Plate interior vs plate boundary seismicity: Implications for hazards in Quebec and Ontario

Alex Peace, Jeremy Rimando, Ugi Gusti

2021 Western - ICLR Multi-hazard Risk and Resilience Workshop

McMaster Structural Geology and Tectonics Group,
School of Earth, Environment and Society,
McMaster University

Presentation overview

- Plate tectonics: Boundary vs interior processes
- Numerical stress modelling of intraplate faults in WQSZ
- Challenges of deciphering processes in intraplate regions
- Current work: geological and geophysical fieldwork in QC and ON
- Conclusions and future directions

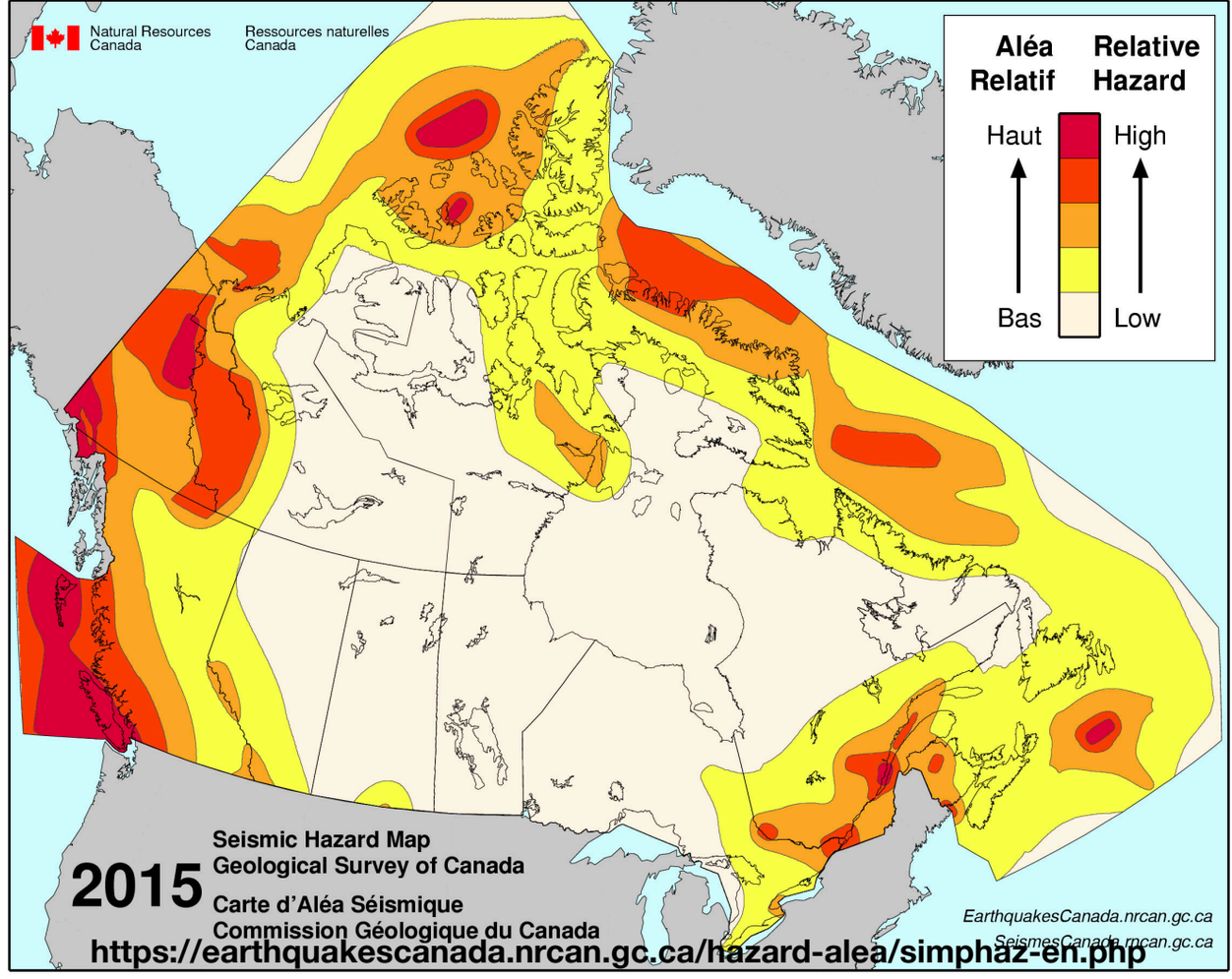
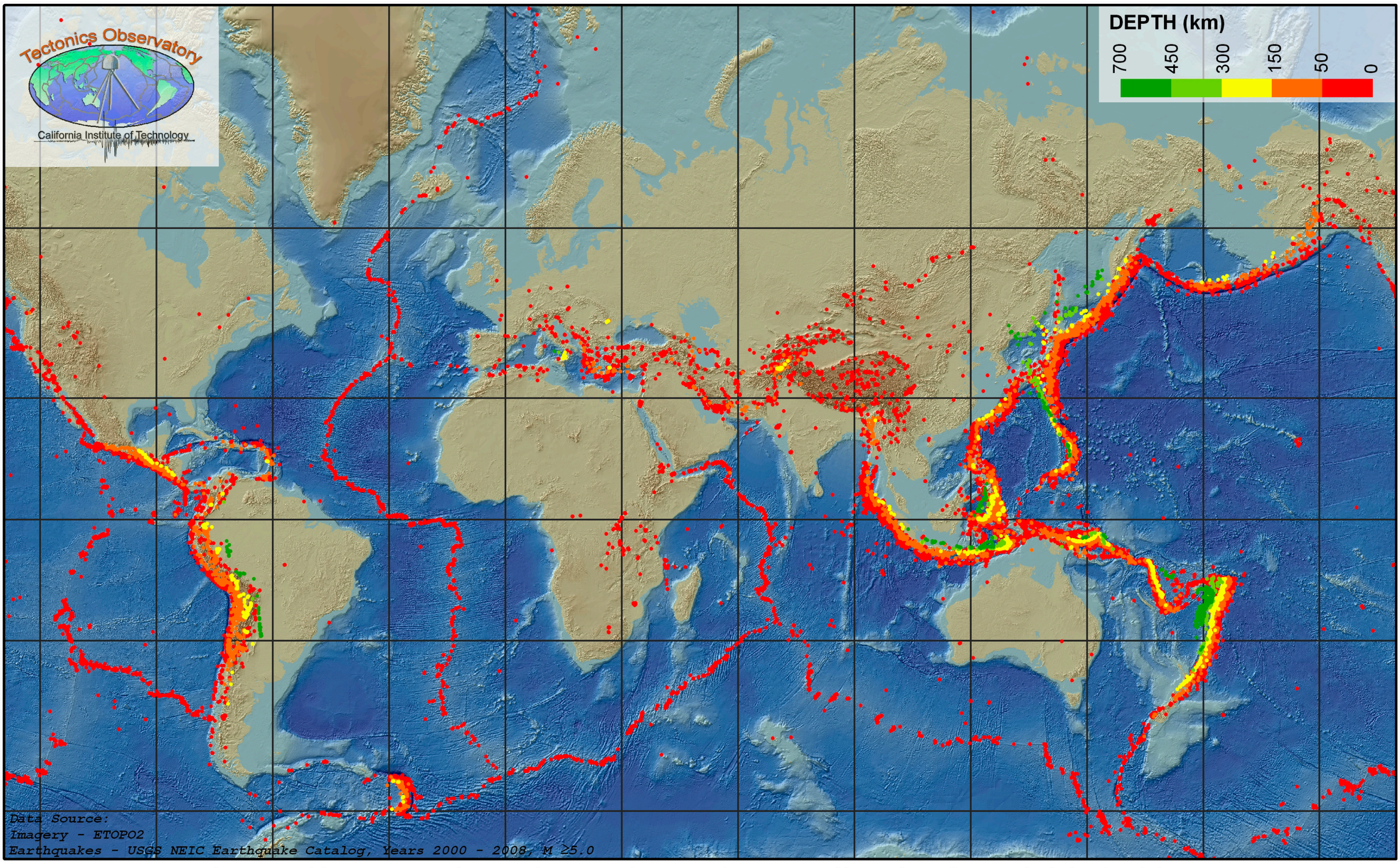
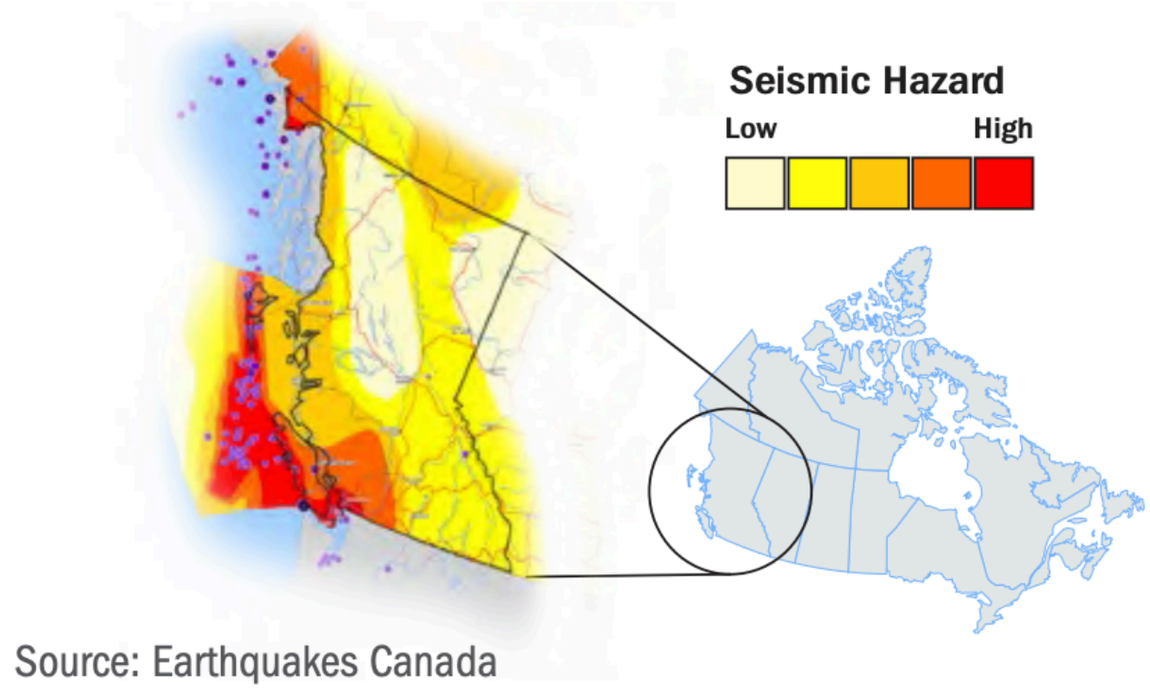


