Braun, J. (2019): Response to comment by Japsen et al. on “A review of numerical modeling studies of passive margin escarpments leading to a new analytical expression for the rate of escarpment migration velocity”. - *Gondwana Research*, *65*, pp. 174—176.

DOI: http://doi.org/10.1016/j.gr.2018.10.003

Response to: Elevated passive continental margins: Numerical modeling vs observations. A comment on Braun (2018) by Japsen, Green, Chalmers, Duddy and Bonow (hereafter refer to as JGCDB)

Contrary to what JGCDB claim, Braun (2018) does not *"support a preconceived notion of margin development on one side of the debate"*. In their comment, JGCDB systematically misquote or improperly represent my work (Braun, 2018) in an attempt to push it into what I consider as a non-existing debate. In support of this statement, I first demonstrate that my paper (Braun, 2018) clearly quoted many hypotheses for the formation of margin escarpments, including the idea that it is not related to rifting as proposed by JGCDB. I then review some of the "observational evidence" that JGCDB use to support their claim that passive margin escarpment topography is much younger than rifting and show that, in the case of South Africa for example, this claim is speculative.

JGCDB are trying to construct an argument by misquoting my work. They state that Braun (2018) *"discussed possible ways to explain one of the most surprising characteristics of EPCMS, namely their apparent longevity."* In Braun (2018), I wrote: *"Although there has been some controversy on the origin of this topography, i.e. whether it predates, is concomitant or postdates the rifting event that led to the formation of the margin, one of the most surprising characteristics of high elevation passive margins is their apparent longevity..."* Firstly, JGCDB have conveniently omitted to quote the first part of my sentence, i.e. *"Although there has been some controversy on the origin of this topography, i.e. whether it predates, is concomitant or postdates the rifting event that led to the formation of the margin"* as well as the adjective *"apparent"* qualifying the word "longevity", in an attempt to sell their argument that I have *"a preconceived notion of margin development"*. Secondly, nowhere do I state that the principal aim of the modeling section of my paper is to explain the longevity of escarpments. In the abstract I do state that much past modeling work has been driven by the question of explaining this longevity and I later quote/cite that work. However, the outstanding issues that I address in the modeling section of Braun (2018) are clearly stated in section 4.3. They are (1) *"what controls the velocity at which an escarpment, and, more generally, a drainage divide propagates"* and (2) *"why flexure controls the rate of propagation of the escarpment"*.

In their concluding remarks, JGCDB state *"We submit that Braun's numerical studies of escarpment development and elevated passive margin longevity are designed to support a preconceived notion of margin development on one side of the debate"*. This is untrue. To make this point, JGCDB intentionally failed to quote the section of Braun (2018) that addresses the point they wish to raise (section 3, *"The origin of the uplift"*) and in which I state: *'Several authors have, however, argued that some if not most of the present-day topography observed along elevated passive margins is young, i.e. younger than the time of continental rifting that led to the formation of the margin. The mechanisms that could lead to such rejuvenation of the topography remain poorly known and/or debated. It may be caused by the propagation of compressional in-plane stresses from far-away tectonically active regions (Japsen et al, 2012) or by active mantle flow causing dynamic topography (Walford and White, 2006)."*

I will now review some of what JGCDB regard as evidence and quote in their comment in support of their hypothesis that passive margin escarpment topography is younger than rifting. Because of the short time given to me to prepare this response (two weeks) and the space available, I will focus on southern Africa. As explained in Braun (2018) (page 2 paragraph starting with *"Guillocheau et al (2012) quantified the terrigeneous flux ..."*) there is an emerging consensus based on available evidence (from sedimentary flux data and thermochronology) that uplift of the South African plateau is the likely product of three phases of tectonic activity, namely rifting in the Early Cretaceous, broader uplift potentially caused by mantle processes in the Late Cretaceous and a mild phase of Cenozoic uplift. On the contrary JGCDB state that *"high topography of EPCMs is young, the end-product of post-rift episodes of burial and exhumation"*. Please note that this statement implies that ALL the topography of ALL EPCMs is young. Several authors among JGCDB have published papers claiming that the escarpment surrounding the southern African plateau is younger than 30 Myr, based partly on "evidence" that the top of the present day escarpment experienced burial in the mid- to late Cenozoic. JGCDB quote this work (Green et al., 2017). I now review all the evidence cited in JGCDB pertaining to southern Africa supporting this assertion.

