Basin-scale assessment for CO₂ storage prospectivity in the Province of Québec, Canada



Michel Malo, Karine Bédard



Institut national de la recherche scientifique, Centre - Eau Terre Environnement

OVERVIEW OF SITE SELECTION AND CHARACTERIZATION

Characterization of basin suitabilit for geological CO₂ sequestration

Identification of prospective sites for geological CO₂ sequestration

Detailed characterization and capacity evaluation for selected sites

PROVINCE OF QUÉBEC

Bachu (2003). He identify 15 criteria that should be used for evaluating the suitability of each basin for geological CO₂ sequestration.

- Each of the criterion has classes with specific values (scores)
- Each of the criterion has a relative weight
- The general score of each basin is the weighted mean of the normalized score of each criterion score and the weight of the criteria (see equations below)
- and/or priorities

This procedure allows to transform qualitative characteristics of the basins into quantitative values in order to compare the basins in a objective manner.

Normalized score of each basin K for each criterion i:

 F_{ii} = individual score of the basin for the criterion i

 $F_{i,l}$ = score of the criterion i for its lowest class j=1

 $F_{in} =$ score of the criterion **i** for its highest class **j=n**

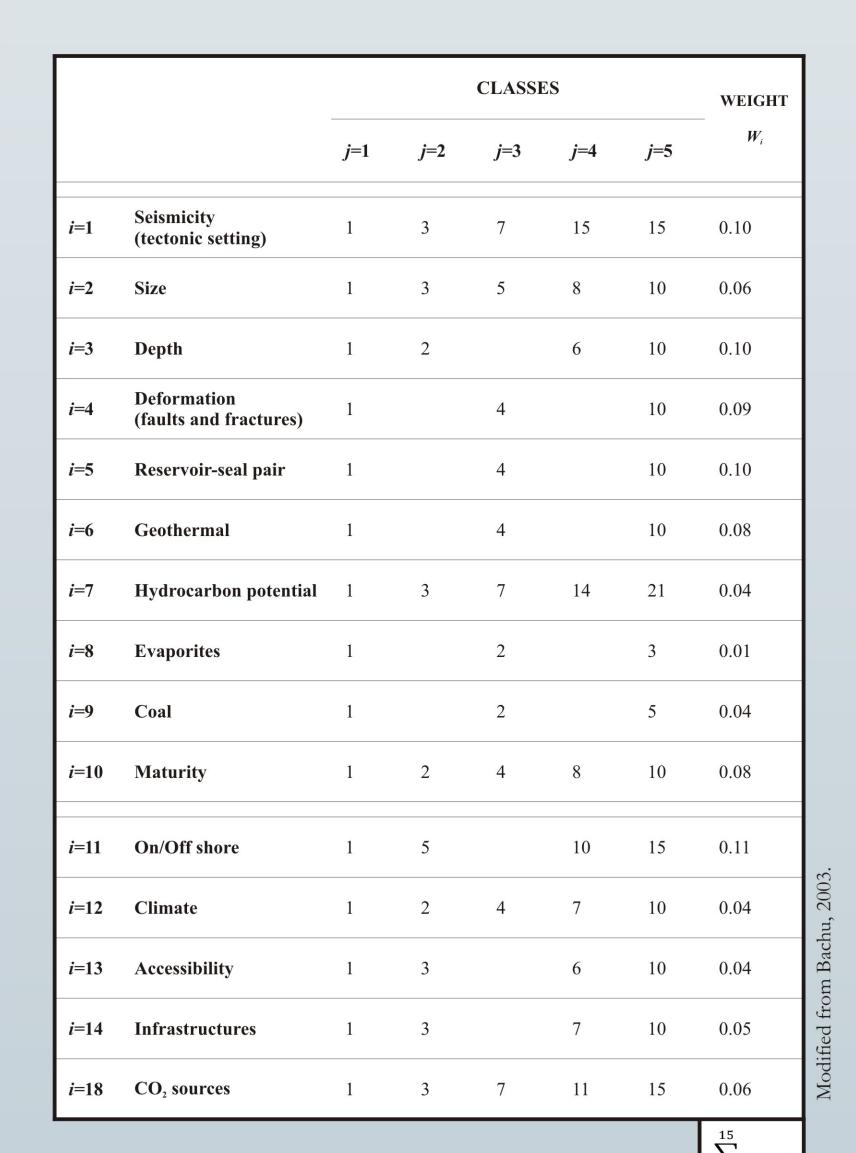
 P_i^k = normalized score of the basin K for each criterion i

and the class j

General score of each basin K:

