

STRUCTURAL MAPS OF THE ST. LAWRENCE LOWLANDS PLATFORM, QUÉBEC : TOOL FOR THE IDENTIFICATION OF COLLAPSE ZONES (SAGS) AND POTENTIAL HYDROTHERMAL DOLOMITE RESERVOIRS

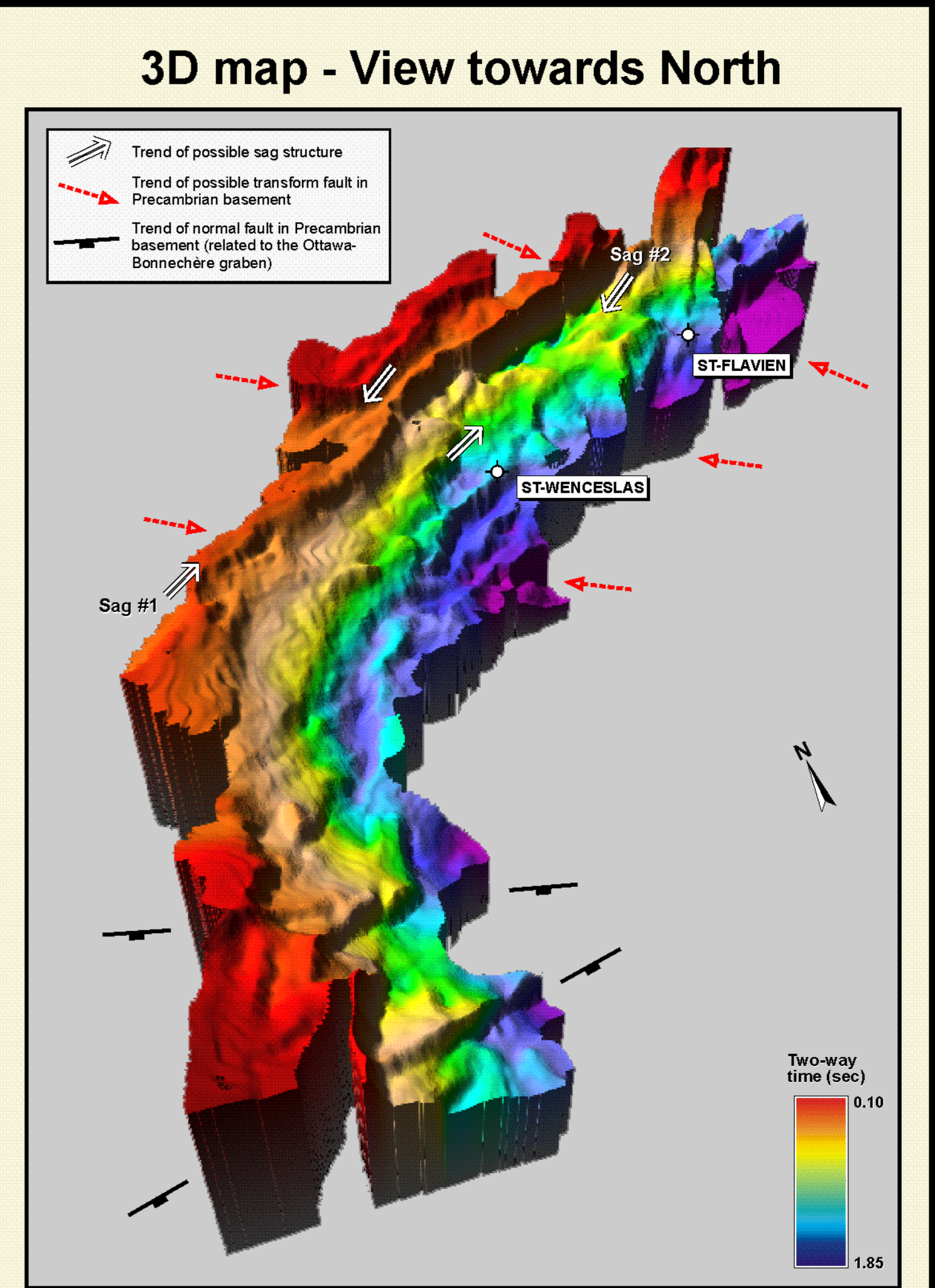
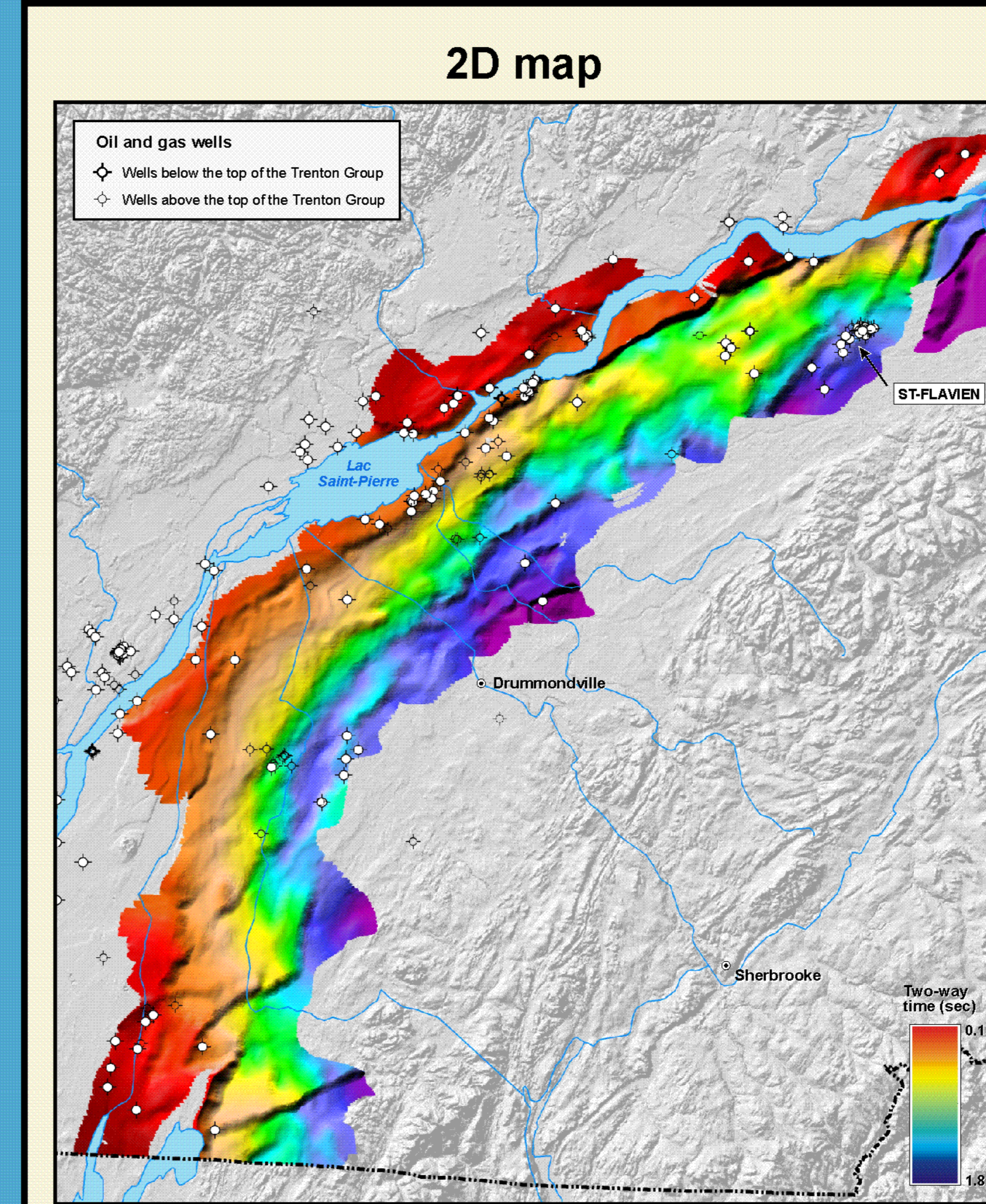
