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Controls on accumulation of anomalously thick coals: implications for sequence stratigraphic analysis

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Short title – Sequence stratigraphy of anomalously thick coals

1 ABSTRACT

2 Coal seams preserve high-resolution records of ancient terrestrial water table (base level)
3 fluctuations in ancient peat accumulations, but little is known about base level change in
4 anomalously thick coal seams. Using the Early Cretaceous 91-m anomalously thick No. 6 coal
5 (lignite) seam in the Erlan Basin (NE China) as a case study, the origin and evolution of peat

6 accumulation in a continental faulted basin is revealed by sedimentological, sequence stratigraphic,
7 and coal petrological analyses. The lignite is dominated by huminite, indicating oxygen-deficient
8 and waterlogged conditions in the precursor mire. Five types of key sequence stratigraphic surfaces
9 are recognized, including paludification (PaS), terrestrialization (TeS), accommodation-reversal
10 (ARS), give-up transgressive (GUTS), and nonmarine flooding (NFS) surfaces. Vertically, the No. 6
11 coal seam consists of fourteen superimposed wetting-up and drying-up cycles separated by key
12 sequence stratigraphic surfaces, with each of these cycles spanning about 156–173 kyr. [In a high](#)
13 [accommodation peat swamp system, The the](#) wetting-up cycles are [generally](#) characterized by
14 [gradual an upward increase transitions from inertinite-dominated to huminite-dominated coal in](#)
15 [mineral matter and inertodetrinite and an upward decrease in huminite](#) with the PaS as their base
16 and the GUTS or ~~NFS-ARS~~ as their top, representing a trend of upward-increasing accommodation.
17 In contrast, the drying-up cycles are [generally](#) characterized by ~~gradual an upward~~ [decrease in](#)
18 [mineral matter and inertodetrinite and an upward increase in huminite-transitions from](#)
19 [huminite-rich to inertinite-rich coal](#), with the TeS as their base and the ARS as their top,
20 representing a trend of upward-decreasing accommodation. A multi-phase mire stacking model for
21 accumulation of the coal seam is proposed based on high-frequency accommodation cycles and the
22 stratigraphic relationships between coal and clastic sediments. High-frequency accommodation
23 cycles in the coal are closely related to water table fluctuations in the precursor mires and are driven
24 by high-frequency climate [via changes in the intensity and seasonality of precipitation](#) in a
25 relatively stable subsidence regime. Recognition that the No. 6 seam is composed of multiple
26 stacked mires has implications for studies addressing palaeoclimatic inferences and genesis of
27 anomalously thick coals seams.

Keywords Erlian Basin, Shengli coalfield, Jiergalantu Sag, Early Cretaceous, anomalously thick coal seam, maceral, sequence stratigraphy, multi-phase mire stacking model.

INTRODUCTION

Coal seams are the product of the burial and compaction of peat (Diessel, 1992). In addition to being an important natural resource, coals are important sources of paleoenvironmental information relating to prevailing conditions ([watertable, plant material and mire types](#)) at the time of peat formation and geological evolution of sedimentary basins (Shao et al., 2003; Holdgate et al., 2007, 2009; Lu et al., 2017). Peat formation is sensitive to fluctuations in the watertable (base level) (Waksman and Stevens, 1929; Jager and Bruins, 1975; Benner et al., 1984; Clymo, 1987; Holdgate et al., 1995; Petersen et al., 1998; Moore and Shearer, 2003) and such changes can be recorded in the composition of the resulting coal beds. Anomalously thick coal seams comprising single coals > 40-m thick, that are sometimes termed “super-thick coal seams” (e.g., Zhao, 1982; Wang et al., 2016), can be particularly effective to infer ground watertable changes through long periods of peat deposition. In paralic settings where the watertable is connected to the sea and rises landward in accordance with the optimum graded profile of a mature stream (Diessel, 1992), watertable fluctuations can be correlated to changes in relative sea level (e.g., Bohacs and Suter, 1997). Conversely, in true continental settings, where ground watertable is not influenced by the sea, watertable fluctuations are correlated with climatic changes (e.g., Large, 2007). Such concepts of how watertable fluctuations relate to either relative sea level or palaeoclimatic drivers are extensively based on thin coal seams, with little information known about anomalously thick coal seams and how these might differ.

The genesis of the anomalously thick coal seams has been extensively discussed in the past

(e.g., Shearer et al., 1994, 1995; Wu et al., 1996; Bohacs and Suter, 1997; Wang et al., 1999, 2000; Diessel et al., 2000; Wadsworth et al., 2002; Davies et al., 2005; Moore et al., 2006; Diessel., 2007; Jerrett et al., 2011a; O’Keefe et al., 2013; Wang et al., 2016; Li et al., 2017; Guo et al., 2018) including the application of allochthonous and autochthonous coal depositional models. The allochthonous coal accumulation model has been demonstrated from analysis of sedimentary features of thick coal seams in coal-forming faulted basins, including late Carboniferous-Permian thick coal seams in the faulted basin of the Central Massif (France) and Eocene thick coal seams in the Fushun Basin of East China (Wu et al., 1996; Wang et al., 1999, 2000). In the allochthonous model, there are abundant gravity-flow sediments such as debris flow, turbidity current sediments, contemporaneous gravity slumps, and deformation structures in thick coal seams that indicate they formed in profundal and unstable lacustrine environments (Wang et al., 1999, 2000). The autochthonous coal depositional model has been used to explain the response of peat-forming environments, as well as coal geometry and properties, to changes in the rate of accommodation space (Fielding, 1984, 1987; Bohacs and Suter, 1997; Holdgate and Clark, 2000; Wadsworth et al., 2002). In the autochthonous model, coals correspond to single palaeo-peat bodies and the long-term accommodation rate must balance the peat production rate so that peat can accumulate and be preserved over long time periods (Bohacs and Suter, 1997; Wadsworth et al., 2002). However, alternative concepts have considered that coals do not correspond to single palaeo-peat bodies and may represent successions of stacked mires separated by hiatal surfaces (Moore and Shearer, 1993; Moore, 1994; Shearer et al., 1994; Banerjee et al., 1996; Moore et al., 2006; Jerrett et al., 2011a; Wang et al., 2016). These models require further study in order to understand fully how anomalously thick coal seams accumulated and to elucidate the main controls on their formation.

Previous studies have demonstrated that the high-frequency accommodation record in coal

seams could be identified by recognizing changes in the internal lithotypes and compositional characteristics of the coal (Diessel, 1992; Diessel et al., 2000; Holz et al., 2002; Wadsworth et al., 2002, 2003; Davies et al., 2005, 2006; Silva et al., 2008; Jerrett et al., 2011a, 2011b, 2011c; Opluštil et al., 2013; Guo et al., 2018). The Early Cretaceous No. 6 coal seam from the Erlian Basin in NE China, a 91-m anomalously thick coal, should contain information of high-frequency accommodation record as well. The controls on the accumulation of peat ~~accumulation~~ in a continental faulted basin can be properly addressed by investigating the sedimentology, coal petrography and sequence stratigraphy of the basin fill.

