Reply to Reviewer Dr. Licht

We thank Dr. Licht for his helpful comments and encouragement, and we are grateful for his time, efforts, and suggestions. As Dr. Licht pointed out, the EOT event is virtually not documented in low-latitude East Asia sedimentary records, but it is critical to understand the impact of Eocene greenhouse conditions on the proto-monsoon. Therefore, our work could make important contributions to fill in this critical gap of our knowledge about the Late Eocene environment in low-latitude Asia.

Dr. Licht has two major comments: 1) many important details about sedimentology and the biostratigraphy are lacking; 2) paleomagnetic correlations are weakened by some specific scientific points. For the first comment, Dr. Licht acknowledged that we indeed has cited a MS thesis that documented many more details about sedimentology and biostratigraphy, but criticized that the MS thesis was in Chinese and not accessible to many readers. In the revision, we shall expand the introduction to include a synthesis of sedimentology to show more details. These two aspects of concerns are detailed in the following-up specific comments. Below are our point-by-point responses (in blue) to Dr. Licht's concerns, and more details will be incorporated into the revision as suggested.

The paper provides interesting new paleomagnetic data from the Maoming Basin, China, to locate the stratigraphic interval of the critical Eocene-Oligocene Transition (EOT). I must first say that I am sympathetic with the effort made by the authors to identify and study the EOT in the East Asian sedimentary record, because this event is virtually undocumented in continental Southeast Asia and is particularly critical to understand the impact of Eocene Greenhouse conditions on the proto-monsoons. Accordingly, the topic of this paper is potentially suitable for CotP. However, I think that the manuscript still needs a fair amount of work to make it ready for publication. First, many important details about the sedimentology and the biostratigraphy of the localities are lacking. I acknowledge that a big part of this initial work seems to have been previously published in Chinese journals, but this work is not available for the common, non-Chinese reader and needs to be synthesized and summarized (at least in the introduction of the paper). Moreover, this paper has some critical issues with specific scientific points that significantly weaken their paleomagnetic correlations and I am not sure that there is the potential for the authors to address these concerns by reorganizing their arguments or providing more data.

1. Sedimentological interpretations

The main -and critical- sedimentary change in the studied section is a shift from lacustrine to deltaic conditions, eventually attributed to the EOT. But the sedimentological part of the paper is very weak, and most of the sedimentary interpretations are referred to a Chinese MS thesis. The results of this previous study must be synthesized, with a clear explanation of the different lithofacies / architectural units that are found in the basin. Among the questions that remain unanswered:

1) What is the environmental interpretation of the different facies that are described by the authors? "lacustrine" and "deltaic" are too vague and do not qualify facies. For instance, how are the "massive sandstone" beds of the Haungniuling Fm interpreted? Are those channel body, mouth bar, or delta front deposits? What is their lateral extent?

   We appreciate this comment. The majority of the Youganwo Fm is interpreted to be profundal facies and only the uppermost part of the Youganwo Fm represents shallow lake deposits (Guo, 2006). The massive sandstone beds at the base of the Huangniuling Fm extend hundreds of meters laterally with uniform thickness in the open mine pit. Based on the nature of gradual transition at the interface between the Youganwo Fm and the Huangniuling Fm, the massive sandstone likely represents delta front to distal mouth bar deposits.

2) How do the authors interpret their "parasequences" in terms of deltaic environment? note that fining-upward sequences as they are described in the paper are not very common in deltaic setting. The few information provided in this paper would rather suggest sequences made of stacked channel bodies, and thus a fluvial environment.

   Because the sandstone and mudstone beds in a parasequence are nearly flat and extend laterally for hundreds of meters in the lower part of the Huangniuling Fm, the fining-upward trend within a parasequence and the repeated occurrence of the parasequence may suggest that they were deposited in an interdistributary bay environment with fluctuating lake levels. In the upper part of the Huangniuling Fm, lense-shape channels are occasionally observed, suggesting that delta plain deposits gradually became dominant in the upper section.

3) the authors described a colored mudstone layer at the interface between both Paleogene units. Could it be a paleosol? If so, that would significantly change their paleomagnetic correlation; if not, what is it?

The interface between the two units shows a gradual transition. The light brown oil shale at the uppermost of the Youganwo Fm gradually gives rise to a pale grey mudstone layer that is capped siltstone and sandstones, displaying a coarsening upward trend of grain sizes. This gradual transition indicates that lake level gradually dropped. The pale grey mudstone layer may represent lacustrine deposition and/or muddy prodelta deposition, and the coarsening upward of siltstone and sandstone could represent a transition from prodelta to delta front environment. Also, there is no evidence of subaerial exposure for this interval. So it is not a paleosol.

