Response to referee 2

We gratefully thank anonymous referee #2 for his/her thoughts, suggestions and comments on our manuscript. Below are our *(italics)* answers to the referee **("bold")** comments.

"The paper presents field structural data from a part of a fold belt, exposed by extensive mining operations. These field data provide the base for a model of fold development and strain distribution. According to this model, different types of folds originated during a single deformation episode. Different fold styles and intensities are related to different lithofacies and variations in the mechanical properties of these facies. The topic of the paper is clearly relevant for the scope of the journal. Apart from some minor language problems (marked on the file), the paper is well presented.

The proposed model appears to be plausible. However, the result of the authors' interpretation of their data does not provide a unique solution. There are a number of different models, which can be envisaged. These models need to be discussed and evaluated, in order to convince the reader, that the authors' model is the best one. "

"For example, the following questions need to be addressed:"

- **Figures 1 and 2 show a regional-scale bending of fold traces. How much does this effect the structural changes in the present area?**
- **What is the relationship of the presented structures to structures in the underlying basement rocks? Are there indications of re-activation of basement structures?"**

To better discuss other regional structural models, we have reworked section 7.3 as follows:

*"**7.3 Strain accommodation during compressional tectonics***

Compressional strain accommodation in the Lower Roan during the Lufilian orogeny at Nkana was mainly via folding on multiple scales, with relatively little accommodation of deformation via faulting. The importance of folding is true for most deposits in the Eastern Zambian Copperbelt (Mendelsohn 1961; Selley et al., 2005; Hitzman et al., 2012) except perhaps for Nchanga (Fig. 2), where clear detachment faults and fault-propagation folds are seen, strongly influenced by the presence of the Nchanga granite (McGowan et al., 2003, 2006). In several mines of the Eastern Zambian Copperbelt, areas of intense asymmetric and disharmonic folding have been interpreted to be related to thrusting, with folding above a decoupling zone that has significant layer-parallel shearing (e.g. Luanshya, Nchanga, and Mufulira; McGowan et al., 2003, 2006; Coward & Daly, 1984; Daly et al., 1984). At Nchanga, sheared granite has indeed been thrust into the Lower Roan (Daly et al., 1984). At Nkana, however, we observed no obvious evidence for a decollement or thrusting near the basement-basin interface in the underground exposures, or higher up the sequence. The non-cylindrical parasitic folding is readily explained by rheology contrasts in the multilayer-cake sedimentary sequence during compression. Since it is clear that both basement and Katanga cover were deformed together in the Lufilian orogeny (Coward & Daly, 1984; Daly et al., 1984) and from these different structural styles, it is likely that both basement-involved thrusting as well as rheologically controlled folding processes were active together in the Eastern Zambian Copperbelt. Any large-scale tectonic model therefore needs to carefully assess the contribution of either.

Although there is ample evidence for evaporitic conditions in the Chambishi-Nkana basin, as evident from the lithofacies descriptions (and e.g. Bull et al., 2011), we do not see the effects of salt-driven (detachment) tectonics generating allochtonous pieces of geology. This is in line with other studies in the Eastern Zambian Copperbelt (McCowan et al 2003; Selley et al 2005; Torremans et al., 2013), indicating that salt-tectonics, which are hugely important in many parts the Outer Lufilian in D.R. Congo (e.g. Jackson et al., 2003; Hitzman et al., 2012), are much more subdued or absent in the Eastern Zambian Copperbelt.

When comparing the relative orientation of Li lineations, fold hinge lines, π-poles-to-S_1-cleavage and fault orientation between sections, these structural elements all consistently rotate between sections (Fig. 4). This rotation reflects that of the 1st order syncline from 318° at the SE end of the Basin (e.g. sections 8 and 9; Fig. 4) to c. 300° the northwest of Mindola (Fig. 4). The first possible explanation for this covariation and rotation is that this is a natural consequence of 3D fold growth and linkage, especially since small initial perturbations in palaeo-topography can have a big influence on fold orientation and interaction (Schmid et al., 2008; Bretis et al., 2011; Grasemann and Schmalholz 2012). A second possibility (not excluding elements of the first) is that inherited extensional basin geometries or basement play a significant role in controlling structure development during later shortening (O'Dea and Lister 1995; Holdsworth et al., 1997; Bailey et al., 2002; Potma and Betts 2006)."