 W_i = weight of each criterion i

		CLASSES					
		1	2	3	4	5	
GEOLOGICAL CRITERIA	Seismicity (tectonic setting)	Very high (e.g. subduction zone)	High (e.g. syn-rift, strike-slip)	Intermediate (e.g. foreland)	Low (e.g. passive margin)	Very low (e.g. cratonic)	
	Size	Very small (<1000 km²)	Small (1000 - 5000 km²)	Medium (5000 - 25,000 km²)	Large (25,000 - 50,000 km²)	Very large (>50,000 km²)	
	Depth	Very shallow (<300 m)	Shallow (300-800 m)		Deep (>3500 m)	Intermediate (800 - 3500 m)	
	Deformation (faults and fractures)	Extensive		Moderate		Limited	
	Reservoir-seal pair	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		Deep (>800m)		Shallow (200 - 800 m)	
	Maturity	Unexplored	Exploration	Developing	Mature	Super mature	
PRACTICAL CRITERIA	On/Off shore	Deep offshore	Shallow offshore		Shallow offshore and onshore	Onshore	
	Climate	Arctic	Sub-arctic	Desert	Tropical	Temperate	
	Accessibility	Inaccessible	Difficult		Acceptable	Easy	
	Infrastructures	None	Minor		Moderate	Extensive	
	CO, sources	None	Few	Moderate	Significant	Manv	



STEP 1 - BASIN SUITABILITY

The basin classification method used for Southern Québec is based on the work of

- The number of criteria and their weight can be adapted to changing conditions

The Magdalen Basin is composed of a

(section H-I-J)

GEOLOGICAL CONTEXT

- Humber-Dunnage Basin

- Anticosti Sub-Basin

- Magdalen Basin

- Gaspé Basin

5 sedimentary basins in southern Québec:

- St. Lawrence Platform basin divided in 2

- St. Lawrence Lowlands Sub-Basin

The Gaspé Basin is the post-Taconian successor basin composed of Upper Ordovician to Lower Devonian rocks. The succession has been moderately folded and faulted due to the Acadian orogeny. (section C-D-E)

Devonian to Carboniferous thick sedimentary

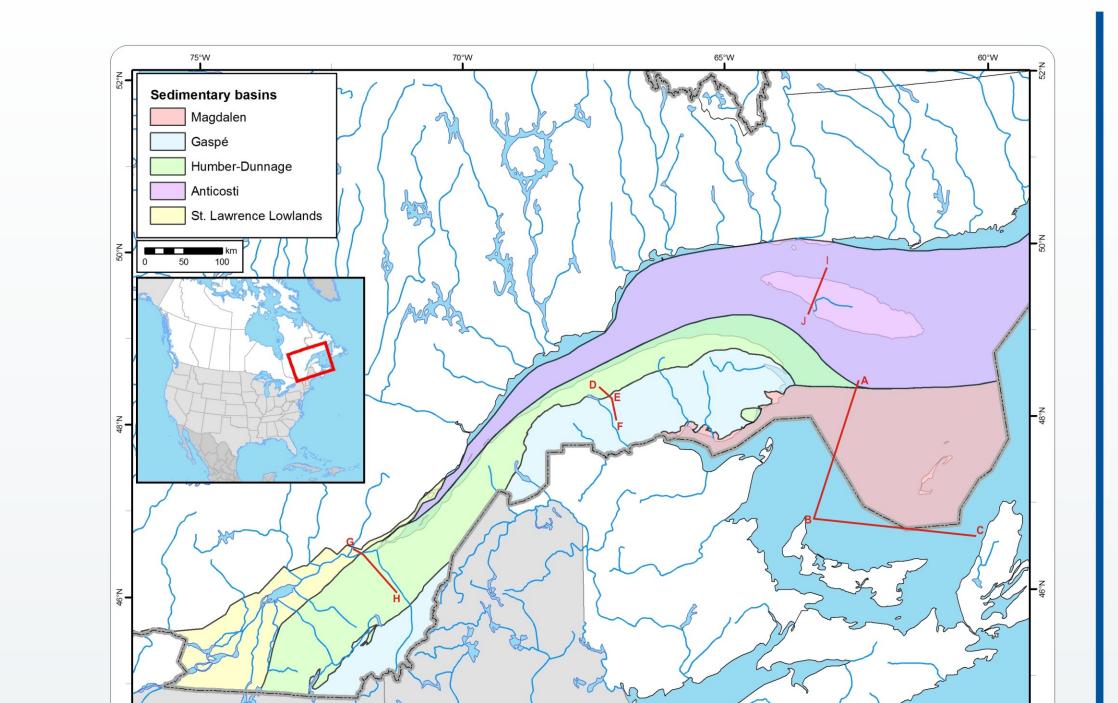
succession forming the post-Acadian successor

