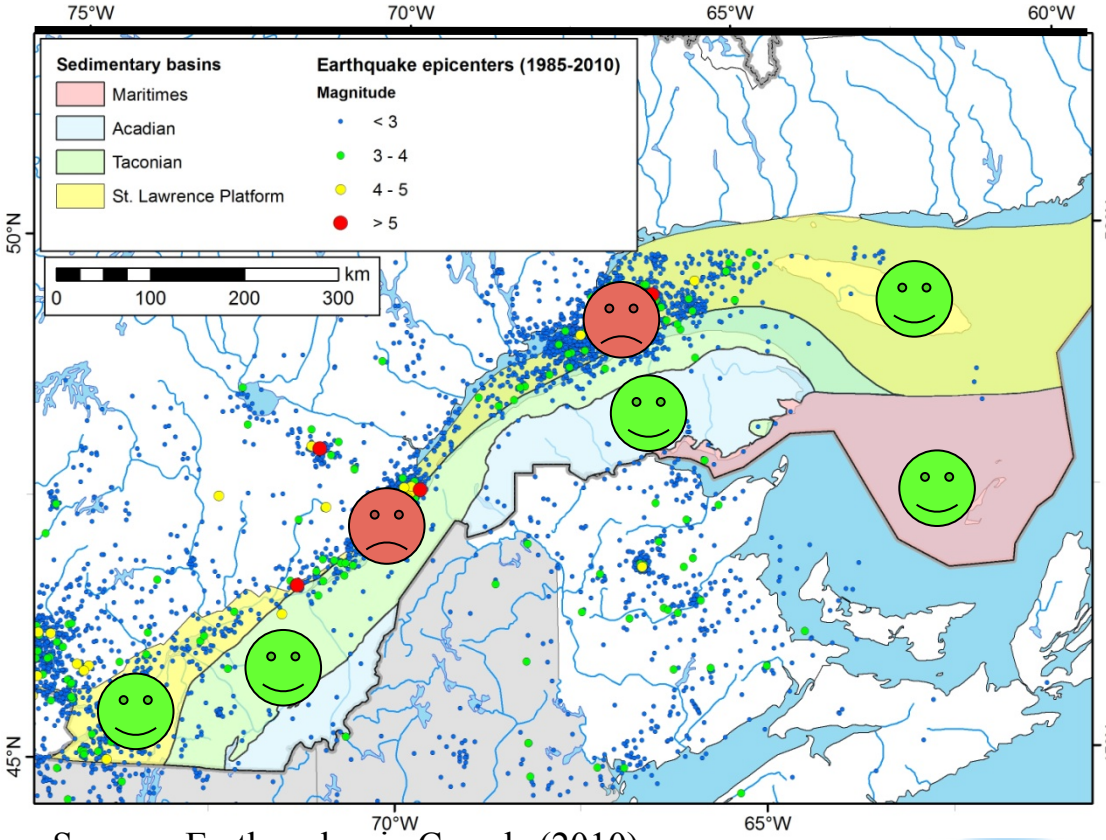
$$P_i^k = \frac{F_{i,j} - F_{i,1}}{F_{i,n} - F_{i,1}}$$

- ***General score* of each basin**
  - Weighted mean of the *normalized scores* and *weights*

$$R^k = \sum_{1}^{15} w_i P_i^k$$

Geological criteria

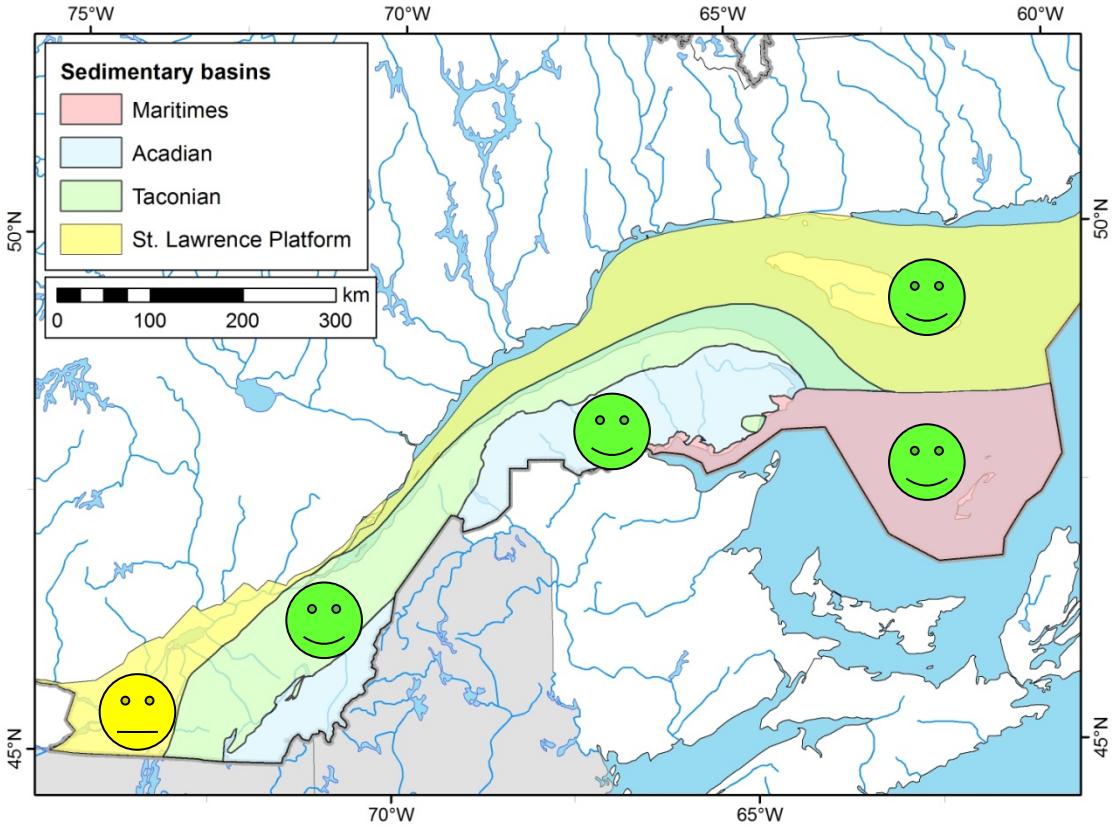
- Seismicity



Source : Earthquakes in Canada (2010)

