Investigating stress and seismicity in the Charlevoix seismic zone, evidence from seismic anisotropy

DI11A-2165

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Introduction

The Charlevoix seismic zone, located in the St. Lawrence Valley of Quebec Canada, is one of the most seismically active intra-plate regions in the World, with five earthquakes larger than magnitude 6 occurring since records began in the 1660s. It is also a site with unusual structural setting with potentially anomalous stress conditions. Here we investigate these conditions using SKS and local shear-wave splitting.

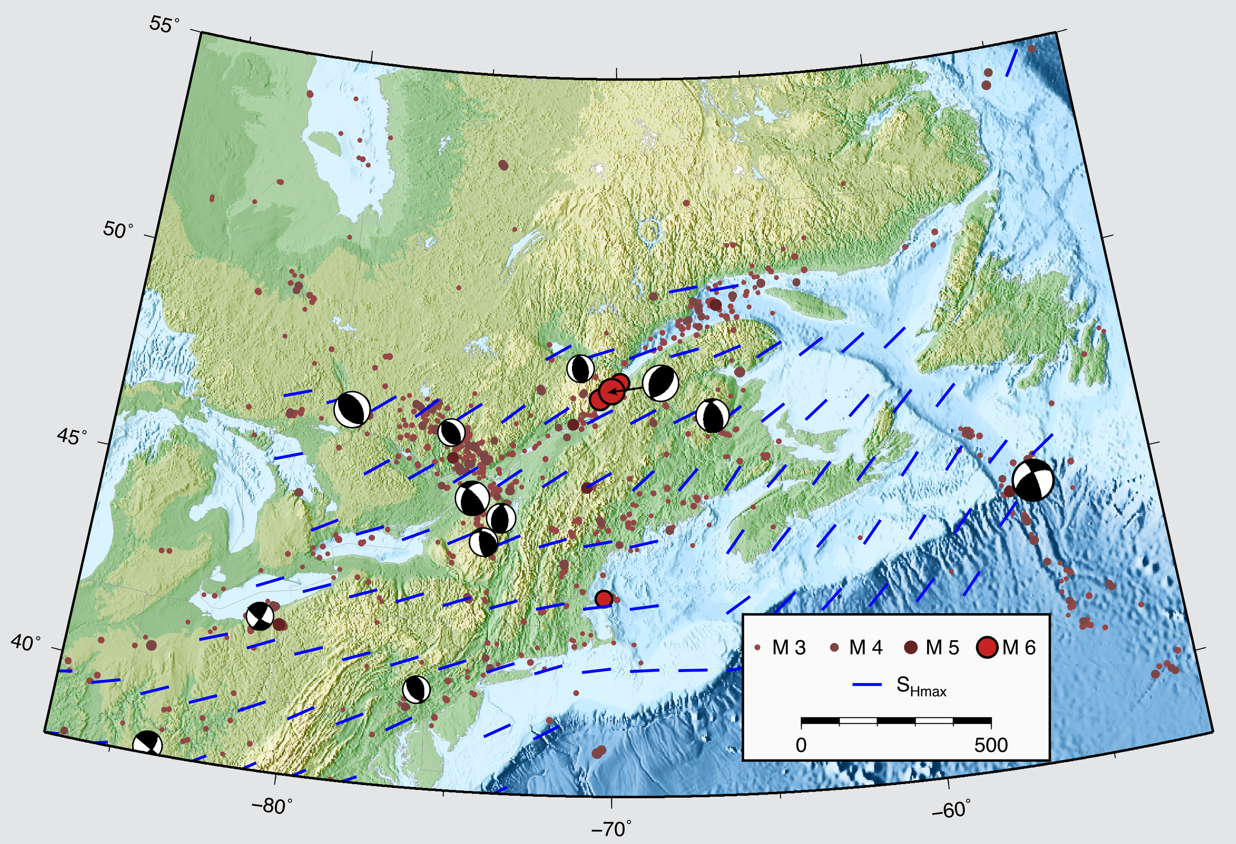

Fig. 1 - Seismicity and stress orientations in eastern Canada, showing the location of the Charlevoix seismic zone. The P-axes of moderate earthquakes align with regional stress (S_H) in most areas, however the 1925 M 6.2 event at Charlevoix shows compression strongly oblique to S_H.

