Three-Dimensional Dynamics of Slab Detachment Due to Ridge-Trench Collision

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TO Meeting 2010

I. Motivations

(1) Understanding the end of subduction: physics/causes of loss of slab pull, and implications for changes in plate motions.

(2) What happens when an active spreading ridge encounters a trench (slab and ridge dynamics/timing and resulting surface deformation)?

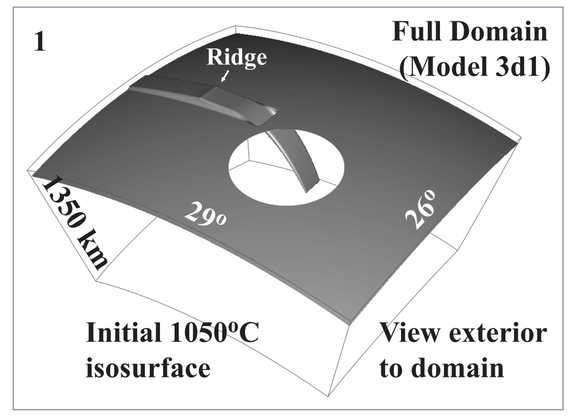
(3) Understanding the three-dimensional nature of slab detachment: simultaneous along strike, lateral propagation, tear initiation at slab edges or central to slab?

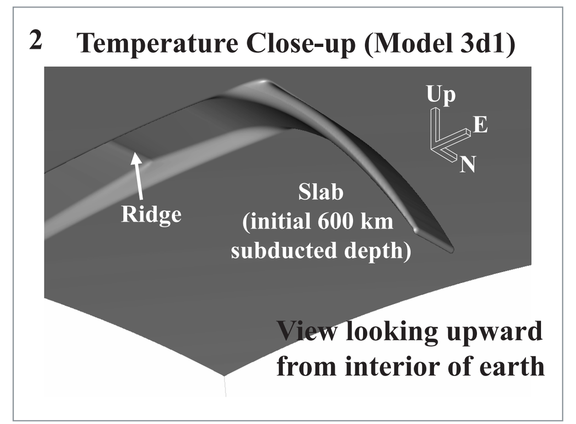
(3) Linking observations to detachment: explain temporal and spatial relationships between slab evolution and observed (slab-gap?) magmatism and tectonic changes (e.g., Baja California, Central Mexico, and possibly Chile Triple Junction)

II. Model Setup

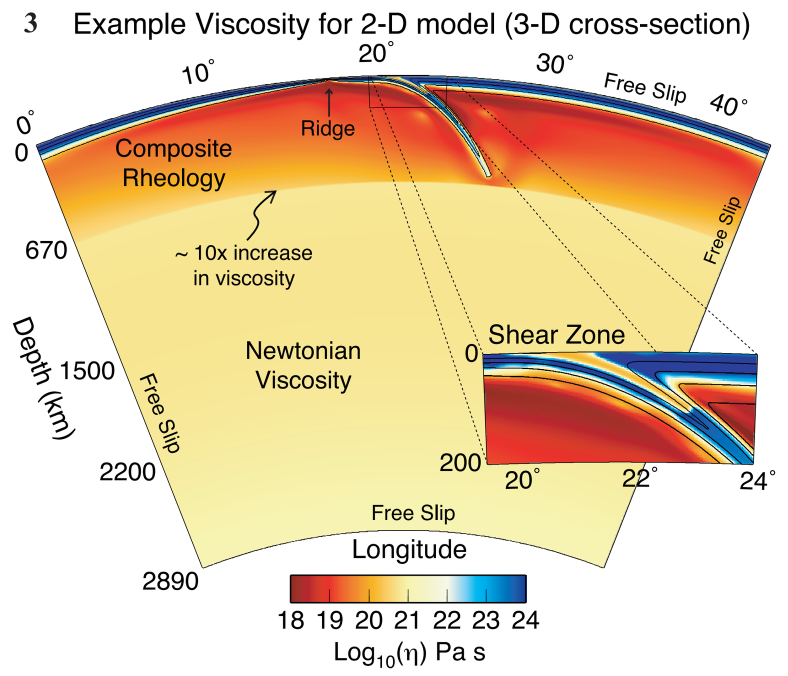
Numerical models are run using the 3D numerical finite element code CitcomCU[1,2] which solves the standard equations for incompressible viscous flow (conservation of mass, momentum, and energy).

