The Stability Of Fault Systems In The South Shore Of The St. Lawrence Lowlands Of Québec Implications For Shale Gas Development

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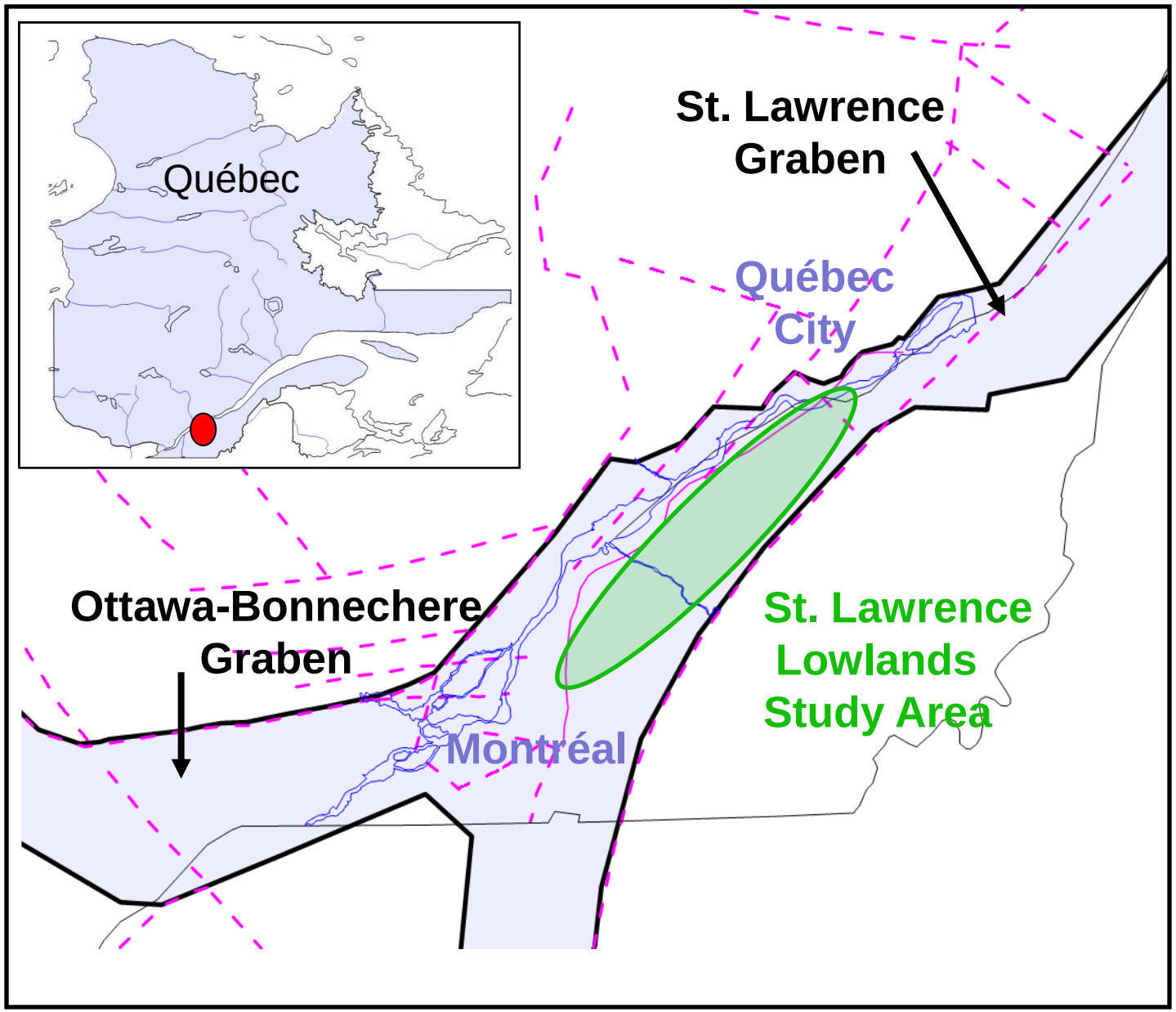
Outline

- Majority of Québec Utica shale gas exploration in south shore area of St. Lawrence Lowlands
- Natural and man-made earthquakes in south shore
- Tectonic domains, in-situ stress and fault styles
- Fracture stimulation containment within shale gas target
- Hydrofracturing Utica very unlikely to damage surface structures or shallow aquifers

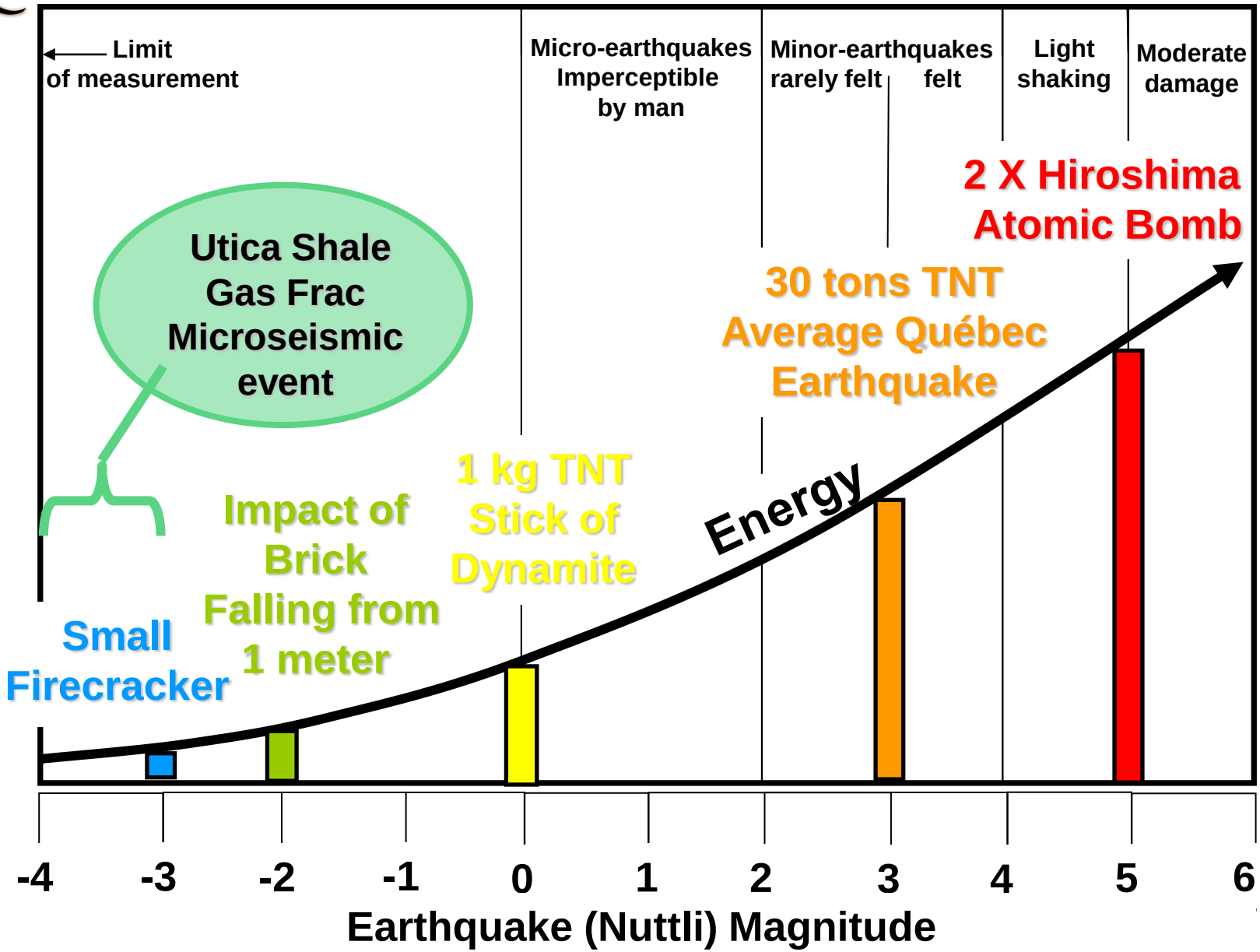
Study Area


Québec
St. Lawrence
Graben
Québec
City
Ottawa-Bonnechere
Graben
St. Lawrence
Lowlands
Study Area
Montréal

