Review of the manuscript „Multiphase, decoupled faulting in the southern German Molasse Basin—evidence from 3D seismic data" by Vladimir Shipilin, David C. Tanner, Hartwig von Hartmann and Inga Moeck

Hugo Ortner

General comments

The authors present a well-written manuscript on the interpretation of a 3D-seismic block close to the Alpine frontal thrust. After description of the geometries observed, they analyze fault geometry, kinematics and stresses during the tectonic evolution of this segment of the foreland basin. This has not been done before, and is well worth publishing. The manuscript is written in fluent English.

Specific comments

Several passages in the manuscript need some attention:

In the Introduction (lines 59ff), the authors describe the unconformity at the base of the foreland succession as a result of "…the Late Cretaceous-Paleocene contractional event as consequence of the change in the African plate motion…". However, in most publications on the Alpine Foreland Basin, this unconformity is referred to as the "foreland unconformity", which has been described as a result of the passage of the forebulge rolling through. In their figure 3, the authors label the unconformity as the foreland unconformity. This should be discussed in this paragraph.

In their discussion of stress field evolution (lines 329-339), the authors claim that the lower normal fault array formed when the forebulge reached the study area. However, the forebulge should have passed the area already when the foreland unconformity formed. At any stage of the foreland basin, the forebulge should be positioned north of the pinchout of any wedge-shaped sedimentary body onlapping the forebulge. Lemcke (1988), and more recently Freudenberger & Schwerd (1996) published maps displaying pinchout-lines of most units of the foreland basin fill. These data should be respected, or it should be discussed, why these data are not regarded.

In their discussion of the Tilted Molasse (Iines 417ff), the authors suggest that thrusting in the study area is a direct consequence of flexure-related normal faults, and this thrusting controls tilting. However, on the larger scale of the Bavarian Foreland Basin, the width of the Tilted Molasse is controlled by the presence and depth of a triangle zone. The triangle zone is a rather continuous feature along the Alpine front, while the inherited normal faults are not. The triangle zone seems to be tied to the presence of coarse-grained deposits (see Ortner et al. 2015). Maybe this should be discussed here.

Moreover, in the cross sections of Figs. 10 and 11, a Tilted Molasse seems to be absent. From a structural point of view, there is no triangle zone, that could have caused the very mild tilting seen in the seismic sections, and drag across the frontal thrust is not visible. Could it be that the apparent tilting is related to a velocity pull-up, caused by increasing horizontal compaction toward the Alpine front?

The recognition of the Geretsried thrust is new. However, Müller (1975/1976) interpreted the structural geometry between the Darching and Miesbach wells with a structural geometry very similar to the present paper. This should be mentioned somewhere. It might have impact on the general interpretation, as it shows that the frontal structure is comparable over a rather broad area.

Technical Corrections

Line 3: **“two normal fault arrays”** instead of “two fault arrays”

Line 3: **“a clay-rich detachment horizon”** – The detachment follows a stratigraphic layer, so it is rather a decollement.

Line 3: **“A large-scale thrust”** - This thrust has not a lot of offset - I would not call it "large-scale"

Line 5: **“(1) initiation of the lower fault array”** – better “(1) initiation of the lower normal fault array”

Line 6: **“(2) development of the upper fault array”** – better “(2) development of the upper normal fault array”

Line 8: **“during the migration of the forebulge (phase 1), foredeep (phase 2)”** – these phases have not been explicitely defined in the text; this should be done if this phrase is retained. But see also comments on these specific "phases".

Lines 49-50: **“After a profound hiatus in sedimentation caused by the Late Cretaceous-Palaeocene contractional event as consequence of the change in the African plate motion”** - This hiatus is the foreland unconformity (see e.g., Allen et al. 1991), or coincides with it. This should be mentioned (as in Figure 3). In most interpretations, the foreland unconformity marks the passage of forebulge rolling through the flexed European plate. To my knowledge there is no evidence of basement-involved thrusting in the Alpine foreland so close to the Alps in the sense of Kley and Voigt (2015).

Line 59: **“transgressive sandstones”** - It remains unclear, what "transgressive" in this context means. You want to say, that sandstones, carbonates, shales and marls define a transgressive sequence? Or that "transgressive sandstones" overlie the foreland unconfromity? Clarify!

Line 60: **“shallow-marine to coastal”** - probably better "litoral"

Lines 65-67: **“This suggests that the foreland plate was not affected by further flexure and that the marine transgression during the deposition of OMM was the result of lower sediment input into the basin (Zweigel, 1998; Kuhlemann and Kempf, 2002; Ortner et al., 2015).”** - Foreland flexure ended in the eastern part of the basin; the western half continued to subside. Your study area is transitional, but the base of the OMM is still slightly flexed in the TRANSALP section across the foreland (see, e.g., the cross sections of Abele et al. 1955).

