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Influence of heterogeneities within the lithosphere on the deformation pattern of continental rift systems.

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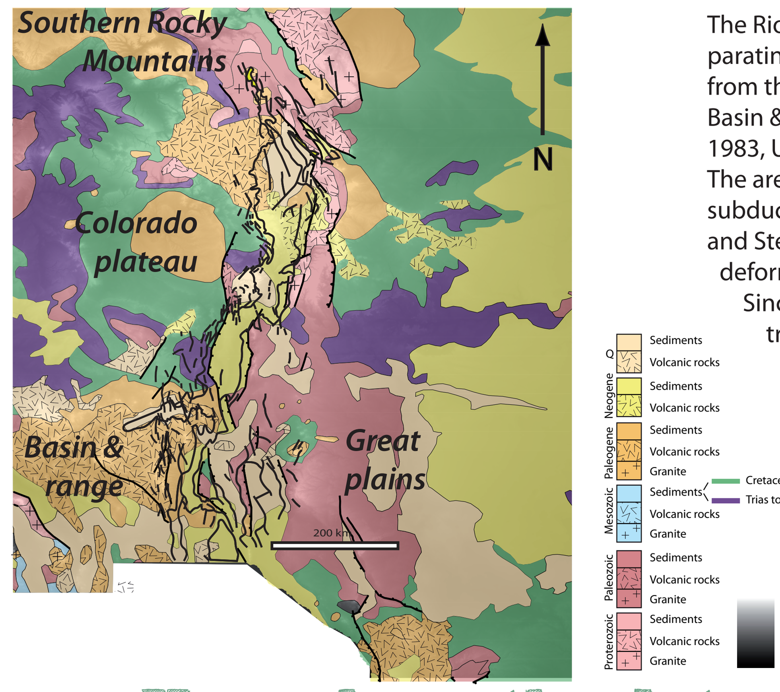
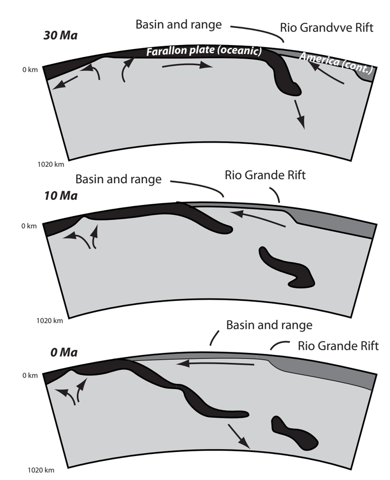
Introduction

Understanding how heterogeneities within the lithosphere influence the deformation pattern in continental rifts still remains a challenge and is of real importance to constrain continental break-up. We have selected the Main Ethiopian Rift in East Africa and the Rio Grande Rift in the south-western U.S. These two rifts are perfect natural laboratories to investigate the effect of inherited as they share similar structural characteristics but develop above different kinds of lithosphere-scale heterogeneities. From a structural point of view both rifts show similar length (1000km), width (50 to 70 km) and asymmetry. The Main Ethiopian rift is the NE-SW trending plate boundary between the Nubian and Somalian plates that has been developing for the past 11 Ma above a palaeo-Proterozoic lithospheric-scale weak zone re-heated by the Afar hotspot, whereas the Rio Grande Rift is the eastern "boundary" of the Basin & Range system which has been developing for the past 30 Ma in the frame of a westward-retreating Farallon subduction zone. However, the Rio Grande Rift shows evidence of low angle normal faulting whereas the Main Ethiopian Rift shows steeply dipping (with a mean close to 70°) normal faults. The Main Ethiopian Rift shows larger volume of erupted lavas than the Rio Grande Rift. Combined with a structural analyses of both rifts, we present here a series of 2D cross sections numerical models that allow better understanding of the influence of initial heterogeneities such as 1) the rheological state of the crust; 2) the presence of a crustal-scale to lithospheric-scale discrete weak zone.