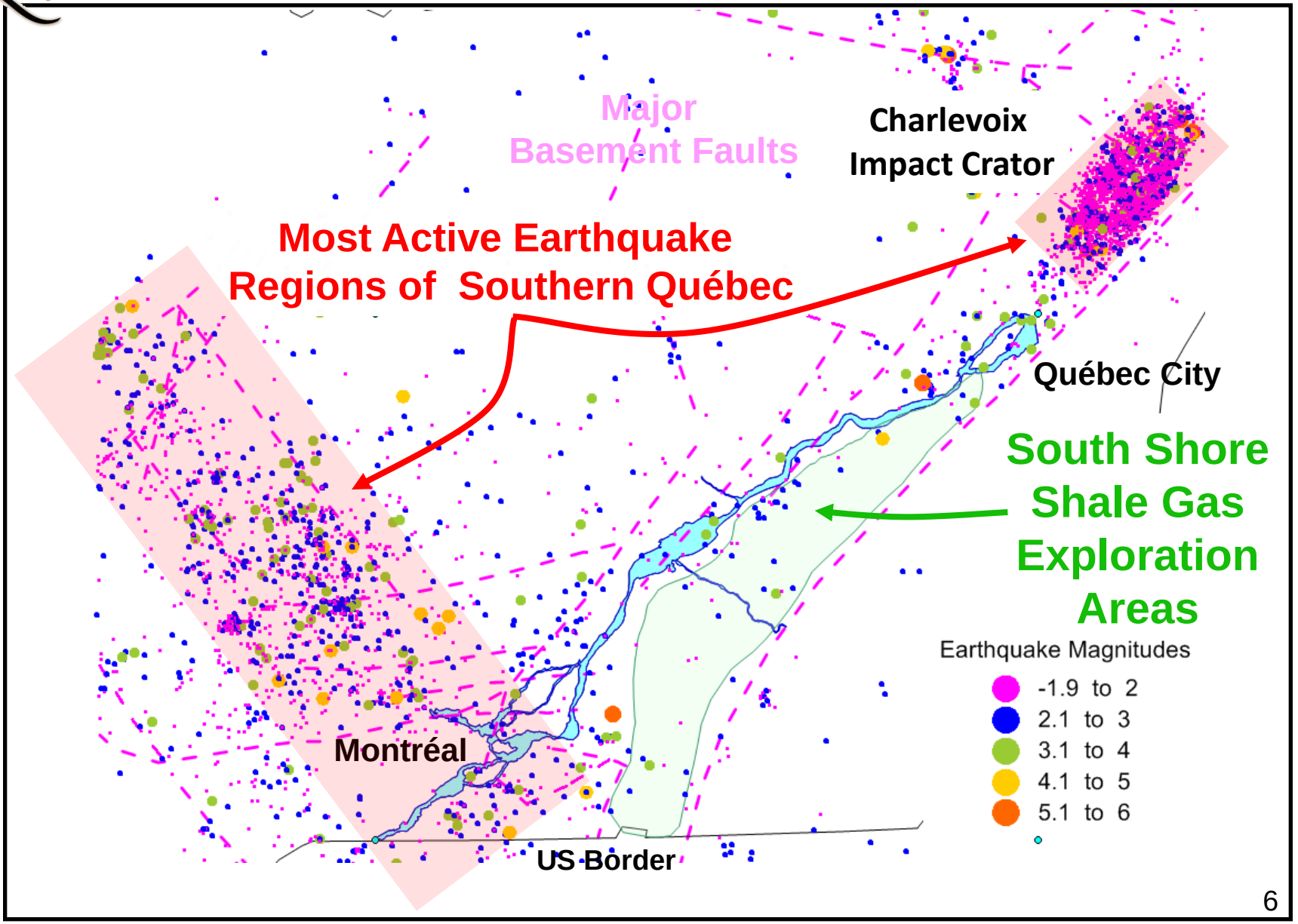
Earthquake

- A **sudden release of energy** in the earth's crust or upper mantle as a result of fault slip
- Destructive at magnitudes of 5 and above
- Minor earthquakes magnitude 2 to 5
- Micro-earthquake is a very low intensity earthquake generally magnitude 2 or less