Sources of anisotropy in the crust

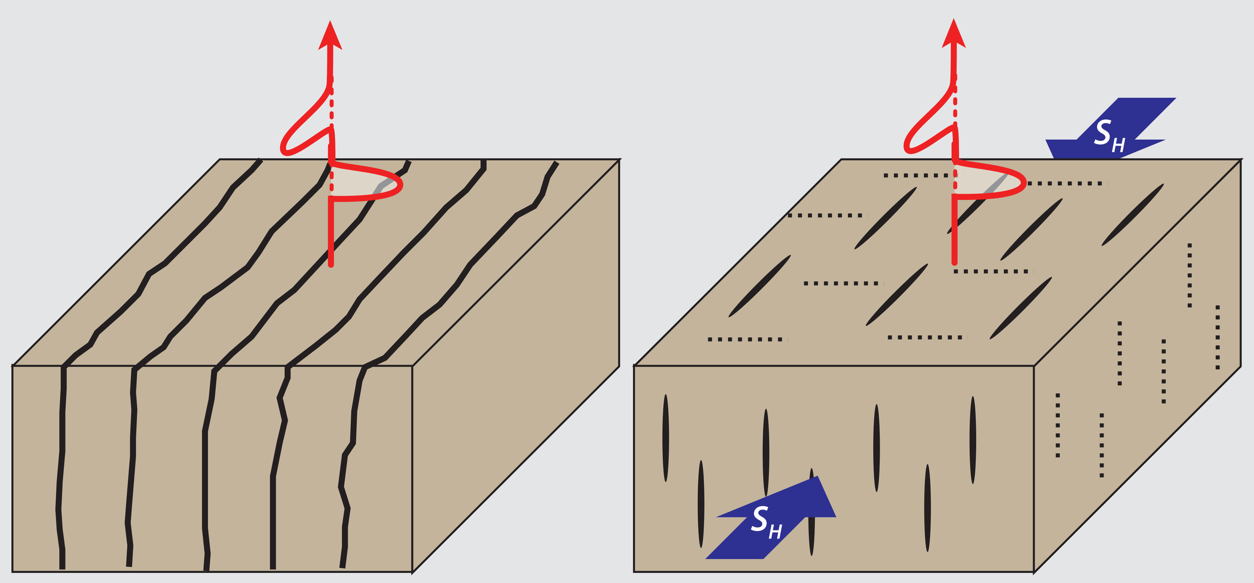

Fig. 2 - Anisotropy in the crust can be caused by aligned minerals or macroscopic fractures or faults (left), in which case the fast polarization direction of a steeply propagating S-wave will align with the strike of the structural fabric. However, it is often assumed that crustal anisotropy is dominated by stress-aligned microcracks (right), such that the fast direction corresponds to the maximum compressive stress direction (S_H).

Structural setting and seismicity

The region is structurally complex, comprising rift faults formed during the opening of the Iapetus Ocean (the St. Lawrence rift), superimposed by a 350 Ma meteorite impact structure. Seismicity occurs along two parallel clusters between the main rift faults (Fig. 3). A difficulty in explaining the seismicity is that the rift faults strike NE-SW, subparallel to the regional compressive stress orientation, and thus are poorly oriented for reactivation. However, a recent stress inversion[1] from earthquake focal mechanisms suggest that the stress field within the CSZ may be locally variable in orientation, with some regions deviating from the regional trend by as much as a 50° CW rotation (Fig. 4).