Rio Grande Rift

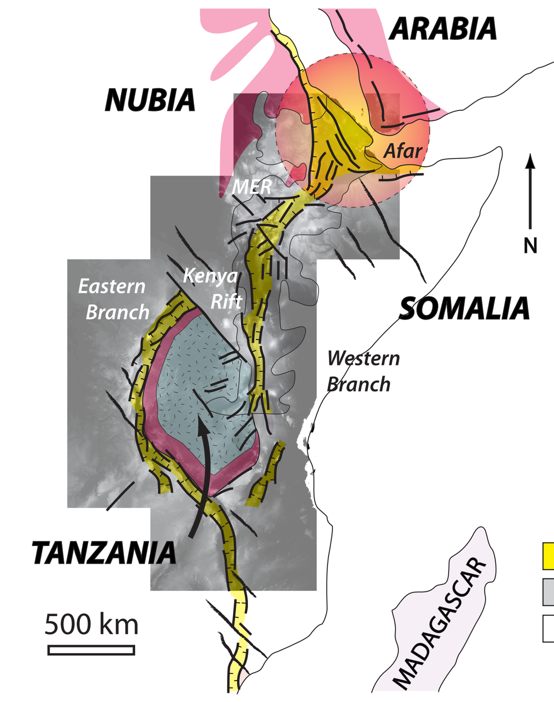


The Rio Grande Rift is an active zone of extension separating the Colorado plateau from the Great Plains from the Southern Rocky Mountains (North) to the Basin & Range (south) (Map after Golombek et al., 1983, USGS GIS database).
The area consists of the upper plate of the Farallon subduction zone (cross sections modilied after Liu and Stegman 2011). The dynamic of subduction and deformation of the upper plate are closely linked.
Since Eocene, the subduction has started to retreat and the upper plate was first affected by wide type rifting: the basin and range developped untill Mid Oligocene (30 Ma).
Then, extension switch from wide to narrow rift in the Rio Grande Area. The early rifting stage started in mid-Oligocene (30 Ma). Opening continued during late Miocene (10 Ma). The rift is still active these days (Seager and Morgan, 1979, Manley 1979).



How does the lateral variations within the lithosphere influe on rift geometry?

East African rift



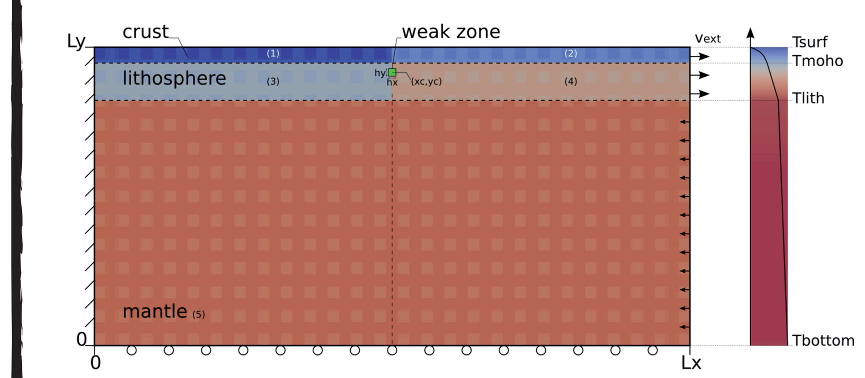
From North to South, the East African rift is composed of the Main Ethiopian Rift (MER), the Kenya Rift, the eastern and western branches that surrounds the Tanzania craton (Map after Krome et al 1983).

In the east African horn, continental breakup that leads to the individualization of Nubia, Arabia and Somalia plates occurred along the Mozambic Ocean Suture Zone (MOSZ) that trends NNW-SSE (Kazmin et al., 1978, Stern 1994).
During Eocene, the evolution from collision to active subduction of the boundary conditions at the northern convergent margin of the African plate (Bellahsen et al., 2003) , coupled with the presence of the Afar plume, helped strain localization along the MOSZ and lead to the Red Sea sea opening (Gass, 1977).
During Miocene, a second episode of "pre-rift" basaltic flood emplaced (Zanettin et al.,1978; Ebinger et al., 1993) and predates the opening of the Main Etiopian Rift (MER), south of the Afar region, that separates the Nubia and Somalia plates.
The western and eastern branch of the East African Rift starts to open at the same time and (12–10 Ma) (Baker, 1987, Ebinger, 1989, Ebinger et al., 1997), and is still in its early stage of development contrary to the MER that is close to beakup is its northern part.

Rift valley
Cenozoic lava flows
Basement+Cenoizoic sediments
Neo-Proterozoic Suture zones
Craton
strike slip (Inherited strucures)
Normal fault

How does the location of the weak zone influe on rift geometry and plume emplacement?