JGCDB state that *"...the presence of post-rift, marine sediments at high elevation on EPCMs or in their hinterland, documenting that rifting and break-up was followed by subsidence and burial, and that the present elevation of these marine sediments resulted from uplift at a later stage of the margin development. Notable examples are marine sediments ... of Eocene age at 400 m a.s.l. at Need's Camp, South Africa (Partridge and Maud, 1987)..."*. There are indeed two quarries in Needs Camp at 336 and 367 m a.s.l. (not 400 m) that contain marine sediments of debated age. The best paper that describes the evidence and the paleontological debate surrounding these deposits is by Lock (1973) and not Partridge and Maud (1987) who only proposed an interpretation based on the putative existence of "surfaces" connecting the present-day coastline to the top of the escarpment and the plateau behind it. But let's assume, indeed, that those sediments are Eocene. Global (eustatic) sea level in the early Eocene was somewhere between 70 m (Rowley, 2013) and 220 m (Miller et al, 2005) higher than present-day (see Bessin et al (2017) for a compilation/review of global sea level curves suggesting that early Eocene sea level was around 100 m above present-day). This means that Needs Camp has experienced of the order of 250 m of uplift at most since the early Eocene (not 400 m). Considering now that Needs Camp is located approximately 15 km from the present-day coastline and 60 km from the present-day escarpment/plateau edge, I have real difficulties assessing why evidence of uplift by ≈250 m since the Eocene at the base of the coastal plain is proof that the escarpment and the entire South African Plateau was at sea level or buried under marine sediments at that time. This point was already raised in Van der Beek et al. (2002). To state that the presence of Eocene marine sediments deposited ≈250 m above present-day sea level and located more than 60 km from the top of the ≈1000 m high present-day escarpment as proof that the topography of the escarpment is less than 30 Myr old is a speculation, at most an interpretation but certainly not hard evidence.

JGCDB state that *"The relative youth of EPCM landscapes is further supported by ... apatite fission-track studies that reveal cooling/exhumation of EPCMs extending well inland of the escarpment and post-dating rifting and breakup by millions of years"*. As already remarked above, I stated in Braun (2018) that there is thermochronological and sedimentological evidence for a major uplift of the South African Plateau in the late Cretaceous, well after rifting. I am first author on a paper proposing a mechanism to explain it (Braun et al., 2014a), which I also cite in Braun (2018). In support of a much younger age for the South African escarpment, JGCDB quote a paper (Green et al., 2017) published by four of the authors (Japsen, Green, Duddy and Bonow), which claims that *"Features such as the Great Escarpment are not related to continental breakup, as is often supposed, but are much younger (post-30 Ma)"*. The data on which this interpretation is based consist of 7 samples collected in the near vicinity of the present-day escarpment (GC1070-33 to GC1070-39, part of a larger dataset) from which apatite fission track ages ranging between 90 and 110 Ma have been obtained (their Figure 7 and Table 1) as well as fission track length distributions (given in the supplementary material). From this data Green et al. (2017) construct *"... thermal history solutions derived from AFTA data based on assumed heating and cooling rates of 1* $^\circ C\ Ma^{-1}$ *and 10* $^\circ C\ Ma^{-1}$*, respectively"* which, according to the authors, fit the observed ages and length distributions (the fit is not shown in the paper). They show that these thermal histories imply a major phase of cooling in the late Cretaceous followed by a phase of slow cooling that may have lasted until the present-day. This interpretation agrees with many other studies that the Plateau is likely to have undergone a major phase of uplift in the late Cretaceous. To make their case that the escarpment is a much younger feature (post-30 Ma), Green et al. (2017) add a black zig-zag line to the relevant panel (top-center panel of Figure 9) to imply that there was not only slow cooling but finite episodes of burial and erosion along the escarpment (one between 100 and 80 Ma, the other between 70 and 30 Ma). This, in turn, implies that the escarpment grew from a topographic minimum (where deposition takes place) to a present-day topographic maximum over the past 30 Myr. In their paper or the lengthy supplementary material, Green et al. (2017) do not show or state whether the data (age and track lengths) collected in the vicinity of the escarpment are better fitted by a monotonous or non-monotonous cooling history. They state: *"In this study, where basement samples are directly overlain by Late Jurassic to Early Cretaceous Uitenhage Group sediments, scenarios involving episodic heating and cooling are clearly appropriate ..."*; note that they do not state "more appropriate". They add: *"... while experience in a wide variety of different settings (Green et al, 2013) leads us to conclude that this style of thermal history is generally more appropriate than slow monotonic cooling"*. There is no young (i.e. post 30 Ma) sedimentary cover near the escarpment. The "finding" by Green et al. (2017) that the escarpment flanking the South African Plateau is a young (post-30 Ma) topographic feature is based on a correlation they make with other margins world-wide. In contrast to this speculative interpretation of data, many studies have demonstrated, in a statistically meaningful manner, that there is no need to "peneplain" the African Plateau in the Eocene to reproduce low temperature thermochronological constraints (Brown et al., 2002; Flowers and Schoene, 2010; Kounov et al., 2008, 2009, 2013; Stanley et al., 2013, 2015; Wildman et al., 2015, 2016).

