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Lithostratigraphic context of Oligocene mammalian faunas from Ulantatal, Nei Mongol, China

Contexte lithostratigraphique des faunes mammaliennes oligocènes d'Ulantatal, Nei Mongol, Chine

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ABSTRACT

The Ulantatal area is well-known for its extraordinarily rich Oligocene mammalian fossils. The Ulantatal fauna was originally considered to be the representative fauna for the Chinese Land mammalian Age, Ulantatalian. However, the abundant fossils collected in the 1980s lack coordinates and/or detailed stratigraphic levels, and have been lumped together as either single, coeval fauna or grouped into three units. This lack of stratigraphic information hampers more precise biostratigraphic division and correlation of the faunas. Here we present a complete lithostratigraphic profile of the Ulantatal Formation with new fossil localities calibrated into the profile. Lithologically, the sequence shows a rather uniform pattern characterized by interbedded reddish to yellowish brown claystones and siltstones, with minor fine-grained sandstones. Preliminary biostratigraphic analysis shows that the Ulantatal Formation covers most of the Oligocene, and offers a long sequence and successive fossil records for understanding the evolution of mammal faunas after the critical Eocene/Oligocene transition.

RÉSUMÉ

La région d'Ulantatal est bien connue pour sa richesse extraordinaire en fossiles mammaliens oligocènes. La faune d'Ulantatal a été considérée à l'origine comme étant la faune mammalienne représentative du continent chinois, d'âge Ulantatalien. Cependant, les nombreux fossiles récoltés manquent de coordonnées précises et/ou de niveaux stratigraphiques détaillés et ont été réunis en unités, soit uniques, soit contemporaines, soit encore en trois unités. Le manque de renseignements stratigraphiques empêche une division biostratigraphique et des corrélations plus précises des faunes. Ici est présenté un profil lithostratigraphique complet de la formation Ulantata, avec de nouveaux sites fossilifères répertoriés dans le profil. Lithologiquement, la séquence présente une disposition plutôt

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uniforme, caractérisée par une alternance de lits de claystones et de siltstones bruns, rougeâtres à jaunâtres, avec quelques couches de grès à grain fin. Une analyse biostratigraphique préliminaire montre que la formation Ulantatal recouvre en grande partie l'Oligocène et offre une longue séquence et des registres fossiles successifs pour comprendre l'évolution des faunes mammaliennes après la transition critique Éocène/Oligocène.

1. Introduction

The Oligocene is a critical transitional period in the evolutionary history of Cenozoic mammals, and it also witnessed severe climatic changes (Dupont-Nivet et al., 2007; Hren et al., 2013; Liu et al., 2009; Zachos et al., 2001). However, the response of faunal turnover in different areas (Europe, Asia and North America) to the global scale temperature drop across the Eocene-Oligocene transition shows divergent patterns. The Grande Coupure at the start of the Oligocene marks a sudden change from the endemic European faunas to ones with major components of Asian origin in Europe (Hooker et al., 2004; Stehlin, 1910). The Mongolian remodeling pattern suggests that the Eocene perissodactyl-dominant faunas were replaced by the Oligocene rodent-lagomorph-dominant faunas in the Mongolian Plateau (Meng and McKenna, 1998). In sharp contrast, mammalian faunas in North America show minimal turnover across the boundary (Prothero and Heaton, 1996). To further explore the interaction of faunal turnovers and climatic changes, long and fossiliferous continental successions are required.

The Ulantatal Formation, named after the Ulantatal gulley in Alxa Zuoqi, western Nei Mongol (Inner Mongolia) (Wang and Wang, 1992) (Fig. 1) is well-known for producing extraordinarily rich Oligocene mammalian fossils. The first mammal fossils were discovered by a geological team from the Ningxia Geological Survey in 1977. In 1978, Huang Xueshi and his colleagues from the IVPP (Institute of Vertebrate Paleontology and Paleoanthropology) made a short survey in this area and found over a thousand specimens (Huang, 1982). Supported by the Academia Sinica and the Max Planck Gesellschaft, Germany, a Chinese-German expedition returned to this area in 1985. An extensive geological survey and screen washing of eight localities in a month produced thousands of isolated teeth of small mammals (Vianey-Liaud et al., 2006). In 1988 and 1989, Wang Banyue and her colleagues found the Kekeamu locality in the eastern part of the main locality area (Wang, 2010; Wang and Wang, 1991), and some Early Miocene fossils from the Wuertu area west from the main localities (Wang and Wang, 1990), adding new faunal horizons to the sequence. Extensive studies on fossils from these collections have been published (Huang, 1984, 1985a,b, 1986, 1992, 1993a,b, 1998; Huang and Zhu, 2002; Rodrigues et al., 2012, 2014; Vianey-Liaud et al., 2006, 2010, 2013; Wang, 1997a,b,c, 2010; Wang and Wang, 1991).