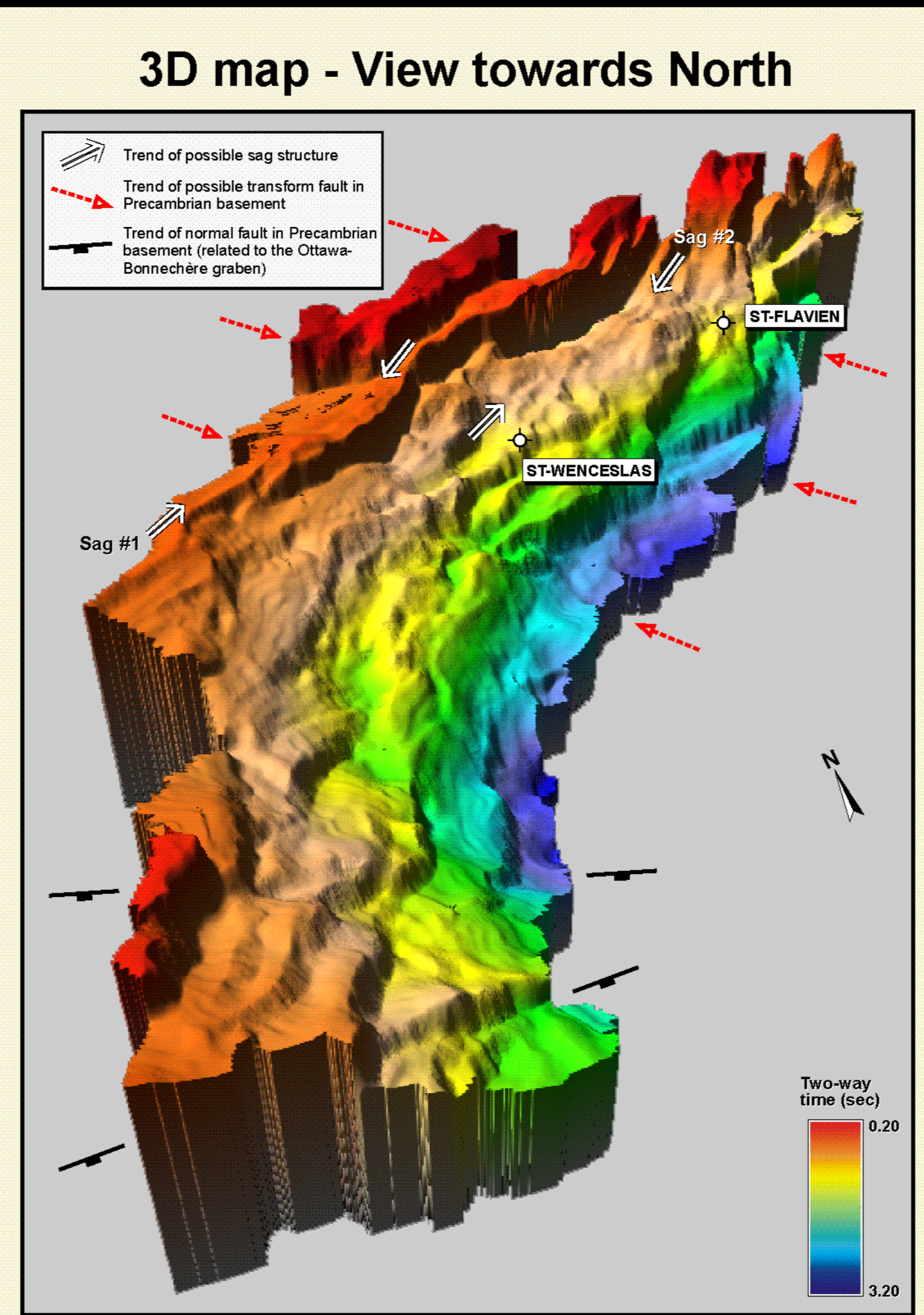
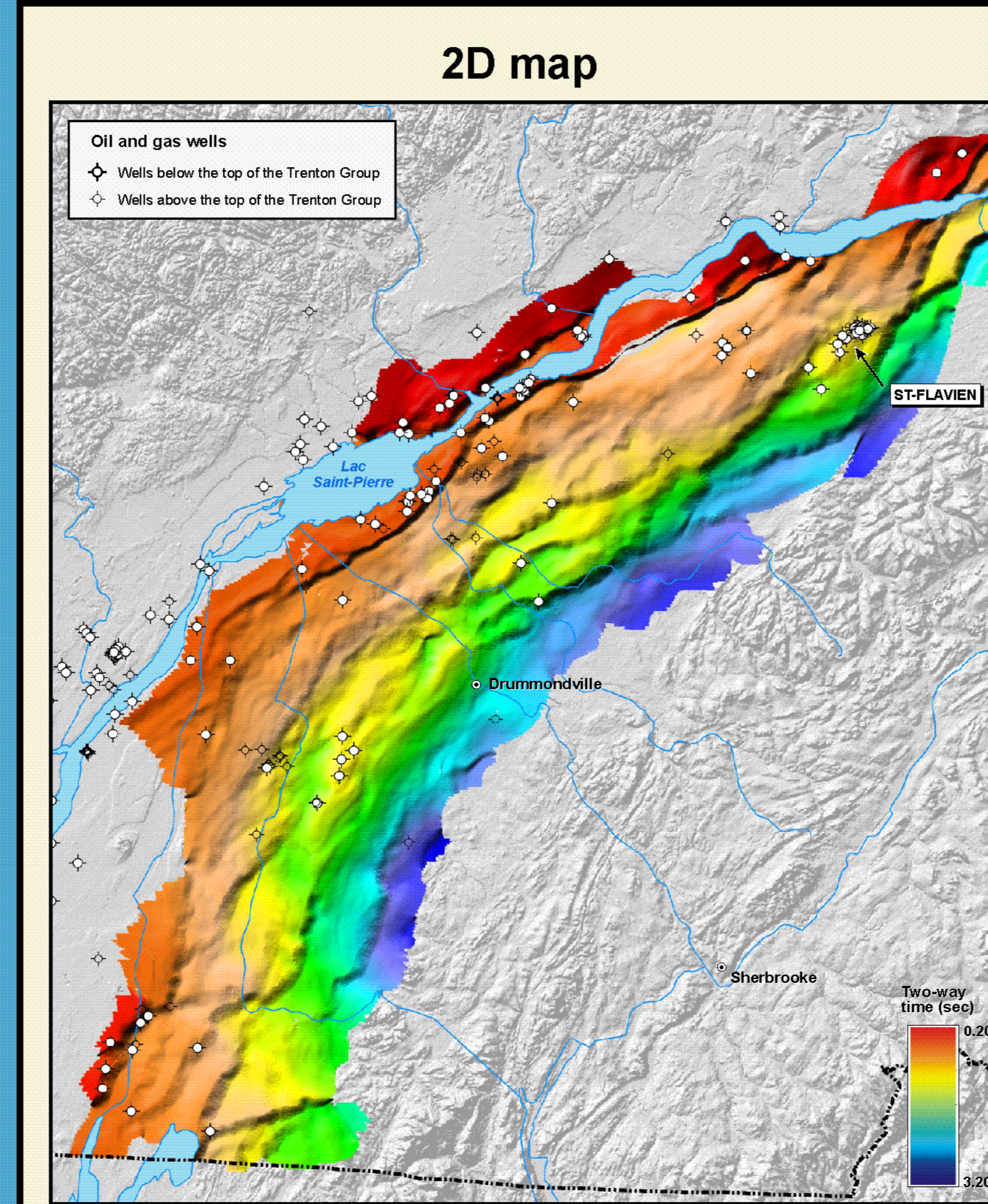
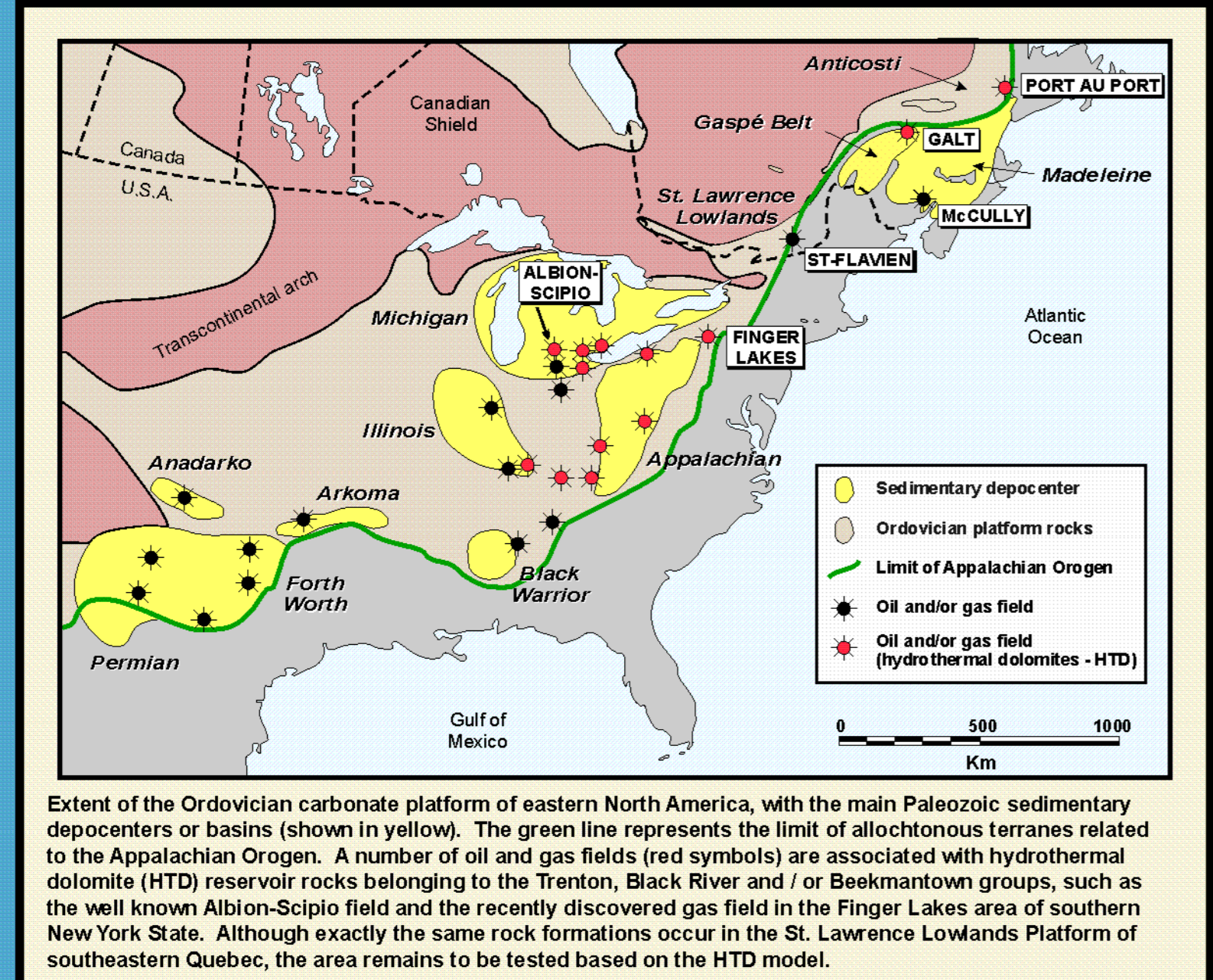
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Abstract Regional setting Precambrian basement time-structure maps Top of Trenton time-structure maps

