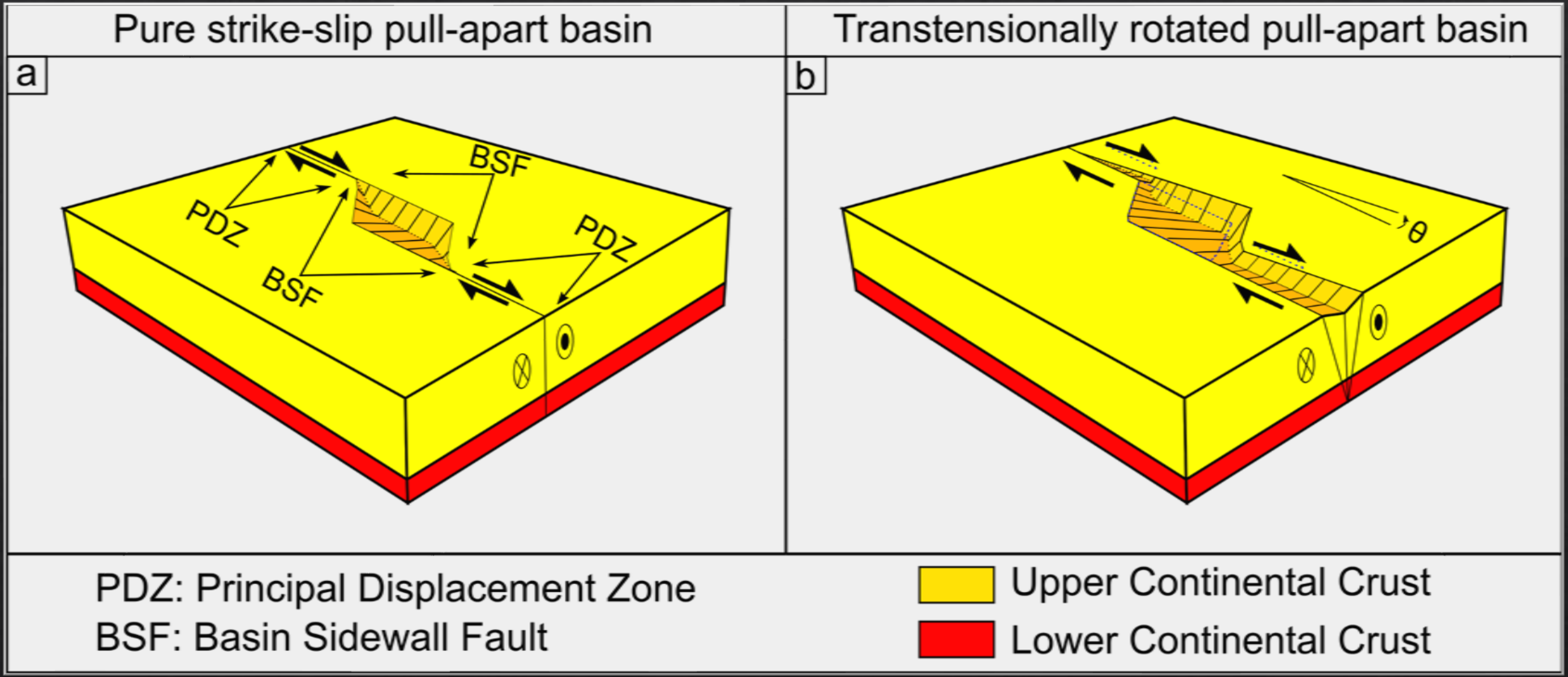
The structural evolution of pull-apart basins in response to relative plate rotations; A physical analogue modelling case study from the Northern Gulf of California.



