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1 **JURASSIC PALEO GEOGRAPHY OF THE TIAN SHAN: AN**2 **EVOLUTION DRIVEN BY FAR-FIELD TECTONICS AND CLIMATE**

3
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14
15 **ABSTRACT**

16
17 The strongly intracontinental Tian Shan region, in Central Asia represents a key area
18 to understand the long term evolution of continents in general and Asia in particular. If its
19 Paleozoic and Cenozoic geodynamics are well understood, its Mesozoic evolution remains
20 poorly constrained. In order to decipher the paleogeographic and large-scale tectonic
21 evolution of the Tian Shan area during the Jurassic, we compiled, detailed field analyses of
22 sedimentary rocks acquired within and around the Chinese Tian Shan region together with
23 previously published data. We present three paleogeographical maps corresponding to the late
24 Early – early Middle Jurassic, late Middle – early Late Jurassic and Late Jurassic - Early
25 Cretaceous transition periods. We provide a large - scale picture of the Jurassic
26 paleogeographic and climatic evolution of the Tian Shan region and discuss the geological

27 evolution of the range together with the possible driving mechanisms. During the Early to
28 early Middle Jurassic, the topographic evolution of the Tian Shan Range was dominated by
29 progressive planation of late Paleozoic to early Mesozoic relief, locally interrupted by short-
30 lived tectonic uplift. Throughout the region, contemporaneous sedimentation was
31 characterized by alluvial to lacustrine strata deposited under humid conditions. During this
32 period, recurrent limited deformation events associated with strike-slip and compressive
33 tectonics occurred that cannot be explained by far field effect of the Qiangtang collision but
34 could instead be associated to the coeval subduction-related extension affecting the Caspian -
35 Turan domains. During the late Middle to early Late Jurassic, the planation of the Paleozoic –
36 early Mesozoic Tian Shan Range then continued. A shift to more semi-arid conditions during
37 the Late Jurassic is also recorded in the sedimentary series all over the region. At that time,
38 few evidences of deformation exists in the Tian Shan or within the Caspian – Turan domains.
39 We propose that the late Middle – early Late Jurassic corresponded to a period of relative
40 tectonic quiescence in the area. Finally, the Late Jurassic – Early Cretaceous transition was
41 marked by a tectonic reactivation leading to the inversion of the Yarkand – Fergana Basin and
42 to localized relief building in the Tian Shan. This renewed transpressive deformation phase
43 could be mainly related to the coeval accretion of the Helmand block to the south-west, and
44 possibly to the onset of the accretion of the Lhasa Block along the southwestern margin of
45 Eurasia. Finally, this period was also characterized by the climax of aridification which
46 played a major role on the emplacement of extensive alluvial fan systems in the basins
47 surrounding the range.

48

49 **KEYWORDS:** Jurassic, Tian Shan, Paleogeography, Climate, Tectonics

50

51

52 **1. INTRODUCTION**

53

54 The long-term geodynamic evolution of Asia is characterized by a succession of
55 orogenesis driven by accretion of continental blocks along the southern margin of the
56 continent (e.g., Jolivet, 2017). These collisional orogenic events succeeded one another from
57 the Paleozoic, with the final accretion of the Central Asian Orogenic Belt during the Permian
58 (e.g., Windley et al., 2007; Wilhem et al., 2012), the Permian-Triassic Indosinian orogeny and
59 the closure of the paleo-Tethys ocean (e.g., Roger et al., 2010, 2011), the Mesozoic accretion
60 of the various blocs that form the Tibetan and South Caspian domains (e.g., Zonenshain and
61 Le Pichon 1986; Thomas et al., 1999; Brunet et al., 2003), the Cretaceous closure of the
62 Mongol-Okhotsk ocean in Siberia (e.g., Enkin et al., 1992; Zorin, 1999; Cogné et al., 2005;
63 Jolivet et al., 2017b), and finally the Cenozoic collision of India (e.g., Allègre et al., 1984;
64 Tapponnier et al., 2001). These successive events bring the idea of a continent essentially
65 affected by compressive deformation and largely characterized by the growth of large
66 mountain ranges. Within this largely compressive geodynamic setting, the Jurassic period
67 corresponds to a peculiar time span comprised between two major orogenic events: 1) the
68 Cimmerian orogeny which began during the late Paleozoic and ended during the Triassic –
69 Jurassic transition (e.g., Sengör, 1979; Watson et al., 1987; Mattauer et al. 1992; Roger et al.,
70 2010; Metcalfe, 2013) and 2) the Cenozoic Himalayan orogeny (e.g., Molnar and Tapponnier,
71 1975; Yin, 2009). During the Jurassic, the Eurasian continent was mostly surrounded by
72 subduction zones leading to late Early – Middle Jurassic extension within the Caspian – Turan
73 domains (e.g., Zonenshain and Le Pichon 1986; Nikishin et al. 1998; Thomas et al., 1999;
74 Brunet et al., 2003, 2017; Robert et al., 2014; Mordvintsev et al., 2017) and to Late Jurassic –
75 Cretaceous extension within the Siberian - Mongolian domains (e.g., Zorin 1999; Graham et
76 al., 2001; Johnson et al., 2004; Daoudene et al., 2009; Donskaya et al., 2008; Ritts et al.
77 2010). However, the Jurassic paleogeographic and kinematic evolution of the probable relay

78 zone corresponding to the Tian Shan region in Central Asia is yet to be fully understood.
79 Some studies indicate that during its Jurassic evolution, this area was dominated by
80 progressive planation of the Tian Shan relief (Dumitru et al., 2001; Jolivet et al., 2010) while
81 others propose that the region underwent recurrent periods of relief building (e.g., Allen et al.,
82 1991; Hendrix et al., 1992; Yang et al., 2015). Recurrent tectonic activity did occur during
83 that period but the kinematics and driving mechanisms of these events are highly debated.
84 Some consider that the Tian Shan region was dominated by strike-slip and transpressive
85 tectonics in a rather quiescent geodynamic setting (Jolivet et al., 2013) whereas others
86 propose that the Tian Shan was rather under a compressional setting related to far-field
87 collisions (e.g., Hendrix et al., 1992; Eberth et al., 2001; Vincent et al., 2001; Greene et al.,
88 2001; Yang et al., 2013; Liu et al., 2013; Yang et al., 2015).

89 Finally, a Late Jurassic – Early Cretaceous tectonic reactivation has been recorded by
90 low-temperature thermochronology data within the Kyrgyz Tian Shan, although to the east, in
91 the Chinese Tian Shan, the same type of data only suggest slow cooling (Dumitru et al., 2001;
92 Jolivet et al., 2010; De Grave et al., 2007, 2012, 2013; Glorie and De Grave., 2016;
93 Nachtergaele et al., 2018). At the same period, extensive alluvial fan systems have been
94 deposited in several basins surrounding the Tian Shan Range. These alluvial fans were
95 inferred to have been formed in response to renewed tectonic activity (Hendrix et al., 1992;
96 Sobel et al., 1999; Vincent et al., 2001; Yang et al., 2015). Moreover, a rapid transition from
97 humid conditions that prevailed during the Middle Triassic to Middle Jurassic to a semi-
98 arid/arid climate that developed during the Late Jurassic – Early Cretaceous period also
99 occurred in the Tian Shan area (Hendrix et al., 1992; Eberth et al., 2001; Shao et al., 2003;
100 Jolivet et al., 2017a). This change in climatic conditions is thought to have had a major impact
101 on the paleogeographical evolution of this region by controlling the emplacement of the
102 extensive Late Jurassic – Early Cretaceous alluvial fan systems (Jolivet et al., 2017a).
103 However, available descriptions of the Jurassic paleogeography or tectonic evolution of the

104 Tian Shan Range usually address too restricted areas and/or stratigraphic intervals to fully
105 understand the impact of far-field deformation within this peculiar period in Central Asia
106 history (e.g., [Shao et al., 2003](#); [Bian et al., 2010](#); [Feng et al., 2015](#); [Yang et al., 2015](#); [Jolivet](#)
107 [et al., 2017a](#); [Gao et al., 2017](#)).

108 Therefore, in order to better understand the paleogeographic and large-scale tectonic
109 evolution of the Tian Shan area, we compiled, our own detailed field analyses of sedimentary
110 rocks in various basins associated with the range and previously published data to construct
111 three paleogeographic maps for the periods of to the late Early – early Middle Jurassic, late
112 Middle- early Late Jurassic and Late Jurassic - Early Cretaceous transition. We provide a
113 large - scale picture of the Jurassic paleogeographic and climatic evolution of the Tian Shan
114 region and discuss the kinematic evolution of the range together with the possible driving
115 mechanisms.

116

117 2. GEOLOGICAL SETTING

118

119 2. 1. LATE PALEOZOIC LITHOSPHERIC STRUCTURES AND MESO-CENOZOIC 120 REACTIVATIONS:

121

122 The lithospheric structure of the Tian Shan results from the late Paleozoic
123 amalgamation of continental blocks and magmatic arcs along the southern margin of the
124 Central Asian Orogenic Belt (CAOB; [Sengör et al., 1993](#); [Windley et al., 2007](#); [Charvet et al.,](#)
125 [2011](#); [Alexeiev et al., 2017b](#)). Subsequently, the Tian Shan Range underwent transpressive
126 deformation during the Permian – Early Triassic in response to the oblique convergence
127 between Siberia and Baltica ([Bazhenov et al., 1999](#); [Van der Voo et al., 2006](#)). This induced
128 dispersed rotations and motion along numerous strike-slip faults such as the Talas – Fergana
129 fault, the Nikolaev line or the North Tian Shan fault (Fig. 1) (e.g., [Allen et al., 1991](#); [Laurent-](#)

130 Charvet et al., 2002; Buslov et al., 2004; Van der Voo et al., 2006 and references therein;
131 Rolland et al., 2013). An alternative model proposed that counterclockwise rotation of the Yili
132 – West Junggar blocks with respect to Tarim and Siberia induced large strike-slip
133 motions along the previously mentioned lithospheric faults, resulting in about 1160 ± 380 km
134 lateral displacement in the Tian Shan belt (Wang et al., 2007a). Independently to the tectonic
135 model, thermochronology data recorded a strong Permian-Triassic cooling- exhumation phase
136 within the Tian Shan Range implying the build-up of a major topography during that period
137 (Dumitru et al., 2001; Jolivet et al., 2010).

138 During the Meso-Cenozoic, the Paleozoic faults played a major role in localizing the
139 deformation during the successive tectonic episodes that affected the Tian Shan Range (Allen
140 et al., 1991, 2001; Hendrix et al., 1992; Sobel et al., 1999; Dumitru et al., 2001; Jolivet et al.,
141 2010; Rolland et al., 2013; Alexeiev et al., 2017). From the Triassic to the Cretaceous, several
142 accretion-collision events (generally known as the Cimmerian Orogeny) took place along the
143 southern Eurasian margin including the collision of the Qiangtang (Late Triassic-Early
144 Jurassic), Lhasa (Late Jurassic-Early Cretaceous) and the Kohistan-Ladakh (Late Cretaceous)
145 blocks (Matte et al., 1996; Kapp et al., 2007; Roger et al., 2010). These events induced the
146 reactivation of the Palaeozoic structures, which led to crustal deformation in the Tian Shan
147 area (Hendrix et al., 1992; Allen et al., 2001; Dumitru et al., 2001; De Grave et al., 2007;
148 Jolivet et al., 2010; Glorie and De Grave., 2016). Finally, tectonic reactivation related to far-
149 field effects of the India-Asia collision initiated during the late Oligocene – Miocene and led
150 to the growth of the present-day Tian Shan Range (e.g., Molnar and Taponnier, 1975; Thomas
151 et al., 1999; Sobel et al., 1999; Macaulay et al., 2014; Jia et al., 2015).

152

153

154 **2. 2. LATE PALEOZOIC – EARLY CRETACEOUS EVOLUTION OF THE TIAN**
155 **SHAN SEDIMENTARY BASINS**

156

157 **2. 2. 1. The Junggar Basin**

158

159 The Junggar (Fig. 1) is an intracontinental basin bordered by the Tian Shan Range to
160 the south, the Halaalate mountains to the west, and the Altai Range to the north-east. This
161 basin preserves, in its thickest part, around 16 km of late Paleozoic to Quaternary sediments.
162 The formation of the Junggar Basin followed the southward subduction of the North Tian
163 Shan Ocean underneath the Yili block and its subsequent Late Carboniferous – Early Permian
164 closure (e.g., Gao et al., 1998; Wang et al., 2006; Charvet et al., 2011). Depending on the
165 authors, the Junggar Basin initiated either during the Late Carboniferous in a post-collisional
166 extensional setting (Qiu et al., 2005; Yang et al., 2013; Liu et al., 2015) or during the Permian
167 as a response to a transtensional tectonics (Allen et al., 1991) associated with magmatism
168 (Carroll et al., 1995; Wang et al., 2009).

169 In this basin, the Upper Carboniferous strata consist of interbedded marine mudstone,
170 siltstone and rare clayey limestone units followed upward by thick units of sandstone
171 (Novikov, 2013). The Lower Permian then marks the end of marine sedimentation with the
172 deposition of a regressive sequence representing the final retreat of the sea from the South
173 Junggar and the onset of continental sedimentation (Carroll et al., 1990, 1995). The top of the
174 Permian sequence consists of conglomerates, sandstones, siltstones and mudstones interpreted
175 as alluvial plain and lacustrine deposits (Carroll et al., 1995; Bian et al., 2010; Yang et al.,
176 2013).

177 During the Triassic, the Junggar Basin evolved either as a foreland basin (Hendrix et
178 al., 1992; Bian et al., 2010) or as a transtensional basin (Allen et al., 1995). Lower and Middle
179 Triassic units consist of conglomerates, sandstones and red to brown siltstones typical of

180 continental sediments deposited in alluvial fan and alluvial plain environments. They are
181 locally associated to caliche beds indicating deposition in seasonal semi-arid to arid
182 conditions (Hendrix et al., 1992; Bian and al., 2010; Nivokov, 2013). Finally, the Upper
183 Triassic sedimentary rocks consist of interbedded conglomerates, sandstones and grey
184 siltstones interpreted as deposited in alluvial fan to alluvial plain environments under humid
185 conditions (Hendrix et al., 1992; Ashraf et al., 2010; Bian et al., 2010; Nivokov, 2013).
186 Subsequently, the Junggar Basin is thought to have evolved either as a flexural depression
187 (Bian et al., 2010; Yang et al., 2012; Feng et al., 2015) or as a transpressional basin (Dengfa
188 et al., 2008; Gao et al., 2017) during the Jurassic period. The contemporaneous conglomeratic
189 to sandy and silty deposits are mainly related to alluvial to lacustrine environments (Hendrix
190 et al., 1992; Eberth et al., 2001; Bian et al., 2010; Feng et al., 2015; Yang et al., 2015). The
191 occurrence of widespread coal deposits in the Lower to Middle Jurassic series suggests humid
192 conditions (e.g., Hendrix et al., 1992; Eberth et al., 2001; Vincent et al., 2001). Upper Jurassic
193 series are then characterized by the disappearance of coal and by the formation of calcareous
194 paleosols indicative of semi-arid conditions (Hendrix et al., 1992; Eberth et al., 2001; Vincent
195 et al., 2001; Jolivet et al., 2017a). Finally, the Jurassic-Cretaceous transition is characterized
196 by the emplacement of well-developed conglomerates thought either to mark a tectonic
197 reactivation of the Tian Shan Range (Hendrix et al., 1992; Yang et al., 2015) or to be mostly
198 driven by climate (Jolivet et al., 2017a).

199

200 2. 2. 2. The intra-mountain basins

201

202 Several intra-mountain basins such as the Yili, Bayanbulak, and Turfan basins are
203 preserved within the interior of the Tian Shan Range (Fig. 1). They formed concurrently to the
204 Junggar Basin and are associated to the same late Paleozoic post-orogenic phase of extensive

205 or transtensive deformation (Wang et al., 2006, 2009; Charvet et al., 2007; Jolivet et al., 2010;
206 Xia et al., 2012).

207 The Yili Basin is bordered by the Borohoro Range (North Tian Shan) to the north and
208 by the Narat Range (South Tian Shan) to the south. In its thickest part, this basin preserves
209 around 5 km of Permian to Quaternary sediments. Its Permian series consist of marine
210 sediments followed by the emplacement of volcanics and volcanoclastics deposits during the
211 Upper Permian (Li et al., 2015). These series are unconformably overlaid by the Triassic
212 sediments, implying tectonic deformation at least up to the Lower Triassic (Li et al., 2015).
213 Jurassic series consist of alluvial, lacustrine delta and lake deposits containing extensive coal
214 beds that indicate humid conditions (Li et al., 2014). However this basin does not contain
215 Upper Jurassic - Lower Cretaceous sediments (AGMCA, 2008).

216 The Bayanbulak Basin is located between the Narat Range to the north, the South Tian
217 Shan Range to the south, and the Erbin Shan Range to the east. It preserves Mesozoic and
218 Cenozoic sediments but its late Paleozoic to Mesozoic evolution is poorly known.

219 The Turfan Basin is a flexural basin containing in its deepest part around 7 km of
220 Permian to Quaternary sediments (Shao et al., 1999). It is located between the Bogda Shan-
221 Barkhol Tagh ranges to the north and the Chöl Tagh mountain range to the south. Its Lower
222 Permian strata consist of continental and marine deposits interbedded with volcanic and
223 volcanoclastic series (Shao et al., 1999; Wartes et al., 2002). During the Late Permian – Early
224 Cretaceous, the Turfan Basin then evolved as a compressive basin (Hendrix et al., 1992; Allen
225 et al., 1993; Shao et al., 1999; Wartes et al., 2002). Its Upper Permian to Early Cretaceous
226 series are entirely continental and consist of alluvial to lacustrine deposits (Hendrix et al.,
227 1992; Shao et al., 1999; Greene et al., 2001; Wartes et al., 2002).

228 In the Kyrgyz Tian Shan, the Issyk-Kul, Naryn, Aksai and Ming-Kush basins are intra-
229 mountain depressions containing Jurassic to Quaternary sediments (Fig. 1) (Lasovskiy and
230 Mozolev, 1961; VNIGNI and Beicip Franlab, 1992; Macaulay et al., 2014; De Pelsmaeker et

231 al., 2018). In the Issyk-Kul Basin, these sedimentary rocks consist mainly of alluvial to
232 shallow lacustrine deposits containing numerous coal beds and plant fragments indicating
233 humid conditions but they also contain caliche - type paleosols more typical of semi-arid
234 conditions (De Pelsmaecker et al., 2018). The Ming-Kush Basin is a narrow transpressive
235 depression containing 100-680m thick Jurassic deposits resting unconformably on Paleozoic
236 basement rocks (Lasovskiy and Mozolev, 1961; De Pelsmaecker et al., 2018). They mainly
237 consist of alluvial plain, fan delta and shallow lacustrine deposits associated with coal-rich
238 layers and plant fragments indicating humid conditions (Lasovskiy and Mozolev, 1961; De
239 Pelsmaecker et al., 2018). Finally, Jurassic sedimentary rocks consisting mainly of coal-
240 bearing continental deposits resting unconformably on Paleozoic rocks occur in both the
241 Naryn and Aksai basins (VNIGNI and Beicip Franlab, 1992; AGMCA, 2008).

242

243 2. 2. 3. The Tarim Basin

244

245 The Tarim Basin (Fig. 1) is a large intracontinental basin located between the Tian
246 Shan to the north, and the Western Kunlun and Altyn Tagh ranges to the south. In its thickest
247 part, it contains up to 16 km of Late Precambrian to Quaternary sediments. This basin
248 underwent multiple phases of tectonic deformation since the Late Precambrian (Desheng et
249 al., 1996). The Tarim craton accreted to the Kazakhstan-Yili terrane in the Late
250 Carboniferous-Early Permian during the final amalgamation of the CAOB and the closure of
251 the South Tian Shan Ocean (Carroll et al., 1995; Chen et al., 1999; Liu et al., 2014; Alexeiev
252 et al., 2015). During that period, the Tarim Basin evolved as a compressive basin with Upper
253 Carboniferous to Lower Permian series consisting of marine limestones, volcanoclastics and
254 continental conglomerates, sandstones and siltstones (Carroll et al., 1995; Lin et al., 2012).
255 Subsequent Early Permian extension then occurred and was associated to the emplacement of
256 a LIP province within the basin (Carroll et al., 1995; Qin et al., 2011; Yu et al., 2011).