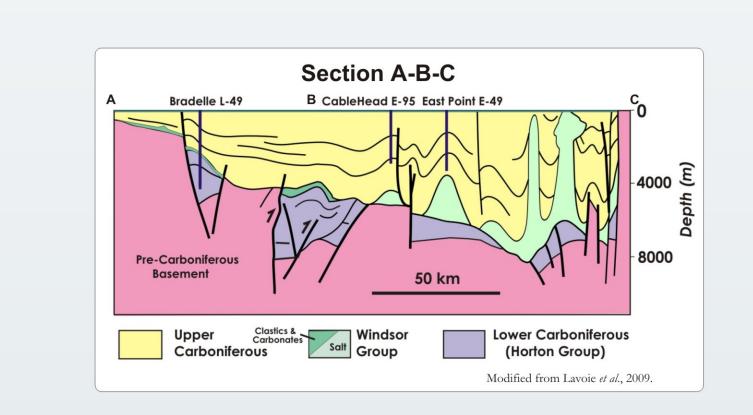
The Humber-Dunnage Basin is made of highly folded and faulted Cambrian to Upper Ordovician rocks and correspond to the fold and thrust belt of the Canadian Appalachians. Rocks were deformed by many successive orogenies (Taconian, Salinic and Acadian). (section G-H)

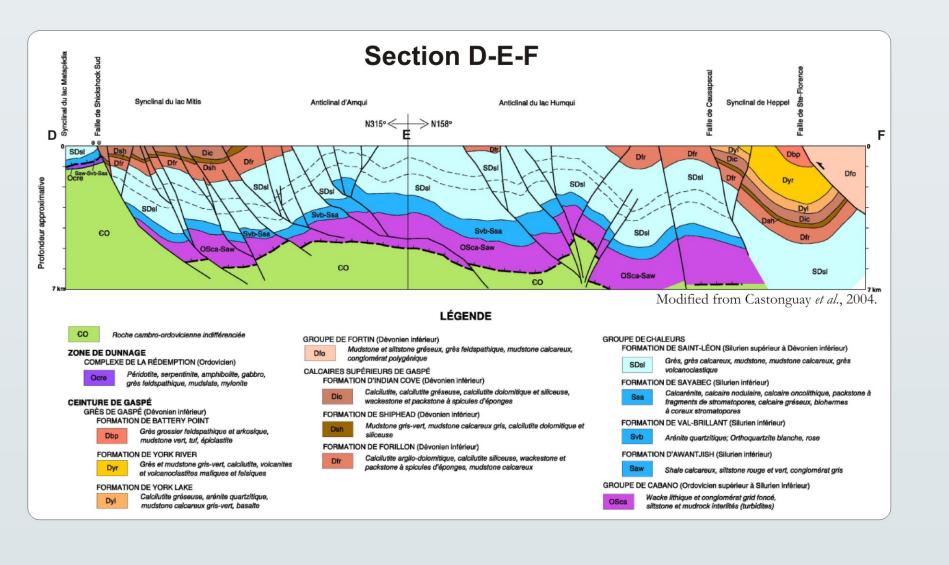
The St. Lawrence Lowlands Sub-Basin is made up of Cambrian to Upper Ordovician rocks resting unconformably on the Precambrian Shield. It represents a complete siliciclastic and carbonate platform succession. NE-SW normal syn-sedimentary faults affect the succession as well as the bedrock which result in a deepening of the basin toward to Appalachians to the SE. (section G-H)