Plate interiors vs boundaries: Global scale

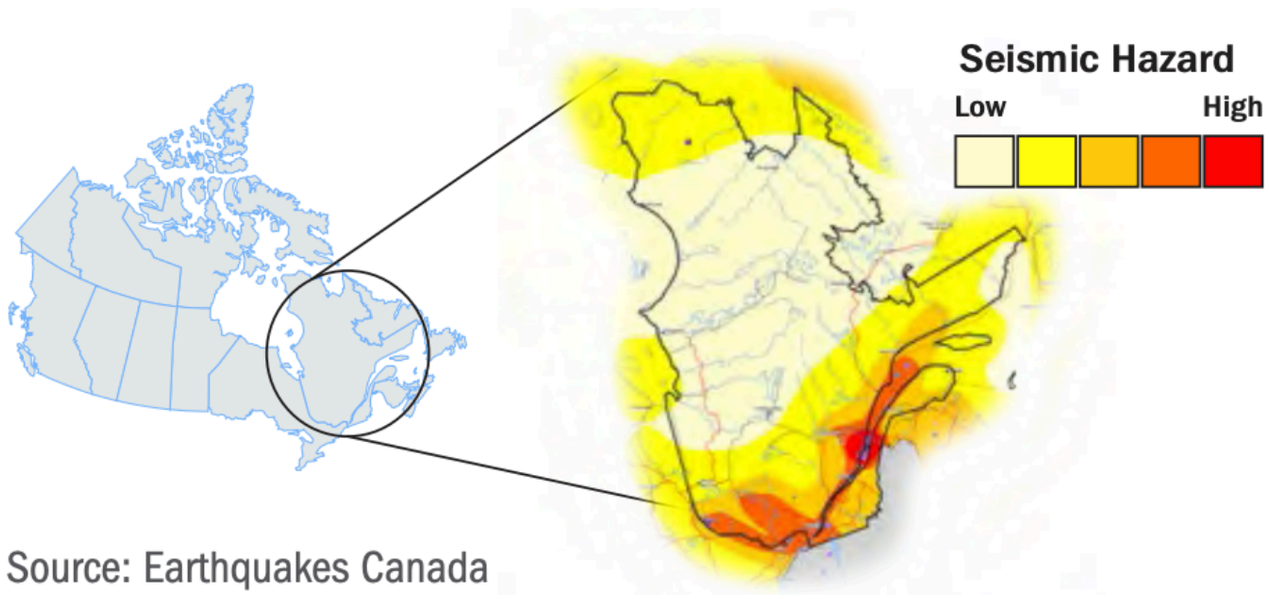


https://www.nsf.gov/news/mmg/mmg_disp.jsp?med_id=64691

Plate interiors vs boundaries: Continent scale



Source: Earthquakes Canada

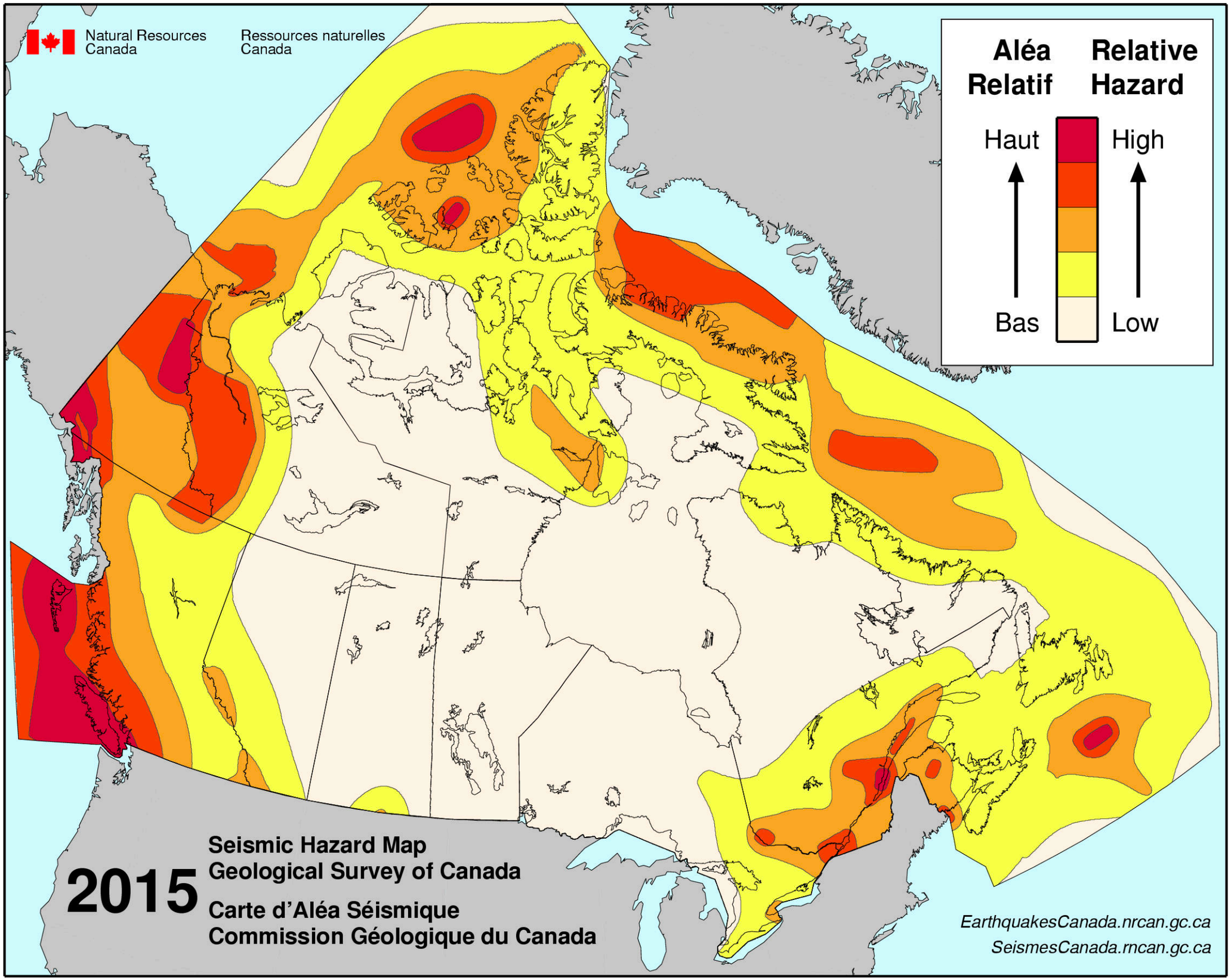


Source: Earthquakes Canada

https://earthquakescanada.nrcan.gc.ca/hazard-alea/earthquake_hazards_risks.pdf

- According to NRCan
  - ~5000 earthquakes occur each year in Canada of which about ~50 of these are felt annually
  - 90% of earthquakes occur at plate boundaries
- BC is one such location and is the most seismically active region in Canada
- In eastern Canada the most active area is the Charlevoix Seismic Zone, QB
- Over the past 350 years, at least 5 earthquakes greater than magnitude 6.0 have occurred in this region.

Seismic Hazard map of Canada (2015)



https://earthquakescanada.nrcan.gc.ca/hazard-alea/simphaz-en.php

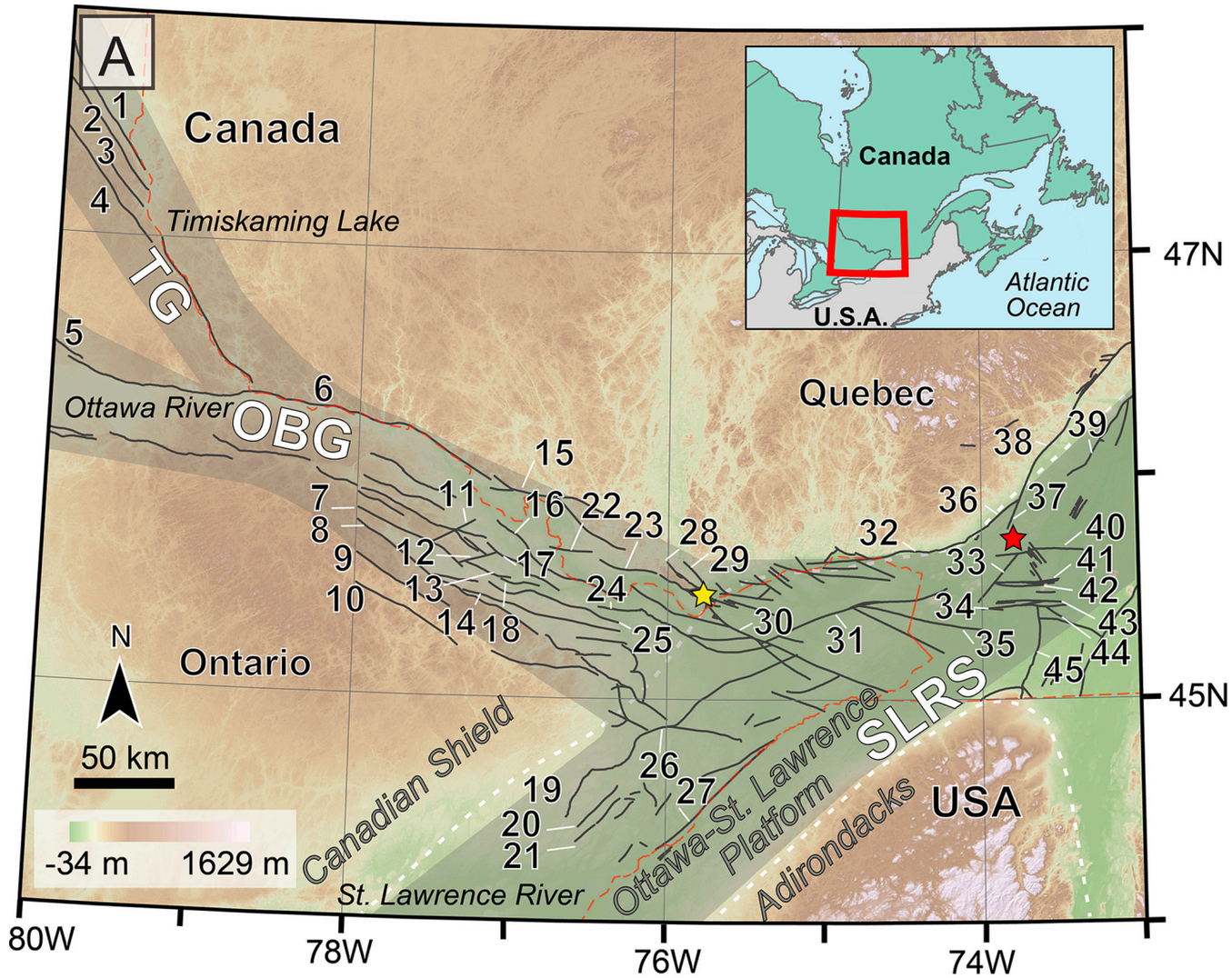
Stress modelling of Western Quebec: Project overview and geological setting

- WQSZ is an intraplate continental region characterized by spatial clustering of weak to moderate recent seismicity

