Dear Frank, dear Federico,

thank you very much for your comments and suggestions for the ms “Reconstructing 3D subsurface salt flow”. We have considered all comments and worked on the respective parts in the text. Please find below a detailed description of the changes made, indicated by arrows. Please find furthermore one version of the text and figures uploaded with track changes, and a final document uploaded with all changes accepted. All corrections marked in the annotated ms were made.

Revisions:

1. “Abstract – This could state that the paper presents an approach to palinspastic restoration that is radically different from from the usual methods.”

-> lines 19-21: The 3D reconstruction procedure is radically different from classic backstripping in limiting palinspastic restoration to the salt overburden; followed by volume-constant balancing of the salt substratum.

2. “Introduction (line 75) - I think that you need to say more about the geological setting and structural style of the salt here. To introduce the salt structures (…)”

-> now introduces more about the geological setting and the type of salt structures: The Permian Zechstein Group in the subsurface of the Netherlands, Central Europe (Fig. 2a) accumulated in the foreland of the Variscan orogen (Geluk 2007). The Zechstein Group of the onshore Netherlands comprises five evaporite cycles (Z1-Z5; Van Adrichem Boogaert and Kouwe, 1993; Geluk, 2007) with several hundreds of metres of rock salt and anhydrite deposited mainly in Z2 and Z3 (Fig. 2b). Several small tectonic pulses are reported to have occurred during Zechstein times, with partly extensional and partly compressional faulting mainly affecting anhydrite platforms at the Zechstein Basin margins (Geluk, 1999). The occurrence of Zechstein evaporites in the Netherlands’ subsurface influenced the post-Permian geological development. The visco-plastic behaviour of salt under loading and compressive tectonic stress (Remmelts, 1995) led to the development of numerous salt structures, mainly salt rollers, salt anticlines and salt walls (e.g. Fig. 3). Many of these structures were not actively diapiric and did not grow further when buried (e.g. Trusheim, 1963).

-> Caption figure 3 additionally mentions type of salt structures

3. “Sediment densities and compaction (line 105)”

-> revision of significant parts of the text. We have not added an additional figure with depth, porosity, and/or density trend; figures A1a, A1b and A2 of Sclater and Christie (1980):

Sclater and Christie: Continental Stretching-North Sea

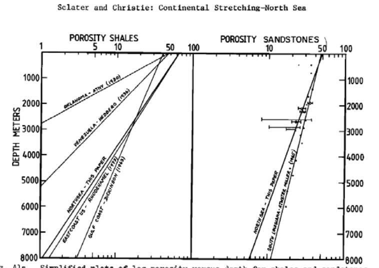

Fig. A1a. Simplified plots of log porosity versus depth for shales and sandstones. The North Sea shale data were computed from the observed sonic log plots for a normal pressured section of Schlumberger [1974] using the sonic log velocity/porosity relation of Magara [1976a]. The sandstone data for the North Sea are from Sealey [1976] supplemented with data calculated using observed sonic velocities and the velocity/porosity tables of Schlumberger [1974]. The best fit straight line through the data and that through the Atwater and Miller [1965] data is constrained to pass through the surface porosity values of Pryor [1973].

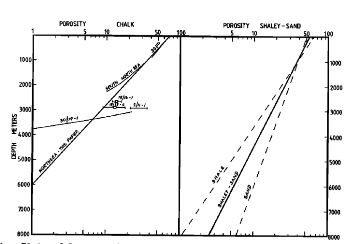

Fig. A1b. Plots of log porosity versus depth for chalks and shaley sands in the North Sea. The chalk data are from Scholle [1976] supplemented by porosity values in two normally pressured holes, calculated using the sonic logs and the velocity/porosity relations of Schlumberger [1974]. The best fit straight line through the data is constrained to pass through the DSDP data and the lowest values of the two chalks in the northern portion of the Central Graben. The porosity of the shaley-sand used to estimate compaction in sections below the Late Cretaceous was taken as the average of the relations for sand and shale individually.

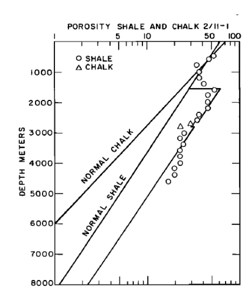

Fig. A2. Estimated porosity versus depth relation for Amoco 2/11-1. The relation was determined assuming that total sealing occurred at the end of the Eocene and with normal pressure above.

as these show in a very clear way the porosity versus depth relation for their template lithologies used (without modification; now explicitly stated – see below) in this study.