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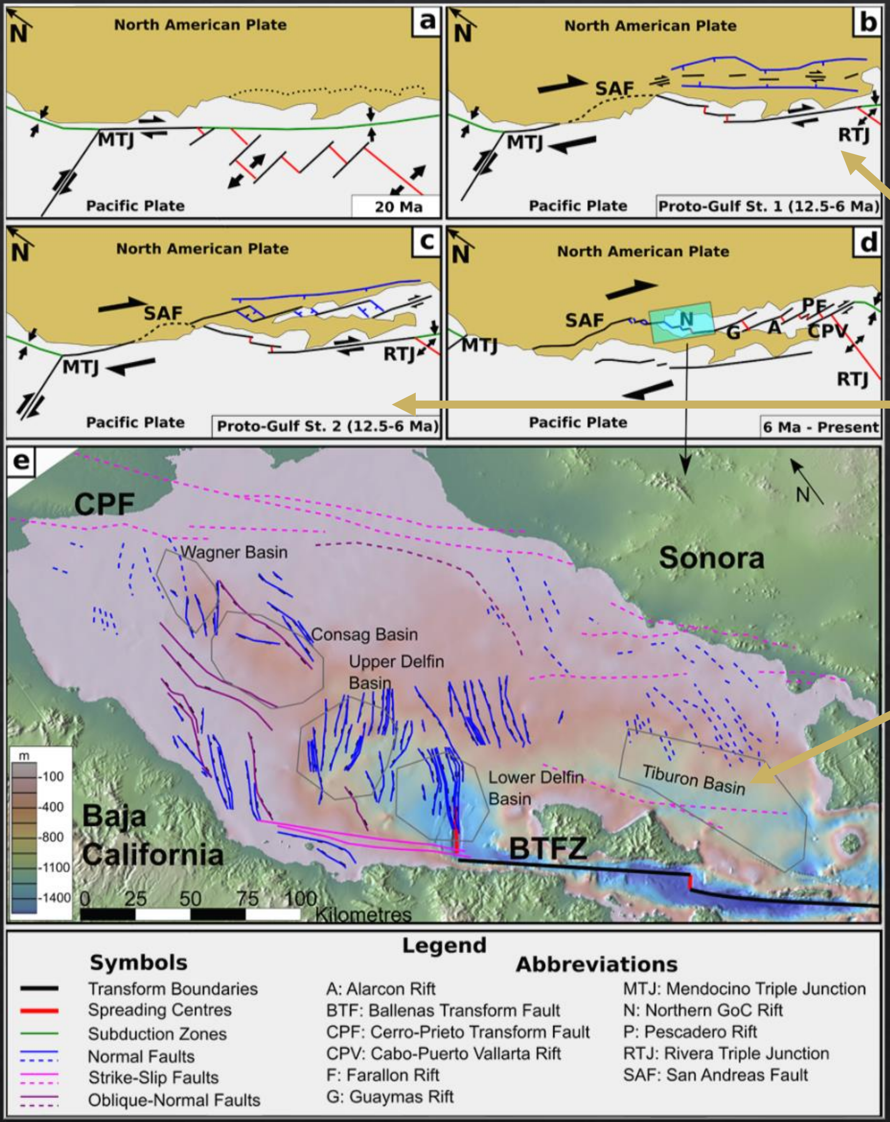
Geological Background



Area of Interest: N. Gulf of California (N.GoC) (panel d) transtensional pull-apart

Key evolution points:

a) 7-15º rotation in the relative plate motion at ~8 Ma increased rift obliquity favouring strike-slip faulting (Bennett & Oskin, 2014).

b) This change results in transtensional opening and breaching of pull-apart basins in the Gulf of California from south to north (Umhoefer et al., 2018).

