

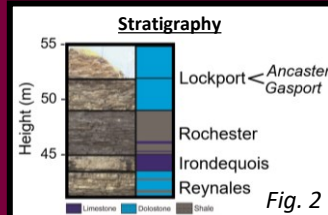
Fractures in the Niagara Escarpment: Distribution, Connectivity, and Implications for Geohazards

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Introduction and Geologic Setting

The Niagara Escarpment (Fig. 2) is a sedimentary cuesta stretching over 700km through Southern Ontario, Canada (Fig. 1) and the north-eastern United States, composed of Ordovician to Silurian dolostones, shales and sandstones. Today, erosion and rockfalls threaten the urban infrastructure of neighboring cities, including that of Hamilton, through which the escarpment passes.



Methods

- Orientation data for fractures and bedding planes were collected using 10m scanlines and 1m² area surveys at 11 sites around Hamilton.
- Data from the Lockport dolostone were statistically analysed in Orient (Vollmer 1990) to identify joint sets.
- Fractures were modelled in MOVE™

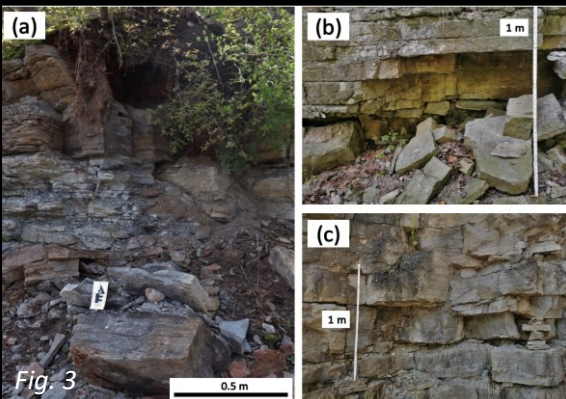


Fig. 3: Rockfalls on north (a and b) and east (c) facing dolostone sections of the escarpment showing cuboid blocks of rock.

Results

- All sites display nearly vertical, stratabound joints (Table 1, Fig. 3) with horizontal bedding planes.
- Rockfall blocks observed in the field are frequently cuboid in shape (Fig. 3) and their frequency increases with fracture density while block size decreases.
- Modeling in MOVE™ (Fig. 5) showed a high degree of connectivity in fracture sets, resulting in similar relative porosity and permeability values and calculated fluid flow properties (Fig. 6). Joint apertures were shown to offer considerable fluid storage.

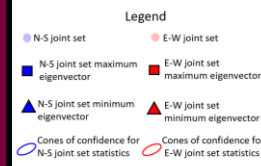
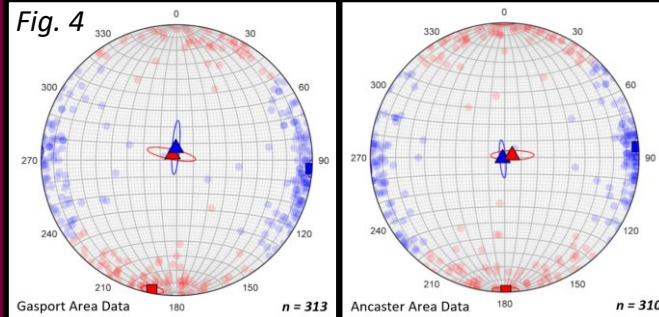


Fig. 4: Stereonets for area survey data. Cluster analysis identified two clusters of joint orientations, characterized by the maximum eigenvectors. The minimum eigenvectors have a dip of nearly zero, closely corresponding to bedding planes. This supports the stratabound nature of the joints by suggesting that they are normal to a nearly horizontal plane.

Table 1: Summary orientations for vertical joint sets in the Lockport Dolostone (composed of the Ancester and Gasport members).

Data Set and Survey Type	Average Strike, N-S Fracture Set (°)	Average Strike, E-W Joint Set (°)
Gasport Area	183 ± 5.0	281 ± 3.5
Gasport Scanline	183 ± 4.5	281 ± 2.5
Ancester Area	175 ± 5.5	269 ± 3.5
Ancester Scanline	179 ± 6.5	096 ± 3.0

Vollmer, F.W., 1990. An application of eigenvalue methods to structural domain analysis. *GSA Bulletin*, 102(6), pp.786-791. [https://doi.org/10.1130/0016-7606\(1990\)102<0786-AAOEMT>2.3.CO;2](https://doi.org/10.1130/0016-7606(1990)102<0786-AAOEMT>2.3.CO;2).

