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Solid Earth
Discussions

Interactive comment on "Formation of linear planform chimneys controlled by preferential hydrocarbon leakage and anisotropic stresses in faulted fine-grained sediments, Offshore Angola" *by* Sutieng Ho et al.

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Answers to comments of Reviewer 1 A. Plaza-Faverola

Answer Part 2

Reviewer's questions are in bold and the authors responses are below.

3. Notes

Please ïňĄnd below my notes while reading through the text; it includes a few typos. The L refers to the paragraph number and the P to the page number.

The authors present replies to the specific technical questions and targeted questions only. Reports of mislabelling and grammar will be addressed automatically the revision process of the manuscript.

- L20/P3: minimum and maximum offsets? I assume these data sets are multi channel with long offsets? It is kind of important to provide this info before it is mentioned that the amplitudes vs. angle were used for verifying the seismic character of the observed features (a sort of undershooting?).

Addressed previously - see above.

- L5/P6: The linear features shown in ïňĄgure 4a-b are indeed strange features. Are these really along polygonal faults? (PFs?). Polygonal faults usually do not have a preferred orientation, but on the contrary, they consist of fault segments oriented covering the whole azimuth range (closing polygons), right? The linear features seem to follow the circular structures to the north of the syncline. There seems to be an overarching control on the orientation and distribution of these features rather than the polygonal faults as such. I guess I am missing a clear deïňĄnition of what the authors are referring to as polygonal faults. For examples, are types 1-3 described by the authors termed polygonal faults because they all formed due to dewatering of ïňĄne-grained sediments? See main comment.

Question already answered above.

- L30/P6: Consider making two different ïňĄgures here. The ïňĄgures have so many parts that it is actually a struggle to go through and understand everything. Is the statistical part of the ïňĄgure really relevant? What do we do with the fact that 54 percent are intersecting the lower portion of PF? What seems most relevant in this paper is to get compared the orientation of the ïňĆuid ïňĆow related features with respect to the orientation local and regional faults and fractures, right?

We will split the figure into two parts.

This study focuses on the formation of linear planform chimneys, is a detailed seismic study and is not a paper which only describes the parallel relationship between Linear Chimneys and PFs. The statistic is important in this study, we focus on the reason why most of the chimneys emanated from the foot wall area of a fault (i.e. topmost point of a same layer in the up-thrown block).

We do not simply focus on the orientation of Linear Chimneys in comparison with PFs, because the nucleation of Linear Chimney in the up-thrown block caused the linear planform of chimneys and hence the parallelism with PFs. Because there are 54/The distribution of gas among PF blocks, nucleation points of chimneys, the propagation of chimneys related to stress around faults, and the orientation of chimneys and PFs are all interlinked.

- L20/P7: Is the evidence by Sonnenberg et al., 2016 related to the polygonal faults in this present study? In that case, it would help to see a sentence hinting what is the observation that works as evidence. I got this advice recently and I kind of see now the need for bringing into the current study the key observations rather than referring the reader too often to the previous studies. This degrades the ïňĆow of the reading and makes difïňĄcult to follow the paper.

The reference to Sonnenberg et al,. 2016 was an example reference to remind the reader that polygonal faulting pre-dates chimney development. We acknowledge the reviewers point and will simply relate to the previous section documenting polygonal fault timing. Some expanded comments on polygonal fault time are below.

Due to the size of polygonal faults unambiguous evidence of fault timing is rarely preserved and this is no different to this study. The throw of these small faults is close to the vertical resolution of the seismic data meaning standard techniques such as upper tip gradients and thickness changes across the footwall and hanging wall are not clear cut for advocating if the upper portion of the polygonal faults here are definitively growth rather than blind faults. However, a collection of observations from the literature in addition to the compaction and contraction process which forms the faults all point to an evolution of faulting during early burial with a late phase of growth faulting ceasing at a paleo-seabed (upper tier boundary).

Specific examples across multiple basins suggest polygonal faulting may having this late growth phase in common. The evidences are bullet pointed below. The authors do not feel it is within the scope to cover all of these points explicitly in this manuscript and that simple summary and reference to the literature is adequate.