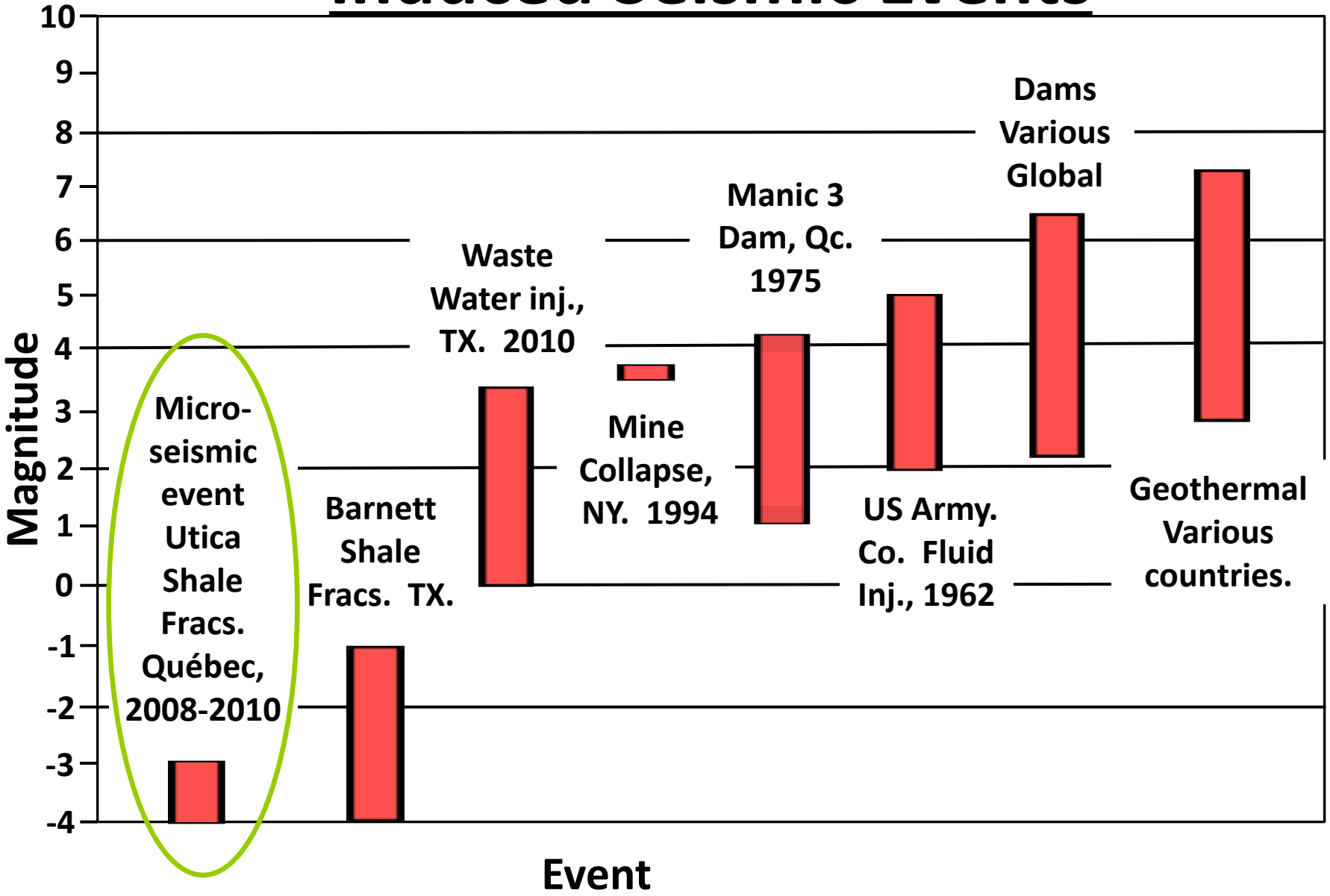
Earthquake Magnitude Comparison



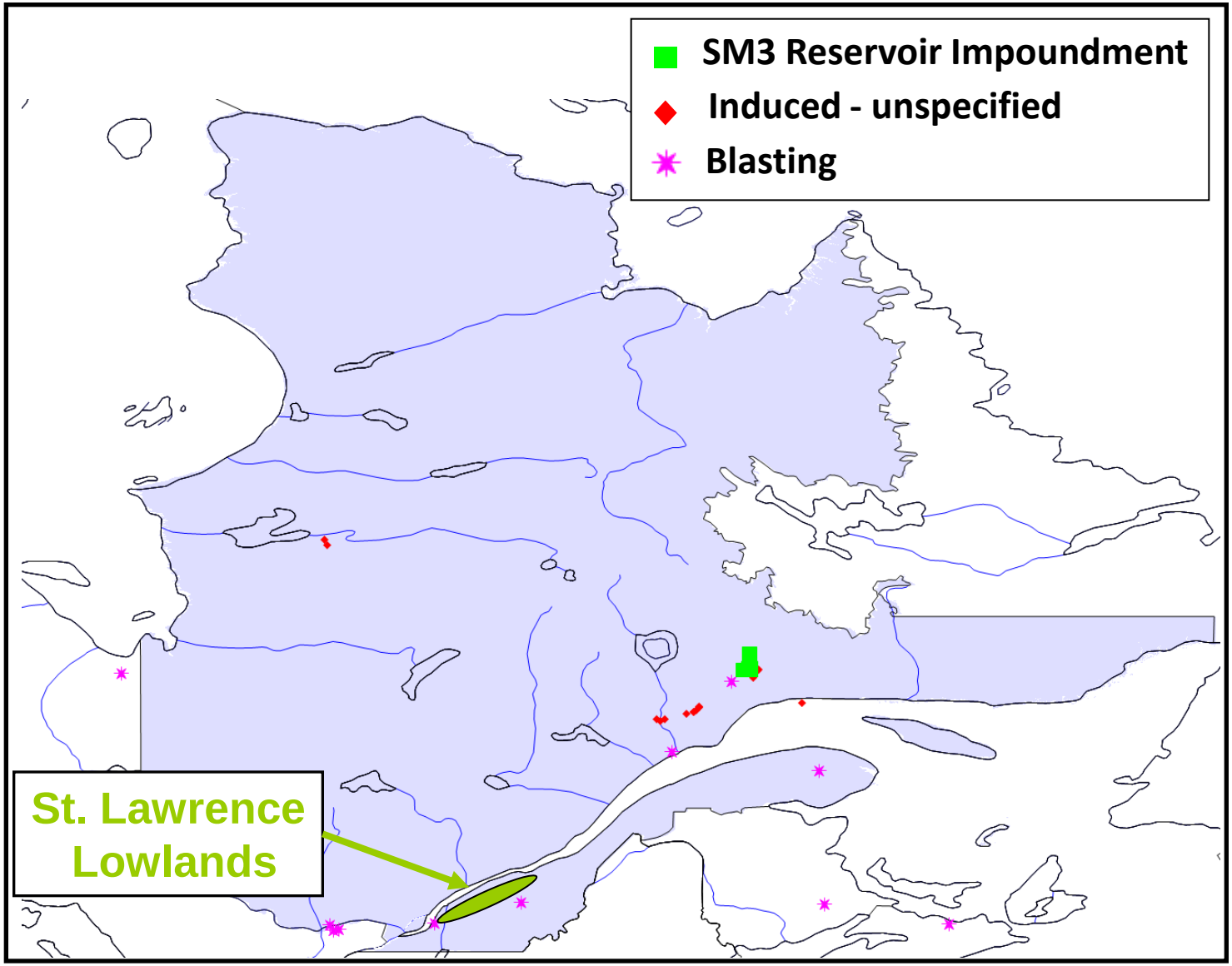
Southern Québec Earthquakes



Comparison of Induced Seismic Events



Induced Seismic in Québec



Risk?

The Earth Sciences Division of the U.S. Department of Energy's Lawrence Berkeley National Laboratory has studied induced seismicity relating to oil and gas activity and to date **hydraulic fracturing has resulted in no known surface earthquakes felt by man**

Update: Blackpool U.K. 2.3 M earthquake attributed to fluid injection following hydraulic fracturing. Felt at surface because of shallow focal depth, very unusual circumstances, no damage to building or aquifers

