Evaluating gneiss dome thermal evolution using coupled thermomechanical finite-element modeling

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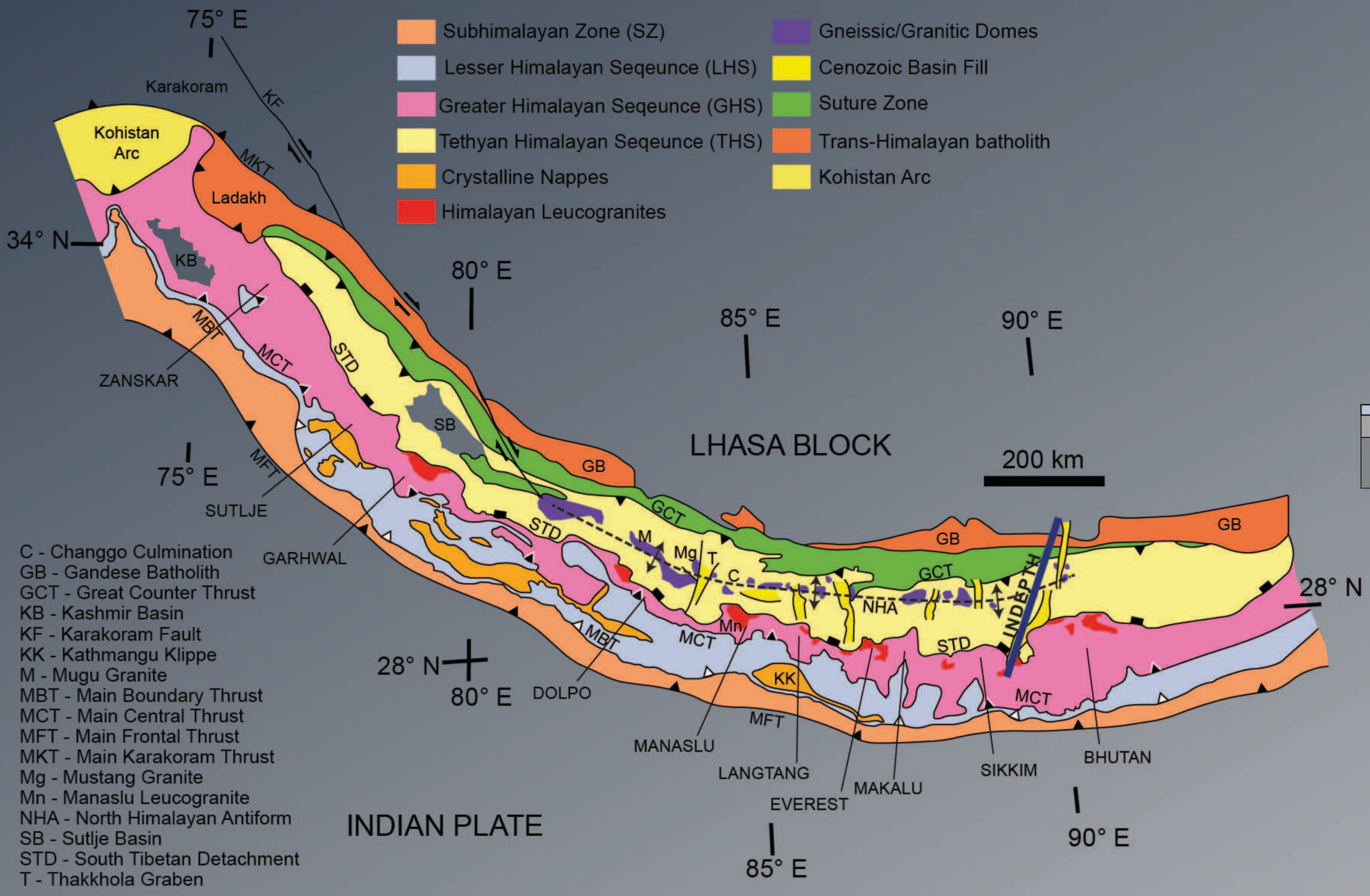
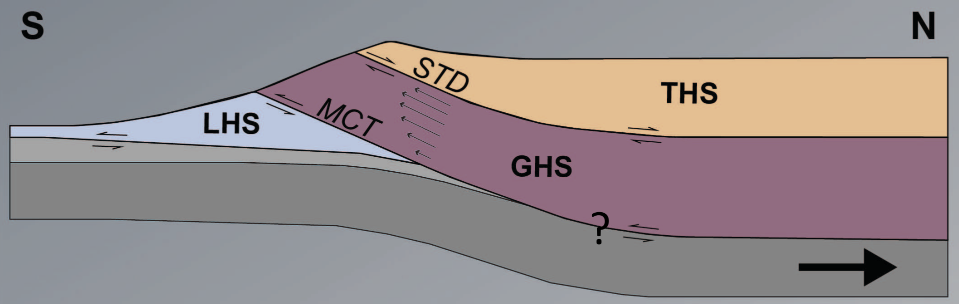
Photo by Jeff Lee

The Himalaya-Tibetan (HT) orogenic system is a result of continental collision between India and Asia since the Eocene (ca. 55-50 Ma) and is comprised of four tectonostratigraphic sequences separated by faults and shear zones

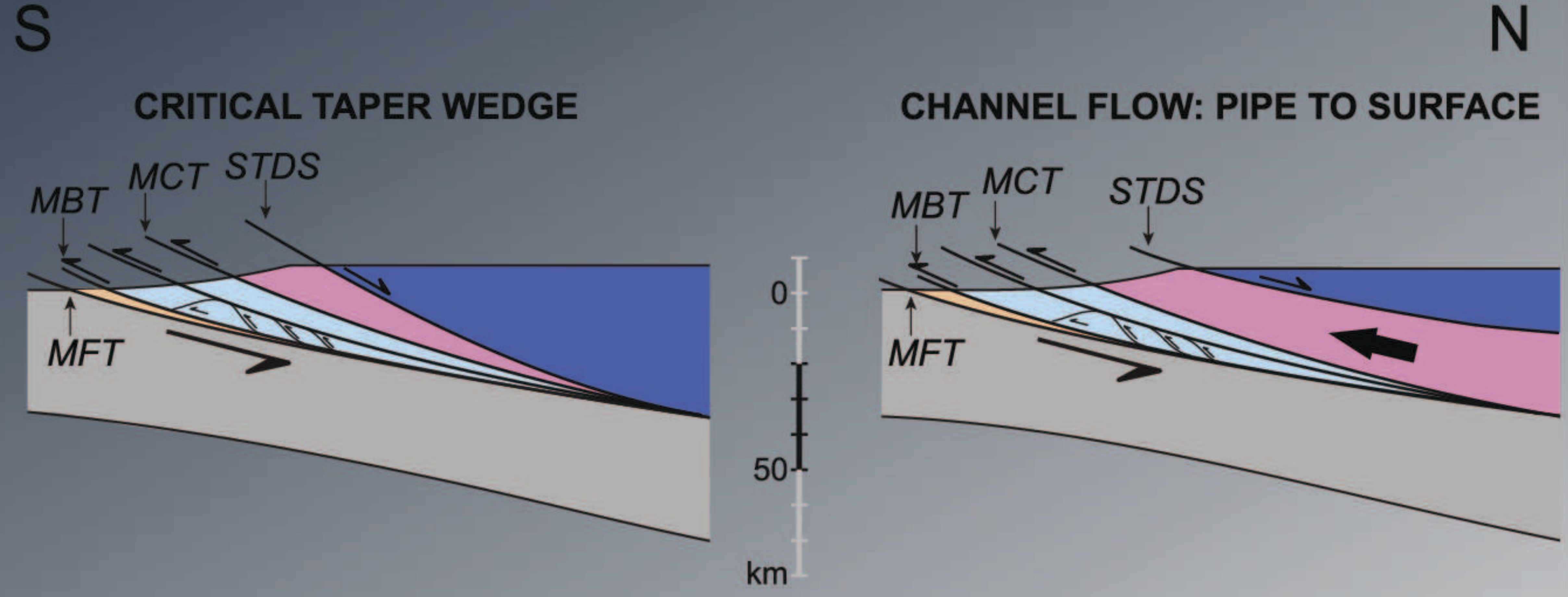




Parsons et al. 2016

STRUCTURE & GEODYNAMICS

This study focuses on two prevailing models for the evolution of the Himalayan orogen: critical taper wedge extrusion and gravity-driven lateral mid-crustal flow (channel flow)