Setup of the experiments

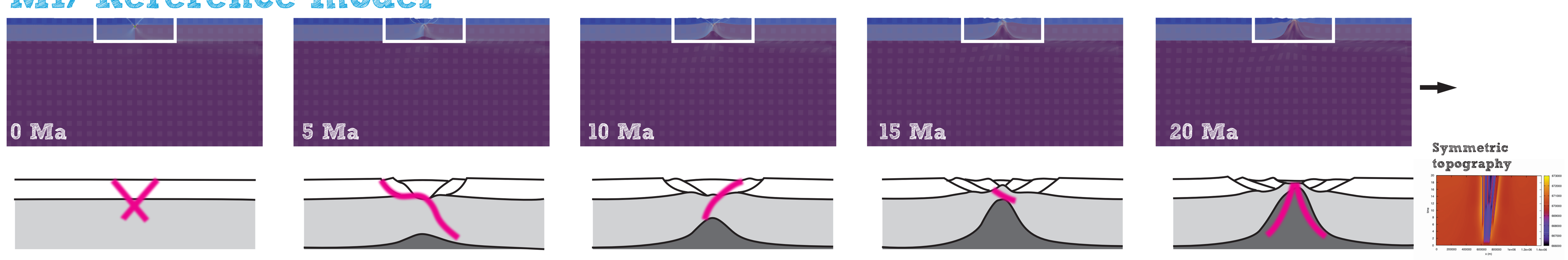


20 Ma of asymmetric extension at a rate of 5 mm.yr 1

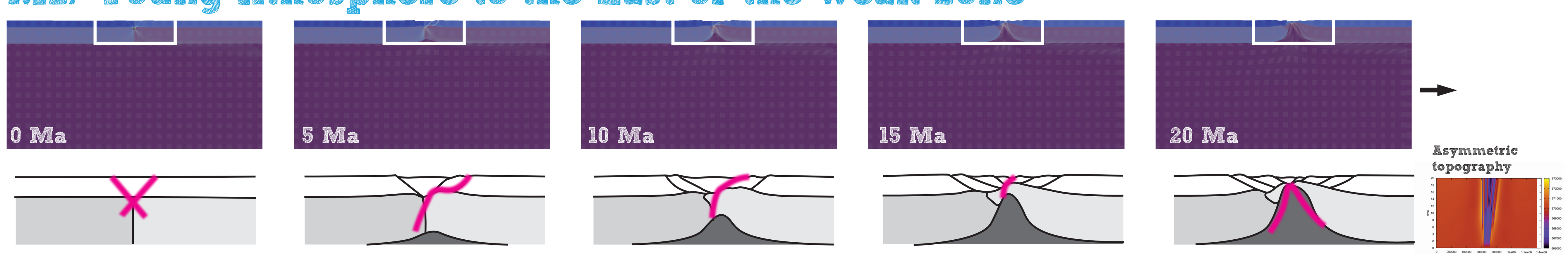
	Age West of the weak zone (Ma)	Age East of the weak zone (Ma)	Weak zone position	Weak zone size (km)
M1	80	80	upper mantle	10x10
M2	80	60	upper mantle	10x10
M3	80	100	upper mantle	10x10
M4	80	80	upper mantle	5x5
M5	80	80	upper crust	10x10
M6	80	80	both in the upper mantle and crust	10x60