The aim of this study is to (1) examine evidence for non-hiatal and hiatal surfaces within coals and peat, (2) reconstruct the dominant control on water table fluctuations within coals, and (3) propose a model for the genesis of anomalously thick coal seams. This can be achieved through analysis and interpretation of the characteristics of No. 6 coal seam within the Early Cretaceous Saihantala Formation from the Shengli coalfield in the Jieryalantu Sag of the Erlian Basin, Inner Mongolia, NE China.

SEQUENCE STRATIGRAPHY OF PEAT AND COAL

A continuously rising water table above the sediment surface produces accommodation for peat to accumulate (Bohacs and Suter, 1997). Accommodation is controlled by the height of the mire water table, basin subsidence and sediment compaction (Bohacs and Suter, 1997). Low accommodation will facilitate intense degradation of plant material (Moore and Shearer, 2003). For the optimum preservation of peat, the rate of accommodation creation must be in equilibrium with the rate of peat accumulation (Diessel, 1992; Bohacs and Suter, 1997). If the accommodation rate (AR) exceeds the peat production rate (PPR), the mire is drowned and buried by marine or

98 lacustrine sediments. If the PPR outpaces the AR, the mire may be exposed, oxidized and reworked
99 (Moore et al., 1996; Jerrett et al., 2011b), a process that is analogous to modern mires in Sarawak
100 (Malaysia) and Sumatra (Indonesia) documented by Esterle and Ferm (1994). Within the
101 comparatively narrow 'peat window', high-frequency variations in the AR/PPR ratio result in
102 hydrological, botanical and therefore compositional changes in the accumulating peat. As maximum
103 peat accumulation rate seems to be relatively constant in a given latitudinal zone (Diessel et al.,
104 2000), changes in peat composition are predominantly controlled by the accommodation rate.

105 Holdgate et al. (1995) identified parasequence boundaries and sequence boundaries within
106 Cenozoic coal seams exceeding 100 m in thickness to analyze the origins of brown coal lithotypes.
107 Diessel et al. (2000), Wadsworth et al. (2003), and Jerrett et al. (2011b) interpreted six key sequence
108 stratigraphic surfaces that correspond to the equivalent of marine flooding surface and sequence
109 boundaries in coal-bearing strata (Fig. 1). These comprise: (1) Terrestrialization surfaces (TeS) that
110 represents the initiation of peat accumulation above marine, lagoon or lacustrine strata, which is
111 non-hiatal because it indicates a transition from clastic sedimentation to peat accumulation in
112 response to shallowing; (2) Erosional subaerial exposure surfaces (ES) that represent the
113 termination of peat accumulation due to a continued decrease in the accommodation, ultimately
114 resulting in zero accommodation, which is hiatal; (3) Paludification surfaces (PaS) represent the
115 initiation of peat accumulation about subaerial, terrigenous strata, which may be hiatal or non-hiatal,
116 depending on the rate of clastic influx; (4) Accommodation reversal surfaces (ARS) correspond to a
117 level where a reversal in the accommodation trend occurred, which may be equivalent to a sequence
118 boundary or maximum flooding surface; (5) Give-up transgressive surface (GUTS) that corresponds
119 to the level at which peat accumulation is gradually replaced by clastic or lacustrine sedimentation
120 due to drowning, which is non-hiatal and represents the termination of peat accumulation; and (6)

121 Non-marine flooding surfaces (NFS) that correspond to the level at which peat accumulation is
122 drowned due to a sudden increase in accommodation, which is hiatal and represents the termination
123 of peat accumulation. These six key surfaces have been used in the present study, with each
124 expressed as a composition change in the coal that can be traced from adjacent and coeval marine
125 and terrestrial clastic strata into the coal seam (Wadsworth et al., 2002, 2003; Davies et al., 2005,
126 2006).

127 In a high accommodation peat swamp system, the wetting-up cycles are generally
128 characterized by an upward increase in mineral matter and inertodetrinite and an upward decrease in
129 huminite, representing a trend of upward-increasing accommodation. In contrast, the drying-up
130 cycles are generally characterized by an upward decrease in mineral matter and inertodetrinite and
131 an upward increase in huminite, representing a trend of upward-decreasing accommodation.

132

133 GEOLOGICAL BACKGROUND

134 The Erlian Basin is a Mesozoic–Cenozoic intra-continental faulted basin. It is situated on the
135 southern margin of the Xing Mongolian Orogenic Belt, which is located on the suture between the
136 Asia and Siberian plates (Zhu et al., 2000). The basin is elongated from southwest to northeast, with
137 the western margin marked by the Suolunshan Uplift and the eastern margin bounded by the middle
138 Yanshanian Daxing'anling Uplift. It is bounded to the north and south by the
139 Caledonian–Hercynian Bayanbaolige and the Caledonian Wenduermiao Uplifts, respectively (Wang
140 et al., 2013). The basin has five major sub-basins: the Chuanjing sub-basin to the west, the
141 Wulanchabu sub-basin to the central-west, the Manite sub-basin to the central-north, the Wunite
142 sub-basin to the north-east, and the Tengger sub-basin to the south-east (Lin et al., 2001) (Fig. 2).
143 The Sunite Uplift occupies the central area of the Erlian Basin and divides the basin into two

144 northern and southern sections (Bonnetti et al., 2014). Within the Erlian Basin, approximately 53
145 north-northeast trending sags occur that are controlled by a series of normal-faults that formed
146 synchronously, with each displaying similar basin fill and patterns of tectonic evolution (Lin et al.,
147 2001). The sags were formed by extension during the Jurassic and Cretaceous, with approximately
148 90% of these being half-grabens and 10% being grabens (Wang et al., 2013).

149 The Erlian Basin underwent two long and complicated evolution stages, including the Paleozoic
150 trough stage and the Mesozoic–Cenozoic continental rift basin stage, forming two distinctly
151 different tectonic layers of the Xing'an Mongolian folded basement and cap rock (Zhu et al., 2000).
152 The Lower Cretaceous basin fill formed from approximately 124–105.5Ma and is composed of
153 (from bottom to top) the Aershan, Tengger, and Saihantala ~~formations Fformations~~ (Fig. 3),
154 consisting of conglomerates, sandy conglomerates, sandstones, siltstones, mudstones, shales, and
155 coals (mainly lignites), with a total thickness of 2100–4500 m (Wang et al., 2013; Wang et al.,
156 2019). The Aershan Formation was deposited during the lower Aptian, the Tengger Formation
157 during the upper Aptian, and the Saihantala Formation during the Albian stages of the Cretaceous
158 (Sun and Zhen, 2000; Zhang et al, 2015; ICS, 2017). The basin underwent a tensional stress during
159 the deposition of the Aershan and Tengger Formations, changing to ~~a~~-compressional stress during
160 the deposition of the Saihantala Formation (Lin et al., 2001; Bonnetti et al., 2014). The
161 palynological assemblages in Erlian Basin ~~implied-imply~~ a warm and humid climate during the
162 Early Cretaceous (Zhu et al., 2000).

