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

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Keypoint

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

Keywords

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

Abstract.

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

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

Introduction

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

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

However, dating continental sediments is difficult and, whilst these contains volcanodetritic levels and are crosscut by plutonic rocks, no systematic study was previously conducted to provide the absolute ages of the sedimentary formations. These ages could then be used to constrain the tectonic and altitudinal variations through time. We performed geological 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

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

2. Stratigraphy of the Jianchuan Cenozoic basin

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 (E_1 or Ey) and Guolang (E_2 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 (E1m) [Yunnan Geological Survey, 2008; BGMRYP,

131   1996] or Gaolacun Fm ($E_2{}^3$) [BGMRYP, 1990]. The Baoxiangsi Fm (E_2 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 *Gyrogona 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 (N_1s) 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 (N_2j) 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 $\geq 70°$.

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

6

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

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

on top of green schists (Shigu schists) dipping ~40° to the west. These limestones possibly belong to the Jiuziyan Fm but their exact extent and age are still unknown.

The Shuanghe Fm (E_2s) resting on top of the Jiuziyan Fm consists of poorly consolidated yellow sandstones, intercalated with rare centimetric-scale lacustrine carbonate layers. The sandstones are regularly interbedded with coal deposits and occasional lava flows (**Figure 6a)**, tuff and volcano-sedimentary levels. The Shuanghe Fm is cut by intrusive rocks, mostly lamprophyres, forming numerous sills in the coal levels (**Figure 6d**). The formation extends on the eastern side of the basin, further south than the Jiuziyan Fm. The formation may have had a much wider extent, since it is found in the deformed slice along the Qiaohou Fault (i.e S222, **Figure 2**).

At site S272 (**Figure 2**), along the road between Jianchuan and Lanping, the base of the Jinsichang formation (E2js) monoclinally dips to the NNW and directly rests on E1m siltites that are affected by folds with NE-SW axis. Cartographically the conglomerates also rest on top of the E2b Fm, especially in the northern part of the basin, but we could not confirm this relationship. Boulders are mostly composed of Triassic sandstones but at one location (S556) the clasts also contain syenite. On some maps, the Jinsichang formation extends to the northeastern part of the Jianchuan basin. However, field investigation showed that red conglomerates in that area are found within E1m below E2jz limestones. The Jinsichang formation was thus probably deposited in medium to distal alluvial fans, most likely originating laterally, from the western margin of the main basin axis.

Between sites S254 and S805, the Shuanghe formation is affected by an anticline with a wavelength of a few km and an axis trending NNW-SSE (**Figure 7b**). The Jianchuan formation (E_2Jc) appears to dip monoclinally to the east above this fold and it has been interpreted to correspond to a Neogene volcanodetritic event. However our observations suggest that the Jianchuan formation directly originates from the Shamao Shan Syenite complex and that it is not Neogene but Eocene in age (see below).

On top of the southern outcrops of the E_2s Fm we found distinctive quartz-rich conglomerates and conglomerates with gypsum that where not previously described. It is not clear if these conglomerates are lateral equivalent of the E2js, or more probably correspond to much more recent (Neogene ?) deposits that we ascribe to the Sanying Fm (N_2S) (see below) but without many evidence.

8

Quaternary basins develop in the hanging wall at the foot of the Jianchuan fault. In the southern part of the Dianwei basin outcrop yellow-white lithic sandstones and mudstones interbedded with purple mudstone and lignite (i.e. S633). Most maps allocate this outcrop to the Shuanghe Fm because it contains coal deposits. However the legend of the Jianchuan 1 / 200 000 geological map reports the occurrence of a distinctive Pliocene Sanying Fm (N$_2$S) corresponding to that description, and we thus ascribe these deposits to that particular formation. At the regional scale the Pliocene and Quaternary formations are often found in the hanging wall of active faults.

3. Absolute age constraints

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

3.1. Geochronologic constraints

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

3.1.1. New geochronologic data.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

are subconcordant at ~35 Ma (**Table SM 9**) (**Figure 8s**) and 12 of them yield a 34.73 ± 0.76 mean weigthed age (n=12, MSWD = 1,5) (**Figure 8t**).

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

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

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

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

Along the Qiaohou fault, a slice of rock most probably belongs to the Shuanghe Fm (**Figure 2**). Yang et al. [2014] report volcanoclastic sediments outcropping in that slice (sample DX039-5, site S222, **Figure 2**). Alike for sample J120 the zircons are rounded and yield ^{206}Pb/^{238}U ages spanning from 1777 to 34 Ma, the youngest four concordant dates yielding a ^{206}Pb/^{238}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 ~35 ± 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 ±

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 Schärrer 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 ~34.5±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

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 interbeded 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

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

4. Implication on Eocene Tibet evolution

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

4.1. Implications on tectonics of SE Tibet.

4.1.1. Timing of deformation phases.

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

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

Regarding the first and second unconformities, only the base of the Jianchuan Fm is a clear angular unconformity, with stratifications below sometimes showing dips ≥70° and

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

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 prefolding
549   primary remanence (DS=29.7°, Is= 32.0°, K=44,9, α95=5,6°). 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 prefolding primary remanence (DS=200.9°, Is= -31.3, K=52,8, α95=7,7°).
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±1Ma. As these directions are Eocene they can be compared with that obtained
555   by Sato et al., [2001] in the Eocene Lamping and Yunlong basins located south of the ASRR
556   (D= 266.13, I =339.83 with K95 =11.23). That comparison implies a large clockwise rotation
557   of 65.3±12.5°, and southward motion of 5.7±7.5°, of the Lamping/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 (≤20°), 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. Paleoenvironmental 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 occasionnally 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 Boaxingsi 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 occuring 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)

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

4.2.2. Implication on provenance studies and river network reorganization

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

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

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

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 (~35 ± 1.5 Ma).

748 High K magmatism is contemporaneous from ~E-W shortening that affected a ~200-km-wide
749 area. The Ailao Shan-Red River shear zone later led to a left-lateral offset of ~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+/-1200m 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

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 BRGMY [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   (Baoxiangsi formation) on top of siltstones from the Mengyanjing formation, with local

799   bioturbation evidence. **b)** Megaripple, Baoxiangsi 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. Geologoical

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 $^{206}Pb/^{238}U$ vs $^{207}Pb/^{235}U$ Concordia diagrams

826   on the left and $^{207}Pb/^{206}Pb$ vs $^{238}U/^{206}Pb$ 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 $\Delta\delta^{18}O_p$ 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     $\delta^{18}O_p$ is plotted for comparison. $\Delta\delta^{18}O_p$ is the difference between $\delta^{18}O_p$ at the studied site and

837     $\delta^{18}O_p$ 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.** $^{40}Ar/^{39}Ar$ 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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