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Original Article

Lithofacies and paleoenvironmental analysis of the Upper Cretaceous successions: Yagaan Khovil fossil locality, central Gobi region, Mongolia

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ABSTRACT

The Upper Cretaceous successions are exposed at the Yagaan Khovil fossil locality in the central Gobi region, Mongolia. The successions comprise fluvial deposits that are divided into two units based on the lithological characteristics of the floodplain deposits. The lower unit (Unit 1) is characterized by eolian-influenced environments, whereas the upper unit (Unit 2) is composed predominantly of meandering river systems with lateral accretionary channel fill deposits that show concretion at the top of the bed. The shift in depositional processes from the lower to the upper unit can be hypothesized as the result of the change in the proximity of the eolian-affected area to the study area. The successions preserving the similar paleoenvironmental transition are also present in the Nemegt Basin, where the successions shift from reddish mud beds affected by eolian processes to meandering fluvial successions. Additionally, to the similar sedimentological features, similarities in vertebrate fossils between Yagaan Khovil and the formations in the Nemegt Basin imply the close relationship between the two areas in terms of environmental conditions, ages, and stratigraphic positions. To enhance the stratigraphic framework of the Upper Cretaceous strata in Mongolia, future work should integrate the findings of this study with new radiometric dating techniques.

Keywords: Flavio-eolian deposits, facies analysis, Dinosaur habitats

INTRODUCTION

The Upper Cretaceous sedimentary successions in the Gobi Desert of Mongolia have yielded numerous fossils of dinosaurs, reptiles, and mammals, as well as ichnofossils such as dinosaur footprints (e.g., Berkey and Morris, 1927; Gradziński et al., 1977; Kurzanov, 1981; Tumanova, 1987; Ivakhnenko and Kurzanov, 1988; Perle et al., 1993; Novacek et al., 1997; Maryańska et al., 2004; Norell et al., 2009). Not only fossil remains, numerous previous studies have examined the sedimentary characteristics of the Upper Cretaceous strata and their paleoenvironmental settings, revealing Cretaceous strata in the Gobi Desert are mainly composed of a combination of successions dominated by fluvial of the Nemegt Formation and eolian deposits of the Djadokhta and Baruungoyot formations (e.g., Jerzykiewicz and Russel, 1991; Fastovsky et al., 1997; Jerzykiewicz, 2000; Shuvalov, 2000; Eberth et al., 2009; Eberth, 2018; Fanti et al., 2018; Saneyoshi et al., 2021b). The relationship between the dinosaurs and their habitats in the eolian deposits has attracted much scientific attention for 100 years (e.g., Berkey and Morris, 1927; Fastovsky et al., 1997; Saneyoshi et al., 2021a). The majority of such investigations have been conducted in the central Gobi region, where the Djadokhta Formation is prominently exposed, as well as in the Southwest Gobi region, featuring prominent exposures of the Baruungoyot and Nemegt formations (Gradziński et al., 1977; Fanti et al., 2018; Saneyoshi et al., 2021a, 2021b). Notably, recent studies suggest that the Djadokhta, Baruungoyot, and Nemegt formations are partially contemporaneous, and therefore the coexistence of both humid and arid environments within a relatively small geographical extent (e.g., Fanti et al., 2012; Eberth, 2018; Jerzykiewicz et al., 2021). The eolian deposits of the Djadokhta Formation, exposed in the central Gobi region, are often interpreted to be deposited in arid to semiarid conditions (Fastovsky et al., 1997; Dashzeveg et al., 2005; Saneyoshi et al., 2021b). Dinosaurs preserved in these deposits thus have been thought to have lived in extremely dry areas with very few wet areas (Saneyoshi et al., 2021a). However, similarly to the recent arguments of the temporal overlap of the three formations, eolian deposits in several fossil localities in the basin, such as Alag Teeg, Khongil, and Yagaan Khovil, are accompanied by fluvial deposits with paleosol successions (Tsogtbaatar and Chinzorig, 2007; Saneyoshi et al., 2010), suggesting paleoenvironment of these localities are fundamentally different from those in the localities only dominated by eolian deposits.