- The WQSZ seismicity results from reactivation of inherited structures under the present-day stress

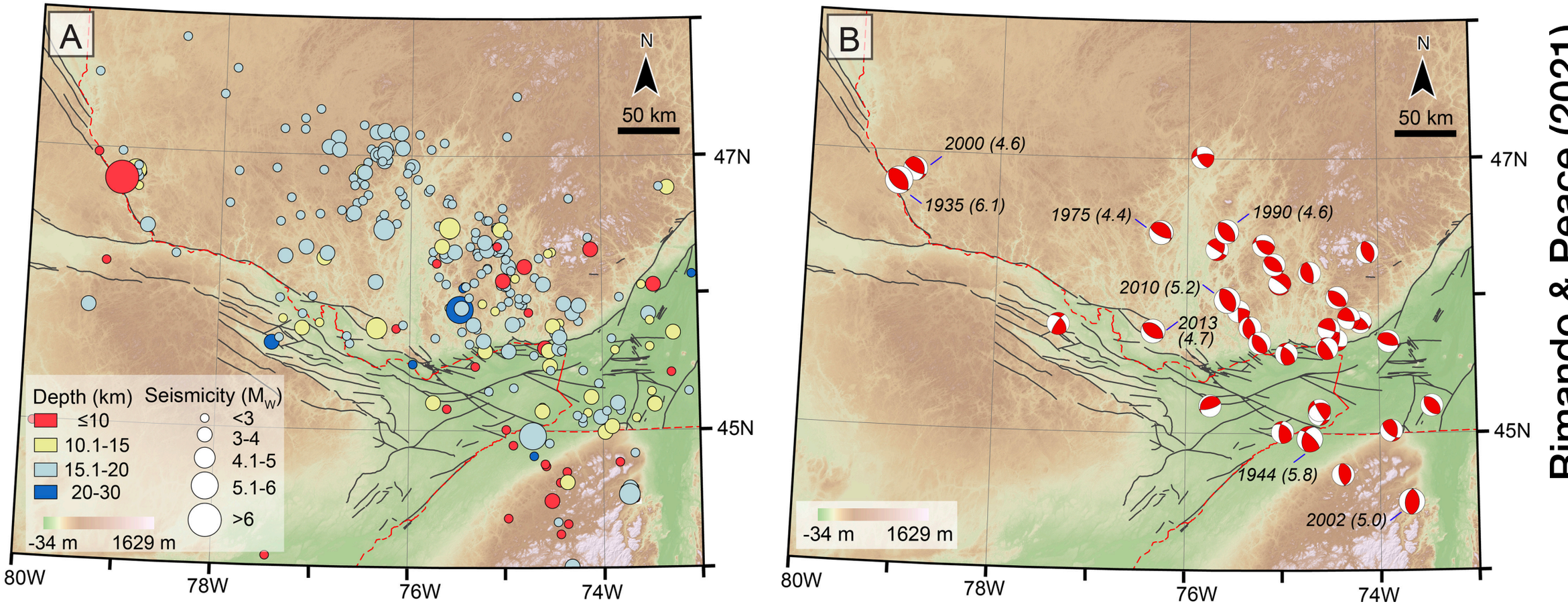
- The regional maximum horizontal stress (S_H) field is NE-SW-striking

- There is also a possible minor stress contribution from glacio-isostatic adjustment



Rimando & Peace (2021)

Stress modelling of Western Quebec: Project overview and geological setting



Seismicity in the western Quebec seismic zone (WQSZ).

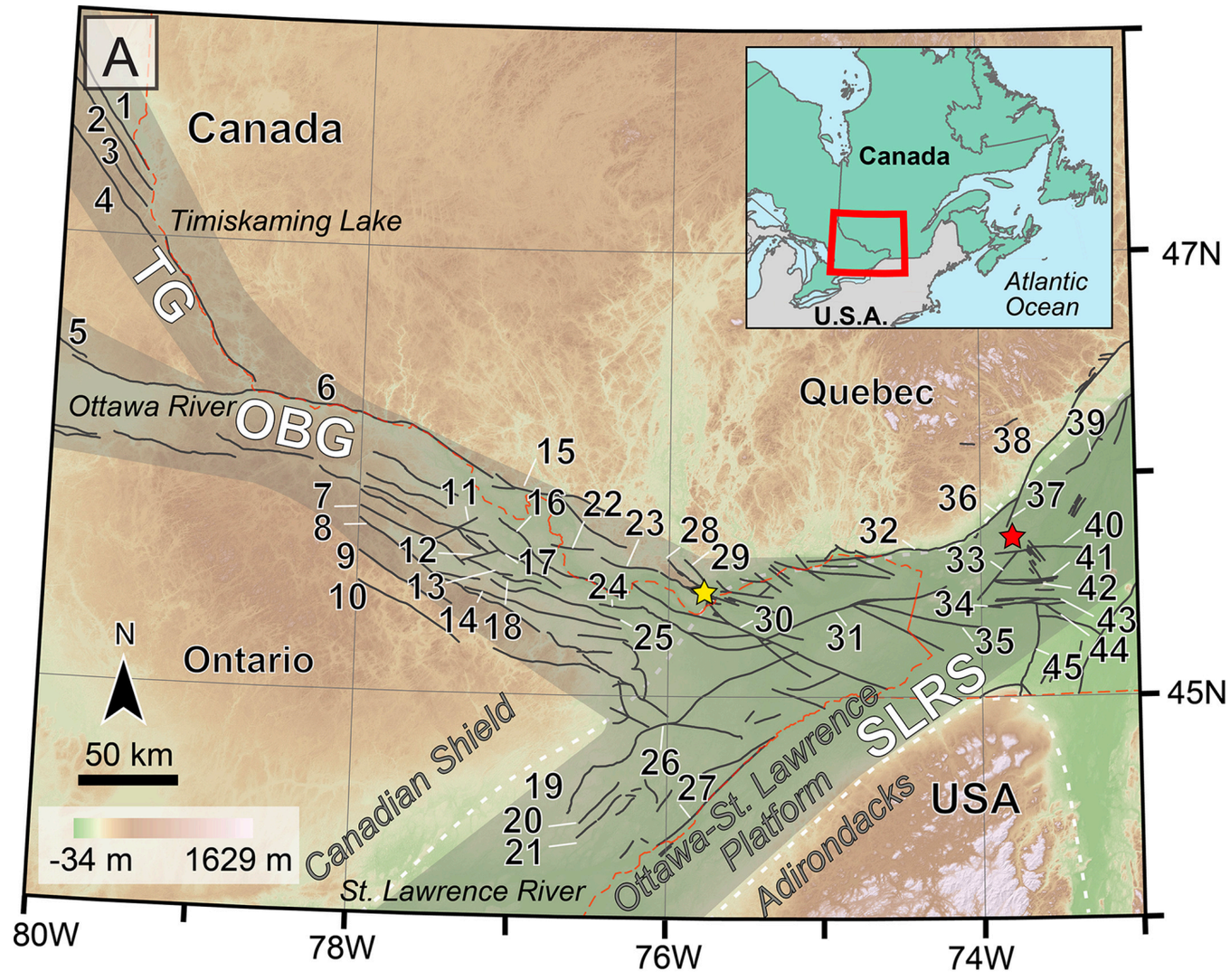
A. Earthquake epicentral plots are colour-coded according to depth and scaled to magnitude.
B. Earthquake focal mechanisms with labels of year and magnitude of notable events.

Data from: Natural Resources Canada (https://earthquakescanada.nrcan.gc.ca/index-en.php) and the United States Geological Survey (https://www.usgs.gov/natural-hazards/earthquake-hazards/earthquakes).

WQSZ Stress modelling study aims

- Determine if the present day regional stress regime in Western Quebec can account for observable regional seismicity

- Determine if the spatial distribution, trends, and sense of slip of contemporary fault reactivation can be accounted for with regional stress



Rimando & Peace (2021)

Stress modelling of Western Quebec: Methods

Slip tendency analysis

- We modelled slip tendency using MOVE structural geology software

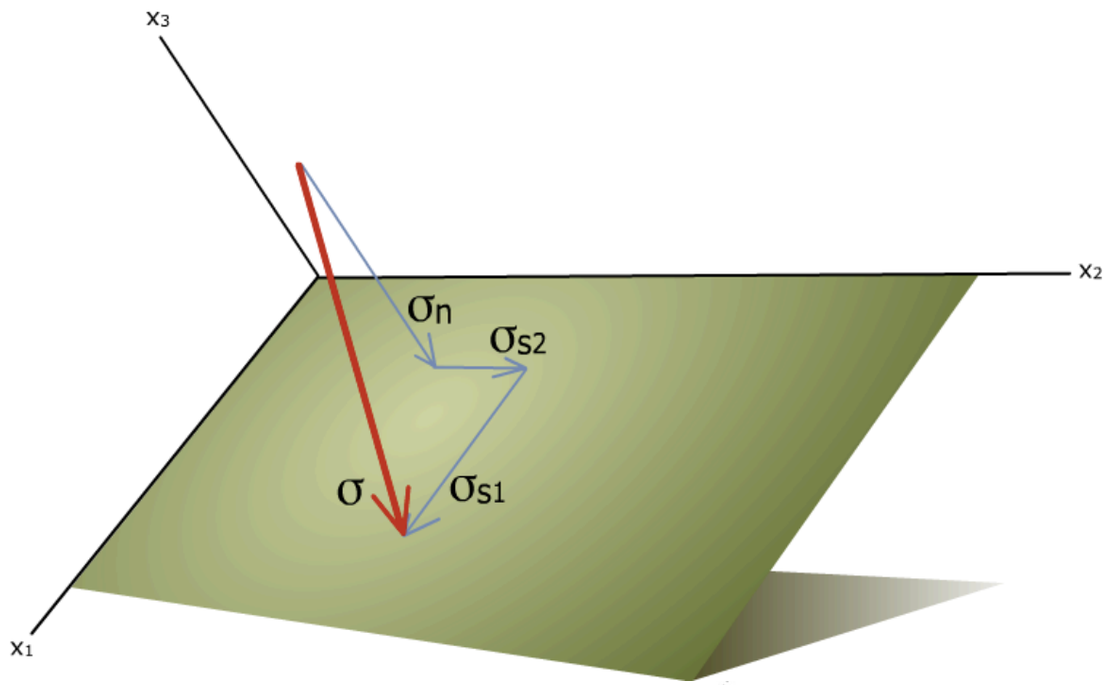
- Slip tendency (Morris et al., 1996) is the ratio of the shear stress to the normal stress on a fault surface, which is expressed as the following equation:

