Dawn and Dusk of Late Cretaceous Basin Inversion in Central Europe

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Comments to the review of Jef Deckers

Thank you for the careful and comprehensive review! We corrected the mistakes you pointed out and discussed additional arguments where we stuck to our text.

Overall, the review helped us to make some things clearer and more precise. Sorry for the missing literature about Belgium and the Netherlands about Cretaceous inversion; we included these papers, although the focus was initially to the German basins. We have added a short remark on the Paleogene events, but keep our focus on the compressive late Cretaceous event.

Our replies will discuss all comments in the original manuscript. We refer to the line numbers there.

1. Title: As we consider only processes related to the late Cretaceous Basin compression and not later tectonic events, which are oriented in different directions, we will use the present title. The open question is, where the boundary between western and central Europe is situated (our focus was on Germany, western Poland and the Czech Republic. But, as we sometimes refer to the Anglo-Paris Basin, we will include the Roer Valley Graben, the inverted Central Netherlands Basin and the inversion structures in the North Sea additionally during discussion.
2. Line 8: although we worked mainly in the type locality of the "Subhercynian Phase", we avoid the use of this term – the name is too closely related to the locality where the exact timing **cannot** be fixed. The same is true in our opinion for the Laramide and the Pyreneen phases (established by Stille in the last century). These "phases" suggest worldwide deformation but represent in fact very different processes (as you proved in your own papers) and are not necessarily connected to each other.
3. Line 12: Added (as proposed): on the basis of borehole data and facies and thickness maps
4. Line 15: this is no contradiction, because the end-Maastrichtian timing is often fixed in the sea-covered northern parts, but in the large area of inversion structures in Northern Germany either already Campanian or Maastrichtian transgresses on inverted structures, and no clear change in basin configuration occurs in the Paleogene/Eocene. This is only possible if the uplift rates decline slowly in a time-span of at least 5-10 Ma, regardless which processes are responsible for this.
5. Line 18: again, the boundary between Central, Northern and Western Europe is a matter of convention. To avoid ambiguity, we rewrote the sentence as follows: During the Late Cretaceous/Earliest Paleogene, Europe was affected by a compression event.
6. Line 20: you are right; added: transpression at normal faults with high angle to compression.
7. Line 21: added: de Jager 2003
8. Line 24: the main inversion structures in Central Europe (north and east of the Rhenish Massif) show indeed mostly sands and conglomerates and hemipelagic marlstones (also marls are partly composed of clays), but we add: and redeposited carbonates
9. Line 24: This statement is true, because the amount of inversion at the basement uplifts is between 5 and 12 km, in comparison to 500-2000 m at structures outside this belt. All basement uplifts are arranged in this belt. Important: As this sentence re-appears some lines below, it will be skipped from this place.
10. Line 35 (extended figure): this is a good point, but would be very time-consuming and the figure would be rather complex. Should be an additional paper. Altmark basin (AM) was added to the figure.
11. Line 40: authors added: (Lange et al., Senglaub et al., Danisik et al, von Eynatten et al.)
12. Line 54: added (slickensides, fold axes and fault orientation)