JGCDB also quote as evidence for the relative youth of EPCM landscapes *"studies based on river profiles that indicate late rejuvenation of the landscape"*. It is correct that one research group has focused on using river profiles to infer spatial and temporal patterns of uplift and that they have applied this method to the uplift of Africa (Roberts and White, 2010; Paul et al., 2015; Rudge et al., 2015). These are modeling studies that all rely on the assumption that Africa was a peneplain 30 Myr ago: *"... $z(x) = 0$ (i.e., no topography) before Neogene times"* (Roberts and White, 2010), *"... the African landscape was low lying during Paleogene times"* (Paul et al., 2015), or that *"... prior to 35 Ma, the African continent was low lying"* (Rudge et al., 2015). This implies that none of these studies can be used to prove that the uplift of Africa (and in particular South

Africa) is young as it is one of their assumptions and cannot therefore be one of their conclusions. Making the assumption that the topography of Southern Africa is less than 30 Myr old to use river profiles as evidence that the topography of Southern Africa is young is a speculation, at most an interpretation but certainly not hard evidence.

JGCDB write: *"... models can prove anything with the appropriate choice of parameters."* My view is that Geology is based on the study of an incomplete record implying that we cannot state that we "know" something for certain, at most do we formulate hypotheses that we test against the observational evidence. Fortunately Earth processes must obey the laws of Physics. This provides us with ways to test hypotheses suggested by the geological record through quantification and modeling. But, at the end of the day, Geology remains a science of compromise: we will accept the hypothesis (or hypotheses) that fits the observations in a most comprehensive manner. This process requires, however, that we do separate what is observations from their interpretation or from speculative statements or hypotheses. These latter are very useful for the advance of our understanding of how the Earth works but should only challenge or replace the consensus when they are shown to better explain the observational evidence while still obeying the laws of Physics.

References

Bessin, P., Guillocheau, F., Robin, C., Braun, J., Bauer, H., and Schroetter, J.-M. (2017). Quantification of vertical movement of low elevation topography combining a new compilation of global sea-level curves and scattered marine deposits (Armorican Massif, western France). *Earth and Planetary Science Letters*, 470:25–36.

Braun, J. (2018). A review of numerical studies of passive margin escarpments leading to a new analytical expression for the rate of drainage divide migration. *Gondwana Research*, 53:209–224.

Braun, J., Guillocheau, F., Robin, C., Baby, G., and Jelsma, H. (2014). Rapid erosion of the Southern African Plateau as it climbs over a mantle superswell. *Journal of Geophysical Research: Earth Surface*, 119:6093–6112.

Brown, R., Summerfield, M., and Gleadow, A (2002). Denudational history along a transect across the Drakensberg Escarpment of southern Africa derived from apatite fission track thermochronology. *Journal of Geophysical Research: Solid Earth.* 107:ETG–10.

