Forum Reply

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How local crustal thermal properties influence the amount of denudation derived from low-temperature thermochronometry

Katarzyna Łuszczak[1,2], Cristina Persano[2], Jean Braun[3], and Finlay M. Stuart[4]

[1]Institute of Geological Sciences, Polish Academy of Sciences, Twarda 51/55, 00-818 Warsaw, Poland

[2]School of Geographical and Earth Sciences, University of Glasgow, Glasgow G12 8QQ, UK

[3]Helmholtz Centre Potsdam, German Research Center for Geosciences (GFZ), Telegrafenberg, 14473 Potsdam, Germany

[4]Isotope Geoscience Unit, Scottish Universities Environmental Research Centre, East Kilbride G75 0QF, UK

In the Łuszczak et al. (2017) paper, we present the results of modeling the impact of spatially variable crustal heat production and thermal conductivity on apatite fission-track thermochronometry (AFTT). We welcome this opportunity to clarify the reasoning and conclusions of our study in response to the Comment of Westaway (2018).

Firstly, we want to emphasize that the main aim of our study was not to provide a detailed estimate of Cenozoic denudation of Britain. Central-west Britain was used as a case study. We clearly state that our model has simplifications, and that overcoming them will improve denudation estimates. In the first paragraph of his Comment, Westaway misrepresents our work by stating that our main conclusion is that previous studies of Green (2002) and Green et al. (2012) have overestimated denudation. We do not make such a statement anywhere in the paper. These papers suggest the need for a high paleo-geothermal gradient (∇T_P)—as we point out; the issue our paper addresses is the cause of the elevated ∇T_P.

Westaway argues that our criticism of the Green et al. (2012) explanation of high ∇T_P is invalid and suggests that our assumption of instantaneous underplating lowers the impact of heating. However, instantaneous emplacement of a thick underplating layer influences the thermal structure of the upper crust more than when it is emplaced as successive thinner layers (Clift and Turner, 1998). To calculate the thermal perturbations caused by underplating, Green et al. (2012) applied the equation originally used to quantify thermal perturbations due to the removal of the entire lithospheric mantle. In this case, the crust is exposed to abnormally high temperatures for a long period of time; however, when underplating occurs, the thermal anomaly decays faster because the magmatic layer is within the lithosphere and is surrounded by cooler material; more so if the underplated material is emplaced as short-lived pulses. Setting the lower boundary of the crust to 1100 °C for 10 m.y. is clearly incorrect, as it assumes that underplating (1) has the same thermal effect as the asthenosphere, and (2) lasted for 10 m.y., whereas the bulk of the British Paleogene Igneous Province was emplaced within a few million years (e.g. Wilkinson et al., 2017).

In the third paragraph, Westaway points to a discordance between the late Cenozoic uplift rates used in our Pecube model and those proposed elsewhere. Previous studies of the Neogene and Quaternary uplift of Britain indicate several hundreds of meters of post mid-Pliocene denudation. However, we stress that AFTT data are insensitive to this, unless it occurs within a crust characterized by an extremely high geothermal gradient. The constant post-57 Ma uplift rate of 0.0088 mm/yr used in our study cannot be unequivocally constrained by our data, but was taken as the simplest solution to account for the remaining 500 m of Cenozoic denudation, as predicted by other studies. The rate at which this more-recent denudation occurred does not affect our model; more importantly, it lies beyond the resolution of AFTT data and thus beyond the scope of our paper. Later, Westaway states that we did not present any result for <2000 m of uplift. This is because such scenarios would significantly overestimate AFTT ages for all reasonable values of thermal conductivity. Subsequently, he links our results to the amount of Cenozoic denudation in Britain inferred from the isostatic model of Brodie and White (1994) and calls this model over-simplistic. The two cited papers, however, do not discuss the Brodie and White model and we are, therefore, not able to respond to this point.

Westaway criticizes our work for a lack of data from high elevations, and we acknowledge the usefulness of vertical profiles in studying the impact of basal heat flow changes on ∇T_P. However, the main conclusion derived from our 1-D model is that the low conductivity of the sedimentary 'blanket' raises the overall temperature of the underlying basement, without affecting its geothermal gradient; reconstructing the thermal structure of the shallow crust from a present vertical profile, without considering the eroded section, will actually be misleading. The estimate of ∇T_P presented by Green (2002) lacks a verifiable explanation for the cause of the ∇T_P increase. Also, the robustness of the paleotemperature estimates, based on which the ∇T_P is calculated, is equivocal. The data were modeled individually rather than as a quasi-vertical profile, and for some samples, the AFTT ages were based on a statistically low number of counted grains and measured track lengths. Given that Green (2002) does not provide the uncertainties associated with his models, nor an explanation of how the model works, assessing his conclusions is impossible. The wide range of geothermal gradients that could fit the data of Green (2002) is not irrefutable evidence for high ∇T_P within the preserved rock section. Moreover, nowhere in our paper do we state that the heat flow, and thus ∇T_P in the preserved rocks, was not elevated. This is a possibility, and we emphasize that the denudation estimates presented in our paper are maxima. Models that consider both variable thermal properties of rocks and the possibility of a slightly elevated basal heat flow would be surely interesting.

Nature is always much more complicated than the models we create to explain it; clearly stating these simplifications and the uncertainties associated with the data used to test the modeled scenarios, is, we feel, a strong way forward to ascertain the robustness of our conclusions.

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