13. Line 58: added: furthermore
14. Line 60: added: on the base of detailed fault analysis,
15. Line 75: foreland is the structural relationship to the inversion structure, marginal trough the resulting structure, (…means we will keep it)
16. Line 79: you are right, changed: …within the Danian. This is in agreement with the results of Deckers and van der Voet (2018) for the timing of inversion in the Roer-Graben and the West-Netherland basin inversion
17. Line 80: better explained: Due to lacking Paleocene deposits and later erosion of both marginal troughs and uplifting structure, these potential secondary marginal troughs are not preserved
18. Line 84: added Central Europe
19. Line 87: changed as proposed
20. We are sure that at least these "pulses" of Late Cretaceous inversion are artefacts, produced by the interaction of continuous tectonics and global sea-level changes. Unconformities develop due to erosion during base-level fall and are covered during base-level rise. These pulses correlate perfectly with late Cretaceous transgressions (see Voigt et al 2004: Late Cretaceous unconformities in the Subhercynian Cretaceous Basin (Germany). The unconformity becomes obvious not until the underlying succession is covered by the next sequence. Therefore, also the interpretation of Betz (1987) of the LSB was in error.
21. Pulsating changes of intraplate-stress patterns are difficult to explain and not really verified by data (explanation follows in the text). We see on all active structures a continuous rotation of the involved succession and no changes in subsidence/sedimentation rates in the basins. Most published data fit perfectly to the observed evolution of unconformities. We published our interpretation (Voigt et al 2004) before, but the implications were not discussed in some following papers about inversion tectonics in the North Sea (probably too strongly focused on their own targets of investigation). We extended this section.
22. Line 103-105: Since we are concerned with the termination of the Late Cretaceous event, the interpretation of the Cenozoic events is not of key importance for our analysis. Nevertheless, we have added a short paragraph introducing the concept of discrete deformation events with new references as suggested.
23. Line 125: Late Cretaceous
24. Line 126: Late Jurassic-Lower Cretaceous
25. Line 160: fig. 1
26. Line 190: changed: The whole sentence was deleted. As the basins were not interesting for oil exploration, no high quality seismic data exist.
27. Line 289: repeated section was deleted
28. Line 292: Osning thrust was added on Fig. 2
29. Line 309: Jurassic to Lower Cretaceous graben fill
30. Fig 4: Q1 was enlarged
31. Line 212: Betz et al. 1987: We found only one hint to the Turonian slumps at the southern border of the basin in their paper. The mentioned clastic carbonates and iron ores (Upper Campanian) were deposited on top of the inverted basin (Damme syncline). Furthermore, there is no clear evidence for a Laramide phase of inversion, because the first post-inversion deposits are of Rupelian age. There is some minor evidence for post Campanian tectonics (folding, fault with minor displacement, tens of metres) which is either late Cretaceous or early Paleogene in age.
32. Line 369: Fault is already displayed on fig. 4., but was added on fig. 5
33. Line 379: The possible timing of this unconformity spans at least 35 Ma, all of the late Cretaceous and Paleogene phases
34. Line 441: principal stream/principal NW-directed river
35. Line 446: you are right, this is a better expression

36. Line 454: it was changed
37. Line 455: thank you for this precise information, we added it
38. Line 460: the sentence refers to northern Germany
39. Line 470: initially we wanted to concentrate on the German basins, but we will add your advices, because it fits to the overall picture and gives better time-constraints than further to the east. The paper of Best et al 1987 is not the actual state of the art (several papers of Baldschuhn and Kockel in the nineties; the best actual summary is in Littke et al (2008): Dynamics of complex intracontinental basins; Paleocene is only north of the LSB, the Thanetian mirrors the same structural style as the Ypresian and the following Eocene succession, We found no source which confirms the occurrence of Danian on the inverted LSB
40. Line 509: We will add this
41. Line 528: corrected
42. Line 535: we will include the hint to the Netherlands!
43. Line 547-549: follows in the discussion, at this place we are not able to say anything
44. Line 660 (start of marginal troughs at the borders of the Roer Valley Graben). The Roer Valley Graben and inverted Central Netherlands basin seem to be responsible for the delivery of sand towards the east (Münsterland Basin), starting in the Santonian (not before), according to Luijendijk et al (2011) the exhumation (amount of inversion) of the RVG is weak (between 1000-1250 m); possibly the differentiated subsidence started later.
45. Line 715: Could it be that these phases were a continuous process, and the unconformities were formed due to the fluctuating sea-level? Another explanation would be decoupling along the extensional system Upper Rhine-Graben – Lower Rhine-Graben. There is no evidence for major intra-Cenozoic uplift east of it.
46. Line 720 (fig): *comment: It would be nice to compare these with other basins in Western Europe because based on your data, it is difficult to constrain the end of inversion…* This is true, the only evidence is the deformation of the Damme syncline (folding and central thrust), which is close to the border of the Netherlands. Possibly one of the Paleogen pulses, but impossible to date.
47. Line 725 (fig text): we added the major unconformities in Germany
48. Line 748: no problem with this, added
49. Line 756: Maastrichtian added