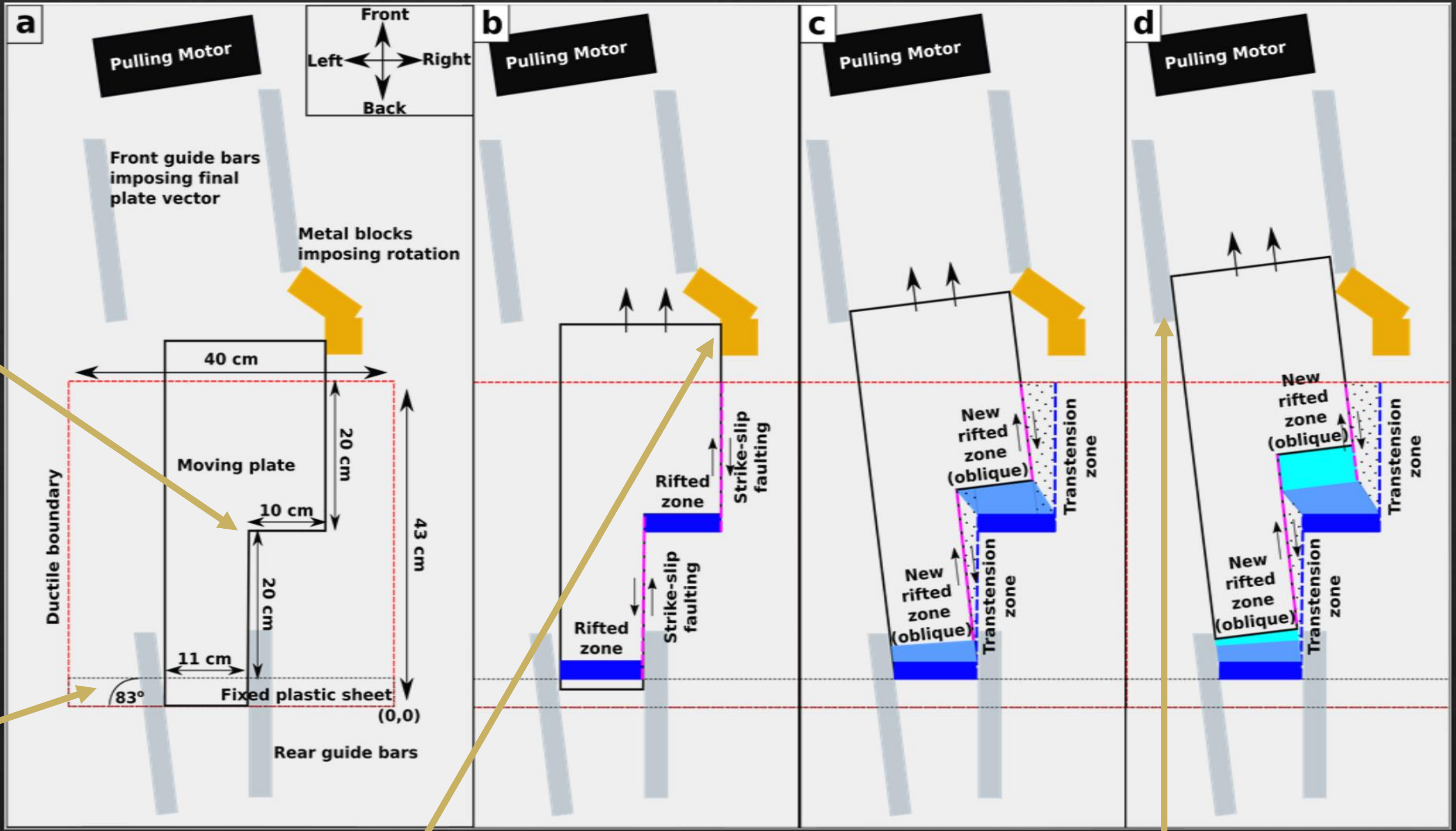
c) Deformation in the N.GoC pull-apart has experienced a westward jump from the Tiburon Basin ~3.5-2 Ma following a plate reorganisation (Seiler et al., 2009).

a-d: Stages of evolution of the Gulf of California from 20 Ma to present (modified from Bennett et al., 2013) e: close-up map of the northern Gulf of California (faults in continuous lines from this work and Persaud et al. 2003, faults in dashed lines from Martin-Barajas et al., 2013, basin outlines in grey colour). (From Farangitakis et al., in prep)

Modelling - Kinematics

Right hand side of moving plate is cut in order to impose two right-lateral strike-slip faults connected by a rift segment.

At the trailing edge of the plate, a thin plastic sheet is fixed above the moving plate acting as a second VD, imposing another rift.