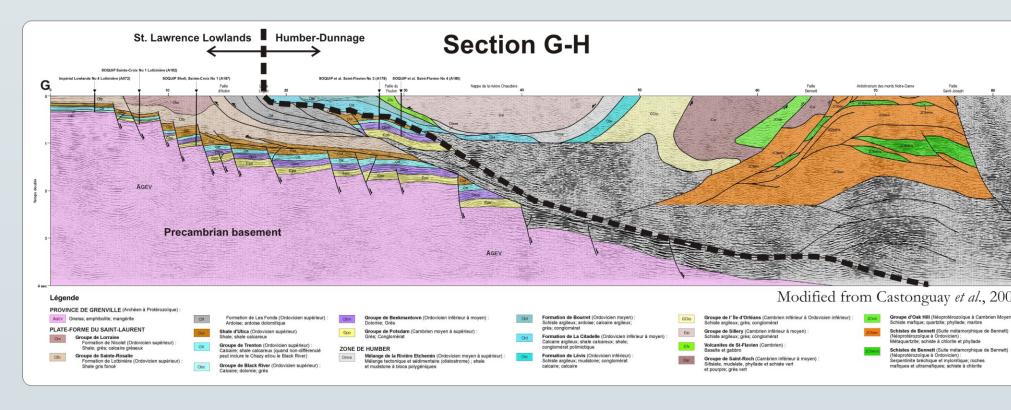
The Anticosti Sub-Basin is composed of Lower Ordovician to Lower Silurian rocks unconformably resting on the Precambrian Shield. It is mostly composed of carbonate facies typical of a platform sedimentation. The succession is relatively non-deformed and dips shallowly to the SW. (section I-J)

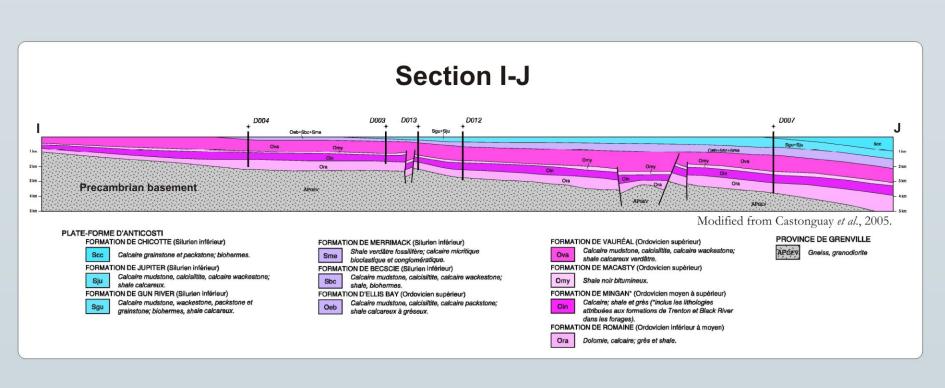
Eastern Canada. Geological Survey of Canada, Open File 6174.











References

Bachu, S. (2000) Sequestration of CO₂ in geological media: criteria and approach for site selection in response to climate change. Energy Conversion & Management, 41, 953-970. Bachu, S. (2003) Screening and ranking of sedimentary basins for sequestration of CO₂ in geological media in response to climate change. *Environmental Geology*, 44, 277-289. Blackwell, D.D. and Richards, M. (2004) Geothermal Map of North America. American Association of Petroleum Geologists, 1 sheet, scale 1:6 500 000.

Kaldi, J.G. and Gibson-Poole, C.M. (Eds.) (2008) Storage Capacity Estimation, Site Selection and Characterisation for CO₂ Storage Projects. CO2CRC, Report No: RPT08-1001.

