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1 **Block Tectonics across Western Tibet and Multi-Millennial Recurrence of Great** 2 **Earthquakes on the Karakax Fault**

3
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6
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20 21 **Key Points:**

- 22 • The ~400 km-long, left-lateral Karakax fault (western Altyn Tagh fault) slip rate has been
23 ~2.5±0.5 mm/yr for ~210 ka
24 • Four M~7.6 earthquakes (150 km rupture length; 2.5 ka return time) have offset
25 Holocene terraces (6, 12, 18 and 24 m characteristic slip)

- 26 • Block tectonics and triple junction kinematics account for 24 Ma deformation of west
27 Tibet and rise of ≥ 8000 m-high Karakorum range

28

29 **Abstract**

30 Fault slip rates are critical to quantify continental deformation. Those along the Karakax
31 fault (northwestern Altyn Tagh Fault: ATF) have been debated, even though it is one of Tibet's
32 most outstanding active faults. At Taersa, using LiDAR measurements of terrace and fan riser
33 offsets (~6 to ~500 m) and $^{10}\text{Be}/^{26}\text{Al}$ dating of alluvial surfaces (<210 ka), we obtain a late
34 Quaternary slip rate of $\sim 2.5 \pm 0.5$ mm/yr. This doubles the $\sim 2.6 \pm 0.5$ mm/yr rate time span found
35 to the east and west. We interpret the ~150 km-long, free-faced rupture along the fault to be that
36 of the $M \sim 7.6$ event felt in Hotan in 1882. Characteristic slip (~6 m) during four large
37 earthquakes since ~10 ka implies a $\sim 2500 \pm 500$ yrs return time. A ~3 mm/yr rate is consistent
38 with the ~80 km offset of the Karakax river since uplift of the West Kunlun range and sediment
39 deposition in the Tarim foreland accelerated, ~24 Ma ago. The faster slip rate (~10.5 mm/yr) on
40 the central ATF matches the sum of those along the reactivated West Tibetan terrane boundaries
41 (Karakax and Longmu-Gozha Co faults) at the Uzatagh triple junction (~36°N,
42 83°E). The abrupt termination and altitude drop of the Karakorum range where the Longmu Co
43 and Karakorum faults meet (Angmong junction), also reflect triple junction kinematics. Such
44 localized changes account for the rise of the Karakorum and West Kunlun ranges and support
45 lithospheric block tectonics rather than diffusely distributed deformation.

46

47 **Plain Language Summary**

48 How the Tibetan plateau rose to ~4500 m and deforms today remain outstanding
49 questions. Tibet's northern edge follows the ~2000 km-long Altyn Tagh fault, whose
50 westernmost branch is the Karakax fault. Despite the spectacular escarpments and offsets

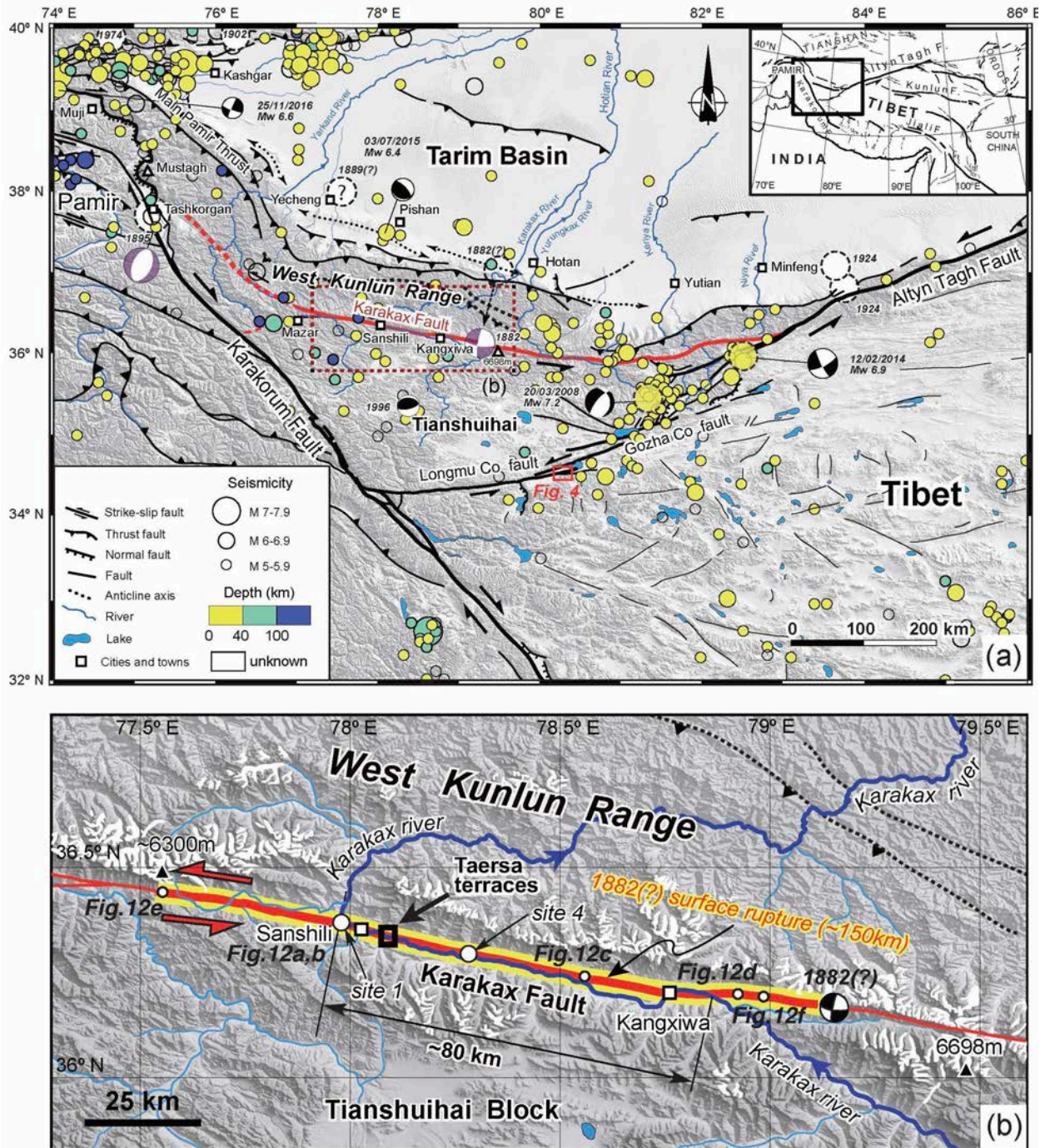
51 observed along that fault, its slip rate, critical to quantify continental deformation, has remained
52 controversial. Here, we corroborate that, for the last ~210,000 yrs, that rate has been $\sim 2.5 \pm 0.5$
53 mm/yr, based on high-resolution topography and dating of left-laterally offset fluvial surfaces.
54 The ~80 km offset of the Karakax river implies that this rate may have remained constant since
55 the rise of the Kunlun range above the Tarim basin started ~24 Ma ago. The sharp fault trace
56 reflects the exceptional preservation, since ~10,000 years ago, of four $M \sim 7.6$ earthquake ruptures
57 (the last in 1882), each with ~6 m of slip (~2500 yrs return time). Fault slip rates, GPS vectors
58 and mountain altitudes across western Tibet reflect block motions and triple junction kinematics
59 rather than continuum deformation. Specifically, localized velocity changes appear to account
60 for the rise of the West Kunlun and Karakorum ranges. Our results bridge the gaps between
61 present and long-term geological history, and broad-scale geodesy and local field evidence.

62

63 **1 Introduction**

64 The accurate determination of fault slip rates at various timescales is key to quantifying
65 continental deformation kinematics, long-term seismicity and lithospheric rheology. Yet, because
66 fault offsets and marker ages derived from different measurements and dating techniques are
67 often difficult to constrain beyond doubt or to interpret jointly, and because slip-rates can be
68 time-dependent (e.g., Chevalier et al., 2005), conflicting long-term slip rate values have been
69 proposed along even the best studied active faults. In western Tibet, the longest segment of the
70 ~400 km-long, ~100°E-striking Karakax fault (KXF), northwestern branch of the ~2000 km-long,
71 left-lateral Altyn Tagh fault (ATF), is partly confined along the ~3-4 km-wide Karakax river
72 valley. It follows the southern edge of the West Kunlun range, along the northern boundary of
73 the Tianshuihai terrane (Fig. 1). Together with the sinistral Longmu-Gozha Co and dextral

74 Karakorum faults farther south, it contributes to absorb the convergence between India and Asia,
75 and to steer the eastward extrusion of Tibet (e.g., Tapponnier and Molnar, 1977; Armijo et al.,
76 1989; Avouac and Tapponnier, 1993; Tapponnier et al., 2001; Chevalier et al., 2017). Due to
77 access restrictions and a remote location at ~3700 m, the KXF has been the target of few field
78 studies (e.g., Matte et al., 1996; Li et al., 2012; Gong et al., 2017; Peltzer et al., 2020), in spite of
79 spectacular, long-identified geomorphic markers (pull-apart basins, pressure ridges, and offset
80 streams, terraces, fans and moraines) (Peltzer et al., 1989).



81
 82 **Figure 1.** Active faulting in the Altyn Tagh - Karakorum junction area. (a) Simplified map of
 83 Quaternary faults across western Tibet and Tarim (Karakax fault in red). Inset shows location
 84 within India-Asia collision zone. Circles are epicenters of $M \geq 5$ earthquakes since 1976 (SBX,
 85 1997; USGS), colored as a function of depth. Dashed large white circles are reported or inferred
 86 locations of older historical earthquakes. Black/white fault plane solutions are for $M \geq 6.4$

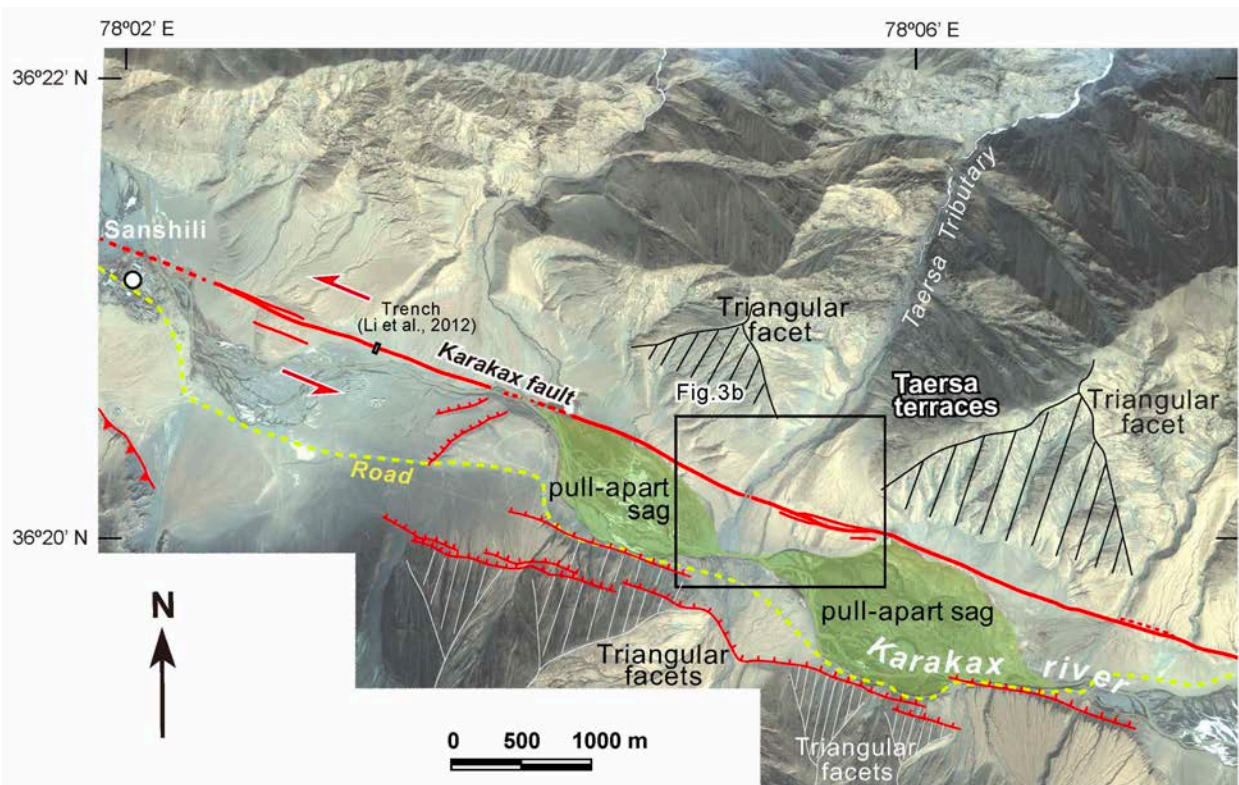
87 *earthquakes recorded by www.globalcmt.org, while two light-purple/white ones are those of the*
88 *1882 and 1895 historical events, consistent with surface rupture observations (Liu, 1993). (b)*
89 *Close-up of left-lateral Karakax fault main trace. Black square is location of Taersa terraces site.*
90 *Thick yellow/red line shows ~150 km length of inferred sinistral surface rupture of 1882*
91 *earthquake (black/white focal mechanism). Note ~80 km sinistral offset of Karakax river. Large*
92 *white circles are Sites 1 and 4 from Peltzer et al. (2020) and small white circles refer to surface*
93 *rupture field photographs and satellite images shown in Figure 12.*

94

95 Pioneering observations with Landsat images demonstrated that the KXF is an active left-
96 lateral strike-slip fault (Tapponnier and Molnar, 1977). The subsequent use of 10 m-resolution
97 Spot images provided the first measurements of syn- or post-glacial offsets of up to 250 m
98 (Peltzer et al., 1989). This initially suggested an inferred Holocene slip rate as large as ~20-24
99 mm/yr, in keeping with the youthful geomorphic trace of the fault. Such a fast rate similar to that
100 along California's San Andreas fault and compatible with that formerly inferred along the central
101 ATF (~30 mm/yr, e.g., Molnar et al., 1987; Armijo et al., 1989; Molnar and Lyon-Caen, 1989)
102 was long deemed plausible (e.g., Avouac and Peltzer, 1993; Avouac and Tapponnier, 1993). This
103 was also consistent with a convergence rate between India and Asia formerly estimated to be as
104 large as ~5 cm/yr based on Nuvel 1 and plate tectonic reconstructions (DeMets et al., 1990).
105 Later on, quantitative field measurements and sampling suggested a slip rate bracket of 12-25
106 mm/yr in the last ~115 ka (Ryerson et al., 1999; dataset published in Peltzer et al., 2020). Much
107 slower slip rates, however, have been proposed in recent years. Li et al. (2012) suggested ~6-7
108 mm/yr during the last ~1000 years, based on one ¹⁴C age in a trench ~2 km east of Sanshili (Fig.
109 2). At the location of our present study, from Optically Stimulated Luminescence (OSL) dating
110 of fluvial sand samples from offset river terraces, Gong et al. (2017) obtained a similar rate of
111 7.8±1.6 mm/yr during the last ~40 ka. Yet more recently, Peltzer et al. (2020) obtained an even

112 slower rate of 2.6 ± 0.5 mm/yr since ~ 115 ka, by combining diffusion modeling of fault scarps,
 113 3D fan offset reconstructions, and OSL/ ^{10}Be dating of offset terraces at two sites ~ 35 km apart
 114 (Fig. 1b).

