Cretaceous Research 48 (2014) 177–192

Contents lists available at ScienceDirect

Cretaceous Research

journal homepage: www.elsevier.com/locate/CretRes

Sedimentology, stratigraphy and palynological occurrences of the late Cretaceous Erlian Formation, Erlian Basin, Inner Mongolia, People's Republic of China

Christophe Bonnetti [a,*], Fabrice Malartre [a], Vincent Huault [a], Michel Cuney [a], Sylvain Bourlange [a], Xiaodong Liu [b], Yunbiao Peng [c]

[a] Université de Lorraine, GéoRessources - CNRS - CREGU, BP239, F54506 Vandoeuvre-lès-Nancy, France
[b] East China Institute of Technology, 56 Xuefu Road, Linchuan, 344000 Fuzhou, Jiangxi, China
[c] Geological Team No. 208, BOG, CNNC, Baotou, Inner Mongolia, China

A R T I C L E I N F O

Article history:
Received 10 April 2013
Accepted in revised form 30 September 2013
Available online 6 February 2014

Keywords:
Late Cretaceous
Erlian Basin
Erlian Formation
Sedimentology
Stratigraphy
Palynology

A B S T R A C T

The Erlian Basin is one of the non-marine Cretaceous basins of north-east China that developed during the late Mesozoic continental extension in eastern Asia. This basin experienced two major tectonic events: (i) a syn-rift stage that was dominated by a fluvial–lacustrine depositional environment and (ii) a post-rift stage that was dominated by a fluvial environment. A new sedimentological study performed on Erlian Formation drill cores has led to the determination of an architectural model and to the subsequent characterisation of the stratigraphic evolution of this sedimentary unit during the late Cretaceous. The palynological occurrences that were identified in samples provided a possible stratigraphical age for the Erlian Formation.

Sediments of the Erlian Formation occur at the top of the Cretaceous stratigraphic column of the Erlian Basin and were deposited during the post-rift stage. Facies architecture and the ideal succession of facies that were identified for this formation exhibit two different members, both dominated by a fluvial depositional environment: (i) the lower member, which is dominated by channels of a braided river system and (ii) the upper member, which is dominated by overbank deposits. The lower member expresses a tectonically induced uplift as indicated by channels clustering under negative accommodation, whereas a period of stratigraphic base-level rise that is associated with an increase of accommodation is identified in the upper member. Therefore the Erlian Formation highlights an alternation of short uplifts that were dominated by braided fluvial channel deposits with periods of stratigraphic base-level rise that were dominated by overbank deposits. This sedimentological architecture has significant metallogenic implications for the origin of confined permeable sandstone layers, which represent adequate host-rocks for roll front-type uranium deposits.

The palynological assemblage *Exesipollenites*, *Ulmipollenites/Ulmoideipites*, *Buttinia* and *Momipites* that were recognised in two samples of the Erlian Formation has revealed a post-late Campanian age therefore more likely indicating a late Cretaceous age of deposition for the sediments of the Erlian Formation.

1. Introduction

In north-eastern China, Cretaceous to Tertiary sediments are widely distributed in several fault-controlled sedimentary basins (Sha, 2007), especially in the Heilongjiang, Jilin and Liaoning provinces and in eastern Inner Mongolia. Mesozoic sedimentary basins of north-east China are highly prospective mainly because of their coal-bearing Cretaceous deposits (e.g., the Jixi, Boli, Shuangyashan, Hegang and Fuxin coal basins; RTMCFEH, 1986), oil and gas fields (e.g., in the Daqing and Liaohe oil and gas fields; Ye et al., 1990) and sandstone-hosted uranium deposits (e.g., in the Erlian and Ordos basins; Cai et al., 2007; Dahlkamp, 2009). Energy resources such as uranium deposits are mainly hosted in post-rift sediments that were deposited in a fluvial environment (e.g., the Nuheting and the Subeng uranium deposits hosted in the Erlian Formation of the Erlian Basin, Dahlkamp, 2009; the Qianjiadian uranium deposit hosted in the Yaojia Formation of the Kailu Basin,

* Corresponding author. UMR GeoRessources 7359, Université de Lorraine, 54506 Vandœuvre-lès-Nancy Cedex, France. Tel.: +33 (0) 679882458.
E-mail address: christophe.bonnetti@univ-lorraine.fr (C. Bonnetti).