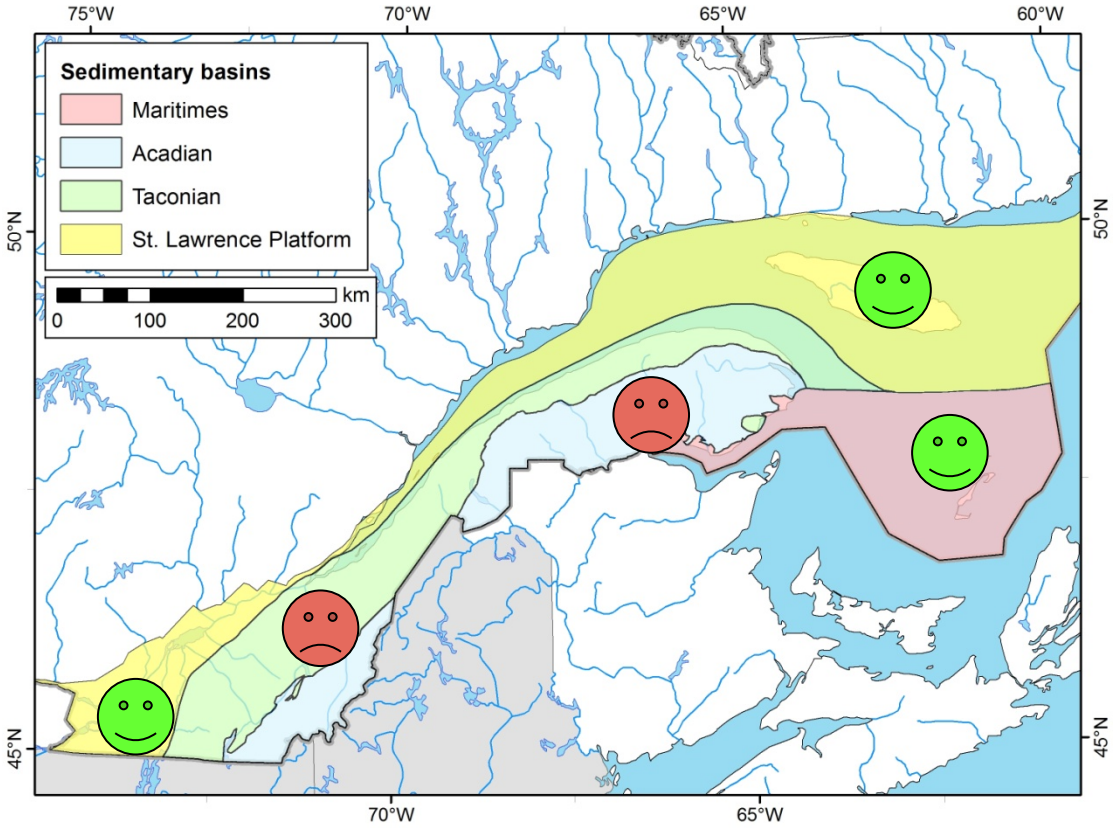
Geological criteria

- **Seismicity**
- **Size**



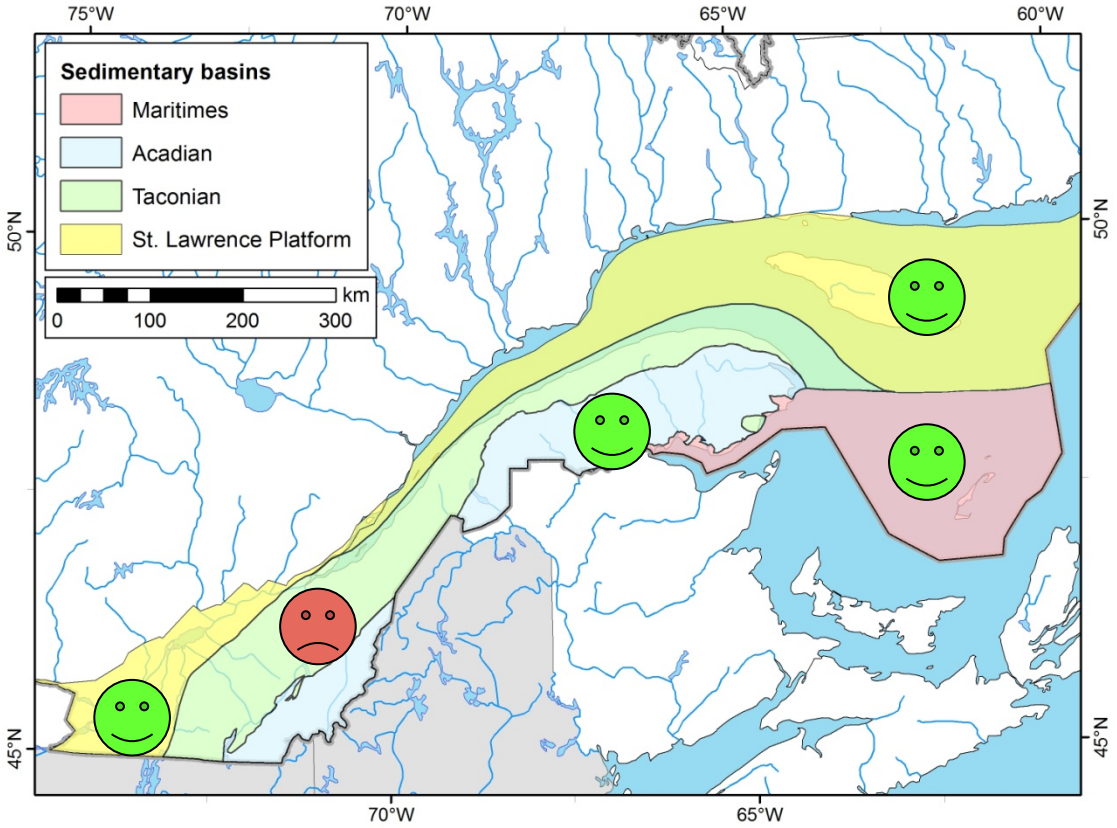
Geological criteria

- Seismicity
- Size
- Faulting
- Reservoir-seal pairs



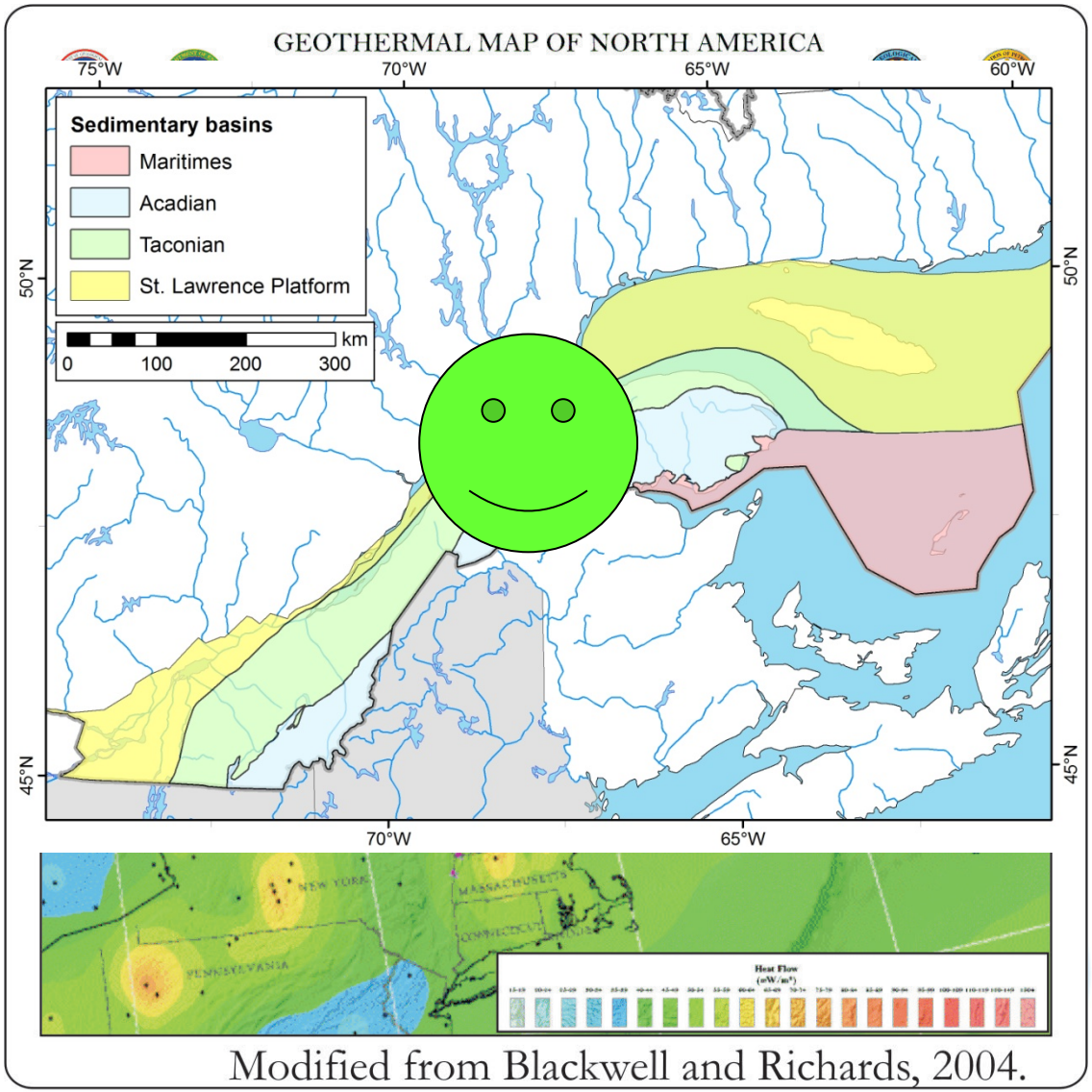