Line 70: **“Alpine front”** - The Alpine front is a line, that cannot incorporate volume. "Alpine wedge" would be more correct.

Line 234: **"Its stratigraphically higher upper branch"** - How can a thrust branch be "stratigraphically higher"? This would only be possible at a specific location, where you have an upper and lower thrust, whatever stratigraphy is.

Line 240: **"At the foot of"** – Below?

Line 321: **"This implies a forward-propagating Alpine thrust system, which is most likely."** - Yes, but Ortner et al. 2015 showed that the thrusts of the Subalpine Molasse are hinterland breaking, where a clear sequence can be recognized. Maybe the Geretsried thrust marks the turnaround from foreland- to hinterland-breaking.

Line 336: **"lower fault activity"** – better "activity of the lower fault array"

Line 337: **"initiated as the forebulge, the region of maximum flexure, reached the Geretsried area in the early Rupelian"** - This is difficult. When the forebulge is related to the foreland unconformity (depicted in Fig. 3) and the normal faults are related to the forebulge, then normal faulting should have initiated during continental conditions and erosion. However, fault activity might have extended into the Rupelian, when the Alpine wedge still moved onto the European plate rapidly (see e.g., Pfiffner, 1986), and flexure was ongoing.

Line 343: **"By the Chattian times, the foreland foredeep approached the study area,"** - I do not understand. The complete foreland sequence is in the foreland foredeep. The thickness of all units below the OMM diminishes toward the forebulge to the N (see lines 62-68, and references cited there; see also cross sections of Abele et al. 1955).

Line 344: **"This"** - To which part of the preceding sentence does "this" relate? Neither possibility makes any sense - rapid sedimentation cannot be caused by the approach of the foredeep (see remark there), and not caused by the thickness increase (being an effect and not a cause).

Reformulate and clarify. Probably the arguments in this whole paragraph need to be reconsidered, reformulated and reordered.

Lines 346-347: **"Increasing sedimentary load towards the orogen produced an increase in the vertical stress magnitude (Drews et al., 2018) and therefore favoured normal faulting."** - See last remark. This information needs to be given before you argue that pressure distribution may support your idea.

Lines 422-423: **"We postulate that the varying amplitude of the tilted zone from west to east must be controlled by the occurrence of early-orogenic normal faults that facilitate thrusting. In the Geretsried area and south of it, the Geretsried Thrust accommodated shortening and thereby prevented large-scale folding in front of the propagating Alpine thrust sheets."** - (1) In the absence of available seismic data in the area, I put the northern limit of the Tilted Molasse at the northern limit of tilting as shown in the cross sections of Abele et al. (1955).

(2) On the scale of the Bavarian Molasse, the width of the Tilted Molasse is mostly controlled by the presence and depth of a triangle zone. The triangle zone is a rather continuous feature along the Alpine front, while the inherited normal faults are not. The triangle zone

seems to be tied to the presence of coarse-grained deposits (see Ortner et al. 2015). Maybe this should be discussed here.
(3) In the cross sections of Figs. 10 and 11, a Tilted Molasse seems to be absent. From a structural point of view, there is no triangle zone, that could have caused the very mild tilting seen in the seimic sections, and drag across the frontal thrust is not visible. Could it be that the apparent tilting is related to a velocity pull-up, caused by increasing horizontal compaction toward the Alpine front?

Lines 423-425: **“In the Geretsried area and south of it, the Geretsried Thrust accommodated shortening and thereby prevented large-scale folding in front of the propagating Alpine thrust sheets.”** - Keep in mind that there is almost no offset across this thrust. If there would be a few kilometers of offset, then there would be folding for sure.

Line 444: **“Walsch”** – It is “Walsh”

Line 453: **“Walsch”** - Again, “Walsh”!

Comments to figures:

Figure 2: Strange that all normal faults die out in the deepest layer. Distinguish wells and faults graphically!

Figure 3: In the column “Local stratigraphy”:
“Laminated marl” instead of “Laminated barl”

Chattian sandstone: A significant part of these Chattian sands, and the "Aquitanian beds" are in fact an alternation of sands, carbonates, coal and shales, and has been termed the Cyrena beds, a brackish facies transitional between the continental USM and the marine UMM. This should probably be mentioned somewhere.

Rupelian clay
Banded marl
Heller Mergelkalk
Fish shale
mixture of German and English here. The German terms are "Heller Mergelkalk", "Bändermergel" and "Tonmergel". Either translate all of them, or use the German terms consistently.

Tonmergel would be Rupelian clayey marl in English, 'Rupelian clay' is misleading.

Figure 18: You might want to color negative and positive throw differently

Figure 20 lower row of sketches: How can the basement fold with such a short wavelength? I really have problems imagining this. In such a scenario, folding of the basement would be one of the controlling factors. This should be mentioned and discussed in the text. In the seismic lines there seems to be less folding.

References

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