Stratigraphy

Queenston/Lorraine

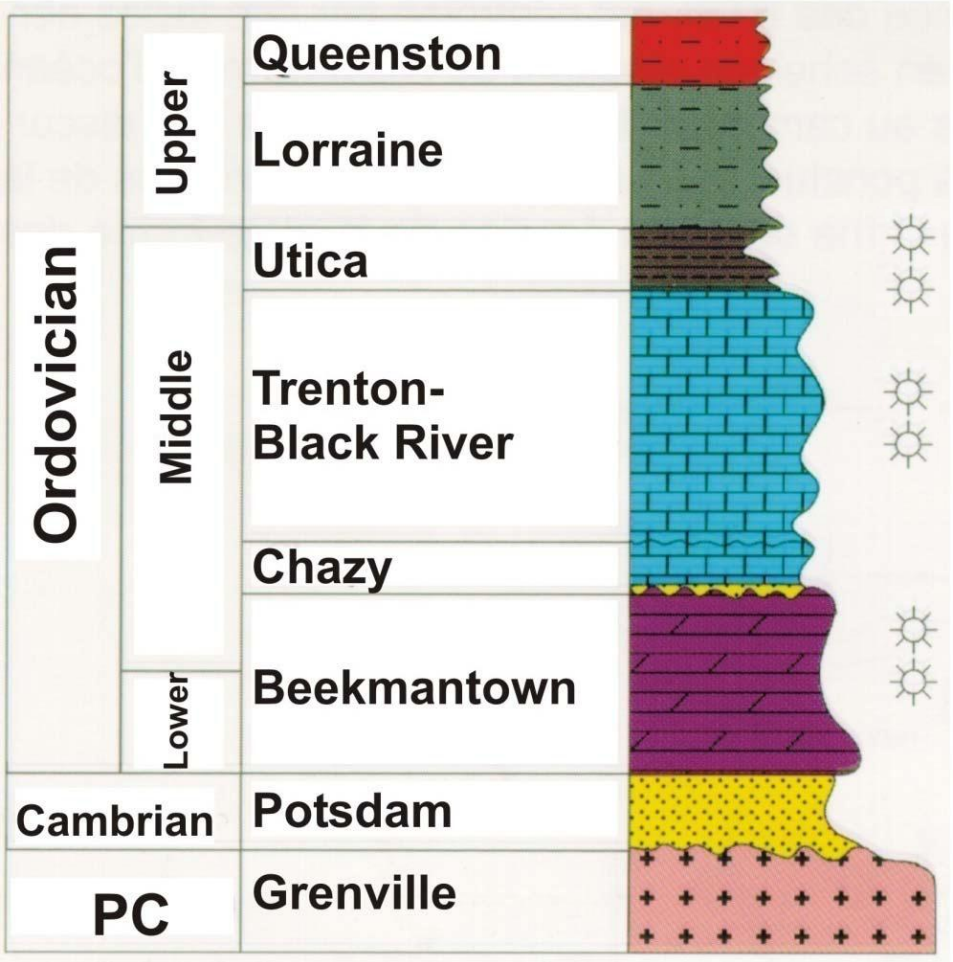
Sandstone, siltstone and shale

Utica Shale Gas target

Quartz/carbonate organic shale

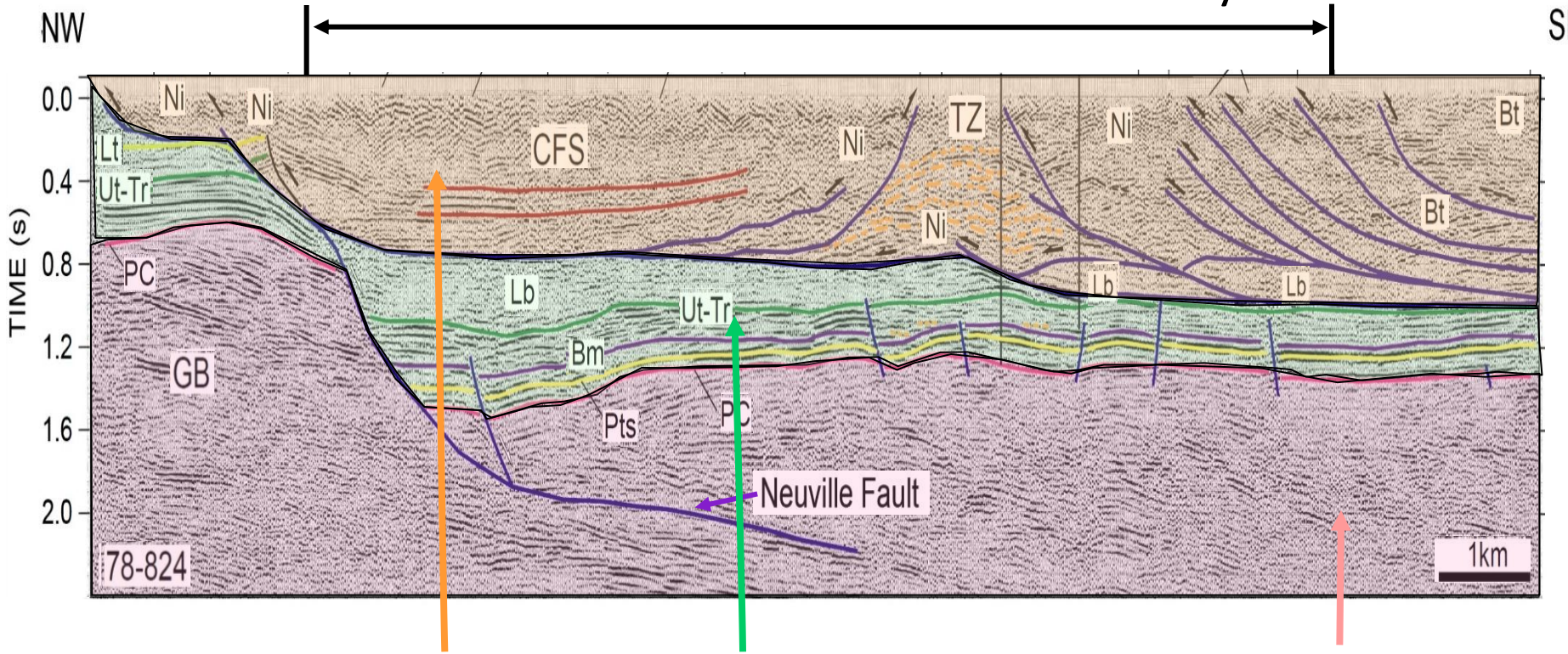
Potsdam

Regional seismic reflector



3 Major Tectonic Domains

South Shore Utica Shale Gas Fairway



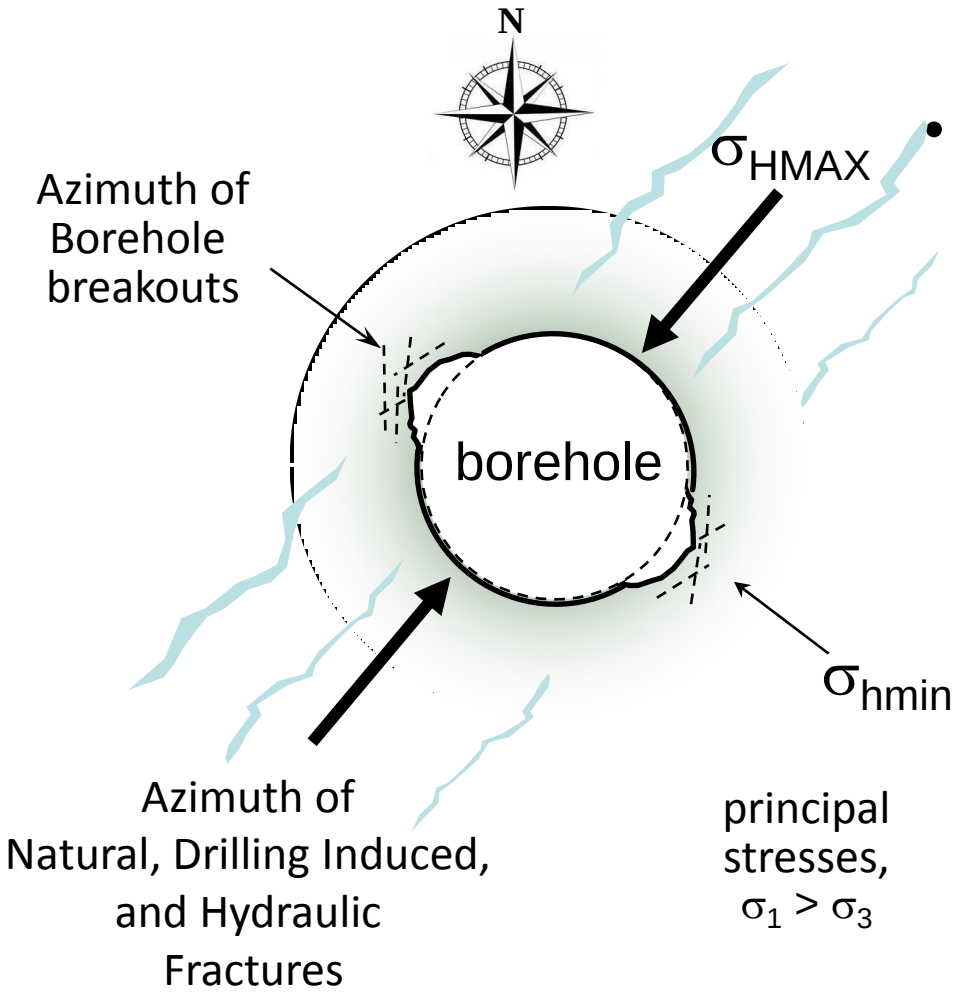
Disturbed Domain
Convergent margin Sediments
U Ordovician
Lorraine and Queenstown

Autochthonous Domain
Passive margin Sediments
Cambro-Ordovician
Shale gas target

Grenville Basement
Granite & Metasediments

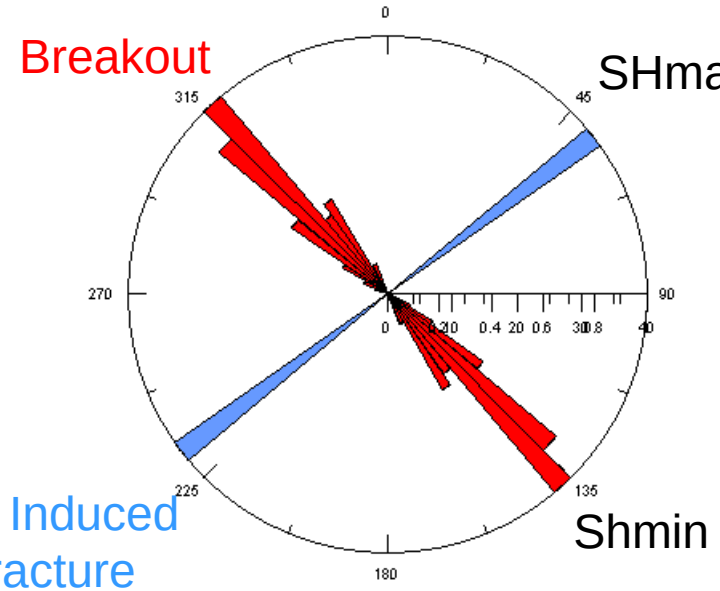
Image Modified from: TRIANGLE ZONES IN ACCRETIONARY WEDGES: EXAMPLES FROM THE QUÉBEC APPALACHIANS AND PHYSICAL MODELING
Konstantinovskaya et al, AAPG Poster, 2010

Borehole Breakouts, Fractures and In-situ Stresses



- Bore hole break outs in the direction of Shmin = 315 degrees
- Drilling induced fractures in direction of SHmax = 45 degrees