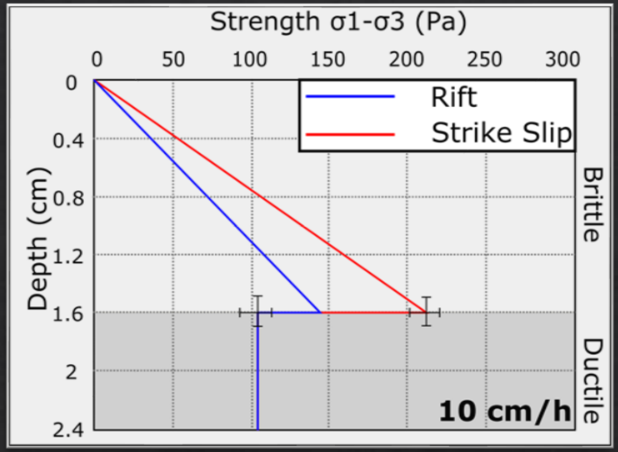
Moving plate sits underneath the ductile layer of the model to impose velocity discontinuities (VDs). Similar modelling array to Farangitakis et al. (2019).

(From Farangitakis et al., in prep)

Kinematic stages:

a) initial configuration and dimensions
b) orthogonal motion stage (imposed by metal blocks)
c) end of rotation stage
d) new oblique plate motion vector stage (plate slides into guide bars)

Modelling - Scaling



Scaling

Prototype/model thickness ratio $T=T_p/T_m$ 0.417 x 10^6 to 0.625 x 10^6 (dimensionless – from Lizarralde et al., 2007; Persaud et al., 2017)

Rheology

Governing equations (from Brun 2002)

Brittle layer strength (rift): $\sigma1 - \sigma3_{(r)} = \frac{2}{3}(\sigma1 - \sigma3)_{(ss)}$

Brittle layer strength (strike slip): $\sigma1 - \sigma3_{(ss)} = \rho g T_b$

Ductile layer strength: $\sigma1 - \sigma3_{(d)} = 2\left(\eta \frac{V}{T_d}\right)$

Brittle crust: dry feldspar sand, ρ = 1.3 g/cm^3 (Luth et al., 2010), d = 100-350 µm and μ_{fric} = 0.6 (Sokoutis et al., 2005).
Ductile crust: transparent silicone putty SGM-36 , ρ = 0.970 g/cm^{3}and μ_{vis} = 5*10^4 Pa.s (Weijermars, 1986a; Weijermars, 1986b; Weijermars 1986c).