115 Here, based on Light Detection And Ranging (LiDAR) geomorphic measurements and
 116 $^{10}\text{Be}/^{26}\text{Al}$ cosmogenic surface-exposure and depth profile dating at Taersa, 5 km east of Sanshili,
 117 we further assess plausible values of the KXF slip rate in the last ~ 210 ka and infer the return
 118 times of four Holocene great earthquakes on the fault. This is possible because of the outstanding
 119 preservation of superficial morphology due to a particularly arid climate (36 mm/yr of annual
 120 precipitation in Kangxiwa, Yao et al., 1996). We also re-assess the ~ 150 ka slip rate along the
 121 Longmu Co fault, ~ 250 km SE of the Karakax valley, and examine how such large faults control
 122 the large-scale kinematics of block deformation across western Tibet.



123
 124 **Figure 2.** Map of main active strands of Karakax fault system around Taersa site, based on
 125 *Ikonos* image and field mapping of recent surface traces (red) across Karakax valley near

126 *Sanshili. The Taersa tributary flows south into a deep, swampy pull-apart sag (green shade)*
127 *along the river valley, abandoning uplifted fans and terraces across the fault. Recent, north-*
128 *facing and NE-striking normal fault scarps (red lines with tick bars) also cut fluvial fans south of*
129 *the river. Triangular facets attesting to components of normal faulting south and north of the*
130 *river are also indicated. Black rectangle shows location of trench site from Li et al. (2012).*

131

132 **2 Methods**

133 Meltwaters from the West Kunlun range glaciers flow into the ~EW-trending Karakax river
134 valley (Fig. 2), depositing large fans and terraces (Fig. 3). The Karakax strike-slip fault, which
135 runs parallel to the Karakax river, cuts and left-laterally displaces by tens to hundreds of meters
136 most of these tributary landforms (Figs. 2 and 3). This ideal setting creates piercing points on
137 each side of the fault that can be used to measure offsets, with assessable uncertainties thanks to
138 the fairly linear geometry of the terrace risers.

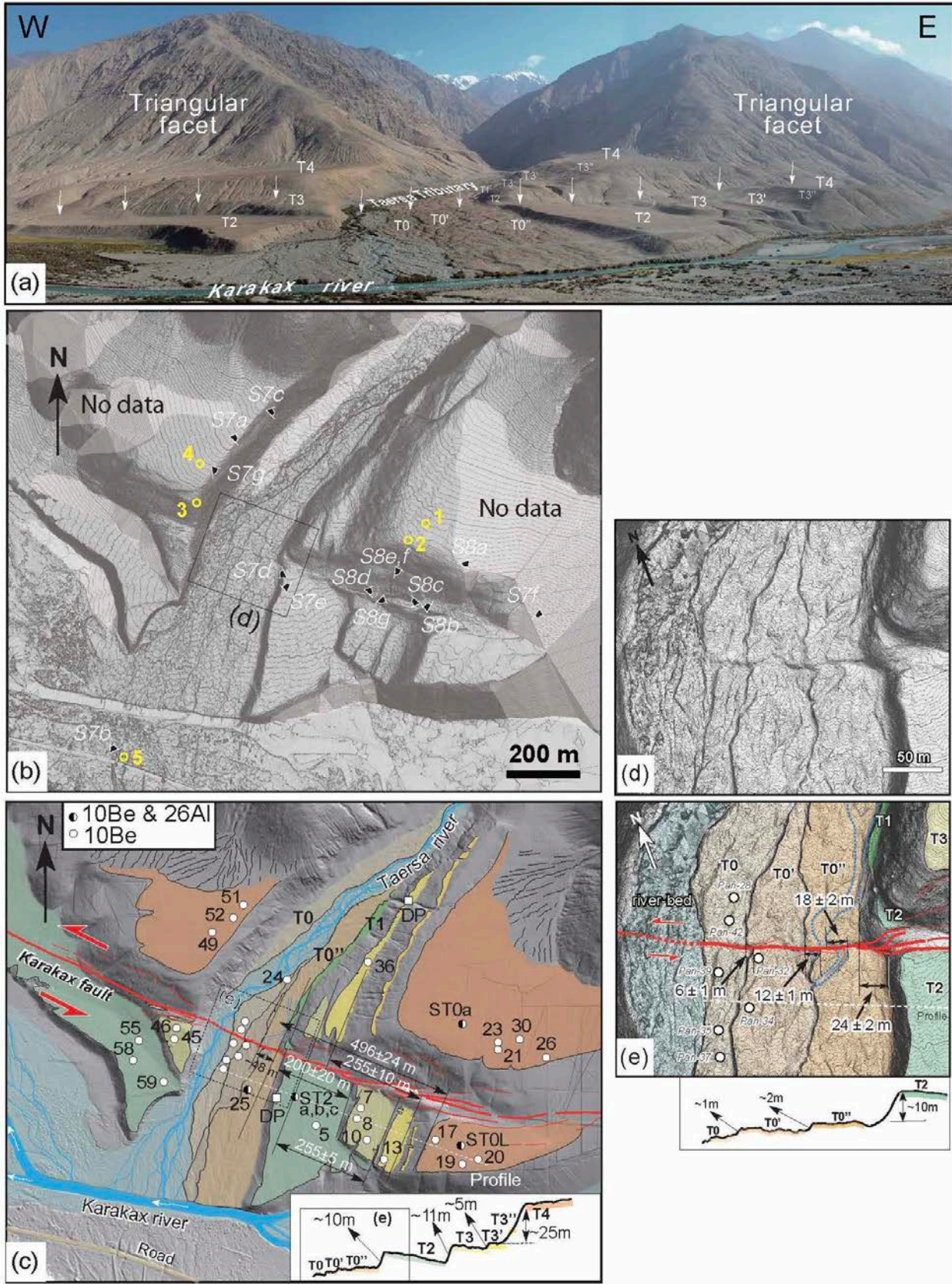
139 We combined field measurements and high-resolution satellite image interpretation to map
140 active fault strands and offset geomorphic features, particularly within the Taersa paleo-fans and
141 inset terraces (Fig. 3). In the field, using a tape, we first measured horizontal strike-slip offsets
142 smaller than 30 m. We also used a Riegl VZ-1000 terrestrial LiDAR (angular resolution of 0.02°
143 for raw data) to scan the Taersa fan and fan/terrace surfaces (five bases, Fig. 3b,d). After
144 generating the point cloud using Riegl's "RiscanPro" software, we exported the data into "Global
145 Mapper" to build a Digital Elevation Model (DEM) with a resolution of 0.5 m. We then
146 extracted topographic profiles from the DEM and precisely measured cumulative horizontal and
147 vertical fault offsets (Fig. 5). All DEM-derived measurements were compared with those directly
148 measured in the field. Our high-resolution DEM, combined with the Ikonos satellite image of the
149 entire Taersa site, was finally used to quantify the overall geometry of the fans and their offsets
150 by the KXF (Figs. 5 and 6b).

151 At a more detailed level, we used the Matlab code “3D_Fault_Offsets” of Stewart et al.
152 (2018) to measure the horizontal and vertical offsets of the youngest terrace risers (T0, T0', T0"
153 and T2) (Figs. S1-S4). That code requires tracing of the fault on the DEM and identifying
154 polygons to delineate terrace risers on both sides of the fault. Channel meandering along the
155 various risers requires reducing the width of the polygons. The DEM uncertainties were set to be
156 0.5 m, and 2 m for the position of the fault whose dip was taken to be $70\pm 10^\circ$ (from trenching by
157 Li et al., 2012).

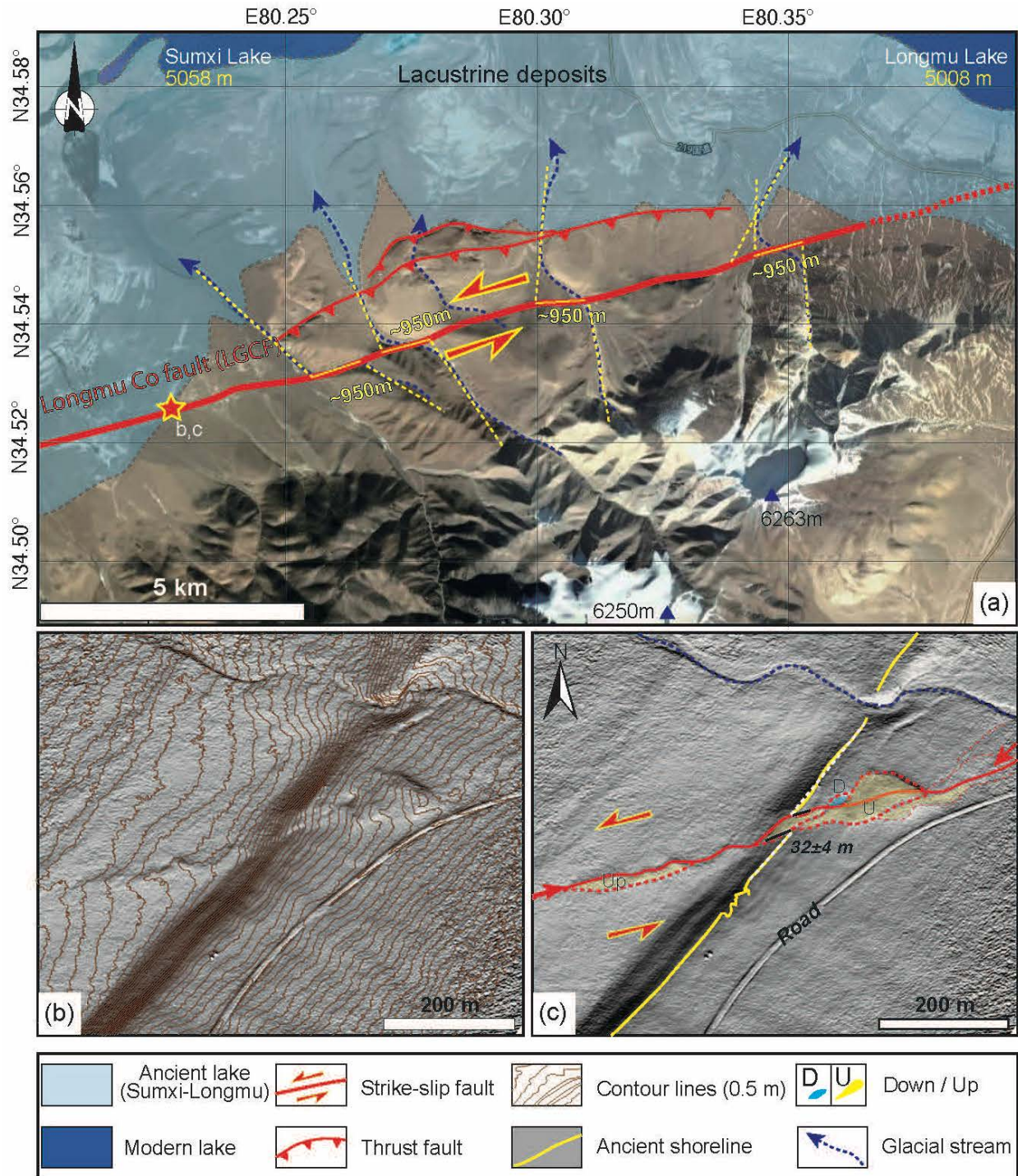
158 We also show in Figure 4 the DEM (9.78 cm/pix) that we recently obtained across the
159 Longmu Co fault, where it offsets the highest shoreline of Sumxi-Longmu Lake (location in Fig.
160 1a). That DEM was built by merging dozens of photos taken by our Unmanned Aerial Vehicle
161 (UAV, DJI Phantom 4) using the software “Agisoft Metashape Professional”.

162 Our dating of fans and terraces at Taersa was based on the collection of a total of 35 quartz-
163 rich cobbles (<25 cm in diameter) on the surfaces, as well as of nine samples in two depth
164 profiles (down to ~140 cm) (Figs. 3, 8 and S5). From these samples, we obtained 35 ^{10}Be and six
165 ^{26}Al cosmogenic model ages (Table 1). The clear desert varnish coating all the cobble surfaces
166 (Figs. 8 and S5) (Farr and Chadwick, 1996), including on the lowest, youngest terraces, strongly
167 suggests an absence of post-depositional reworking, and minimal rock weathering. The cobbles
168 were crushed and sieved, and mineral separation and quartz cleaning were performed following
169 standard procedures (e.g., Kohl and Nishiizumi, 1992). ^{10}Be and ^{26}Al model ages were calculated
170 using the Lifton et al. (2014) ‘LSDn’ model in CRONUS version 3 (Balco et al., 2008) and are
171 reported with 1σ uncertainties (Table 1). The model ages from the two depth profiles were
172 calculated using the Hidy et al. (2010) software (version 1.2).

173 We used statistical analyses based on Chauvenet's criterion (Bevington and Robinson, 2002)
174 to discard potential outliers (including samples with excessive or insufficient ^{10}Be or ^{26}Al
175 concentrations) out of the age distributions. Slip rates during different time spans were then
176 derived from the ranges of fan and terrace riser offsets and abandonment ages using the method
177 of Zecher and Frankel (2009). We report the median rates (with uncertainties at the 68.27%
178 confidence interval about the median) obtained using their Gaussian uncertainty model.
179



181 **Figure 3.** Taersa terraces site: (a) View to NE of offset Taersa terraces and triangular facets.
182 White arrows indicate main surface trace of Karakax fault. Note similar, maximum elevations of
183 highest T4 fan surfaces on either side of the Taersa tributary valley. Location of photos in
184 Figures S7 and S8 is indicated. (b and d) LiDAR DEM images (with 1 and 0.2 m contour lines,
185 respectively), with (c and e) detailed field-based mapping of T0-T4 alluvial surfaces (colored)
186 and seismic offsets, respectively. White areas in b are shielded from LiDAR surveys and five
187 yellow circles show positions of survey bases. Small white circles (with numbers) indicate
188 locations of dated cosmogenic surface samples. White squares labeled 'DP' are locations of
189 depth profiles on T3' north of the fault and T2 south of the fault. Double arrows with numbers
190 (in c) are apparent offsets of T4-T3'-T3 fan risers east of Taersa Holocene T0"/T0' fluvial
191 channel (see text for details). Bottom right insets show profiles parallel to the fault (white dashed
192 lines in c and e) across alluvial surfaces, extracted from LiDAR DEM. Single arrows with
193 numbers (in e) point to single and cumulative co-seismic offsets of lowest T0 to T2 terrace risers.