Yagaan Khovil is located in between the classic fossil localities of the Baruungoyot / Nemegt formations to the west and those of the Djadokhta Formation to the east. Due to the location, the age of the deposits in Yagaan Khovil is somewhat enigmatic but tentatively correlated to the Nemegt Formation (Watabe et al., 2010). The paleoenvironment of the deposits has been variously interpreted from arid to wet conditions or the mixture of those based on vertebrate and bivalve fossils (Martinson, 1982; Sukhanov and Narmandakh, 2006; Danilov and Syromyatnikova, 2008; Watabe et al., 2010; Niedzwiedzki et al., 2012). In this study, we provide the first detailed sedimentological

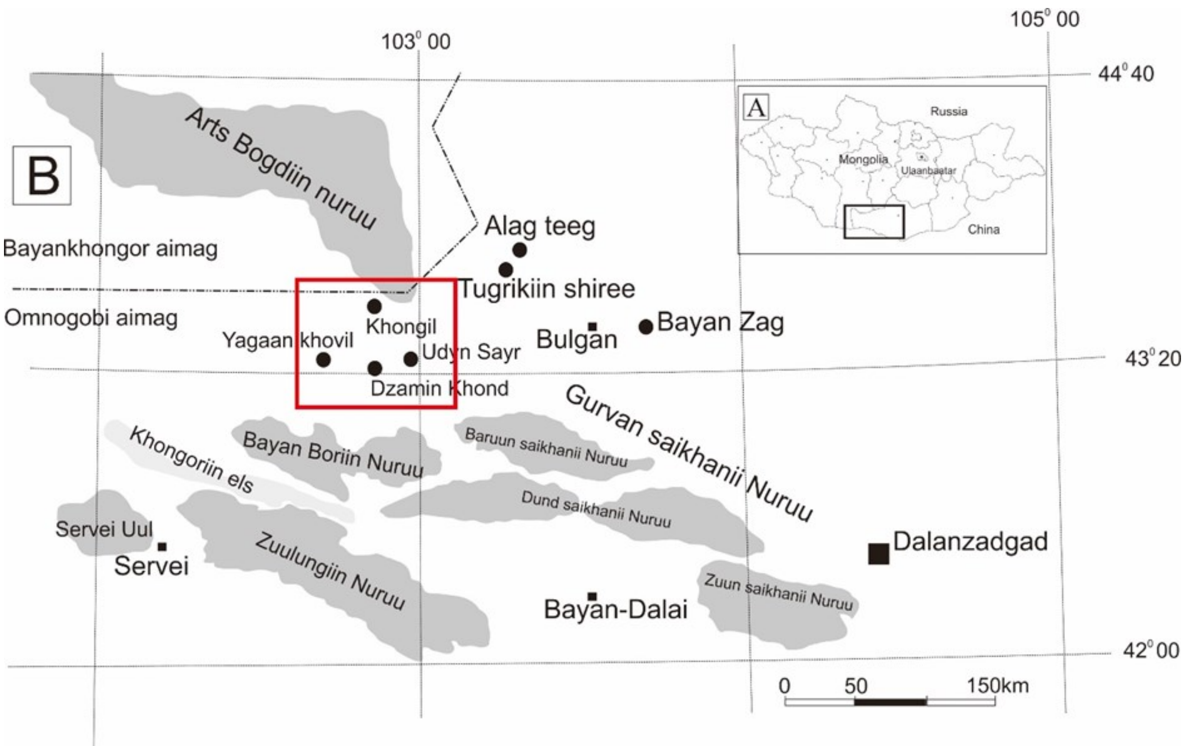

Fig. 1. Map showing the dinosaur localities in the Arts Bogd. Yagaan Khovil is located in the western part of the central Gobi region

description and paleoenvironmental interpretations based on the sedimentological features of the successions at Yagaan Khovil with the implication of the lithological correlation to the Nemegt Formation.

LITHOFACIES OF THE STUDY AREA

The Yagaan Khovil fossil locality is located in the central Gobi region, Mongolia, 80 km west of Bulgan township, Umnogovi aimag (Fig. 1). The Upper Cretaceous sediments are well-exposed owing to the sparse vegetation in the area. The coordinates and altitude of the main outcrop in the area are 44°05'13"N, 102° 10'08"E and 1300 m above sea level, respectively (e.g., Watabe et al., 2010). The sedimentary successions are widely exposed along an NW-SE trend in the locality (Watabe et al., 2010). Eight stratigraphic sections were taken throughout the locality (Fig. 2). The vertical and lateral variations of the lithofacies in the sections were described and characterized using facies analysis (Walker, 1984; Walker and James, 1992). The deposits were divided into Unit 1 and Unit 2. Unit 1 crops out in the central part of the main outcrop area (Fig. 2), and Unit 2 conformably overlies Unit 1 and is exposed in the south, southeast, and north of the study area (Figs. 2, 3).