Cottle et al. 2015

Resolving uncertainties regarding gneiss dome evolution leads to richer understanding of how the middle crust accommodates shortening in large collisional systems

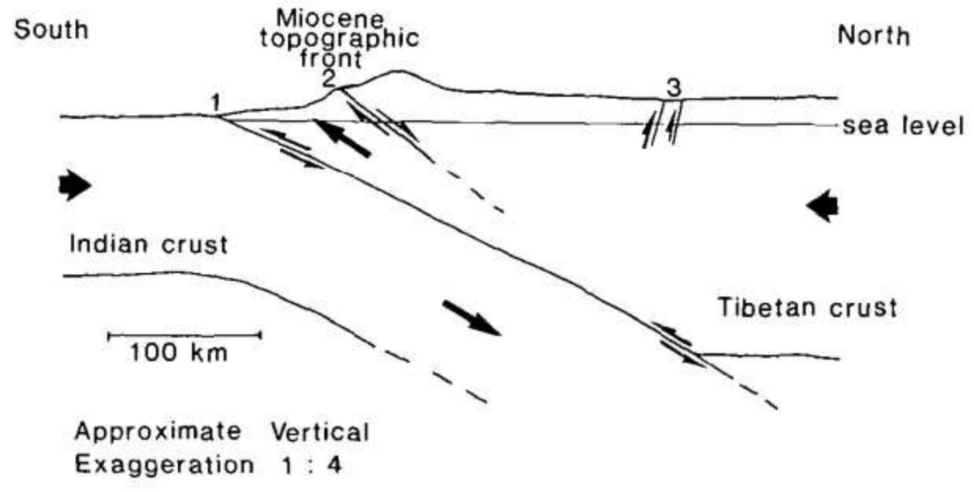
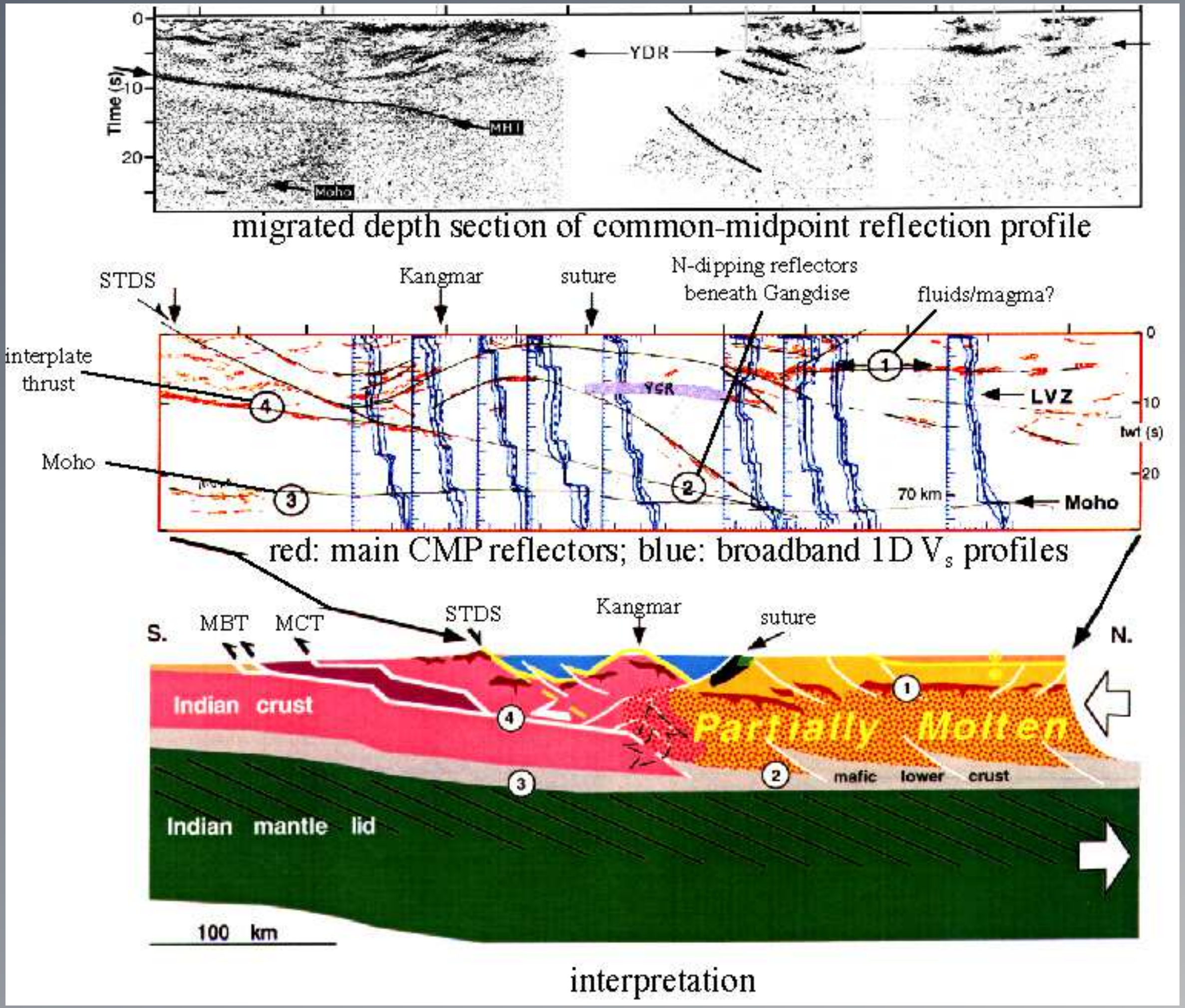