Geological criteria

- Seismicity
- Size
- Faulting
- Reservoir-seal pairs
- Depth



Geological criteria

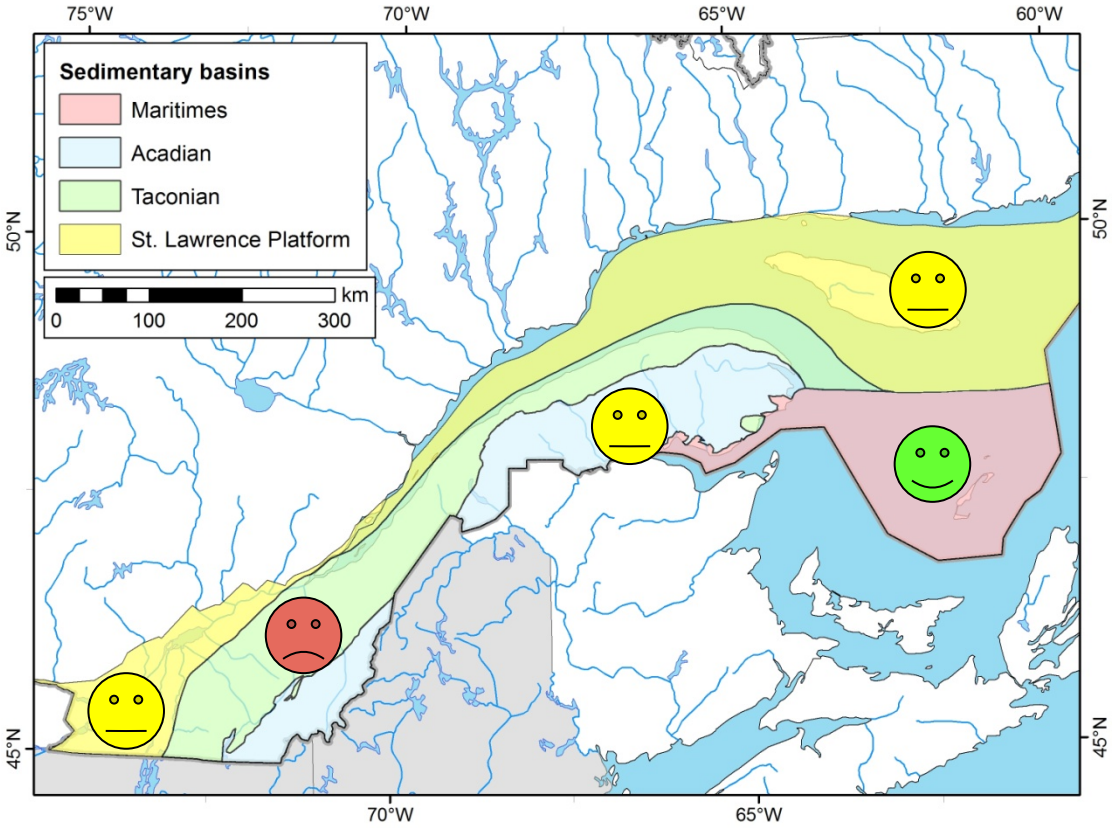
- Seismicity
- Size
- Faulting
- Reservoir-seal pairs
- Depth
- Geothermal
  - ~20°C/km in SLL