163 The Shengli coalfield is located in the Jiergalangtu Sag in the southeast of the Erlian Basin and
164 is part of the Xilinhot administrative division in Inner Mongolia. It is a half-graben bounded by
165 syn-depositional faults to the northwest and the southeast and in it the dominant coal-bearing unit is
166 the Saihantala Formation. The Saihantala Formation comprises sandy conglomerate, sandstone,

Commented [JH1]: The text refers to 3 formations, so no upper case F should be used. 'formations' is correct.

167 siltstone, mudstone and lignite, [which were](#) deposited in fluvio-lacustrine environments (Fig. 4)
168 (Lin et al., 2001; Wang et al., 2015). Based on ~~the~~ key stratigraphic surfaces, the Saihantala
169 Formation is subdivided into two third-order sequences (average 3.75 Ma for each sequence) (Wang
170 et al., 2019). The No. 6 coal seams ~~are~~ [is](#) considered to have accumulated in a braided fluvial delta
171 setting and located in the early transgressive systems tract (Wang et al., 2015). Palynological
172 analysis of [the](#) No. 6 coal seam shows the spore-pollen assemblage is dominated by bryophytes,
173 pteridophytes, and gymnosperms (Dai et al., 2012).

174

175 **METHODS AND PRINCIPLES**

176 **Sampling and analytical methods**

177 A total of 66 coal samples were contiguous and collected based on the coal lithotype from the
178 No. 6 coal seam at the Jimei 2 borehole with samples spanning the 91-m total seam thickness (Fig.
179 4). All samples were stored immediately in plastic bags to eliminate contamination and reduce
180 oxidation as much as possible. Sample number and location are shown in Fig. 4. Maceral analyses
181 and huminite reflectance measurements were carried out on 66 and 9 samples, respectively (Table
182 1).

183 Coal samples were crushed to less than 1 mm diameter in the State Key Laboratory Coal
184 Resources and Safe Mining (Beijing, China), and a representative portion of each was set in epoxy
185 resin. After curing, the samples were cut and polished according to standard methods. The maceral
186 classification and terminology in this study is based on conventional procedures (ICCP, 2001;
187 Sýkorová et al., 2005) and the Chinese National Standard Method for Determining Maceral and
188 Minerals in Coal (GB/T 8899-2013). Maceral analyses and huminite reflectance measurements
189 were conducted under white reflected and fluorescent light, with a 50x oil-immersion objective

190 using a Leica DM4500P LED microscope. For maceral analyses, a total of around 500 points in
191 each polished block was counted. For reflectance measurements, YAG (0.903%), GGG (1.719%),
192 sapphire (0.590%), and optically black (zero) standards at 23 °C were used, with a total of 100
193 points in each polished block counted. Finally, the testing results were converted into percentage
194 values for each maceral and average huminite reflectance values.

195 The vertical documentation of petrographic trends through the Jimei 2 borehole and the
196 transverse correlation of coal and clastic intercalations are based on the lithostratigraphic and coal
197 correlation frameworks of Wang et al. (2015). ~~The~~ Depositional environments were identified on
198 the basis of lithology, sedimentary structures, sediment body geometries, and fossils, and vertical
199 and lateral relationships with other facies (Lin et al., 2001; Wang et al., 2015).

200

201 **Palaeoenvironmental implications of macerals and minerals**

202 Organic matter reacts with great sensitivity to groundwater oscillations and associated
203 changes in pH and redox potentials so that even weak changes in hydrological regimes of peat mires
204 may be translated into compositional differences in the subsequent coal seams (Frenzel, 1983).
205 Therefore, ~~identification of~~ variations in maceral compositions ~~though the lignite bed~~ can be used as
206 criteria for assessing water table and degree of fluctuation in the peat-forming environment (Moore
207 et al., 2003; Jerrett et al., 2011b). Vertical variations in coal composition are assumed to indicate
208 adaption to changes in the original peat mire environment. In the present study, the contents of
209 huminite, inertinite, inertodetrinite, and minerals have been emphasized (Petersen and Ratanasthien,
210 2011).

211 Huminite macerals, derived from the humification of vascular plant tissue, are interpreted as
212 suggesting preservation in low pH, anoxic conditions associated with a high watertable (Diessel,

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1992). Inertinite macerals consist of the same plant parts as huminite and liptinite, but have experienced severe degradation under conditions of microbial or fungal oxidation, desiccation, or partial combustion in wildfires (Diessel, 1992; Moore et al., 1996; Scott, 2000; O’Keefe et al., 2011; Hower et al., 2013). High inertinite content may indicate a low or fluctuating mire watertable (Moore et al., 1996) and low accommodation relative to peat production (Diessel, 1992). Inertodetrinite is easily dispersed because it consists mainly of fragmented fusinite and semifusinite and is frequently found as an allochthonous component (Diessel, 2007). ~~Inertodetrinite may represent small fragments of oxidized material (Moore et al., 1996).~~ It may also include wind-blown charcoal particles, waterborne small charcoal particles and fragmented large waterborne charcoal fragments (Clark and Royall, 1995). In contrast to well-structured macerals which were well preserved in situ, fragmented macerals of any type may represent transport or reworking (Jerrett et al., 2011b).

Minerals are generally syngenetic and could be widely used to infer the depositional conditions in the precursor mire (Diessel et al., 2000; Davies et al., 2006). Increased mineral content may indicate more frequent inundations of the precursor mire resulting in deposition of siliciclastics (Petersen and Ratanasthien, 2011). Mires can be classified into two fundamentally different types based on the key control on the position of water table, including low-lying and raised mires (Jerrett et al., 2011c). Low-lying and rheotrophic (groundwater-fed) mires are easily subject to fluvial or flooding inundations, resulting in high contents of minerals in coals. In contrast, ombrotrophic (rainwater-fed) mires can prohibit clastic influx topographically due to being above the regional water table (Anderson, 1964, 1983). A mineral proportion of less than 10% is interpreted as suggesting oligotrophic peat-forming conditions that existed in ancient ombrotrophic raised mires (Diessel et al., 2000). Mineral contents ranging between 10% and 30% have been taken to signify

mostly rheotrophic, limnotelmatic peat-forming conditions in which the topogenous mires were intermittently covered by shallow water (Diessel et al., 2000). Rheotrophic mires, where the water table corresponds to the regional ground water table (base level), are characterized by high accommodation conditions (Opluštil and Sýkorová, 2018). However, some rheotrophic mires can develop peat that is low in mineral content because of possible ~~absent~~lack of –clastic sources, the filter effect of margin mire vegetation, and flocculated clay mineral (Jerrett et al., 2011b; Opluštil and Sýkorová, 2018). Therefore, low mineral matter content may represent a rheotrophic mire. In contrast, domed, ombrotrophic mires can develop when the rate of peat production exceeds the accommodation rate under low accommodation conditions. Ombrotrophic typical peat could be used as analogs of ~~themany~~ inertinite-rich durain ~~Pennsylvanian~~ ~~coals of many Pennsylvanian~~ (Grady et al., 1993). The lowest mineral content in coals indicates a balanced ratio of accommodation/peat accumulation ~~in a raised mire~~ (Diessel et al., 2000).