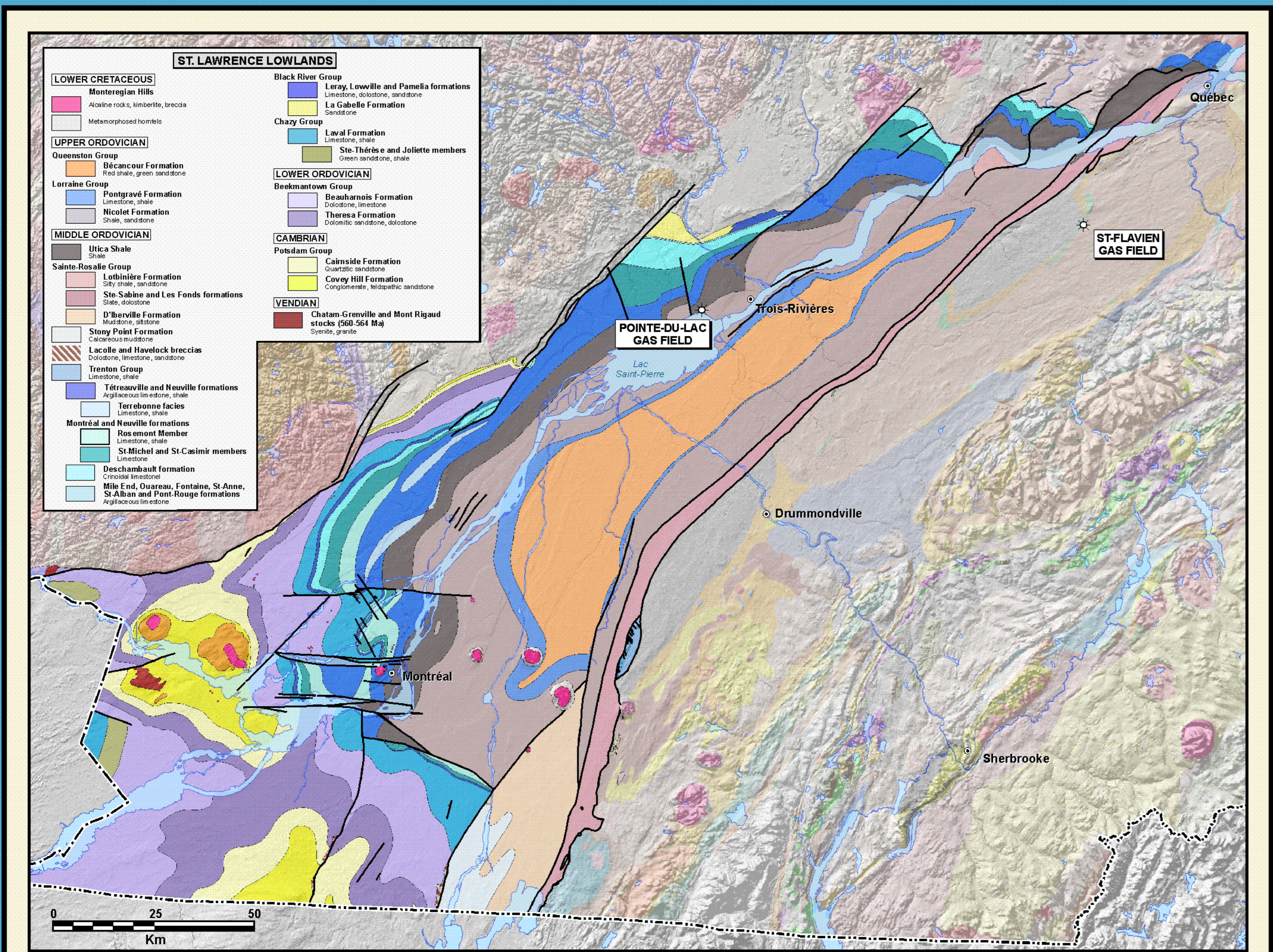
Regional structural maps of the top of the Precambrian basement and top of the Trenton Group have been digitized based on the interpretation of about 400 seismic lines and 120 oil and gas wells from the St. Lawrence Lowlands Platform. These new maps show the presence of NS to NE-SW anastomosing basement faults that parallel the axis of the St. Lawrence River, and which compartmentalize the basement into a series of southeastward-deepening steps of half-graben geometry. The faults are interpreted to have formed during the Cambrian rifting event of Laurentia which led to the opening of the Iapetus Ocean. A second system of orthogonal EW oriented faults are interpreted to be genetically related to the Ottawa-Bonnechère graben (autochthon) and/or to the westward propagation of transform faults associated with the drift phase of Iapetus. This structural pattern is also observed on the top of Trenton structural map, which implies that these two fault systems were active from the Cambrian to at least the Late Ordovician. Reactivation of these faults may also have taken place in the Late Ordovician during the Taconian Orogeny, with a possible strike-slip component to produce wrench faults and associated flower structures. Such structures represent elsewhere prime targets for the formation of hydrothermal dolomite (HTD) hydrocarbon reservoirs.