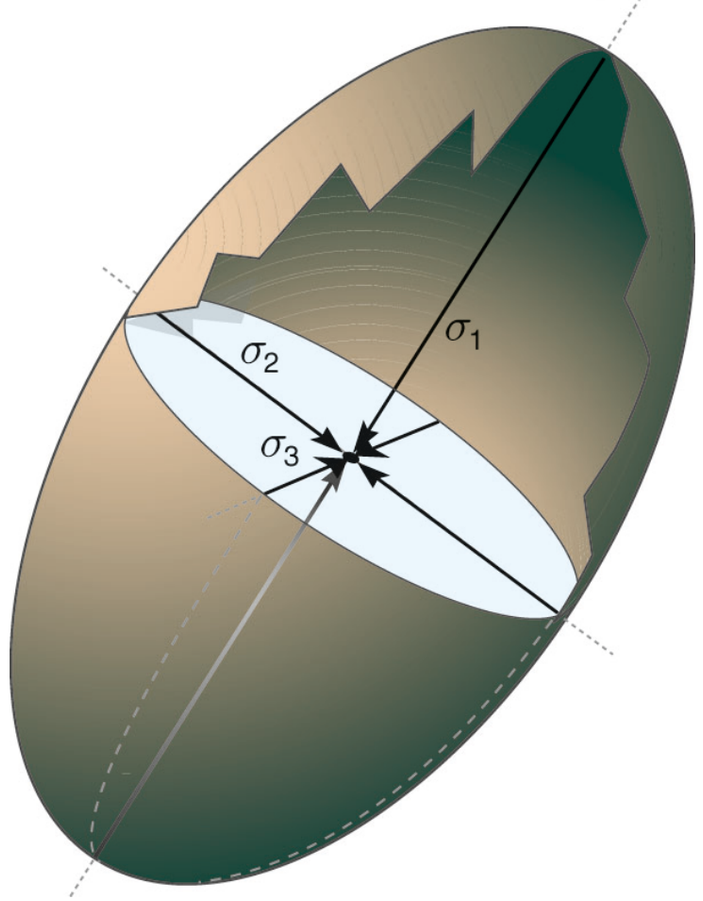
$$T_s = \tau / \sigma_n,$$

- where T_S is the slip tendency, τ is the shear stress, and σ_n is the normal stress.

- Reactivation potential of faults modelled using the “Slip Tendency” function in the “Stress Analysis” module of the software Move™ by Petroleum Experts Limited,

- Sense of fault slip predicted using the “Slicken 1.0” software (Xu et al., 2017).





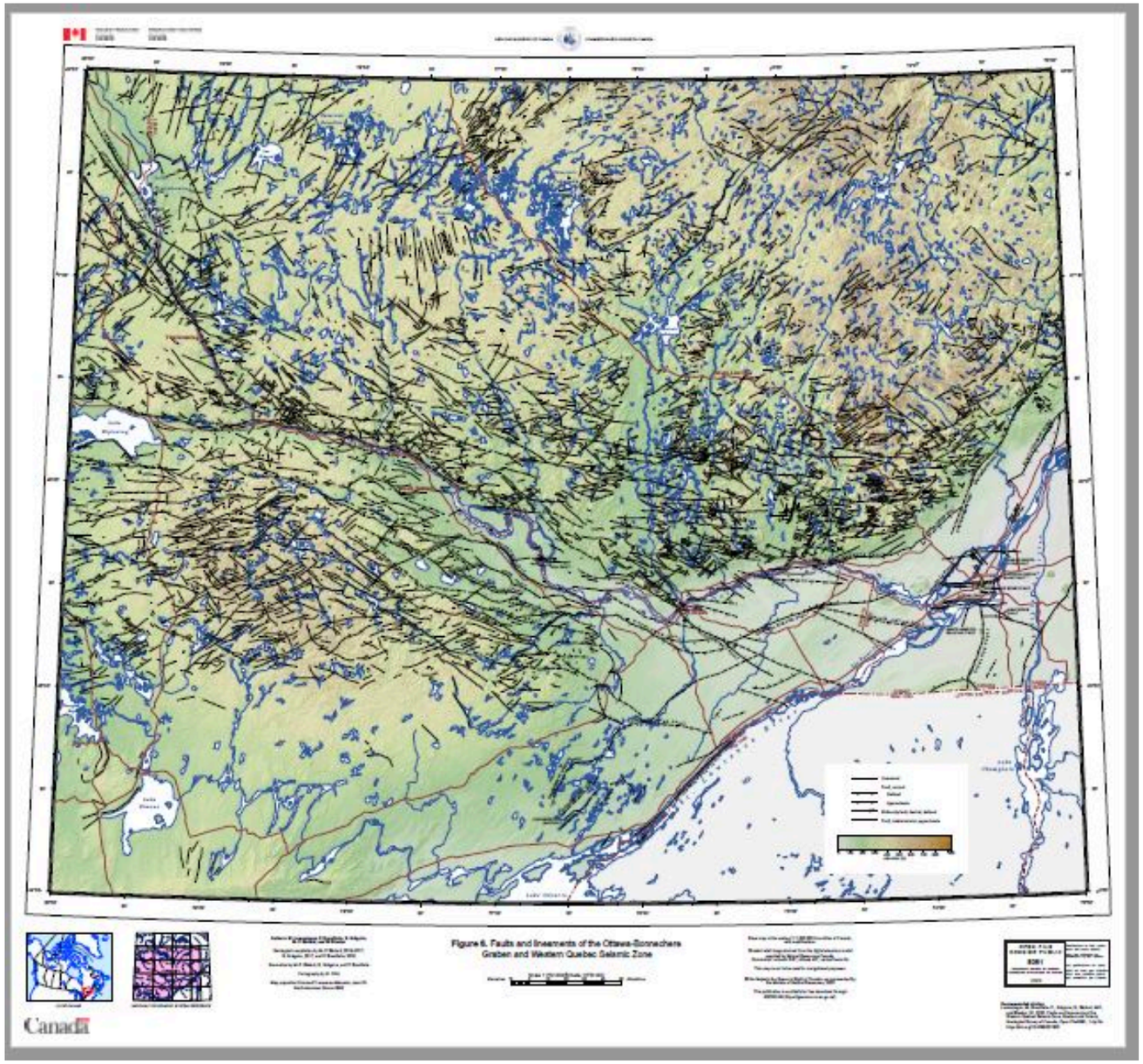
Stress modelling of Western Quebec: Methods

Fault orientation and geometry

- 3D models were built by projecting surfaces from shapefiles of the GSC WQSZ faults map (Lamontagne et al., 2020).

- We assumed a dip of 60° to build 3D fault surface models based on limited regional reporting

- We also ran simulations over a range of fault dips (at 15° increments) to test the effect of underestimating or overestimating the actual fault dip on the calculated slip potential and sense of slip of faults.

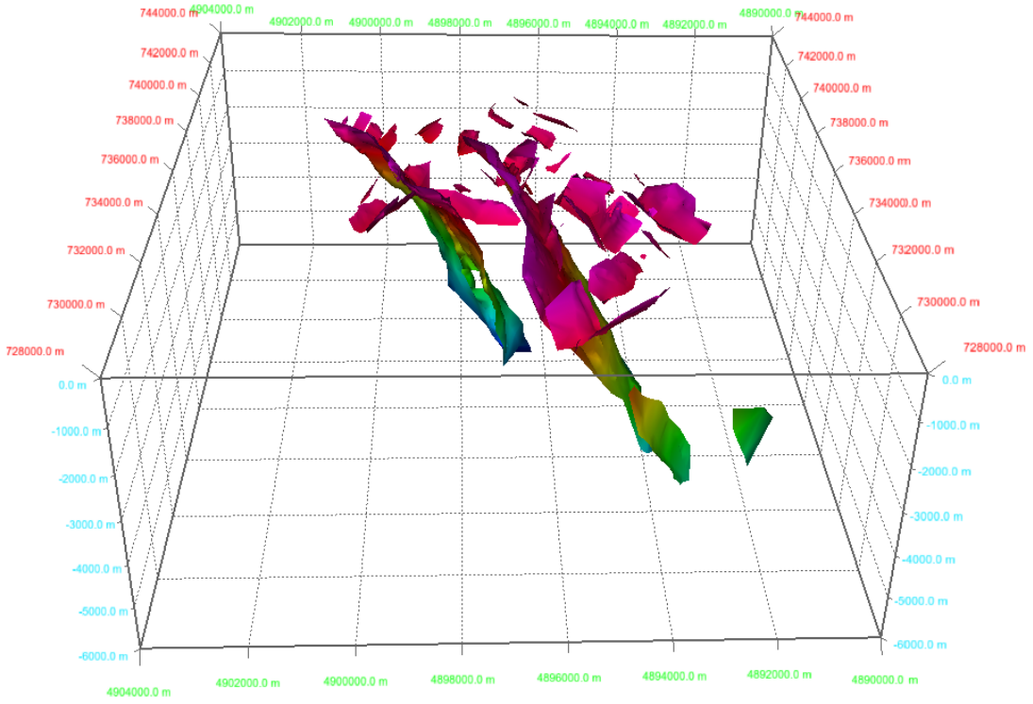


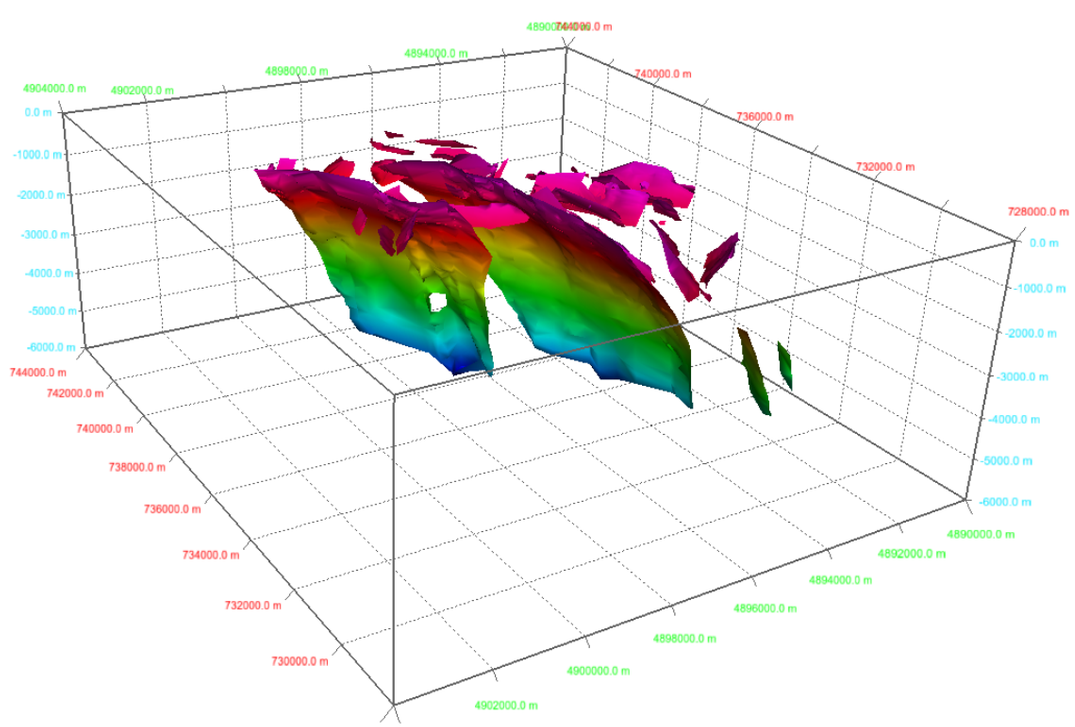
Lamontagne et al (2020) https://doi.org/10.4095/321900