- Polygonal faulting in London Clay not below a few hundred metres of burial today (Henriet et al., 1982).
- Polygonal faults observed tipping out present seabed in Lake Superior (Berkson et al., 1973, Wattrus et al., 2003).
- Unambiguous growth sequences observed in some large examples of polygonal faults (Carruthers, 2012).
- High upper tip gradients inconsistent with blind faulting (Carruthers, 2012).
- Limited evidence of upper tier boundaries being mechanical barriers to upward propagation (e.g. Laurent et al., 2012, Berndt et al., 2012).
- In many examples upper fault tips occur at a single seismic horizon in systems

which span several hundred sq km and this is best explained with the horizon being a paleo-seabed at which faulting ceased (e.g. Berndt et al., 2012, Christopher et al., 2014).
- Fault tiers very thin in some cases meaning if the upper tier boundaries are paleo-seabed horizons then faulting initiates soon after burial (e.g. PFs in the pinch out of Tier-2's wedge shown in Appendix 5).

- L30/P7: do polygonal faults really reactivate? How is the accommodation of such movement if the fault planes can converge to each other rather than been parallel? Aren't these kind of faults associated with diagenetic processes and are hence a kind of one-time event?

This point has been discussed from a general perspective earlier. In this specific example, the horst which has developed onlaps in the section above the upper tier boundary (possible reactivation post-dating polygonal fault development) has a concentric geometry. The concentric geometry is most likely due to the process of pockmark development locally perturbing the horizontal stresses in a way to produce concentric fault strikes (Carruthers, 2012, Ho et al., 2013). The pockmark clearly formed during early tier sedimentation but differential compaction after polygonal faulting above the pockmark may have caused this specific fault to continue forming. Due to the points raised previously on polygonal fault genesis and timing this example shows some specific evidence in this study that even a reactivated polygonal fault still occurred before the chimney formation. All of the other polygonal faults had already formed prior to this phase of reactivation.

- L20/P8: 60 m deep and 4.5 m wide pockmark??? That is quite deep compare to the with, it is almost a conduit rather than a pockmark.

We have made a typo here for the unit here, it should be 60cm depth.

- L30/P8: so there is active gas release at the seaïňĆoor at present? Or you mean active in the sense that there is gas ïňĄlling the near-surface systems through the gas chimney structures?

When we refer to the chimneys being active, we mean there are still fluid activities on going at the present day or in the very past representing deposition of the seabed surface . The fact that there are interpreted seep carbonates inside the depressions at the top of chimneys indicated the recent activities, although we cannot confirm whether these chimneys represent activity at this present moment because we do not monitor them.

- L30/P8: this model is hard to digest here since there are so many faults and pre-existing weak planes that one would think that the ïňĆuids would ïňĄnd preferential path- ways without much effort and hence gas chimneys would not be favor?

The argument that high-density faulting would allow enough fluid migration without chimney formation is wholly dependent on the assumption that the faults are migration pathways. Whilst faults often do provide leakage pathways the extensive literature on fault seal indicate it is far more complicated. In some cases polygonal faults have been shown to be migration pathways whilst in other cases polygonal faults deform important seal packages in many petroleum basins (Carruthers, 2012). We do not feel this assumption is valid because all the available evidence in this study suggests there have been phases of overpressure and fluid venting from intervals within the lower-middle stratigraphic levels of the polygonal fault tier.

A discussion this particular topic in presented in section 5.2.4.

- L20/P9: The use of appendix ïňĄgures to illustrate what seems to be the main conceptual model of the paper is not ideal. One ïňĄgure in the main text should be enough to illustrate description of the model for ïňĆuid migration and development of chimneys. Figure 8a doesn't illustrate this, or did I miss something? When you mention PF tier here is it 1 or 2? It is very easy to get lost while reading, I think it is due to the fact that there are so many ïňĄgures overloaded with details.

Agree and will be changed into main body.

- L25/9: typo: the PRESENCE of. . .And please revise this paragraph. These aspects are not necessarily ruling out each other and a combination of them could be a pre-condition for explaining your observations. Consider reformulating the paragraph.

