Ultra-Slow Throw Rates of Polygonal Fault Systems

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1. Introduction

What are Polygonal Fault Systems (PFS)?

- Laterally extensive arrays of ***layer bound*** normal faults typically spanning ~10^5-10^7 km^2.
- Exclusively found in ***fine-grained sediments***.
- Form complex interlinking ***polygonal planform patterns.***
- Formation is ***non-tectonic***.

Where are PFS found?

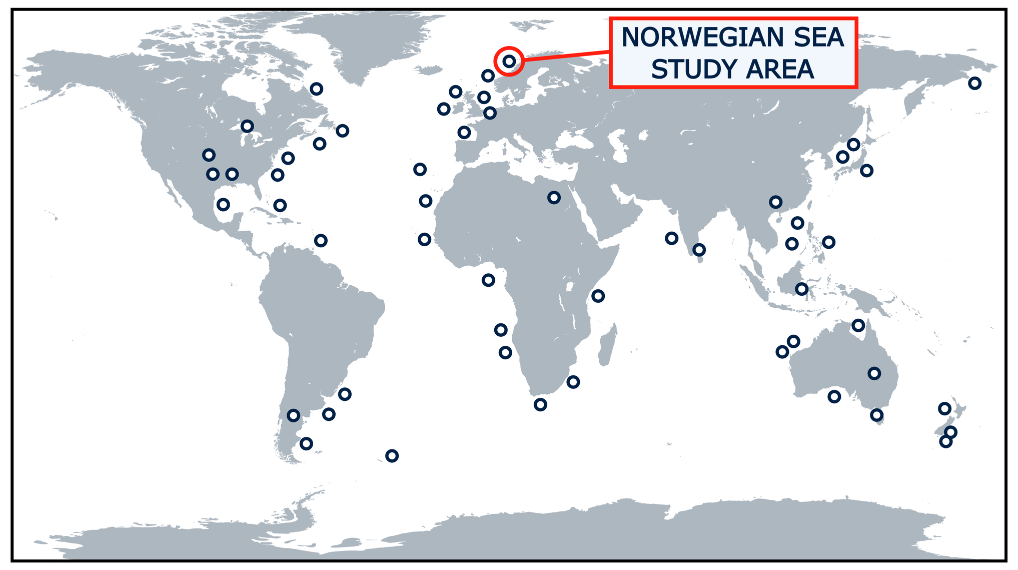

Figure 1: PFS are hosted in fine-grained sediments in basins around the world.

The Polygonal Fault System Enigma

- Despite ~30 yrs of research a universal PFS genetic mechanism remains elusive.
- Suggested mechanisms include '***Gravity Sliding***', '***Density Inversion***', '***Overpressure***', '***Gravitational Loading***', and '***Diagenetically-Induced Shear Failure***' (Goulty, 2008; *Cartwright, 2011*).
- To date, the rate at which polygonal faults grow has remained unconstrained.

Research Aims

- Derive the first measurements of ***PFS throw rates***.

2. Data & Methodology

Data

- Two-adjoining ***3D seismic surveys*** with bin spacings of 6.25 m and 25 m respectively, and vertical resolutions of ~6 m and ~10 m respectively.
- Seismic chrono- and lithostratigraphic calibration from ***ODP 644,*** 6604/2-1, and 6603/5-1 wells (Fig. 2).

Methods

- Dated horizons calibrated to seismic using a velocity of 1600 m/s, with uncertainty of +/-0.1 Ma and +/-0.2 Ma for horizons <1 Ma and >1 Ma respectively.
- Throw rate = ΔThrow / ΔTime
- Displacement rate = Throw rate / sin(fault dip)

3. Geological Setting

Study Area

- Located within the Vøring Basin, Norwegian Sea.
- PFS tier is ~1000 m thick across the study area.