Stress modelling of Western Quebec

Assumptions

- Slip on faults is expected to occur along the direction of the maximum resolved shear stress
- Simple planar faults and a relatively uniform stress field
- Fault do not interact
- Fault blocks do not rotate
- There is no internal deformation
- Despite these caveats, it has been shown through numerical studies to be a good first-order approximation (Dupin et al., 1993; Pollard et al., 1993)
- Deviation between actual and theoretical slip kinematics are on average less than 10°





move

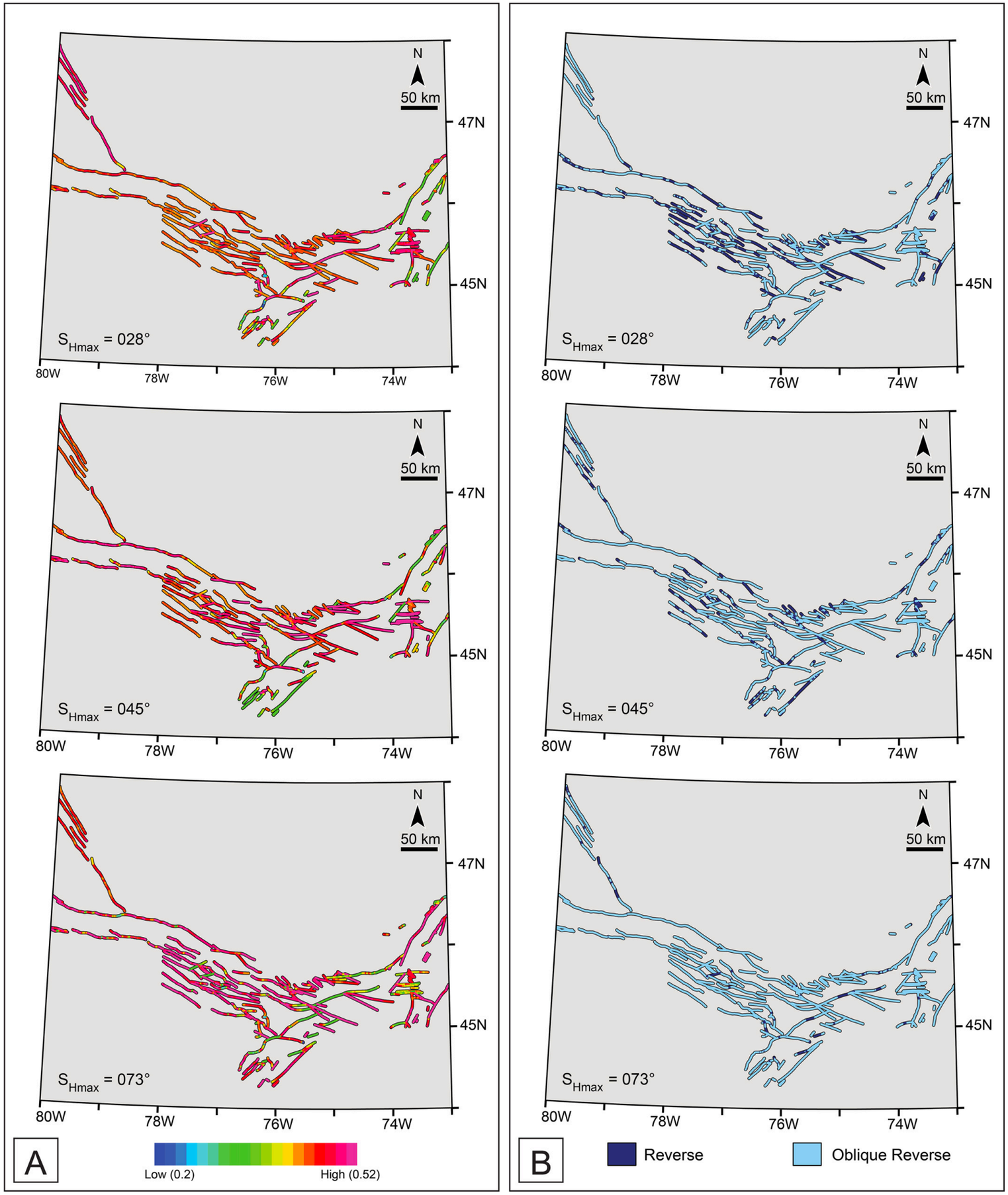
Stress Analysis

Example fault population from Penobscot 3D survey offshore NS showing fault interaction across population during growth

Stress modelling of Western Quebec: Results

Variable horizontal stress (S_H)

(a) Slip tendency maps and (b) predicted slip kinematics of faults dipping 60° with S_H azimuth values of 028°, 045°, and 073°.

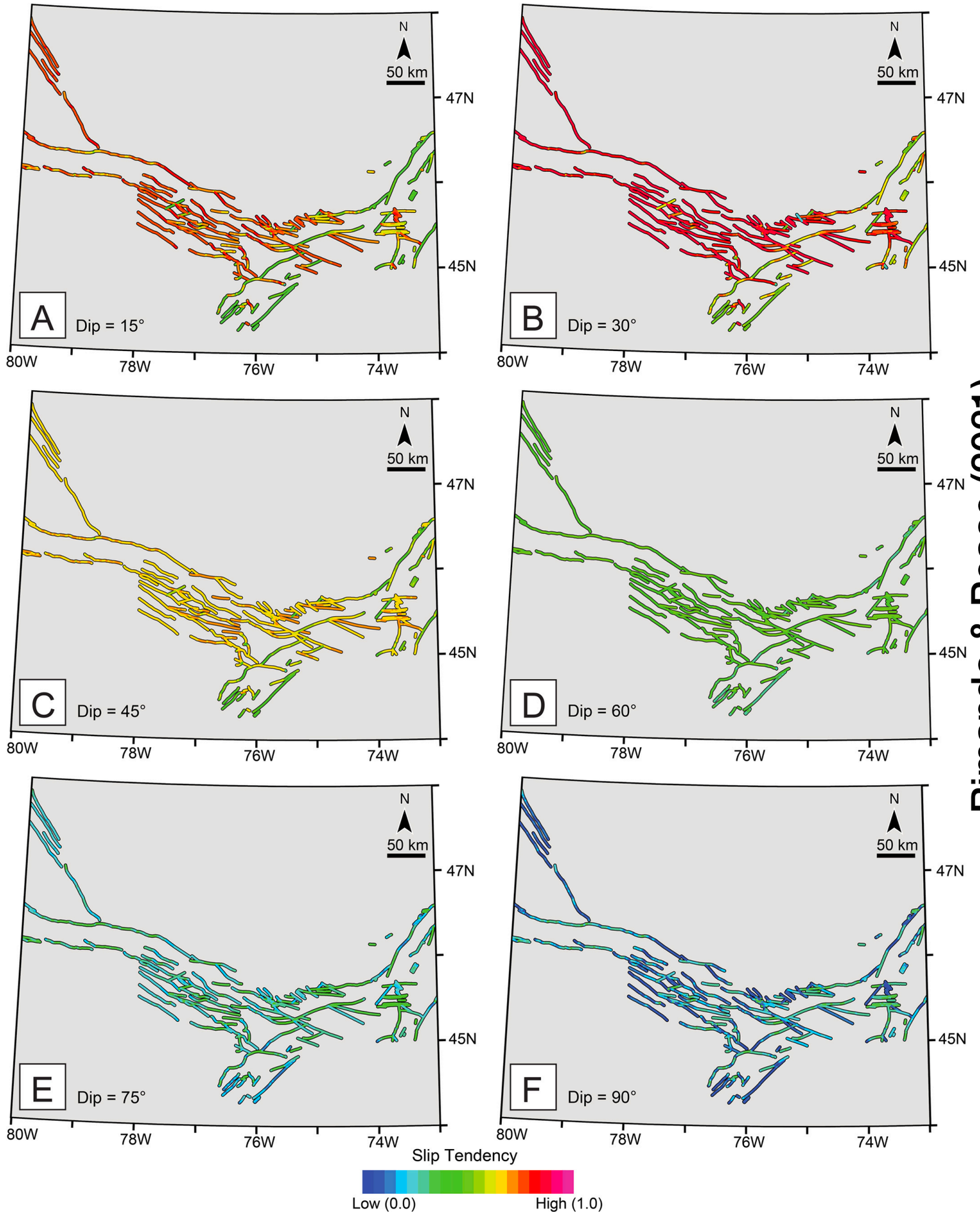


Rimando & Peace (2021)

Stress modelling of Western Quebec: Results

Variable dip scenarios (slip tendency)

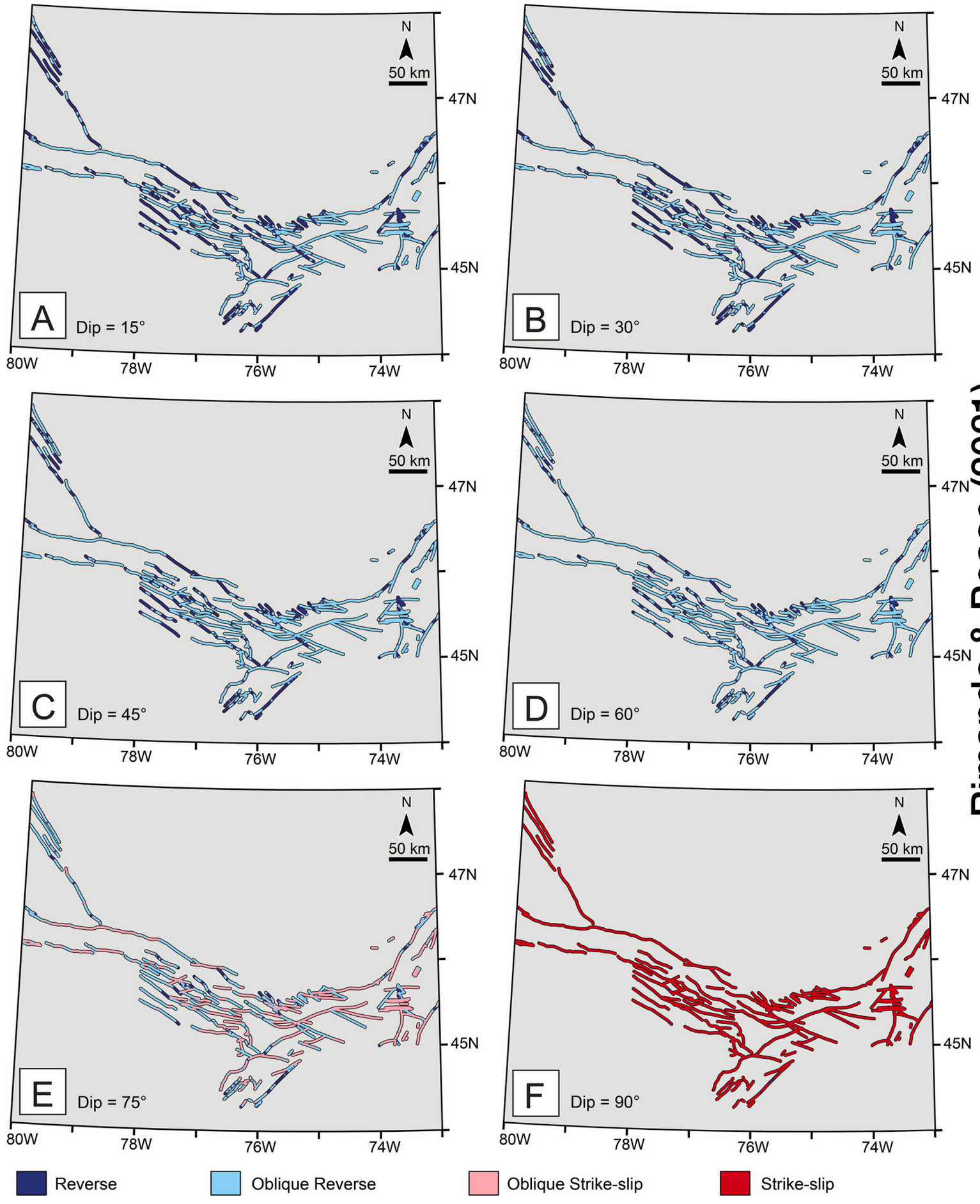
Slip tendency maps for different fault dip scenarios (with an SH azimuth of 45°). (a) 15°, (b) 30°, (c) 45°, (d) 60°, (e) 75°, and (f) 90°.



