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Thermal refraction and the rheological basis of “cold” intraplate basin inversion: geologically constrained numerical model of the Donbas Foldbelt

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The Donbas Foldbelt is a mildly inverted (folded and faulted) segment of a Late Palaeozoic intracratonic rift basin (the Dniepr-Donets Basin, lying within the Archean-Paleoproterozoic East European Craton). Excellent deep seismic reflection data (with coincident crustal velocity structure from wide-angle/refraction data) image the entire basin, its flanks, and underlying crystalline crust. The sedimentary succession is about 20 km thick and the inversion is seen to have occurred primarily as a crustal scale pop-up, with a main, north-east vergent, thrust (shear) zone cutting the Moho and the basement-sediment horizon, coming to the surface within sediments near the northern margin of the rift. A slightly steeper, south-west vergent, back-thrust originating at the main thrust within crystalline basement rises through the basement-sediment interface emerging near the southern margin of the rift also within the sedimentary succession. Although there are several subsidiary, originally normal, faults within the sedimentary complex that have been slightly inverted, the crustal-scale main thrust and back-thrust appear to be new structures developed initially during the inversion stage. Shortening of the basin, based on palinspastic reconstructions of the seismic image, was about 12 kilometres ($\sim$10% strain) and occurred primarily at the end of the Cretaceous. This is about 300 Myr after rifting (Late Devonian-Early Carboniferous) and about 200 Myr after the youngest inferred (tectonic) extensional reactivation (Late Carboniferous-Early Permian) indicating that any thermal perturbation associated with these events was relaxed by the time of inversion. We have modelled the inversion using an elastic-viscous-plastic finite element code, simply by applying a 10% horizontal shortening strain, for a range of strain rates, on the pre-inversion crust-basin geometry as reconstructed from the seismic image. The results show that the accommodation of shortening occurs mainly on major, primary, bivergent structures that very closely mimic those imaged by the seismic data. The locations of these primary structures, beneath the flanks of the basin, are controlled by the thermal structure of the crust-basin model which, in turn, is dominated by a significant thermal refraction effect caused by the thick sedimentary basin succession itself. The presence of this effect in the actual crustal temperature structure can be seen in the observed surface heat flow pattern measured in the Donbas Foldbelt, which shows a relative low along the axis of the basin flanked by relative highs. A requisite feature of the model in replicating this is that the bulk thermal conductivity of the basin succession is less than that of the crystalline crust. We have carried out a parameter sensitivity analysis, using a Monte Carlo approach, and can conclude – for the crust-basin geometry being considered – that even a relatively small (grater than unity) contrast in crust-sedimentary basin thermal conductivity is sufficient to explain the style of inversion. The results are rather insensitive to variations in heat production in the basin and crustal units. That the main thrust zone has north-east vergence, with the secondary back-thrust being south-west vergent, is also predicted by the model and this is related to the presence of high velocity lower crustal “rift pillow” lying slightly offset to the north-east relative to the main basin depocentre.