194

195 **Figure 4.** Late Quaternary offsets along Longmu Co fault south of Sumxi-Longmu Lakes: (a)
 196 Active trace of left-lateral fault and associated thrusts. Post-Marine oxygen Isotope Stage MIS-6
 197 glacial valley offsets (950 ± 50 m) and location of offset of highest shoreline of paleo-Sumxi-
 198 Longmu Lake are indicated by dashed blue lines and red star, respectively. (b) UAV-derived
 199 DEM and (c) cumulative surface breaks and highest shoreline (~ 6 ka) offset (~ 32 m), with push-

200 *ups (Up, yellow shades) and pull-apart (Down, blue shade). Figure location is indicated in*
201 *Figures 1a and 13a. See text for details.*

202

203 **3 Morphology, extent and offsets of the Taersa fans/terraces**

204 The Taersa site exposes four main alluvial fan and terrace surfaces (from T0, youngest, to
205 T4, oldest), with several smaller, intermediate sub-levels (nine in total, Fig. 3). The broadest
206 levels (T2, T3-T3' and T4) extend far on both sides of the Taersa tributary valley, north of the
207 Karakax river. They correspond to three main generations of large interglacial fill-fans, that
208 spread out broadly as the tributary reached into the main river valley. The curved, convex-
209 upward, shapes of most of the uplifted terraces indicate that they correspond to conical alluvial
210 fan surfaces (e.g., Meyer et al., 1996; Peltzer et al., 2020), which accounts for their slightly
211 different elevations east and west of the tributary valley (Fig. 5b). Most of the other tributary
212 streams have deposited similar imbricated alluvial fan surfaces along the Karakax valley (Li et
213 al., 2012; Peltzer et al., 2020). The lowest/youngest terraces (T0, T0', and T0''), not far from the
214 current river-bed, are covered with small boulders (<1 m in diameter, Figs. 8f,g and S5)
215 deposited along recent, well-preserved braided channels (Fig. 3d). They are separated by small
216 risers, 1-2 m-high at most (Figs. 3e and 5e). North of the fault, one additional young (low)
217 terrace (T1) has been narrowly preserved (Fig. 3c,e), which we interpret to attest to the oblique
218 component of footwall uplift north of the fault (Fig. 5a,c). Such uplift also promoted stronger
219 lateral erosion of the upstream risers, hence affected their geometries more than that of their
220 shielded counterparts south of the fault and east of the tributary (e.g., Cowgill, 2007; Gold et al.,
221 2009; Mériaux et al., 2012).

222 The much smoother, higher fan surfaces T2-T4 are covered with fewer cobbles (Fig. 8b-e).
223 South of the fault, their risers are higher than those of the T0s-T1 flight, from 5 to 25 m, up to a

224 maximum of 56 m above the present-day river-bed (Figs. 3c,e, insets and 5). North of the fault,
225 that maximum height reaches ~70 m (Fig. 5b). This shows that here, the Karakax main sinistral
226 strand has a significant normal slip component, which we interpret to reflect extension along the
227 northern edge of a pull-apart sag beneath the swampy meanders of the Karakax river east and
228 west of Taersa (Fig. 2). Note that this pull-apart also corresponds to a southwestwards step where
229 the main fault trace crosses the Karakax river from north to south. The pull-apart-related,
230 extensional component has been long-lived since the cumulative vertical throw of fan surfaces
231 T2 to T4 across the fault increases from 2 to 28 m (Fig. 5c). Also, the presence of triangular
232 facets on both the north and south sides of the Karakax valley along mainly that stretch of the
233 KXF supports long-term extension across that pull-apart sag (Figs. 2, S7f and S8f).

234 On the eastern side of the Taersa tributary floodplain, the T0'/ T0 and T0''/T0' risers, one
235 large fluvial paleo-channel within T0'', and the T2/T0'' riser (recall that T1 is not present south of
236 the fault) are left-laterally offset by 6 ± 1 , 12 ± 1 , 18 ± 2 , and 24 ± 2 m, respectively (Fig. 3e), as
237 measured in the field with a tape (Li et al., 2012). Note that the offsets of the channel axes and of
238 the tops and bases of their bounding risers are indistinguishable and that, because of exceptional
239 preservation due to the arid climate, the error bars on their offsets are generally on order of 10%.
240 Using Stewart et al. (2018)'s "3D_Fault_Offsets" code, the corresponding, best-fitting horizontal
241 offsets are 5.9 ± 0.5 m for T0/T0' (Fig. S1), 12.8 ± 2.5 m for the T0'/T0'' riser (Fig. S2), 17.8 ± 1.5
242 m for the gully on T0'' (Fig. S3), and 22.9 ± 1.5 m for the T0''/T2 riser (Figs. S4, S6 and S7e)
243 while vertical offsets are negligible (< 1 m). The automatic restorations thus yield offsets that are
244 consistent (at the 99% level) with our previous field and LiDAR survey measurements. The
245 largest (~23-24 m) offset is also found across several other Holocene fans and fan risers along
246 the Karakax valley (Fig. 1b and Li et al., 2012).

247 The current left-lateral offsets of the higher/older T3/T2, T3'/T3 and T4/T3' riser bases and
248 tops are 200 ± 20 , 255 ± 5 , and 255 ± 10 m (Figs. 3c and S6) and 196 ± 10 , 255 ± 10 and 214 ± 10 m
249 (Fig. 5a), respectively. That the offset of the T4/T3' riser top (~ 214 m) is significantly smaller
250 than that of the T3'/T3 riser (~ 255 m), which stands as much as 38 m down below T4 north of
251 the fault (Fig. 5b), and therefore must be much younger, poses problem. This implies that, here,
252 riser tops cannot simply be used to reliably measure cumulative offsets. One way to account for
253 that puzzling observation is that greater incision associated with the vertical uplift north of the
254 fault affected the now preserved apparent horizontal offsets. In addition, the presence of yet
255 another, intermediate, barely preserved terrace ledge (T3'') between T4 and T3' (Figs. 3c, 5-8)
256 implies that the total incision between the T4 and T3' levels was long-lived, and entailed several
257 distinct episodes. Such long-lasting incision events likely broadened the valley width north of the
258 fault at the T4 level by more than 2×70 m (possibly as much as 258 m on the east side, Fig. 6a).
259 North of the fault, this laterally eroded the currently narrow, remnant, footwall terrace ledges (T2,
260 T3, T3' and T3''), and particularly the highest uplifted T4 fan riser. On the west side of the
261 Taersa tributary, the more steeply incised valley edge ($\sim 30^\circ$ east dip on average compared to $\sim 18^\circ$
262 west dip on average on the east side, Fig. 6a), likely accounts for the complete demise of all
263 surfaces younger than T4, compared to the preservation of the east side ledges.

264 At a more detailed level, Figure 6b shows that the average slopes of the risers on the east
265 side of the Taersa tributary decrease stepwise upwards from $\sim 25^\circ$ to $\sim 18^\circ$, as their overall
266 convexity increases with height, hence age, above river. This is consistent with the much greater
267 degradation of the riser slopes north than south of the fault, which is clear on both the Ikonos
268 imagery (Fig. 6c,d) and in the field (Fig. 8a). The composite T4/T3''/T3' riser, in particular, has
269 been much more strongly incised by deeper and more numerous gullies perpendicular to the

270 Taersa tributary north than south of the fault (Figs. 6c,d and S7a). That the gullies south of the
271 fault are narrower and shallower than those to the north is supported by the multiple yak/sheep
272 paths that cross them, while none are observed to the north (Fig. 6c,d). Note that similar,
273 asymmetric, fan/terrace aggradation and degradation processes have been described elsewhere
274 along the eastern Altyn Tagh fault (e.g., Pingding Shan, Mériaux et al., 2012). Clearly, the strong
275 erosional degradation of the highest, T4/T3' riser east of the Taersa tributary, and its correlative
276 eastward retreat, make it challenging to use its present geometry to constrain a total cumulative
277 offset in a traditional way.

278 In order to do so, one must factor in that the top offset must have been greater than apparent
279 today (214 m, Fig. 5a). Before tectonic uplift and correlative river incision and valley widening
280 north of the fault (Fig. 6a), the initial, upstream position of the top of the western riser of T4 east
281 of the tributary (and to a lesser degree, possibly also of those of T3, T3' and T3'') must have
282 been closer to the eastern edge of the Taersa tributary floodplain. A plausible position for the
283 original western edge of T4 east of the tributary might have been between the present T0''/T0'
284 and T1/T0'' risers, which mark the current minimum and maximum limits of that floodplain, ~48
285 m apart (Fig. 3c). This would also be in keeping with the fact that the upstream Taersa tributary
286 valley is deeply anchored, hence captive, within basement rocks that crop out on either side of
287 the tributary valley almost all the way down to the KXF (Figs. 3a and S7). Consequently, the 214
288 m apparent riser top offset of T4 might be increased to an average of 496 ± 24 m (Figs. 3c and 7).

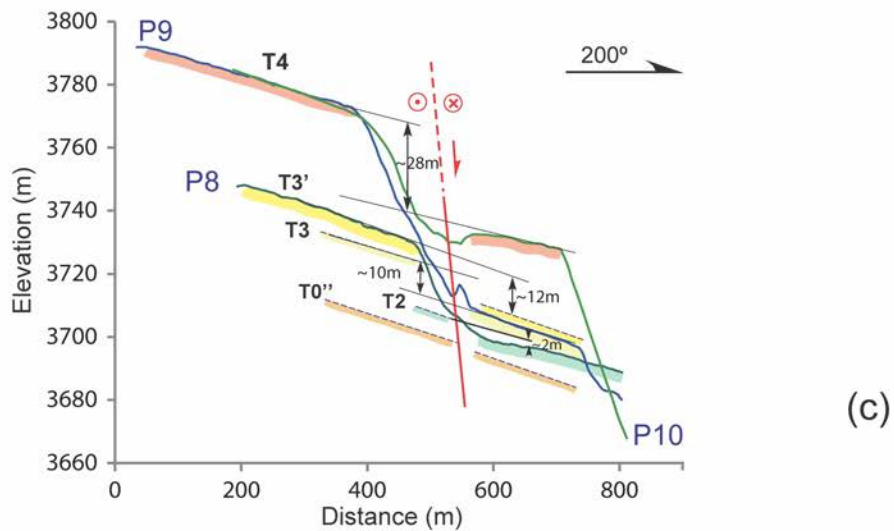
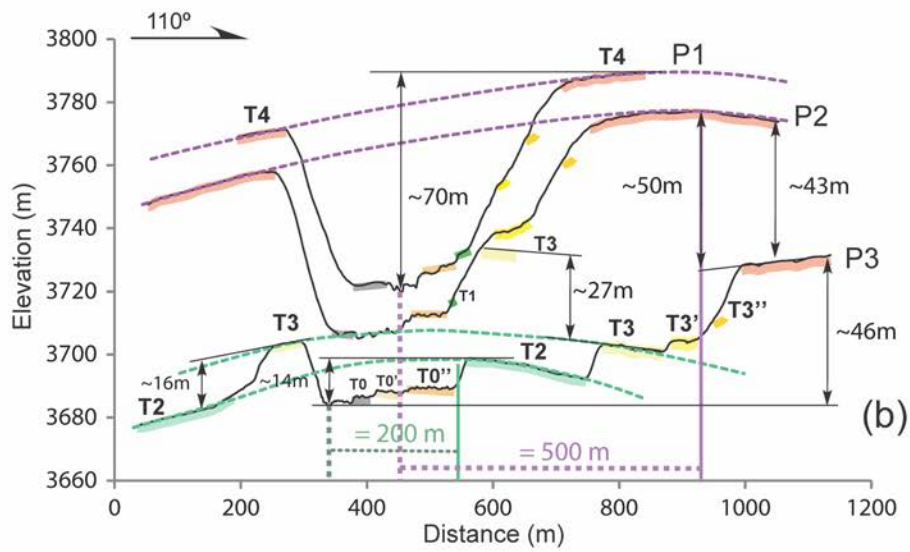
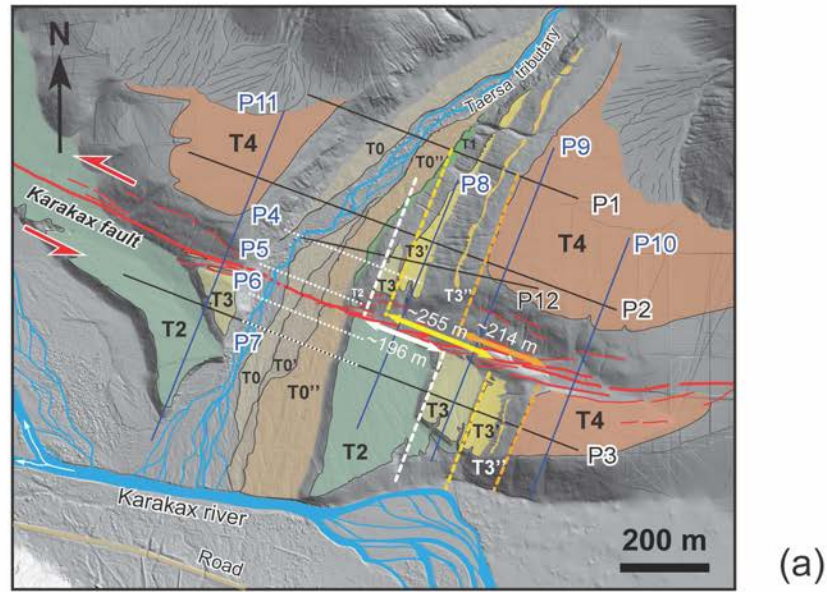
289 The two highest risers north and south of the fault are T4/T3' and T3/T2. The T3'/T3 riser,
290 which is only ~3 to 5 m-high, compared to ~25 m for T4/T3' and ~12 m for T3/T2 (Fig. 5b),
291 appears to be an intermediate feature, likely linked with a minor aggradation/incision change
292 between the main climatic episodes that have shaped the Taersa tributary valley and alluvial fan

