Response to referee 1

We gratefully thank anonymous referee #1 for his/her thoughts, suggestions and comments on our manuscript. Below are our *(italics)* answers to the referee **("bold")** comments.

"The submitted manuscript is a scientifically sound field study on parasitic folding in the Lufilian belt and nicely linked with mineralization in the Copper Belt. The paper reads well, and referencing adequate. I have no objections for publication after minor corrections. There are some minor open questions that could be addressed before publication. These concern regional aspects, mechanics and style of folding and mineralization:"

"Regional aspect concerning timing of tectonometamorphic event: Orogenic phases are determined by geochronology (monazite and argon ages). These ages are obviously derived from "basement" and granitoids but give the impression that the sedimentary cover (Roan, …) is metamorphic. I would mention the fact that no such data (except for mineralization) are available from the sedimentary sequence but from inliers. Thrust slices with eclogite are found, that may provide information upon the geodynamic setting (I suggest to comment on this). Somewhat related to this: There are no comments on the metamorphic grade of the sediments, except that fibres with tremolite are mentioned. The reader wants to be informed upon the metamorphic grade of sediments, at least there was some mass transfer to hinge zones which requires mobility to derive the Ramsay type 1C folds."

The Katanga Supergroup in the study area and by extension in the Eastern Zambian Copperbelt is metamorphosed to greenschist and lower amphibolite facies (e.g. our own detailed observations which are the subject of another paper; Brems et al, 2009; Selley et al., 2005). In these areas, biotite/phlogopite (in siliciclastic rocks) as well as tremolite (in calc-silicate or carbonate rich rocks) represent the main metamorphic minerals (cf. Brems et al., 2009; Selley et al., 2005). It's therefore true that there are relatively little directly datable minerals in the actual sedimentary rocks (due to the limited metamorphic grade). The Katanga basin rocks in the study area are of a slightly higher metamorphic grade as opposed to those of the Outer Lufilian (chlorite zone greenschist facies in External Fold and Thrust Belt). Tremolite-actinolite alteration has been observed post-dating folding (Brems et al. 2009; Torremans, 2016).

We have made some modifications to the last paragraph of section 2.1 to separate history of basement from basin infill. We agree that information on metamorphic grade of sediments needs to be added. Therefore, we have added the following sentence to the manuscript for clarity: "The Katanga Supergroup in the study area was metamorphosed to greenschist and lower amphibolite facies, with biotite/phlogopite and tremolite as main metamorphic minerals (Brems et al., 2009). The metamorphic grade and the general lack of datable minerals makes it difficult to directly date tectono-metamorphic events affecting the basinal rocks."

Deformation creating Ramsay type 1C folds does not necessarily require metamorphic reactions to co-occur with folding, to create a net mass transfer to hinge zones (Passchier & Trouw, 2005; Twiss & Moores, 2007). Deformation at brittle-ductile conditions (cf. Muchez et al., 2010) readily accomplishes this.

With regards to eclogite and talk-kyanite whiteschist facies metamorphism. There's a strong distinction between tectono-metamorphic evolution of different domains/zones in the Central African Copperbelt. Mineral assemblages of HP-LT signature are found in the Inner Lufilian (Domes region) in NW Zambia (see Fig. 1).

We've chosen to very briefly address this. Firstly, we have focused this paper on the Eastern Zambian Copperbelt and implications for structural evolution of this region, so a detailed discussion would be out of scope. Secondly, although important observations for the geodynamic setting in the Domes Region, without additional work and observations, we don't feel re-interpreting this ourselves without adwould add to the scientific knowledge in the literature. *Therefore, we've rewritten parts of the last paragraph of section 2.1: "A peak-metamorphic 531 ± 12 Ma U–Pb monazite age was obtained by Rainaud et al. (2005a) for the Chambishi-Nkana Basin in the Eastern Middle Lufilian. Talc-kyanite whiteschists along the contact between basement and Katangan Supergroup rocks record peak metamorphism in the Western Middle Lufilian in NW Zambia (Cosi et al., 1992; Broughton et al., 2002; Eglinger et al., 2016). These high pressure whiteschists are constrained by a 529 ± 2 Ma monazite age and 524 ± 3 Ma to 532 ± 2 Ma U–Pb ages (John et al., 2004; Eglinger et al., 2016) and indicate crustal burial, exhumation and thrust stacking of migatitic basement and Katangan rocks, linked to closure of a southern ocean basin during the Lufilian oreogeny (Coward & Daly, 1984; Cosi et al., 1992; Porada & Berhorst, 2000; John et al., 2004). Peak metamorphic ages are therefore quite consistently around 530 to 525 Ma along the entire Middle Lufilian (Fig. 3)."*

