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1 **Reappraisal of the Jianchuan (SE Tibet) Cenozoic basin stratigraphy and structural**
2 **implications.**

3 Lorraine GOURBET^{1,*}, Philippe Hervé LELOUP¹, Jean-Louis PAQUETTE², Philippe
4 SORREL¹, Gweltaz MAHEO¹, GuoCan WANG^{3, 4}, Xu YADONG³, Kai CAO^{3, 4}, Pierre-
5 Olivier ANTOINE⁵, Inès EYMARD¹, Wei LIU³, Haijian LU⁶, Anne REPLUMAZ⁷, Marie-
6 Luce CHEVALIER⁶, Zhang Kexin³, Wu JING³, Tianyi SHEN³.

7

8 1 Laboratoire de géologie de Lyon LGL-TPE, UMR 5276, Université de Lyon, Ens de Lyon,
9 Université Lyon 1, CNRS, F-69342, Lyon, France

10 * now at Geologisches Institut, ETH, Zurich, Switzerland.

11 2 Laboratoire Magmas et Volcans, Université Blaise Pascal, CNRS, Clermont-Ferrand,
12 France.

13 3 School of Earth Sciences, China University of Geosciences, Wuhan 430074, China.

14 4 Center for Global Tectonics, China University of Geosciences, Wuhan 430074, China.

15 5 Institut des Sciences de l'Evolution, UMR 5554 CNRS, IRD, EPHE, Université de
16 Montpellier, Place Eugène Bataillon, 34095 Montpellier cedex 5, France

17 6 Institute of Geology, Chinese Academy of Geological Sciences, Beijing, China.

18 7 ISTerre, Université Grenoble Alpes, CNRS, Grenoble, France

19 **Keypoint**

20 Sediments of the Jianchuan basin, SE Tibetan plateau, have a late Eocene age.

21 **Keywords**

22 SE Tibetan plateau, Jianchuan basin, Stratigraphy, Late Eocene, U/Pb dating

23 **Abstract.**

24

25 We present a new stratigraphy of the Jianchuan basin, one of the largest Cenozoic
26 sedimentary basins in southeastern Tibet. This basin was thought to record sedimentation
27 from the Eocene to the Pliocene, and as such was the focus of several studies aiming at
28 constraining the environmental, tectonic and topographic evolution of the area. Within the
29 Shuanghe and Jianchuan formations thirteen new zircon U/Pb ages and one biotite ⁴⁰Ar/³⁹Ar
30 age of interbedded and crosscutting high K magmatic rocks show that a brief magmatic event
31 occurred at $\sim 35.22 \pm 0.30$ Ma. The uppermost formation (Jianchuan), supposedly Pliocene in
32 age, belongs to this magmatic event. All sedimentary formations are thus Eocene in age; with
33 neither Oligocene nor Miocene sediments. The coal-bearing Shuanghe Formation yielded a
34 large amynodontid typical of the Late Eocene Ergilian interval (37.2 to 33.9 Ma).

35 Sedimentation of the Shuanghe Formation took place in a short time interval at $\sim 35.88 \pm 0.35$
36 Ma, after a large-scale drainage reorganization that induced the abandonment of a large
37 braided river system (Baoxiangsi formation). This reorganization was possibly linked with the
38 initiation of the left-lateral Ailao-Shan Red River fault and/or to widespread magmatism in
39 the Jianchuan basin. Previous high paleoaltitude estimates for the Jianchuan basin are re-
40 evaluated and yield a value of 1200 ± 1200 m in the late Eocene. High K magmatism
41 emplaced at the time of E-W shortening in a zone of ~ 200 km of diameter, which was later
42 cut and left-laterally offset ~ 600 km by the Ailao-Shan Red River shear zone.

43

44 **Introduction**

45 Tibet is the widest and highest plateau on Earth. It covers $200\,000\text{ km}^2$ at a mean elevation of
46 5000 m. The formation of this high elevation landscape is considered to be linked with the
47 convergence between the Indian and Eurasian plates and their continental collision that started
48 ~ 55 Ma ago. Debates on how the convergence is absorbed and the timing and geodynamic
49 processes of the plateau uplift are still vivid. Various models have been proposed, such as
50 homogeneous thickening [England et Houseman, 1986; Murphy et al., 1997], mantle
51 delamination [Harrison et al., 1992], Indian plate underthrusting beneath the Asian plate
52 [Powell et Conaghan, 1973], lateral extrusion of continental blocks along major strike-slip
53 faults [Tapponnier et al., 1982 ; Tapponnier et al., 2001], and channel flow [Royden et al.,
54 1997; Clark and Royden, 2000].

55 One key observation that would help to test the various models is the temporal evolution of
56 the deformation and altitude at the plateau margins. In particular, all mechanisms mentioned
57 above have been proposed to take place in SE Tibet. In that zone, the Jianchuan Cenozoic
58 basin has been the focus of several studies as it is a wide basin, which, according to
59 geological maps, records continuous sedimentation from the Eocene to the Pliocene. As such
60 it may contain sedimentary archives allowing following the paleoenvironmental evolutions of
61 the area since the onset of the collision, as well as altitudinal and latitudinal variations.

62 However, dating continental sediments is difficult and, whilst these contains volcanodetritic
63 levels and are crosscut by plutonic rocks, no systematic study was previously conducted to
64 provide the absolute ages of the sedimentary formations. These ages could then be used to
65 constrain the tectonic and altitudinal variations through time. We performed geological
66 mapping and geochronologic dating. This allows us to propose a new stratigraphy and to

67 constrain the absolute timing of sedimentation, which has fundamental bearings on the
68 previous studies conducted in the Jianchuan basin and on the tectonic evolution of eastern
69 Tibet.

70

71 **1. Geological Setting**

72 The Yunnan highlands stand at ~2000 m a.s.l. between the South China sea and the
73 ≥ 4000 m a.s.l. southeastern Tibetan plateau (**Figure 1a**). The area results from the
74 amalgamation of continental blocks through the Paleozoic and Mesozoic with the Qiangtang
75 and Songpan-Garze blocks to the North, and the Indochina and South China blocks to the
76 South. The Jianchuan Cenozoic basin is located in the southernmost part of the Qiangtang
77 block, lying east of the N-S Benzilan suture, part of the Jinsha suture zone [e.g., Leloup et al.,
78 1995; Roger et al., 2003]. The last suturing event dates back to the Lower Triassic (Indosinian
79 orogeny) and the Upper Triassic sediments mark a major angular unconformity [e.g., Roger et
80 al., 2003; Faure et al., 2014]. The Mesozoic corresponds to widespread continental
81 sedimentation from the Triassic to the Eocene (“red beds”).

82 The Jianchuan basin is ~30-km-wide (E-W) and ~100 km long (N-S) [BRGMRYP,
83 1990] (**Figure 1b**). It is one of the largest Cenozoic basins in SE Tibet and Yunnan and has a
84 triangular shape bounded to the west by the Qiaohou thrust belt and to the east by the
85 Jianchuan fault (**Figure 1b, Figure 2, SM 1**). The Cenozoic sediments now stand at
86 elevations between 2300 to 3500 m where sedimentation is limited and erosion prevails.
87 Present day sedimentation takes places in the hanging walls of the Qiaohou and Jianchuan
88 active faults that both show a normal component of motion. The Qiaohou fault is part of the
89 Red River fault system and is predominantly right-lateral [e.g.; Leloup et al., 1995; Replumaz
90 et al., 2001]. The Jianchuan fault belongs to the active Lijiang pull-apart basin (**Figure 1b**),
91 and is predominantly normal with a left-lateral component [e.g.; Leloup et al., 1995] with the
92 Jianchuan city standing in the Dianwei basin, where present-day sedimentation takes place
93 (**Figure 2**).

94 Whilst standing east of the India/Asia collision front, the area was affected by intense
95 post-Eocene deformation with folds and major strike-slip faults. The folds trend mostly ~N-S
96 and reflect a ~E-W compression [e.g.; Leloup et al., 1995]. During the Miocene, such
97 compression was coeval with left-lateral strike-slip motion along the ~900 km long Ailao
98 Shan-Red River (ASRR) shear zone standing along the present-day Red River fault system

99 **(Figure 1a)**. Total left-lateral motion amounts to 700 ± 200 km [e.g.; Leloup et al., 1995,
100 2007; Faure et al., 2014]. The initiation age of the left-lateral motion is still debated and
101 ranges from 28 to 36 Ma [e.g., Cao et al., 2011, Leloup et al., 2007; Zhang and Schärer, 1999;
102 Gilley et al., 2003; Palin et al., 2013]. The end of motion took place probably at 16 ± 1 Ma
103 [e.g. Leloup et al., 2001]. Reactivation of the fault zone in the opposite sense (right-lateral)
104 took place after 11 to 5 Ma for a ~ 60 km offset [e.g.; Leloup et al., 1995; Replumaz et al.,
105 2001].

106 An Eocene-Oligocene ultrapotassic magmatic episode occurred throughout Yunnan
107 [Schärer et al., 1994, Chung et al., 1998, Wang et al., 2001, Liang et al., 2007, Lu et al.,
108 2012], in eastern and central Tibet and in the Qiangtang block [review of Chung et al., 2005].
109 Some of these rocks are found deformed within the ASRR and define a ~ 600 km left-lateral
110 offset [e.g., Leloup et al., 2001] as similar rocks are found in northern Vietnam, south of the
111 fault [e.g., Zhang and Schärer, 1999; Liang et al., 2007] **(Figure 1a)**. These widespread
112 ultrapotassic rocks have been interpreted as products of continental subduction [Wang et al.,
113 2001, Ding et al., 2003], thetysian slab break-off [Kohn and Parkinson, 2002], or lithospheric
114 delamination [Chung et al., 1998, 2005, Lu et al., 2012]. In Yunnan, the emplacement age of
115 the plutonic intrusions and volcanites range between ~ 33 and ~ 37 Ma (**Table SM 2**).