Initial Temperature





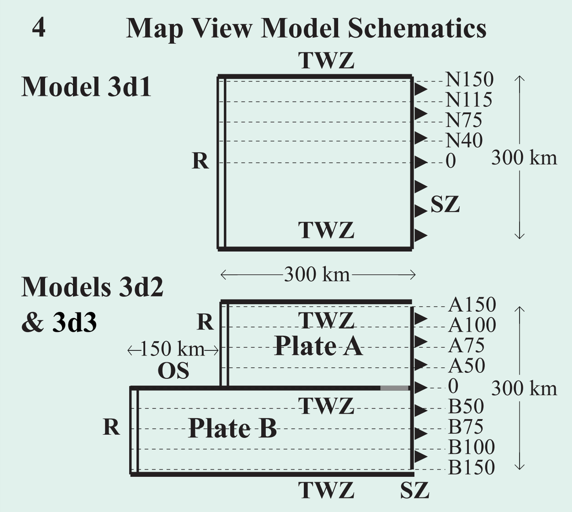
Rheology

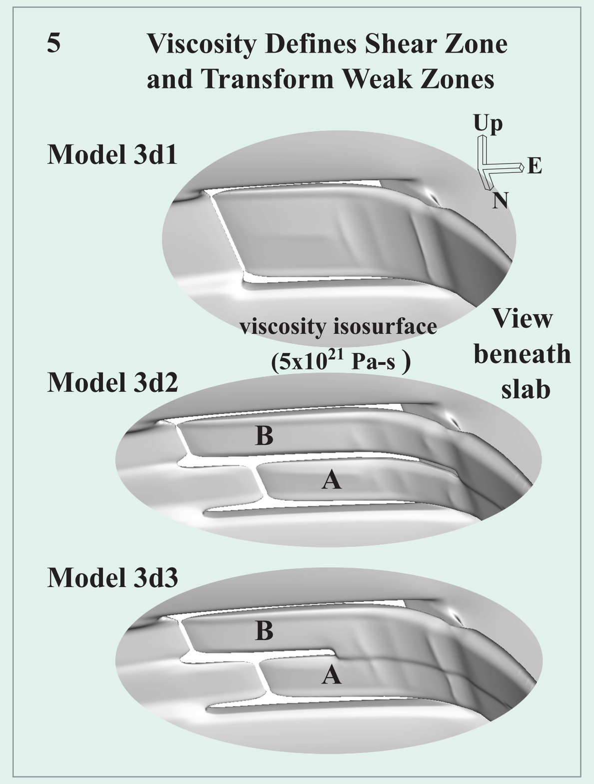


Viscous Rheology: Olivine flow law parameters from Hirth and Kohlstedt (2003)[3].

Plastic Rheology: Yield stress, σ_y, limits maximum allowable stress (depth-dependent 15 MPa/km & maximum 500 MPa)

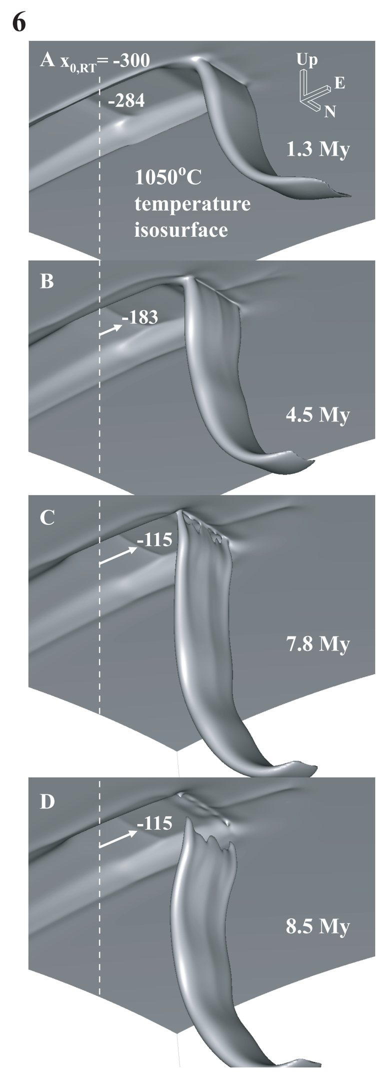
Three 3-D Ridge-Trench Collision Geometries