"Folding aspect: I wonder if there are co-genetic faults associated with folds. There must be huge decollement zones to accommodate different structural styles in basement and sedimentary cover. As far as I remember there is Neoproterozoic salt present that could have easily accommodated shear and solve space problems. Please comment on this."

On the deposit-scale, there are faults of limited throw associated with the folds, generally parallel to the fold axial plane (Fig. 3; Fig. 6A; Fig 7E), but they are formed quite late during compression. We have described these in section 5.3 and interpreted in section 6.5. Low and high angle normal and reverse faults are generally observed to be late and we interpret these faults to be related to fold-lockup at high strains. They postdate folding and development of S_2, given that faults truncate folded bedding parallel veins (Fig. 7D, E), the relation between faults and S_2 cleavage, and the lack of folded faults. These faults were therefore activated at least after the fold amplification stage of 4th order folds and during or after late homogeneous shortening of folds.

We've added the sentence: "We interpret these faults to be related to fold-lockup at high compressional strains."

Salt-tectonics are hugely important in many parts the Outer Lufilian in D.R. Congo (e.g. Jackson et al., 2003; Hitzman et al., 2012) and it effectively explains the formation of megabreccias, nappes and fold-and-thrust deformation in those regions. However, in the Chambishi-Nkana basin, and in the Eastern Zambian Copperbelt, the effect of salt tectonics is much more subdued and often absent. Although there is ample evidence for evaporitic conditions such as we have described in lithofacies sections 4 and 6.1, we simply do not see the style of salt-driven and detachment tectonics generating allochtonous pieces of geology.

Instead, compressional strain during the Lufilian orogeny in the Chambishi-Nkana area appears to have been accommodated predominantly by folding at multiple scales, with relatively little accommodation of deformation via faulting. The predominance of folding appears to be 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), with detachment faults and fault-propagation folds, strongly influenced by the presence of the Nchanga granite (McGowan et al., 2003, 2006). We observed no obvious evidence for a decollement near the basement-basin interface in the underground exposures, which would hint at a more thick-skinned deformation style, at least in this

area – seemingly contrasting with the situation at Nchanga. Nevertheless, we still know relatively little on the nature of deformation in the basement rocks in the region and how it compares to what happens in the Katanga basin rocks. Hopefully, future studies will be able to more precisely define its nature. The increased use of reflection seismic and tomography in mineral exploration will undoubtedly help to elucidate the deeper structure.

"Mineralization aspect: For a potential reader interested in the Lufilian Belt primary precipitation on remobilization of ore is of prime interest. In the abstract you write: "This work provides an essential backdrop to understand the influence of the Lufilian orogeny on metal mineralization and (re–) mobilization in the Copperbelt". I do not fully agree with this statement. You elaborated very well the remobilization and enrichment of ore bodied due to the folding period. However, this is re-mobilization. There is no information of the potential source (except few comments in the intro) and primary mineralization. I am aware that this is not prime topic of your paper but I would appreciate comments on this."