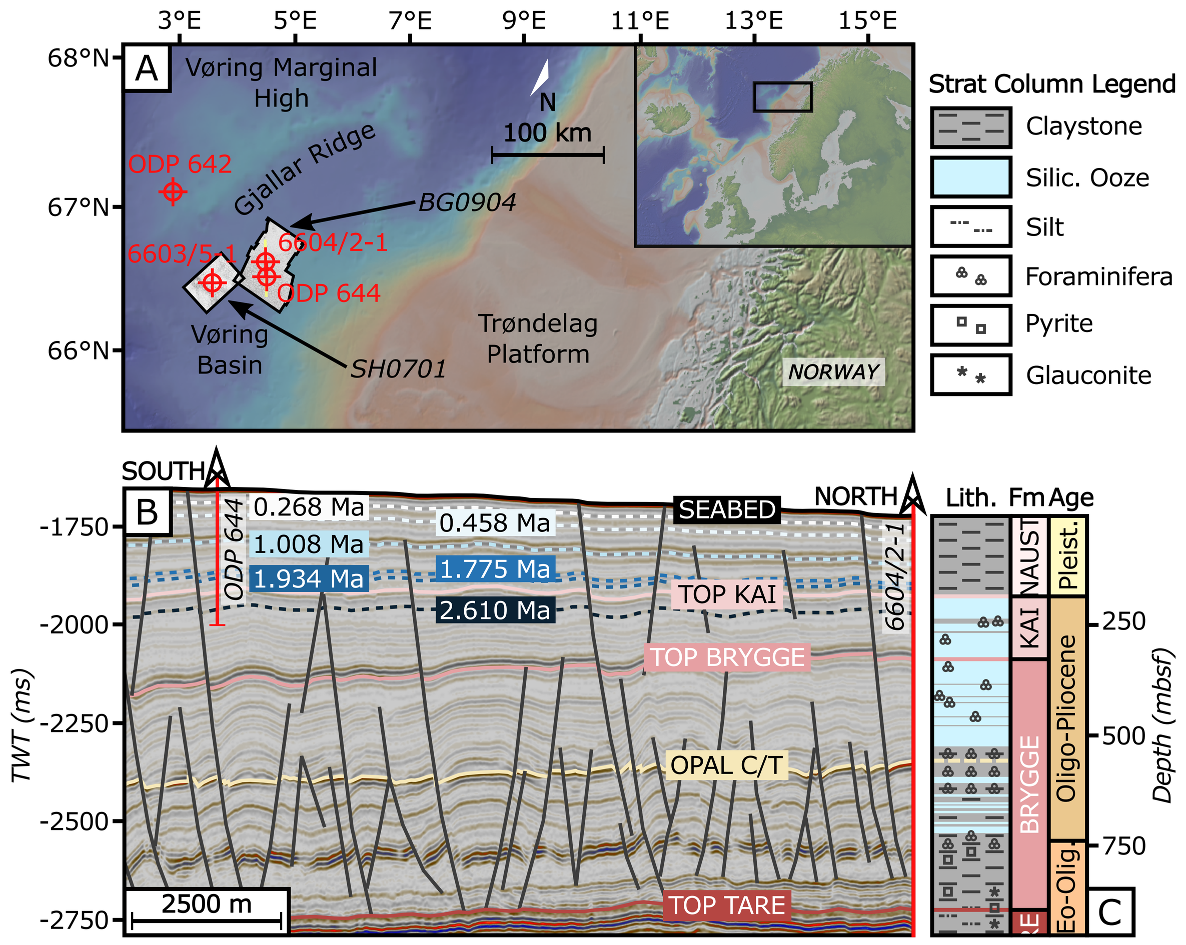

Figure 2: (A) Map of the study area located in the Vøring Basin. (B) Seismic profile through the PFS showing the mapped dated horizons and formation boundaries. (C) Stratigraphic column.

Stratigraphy

- Host strata comprise fine-grained siliceous mudstones, claystones, and oozes of the Naust, Kai, and Brygge Fm.
- Prominent Opal A/CT diagenetic phase boundary in lower third of tier.

