**Comment on “Cenozoic tectonic deformation and uplift of the South Tian Shan: Implications from magnetostratigraphy and balanced cross-section restoration of the Kuqa depression” by Tao Zhang, Xiaomin Fang, Chunhui Song, Erwin Appel, Yadong Wang [Tectonophysics, 2014, doi:10.1016/j.tecto.2014.04.044]**

Qingqing Qiaoa, Baochun Huangb, John D.A. Piperc

a Xinjiang Research Center for Mineral Resources, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China

b Key Laboratory of Orogenic Belt and Crustal Evolution Ministry of Education, School of Earth and Space Sciences, Peking University, Beijing 100871, China

c Geomagnetism Laboratory, Department of Earth and Ocean Sciences, University of Liverpool, Liverpool L69 7ZE, UK

\* Corresponding author: Dr. Qingqing Qiao

Xinjiang Research Center for Mineral Resources

Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences

Beijing South Road 818

Urumqi 830011, China

E-mail: qiaoqq@ms.xjb.ac.cn; bchuang@pku.edu.cn

Tel: +86-991-7885488

**ABSTRACT**

The recent paper entitled: “Cenozoic tectonic deformation and uplift of the South Tian Shan: Implications from magnetostratigraphy and balanced cross-section restoration of the Kuqa depression” by T. Zhang, X.M. Fang, C.H. Song, E. Appel and Y.D. Wang [Tectonophysics, 2014, doi:10.1016/j.tecto.2014.04.044] discusses the Cenozoic tectonic deformation and uplift of the South Tianshan Mountains by integrating tectonic investigations, seismostratigraphic analysis and paleomagnetic dating of the thrust-fold belt in the Kuqa Depression at the southern border of the Tianshan. To support their conclusions the authors have reinterpreted a high resolution magnetostratigraphic study of the Kezilenuer section entitled “Magnetostratigraphic study of the Kuche Depression, Tarim Basin, and Cenozoic uplift of the Tian Shan Range, Western China” by B.C. Huang, J.D.A. Piper, S.T. Peng, T. Liu, Z. Li, Q.C. Wang and R.X. Zhu [Earth and Planetary Science Letters Volume 251, pages 346-364 (2006)]. We note here (i) that apparent conflicts in definition of the Xiyu Formation in the Kuche Depression as proposed by Zhang et al. (2014) require amplification and (ii) argue that their age assignment for the Kezilenuer Section is incorrect and yields an anomalously low sedimentation rate for the infilling of this foreland basin.

**Key words**

Magnetostratigraphy; Tianshan; Cenozoic; uplift

It has long been recognized that the Cenozoic uplift history of the Tianshan Mountains is important both for providing a better understanding of intra-continental deformation and for resolving how this has influenced the climatic history of Central Asia (Tapponnier and Molnar, 1979; Yang et al., 2015). Over the past three decades extensive research has been conducted with the aim of unraveling the orogenic history of the Tianshan Range (Avouac et al., 1993; Hendrix et al., 1994; Métivier and Gaudemer, 1997; Burchfiel et al., 1999; Bullen et al., 2001; Sun et al., 2004; Charreau et al., 2005, 2006; Huang et al. 2006; Jolivet et al., 2010; Yang et al., 2015). Magnetostratigraphic investigations have played a key part in this research because they are able to provide a temporal constraint to the uplift history in terms of deposition rates of the terrigenous sequences shed into foreland basins where diagnostic floral or faunal constraints are largely absent (Sun et al., 2004; Charreau et al., 2005, 2006; Huang et al. 2006; Yang et al., 2015).

The study by Zhang et al. (2014) has conducted a paleomagnetic study for stratigraphic age determination in parallel with restoration of balanced cross-sections across the Kuqu depression. A fossil mammal, *Hipparion chiai*,found in the Kuchetawu section by Sun et al. (2009) and located in the same anticline embraced by their study yields a time interval of 5.4-2.6 Ma for the measured Erbatai section. In addition they reinterpret the Kezilenuer magnetostratigraphic section published by Huang et al. (2006) to propose a temporal extension of ~10 Ma. Here we address two issues raised by their interpretation. Firstly we note differences in the definition of the Xiyu Formation considered to be a problem issue by these authors. Secondly we argue that the age they assign to their magnetostratigraphy of the Kezilenuer section is incorrect. The second point is an issue of resolution and has implications to the first point.