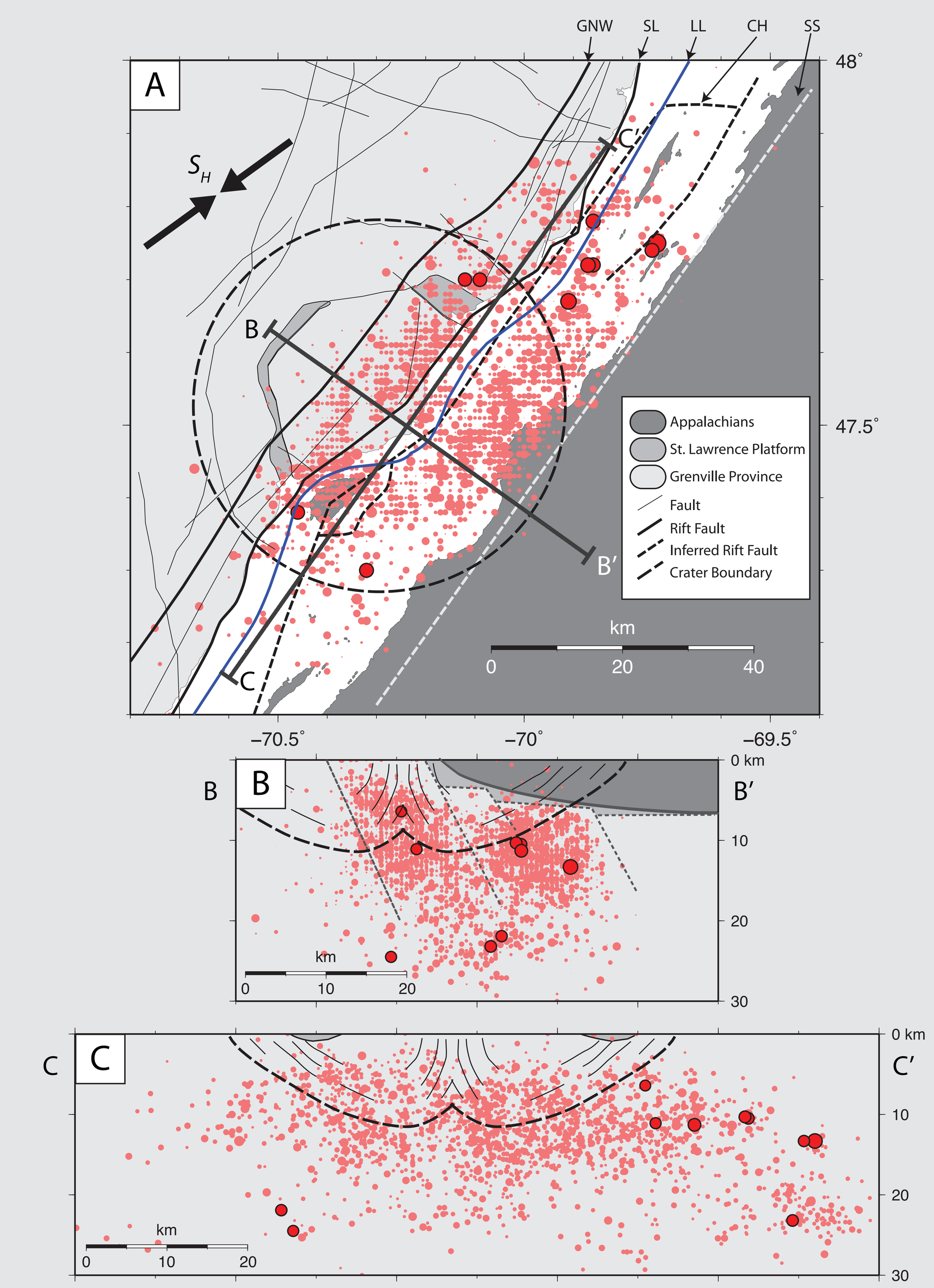

Fig. 3 - (a) Seismicity and structural geology of the Charlevoix seismic zone[2]. Pink and red circles represent earthquakes with magnitudes < 4.0 or > 4.0, respectively. S_H indicates the maximum horizontal compressive stress orientation. (b and c) Cross sectional views of the Charlevoix seismic zone (b) across strike and (c) along strike of the St. Lawrence rift.