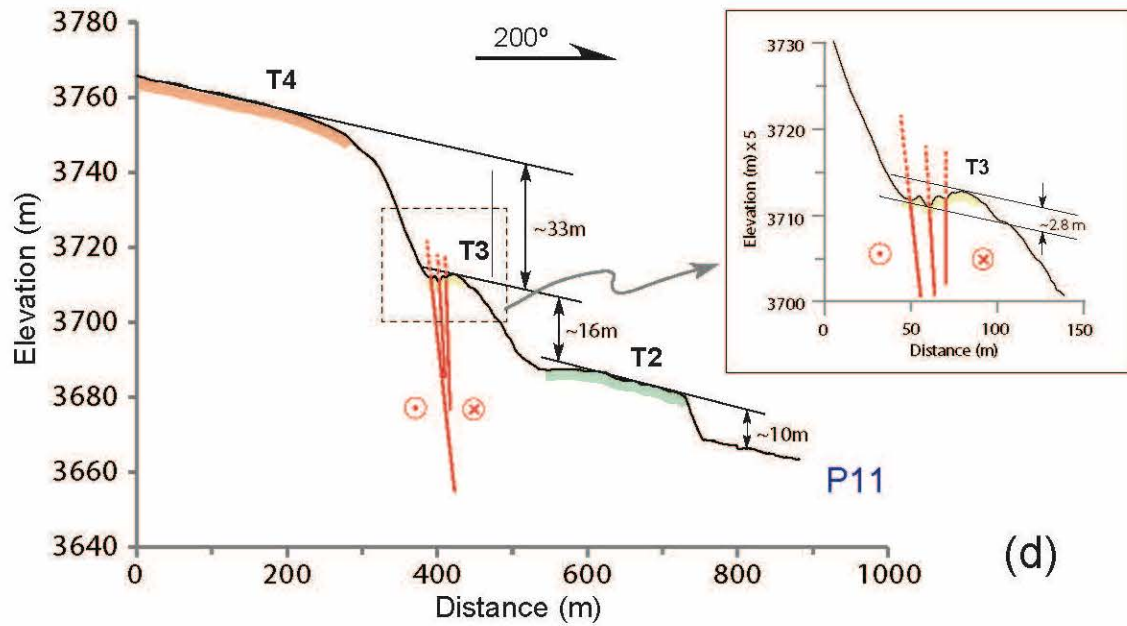
293 deposition. In addition, south of the fault trace, the T3'/T3 riser may have been degraded by the
294 passage and recent incision of the large, mountain-sourced gullies that cross obliquely westwards
295 most of the fan surfaces all the way to the Karakax river (Figs. S8 and S9). The fact that the
296 T3'/T3 riser offset (indistinguishable top and base, 255 ± 10 m) is the same as that of the base of
297 the T4/T3' riser, while their ages ought to be different, also poses problem. However, bearing in
298 mind that T4/T3' and T3/T2 reflect the two major fan depositional events, coeval with the
299 strongest glacial-interglacial transitions, the T3'/T3 offset value should nevertheless be taken
300 into account.

301 The largest possible offset of the T4/T3' riser top (496 ± 24 m) is comparable to that of the
302 southeasternmost T4 fan outer limit along the Karakax river ($\sim 500\pm 50$ m, Fig. 7a,b). That latter
303 offset, as reconstructed in Figure 7a, also realigns the T4/T3' riser top south of the fault with the
304 current eastern limit of the Taersa floodplain north of the fault (equivalent to the T0''/T0' riser),
305 which independently validates the inference made regarding the initial position of that riser. As
306 shown in Figure 7c,d, it is also possible to use 10 m-resolution, Tandem-X DEM data to assess in
307 section the reconstruction of the initial T4 fan geometry. The best reconstructed fan shape
308 corresponds to horizontal and vertical back-slip displacements of $\sim 500\pm 50$ m and $\sim 40\pm 10$ m,
309 respectively. Such a $\sim 500\pm 50$ m horizontal back-slip is the largest to still preserve a ~ 130 m-
310 wide passage for the Taersa tributary channel, broad-enough for it to flow between the T4W
311 upstream and T4E downstream risers at the time (206 ± 25 ka). This corroborates the inference
312 that, on both its west- and southeast-facing limits, the original geometry of the T4 fan since
313 abandonment has accrued approximately 500 m of sinistral offset along the KXF.

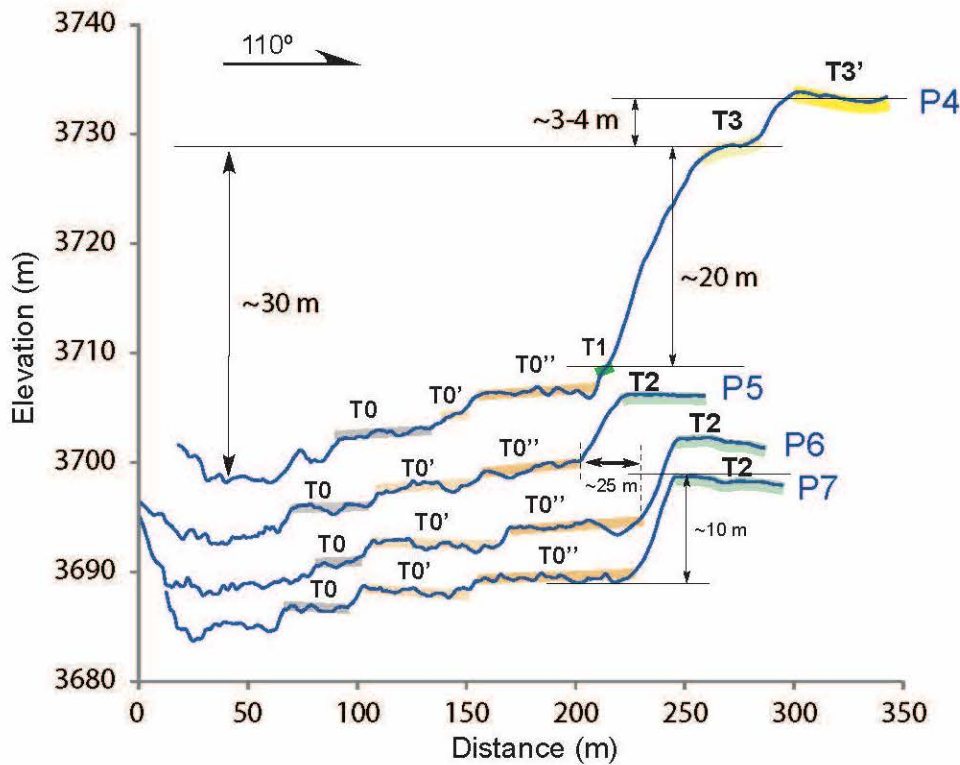
314 Lastly, it should be noted that the offset of the T3'/T3 riser at Taersa ($\sim 255 \pm 10$ m) is
315 commensurate with that of the corresponding Eemian T4 fan reconstruction (300 ± 20 m) at Site 4
316 in Peltzer et al. (2020) located 18 km to the east (Fig. 1b).

317





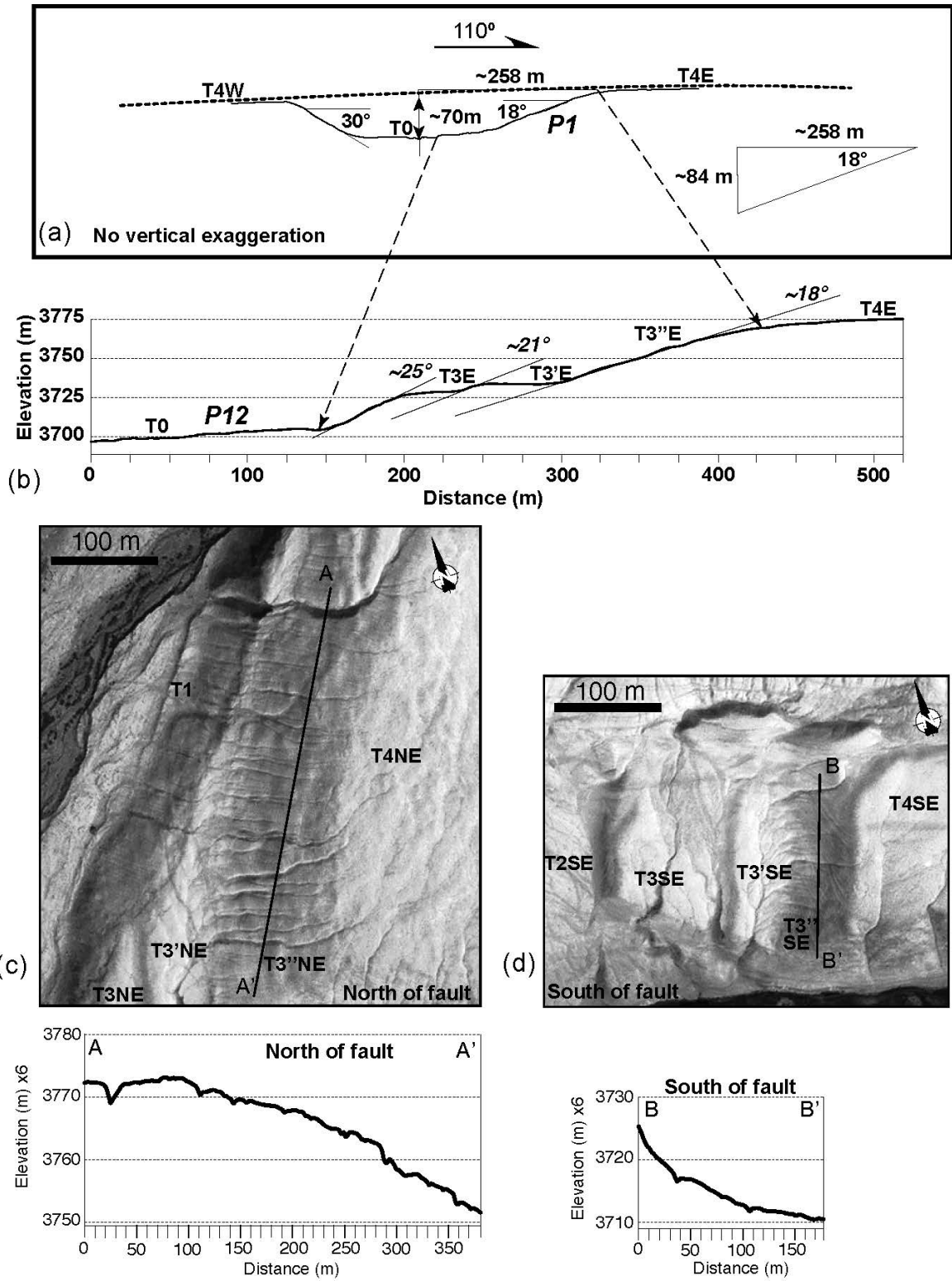
(d)



(e)

319
 320 **Figure 5.** (a) Annotated LiDAR DEM of Taersa fan and terrace surfaces with location of
 321 LiDAR-survey topographic profiles parallel (b and e) and perpendicular (c and d) to the
 322 Karakax fault (vertical exaggeration x5). Note convex-upwards shape of profiles parallel to fault
 323 (purple and green dashed lines), demonstrating fluvial fan origin of surfaces. Numbers indicate

324 *relative heights and distances between fan top (apex) and river bed (200 and 500 m), up- and*
325 *downstream from the fault, respectively. Maximum cumulative co-seismic offset on T0'' (~25 m)*
326 *is also indicated in (e). Note the uplifted, remnant shutter ridges (likely derived from the*
327 *displacement of T4) in c (P9) and d (P11). Profile P12 is shown in Figure 6b.*
328