  - < 30°C/km in southern Quebec



Modified from Blackwell and Richards, 2004.

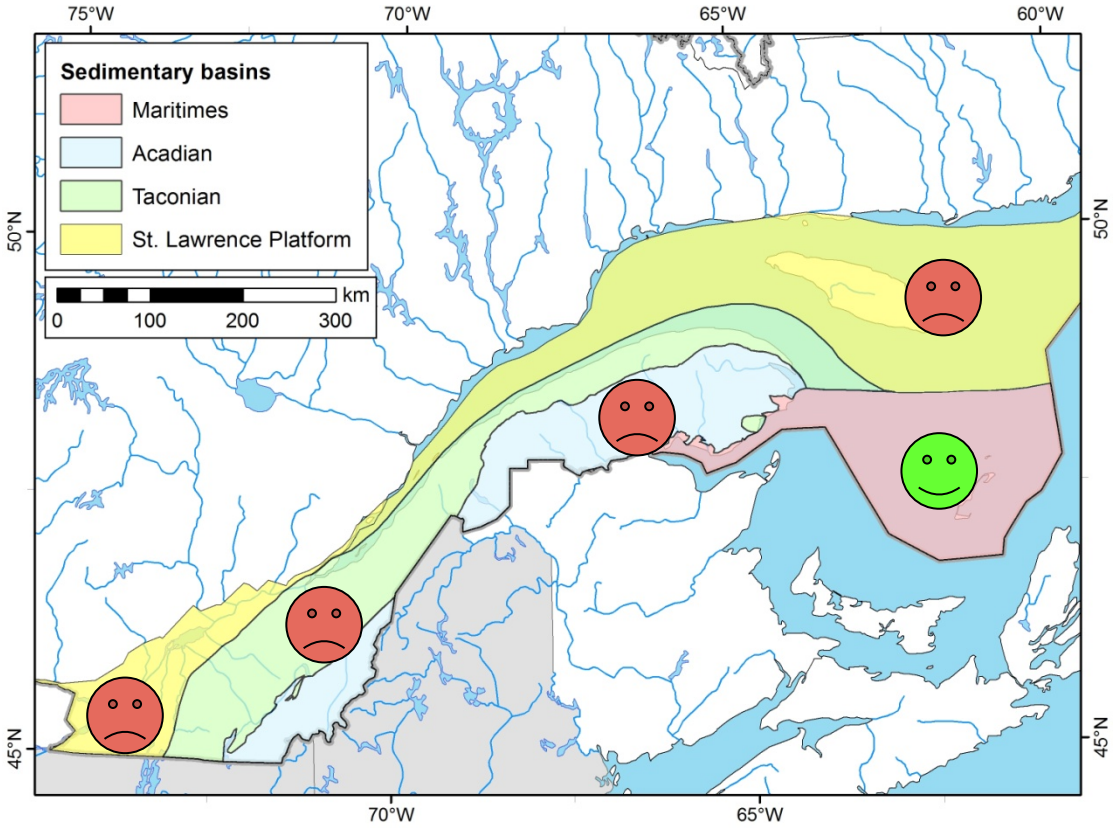
Geological criteria

- Seismicity
- Size
- Faulting
- Reservoir-seal pairs
- Depth
- Geothermal
- Hydrocarbon potential