Huminite and inertinite content are considered to be the best indicators of accommodation change (Jerrett et al., 2011b, 2011c), whilst mineral content is an indication of balanced versus unbalanced accommodation conditions (Jerrett et al., 2011b, 2011c). In order to limit bias caused by ambiguities in the palaeoenvironmental interpretation of individual macerals and minerals, the maceral and mineral associations will be ~~taken into comprehensively considered consideration~~ (Diessel et al., 2000; Jerrett et al., 2011b; Opluštil and Sýkorová, 2018).

RESULTS AND INTERPRETATION

Facies and depositional environments

~~According to~~Based on the lithofacies ~~association and from~~ the characteristics of logging curves, ~~based on observations made on exposed~~ outcrop and cores as well as information from previous

259 studies (Lin et al., 2001; Wang et al., 2015), a total of three facies associations in the Saihantala
260 Formation in the Shengli coalfield were recognized, including fan delta plain, braided fluvial delta
261 plain, and littoral-sublittoral lacustrine environments.

263 *Facies Association A: fan delta plain*

264 *Description*

265 Facies association A is composed of sandy conglomerates and an intercalation of mudstones and
266 coals, [having a thickness of more than 40 m \(Wang et al., 2015\)](#). This facies association has a
267 fining-upward trend from a sandy conglomerate-rich lower part into a coal-bearing upper part (Fig.
268 5 A). Basal matrix supported sandy conglomerates are characterized by mixed fine carbonaceous
269 material and gravel, poor sorting and roundness, [multistorey bodies](#) –and a basal erosional surface
270 (Fig. 5 A). Mudstones, carbonaceous mudstones, and coal seams (Fig. 5B) are developed with
271 horizontal and massive bedding, along with wood fossils (Fig. 5C) and are often incised by sandy
272 conglomerate bodies.

273 *Interpretation*

274 Facies association A is interpreted as a fan delta plain deposit based on the lithological
275 characteristics. It is generally located on the steep slope of the half-graben basin and is
276 characterized by its proximal provenance, coarse-grained clasts, large thickness and narrow
277 distribution belt (Lin et al., 2001). Sandy conglomerate-dominated deposits with erosional bases,
278 poor sorting and roundness are interpreted as distributary channels, similar to distributary channels
279 described by Reading (1978). Overlying mudstones and thin~~ned~~ coals are interpreted as [fresh water](#)
280 [peats \(Dai et al., 2012\)](#) and an interdistributary bay.

281

282 *Facies Association B: braided fluvial delta plain*

283 *Description*

284 Facies association B comprises of sandy conglomerates, sandstones, mudstones and coals, [having a](#)
285 [thickness more than 30 m](#) (Fig. 4). Sandy conglomerates are characterized by moderate sorting and
286 roundness, [multistorey bodies](#) and commonly a basal erosional surface (Fig. 5D). Medium-fine
287 grained sandstones are developed with planar cross-beddings. The overlying mudstones and
288 siltstones display horizontal lamination and contain carbonaceous materials. Thick coal seams ([up to](#)
289 [91 m](#)) are associated with these deposits and are often punctuated by conglomerates and sandstones.

290 *Interpretation*

291 Facies association B shows many characteristics similar to classically described braided fluvial
292 delta plain. It was generally developed in the gentle slope of the half-graben basin. The
293 upward-fining succession from basal sandy conglomerates to sandstones demonstrates distributary
294 channels (Fig. 5D) such as those documented by Walker and James (1992). Overlying mudstones,
295 siltstones and coals deposits are interpreted as [fresh water peats \(Dai et al., 2012\)](#) and
296 interdistributary bay deposits (Fig. 5D).

298 *Facies Association C: littoral-sublittoral lacustrine*

299 *Description*

300 Facies association C is mainly composed of fine-grained sandstones, siltstones, mudstones,
301 carbonaceous mudstones and coals, [having a thickness of more than 50 m](#) (Fig. 4). [Thin](#)
302 [Fine](#) fine-grained sandstones, which often display parallel bedding, are well sorted and rounded with
303 a high mineralogical maturity. [Thick Grey-grey](#) siltstones and mudstones have developed massive
304 beddings and horizontal laminations. Plant fragments, siderite and pyrites concretions are common

305 in these deposits (Wang et al., 2015).

306 *Interpretation*

307 The overall fine-grained sediments indicate a lacustrine origin for facies association C. Fine-grained
308 sandstones with parallel bedding are interpreted as littoral lacustrine deposits (Reading, 1978). Grey,
309 massive and horizontal-laminated siltstones and mudstones represent ~~the~~ sublittoral lacustrine
310 deposits (Widera, 2016).

311 Vertically, littoral-sublittoral lacustrine deposits alternates with those of the braided fluvial
312 delta plain. Laterally, littoral-sublittoral lacustrine deposits grades to fan delta plain deposits in the
313 steep slope and braided fluvial delta plain deposits in the gentle slope (Wang et al., 2015).

314

315 **Huminite reflectance and maceral composition**

316 Random reflectance measurements of the samples were made on ulminite and gelinite
317 macerals, ~~with Samples Random~~ reflectance values ranging from 0.31–0.38% ~~and with an~~
318 average of 0.33% (Table1). Therefore, the rank of the No. 6 coal seam is ~~+~~lignite according to
319 ASTM (2005).

320 The coal is well banded and is mainly composed of bright coal lithotypes. Table 1 shows the
321 maceral (vol.%) and mineral (vol.%) concentrations. Huminite is the most abundant maceral group
322 (17–98%) with an average of 90%, but a few samples show higher values of inertinite and liptinite
323 contents (Table1). The dominant huminite maceral is eu-ulminite, textoulminite, gelinite, and
324 textinite (Fig. 6) with average contents of 36%, 25%, 13%, and 8%, respectively. Maceral contents
325 of all samples for attrinite is 5% and densinite is <1%.

326 Inertinite content of all samples varies between 0–17% and liptinite content between 0–5%.
327 Fusinite, semifusinite, and inertodetrinite are characterized by average contents of <1%, <1%, and

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328 1%, respectively. Macrinite and funginite are rarely observed, and the most dominant liptinite
329 macerals are sporinite and cutinite, with both of which average ~~contents of~~ <1% ~~and~~ <1%.
330 Suberinite, resinite, and bituminite are not common in the samples.

331 The mineral content ranges from 1–73%, which predominantly consists of clay and quartz with
332 average contents of 3% and 2% respectively, while pyrite and calcite are secondary with average
333 contents of 1% and <1%.

334

335 **Mire environments and accommodation trends**

336 As illustrated in Fig. 7, the No. 6 coal seam can be subdivided into the 6A, 6B, and 6C seams
337 separated by ~~the~~ mudstones, which vary in thickness from 50–100 cm. These interseam sediments
338 may have originated as a lacustrine deposit based upon their grey and massive ~~mudstones~~
339 appearance with 50–to 100-cm thick, which is comparable to other documented lacustrine deposit
340 (Widera, 2016). The mudstones are carbonaceous and include plant fossils and coaly material.