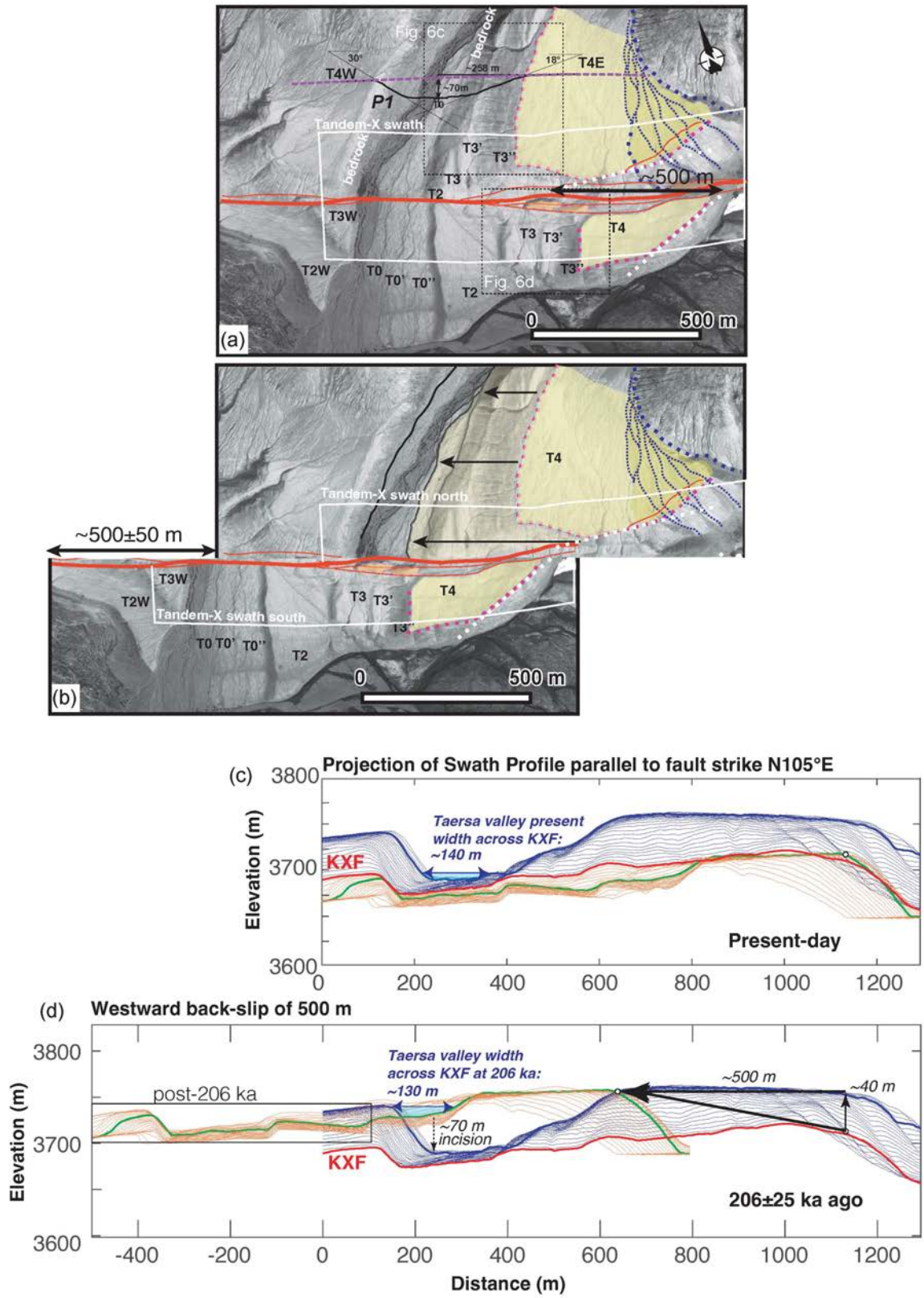
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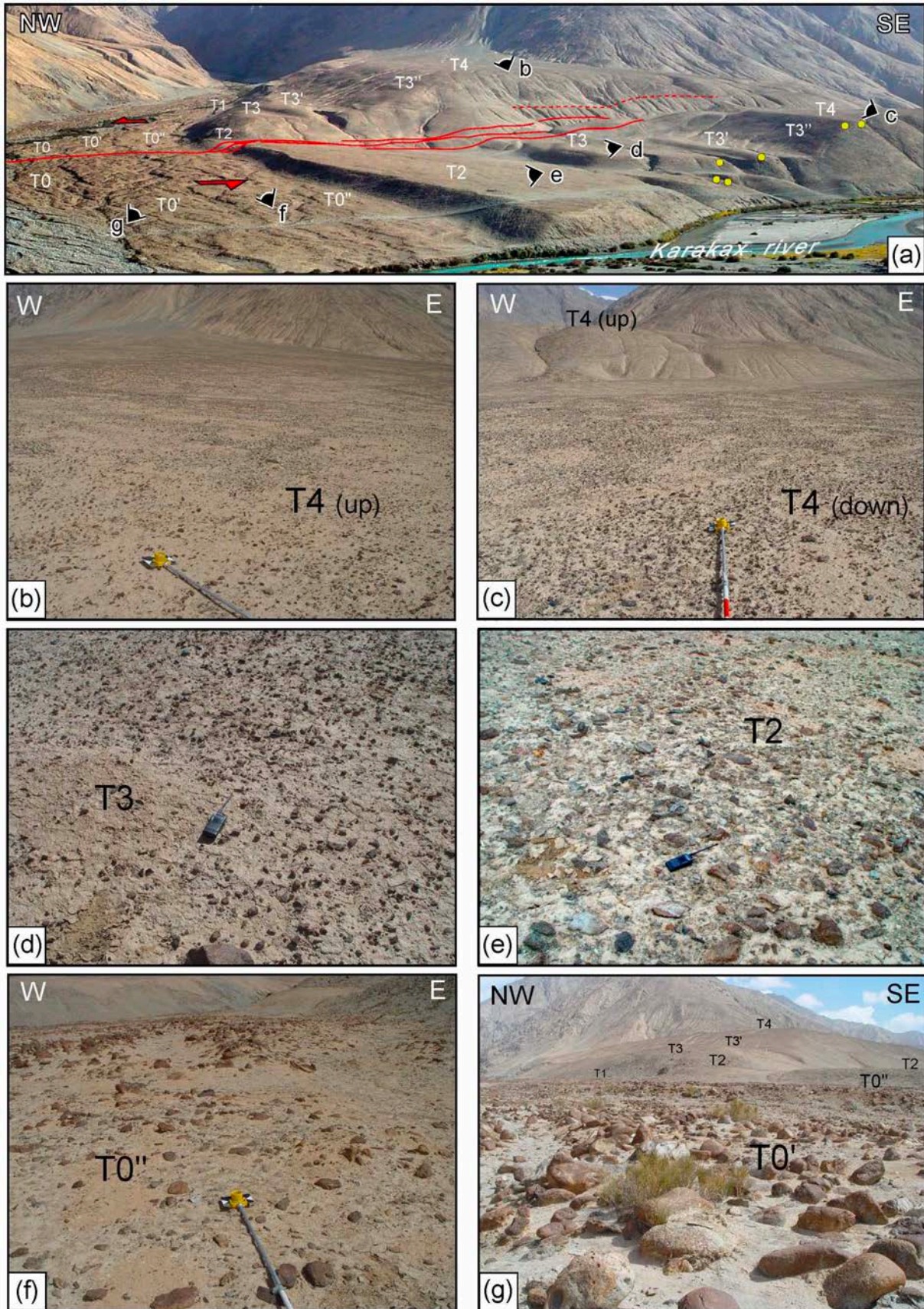
331

Figure 6. Morphology of the Taersa risers: (a) Profile P1 (see location in Fig. 5a) showing comparable elevations of T4E and T4W north of fault with incision depth of Taersa tributary,

332 *and average upstream valley slopes. (b) Higher resolution profile (P12 in Fig. 5a) showing step-*
333 *wise steepening (18 to 25°) of average riser slopes ($T4/T3'$, $T3'/T3$, $T3/T1$) as a function of*
334 *younger age. (c and d) Close-up of Ikonos image (see location in Fig. 7a) showing varying*
335 *degrees of rill incision on west-facing risers north and south of fault, respectively.*
336



338 **Figure 7.** Reconstruction of the complete sinistral offset of oldest T4 fan surface taking into
339 account normal component of uplift along left-lateral Karakax fault at Taersa site: (a) Ikonos
340 image-based interpretation of T4 fan surface (pale yellow) including younger drainages to the
341 east (on darker yellow fan). Position of profile in Figure 6a is indicated across upstream Taersa
342 valley. East-west elongated, orange hills along main KXF trace (red) are shutter ridges likely
343 derived from T4 (see also profiles in Fig. 5c,d). (b) Reconstruction of complete shape of T4 fan
344 before uplift of T4north and incision of Taersa tributary north of fault, consistent with a
345 $\sim 500 \pm 50$ m total offset of both western and southeastern edges of fan. See text for details. (c)
346 Projection, along KXF at Taersa, of 400 m-wide topographic profiles swath (20 south of fault,
347 red; 20 north of fault, blue) from Tandem-X DEM (vertical exaggeration x2). Red line is KXF
348 fault trace. Thick dark blue line is present envelope of highest surface (T4) across Taersa valley
349 (light blue shade) north of fault. Thick green line is present envelope of highest surfaces (T4-T3'-
350 T3) across Taersa valley south of fault. (d) Reconstruction of ~ 500 m westward back-slip (as in b)
351 of red profiles south of fault (vertical exaggeration x2). Note preservation of ~ 130 m-wide valley
352 width across fault at ~ 206 ka, similar to present valley width (~ 140 m). Black vectors to the right
353 indicate vertical and left-lateral offsets across KXF since 206 ka.



355 **Figure 8.** *Field photographs of Taersa fan and terrace surfaces (a) showing distinct cobble*
356 *sizes and surface roughness as a function of abandonment age north (b) and south (c-g) of the*
357 *fault. The younger the surface the larger and coarser the samples, as expected. Yellow circles*
358 *indicate locations of Optically Stimulated Luminescence (OSL) samples from Gong et al. (2017).*
359 *See text for discussion.*

360

361 4 ^{10}Be , ^{26}Al cosmogenic surface and depth profile dating of the alluvial

362 surfaces

363 The ages of the 35 samples dated on the alluvial surfaces along either sides of the fault and
364 Taersa tributary valley (Fig. 3c) are shown in Table 1 and plotted in Figure 9.

365 The youngest ^{26}Al age on T4 may be statistically rejected as a clear outlier, using Chauvenet
366 criterion, while the 13 remaining ages (12 ^{10}Be and one ^{26}Al on both T4E and T4W) range
367 between 162 and 245 ka, with an average of 206 ± 25 ka (1σ). This confirms that the highest T4
368 surfaces belong to the same large fan on both sides of the Taersa tributary. Note that the T4
369 alluvial surface dated at Taersa (the oldest age is 245 ± 16 ka) is amongst the oldest ever dated in
370 and along the margins of Tibet (e.g., Hetzel et al., 2002; Blisniuk and Sharp, 2003; Tao et al.,
371 2020). This attests that regional erosion of the surface tops is minimal, as previously suggested in
372 other areas of NE Tibet (e.g., Hetzel et al., 2002).

373 The two sample ages on T3' (191 and 215 ka) yield an average age of 203 ± 18 ka,
374 comparable to that of T4. The narrow widths of T3', at the base of the high T4/T3' risers that
375 bound the west sloping surfaces of T4 (Fig. 3c), suggest that both samples might have foundered
376 from T4, likely due to co-seismic shaking. High-resolution satellite images and broad-scale field
377 photograph (Fig. 8a) confirm that much of the T4/T3' riser slope is covered with large boulders
378 that have toppled down during rockfalls. This likely accounts for their apparently similar ages,
379 despite the large elevation difference (~ 43 -50 m north, and ~ 25 m south of the fault, Fig. 5b).

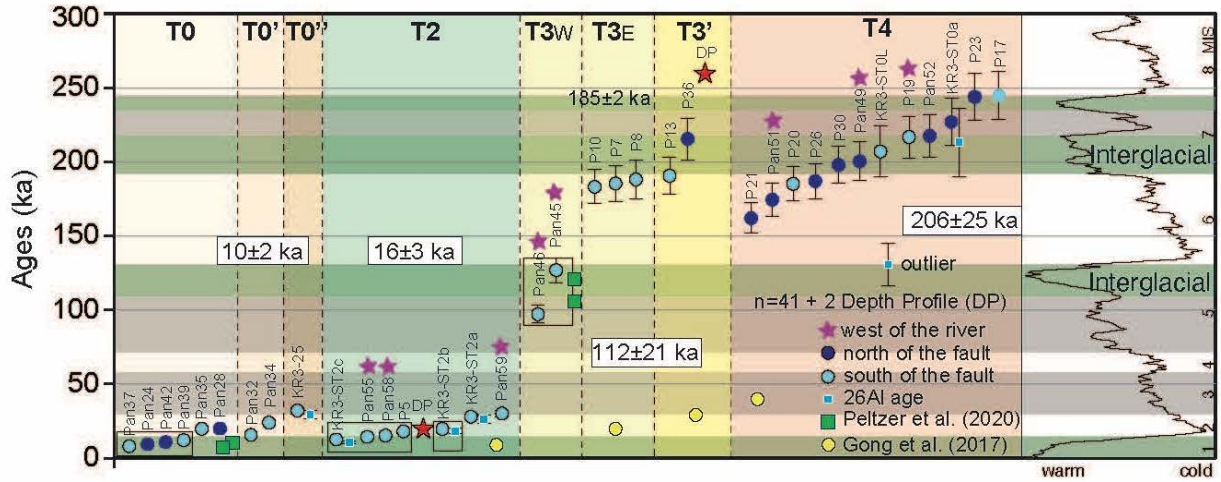
380 The age distribution on T3 is completely different east and west of the Taersa tributary (Fig. 9).
381 To the east, the concordant average ages of the three samples is 185 ± 2 ka, a value roughly
382 consistent with the average ages on T3' and T4. We thus infer that they were similarly
383 transported out of T4, likely along the large south-flowing gullies that drain it (Figs. S8 and S9).
384 To the west, by contrast, the two samples collected on the surface of the small remnant of T3,
385 which is separated from T4 by a ~ 2 - 3 m-deep sag along the fault (Figs. 3 and 5d), have much
386 younger ages (97 ± 6 and 127 ± 8 ka) (Fig. 9). Such ~ 100 ka-younger ages are consistent with the
387 elevation differences between T4 and T3 (~ 33 m, Fig. 5d), or T3 and T0 (~ 26 m, Fig. 5d) on the
388 Taersa tributary west bank. These ages are also similar to those found by Peltzer et al. (2020) on
389 their highest surfaces (T4) ~ 30 m above the local tributary at their Site 4. Hence, although we
390 have only two in situ ages for now, we infer that the average age (112 ± 21 ka) of our two samples
391 on T3W represents the actual age of the Taersa T3-T3' surfaces. At a more detailed level, one
392 might further hypothesize that the small, ~ 3 - 5 m-high riser between T3 and T3' east of the
393 Taersa tributary corresponds to that observed by Peltzer et al. (2020)'s between their T3 and T4
394 surfaces at their Site 4. In that case, the T3 and T3' fan surfaces at Taersa would be even closer
395 in age (97 ± 6 and 127 ± 8 ka) with those dated farther east ($\sim 95.9\pm 2.8$ and 112.9 ± 6.5 ka). It is
396 clear, however, that additional sampling would be needed to confirm that inference.

397 At the level of T3' north of the KXF, one depth profile was retrieved from a refreshed riser
398 in a deep incision that reaches the top of T4 (Figs. 3c and S7). Four individual cobbles collected
399 between 55 and 120 cm-depths yield consistent ^{10}Be and ^{26}Al model ages of ~ 260 and ~ 256 ka
400 (Fig. 10). Such ages, however, are ~ 50 ka older than the average age (~ 206 ka) of the T4 surface
401 above, which is stratigraphically puzzling. They might be interpreted to date reworked colluvium

402 derived from the erosion of surfaces higher than T4, upstream along the Taersa tributary. In any
403 case, these old ‘inherited’ ages must predate the abandonment of either T3’ or T4.

404 On T2, which is well-preserved only south of the fault, ten surface sample ages (seven ^{10}Be
405 and three ^{26}Al) fall between 11 and 30 ka, with an average age of 19 ± 7 ka. Three ages ($\sim 28\pm 2$ ka
406 on average), are significantly older, by ~ 10 ka, than the majority of the seven others (average of
407 16 ± 3 ka). One depth profile in the refreshed eastern T2/T0’’ riser (Fig. S5) yields model ^{10}Be and
408 ^{26}Al surface ages between 11 and 20 ka (average of 15.5 ± 4.5 ka), after rejection of two clear
409 outliers (Fig. 10). Such concordant ages confirm that T2, which fans out of the Taersa gorge into
410 the Karakax valley, is best interpreted as a fan-shaped fill terrace, resulting from post-glacial
411 melting.

412 The morphologies of the lowest terraces (T0-T0’-T0’’), that stand 10 m below T2 but only
413 1-2 m above each other and the present-day river bed, are similar, with remarkably well-
414 preserved braided channels (Figs. 3d,e, 5e and S7b). They must therefore be significantly
415 younger than T2 (~ 16 ka). The unique sample on T0’’, with ages of 32 ka (^{10}Be) and 29 ka (^{26}Al)
416 (average of 31 ± 2 ka) must thus be an outlier derived from erosion of T2. Likewise, the two ^{10}Be
417 samples on T0’ (16 and 24 ka with an average of 20 ± 6 ka) must also be outliers derived from T2.
418 Finally, the six samples on T0 include two ~ 20 ka and four 10 ± 2 ka ages, consistent with
419 inheritance of the two older cobbles, while the youngest majority reflects T0’s actual Holocene
420 age.