257 During the Mesozoic, the Tarim Basin finally seems to evolve again as a compressive
258 basin in its northern and eastern parts (Desheng et al., 1996), with Triassic, Jurassic and Early
259 Cretaceous depositional systems consisting of alluvial plain to lacustrine environments
260 (Desheng et al., 1996; Hendrix et al., 1992). However, there are no Mesozoic deposits to the
261 south-west of the basin, except along the Pamir-Western Kunlun Range, where Jurassic
262 deposits are interpreted to have been deposited in pull-apart basins (Sobel et al., 1999).

263

264 2. 2. 4. The Fergana Basin

265

266 The Fergana Basin is an intracontinental basin situated to the west of the Kyrgyz Tian
267 Shan. It is surrounded by the Chatkal and Kurama ranges to the north, the Fergana Range to
268 the east and by the Alai Range to the south (Fig. 1). In its thickest part, it contains around 10
269 km of Permian to Quaternary sediments.

270 Following the late Paleozoic building of the ancestral Tian Shan, post-orogenic Upper
271 Permian to Lower Triassic alluvial to lacustrine sediments were deposited (Clarke, 1984;
272 Moisan et al., 2011). The basin was then subsequently inverted leading to a Middle – Late
273 Triassic erosional event (Clarke, 1984; Bande et al., 2015). Renewed subsidence started from
274 the Early Jurassic and led to the accumulation of alluvial to lacustrine deposits during the
275 Jurassic and Early Cretaceous (Clarke, 1984; Jolivet et al., 2017a; De Pelsmaeker et al.,
276 2018).

277

278 2. 2. 5. The Yarkand – Fergana Basin

279

280 The Yarkand – Fergana Basin is described as a transtensional pull-apart basin located
281 along the south-western termination of the Talas Fergana/Karatau fault (Fig. 1) (Sobel et al.,
282 1999; Allen et al., 2001; Alexeiev et al., 2017; De Pelsmaeker et al., 2018). The sedimentary

283 thickness progressively decreases away from the fault where up to 5 km of Jurassic sediments
284 were deposited (Sobel et al., 1999; De Pelsmaeker et al., 2018). Lower to Middle Jurassic
285 sediments consist mainly of alluvial, fan delta and deep lake deposits containing coal beds and
286 plant fragments indicating humid conditions (Sobel et al., 1999; De Pelsmaeker et al., 2018).
287 To the south of the basin, in the north-western Tarim region, the Upper Jurassic – Lower
288 Cretaceous transition consists in up to 400 m-thick conglomeratic fluvial channel systems
289 subsequently followed by Lower Cretaceous deposits characterized by fluvial red beds (Sobel
290 et al., 1999).

291

292 3. SEDIMENTOLOGICAL ANALYSES

293

294 3. 1. METHODS AND AGE CONSTRAINTS

295

296 In this study we present new sedimentological data from Upper Triassic to Lower
297 Cretaceous sedimentary units from the south Junggar, north Tarim, Yili and Bayanbulak
298 basins (Fig. 1; see Appendix A for GPS coordinates of analyzed sections). Detailed analyses
299 of field logs (1/1000 scale), sedimentary facies, trace fossils and paleosols were performed on
300 each of the seven sections presented below with the objective of reconstructing the
301 depositional environment evolution through time.

302 To establish the first order age intervals in the sediment sequences and assess the
303 corresponding formation names (Fig. 2; lithostratigraphy from Hendrix et al., 1992), we relied
304 on geological maps (XBGMR, 1969, 1970, 1973 a, b, 1978 a, b), published ages derived from
305 biostratigraphical analyses and sporopollen assemblages (for more references see Hendrix et
306 al., 1992; Deng et al., 2010) and published lithological descriptions (Hendrix et al., 1992;
307 Eberth et al., 2001; Bian et al., 2010; Deng et al., 2010).

308

309 3. 2. FACIES MODEL AND DEPOSITIONAL ENVIRONMENTS

310

311 In the seven sections described below, twelve facies assemblages were defined based
312 on lithology and sedimentary structures before being interpreted in terms of depositional
313 processes (Table. 1). Together with those facies, five different pedogenic and alteration
314 features were also identified (Table. 2). All these facies, pedogenic and alteration features
315 were subsequently associated and interpreted in terms of depositional environments (Table.
316 3). Climatic conditions were inferred from these sedimentological analyses. In total, 10
317 environments ranging from alluvial fan to lake, evolving in both humid and semi-arid/arid
318 conditions have been defined. 3D diagrams have been constructed to illustrate the general
319 organization of each proposed depositional environment (Table. 3).

320 However, some morphological variability exists within those environments, especially
321 for the lacustrine delta systems. Indeed, lithologies and sedimentary structures vary depending
322 on the sections and are, for example, characteristic of different flow regimes. For the purpose
323 of this paper we decided to group these more specific morphologies within one general
324 environment associated with a global architecture (i. e. lacustrine delta (LD), Table. 3).

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333 **Table. 1:** *Summary of the facies characteristics within the Chinese Jurassic Tian Shan and*
334 *their interpretation in terms of depositional processes*

<i>Facies code</i>	<i>Lithology</i>	<i>Sedimentary structures</i>	<i>Inferred depositional processes</i>
<i>Miscellaneous</i>			
F1	a cm- to dm- thick coal beds	Tabular beds containing plant remains	Peat accumulation
F2	Several cm- to dm- thick white tuffaceous beds	Massive	Subaerial volcanic ash deposition
<i>Calcareous facies</i>			
F3	a cm- to dm- thick siltstones interbedded with a cm- to dm- thick calcareous beds	Massive to flat-laminated siltstone layers alternating with tabular calcareous beds with occasionally medium to strong bioturbation	Deposition from suspension fallout alternating with episodes of calcareous production
<i>Heterolithic facies</i>			
F4	a m- to m- thick siltstones containing cm- to dm- thick fine- to medium-grained sandstones	- Massive or flat laminated siltstones sometimes containing desiccation cracks or bioturbation - Tabular sandstone beds with sharp basal boundaries containing current ripples and sometimes bioturbation	- Deposition from suspension fallout with some emergent events - Tractional current deposition (low energy flows; Miall 1978) with occasional periods of subaqueous biological reworking
F5	heterolithic facies composed of cm- to dm-thick siltstones interbedded with cm- to dm-thick fine to medium (rarely coarse) grained sandstone	Flat laminated siltstone beds alternating with tabular sandstone beds containing current, climbing and/or oscillatory ripples; cm-scale soft sediment deformation structures, slightly to moderately bioturbated	Deposition from suspension fallout alternating with overbanks and waning floods, turbidity currents within a permanent water body (Mulder and Alexander, 2001). Deposition or reworking by waves and biological activity
F6	cm- to dm- thick siltstones alternating with cm- to dm-thick beds of fine- to coarse-grained sandstones	Massive to flat-laminated siltstone beds alternating with sandstone beds either - Tabular containing flat laminations, occasional current and climbing ripples. Occasional plant fragments or - Lenticular and massive with erosional basal boundaries with occasional rip-up mud clasts and plant fragments	Deposition from suspension fallout alternating with overbanks, waning flood currents or from tractional currents under stream flows (Miall, 1978)

<i>Sandstone facies</i>			
F7	Stacked to isolated dm- to m- thick medium to coarse grained sandstones	Tabular to slightly lenticular beds with sharp or low erosional basal boundaries. Trough cross-beddings, flat beddings underlined by rip-up clasts and sometimes with current ripples at the top of the beds. Occasional burrows	3D megaripples or planar beds of tractional currents deposits under subaerial or subaqueous sheet flows and stream flows (Miall, 1978)
F8	a m- to m-thick fine-grained to gravelly sandstones	Slightly to strongly lenticular beds with erosional basal boundaries. Trough cross-stratifications or flat beddings (highlighted by gravels, coal and mud clasts) and current ripples; a dm- to a m- scale fining-up trends	3D megaripples, planar beds of tractional currents deposits under subaerial stream flows (Miall, 1978)
F9	dm- to m- thick, stacked medium-grained to gravelly well-sorted, sandstones	Tabular beds with sharp basal boundaries. Flat-beddings, trough and planar cross stratification, sigmoidal beddings highlighted by gravels, coal and mud clasts and occasional current ripples; a dm- to dm scale dewatering structures and soft sediment deformation	Tractional currents with planar beds, 2D and 3D megaripples under subaqueous sheet flows (Miall, 1978) and with some gravitational events
F10	a m- to m- thick fine- to coarse- grained sandstones, well- to moderately well-sorted	m- to a dcm- high foreset composed of grainfalls and inverse climbing ripple. Horizontal laminations or very low angle mm- scale cross-laminations with inverse climbing ripples. Irregular mm horizontal lamination with adhesion warts and ripples	Aeolian dune and traction deposition by high wind velocity or migration of wind ripples (Hunter 1977). Wind-blown sand to a wet surface (Kocurek and Nielsen, 1986)
<i>Conglomerate facies</i>			

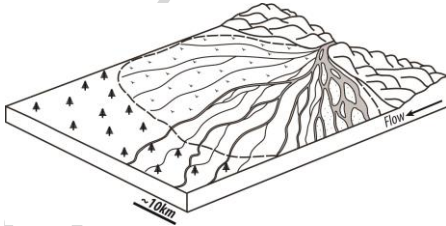
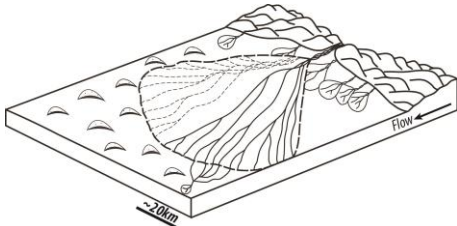
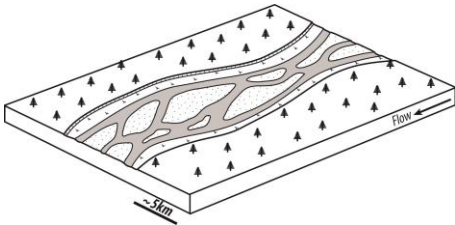
F11	dm- to m- thick clast-supported conglomerates with poorly- to moderately-sorted subangular to subrounded pebbles to boulders alternating with cm to m-thick medium to coarse grained sandstones containing floating gravels	Massive conglomerates with erosive or sharp basal boundaries and occasional pebble imbrications alternating with tabular or lenticular sandstones, structureless or with planar laminations and trough cross-bedding	Hyperconcentrated flows (Svendsen et al., 2003) alternating with 3D megaripple deposits under sheet flows or stream flows (Miall, 1978)
F12	a dm- to m- thick planar couplets of mostly poorly-sorted conglomerates, angular to sub-angular gravels to boulder, and of poorly- to well-sorted sand	Horizontal to sub-horizontal bedded conglomerates and sandstones with erosive or sharp basal boundaries. Sometimes dm to m-thick channelled bed	Sediment-charged flash floods due to either seasonal or irregular rainfalls (e.g., Blair and McPherson, 1994). Occasional sheet flow and stream flow deposits (Miall, 1978)
F13	a m- to pluri m-thick conglomerates with subangular to subrounded pebbles to boulders, poorly-sorted, matrix-supported (sand-rich)	Massive, sometimes with faint horizontal laminations. Erosive or sharp basal boundaries	Gravity flow processes, Debris flows (Postma, 1990; Miall 1996)

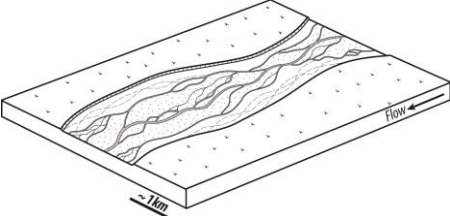
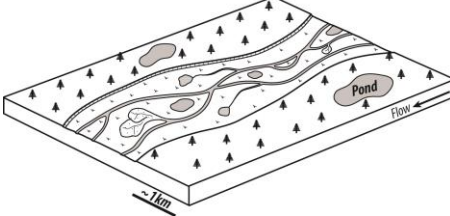
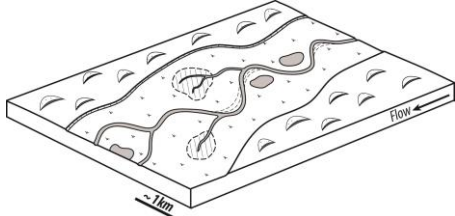
335

336 **Table. 2:** *Description and interpretation of pedogenic and alteration features*

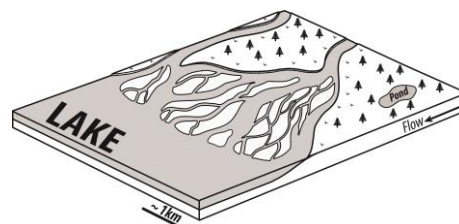
<i>Facies code</i>	<i>Lithology</i>	<i>Interpretations</i>
P1	Closely spaced, disconnected thin vertical root traces, mm in thickness and a few cm-long within siltstones to fine grained sandstones	Paleosols (Retallack, 1988)
P2	Sparse vertical roots, mm wide, a few cm to dm-long within sandstones	Patchy and discontinuous vegetation typical of dry climate conditions (e.g., Hasiotis et al., 2007)
P3	Siltstone and sandstone facies modified by marmorisation processes	Pseudo-hydromorphic palaeoverteosols, wet-dry climate (Kraus, 1999; Klappa, 1980; Hasiotis et al., 2007)
P4	Dispersed to coalescent calcareous nodules, a cm- to several cm in diameter within siltstones to fine grained sandstones	Semi-arid pedogenic processes indicative of seasonality (wet-dry conditions; e.g., Retallack, 1988; Hasiotis et al., 2007)
P5	m- to several m- thick calcareous impregnation/cementation within conglomerates	Long-lasting wet/dry pedogenic processes within semi-arid environment (e.g., Retallack, 1988; 2008)

337 **Table. 3:** Summary of the characteristics of the associated facies and their interpretations in
 338 terms of depositional environments.

<i>Associated facies</i>	<i>Inferred depositional processes</i>	<i>Inferred depositional environment</i>
AF - F11, F13	Debris flow + hyperconcentrated flows + sheet flows and stream flows	Alluvial fan environment (e.g., Blair and McPherson, 1994)
		
AFa – P2, F11, F12, F13	Flash floods + debris flows + hyperconcentrated flows + occasional sheet flows and stream flows + desiccation cracks and root traces typical of dry climates	Alluvial fan environment in semi-arid to arid conditions dominated by ephemeral flows (e.g., Blair and McPherson, 1994; Mather & Hartley 2005)
		
AP1 – F8, F11, (F7), sometimes with coal clasts and plant fragments within F8	Subaerial sheet and stream flows + hyperconcentrated flows	Proximal alluvial plain environment with gravelly alluvial deposits, probably characteristic of a low sinuosity bedload-dominated river system (e.g., Miall 1996)
		

AP1a – P4, F8, F11, (F7)	Same as AP1 but with pedogenic calcareous nodules	Proximal alluvial plain environment with gravelly alluvial deposits, probably characteristic of a low sinuosity bedload-dominated river system (e.g., Miall 1996) in semi-arid conditions (carbonate nodules: Hasiotis 2006; Hasiotis et al., 2007)	
AP2 – P1, P3, F1, F6, F7, F8	Peat accumulation + root traces + suspension fallout + overbank and waning flood currents + subaerial and subaqueous sheet and stream flows	Distal alluvial plain environment with sandy alluvial deposits within floodplains and/or swamps	
AP2a – P4, F6, F7, F8	Same as AP2 but without peat accumulation and with pedogenic calcareous nodules	Distal alluvial plain environment with sandy alluvial deposits within floodplains and/or swamps in semi-arid conditions (carbonate nodules: Hasiotis 2006; Hasiotis et al., 2007)	
EG – F10	Traction deposition by high velocity wind velocity or migration of wind ripples + wind-blown sand to a wet surface	Erg deposits with preservation of large and thick aeolian dunes (up to 50m in thickness) and interdunes deposits	

LD – P1, F1, F4, F5, F7, F9	Possible peat accumulation + root traces + overbank or waning floods + subaqueous sheet flows + turbidity currents and suspension fallout within a permanent water body + deposition or reworking by waves + biological reworking	Lacustrine delta environment with mouth bars and distal alluvial deposits (ie unconfined flows) within lakes
LE1 – F3, F4, F5	Subaqueous suspension fallout + occasional calcareous production + waning floods and turbidity currents within a permanent water body + deposition or reworking by waves + biological reworking	Lacustrine environment with some episodes of fluvial input
LE1a – P4, F3, F4, F5, F7	Same as LE1 but with desiccation cracks and pedogenic calcareous nodules	Shallow or playa lake environment with frequent emergence (desiccation cracks) and episodes of fluvial input in semi-arid conditions (carbonate nodules: Hasiotis 2006; Hasiotis et al., 2007)



339

340 3. 3. THE JURASSIC DEPOSITIONAL ENVIRONMENT EVOLUTION OF THE

341 CHINESE TIAN SHAN

342

343 3. 3. 1. The south Junggar Basin

344

345 3. 3. 1. 1. South Toutunhe section

346

347 The South Toutunhe section (Fig. 6) is located in the south Junggar Basin, along the

348 Toutun River on the northern flank of the Tian Shan Range and more precisely to the south of

349 the Toutun dam (Fig. 1; Appendix B for a general overview of the section). The studied

350 ~2000 m-thick section covers Middle Jurassic (Toutunhe Fm), Upper Jurassic (Qigu and

351 Kalaza fms), and Lower Cretaceous (Qingshuihe Fm) deposits (XBGMR, 1978b).

352 The basal part of the logged Toutunhe Fm consists of distal alluvial plain deposits
353 associated to coal beds indicative of rather humid conditions (AP2) (Table. 3), which pass
354 upward, in the last 230 m of the formation to lacustrine delta deposits (LD) (Fig. 6; Appendix
355 B. 1). The transition with the Qigu Fm is progressive with deposits still characteristic of a
356 lacustrine delta environment (LD) in the first 310 m of this formation. The next 90 m consist
357 of distal alluvial plain deposits containing carbonate nodules indicative of semi-arid climate
358 conditions (AP2a; Fig. 6). The Qigu Fm then evolves up section towards lacustrine delta
359 sediments (LD) to finally ends with proximal alluvial plain deposits (AP1). The boundary
360 with the ~190 m-thick Kalaza Fm is sharp and marks a sharp change in depositional
361 environments (Fig. 6; Appendix B. 3). Indeed, the lower part of the Kalaza Fm is composed
362 of a 50 – 70 m-thick unit interpreted as erg deposits (EG) alternating with ~40 m thick units
363 of alluvial fan sediments (AFa) (Appendix B. 4) (for more details see Jolivet et al., 2017a).
364 This erg confirms the aridification trend already observed between the Toutunhe and Qigu
365 formations. The basal part of the Lower Cretaceous Qingshuihe Fm shows a retrogradation
366 towards a lake environment (LE1) (Fig. 6; Appendix B. 5).

367

368 3. 3. 1. 2. North Toutunhe section

369

370 The North Toutunhe section (Fig. 7) is also located along the Toutun River, to the
371 north of the Toutun dam (Fig. 1; Appendix C for a general overview of the section) and
372 presents ~1650 m of deposits ranging from Late Jurassic (Qigu and Kalaza fms) to Early
373 Cretaceous (Qingshuihe Fm) in age (XBGMR, 1978b).

374 The first 655 m of the logged Qigu Fm consists of interbedded red siltstones and
375 sandstones interpreted as lacustrine delta deposits (LD) evolving in the last 145 m of the
376 formation towards distal alluvial plain sediments containing carbonate nodules and
377 desiccation cracks indicative of semi-arid conditions (AP2a) (Fig. 7; Appendix C. 1, 2) . As in

378 the South Toutunhe section, the boundary between the upper Qigu Fm and the Kalaza Fm is
379 sharp and corresponds to an abrupt change in depositional environments (Appendix C. 3).
380 Indeed the Kalaza Fm (~740 m thick) consists of large aeolian dunes (preserved dune sets are
381 up to 50 m in thickness) and interdune deposits characteristic of erg systems (EG) (Fig. 7).
382 The basal part of the Lower Cretaceous Qingshuihe Fm shows a drastic change in
383 environments with the emplacement of sediments indicative of lacustrine delta (LD) followed
384 by lacustrine deposits (LE1) dominated by fine - grained facies.