Flowers, R., and Schoene, B.(2010). (U-Th)/He thermochronometry constraints on unroofing of the eastern Kaapvaal craton and significance for uplift of the southern African Plateau. *Geology*, 38:827–830.

Green, P.F., Duddy, I.R., Japsen, P., Bono, J.M., and Malan, J.A. (2017). Post-breakup burial and exhumation of the southern margin of Africa. *Basin Research*, 2017:1–32.

Kounov, A., Viola, G., De Wit, M., and Andreoli, M. (2008). A Mid Cretaceous paleo-Karoo River valley across the Knersvlakte plain (northwestern coast of South Africa): Evidence from apatite fission-track analysis. *South African Journal of Geology.* 111:409–420.

Kounov, A., Viola, G., De Wit, M., and Andreoli, M. (2009). *Denudation along the Atlantic passive margin: new insights from apatite fission-track analysis on the western coast of South Africa. Geological Society, London, Special Publications* .324:287–306.

Kounov, A., Viola, G., Dunkl, I., and Frimmel, H. (2013). Southern African perspectives on the long-term morpho-tectonic evolution of cratonic interiors. *Tectonophysics.* 601:177–191.

Lock, B.E. (1973). Tertiary limestones at Needs Camp, near East London. *Transactions of the Geological Society of South Africa*, 76:1–5.

Miller, K.G., Kominz, M.A., Browning, J.V., Wright, J.D., Mountain, G.S., Katz, M.E., Sugarman, P.J., Cramer, B.S., Christie-Blick, N., and Pekar, S. (2005). The Phanerozoic record of global sea-level change. *Science*, 310:1293–1298.

Partridge, T.C., and Maud, R.R. (1987). Geomorphic evolution of southern Africa since the Mesozoic. *South African Journal of Geology*, 90:179–208.

Paul, J.D., Roberts, G.G., and White, N.J. (2014). The African landscape through space and time. *Tectonics*, 32:898–935.

Roberts, G.G., and White, N.J. (2010). Estimating uplift rate histories from river profiles using African examples. *Journal of Geophysical Research: Earth Surface*, 115:B02406.

Rowley, D.B. (2013). Sea Level: Earth's dominant elevation ? implications for duration and magnitudes of sea level variations. *Journal of Geology*, 121:445–454.

Rudge, J.F., Roberts, G.G., White, N.J., and Richardson, C.N. (2015). Uplift histories of Africa and Australia from linear inverse modeling of drainage inventories. *Journal of Geophysical Research: Earth Surface*, 120:894–914.

Stanley, J., Flowers, R., and Bell, D. (2013) Kimberlite (U-Th)/He dating links surface erosion with lithospheric heating, thinning, and metasomatism in the southern African Plateau. *Geology.* 41:1243-1246.

Stanley, J., Flowers, R., and Bell, D. (2015) Erosion patterns and mantle sources of topographic change across the southern African Plateau derived from the shallow and deep records of kimberlites. *Geochemistry, Geophysics, Geosystems.* 16:3235–3256.

Van der Beek, P., Summerfield, M., Braun, J., Brown, R. And Flemin, A. (2002). Modeling escarpment landscape development and denudation history across the southeast African (Drakensberg Escarpment) margin. *Journal of Geophysical Research.* 107:B12-2351.

Wildman, M., Brown, R., Watkins, R., Carter, A., Gleadow, A., and Summerfield, M. (2015). Post break-up tectonic inversion across the southwestern cape of South Africa: New insights from apatite and zircon fission track thermochronometry. *Tectonophysics*, 654:30–55.

Wildman, M., Brown, R., Beucher, R., Persano, C., Stuart, F., Gallagher, F., Schwanethal, J., and Carter, A. (2016). The chronology and tectonic style of landscape evolution along the elevated Atlantic continental margin of South Africa resolved by joint apatite fission track and (U-Th-Sm)/He thermochronology. *Tectonics.* 35:511–545.

Jean Braun[1,2]
[1] *Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Potsdam, Germany*
[2] *Institute of Earth and Environmental Sciences, University of Potsdam, Potsdam, Germany*

August 17, 2018