341 *Mire environments and accommodation trends of Seam 6A*

342 The basal 6A seam is approximately 30.3-m thick and rests on sandy conglomerates developed in
343 the distributary channel of the deltaic plain (Wang et al., 2015) and underlies a 1-m thick mudstone.
344 Seam 6A has been divided into four units on the basis of huminite, inertinite, and mineral
345 distributions.

346 *Unit A1*

347 Description: Unit A1 overlies sandy conglomerates, is 1.7-m thick and is characterized by high total
348 huminite (92%), low-inertinite (1%) and low-mineral matter (6%) (Table 2). A vertical trend
349 through the unit shows consistently an upward decrease in total huminite, and an increase in total
350 minerals.

351 Interpretation: Unit A1 represents the beginning of peat accumulation under ~~raised,~~
352 ~~ombrotrophic~~heotrophic conditions, indicated by ~~the low mineral content~~high huminite and low
353 inertinite contents (Opluštil and Sýkorová, 2018~~Diessel et al., 2000~~). Based on the vertical
354 composition trend, Unit A1 is interpreted as a ~~drying-up~~wetting-up cycle. Therefore, Unit A1 is
355 separated from the underlying sandy conglomerate by a non-hiatal ~~TeS-PaS~~ (Fig. 7).

356

357 *Unit A2*

358 Description: Unit A2 overlies Unit A1 and attains a thickness of 8.6 m. It contains a large amount of
359 huminite (90%) and low amounts of inertinite (1%) and mineral matter (8%) (Table 2). Unit A2
360 shows an upward decrease in total huminite, accompanied by an upward increase in total ~~inertinite~~
361 inertodetrinite and minerals.

362 Interpretation: The vertical petrographic profile of Unit A2 displays a phase of peat affected by
363 ~~oxidation and reworking~~flooding, demonstrated by the rise in ~~inertinite~~inertodetrinite and mineral
364 contents due to ~~decreasing~~increasing accommodation. Unit A2 experienced ~~a change from~~
365 ~~heotrophic ombrotrophic to heotrophic~~ conditions indicated by high-huminite and low-inertinite
366 content based on mineral content changing from 4% to 12% (Diessel et al., 2000). Unit A2 is
367 interpreted as a ~~drying-up~~wetting-up cycle.

368

369 *Unit A3*

370 Description: Unit A3 overlies Unit A2 and is 7.3-m thick. Petrographically, it is dominated by
371 huminite (91%), and characterized by low-inertinite (<1%) and low-mineral matter content (6%)
372 (Table 2). Vertical trend through Unit A3 shows an upward increase in huminite concentrations.
373 This trend is accompanied by an upward decrease in ~~inertinite and~~ mineral matters.

374 Interpretation: The vertical compositional trend through Unit A3 represents high to balanced
375 accommodation in a mire of ~~ombrotrophic-rheotrophic~~ origin (Jerrett et al., 2011b). Unit A3 is
376 interpreted as a ~~wettingdrying~~-up cycle due to a trend of gradually ~~increasing-decreasing~~
377 accommodation. Therefore, an ARS is placed at the base of Unit A3.

378

379 *Unit A4*

380 Description: Unit A4 overlies Unit A3 and underlies mudstone. Unit A4 is 6-m thick. The unit is
381 characterized by low-mineral ~~matter~~ content (5%) (Table 2), but shows a slight increase in huminite
382 (93%) and inertinite (2%) content relative to Unit A4. Vertical trend through Unit A4 displays an
383 upward increase in huminite and ~~inertinite-inertodetrinite~~ content, accompanied by an obvious
384 decrease in mineral ~~matter~~ content.

385 Interpretation: ~~The low mineral content of Unit A4 is indicative of raised ombrotrophic mire~~
386 ~~conditions.~~ The ~~vertical compositional trend~~ upward increase in inertodetrinite indicates that peat
387 accumulation occurred during increasing accommodation. The high huminite and low inertinite
388 content may be indicative of rheotrophic mire conditions. Therefore, Unit A4 represents a
389 wetting-up cycle which is eventually terminated by the drowning of the mire leading to deposition
390 of siliciclastic sediments. Therefore, the contact between Unit 4 and overlying clastics is interpreted
391 as a non-hiatal GUTS, which is formed when accommodation rate exceeds the rate of peat
392 accumulation.

393

394 *Mire environments and accommodation trends of Seam 6B*

395 The 37.5-m-thick 6B seam overlies a 1-m-thick lacustrine mudstone, and underlies a 0.5-m
396 thick lacustrine mudstone. As illustrated in Fig. 7, the 6B seam can be subdivided into seven distinct

397 depositional units.

398 *Unit B1*

399 Description: Unit B1 overlies mudstone and is 6.5-m thick. Unit B1 is characterized by
400 high-huminite (93%), low-inertinite (1%) and low-mineral (5%) (Table 2). A vertical trend through
401 the unit shows a slight upward increase in huminite content and an upward decrease in ~~inertinite~~
402 ~~inertodetrinite~~ and mineral contents.
403 Interpretation: The high-huminite and low-mineral contents of Unit B1 records an ~~ombrotrophic~~
404 ~~rheotrophic~~ mire under high to balanced accommodation. On account of the slight upward increase
405 in huminite content and upward decrease in ~~inertinite-inertodetrinite~~ and mineral contents, Unit B1
406 is interpreted as a ~~wettingdrying~~-up cycle due to ~~increasing-decreasing~~ accommodation. Therefore,
407 Unit B1 is separated from the underlying mudstone by a non-hiatal ~~PaSTeS~~.

408

409 *Unit B2*

410 Description: Unit B2 overlies Unit B1 and attains a thickness of 3.5 m. The unit is dominated by
411 huminite (94%) and characterized by low-inertinite (1%) and low-mineral (4%) content (Table 2). A
412 vertical trend through Unit B2 shows consistently high-huminite concentrations and a gradational
413 decrease in huminite is observed. This trend is accompanied by increase in mineral, inertinite, and
414 inertodetrinite concentrations.
415 Interpretation: The ~~high-huminite and~~ low-mineral content of Unit B2 is indicative of ~~a domed,~~
416 ~~raised ombrotrophic mire-a rheotrophic mire~~ –and an absence of clastic supply ~~under balanced~~
417 ~~accommodation conditions~~ (~~Diessel et al., 2000~~~~Jerrett et al., 2011b~~). The vertical trend through the
418 unit responds to an upward ~~decrease~~ ~~increase~~ in accommodation. Unit B2 is interpreted as a
419 ~~dryingwetting~~-up cycle. The contact between Units B1 and B2 can be interpreted as an ARS.

420

421 *Unit B3*

422 Description: Unit B3 overlies Unit B2 and is 8.4-m thick. The unit contains high amounts of
423 huminite (79%), low amounts of inertinite (2%) and moderate amounts of mineral (17%) (Table 2).

424 Unit B3 shows similar vertical trend to Unit B2, with an upward decrease in huminite content,
425 accompanied by an upward increase in inertinite, inertodetrinite and mineral contents.