Castonguay, S., Dietrich, J., Shinduke, R., Laliberté, J-Y. (2006) Nouveau regard sur l'architecture de la Plate-forme du Saint-Laurent et des Appalaches du sud du Québec par le retraitement des profils de Castonguay, S., Wilson, R.A., Brisebois, D., Desrochers, A., Malo, M. (2005) Compilation géologique, Anticosti-Gaspé-Campbelton, Les ponts géologiques de l'est du Canada, Transect 4, Québec-Nouveau-Castonguay, S., Carroll, J.I., Pinet, N., Brisebois, D., Malo, M. (2004) Compilation géologique, Matane-Restigouche, Les ponts géologiques de l'est du Canada, Transect 3, Québec-Nouveau-Brunswick.

Earthquakes Canada (2010) Geological Survey of Canada, Earthquake Search (On-line Bulletin). Environment Canada (EnvCan) (2010) Facility Greenhouse Gas Reporting program (2009). GHG Division - Environment Canada.

Lavoie, D., Pinet, N., Dietrich, J., Hannigan, P., Castonguay, S., Hamblin, A.P., Giles, P. (2009) Petroleum resource assessment, Paleozoic successsions of the St. Lawrence Platform and Appalachians of

Acknowlegments

Québec * *

CLASSIFICATION OF SOUTHERN QUÉBEC BASINS FOR CO₂ SEQUESTRATION

Each of the sedimentary basins of Southern Québec is analysed following the predefined evaluation criteria. This allows to rank the basins for their suitability for geological CO₂ sequestration and it provides objective information for decisionmaking

Ranking of the basins in Southern Québec with their general score, from the most to the least

- St. Lawrence Lowlands Sub-Basin (0.84) Anticosti Sub-Basin
- 4. Gaspé Basin 5. Humber-Dunnage Basin

As St. Lawrence Lowlands is, by far, the most prospective for CO₂ sequestration in the Province of Québec. More studies should be made to evaluate storage capacity and identify more precisely potential sites.

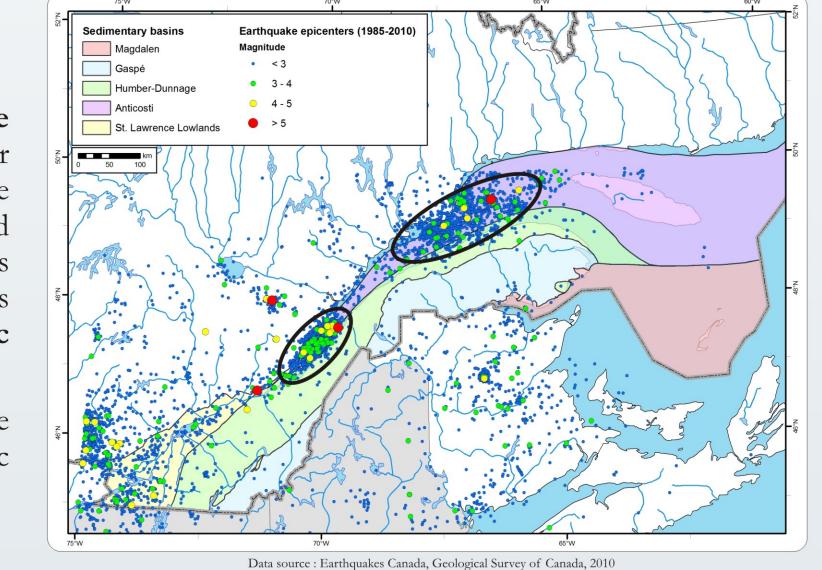
Anticosti and Magdalen basins have approximately the same general score and therefore should be considered as having the same suitability in future studies. Western part of Anticosti Basin is not considered because of higher seismic hazard (see figure below).

Humber-Dunnage and Gaspé basins have a limited potential mostly because deformation is more extensive and reservoir-seal pairs are not well known and thus, badly defined.

SEISMICITY (Tectonic setting)

Normal faults in the St. Lawrence Lowlands are not active and there never had been earthquakes of magnitude higher than 5.5 in the region located between Québec City and Montréal. This basin, as well as all the other basins, is thus considered as having a stable tectonic setting.

Two regions are eliminated from the assessment as they show higher seismic activity (black circles on the map right).



