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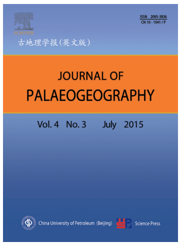

Academic discussion

Reply to comments by G. Shanmugam (2015) and A. J. (Tom) van Loon (2015) on "*3D palaeogeographic reconstructions of the Phanerozoic versus sea-level and Sr-ratio variations*"

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Abstract I use to say that in science, one cannot say what is right, but one can say what is wrong. And a model is, by definition, wrong, otherwise it is not a model, it is the truth. Being aware that a model aims to mimic the truth but will never be the truth, the only worth questions asking to a model are: (1) How wrong are we? And (2) Why are we wrong? The latter questions the foundations of the model, and is mainly the concerns of A. J. (Tom) van Loon's comments (2015, this issue). The first questions the accuracy of the outcomes, and corresponds more to G. Shanmugam's comments (2015, this issue).

I am glad that our paper has aroused so rapidly as much feedbacks and comments, sometimes even before the manuscript is definitely published. We hope this paper will keep on inspiring various axes of research and opening new avenues in geosciences.

Detailed answers to the comments raised by A. J. (Tom) van Loon and G. Shanmugam among others would certainly deserve a book, so my reply will just focus herein around the two aforementioned questions.

1 Reply to A. J. (Tom) van Loon (2015)

Since the advent of global "plate tectonic model" (Dewey and Bird, 1970), the notion of palaeogeography and more specifically of topography, is an issue. Responses were proposed in two ways: (1) Qualitatively, by merely drawing areas of higher continental relief where orogens are known or areas of shallow versus deep water (*e.g.*, Blackey, 2008); such high approximations are used, for instance, as background model for palaeo-climate modelling paradoxically using the most recent and sophisticated techniques (*e.g.*, Dera and Donnadieu, 2012; Sellwood and Valdes, 2008); (2)

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Quantitatively, by estimating elevation from denudation rates (from fission track data for instance) on land or narrowing water-depth of palaeo-environments from various fossils or other lithostratigraphic indicators. Although this approach is undoubtly the more robust and the more precise, it is hardly possible to obtain such data for the entire planet at a given geological time, let alone to 100% of the Earth throughout the Phanerozoic.

To face this challenge, Vérard *et al.* (2015) decided to choose a different way. The main idea is that topography follows, to first order, the same general mathematical rules everywhere and at any times according to the geodynamic settings. For example, the sea-floor depth increases away from the mid-oceanic ridge according to its age, or rifting processes lead to rift shoulders that progressively lower under water as the passive margin cools down. Of course, we can thus only obtain a crude quantification of the topography, but it has the advantage of being based on physical behaviour of the Earth's surface (which can be parametrized), and being applicable over 100% of the Earth surface at any geological time.

In order to test this idea, we applied the 3D conversion technique we developed to our plate tectonic reconstructions (UNIL model, v.2010; © Neftex) and compared the resulting synthetic topography with observed topography. Unfortunately, the only example of topography is the present-day topography, and we chose to assess the quality of the topography in the geological past through indirect evidences, in particular the sea-level variations, which are very sensitive to topography. Doing so, we were very struck to see how fairly good the match between synthetic and "real" topography was. However, the synthetic topography is not perfect as shown in Fig. 11 in Vérard *et al.* (2015); in other words, we indeed are wrong.

Why are we wrong?

The topography of the planet results from an extremely complex process, which will most likely never be modelled in details. To first order and at global scale, however, the proposed model (Vérard *et al.*, 2015, *op.cit.* Fig. 11) shows main discrepancies (in red and blue in Fig. 11, Vérard *et al.*, 2015) between the synthetic and "real" topographies that are well-understood.

The fact that the Tibetan Plateau, for instance, is not high enough in the model comes from the limitations of the plate tectonic model. As mentioned in the text (Vérard *et al.*, 2015, *op.cit.* section 2.4), "*Due to limitations related to the structure of the UNIL plate tectonic model (v.2011; © NEFTEX), the generated topography is only a function of the type and age of geological features that comprise the model* […]. *The modelled topography is not related to date to the amount of stretching/shortening or to any local rheological aspects.*" The problem is now partially resolved using a new type of plate tectonic model currently under development, but it explains also why specific areas, such as the Lord Howe Rise, are too high. The synthetic topography mimics the effect of stretching in designated areas such as passive margin environments, but not diffuse stretching within continental areas such as the continental mass in-between the two passive margins of the Lord Howe Rise.