According to the conclusive model on Figure 13, all of the field examples are situated at one and the same fold limb. Since the fold is shown as changing northwards, the fold intensity is shown as decreasing northwards. It requires discussion, whether the fold intensity in the north, close to the axial trace of the regional fold, is similarly low. In other words, the authors have to make sure that the fold intensity in the north is not increasing towards the axial trace of the fold. In addition, the influence of the gabbros (as shown on the map, Figure 4) on the strength of the rocks in the northern section has to be discussed.

Agreed. We have added the following sentence to section 6.3: "Given the lack of direct observations near the axial trace of the first order fold in the most northern areas (W of Mindola), a discussion point is whether strain intensity in that area is as intense as in the south. If the COM near the axial plane in the northern part of the study area is similar to the argillaceous dolomite at Mindola (broadly expected based on mapping of the lithofacies in Fig. 4), compressive strain would be more evenly distributed across the whole layer Katanga Supergroup package, and less partitioned into the COM compared to the south (Fig. 13)."

Gabbros and mafic intrusions can be quite extensive, in particular in rocks higher up the stratigraphy. We agree with the reviewer that these could influence deformation, although, to our knowledge, the bodies are generally quite small. To frame this better, we have added the following sentences: "Small mafic gabbroic to dioritic bodies are regionally widespread and could potentially influence the deformation style locally (Figs. 1, 2 & 4). Unfortunately, we did not encounter mafic bodies in the studied sections, given the sections were in Lower Roan rocks and the mafics occurs predominantly in the Upper Roan and lowermost Nguba Group (Kampunzu et al., 2000)."

"How much of the total strain is represented by the folds? In other fold belts, strain is generally distributed between folds and, e.g., foliation. In particular the argillaceous rocks may take up a shortening of 50% simply by cleavage formation. The mentioned thin sections could be of help and may be used and documented."
"Another factor, which may be considered is (pressure) solution. Some of the field images show examples of veins, which document some kind of remobilization. The authors need to show whether the effect of solution/remobilization processes is important for the fold formation or not."

Although pertinent, this is not easy to quantify. The foliation and cleavage development in the study area was described in section 5.1 and was used in the discussion. We have previously partially addressed the microscopic observations and quantification of strain in the COM in another article (Torremans et al., 2014) and have now referred to the main relevant findings on strain and cleavage formation from that study in the discussion.

The strain for Nkana South and Central was quantified in Torremans et al. (2014) across several single-layer folds of pre-folding bedding-parallel fibrous dolomite veins in the carbonaceous mudrock lithofacies. The strain contour method of Schmalholz and Podladchikov (2001) was used. This analysis demonstrated that the inferred bulk strain from folding is generally over 65%, and up to 75%. This method obviously does not take into account prior layer-parallel shortening, so that total strain from shortening is actually higher. In that same study, up up to 25% homogeneous flattening post-folding occurred onto the folded veins, from an analysis of vein dolomite fibres. So total estimation of strain onto is generally higher than 80%.

In the carbonaceous mudrock lithofacies of the COM, especially in the crest of the 1st order fold at Nkana South, a significant portion of the shortening is taken up by cleavage formation (as apparent from Fig. 7B). Contrastingly, the quarzites and arkoses of the overlying Rokana Evaporites Member and underlying Mindola Clastics Formation do not show macroscopic cleavage planes in any of the studied areas. The absence of other reliable strain markers makes it difficult to quantify and compare strain due to folding with that due to cleavage formation, without embarking on a whole different set of analyses and methodologies (e.g. AMS).