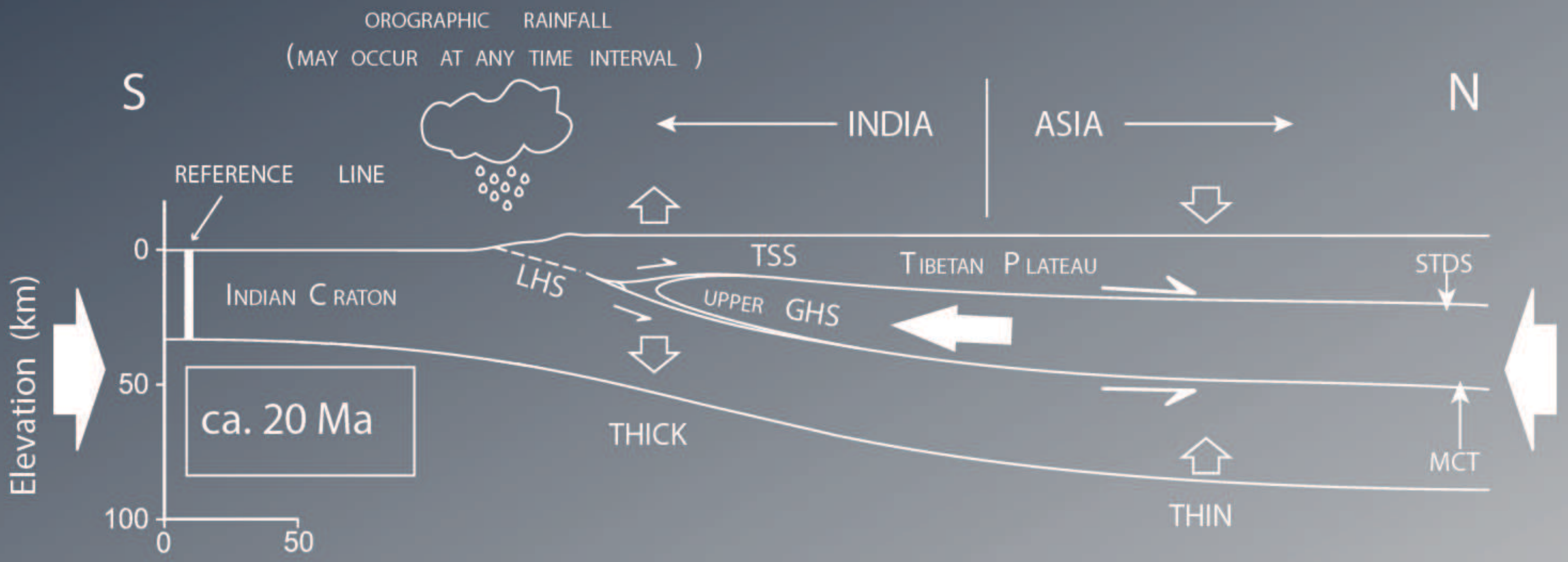
Figure 2. Diagrammatic cross section through Himalaya and southern Tibet showing (1) thrust faulting along MCT (or MBT), (2) normal faulting within Higher Himalayas, and (3) backthrusting near Tsangbo suture zone. Kinematic relationships imply that shallow wedge of crustal material must have moved southward relative to both India and Tibet. Wedge is bounded above by north-dipping normal fault(s) (2) and below by north-dipping thrust faults, possibly but not necessarily MCT or MBT (1). Geometry shown at depth is speculative.

Burchfield and Royden, 1985



Nelson et al., 1996

Uncertainties on the origin of North Himalayan gneiss domes are due to poor constraints on the deep crustal relationships among the MCT, STD, and Great Counter Thrust (GCT)



Larson et al. 2010

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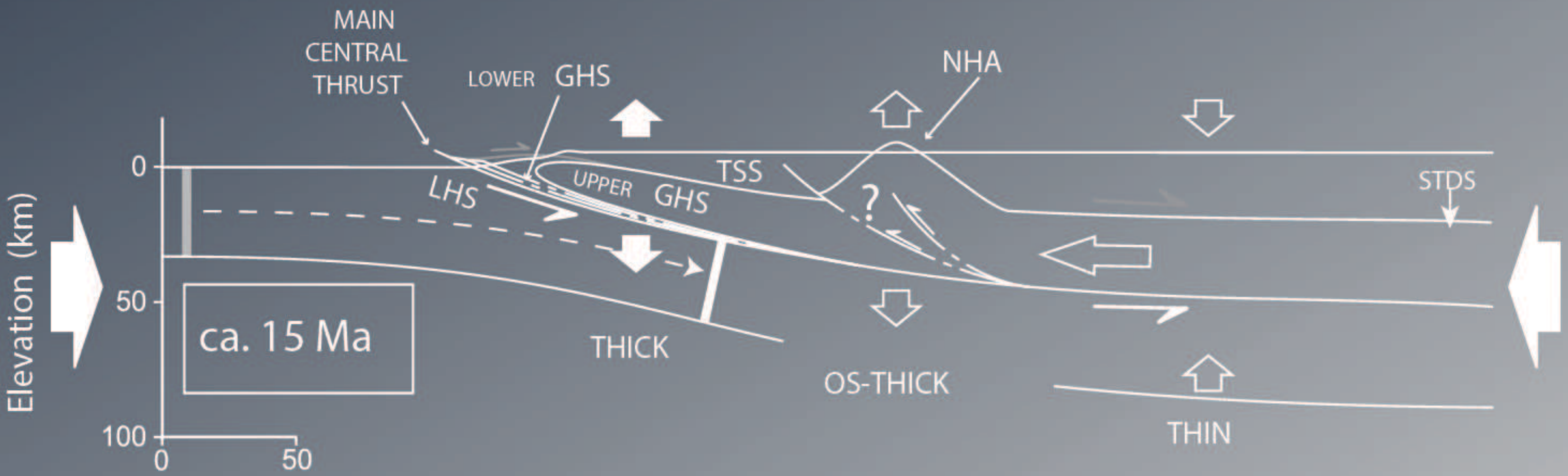