HYDROCARBON POTENTIAL

sequestration. However potential impacts of CO₂ sequestration on future Gaspé: hydrocarbon exploitation needs to be taken into account. (Bachu, 2000)

The region with the greater potential is located offshore in the Magdalen

St. Lawrence Lowlands: 0 to > 3500 m

 $\sim 1000 \text{ to} > 3500 \text{ m}$

difficult interpretation

0 to > 3500 m

0 to > 3500 m

extensive faulting and folding, geological Humber-Dunnage: continuous beds (Kaldi and Gibson-Poole, 2008). interpretation is difficult at depth Some salt domes are present in the **Magdalen Basin** but no evaporites are Winter: snow, down to -40°C moderate faulting and deformation

little faulting and deformation Anticosti: presence of normal faults at depth

St. Lawrence Lowlands: normal faults not reaching the surface

DEPTH

RESERVOIR-SEAL PAIR

Gaspé:

Humber-Dunnage

St. Lawrence Lowlands: ~ 20 000 km²

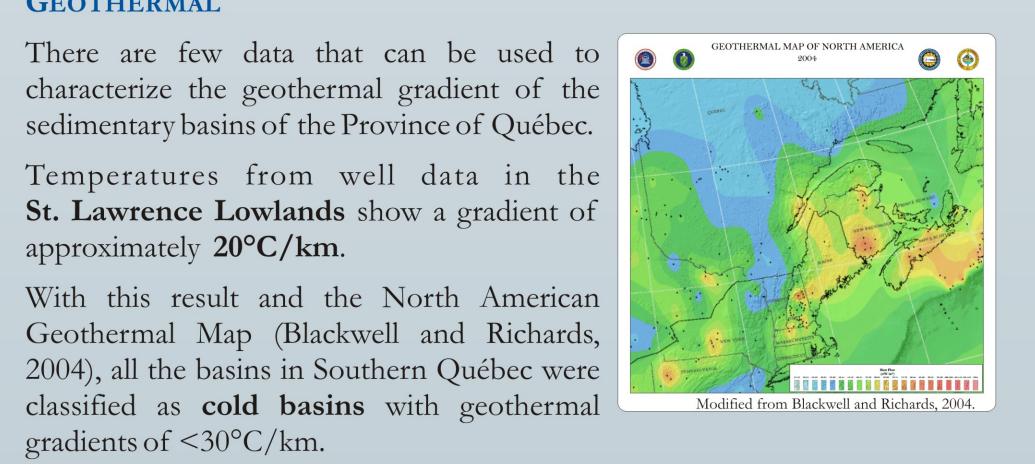
DEFORMATION (Faults and fractures)

ı			Potential reservoirs	Caprocks	
		St. Lawrence Lowlands	Potsdam, Beekmantown and Trenton	Utica Shale and Lorraine	
ı		Anticosti	Romaine, Trenton and Mingan	Macasty	
ı		Humber-Dunnage	difficult interpretation, reservoir-seal pairs poorly known		
ı			reservoir-seal pairs poorly known		
ı		Gaspé	Sayabec, West Point and York River and Upper Gaspé Limestone		
	Magdalen	Bradelle and Horton	Green Gables and Windsor		

GEOTHERMAL

characterize the geothermal gradient of the sedimentary basins of the Province of Québec. Temperatures from well data in the St. Lawrence Lowlands show a gradient of approximately 20°C/km.

With this result and the North American Geothermal Map (Blackwell and Richards, 2004), all the basins in Southern Québec were classified as cold basins with geothermal gradients of <30°C/km.



If a basin has good hydrocarbon potential, it is also probably suitable for CO₂ Magdalen:

EVAPORITES

Evaporites generally provide the best caprock seals, particularly in

known in the other basins.