Influence of the lateral variation of rheology within the lithosphere

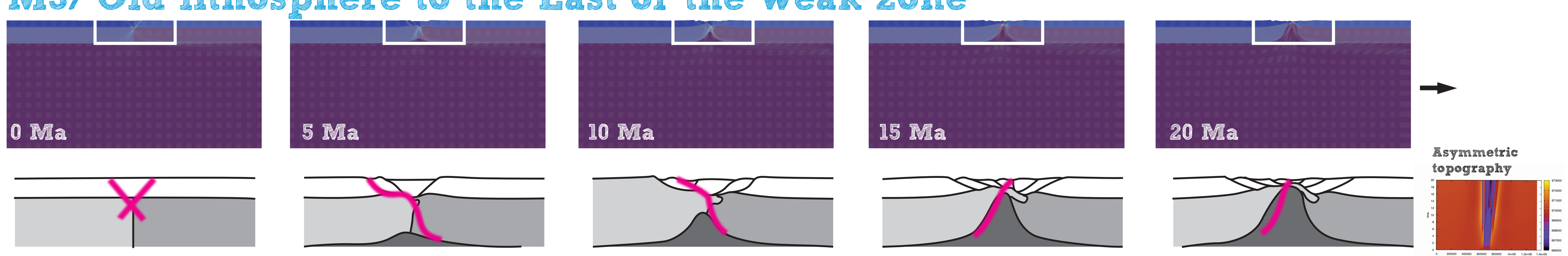
M1/ Reference model



M2/ Young lithosphere to the East of the weak zone



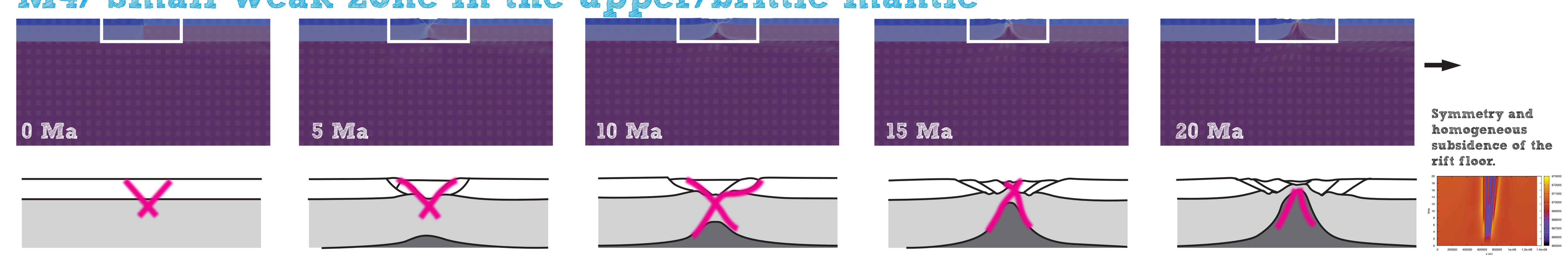
M3/ Old lithosphere to the East of the weak zone



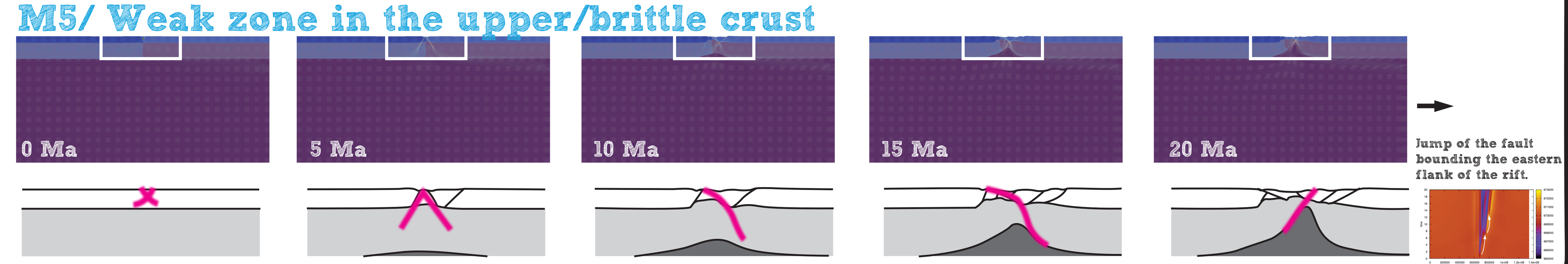
Rift geometrical asymmetry is triggered by the lateral rheological contrast rather than initial boundary conditions.
The piece of lithosphere mantle belonging to the younger lithosphere (M2 and 3), pinched by the asthenosphere rising, may be an analogue to the high-velocity zone commonly observed within the lower crust of continental rifts.