4) Whatever is the origin of the "parasequences" in the Haungniuling Fm (fluvial or deltaic), channel / delta mouth migration is not necessarily controlled by orbital forcing. Avulsions /migrations can be endogenic as well. Orbital forcing must be shown, for example by proving that parasequences alternate with a regular period that corresponds to one of the Milankovitch periods. But there is no data about the frequency of parasequences in the Haungniuling Fm, neither a clear log of the unit.

While channel/delta mouth migration may produce "delta cycles", each of these cycles would tend to show a coarsening-up delta-lobe succession. As mentioned above, a parasequence consists of a fining-up succession and the formation of parasequences may be associated with lake level fluctuation, which could be forced by orbital variations. Also, orbital forcing could take place via different feedbacks. This notion of orbital forcing is supported by the persistent pattern of rhythmic occurrence of the parasequences. This notion is also strengthened by the demonstrated orbital forcing of the deposition in marine (e.g., the Eocene/Oligocene boundary GSSP section in Italy, Jovane et al., 2006) and lacustrine (e.g., the Green River Fm, Meyers, 2008) settings during the similar time interval.

We agree that it is the best to determine the period represented by a paraseuqence and then compare this period with Milankovitch periods. To determine the period of a parasequence, one needs to know at least two numerical ages bracketing the parasequence. But even the age of the Huangniuling Fm remains controversial and we are not aware of any numerical ages available from the Huangniuling Fm that can be used for such a calculation. In fact, one purpose of this study is to establish a refined chronostratigraphic framework for the Huangniuling Fm.

Jovane, L., F. Florindo, M. Sprovieri, and H. Pälike: Astronomic calibration of the late Eocene/early Oligocene Massignano section (central Italy), Geochem. Geophys. Geosyst. 7, Q07012, doi:10.1029/2005GC001195, 2006.

Meyers, S.R.: Resolving Milankovitchian controversies: The Triassic Latemar Limestone and the Eocene Green River Formation. Geology 36, 319–322, doi: 10.1130/G24423A.1, 2008.

2. Weaknesses of the paleomag correlation

The chronostratigraphic correlation proposed in this paper is based on several assumptions that are not very well addressed and should be discussed in more details.

1) The authors claim a "late Eocene" age (what is their definition of "late" Eocene? Upper Eocene?) based on one fossil mammal: Lunania youngi. I cannot read the original papers relating this discovery (in Chinese), but Russell and Zhai attributed this taxa to the Middle and Upper Eocene of China in their anthology of 1984 ("The Paleogene of Asia"). Note that Lunania are still poorly described and understood (Remy et al., 2005, CR Palevol), as well as their exact stratigraphic range. Moreover, the study of pollens from the Maoming Basin by Aleksandrova et al (2014, Stratigraphy and geological correlation) attributed the Youganwo Fm to the Lutetian / Bartonian and the Haungniuling Fm to the Priabonian. It thus appears to me that the biostratigraphic context contradicts the authors' correlation.

   Although the systematic position of the genus Lunania is still not well understood, increasing evidence appears to point its age at Bartonian to Priabonian. To date, two species in total were reported: *Lunania zhoui* from the Yuanqu Basin of central China (Huang, 2002), and *Lunania youngi* from Yunnan (Chow, 1957; Zong et al., 1996) and Maoming (Wang et al., 2007) of southern China, respectively. *Lunania zhoui* was collected from the Hedi Fm (Huang, 2002). Plenty of fossil mammals were found from this formation, i.e. the Yuanqu Fauna. According to the latest study on land mammals, the geological age of this fauna is regarded to be no earlier than Bartonian and no later than Priabonian (Tong et al., 2005, p.111). This is highly consistent with our assumption that the Youganwo Fm with *Lunania* fossils in Maoming Basin was largely deposited during the Bartonian to Priabonian.

   For the *Lunania youngi* from Yunnan, fossils were collected from the Xiangshan Fm of Lijiang Basin (Zong et al., 1996), and Lumeiyi and Caijiacong formations of Lunan Basin (Chow, 1957). According to Zong et al. (1996), the Lijiang Fauna is of the Sharamurunian age in the Asian Land Mammal Ages, largely spanning from the Bartonian to Priabonian (Li and Ting, 1983; Russell and Zhai, 1987; Wang, 1992; Qiu and Wang, 2007) or the Bartonian (Tong et al., 1995).

   Fossil tapir assemblage from the Lumeiyi Fm suggests that its geological age is most probably the early Late Eocene (Huang and Qi, 1982, p.324), while the Caijiachong fauna is considered to be survived in the latest Eocene (Tong et al., 2005, p110-111; Wang, 1997, p.88).