Huang (1982) compared the Ulantatal fauna with the Hsanda Gol fauna from Mongolia, and suggested its Middle Oligocene age. Based on fossils from Ulantatal, Tong and Huang (in: Tertiary Research Group of Chinese National Petroleum Corporation, 1991) named the Ulantatalian mammalian Age. Tong et al. (1995) followed this nomenclature, and included the Kekeamuan fauna (Wang and Wang, 1991) in the Ulantatalian Age. With the updated understanding of the Eocene-Oligocene boundary, the Ulantatalian fauna was later revised to be late Early Oligocene (Wang, 1997b,c). Daxner-Höck et al. (2010) compared the three units from Ulantatal with the biozones from the Valley of Lakes in central Mongolia, and correlated units I–III of Ulantatal roughly with Valley of Lakes biozones B–C1. The stratigraphical scheme was recently refined by Rodrigues et al. (2014), who further included Kekeamu fauna in the Earliest Oligocene and correlated it with biozone A of the Valley of Lakes.

Nevertheless, publications on fossils from the Ulantatal area have neither detailed geographical coordinates nor stratigraphy for localities. Huang (1982) measured a section of 18.6 m with simple description of sediments, but estimated in a later paper (1992) that the Ulantatal Formation might exceed one hundred meters in thickness. Based on lithofacies and distinctive sediment colours, Vianey-Liaud et al. (2006) divided the sequence into three lithological units, with an estimate of 60 meters for the total thickness of the sequence. Wang and Wang (1991) provided a detailed description of the Kekeamu locality, but did not correlate it with the main section.

The lumping of fossils from different horizons into one fauna has undoubtedly hampered more precise biostratigraphical division and correlation with other faunas, and further confused the understanding of the evolution history of taxa and faunal changes during a long geological time interval. From 2009 on, we have made extensive field surveys, excavations and stratigraphical investigations in this area over six field seasons. Our surface collection and excavation have produced over five thousand mammalian specimens (mostly upper and lower jaws) and dozens of well-preserved skulls. All fossil localities have been calibrated with GPS and measured using a Jacob's Staff and Abney level to the lithostratigraphical profile. Detailed study of these fossils is still ongoing.

In this paper, we present the four sections investigated, plot our new localities in them and synthesize the Ulantatal formation into one composite profile. A tentative correlation of previous localities into our profile is also given.

2. Stratigraphy of the sections

Oligocene sediments are well-exposed along the southern bank of the Ulantatal gulley, from the easternmost Kekeamu locality to the westernmost Shaozengtu area,

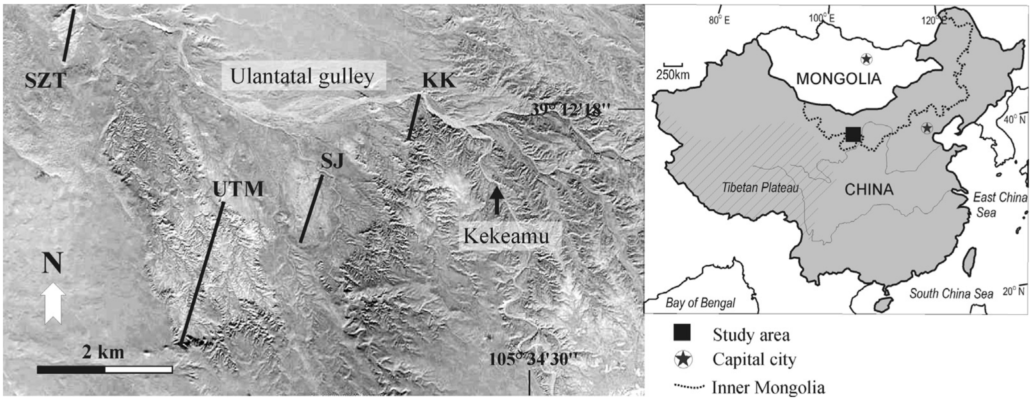

Fig. 1. Google map showing the four sections logged in the Ulantatal gulley. Abbreviations: KK: Kekeamu section; SJ: Shangjing section; UTM: Ulantatal Main Section; SZT: Shaozengtu section.