Detailed analysis of the structural maps and seismic lines have led to the identification of several collapse zones, or sags, originating at the top of the Trenton Group. Well defined sags occur in the Lac St. Pierre area, forming linear depressions measuring approximately one km in width by 15-30 km in length. These synclinal-like structures follow the trend of the Yamaska Fault, an interpreted wrench fault. Most wells drilled in the immediate area have encountered gas shows within the Trenton, Black River or Beekmantown groups, but the sags themselves have yet to be drilled.

A number of oil and gas discoveries have been made along very similar structures in the United States (Albion-Scipio, Lima-Indiana, Finger Lakes) and Ontario (Dover), within hydrothermal dolomite reservoirs associated with the prolific Trenton-Black River interval. However, although these rock formations occur throughout the St. Lawrence Platform in Québec, the hydrothermal dolomite play remains to be tested.



Geology of the St. Lawrence Lowlands



Newly compiled geological map of the St. Lawrence Lowlands Platform and southeastern part of the Québec Appalachians superimposed on a digital elevation map of the shuttle radar topography mission (SRTM). Two significant gas discoveries have been made in the area: 1) The Pointe-du-Lac field, discovered in the mid-1970s just north of Lac St-Pierre, is hosted in the Quaternary sands; and 2) The St-Flavien field, found in the mid-seventies about 50 km southeast of Québec City, occurs in the foothills of the Appalachians. Both reservoirs have been completely emptied, and are now being used as gas storage facilities. The roughly EW alignment of the Cretaceous intrusive rocks of the Monteregian Hills, along with the presence of numerous EW oriented faults along the same trend in the Montréal area, is interpreted to be linked to the Cambrian age Ottawa-Bonnechère graben structure.

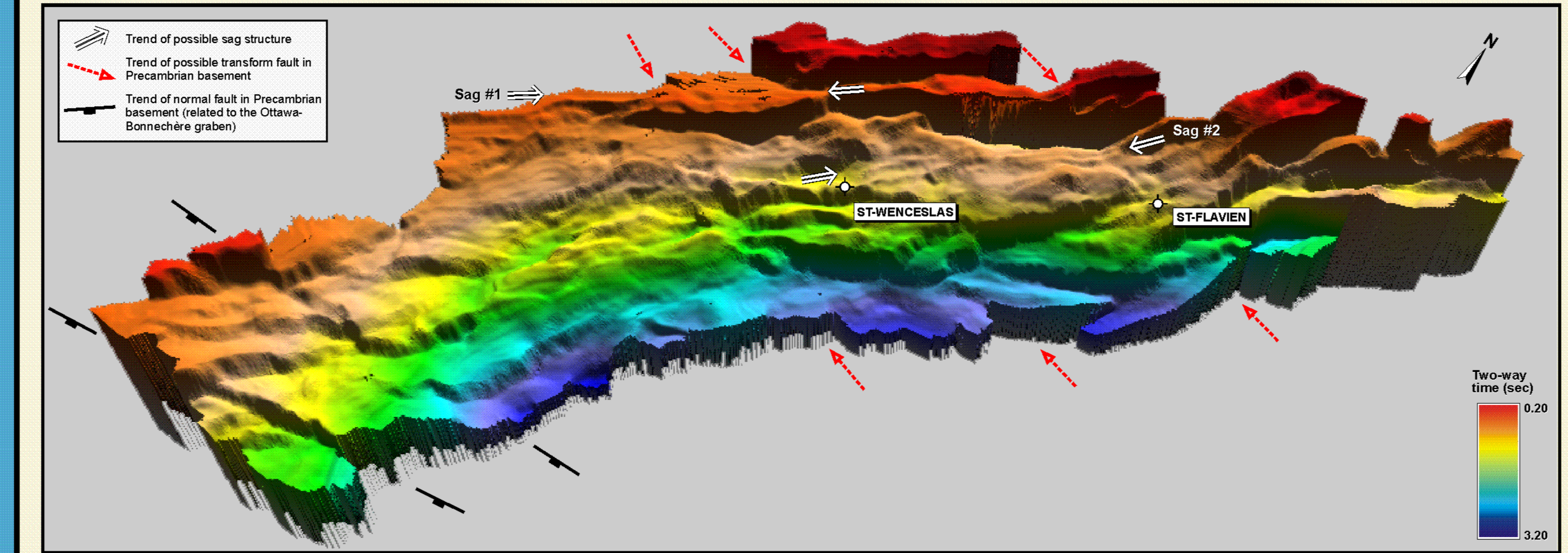
Digitized time-structure map of the Precambrian basement under the Paleozoic rocks of the St. Lawrence Lowlands Platform. Shading was added with an illumination from the NW. The depth to basement is expressed as two-way time, with a time-depth conversion factor of approximately 2.2 km / sec. The main structural trend of the basement topography roughly follows the stratigraphic trend seen at surface. Note the two parallel ENE-WSW oriented normal faults in the southern part of the map, which are likely related to the Ottawa-Bonnechère graben. Approximately 560 oil and gas wells have been drilled in the St. Lawrence Lowlands since the late 1800's, but only 200 or so have reached down to at least the top of the Trenton Group.

3D time-structure map of the Precambrian basement, with view towards the NNE. Shading was added with an illumination from the west, while the vertical exaggeration was set at 2.5. A series of southeastward-deepening normal faults of half-graben geometry compartmentalize the basement, and these follow the axis of the St. Lawrence River. A second system of orthogonal E-W oriented faults are interpreted to be genetically related to the Ottawa-Bonnechère graben and to the westward propagation of transform faults associated with the drift phase of Iapetus. Reactivation of some of these faults may have occurred during the Taconian Orogeny, with a possible strike-slip component in the form of wrench faults and associated flower structures. These typically form 500-1000 m wide linear collapse zones, or sags, and represent elsewhere prime targets for the formation of HTD hydrocarbon reservoirs.