   Regarding the pollen study of Aleksandrova et al. (2015), the ages for the Youganwo Fm and the Huangniuling Fm were based on comparison of their pollen data with pollen assemblages from southern China. However, the ages of most of pollen assemblages in southern China, to which they compared their pollen data, are poorly constrained and are loosely attributed to late Eocene to early Oligocene (Song et al., 1999). Also, pollen results by other authors reported rather different ages for the Youganwo Fm. The pollen study of Yu and Wu (1983, p.115-116) concluded an early Oligocene age for the Youganwo Fm, whereas the pollen study of Li et al. (2006, p.939-940) preferred the late Eocene age for this formation. Despite the fact that the neither of the two studies concluded a middle Eocene age for the Youganwo Fm, Aleksandrova et al. (2015) cited these two studies as evidence for "middle Eocene-early Oligocene" age, which we found is troubling. Below is the quote from Aleksandrova et al (2015):

"The Youganwo Formation was considered to be the middle Eocene–early Oligocene in age on the basis of palynological data (Yu and Wu, 1983; Li et al., 2006) or late Eocene in age on the basis of mammal *Lunania* cf. *youngi* remains (Wang et al., 2007; Jin, 2008)"

Nevertheless, pollen data appear to give a rather wide range of age estimates. It is generally accepted that fauna data provide better age constraints than pollen data. As mentioned above, a number of studies consistently constrain the age of Lunania to the Bartonian to Priabonian. A review of fossil data from the Youganwo Fm also shows that NONE of the reptile, fish, and mammal fossils indicates a middle Eocene age (Jin, 2008).

Given the large age uncertainty of pollen data and the fact that mammal fossils usually provide tighter age constraint than pollen data, Aleksandrova et al. (2015)'s biostratigraphic assignment does not necessarily contradict with our assumption of Bartonian to Priabonian age for the investigated, mammal fossil-bearing Youganwo Fm. Our assumption for the age of the sampled Youganwo Fm (Bartonian to Priabonian) is supported by the available paleontological data from Maoming Basin (Jin, 2008; Wang et al., 2007).

References (all of the Chinese literatures have English summary):

Aleksandrova G.N., Kodrul T.M, Jin J.H. 2015. Palynological and paleobotanical investigations of Paleogene sections in the Maoming basin, South China. Stratigraphy and Geological Correlation, 2015, 23: 300-325.

Chow M.C., 1957. On some Eocene and Oligocene mammals from Kwangsi and Yunnan. Verterbrata PalAsiatica, 1(3): 201-214 (in Chinese with English summary).

Huang X.S., 2002. New emoropid (Mammalia, Perissodactyla) remains from the middle Eocene of Yuanqu Basin. Verterbrata PalAsiatica, 40(4): 286-290 (in Chinese with English summary).

Jin J., 2008. On the age of the Youganwo formation in the Maoming Basin, Guangdong Province. Journal of Stratigraphy, 32:47-50 (in Chinese with English

summary).
Li C., Ting S., 1983. The Paleogene mammals of China. Bull. Bulletin of Carnegie Museum of Natural History, 21: 1-93 (in Chinese with English summary).
Qiu Z.X., Wang B., 2007. Paracerathere fossils of China. Palaeontoligca Sinica, New Ser. C, 29: 1-188 (in Chinese with English summary)
Russell D.E., Zhai R.J., 1987. The Paleogene of Asia: mammals and stratigraphy. Memoires du Museum National d'Histioire Naturelle, 52: 1-490.
Song, Z.C., Zheng, Y.H., Li, M., Zhang, Y., Wang, W.M., Wang, D., Zhao, C.B., Zhou, S., Zhu, Z., and Zhao, Y., 1999. Fossil spores and pollen of China. Vol.1. Late Cretaceous and Tertiary Spores and Pollen: Beijing, Science Press, 910 (in Chinese with English summary).
Tong Y., Zheng S., Qiu Z., 1995. Cenozoic mammal ages of China. Verterbrata PalAsiatica, 33(4): 290-314 (in Chinese with English summary).
Tong Y.S., Li Q., Wang Y.Q., 2005. A brief introduction to recent advance in the Paleogene studies. Journal of Stratigraphy, 29 (2): 109-1133 (in Chinese with English summary).
Wang B., 1992. The Chinese Oligocene: A preliminary review of mammalian localities and local faunas. In: Prothero D.R., Berggren W.A., eds. Eocene-Oligocene Climatic and Biotic Evolution. Princeton: Princeton University Press, 529-547 (in Chinese with English summary).
Wang B., 1997. Problems and recent advances in the division of the continental Oligocene. Verterbrata PalAsiatica, 21(2): 81-90 (in Chinese with English summary).
Wang Y.Y., Zhang Z.H., Jin J., 2007. Discovery of Eocene fossil mammal from Maoming Basin, Guangdong. Acta Scientiarum Naturalium Universitatis Sunyatseni, 46: 131-133 (in Chinese with English summary).
Zong G., 1996. Cenozoic Mammals and Environment of Hengduan Mountains Region. China Ocean Press, Beijing, 279 (in Chinese with English summary).