The metallogenesis and mineralization at Nkana was studied in detail by Brems et al. (2009) and Muchez et al. (2010), as well as a PhD thesis (Croaker, 2011). Three major mineralization/remobilization stages have taken place during the Lufilian orogeny. At Nkana, due to the significant strains, it's difficult to unambiguously recognize and study pre-orogenic mineralization phases. These earlier mineralization stages are better studied in nearby deposits which have experienced lower strains, such as Konkola, Nchanga, Musoshi, etc, as well as several deposits in the D.R.Congo. An excellent overview of the evidence for pre-orogenic mineralization, based on textural, geochemistry, fluid inclusion geothermometry and geochronology is given in Selley et al. (2005), as well as more recently by Hitzman & Broughton (2017) and Muchez et al. (2017).

We've added the following sentence to section 2.2: "Because of the strong deformation and remobilization stages, diagenetic mineralisation is often destroyed or replaced, but is generally assumed to be a significant precursor to the current orebody (Brems et al., 2009; Muchez et al., 2010)."

We would argue that the source of metal/mineralization is not really relevant to the aims of this paper. However, for the interested reader, we've added the following sentence to section 2.2: "Current metallogenetic models as well as Pb, Sr and Nd isotope data indicate that felsic and mafic basement rocks in the Domes region and the overlying sediments constitute the most likely source area for metals (Carr et al., 1987; Selley et al., 2005; Van Wilderode et al., 2015)."

Answers to comments with reference to chapters:
1 Introduction.
> **"Informative and reflects aim of the paper."**

2 Geological and Geodynamic Setting
2.1 Regional geodynamic context
> **"Informative and good summary of events. In addition I suggest mentioning and interpreting the eclogites (hidden in the text "talk kyanite" and in Fig3). Many people are not aware of them and if they are related to a subduction like process they represent one of the most remarkable features in the belt.   "**
>
> *Regarding eclogite facies metamorphism and talk-kyanite whiteschist. See our comments above.*

2.2 The Chambishi-Nkana Basin and Nkana Cu-Co deposit
> **"Fine"**

3 Methodology
4 Lithofacies Variation in the Copperbelt Orebody Member at Nkana (COM).

Commented [KT1]: *More information:*
Several mineralisation/remobilisation stages have been identified at Nkana (Brems et al., 2009; Muchez et al., 2010; Croaker, 2011; Debruyne et al., 2013; Torremans et al., 2014; Van Wilderode et al., 2015; Torremans, 2016). Mineralisation occurs mainly as sulphides disseminated in the host rock, in nodules and many generations of veins. In addition, the location of rich ore bodies is structurally controlled in hinge zones of tight to isoclinal folds and associated with deformation of veins, in faults or linked to burial or tectonic foliations (Brems et al., 2009; Torremans et al., 2014). Because of the strong deformation and remobilization stages, diagenetic mineralisation is often destroyed or replaced, but is generally assumed to be a significant precursor to the current orebody (Brems et al., 2009; Muchez et al., 2010; Van Wilderode et al., 2015).

In many deposits of the Central African Copperbelt, the Cu–Co ores are often associated with different vein generations (Mendelsohn, 1961; Sweeney et al., 1986; McGowan et al., 2003, 2006; Selley et al., 2005; Roberts et al., 2010; Sillitoe et al., 2010; Hitzman et al., 2012; Van Wilderode et al., 2013, 2015, Torremans et al., 2013, 2014). Many vein generations are also found at Nkana (Brems et al., 2009; Muchez et al., 2010; Croaker, 2011; Van Wilderode et al., 2015; Debruyne et al., 2016). The most important veins at Nkana are (1) barren pre-folding closely-spaced bedding-parallel fibrous dolomite veins and (2) several syn-folding and syn-faulting vein generations. The latter includes a set of veins that clearly represent renewed input of metals with mafic affinity (Co, Ni) during compressive deformation (Brems et al., 2009; Muchez et al., 2010; Van Wilderode et al., 2015). A detailed micro-structural and geochemical study of the relation between these veins and progressive deformation was carried out in parallel with this study. These aspects will be the subject of a different publication, using the insights into the structural framework as put forward in this paper.

"Fine but fig 5 is hard to read and, frankly speaking, I do not see the prime value of the figure in the frame of your MS. At least insert a color code to make it better readable."