426 Interpretation: The ~~vertical mineral content~~ high huminite and low inertinite through Unit B3
427 represents ~~a transition between ombrotrophic and~~ rheotrophic conditions. The vertical petrographic
428 profile of Unit B3 displays a trend of increasing ~~oxidation accommodation~~ due to ~~decreasing~~
429 ~~accommodation~~ water table rise. Therefore, Unit B3 is interpreted a ~~drying~~ wetting-up cycle.

430

431 *Unit B4*

432 Description: Unit B4 overlies Unit B3 and is 4.7-m thick. The unit is dominated by huminite (94%)
433 and characterized by low-inertinite (1%) and low-mineral (5%) (Table 2). Vertical trends through
434 Unit C1 show consistently high huminite content. An upward increase in huminite content is
435 observed. This trend is accompanied by an upward decrease in inertinite and mineral contents.

436 Interpretation: The vertical compositional trend through Unit B4 suggests a ~~wetting~~ drying-up cycle
437 under a ~~domed, ombrotrophic~~ rheotrophic condition. As the trend of accommodation change in Unit
438 B4 is the opposite to Unit B3, an ARS has been placed between the two units.

439

440 *Unit B5*

441 Description: Unit B5 overlies Unit B4 and attains a thickness of 4.5 m. The unit is characterized by
442 high-huminite (85%), low-inertinite (2%) and moderate-mineral matter content (12%) (Table 2).

443 Vertical trend through the Unit B5 shows an upward decrease in huminite content and an upward
444 increase in ~~inertinite~~inertodetrinite and mineral contents.
445 Interpretation: ~~Low mineral and high huminite contents in the lower part of Unit B5 indicate that~~
446 ~~the mire was morphologically domed and not subject to periodic inundation. The uppermost part of~~
447 ~~Unit B5 is interpreted as recording a period of drying and oxidation, based on the high values of~~
448 ~~inertinite, inertodetrinite and mineral contents.~~ Vertical petrographic trends through Unit B5 imply
449 that peat accumulation occurred under rheotrophic mires during ~~decreasing~~increasing
450 accommodation. Unit B5 therefore represents a ~~drying~~wetting-up cycle. An ARS has been put the
451 boundary between Units B4 and B5.

452

453 *Unit B6*

454 Description: Unit B6 overlies Unit B5 and is 6.6-m thick. The unit is dominated by huminite (93%)
455 ~~content~~ and characterized by low-inertinite (1%) and low-mineral (6%) contents (Table 2). In
456 contrast to Unit B5, Unit B6 shows an opposite vertical trend with an upward increase in huminite
457 content and an upward decrease in inertinite and mineral contents.

458 Interpretation: The ~~low mineral~~high-huminite and low-inertinite content demonstrates that Unit 6
459 represents a raised-planar peat deposited under ~~ombrotrophic~~rheotrophic conditions. Vertical
460 petrographic trends suggest the peat accumulation was developed during an upward ~~increase~~
461 decrease in accommodation. Therefore, Unit B6 is interpreted as a ~~wetting~~drying-up cycle. The
462 contact between Units B5 and B6 could be interpreted as an ARS.

463

464 *Unit B7*

465 Description: Unit B7 overlies Unit B6 and is 1.5-m thick. Unit B7 is capped by mudstone. The unit

466 is characterized by high-huminite (86%) and low-inertinite (6 %) and low-mineral (7%) contents
467 (Table 2). Vertical trend through Unit B7 shows an upward increase in huminite concentration,
468 accompanied by an upward decrease in inertinite and mineral concentrations.

469 Interpretation: ~~Low mineral content in Unit B7 implies the peat was deposited in domed,~~
470 ~~ombrotrophic conditions.~~ Moderate-inertinite (17%) content in the lower part of Unit B7 implies
471 that the peat was subject to oxidation as a result of low accommodation under ombrotrophic
472 conditions. The high-huminite content (91%) and low-inertinite (<1%) content in the upper part of
473 Unit B7 indicate balanced accommodation/peat accumulation under rheotrophic conditions. Vertical
474 composition trends suggest the peat was deposited during increasing accommodation. Therefore,
475 Unit B7 is interpreted as a wetting-up cycle which is eventually terminated by the drowning of the
476 mire resulting in deposition of mudstone. Therefore, Unit B7 is separated from the overlying
477 mudstone by a non-hiatal GUFS, which is formed when accommodation rate exceeds the rate of
478 peat growth.

479

480 *Mire environments and accommodation trends of Seam 6C*

481 At the sampling site, the 6C seam ~~was is~~ 26.4-m thick, and ~~was is~~ capped by a 5.6-m thick
482 carbonaceous mudstone. The floor of the seam consists of a 0.5-m thick mudstone. As illustrated in
483 Fig. 7, the 6C seam has been divided in to three depositional units.

484 *Unit C1*

485 Description: Unit C1 overlies mudstone and attains a thickness of 5.7 m. The unit is dominated by
486 huminite (94%) ~~content~~ and characterized by low-inertinite (<1%) and low-mineral matter (5%)
487 contents (Table 2). Vertical trend through Unit C1 shows consistently high-huminite
488 concentrations-. ~~A~~ Although A-a gradational increase in huminite is observed upwards. This trend is

489 accompanied by decrease in mineral concentration.

490 Interpretation: Low-~~mineral-inertinite~~ and high-huminite contents of Unit A4 indicate partial
491 exclusion of clastic sedimentation under ~~raised~~planar, ~~ombrotrophic-rheotrophic~~ conditions. The
492 vertical petrographical characters represent an upward ~~increase~~ decrease in accommodation based
493 on ~~a decrease in mineral content and~~ a rise in huminite content. On this basis, Unit C1 represent a
494 ~~wetting~~drying-up cycle, which is separated from the underlying mudstone by the PaS.

495

496 *Unit C2*

497 Description: Unit C2 overlies Unit C1 and is 9.7-m thick. The unit contains high amounts of
498 huminite (89%) and low amounts of inertinite (1%) and mineral (9%) (Table 2). In contrast to Unit
499 C1, Unit C2 is characterized by an opposite trend showing an upward decrease in huminite content
500 and an upward increase in mineral content.

501 Interpretation: ~~High huminite (93%) and low mineral (5%) contents in the lower part of Unit C2-~~
502 ~~indicate that the peat was a raised, ombrotrophic mire under high to balance accommodation-~~
503 ~~conditions. Low-inertinite and high-humite content Moderate mineral (16%) content in the topmost-~~
504 ~~part of~~ Unit C2 implies that the peat was developed in a planar, rheotrophic mire under high to
505 balance accommodation. Vertical compositional trends suggest that Unit C2 represents a
506 ~~drying~~wetting-up cycle due to ~~decreasing~~ increasing accommodation. Therefore, the contact
507 between Units C1 and C2 could be interpreted as an ARS.

508

509 *Unit C3*

510 Description: Unit C3 overlies Unit C2 and is 10.4-m thick. Unit C3 is capped by carbonaceous
511 mudstone. The unit is characterized by high-huminite (87%), low-inertinite (8%) and low-mineral

512 (4%) concentrations (Table 2). Unit C3 shows an upward decrease in huminite and mineral contents,
513 accompanied by an upward increase in inertinite content.