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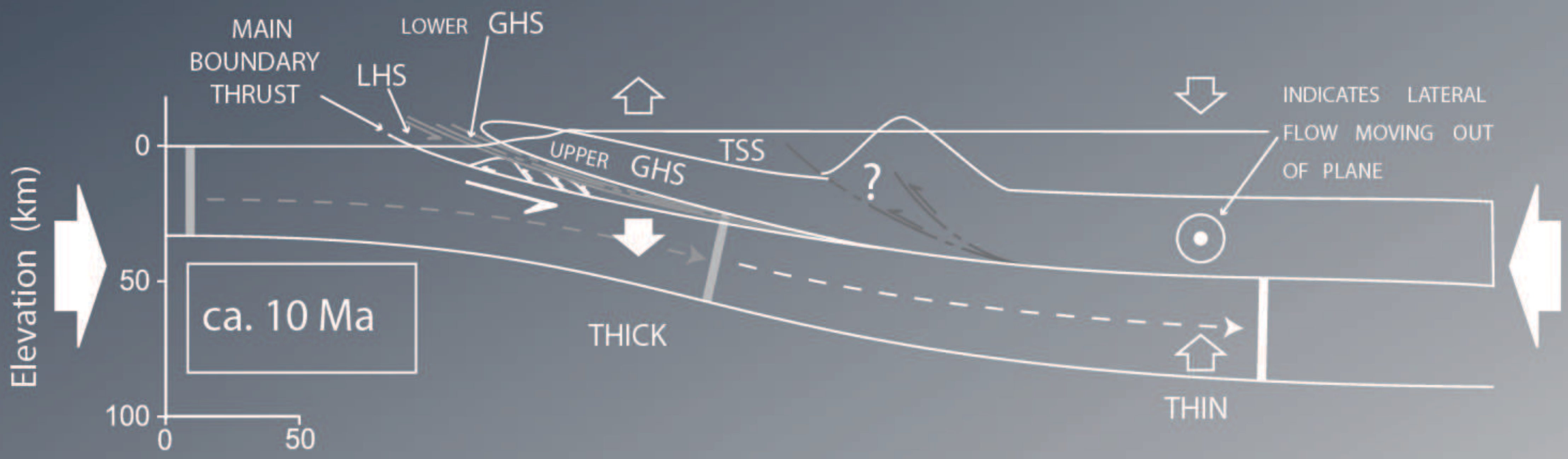
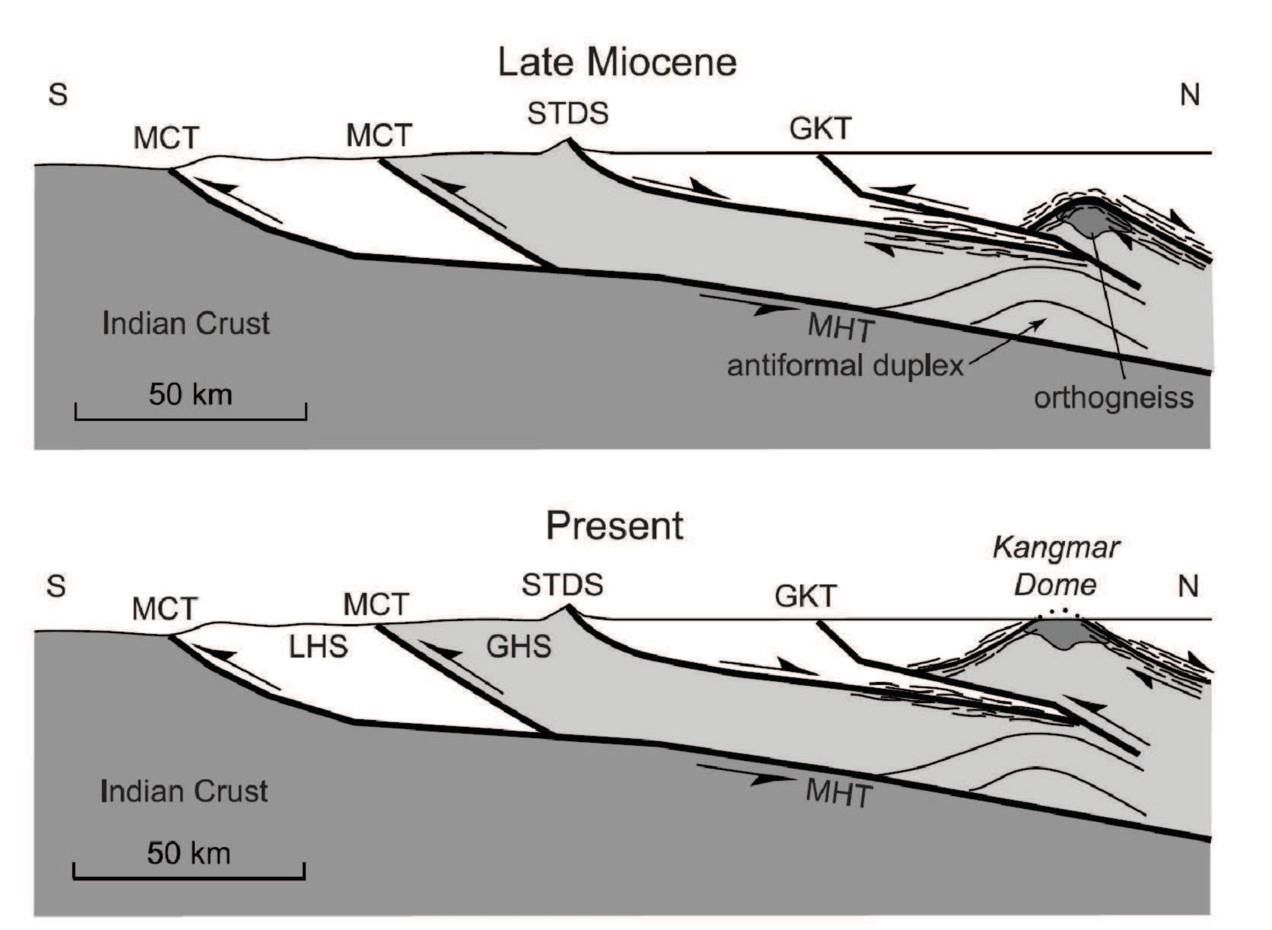


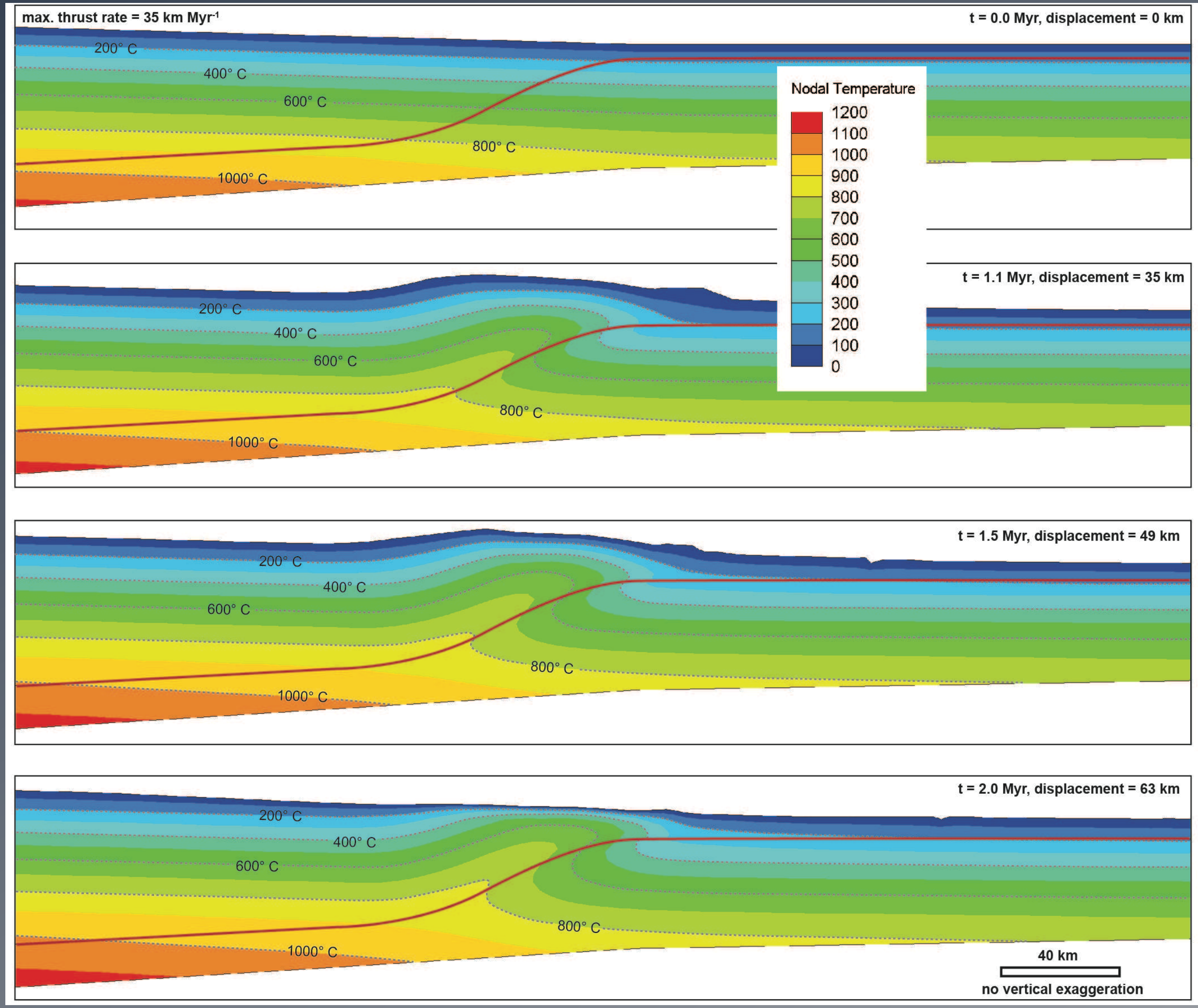
Larson et al. 2010

In one model for the evolution of Kangmar Dome, cooling histories are interpreted to be a result of thrusting upward and southward over a north dipping ramp above cold Tethyan sediments