III. Model Results

Model 3d1: Single, Symmetric, Laterally-Finite Ridge Segment



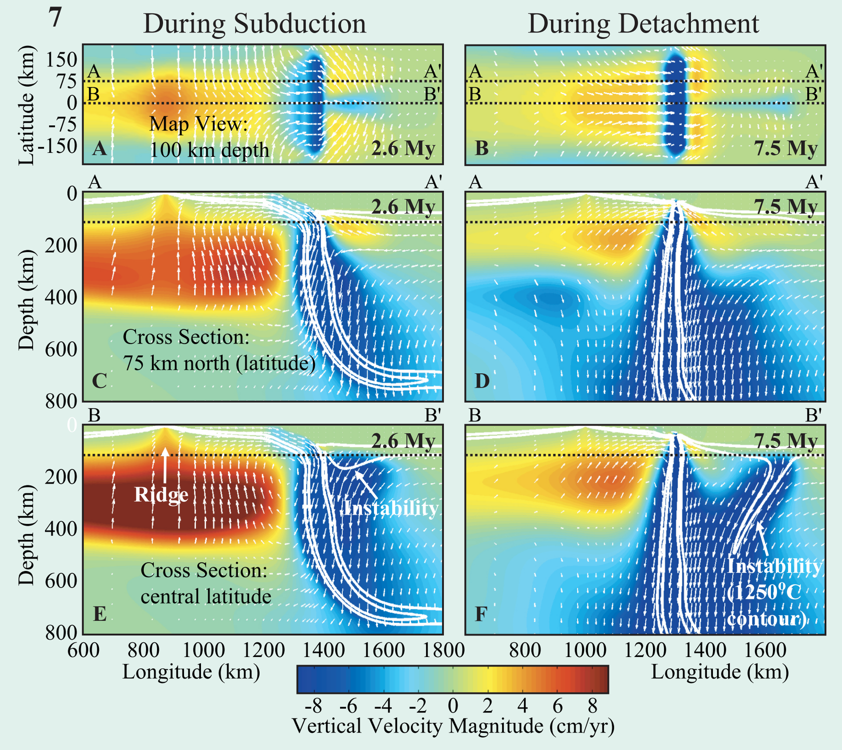
(A) Sinking toward vertical profile

(B) Subduction, ridge migration

(C) Detachment *central* to slab, abandonment of ridge

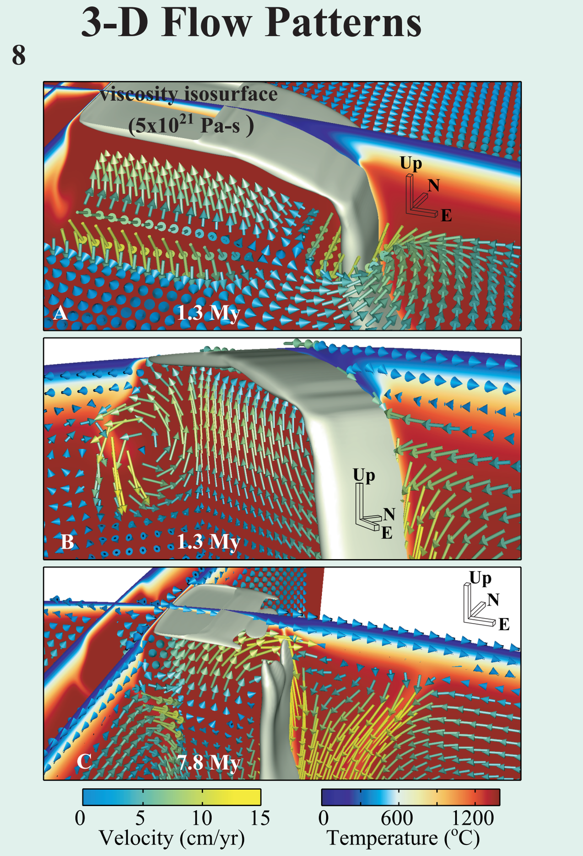
(D) Complete detachment, slab sinking

Flow Field and Vertical Velocity Component



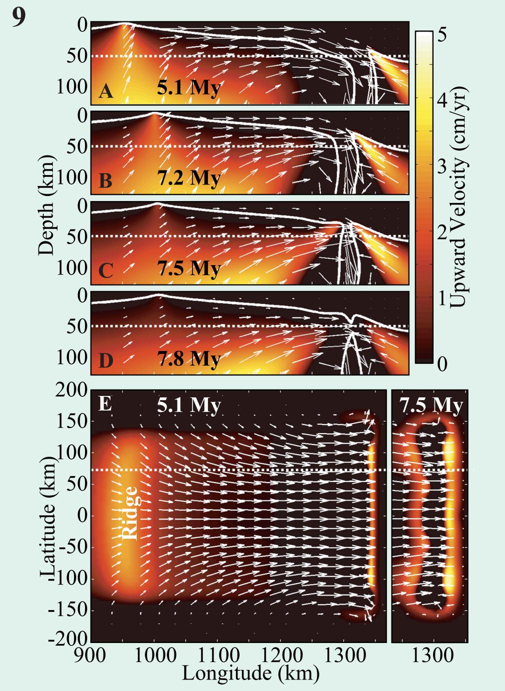
* Downward flow with sinking slab, upward flow focused at spreading ridge (esp. central latitude)