514 Interpretation: Low-~~mineral-inertinite content~~ and high huminite content within Unit C3
515 ~~demonstrates may indicate~~ that the peat was developed under ~~ombrotrophic-rheotrophic~~ conditions.
516 ~~The vertical petrographic profile~~Low-mineral content, decreasing huminite and ~~decreasing~~
517 ~~inertinite, and especially inertodetrinite of in~~ Unit C3 ~~displays may indicate~~ a trend of ~~decreasing~~
518 ~~increasing~~ accommodation ~~under restricted mineral input~~. Therefore, Unit C3 is interpreted a
519 ~~dryingwetting~~-up cycle which is terminated by the drowning of mire leading to deposition of
520 carbonaceous mudstone. Therefore, Unit C3 is separated from the overlying carbonaceous
521 mudstone by a ~~non~~-hiatal ~~NFS~~GUTS.

522

523 DISCUSSION

524 Sequence stratigraphic model for peat accumulation

525 A summary diagram of the relationship between accommodation, coal cycles, and the
526 interpreted sequence stratigraphic surfaces of the No. 6 coal seam is shown in Fig. 7. The No. 6 coal
527 seam is thickest in the central part of the sag, splitting and thinning towards both the steep and
528 gentle slopes (Fig. 8) (Wang et al., 2015). Seam splits record the intervention of peat accumulation
529 by clastic sediment deposition and are suggestive of locally accelerated subsidence (Fielding, 1987).
530 In a study of coal distribution, relatively rapid subsidence in the lower delta plain would result in
531 the development of thick coals (Fielding, 1984, 1987).

532 The high-huminite and the low-inertinite contents throughout the lignite indicate that
533 oxygen-deficient and waterlogged conditions were prevalent in the precursor mire. The results of
534 coal petrographic analyses indicate that the No. 6 coal seam has a complex internal signature

535 representing high-frequency wetting-up and drying-up trends. The thick peat accumulation in the
536 half-graben may be facilitated by faulting-induced subsidence events, as documented in a thick coal
537 body in Queensland, Australia (Jorgensen and Fielding, 1999). The No. 6 coal seam in the central
538 part of [the](#) Shengli Coalfield is characterized by the propensity for continued coal cycle
539 development and stacked cycles in one area without important interruption of interseam sediment
540 incursions. Peat accumulation was developed via genetically separate mires that formed between
541 the key sequence stratigraphic surfaces (Fig. 9).

542 The principal control on accommodation in mires is the position change of the permanent
543 water-table (base level) relative to the sediment surface. The average low mineral content, [low](#)
544 [inertinite and high-huminite](#) of No. 6 coal seam, ~~can be~~ interpreted as ~~dominated raised-~~
545 ~~ombrotrophic mires requiring hydrological isolation from the surrounding water table~~ [planar](#)
546 [rheotrophic mires under high to balanced accommodation](#), ~~may indicate that water table fluctuations~~
547 ~~are more likely to preserve a climate record (Eble et al., 1994). Ombrotrophic mires, where water~~
548 ~~and nutrient supply are derived from precipitation alone (Page et al., 2004), are commonly~~
549 ~~considered to conserve only a record of climatically induced base level oscillations (Wüst and~~
550 [Bustin, 2004; Wüst et al., 2008\).](#)

551 The stacked mires and internal mudstone of No. 6 coal seam may be indicative of a relative
552 stable tectonic environment during the peat accumulation, which was periodically punctuated by
553 small flooding events causing cessation of peat accumulation but bringing in enough essential
554 nutrients for rejuvenation of mires. A [syssyn](#)-depositional fault system in the half-graben may attract
555 and restrict inorganic sediments to a narrow zone, which would promote the development of
556 anomalously thick coal seams. These are analogous to the formation of an anomalously thick
557 Cretaceous-age coal mire in the Greymouth coalfield (Moore et al., 2006). Relatively high, frequent

558 oscillating base levels promote rapid peat growth during relative high accommodation period
559 indicated by high huminite contents (average 90%). Frequent base level fluctuations also promote
560 coal seam cycle stacking in ~~the~~ one place, leading to thick coal development (Holdgate and Clark,
561 2000). Therefore, the optimum “sweet spot” for vertical mire-on-mire stacking is located in the
562 central part of the basin where moderate subsidence and ~~ombrotrophic-rheotrophic~~ mires provide
563 enough accommodation space and favorable settings for peat accumulation.

564

565 **High-resolution accommodation records in the No. 6 coal seam**

566 Evidence of wetting-up and drying-up cycles in the No. 6 coal seam (Fig. 7) demonstrate the
567 occurrence of high-resolution accommodation cycles, which typically may not be recognized or
568 preserved in time-equivalent clastic strata. It is clear that the No. 6 seam contains multiple complete
569 accommodation cycles. Past studies have indicated that similar accommodation cycles can be
570 correlated over distances of at least tens of kilometers (e.g., Greb et al., 2002; Jerrett et al., 2011a,
571 2011b, 2011c). On this basis, it has been accepted that high-resolution accommodation cycles
572 represent subtle responses of peat driven by high-frequency sea-level and climate change in ~~the~~
573 marginal-marine-to-paralic depositional environments ([Jerrett et al., 2011a, 2011b, 2011c](#)). However,
574 in continental faulted basins, watertable fluctuations are controlled by basin subsidence and climate
575 (Guo et al., 2018). The No. 6 coal seam was developed in the shrinkage stage of basin evolution
576 with relatively moderate subsidence rates, which provide a stable condition conducive to the long
577 period of peat accumulation and preservation. It has been suggested that the alternative
578 high-frequency changes between rheotrophic and ombrotrophic mires occurred and were driven by
579 fluctuations in the balance between precipitation and evapotranspiration (Jerrett et al., 2011c). If
580 precipitation outpaces evaporation, an ombrotrophic mire would be developed (Jerrett et al., 2011c).

581 The subtropical warm and humid climate in the Early Cretaceous of the Erlian Basin (Zhu et al.,
582 2000; Shen et al., 2018) may have helped maintain water-saturated conditions, providing enough
583 rain for peat formation.

584 The anomalously thick coal seams in the margin of the sag contain abundant sandstone splits,
585 and these splits represent incised valleys fills which cut into coal seam (Fig. 8), indicating the
586 potential sequence boundaries within amalgamated portion of the seams. Wetting-up or drying-up
587 cycles in the siliciclastic sediments can be identified within the amalgamated coals, providing a
588 method to correlate the coal with the siliciclastic sediments in the relative isochronal stratigraphic
589 framework. The ~~NFS~~-or-GUTS, representing a gradual change terminating the deposition of the
590 mire, may be related to the parasequence boundary in the siliciclastic sediments. The ARS in the
591 coals may correspond to the sequence boundary or parasequence boundary in the siliciclastic
592 sediments, depending on the variable trend of decreasing accommodation and increasing
593 accommodation (Fig. 9). Petrographic analysis reveals the complex internal signatures of
594 wetting-up and drying-up cycles in coals, indicating that a high-frequency palaeoclimatic changes
595 may be ignored in analyses of siliciclastic sediments. The seven cycles in the 6B seam cannot be
596 traced in the adjacent siliciclastic sediments (Fig. 9), suggesting that such low orders of magnitude
597 are generally not resolved by the more conventional sequence stratigraphy of siliciclastic sediments.