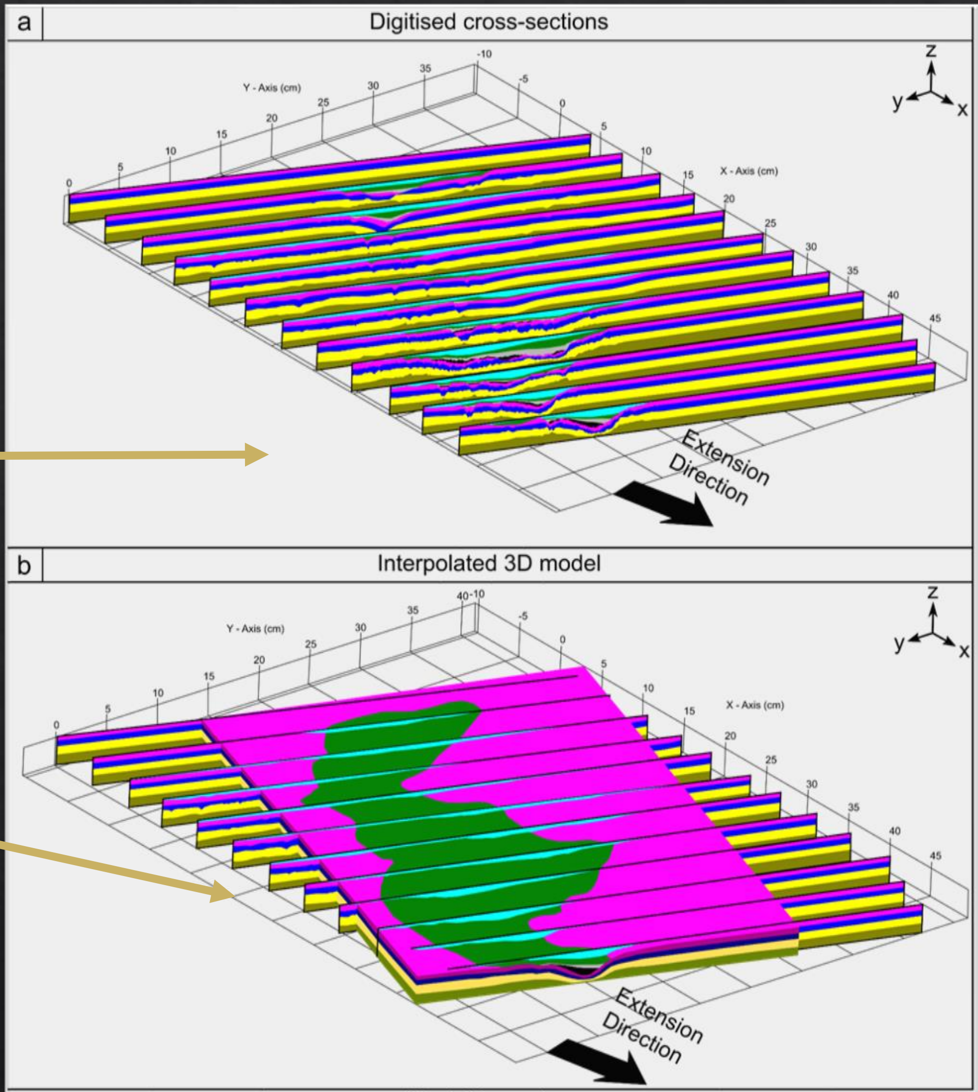
Digitised Model

After the end of the model run, the model is wet and cut in cross-sections (post-processing).

Cross-sections are turned into vector graphics and inserted in seismic interpretation software Schlumberger Petrel^{TM}

Transition between coloured sand layers identified, mapped and interpolated across the whole model volume