116

117 **2. Stratigraphy of the Jianchuan Cenozoic basin**

118 **2.1 Conventional stratigraphy**

119 On small-scale geological maps, the Jianchuan basin sediments are attributed to
120 Eocene to Neogene [i.e., Pan et al., 2004; BGMRYP, 1990]. This is consistent with larger-
121 scale maps and previous papers where five main formations are distinguished in the Jianchuan
122 basin, whilst detailed mapping vary [Yunnan Geological Survey, 2008; Yan et al., 2012;
123 Yang et al., 2014; Wei et al., 2016; Tong et al., 2015]. From bottom to top these are the
124 Yunlong, Guolang, Baoxiangsi, Jinsichang, and Shuanghe formations (Fm) **(Figure 3; Table**
125 **SM 3)**.

126 The Yunlong (E₁ or Ey) and Guolang (E₂ or Eg) Fms. are described as purple–red
127 siltstones, mudstones and sandstones with intercalations of massive conglomerates. Total
128 thickness ranges from 800 to 2800 m. The Yunlong Fm is described as also containing
129 gypsum layers **(Table SM 3)**. However, these two formations are sometimes considered as a
130 single one, called Mengyejing Fm (E_{1m}) [Yunnan Geological Survey, 2008; BGMRYP,

131 1996] or Gaolacun Fm (E₂³) [BGMRYP, 1990]. The Baoxiangsi Fm (E₂ or Eb) corresponds to
132 massive sandstones showing parallel- and cross-bedding with some conglomeratic and breccia
133 levels at the base. The Baoxiangsi Fm total thickness is ~800 m (**Table SM 3**).

134 The Yunlong Fm contains a typical Paleocene charophyte flora, such as *Obtusochara*
135 *lanpingensis*, *Obtusochara elliptica*, *Tectochara subelongata*, and *Gyrogonia qianjiangica*
136 [BGMRYP, 1996]. Paleocene to early Eocene ostracods are present in both the Yunlong and
137 Guolang Fm, including *Limnocythere yunlongensis*, *Limnocythere spinosalata*, *Sinocypris*
138 *excelsa* [BGMRYP, 1996] as well as *Eucypris* and *Candona* [YBGMR, 1974, 1984], together
139 with conchostraceans, and charophytes [BGMRYP, 1996]. The Baoxiangsi Fm contains
140 charophyte assemblages and late Eocene mammalian faunas, such as *Eoentelodon*
141 *likiangensis*, *Lunania* cf. *youngi*, and *Honanodon hebetis* [BGMRYP, 1996]. This led to
142 attribute a Paleocene age to the Yunlong and Guolang Fms and an Eocene age to the
143 Baoxiangshi Fm. Zircon U–Pb dating from a trachydacite, interpreted as a lava flow overlying
144 the Yunlong Fm (sample DX030-6, 36.59 ± 0.57 Ma, **Figure 2**), was considered as evidence
145 that the overlying formations are upper Eocene or younger in age in good accordance with the
146 previously proposed ages [Yang et al., 2014]

147 The Jinsichang Fm (E₂js) is a very thick (> 2600m) series of sandstones and
148 conglomerates (**Figure 3; Table SM 3**). It contains Oligocene plant fossils, such as *Myrica* cf.
149 *angustifolia*, and Taxodiaceae inde. [BGMRYP, 1996], and ostracod assemblages [BGMRYP,
150 1990].

151 The Shuanghe Fm (N₁s) consists of mudrock and coal beds interstratified with
152 sandstones, and includes occurrences of volcanoclastic sediments (**Figure 3; Table SM 3**). Its
153 age is constrained to be Miocene by a variety of fossil plants, bivalves, gastropods, and
154 ostracods [BGMRYP, 1996].

155 The Jianchuan Fm (N₂j) corresponds to volcanic, volcanosedimentary and pyroclastic
156 rocks for which a Pliocene age (2.4–3.1 Ma) has been proposed, based on apatite fission track
157 (AFT) ages [Xiang et al., 2009] (**Figure 3; Table SM 3**).

158 **2.2 New stratigraphy**

159 Whilst the stratigraphy of the Jianchuan basin could appear firmly established and has
160 been extensively used in other studies, our own field observations and new geochronologic
161 ages yield a different chronology and palaeoenvironmental interpretation. The major

162 difference is that only one upper Eocene volcano-plutonic episode affected the area. As a
163 consequence, the whole basin must have deposited prior to the Oligocene. We thus propose a
164 new stratigraphic column, structural map and geological cross sections of the Jianchuan basin
165 (**Figure 2; Figure 3; Table SM 3**). As the main characteristics of the formations stay valid
166 we kept some of the old designations but clarify below their extent, relationships and
167 depositional (environmental) settings. The absolute age constraints are discussed thereafter in
168 Section 3.

169 No gypsum interbedded with red siltstones was found in the Jianchuan basin. We thus
170 consider that the purple-red sandstones, siltstones and mudstones that outcrop at the base of
171 the basin belong to the Mengyanjing Fm (E1m) as defined by BGMRYP [1990] for the
172 Zhongdian -Lijiang subregion encompassing the Jianchuan basin. This formation was referred
173 to as the Guolang (E1g) or Denghei (E2d) formations in previous studies (**Table SM 3**). The
174 Mengyanjing (E1m) Fm consists of red siltstones, with occurrence of local conglomerate
175 levels. Some outcrops show root traces, bioturbation evidence and thin carbonate levels
176 (**Figure 4a**). Channel-fill conglomerates and metric carbonates levels are locally found
177 interbedded within red siltstones, particularly in the northeastern part of the basin, where the
178 series locally onlap on a paleorelief carved in Paleozoic Shigu metamorphic schists (**Figure**
179 **5**). These sediments are consistent with a deposition in a flood-plain (i.e. low energy)
180 environment with local occurrences of alluvial-fan debris-flow deposits. The precise
181 relationship of the lower part of the Mengyanjing Fm with the top of the Cretaceous sequence
182 has not been observed. Red siltstones are cut by numerous metric to decametric lamprophyres
183 sills surrounded by centimeter-scale contact aureoles. Locally the formation is folded with
184 bed dips $\geq 70^\circ$.

185 The Baoxiangsi Fm (E2b) consists of massive, well-sorted, multi-storey channel-fill
186 fluvial sandstones that produce large cliffs and spectacular erosion features at several
187 locations (Shibaoshan in the south and Liming in the north for instance). In many places beds
188 are nearly horizontal and concordant with the underlying Mengyanjing Fm. However, along
189 the northern margin of the basin the Baoxiangsi Fm rests on the Shigu metamorphic schists
190 over a basal conglomerate [Studnicki-Gizbert, 2006]. Wei et al., [2016] advocate for an
191 angular unconformity between the base of the Baoxiangsi Fm and the top of the Mengyanjing
192 Fm, but we did not find direct evidence for it. Massive sandstone levels are locally eroded by
193 meter-thick conglomerates corresponding to channel-fill geometries. Conglomerates include
194 rounded centimeter to decimeter-scale boulders, mainly composed of Triassic carbonates and

195 without volcanic rocks. Few dykes have been mapped as crosscutting the sandstones. The
196 sandstone levels locally contain vegetation remains. Sandstone colors vary from orange to
197 yellowish. Centimeter-scale mud balls were often observed at the base of channel fills. Bed
198 thickness ranges between 50 cm and a few meters. Sandstone bodies mostly rely on stacked-
199 fluvial bars, themselves formed from compound cross-bedded units. The occurrence of
200 downstream accreting barforms and channel-fills deposits with a low range of foreset dip
201 azimuths (most often dipping east-southeast), the abundance of planar cross-bedding and the
202 presence of mid-channel longitudinal bars is characteristic of braided-fluvial systems [e.g.,
203 Best et al., 2003] (**Figure 4b, c, d**). Given the presence of conglomerate levels, the braided-
204 river system was proximal to a local relief, in particular to the northeast basin-margin from
205 which lateral sources likely originate. Outcrops of the Baoxiangsi Fm extend for ~100km in a
206 NW-SE direction all the way across the Jianchuan basin. Some outcrops have been reported
207 SE of the Jianchuan basin resting directly on top of Paleozoic rocks. Regional maps also
208 reports the occurrence of similar sediments ~40km east, immediately East of the Quaternary
209 Lijiang-Heqing basin (**Figure 1a**).