1. Definition of the Xiyu Formation

In their magnetostratigraphic study of the Erbatai section, Zhang et al. (2014) recognize the first appearance of a thick dark grey conglomerate bed succeeded by dominant conglomerate deposition as the base of the Xiyu Formation. Unfortunately this confuses the definition of the Xiyu Formation. As originally proposed by Huang et al. (1947), the Xiyu conglomerate Formation was assigned to a suite of typical massive molassic deposits comprising dark-gray pebble to boulder conglomerates with minor interbeds of mudstone or sandstone in the base of the Dushanzi Section of the northern Tianshan (Huang et al., 1947). This description implies that the Xiyu is a coherent and continuous unit lying at the top of the sedimentary pile in most of the central Asian foreland basins. In fact the Xiyu conglomerates are variable and transgressive deposits consisting of massive to horizontally- and cross-bedded conglomerates made up of pebble to blocky clasts with a coarse-grained sandy matrix. At their base they are seen to progressively cover underlying unit such as the Dushanzi, Kuche, and Atushi formations in southern Junggar, Kuche, and Kashi depressions respectively with highly variable lithologies composed of massive and horizontal to cross-bedded conglomerates alternating with claystone, siltstone and sandstone (Charreau et al., 2009). Thus the wider regional definition of the Xiyu Formation remains controversial; at Kekeya for example, the first appearance of pebble conglomerate is defined as the base of the Artux Formation (Zheng et al., 2010, 2015). We contend that it is unrealistic to describe the first appearance of a thick dark grey conglomerate as the commencement of Xiyu Formation deposition because this obscures the highly transgressive nature of the deposit (Charreau et al., 2009; Huang et al., 2010) and the difficulty of defining where the base of the formation should actually be placed. Sun et al. (2004) also note that late Pliocene conglomerates with interbedded siltstones or mudstone gradually change to the dominant conglomerates of the Xiyu Formation to further obscure definition of the basal age of this formation in western China.

1. Correlation of the Kezilenuer magnetostratigraphy

The Kezilenuer section contains a continuous, thick and well-exposed sequence of terrestrial sediments ranging from the Kumugeliemu Group to the Kuche Formation within the Kuche Depression of the Tarim Basin (Li et al., 2006). The magnetostratigraphic study of this succession by Huang and colleagues (Huang et al., 2006) resolved a magnetic polarity sequence based on 969 accepted horizons which is more than four times the resolution of the 224 levels reported by Zhang et al (2014). The polarity zonation of Huang et al. dates the time interval between the upper Kumugeliemu Formation and the base of the Kuche Formation between 31.0 Ma and 5.5 Ma employing the CK95 geomagnetic polarity time scale (Cande & Kent, 1995). Whilst Zhang et al. (2014) accept Huang’s original correlation for the upper part of the succession; they extend the lower part back to ca. 40 Ma which leads them to deduce a lengthened history of uplift for the orogeny and a reduced sedimentation rate in the foreland basin since late Eocene times.

Zhang et al. (2014) suggest this extended correlation on the basis of calcareous nannofossil assemblages in Bashijiqike Formation (Guo et al., 2002; Hao et al.,2000; Su et al., 2003), which would make the Kezilenuer section in the Kuqa Depression 10 Ma older than proposed interval occupied by the succession studied by Huang et al. (2006). Although the presence of a paleontological constraint could help quantify the correlation of a specific section, this assignment fails to take into account spatial variations of the sedimentary facies (Zhou et al., 2001) together with the clear diachronicity of the marine transgressions and regressions in the Tarim Basin (Bosboom et al., 2014; Sun et al., 2013). As a consequence there are no reliable criteria for correlating the regional biostratigraphy established by Chinese geologists in the eastern basin with the succession in the western basin.

However, the major drawback of the magnetostratigraphic dating technique is the subjectivity involved in visual correlation of digital polarity records with the Geomagnetic Polarity Timescale (GPTS); errors will be incurred both as the magnetostratigraphic resolution deteriorates and as age increases. To refine the correlation of the magnetostratigraphic succession in the Kuqa Depression and reduce these uncertainties we use a numerical method based on the Dynamic Time Warping algorithm as proposed by Lallier et al. (2013). We apply the method here to the higher resolution (Huang et al., 2006) and lower resolution (Zhang et al., 2014) Kezilenuer magnetostratigraphic analyses by correlating the observed polarity sequence with the GTS2012 timescale (Gradstein et al., 2012, Figs. 1 and 2). We output the 3000 minimum cost correlations considering all magnetic polarity changes identified. The result is that the 50 minimum cost outputs unanimously date the record of Huang et al. between reference polarity chrons C10r to C3A.1n in accordance with the age interval originally proposed by these authors. The 50 correlations and their costs are given in the supplementary materials.