We've added a color code to make the figure better readable. See new version of figure 5 below.

5. Structural analysis

5.1 Foliations and structural polarity

5.2 Folds

5.2.1 Multiple order folds along the eastern limb of the Chambishi-Nkana syncline

"For unfamiliar reader specify shortly the range of C and K and the meaning of those numbers."

We had a short explanation on this in the methodology section, but we've added some more explanation on what the numbers mean. Text in methodology now reads: "To test for preferred orientations or randomness in the 3D data, the eigenvalue technique of Woodcock and Naylor (1983) was used. Here, parameters K and C are strength and shape parameters respectively. Low and high K values indicate girdle distributions or clustered data, respectively. The strength parameter C indicates the strength of the preferred orientation in the data sample. Values of K = 1 and C = 0 are completely randomly distributed."

5.2.2 Non-cylindrical periclinal fold geometries

5.3 Faults and shear zones

5.4. Mineralization in relation to structural elements

"Fine"

6. Interpretation

6.1 Lithofacies variation

6.2 Development of foliation fabrics

6.3 Apparent strain gradients and strain partioning along the eastern limb of the Chambishi-Nkana syncline

6.4 Non-cylindricity, interference patterns and strain accommodating mechanisms in folds

6.5 Timing of faulting

"All fine"

7 Discussion

7.1 Synthesis and timing of structural events in the SE Chambishi-Nkana Basin

7.2 Factors influencing fold geometries

"I agree with the simpler version of monophase folding."

7.3 Influence of basement and extensional basin structures on inversion tectonics.

"Just statements in that chapter – may or may not be. Too little work is done on pre-convergent configuration"

8 Conclusions

"Fine"

Figures:

"I could not relate the Kafue Evaporate Member (KEM) on Fig 2, instead I found REM."

This needs to be REM: Rokana Evaporites Member. Changed accordingly.

Our *answers* to further (minor) comments of the referee in attachment se-2018-6-RC1-supplement.pdf

Page 2 Line 27 and 28: **"Make sure that location names appear on figures or locate by other means."**
The words Nchanga and Nkana are highlighted.

Agreed. Nchanga and Nkana were indicated in Figure 2 by symbols. But for clarity, we've added a reference to that figure in the text where Nchanga, Nkana and Mindola were highlighted.

Page3 Line 7: **"see comment above"** The word Mindola is highlighted

See above. We've added reference to Nkana South, Central and Mindola to the figure caption in Figure 2.

Page 3 Line 22 and 23: **"Is there an age information from basement inliers older than Katanga." The words Lufubu and Muva Supergroups are highlighted."**

There is. In the highlighted sentence we refer to the excellent mapping and isotopic work on the Irumide belt and Bangweulu block, by Bert De Waele and co-authors. Their study shows four main different igneous phases in the basement of the Domes region in Zambia, the Bangweulu block and Irumide belt: the Usagaran phase (2.05–1.93 Ga), the Ubendian phase (1.88–1.85 Ga), the Lukamfwa phase (1.65–1.55 Ga) and the Irumide phase (1.05–0.95 Ga), recognised along the southern margin of the Congo Craton in the Bangweulu Block and Irumide Belt of Zambia. The geodynamic connection between the Domes region and neighbouring basement units was recently explored further by Debruyne et al. (2014). Of course, a treatment of the basement is not in the scope of this paper, so we refer to those papers for more information.

- *De Waele, B., Liégeois, J.-P., Nemchin, A. and Tembo, F.: Isotopic and geochemical evidence of proterozoic episodic crustal reworking within the irumide belt of south-central Africa, the southern metacratonic boundary of an Archaean Bangweulu Craton, Precambrian Res., 148(3–4), 225–256, doi:10.1016/j.precamres.2006.05.006, 2006.*
- *Debruyne, D., Van Wilderode, J., Balcaen, L., Vanhaecke, F., & Muchez, P. (2014). Geochemistry and isotopic evolution of the Central African Domes, Bangweulu and Irumide regions: Evidence for cryptic Archean sources and a Paleoproterozoic continental arc. Journal of African Earth Sciences, 100, 145-163.*

Page 5 Line 12: **"upper case" The words 10^3-104 m are highlighted**

Fixed, thanks.