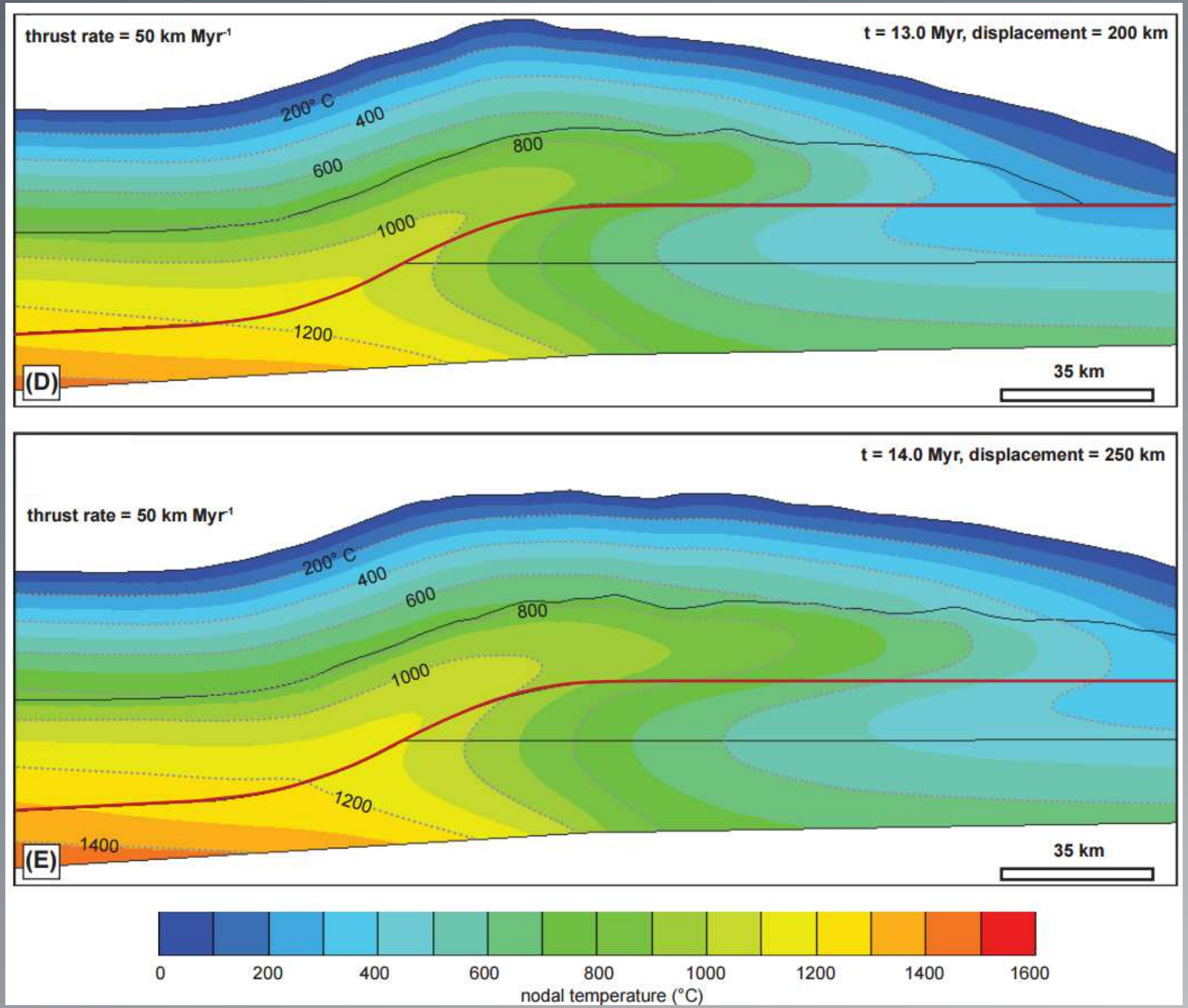


Wagner et al. 2010

Models of thrust emplacement for a Mohr-Coulomb material show temperature distributions consistent with extension above the thrust

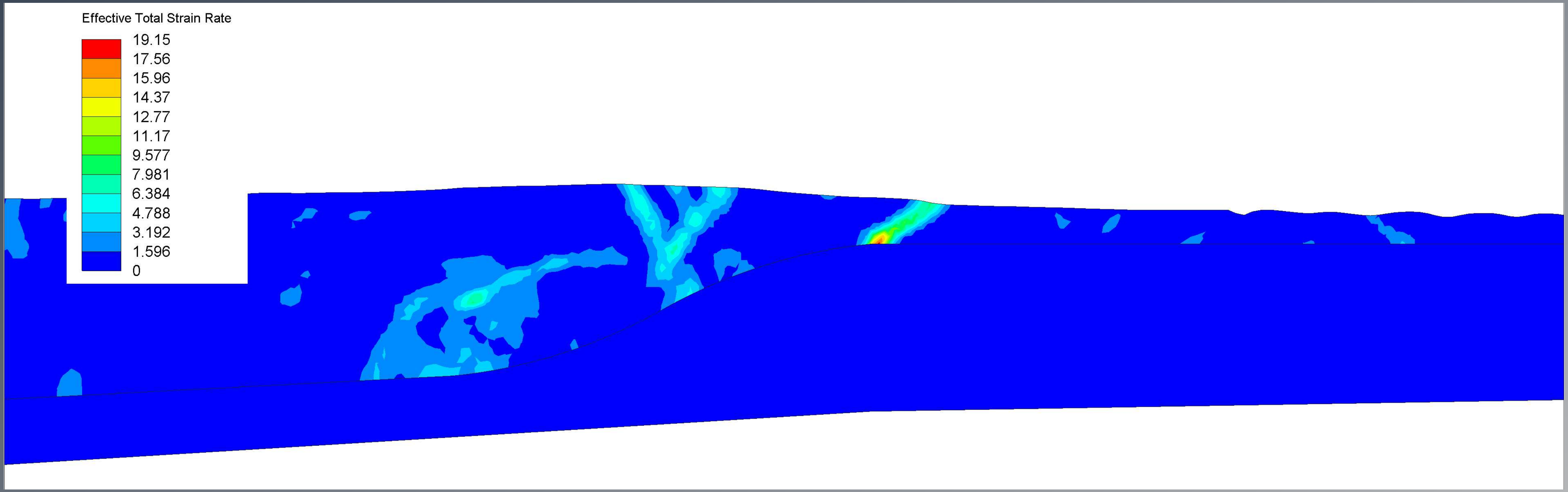


Thigpen et al. (in prep) Tectonics



Thigpen et al., (in press) GSA Special Publications

Models of thrust emplacement for a Mohr-Coulomb material indicate normal fault development



Thigpen et al. (in prep) Tectonics

Brittle-to-ductile transition is modeled using combined Drucker-Prager/von Mises stress criterion