385

386 3. 3. 1. 3. *The Manas section*

387

388 The ~5510 m-thick Manas section (Fig. 8), located in the south Junggar Basin, along
389 the Manas River on the northern flank of the Tian Shan Range (Fig. 1; Appendix D for
390 general pictures of the section) encompasses Upper Triassic, Lower Jurassic (Badaowan and
391 Sangonghe fms), Middle Jurassic (Xishanyao and Toutunhe fms), Upper Jurassic (Qigu and
392 Kalaza fms) and Lower Cretaceous (Qingshuihe Fm) deposits (XBGMR, 1978a; Hendrix et
393 al., 1992; Eberth et al., 2001; Deng et al., 2010).

394 The upper part of the Triassic succession (only the topmost ~200 m were logged in
395 this work) displays distal alluvial plain (AP2) and lacustrine delta environments (LD)
396 evolving towards alluvial fan systems (AF) (Fig. 8). The first 780 m of the Lower Jurassic
397 series (Badaowan Fm) consists of an alternation of distal alluvial plain (AP2) and alluvial fan
398 (AF) deposits. The latter are dominated by clast-supported conglomerates with sub-rounded
399 pebbles, occasionally associated with coal beds, which suggest rather humid conditions (AF)
400 (Fig. 8; Appendix D. 1). These deposits pass upwards in a retrogradational trend into
401 sediments indicative of a lacustrine delta environment (LD). Above, the top 400 m of the
402 Lower Jurassic series correspond to the Sangonghe Fm, which is characterized by a
403 progradational trend towards a proximal alluvial plain system (AP1) followed by a

404 retrogradational trend with depositional environments evolving from a proximal to a more
405 distal alluvial plain (AP1, AP2) and finally to a lacustrine delta (LD).

406 The Middle Jurassic Xishanyao Fm (~1705 m thick; Appendix D. 2) then comprises a
407 poorly exposed basal series (570 m thick) showing a progradational trend from lacustrine
408 delta (LD) to proximal alluvial plain (AP1) deposits. The topmost 1135 m of this formation
409 show a retrogradational trend with environments evolving towards a distal alluvial plain
410 (AP2) and a lacustrine delta (LD) associated with the presence of numerous coal beds
411 indicative of rather humid climate conditions (Fig. 8; Appendix D. 3). At the top of the
412 Middle Jurassic series, the sediments of the Toutunhe Fm are interpreted to represent a distal
413 alluvial plain environment (AP2; Appendix D. 4). Following the Toutunhe Fm, a thick red
414 beds series corresponds to the Upper Jurassic Qigu Fm (Appendix D. 5). The basal 315 m of
415 this formation were interpreted as lacustrine delta deposits (LD) directly followed by ~65 m
416 of distal alluvial plain sediments (AP2) (Fig. 8). The rest of the Qigu Fm is characterized by a
417 retrogradational trend with environments evolving from distal alluvial plain (AP2), to
418 lacustrine delta (LD) and finally to a playa lake (LE1a). In the latter, desiccation cracks and
419 carbonate nodules are indicative of semi-arid conditions. The transition with the Kalaza Fm is
420 sharp with depositional environments passing from a playa lake (LE1a) to an alluvial fan
421 (AFa) systems (Appendix D. 6, 7). The lower part of the Kalaza Fm corresponds to a rather
422 proximal alluvial fan environment characterized by matrix-supported conglomerates
423 associated with desiccation cracks and sparse root traces indicating arid/semi-arid conditions
424 (AFa) (Fig. 8). It passes up section into horizontal to sub-horizontal laminated clast-supported
425 conglomerates characteristic of a more distal alluvial fan environment and deposited under
426 semi-arid conditions. The transition with the basal part of the Lower Cretaceous Qingshuihe
427 Fm is sharp with environments retrograding sharply toward a lacustrine system (LE1).

428

429 3. 3. 1. 4. *The Wusu section*

430

431 The Wusu section (Fig. 9) is also located on the southern Junggar Basin, to the south
432 of the Wusu City on the northern flank of the Tian Shan Range (Fig. 1; Appendix E for a
433 general overview of the section). Based on the geological map (XBGMR, 1978a), this ~1650
434 m-thick section encompasses Middle (Xishanyao and Toutunhe fms) to Upper Jurassic (Qigu
435 and Kalaza fms) deposits. The lower and upper parts of this sedimentary section (up to the
436 Qigu Fm) have been respectively logged in the west and east of Sali Keti village (Appendix
437 A for GPS coordinates), with a few meters of overlap expected between them.

438 The first 190 m of the Xishanyao Fm correspond to alluvial fan deposits (AF)
439 retrograding sharply towards a ~85 m-thick unit of lacustrine sediments (LE1) (Appendix E.
440 1, 2). This unit marks the onset of a 200 m-thick progradational trend with depositional
441 environments evolving from a lacustrine delta (LD) to more and more proximal alluvial plains
442 (AP2, AP1), followed by an alluvial fan system (AF) (Fig. 9; Appendix E. 3). The upper part
443 of the Xishanyao Fm then consists of alluvial fan (AF) and proximal alluvial plain (AP1)
444 deposits. These proximal alluvial deposits are still present in the lower part of the Toutunhe
445 Fm and pass upward into sediments deposited in a more distal alluvial plain environment
446 (AP2) in a retrogradational trend (Fig. 9; Appendix E. 4, 5). Both the Middle Jurassic
447 Xishanyao and the Toutunhe fms contain several tuffaceous beds (cm to dm thick) indicating
448 volcanic activity as well as numerous coal beds associated with alluvial plain deposits
449 indicating rather humid climate conditions. Above, the lower part of the Upper Jurassic Qigu
450 Fm consists of red siltstones and sandstones displaying root traces and interpreted as proximal
451 alluvial plain (AP1) deposits (Appendix E. 6). The upper Qigu Fm displays alluvial fan
452 deposits (AF) retrograding towards proximal alluvial plain (AP1) to distal alluvial plain
453 (AP2a) deposits containing carbonate nodules indicating semi-arid climatic conditions (Fig.
454 9). The Qigu Fm ends with a sharp boundary marking the transition between the deposits of a

455 proximal alluvial plain environment (AP1) and the 150 m-thick Kalaza Fm (Fig. 9). The latter
456 is dominated by planar to sub-planar laminated conglomerates (Appendix E. 7) interpreted as
457 an alluvial fan sediments deposited in semi-arid conditions (AFa). Finally, the transition
458 between the Kalaza Fm and the basal part of the Qingshuihe Fm is marked by a rapid
459 retrogradation towards a distal alluvial plain environment (AP2).

460

461 3. 3. 2. Intra-mountain basins

462

463 3. 3. 2. 1. The Nieleke section

464

465 The Nieleke section (Fig. 10) is situated in the Tian Shan Range within the Hexilagen
466 Basin (Fig. 1; Appendix F for a general overview of the section) and covers ~925 m of
467 Middle Jurassic (Toutunhe Fm) deposits (XBGMR, 1978b).

468 The first 310 m of the section consist mostly of interbedded siltstones and sandstones
469 associated with coal deposits and interpreted to be deposited in a lacustrine delta (LD).
470 Several oxidized paleosols are also visible in the bottom part of this unit (Fig. 10; Appendix
471 F. 1) suggesting warm and humid climatic conditions. The next 410 m show successive
472 retrogradational and progradational trends with depositional environments evolving from a
473 distal alluvial plain (AP2) to a lacustrine delta (LD) and back to a distal alluvial plain (AP2)
474 deposits (Fig. 10; Appendix F. 2). The upper part of the section is characterized by a 50 m-
475 thick unit of stacked, coarse-grained to gravelly sandstone beds interpreted to be lacustrine
476 delta deposits (LD) (Fig. 10). This marks the onset of a progradational trend from a lacustrine
477 delta (LD) to more and more proximal alluvial plain environments (AP2, AP1) (Appendix F.
478 3).

479

480 3. 3. 2. 2. *The Bayanbulak section*

481

482 The Bayanbulak section (Fig. 11) is situated in the Tian Shan Range, in the northern
483 part of the Bayanbulak Basin (Fig. 1; Appendix G for a general overview of the section). It
484 presents ~420 m of Middle Jurassic deposits (XBGMR, 1969), which we attribute to the
485 Toutunhe Fm based on their lithology.

486 The lowest ~70 m of sediments of this section indicate a proximal alluvial plain
487 environment (AP1) with several coal deposits. They pass upward into alluvial fan deposits
488 (AF) (Appendix G. 1). The rest of the succession is characterized by an alternation between
489 proximal alluvial plain (AP1) and alluvial fan (AF) deposits (Fig. 11). The last ~20 m of the
490 section are attributed to the Paleogene (XBGMR, 1969; Heilbrom et al., 2015) and comprise
491 red conglomerates impregnated/cemented by limestone (Appendix G. 2, 3) interpreted to be
492 calcrete formed by long-lasting pedogenic processes within semi-arid, seasonal climates (see
493 table 2).

494

495 3. 3. 3. The north Tarim Basin

496

497 3. 3. 3. 1. *The Yaha section*

498

499 The Yaha section (Fig. 12) is located in the Kuqa depression, of the north Tarim Basin
500 along the Yaha River on the southern flank of the Tian Shan Range (Fig. 1; Appendix H for a
501 general overview of the section). This ~1525 m-thick section encompasses Lower Jurassic
502 (Yengisar Fm), Middle Jurassic (Kezilenuer and Kalemake fms), Upper Jurassic (Qigu and
503 Kalaza fms), and Lower Cretaceous (Yageliemu Fm) deposits (XBGMR, 1970; Hendrix et al.,
504 1992).

505 The Yengisar Fm (~100 m-thick) consists of stacked, thick bedded gravelly sandstones
506 interpreted as lacustrine delta deposits (LD) (Appendix H. 1, 2). They evolve, at the base of
507 the Kezilenuer Fm, towards distal alluvial plain deposits (AP2) and finally back to lacustrine
508 delta sediments (LD) in the upper part of this formation (the last 325 m) (Fig. 12; Appendix
509 H. 3, 4). The base of the Kalemake Fm (~230 m) still consist of lacustrine delta deposits (LD)
510 retrograding toward lacustrine environments characterized by the presence of calcareous beds
511 with some turbiditic events in the top ~200 m of the formation (Appendix H. 5). Their oxygen
512 and carbon isotope compositions are typical of lacustrine carbonates (Heilbromm et al., 2015).
513 These observations seem to indicate a rather deep lacustrine environment (LE1) in
514 comparison to lake environments encountered in the previous sections. Middle Jurassic units
515 are also associated to numerous coal beds indicating humid climate conditions. The Qigu Fm
516 (~200 m in thickness) is characterized by a thick red-bed series (Appendix H. 6) interpreted as
517 playa lake deposits (LE1a) prograding towards more and more proximal alluvial plain
518 deposits associated to carbonate nodules that indicate semi-arid climate conditions (AP2a,
519 AP1a). Above, the Kalaza Fm is particularly thin (~35 m) in comparison to other sections and
520 consists of alluvial fan deposits (AFa) (Fig. 12; Appendix H. 7). Finally, the lower part of the
521 Lower Cretaceous Yageliemu Fm is characterized by proximal to distal alluvial plain
522 sediments deposited under semi-arid conditions (AP2a, AP1a) (Appendix H. 8). Within the
523 upper part of the section, the sediments evolve towards deposits associated to a more distal
524 lacustrine delta environment (LD).

525

526 4. JURASSIC PALEOGEOGRAPHICAL EVOLUTION OF THE TIAN SHAN

527

528 As mentioned above, the present-day geometry of the range results from a series of
529 Meso-Cenozoic reactivations of late Paleozoic tectonic structures (e.g., Molnar and Taponnier,
530 1975; Hendrix et al., 1992; Sobel et al., 1999; Dumitru et al., 2001; De Grave et al., 2007;

531 Jolivet et al., 2010). However, the exact pattern of Cenozoic deformation in the Tian Shan
532 Range is still poorly understood. The total Cenozoic shortening is estimated to be 124 ± 30
533 km at the longitude of Manas (ca. $85,5^\circ$ E; Chinese Tian Shan) and 203 ± 50 km at the
534 longitude of Kashgar (ca. 76° E; Kyrgyz Tian Shan) (Avouac et al., 1993). Though, this
535 deformation is distributed on a number of faults, the exact kinematics of which being poorly
536 constrained with likely significant strike-slip displacements. In addition, no Mesozoic
537 deformation estimates are available. Due to this lack of kinematic constraints, we decided not
538 to attempt to palinspastically restore the proposed paleogeographic maps.

539

540 4. 1. EARLY – EARLY MIDDLE JURASSIC

541

542 The Early to early Middle Jurassic paleogeography of the Tian Shan region was
543 characterized by the presence of several sedimentary basins separated by significant reliefs
544 (Fig. 13).

545 In the northeastern Junggar Basin (Kelameili region), the sedimentation was
546 dominated by alluvial fan and alluvial plain deposits (Eberth et al., 2001; Vincent et al., 2001;
547 Yang et al., 2015), indicating the existence of an eroding relief to the east within the vicinity
548 of the present-day Altai Range. Indeed, Upper Triassic and Lower Jurassic angular
549 unconformities were associated with coarse-grained pulses in the sedimentation suggesting
550 that episodes of deformation and erosion took place in this area (Vincent et al., 2001). This is
551 in agreement with seismic data showing that this region underwent transpressional
552 deformation during Early Jurassic times (Zhao et al., 2014). To the south-east, sedimentation
553 in the Junggar and Turfan basins consisted mainly of alluvial to lacustrine deposits.
554 Widespread perennial lakes and associated lacustrine deltas developed within the central part
555 of both basins while alluvial environments dominated in the areas nearby the reliefs (this
556 study; Hendrix et al., 1992; Eberth et al., 2001; Vincent et al., 2001; Shao et al., 2003; Bian et

557 al., 2010; Feng et al., 2015; Yang et al., 2015). Paleocurrent measurements together with
558 sedimentological and provenance analyses seem to indicate the presence of a low relief
559 between the Junggar and Turfan basins (the present day Bogda Shan area) (Hendrix et al.,
560 1992; Greene et al., 2001; Shao et al., 2003; Tang et al., 2014). However, the lack of Early
561 Jurassic ages in the low-temperature thermochronology data of the Bogda Shan area indicates
562 the absence of significant tectonic exhumation (Tang et al., 2015). This suggests that the relief
563 was not derived from an Early Jurassic uplift and deformation event, but was probably
564 inherited from the Permian to Triassic topography.

565 In the western Junggar Basin (Karamay region), several unconformities within the
566 Lower Jurassic series are directly followed by conglomerate deposits (Eberth et al., 2010;
567 Deng et al., 2010; Ma et al., 2014) and indicate that several deformation events also occurred
568 in this area. The presence of alluvial fan and alluvial plain environments (Eberth et al., 2001)
569 together with braided delta prograding eastward into a lake (Feng et al., 2015), point again to
570 the existence of an eroding relief in place of the present day Halaalate mountains which
571 provided sediments to the Junggar Basin.

572 Along the southern margin of the Junggar Basin, depositional environments consisted
573 of alluvial fans to alluvial plains. The occurrence of numerous coal beds together with plant
574 remnants in the associated series suggests rather humid conditions (this study; Hendrix et al.,
575 1992; Eberth et al., 2001). Even though the Early to early Middle Jurassic sedimentation in
576 that area is mostly regarded as continental, Sha et al. (2011) and Pan et al. (2012) suggested
577 the occurrence of brackish water fauna (“*Waagenoperna*”) in the south Junggar Basin
578 indicative of an intermittent connection with the Tethys Sea to the west. However, due to poor
579 preservation, the “*Waagenoperna*”, as figured and described from the Badaowan Fm by Sha
580 et al. (2011, 2016) and Pan et al. (2012) shows none of the characteristic generic features
581 situated on the inner side of the shell (Simon Schneider, pers. com.). Moreover, it co-occurs
582 with other bivalves which are clearly freshwater taxa, as stated by Sha et al. (2011) and Pan et

583 al. (2012) themselves. We thus propose that the “*Waagenoperna*” described in the Junggar
584 Basin is most likely a misidentified freshwater bivalve of unknown affinities and that no
585 marine incursion occurred in the southern area of the Junggar Basin during the Early Jurassic
586 epoch.

587 Along the Manas section (Fig. 1 for location; Fig. 8), the unconformity between the
588 Upper Triassic and Lower Jurassic sediments suggests that deformation and erosion events
589 took place at the southern margin of the Junggar Basin during this period (Eberth et al., 2001;
590 Yang et al., 2015). North directed paleocurrent measurements together with provenance data
591 indicate that these sediments were derived from the south, locating a relief in the place of the
592 present day Tian Shan Range (Hendrix et al., 1992; Yang et al., 2013). These observations are
593 in agreement with low-temperature thermochronology data which highlight a Late Triassic -
594 Early Jurassic cooling phase associated with the reactivation of the main Paleozoic structures
595 of the North Tian Shan region (Dumitru et al., 2001; Jolivet et al., 2010).

596 Several intra-mountain basins were also active within the Tian Shan Range during the
597 Early to early Middle Jurassic. The Yili Basin was principally occupied by alluvial plain,
598 lacustrine delta and lacustrine environments with coal deposits suggesting humid conditions.
599 The main depocenter was located in the northern part of the basin (Li et al., 2014). To the
600 south, the Zahosu depression was also active (Li et al., 2015). Coarse grained fan delta
601 deposits prograding towards the north in the Yili Basin (Li et al., 2014) and the sediment
602 grain-size evolving southward from conglomerates to sandstones and siltstones in the Zahosu
603 depression (Li et al., 2015) imply that a physiographic separation existed between the two
604 basins at that time. To the south-east, preserved Lower Jurassic sediments along the northern
605 edge of the Bayanbulak Basin (XBGMR, 1969) suggest that this depression was also active
606 during this period. Finally a Late Triassic – Early Jurassic cooling phase was identified in the
607 low-temperature thermochronology data along the Narat Range between the Bayanbulak and

608 Yili basins. This suggests the presence of an eroding relief separating these basins (Dumitru et
609 al., 2001; Jolivet et al., 2010).

610 To the south-east of the Tian Shan, the Yanqi Basin presents deposits associated to
611 environments evolving from alluvial fan to lacustrine systems (Al-Qaraafi and Guangqing,
612 2013). Sedimentological analyses within both the Turfan and Yanqi basins suggest that they
613 were separated from each other by an eroding relief (Shao et al., 2003; Al-Qaraafi and
614 Guangqing, 2013). However, whether the Yanqi and Tarim basins were connected or
615 separated by a relief during the Early to early Middle Jurassic is unclear due to the lack of
616 data in that region.

617 During this period, the north Tarim Basin was characterized by alluvial fan systems
618 evolving southward to alluvial plain, lacustrine delta and lacustrine environments (Fig. 12).
619 Provenance analyses together with south directed paleocurrents indicate the existence of an
620 eroding relief to the north forming the main source area for the detrital material deposited in
621 this part of the basin (Hendrix et al., 1992; Li and Peng., 2010; Liu et al., 2013; Wang et al.,
622 2015). The very monogenic (quartz) and well-sorted grain size of the lacustrine delta
623 sediments encountered in the Yaha section (Yengisar Fm; Fig. 12) could indicate that these
624 deposits were possibly reworked from an old weathering profile. This statement is in
625 agreement with the provenance data (Liu et al., 2013) which indicate that topography of the
626 source area could have already been partially flattened at that time.