0195-6671/$ – see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.cretres.2013.09.013

Cai and Li, 2008). Therefore, the understanding of both the development of these basins and the geological processes leading to the genesis of oil and gas, coal and uranium deposits appears to be a key for exploration and discovery of energy resources. Cretaceous strata of Mesozoic sedimentary basins in north-east China has been the focus of much research since the 1920s (e.g., Granger and Berkey, 1922; Grabau, 1923; Wang, 1929). All of these basins (Sha, 2007; Carroll et al., 2010) mainly developed from the late Jurassic to the early Cretaceous during a major NW–SE continental extension (Charles et al., 2013). Authors considered the deposition of late Cretaceous sediments (Ren et al., 2002; Meng et al., 2003; Charles et al., 2013) as part of a post-rift stage likely corresponding to the closure of these basins. However, whereas early Cretaceous sedimentary units are mostly well defined in most of the basins in north-east China (e.g., the Bayanhua Group in the Erlian Basin, Song et al., 1986; Lin et al., 2001), the stratigraphic scheme of late Cretaceous sediments remains doubtful. Indeed, except for the Songliao Basin where the late Cretaceous sediments have continuously been deposited (Sha, 2007; Li et al., 2011; Wan et al., 2013), late Cretaceous sediments are absent or only partially occur in many other basins because of either a lack of deposition or erosion (Sha, 2007). Therefore, in some basins, such as the Erlian Basin, both the characterisation of the stratigraphic evolution and the determination of accurate biostratigraphic ages of late Cretaceous sediments is of a great interest to better characterise the sedimentological expression of the post-rift stage, part of the tectono-sedimentary evolution of these basins. In the Erlian Basin, sedimentary facies and the depositional environment of the Erlian Formation were characterised from outcrop observations by Currie and Eberth (1993) and Van Itterbeeck et al. (2005). However, no continuous succession of facies along the stratigraphic column of this formation was suitable on outcrops. Therefore no accurate architectural model with stratigraphic evolution has been proposed previously in the literature. Cretaceous sediments delivered valuable palaeontological data such as in the dinosaur-bearing Erlian Formation (Van Itterbeeck et al., 2005). Among land plants, the most important event was the appearance of flowering plants or angiosperms (e.g., *Archaefructus*, Sun et al., 2002; Taylor et al., 2009), which most likely originated in the early Cretaceous (or in late Jurassic) and then rapidly diversified in the late Cretaceous to become the dominant land plants of the Cenozoic (Skelton, 2006). A late Cretaceous age was proposed for the Erlian Formation (Rozhdestvensky, 1966, 1977; Brett-Surman, 1979; Gou et al., 1986; Weishampel and Horner, 1986; Cai et al., 1990; Jerzykiewicz and Russel, 1991; Currie and Eberth, 1993; Ma, 1994; Van Itterbeeck et al., 2005). Nevertheless, there is a significant distinction according to the species used for dating this formation. Indeed all age determinations that were based on the dinosaur fauna (Rozhdestvensky, 1966, 1977; Brett-Surman, 1979; Weishampel and Horner, 1986) indicated a Cenomanian to Santonian age whereas Van Itterbeeck et al. (2005) used charophytes and ostracods to prove a correlation with the Nemegt Formation which is considered Campanian–Maastrichtian in age. Only Van Itterbeeck et al. (2007) have presented a description of spores and pollen (i.e., palynology is the most accurate biostratigraphic tool in fluvial palaeoenvironment) and also proposed a late Cretaceous age for the Erlian Formation.