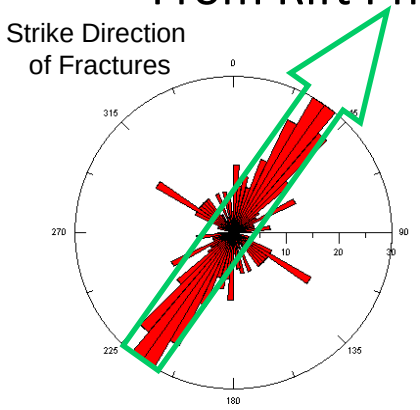
Present day in-situ Stress

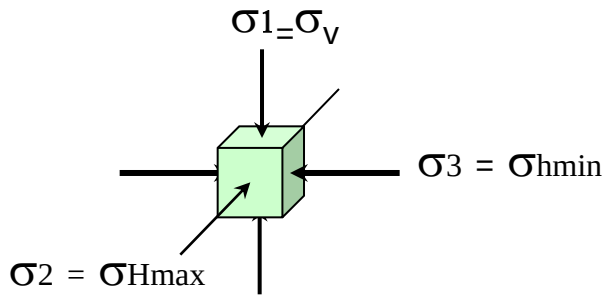


Autochthonous Domain

- Tensional passive margin Normal faulting
- Result of opening of the Iapetus Sea
- Hydraulic fractures propagate vertically
- 488.3–443.7 ***million years*** old
- Fractures in direction of SHmax = 38 degrees

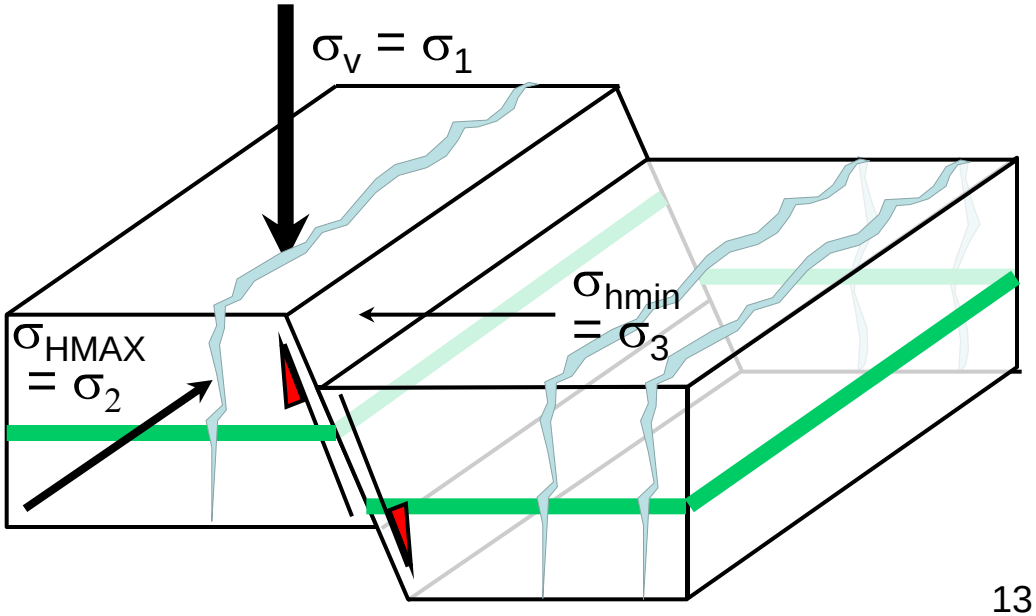
Old Healed Fractures From Rift Phase





In Situ Stresses

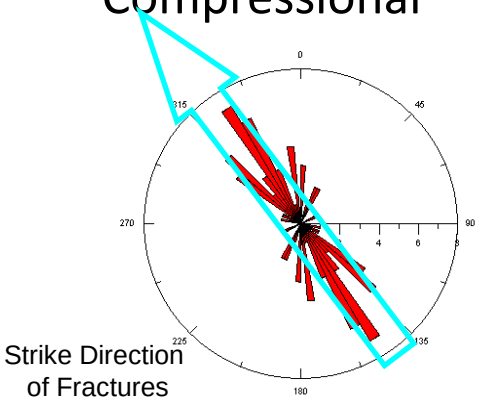
σV>σHmax>σhmin



Disturbed Domain

- Compressional thrusting
- Hydraulic fractures in direction of SHmax = 325 degrees