* Flow diverted from ridge to necking slab during detachment, ceases at ridge upon ridge abandonment

3-D Flow Patterns



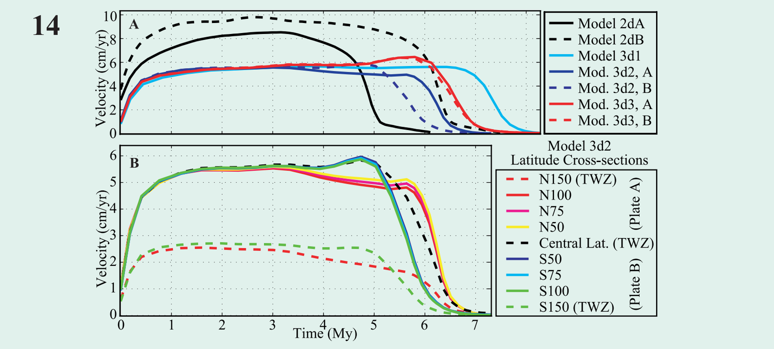
(A) Flow around, down with slab, flow up at ridge
(B) Rotational flow pattern in latitude
(C) Flow toward slab detachment gap

Upward Flow: Proxy for Decompression Melting

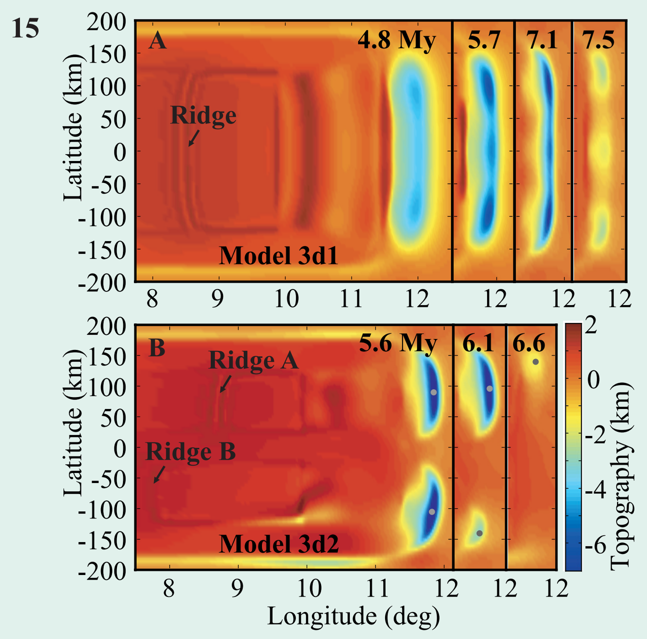


(A) subduction
(B) ridge migration, shallowing wedge
(C) focusing toward necking slab
(D) detachment, lessened upward flow
(E) lateral variation in magnitude