-> We have however integrated the explicit mentioning of high chalk porosity but also limited burial of the sand-prone North Sea Group as suggested by Frank. The revised text is now: “Strata above the Zechstein were assigned average lithologies (Table 1) with the definition of average rock type (shale, sand, chalk, shaley sand), compaction trends and density/depth relationships taken from the North Sea database of Sclater and Christie (1980) without modification. Young’s Modulus and Poisson Ratio data are from Hunfeld et al. (2021). In all cases the present-day cumulative average density of the column of vertical overburden (= grain density + porosity; pores filled with water) was lighter than the density of the evaporite substratum (fluid with ρ = 2.2 g/cm3), and should have been so in the past.

The backstripping observation that the cumulative average overburden density remained in the study area always lower than that of the Zechstein Group might be surprising, as every sediment will become at some depth denser than salt. Yet, in the study area the depth of Top Zechstein was never very great (in most areas < 2500 m; see Fig. 3 for present-day situation). Since i) both the Chalk Group and the North Sea Group were never deeply buried; ii) both groups constitute the main part of the overburden (Fig. 3); and iii) chalk can preserve very high porosities at depth (30-50% at ca. 2500m in the North Sea example of Sclater and Christie, 1980), we estimate that in the study area over 3000 m of sedimentary cover with a significant shale content would be needed to attain a cumulative average overburden density exceeding 2.2 g/cm3.”

-> going back into the Sclater and Christie (1980) depth-porosity curves with the average lithology densities and pores filled with water, burial of > 2500m would be needed to get cumulative average density of the sediment column > 2.2 g/cm3.

4. At the end of the discussion, I think that it would be valuable to add a paragraphs that compare/contrasts your method with conventional restoration, and a paragraph that discusses where the method might be applicable and when it might not.
-> We have re-written the two last paragraphs of the discussion. We didn’t include a comparison with conventional restoration – this is already mentioned in the methods section; and in lines 294-298 with the reference to figure 11. We however state, as suggested, that the method could apply both for scenarios where the sediment is less dense than the salt, and in scenarios where the sediment is denser than the salt. In the latter case, however, the method can only be introduced at a later stage in the restoration. With our simple loading model, a too dense overburden column will simply fall through a too light substratum (with cumulative average overburden density greater than that of the substratum).

-> The last paragraph explicitly states where and why the method might not work.

-> The revised text is now: “The case study presented here for the onshore NE Netherlands concentrates on a structurally relatively simple area dominated by vertical subsidence, with limited influence from thick-skinned tectonic activity. The applied method yields in this area promising results. The approach should be equally applicable in other scenarios where a “solid” overburden is less dense than a mobile “fluid” substratum; this potentially includes areas underlain by mobile shale. In scenarios where the overburden reached a cumulative average density above that of the substratum, the unloading methodology can be potentially applied at a later stage in backstripped (restored) former stratigraphic configurations in which an Archimedean equilibrium existed.

The method yet will only work in settings where the salt had enough time to flow so that the sediments and salt could approach Archimedean equilibrium (Fig. 1). In systems where the geology has not yet achieved an equilibrium state the method will not be applicable. For example, if applied to areas where allochthonous salt sheets flow at the surface (e.g. Gulf of Mexico: e.g. Fletcher et al., 1996; Fort and Brun, 2012; Duffy et al., 2019); where complex structures such as salt canopies occur (e.g. Santos Basin: Jackson et al., 2015; Moroccan margin: Neumaier et al., 2016); where large salt nappes have flowed many 10's of kilometres seaward, accommodating long-distance lateral translation of the overburden relative to the base of salt (e.g. offshore Angola; Fort et al., 2004; Hudec and Jackson, 2004); or where sedimentation accumulated rapidly and thick above salt, possibly associated with actively rising salt diapirs, the whole basin system is far from equilibrium and the simple Archimedean method applied here will be insufficient. In such cases a reconstruction coupling 3D salt-thickness restoration and 3D salt tectonic retro-deformation might be successful.

In summary, we are very very grateful for the thoughts, comments and suggestions provided by Frank Peel! We see these as a major contribution to the manuscript, ultimately leading to a more accurate scientific document with broader significance. Thank you very much! Otherwise we hope that the ms is now in an accepteable form; we highly appreciate the professional editorial handling of the ms!

Best wishes

Stefan et al.