Stress modelling of Western Quebec: Results

Variable dip scenarios (slip kinematics)

Predicted slip kinematics for different fault dip scenarios (with an SH azimuth of 45°). (a) 15°, (b) 30°, (c) 45°, (d) 60°, (e) 75°, and (f) 90°.



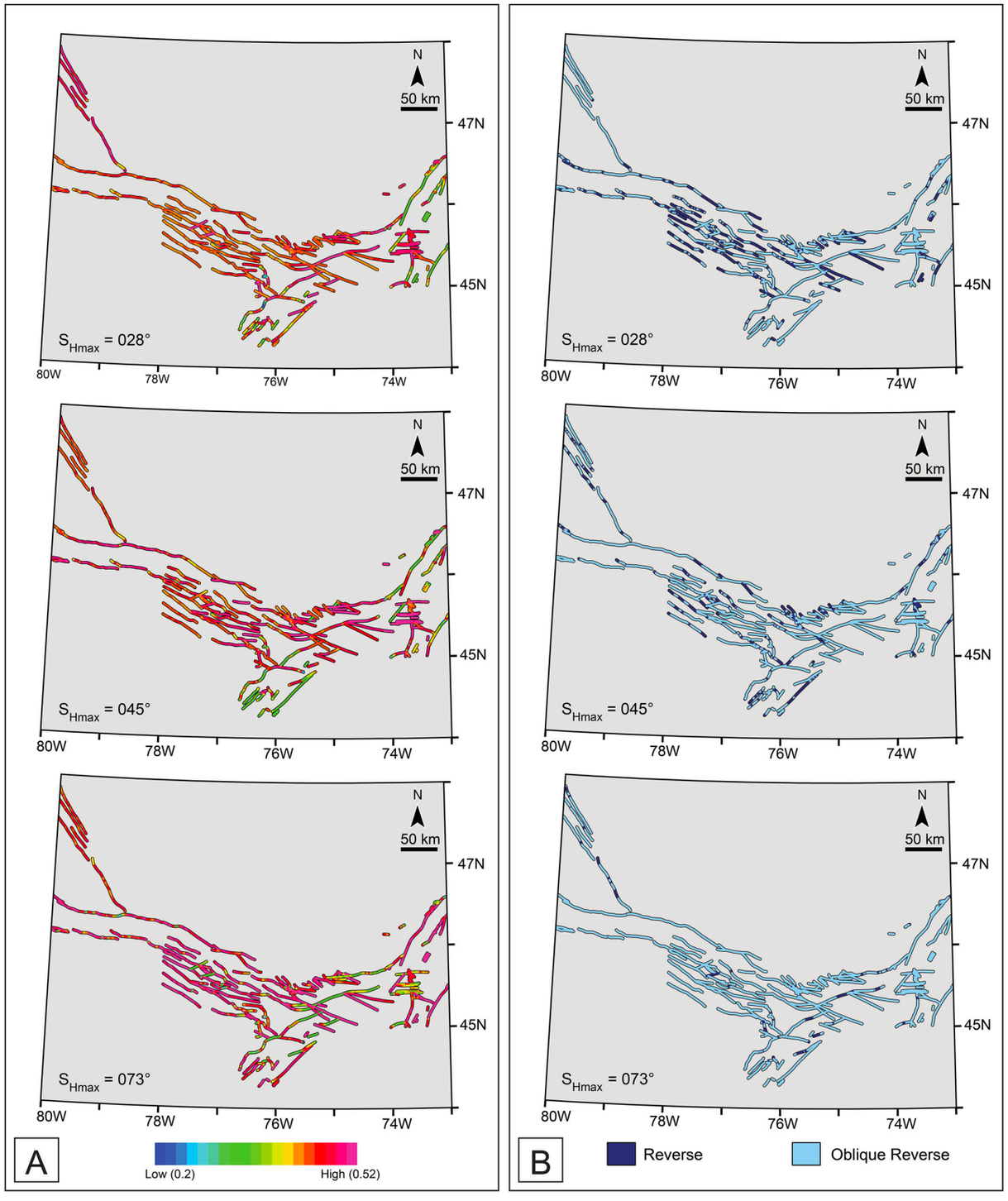
Stress modelling of Western Quebec: Summary of results

- NNW-SSE-striking to NW-SE-striking faults of the WQSZ consistently exhibit relatively higher slip tendency values.

- Modelled fault reactivation kinematics (i.e., predominantly reverse and oblique reverse) are largely in agreement with the observed kinematics indicated by FMS

- Spatial patterns of slip tendency and kinematics of reactivation are consistent with the observed seismicity.

- Future studies: More detailed work with realistic fault geometries (e.g. ramp-flat-ramp) and behaviour/interaction is needed to build on this work