2) The authors argue that sedimentation rates in the Haungniuling Fm should be higher than in the Youganwo Fm because of "changes of lithology" and coarser grain-size. This assumption is clearly incorrect. Changes in lithology and grain-size increase can be caused by simple paleoenvironmental changes (lake level fall, for example) without any change of sedimentation rate.

We believe that this is an appropriate assumption in a general sense. Let us take sandstone and mudstone as an example to explain the reasoning behind this assumption. During deposition, clays generally take longer time than sands to get settled. Also, in the subsequent lithificational compaction stage, clay-rich sediments would have more volume loss than sand-rich sediments (sands act as skeletons and are thus less compactable than clays), and thus represent more condensed time interval. Therefore, for the same thickness of mudstone and sandstone, mudstones generally represent longer time than do sandstones, i.e., the sedimentation rate for mudstone is generally slower than that of sandstone. Because the Youganwo Fm is dominated by oil shale and the Huangniuling Fm is dominated by sandstone, it is reasonable to assume a faster sedimentation rate for the Huangniuling Fm than for the Youganwo Fm.

3) Finally, the authors argue that accumulation rates above 1.5 cm.kyr-1 are too high for oil shales. This is incorrect as well. In lacustrine context, accumulation rates can be up to 5-10 times higher. See, for example, the accumulation rates in Paleogene deposits of the Greenriver Basin, Wyoming. For all these reasons, it appears to me that almost all the other chronostratigraphic hypotheses introduced in the paper are as pertinent as the one that is eventually proposed. Actually, Hypothesis 1 (previously rejected) seems the most reliable, because it works with Aleksandrova et al's pollen study and yields reasonable accumulation rate estimates.

It is true that sedimentation rates in a lacustrine environment are overall faster than in a marine setting. But sedimentation rates can vary widely among different types of lacustrine environment. For example, playa/evaporative lithofacies have higher sedimentation rates than profundal lithofacies (e.g., Smith et al., 2003). Even within a lacustrine environment, sedimentation rates at littoral zones are generally faster than at profundal zones. For the Paleogene deposits in Green River Basin, sedimentation rates also vary depending on the type of lacustrine environment and/or subfacies. For example, the Wilkins Peak member the Green River Fm contains playa lithofacies (e.g., Eugster and Surdam, 1973) and oil shale in this member is often sandwiched into calcareous siltstone and sandstone (e.g., Pietras et al., 2003). Because of the presence of siltstone and sandstone, the overall sedimentation rates of this member must be higher than for oil shale-only interval alone. Oil shale in the Youganwo Fm was formed in a semi-deep to deep lake environment (Guo, 2006) and the lithology of the investigated interval of the Youganwo Fm is monotonic, consisting of only oil shale. We use the well-dated organic rich black shale in the mid-Cretaceous as an analogue to constrain the sedimentation rates for the Youganwo Fm.

As to the correlation, multiple scenarios are possible due to the lack of an anchoring point. Our approach is to use all the known constraints jointly, not in isolation, to find the most viable correlation that can satisfy most, if not all, the known constraints. We analyzed six scenarios (Section 5.3, Table 1) and found that Ensemble 6 meets the criteria and thus is our preferred correlation.

Eugster, H.P. and Surdam, R.C., 1973. Depositional environment of the Green River Formation, Wyoming: A preliminary report. Geological Society of America Bulletin,84, 1115-1120.

Guo, M. 2006. Characteristics and mineralization controlling factors of oil shale in

Maoming Basin. M.sc. Thesis, Jilin University, p 86.
Pietras, J.T. Carroll, A.R., Singer, B.S. Smith, M.E. 2003. 10 k.y. depositional cyclicity in the early Eocene: Stratigraphic and $^{40}Ar/^{39}Ar$ evidence from the lacustrine Green River Formation. Geology 31, 593–596.
Smith, M.E., Singer, B.S., and Carroll, A.R., 2003, $^{40}Ar/^{39}Ar$ geochronology of the Eocene Green River Formation, Wyoming: Geological Society of America Bulletin, 115, 549–565.