Focal mechanisms and stress

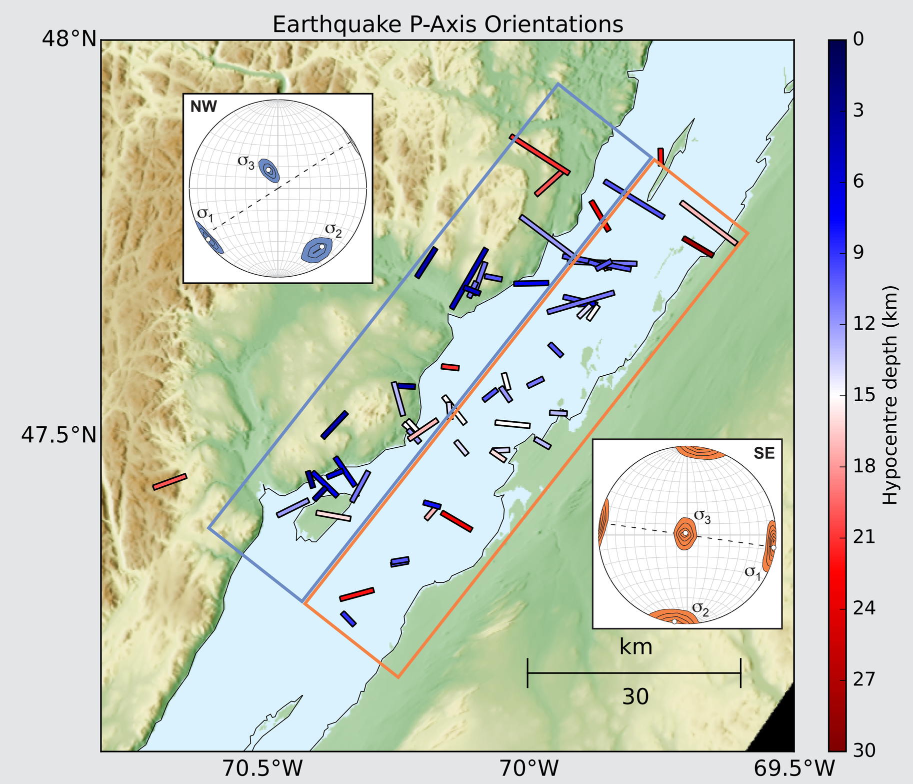

Fig. 4 - Earthquake P-axis orientations and inverted stress orientations from Mazzotti and Townend (2010)[1] for the NW and SE clusters of seismicity. The length of the bars indicate the magnitude range of the earthquake (M<2.5, 2.3<M<3.5, M>3.5). Focal mechanisms from the NW cluster indicate compression parallel to the regional stress field (NW-SE), while those in the SE indicate compression strongly oblique. A possible mechanism to explain the stress perturbation is the concentration of postglacial rebound stresses by a local zone of weakness in the lithosphere related to the St. Lawrence rift. Such weaknesses could be low upper-mantle viscosity or unusually low-friction faults in the crust.