The comparison between the correlation proposed by Huang et al. (2006) and the minimum cost correlation is shown in Fig. 1. The statistically-best correlation bears a strikingly similarity to the original chronology and places the visual comparison of 2006 on a firmer basis. Unfortunately Zhang et al. (2014) have not presented depth/time diagrams or statistical analyses to argue why their reinterpretation should supersede that of Huang et al. (2006).

Fig.2 shows the proposed correlation of their data (left) with the GTS2012 (Gradstein et al., 2012) compared with the correlation of Huang et al. (right). The Zhang et al. (2014) correlation contains more than 50% chrons missed or unidentified that should correlate with GTS2012; this seems to be unacceptable for a reliable magnetostratigraphy. In addition, the anomalously low sedimentation rates imposed by their correlation, not exceeding 5cm/yr in the lower part of the section, are improbably low compared with published average sedimentation rates in foreland-basin environments (Burbank et al., 1992; Harrison et al., 1993).

Zhang et al. (2014) also claim that the interpretation of Huang et al. fails to correlate lithological signatures of climate change with the wider global record and consider that their re-interpreted magnetostratigraphy provide a better correlation with the Cenozoic climate signature. In fact as shown in Fig.3 the reverse is the case. The redness versus drabness of the formations comprising the Kezilenuer Section (Li et al., 2006) correlates well with temperature variations deduced from the deep-sea oxygen-isotope record (Zachos et al., 2001) according to the magnetostratigraphic correlation of Huang et al. (2006) but fails to correspond obviously to the correlation proposed by Zhang et al. (2014). We specifically note the strongest signature of red coloration in this section corresponding to the highest δ18O (%) values continuing to ~13.5 Ma following the dramatic rise at ~25 Ma employing the original correlation.

Finally Zhang et al. (2014) correlated a supposed Eocene extensional subsidence with eruption of basalt in parts of the Central and South Tian Shan during the Paleocene to Eocene. In fact this basaltic episode is concentrated only in the Tuyon Basin of SW Tian Shan (Ji et al., 2006; Sobel and Arnaud, 2000) and is not relevant to the Cenozoic infilling of the Kuche Depression which did not commence until much later. We therefore submit that the original magnetostratigraphic correlation of Huang et al. (2006) is reaffirmed and reject the revised correlation of Zhang et al. (2014).

**Conclusions**

In this note we address two issues raised by the analysis of Zhang et al. (2014). Firstly we amplify understanding of the base of the Xiyu Formation, a stratigraphic unit widely recognized to constrain the sedimentation history across the foreland basin to the Tianshan Range, to demonstrate that apparent differences of interpretation relate to points of gradation and diachronism. Secondly, and more importantly, we use a refined analysis to show that these authors have introduced a magnetostratigraphic correlation based on poorer resolution which both weakens an original more-precise correlation with the Geomagnetic Polarity Timescale, fails to correlate with a palaeoclimatic signature, and introduces implausible sedimentation rates for the Cenozoic infilling of the Kuche Depression.

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**Figure Captions:**

Figure 1: Magnetostratigraphic correlation of the Kezilenuer Section comparing the minimum cost correlation (Lallier et al., 2013) with the correlation as originally proposed by Huang et al. (2006).

Figure 2: Age versus depth plot of the Kezilenuer magnetostratigraphic section comparing the correlations of Huang et al. (2006) (circles) and Zhang et al. (2014) (crosses) with the GTS2012. The white boxes list the correlation coefficient (R2) for the different segments.

Figure 3: The variation in lithologic color through the Kezilenuer Section after Li et al. (2006) linked to the chronology derived from the magnetostratigraphy of Huang et al. (2006, Column C) and the stratigraphy as revised according to the reinterpretation of Zhang et al. (2014, Column A). In Column C we observe that the time series of the stratigraphic redness determined by the magnetostratigraphy of Huang et al. (2006) actually matches the global Cenozoic temperature record determined from δ18O(%) (Column B, Zachos et al., 2001) with the signature rise at ~25 Ma following the elevated plateau of values going forward to ~13.5 Ma.