- **Elastic behavior**

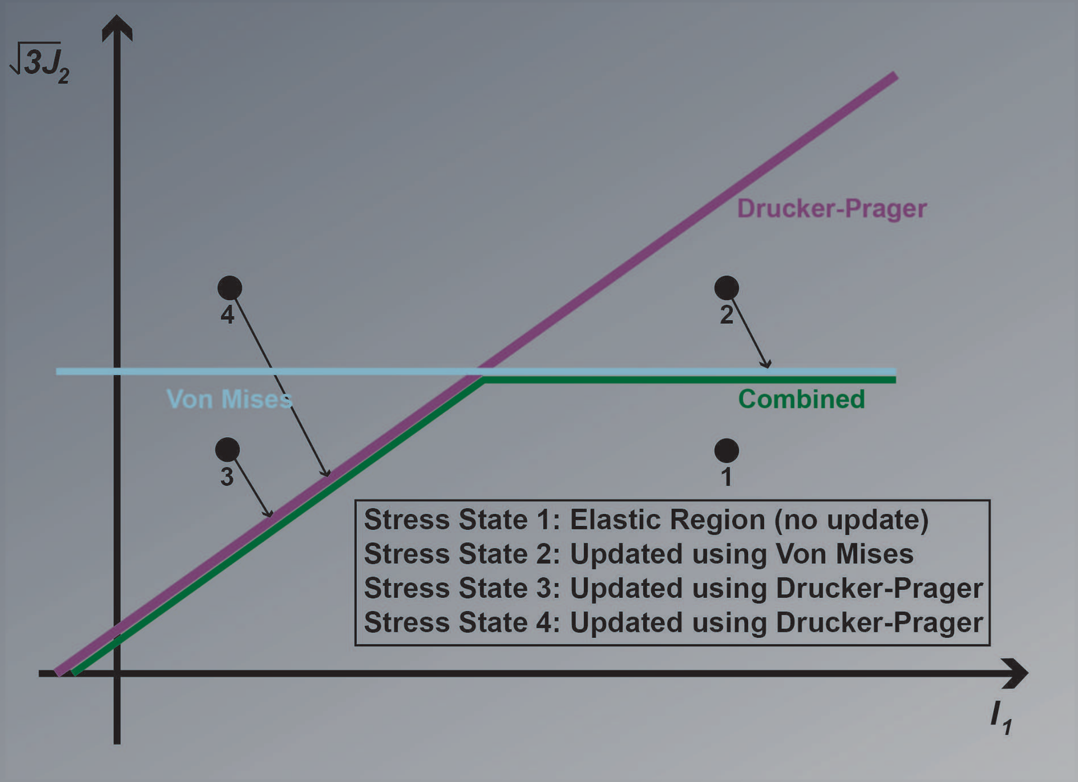
$$\varepsilon_{ij} = \left(\frac{1+\nu}{E}\right)\sigma_{ij} - \frac{\nu}{E}\,\mathrm{trace}\left(\underline{\sigma}\right)\delta_{ij}$$

- **Brittle behavior**

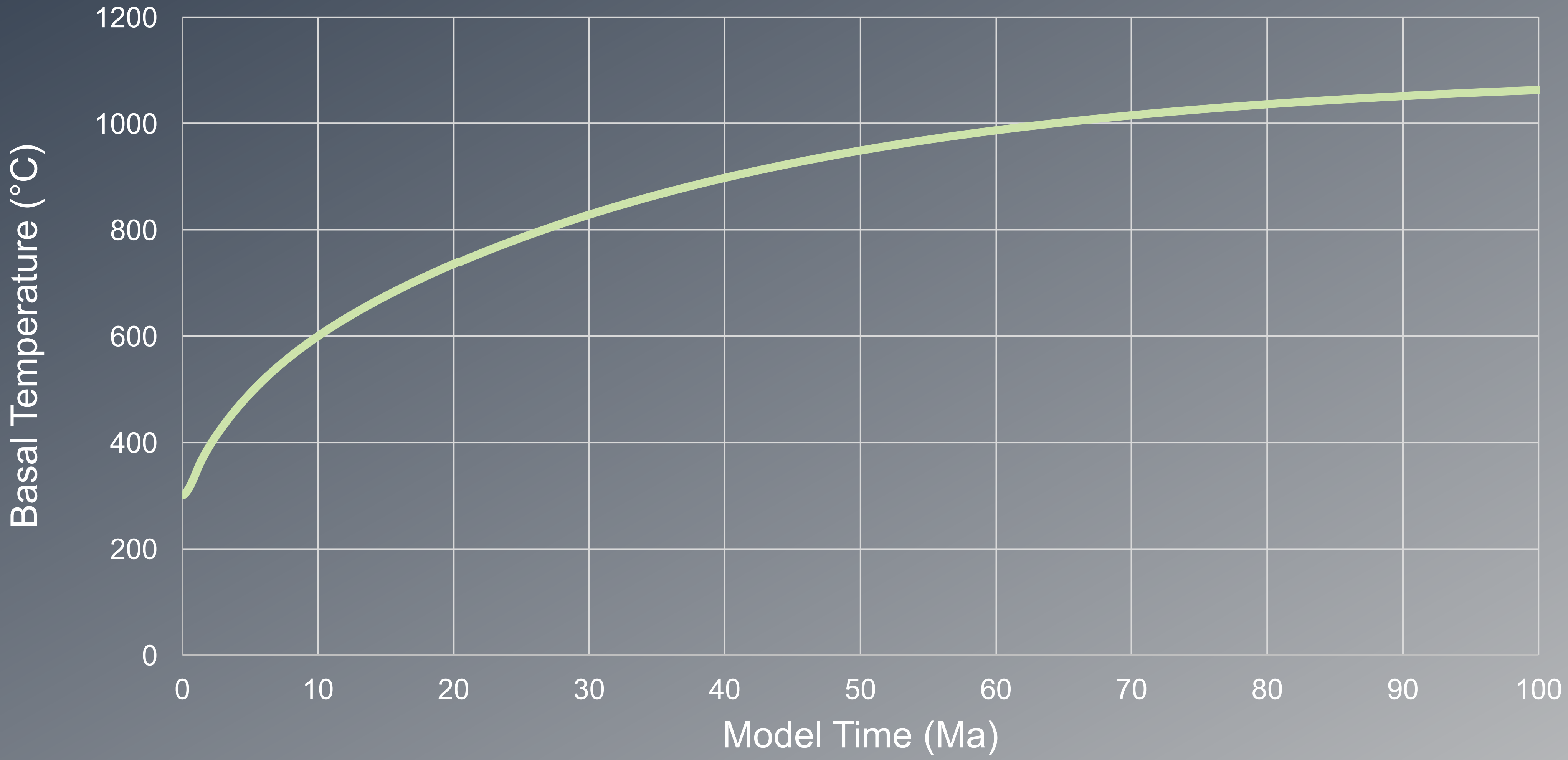
$$\tau_{DP} = c\cos\varphi + p'\sin\varphi$$

- **Viscous time-dependent deformation**

$$\tau_c = A^{-\frac{1}{n}}\dot{\varepsilon}^{\frac{1}{n}}\exp\left(\frac{Q}{nRT}\right)$$