The area around Greenland is equally an area where large discrepancies exist. Again the reason is that the model does not account for post-glacial isostatic rebound. Because the 3D conversion method aims to produce synthetic topographies on past reconstructions with typical time intervals of the order of 10 Ma, we considered that topographies have reach equilibrium.

The South Africa area is another example where the synthetic topography is not high enough relative to the "real" topography. In this case, one can invoke the dynamic topography, which is not taken into account in the 3D conversion technique. The dynamic topography corresponds to uplift or sink of the lithosphere with long wave length in association with mantle convection processes. The dynamic topography might be responsible to variations up to 1000 m in topography (Hans-Peter Bunge, *pers. com.*, 2014; J. Huw Davies, *pers. com.*, 2012). Now, the fairly good fit throughout the Phanerozoic between the synthetic and the "observed" sea-level curves shows that this effect is averaged out at global scale (Vérard *et al.*, 2015, *op.cit.* Fig. 17). In terms of palaeogeography, however, dynamic topography can only be considered by coupling the plate tectonic model with a global model of mantle flow such as done regionally by Shephard *et al.* (2012) or Warners-Ruckstuhl *et al.* (2012, 2013) for instance. Nevertheless, the comparison of the synthetic and "real" coast-line (Vérard *et al.*, 2015, *op.cit.* Fig. 11), which is highly sensitive to discrepancies on topography, shows that the result of the model is not highly impacted by those effects.

In one sentence, the model is by definition wrong, because it does not take all topographic effects into account, but we know globally where and why it is wrong. Although much can be done to improve the technique (work under progress), we believe therefore that the foundations of our approach are reliable and that its bases are solid.

2 Reply to G. Shanmugam (2015)

A strong concern of G. Shanmugam (2015, this issue) is that the 3D conversion technique proposed by Vérard *et al.* (2015) does not take all available datasets on present-day topography into account, and in particular data published by G. Shanmugam himself.

The aim of our work is not to model the present-day topography: We know how it looks like. The goal is to propose a comprehensive solution for the topography, for example for the Siberian area in the Silurian or even for the disappeared panthalassic realm in the Devonian, *i.e.*, for zones where we usually have no clues regarding the topography.

The technique has indeed the advantage of being applicable all over the planet at any geological times provided that the chosen plate tectonic model has the necessary attributes to convert the various geodynamic environments into 3D topographic surface. The fact that it is possible to convert any given model into synthetic topography does not mean that the defined palaeogeography is perfect (see reply to A. J. (Tom) van Loon, above).

How wrong are we?

It is not possible to model at global scale every single valley with its tiny cute flowers. It seems that G. Shanmugam (2015, this issue) has not realized that most of the topographic features he is quoting, submarine canyons he has studied for instance, are below the resolution of the global plate tectonic model and consequently of its 3D conversion. The plate tectonic model used has a resolution not better than about 100 km (*i.e.*, ~1°) meaning that a palaeogeographic feature like Lake Geneva in Switzerland cannot exist in the model. Such caveat implies that any comparison done at local scale from a global plate tectonic model has little significance for the moment. Thus, the problem is not so much the accuracy of 3D conversion technique than the accuracy of the underlying plate tectonic model.

Another misunderstanding, although clearly stated in the paper and actually part of the conclusion (Vérard *et al.*, 2015, *op.cit.* section 4), is the fact that the presented 3D topographic surface purely stems from geodynamic consideration. It is climatic-free. Consequently, the presented model does not account for spatial variations of rain fall, subsequently for spatial variations of erosion or sedimentation, and thus there are no rivers (and subsequently submarine canyons).

At first glance, it is a serious flaw, and all our efforts are currently focused on the coupling of the plate tectonic model with a global model of climate (the MIT General Circulation Model; Brunetti *et al.*, 2015; Brunetti *et al.*, *in prep.*; Perroud *et al.*, *in prep.*) in order to define where it rains and where rivers flow.