4. Syn-Sedimentary PFS

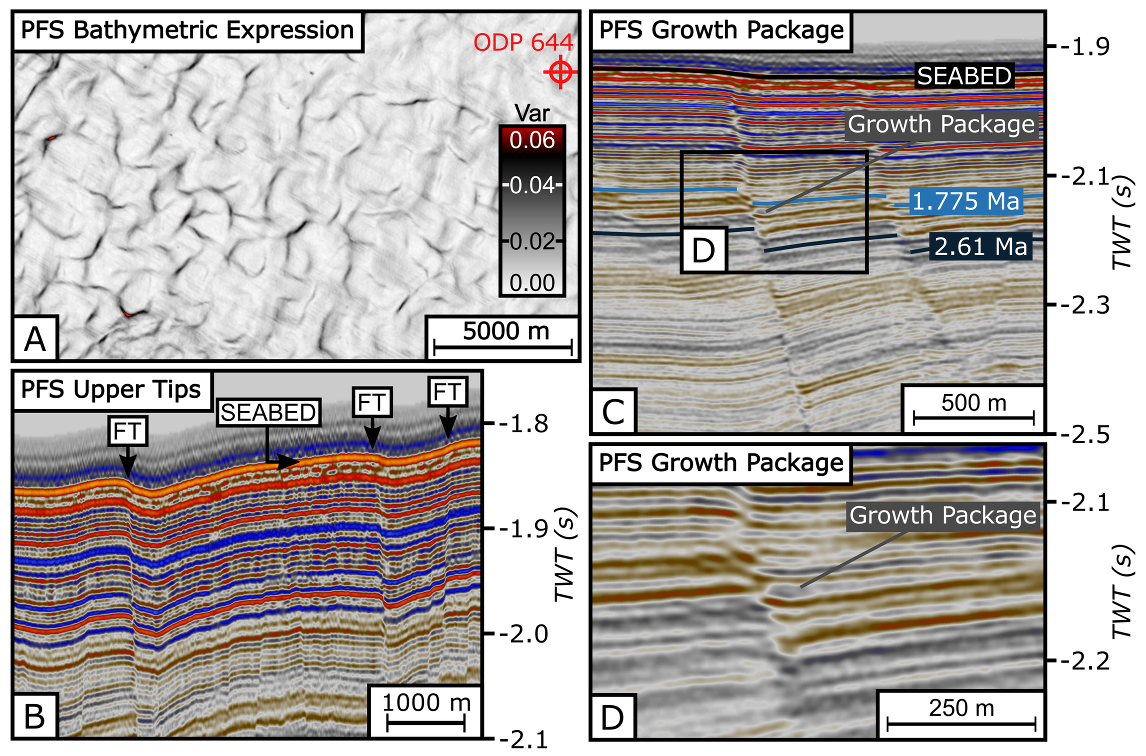

Figure 3: Bathymetric expression of PFS upper tips in (A) map view and (B) cross-section. (C, D) Syn-sedimentary growth package within age-calibrated stratigraphy.

5. Results

PFS Throw vs Horizon Age Plots

- Individual faults (n=52) exhibit a range of profiles of throw with time (Fig. 4), from almost linear to singly or multiply stepped.
- Of the 52 faults, around 60% of profiles are approx. linear or smoothly varying.
- Short-term throw rates range from 0 to 18 m/Ma.