Fig. 1. Carte Google montrant les quatre coupes dans le ravin d'Ulantatal. Abréviations : KK : coupe Kekeamu ; SJ : coupe Shangjing ; UTM : coupe principale Ulantatal ; SZT : coupe Shaozengtu.

with no more recent sedimentary cover or vegetation (Fig. 1). The topographic scheme of this area is gentle with low uplands and small gullies. Fossils are rich and often detectable *in situ* at the weathered surface, allowing further excavations in the vicinity (Fig. 2D).

The strata dip gently at about 1 to 2 degrees towards the west-southwest (260°). This slight dipping and the gentle topography made the logging of sections challenging. For the convenience of lithostratigraphical investigations and fossil collection, we divided the study area into four

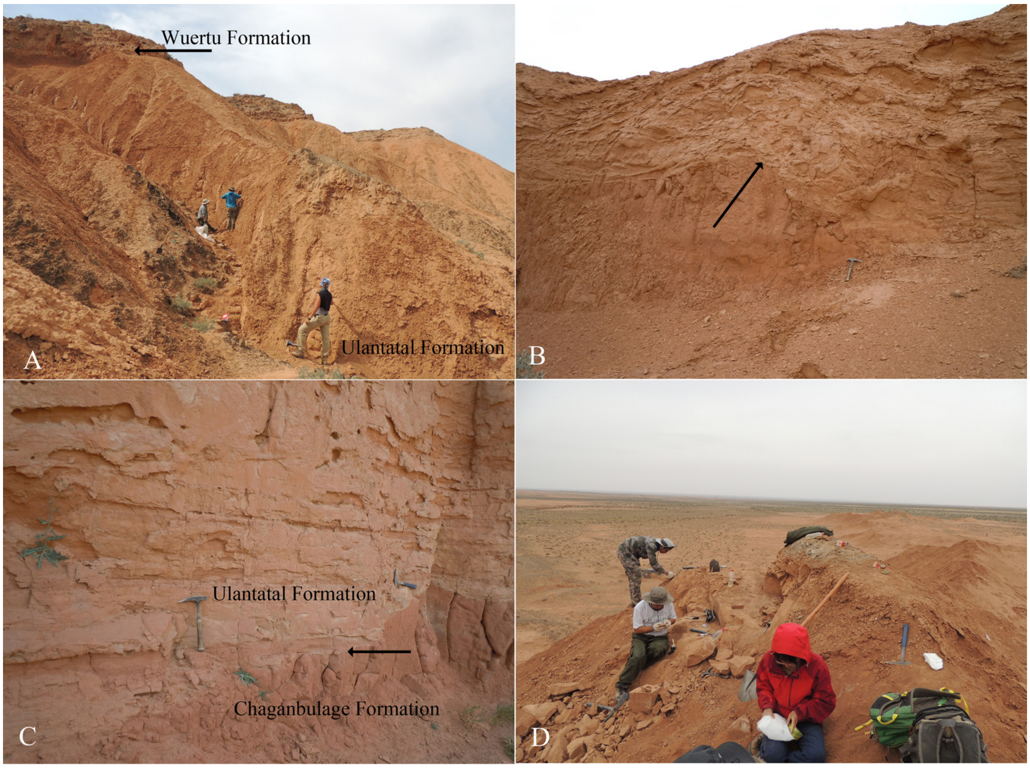

Fig. 2. (Color online). Field photos showing the lithologic boundaries and field excavation. A. The top part of the Ulantatal Main Section (UTM) showing the lower boundary of the Wuertu Formation (N39°10′43″, E105°31′23″). B. The arrow shows the main erosion surface in the UTM section (N39°11′26″, E105°32′00″). C. The lowermost part of the KK section, showing the contact between the Ulantatal Formation and the Chaganbulage Formation (N39°12′11.9″, E105°33′46″). D. The excavation in the KK section (N39°11′48″, E105°33′09″).