627 To the west of the Tian Shan, in the Fergana Basin, renewed subsidence occurred
628 during the Early Jurassic following the erosion event that characterized the Triassic period in
629 that region (Clarke, 1984). This led to the accumulation of 90-400 m-thick deposits in
630 alluvial, lacustrine fan delta to shallow lacustrine environments, which unconformably
631 overlay the Paleozoic basement (Clarke, 1984; De Pelsmaecker et al., 2018). Numerous coal
632 beds and plant remnants were described in these deposits indicating abundant vegetation and
633 humid climate conditions. At the same time, to the east of the Fergana Basin, ~4000 m of

634 sediments were deposited within the Yarkand-Fergana Basin (Sobel et al., 1999). This strong
635 sediment accommodation is thought to be induced by strike-slip motion on the Talas
636 Fergana/Karatau fault leading to the formation of an Early – Middle Jurassic pull-apart basin
637 (Sobel et al., 1999; Allen et al., 2001; Alexeiev et al., 2017). Within this Yarkand - Fergana
638 Basin, depositional environments consist mainly of alluvial, fan delta and deep lake systems
639 (Sobel et al., 1999; De Pelsmaecker et al., 2018). Low-temperature thermochronology data also
640 indicate a Late Triassic – Early Jurassic cooling phase within the Kyrgyz Tian Shan area
641 probably induced by the reactivation of Paleozoic structures and basement exhumation (Sobel
642 et al., 2006; De Grave et al., 2007, 2012; Glorie and De Grave, 2016; Nachtergaele et al.,
643 2018).

644 Several Lower to Middle Jurassic outcrops have also been described by De
645 Pelsmaecker et al. (2018) in the Ming-Kush and south Issyk-Kul basins and similar age
646 deposits were observed in both the Naryn and Aksai basins (VNIGNI and Beicip Franlab,
647 1992) located within the northern part of the present day Kyrgyz Tian Shan (Fig. 1 for
648 location). Generally, the stratigraphic ages of these sediments reported on the geological maps
649 are Lower Jurassic (e.g., Lasovskiy and Mozolev, 1961), however, no biostratigraphic data
650 are available for these series. Sedimentation mainly consisted of alluvial plain, fan delta and
651 shallow lacustrine deposits. These deposits are often associated with coal-rich layers and plant
652 fragments indicating humid climate conditions although some caliche-type paleosols more
653 typical of semi-arid conditions were also identified in the south Issyk-Kul Basin (De
654 Pelsmaecker et al., 2018; VNIGNI and Beicip Franlab, 1992). Low-temperature
655 thermochronology data support a Middle Triassic - Early Jurassic cooling phase within the
656 basement separating all these basins (e.g., De Grave et al., 2011; Glorie et al., 2011)
657 indicating the presence of eroding reliefs between these intra-mountain basins.

658 To the north of the Kyrgyz Tian Shan, no Lower Jurassic sediments have been
659 described within the south Chu-Sarysu and Yili-Balkhash basins (VNIGNI and Beicip

660 [Franlab, 1992; AGMCA, 2008](#)). We propose that these domains were dominated by sediment
661 by-pass (i. e. lowland areas dominated by soil alteration, low erosion and/or low sedimentary
662 export or by a poor preservation of thin sediment deposits) during the Early – early Middle
663 Jurassic. Similarly, no Jurassic sediments have been deposited in the western part of the
664 Tarim Basin, except for Jurassic series exposed more to the south, along the West Kunlun –
665 Pamir Range ([Lee 1985a, b; Sobel et al., 1999; Yang et al., 2017](#)). We thus propose that this
666 domain was also dominated by sediment by-pass during the Early – early Middle Jurassic.
667 Nevertheless, some restricted piedmonts deposits could have existed that were not preserved
668 within the stratigraphic record.

669

670 **4. 2. LATE MIDDLE – EARLY LATE JURASSIC**

671

672 The late Middle to early Late Jurassic paleogeography of the Tian Shan region was
673 mostly characterized by sedimentary basins surrounded by relatively low- relief basement
674 areas (Fig. 14).

675 In the northeastern Junggar Basin (Kelameili region), the late Middle – early Late
676 Jurassic strata consist mainly of alluvial plain to shallow lacustrine deposits ([Eberth et al.,
677 2001; Vincent et al., 2001](#)). These environments are more distal compared to the Early
678 Jurassic ones and potentially indicate a lowering or a retreat further to the east of the Early
679 Jurassic relief. However, some local Middle Jurassic unconformities have been identified in
680 this area which suggests recurrent periods of localized deformation and erosion ([Eberth et al.,
681 2001; Vincent et al., 2001](#)). To the north-east, in the Junggar and Turfan basins, late Middle –
682 early Late Jurassic deposits reflect alluvial to lacustrine depositional environments ([this study;
683 Hendrix et al., 1992; Eberth et al., 2001; Vincent et al., 2001; Shao et al., 2003; Bian et al.,
684 2010; Yang et al., 2015](#)). The paleocurrent measurements, sedimentological analyses and
685 provenance studies indicate the presence of an existing relief between the two basins

686 persisting from the Early Jurassic (Hendrix et al., 1992; Shao et al., 1999, 2003; Tang et al.,
687 2014; Ji et al., 2017). Based on provenance studies, some authors proposed that this area also
688 underwent several uplift episodes during the Middle Jurassic (Tang et al., 2014; Ji et al.,
689 2017). However, the lack of contemporaneous exhumation ages and the occurrence of fine
690 grained sediments in both the Junggar and Turfan basins rather suggest the absence of strong
691 exhumation events in this region (Shao et al., 2003; Tang et al., 2015; Yang et al., 2015).

692 To the west of the Junggar Basin (Karamay region), the sedimentation was dominated by
693 alluvial fan to alluvial plain deposits (Eberth et al., 2001). The presence of a Middle Jurassic
694 unconformity sealed by conglomerates again indicates that deformation persisted in that area
695 during this period (Eberth et al., 2001; Deng et al., 2010).

696 Along the southern margin of the Junggar Basin, the strata exposed in the Wusu
697 section consist mainly of alluvial fan to alluvial plain deposits (Fig. 9). Further east, along the
698 Manas and Toutunhe sections, the sediments are characteristic of more distal environments
699 such as alluvial plain to lacustrine delta (Figs. 6, 7, 8) (this study; Hendrix et al., 1992; Eberth
700 et al., 2001; Deng et al., 2010). North-oriented paleocurrents attest of the presence of an
701 eroding relief to the south (Hendrix et al., 1992). The more distal depositional environments
702 in the Manas region potentially indicate that this relief was lower or located further south than
703 during the Early Jurassic. This trend is in agreement with the low-temperature
704 thermochronology data which associate the Middle Jurassic to a period of low basement
705 cooling rates and thus to a period of flattening of the relief in the North Tian Shan region
706 (Dumitru et al., 2001; Jolivet et al., 2010). In the southern margin of the Junggar Basin, the
707 late Middle Jurassic deposits contain numerous coal beds (Figs. 6, 7, 8) (this study; Hendrix et
708 al., 1992; Eberth et al., 2001; Deng et al., 2010). The occurrence of these coal beds indicates
709 that rather humid conditions persisted during that period. This coal disappears in the early
710 Late Jurassic deposits, while extensive calcareous paleosols indicative of semi-arid conditions
711 developed (This study; Hendrix et al., 1992; Eberth et al., 2001; Vincent et al., 2001; Deng et

712 al., 2010; Jolivet et al., 2017a). Several volcanic tuff layers and syn-sedimentary volcanic
713 zircons have also been described in the Middle Jurassic series along the southern margin of
714 the Junggar Basin (Wusu and Manas sections, Bogda Shan) indicating a volcanic activity
715 within the north Tian Shan region during that period (Fig. 9; Yang et al., 2013; Simonov et
716 al., 2015; Ji et al., 2017). However, the eruption center has not yet been located.

717 The Middle Jurassic sediment in the Yili Basin consists of alluvial to lacustrine
718 deposits (Fig. 10; Li et al., 2014). Due to the absence of coarse grained sediments and to the
719 presence of extensive coal beds in the southern part of the basin as well as in the Zahosu
720 depression immediately to the south (Li et al. 2014; Li et al., 2015), we suggest that no erosive
721 domain separated these two basins during that period. However, the occurrence of alluvial fan
722 to proximal alluvial plain deposits in the northern part of the Bayanbulak Basin (Fig. 11)
723 implies the existence of a nearby eroding relief. Moreover, low-temperature
724 thermochronology data indicate a Middle Jurassic period of slow cooling in the Narat region
725 interpreted as a period of slow erosion (Dumitru et al., 2001; Jolivet et al., 2010). We thus
726 propose that the relief established along the Narat fault during the Late Paleozoic – Early
727 Jurassic was not entirely flattened by Middle Jurassic and therefore, that it still constituted a
728 physiographic separation between the Bayanbulak and Yili basins.

729 To the south-east of the Tian Shan, no data are available for the Middle – Late Jurassic
730 strata of the Yanqi Basin. However, sedimentological analyses within the Turfan Basin
731 indicate the presence of an eroding relief separating the Turfan Basin from the Tarim Basin
732 (Shao et al., 2003).

733 Along the Yaha section in the north Tarim Basin, the Middle Jurassic strata were
734 deposited in alluvial plain to lacustrine environments (Fig. 12). South-directed paleocurrents
735 and provenance analyses also indicate the presence of an eroding relief to the north (Hendrix
736 et al., 1992; Li and Peng., 2010; Liu et al., 2013; Wang et al., 2015). However, the more distal
737 depositional environments compared to the Early Jurassic ones suggest a lowering or a

738 northward retreat of the relief with a widening of the basin. This is also supported by detrital
739 zircon U-Pb data showing a widening of the sediment source area during the Middle Jurassic
740 (Liu et al., 2013).

741 To the west of the Tian Shan, the Middle Jurassic series in the Fergana Basin consist
742 of 100-300 m-thick alluvial to lacustrine deposits (Clarke, 1984; De Pelsmaecker et al., 2018).
743 Coal beds and plant fragments are abundant within these sediments and indicate humid
744 conditions (De Pelsmaecker et al., 2018). To the east of the Fergana Basin, the Yarkand-
745 Fergana Basin was still subsiding due to strike-slip motion along the Talas Fergana/Karatau
746 fault and it accommodated ~600–1550 m of Middle Jurassic sediments (Sobel et al., 1999;
747 Allen et al., 2001; Alexeiev et al., 2017). The facies of the latter indicate the occurrence of
748 alluvial plain, lacustrine delta and lacustrine depositional environments (Sobel et al., 1999; De
749 Pelsmaecker et al., 2018). Like in the Chinese Tian Shan, low-temperature thermochronology
750 data indicate low cooling rates during the Middle Jurassic within the Kyrgyz Tian Shan. This
751 was interpreted as a period of slow erosion leading to progressive planation of the basement
752 areas (De Grave et al., 2007, 2013; Macaulay et al., 2014; Glorie and De Grave, 2016).
753 Meanwhile, in the Ming-Kush, south Issyk-Kul, Naryn and Aksai basins, a Middle Jurassic to
754 Eocene hiatus in sedimentation has been identified (VNIGNI and Beicip Franlab, 1992;
755 Burbank et al., 1999; De Pelsmaecker et al., 2018).

756 Further north, no Middle - Late Jurassic sediments were described within the south
757 Chu-Sarysu and Yili-Balkhash basins (VNIGNI and Beicip Franlab, 1992; AGMCA, 2008).
758 We propose that these domains were still dominated by sediment by-pass during this period.
759 Similarly to the Early Jurassic period, the western Tarim Basin seems also dominated by
760 sediment by-pass during the Middle - Late Jurassic (Lee 1985a, b). Nevertheless, some
761 restricted piedmonts deposits could again have existed that were not preserved within the
762 stratigraphic record.

763

764 **4. 3. LATE JURASSIC - EARLY CRETACEOUS TRANSITION**

765

766 In the Tian Shan region, the Late Jurassic - Early Cretaceous transition corresponds to
767 a drastic paleogeographic change in comparison to the Early and Middle Jurassic periods (Fig.
768 15). In the Junggar and Turfan basins, the sedimentation was dominated by alluvial fan to
769 alluvial plain deposits (Hendrix et al., 1992; Shao et al., 1999; Eberth et al., 2001; Vincent et
770 al., 2001; Bian et al., 2010; Jolivet et al., 2017a). Low-temperature thermochronology data
771 indicate a Jurassic - Early Cretaceous fast cooling event in the present day Bogda Shan area
772 implying that this region underwent deformation and uplift during this period (Tang et al.,
773 2015).

774 To the north-east and north-west of the Junggar Basin, in the Kelameili and Karamay
775 regions (Fig. 15), the Upper Jurassic - Lower Cretaceous deposits are associated with alluvial
776 fans and alluvial plain environments (Eberth et al., 2001; Vincent et al., 2001; Jolivet et al.,
777 2017a). Angular unconformities at the base of the alluvial fans sediments (corresponding to
778 the Kalaza Fm) have been identified in both regions and are, in the Kelameili area, associated
779 with incised paleo-valleys (Eberth et al., 2001). They imply uplift and relief building in these
780 areas, in agreement with the seismic data indicating that transpressive deformation occurred
781 within the eastern and western part of the Junggar Basin during the Jurassic (Zhao et al.,
782 2014; Yu et al., 2016). Such a tectonic setting could have led to widespread deformation
783 leading to the generation of a relief within the Junggar Basin.

784 Indeed, a NE-SW-orientated erosional area, the Chemo uplift, started to develop
785 within the central part of the Junggar Basin during the Middle Jurassic and reached its peak
786 stage during the Late Jurassic - Early Cretaceous (Lianhua et al., 2009; Yang et al., 2015; Gao
787 et al., 2017). Erosion of this topographic high provided terrigenous material that was shed into
788 the adjacent, still subsiding areas (Lianhua et al., 2009; Yang et al., 2015; Gao et al., 2017).

789 Based on seismic data, Lianhua et al. (2009) estimated that the amplitude of this paleorelief
790 could have reached 740 m during its peak development stage.

791 Along the southern margin of the Junggar Basin, the sedimentation consisted mainly
792 of several meters to hundred meters-thick alluvial fan deposits typical of semi-arid to arid
793 climate conditions (Figs. 6, 8, 9) (this study; Jolivet et al., 2017a). Indeed, aeolian deposits are
794 present in the Kelameili and Toutunhe regions (Fig. 1 for location). Along the south Toutunhe
795 section, they are interbedded with ephemeral alluvial fan deposits (Fig. 6) and evolved
796 northward to erg deposits with large dunes and interdunes (Fig. 7). The occurrence of these
797 thick aeolian deposits indicate that this region was under semi-arid to arid climate conditions
798 during the Late Jurassic - Early Cretaceous (this study; Eberth et al., 2001; Vincent et al.,
799 2001; Jolivet et al., 2017a).

800 As in the north of the Junggar Basin, angular unconformities have been identified at
801 the base or within the Kalaza Fm (Hutubi and North Toutunhe sections) (this study; Jolivet et
802 al., 2017a). Moreover, provenance analyses demonstrate that recycling of Mesozoic sediments
803 took place in this area. These observations imply that some tectonic movements and rock
804 uplift also occurred during the Late Jurassic - Early Cretaceous within the North Tian Shan
805 foothills (Yang et al., 2013). However, low-temperature thermochronology data on basement
806 rocks from the central Tian Shan do not identify any evidence of tectonic movements during
807 this period and show that exhumation was in fact controlled by slow erosion since the Middle
808 Jurassic (Dumitru et al., 2001; Jolivet et al., 2010). Accordingly, we propose that small
809 amplitude tectonic movements occurred within the North Tian Shan Range and its piedmont,
810 leading to limited relief building during the Late Jurassic - Early Cretaceous.

811 Within the Tian Shan Range, both Yili and Bayanbulak basins do not contain Upper
812 Jurassic – Lower Cretaceous sediments (AGMCA, 2008). Following an Late Jurassic – Early
813 Cretaceous unconformity, a ~40 m-thick weathered layer formed within the Yili Basin,
814 overlain by Upper Cretaceous sediments and indicating rather stable conditions for a long

815 period of time (VNIGNI and Beicip Franlab, 1992). Therefore, we propose that this domain
816 was dominated by sediment by-pass during the Late Jurassic – Early Cretaceous. To the
817 south, low-temperature thermochronology data indicate slow cooling, hence low erosion
818 within the Narat Range. This suggests a continuous flattening of the topography during this
819 period (Dumitru et al., 2001; Jolivet et al., 2010). In the Bayanbulak Basin, Eocene (?) strata
820 rest unconformably on the Middle Jurassic series again implying that the basin was dominated
821 by sediment by-pass and/or erosion during the Late Jurassic - Early Cretaceous.

822 To the south-east of the Tian Shan, the relation between the Yanqi and the Tarim
823 basins is not clear. No Upper Jurassic – Lower Cretaceous sediments were described within
824 the Yanqi Basin (AGMCA, 2008; Huang et al., 2015). We therefore propose that this region
825 was dominated by sediment by-pass during this period.

826 In the northern part of the Tarim Basin, the Late Jurassic – Early Cretaceous
827 sedimentation was characterized by relatively thin alluvial fan deposits (in comparison to the
828 Junggar Basin) evolving southward towards alluvial plain deposits (Fig. 15). Provenance and
829 petrographic analyses point to a sediment source from the South Tian Shan Range, altogether
830 with local recycling of Mesozoic sediments indicating a southward migration of the eroding
831 topography (Li et al., 2004; Li and Peng, 2010).

832 To the west, the Late Jurassic - Early Cretaceous sedimentation in the Fergana Basin
833 consisted of alluvial fan and alluvial plain deposits (Fig. 15). In the northern part of the basin
834 (Tash-Komyr section; Fig. 1), the transition between the Jurassic and the Cretaceous is
835 marked by an erosional unconformity directly followed by > 110 m-thick alluvial fan deposits
836 (De Pelsmaeker et al., 2018). This suggests that some tectonic movements occurred during
837 that period. To the south (Jetim-Dobo section; Fig. 1) the sedimentation consists of alluvial
838 plain deposits containing calcareous paleosols, and indicating semi-arid climate conditions
839 (De Pelsmaeker et al., 2018).

840 Meanwhile to the east, alluvial fan and proximal alluvial plain systems developed in
841 the western and southern parts of the Yarkand–Fergana Basin (Sobel et al., 1999; De
842 Pelsmaeker et al., 2018). Provenance studies on Late Jurassic – Early Cretaceous samples
843 indicate potential recycling of older Jurassic sediments and smaller drainage area compared to
844 the Early – Middle Jurassic paleogeography (De Pelsmaeker et al., 2018). Together, these data
845 imply a Late Jurassic – Early Cretaceous inversion of the Yarkand-Fergana Basin. This
846 renewed tectonic activity is further supported by low-temperature thermochronology data
847 which identify a Late Jurassic –Early Cretaceous cooling event in the Kyrgyz Tian Shan
848 Range suggesting a localized relief building (De Grave et al., 2007, 2012, 2013; Glorie and
849 De Grave., 2016; Nachtergaele et al., 2018).

850 No Upper Jurassic – Lower Cretaceous sediments were described within the Chu-
851 Sarysu, Yili–Balkash and west Tarim basins (Lee 1985a, b; VNIGNI and Beicip Franlab,
852 1992; AGMCA, 2008). We therefore propose that these domains were still dominated by
853 sediment by pass during this period even though some restricted piedmont deposits could
854 have existed and not subsequently preserved within the stratigraphic record.