Unit 1

Description: The unit, typically light reddish to light grey to pale yellow, is characterized by muddy sandstone beds and has well-sorted massive lithofacies with crudely parallel laminations in part (Fig. 4). The sandy part is composed of medium to fine sand. The lithofacies is 1.5–5.5 m thick and tapers towards the southwest. The unit crops out at the base level of the main outcrop of the Yagaan Khovil and can be traced laterally for at least 100 m. The lithofacies overlie the well-sorted sandstone beds with ripple lamination of Unit 2.

Interpretation: These facies consist of well-sorted muddy sandstone with massive facies. The crudely parallel lamination shows that flows may have been responsible for the bed formation, but there are no clear sedimentary structures. In addition, massive facies in the unit indicate the existence of stable water conditions. Thus, based on the presence of massive facies, the paleoenvironments of this unit are interpreted as floodplain environments with

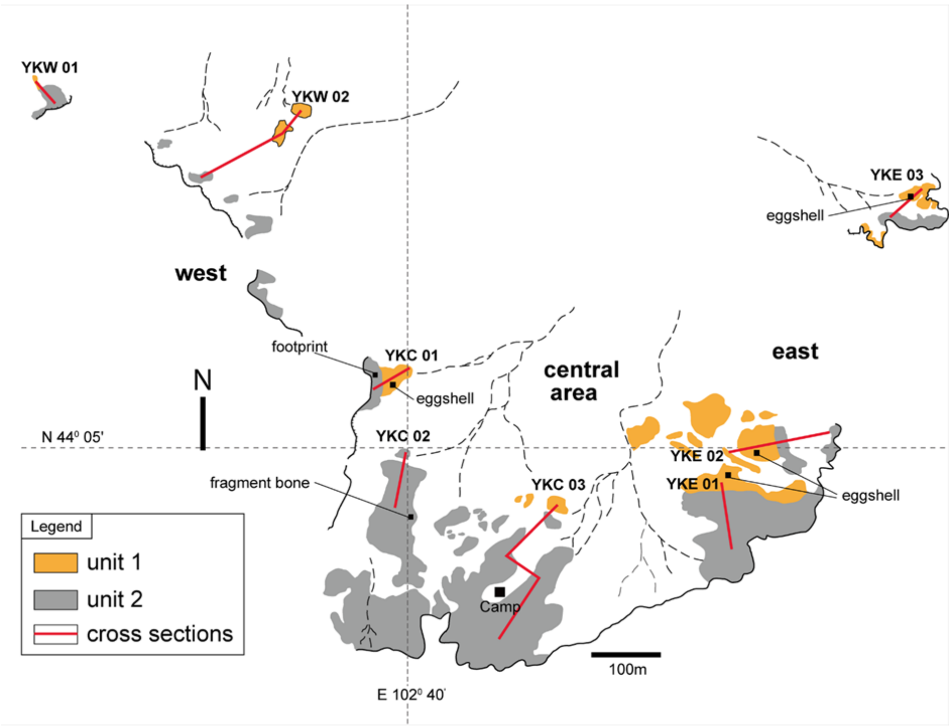

Fig. 2. Schematic geological map of Yagaan Khovil. Line and numbers show the location of columnar sections in Fig. 3.