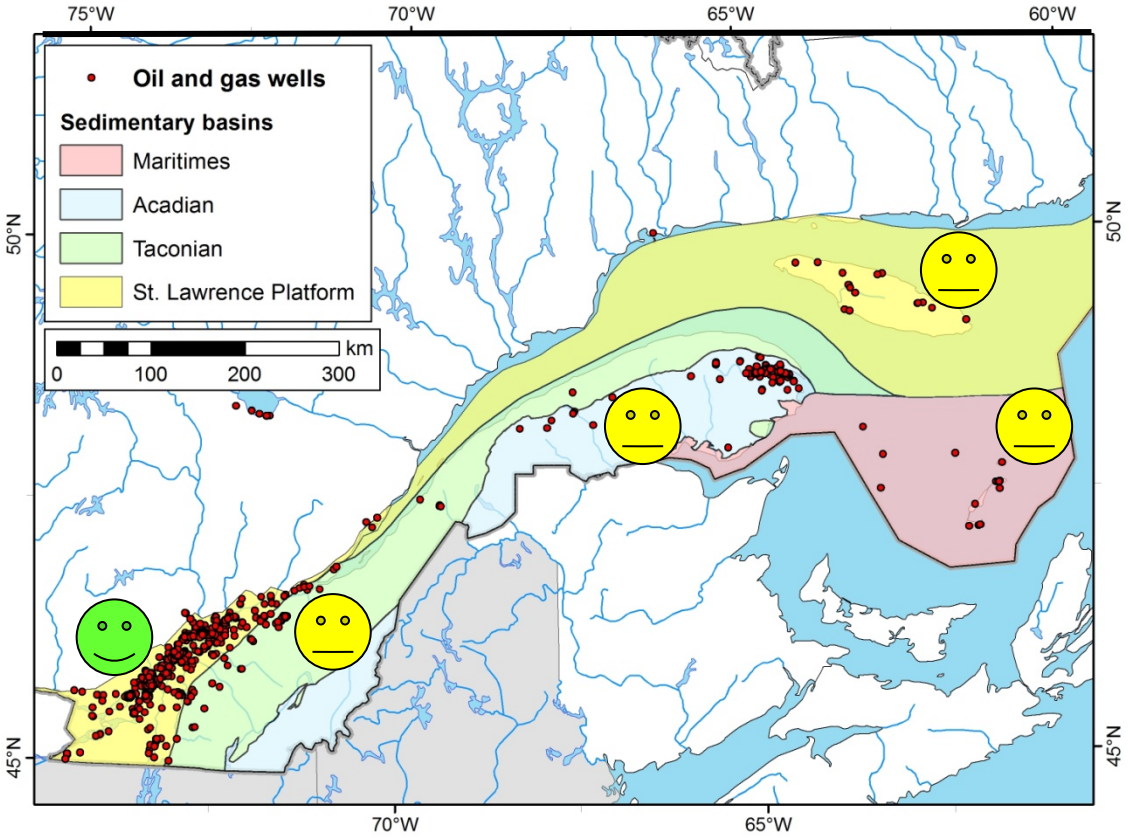
Geological criteria

- Seismicity
- Size
- Faulting
- Reservoir-seal pairs
- Depth
- Geothermal
- Hydrocarbon potential
- Evaporites
- Coal