Fig. 2. (Couleur en ligne). Photos de terrain montrant les limites lithologiques et l'excavation sur le terrain. A. La partie sommitale de la coupe principale Ulantatal (UTM) montre la limite inférieure de la formation Wuertu (N39°10′43″, E105°31′23″). B. La flèche montre la surface d'érosion principale dans la coupe UTM (N39°, E105°32′00″). C. Partie inférieure de la coupe KK, montrant le contact entre la formation Ulantatal et la formation Chaganbulage (N39°12′11,9″, E105°33′46″). D. Excavation dans la coupe KK (N39°11′48″, E105°33′09″).

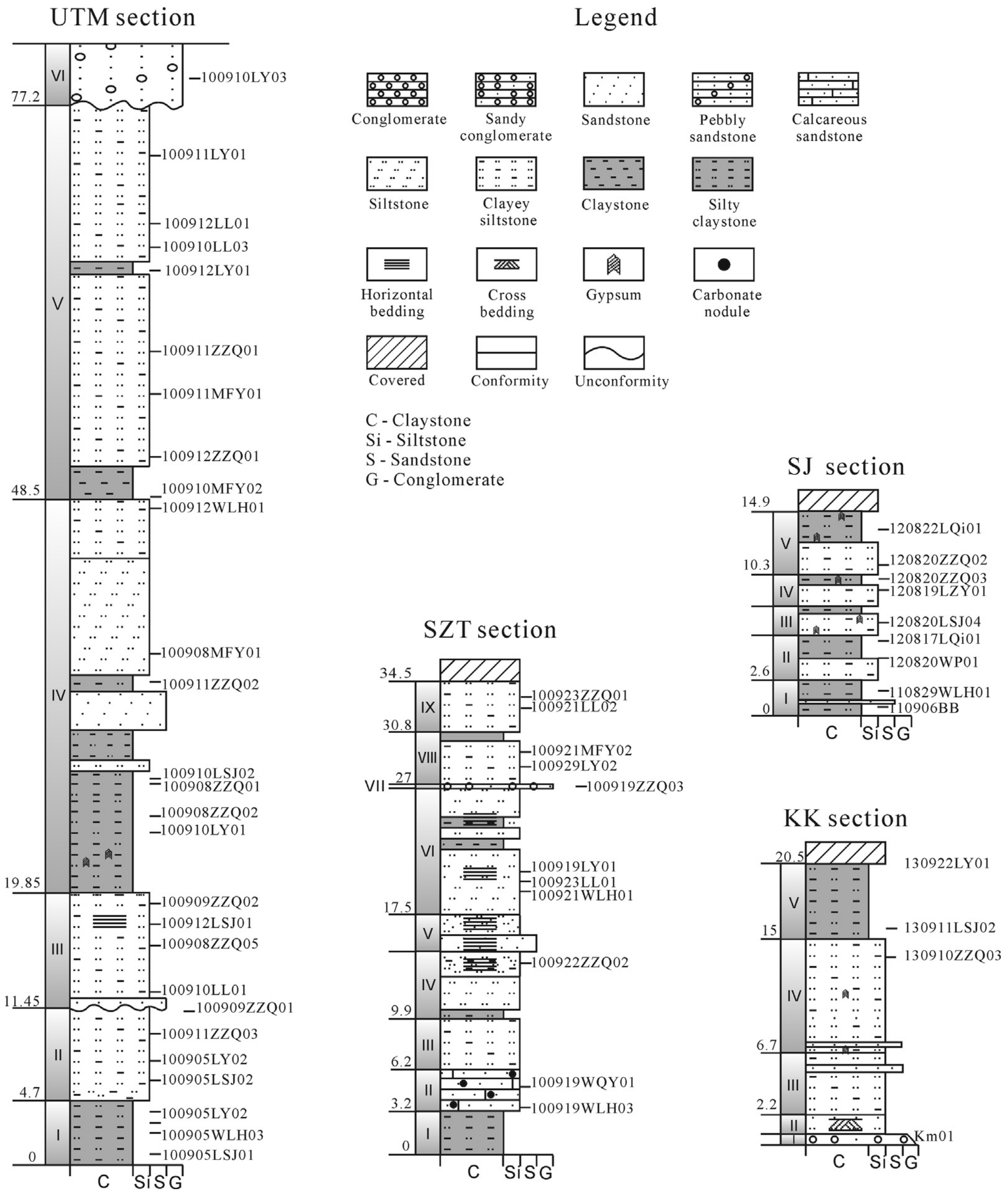

Fig. 3. Profiles of the sections examined, with localities calibrated to the sequence (thickness in meters).