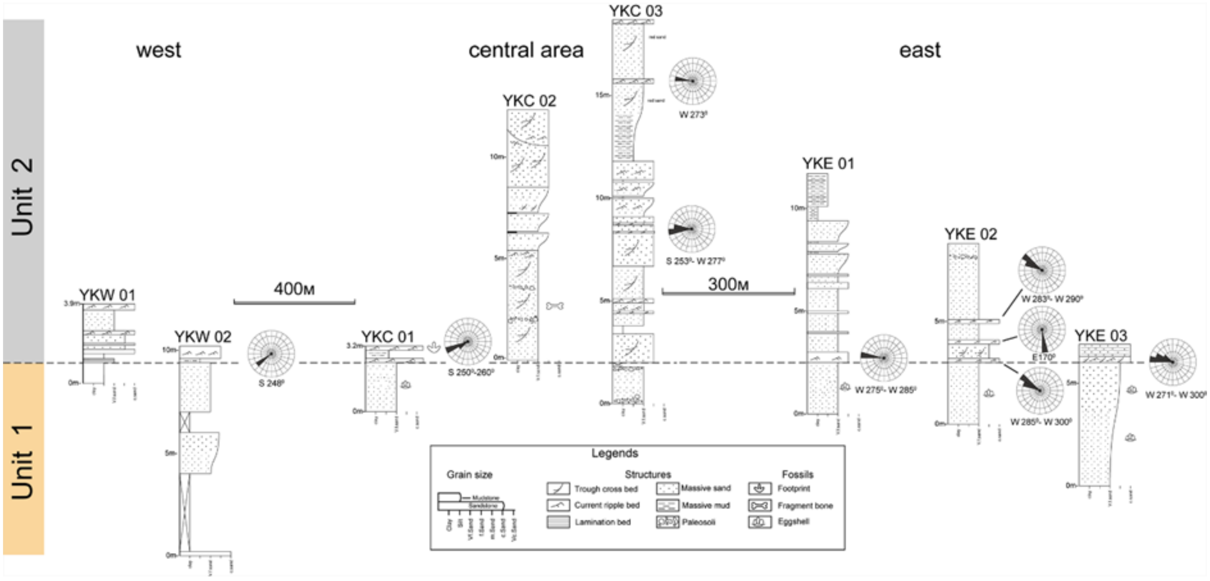

Fig. 3. Columnar cross-sections of the study area. Black arrows show the paleocurrent (up = north). The sedimentary successions consist of two units (Unit 1 and Unit 2).

weak unidirectional flow conditions.

Unit 2

Well-sorted sandstone beds with trough cross -stratification and ripple lamination

Description: These beds are composed mainly of medium- to fine-grained sand with rare granules of mud clasts with concave-up erosional bases. These sandstone beds are up to 0.1–0.3 m thick and exhibit trough and planar cross-stratification with current ripple lamination (Fig. 4). The surface of the sandstone beds has current ripple lamination. Some beds show concretion at the top of the bed that includes tabular rhythmic sheets of a lateral accretionary origin (Fig. 4). These concretionary parts occur less frequently than the lower part of the unit. Based on cross-stratification, the dominant paleocurrent direction is from the east to the southwest (Fig. 4). The structures displaying the paleocurrent directions are oriented perpendicular to the direction of lateral accretion.

Interpretation: The sedimentary structures formed by unidirectional currents, granule-sized mud clasts, and erosional bases indicate that this sandstone bed is of a fluvial channel fill origin. Lateral accretionary structures with concreted beds are interpreted as a meandering fluvial channel (e.g., Eberth, 2018). Tabular rhythmic sheets of a lateral accretionary origin in this sandstone are interpreted as being point bars in meandering paleo-channel systems. The orientation of paleo flow within the sedimentary facies is perpendicular to the direction of lateral accretion, providing further support for these interpretations.

Well-sorted mudstone beds

Description: The massive mudstone beds are reddish to light brown, very well-sorted, and overlain by well-sorted sandstone beds (Fig. 4). The mudstone facies beds are 0.1–0.7 m thick and contain burrows measuring 0.1 cm in diameter and 1.0–5.0 cm at most in length. Some parts of the mudstone beds are 0.03–0.05 m thick and exhibit a sheet-like or lenticular geometry (Fig. 4). These facies beds occur in the eastern and central parts of the study area. The well-sorted mudstone beds of Unit 2 have yielded numerous bone fossils of dinosaurs, including Avimimus skeletons (Watabe et al., 2010), dinosaur footprints, and egg shells (Saneyoshi et al., 2010).

Interpretation: The presence of paleo-channel deposits above and below these facies is a good indicator of a floodplain environment. Thin mudstone beds with a lenticular geometry are interpreted as small oxbow lake-like environments in meandering river systems