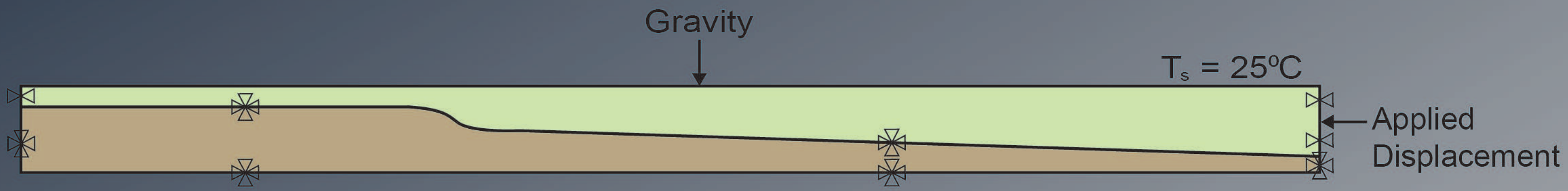


Thermal steady state is approached starting at 60 million years



STRUCTURE & GEODYNAMICS

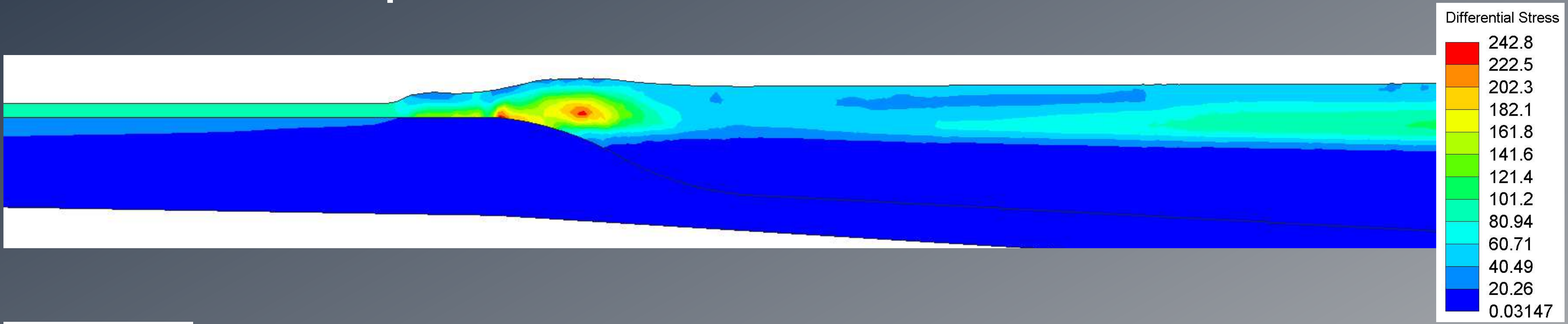
A fully coupled 2-D model of a large, hot collisional orogen with upper-to-middle crust mechanical and thermal properties is used to monitor thermal effects of heat transport

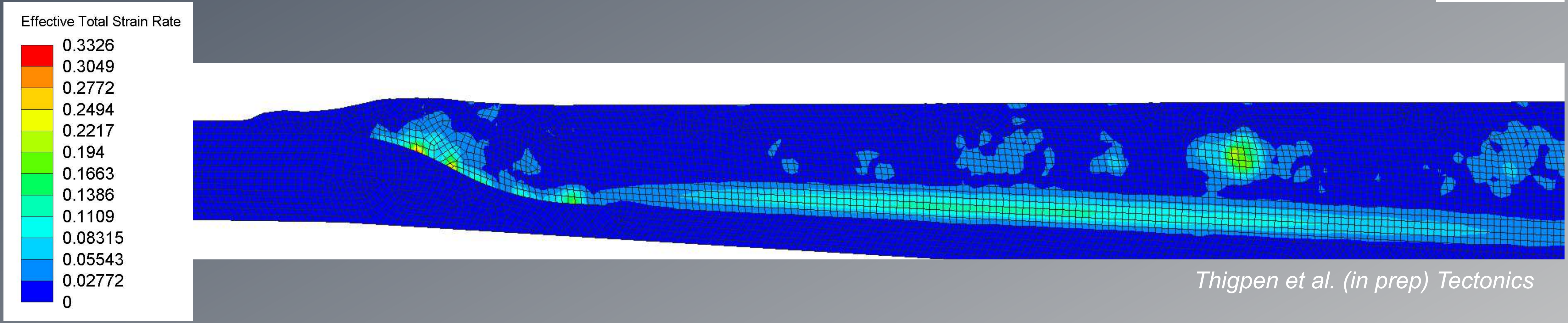


Mechanical Properties	
Density, $kg \cdot m^{-3}$	2900
Elastic modulus, GPa	20
Poisson's ratio	0.25
Cohesion, MPa	10
Internal friction angle, º	30
Dilatancy angle, º	0
Creep Parameters	
Standard fluidity constant (A), $Pa^{-n} \cdot s^{-1}$	1.2×10^{16}
Power law exponent	2.4
Activation energy, $kJ \cdot mol^{-1}$	212

Thermal Properties	
Heat capacity, $m^{2} \cdot s^{-2} K^{-1}$	750
Thermal conductivity, $W \cdot m^{-1} K^{-1}$	2.25
Thermal expansivity, K^{-1}	2×10^{-5}
Basal heat flux, $W \cdot m^{-2}$	0.025
Radiogenic heat sources	
[U], ppm	1.2
[Th], ppm	5
[K], %	1.6

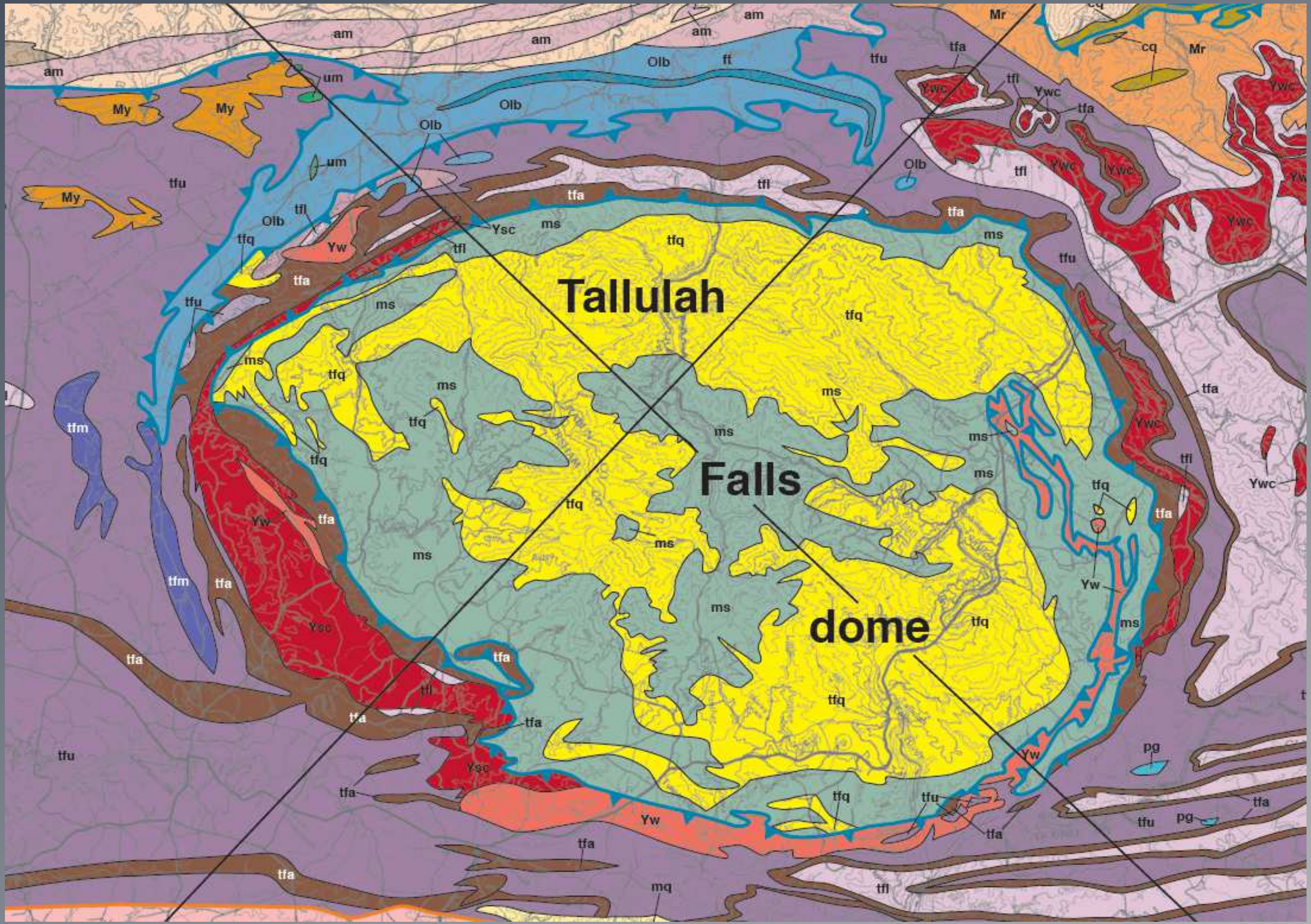
Rheologically weak middle crust presents difficulties in performing numerical experiments but preliminary results indicate potential for gneiss dome evolution and channel development