OK

- L30/9: where do we see the gas accumulating at the foot wall? The foot wall of a major tectonic fault or are you referring to small faulted compartments resulting from the polygonal faulting? If so, is it really meaningful to talk about footwall if the blocks are somehow both footwalls and hanging walls with respect to each other?

We will improve the connection between text and figures.

- L5-10/P10: Why would these areas be subjected to "relative" compressional strain? What do the authors mean here? Would it be more appropriate to say "less" com- pressional state rather than relative? In analogy with the particle motion maps for earthquakes (focal mechanisms) one would expect that the

lower part of the hanging wall and the upper part of the footwall would experience more compression while di- lation would dominate the upper hanging wall and the lower footwall (which is indeed consistent with Barnett et al.,)

We will remove relative.

- L10/P10: again, no ïňĄgure 6d and also the interpretation that the gas is accumulated in the footwall of polygonal faults is not easy to digest. A block can be considered a footwall or a hanging wall, depending on which fault plane is used as reference. I can see high amplitudes in both hanging and footwalls in ïňĄgure 6c for example.

Point already raised and addressed in previous replies. Similarly we will improve the clarity of statements and figures.

- L20/P12: Again, the model of shear stress distribution through the four quadrants of the faulted blocks is very sounding for explaining the distribution of gas into more permeable zones. However, where these more permeable zones are entirely correlated with footwalls and hanging walls in these polygonal fault system is hard to assimilate. Is it really necessary to use this terminology? See main comment.

Point already addressed above.

- L25/P12: So the chimneys grow episodically? You foresee that the growth occurred in several episodes of reactivation of the system? It is important to describe this more explicitly in order to be able of comparing to systems from other margins with comparable settings.

No the authors did not indicate that the chimneys grow episodically. Last point beyond the scope of the paper.

- L25/P14: point 6 in the discussion. Check the grammar here. The sentence has a problem. When are the chimneys circular in isotropic stress ïňĄelds? And when are they linear, isotropic and anisotropic? Clarify.

We will check the grammar. Chimneys are circular while they are in isotropic stress fields; they are linear when they occur in anisotropic PF network where stress field is anisotropic.

- Figure 1: great ïňĄgure. The use of a dip map to show all the elements of the study works extremely well, we can see the ïňĆanks of the salt domes and even the ïňĄne scale faults and fractures. However, isn't the present day bathymetry important to understand the stress regime?

We expand briefly on the previous replies to the topic of polygonal faults and their ability to give indications of paleo-stress anisotropy. Improvements in the clarity within the revised manuscript on this topic will hopefully improve the readers understanding of stress throughout. Answering the reviewed specific question here; polygonal faulting represents a brief phase of the basins compaction history and any stress anisotropy that was imparted on the compacted sediments during faulting are reflected in alignment and variety of fault strikes in that tier. The polygonal fault geometry and variations in geometry thus reflect an insight into the paleo-stress state at the time of tier sedimentation. The present day bathymetry and of units above the tier in question may give some broad insight into the structural development of the basin which may in turn have some similarities with the polygonal fault tier. However, the isopach and paleo-bathymetry of the PF tier are more important for understanding what was driving the stress anisotropy and thus the resultant polygonal fault geometry. Carruthers, 2013 discussed this in detail. The authors feel the question of the specific drivers of

the stress anisotropy are beyond the scope of this paper.

- Figure 2b – typo: linear positive high amplitude. . .It is a bit difïňĄcult to read through the symbols of this ïňĄgure. The idea of overlapping the symbols related to different ïňĆuid ïňĆow features on the seismic proïňĄle is great. However, it is not easy to see the actual seismic feature (in particular the high amplitude anomaly depressional network). I assume the location of the symbols just indicate the interval where each feature is observed rather than the actual feature? Maybe this can be hinted in the caption (as a help for the reader). Is the seismic section a compressed version of the geological section in 2a or C8only part of that transect?

Improvements to be made during revision phase of manuscript.

- Figure 5: Can you really tell that the high amplitude analogies in inset ii are gas accumulations, without any clear sign of polarity change?

Error - it should be water-saturated sand

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