COAL

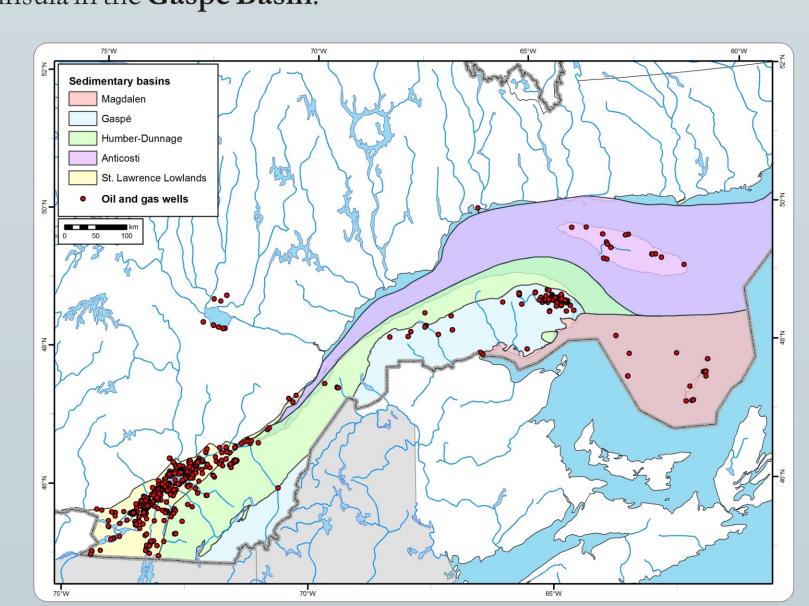
Unminable coal seams are potential CO₂ reservoirs as they could adsorb CO₂: hence, their presence provide another possibility for CO₂ sequestration **Dunnage** basins because the population density is relatively high. In the (Kaldi and Gibson-Poole, 2008).

The only basin with coal seams in southern Québec is the Magdalen Basin.

MATURITY

The more a basin is mature, the more it has been explored/exploited, and CO, SOURCES thus, better its geology is understood and greater is the quantity of available data (Bachu, 2000).

The map of oil and gas exploration wells in the Province of Québec shows that the St. Lawrence Lowlands is the more explored up to now. The other basins are very little explored, apart from a region in the east of the Gaspésie region. Peninsula in the Gaspé Basin.



(tectonic setting (faults and fractures) Reservoir-seal pair **Hydrocarbon potential** Difficult Less favorable More favorable

ON/OFF SHORE

shallow offshore Humber- Dunnage:

shallow offshore and onshore St. Lawrence Lowlands: onshore

CLIMATE

Climate is relatively the same all over the Province of Québec.

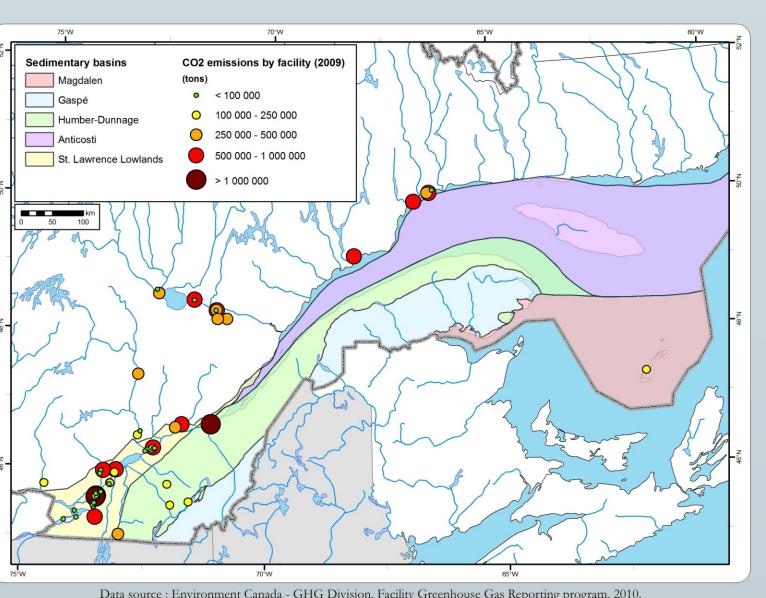


ACCESSIBILITY AND INFRASTRUCTURE

Accessibility is easy in the St. Lawrence Lowlands, Gaspé and Humbersame basins, infrastructure is extensive for the same reasons.

As the major part of Anticosti and Magdalen basins is offshore, their accessibility is limited. In those basins, infrastructure is particularly localized where population is more dense.

As shown on the map below, many major CO₂ emitters are localized directly in the **St. Lawrence Lowlands**. They could eventually become CO₂ providers, through CO₂ capture technology, for sequestration projects in that



Data source: Environment Canada - GHG Division, Facility Greenhouse Gas Reporting program, 2010.