855

856 5. DISCUSSION

857

858 5. 1. TOPOGRAPHIC AND CLIMATIC EVOLUTION OF THE TIAN SHAN

859

860 The Jurassic topographic evolution of the Tian Shan was dominated by the progressive
861 planation of a late Paleozoic to early Mesozoic relief, locally interrupted by discreet
862 topographic rejuvenations (Fig. 16) (e.g., this study, Dumitru et al., 2001; Jolivet et al., 2010;
863 Li and Peng, 2010; Liu et al., 2013; Macaulay et al., 2014). In both the north and south Tian
864 Shan foothills, a progressive transition can be observed from Early Jurassic coarse-grained
865 sediments associated with proximal alluvial environments, to finer-grained deposits

866 characteristic of distal alluvial to lacustrine systems during the Middle Jurassic (this study;
867 [Hendrix et al., 1992](#); [Eberth et al., 2001](#); [Bian et al., 2010](#)). This highlights the progressive
868 decrease of the Tian Shan relief. During the Early to Middle Jurassic, the sedimentation, in
869 the basins surrounding the range and in the intra-mountain depressions, was characterized by
870 alluvial to lacustrine deposits containing numerous coal beds and plant fragments indicating
871 humid climate conditions (Fig. 16; this study; [Hendrix et al., 1992](#); [Sobel et al., 1999](#); [Eberth](#)
872 [et al., 2001](#); [Bian et al., 2010](#); [De Pelsmaeker et al., 2018](#)). Finally, the Middle Jurassic period
873 was also characterized by volcanic activity within the north Tian Shan region (this study;
874 [Yang et al., 2013](#); [Simonov et al., 2015](#); [Ji et al., 2017](#)). During the early Late Jurassic, the
875 Tian Shan relief was still decreasing, with contemporaneous fine-grained sediments deposited
876 in distal alluvial to lacustrine environments. However, this period was marked by a change in
877 climate conditions, recorded all over the Tian Shan area by the disappearance of the humid
878 conditions marked by coal layers and the extensive formation of calcareous paleosols,
879 indicative of semi-arid conditions (this study; [Hendrix et al., 1992](#); [Eberth et al., 2001](#);
880 [Vincent et al., 2001](#); [De Pelsmaeker et al., 2018](#)). This Late Jurassic aridification affected
881 most of Central Asia and was also identified in the West Siberian Basin (e.g., [Hendrix et al.,](#)
882 [1992](#); [Le Heron et al., 2008](#)) and within the Turan domain where sedimentation partly
883 consisted on thick evaporite units ([Brunet et al., 2017](#)).

884 The Late Jurassic – Early Cretaceous transition was marked by a tectonic reactivation
885 leading to localized relief building within the Tian Shan and coarse-grained proximal alluvial
886 deposits surrounding the range (Fig. 16) (; [De Grave et al., 2007, 2012, 2013](#); [Tang et al.,](#)
887 [2015](#); [Glorie and De Grave., 2016](#); [Nachtergaele et al., 2018](#)). Meanwhile, the Yili and
888 Bayanbulak basins were dominated by sediment by-pass and/or limited erosion.
889 Contemporaneous, limited relief building is also suggested in the Altai ([Eberth et al., 2001](#);
890 [Yuan et al., 2006](#)). The Late Jurassic – Early Cretaceous transition was further characterized
891 by the climax of the aridification trend which was prevailing since the early Late Jurassic. In

892 the Junggar Basin, this peak in aridity has been associated to the deposition of alluvial fans
893 together with large - scale aeolian dunes (Jolivet et al., 2017a).

894

895 **5. 2. AN EARLY - MIDDLE JURASSIC KINEMATIC FRAMEWORK DRIVEN BY** 896 **FAR-FIELD TECTONICS**

897

898 The Jurassic tectonic and topographic evolution of the Tian Shan region is thought to
899 be mostly controlled by compressive or transpressive events at continental scale (Allen et al.,
900 1991; Hendrix et al., 1992; Sobel et al., 1999; Vincent et al., 2001; Allen et al., 2001; Yang et
901 al., 2015). Thus, Late Triassic-Early Jurassic evidences of deformation in the area are often
902 related to the Qiangtang collision along the southern margin of Eurasia to the south, which
903 ended at that time (Kapp et al., 2007; Roger et al., 2010). However, no major collision
904 episode has been reported along this Eurasian margin between the Qiangtang collision and the
905 Early Cretaceous Lhasa collision (Kapp et al., 2007; Roger et al., 2010). The absence of
906 significant collision suggests that other kinematic events occurred during the Jurassic, leading
907 to tectonic activity in the Tian Shan region. To the south, in the Tibet area, no major Jurassic
908 geodynamic event has been described (Roger et al., 2004, 2010; Reid et al., 2005). To the
909 north-east, the timing of the final closure of the Mongol-Okhotsk Ocean remains poorly
910 constrained. It is thought to occur during the Late Jurassic-Early Cretaceous time (e.g., Zorin,
911 1999; Donskaya et al. 2013; Daoudene et al., 2017) and was probably not associated with
912 strong compressive deformation (Fig. 17. A) but rather with distributed extension affecting a
913 thin, abnormally warm crust (Daoudene et al., 2017; Jolivet et al., 2017b).

914 As mentioned above, in the Tian Shan region, east of the Talas Fergana/Karatau fault,
915 the first order geometry of the Jurassic sediments preserved within the Tarim and Junggar
916 basins is characterized by depocenters located along the Tian Shan Range (Fig. 17. B) (Lee,
917 1985; Hendrix et al., 1992; Bian et al., 2010; Yang et al., 2015). Moreover, recurrent periods

918 of localized and limited Jurassic deformation associated with thrust faults have been reported
919 within the two basins (e.g., Eberth et al., 2001; Vincent et al., 2001; Liu et al., 2006; Wang et
920 al., 2012; Zhao et al., 2014; Chen et al., 2015; Ma et al., 2015; Yang et al., 2015). These
921 observations indicate that the Jurassic Junggar and Tarim basins were compressive basins and
922 that the Tian Shan region was under compressional setting at that time (Allen et al., 1991;
923 Hendrix et al., 1992; Yang et al., 2015). Nonetheless, the Early-Middle Jurassic period was
924 mainly characterized by the progressive planation of the Tian Shan relief established during
925 the late Paleozoic – early Mesozoic (Dumitru et al., 2001; Jolivet et al., 2010; Glorie and De
926 Grave, 2016). This implies that no major compressive tectonic event leading to an extensive
927 relief building occurred in that area. The attested recurrent tectonic activity, together with the
928 absence of a major relief build-up during this period, suggest strike-slip fault kinematics with
929 limited vertical motion rather than true compressional tectonics. This idea is supported by
930 seismic data interpretations that also indicate a Jurassic transpressional deformation in the
931 Junggar Basin (Liu et al., 2006; Wang et al., 2012; Yu et al., 2016), which is potentially
932 related to the Jurassic- Early Cretaceous rotation of the Junggar block (Lianhua et al., 2009;
933 Yu et al., 2016). Jurassic to Cretaceous strike-slip tectonics has also been described in the
934 eastern part of the Tarim Basin (Wang et al., 2012) as well as extensional faults (Yang et al.,
935 2017).

936 In the Tian Shan area, several NW-SE and E-W oriented lithospheric faults (e.g., the
937 Talas Fergana fault, the Nikolaev line, the North Tian Shan fault and numerous smaller ones)
938 accommodated late Paleozoic block rotations (Bazhenov et al., 1999; Van Der Voo et al.,
939 2006 and references therein). Similarly, we propose that these structures could have been
940 reactivated during the Jurassic accommodating the rotation of several blocks localized in the
941 Tian Shan region. Such motion would favor the development of localized, small scale relief
942 along these main faults. Early Jurassic reactivation along the Talas Fergana/Karatau fault has
943 indeed been identified by kinematic analysis conducted on the south Turgay Basin and by

944 geochronological studies (Rolland et al., 2013; Alexeiev et al., 2017). Along the southern edge
945 of the Tarim Basin, geochronology data indicate that strike-slip motion of the Altyn Tagh
946 fault occurred during Middle Jurassic times (Sobel et al., 2001; Liu et al., 2007). However, the
947 exact kinematic of these strike-slip motion as well as the direction of rotation of the blocks
948 localized in the Tian Shan region is still unclear. Indeed, Jurassic clockwise or anticlockwise
949 rotation of the Junggar Basin has been proposed in the literature (for example respectively in
950 Lianhua et al., 2009 and Yu et al., 2016). Similarly, both Jurassic dextral and sinistral motion
951 along the Altyn Tagh fault have been suggested (Sobel et al., 1999; Liu et al., 2007). Finally,
952 post early Permian sinistral strike-slip motion has been identified along the Nikolaev line in
953 Kyrgyztan (Bazhenov and Mikolaichuk, 2004) but it is not clear if this kinematic prevailed
954 during the Jurassic.

955 West of the Talas Fergana/Karatau fault, compressional events of regional significance
956 occurred throughout the Caspian, Turan and south Kazakh domains during the Late Triassic
957 leading to the inversion of numerous basins in this area (Otto, 1997; Thomas et al., 1999).
958 Following this compressional phase, a widespread late Early to Middle Jurassic extension
959 associated to back-arc development driven by the northward subduction of the Neo-Tethys
960 oceans affected these regions (Zonenshain and Le Pichon 1986; Nikishin et al. 1998; Thomas
961 et al., 1999; Brunet et al., 2003, 2017; Robert et al., 2014; Mordvintsev et al., 2017). This
962 extension reactivated mainly NW-SE orientated Paleozoic structures as normal faults. In turn,
963 these normal faults induced localized subsidence leading to the emplacement of elongated
964 NW-SE depocenters in the Amu-Darya and Kopet Dagh basins (Fig. 17) (e.g., Robert et al.,
965 2014; Brunet et al., 2017; Mordvintsev et al., 2017). Further east, Triassic – Middle Jurassic
966 extension has also been reported in the western part of the Afghan - Tajik Basin (Brookfield
967 and Hashmat, 2001).

968 Accordingly, the Talas Fergana/Karatau fault seems to be a major NW-SE structure
969 separating the Tian Shan domain to the east, dominated by possible strike slip tectonics and

970 block rotations and the Turan and southwest Kazakh domains to the west, dominated by
971 extension. Along this fault, several basins formed during the Early-Middle Jurassic (Fig. 17).
972 To the north, the South Turgay Basin is characterized by a series of N to NW orientated
973 grabens and half grabens, separated by basement highs and filled by up to 2.5 km of Lower to
974 Middle Jurassic fluvio-lacustrine sediments (Moseley and Tsimmer, 2000; Allen et al., 2001;
975 Shi et al., 2016; Alexeiev et al., 2017). Within the central part of the Talas Fergana/Karatau
976 fault, the Leontiev Graben is an elongate basin containing up to 1.5 km of Jurassic fluvial and
977 lacustrine sediments (Sobel et al., 1999; Allen et al., 2001). Finally, at the south-eastern
978 termination of the fault, the Yarkand-Fergana Basin consists of thick (c. a. 5 km) Lower to
979 Middle Jurassic series of continental deposits (Sobel et al., 1999; De Pelsmaeker et al., 2018).
980 Several studies propose that these basins formed in response to dextral strike-slip motion
981 along the Talas Fergana/Karatau fault. This would induce the opening of the South Turgay
982 Basin as a trailing imbricate fan and the opening of both the Leontiev and Yarkand-Fergana
983 basins, either as dextral transtensional structures at right-stepping jogs in the fault system
984 (e.g., Allen et al., 2001; Alexeiev et al., 2017) or as pull-apart basins (Sobel et al., 1999). This
985 kinematic model has been mainly based on geometrical analysis of seismic data conducted on
986 the Turgay system (Alexeiev et al., 2017). These authors suggest that consequent Jurassic
987 dextral strike-slip motion occurred along the Talas Fergana/Karatau fault, and its maximum
988 offset was estimated by Alexeiev et al., (2017) to reach 70 km. On the other hand, Burtman
989 (1980) considered Jurassic slip as insignificant along this fault in the Kyrgyzstan region.
990 Finally, the driving mechanism leading to such dextral motion along the Talas
991 Fergana/Karatau fault during the Early to Middle Jurassic period is yet to be fully understood.
992 Indeed, the precise onset age of formation of these basins is unclear. In the Leontiev Basin,
993 Lower Jurassic sediments have a pre Toarcian age based on palynological and geochemical
994 studies (Schnyder et al., 2016) while no clear stratigraphic ages are available for the south
995 Turgay and Yarkand Fergana basins. Geochronological data indicate that the Talas

996 Fergana/Karatau fault was already active close to the Triassic - Jurassic transition in the
997 Kyrgyz region (Rolland et al., 2013). The only coeval geodynamic event known in this region
998 that could cause such dynamic is the Qiangtang collision which ended during the Late
999 Triassic-Early Jurassic (Kapp et al., 2007). Therefore we propose that the early Early Jurassic
1000 dextral motion along this fault could have been induced by far-field effects of the final stage
1001 of the Qiangtang collision. However, it is difficult to understand how such a far-field induced
1002 compressional regime could have led to the opening of the Yarkand-Fergana Basin. Indeed,
1003 Sobel et al. (1999) proposed the existence of a strike-slip fault system located in the Kunlun
1004 area during that same period, allowing the formation of a Jurassic transtensional basin
1005 encompassing both the Yarkand-Fergana and the western Tarim Jurassic deposits. However,
1006 seismic data obtained within the western margin of the Tarim Basin neither show the presence
1007 of a Jurassic depot-center nor the presence of any fault parallel to the Talas Fergana/Karatau
1008 one in this area (Fig. 17) (Yang et al., 2017). This implies that both of these systems were
1009 disconnected from each other at that time. Moreover, opening of these basins continued
1010 during the late Early to Middle Jurassic (Sobel et al., 1999; Moseley et al., 2000; Allen et al.,
1011 2001; Alexeiev et al., 2017). During this period, no major collisional event has been identified
1012 along the Eurasian margin implying that another kinematic event induced the tectonic activity
1013 observed along the Talas Fergana/Karatau fault. As mentioned previously, simultaneous
1014 widespread extension affected the whole Caspian-Turan domains to the west. We propose that
1015 this subduction related extension could also have affected the Talas Fergana/Karatau region
1016 leading to continuous opening of the South Turgay, Leontiev and Yarkand Fergana basins
1017 during the late Early-Middle Jurassic period.

1018 Therefore, we propose that the early Early Jurassic evolution of the Tian Shan region
1019 was driven by the far-field effects of the Qiangtang collision final stage. However, recurrent
1020 tectonic activity persisted throughout the Tian Shan region during the Early – Middle Jurassic
1021 and such dynamic cannot be explained by this collision. The only regional geodynamic event

1022 affecting Central Asia during this period is the subduction of the Neotethys oceans which led
1023 to extension throughout the Caspian, Turan and south Kazakh domains (Zonenshain and Le
1024 Pichon 1986; Nikishin et al. 1998; Thomas et al., 1999; Brunet et al., 2003, 2017; Robert et
1025 al., 2014; Mordvintsev et al., 2017). We therefore assume that the extensional stress-field
1026 induced by the Neo-Tethys subduction also played a major role in driving the late Early to
1027 early Middle Jurassic tectonic and topographic evolution of the Tian Shan region. The far-
1028 field extension could have led to continuous opening of the basins previously formed along
1029 the Talas-Fergana Karatau fault while the rest of the Tian Shan was still possibly dominated
1030 by strike slip tectonics accommodated by the reactivation of the major NW-SE and E-W
1031 Paleozoic structures located within the range.

1032

1033 **5. 3. A LATE MIDDLE TO EARLY LATE JURASSIC PERIOD OF RELATIVE** 1034 **TECTONIC QUIESCENCE**

1035

1036 As explained above, the Jurassic topographic evolution of the Tian Shan Range was
1037 dominated by the progressive planation of a late Paleozoic to early Mesozoic relief. By Late
1038 Jurassic, almost all of the Tian Shan relief was thus flattened. Accordingly, even if a tectonic
1039 activity still occurred during the late Middle – early Late Jurassic, leading to the building of
1040 the Chemo uplift in the western part of the Junggar Basin for example (Lianhua et al., 2009;
1041 Yang et al., 2015; Gao et al., 2017), it stayed moderate and localized on the major tectonic
1042 structures. Meanwhile, west of the Talas Fergana/Karatau fault, this period marked the onset
1043 of a post rift phase dominated by thermal subsidence following extension in the Caspian –
1044 Turan – Kazakh domains (Thomas et al., 1999; Brunet et al., 2017; Mordvintev et al., 2017).
1045 Thermal subsidence also occurred in the South Turgay and Fergana basins (Clarke, 1984;
1046 Moseley and Tsimmer, 2000; Alexeiev et al., 2017).

1047

1048 **5. 4. A LATE JURASSIC – EARLY CRETACEOUS EVOLUTION CONTROLLED BY**
1049 **FAR-FIELD COLLISION AND CLIMATE**

1050

1051 The Late Jurassic - Early Cretaceous transition corresponds to a period of renewed
1052 transpression and localized uplift in the Tian Shan area (this study; [Hendrix et al., 1992](#);
1053 [Eberth et al., 2001](#); [Vincent et al., 2001](#); [De Grave et al., 2007, 2012, 2013](#); [Yang et al., 2015](#);
1054 [Tang et al., 2015](#); [Glorie and De Grave., 2016](#); [Nachtergaele et al., 2018](#)). Throughout the
1055 region, this period is marked by a sharp change in depositional environments with the
1056 emplacement of alluvial fan systems in the adjacent Junggar, Turfan, Tarim and Fergana
1057 basins. Along the Junggar Basin margins, the presence of angular unconformities at the base
1058 of conglomerate deposits indicates that tectonic movements occurred during this period
1059 ([Hendrix et al., 1992](#); [Eberth et al., 2001](#); [Vincent et al., 2001](#)). Meanwhile, the Chemo-uplift
1060 reached its peak stage leading to the formation of a widespread paleorelief within the basin
1061 ([Lianhua et al., 2009](#); [Yang et al., 2015](#); [Gao et al., 2017](#)). Similarly, in the Fergana Basin, the
1062 presence of an angular unconformity sealed by alluvial fan systems at the Jurassic-Cretaceous
1063 transition suggests that some tectonic movements occurred ([De Pelsmaecker et al., 2018](#)).
1064 Finally, Late Jurassic-Early Cretaceous compression has also been identified along the Talas
1065 Fergana/Karatau fault, since tectonic inversion and deformation have been described in the
1066 South Turgay ([Yin et al., 2012](#)), Leontiev ([Allen et al., 2001](#)) and Yarkand-Fergana basins
1067 ([De Pelsmaecker et al., 2018](#)). However, if episodes of deformations have been reported in the
1068 Tian Shan region, numerous large-scale, pre-orogenic planation surfaces have been preserved
1069 throughout the Tian Shan Range (e.g., [Burbank et al., 1999](#); [De Grave et al., 2011](#); [Jolivet et](#)
1070 [al., 2010](#); [Jolivet, 2017](#)). In the western Tian Shan, Upper Cretaceous strata overlying
1071 perfectly flat surfaces imply that no high relief existed in this region during the Early
1072 Cretaceous. Meanwhile, low temperature thermochronology data identified localized Late
1073 Jurassic –Early Cretaceous cooling event in the Kyrgyz Tian Shan Range suggesting only

1074 restricted relief building (De Grave et al., 2007, 2012, 2013; Glorie et al., 2011; Glorie and De
1075 Grave., 2016; Nachtergaele et al., 2018). However, despite, the lack of strong relief build up,
1076 this period is characterized by the emplacement of extensive alluvial fan systems in the basins
1077 surrounding the range (Fig. 15). Their development could be also strongly controlled by the
1078 contemporaneous climate aridification affecting this region (Jolivet et al., 2017a).

1079 To the west of the Tian Shan area, a Late Jurassic – Early Cretaceous phase of tectonic
1080 deformation associated to the accretion of the Helmand Block also affected the Caspian –
1081 Turan –Kazakh domains and led to the inversion of the southern basins of Central Iran and
1082 Central Afghanistan (Brunet et al., 2017). This deformation event also induced uplift within
1083 the Amu-Darya Basin (Brunet et al., 2017) and up to the North Ustyurt Basin (Otto, 1997).

1084 Based on the concordant ages of these events, we suggest that the Late Jurassic – Early
1085 Cretaceous tectonic activity and the renewed localized relief building observed in the Tian
1086 Shan area was mainly related to the accretion of the Helmand Block to the south-west, and
1087 possibly to the onset of accretion of the Lhasa Block along the southwestern margin of
1088 Eurasia. This could also explain why stronger relief building occurred in the western part of
1089 the Tian Shan compared to its eastern part.

1090

1091 6. CONCLUSIONS:

1092

1093 Using both detailed field analysis conducted on the Chinese Tian Shan region and
1094 previously published data we reconstructed the Jurassic paleogeographical evolution of the
1095 Tian Shan region.