421
 422 **Figure 9.** Ages at the Taersa site. ^{10}Be and ^{26}Al surface-exposure cosmogenic ages (numbered
 423 as in Fig. 3c,e and Table 1) using the Lifton et al. (2014) 'LSDn' model in CRONUS version 3,
 424 with 1σ uncertainties. Ages in white boxes are average of all individual ages for T4, and average
 425 of ages in thin black boxes for T3W, T2 and T0. Green squares refer to ages from Site 4 in
 426 Peltzer et al. (2020) (location in Fig. 1b). Yellow circles are OSL ages from Gong et al. (2017).
 427 Right panel shows global climatic proxy curve of Lisiecki and Raymo (2005), with grey-shaded
 428 sectors indicating Marine oxygen Isotope Stages (MIS) 1 to 8. Green bands are interglacial
 429 periods, during which glaciers melt coeval with deposition of large alluvial fans and terraces.
 430 See text for details.

431
 432 **Table 1:** Analytical results of ^{10}Be and ^{26}Al geochronology and surface-exposure model ages at
 433 Taersa site along Karakax fault.

Surface	Sample name	Lat (N)	Long (E)	Elev (m)	Depth (cm)	Quartz (g)	Be carrier (mg)	Al carrier (mg)	$^{10}\text{Be}/^{26}\text{Al}^{27}$ (10^{-15})	^{10}Be (10^6 atom/g)	^{26}Al (10^6 atom/g)	Lm (+ ext. uncert.)	LSDn (+ ext. uncert.)	(int. Uncert.)	(int. Uncert.)
T0SE	KXW-Pan 39*	36.33562	78.08641	3711	0	20.4503	0.3464	/	450±8	0.509±0.009	/	12155±945	237	12155±758	237
	KXW-Pan 35*	36.3352	78.0863	3707	0	20.050	0.3461	/	783±10	0.903±0.012	/	20261±1555	279	19751±1204	272
	KXW-Pan 37*	36.33505	78.0863	3706	0	20.112	0.3465	/	276±7	0.318±0.008	/	7908±628	201	8059±519	205
T0NE	KXW-Pan 24**	36.33717	78.08839	3729	0	26.138	0.3799	/	379±12	0.368±0.012	/	9138±750	299	9366±633	307
	KXW-Pan 28**	36.33619	78.08708	3720	0	25.267	0.3774	/	919±26	0.917±0.026	/	20414±1651	592	19881±1314	577
	KXW-Pan 42**	36.33612	78.08694	3719	0	24.964	0.3796	/	421±14	0.428±0.014	/	10524±871	361	10716±733	368
T0'SE	KXW-Pan 32*	36.33569	78.08686	3716	0	20.130	0.3464	/	614±8	0.706±0.009	/	16066±1232	224	15737±959	219

	KXW- Pan 34*	36.33534	78.08664	3710	0	20.101	0.3455	/	991± 14	/	1.138±0.016	/	24867±1914	355	23934±1464	342	
	KR3-25								921±								
T0'SE	\$	36.33441	78.08694	3710	0	15.008	0.4259	/	17	/	1.79±0.049	/	33792±2731	941	32046±2109	892	
									2.2233	/	2815± 106	/	9.639 ±0.37 2	26Al: 29973±3099	1177	26Al: 29475±2826	1157
T2SE	KXW- P5**	36.33336	78.0889	3714	0	25.657	0.3801	/	824± 19	/	0.816±0.019	/	18407±1457	440	17994±1151	430	
	KR3- ST2-a	\$ 36.33433	78.08817	3710	0	15.848	0.4395	/	841± 16	/	1.56±0.044	/	29182±2359	824	27902±1839	787	
									2.1199	/	2745± 89	/	8.518 ±0.35 9	26Al: 26577±2780	1137	26Al: 26195±2547	1121
	KR3- ST2-b	\$ 36.33433	78.08817	3710	0	15.183	0.4376	/	540± 11	/	1.041±0.029	/	20158±1625	569	19655±1292	555	
									7.7873		473±2 5	/	5.635 ±0.29 9	26Al: 18274±1993	979	26Al: 18406±1879	986
	KR3- ST2-c	\$ 36.33433	78.08817	3710	0	15.154	0.4361	/	320± 6	/	0.616±0.018	/	12618±1016	360	12583±827	359	
									2.5932	/	716±3 3	/	2.841 ±0.14 8	26Al: 10096±1091	529	26Al:10588±1071	555
DP T2	KR3-3	\$ 36.33433	78.08817	3710	50	15.006	0.4364	2.6239	1027 ±20	2614± 95	1.998±0.056						
	KR3-12	\$ 36.33433	79.08817	3710	106	15.126	0.6625	1.1776	312± 11	2565± 112	0.916±0.037						
	KR3-13	\$ 36.33433	80.08817	3710	110	15.106	0.6573	2.4222	372±2 87±4	4	0.254±0.013						
	KR3-18	\$ 36.33433	81.08817	3710	130	15.389	0.6546	2.0230	286±3 53±2	1	0.15±0.007						
	KR3-20	\$ 36.33433	82.08817	3710	140	13.499	0.4570	0.9900	714±4 92±3	1	0.208±0.008						
T2SW	KXW- P5**	36.33561	78.08362	3705	0	25.572	0.3786	/	640± 20	/	0.633±0.02	/	14634±1202	477	14405±975	470	
	KXW- P5**	36.33506	78.08346	3699	0	27.118	0.3784	/	726± 23	/	0.677±0.021	/	15577±1279	506	15292±1034	497	
	KXW- P5**	36.33455	78.08461	3703	0	25.830	0.3783	/	1493 ±47	/	1.461±0.046	/	31770±2615	1019	30135±2039	966	
T3SE	KXW- P8**	36.33362	78.09042	3717	0	6.862	0.3734	/	2535 ±75	/	9.221±0.275	/	199175±17190	6351	188071±13245	5975	
T3SE	KXW- P7**	36.33354	78.09035	3716	0	20.886	0.2935	/	9683 ±176	/	9.118±0.166	/	195720±16139	3812	185330±12184	3597	
T3SE	KXW- P10*	36.33332	78.09059	3714	0	20.008	0.3277	/	8148 ±54	/	8.917±0.059	/	193279±15530	1376	183143±11565	1300	
T3SW	KXW- Pan 46*	36.33608	78.08486	3724	0	20.106	0.3461	/	4079 ±23	/	4.692±0.026	/	101486±7897	596	97092±5945	570	
T3SW	KXW- Pan 45**	36.33597	78.08498	3721	0	16.5205	0.3794	/	4126 ±96	/	6.331±0.1476	/	135174±11109	3298	126805±8394	3085	
T3'SE	KXW- P13**	36.33289	78.09108	3711	0	22.405	0.3793	/	8259 ±111	/	9.343±0.125	/	202703±16535	2920	190625±12299	2735	
T3'NE	KXW- P36**	36.33745	78.09018	3758	0	25.269	0.3797	/	1086 1±14	/	10.905±0.142	/	232977±19185	3293	215461±14000	3028	
DP T3'	KR3-29	\$ 36.33921	78.09165	3770	55	12.7368	0.3639	2.1456	4331 ±58	10441 ±361	8.279±0.199						
	KR3-31	\$ 36.33921	79.09165	3770	100	35.0026	0.4584	1.7434	5883 ±84	25547 ±771	5.155±0.127						
	KR3-33	\$ 36.33921	80.09165	3770	110	20.8226	0.3026	2.0375	3820 ±74	8206± 235	3.715±0.103						
	KR3-34	\$ 36.33921	81.09165	3770	120	24.5691	0.2943	5.9325	4910 3497±	3.935±0.129	19.33						

	§								±128	112		5±0.6					
												27					
T4SE	KXW-P20*	36.33283	78.09419	3740	0	20.372	0.3272	/	8540	/	9.165±0.063	/	195637±15738	1455	185071±11701	1371	
	KXW-P17**	36.33317	78.09257	3733	0	25.926	0.3796	/	1231	/	12.046±0.161	/	263775±21969	3870	244714±16081	3567	
	KXW-P19**	36.33271	78.09392	3736	0	25.267	0.3794	/	4±16	/	10.82±0.145	/	234059±19299	3411	216647±14103	3139	
	KR3-STOL §	see map	see map	3740	0	15.110	0.4376	/	1078	/	11.998±0.596	/	222489±21572	11912	206956±17113	11022	
									6192								
									±281								
									2.3834	/			43.57				
									11867	/			2±2.3		26Al:		Al26:
									±519	/			76	135936±15988	8022	130901±14384	7702
T4NE	KR3-ST0a §	see map	see map	3790	0	15.001	0.4363	/	6927	/	13.482±0.373	/	245894±21358	7397	226885±15962	6781	
									2.3458	/			71.05				
									19579	/			2±2.9		26Al:		26Al:
									±511	/			34	223583±26172	10525	213150±23039	9972
	KXW-P30*	36.3356	78.09543	3786	0	20.265	0.3288	/	9412	/	10.206±0.07	/	213090±17244	1591	197897±12566	1470	
	KXW-P21**	36.3347	78.09499	3771	0	24.5581	0.379	/	7936	/	8.185±0.1112	/	173423±14011	2497	161960±10354	2323	
	KXW-P23**	36.33473	78.09479	3771	0	24.965	0.3797	/	1208	/	12.276±0.159	/	263360±21912	3751	243802±15993	3449	
	KXW-P26**	36.33454	78.09664	3748	0	26.150	0.3791	/	0±15	/	9.326±0.123	/	198063±16122	2794	186999±12039	2628	
	KXW-Pan 52**	36.33884	78.08673	3776	0	26.497	0.3796	/	9626	/	11.119±0.199	/	235556±19665	4571	217467±14428	4194	
	KXW-Pan 49**	36.33823	78.08601	3769	0	17.922	0.2912	/	1161	/	10.299±0.166	/	215554±17790	3754	200287±13112	3470	
	KXW-Pan 51**	36.33906	78.08698	3778	0	18.749	0.2906	/	6±20	/	8.856±0.145	/	185259±15142	3242	174411±11330	3041	

Samples “*” and “**” were collected in 2011 and processed at Stanford University's cosmogenic facility and samples “§” were collected in 1995 and processed and measured at Center for Accelerator Mass Spectrometer (CAMS) at Lawrence Livermore National Laboratory (LLNL).

¹⁰Be/⁹Be ratios “*” were measured at CAMS at LLNL and ¹⁰Be/⁹Be ratios “**” measured at ASTER (CEREGE).

Ages calculated with the CRONUS 3 calculator (Balco et al., 2008). Lm= Lal (1991)/Stone (2000) time-dependent production rate model. LSDn = Lifton et al. (2014) model ages discussed in text.

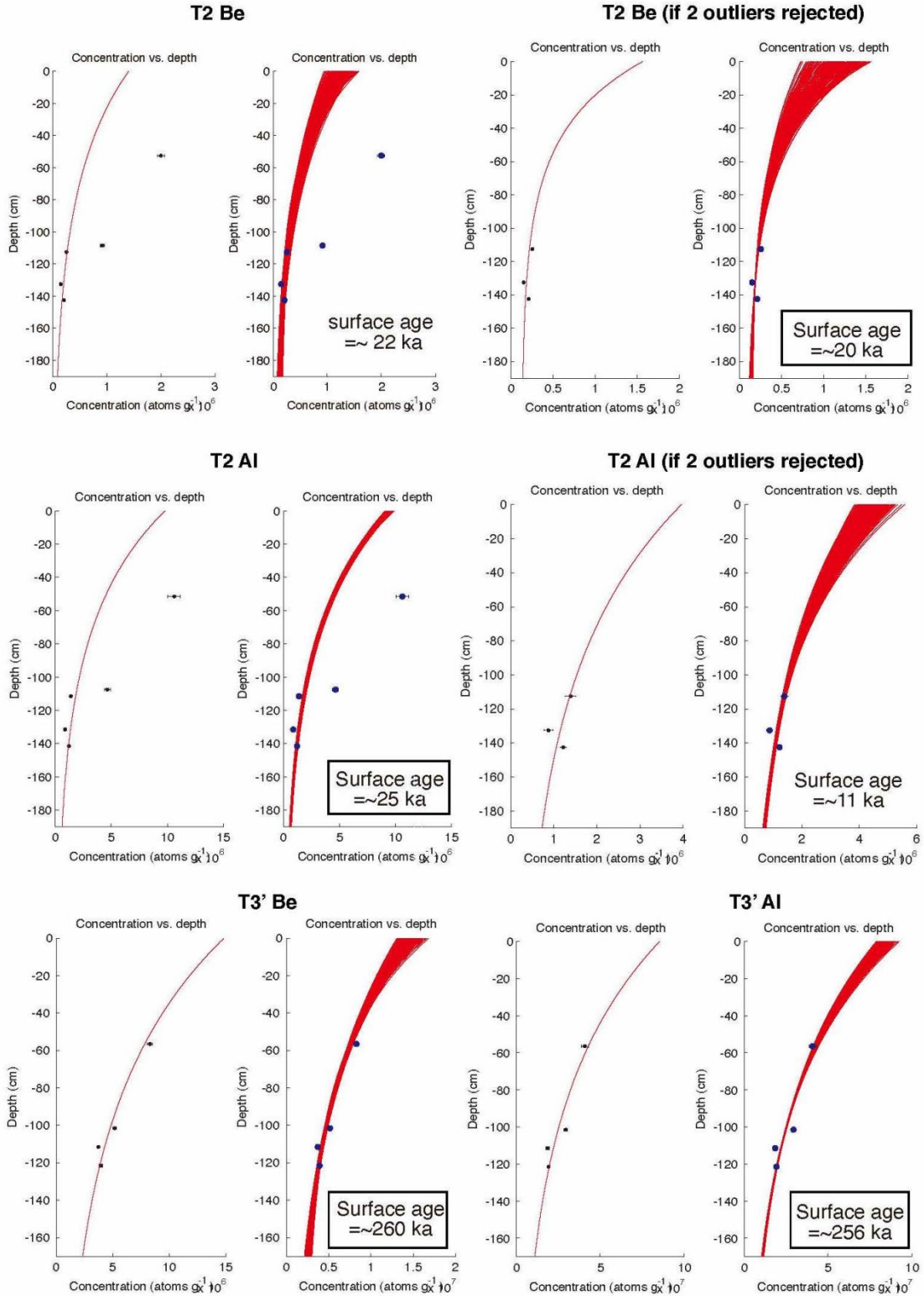
“See map” refers to Figure 3c, because no exact GPS location was measured in the field.