Page 5 Line 20: **"I do not understand "faults or burial" The words faults or burial are highlighted**

We should have written "… faults, or burial or tectonic foliations." That is: faults, burial [foliations] and tectonic foliations. We've added an 'Oxford Comma' to save the day: "… faults, and burial or tectonic foliations."

Page 8 Line 20: **"Which is also clear from figure 4. By the way, not many authors do such a clear distinction between syforms and synclines...." The words Antiforms are thus anticlines, synforms synclines are highlighted**

We agree this is important, certainly in orogenic belts.

Page 13 Line 2: **"gain or grain?" the word grain is highlighted**

In this instance we do mean structural grain of the orogeny.
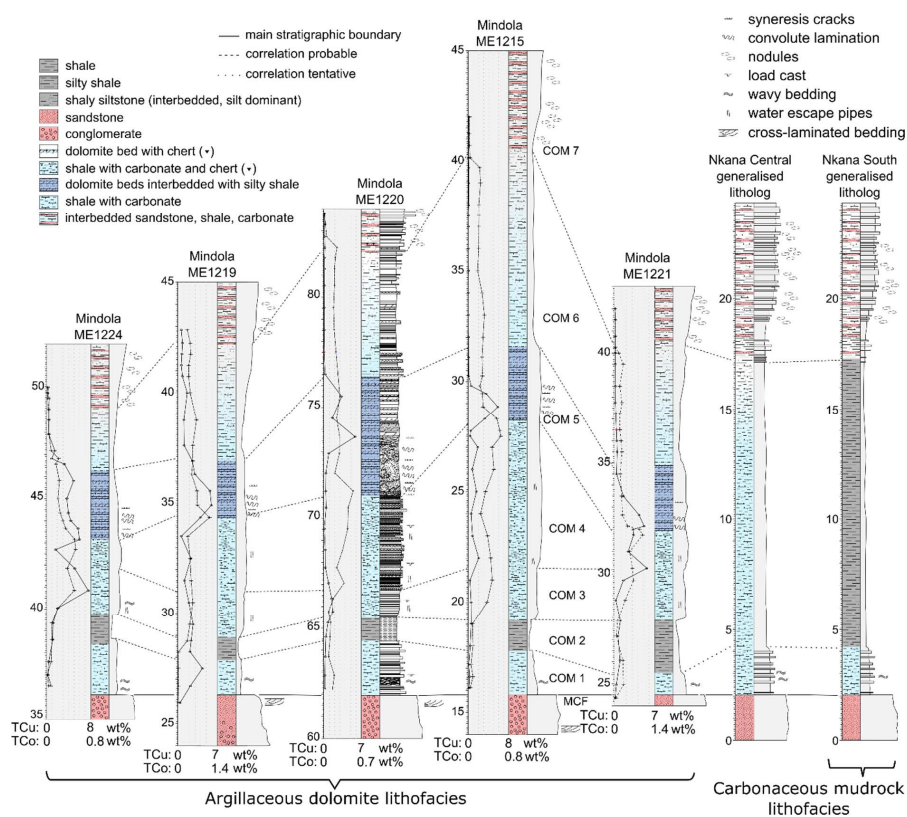
Figure 1: Lithologs of sections at Mindola (typical argillaceous dolomite), Nkana Central and Nkana South (typical carbonaceous mudrock). Log at Mindola is from individual boreholes as listed, whereas composite generalized lithologs are shown for Nkana South and Central, because of the deformed nature COM there. Correlations are based on observed lithological contacts. Total Cu and Co values in % are given in blue and red respectively, reproduced from data provided by Mopani Copper Mines Plc. These analyses were carried out on drill core halves in sections generally 10 to 15 cm long and averaged over the length of the section. MCF: Mindola Clastics Formation; COM: Copperbelt Orebody Member.

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