Influence of the seed location within the lithosphere

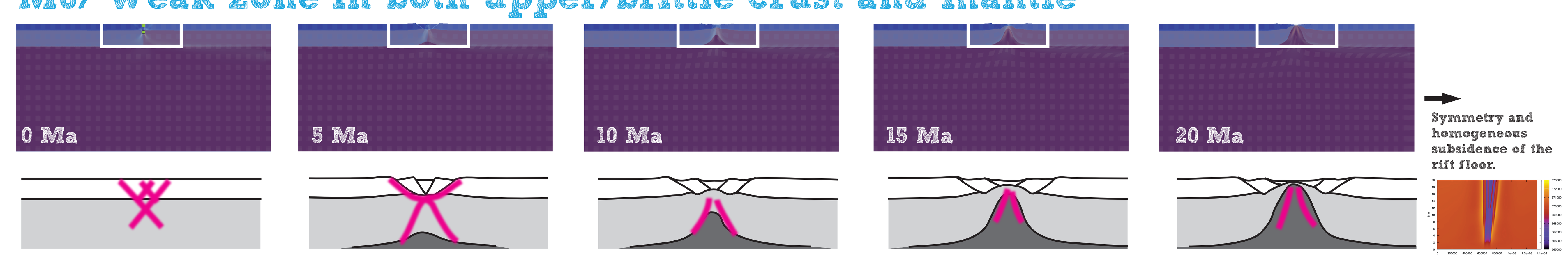
M4/ Small weak zone in the upper/brittle mantle



M5/ Weak zone in the upper/brittle crust



M6/ Weak zone in both upper/brittle crust and mantle



Weak zone located in the upper crust is triggering an asymmetric rift.
Weak zones affecting the strength of the whole lithosphere, such as suture zones, are triggering a fast mantle rising and therefore may trigger plume emplacement.

References
Amante, C. and Eakins, B.W. 2009. ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24, 19 pp. // Baker, B.H., 1987. Outline of the petrology of the Kenya rift alkaline province, in Fitton, J.G., and Upton, B.G.J., eds., 1987, Alkaline igneous rocks: Geological Society London Special Publication 30, p. 293–311.//Bagherbandia M. and Sjöberga, L.E. Modelling the density contrast and depth of the Moho discontinuity by seismic and gravimetric–isostatic methods with an application to Africa//Ebinger, C. J., 1989. Tectonic development of the western branch of the East African Rift system, Geol. Soc. Am. Bull., 101, 885 – 903.//Ebinger, C.J., Poudjom, Y., Mbede, E., Foster, F., and Dawson, J.B., 1997. Rifting Archean lithosphere: The Eyasi-Manyara-Natron rifts, East Africa: Geological Society [London] Journal, v. 154, p. 947–960.//Golombek, M.P., MCGill, G.E. and Brown, L.1983.Tectonic and geologic evolution of the Espanola basin, Rio Grande Rift: structure, rate of extension and relation to the state of the stress in the western united states. Tectonophysics, 94, 483-507.//Korrnel, T., Acocella, V., and Abebel, B. 2004. The Role of Pre-existing Structures in the Origin, Propagation and Architecture of Faults in the Main Ethiopian Rift. Gondwana Research, 7 (2), pp. 467-479.//Liu L. and Stegman D.R. 2011. Segmentation of the Farallon slab. Earth and Planetary Science Letters. 311,(1–2),1–10.//Manley, K.. 1979. Stratigraphy and structure of the Espaiiola basin, Rio Grande rift, New Mexico, In: R.E. Riecker (Editor), Rio Grande Rift: Tectonics and Magmatism. American Geophysical Union. Washington, D.C.. pp. 71-86.//Pérez-Gussinyé, M., Metois, M., Fernández, M., Vergés, J., Fullea, J., Lowry, A.R. 2009. Effective elastic thickness of Africa and its relationship to other proxies for lithospheric structure and surface tectonics. Earth and Planetary Science Letters 287, 152–167.//Priestley K., Tilmann, F..Relationship between the upper mantle high velocity seismic lid and the continental lithosphere. Lithos 109 (2009) 112–124//Seager, W.R. and Morgan, P.. 1979. Rio Grande rift in southern New Mexico, west Texas, and northern Chihuahua. In: R.E. Riecker (Editor), Rio Grande Rift: Tectonics and Magmatism. Am. Geophysical Union, Washington, D.C., pp. 87-106.//Thieulot, C., 2011. Two- and three-dimensional numerical modelling of creeping flows for the solution of geological problems. Physics of the Earth and Planetary Interiors, doi:10.1016/j.pepi.2011.06.011.