Open Fractures From Compressional



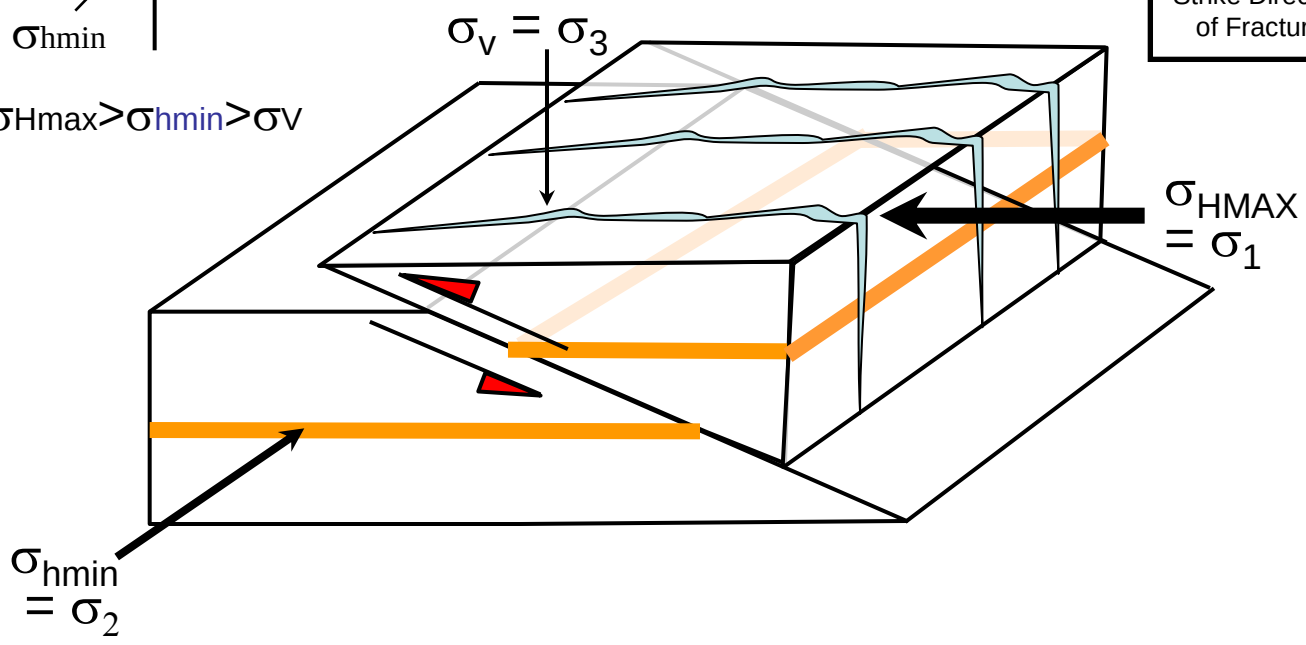
In Situ Stresses

$\sigma_{3}=\sigma_{v}$

$\sigma_1 = \sigma_{hMAX}$

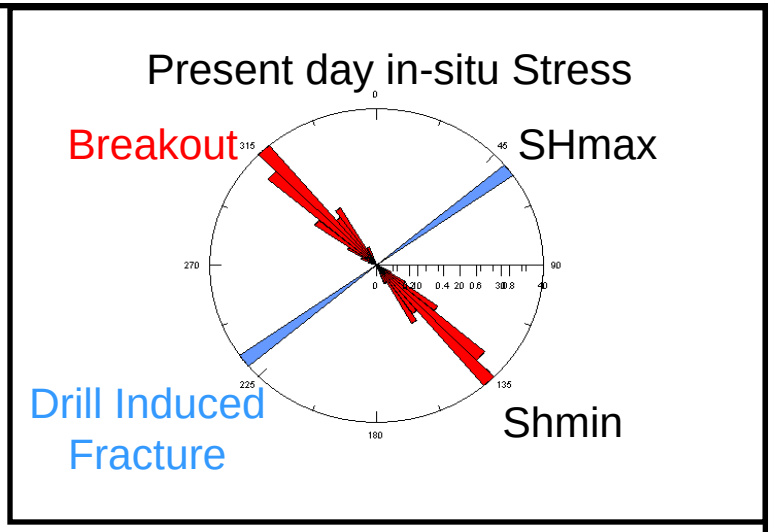
$\sigma_2 = \sigma_{hmin}$

$\sigma_{Hmax} > \sigma_{hmin} > \sigma_V$

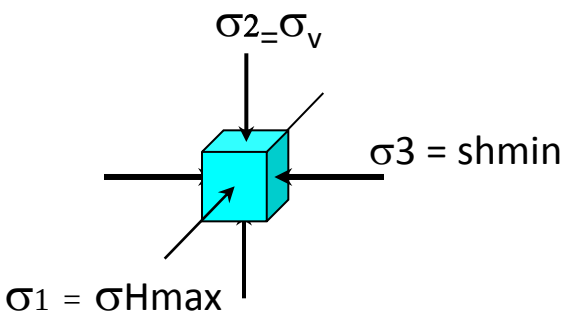


Wrenching

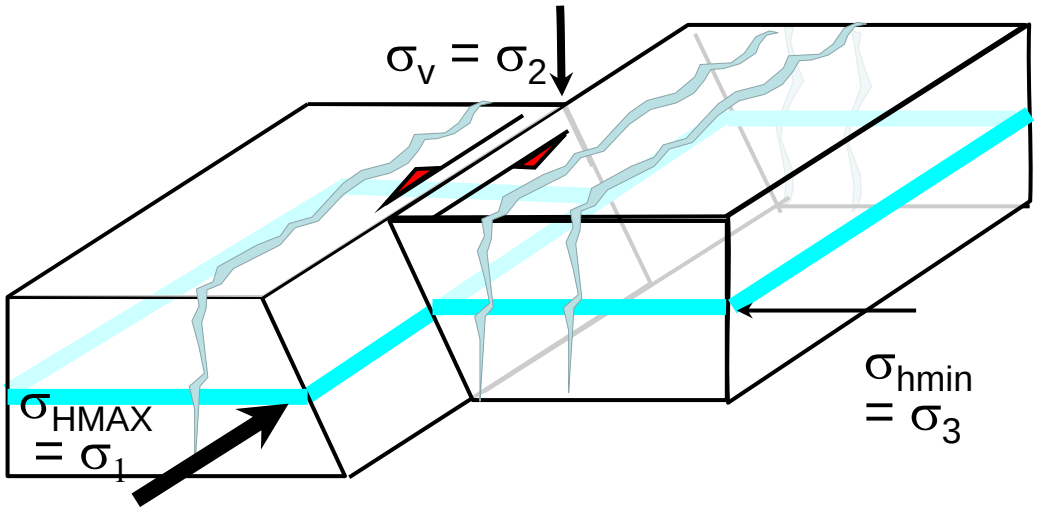
- Bore hole break outs in direction of Shmin = 315 degrees
- Drilling induced fractures in direction of SHmax = 53 degrees