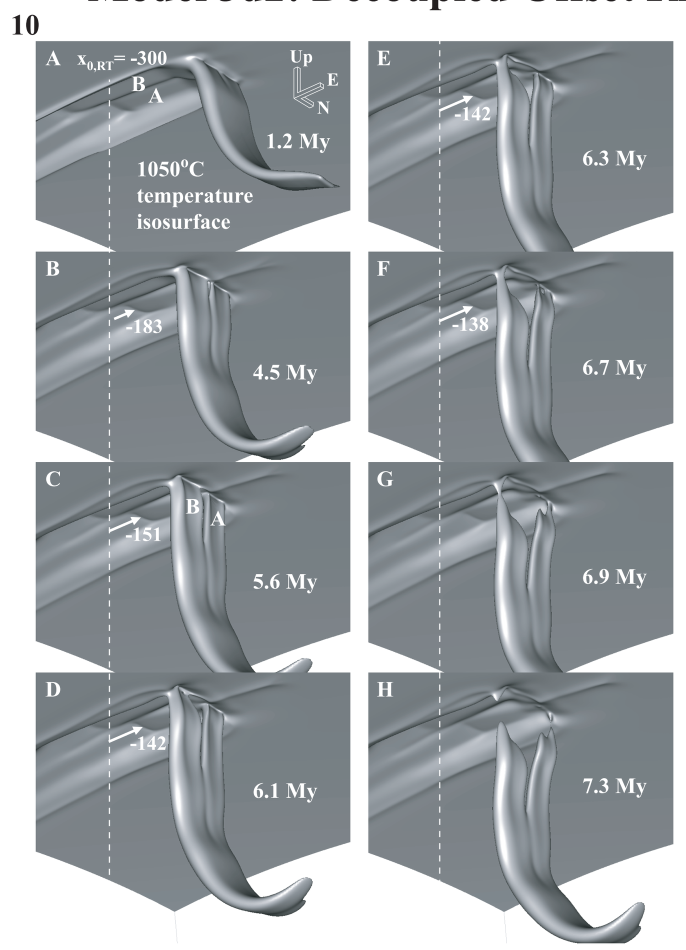
Dynamics Reflected in Plate Subduction Velocity History



Topography Reflects Timing of Detachment, Tear Propagation

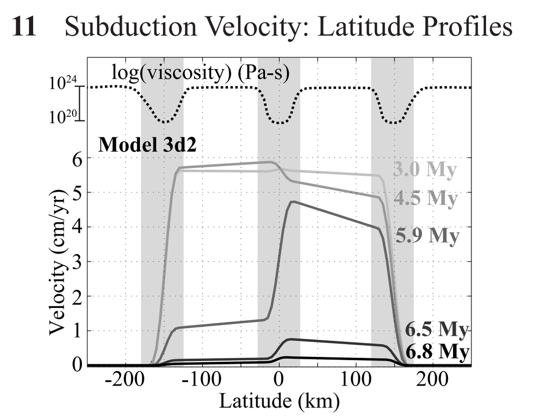


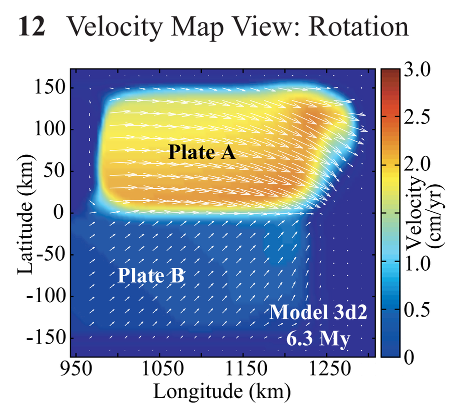
Model 3d2: Decoupled Offset Ridge/Plate Segments