1096 Following a Late Triassic – Early Jurassic period of relief build-up, the Early to early
1097 Middle Jurassic topographic evolution of the Tian Shan Range was dominated by the
1098 progressive planation of this previously established relief, locally interrupted by discreet
1099 topographic rejuvenations. Throughout the region, the contemporaneous sedimentation was

1100 characterized by alluvial to lacustrine deposits settled under rather humid conditions.
1101 Sediment by-pass dominated to the north-west and south-west of the range, in the Chu-
1102 Sarysu, Yili-Balkhash and west Tarim basins. The Early to early Middle Jurassic was also
1103 marked by recurrent limited deformation events recorded within the basins surrounding the
1104 range and associated with both strike-slip and compressive tectonics. These episodes of
1105 deformation cannot be explained by the Qiangtang collision but could instead, be associated
1106 to the coeval subduction-related extension affecting the Caspian - Turan domains to the west
1107 of the Tian Shan area. During the late Middle to early Late Jurassic, the planation of the
1108 Paleozoic – early Mesozoic Tian Shan Range continued with contemporaneous fine-grained
1109 sediments being deposited in distal alluvial to lacustrine environments throughout the area,
1110 except to the north-west and south-west where sediment by-pass still prevailed. During that
1111 period, a drastic climate change occurred across the entire Tian Shan region, shifting from
1112 humid conditions during the late Middle Jurassic to more semi-arid conditions during the Late
1113 Jurassic. At that time, relatively few evidences of deformation exist in the Tian Shan. Further
1114 west, the tectonic evolution is marked by the onset of a post-rift phase dominated by thermal
1115 subsidence following the extension in the Caspian - Turan domains, and up to the South
1116 Turgay and Fergana basins.

1117 By Late Jurassic, almost all of the Tian Shan relief was flattened. The Late Jurassic –
1118 Early Cretaceous transition was then marked by a tectonic reactivation leading to localized
1119 relief building in the Tian Shan and to the deposit of coarse-grained proximal alluvial
1120 sediments. Contemporaneously, the sediment by-pass and erosion extended within and around
1121 the range. In addition, the Late Jurassic – Early Cretaceous transition was characterized by the
1122 climax of the aridification trend prevailing since the early Late Jurassic. This aridification
1123 trend also played a major role in the Late Jurassic - Early Cretaceous paleogeography of the
1124 Tian Shan. At that time, renewed deformation and uplift occurred in the Tian Shan area from
1125 west to east, leading to the inversion of the Yarkand–Fergana Basin and to the formation of

1126 localized relief builds up. We propose that this renewed transpressive deformation phase was
1127 mainly related to the coeval accretion of the Helmand Block to the south-west, and possibly to
1128 the onset of the accretion of the Lhasa Block along the southwestern margin of Eurasia.

1129

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1136

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1629

1630 **FIGURES CAPTIONS:**

1631

1632 Fig. 1. General topography and tectonic framework of the Tian Shan region. The locations of
1633 the sedimentological sections are indicated by red stars and white circles: T-K, Tash-Kumir;
1634 J-D, Jetim-Dobo; Te, Terek; Ku, Kuzigongsu; M-K, Ming-Kush; K-S, Kadji-Sai; J-O, Jeti-
1635 Oguz; Ya, Yaha; Ba, Bayanbulak; Ni, Nieleke; Wu, Wusu; Ma, Manas; To, Toutunhe (north
1636 and south); Ai, Aiwegou; Ke, Kerjan; Ta, Taoshuyan; Ke, Kelameili; Ka, Karamay. TFF,
1637 Talas-Fergana fault; DNF = Dzhair – Naiman Fault; NTSF, North Tian Shan fault. Y-F B,
1638 Yarkand-Fergana Basin; Bay. B., Bayanulak Basin.

1639 Fig. 2. Synthesis of the chronostratigraphic charts available for the Jurassic to Early
1640 Cretaceous series in the Junggar, Tarim and Fergana basins.

1641 Fig. 3. Pictures illustrating the various Jurassic sedimentary facies of the Tian Shan region.
1642 See Table. 1 for the facies codes and descriptions. Pictures of facies respectively from: F1,
1643 Toutunhe Fm (Wusu section); F2, Xishanyao Fm (Wusu section); F3, Kalemake Fm (Yaha
1644 section); F4, F7 Qigu Fm, (Yaha and South Toutunhe sections); F5, Kalemake Fm (Yaha
1645 section); F6, Kezilenuer Fm (Yaha section)

1646 Fig. 4. Pictures illustrating the various Jurassic sedimentary facies of the Tian Shan region.
1647 See Table. 1 for the facies codes and descriptions. Pictures of facies respectively from: F7,
1648 Qigu Fm (Yaha section), F8, Qigu Fm (South Toutunhe section) F9, respectively from
1649 Yengisar Fm (Yaha section), Toutunhe Fm (Nieleke section); F4, F10, Kalaza Fm (South
1650 Toutunhe section); F11, Kalaza Fm (Yaha section); F12, Kalaza Fm (Manas section); F13,
1651 Xishanyao Fm (Wusu section).

1652 Fig. 5. Pictures illustrating the various Jurassic pedogenic and alteration features encountered
1653 within the Tian Shan region. See Table. 2 for facies codes and descriptions. Pictures of
1654 pedogenic features respectively from: P1, Yengisar Fm (Yaha section); P2, Kalaza Fm
1655 (Manas section), P3, Qigu Fm (Wusu section); P4, Qigu Fm (Wusu and Yaha sections); P5
1656 (Bayanbulak section)

1657 Fig. 6. Sedimentary log of the South Toutunhe section in the south Junggar Basin. Associated
1658 facies assemblages and their interpretation in term of depositional environments as in Table.
1659 3.

1660 Fig. 6 bis. Graphical caption presenting the various symbols used in Figs 6-12.

1661 Fig. 7. Sedimentary log of the North Toutunhe section in the south Junggar Basin. Symbols as
1662 in Fig. 6. Associated facies assemblages and their interpretation in term of depositional
1663 environments as in Table. 3.

1664 Fig. 8. Sedimentary log of the Manas section in the south Junggar Basin. Symbols as in Fig. 6.
1665 Associated facies assemblages and their interpretation in term of depositional environments as
1666 in Table. 3.

1667 Fig. 9. Sedimentary log of the Wusu section in the south Junggar Basin. Symbols as in Fig. 6.
1668 Associated facies assemblages and their interpretation in term of depositional environments as
1669 in Table. 3.

1670 Fig. 10. Sedimentary log of the Nieleke section in the Yili Basin. Symbols as in Fig. 6.
1671 Associated facies assemblages and their interpretation in term of depositional environments as
1672 in Table. 3.

1673 Fig. 11. Sedimentary log of the Bayanbulak section in the Bayanbulak Basin. Symbols as in
1674 Fig. 6. Associated facies assemblages and their interpretation in term of depositional
1675 environments as in Table. 3.

1676 Fig. 12. Sedimentary log of the Yaha section in the north Tarim Basin. Symbols as in Fig. 6.
1677 Associated facies assemblages and their interpretation in term of depositional environments as
1678 in Table. 3.

1679 Fig. 13. Early – early Middle Jurassic paleogeography of the Tian Shan region atop of the
1680 present-day topography; AB: Aksai Basin; BB: Bayanbulak Basin; FB: Fergana Basin; IB:
1681 Issyk-Kul Basin; MB: Ming Kush Basin; NB: Naryn Basin; TB: Turfan Basin; YB: Yili
1682 Basin; YFB; Yarkand-Fergana Basin; ZB: Zahosu Basin.

1683 Fig. 14. Late Middle – early Late Jurassic paleogeography of the Tian Shan region atop of the
1684 present-day topography; AB: Aksai Basin; BB: Bayanbulak Basin; FB: Fergana Basin; IB:
1685 Issyk-Kul Basin; MB: Ming Kush Basin; NB: Naryn Basin; TB: Turfan Basin; YB: Yili
1686 Basin; YFB; Yarkand-Fergana Basin; ZB: Zahosu Basin.

1687 Fig. 15. Late Jurassic – Early Cretaceous paleogeography of the Tian Shan region atop of the
1688 present-day topography; AB: Aksai Basin; BB: Bayanbulak Basin; FB: Fergana Basin; IB:
1689 Issyk-Kul Basin; MB: Ming Kush Basin; NB: Naryn Basin; TB: Turfan Basin; YB: Yili
1690 Basin; YFB; Yarkand-Fergana Basin; ZB: Zahosu Basin.

1691 Fig. 16. Synthetic chart of the Tian Shan region: stratigraphic record, thermochronology
1692 (Thermo.), topography, climate and geodynamic events.

1693 Fig. 17. A. Late Early to Middle Jurassic paleogeography of the Asian continent (modified
1694 from Jolivet, 2017c); EU, European Craton; CIB, GCB; Great Caucasian Basin; SCB, South
1695 Caspian Basin; Central Iran Blocks; LH, Lhasa Block; QI, Qiangtang Block; SG, Songpan-
1696 Garzê prism; Q, Qaidam Block; Mon, Mongolian Block; NC, North China Block; SC, South
1697 China Block; IND, Indochina Block; SIB, Sibumasu Block; WB, West Burma Block; TFF,
1698 Talas Fergana fault. B. Late Early to Middle Jurassic kinematic framework of the west
1699 Central Asia region. Regional Jurassic basins and main depocenters were derived from these
1700 studies; Lee (1985a, b); Thomas et al., (1999); Sobel et al., (1999); Fedorenko and Miletenko.
1701 (2002); Alexeiev et al., (2017). Tectonic structures were compiled from VNIGNI and Beicip
1702 Franlab., (1992); Thomas et al., (1999); Wang et al., (2012); Robert et al., (2014); Yang et al.,
1703 (2015); Brunet et al., (2017). The location and the geometry of the subduction zone were
1704 derived from Brunet et al., (2017). ST: South Turgay Basin; LT: Leontiev Basin; YF:
1705 Yarkand Fergana Basin; B: Bayanbulak Basin; T: Turfan Basin; TFF: Talas Fergana/Karatau
1706 fault; NTSF: North Tian Shan fault; ATF: Altyn Tagh fault; 1, Paleotethys suture; 2,
1707 Turkestan suture; 3, Jinsha suture; 4, Kunlun suture.