SKS splitting

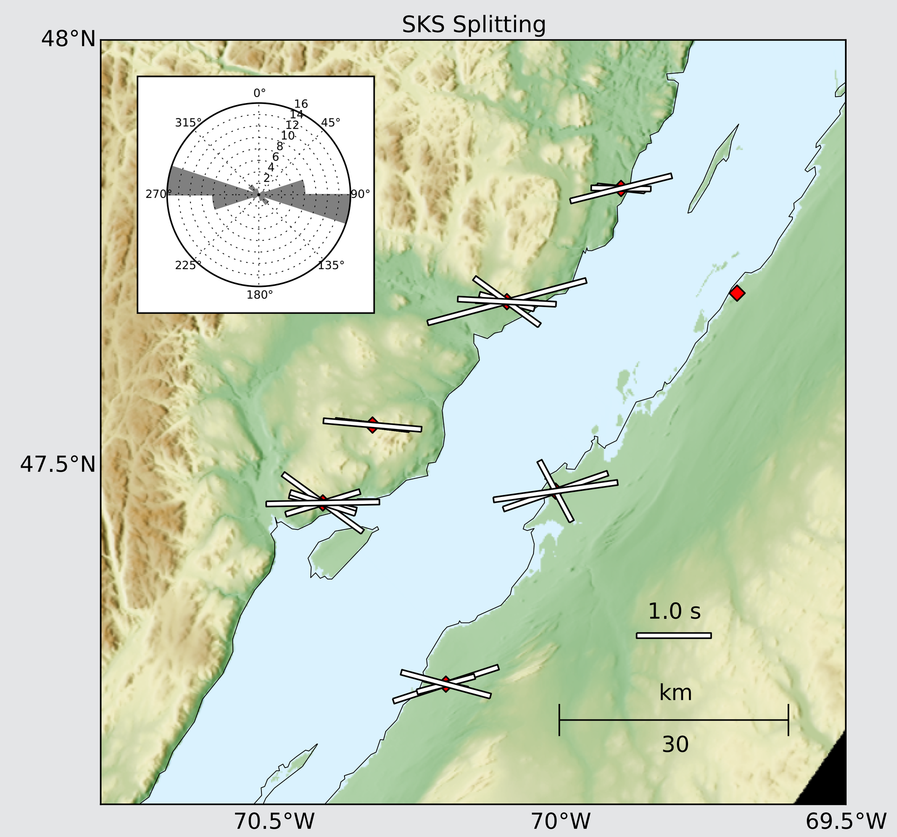

Fig. 6 - Shear wave splitting from SKS phases. The dominant fast direction is E-W, which is oblique to the regional stress field and structural fabric. The difference in fast direction from the local events (Fig. 5) suggest that the SKS splitting is measuring upper mantle anisotropy which is decoupled from the crust.

Local S-wave splitting

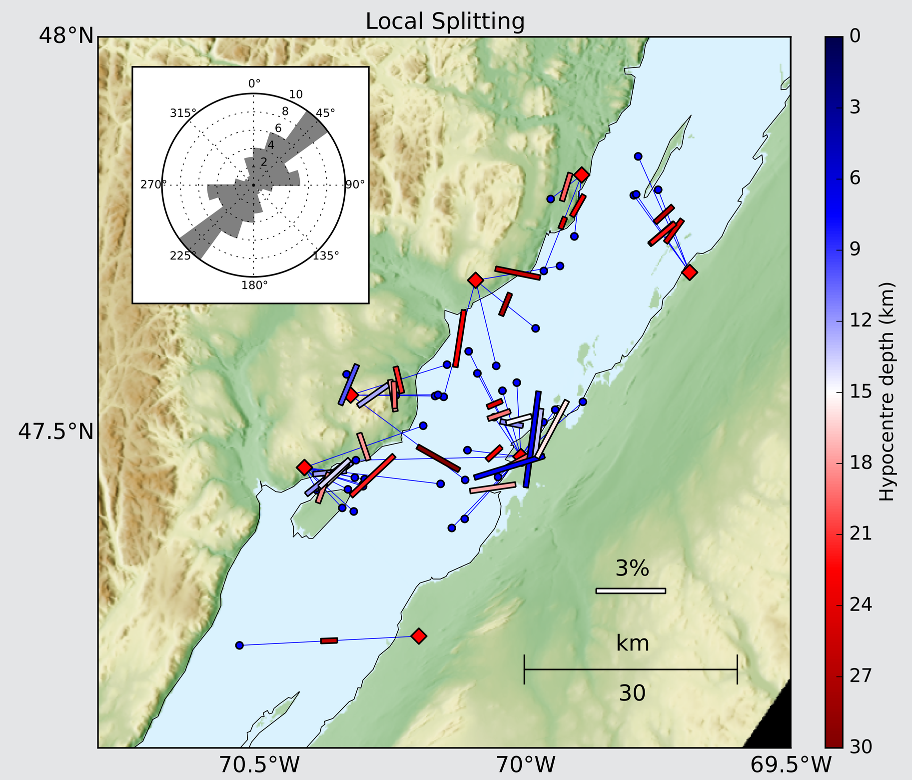

Fig. 5 - Shear wave splitting from local earthquakes. Tick marks are plotted at source receiver midpoints with orientations indicating fast polarization directions coloured by earthquake depth. Although there is some variation in fast direction most measurements are aligned NE-SW subparallel to both the regional stress and the St. Lawrence rift.

Discussion

1. Local fast directions are oriented NE-SW parallel to the rift and to the regional stress field (as indicated by borehole measurements of stress).
2. Local fast directions show no clear relationship with earthquake P-axes or with the inferred stress orientation anomaly suggested by Mazzotti and Townend.[1]
3. The SKS fast directions are oblique to the local S directions suggesting that they are measuring decoupled strain fields. Thus, it seems unlikely that a low upper-mantle viscosity would be the source of weakness causing the apparent stress perturbation. SKS splitting may be measuring fossil anisotropy associated with oblique extension during the rifting event. However deeper anisotropy due to asthenospheric flow cannot be ruled out.
4. Unusually low friction faults along the St. Lawrence may produce a weak zone capable of amplifying stress perturbations. However, such weak faults will also make focal mechanisms less reliable as stress indicators. Similar to plate boundary related mechanisms such as those on the San Andreas fault.[2,4]

References

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