Faults cross-correllated across cross-sections



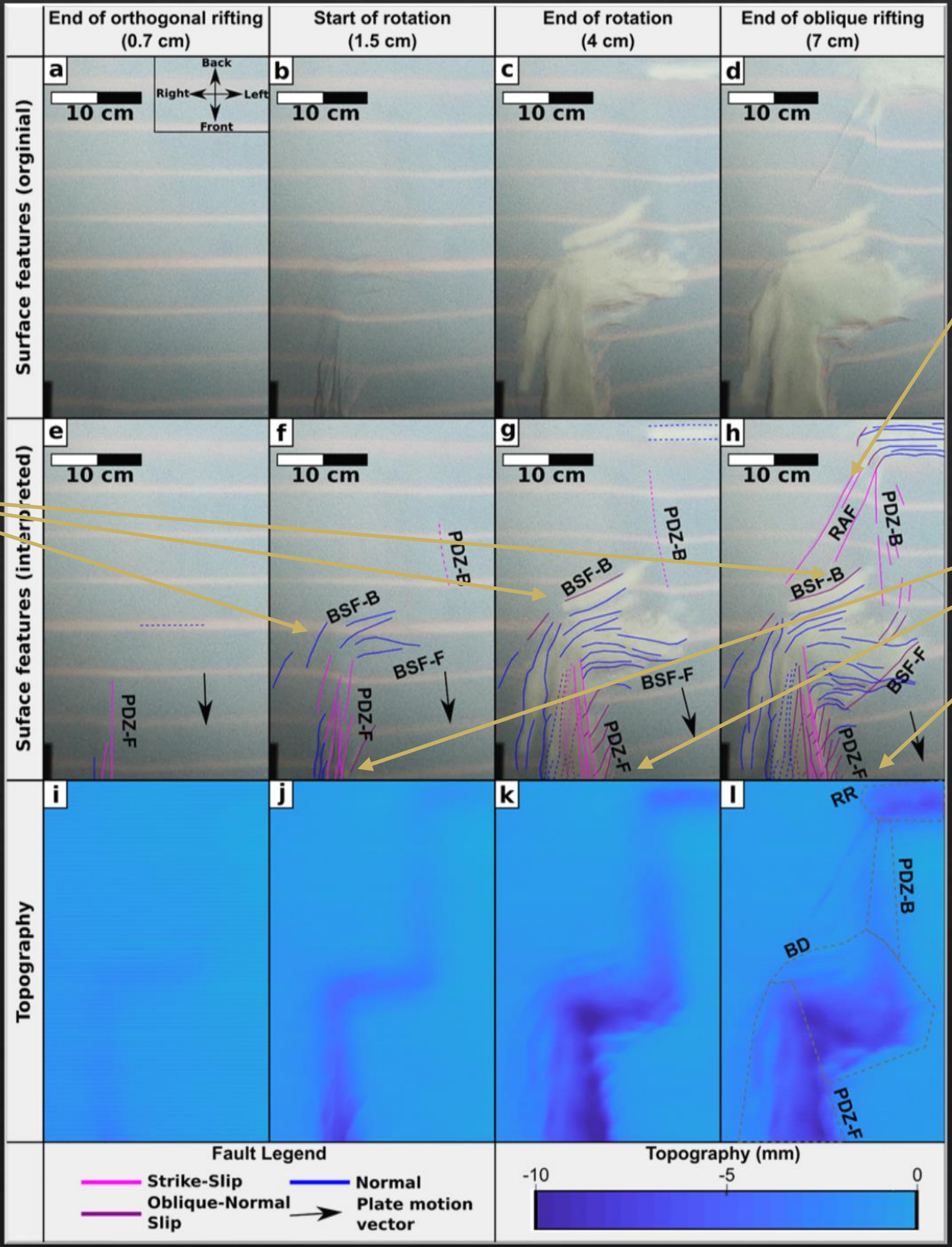
Model Layering

Original Layer Colour	Digitised Layer Colour	Description	Role of Layer
Black	Cyan	Quartz sand	Protective cover (added)
Green	Green	Feldspar sand	Post-rotational sediments (added)
White Black	Gray Black	Feldspar sand	Syn-rotational sediments (added)
Pink Blue Yellow	Pink Blue Yellow	Feldspar sand	Brittle upper crust (original)
Transparent	Brown	Silicone putty	Ductile lower crust (original)

(From Farangitakis et al., in prep)

Model Results

(a–d) Surface feature development (uninterpreted).
(e–h) Surface feature development (interpreted).
(i-l) Topography evolution.



Note the formation of two strike-slip faults in the back of the pull-apart having accommodated rotation

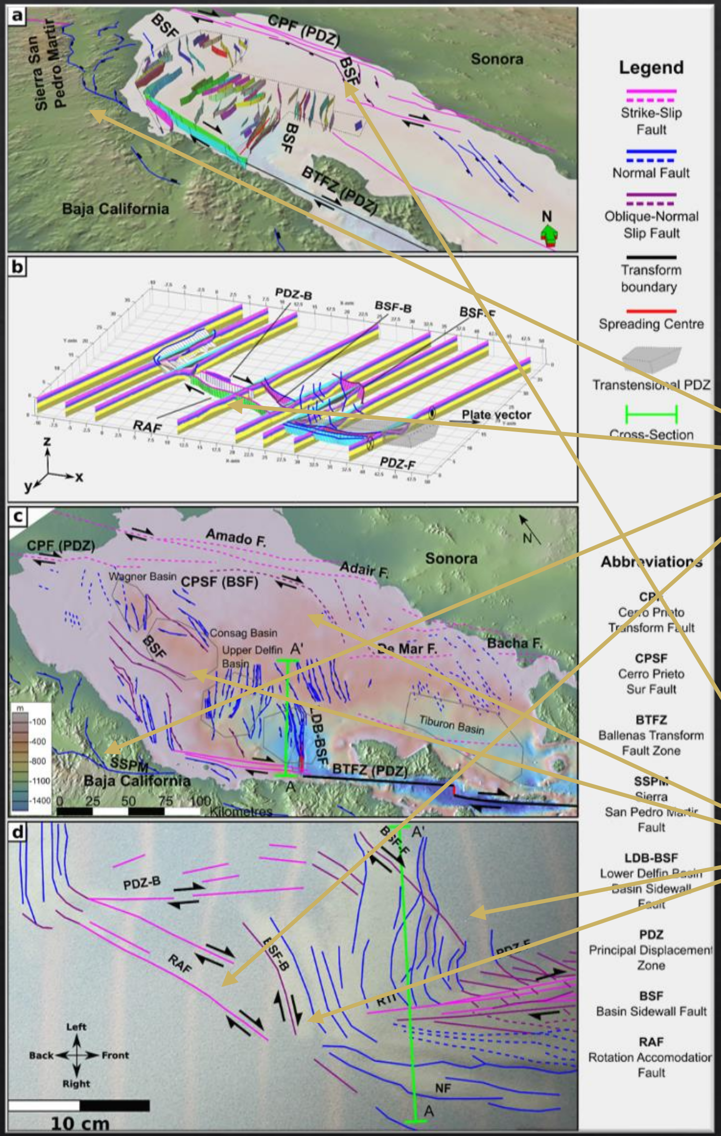
Note the evolution of normal faulting (blue faults) in the midsection and top of panels f-h.