210 The Shuanghe Fm (E2s) is usually described as resting unconformably on all
211 underlying units. However it is never found on top of the Baoxiangsi Fm but rather aside, and
212 appears conformable to the Mengyanjing Fm. The base of the formation corresponds to a
213 multi-storey carbonate level that we designate as the Jiuziyan Fm (E2jz). In particular, at site
214 S254 (**Figure 2**) a quarry shows a ~30-40m-thick level of carbonates that consist of green
215 partially carbonated claystones and carbonate-fill channels. The carbonates contain peloids,
216 fossils reeds and stromatolites, most of them in life position. The claystones matrix often
217 contains poorly sorted gravels (0.5 to 1.5 cm), some of them being of magmatic origin, and
218 centimetric boulders. The base of the Jiuziyan Fm locally corresponds to carbonate
219 conglomerates with channel-fill geometries (i.e at site S607, **Figure 4f, g**). This erosive base
220 suggests a sedimentation gap between the top of the Mengyanjing Fm and the bottom of the
221 Jiuziyan Fm whilst the two formations appear conformable. The upper part of the Jiuziyan Fm
222 is locally capped by few meter-thick green sandstones. The Jiuziyan Fm appears to be
223 restricted to a ~15x10 km area in the NE of the Jianchuan basin. Other outcrops of limestones
224 are located outside of the Jianchuan basin close to the Yangtze river first bend (S862, **Figure**
225 **2**). There, a >110m-thick series of pale recrystallized limestones including bio-constructions,
226 lies horizontally above a ~2m thick conglomeratic level. These sediments are unconformable

227 on top of green schists (Shigu schists) dipping $\sim 40^\circ$ to the west. These limestones possibly
228 belong to the Jiuziyan Fm but their exact extent and age are still unknown.

229 The Shuanghe Fm (E_{2s}) resting on top of the Jiuziyan Fm consists of poorly
230 consolidated yellow sandstones, intercalated with rare centimetric-scale lacustrine carbonate
231 layers. The sandstones are regularly interbedded with coal deposits and occasional lava flows
232 (**Figure 6a**), tuff and volcano-sedimentary levels. The Shuanghe Fm is cut by intrusive rocks,
233 mostly lamprophyres, forming numerous sills in the coal levels (**Figure 6d**). The formation
234 extends on the eastern side of the basin, further south than the Jiuziyan Fm. The formation
235 may have had a much wider extent, since it is found in the deformed slice along the Qiaohou
236 Fault (i.e S222, **Figure 2**).

237 At site S272 (**Figure 2**), along the road between Jianchuan and Lanping, the base of
238 the Jinsichang formation (E_{2js}) monoclinally dips to the NNW and directly rests on E_{1m}
239 siltites that are affected by folds with NE-SW axis. Cartographically the conglomerates also
240 rest on top of the E_{2b} Fm, especially in the northern part of the basin, but we could not
241 confirm this relationship. Boulders are mostly composed of Triassic sandstones but at one
242 location (S556) the clasts also contain syenite. On some maps, the Jinsichang formation
243 extends to the northeastern part of the Jianchuan basin. However, field investigation showed
244 that red conglomerates in that area are found within E_{1m} below E_{2jz} limestones. The
245 Jinsichang formation was thus probably deposited in medium to distal alluvial fans, most
246 likely originating laterally, from the western margin of the main basin axis.

247 Between sites S254 and S805, the Shuanghe formation is affected by an anticline with
248 a wavelength of a few km and an axis trending NNW-SSE (**Figure 7b**). The Jianchuan
249 formation (E_{2Jc}) appears to dip monoclinally to the east above this fold and it has been
250 interpreted to correspond to a Neogene volcanodetritic event. However our observations
251 suggest that the Jianchuan formation directly originates from the Shamao Shan Syenite
252 complex and that it is not Neogene but Eocene in age (see below).

253 On top of the southern outcrops of the E_{2s} Fm we found distinctive quartz-rich
254 conglomerates and conglomerates with gypsum that were not previously described. It is not
255 clear if these conglomerates are lateral equivalent of the E_{2js} , or more probably correspond to
256 much more recent (Neogene ?) deposits that we ascribe to the Sanying Fm (N_2S) (see below)
257 but without many evidence.

258 Quaternary basins develop in the hanging wall at the foot of the Jianchuan fault. In the
259 southern part of the Dianwei basin outcrop yellow-white lithic sandstones and mudstones
260 interbedded with purple mudstone and lignite (i.e. S633). Most maps allocate this outcrop to
261 the Shuanghe Fm because it contains coal deposits. However the legend of the Jianchuan 1 /
262 200 000 geological map reports the occurrence of a distinctive Pliocene Sanying Fm (N₂S)
263 corresponding to that description, and we thus ascribe these deposits to that particular
264 formation. At the regional scale the Pliocene and Quaternary formations are often found in the
265 hanging wall of active faults.

266

267 **3. Absolute age constraints**

268 As emphasized in sections 1 and 2, the Jianchuan area is rich in magmatic bodies and
269 volcanosedimentary rocks that can be dated using geochronological techniques. In order to
270 constrain the age of some of the formations and help to assess the various proposed
271 stratigraphic columns, we compiled available geochronological ages and conducted *in situ* U-
272 Pb dating on zircons from thirteen samples (**Figure 2, Table 1**). We also dated biotites from a
273 sample with the ⁴⁰Ar/³⁹Ar method. Moreover, the analysis of paleontological remains within
274 the Shuanghe Fm gives important time constraints.

275 **3.1. Geochronologic constraints**

276 An important prerequisite for the interpretation of geochronologic ages is to determine
277 the precise nature of the dated rocks. If they are interstratified (effusive or volcano-
278 sedimentary) their age will give a minimum age for the layers they overlay, while if they are
279 intrusive, their emplacement age will give a maximum age for the layers they cut. Nine
280 samples correspond to lava flows or volcano-sedimentary sediments interbedded within the
281 series, and four samples are intrusive rocks (sill, dyke and neck). Ages from the literature
282 correspond both to intrusive and interstratified rocks (see **SM 2** for details).

283 **3.1.1. New geochronologic data.**

284 Most samples were crushed and zircon grains separated at the Laboratoire de Géologie
285 de Lyon, France, using standard magnetic and density techniques (see **SM 4** for details). U/Pb
286 dating was performed by laser ablation inductively coupled plasma mass spectrometry (LA-
287 ICP-MS) at the Laboratoire Magmas et Volcans, Clermont-Ferrand, France (see **SM 4** for
288 details). The analytical results were plotted on ²⁰⁶Pb/²³⁸U versus ²³⁷Pb/²³⁵U (concordia)

289 diagrams and $^{207}\text{Pb}/^{206}\text{Pb}$ versus $^{238}\text{U}/^{206}\text{Pb}$ diagrams [Tera and Wasserburg, 1972]. A special
290 attention was given to the rim of the crystals and to young ages, more likely to correspond to
291 the emplacement age. Detailed data are provided in **SM 5**, the age populations spectra are
292 shown in **Figure SM 6**, and a synthesis of the emplacement ages appears in **Table 1**. All early
293 Eocene zircon grains display characteristic high Th/U magmatic values (**Table SM 5**).

294 For sample CD321-1, zircon U-Pb geochronological analyses were carried out by laser
295 ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the State Key
296 Laboratory of Geological Processes and Mineral Resources, China University of Geosciences,
297 Wuhan, China (see **SM 7** for details)

298 Biotites from sample J279 were extracted in order to perform $^{40}\text{Ar}/^{39}\text{Ar}$ dating at the
299 Rare Earth Laboratory of the geochronology laboratory of Geosciences Montpellier
300 (University Montpellier 2, France). The irradiation factor J was determined using duplicate
301 analyses of the TCR2 sanidine standard with an age of 28.340 ± 0.099 Ma [Renne et al. 1998]
302 and ages are quoted at 2σ (**SM 8**).

303 At site S224, two horizontal trachy-andesitic lava flows are interstratified within white
304 volcanic tuffs, volcano-sedimentary levels and thin lacustrine carbonates attributed to the
305 Shuanghe Fm (**Figure 6a**). Sample **J121** from the lower lava flow contains K-feldspar and
306 biotite with oxide inclusions, minor phases include apatite and euhedral zircon. Twenty-five
307 analyses were performed on 12 zircons. Grains are homogeneous, without age difference
308 between the crystal's core and the rim. Except for one Ordovician grain (**Figure 8a**), 11
309 zircons (22 analyses) yield a concordant $^{206}\text{Pb}/^{238}\text{U}$ age around 35 Ma. The corresponding
310 lower intercept on the Tera and Wasserburg diagram is 35.8 ± 0.3 Ma (**Figure 8b**), which we
311 interpret as the emplacement age of the lava flow.

312 Most zircon grains of sample **J120** from the upper lava flow have a rounded
313 morphology, which suggests that they are inherited. Forty-three ages were calculated using 36
314 zircons. The ages are scattered, ranging from late Eocene to Mesoproterozoic. One single
315 grain (not shown in the figures) is 1.5 Ga old. Eight zircons define an upper intercept on the
316 Concordia diagram at 816 ± 8 Ma (**Figure 8c**). Their high U/Th ratio indicates a magmatic
317 event. Some zircons with ages ranging from 500 to 600 Ma are probably metamorphic grains,
318 because their Th/U ratio is low (< 0.05). Another group (5 zircons) has a Triassic age (**Figure**
319 **8d**). One single grain (2 spots) is 35 ± 1 Ma old (**Figure 8d**). The high content of this sample
320 in inherited zircons with various ages is consistent with the smooth morphology of the grains.

321 The youngest grains age at *ca.* 35 Ma is the closest to the emplacement age and thus yields an
322 upper boundary for the underlying sandstone deposition (Shuanghe Fm).

323 At site S263, sample **J203** comes from a 30-cm-thick level of a volcanic tuff
324 interbedded within decimeter-thick sandstone and clay strata of the Shuanghe Fm. The tuff
325 contains K-feldspar and coal fragments as well as automorphic zircon crystals. 32 analyses on
326 24 zircon grains showed no age difference between the cores and the rims. Grains have a high
327 U content (> 1000 ppm). 10 zircons yield concordant ages ranging from 2.5 Ga to 51 Ma
328 (**Figure 8e, Figure SM 6**). 14 zircons have Cenozoic ages with 16 analytical points out of 18
329 plotting at 35-38 Ma. The 18 data define a lower intercept at 36.4 ± 0.4 Ma (**Figure 8f**).