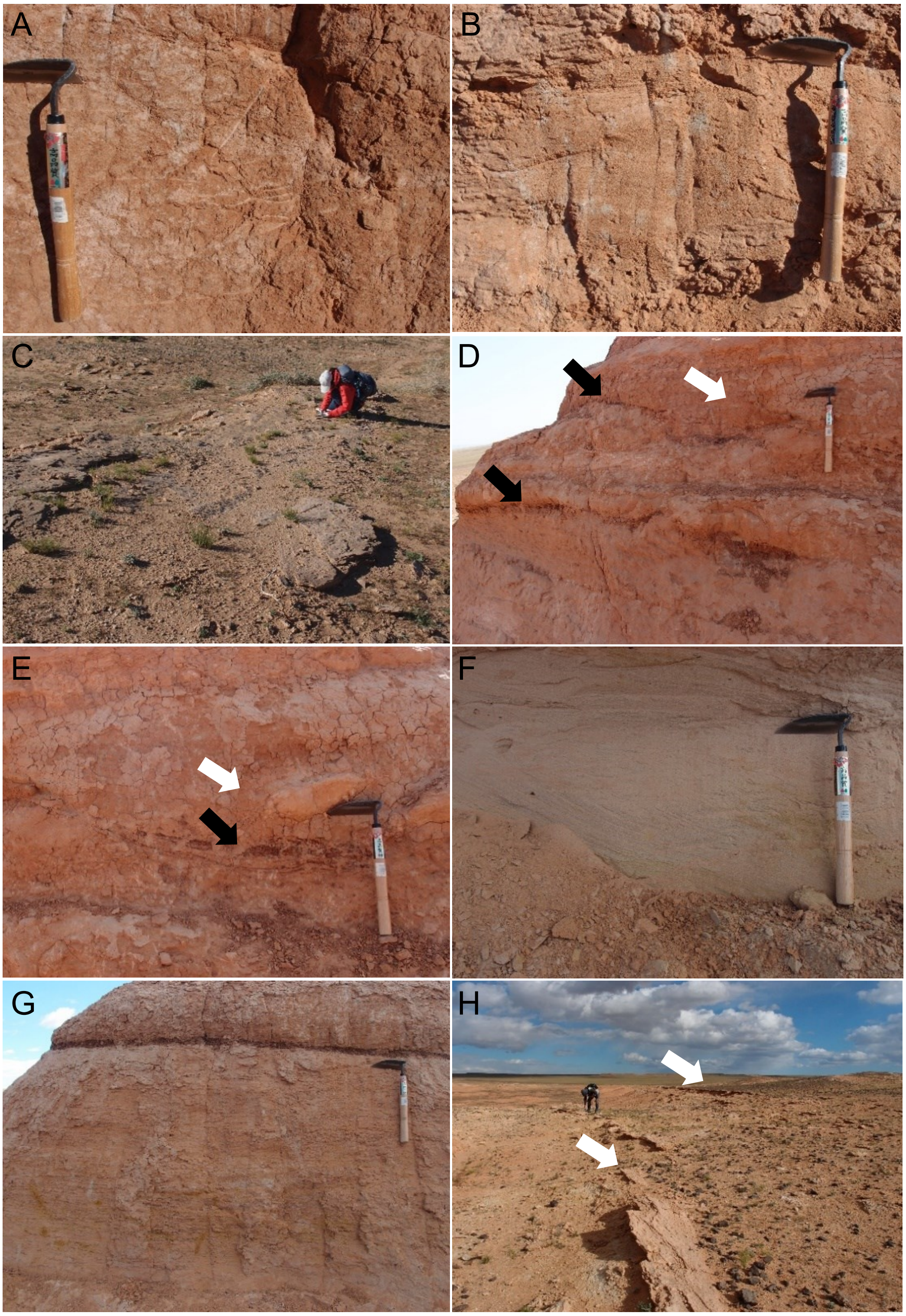

Fig. 4. Photography of an outcrop showing Unit 1 and Unit 2. (A) Well-sorted muddy sandstone with massive facies in Unit 1. (B) Crudely stratified beds of muddy sandstone beds in Unit 1. (C) Exhumed top sets of lateral accretional paleochannel deposits in the base of Unit 2. (D) Alternation of sandstone (white arrow) and mudstone (black arrow) beds in Unit 2. (E) Sandstone beds of a white arrow in a (D) photograph. (F) well-sorted sandstone beds with current ripple lamination in the middle horizon of Unit 2. (G) small oxbow lakes-like environments in meandering river systems. (H) Cemented top sets with shallow meandering paleochannels (white arrows) in the upper horizon of Unit 2.

(Miall, 2016). The 1.0–2.0 m-thick upward fining successions comprise well-sorted sandstone beds with a lateral accretionary origin to well-sorted mudstone beds. This stacking pattern can be explained by the deposition of point bars within meander belts. In summary, the mudstones in Unit 2 can be interpreted as a combination of meandering river systems and small oxbow lake environments, whereas those in Unit 1 are floodplain deposits composed of massive muddy sandstone beds with evidence of crude lamination.