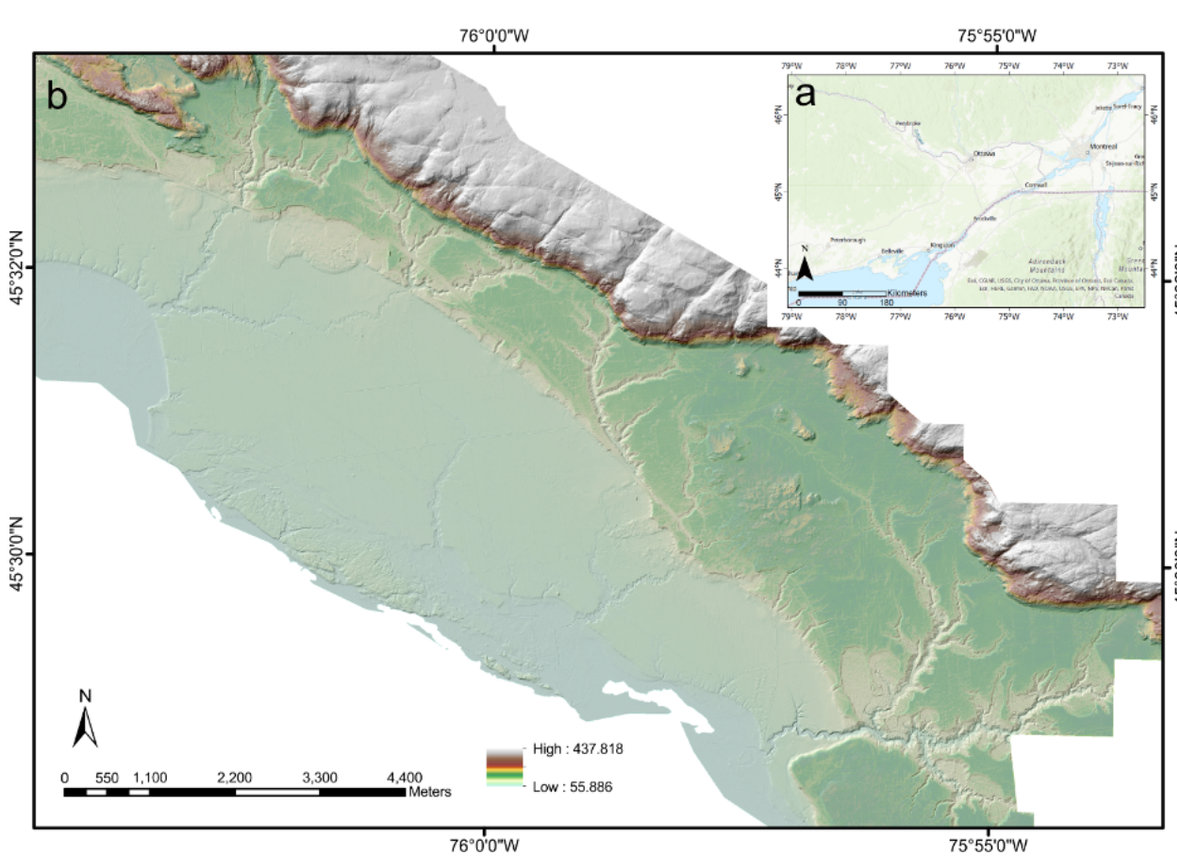


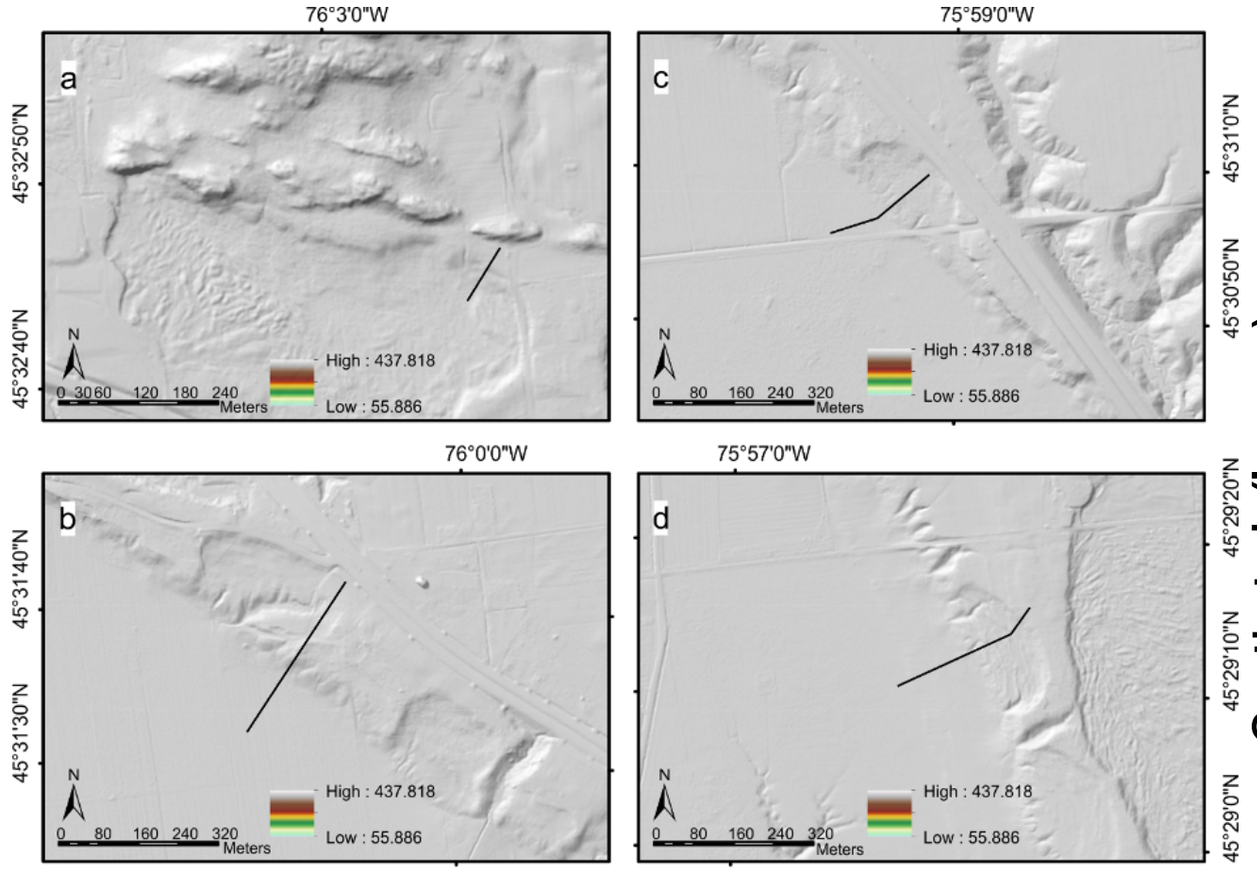
Rimando & Peace (2021)

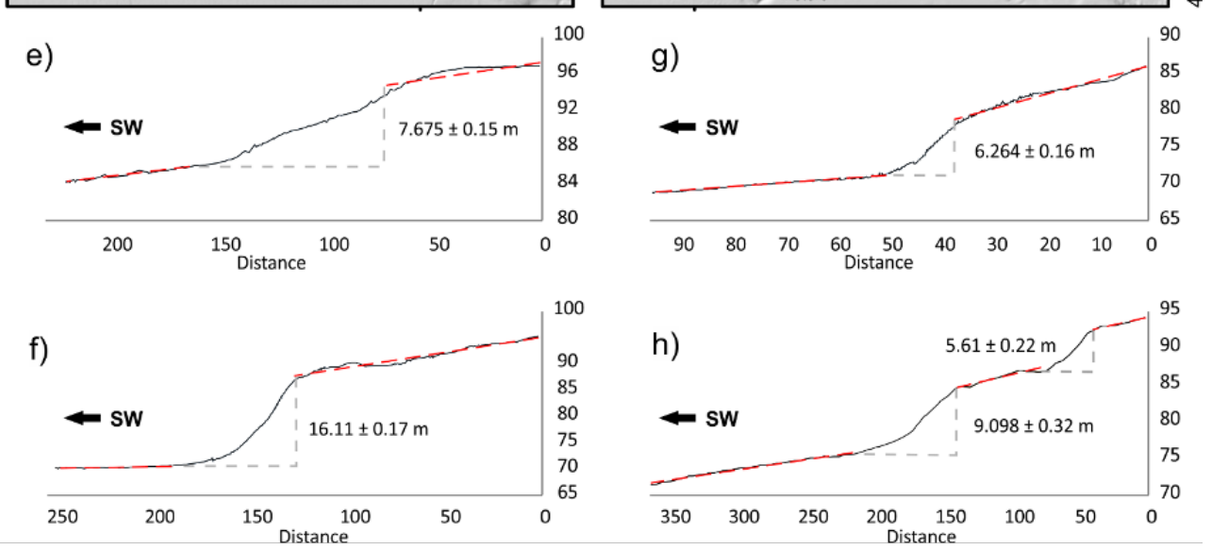
Ongoing work: Western Quebec

Ongoing work: Western Quebec

Interpreting geomorphological features

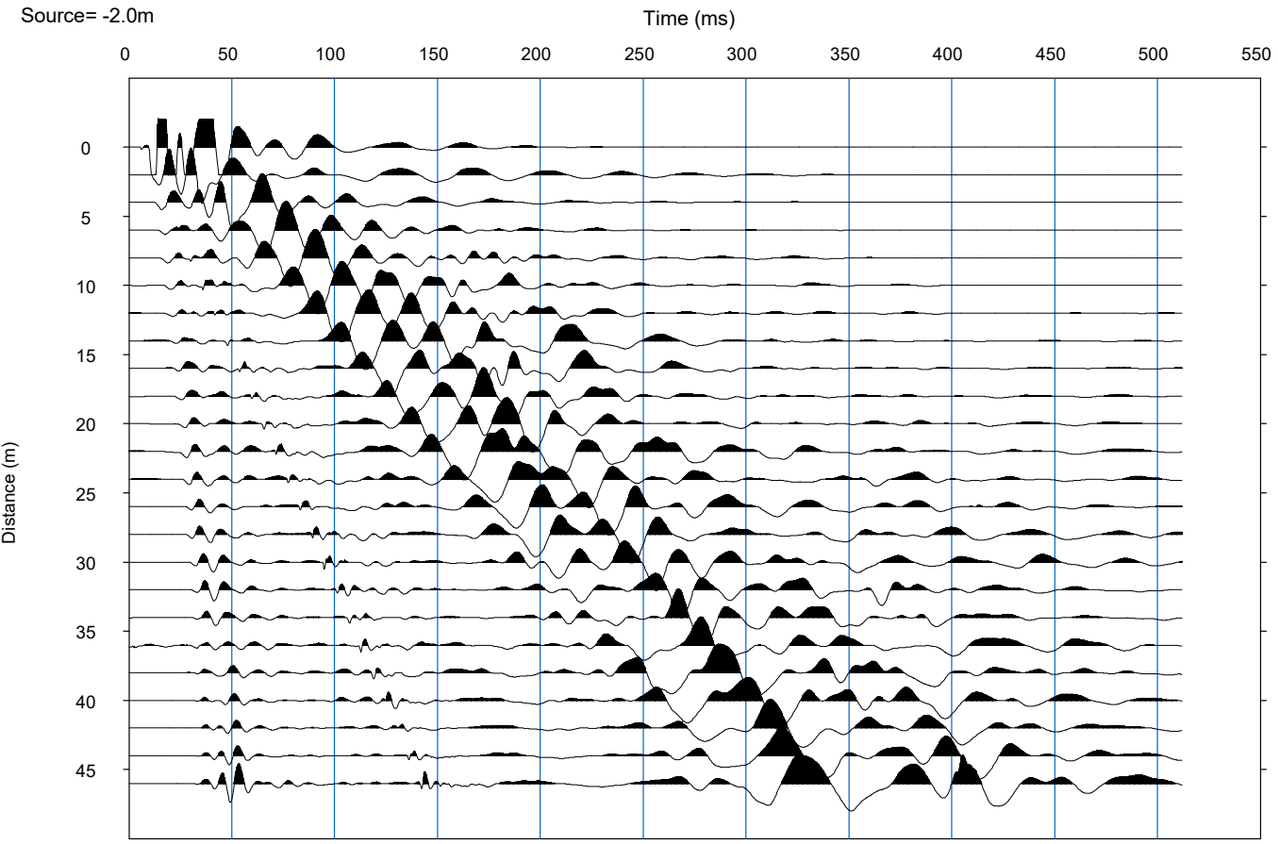






- Poor exposure of candidate structures
- Geomorphological expressions of tectonic activity can be ambiguous

Ongoing work: Western Quebec seismic reflection survey



Ongoing work: Rouge River, GTA

Conclusions and take away messages

- Intraplate seismicity is a genuine hazard that is perhaps under recognised

- The study of intraplate seismicity requires a multi-disciplinary approach due to the poor exposure and subtle nature of outcrops

- Numerical modelling of stress in WQSZ reveals that spatial patterns of slip tendency and kinematics of reactivation are consistent with the observed seismicity

Acknowledgements

- Thanks for the opportunity to present at this workshop!

- Collaborators and research team

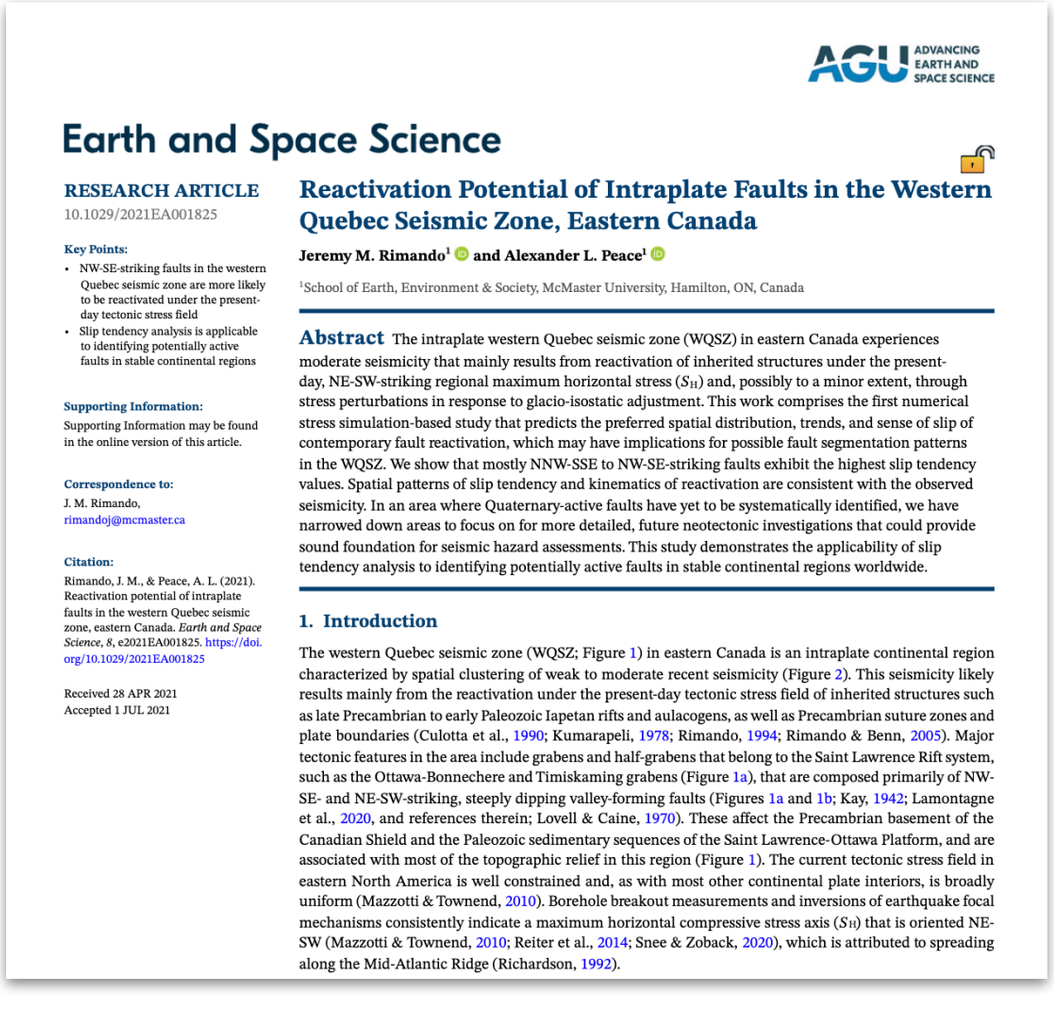
- Funding from: NSERC Discovery Grant RGPIN-2021-04011 and Kieth MacDonald fund

- MOVE software donation from Petroleum Experts Ltd.