Shielding factor is 0.98; Sample density is 2.65 g/cm³ (all samples are quartzite). Thickness was taken as 5 cm.

Standard used at CAMS for samples “*” is 07KNSTD with ¹⁰Be isotope ratios = 2.85x10⁻¹². For samples “§” standard is LLNL3000 with ¹⁰Be isotope ratios = 3x10⁻¹². KNSTD is the standard for Al samples.

Standard used at ASTER is NIST SRM4325 (=NIST_27900) with ¹⁰Be isotope ratios = 2.79x10⁻¹¹, equivalent to 07KNSTD.

ext. (int.) Uncert. = external (internal) uncertainty



435

436 **Figure 10.** Depth profile (photos in Figs. S5 and S7) results using the Hidy et al. (2010)
 437 software. Model surface ages consistent with ^{10}Be and ^{26}Al concentrations for T2 and T3' depth
 438 profile samples, with or without outliers, are indicated.

439

440 **5 Interpretation and discussion**

441 **5.1 Correlation of terrace ages with climate**

442 Whether a stream can transport sediments (hence emplace fans) or incise along its channel
443 (hence abandon terraces) is highly dependent on climate (e.g., Whipple and Tucker, 1999;
444 Mériaux et al., 2012). Typically, during glacial periods, stream power and sediment load are
445 limited, thus unfavorable to fan deposition. Glacier melting at the beginning of interglacials, due
446 to warmer climate, causes rapid increase of stream power and sediment transport, which in turn
447 promotes fill terrace aggradation and broad fan deposition. Conversely, it is well-established that
448 at the end of the warm and humid early Holocene Climatic Optimum (HCO, ~10 to ~5 ka),
449 coeval with lake high-stands on the Tibetan plateau (Gasse et al., 1991), a shift to drier climate
450 led to generally renewed river incision, terrace abandonment and lake level drop throughout
451 North-Africa, Eurasia and Tibet (e.g., Gasse et al., 1990; Avouac et al., 1996; Brown et al., 2003;
452 Li et al., 2005; Van Der Woerd et al., 2002).

453 The four main surface age groups we obtain, 206 ± 25 ka for T4, 112 ± 21 ka for T3-T3' (or
454 ~96 ka for T3 and ~113 ka for T3'), 16 ± 3 ka for T2 and 10 ± 2 ka for T0s, correlate well with the
455 last four warm climatic periods at ~200 ka (MIS-7 interglacial), ~115 ka (Eemian interglacial),
456 ~16 ka (post-Last Glacial Maximum, MIS-2, melting), and ~10 ka (Holocene interglacial) (green
457 bands in Fig. 9). The Eemian and Holocene ages we obtain at Taersa are similar, within
458 uncertainty, to the ^{10}Be ages (~110 and 11 ka) found 18 km to the east, north of the Karakax
459 river by Peltzer et al. (2020) (their Site 4: large fan offsets first identified by Peltzer et al., 1989).
460 Likewise, within uncertainty, our youngest terrace ages are consistent with the OSL

461 abandonment age ($\sim 9 \pm 1$ ka) they found ~ 10 km west of Taersa (Fig. 1b) for one offset terrace
462 (~ 10 m above present fluvial channel, their Site 1) of a southern tributary of the Karakax river.

463 The Taersa site, however, uniquely preserves the oldest (~ 210 ka) and highest (> 110 m above
464 the Karakax river) conical fan surface dated thus far along the Karakax valley, and possibly for
465 now within the northern Tibet Plateau. Consequently, it is possibly also the only site where the
466 largest horizontal and vertical cumulative offsets are preserved along the KXF.

467

468 **5.2 Fault slip rates since ~ 210 ka**

469 Combining alluvial surface abandonment ages and riser offsets provides bounds on slip rates
470 over a ~ 210 ka-long timescale. Matching the T4 abandonment age (206 ± 25 ka) with the total
471 offsets of the current T4 southeastern limit and the inferred western T4 riser top ($\sim 500 \pm 50$ and
472 496 ± 24 m, respectively) yields $2.4(+0.4/-0.3)$ mm/yr (Figs. 3c, 7, 11a and Table 2). Combining
473 the T4/T3' current riser base offset (255 ± 10 m) with the inferred oldest age of T3' east (127 ± 8 ka
474 based on that on T3 west) yields a minimum rate of $2.0(+0.2/-0.1)$ mm/yr. Taking the inferred
475 youngest age of T3 east (97 ± 6 ka based on that on T3 west) with the current offset (255 ± 5 m) of
476 the T3'/T3 riser base yields 2.6 ± 0.2 mm/yr. Matching the offset of the current T3/T2 western
477 riser base (200 ± 20 m) with the inferred youngest 97 ± 6 ka age of T3 yields $2.1(+0.3/-0.2)$ mm/yr
478 (Figs. 3c, 11a, S6 and Table 2). Lastly, we take the age of the 22.9 ± 1.5 m offset of the base of
479 the T2/T0' riser (Figs. 3e, S4 and S6), that necessarily postdates the total incision (10 m) of T2
480 (abandoned after 16 ± 3 ka) by the Holocene Taersa tributary, to be 10 ± 2 ka, which is consistent
481 with a slip rate of $2.3(+0.6/-0.4)$ mm/yr (Figs. 11a,b, S6 and Table 2). The normal throw
482 component across the fault at Taersa may also be estimated using the vertical offsets of T4 and
483 T3' (Fig. 5c). The ~ 28 m offset of T4 implies a throw rate of 0.14 ± 0.2 mm/yr, while the 12 and

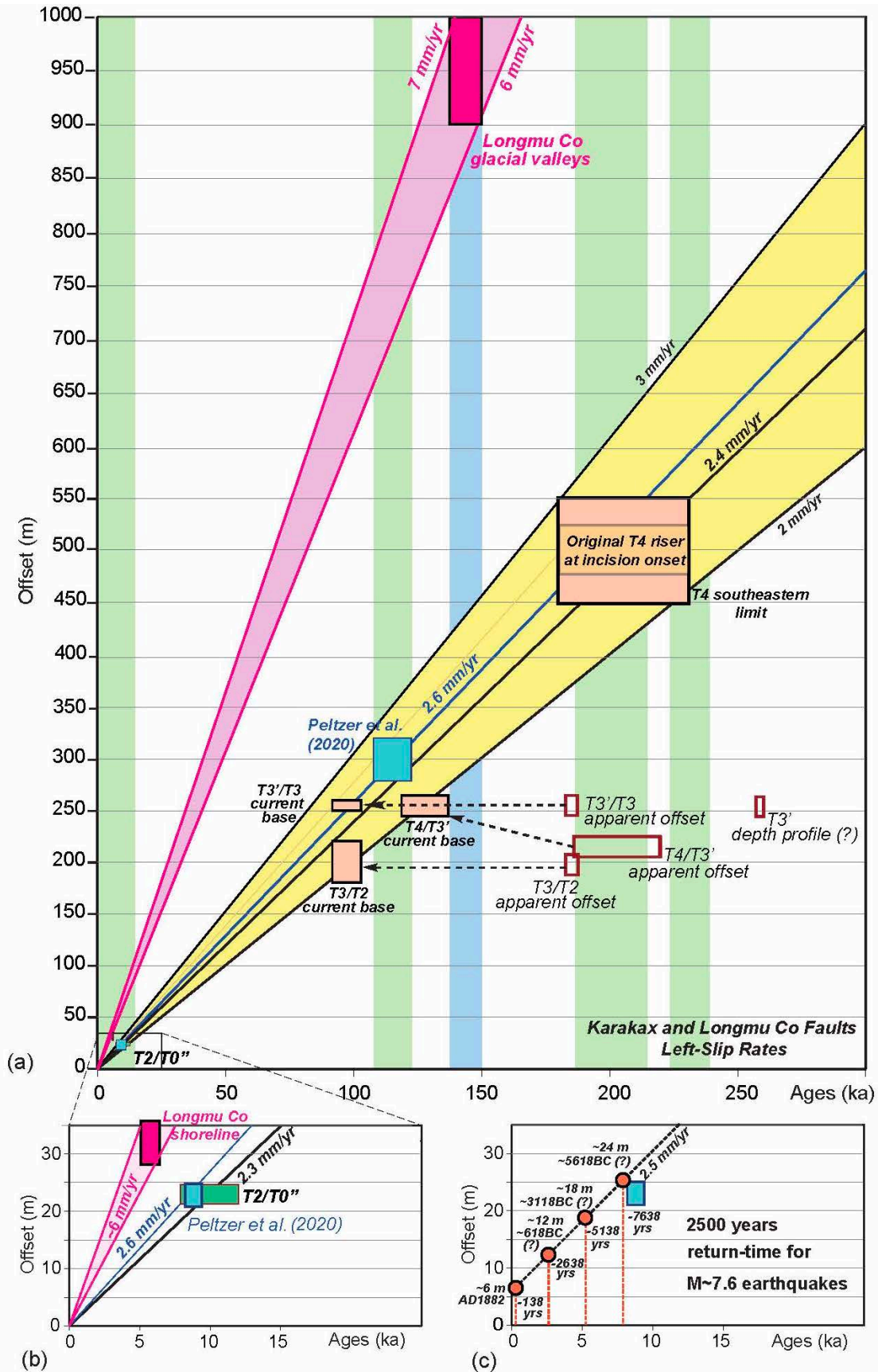
484 10 m vertical offsets of T3' and T3, respectively, are consistent with a throw rate of 0.1 ± 0.01
 485 mm/yr.

486

487 **Table 2.** Summary of offsets, ages and slip rates at Taersa.

	Offsets (m)	Ages (ka)	Slip rate (mm/yr)
T4 southeastern limit	500±50	206±25	2.4(+0.4/-0.3)
Original T4 riser at incision onset	496±24	206±25	2.4(+0.4/-0.3)
T4/T3' current base	255±10	127±8	2.0(+0.2/-0.1)
T3'/T3 current base	255±5	97±6	2.6±0.2
T3/T2 current base	200±20	97±6	2.1(+0.3/0.2)
T2/T0'' current base	22.9±1.5	10±2	2.3(+0.6/-0.4)
T0''/T0'	17.8±1.5	<10±2	2-3
T0'/T0	12.8±2.5	<10±2	2-3
T0/river bed	5.9±0.5	1882 AD	n/a

488



490 **Figure 11.** Slip rates on Karakax and Longmu Co faults. (a) Late Quaternary slip rates derived
491 from offset/age relationships. Dashed black arrows indicate most plausible shifts of offset and
492 ages of risers east of Taersa tributary based on T3 ages west of tributary (see text for details).
493 Green bands are interglacial periods as in Figure 9, blue band is coldest glacial within MIS-6.
494 See text for details. (b) Zoom on youngest terrace age range, including Peltzer et al. (2020)
495 result. (c) Inferred large earthquakes return times consistent with simplified characteristic co-
496 seismic slip (~6 m) and constant Holocene ~2.5 mm/yr slip rate.

497

498 Overall, the above left-lateral rates (Table 2) range between extreme values of 1.9 and 2.9
499 mm/yr, hence a most likely long-term average between 2 and 3 mm/yr (Fig. 11a). Within ~20%
500 uncertainty (0.4 to 0.6 mm/yr), these rates appear to have been constant over a much longer
501 timescale (~210 ka), ~100 ka older than that documented so far. They compare well with the
502 2.6 ± 0.5 mm/yr rate recently determined by Peltzer et al. (2020) in the last ~115 ka. Locally, the
503 total Taersa long-term rates include a vertical component (~0.1 mm/yr) that absorbs some
504 cumulative displacement. Additionally, faulting along the southern side of the pull-apart sag
505 within the Karakax valley (Fig. 2) may contribute to increase slightly the total Taersa slip rate.

506 Such consistent, ~2.5 mm/yr average rate values at three sites over a ~35 km-long stretch of
507 the fault suggest that previous estimates of rates 2 to 3 times faster (6-9 mm/yr), may have been
508 biased. Li et al.'s (2012) estimate (6-7 mm/yr) was based on just one ^{14}C date (975-1020 AD) in
509 one trench west of Taersa with no *in situ* horizontal offset measurement (Fig. 2). Gong et al.'s
510 (2017) rate (7.8 ± 1.6 mm/yr) was derived from the OSL dating of six, reportedly fluvial, sand
511 samples (39.7 \pm 2.5 ka for T4 [their T5], 28.5 \pm 1.7 ka for T3' [their T4], 21.2 \pm 1.2 ka for T3 and
512 14.5 \pm 1.0 ka for T2) retrieved from the very top of unstable, south-facing risers, likely still
513 retreating and affected by steady, long-term rejuvenation due to ongoing erosion by the Karakax
514 river (Fig. 8a). In fact, more importantly, since the depth of these OSL samples is very shallow

515 (15-45 cm, Gong et al., 2017), and their ages much younger than those we obtain on all the
516 relevant surfaces (Fig. 9), we suspect that the deposits they dated may include loess windblown
517 atop the terrace surfaces much later than their fluvial abandonment ages.