330 Sample **J168A** is a volcanoclastic rock that was sampled in the debris of a local coal
331 mine (site S261 – Shuanghe Fm). It is rich in biotite, contains amphibole, K-feldspar and
332 plagioclase. Minor phases include apatite and automorphic zircon. 38 spots were analyzed on
333 22 zircon grains. They have a rough content in U of 200 ppm. One single zircon shows a ~740
334 Ma core (**Figure 8g**) with a Cenozoic rim. All other grains, both in the cores and rims, are
335 Cenozoic in age with 32 analytical data plot in a concordant position at 35-36 Ma ($^{206}\text{Pb}/^{238}\text{U}$
336 age) on the Tera and Wasserburg diagram (**Figure 8h**). The lower intercept given by the
337 linear regression through 34 data (2 discordant points) is 35.7 ± 0.2 Ma.

338 Sample **J278** is a volcanodetrital rock sampled at site S805, probably near the top of
339 the Shuanghe formation. It contains amphibole and K-feldspar, and few biotite grains. 51
340 zircon grains were analysed. Sample J278 yields a wide scatter of concordant ages from
341 ~2300 to ~37 Ma. Most grains have an age of about 820 Ma (12 grains out of 51) and about
342 220 Ma (9 grains) (**Figure 8i, Figure SM 6**). The single youngest concordant age is $36.8 \pm$
343 1.0 Ma (**Figure 8j**).

344 Sample **J308** (site S882) is a volcanosedimentary rock from an outcrop located in a
345 slice of rocks between two branches of the Qiaohou fault west of the Jianchuan basin. It
346 contains amphibole, quartz and automorphic feldspar. 10 grains out of 37 euhedral zircon
347 grains have $^{206}\text{Pb}/^{238}\text{U}$ ages ranging from 245 to 849 Ma. 26 analytical points, each of them
348 corresponding to a single grain, are concordant at ~35 Ma ($^{206}\text{Pb}/^{238}\text{U}$ age) and define a lower
349 intercept at 34.74 ± 0.17 Ma. (**Figure 8k**).

350 **J161**, sampled at site S257, is a volcanoclastic sandstone of the Jianchuan Fm (E2Jc)
351 that contains plagioclase feldspar, pyroxene, oxide and weathered biotite. 30 analyses were
352 performed on 20 euhedral zircons. Grains show no age difference between the core and the

353 rim. 17 data, corresponding to 9 zircons, define a Discordia with an upper intercept at $819 \pm$
354 8 Ma (**Figure 8l**) while 8 data yield a Concordia age of 223.9 ± 2.2 Ma (Upper Triassic)
355 (**Figure 8m**). 3 analytical points (2 zircons) are nearly concordant and define a lower intercept
356 at 35.9 ± 1.1 Ma (MSWD = 1.5) (**Figure 8m**) that we consider as a lower boundary
357 (maximum age) for the sandstone deposition.

358 Sample **J284**, collected at site S819, is as a boulder fallen from the overlying cliff
359 carved in the Jianchuan Fm. It is a rhyolitic tuff that contains plagioclase feldspar, few biotite
360 crystals and few xenoliths. 29 zircons out of 33 show U/Pb ages ranging from 1800 to 210 Ma
361 (**Figure 8n**). 4 grains have Cenozoic ages and the three youngest concordant data have an
362 average Concordia age of 34.8 ± 1.1 Ma (**Figure 8n**) that is a maximum age for the tuff
363 emplacement.

364 Lamprophyres sampled both in the Mengyanjing formation (Sample **J108**, site S213)
365 and in the Jianchuan Fm (Sample **J279**, site S808) both yield only pre-Cenozoic ages (**Figure**
366 **8o-7p**, **Figure SM 6**). Biotites of sample J279 yield an age spectra with ages progressively
367 decreasing from 44 to 37 Ma and an integrated age of 39.40 ± 0.90 (**Figure SM 8a**), that has
368 probably no geological signification. This age is probably due to alteration and partial
369 chloritization of the biotites that possibly induced ^{39}Ar recoil during irradiation. Indeed, the
370 K/Ca correlation plot indicates heterogeneous K distribution with low amounts at the
371 beginning and the end of the spectra (**Figure SM 8b**). On an inverse isochrone plot the data
372 appear to define several array possibly corresponding to different argon reservoirs, the one
373 corresponding to the last 55 % of gas release yielding an age of 34.48 ± 1.02 Ma for an initial
374 $^{40}\text{Ar}/^{36}\text{Ar}$ ratio of $ca\ 1474 \pm 300$ and a fairly large MSWD = 7.51 (**Figure SM 8c**). On the age
375 spectra these steps yield a mean weighted age of 36.60 ± 0.61 (**Figure SM 8a**). The
376 emplacement age of the dyke is interpreted to be younger than 36.60 Ma, and possibly close
377 to ~ 34.5 Ma.

378 Sample **J296** was sampled in a trachy-andesitic neck standing in the north of the basin
379 (site S849) above the Mengyanjing Fm. It yields many inherited ages (**Figure 8q**, **Figure SM**
380 **6**) while three grains yield subconcordant ages between ~ 34 and ~ 43 Ma (**Figure 8r**). The
381 youngest age (33.7 ± 0.9 Ma) could be considered as the emplacement age but the point is
382 barely concordant and thus does not give a robust age constraint.

383 Sample **CD321-1** comes from a granite porphyry dyke within the Jinsichang Fm and
384 close to a diorite intrusion. It contains zircon. Few ages are pre-Cenozoic but most of these

385 are subconcordant at ~ 35 Ma (**Table SM 9**) (**Figure 8s**) and 12 of them yield a 34.73 ± 0.76
386 mean weighed age ($n=12$, MSWD = 1.5) (**Figure 8t**).

387 *3.1.2. Constraints on the age of the Shuanghe Fm from interbedded deposits.*

388 At site S224, in the Ziangchong valley, our results indicate that the lower and upper
389 trachy-andesitic lava flows are respectively 35.8 ± 0.3 (J121) and 35 ± 1 (J120) Ma old, thus
390 constraining part of the sedimentation of the Shuanghe Fm at ~ 35.5 Ma (**Figure 3c**). Yang et
391 al. [2014] report a trachydacite volcanic level (sample DX-030-6) containing zircon they
392 dated at 36.59 ± 0.67 Ma with the U/Pb method. The precise sample location is not given but
393 appears to be ~ 150 m east of site S224. They interpreted the trachydacite volcanic level to be
394 interstratified in a trachyandesite level supposed to lie at the boundary between the Yunlong
395 and Mengyanjing formations. We think that this level is in fact the same level as the one we
396 observed at site S224 (possibly the lower lava flow). However, the lava flows they described
397 ~ 2 km further to the west (site S841) are in fact sills intruded, not interstratified, at the base of
398 the Baoxiangxi Fm (**Figure 6c**). We thus think that the trachydacite volcanic level(s) is not
399 located at the base of the Baoxiangsi Fm but within the Shuanghe Fm. The fact that the age of
400 DX-030-6 is the same within error bars of that of J121 strengthens our interpretation that the
401 Shuanghe Fm emplaced at ~ 35.5 Ma (Upper Eocene).

402 In the Shicaijiang valley, at site S263, sample J203 (volcanic tuff) is 36.4 ± 0.4 Ma
403 old. Hoke et al. [2014] provide a $37.1^{+0.78}_{-1.59}$ Ma U/Pb age for tuffaceous sandstone (sample
404 JIAN-11-05) in the same area. While the precise location of their sampling is not given it
405 appears close to S263 (Liu-Zheng, personal communication), and is compatible with our more
406 tightly constrained age. In the same zone but ~ 120 m higher in the topography volcanodetritic
407 sample J168A yields an age of 35.7 ± 0.2 Ma. J278, sampled ~ 2.5 km further east, yields an
408 age of 36.8 ± 1.0 Ma.

409 Despite large uncertainties in relative stratigraphic position within the formation and
410 in absolute age, the Shuanghe Fm appears to have deposited between ~ 37 and ~ 34.7 Ma, with
411 a mean weighed average age of 35.88 ± 0.35 Ma (weighed mean, MSWD=3.9) (**Figure 3c**).

412 Along the Qiaohou fault, a slice of rock most probably belongs to the Shuanghe Fm
413 (**Figure 2**). Yang et al. [2014] report volcanoclastic sediments outcropping in that slice
414 (sample DX039-5, site S222, **Figure 2**). Alike for sample J120 the zircons are rounded and
415 yield $^{206}\text{Pb}/^{238}\text{U}$ ages spanning from 1777 to 34 Ma, the youngest four concordant dates
416 yielding a $^{206}\text{Pb}/^{238}\text{U}$ age of 35.0 ± 2.3 Ma. At site S882, 17 km further SE, in the same slice

417 along the fault, sample J308 yields a 34.74 ± 0.17 Ma emplacement age that is consistent with
418 that of DX039-5. These two ages are coherent whilst slightly younger than the other ages for
419 the Shuanghe Fm (**Figure 3c**).