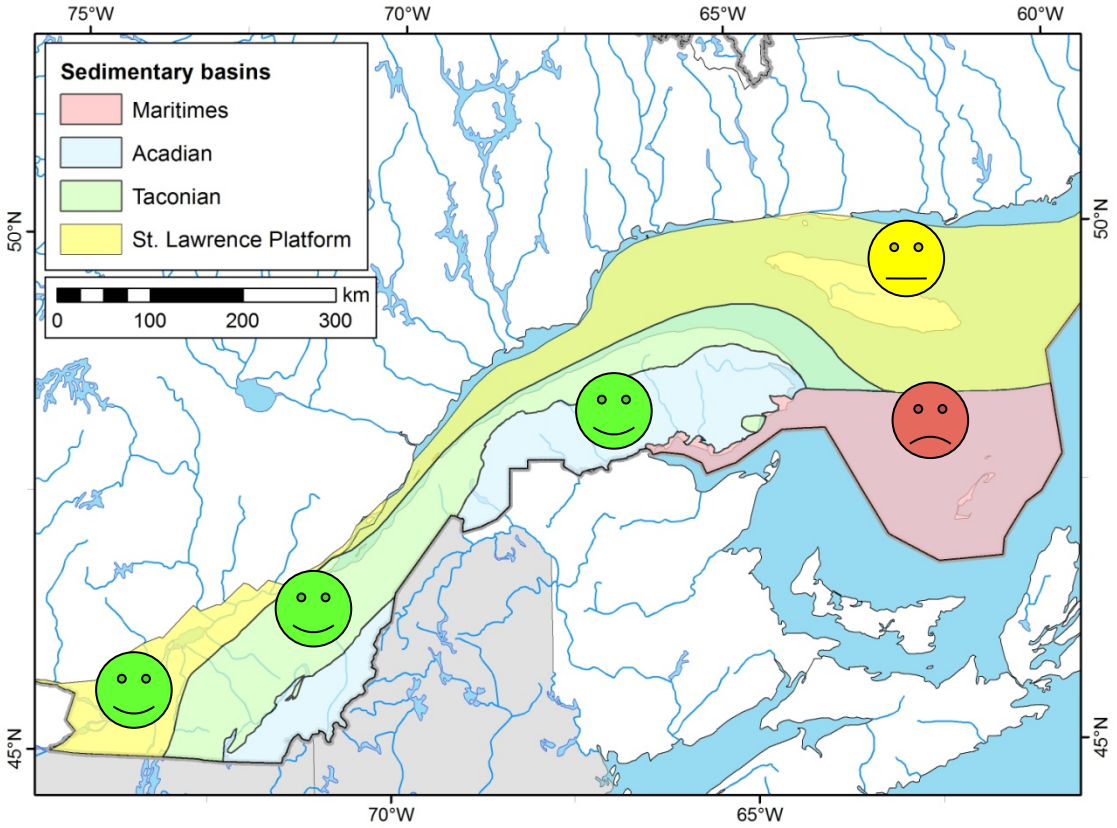
Geological criteria

- Seismicity
- Size
- Faulting
- Reservoir-seal pairs
- Depth
- Geothermal
- Hydrocarbon potential
- Evaporites
- Coal
- Maturity