Fig. 3. Profils des coupes examinées, avec calibrage des sites dans la séquence (épaisseur en mètres).

parts, from east to west: Kekeamu, Shangjing, Ulantatal main section, and Shaozengtu respectively. Based on field observations, sedimentological units were differentiated from each of the sections examined (Fig. 3).

2.1. Kekeamu Section (KK)

Wang and Wang (1991) found this locality (N39°11′47.5″, E105°34′29.8″) in a side branch of the Ulantatal main gulley. The exposure of the fossil locality is only about 2 meters thick, and it is covered by thick conglomerates of the Wulanhaolai Formation (possibly Late Miocene). We traced the fossil horizons along the gulley towards northwest to get a better exposed section over 20 meters thick.

The lower boundary of the Kekeamu section is only occasionally visible along the gulley, and lies unconformably on a bed of red clay (Fig. 2C). Wang and Wang (1992) named these red clays below the Ulantatal Formation as the Yuzuitao Formation based on drill data, but later changed the name to the Chaganbulage Formation (Wang and Wang, 1998), of Late Eocene age.

Overall, the Kekeamu section (KK) (Fig. 3) shows a fining-upward trend. The sequence begins with brownish yellow sandstones of varying thickness, overlain by alternating beds of brownish red and brown silty clay and sandy silt. The fossil locality of Wang and Wang (1991) occurs within the lowermost beds (units I–II in Fig. 3).

2.2. Shangjing Section (SJ)

The Shangjing area is a very gentle highland in the east part of the main Ulantatal section. The datum point was marked at the bottom of a small gulley (N39°11.916′, E105°32.623′). Sediments are mainly composed of brownish red silty clay and brownish yellow clayish silt, without an obvious hiatus in this section. The total thickness measured is ca 15 meters (Fig. 3). Fossils are rich throughout the entire sequence.

2.3. Ulantatal Main Section (UTM)

The Ulantatal area is the main location of previous studies, including the localities 1–6 of Vianey-Liaud et al. (2006). The datum point of this section is at the bottom of the highland area of the Ulantatal area (N39°12.147′, E105°31.524′). The lowermost portion of the section (units I and II; Fig. 3) is ca. 11.5 m thick and is characterized by brownish red claystones and brownish yellow siltstones. These fine-grained units are erosionally truncated by light brownish yellow silty sands (unit III) extending laterally for hundreds of meters (Fig. 2B). The thickness of this unit is variable, but attains its maximum (8.4 m) at the outcrop examined. The richest vertebrate localities in the entire Ulantatal area occur in this bed, yielding the main elements of the traditional Ulantatal fauna. The upper part of the sequence is dominated by alternating beds of silty clay and fine silty sands, with two horizons of dark reddish clay with gypsum occurring at the ca. 20 m level. The whole succession is capped by laterally continuous orange yellow sandstone (Fig. 2A), possibly of the Wuertu formation. The lower boundary of the sand unit is marked by a clear erosional unconformity, suggesting it represents a substantial hiatus in the record.

2.4. Shaozengtu Section (SZT)

The Shaozengtu area constitutes the most northwestern part of the study area, where localities 7 and 8 of Vianey-Liaud et al. (2006) were found. The section starts from the bottom of the gulley (N39°13.001′, E105°30.563′) and totals 34.5 meters. The SZT section is similar to the UTM section but is much shorter. At ca. 27 m in the measured section (unit VII) a bed of sands and conglomerates is present, and becomes laterally coarser and thicker towards the west.

3. The correlation of the sections and the composite profile

The distance from the KK section to the datum point of the SJ section is about 1200 m. Fortunately, there is some exposure in between. The correlation is based on logging in the field using a Jacob's Staff, and using a marker horizon of a carbonate-rich silt bed with whitish weathered surface as a tie point. The topmost part of the SJ section is very close to the UTM, with only a small gulley separating these two sections. The unit V of SJ is correlated with unit II of UTM, having the carbonate-rich marker at the base of the bed. In the SZT section, two characteristic horizons allow correlation with the UTM. The SZT unit II has an erosive contact to the underlying bed, and can be traced eastwards to level III of the UTM. The conglomerate bed (unit VII) in the middle part of the SZT section can be equated to the middle part of unit IV in the UTM section. Based on the above sedimentary logging and correlation, we composed a synthesized profile for the whole sequence (Fig. 4), which has a total thickness of 105.3 meters for the Ulantatal Formation.