420

421 *3.1.3. Constraints on the age of the Jianchuan Fm from interstratified deposits.*

422 The two youngest zircons found in sample J161 (volcanoclastic) imply a maximum
423 age of 35.9 ± 1.1 Ma for the Jianchuan Fm, while the youngest concordant data for J284
424 rhyolitic tuff suggest an emplacement age of 34.8 ± 1.1 Ma. This age is imprecise because
425 most of the zircons are inherited, but the most plausible interpretation is that the Jianchuan
426 Fm is $\sim 35 \pm 1.5$ Ma (Upper Eocene) old (**Figure 3c**). In fact, it cannot be excluded that all
427 zircons are inherited and that the Jianchuan Fm would correspond to a young volcanic event
428 (Neogene) that would not have produced any new zircon. In support to such interpretation
429 Xiang et al. [2009] reported apatite fission track (AFT) ages from the Jianchuan Basin
430 spanning from 1.6 to 15.8 Ma. The ages of sample FT03 within the Shuanghe Fm at $15.8 \pm$
431 0.8 Ma (Miocene) and that of FT 10 in the Jianchuan Fm. at 2.4 ± 0.8 Ma (Pliocene) were
432 interpreted as emplacement ages sustaining the conventional stratigraphy. However a closer
433 look to the AFT data set reveals that all samples whatever the formation, except for FT03, are
434 Pliocene including the one from the Shamao Shan syenite whose emplacement age is well
435 constrained at 35.5 ± 1 Ma [Schärer et al., 1994 ; Lu et al., 2012] (**Table SM 2**). It is thus
436 most likely that all AFT ages are cooling ages and not emplacement ages. Furthermore the
437 authors did not yield the conventional plots that would allow checking the accuracy of their
438 data.

439 *3.1.4. Cross-cutting intrusive rocks.*

440 As mentioned in section 1 and depicted in all geological maps the Jianchuan basin
441 contains several intrusive bodies (**Figure 2**). These plutons cut across the Mengyanjing,
442 Baoxiangsi and Jinsichang formations (**Figure 2**). The relationship with the Jiuziyan, and
443 Shuanghe formations is more difficult to establish as no direct contact exist with the plutonic
444 rocks. At the top of the lithologic pile the Jianchuan formation surrounds the Shamao Shan
445 syenite. At site S251 the Jianchuan formation appears to be intruded by the syenite as this one
446 shows a chilled margin (**Figure 6f**). 600 m to the west, at site S808, the Jianchuan formation
447 is cross-cut by a lamprophyre dyke which given its composition is likely genetically related to
448 the nearby Shamao Shan syenite (**Figure 6e**). This would again suggest that the Jianchuan

449 formation is at least in part antecedent to the syenite, and thus that the whole sedimentation
450 within the Jianchuan basin took place prior to the syenite emplacement.

451 Following the pioneering work of Schärer et al. [1994] several other studies have
452 yield zircon U/Pb ages for the magmatic bodies of the Jianchuan basin [e.g., Liang et al.,
453 2007; Lu et al., 2012] (**SM 2, Figure 2**). The Shamao Shan Syenite yielded U/Pb zircon ages
454 of 35 ± 0.1 Ma [Schärer et al., 1994] and 35.6 ± 0.3 [Lu et al., 2012]. All eight published
455 high-precision ages from the various intrusive bodies within the Jianchuan basin span
456 between 34.5 and 35.7 Ma. They indicate a brief plutonic event of weighted average mean age
457 of 35.22 ± 0.30 Ma (Upper Eocene). This age is similar within uncertainties to that proposed
458 above for the Shuanghe formation (35 ± 1.5 Ma). The sample taken from the dyke at site S808
459 (J279) only yielded U/Pb inherited ages but the Ar/Ar data suggest an age close to $\sim 34.5 \pm 1$
460 Ma compatible to that of the other intrusive bodies.

461 Because we did not observe its field relationships with the Jiuziyan, Shuanghe and
462 Jianchuan formations, and because it cannot be dated directly, the age of the Jinsichang Fm is
463 difficult to constrain. Based on geometrical relationships between the formations that are
464 available on the maps, the Jinsichang Fm has to be younger than the Mengyanjing and
465 Baoxiangsi Fms. According to the maps, the Jinsichang Fm is clearly cut by at least three
466 intrusions dated at ~ 35 Ma (**SM 2, Figure 2**). This is confirmed by the age of 34.7 ± 0.8 Ma
467 of dyke CD321 that is intrusive within the Jinsichang Fm (**Fig. 2a**). Sedimentation of the
468 Jinsichang Fm thus started prior to 35.22 ± 0.30 Ma. However, as syenite boulders are locally
469 found within the Jinsichang Fm (site S556), it suggests that sedimentation and emplacement
470 of the intrusions was partly coeval and that sedimentation lasted until some portions of the
471 plutonic bodies were eroded.

472

473 ***3.2. Palaeontological remains***

474 At site S603, near the Dongfengping village (**Figure 2**) local people discovered well-
475 preserved mammal dental remains in yellow sandstones interbedded with coal deposits of the
476 Shuanghe Fm. The left hemimandible includes two well-preserved molars (m1-m2, **Figure**
477 **6b**). An isolated left lower third premolar (p3) and a right fourth premolar (p4) were also
478 found in the same locality. Due to compatible patinae, morphological features, and tooth
479 wear, all these specimens were most likely belonging to the same adult individual. Features
480 such as the huge dental size, the extreme reduction of p3, the presence of flat ectolophids, the

481 strong obliquity of lophids, and the moderate crown height point to a giant amynodontid
482 rhinocerotoid, further referable to *Zaisanamynodon* [Belyaeva, 1971; Lucas and Emry, 1996;
483 Lucas et al., 1996]. This genus corresponds to a giant hippo-like amynodontine, thus far
484 restricted to the late Eocene Ergilian Asian Land Mammal Age in China, Kazakhstan, and
485 Japan [Tsubamoto et al., 2007]. In Yunnan, the Ergilian interval (37.2 to 33.9 Ma) yields a
486 rich and diversified mammalian assemblage [BGMRYP, 1990] including *Zaisanamynodon*
487 [Lucas and Emry, 1996]. This age interval is in full agreement with the one proposed above
488 for the Shuanghe Fm from the absolute ages (35.3 ± 0.47 Ma), but is in contradiction with the
489 paleontological constraints previously proposed (**Figure 3**).

490

491 **4. Implication on Eocene Tibet evolution**

492 The Jianchuan basin was considered to be the only large sedimentary basin spanning
493 the whole Cenozoic in a key area between SE Tibet and the Yunnan highlands. Consequently,
494 it has been the target of several studies aiming at constraining the palaeoenvironmental,
495 latitudinal and altitudinal evolution of the area. Furthermore, the relationship of the Jianchuan
496 sediments with a possible paleo-course of the Yangtze river, which first bend is only ~30 km
497 to the north, has been extensively discussed. All these studies needed robust age constraints
498 but rested on the conventional stratigraphy. Below we discuss the implication of the new
499 stratigraphy proposed in this study.

500 **4.1. Implications on tectonics of SE Tibet.**

501 *4.1.1. Timing of deformation phases.*

502 Our study evidences three main stratigraphic unconformities: first at the bottom of the
503 Jinsichang (E2js) – Jiuziyan (E2jz) Fms, second below the Jianchuan (E2jc) Fm, and third at
504 the base of the Sanying (N2s) Fm (**Figure 2**).

505 The third unconformity has been extensively described and corresponds to
506 sedimentation in basins located at the footwall of faults that are still active today and that
507 corresponds to the last phase of deformation in the area with the Red River fault dextral and
508 N-S normal faults [e.g., Leloup et al. 1995] since ~10 – 5 Ma [e.g., Leloup et al., 1993;
509 Leloup et al., 2001; Replumaz et al., 2001].

510 Regarding the first and second unconformities, only the base of the Jianchuan Fm is a
511 clear angular unconformity, with stratifications below sometimes showing dips $\geq 70^\circ$ and

512 stratifications above monoclinaly dipping $\sim 20^\circ$ to the east (section A-B, **Figure 5**). Below
513 the unconformity, the steeply dipping stratification planes ($\geq 45^\circ$) do not show any preferential
514 direction (**Figure 7a**). This could result from several folding phases. For example three
515 directions of folding (N-S, NE-SW, and NW-SE folds) could explain the data. However these
516 three phases would have affected all formations below the Jianchuan Fm, which implies they
517 took place in a very short time interval ($\ll 1$ Ma). It is more likely that many strata were tilted
518 at the vicinity of the intrusives, rendering a precise analysis of the fold axis meaningless.
519 However, along the Shicaijiang valley a ~ 1800 m-long section exposes an anticline affecting
520 all sediments below the Jianchuan formation. When plotted together the stratification planes
521 imply a fold axis dipping $\sim 7^\circ$ to $N5^\circ$ (**Figure 7b**). This direction is parallel with the overall N-
522 S direction of folds that, according to the regional geological maps [i.e., BGMRYP, 1990],
523 affect both the Mesozoic and Eocene sediments. Such folds imply an \sim E-W direction of
524 shortening, which is compatible with left-lateral motion along the ASRR shear zone that was
525 active in the Oligo-Miocene [e.g., Leloup et al., 1995; 2001]. The age of $\sim 34.5 \pm 1.0$ Ma of the
526 Jianchuan Fm implies that the \sim E-W shortening was ongoing just prior to that age, coevally
527 with magmatism. A synthesis of the ages of the ultra-potassic magmatic rocks on both sides
528 of the ASRR shows that they emplaced between 32.5 ± 0.3 and 36.9 ± 0.3 (36 U/Pb data,
529 average 35.1 ± 0.3 Ma, **Table SM 2**). They thus emplaced in a very brief time interval (≤ 5 Ma)
530 during \sim E-W compression. In the area, significant normal faults initiated much latter (≤ 10
531 Ma) and are not linked with that phase of magmatism. When the original shape of the
532 magmatic province is restored by matching the PhanSiPan intrusives with the Jianchuan ones
533 (~ 600 km of left-lateral offset along the ASRR) [e.g., Leloup et al, 2001] it appears as a zone
534 ~ 200 km in diameter and where ages are older in the centre (Beiya) than in the periphery.
535 This magmatic province has been interpreted to be the eastern prong of the Qiangtang
536 Cenozoic magmatism (Fig. 1a), suggesting a common origin (e.g. Lu et al., 2014). However,
537 the Qiangtang magmatism starts much earlier (~ 45 Ma) and is on the other side of the Triassic
538 Jinsha suture. The geometry of the Upper Eocene magmatic province together with the
539 concomitance with the E-W compression are barely compatible with a large-scale lithospheric
540 delamination [Chung et al., 1998, 2005, Lu et al., 2012], and are incompatible with a
541 continental subduction along the ASRR – Jinsha suture zone to generate the Eocene
542 magmatism [Wang et al., 2001, Ding et al., 2003]. The first hypothesis would rather require
543 extension, while the second would rather require NE-SW shortening along the whole length
544 of the ASRR and magmatism limited to the north of the ASRR (upper plate).