Digitized time-structure map of the top of the Trenton Group in the St. Lawrence Lowlands Platform. Shading was added with an illumination from the NW. A very similar structural pattern to the previous 2D time-structure map (i.e. top of Precambrian basement) is observed, which implies that several of these structures have been active from the Cambrian until at least the Late Ordovician. Note that the ENE normal faults observed in the southern part of the map (especially associated with the Ottawa-Bonnechère graben) are generally more strongly developed than the structures that parallel the rift axis of the St. Lawrence River. This suggests that the former structures, which occur at a high angle relative to the maximum strain direction of the Appalachian Orogen, were reactivated during and/or after Trenton time, with a possible strike-slip component.

3D time-structure map of the top of the Trenton Group, with view towards the NNE. Shading was added with an illumination from the west, while the vertical exaggeration was set at 2.5. The structural elements observed on this map are fairly similar to those of the time-structure map at the top of the Precambrian Shield.

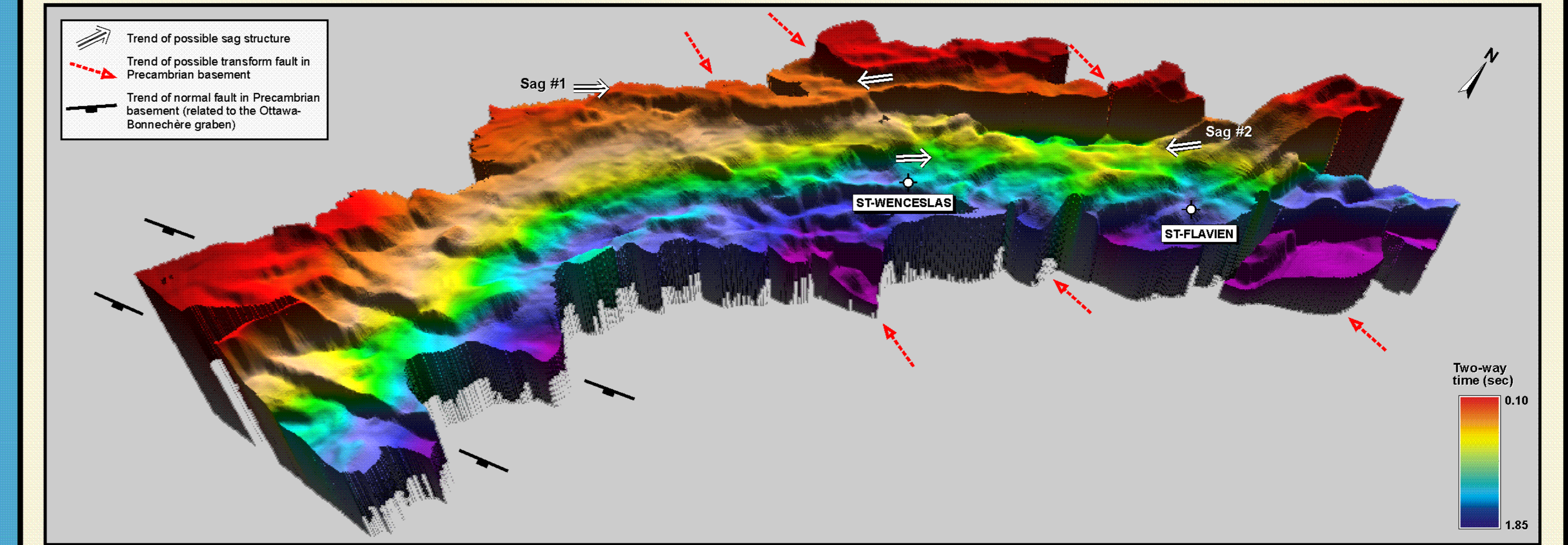
3D map - View towards West



3D time-structure map of the top of the Precambrian basement, with view towards the WNW. Shading was added with an illumination from the northwest, while the vertical exaggeration was set at 2.5. Although the same structural features as the previous map (i.e. North view) are observed, this particular view makes the E-W oriented structures in the northern part of the map (outlined by the red arrows), which we interpret as a series of transform faults related to the opening of the Iapetus Ocean during the Cambrian, have a fault spacing of approximately 40 km, which is a fairly good estimate of the thickness of the Precambrian crust in this area. It may not be fortuitous that the St-Flavien gas field is situated directly along the most northerly of these structures. This view also outlines nicely a potential SW-NE oriented structural collapse zone (sag #2), which extends for about 50 km. This sag passes near the St. Wenceslas well, where saddle dolomite crystals indicative of the percolation of hydrothermal fluids were identified in drill samples.

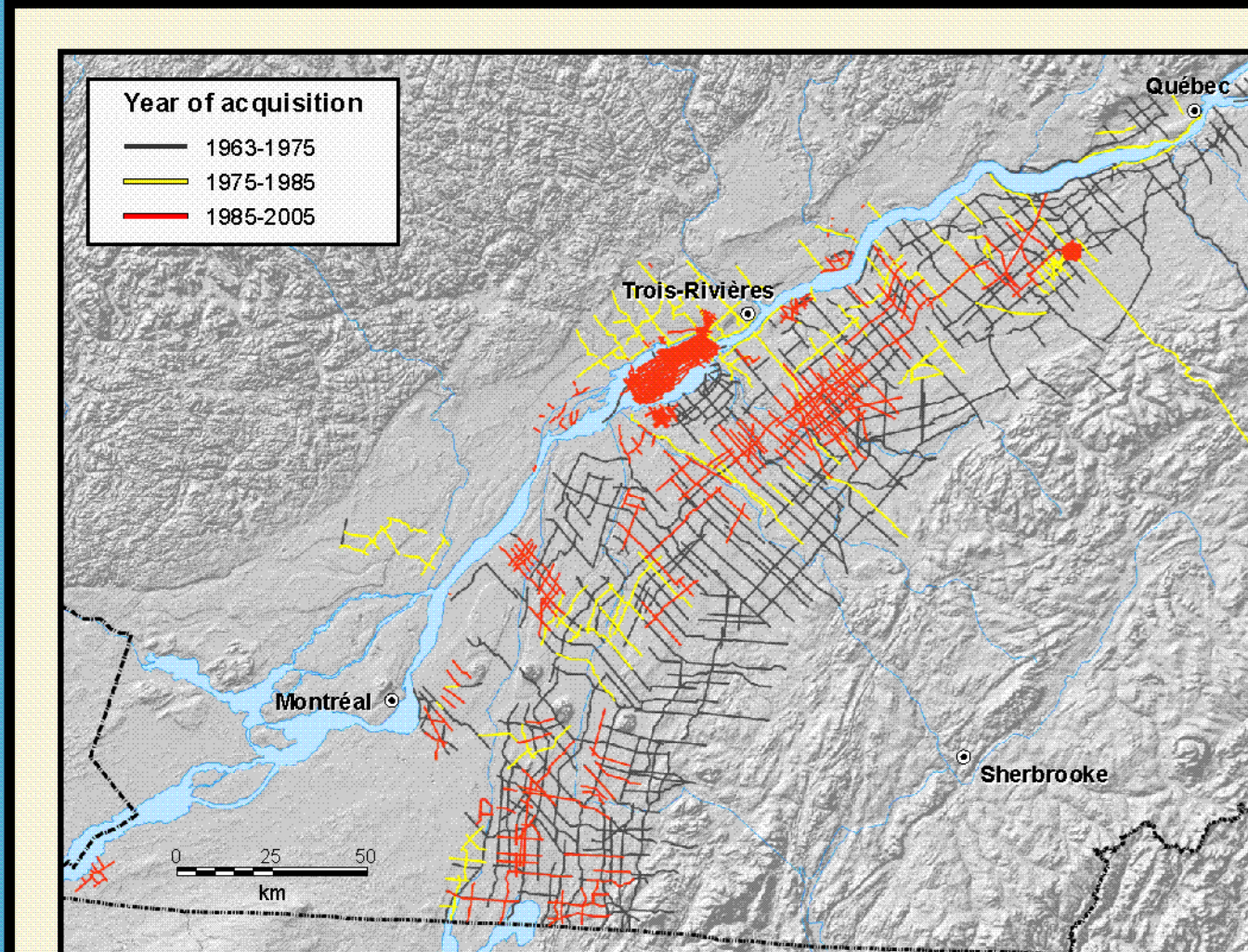
3D time-structure map of the top of the Trenton Group, with view towards the WNW. Shading was added with an illumination from the northwest, while the vertical exaggeration was set at 2.5. As mentioned before, this view outlines very well the E-W oriented normal faults spatially associated with the Ottawa-Bonnechère graben. Furthermore, the two E-W structures observed in the central part of the map are nicely depicted, and these extend westerly on both sides of Lac St-Pierre. These two possible transform faults appear to delineate a distinct structural block resembling a horst structure.