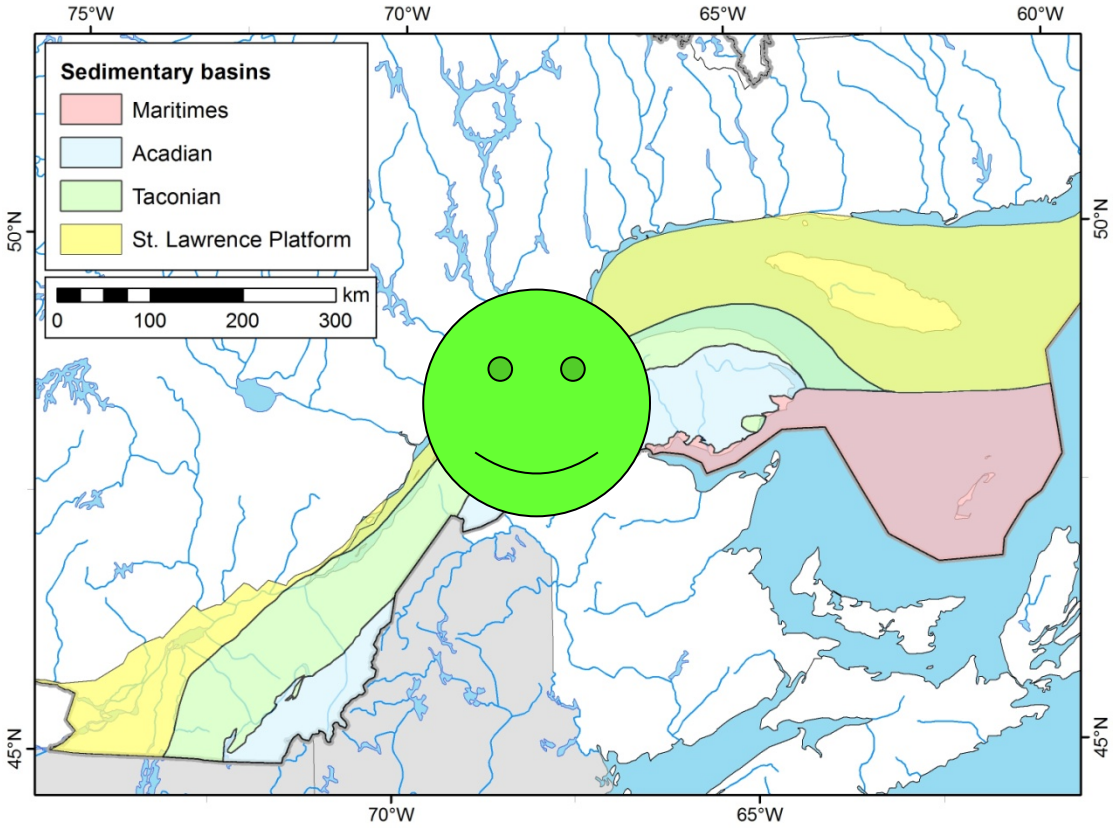
Practical criteria

- On / Off shore



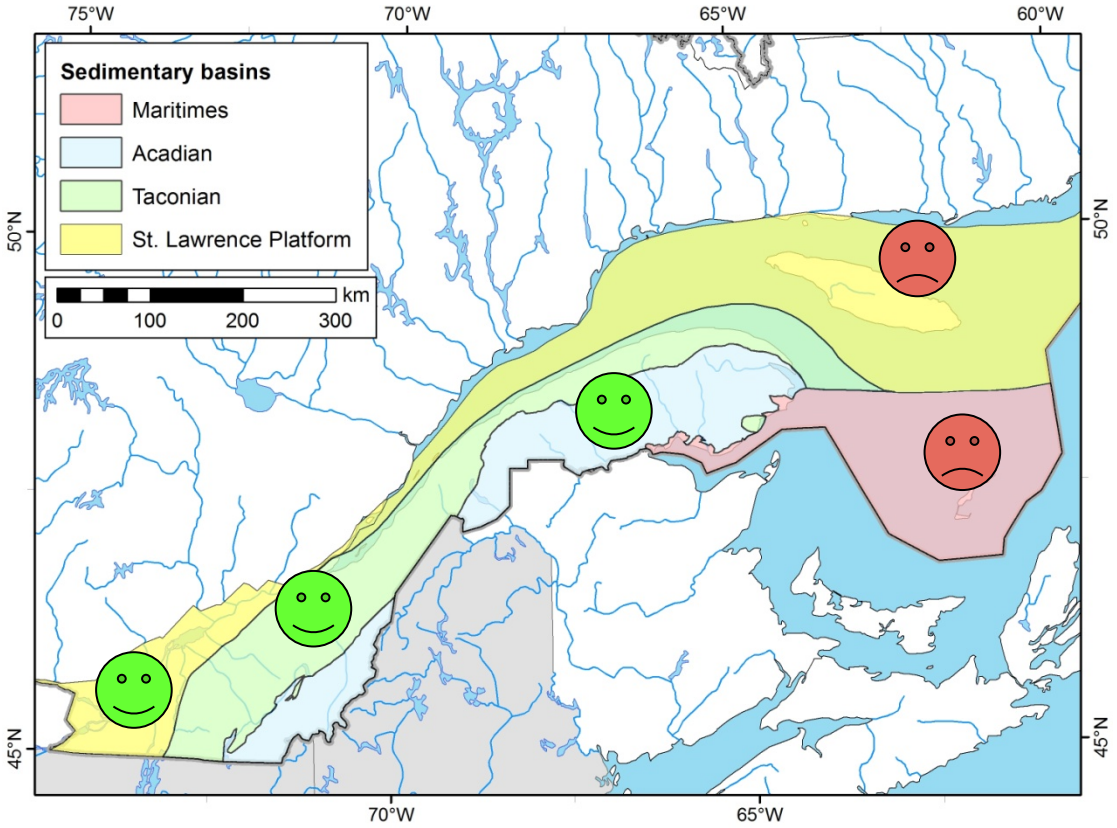
Practical criteria

- **On / Off shore**
- **Climate**
  - Temperate



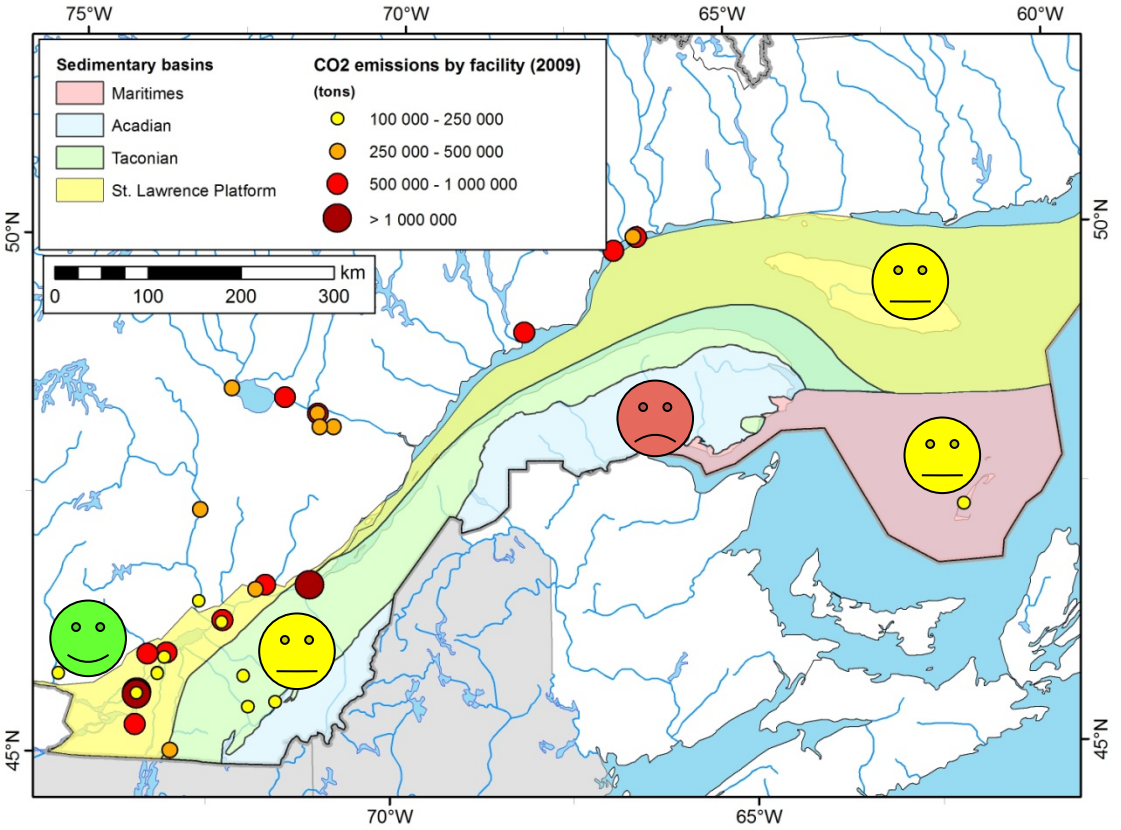
Practical criteria

- On / Off shore
- Climate
- Accessibility
- Infrastructures



Practical criteria

- On / Off shore
- Climat
- Accessibility
- Infrastructures
- CO_2 sources

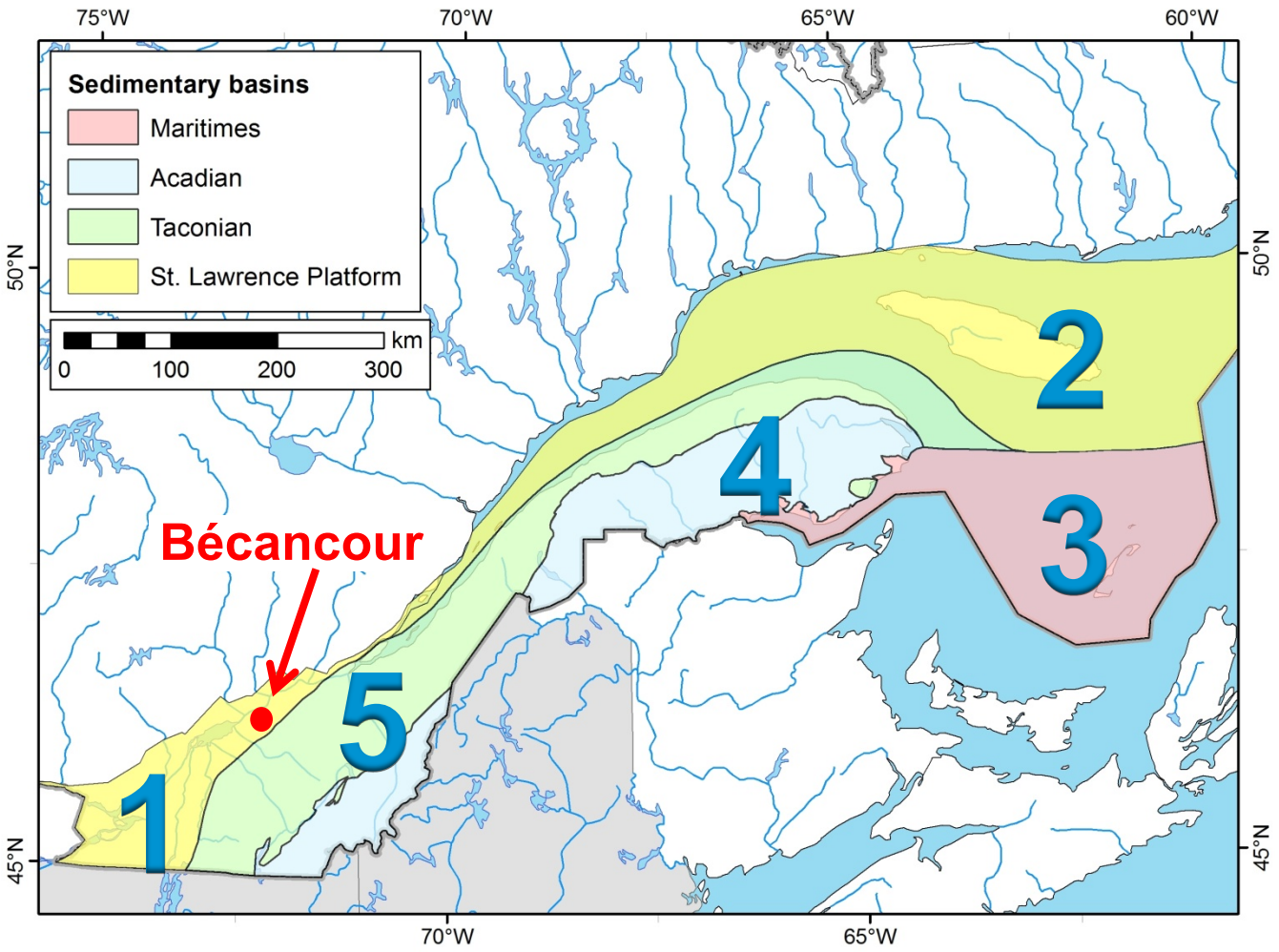


Sources : Environnement Canada (2010) GHG Emissions by industry (2009).

Basin assessment for the Province of Québec - Results

		St. Lawrence Platform		Taconian	Acadian	Maritimes
		St. Lawrence Lowlands	Anticosti			
Geological criteria	Tectonic setting	4	4	4	4	4
	Size	3	5	5	4	4
	Depth	5	5	N/D	5	5
	Deformation (faults & fractures)	5	5	1	1	5
	Reservoir-seal pair	5	5	1	1	5
	Geothermal	5	5	5	5	5
	Hydrocarbon potential	3	3	1	2	4
	Evaporites	1	1	1	1	3
	Coal	1	1	1	1	2
	Maturity	3	2	2	2	2
Practical criteria	On/Off shore	5	4	5	5	3
	Climate	5	5	5	5	5
	Accessibility	5	2	5	5	2
	Infrastructure	5	2	5	5	2
	CO_2 sources	5	2	3	1	2
Score - R^k		**0.84**	**0.69**	**0.51**	**0.58**	**0.67**
Ranking		**1**	**2**	**5**	**4**	**3**

Ranking of Québec sedimentary basins



Conclusions

- The St. Lawrence platform basin is the most prospective basin for CO_2 storage particularly the St. Lawrence Lowlands sub-basin
- The Maritimes basin must be considered even if it is largely an offshore basin
- Sites were selected and characterization is ongoing at the Bécancour site

SÉQUESTRATION GÉOLOGIQUE DU CO_2

CHAIRE DE RECHERCHE

INRS

Université d'avant-garde

Acknowledgments

Développement durable, Environnement et Parcs

Québec

CANADA 1842

GEOLOGICAL SURVEY - COMMISSION GÉOLOGIQUE