The plume head - lithosphere interactions near intracontinental plate boundaries

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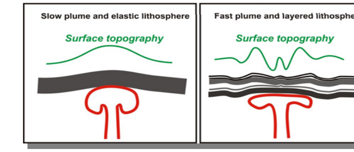


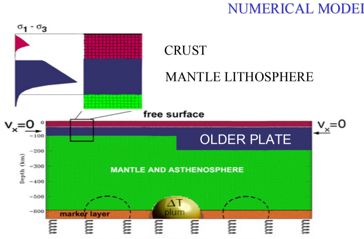
Difference in topographic response to a plum impact of a single layer plate (e.g., oceans) and stratified continental lithosphere

Summary

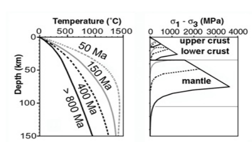
Zones of plum-continental lithosphere interactions (PLI) are often located near intra-plate boundaries, in particular, near the boundaries between younger (e.g., orogenic) plates and older plates (Archean West Africa, Australian craton, Pannonian – Carpathian system). These interactions have important consequences both for tectonic and mineralogical evolution. For example, Archean metallogenic crisises at the boundaries of the West African and Australian cratons coincide with the presumed plum events. Yet, crustal and lithospheric signatures of PLI appear to be strongly influenced by lithosphere rheology and structure, which requires a through account for lithosphere in plum models. We study this problem using a numerical model that incorporates realistic **visco-elasto-plastic stratified lithosphere with free a surface**. The results show that lateral heterogeneities may have following effects on PLI:

(**A**) horizontal plume head flattening is blocked from one side by cold vertical boundary of the craton, leading to crust – mantle decoupling, stress concentration and faulting at the cratonic margin; (**B**) return flow from the plum head results in sub-vertical down-thrusting of the lithosphere at the cratonic margin providing sharp sub-vertical "cold" boundaries down to the depths of 400 km; (**C**) the asymmetric plum head flattening towards the younger plate is followed by simultaneous extension and mantle thinning in the middle of the plate and down-thrusting both at the cratonic border and at the opposite border of the young plate; (**D**) topographic signatures of the PLI show basin-scale uplifts and subsidences. Rayleigh-Taylor instabilities that develop around the plume head, provide a mechanism for crustal delamination. Lateral flow of mantle lithosphere, from plume head to the base of the craton suggests a new mechanism for crustal growth, where surface magmatism is not required. Lithospheric faulting at cratonic edges and enhanced magmatic activity could explain the apparent plume-related metallogenic crises, as suggested for West Africa and Australia. PLI can explain a number of key phenomena such as simultaneous occurrence of climax of extension of the young plates/segments and climax of compression in the surrounding belts.

NUMERICAL MODEL SETUP

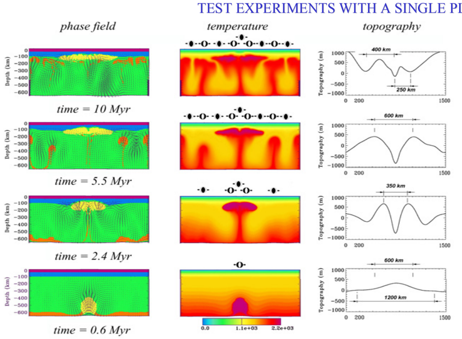


Setup for large-strain brittle-elastic-ductile fully coupled thermo-mechanical numerical model based on Paro(a)voz v9 FLAC-like code



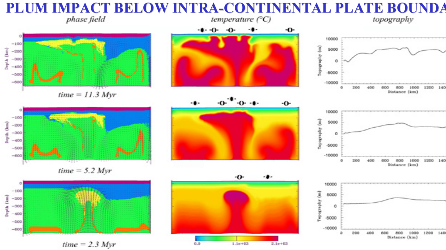
Geotherms and brittle (plastic) -elastic-viscous (ductile) profiles as function of thermo-tectonic age. Mohr-Coulomb brittle-plastic rheology and power-law non-Newtonean creep viscous-ductile rheology

TEST EXPERIMENTS WITH A SINGLE PLATE



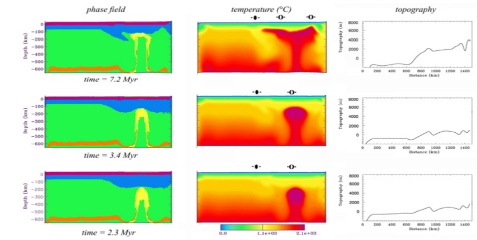
Preliminary test with a single continental lithosphere of representative 150 Ma age and a 200 km plum. This experiment in based on the model from (Burov and Guillou-Frottier, 2005). Color code for the phase field: purple - crust, blue - mantle lithosphere, green – upper mantle, yellow - plum, orange – marker layer at the bottom. Note significant erosion of the mantle lithosphere, down-sagging above the middle of the plum head, complex behavior of surface (periodic undulations / basins and uplifts). Circular diagrams show zones of plastic yielding (= faulting), following same graphical conventions as the Schmidt's diagrams for focal depth solutions used in seismology.

PLUM IMPACT BELOW INTRA-CONTINENTAL PLATE BOUNDARY



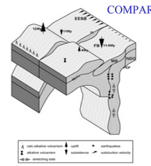
Experiment with 2 plates (younger 150 Ma old lithosphere and > 400 Ma old craton); plum head is located in centre, below the plate boundary. Color code for the phase field: purple - crust, blue - mantle lithosphere, green – upper mantle, yellow - plum, orange – marker layer at the bottom. Note significant erosion of the mantle lithosphere, "verticalization" of the cratonic boundary, multiple down-sagging above the middle of the plum head with hot material arriving at Moho depth, asymmetric flattening of the plum head towards the younger lithosphere and down-thrusting of the mantle lithosphere at both sides of the plum, asymmetric doming at surface. Circular diagrams show zones of plastic yielding (= faulting), following the same conventions as Schmidt's diagrams for focal depth solutions.