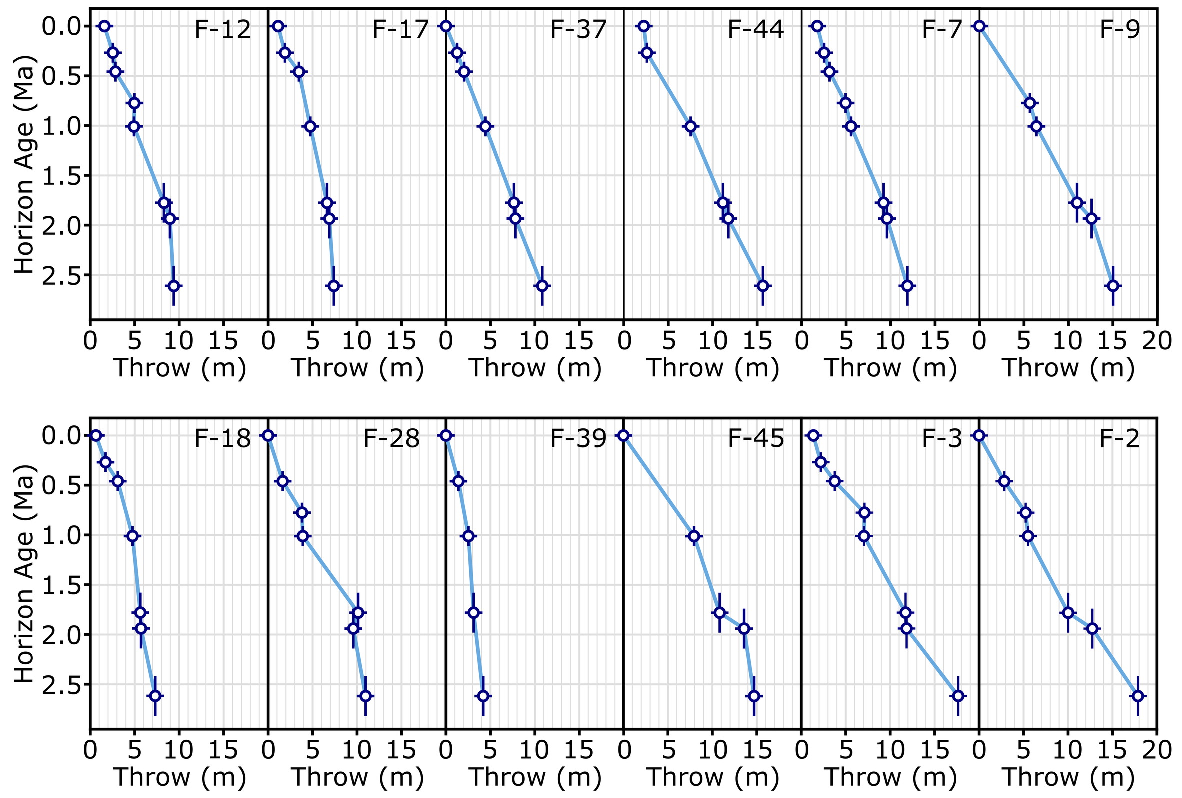

Figure 4: PFS throw versus horizon age for 12 upper tips.

PFS Time-Averaged Throw Rates

- Derived from the 2.61 Ma horizon.
- Range between ***1.4-10.9 m/Ma***, with a mean and median of 5.7 m/Ma and 5.6 m/Ma respectively.

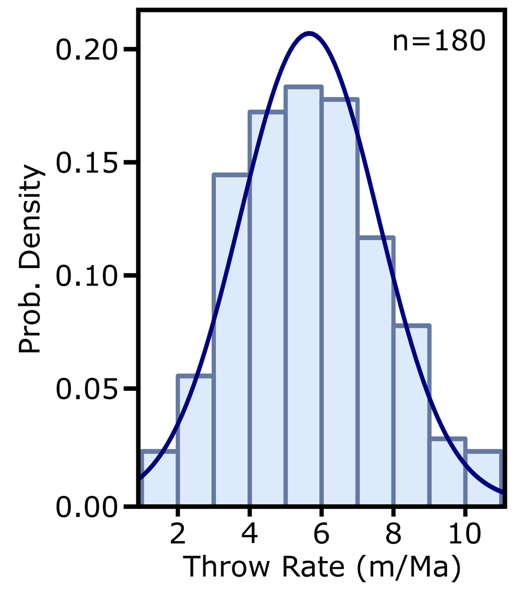

Figure 5: Probability density function of time-averaged PFS throw rates for 180 faults. →

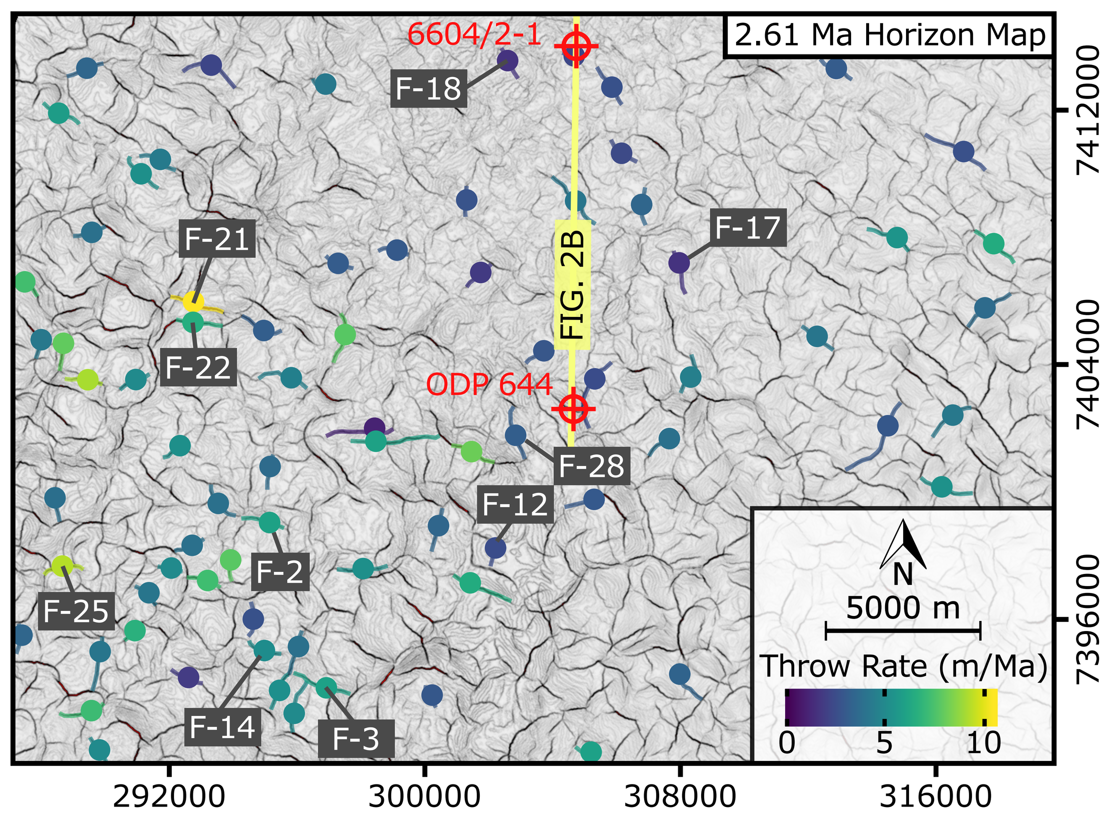

Figure 6: Map of the 2.61 Ma horizon showing the spatial distribution of measured PFS throw rates.