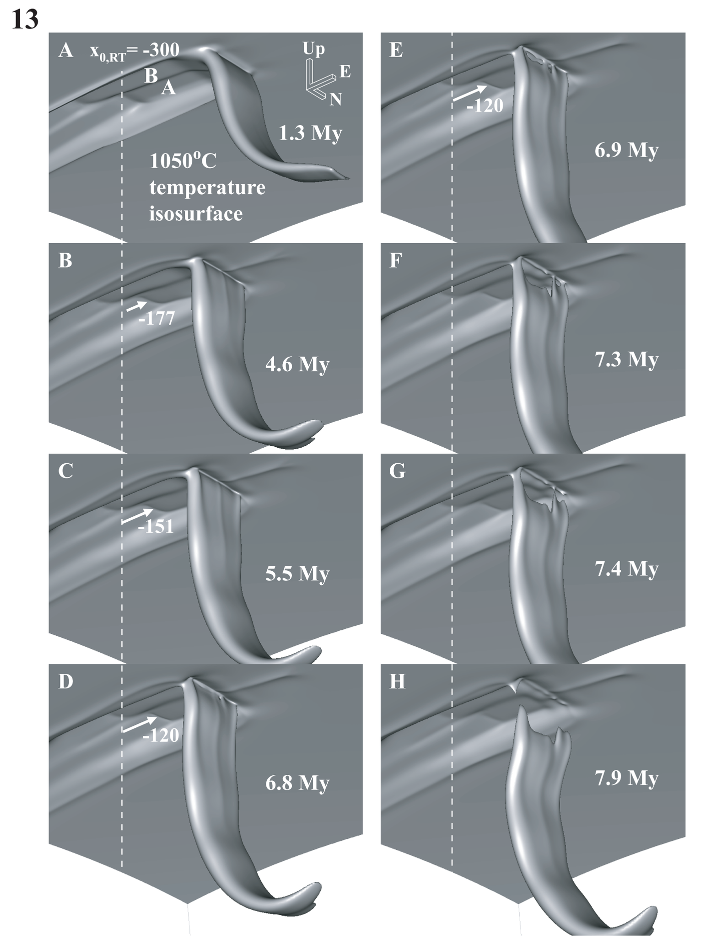
(A) subduction
(B) vertical gap initiation
(C) downward gap propagation
(D) horizontal tear propagation (Slab B)
(E) stretching of Slab A, tearing of Slab B
(F) central gap in Slab A
(G) horizontal detachment of Slabs A and B
(H) complete detachment, sinking

Central transform fault weakening through subduction zone facilitates:
- development of vertical separation (Fig. 10)
- decoupling of motion of between plates (Fig. 11)
- plate rotation (Fig. 12)





Model 3d3: Partially-coupled Offset Ridge/Plate Segments



For 'healing' of transform fault/fracture zone 50 km outboard of trench (Model 3d3):

- offset ridges migrate together; no separation of offset plates and relative motions (A-D)

- detachment of Slab B before Slab A, but nearly simultaneous along each slab (no single-directional horizontal propagation), with gaps opening central to slabs (E-F)

IV. Comparisons with Observations

	Baja California:	3-D Models:
Ridge abandonment distance:	50-200 km outboard of the trench[4]	103-273 km
Distance from trench to magmatic arc: (for models, distance to slab gap)	100-250 km inboard of the trench[5]	186-223 km
Timing:	- subduction ended ~12 Ma and magmatism possibly related to slab detachment ages range from 14 to 5 Ma[5]	- cessation of subduction velocities, detachment, and slab gap vertical flow occur within ~1 My
	Central Mexico:	
Horizontal tear propagation:	- tear propagation in Cocos slab inferred from propagating magmatism: ~100-250 km/My[6]	- propagation of tearing of Slab B in Model 3d2: ~100 km/My

V. Summary/Conclusions

(1) As in 2-D models[7], detachment of 3-D slabs occurs within young lithosphere before approach of the spreading ridge axis within ~100 km of trench

(2) 3-D detachment can involve vertical and/or horizontal slab tearing, or nearly laterally simultaneous in the form of boudinage-type necking and opening of holes central to slab[8]

(3) Center-initiating detachment is caused by quicker detachment of plastically yielding lithosphere, in contrast to detachment of warmer lithosphere (e.g, slab edges) that can accommodate deformation by stretching and thereby delay and deepen the process

(4) Vertical separation/tearing may initiate at an age offset boundary within a subducted slab that was previously weakened by the presence of a transform fault or fracture zone (Model 3d2)

(5) Horizontal propagating detachment may result from lateral transfer of slab pull between surface plates (Mod. 3d2)

(6) Lateral decoupling between offset adjacent plate segments and propagating nature of vertical and horizontal tearing are dependent upon fracture zones remaining weak through subduction zone (Model 3d2 vs. Model 3d3)

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