3. Paleoclimatic discussion

The paleoclimatic interpretation of the correlation proposed in the paper is virtually non-existent.

We appreciate this comment and we will elaborate on the paleoclimatic interpretation of the correlation in the revision.

Among the questions that should be addressed:

1) How do the authors explain the shift from lacustrine to deltaic at the EOT? What does this mean for the hydrological cycle?

   In terms of the implications for hydrological cycle, the shift in low-latitude Asia may represent a transition from humid to dry conditions in response to global cooling at EOT.

2) How to explain the impressive increase of accumulation rates at the EOT, if their correlation is right? -How does it compare with other records in East Asia?

   As dry conditions prevailed, lake area may have shrunk. The increase in sedimentation rate is dictated by the depositional environment change from lacustrine environment to deltaic environment. Enhanced erosion of upland in the arid and cold conditions may have also contributed to the increase in sedimentation rates. Similar depositional environmental change and sedimentation rate increase between 34.5 and 31 Ma are observed in Xining Basin and the E/O climatic transition is also considered as a possible cause (Dai et al., 2006).

Dai, S., X. Fang, G. Dupont-Nivet, C. Song, J. Gao, W. Krijgsman, C. Langereis, and W. Zhang (2006), Magnetostratigraphy of Cenozoic sediments from the Xining Basin: Tectonic implications for the northeastern Tibetan Plateau, J. Geophys. Res., 111, B11102, doi:10.1029/2005JB004187.

3) What does the hypothetical eccentricity signal found in their section mean in terms of paleoclimate? How does it compare with other contemporaneous orbital record?

   The recognition of eccentricity signal in Maoming Basin suggests that sedimentation in Maoming Basin during this time interval may have been modulated by orbital variations and the terrestrial responses in low-latitude Asia to the EOT may be superimposed on the long-term variations at orbital frequency. The long and short eccentricity signals are also detected from the Eocene/Oligocene Massignano section, Italy (Jovane et al., 2006), which is the GSSP section for the Eocene/Oligocene boundary. The eccentricity signals are also found in other marine successions (e.g., Westerhold et al., 2014) and lacustrine deposits (e.g., Meyers, 2008; Okacoğlu et al., 2012) at the similar age.

Jovane, L., F. Florindo, M. Sprovieri, and H. Pälike: Astronomic calibration of the late Eocene/early Oligocene Massignano section (central Italy), Geochem. Geophys. Geosyst. 7, Q07012, doi:10.1029/2005GC001195, 2006.

Meyers, S.R.: Resolving Milankovitchian controversies: The Triassic Latemar Limestone and the Eocene Green River Formation. Geology 36, 319–322, doi: 10.1130/G24423A.1, 2008.

Ocakoğlu, F., Açıkalın, S., Yılmaz, I.Ö., Safak, Ü., and Gökçeoglu, C.: Evidence of orbital forcing in lake-level fluctuations in the Middle Eocene oil shale-bearing lacustrine successions in the Mudurnu-Göynük Basin, NW Anatolia (Turkey). Journal of Asian Earth Sciences 56, 54–71, 2012.

Westerhold, T, U. Röhl, H. Pälike, R. Wilkens, P. A. Wilson, and G. Acton: Orbitally tuned timescale and astronomical forcing in the middle Eocene to early Oligocene. Clim. Past, 10, 955–973, doi:10.5194/cp-10-955-2014, 2014.

4. Finally, a few additional comments:

1) The authors state that the magnetostratigraphy of the area was already study by Wang et al. (1994). They should clearly indicate what has been done in that study and where, and how it overlaps with their own work.

   The location of the study site of Wang et al (1994) will be marked in Fig. 1 and more details about the stratigraphic interval of the previous study will be included in the introduction in the revision.

2) Table 1 should be reorganized (It is unclear, too much infos in parentheses), Fig. 2 should be enlarged (and subfig 2d should be explained).

   Thanks and will be done in the revision. Note that the submitted Fig. 2 was large. The size of Fig. 2 was set by the CP copy-editing office.

3) The scientific English writing is for me comprehensible. I am not a native English speaker so I leave this to the discretion of the editor. I have noticed a few spelling mistakes, as well as unclear statements, suggesting that the manuscript should be proof-read by an English speaker. My feeling is that I am not sure that this manuscript can be saved, unless the authors succeed to clean their

sedimentological interpretations and strengthen their correlation by additional biostratigraphic data.

The English will be improved in the revision to make it more readable than the initial version.

We hope you would be pleased to see the improvements that we have made for this paper.