3D map - View towards West

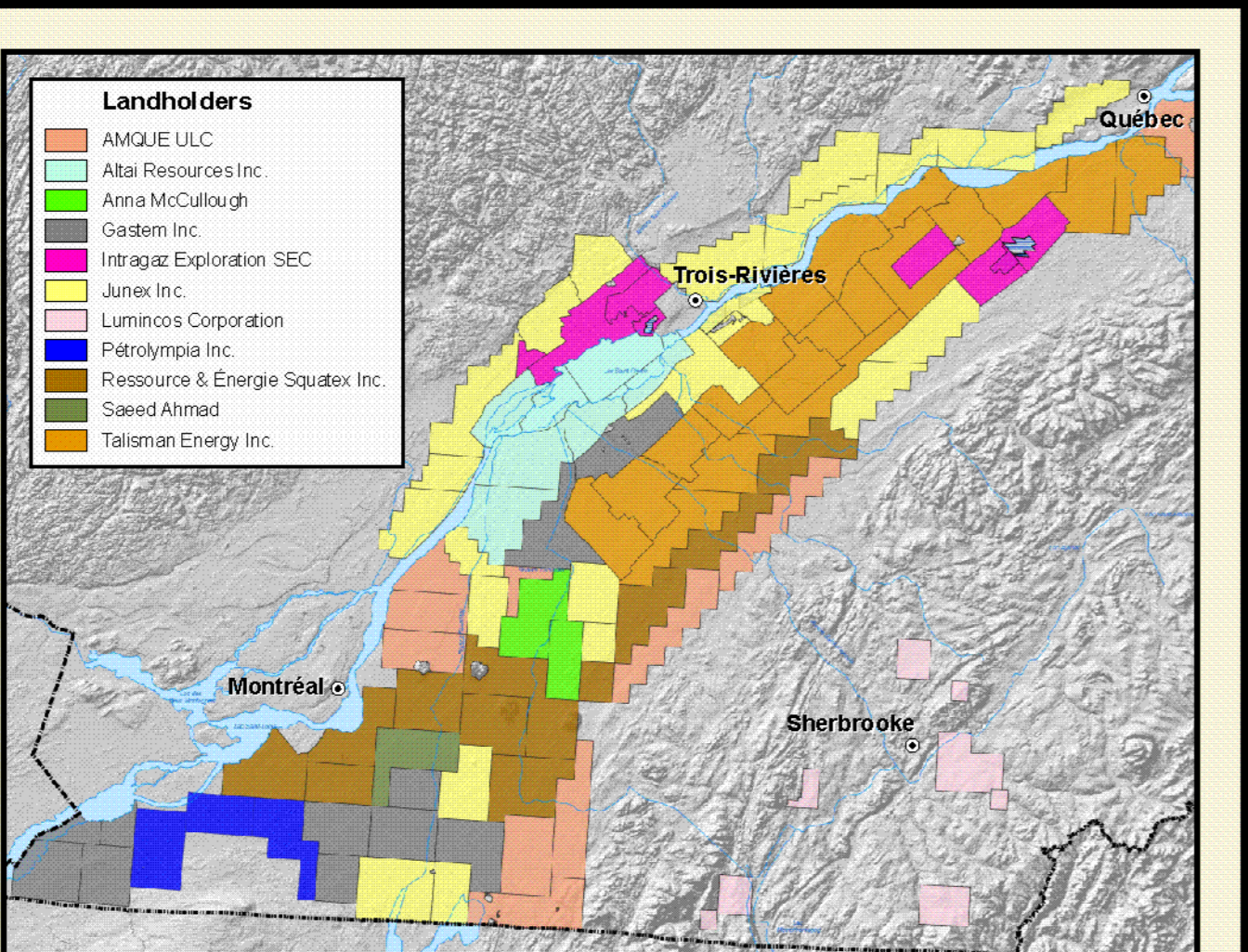


Seismic lines

Exploration licences

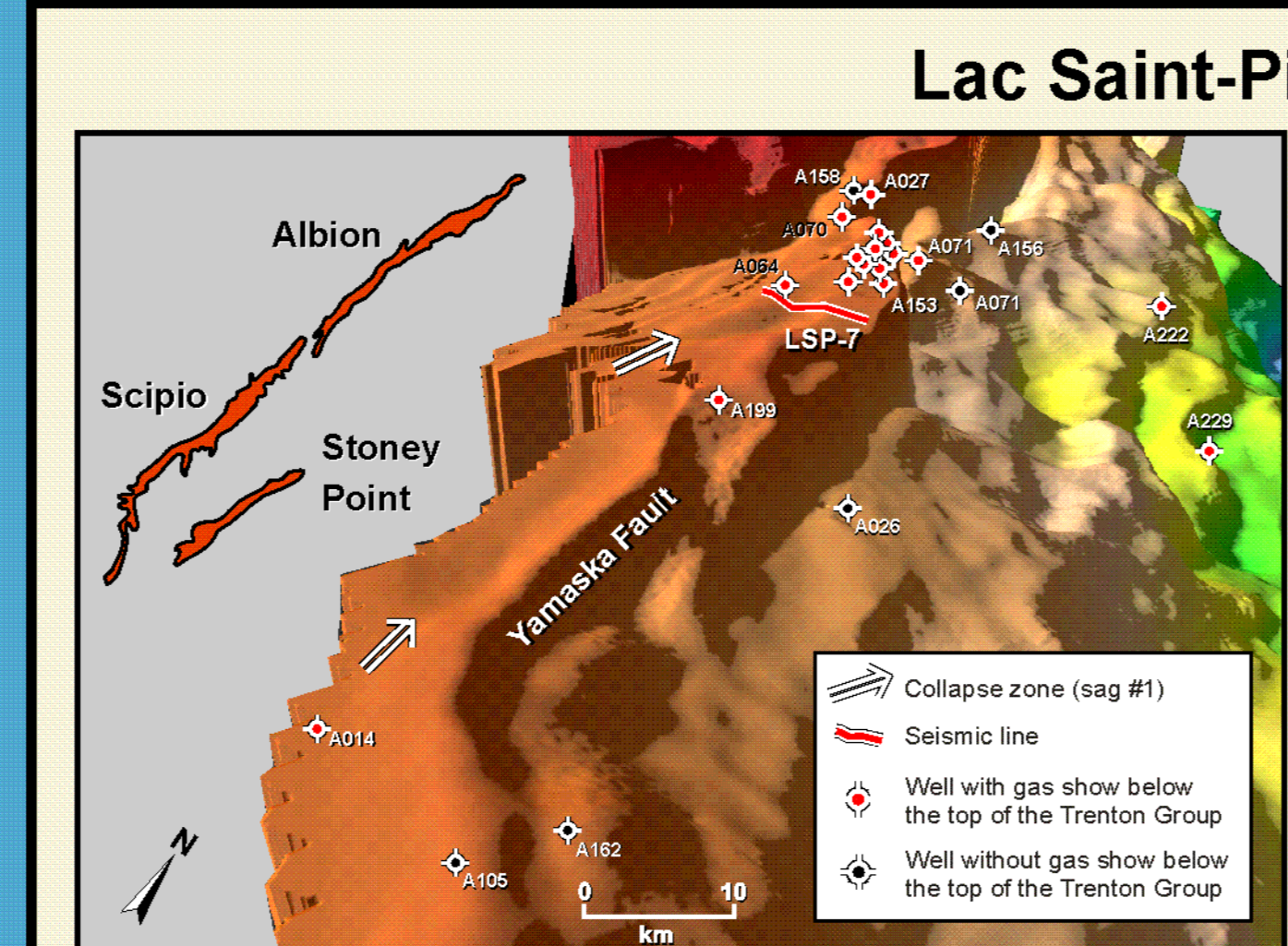


SRTM digital elevation model map of the St. Lawrence Lowlands area showing the large quantity of seismic lines acquired since the early sixties. However, note that a large part of the seismic data was acquired prior to 1985.