Giuffrida, A., Agosta, F., Rusticelli, A., Panza, E., La Bruna, V., Eriksson, M., Torrieri, S. and Giordano, M., 2020. Fracture stratigraphy and DFN modelling of tight carbonates, the case study of the Lower Cretaceous carbonates exposed at the Monte Alpi (Basilicata, Italy). *Marine and Petroleum Geology*, 112, p.104045. <https://doi.org/10.1016/j.marpetgeo.2019.104045>.

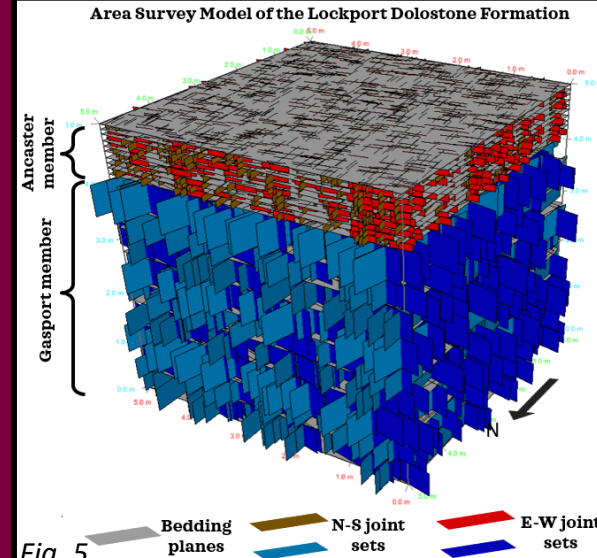


Fig. 5: Geologic model of the uppermost Lockport Dolostone showing the Gasport member with blue joints, the Ancester member with red/orange joints, and stratigraphic bedding planes as a grey fracture network. The three fracture sets are perpendicular to one another, clearly corresponding to the cuboid rockfall blocks (Fig. 3).

Discussion

- **Joint provenance:** Results of this study suggest that joints were formed in response to vertical stress from a previously overlying ice sheet. Bedding planes would act as free surfaces, promoting the formation of vertical joints, perpendicular to the previously defined stratigraphic discontinuities.
- **Field data collection:** The area method was more tedious, and measuring bedding planes was redundant due to the negligible dip of the strata (0.3° S) and measurement inaccuracy when using the right-hand rule
- **Modeling limitations:** Building stratabound joints is not natively supported in MOVE™. Therefore, joint height (z) was manually manipulated to accommodate for this. In addition, host lithology is not considered in fluid flow calculations (Fig. 6), however, fractures are recorded in the literature to dominate fluid flow properties compared to the host rock (Giuffrida *et al.* 2020).
- **Fluid flow implications:** Similar models can be applied in economic geology to understand hydrocarbon migration and storage in carbonate reservoirs.

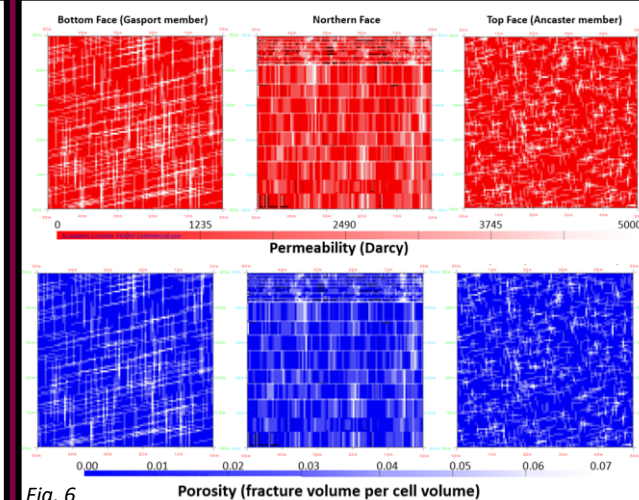


Fig. 6: Permeability (red scale) and porosity (blue scale) are closely linked as bedding planes connect vertical joints of neighboring beds. Joint aperture drastically affects fluid flow properties, as determined by model parameter manipulation.

Conclusions

- (1) Three fracture sets were identified: 1. nearly horizontal bedding planes, 2. a N-S oriented high angle stratabound joint set, and 3. an E-W high angle stratabound joint set.
- (2) The vertical joints are hypothesized to have originated from the retreat of the Laurentide Ice Sheet in the Holocene, though more research is needed to confirm this.
- (3) The scanline method proved superior over the area method for data acquisition at this site.
- (4) The fracture sets promote the dislocation of blocks of rock, which is considered a local geohazard.
- (5) DFNs provide a tool for quantifying parameters associated with fracture networks.

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