DISCUSSION

In the study area, the paleoenvironments of Unit 1 differ from those in Unit 2. Unit 1 is characterized by a thick floodplain with weak unidirectional flow conditions and well-sorted reddish-colored sand facies. Similar lithofacies, such as structure-less sandstone beds, have been reported from the Djadokhta and Baruungoyot formations at the Ukhaa Tolgod and Nemegt fossil localities (e.g., Loope et al., 1999; Eberth et al., 2009). Previously, these sedimentary facies characteristics have been characterized as eolian-related alluvial fan deposits (Loope et al., 1998; Dingus et al., 2008). However, in the study area, Unit 1 is characterized by the presence of crude sedimentary structures that have been attributed to the existence of unidirectional weak flow conditions. In addition, the absence of extensive cross-bedding, which is characteristic of eolian lithofacies (Fastovsky et al., 1997), is also a good indicator of water-affected conditions in closed eolian deposits (Eberth, 2018). There is no evidence of eolian facies at the locality, but sedimentary facies show that Unit 1 probably accumulated on floodplains close to eolian environments. The paleoenvironmental interpretation, the juxtaposition of arid and fluvial conditions in close proximity, is congruent with the inferences from vertebrate and bivalve fossil remains, which are indicative of the mixture of wet and dry conditions (Martinson, 1982; Sukhanov and Narmandakh, 2006; Danilov and Syromyatnikova, 2008; Watabe et al., 2010; Niedzwiedzki et al., 2012). A similar juxtaposition of fluvial and arid habitats has also been inferred in Udiin Sair, close to the study area (Saneyoshi et al., 2021a). Therefore the similar paleoenvironmental condition seemed to have had a certain geographical extent, or the marginal environment was shifted through time.

The aforementioned sedimentological data with the reconstructed paleoenvironment may also contribute to the correlation of the successions at Yagaan Khovil to those in other localities. In Unit 1, the input of large amounts of eolian material may have significantly affected the sedimentation process at the site, and Unit 2 consists of a meandering fluvial belt with fining upward sequences of 1.0–2.0 m thick (Fig. 2). Such meandering fluvial system is well exposed in the middle successions at Bugin Tsav in the Nemegt sedimentary basin in the southwestern Gobi Desert (Eberth, 2018; Jerzykiewicz et al., 2021). Additionally, the fossil assemblages from Yagaan Khovil and the Bugiin Tsav fossil locality share a small theropod Avimimus as well as other vertebrate taxa and dinosaur footprints (e.g., Ishigaki et al., 2009; Watabe et al., 2010; Averianov and Lopatin, 2020). These sedimentological and paleontological similarities may suggest that Unit 2 can be correlated with the sedimentary successions and paleoenvironments at the fossil locality in the Nemegt sedimentary basin.

CONCLUSION

Facies analysis was conducted for the Upper Cretaceous successions at Yagaan Khovil to describe fluvial depositional sequences. The lithostratigraphic analysis conducted in this study provides valuable insights into the paleoenvironmental conditions that were prevalent in the Yagaan Khovil region. Two types of floodplain deposits were identified in the successions. Unit 1, the lower part of the successions in the study area, is composed predominantly of floodplain deposits affected by eolian-alluvial mixed systems. Unit 2 occupies the upper part of the successions and consists of meandering fluvial systems. Distinct differences in the depositional environments of the floodplain deposits in Units 1 and 2 are inferred as the relative influence of eolian environments. In summary, overlapping successions from Unit 1 to Unit 2 suggest eolian-affected environments, closely located to meandering fluvial environments at the site.

The lithostratigraphic data could also complement the existing knowledge of the stratigraphic relationships of the successions in this area. The combination of eolian-influenced fluvial deposits and suggested paleoenvironment at the western end of the central Gobi region is similar to those of the Baruungoyot and Nemegt formations in the Nemegt Basin. Therefore, we consider that our findings are congruent with the recent argument of Jerzykiewicz et al. (2021), suggesting the close spatial and temporal relationship between the Djadokhta Formation in the western end of the central Gobi region and the Baruungoyot and Nemegt formations in the Nemegt Basin.

Although the lithostratigraphic data here are helpful but not conclusive to make some inferences for the correlation of the successions in the area due to the lack of continuous exposures of the Upper Cretaceous successions, informative biostratigraphic indicators, and igneous rocks for radiometric dating. This is not only a profound issue in this study area but the whole Upper Cretaceous stratigraphic horizon in the Gobi Desert. Therefore, in future work, the findings of this study should be combined with new radiometric dating techniques reported by Kurumada et al. (2020) and Tanabe et al. (2023) to develop the rigorous stratigraphic and temporal framework of the Upper Cretaceous strata in the Gobi Desert, Mongolia.

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