4. Tentative calibration of previous collection

Precise calibration of the old collections into this profile is difficult, due to a lack of detailed information. Based on the description and the sketch map provided by Huang (1982), it is possible that the fossils collected in 1978 are mainly from the Shaozengtu area, from units II to VII of our SZT section. Our new findings from these levels encompass mostly the taxa described by Huang (1982, 1984, 1985a,b, 1987, 1992, 1993a,b), thus approximately confirming the calibration. However, the faunal correlation does not exclude the possibility of mixture from other horizons; for example *Sinolagomys* may originate from stratigraphically younger levels.

According to the topographic map of Vianey-Liaud et al. (2006) and the description of lithology in their text, UTL 8 of Vianey-Liaud et al. (2006) can be easily recognized in the field and calibrated to unit VII of our SZT section, while the fossil locality UTL 6 is possibly lower than UTL 8 according to the schematic section in Fig. 1 (Vianey-Liaud et al., 2006). Rodrigues et al. (2012) confirm that these two localities belong to the same lithostratigraphical unit (unit III of Vianey-Liaud et al., 2006), however, indicating that UTL 6 is possibly higher than UTL 8 based on their study of cricetids. It is almost impossible to solve this discrepancy without exact coordinate data for UTL 6, which is located in a gulley with several well-exposed horizons. UTL 1 occurs in the lowermost level of the composite sequence with *Karakoromys decessus*, which is lacking in all the other localities (Vianey-Liaud et al., 2006). Through our investigation and referring to their topographic map, we postulate that UTL 1 may be correlated to unit I or II of our UTM section. UTL 2–5 + 7 may be roughly eqivalent to beds III-IV of the UTM section.

5. Biostratigraphy of mammalian faunas from the Ulantatal Formation

With GPS coordinates, we can precisely correlate our new localities into the profiles. Fig. 4 lists only some productive localities. Systematic study of the fossils is still ongoing, and many well-preserved skulls and skeletons are still undergoing preparation. Future work will correlate all the fossils into profiles for detailed biostratigraphy.

Wang and Wang (1991) listed 11 taxa from the Kekeamu locality (KM01). New findings enriched the range of fauna. Ctenodactylids and zapodids are the most common taxa. Except for the primitive species *Ageitonomys neimongolensis*, another form listed by Wang and Wang (1991) as *Karakoromys* cf. *decessus* is most probably a new form,