However, the interesting point raised in Vérard *et al.* (2015) is that, because the model is climatic-free, and since the sea-level variations match fairly-well the variations reported in the literature (at least for long-term variations), it suggests that those variations are purely tectonically-driven.

In terms of palaeogeography, the synthetic topography has already proved useful for climate modelling (Brunetti *et al.*, 2015) or for intra-plate stress modelling involving lithospheric body forces (Hafkenscheid *et al.*, 2013; Warners-Ruckstuhl *et al.*, 2012, 2013). Now, the accuracy is for the moment too low to significantly impact conclusions on local geological issues and lithofacies aspects. To the question "how wrong are we?", we conclude that the synthetic topography seems, to date, relatively wrong at local scale (although the synthetic coast-line is defined at a resolution below the plate tectonic model resolution), but probably fairly-good at global to regional scale (with implications for sea-level curves or other palaeo-climatic indicators for instance).

3 Conclusions

The 3D conversion technique presented in Vérard *et al.* (2015) is regarded as a first step towards synthetic palaeogeography at global scale throughout geological times. Much needs to be done, in particular through coupling with other global modelling such as palaeo-climatic model, lithospheric stress and deformation models, mantle flow models, but we believed that we opened the way to define synthetic palaeogeography which will be able to challenge palaeogeographic and lithofacies maps generated using direct geological indication. The comparison between the two approaches is viewed as complementary and the only way to validate or invalidate the numerous hypotheses concerning the proposed palaeogeography that the Earth had over its geological evolution.

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References

1. Blackey, R., 2008. Gondwana palaeogeography from assembly to breakup —— A 500 m.y. odyssey, in: Fielding, C., Frank, T., Isbell, J., (Eds.), Resolving the Late Paleozoic Ice Age in Time and Space. *GSA*, *Special Paper*, 441, pp. 1–28.
2. Brunetti, M., Vérard, C., Baumgartner, P., 2015. Modelling the Middle Jurassic Ocean Circulation. *Journal of Palaeogeography*, in press.
3. Dera, G., Donnadieu, Y., 2012. Modeling evidences for global warming, Arctic seawater freshening, and sluggish oceanic circulation during the Early Toarcian anoxic event. *Paleoceanography*, 27, PA2211.
4. Dewey, J., Bird, J., 1970. Plate tectonics and geosynclines. *Tectonophysics*, 10(5–6), 625–638.
5. Hafkenscheid, E., Warners-Ruckstuhl, K., van Oosterhoot, C., Bergman, S., Davies, H., Govers, R., Hochard, C., Kennan, L., Ross, M., Stampfli, G., Vérard, C., Webb, P., Wortel, R., 2013. Integrating plate tectonic reconstruction and mantle dynamics: A valuable aid in frontier exploration. Poster # EGU2013–3204 at the EGU General Assembly, Vienna.
6. Sellwood, B., Valdes, P., 2008. Jurassic climates. *Proceedings of the Geologists' Association*, 119, 5–17.
7. Shanmugam, G., 2015. 3D palaeogeographic reconstructions of the Phanerozoic versus sea-level and Sr-ratio variations: Discussion. *Journal of Palaeogeography*, 4(3), 234–243.
8. Shephard, G., Liu, L., Müller, R.D., Gurnis, M., 2012. Dynamic topography and anomalously negative depth of the Argentine Basin. *Gondwana Research*, 22(2), 658–663.
9. Van Loon, A., 2015. The Vérard *et al.* (2015) method for 3D palaeogeographic reconstructions: How solid is its base? *Journal of Palaeogeography*, 4(3), 244–247.
10. Vérard, C., Hochard, C., Baumgartner, P., Stampfli, G., 2015. 3D palaeogeographic reconstructions of the Phanerozoic versus sea-level and Sr-ratio variations. *Journal of Palaeogeography*, 4(1), 64–84.
11. Warners-Ruckstuhl, K., Govers, R., Wortel, R., 2012. Lithosphere-mantle coupling and the dynamics of the Eurasian plate. *Geophysical Journal International*, 189, 1253–1276.
12. Warners-Ruckstuhl, K., Govers, R., Wortel, R., 2013. Dynamics and stress field of the Eurasian plate. Poster # EGU2013–9094 at the EGU General Assembly, Vienna.

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