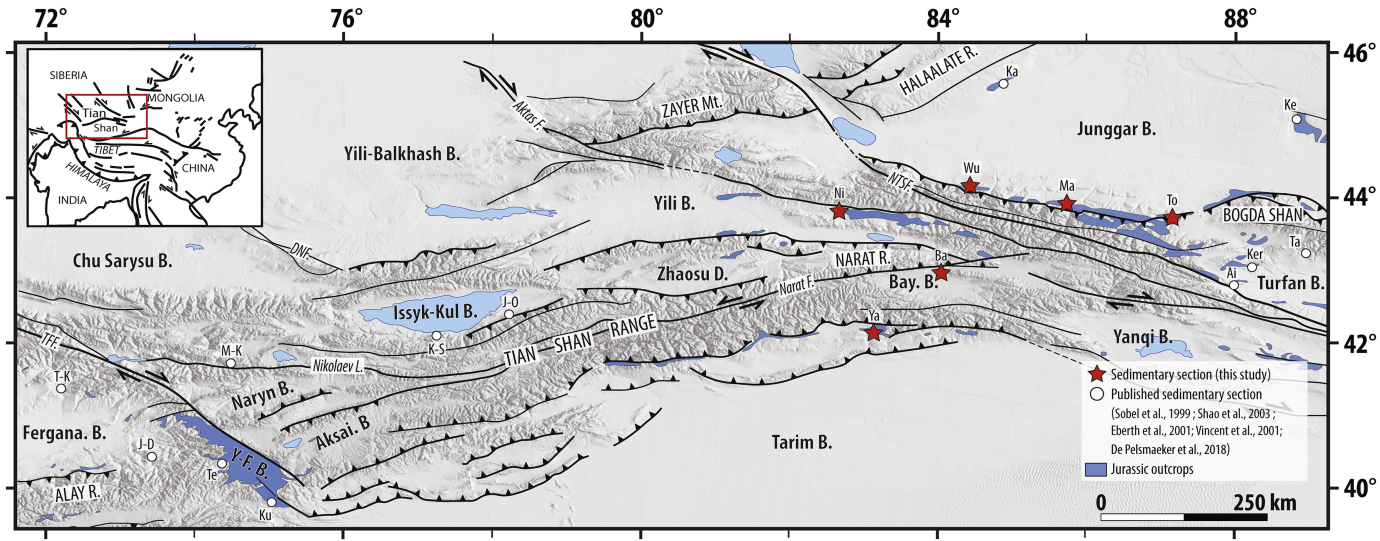


Figure 1

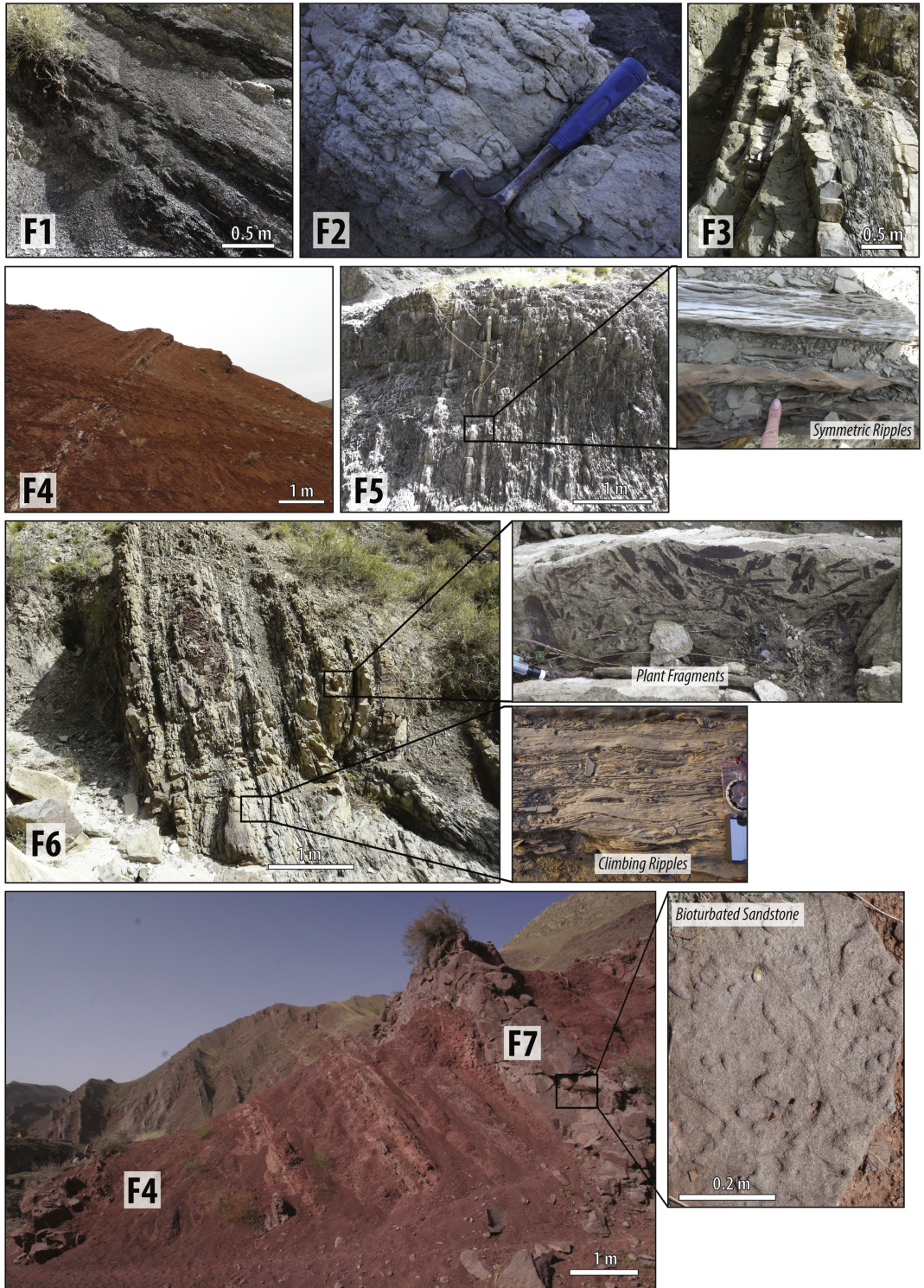


Figure 3

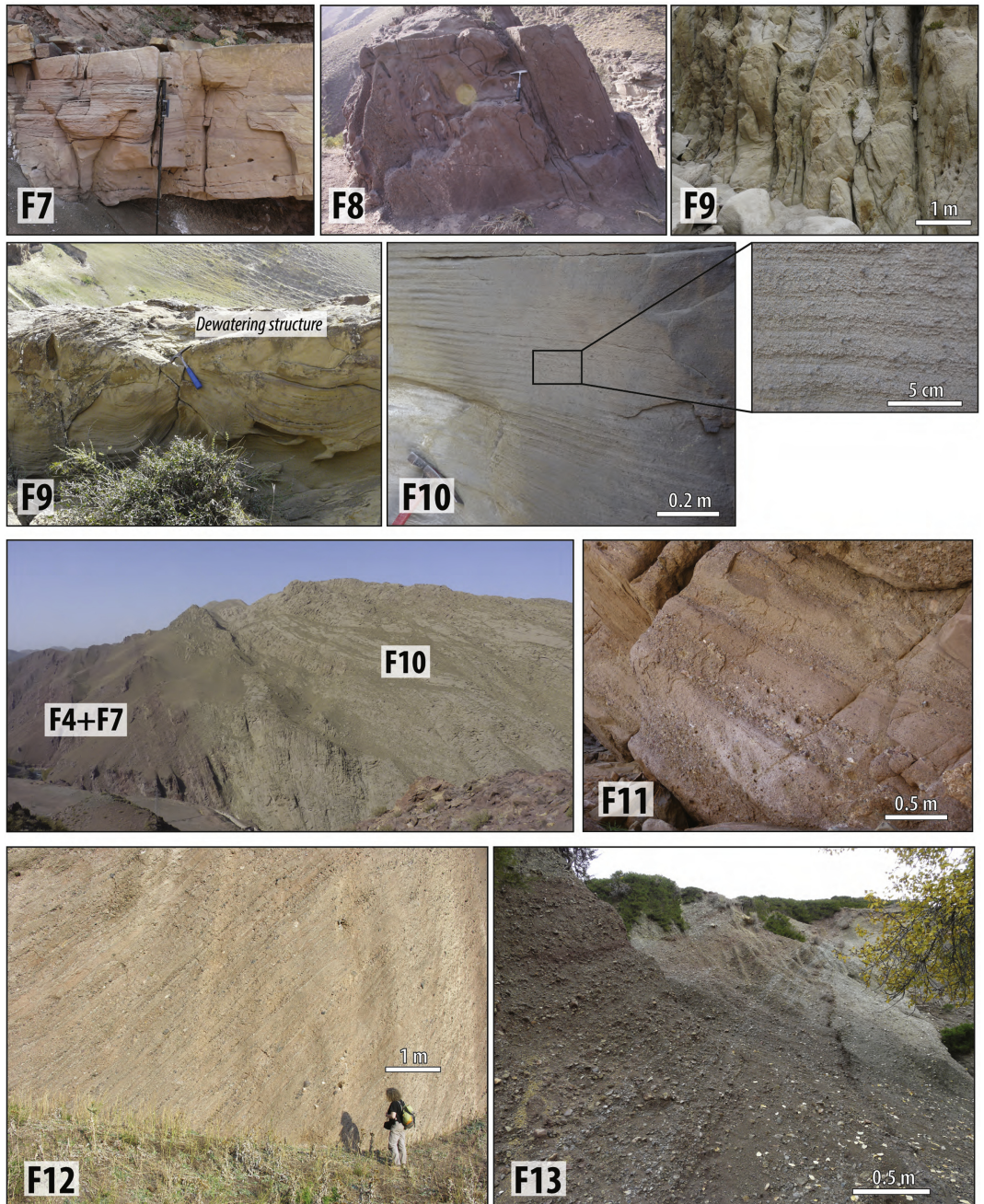


Figure 4

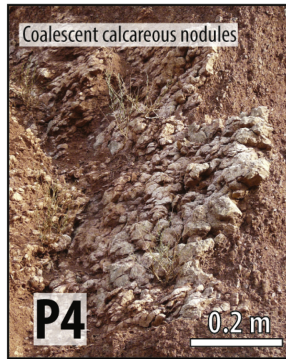
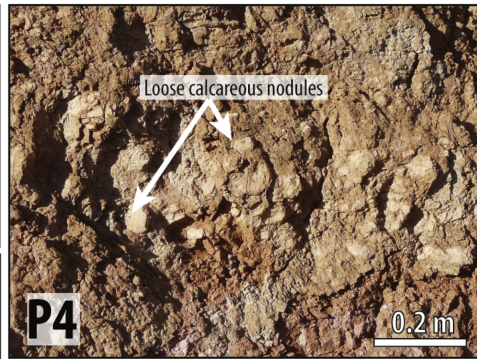
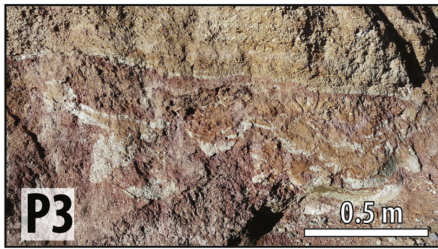
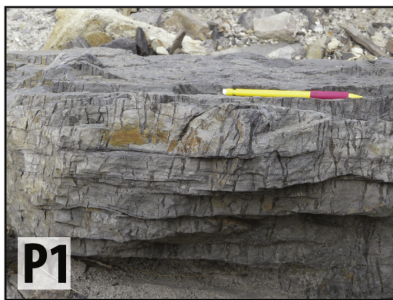
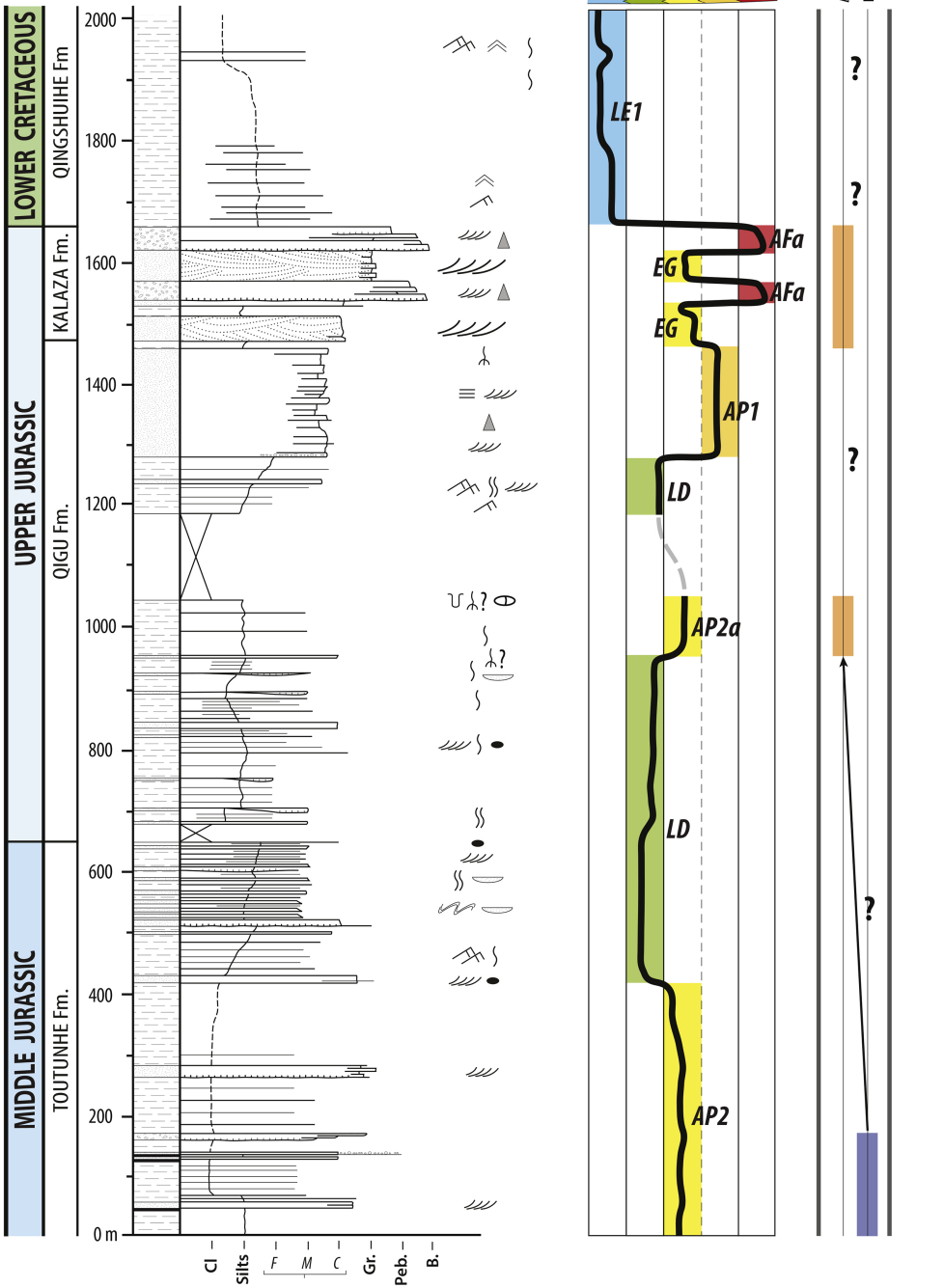


Figure 5

SOUTH TOUTUNHE SECTION



BEDDINGS		BIOTURBATIONS		SYMBOLS	
	Current ripples		Horizontal burrows		Plant fragments
	Climbing ripples		Vertical burrows		Root traces
	2D megaripples		Pervasive <i>intensity</i> + Bioturbation		Rip-up clasts
	3D megaripples		Shell remains?		Lenses or channels
	flat laminations				Amalgamated lenses / channels
	Wave features				Normal grading
	Aeolian 3D megaripples				Flute cast
					Desiccation cracks
					Slumps
					Tuffs
					Carbonated nodules
					Dewatering structures
LITHOLOGY		BASAL BOUNDARIES			
	Conglomerate		Siltstone		Slightly erosional basal boundary
	Sandstone		Siltstone (grey/black)		Strongly erosional basal boundary
	Aeolian sandstone		Coal-rich layer		