545 *4.1.1. Implications on paleomagnetic studies.*

546 Tong et al. [2015] have collected samples in 21 sites (JL 1-21) in red siltstone within
547 the Jianchuan basin that they attribute to the early-middle Eocene Guolang formation (our
548 Mengyanjing Fm). These sites yield a high magnetic component that reflects a pre-folding
549 primary remanence ($DS=29.7^\circ$, $I_s=32.0^\circ$, $K=44,9$, $\alpha_{95}=5,6^\circ$). 14 other sites (SJ1-14)
550 correspond to the Jinsichang formation (E2js), and yield a high magnetic component that also
551 appears to reflect a pre-folding primary remanence ($DS=200.9^\circ$, $I_s=-31.3$, $K=52,8$, $\alpha_{95}=7,7^\circ$).
552 These two directions are antipodal in good accordance with the fact that a short time probably
553 elapsed between the deposition of the two formations and that the Jinsichang is not Oligocene
554 but predates 35 ± 1 Ma. As these directions are Eocene they can be compared with that obtained
555 by Sato et al., [2001] in the Eocene Laming and Yunlong basins located south of the ASRR
556 ($D=266.13$, $I=339.83$ with $K_{95}=11.23$). That comparison implies a large clockwise rotation
557 of $65.3\pm 12.5^\circ$, and southward motion of $5.7\pm 7.5^\circ$, of the Laming/Yunlong area with respect
558 to Jianchuan. When compared with results from other Cenozoic basins north of the ASRR, the
559 paleomagnetic results imply no latitudinal motion, and limited rotation ($\leq 20^\circ$), with respect to
560 Jianchuan. Such results are compatible with the previous paleomagnetic studies conducted on
561 older sediments that advocate for a large extrusion of the Indochina block south of the ASRR
562 in the Cenozoic [e.g., Yang et al, 1995; Cogné et al., 2013]. However the uncertainty in
563 paleolatitude is so large that the amount of post Eocene extrusion cannot be quantified from
564 the data of the Jianchuan basin.

565

566 **4.2. Palaeoenvironmental implications**

567 *4.2.1. Palaeoenvironmental evolution of the Jianchuan basin during the late Eocene*

568 Five main phases can be distinguished in the late Eocene evolution of the Jianchuan
569 basin: (i) Suspension fallout occurred in a floodplain environment (i.e. low-energy
570 depositional system) (Mengyanjing Fm). Red strata are occasionally interbedded with sheet-
571 like sandstones (overbank deposits) and/or pebble/cobble conglomerates corresponding to
572 alluvial-fan debris-flow deposits, especially near the eastern margin of the basin. However, no
573 lacustrine deposits were found in the Mengyanjing Fm. Occurrence of carbonate levels as thin
574 carbonate layers and channelized structures are rather indicative of palustrine conditions and
575 carbonate-fill stream channel deposits, respectively (e.g., floodplain deposits). (ii) A large
576 braided-fluvial system flowing in a piedmont environment developed on a low-relief

577 topography, possibly merging with another river near the Diancang Shan. Our observations
578 match with former reconstructions suggesting that the paleodrainage network of southeastern
579 Tibet possibly resembled the large-scale dendritic patterns observed in continental interiors
580 developed in areas of low regional relief [Clark et al., 2004]. However, albeit our
581 interpretation (e.g., a braided-fluvial system) is not at odds with the reconstructed depositional
582 pattern of Wei et al. [2016], neither braid-delta and delta-front macroforms, nor
583 lacustrine/turbiditic facies deposits were observed in the Baoxiangsi Fm. Moreover, regular
584 occurrences of siltstones interbedded into dark finer facies (e.g., mudstones/marls) most likely
585 belong the overlying Jiuziyan and Shuanghe Fms in which definite palustrine-lacustrine (and
586 associated floodplain) depositional environments are evidenced [Sorrel et al., submitted], but
587 are never observed in the Baoxiangsi Fm. Hence, though more paleocurrent restoration data
588 would help to better constrain palaeo-flow directions in the Baoxiangsi Fm, our fieldwork
589 study does not support Wei et al.'s [2016] conclusions contending that no large fluvial system
590 flowed through the Jianchuan basin during the timespan of the Baoxiangsi Fm. In any event,
591 the depositional processes and sedimentary dynamics characteristics of the Baoxiangsi Fm, i.e.
592 a large braided-river system made of stacked-fluvial bars possibly flowing in a piedmont
593 environment proximal to a local relief, are not compatible with palustrine-lacustrine
594 conditions, which thus occur later in the succession. Ages of these two formations (i.e.,
595 Mengyanjing and Baoxiangsi Fms) are not constrained from our work unless they are older
596 than ~35 Ma. Regional correlations suggest they are Paleocene-Eocene in age. (iii) At ~35
597 Ma, the braided fluvial system is deactivated following a large-scale drainage reorganization
598 (see Section 4.2.2). Consequently, the Jianchuan basin filled-up, and the sedimentation was
599 restricted to more local depositional settings with (1) palustrine-lacustrine (e.g., near-shore)
600 environments (Jiuziyan Fm) evolving into swamps (Shuanghe Fm) to the east of the basin,
601 while (2) medium to distal alluvial fans delivering detritus prevailed from both western
602 (Jinsichang Fm) and eastern (Jiuziyan Fm) basin margins. This sedimentary succession, as
603 well as the progressive occurrence of coal-bearing beds, is also indicative of a stepwise
604 pattern of environmental change interspersed with climatic change and the onset of moister
605 conditions in the Jianchuan basin [Sorrel et al., submitted], coevally to the first volcanic
606 eruptions occurring at ~35Ma. (iv) At ~35 Ma, a large episode of plutonism occurred, leading
607 to the deposition of volcanoclastic sediments at the surface (Jianchuan Fm) and of large
608 plutons at depth. This episode probably lasted less than 1 Ma and was over by 34 Ma. Since
609 then, sedimentation in the Jianchuan basin has been very limited. (v) The activation of the
610 left-lateral / normal Jianchuan fault induced the formation of limited Pliocene (Sanying Fm)

611 and Quaternary basins in its hanging wall (east), and possibly enhanced erosion in its footwall
612 (west). We do not dispose of direct age constraints for the Jianchuan Fault initiation but is
613 part of the Lijiang – Dali pull-apart basin between the Zhongdian and Red River active
614 dextral faults (Fig. 1b) [i.e. Leloup et al., 1995]. The Diancang Shan normal fault, 50 km to
615 the SE, initiated at ~5 Ma [Leloup et al., 1993], possibly providing an age for the initiation of
616 the Jianchuan fault.

617 *4.2.2. Implication on provenance studies and river network reorganization*

618 20 km north of the basin flows the major Yangtze River (**Figure 1b**). Its peculiar hair-
619 pin shape (called the Yangtze first bend) has intrigued geologist for decades. Recent studies
620 [Clark et al., 2004, Kong et al., 2012, Wang et al., 2013] seem to confirm the first hypothesis
621 of Barbour [1936] who thought that the Yangtze River was flowing southward and was
622 connected to the Red River, at the location of the Jianchuan basin, before experiencing a
623 reorganization of its course. However, the connection between the paleo-Yangtze and the Red
624 River *via* the Jianchuan area is disputed [e.g., Wei et al, 2016], as well as the timing of the
625 drainage reorganization; it ranges from the Pleistocene [Kong et al., 2013] to the Eocene
626 [Zeng, 2002]. Several studies focusing on this problem are based on sediments from the
627 Jianchuan basin.

628 Yan et al. [2012] assess the river reorganization in SE Tibet by tracing the source of
629 the sediments of the Jianchuan basin. To do so, they compare zircon U/Pb ages of potential
630 bedrock sources and sand from the modern Yangtze river, to detrital zircon U/Pb ages of the
631 Baoxiangsi Fm (sample JSJ150), the Jinsichang Fm (sample JSJ18), the Shuanghe Fm
632 (sample JC13) and the Jianchuan Fm (sample JC18). Yan et al. [2012] suggest a major change
633 in the sediment provenance; the source of the Baoxiangsi Fm belonging to the North China
634 block (Songpan-Garze) whereas the source of the sediments of the Jinsichang, Shuanghe and
635 Jianchuan Fm would be more local belonging to the South China block and Yidun arc. They
636 relate this change to a change in the course of the Red River in late Oligocene, possibly linked
637 with the onset of strike-slip faulting along the ASRR shear zone. Using our revised
638 stratigraphy, the drainage change proposed by Yan et al. [2012] would have occurred prior to
639 ~35 Ma not in the late Oligocene (~23 Ma) as previously thought. This could imply that the
640 ASRR left-lateral motion started during late Eocene time as suggested by some studies [e.g.,
641 Leloup et al., 2001, 2007].