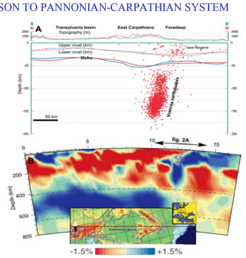
PLUM IMPACT BELOW A CRATON



Experiments with plum head located below the craton (younger 150 Ma old lithosphere and > 400 Ma old craton), 300 km away from plate boundary. Color code for the phase field: purple - crust, blue - mantle lithosphere, green – upper mantle, yellow - plum, orange – marker layer at the bottom. Note significant erosion of the cratonic mantle lithosphere, asymmetric flattening of the plum head and down-thrusting "subduction" of the younger and cratonic mantle lithospheres below the craton. Circular diagrams show zones of plastic yielding (= faulting), following the same conventions as Schmidt's diagrams for focal depth solutions.

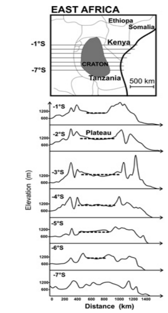
COMPARISON TO PANNONIAN-CARPATHIAN SYSTEM



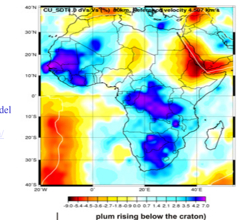


Interpretation of seismic tomography (left, Wortel and Spakman, 2000) , geology, geodetic data and modelling results (after Cloetingh et al., 2004)

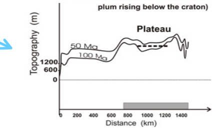
COMPARISON TO EAST-AFRICAN DATA



Surface shear wave tomography model (horizontal slice at 80 km depth) reveals strong variations in horizontal structure of mantle lithosphere (source: CUB shear velocity model by N. Shapiro (http://ciei.colorado.edu/~nshapiro/MODEL/#model description)

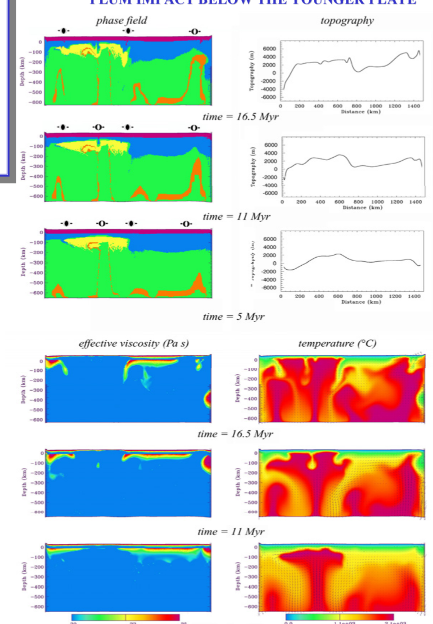


Topographic profiles across the Tanzanian craton area, where a "topographic plateau" surrounded by short-scale topographic undulations can be identified, from latitude -2°S to -6°S



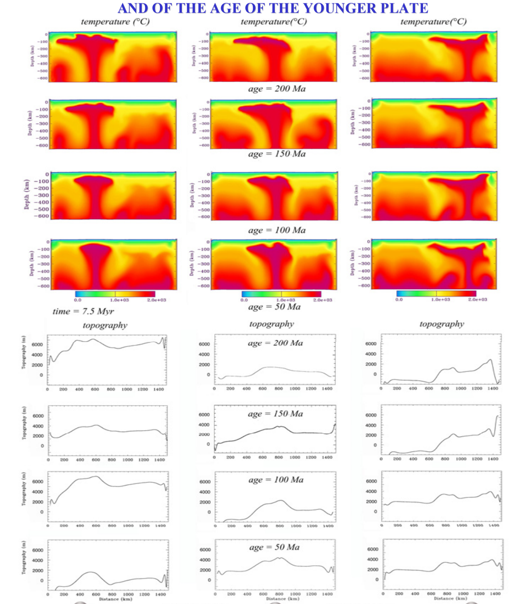
Topographic signature generated by the model (below, left). In case of a plum ascending below a lithospheric plate of limited size, plum edges may have more impact on surface topography than the center of the plum head.

PLUM IMPACT BELOW THE YOUNGER PLATE



Experiment with 2 plates (younger 150 Ma-old lithosphere and > 400 Ma-old). Color code for the phase field: purple - crust, blue - mantle lithosphere, green – upper mantle, yellow - plum, orange – marker layer at the bottom. Note erosion of the mantle lithosphere, "verticalization" of the cratonic boundary,extension and multiple down-sagging above the plum head, asymmetric flattening of the plum head towards the younger lithosphere and down-thrusting of the mantle lithosphere at both sides of the plum.

INFLUENCE OF THE POSITION OF THE PLUM HEAD AND OF THE AGE OF THE YOUNGER PLATE



Comparison of developed stages (7.5 Myr since initialization) of experiments for different initial thermal ages (50,100,150, 200Ma) of the younger lithosphere (thermal field). Left column: plum rising below the younger plate; Middle – plum rising below the cratonic boundary; Right – plum rising below the craton. In all cases, the presence of intraplate boundary results in asymmetric plum spreading towards the younger lithosphere and in down-thrusting of the mantle lithosphere at plum borders.

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