Note the evolution of oblique slip and strike-slip faulting zones (pink/purple faults) in the PDZ.

PDZ-F/B: Principal Displacement Zone (Front/Back), BSF-F/B: Basin Sidewall Fault (Front/Back), RAF: Rotation Accommodation Fault, BD: Basinal Depression, RR: Rear Rift.

(From Farangitakis et al., in prep)

Comparison with the N.GoC



(From Farangitakis et al., in prep)

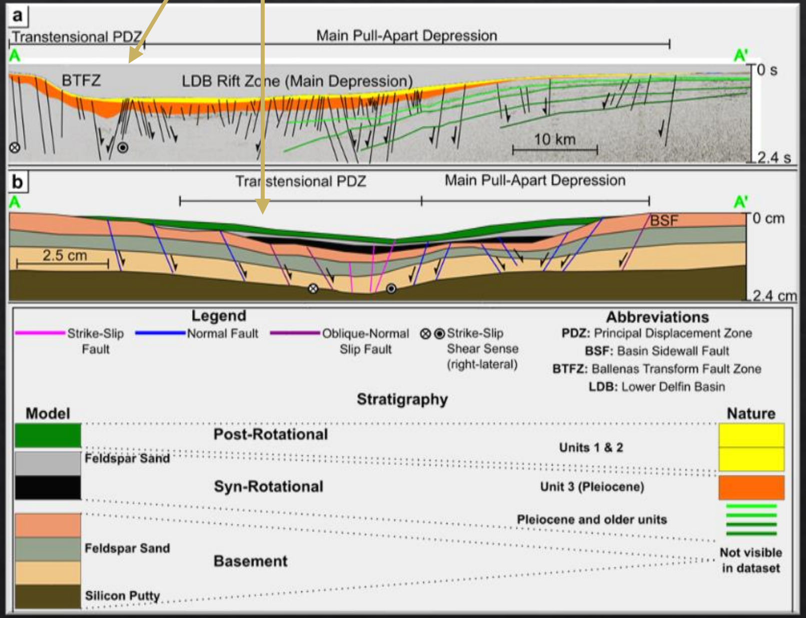
Comparison with UL9905 high resolution seismic dataset (Stock et al., 2015)

Similar structural elements between our model and the N. GoC.

Some of the rotational motion is taken up by faults outside the pull-apart depression (left figure): RAF's in model, Sierra San Pedro Martir normal faults in the Gulf of California (Bennett et al., 1996).

In both cases the BSFs appear to be oblique-normal faults.

Dextral motion is accommodated in a wider Principal Displacement Zone (PDZ) in the N.GoC (right figure, top) and in our model (right figure, bottom).



(From Farangitakis et al., in prep)

Conclusions

- Model produces structural patterns that are in very good agreement with the natural example. Both the N. Gulf of California and our model develop an asymmetrical triangular pull-apart basin, bound by strike-slip faults (PDZs) and oblique-normal faults (BSFs) on either side.

- Presence of features such as: asymmetrical triangular pull-apart basins, wide PDZs with oblique faulting and normal faults with an oblique component, are strong indications that the pull-apart basin has undergone a transtensional rotation change due to a change in the motion vector along the strike-slip zones that define it.

Stay safe and thank you for participating in our session!

Acknowledgements

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