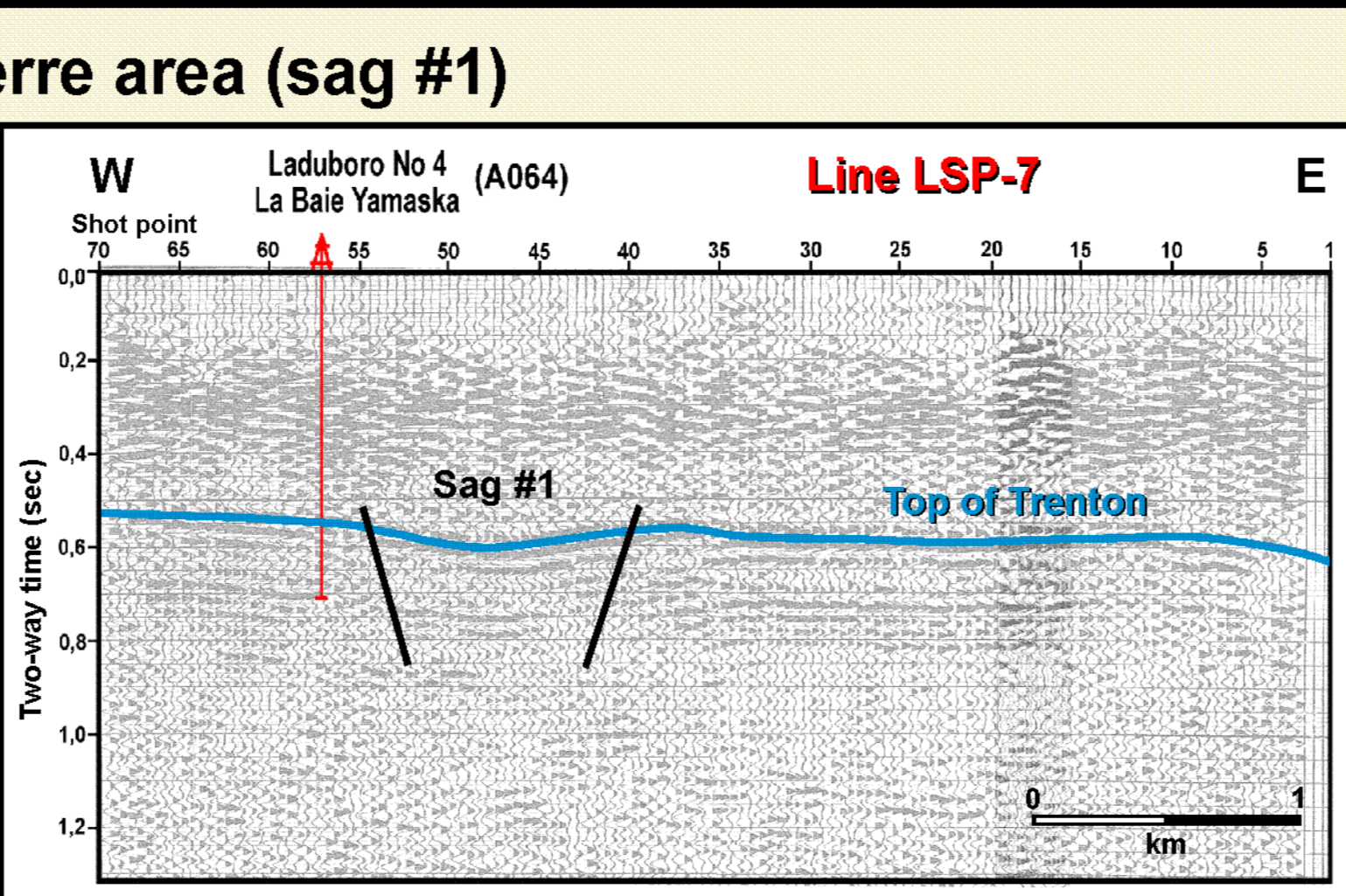


SRTM digital elevation model map showing the present-day distribution of the oil and gas exploration licences in the St. Lawrence Lowlands and southern Appalachians. A total of 11 different landholders own the rights to nearly 3 million hectares (20 700 km²) of land in this area, a figure which is unprecedented in history and explained by the recent hydrocarbon discoveries in hydrothermal dolomite reservoirs in nearby New York State and Ontario.

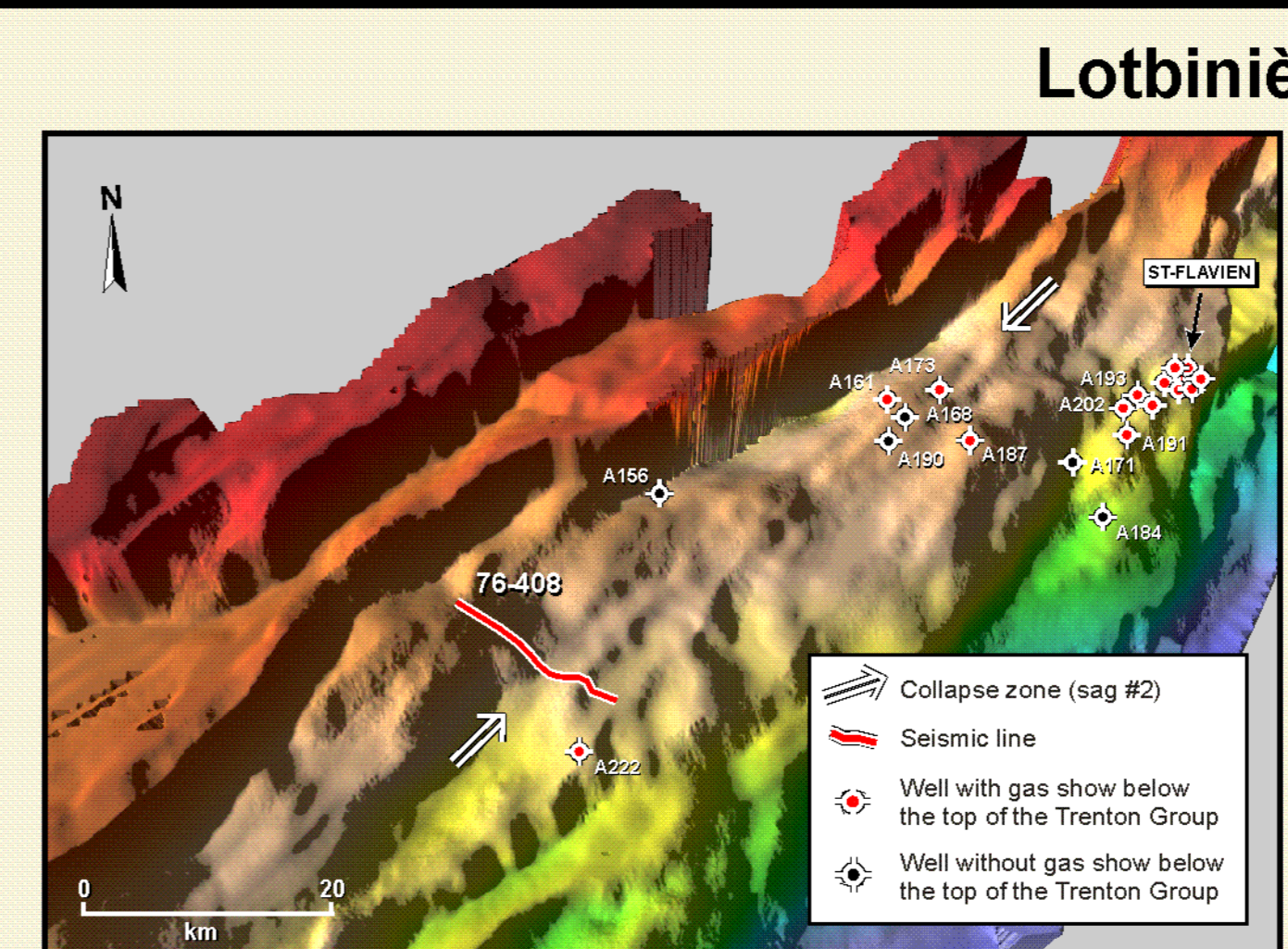
Hydrothermal dolomite play - Structural collapse zones (sags)