The following study of the Erlian Formation results from a collaborative work between the GéoRessources Laboratory of Lorraine University (France), the East China Institute of Technology (ECIT) and the Chinese National Nuclear Corporation (CNNC). In 2011, a field trip was conducted in the Erlian Basin to (i) characterise the facies architecture of the Erlian Formation occurring in the Erennaoer Sag in the Wulanchabu Sub-basin and (ii) collect drill-core samples from the Nuheting uranium deposit. The main purpose of this paper is to propose an architectural model of the sedimentary facies belonging to the Erlian Formation and to characterise its stratigraphic evolution. Some samples from the Erlian Formation were selected and analysed to identify pollen and spore occurrences.

2. Geological and stratigraphical setting

2.1. The Erlian Basin

The Erlian Basin (or Eren Basin) is located in north-east China (Fig. 1), Inner Mongolia, near the border of China and Mongolia. This basin occurs in the Northern China – Mongolia Tract (NCMT), to the south of the Mongol-Okhotsk Zone separating the Sino-Korean Craton to the south from the Siberian Craton to the north (Meng et al., 2003). It is an intracontinental basin formed during the Mesozoic continental extension of eastern Asia (Charles et al., 2013) and framed by the Songliao Basin to the east, the Hailar Basin to the north, the east Gobi Basin to the west and the Ordos Basin to the south-west (Meng et al., 2003).

The Erlian Basin lies on a folded and metamorphosed basement corresponding to the southern margin of the Xing'an or Xing Meng Mongolian Orogenic Belt (Lin et al., 2001; Dou and Chang, 2003). The Xing'an Mongolian Orogenic Belt represents the eastern part of the Central Asia Orogenic Belt that was accreted during the Palaeozoic (Zhou et al., 2010). This basement mainly composed of both Palaeozoic and early Mesozoic intermediate to felsic granitic plutons (Wu et al., 2005a, 2005b, 2005c), mafic to felsic volcanic rocks (Chen and Chen, 1997; Ying et al., 2010) and Proterozoic to Palaeozoic sedimentary or metasedimentary units (Wu et al., 2005b; Zhou et al., 2010). From north to south there is a parallel alternation of horsts and half-grabens that could be related to a "Basin and Range" structural pattern (Wernicke et al., 1988; Ren et al., 1998). The Erlian Basin is divided in approximately 52 half-graben-shaped depressions (Dou and Chang, 2003; Meng et al., 2003) that are controlled by a normal-fault system.

The Erlian Basin is approximately 800 km long and 50–200 km wide, oriented ENE–WSW, and corresponding to a surface area of approximately 130,000 km^2 (Dou and Chang, 2003; Fig. 1). It comprises five major sub-basins: the Chuanjing Sub-basin to the west, the Wulanchabu Sub-basin in the central-west, the Manite Sub-basin in the central-north, the Tengge'er Sub-basin in the south-east and the Wunite Sub-basin to the north-east. These sub-basins are framed by a series of horsts or ranges oriented ENE-WSW: the Daxing'anling Ranges to the east, the Bayinbaolige Horst to the north and the Suolunshan Horst further to the west, and finally the Wendurmiao Horst to the south. The Sunite Horst occupies the central part of the Erlian Basin and divides it into two different main parts, north and south (Dou and Chang, 2003).

2.2. Tectono-stratigraphic evolution

The main stage of the Erlian Basin infilling occurred in the early Cretaceous, during the rifting phase (Lin et al., 2001; Meng et al., 2003). The entirety of the depositional systems occurring in the basin corresponds to an intracontinental environment and the sediments are alluvial, fluvial and fluvial–lacustrine (Lin et al., 2001). The accommodation in the basin is controlled by the combination of several factors such as tectonic subsidence, lake-level variations, sedimentation rate and climatic changes (Lin et al., 2001). The Erlian Basin developed in three main tectonic stages that are bounded by two major unconformities (Graham et al., 2001) and associated with different stratigraphic units, various depositional systems and lithologies (Lin et al., 2001; Sha, 2007; Fig. 2).