Related Articles

- Rimando, J. & Peace, A. (2021). Reactivation potential of intraplate faults in the western Quebec seismic zone, eastern Canada. *Earth and Space Science*, 8, e2021EA001825. https://doi.org/10.1029/2021EA001825

- Rimando, J & Peace, A. ‘Contrary to popular belief, Eastern Canada is more at risk of earthquakes than perceived’. September 15th 2021, *The Conversation*. https://theconversation.com/contrary-to-popular-belief-eastern-canada-is-more-at-risk-of-earthquakes-than-perceived-167743



AGU ADVANCING EARTH AND SPACE SCIENCE

Earth and Space Science

RESEARCH ARTICLE
10.1029/2021EA001825

Key Points:
- NW-SE-striking faults in the western Quebec seismic zone are more likely to be reactivated under the present-day tectonic stress field
- Slip tendency analysis is applicable to identifying potentially active faults in stable continental regions

Supporting Information:
Supporting Information may be found in the online version of this article.

Correspondence to:
J. M. Rimando,
rimandoj@mcmaster.ca

Citation:
Rimando, J. M., & Peace, A. L. (2021). Reactivation potential of intraplate faults in the western Quebec seismic zone, eastern Canada. *Earth and Space Science*, *8*, e2021EA001825. https://doi.org/10.1029/2021EA001825

Received 28 APR 2021
Accepted 1 JUL 2021

Reactivation Potential of Intraplate Faults in the Western Quebec Seismic Zone, Eastern Canada

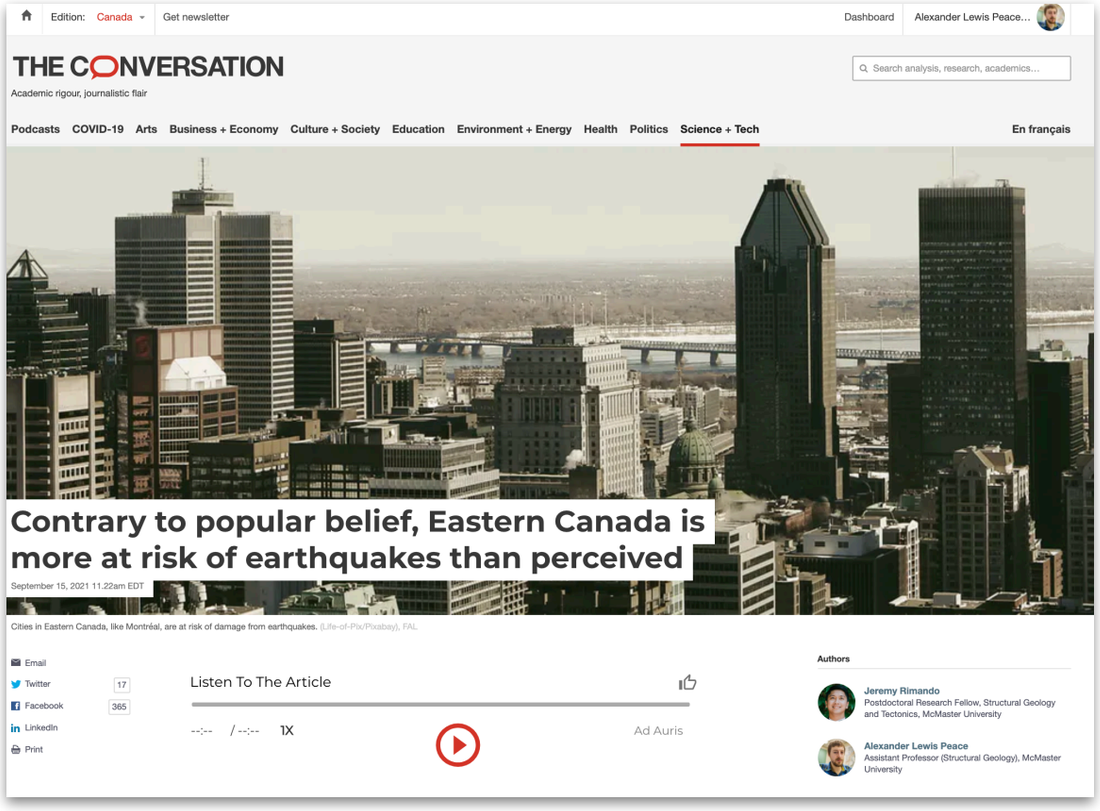
Jeremy M. Rimando[1] **and Alexander L. Peace**[1]

[1]School of Earth, Environment & Society, McMaster University, Hamilton, ON, Canada

Abstract The intraplate western Quebec seismic zone (WQSZ) in eastern Canada experiences moderate seismicity that mainly results from reactivation of inherited structures under the present-day, NE-SW-striking regional maximum horizontal stress (S_H) and, possibly to a minor extent, through stress perturbations in response to glacio-isostatic adjustment. This work comprises the first numerical stress simulation-based study that predicts the preferred spatial distribution, trends, and sense of slip of contemporary fault reactivation, which may have implications for possible fault segmentation patterns in the WQSZ. We show that mostly NNW-SSE to NW-SE-striking faults exhibit the highest slip tendency values. Spatial patterns of slip tendency and kinematics of reactivation are consistent with the observed seismicity. In an area where Quaternary-active faults have yet to be systematically identified, we have narrowed down areas to focus on for more detailed, future neotectonic investigations that could provide sound foundation for seismic hazard assessments. This study demonstrates the applicability of slip tendency analysis to identifying potentially active faults in stable continental regions worldwide.

1. Introduction

The western Quebec seismic zone (WQSZ; Figure 1) in eastern Canada is an intraplate continental region characterized by spatial clustering of weak to moderate recent seismicity (Figure 2). This seismicity likely results mainly from the reactivation under the present-day tectonic stress field of inherited structures such as late Precambrian to early Paleozoic Iapetan rifts and aulacogens, as well as Precambrian suture zones and plate boundaries (Culotta et al., 1990; Kumarapeli, 1978; Rimando, 1994; Rimando & Benn, 2005). Major tectonic features in the area include grabens and half-grabens that belong to the Saint Lawrence Rift system, such as the Ottawa-Bonnechere and Timiskaming grabens (Figure 1a), that are composed primarily of NW-SE- and NE-SW-striking, steeply dipping valley-forming faults (Figures 1a and 1b; Kay, 1942; Lamontagne et al., 2020, and references therein; Lovell & Caine, 1970). These affect the Precambrian basement of the Canadian Shield and the Paleozoic sedimentary sequences of the Saint Lawrence-Ottawa Platform, and are associated with most of the topographic relief in this region (Figure 1). The current tectonic stress field in eastern North America is well constrained and, as with most other continental plate interiors, is broadly uniform (Mazzotti & Townend, 2010). Borehole breakout measurements and inversions of earthquake focal mechanisms consistently indicate a maximum horizontal compressive stress axis (S_H) that is oriented NE-SW (Mazzotti & Townend, 2010; Reiter et al., 2014; Snee & Zoback, 2020), which is attributed to spreading along the Mid-Atlantic Ridge (Richardson, 1992).



Edition: Canada | Get newsletter | Dashboard | Alexander Lewis Peace...

THE CONVERSATION
Academic rigour, journalistic flair

Search analysis, research, academics...

Podcasts COVID-19 Arts Business + Economy Culture + Society Education Environment + Energy Health Politics Science + Tech En français

Contrary to popular belief, Eastern Canada is more at risk of earthquakes than perceived

September 15, 2021 11.22am EDT

Cities in Eastern Canada, like Montréal, are at risk of damage from earthquakes. (Life-of-Pix/Pixabay), FAL

Email
Twitter 17
Facebook 365
LinkedIn
Print

Listen To The Article

--:-- / --:-- 1X

Ad Auris

Authors

Jeremy Rimando
Postdoctoral Research Fellow, Structural Geology and Tectonics, McMaster University

Alexander Lewis Peace
Assistant Professor (Structural Geology), McMaster University

[Programme]

TS4.2

EDI

Deformation, seismicity, and hazards of low-strain, slowly deforming regions

Co-organized by NH4

Convener: Tamarah King[ECS] | Co-conveners: Veronica Prush[ECS], Jeremy Rimando[ECS], Zoe Mildon[ECS], Alexander L. Peace[ECS]

Abstract submission

Regions of slow deformation and low strain, often located in continental interiors or intraplate settings, can present substantial, under-recognised seismic hazards. The styles, rates, and spatial patterns of strain distribution and seismicity in these areas are often dissimilar to plate-boundary regions, where most of our current understanding of deformation drivers was derived. Challenges in studying slowly deforming regions include: 1) poor surface exposure and/or preservation of Quaternary-active structures, 2) long earthquake recurrence intervals, and 3) complex fault geometries, mechanics, and deformation histories, often including reactivation of inherited structures.

Interdisciplinary studies combining a diverse range of geoscientific disciplines have helped us develop a better understanding of drivers of low strain deformation. In this session, we want to explore the roles, behaviours, and associated seismic hazards of short-to-long-term active deformation and key inherited tectonic structures in these regions. We seek studies from around the globe that illuminate our understanding of these complex zones using field-based analyses, geophysics, seismology, active tectonics, geomorphology, remote sensing, numerical and analogue modelling, sedimentology, and geochronology. We particularly encourage interdisciplinary presentations, thought-provoking studies that challenge conventional wisdoms, and submissions from early career researchers.