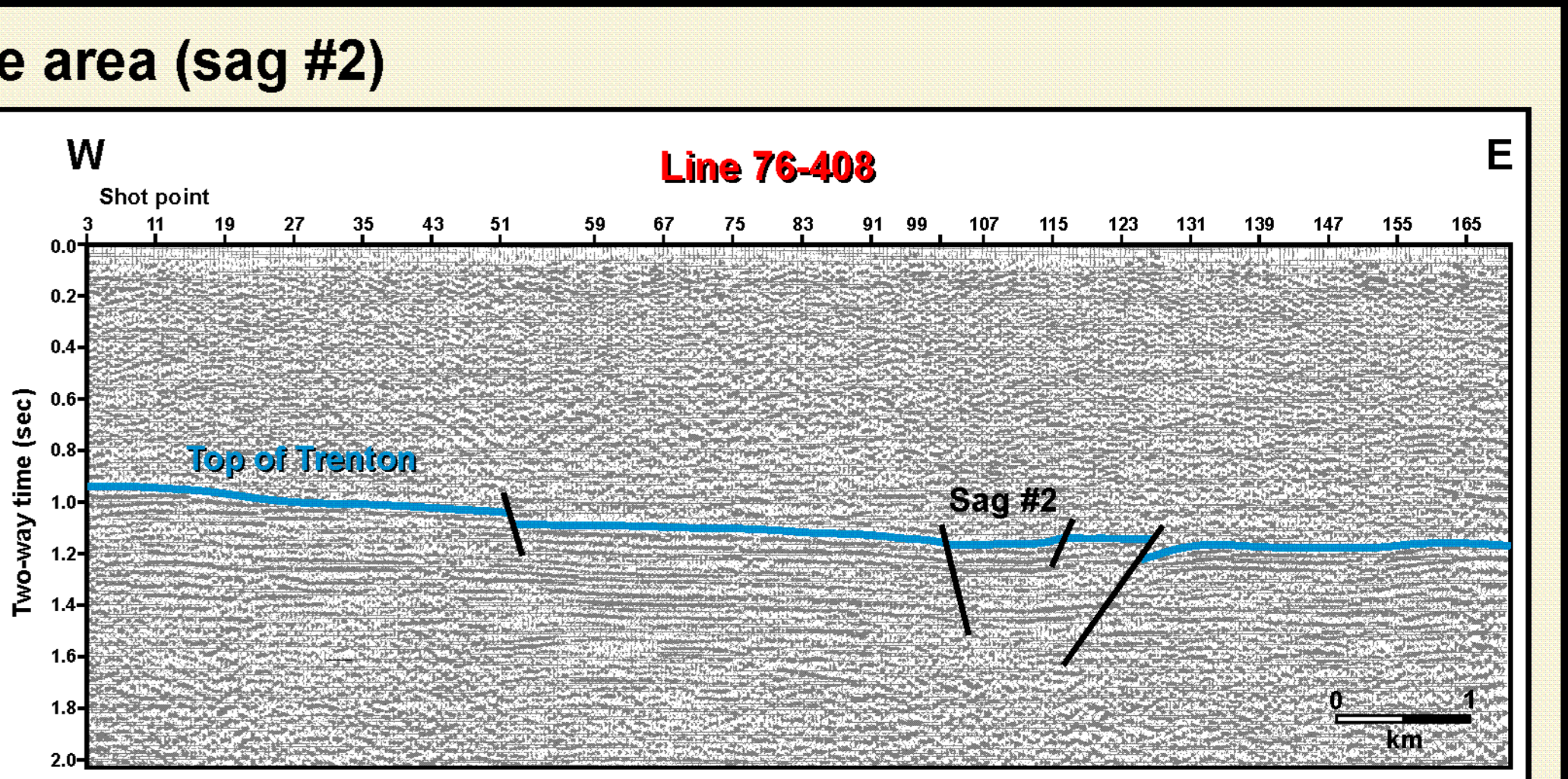
3D time-structure map of the Precambrian basement in the lac St-Pierre area showing a close-up view of a graben-like collapse zone (sag #1) that follows the trend of the Yamaska Fault. The latter structure shows a large vertical displacement, and likely formed during the Cambrian rifting event to be later reactivated during the Ordovician Taconian Orogeny. Note that although a significant number of wells located in the vicinity of the sag have encountered gas shows below the top of the Trenton, the structure itself as never been drilled. Interestingly, its size is comparable to the sag structure of the giant Albion-Scipio-Stoney Point oil and gas field in Michigan.



Seismic profile of line LSP-7, which runs across the structural sag outlined in the previous figure (see map for exact location of seismic line). The sag is very nicely imaged on the profile, with a downdrop of the reflectors within the graben-like structure. The width of this fault-bounded depression is between 800 and 1000 meters, which is similar to the size of the hydrocarbon-rich sag structures hosting the world-class Albion-Scipio (Michigan) and Finger Lakes (New York) hydrothermal dolomite fields. The presence of deep faults penetrating the Precambrian basement plays a key role in providing conduits for the migration of hydrothermal fluids. This ultimately leads to diatomization of the host limestones and formation of the reservoir through increases in porosity and permeability of the host rocks.



3D time-structure map of the Precambrian basement in the Lotbinière area showing a close-up view of a (perhaps several?) graben-like collapse zone (sag #2) that can be followed along strike for a distance of over 50 km. A few wells have been drilled in the northeastern part of the structure, and two of them have encountered gas shows below the top of the Trenton. The location of seismic line 76-408 is shown on the map, and the profile is presented in the next figure.



Seismic profile of line 76-408, which crosses the southern part of the observed sag in the Lotbinière area. Again, a faint depression of the reflectors associated with the top of the Trenton Group (and rocks below) is observed, corresponding to the interval where the seismic line passes over the sag structure observed on the adjacent time-structure map. Note that the lowermost, well-defined reflector, which corresponds to the top of the Precambrian basement, as a similar synclinal-like shape. Either the sag affected the basement rocks, or more interestingly, this lowermost downdrop of the reflector represents a seismic artifact, termed pulled-updown, which typically occurs underneath gas-rich layers due to the lower velocity of gas relative to rocks.