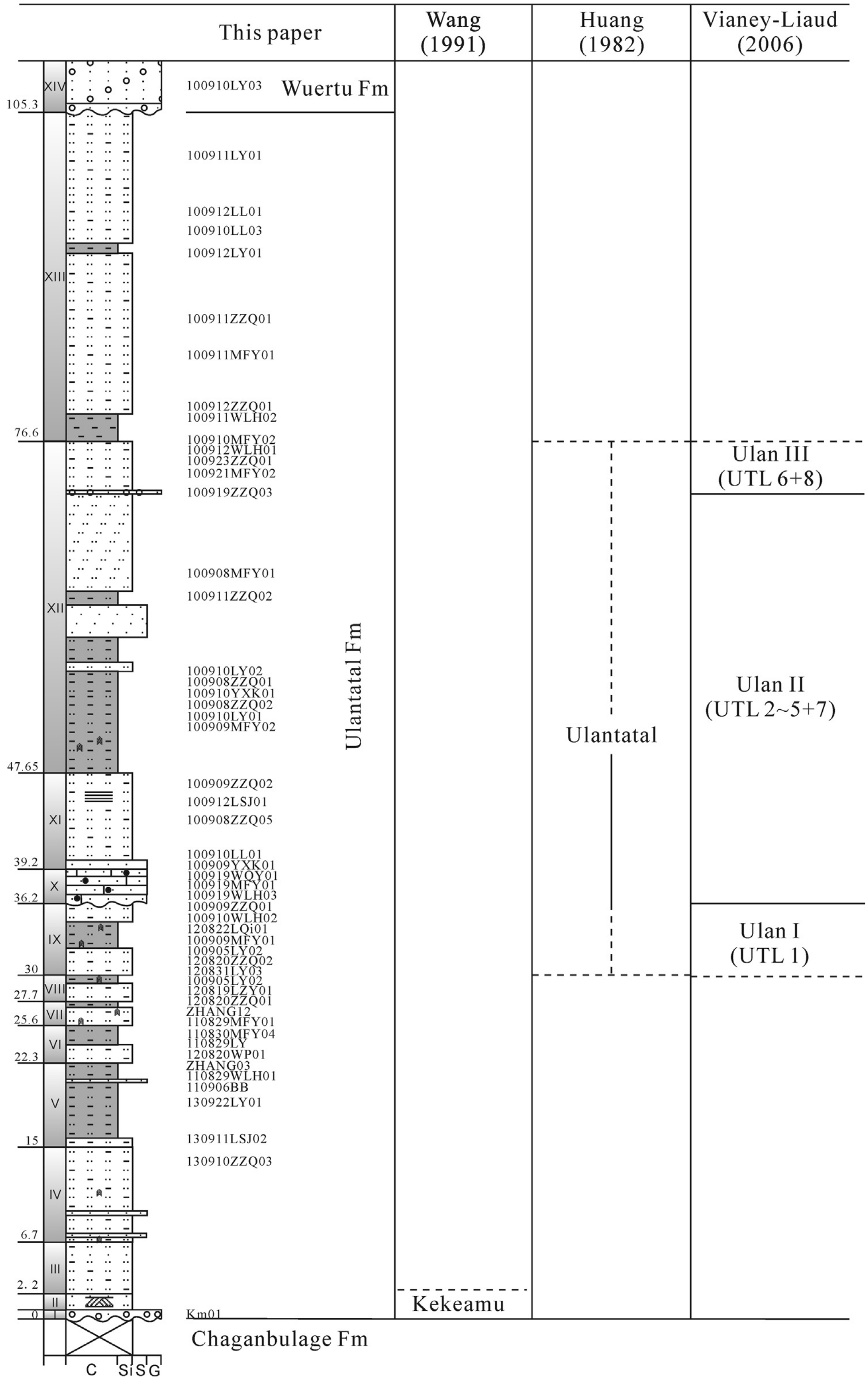

Fig. 4. Composite profile of the Ulantatal Formation and tentative correlation with previous localities and units. Legends are the same as on Fig. 3.

Fig. 4. Profil composite de la formation Ulantatal et tentative de corrélation avec les sites et unités précédemment répertoriés. Légendes identiques à celles de la Fig. 3.

more primitive than the type species. Three new forms of zapodid genera can be recognized, e.g. *Allosminthus*, *Heosminthus*, *Shamosminthus*. Referring to the type species of *Allosminthus* and *Heosminthus* from Qujing (Wang, 1985), the Kekeamu taxa are more advanced in tooth morphology. Fossil lagomorphs are not rich, but show the existence of a species of *Desmatolagus*, and a possibly a new species of Leporidae. All of these taxa are more primitive than those found in biozone A of the Valley of Lakes, Mongolia, which is earlier than 31.5 Ma based on the $^{39}Ar/^{40}Ar$ ages of the basalt I (Daxner-Höck et al., 2010). Hence, we propose the Kekeamu fauna is probably Latest Eocene or Earliest Oligocene in age.

The SJ section is also productive. Fossils include *Ordolagus teilhardi*, *Desmatolagus gobiensis*, *Anomoemys lohiculus*, *Karakoromys decessus*, *Euryodontomys*, *Tataromys* sp. nov., *Cricetops* sp. nov., *Eucricetodon* sp. nov., *Zaraalestes minutus*, *Didymocomus*, etc. The assemblage shows a strong similarity with Biozone A of central Mongolia (Daxner-Höck et al., 2010).

We found a rich locality from the topmost horizon of the SZT section, producing *Sinolagomys major*, *Sinolagomys kansuensis*, *Litodonomys* sp., *Parasminthus parvulus*, *Gobiosminthus* sp.,? *Heterosminthus*, *Yindirtemys* cf. *suni*, *Yindirtemys grangeri*/*xiningensis*, etc. This assemblage is comparable to the traditional Late Oligocene Yindirte (Yandantu) fauna (Bohlin, 1942, 1946; Wang et al., 2003). In between this level and the SJ section, there are many horizons with the richest fossil occurrences in this area, including the three units of Vianey-Liaud et al. (2006) and Huang (1982). Hence, the Ulantatal Formation covers most of the Oligocene, and offers a long sequence and successive fossil records for understanding the evolution of mammal faunas after the critical transition from the Eocene to the Oligocene. Further biochronological work is pending, waiting for the results from the ongoing magnetostratigraphic study.

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