We have added the following sentences to the discussion: "Analysis of single-layer folded bedding-parallel veins in the carbonaceous mudrock lithofacies of Nkana Central and South showed that the inferred bulk strain from single-layer folding is over 65%, not taking into account prior layer-parallel shortening (Torremans et al., 2014). Microtextural strain analysis of vein fibres revealed additional post-folding homogeneous shortening of 25% in the form of cleavage formation during fold lock-up (Torremans et al., 2014).

Locally, in the carbonaceous mudrock lithofacies of the COM at Nkana Central and South, a significant portioning of the shortening is taken up by cleavage formation. In Mindola, cleavage is not well developed. In the most intensely folded areas (high strain), precipitation of sulphides, quartz, dolomite and mica along disjunctive S_2 cleavage planes indicates that significant pressure solution and diffusion mass transfer must have taken place. The observation that cleavage formation affects syn-folding veins, as well as the geometrical relation between cleavage and folded veins (Figure 7B) indicate that development of strong spaced disjunctive cleavage in the COM is late-kinematic to folding in general, at least after fold lock-up (see detailed analysis in Torremans et al., 2014). These observations, combined with the observation that areas of intense cleavage formation coincide with intensely folded and faulted areas, are evidence of progressive strain partitioning towards certain zones of highly intense deformation."

Our *answers* to further (minor) comments of the referee in attachment se-2018-6-RC2-supplement.pdf

- **p1 line 8: Please, specify "certain".**
  We've changed the sentence into: "A clear relation is observed between the intensity of parasitic folding and the degree of shale content in the Copperbelt Orebody Member, which hosts most of the ore."
- **P2 line 25: "please, explain" on "strong relations are sometimes observed between ore and structural features"**
  There are two examples in the sentences after this one. We've clarified what we mean and the flow of the paragraph by changing this into "In the Eastern Middle Lufilian ('Zambian Copperbelt'; Figs. 1 and 2), some of the ore within the deposits is strongly structurally controlled (Brock 1961; Daly et al., 1984; Selley et al., 2005; Hitzman et al., 2012; Eglinger et al., 2013; Turlin et al., 2016). For example, o~~O~~re is~~ for example~~ localized along thrust fault-

propagation folds or detachment structures at Nchanga (McGowan et al., 2003, 2006). In addition, aAt Nkana, ore appears enriched in fold hinges, along tectonic cleavage planes or in several generations of fold-related veins, in addition to disseminated and lenticular ore (Brems et al., 2009; Croaker 2011; Torremans et al., 2014)."

- **P3 line 23: please explain, give ages on "pre-Katangan granites"**
  We should indeed have introduced the "Katanga Supergroup" before discussing the basement. We have rejigged parts of the sentences and added the following short sentence to the beginning of the paragraph: "The rocks in the study area belong to the Neoproterozoic to early Cambrian Katanga Supergroup (Fig. 1, 2)." The rejigging of bits of text should clarify the age information for the pre-Katangan granites, which was described a bit further down.
- ***P 9 line 1: "unusual in English/American" on "Many (sub)hectometer scale 2rd order folds".***
  We have changed this to "Many <100m scale 2nd order folds"
- ***P9 line 26: "Please define" on "… the COM is often isoclinally folded with extremely angular fold hinges".*** *We have clarified this by changing the sentence to "… the COM is often isoclinally folded with high aspect ratios between fold amplitude and wavelength (>3)"*
- **P28 figure 2. "show ages or refer to next figure"** *We have added sentence "See Fig. 3 for ages of the units."*
- **P30 figure 4 Basement Complex "not found on map".** *This box should have been white in colour, missed this one due to png transparancy. We have changed accordingly.*
- **P33 figure 6g "there are two sets of lines; please explain"** *We have changed one set to full lines and the other set to dashed lines and explained in figure caption.*
- **P38 figure 10 "text missing."** *Fixed, thanks!*
- **P41 figure 13: "please explain" on "sometimes reveal reversed plunges".** *We changed this to "sometimes plunge southwards."*