Thigpen et al. (in prep) Tectonics

Understanding gneiss dome evolution leads to richer understanding of how the middle crust accommodates shortening in large collisional systems



Thigpen and Hatcher, 2009

Acknowledgements

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Rockfield

NSF

AAPG
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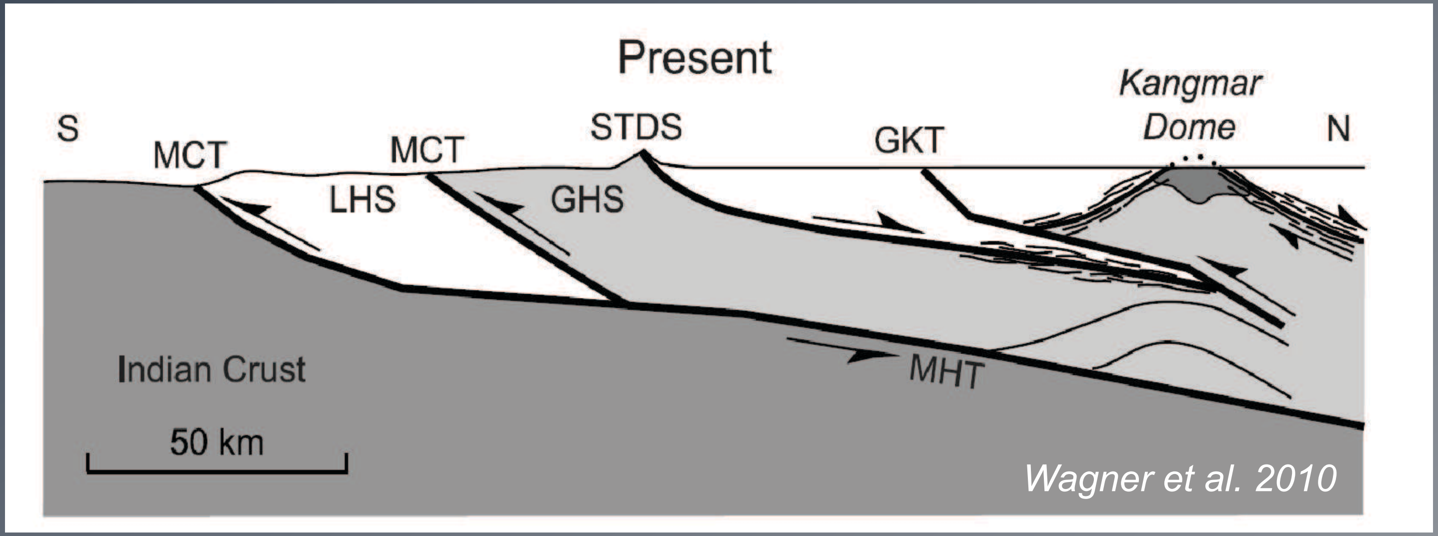
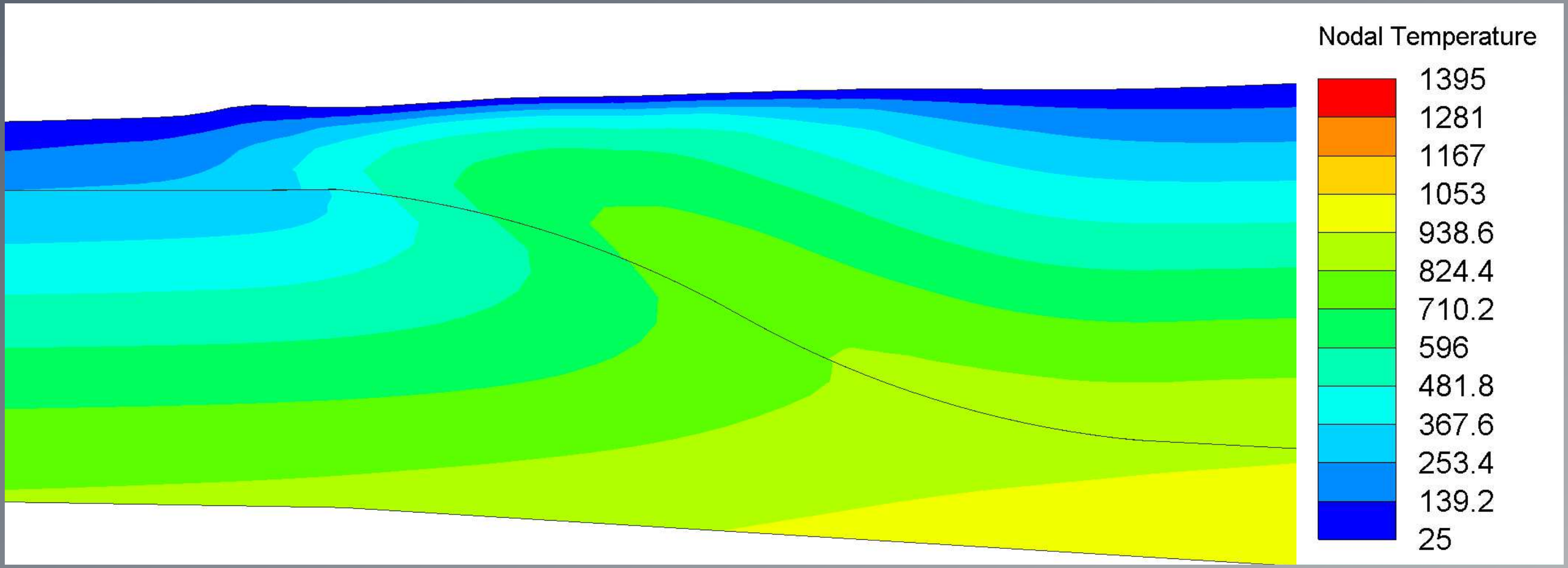
Questions?


Present
S
MCT
MCT
STDS
GKT
Kangmar
Dome
N
LHS
GHS
Indian Crust
MHT
50 km
Wagner et al. 2010


Nodal Temperature
1395
1281
1167
1053
938.6
824.4
710.2
596
481.8
367.6
253.4
139.2
25