598 Yan et al. (2016) identified the Milankovitch cycles of the No. 6 coal seam by applying the
599 spectrum analysis to geophysical logs. Based the rates of coal deposition from 0.037 to 0.041
600 m-kyr⁻¹, the depositional period of the No. 6 coal seam was calculated as 2183–2419 kyr. Therefore,
601 the average depositional period for each unit is 156–173 kyr.

602

603 **CONCLUSIONS**

Commented [JH2]: This is a really good conclusion and it shows why this work is important; we could use adapt this as the final sentence of the abstract to give importance to the work?

604 (1) Analysis of the lithofacies association and the characteristics of logging curves has
605 indicated that the Saihantala Formation in the Shengli coalfield was deposited in the fan delta plain,
606 braided fluvial delta plain, and littoral-sublittoral lacustrine environments.

607 (2) The Early Cretaceous anomalously thick coal seam from the Shengli coalfield is
608 predominated by huminite indicating oxygen-deficient and waterlogged conditions in the precursor
609 mire. Five types of key sequence stratigraphic surfaces showing the relationship between
610 accommodation rate and peat production rate are identified in the No. 6 coal seam based on the
611 vertical maceral trends, including paludification surface (PaS), terrestrialization surface (TeS),
612 accommodation-reversal surface (ARS), give-up transgressive surface (GUTS), and nonmarine
613 flooding surface (NFS).

614 (3) The No. 6 coal seam vertically consists of fourteen superimposed wetting-up cycles and
615 drying-up cycles, which are separated by key sequence stratigraphic surfaces, with each of these
616 cycles spanning about 156–173 kyr. In a high accommodation peat swamp system, the wetting-up
617 cycles are generally characterized by an upward increase in mineral matter and inertodetrinite and
618 an upward decrease in huminite with the PaS as their base and the GUTS or ARS as their top,
619 representing a trend of upward-increasing accommodation. In contrast, the drying-up cycles are
620 characterized by an upward decrease in mineral matter and inertodetrinite and an upward increase in
621 huminite, with the TeS as their base and the ARS as their top, representing a trend of
622 upward-decreasing accommodation. A wetting-up cycle is characterized by a gradual upward
623 transition from inertinite-dominated to huminite-dominated coal, with the PaS as their base and the
624 GUTS or NFS as their top, which indicate a trend of upward-increasing accommodation. In contrast,
625 a drying-up cycle is characterized by a gradual upward transition from huminite-rich to
626 inertinite-rich coal, with the TeS as their base and the ARS as their top, which represent a trend of

627 ~~upward-decreasing accommodation.~~

628 (5) High-frequency accommodation cycles inferred by the variations of maceral and mineral
629 contents in the coals are closely related to water table fluctuations in the precursor mires, which are
630 driven by high-frequency climate change in the relative stable subsidence regime.

631

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637

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860 **FIGURE CAPTIONS**

861

862 **Fig. 1.** Idealized curve to show the relationship between accommodation change, peat production,

863 peat facies and resultant coal types (modified from Jerrett et al., 2011b). Left-hand limb shows

864 the drying-up succession deposited during decreasing accommodation; right-hand limb shows

865 wetting-up succession deposited during increasing accommodation.

866

867 **Fig. 2.** Outline map showing the Early Cretaceous Sags of the Erlian Basin (modified from Wang et

868 al., 2019).

869

870 **Fig. 3.** Summary stratigraphic succession through the Lower Cretaceous sediments of the Erlian

871 Basin (Lin et al., 2001).

872

873 **Fig. 4.** Summary column showing sedimentary facies and sequence stratigraphy of the Early

874 Cretaceous Saihantala Formation in the Shengli coalfield of the Erlian Basin from the Jimei2

875 borehole (modified from Wang et al., 2015).

876

877 **Fig. 5.** Field photographs from outcrops and cores of the Early Cretaceous Saihantala Formation in

878 the Shengli coalfield of the Erlian Basin. (A) The fining-up succession from sandy

879 conglomerate to sandstone and coal. Facies association A, Shengli coal mine, the partial pencil

880 is 12 cm length. (B) The coal seams, Shengli coal mine, the pencil is 20 cm length. (C) Fossil

881 wood, Shengli coal mine, the hammer is 30 cm length. (D) The fining-up succession from

882 basal sandy conglomerates to medium-fine grained sandstone with tabular cross-bedding and

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883 coal, Facies association B, Jimei 2 borehole.

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885 **Fig. 6.** Reflected light photomicrographs of typical coal macerals under oil immersion in the No. 6

886 coal seam from the Early Cretaceous Saihantala Formation in the Shengli coalfield of the

887 Erlian Basin. Huminite maceral group: Tex-textoulminite; Eu-eu-ulminite, Co-corpohuminite,

888 Ge-gelinite. Inertinite maceral group: Sf-semifusinite; Id-inertodetrinite, Fg-funginite. Mineral:

889 Pv-pyrite.

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891 **Fig. 7.** Coal facies evolution, watertable level and AR/PPR change in mire of the No. 6 coal seam

892 from the Early Cretaceous Saihantala Formation in the Shengli coalfield of the Erlian Basin.

893 The No. 6 coal seam consists of superimposed shallowing-upward and deepening-upward

894 cycles indicating high-frequency accommodation variations.

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896 **Fig. 8.** Schematic cross section showing vertical and lateral variation of the No. 6 coal seam from

897 the Early Cretaceous Saihantala Formation in the Shengli coalfield of the Erlian Basin. The

898 commonly observed basin-margin splitting of basinward amalgamated coal seams into several

899 daughter coals indicates that accommodation change has a significant control on the thickness

900 and splitting of coal seams.

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902 **Fig. 9.** A multi-phase mire stacking model for accumulation of the No. 6 coal seam from the Early

903 Cretaceous Saihantala Formation in the Shengli coalfield of the Erlian Basin. Schematic chart

904 shows interpreted sequence stratigraphic surfaces and the spatial and temporal correlation of

905 coal units representing the No. 6 coal seam.

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TABLE CAPTIONS

Table 1. Maceral and mineral contents and vitrinite reflectance of the No. 6 coal seam from the Early Cretaceous Saihantala Formation in the Shengli coalfield of the Erlian Basin. Te — textinite; Tex — textoulminite; Eu: eu-ulminite; At: Attrinite; De — densinite; Ge — gelinite; Co — corpogelinite; Su — suberinite; Sp — sporinite; Cu — cutinite; Bi — bituminite; Re —resinite; Ld — liptodetrinite; Fu — fusinite; Sf — semifusinite; Fg — funginite; Ma — macrinite; Id — inertodetrinite.

Table 2. Average composition of each unit in the No. 6 coal seam from the Early Cretaceous Saihantala Formation in the Shengli coalfield of the Erlian Basin.

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