6. Discussion

Comparison to Tectonic & Gravity-Driven Faults

- Norwegian Sea PFS displacement rates mark the ***lower limit*** of a continuous spectrum of extensional fault displacement rates (Fig. 7).

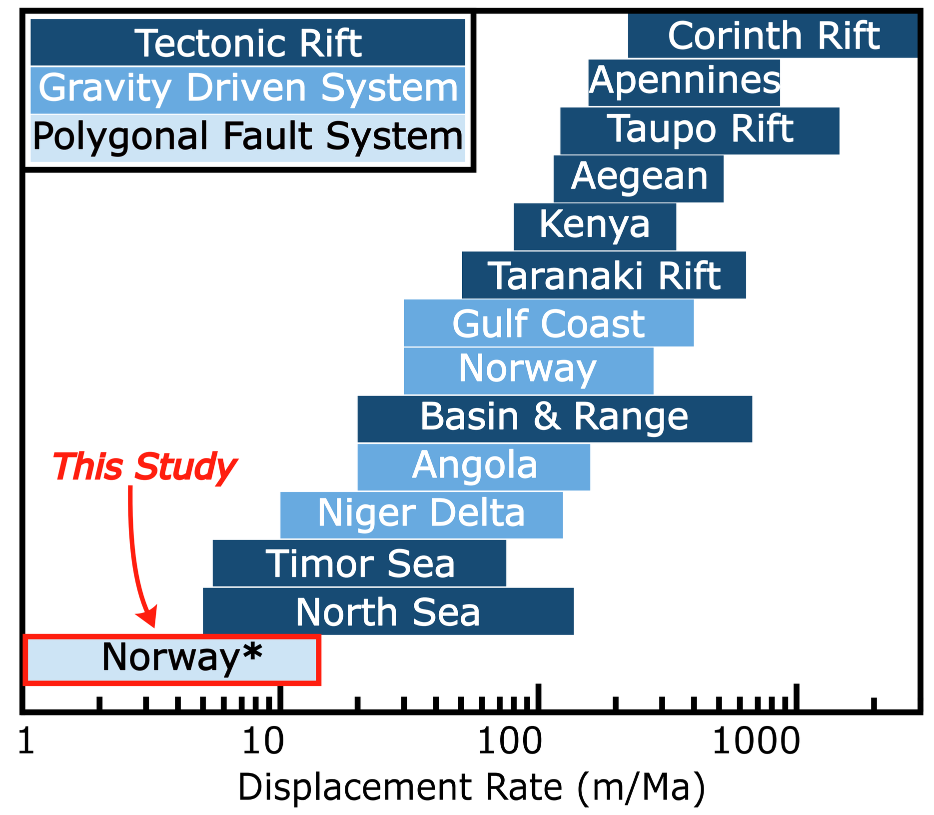

Figure 7: Log plot of displacement rates from extensional fault systems around the world. Sources; *Nicol et al., (1997); Pochat et al., (2009); Mouslopoulou et al., (2009); Dutton & Trudgill (2009); Jackson (2018).*

- Do polygonal faults ***creep*** with sedimentation (*cf. Goulty, 2008*) or do they exhibit ***stick-slip*** behaviour?
- ***Ultra-slow PFS throw rates*** are not surprising given the ***slow rates of geological processes*** governing volumetric reductions in ***shallowly buried fine-grained sediments***.

7. Conclusions

- ***First throw rates*** for a Polygonal Fault System.
- Time-averaged ***throw rates*** over the last 2.61 Myrs are ***normally distributed*** and range between ***1.4-10.9 m/Ma***.
- PFS displacement rates mark the lower limit of extensional fault displacement rates.
- Ultra-slow PFS throw rates are consistent with ***slow geological processes*** that drive ***differential volumetric reductions*** between footwalls and hangingwalls.
- Throw rates offer a temporal benchmark to model PFS growth.

Acknowledgments

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