642 Wei et al. [2016] assess the same problem with a different approach; to reconstruct the
643 river network evolution, they restore paleoflow directions in the Baoxiangsi and the
644 Jinsichang Fm. Combined with a sedimentology analysis of sediments outcropping in the
645 Jianchuan basin and collected in drill holes in the Dianwei basin, Wei et al. [2016] conclude
646 the Yangtze first bend, *i.e.* the Yangtze River modern course, was set up during the late
647 Miocene or later. Although our findings do not necessarily contradict the paleoflow
648 restoration of Wei et al. [2016], their estimated timing for the establishment of the upper
649 Yangtze River has to be reevaluated. The authors consider the Baoxiangsi Fm as formed in
650 an internally drained basin, whereas there is no evidence of internal drainage in the
651 sedimentary record. Wei et al. [2016] use the top of the Shuanghe Fm (being attributed to the
652 Oligocene based on the BRGM [1990] stratigraphy) as a lower boundary for the
653 establishment of the modern river configuration, the argument being that lacustrine sediments
654 from this formation are not compatible with a major river such as the Yangtze River. Based
655 on the revised late Eocene age of this formation and our interpretation of the sedimentary
656 facies, the Jianchuan area probably experienced a change in its drainage system during the
657 late Eocene.

658 Indeed, our results evidence an abrupt decrease in sedimentation at the end of the
659 Eocene. This can be related to a river network reorganization, although other potential factors
660 such as climate evolution could be at play. The latest major stage of sedimentation seems to
661 coincide with the paroxysm of the volcanic activity in the area. It is then tempting to consider
662 a cause and effect relationship between both events, as hypothesized by Zeng [2002]. Braided
663 river sediments are generally related to a moderate regional slope. The appearance of
664 eruptions and multiple volcanic bodies might have been sufficient enough to locally modify
665 this slope, thus leading to a possible change in the river network. Alternatively, tectonic
666 activity, e.g. the ASRR shear zone, could be responsible for this change. Today, the upper
667 Yangtze flows parallel to the ASRR shear zone and its drainage system is clearly deflected by
668 active strike-slip faults, such as the Zhongdian left-lateral fault (**Figure 1b**). As mentioned
669 above, the left-lateral motion of the ASRR shear zone started between 36 and 28 Ma; this age
670 range overlaps the end of the sedimentation in the Jianchuan basin. Although this study does
671 not allow assessing the potential connection between the Paleo-Yangtze and the main river
672 that used to flow in the Jianchuan area, both were likely affected by the motion on the ASRR
673 shear zone.

674 **4.3. Implication on paleoelevation studies**

675 Several studies focussed on the elevation evolution of eastern Tibet [Hoke et al., 2014;
676 Jacques et al., 2014; Li et al., 2015]. The main objective was to reconstruct the onset of this
677 part of the plateau uplift. This timing can thus be compared with the age of the India-Asia
678 collision and of the central Tibetan plateau uplift. Then models of Tibetan plateau
679 development and propagation can be tested. Many of these studies are based on stable isotope
680 paleo-altimetry on carbonates (lacustrine and paleosol) and require (1) a robust constrain on
681 the age of the sampled formation, (2) an estimate of the Mean Annual Air Temperature
682 (MAAT) to convert the oxygen isotopes composition of the carbonates ($\delta^{18}\text{O}_{\text{carb}}$) to the one of
683 the precipitation ($\delta^{18}\text{O}_{\text{p}}$), (3) the surface water oxygen isotopic composition at low elevation
684 along the moisture path and (4) an appropriate surface water oxygen isotopic composition –
685 elevation relationship [e.g. Poage and Chamberlain, 2001; Rowley, 2007; Rowley &
686 Garzione, 2007]. Two studies have been performed in the Jianchuan basin, based on
687 lacustrine and paleosol carbonates from the Shuanghe Fm. [Hoke et al., 2014], and Jiuziyan
688 Fm. [Li et al., 2015]. Hoke et al. [2014] propose a 3300 \pm 1000m elevation during late
689 Eocene time, while Li et al. [2015] propose a 2600 +800/-1100 m elevation for Miocene time.
690 To convert the $\delta^{18}\text{O}_{\text{carb}}$ to $\delta^{18}\text{O}_{\text{p}}$ both studies use the Sun et al. [2011] MAAT estimates based
691 on paleobotanic studies of the Shuanghe formation that was previously ascribed to the
692 Miocene. Li et al. [2015] apply a conservative +5°C correction to take into account the
693 temperature difference between lake water and MAAT. Hoke et al. [2014] recognize a late
694 Eocene age for their studied pedogenic carbonates and then use the MAAT from Sun et al.
695 [2011] with a +10°C correction to account for the warmer Eocene climate. The revised
696 stratigraphy implies that the Sun et al. [2011] MAAT estimates on the Shuanghe formation
697 does not apply to Miocene time but rather to late Eocene. Thus the $\delta^{18}\text{O}_{\text{p}}$ calculation of Li et
698 al. [2015] applies to the lower Eocene and the +10°C correction applied by Hoke et al. [2014]
699 is not justified. Moreover, Li et al. [2015] used a modern oxygen stable isotope versus
700 elevation relationship rather than the Eocene calibration, resulting in an underestimate of
701 paleo-elevation (**Figure 9**). The new stratigraphic age possibly also influences the $\delta^{18}\text{O}_{\text{p}}$ at
702 low elevation along the moisture path that is required for paleo-elevation calculations. Li et al.
703 [2015] use a $\delta^{18}\text{O}_{\text{carb}}$ from Miocene paleosol of the western Siwalik [Quade & Cerling, 1995]
704 that they convert into a $\delta^{18}\text{O}_{\text{p}}$ of -6.6 \pm 1.4‰ VSMOW. We rather use the $\delta^{18}\text{O}_{\text{p}}$ (-8.2 \pm
705 1‰ VSMOW) reconstructed from late Eocene gastropods sampled in Myanmar [Licht et al.,
706 2014]. Such choice is also consistent with Licht et al. [2014] modeled Eocene moisture paths.
707 Thus, we combine the $\delta^{18}\text{O}_{\text{p}}$ calculated from lacustrine and paleosol carbonate of Li et al.

708 [2015] and Hoke et al. [2014] that we ascribe to late Eocene time with the late Eocene $\delta^{18}\text{O}_p$
709 estimated in Myanmar and apply the Eocene oxygen stable isotopes versus elevation
710 calibration of Rowley [2007]. The obtained late Eocene paleo-elevation for the Jianchuan
711 basin is then of 2800 +/- 1000m, which is similar with previous studies (**Figure 9**). However,
712 this calculation does not take into account the continentality effect. Along the moisture path,
713 the $\delta^{18}\text{O}_p$ decreases inland of about 2‰ / 1000 km [Rozanski et al., 1993]. Li et al. [2015]
714 consider that the Jianchuan basin was 150 km inland to calculate this correction. However
715 using the plate reconstruction of Replumaz & Tapponnier [2003] at ~40Ma the distance
716 between the Myanmar reference site and the Jianchuan basin is of about 1500km, resulting in
717 a -2.5‰ correction. The corrected paleo-elevation is then of 1200+/-1200m (**Figure 9**). In
718 conclusion, the revised stratigraphy has multiple implications on paleo-elevation calculations.
719 The revised estimates suggest that in late Eocene time, the Jianchuan area may have been at
720 low elevation or at least at a lower elevation that in present time. This implies that significant
721 uplift may have occurred only after late Eocene time.

722

723 **Conclusion**

724 A new stratigraphy is proposed for the Jianchuan basin. Sandstone, siltstone and mudstone
725 beds of the lowest Menyanjing formation (E1m) correspond to a floodplain environment.
726 They are overlain by the massive sandstones of the Baoxiangsi Fm (E2b), which corresponds
727 to a wide braided-fluvial system. Above this are the Jiuziyan Fm (E2jz) limestones that
728 deposited in the eastern part of the basin in a lacustrine-palustrine environment, and the
729 Jinsichang Fm (E2js) sandstones and breccia in the western part of the basin that correspond
730 to alluvial fans. The Jiuziyan Fm is overlain by the Shuanghe (E2s) sandstones and coal
731 deposits. The appearance of coal-bearing beds in the Shuanghe Fm suggests that stepwise
732 environmental change occurred in the Jianchuan basin. These modifications were interspersed
733 with climate change and the onset of moisture conditions. The Jiuziyan, Jinsichang, and
734 Shuanghe formations correspond to the filling of the basin after the deactivation of the main
735 river system, due to a large-scale drainage reorganization. Potential causes for this river
736 network modification are the initiation of the left-lateral Ailao Shan – Red River shear zone
737 and/or the brief high K magmatic event that occurred in SE Tibet, including in the Jianchuan
738 basin. The Jianchuan Fm (E2jc) volcanosedimentary deposits rest above all formations
739 through an angular unconformity. ~E-W shortening affected the basin prior to the deposition

740 of the Jianchuan Fm. After deposition of the Jianchuan Fm, sedimentation was extremely
741 limited and controlled by the active normal Jianchuan fault.