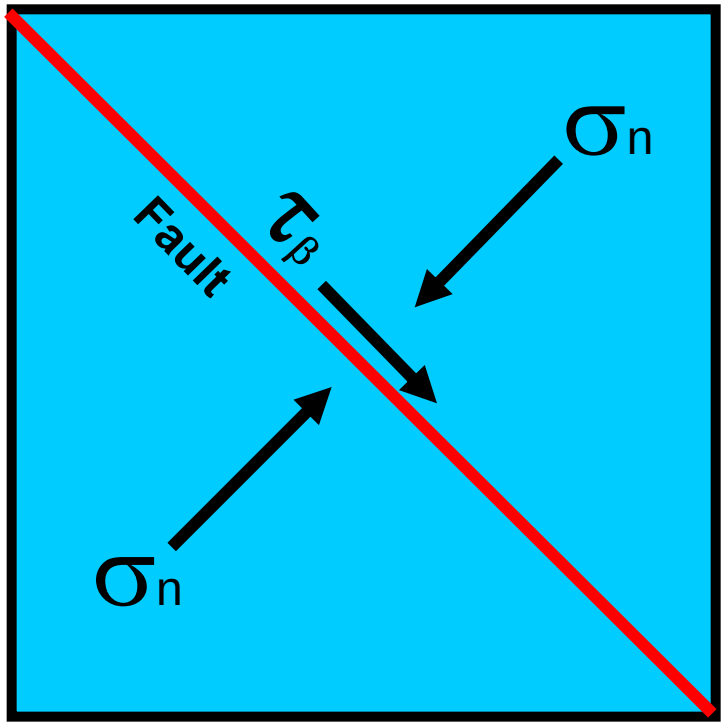
In Situ Stresses



σHmax>σv>σhmin



Fault Slip



$$\text{Coulomb Stress} = \tau_\beta + \mu(\sigma_n + P)$$

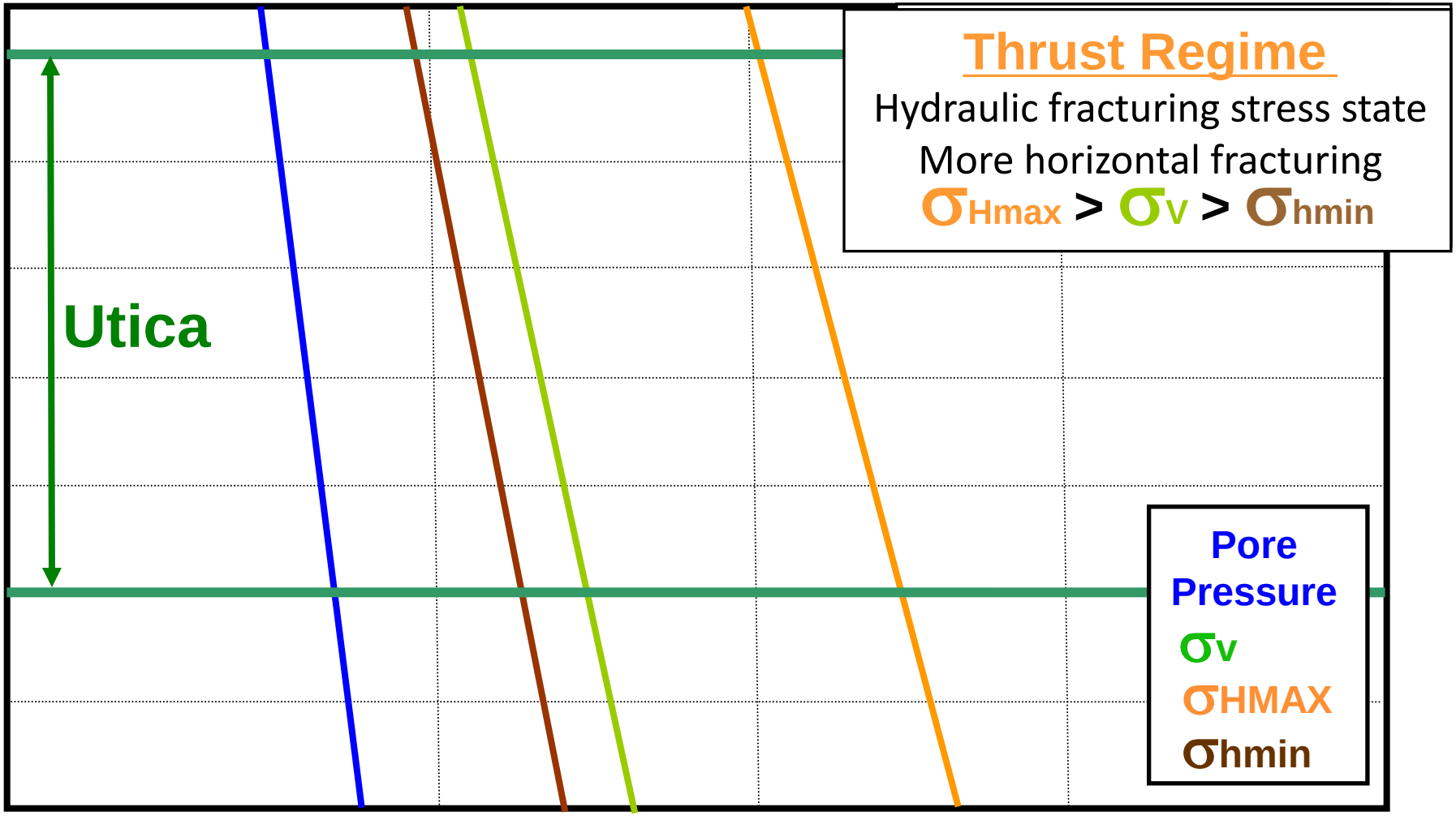
τ_β = **shear stress**

μ = **coefficient of friction**

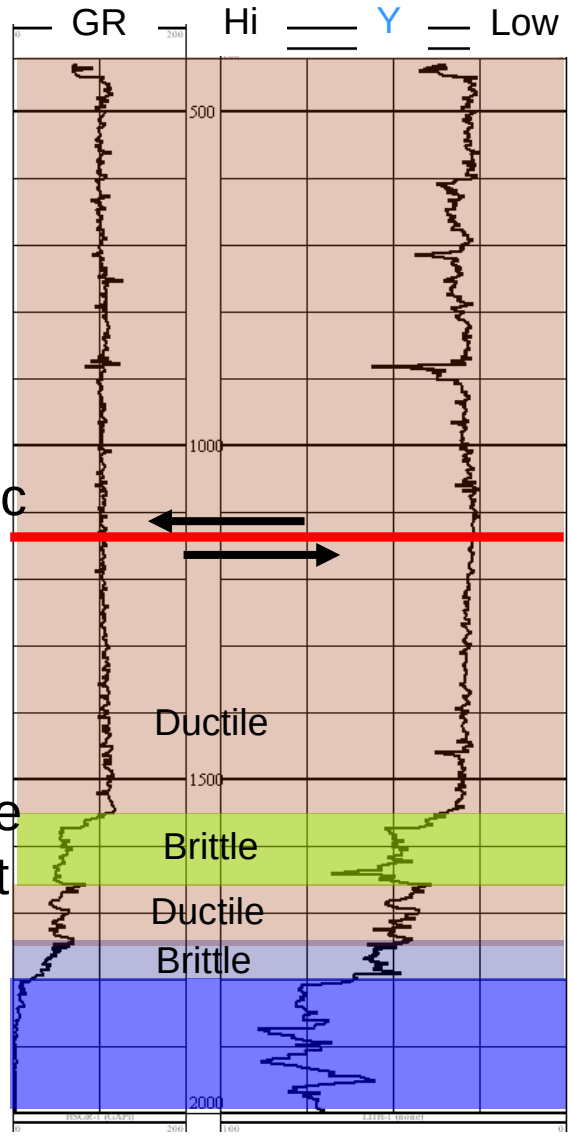
P = **pore pressure**

σ_n = **normal stress**

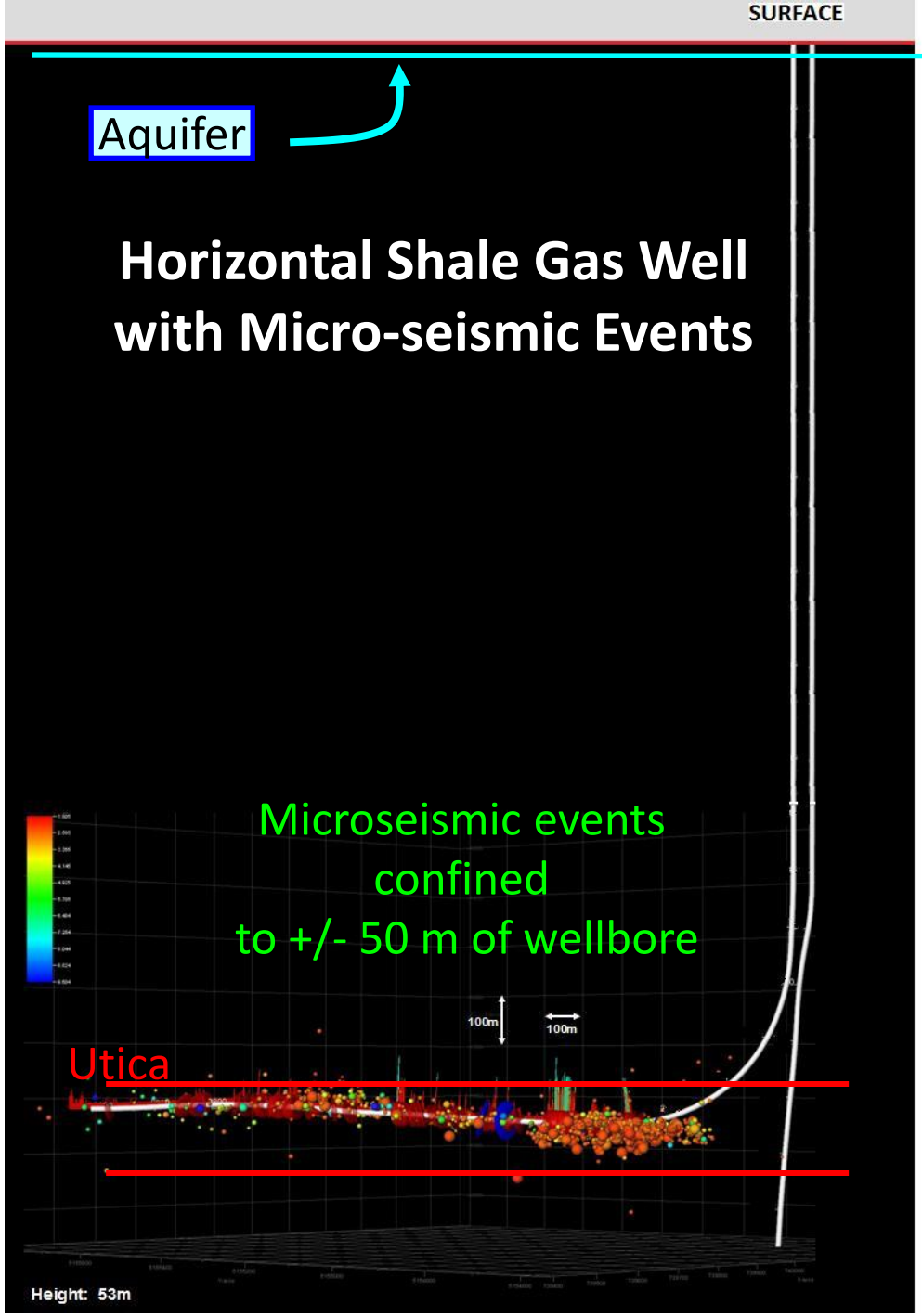
Stress Affects on Completions



Hydraulic Fracture Height Containment

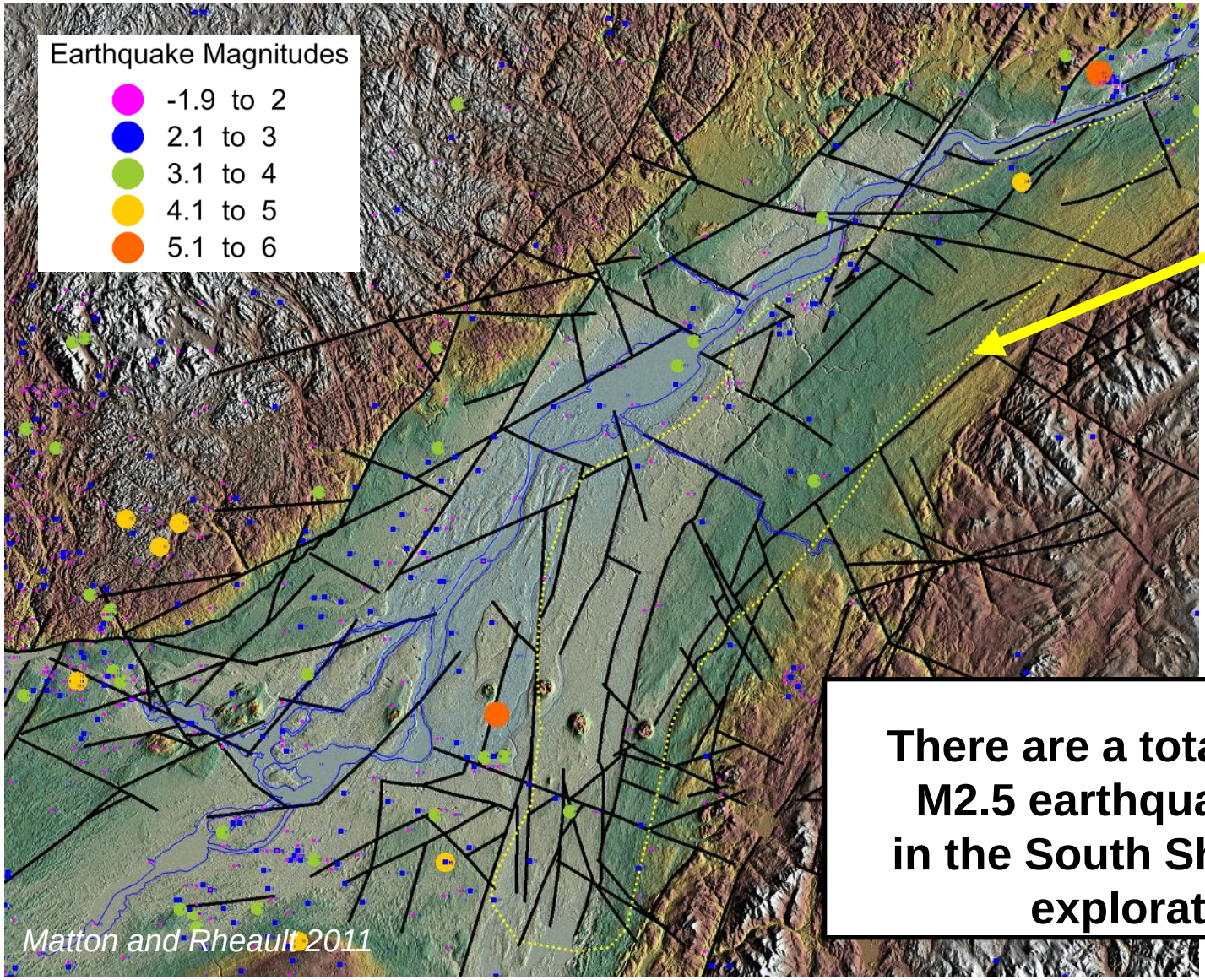


- Contrasts in fracture toughness form barriers
- High Young's modulus (Y)=Brittle=low toughness
- Low Young's modulus=Ductile=high toughness
- Frac target a brittle zone with low toughness between ductile zones
- High toughness ductile zones are barriers
- Thrust fault are barriers



- Minimal vertical height growth
- Formations above and below zone likely acting as barriers
- No communication or propagation to shallow aquifers.

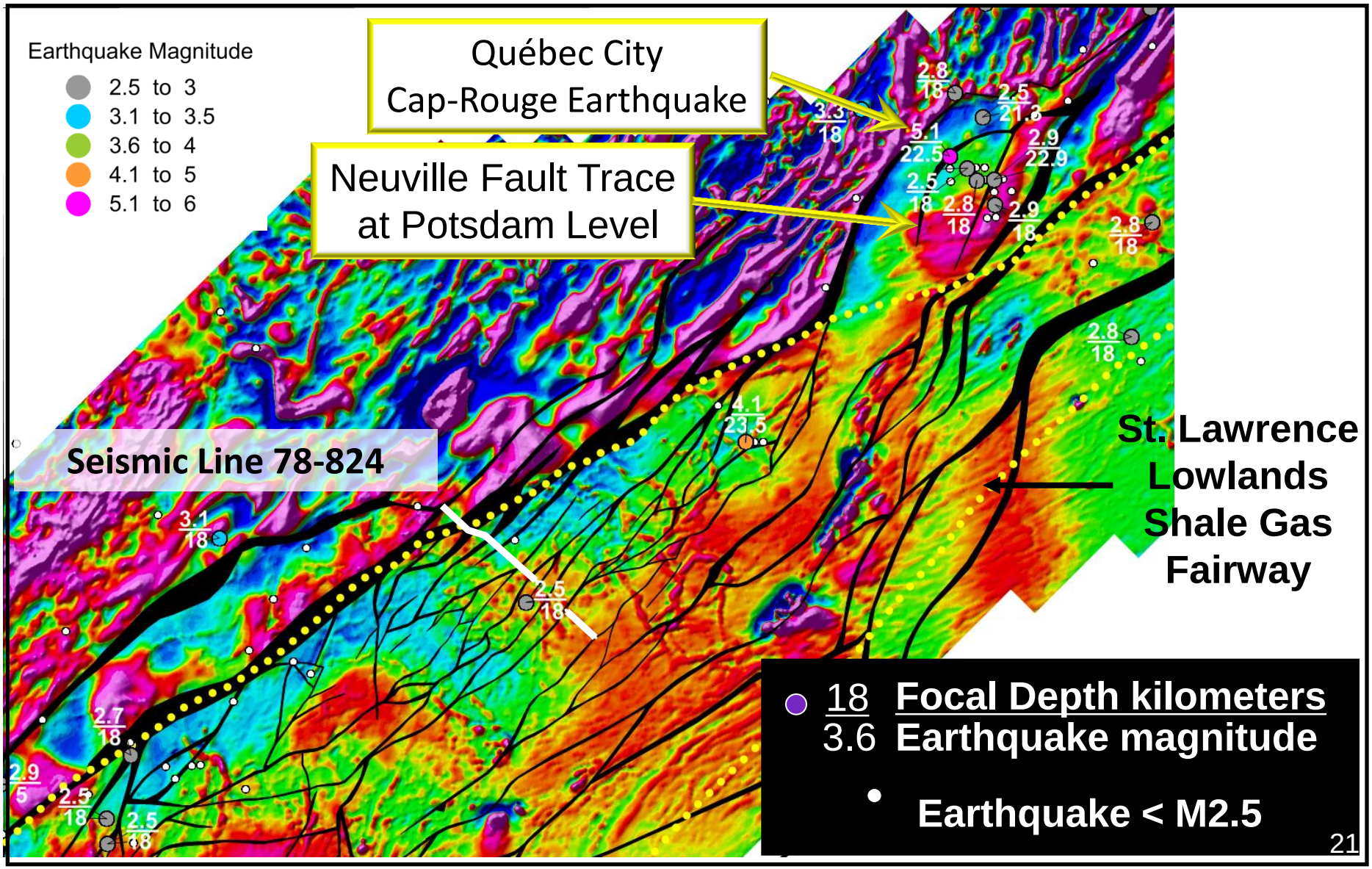
Surface Lineament Analysis



South Shore Shale Gas Exploration Area (Study Area)

There are a total of 14 minor > M2.5 earthquakes recorded in the South Shore Shale Gas exploration Area

Inset Map


Earthquake Magnitude
2.5 to 3
3.1 to 3.5
3.6 to 4
4.1 to 5
5.1 to 6
Québec City
Cap-Rouge Earthquake
Neuville Fault Trace
at Potsdam Level
Seismic Line 78-824
St. Lawrence
Lowlands
Shale Gas
Fairway
18 Focal Depth kilometers
3.6 Earthquake magnitude
Earthquake < M2.5

Summary

- South shore shale gas exploration region is in stress relaxed state and less prone to fault reactivation
- No correspondance between natural and man-made earthquakes and shallow faults in study area
- In- situ stress, rock toughness, and thrust faults all act as barriers to vertical propagation of fractures and faults
- Fracture stimulations are contained within shale gas target
- Hydrofracturing is very unlikely to cause damage to shallow aquifers or surface structures

Acknowledgements

Michael Binnion Questerre Energy Corporation

Marianne Molgat Talisman Energy Inc

Geoff Rait, - IEX Structural Geologist, Talisman Energy

Scott McLellan, - IEX Geophysicist, Talisman Energy

Heather Davey Exploration Specialist Geology

Questions?