Figure 6

NORTH TOUTUNHE SECTION

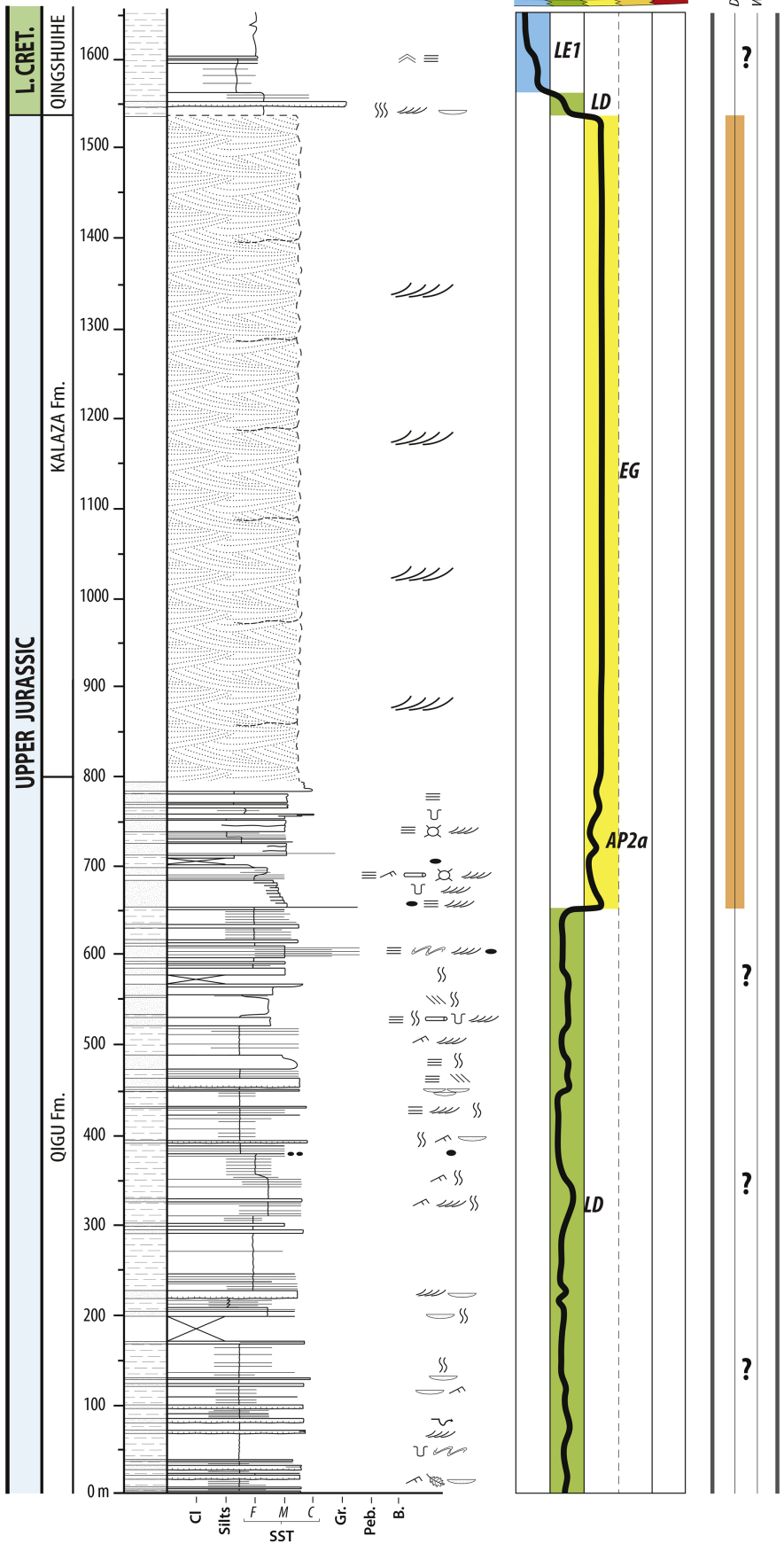


Figure 7

MANAS SECTION

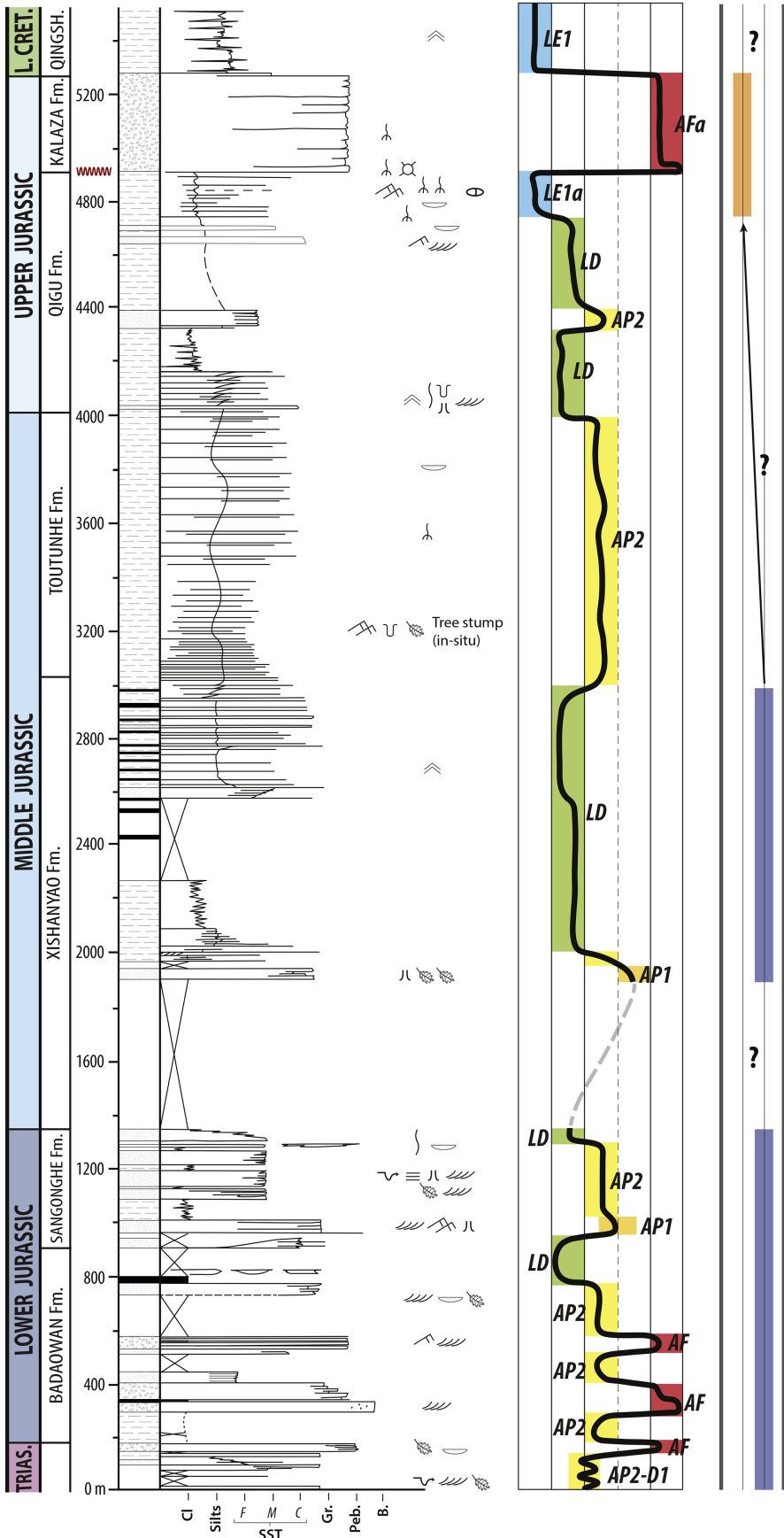


Figure 8

WUSU SECTION

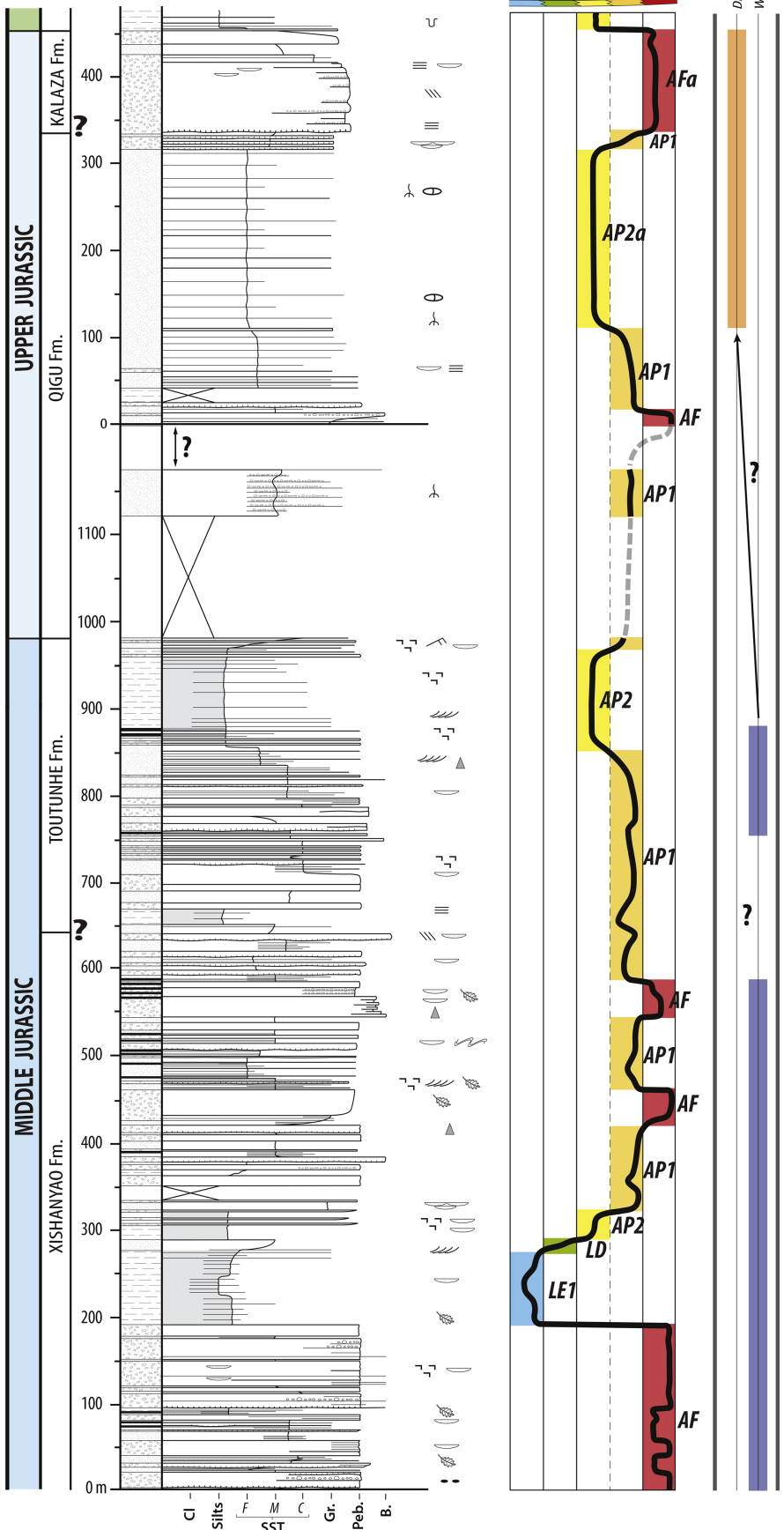


Figure 9

NIELEKE SECTION

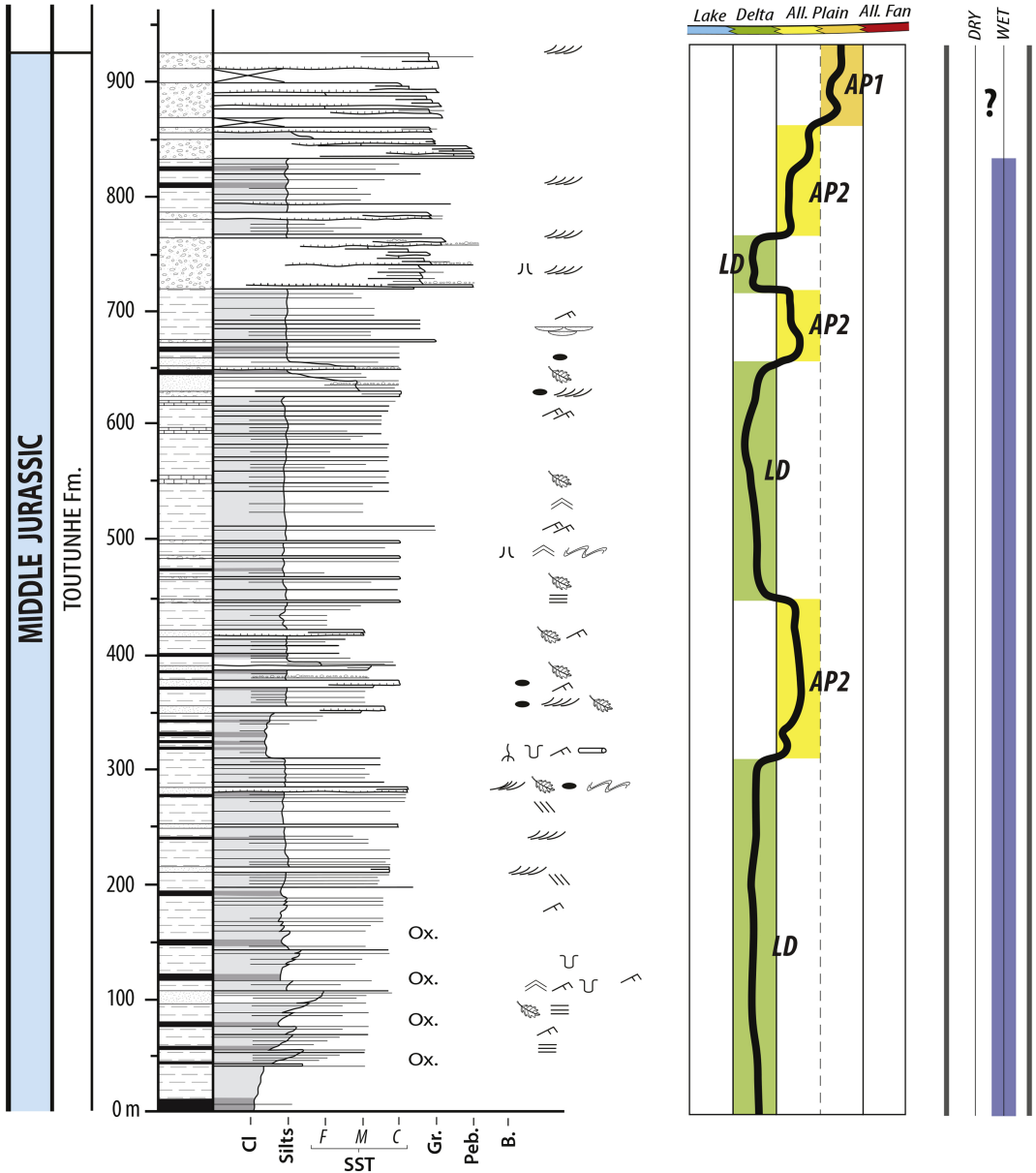


Figure 10

BAYANBULAK SECTION

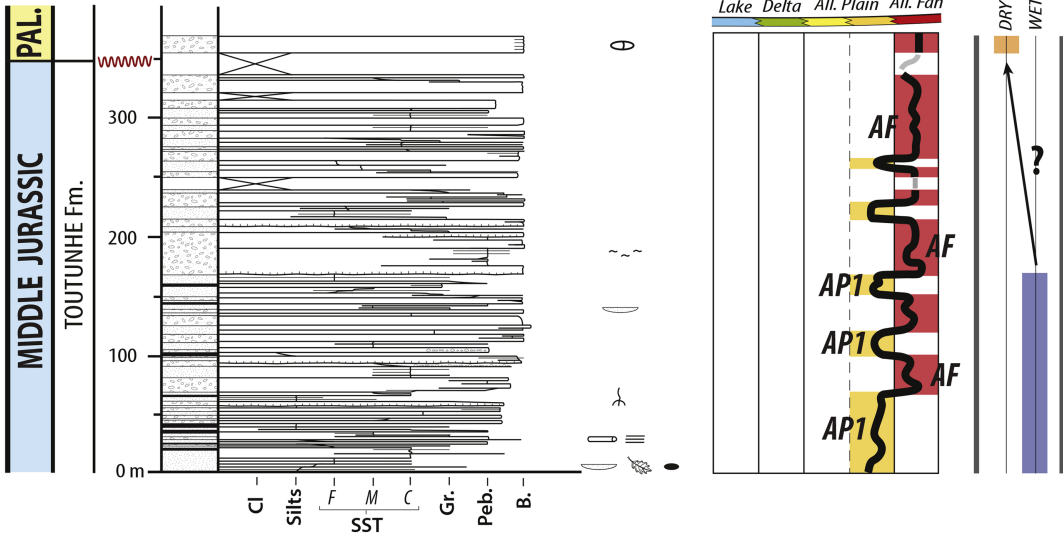


Figure 11

YAHA SECTION

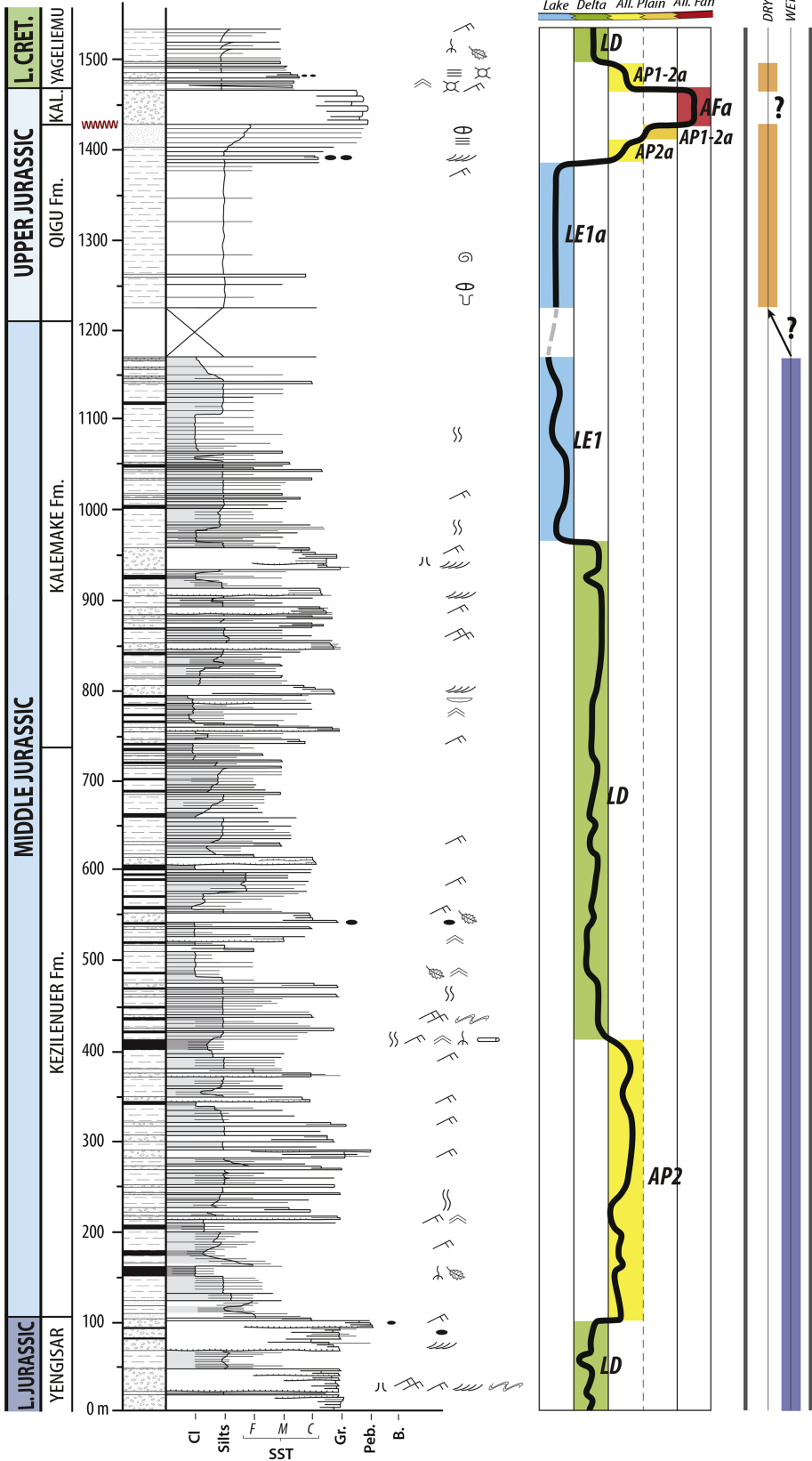
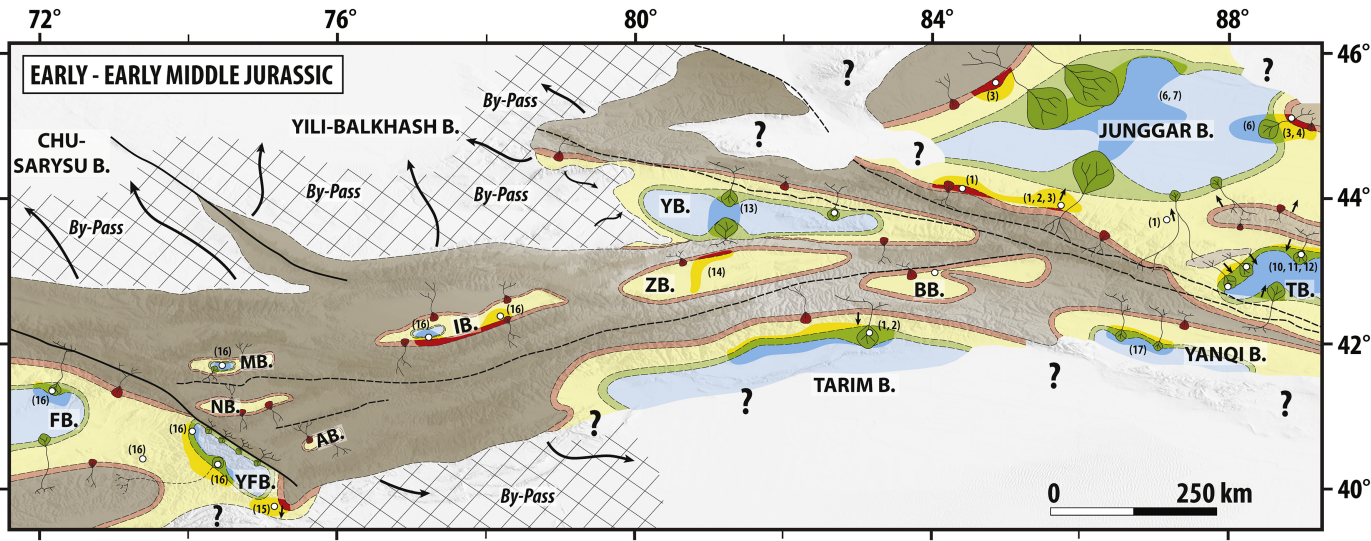


Figure 12



(1) This study ; (2) Hendrix et al., 1992; (3) Eberth et al., 2001; (4) Vincent et al., 2001; (5) Jolivet et al., 2017; (6) Feng et al., 2015; (7) Yang et al., 2015; (8) Lianhua et al., 2009; (9) Gao et al., 2017; (10) Shao et al., 1999; (11) Greene et al., 2001; (12) Shao et al., 2003; (13) Li et al., 2014; (14) Li et al., 2015; (15) Sobel et al., 1999; (16) De Pelsmaecker et al., 2018; (17) Al-Qaraafi and Guangqing, 2013

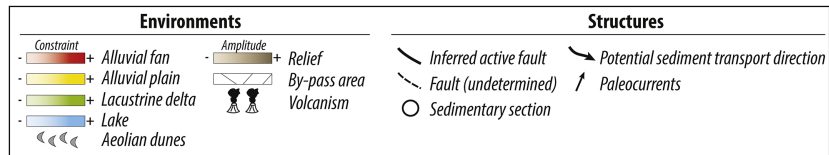
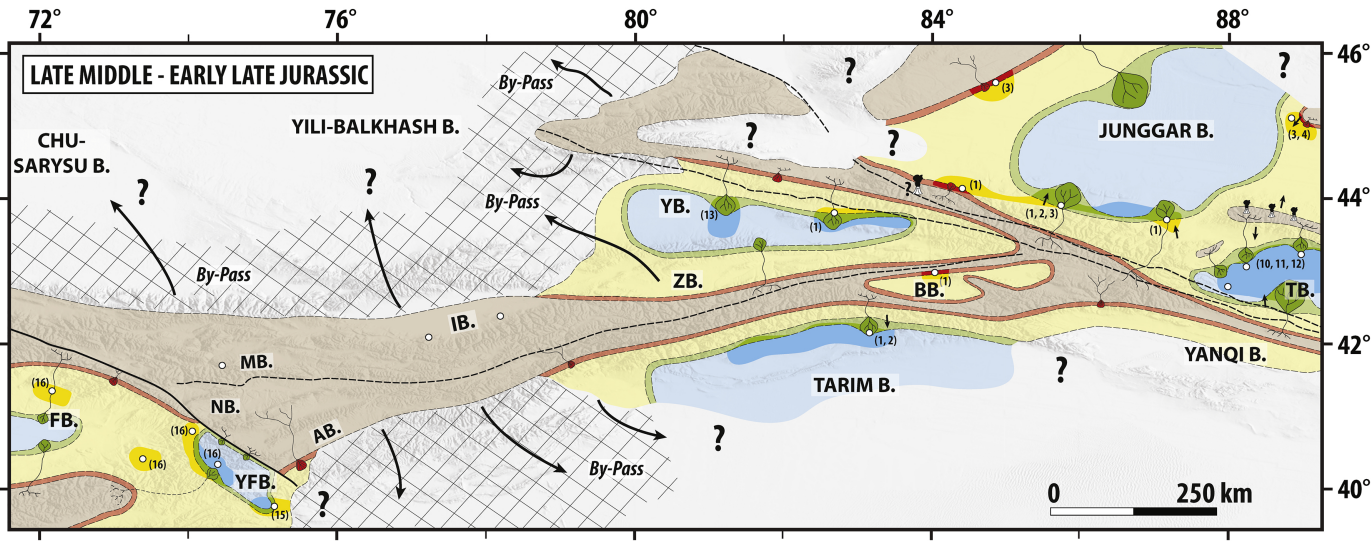


Figure 13



(1) This study; (2) Hendrix et al., 1992; (3) Eberth et al., 2001; (4) Vincent et al., 2001; (5) Jolivet et al., 2017; (6) Feng et al., 2015; (7) Yang et al., 2015; (8) Lianhua et al., 2009; (9) Gao et al., 2017; (10) Shao et al., 1999; (11) Greene et al., 2001; (12) Shao et al., 2003; (13) Li et al., 2014; (14) Li et al., 2015; (15) Sobel et al., 1999; (16) De Pelsmaecker et al., 2018; (17) Al-Qaraafi and Guangqing, 2013

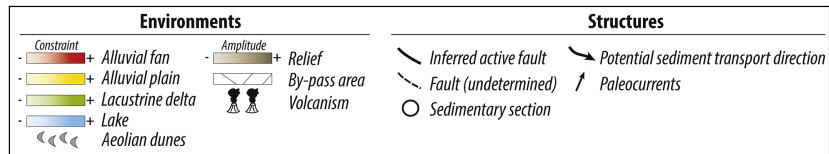
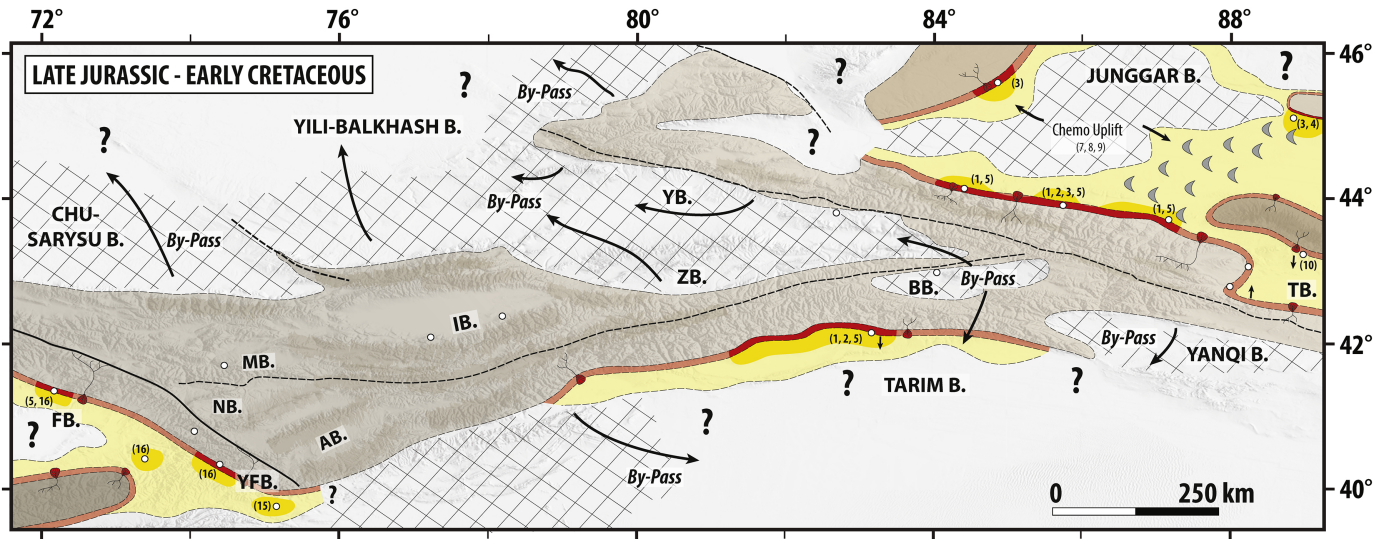


Figure 14



(1) This study ; (2) Hendrix et al., 1992; (3) Eberth et al., 2001; (4) Vincent et al., 2001; (5) Jolivet et al., 2017; (6) Feng et al., 2015; (7) Yang et al., 2015; (8) Lianhua et al., 2009; (9) Gao et al., 2017; (10) Shao et al., 1999; (11) Greene et al., 2001; (12) Shao et al., 2003; (13) Li et al., 2014; (14) Li et al., 2015; (15) Sobel et al., 1999; (16) De Pelsmaecker et al., 2018; (17) Al-Qaraafi and Guangqing, 2013

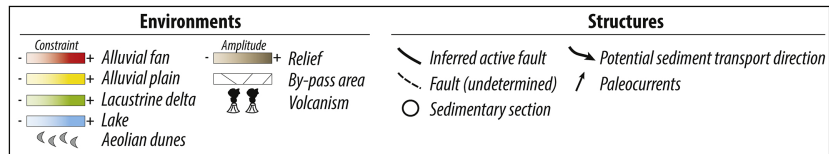


Figure 15

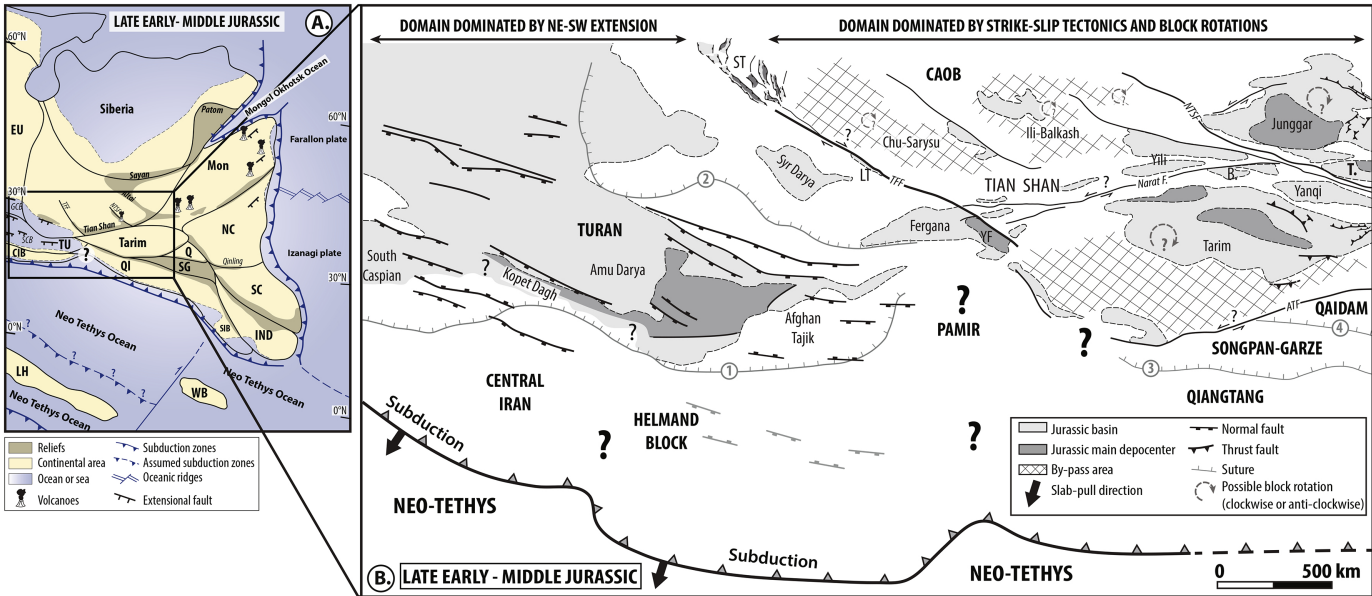


Figure 17