742 Sedimentation of the Shuanghe Fm occurred during a short time lapse (35.88 ± 0.35 Ma) in
743 part coevally with the magmatic event (35.22 ± 0.30 Ma). These late Eocene absolute ages are
744 confirmed by the discovery of dental remains of *Zaisanamynodon* Belyaeva, 1971, a large
745 amynod rhinocerotoid that lived in Asia during the Ergilian (Upper Eocene, 37.2 to 33.9 Ma).
746 Sedimentation of the Jinsichang Fm started prior to 35.22 ± 0.30 Ma. The age of the
747 Jianchuan Fm is close to that of the underlying formations ($\sim 35 \pm 1.5$ Ma).

748 High K magmatism is contemporaneous from \sim E-W shortening that affected a \sim 200-km-wide
749 area. The Ailao Shan-Red River shear zone later led to a left-lateral offset of \sim 600 km of this
750 area. Our reconstruction is barely compatible with models of large-scale lithospheric
751 delamination [Chung et al., 1998, 2005, Lu et al., 2012] and in contadiction with models of
752 continental subduction along the ASRR – Jinsha suture zone [Wang et al., 2001, Ding et al.,
753 2003] that have been proposed to explain that magmatism.

754 Previous high paleoaltitude estimates for the Jianchuan basin [Hoke et al., 2014; Li et al.,
755 2015] using the conventional stratigraphy have to be re-evaluated. The paleosol and lacustrine
756 carbonate stable oxygen isotopic composition measured by Hoke et al. [2014] and Li et al.
757 [2015], when affected to the new age and corresponding proper corrections (MAAT, moisture
758 path, low elevation isotopic composition, continentality effect) yield a paleo-elevation of
759 1200 ± 1200 m suggesting that uplift of the Jianchuan basin took place after ~ 35 Ma.

760 This study highlights an often neglected problem: continental sediments are difficult to
761 precisely date but determining their age is fundamental to properly unravel the structural
762 evolution of continents.

763

764

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772

773 **Table captions**

774 **Table 1** Main sites cited in text together with Cenozoic geochronologic ages from this study
775 and those of comparable samples available from the bibliography. All sites appear on **Figure**
776 **2**.

777

778 **Figure captions**

779 **Figure 1. a)** Topographic map of Tibet with main faults (black), suture zones (green) and
780 Eocene ultra K magmatism (red). The frame corresponds to b. **b)** Simplified geological map
781 of the SE edge of the Tibetan plateau with location of the major faults and main Cenozoic and
782 Quaternary sedimentary basins. The grey box indicates Figure 2 location. Tectonic features
783 are after Leloup et al. [1995].

784 **Figure 2.** Structural map of the Jianchuan area based on existing maps revisited after new
785 fieldwork including new stratigraphic and structural interpretations. Main sites (stars) are
786 located as well as some geochronologic ages with numbers referring to bibliography: (1)
787 Schärer et al. [1994] ; (2) Yang et al. [2014] ; (3) Lu et al. [2012] ; (4) Liang et al. [2007].
788 Other results are from this study. The inset in the lower-left corner depicts the geometrical
789 sedimentary relationships between the formations, with blanks corresponding to
790 sedimentation gaps and undulations to angular unconformities (see text for details). Magmatic
791 rocks lithology: ξ syenite, δ diorite, γ granite, η norite, τ trachyte. A version of this map
792 without ages is given as SM 8.

793 **Figure 3.** Comparison of concurring stratigraphies proposed for the Cenozoic Jianchuan
794 basin. **a)** Conventional stratigraphy modified from BRGM [1990]. **b)** Revised stratigraphy
795 [This study]. **c)** Absolute ages of deposits interstratified within the Shuanghe Fm (**Table 1,**
796 **SM 2**). A complete comparison is given in **SM 3**.

797 **Figure 4.** Field pictures illustrating some sedimentary formations. **a)** Massive sandstones
798 (Baixiangsi formation) on top of siltstones from the Mengyanjing formation, with local
799 bioturbation evidence. **b)** Megaripple, Baixiangsi formation. **c)** Detail of b) showing
800 downstream accretion towards the palaeoflow direction foresets (red dotted line) in fine
801 fluvial sands. The upper dotted line shows a reactivation surface over underlying deposits. **d)**
802 Multi-storey sandstones composed of vertically amalgamated channel-fill geometries and
803 stacked-fluvial bars at Shibaoshan Temple (site CD126). **e)** Limestones of the Jiuziyan

804 formation. **f)** Limestones of the Jiuziyan formation resting on top of red siltites of the
805 Mengyanjing formation (site S607). The black frame corresponds to **g)** **g)**. Detail of **f)**
806 showing the basal conglomerate.

807 **Figure 5.** Geologic cross sections corresponding to the gray lines on Figure 2. Geological
808 formations colors are shaded when inferred above topography.

809 **Figure 6.** Field pictures illustrating some age constrains. **a)** White volcanoclastic sandstone
810 level of the Shuanghe formation (Site S224) interbedded between two trachytic lava flows. **b)**
811 Dental remains of *Zaisanamynodon* found at site S603 within the Shuanghe formation. **c)**
812 Lamprophyre sill intruding the base of the Baoxiangsi formation (site S841). **d)** Lamprophyre
813 sill within a Shuanghe formation coal level (site S802). **e)** Lamprophyre dyke cutting across
814 the Jianchuan formation (site S808). **f)** Contact zone of the Shamao Shan syenite with the
815 Jianchuan formation (site S251).

816 **Figure 7.** Stratigraphy attitudes within the Jianchuan basin. Schmidt lower hemisphere
817 projections were performed using stereonet 6.3.3 [Allmendinger et al., 2012], showing
818 stratification (great circles) and poles to stratification (dots). **a)** All measurements from
819 Mengyanjing (E1M - red), Baoxiangsi (E2b –orange), Jinsichang (E2js – pink), Jiuziyan
820 (E2jz – blue) and Shuanghe (E2s – yellow) formations **b)** Measurements from the anticline
821 within the Shicaijiang valley (sites S259 (E2jZ – blue), S564 (E2jZ), S800 (E1M - red), S567
822 (E2jZ), S568 (E2S - yellow), S569 (E2S), and S570 (E2S)) and the overlying Jianchuan
823 formation (S258, S806 and S808 - brown). The plane that best fits with the stratification poles
824 is in red and its pole corresponding to the fold axis (N7 5) is a red square.

825 **Figure 8.** New zircon U/Pb dating results, with $^{206}\text{Pb}/^{238}\text{U}$ vs $^{207}\text{Pb}/^{235}\text{U}$ Concordia diagrams
826 on the left and $^{207}\text{Pb}/^{206}\text{Pb}$ vs $^{238}\text{U}/^{206}\text{Pb}$ Terra and Wasserburg diagrams on the right, for each
827 samples J121 (**a, b**), J120 (**c, d**), J203 (**e, f**), J203 (**g, h**), J203 (**i, j**), J296 (**q, r**). For sample
828 J308 only the Terra and Wasserburg diagram is shown (**k**). For samples J168, J284, J108, and
829 J279 only the Concordia diagram are shown (**l, n, o, p**). For sample CD321-1 the Terra and
830 Wasserburg diagram is shown on the left and the mean average age on the right (**s, t**), errors
831 are reported at the 1σ level, and on s dashed data are not taken into account in the age
832 calculation.

833 **Figure 9.** Reconstructed paleo-elevation of the Jianchuan basin in the late Eocene. The
834 Eocene $\Delta\delta^{18}\text{O}_p$ vs elevation relationship (back curve) of Rowley [2007] has been used.
835 Modern relationship (dashed curve) of Rowley [2007] implying lower elevations for similar

836 $\delta^{18}\text{O}_p$ is plotted for comparison. $\Delta\delta^{18}\text{O}_p$ is the difference between $\delta^{18}\text{O}_p$ at the studied site and
837 $\delta^{18}\text{O}_p$ at low elevation along the moisture path. The empty black rectangle corresponds to the
838 paleo-elevation estimate without taking into account the continentality effect correction while
839 the grey rectangle was obtained using a -2.5‰ correction. Hoke et al. [2014] and Li et al.
840 [2015] paleo-elevation estimates are plotted on the left for comparison. See text for details.

841

842 **Supplementary Material**

843 **SM 1** Structural map of the Jianchuan basin (.kmz file).

844 **SM 2.** Geochronologic ages for the Jianchuan formation and alkaline plutonic rocks in
845 Yunnan and Vietnam.

846 **SM 3.** Comparison between the various stratigraphies proposed for the Jianchuan basin.

847 **SM 4.** Analytical techniques for U/Pb dating (LMVC).

848 **SM 5.** Detailed U/Pb results for samples J121, J120, J203, J168A, J278, J308, J161, J284,
849 J108, J279 and J296.

850 **SM 6.** Relative probability density plot of zircon U/Pb ages for each sample. Only data more
851 than 95% concordant are plotted.

852 **SM 7.** Analytical techniques for U/Pb dating for sample CD321-1 (Wuhan).

853 **SM 8.** $^{40}\text{Ar}/^{39}\text{Ar}$ data, sample J279. **a)** Age spectrum, **b)** K/Ca spectrum, **c)** inverse isochrone,
854 **d)** data table.

855 **SM 9.** Detailed U/Pb results for sample CD321-1.

856

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