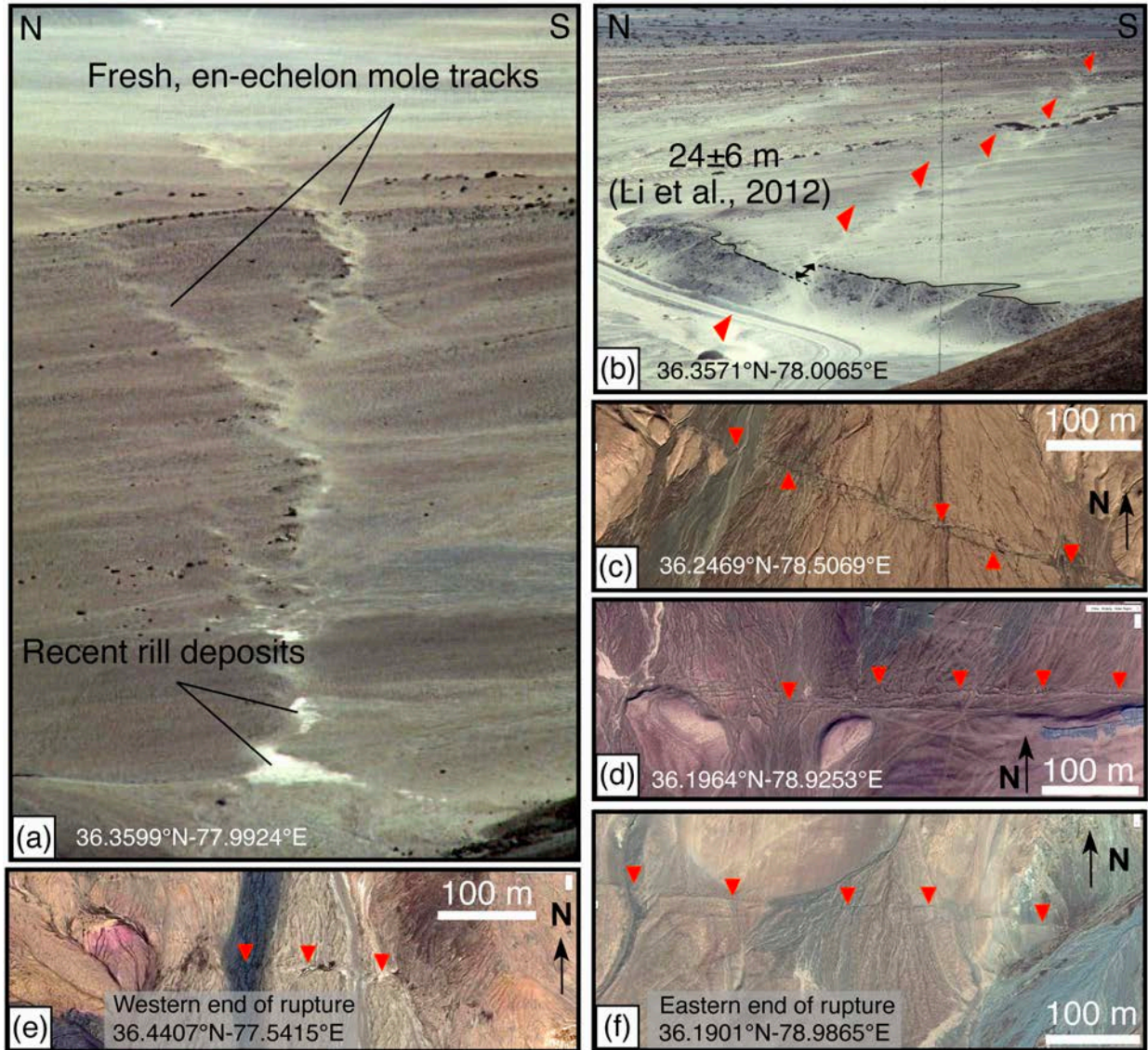
518

519 **5.3 Regular recurrence times of comparably large earthquakes along the** 520 **Karakax fault**

521 In the last 150 years, seven large ($M \geq 7$) earthquakes have struck the broad region
522 surrounding the West Kunlun range and western branches of the Altyn Tagh fault (ATF) (Figs. 1
523 and 13) (SBX, 1997). The most recent (M_w 6.9, 2014 and M_w 7.2, 2008 Yutian earthquakes)
524 ruptured the Ashikule left-lateral fault (Li et al., 2016) and the West Pingding normal fault (e.g.,
525 Xu et al., 2013), within the transition zone between the ATF and the Longmu-Gozha Co fault
526 (LGCF). Another event (M_s 6.9 in 1996) ruptured a poorly studied, probably ~EW-striking fault
527 within the Tianshuihai block, with a debated left-lateral or thrust mechanism (USGS; Ma et al.,
528 1997). One century ago, in 1924, two events with estimated magnitudes of 7.2 and 7.5 (Chen,
529 1988) likely ruptured segments or splays of the western ATF east of Minfeng. Even earlier on, in
530 1882 and 1889, two large earthquakes are reported to have been strongly felt in Hotan and
531 Yecheng, respectively (Nikonov, 1975; Ma, 1989; Avouac and Peltzer, 1993). Since little is
532 known about these two events, however, doubts have been raised on their existence or location
533 (Yang et al., 1991).

534 Yet, during our field work across the region, we found only one large, fresh surface rupture
535 along faults in the West Kunlun range south of Hotan and Yecheng (Fig. 12). In the field and on
536 high-resolution satellite images, this rupture (yellow swath in Fig. 1b) may be followed
537 continuously for ~150 km, from ~77.5°E to 79°E. Where the fault is single-stranded, field

538 measurements imply an average left-lateral co-seismic displacement of 6 ± 1 m (Li et al., 2012).
539 The facts that this rupture displays well-preserved, ~ 1.5 m-high, free-faces and en-echelon mole
540 tracks across the Sanshili and other fans (Li et al., 2012), that it affects the most recent terraces,
541 and that it is still visible across some of the floodplains of the Karakax tributaries (Fig. 12), are in
542 keeping with the inference that it is less than 200 years old. The measured rupture length and slip
543 amount are consistent with a magnitude $M7.6$ ($M=5.08+1.16*\log[\text{surface rupture length}=150 \text{ km}]$
544 or $M=6.93+0.82*\log[\text{average displacement}=6 \text{ m}]$, Wells and Coppersmith, 1994). Hence, as
545 inferred by Avouac and Peltzer (1993), we conclude that this rupture is most likely that of the
546 1882 Hotan earthquake (Fig. 1b).
547



548

549 **Figure 12.** Fresh surface rupture of 1882 earthquake (see image locations in Fig. 1b). (a)
 550 Field photograph (P. Tapponnier, 1989) of en-echelon, right-stepping scarps across fan south of
 551 Karakax river, west of Sanshili. Note slight vertical offset north of rupture and fresh white
 552 pluvial deposits dammed by scarp. (b) Field photograph of offset, western riser of Sanshili fan
 553 ($\sim 24 \pm 6$ m) and fresh surface rupture across fan surface. Note again slight vertical offset north of
 554 fault trace. (c and d) Maxar satellite images of fresh seismic rupture across recent Karakax
 555 tributary alluvial surfaces and active seasonal streams. (e and f) Deep open cracks close to
 556 western and eastern terminations of ~ 150 km-long, 1882 surface rupture, respectively.

557

558 Finally, the epicenters of one historical event and one recent earthquake both lie in the SW
559 Tarim basin, just north of the West Kunlun range. The 2015, Mw 6.4 Pishan earthquake ruptured
560 a blind, south-dipping thrust west of Hotan (Fig. 1a) (e.g., Lu et al., 2016; Wen et al., 2016;
561 Guilbaud et al., 2017; Laborde et al., 2019). The poorly documented, possibly larger, 1889 event,
562 tentatively located near Yecheng, might also have ruptured a blind thrust in the Kunlun foreland,
563 south of the emergent, active Mazartagh thrust ramp (Fig. 13a).

564 The large 1882 Karakax surface break appears to be the latest in a sequence of similar
565 ruptures with comparable amounts of co-seismic slip. Previous field measurements (Li et al.,
566 2012) documented cumulative offset amounts of ~12, ~18 and ~24 m across four young fluvial
567 fans along the central ~50 km of the rupture. At Taersa, our new Matlab measurements confirm
568 values of ~6, ~13, ~18 and ~23 m across the lowermost, Holocene (10 ± 2 ka), alluvial terraces
569 (Fig. 3e). The $\sim 2.5 \pm 0.5$ mm/yr slip rate at this site would thus be consistent with characteristic
570 slip (~6 m) event's return times of $\sim 2500 \pm 500$ years (Fig. 11c). Note that such long recurrence
571 times preclude the use of historical records to assess seismic hazard on the fault. The rare
572 preservation of four cumulative co-seismic offsets over the entire Holocene period yields a
573 characteristic slip record that would be hard to obtain from trenching, even where sedimentary
574 records reach back that long (e.g., Daëron et al., 2007).

575

576 **5.4 Slip-rate along the Karakax fault at the millennial timescale**

577 The ~210 ka, 2-3 mm/yr slip rate we obtain is slower than average rates estimated
578 geodetically across the West Kunlun range during the last ~20 years: e.g., 7 ± 3 mm/yr (GPS,
579 Shen et al., 2001), 5 ± 5 mm/yr (Interferometric Synthetic Aperture Radar [InSAR], Wright et al.,

580 2004). As discussed below, this may be a corollary consequence of the complex crustal
581 deformation and faulting geometry across the western tip of Tibet (Figs. 1 a and 13a).

582 On a long-term, geological timescale, matching the Karakax river ~80 km offset (Gaudemer
583 et al., 1989, Ding et al., 2004) with the likely onset age (≥ 24 Ma) of rapid sedimentation in the
584 Tarim basin's Kunlun foreland and of sustained tectonic uplift along the West Kunlun range (e.g.,
585 Matte et al., 1996; Sobel and Dumitru, 1997; Métivier et al., 1999; Cao et al., 2015), would yield
586 a long-term slip rate of ≤ 3.3 mm/yr, consistent, within uncertainties, with the average late
587 Quaternary rate we document here. The similar ~80 km offset of the neighboring Karakax and
588 Yurungkax, two comparably large rivers crossing the KXF across nearly impassable
589 gorges/canyons (Fig. 1a), have long been described and clearly attributed to sinistral movement
590 along the fault (e.g., Gaudemer et al., 1989; Ding et al., 2004). The two river floodplains are, and
591 must have long been, captive within their deeply incised passages across mountain ranges that
592 are now 6000 to 7000 m-high. That the highest Kunlun peaks NW and SE of the offset Karakax
593 river are ~6300 and ~6698 m-high, i.e., ~2600 m and ~3000 m above the present valley floor
594 (~3700 m), respectively (Fig. 1b), requires that these large offsets be nearly coeval with the onset
595 of mountain uplift.

596 The ~24 Ma, ~210 ka, ~110 ka, and ~10 ka slip rates along the Karakax splay of the ATF
597 would thus all fall between 2 and 3.3 mm/yr, in keeping with a long (~2500 years) return time
598 for $M \sim 7.6$ earthquakes and a total, post-early Miocene offset of ~80 km. That relatively slow rate
599 is surprising given the clear, continuous surface trace, the fairly large co-seismic and geological
600 offsets, the prominent ~150 km-long 1882 surface rupture, and the exceptionally well-preserved
601 geomorphic expression of the fault (Fig. 12). Peltzer et al. (2020) suggested that variable slip or
602 erosion rates might account for the non-linear relationship between progressive scarp

603 degradation and cumulative displacement along the fault. Our results tend to support the latter,
604 although complexities in the fault trace involving pull-apart sags and releasing bends, hence sub-
605 parallel surface strands, in part hidden within the fast-evolving, modern Karakax river floodplain,
606 likely play a significant role.

607

608 **5.5 Left-lateral slip rate along the Longmu Co fault**

609 While we do not provide here more local dates along the Longmu Co fault (southern branch
610 of the LGCF) south of the Sumxi-Longmu Lakes, the offsets shown in Figure 4 (32 ± 4 and
611 950 ± 50 m) are newly-derived from a dedicated, small-scale UAV survey and from recent (2021)
612 high-resolution “Maxar Technology” satellite images, respectively. Age constraints for these two
613 different cumulative offsets may be suitably deduced from reliable, published, local and regional
614 dating by Gasse et al. (1991), Avouac et al. (1996), and Amidon et al. (2013). The twin Sumxi
615 and Longmu Lakes were long-connected as a unique, large lake with maximum water heights at
616 least ~ 230 m above present level (Avouac et al., 1996) during the early HCO (~ 10 to ~ 5 ka,
617 Gasse et al., 1991). The 32 ± 4 m left-lateral offset of the topmost shoreline of the paleo-Sumxi-
618 Longmu Lake must post-date the abandonment of that shoreline as the lake level rapidly dropped
619 down at the end of the HCO (6-5.5 ka, Avouac et al., 1996). This implies a slip rate on the
620 Longmu Co fault of 5.6 ± 0.9 mm/yr (Fig. 11b).

621 The larger offsets ($\sim 950\pm 50$ m) of the narrow glacial streams, now captive within the
622 abandoned glacial valleys crossing the fault south of the lakes, likely post-date the MIS-6 glacial
623 maximum (~ 180 - 140 ka, Fig. 9), after which incision began, a timing in keeping with the age of
624 the oldest, recessional frontal moraine (34.414°N - 80.046°E) dated at 123 ± 5 ka by Amidon et al.
625 (2013). Note that this moraine is located only ~ 21 km southwest of the offset shoreline site (Fig.

626 4) and ~8 km due south of the westernmost abandoned shorelines of Sumxi-Longmu Lake
627 (Avouac et al., 1996). Assuming that the glacial valley offsets post-date glacial retreat (e.g.,
628 Chevalier et al., 2005), between ~150 and 140 ka, their 950 ± 50 m average sinistral offset would
629 imply a slip rate of 6.5 ± 0.4 mm/yr (Fig. 11a). We conclude that the slip rate along the Longmu
630 Co fault may be significantly faster than the value proposed by Chevalier et al. (2017) (< 3 mm/yr
631 at a site located ~15 km west of the offset shoreline above), that may have been biased by the
632 ages of cobbles transported downstream by post-glacial reworking of upstream moraine deposits.
633 Note that the two rate values derived here along the central Longmu Co fault south of Lake
634 Sumxi are within the range of those inferred at various timescales by Raterman et al. (2007).

635

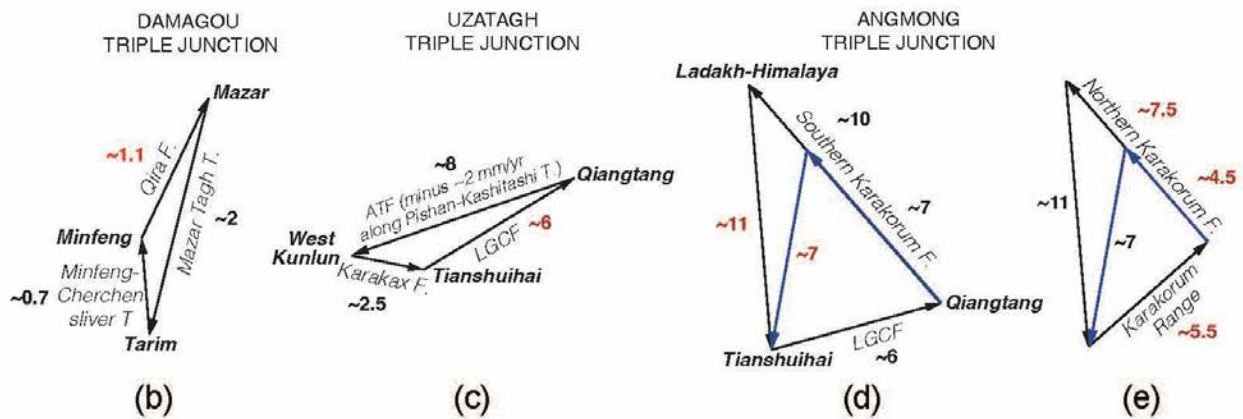
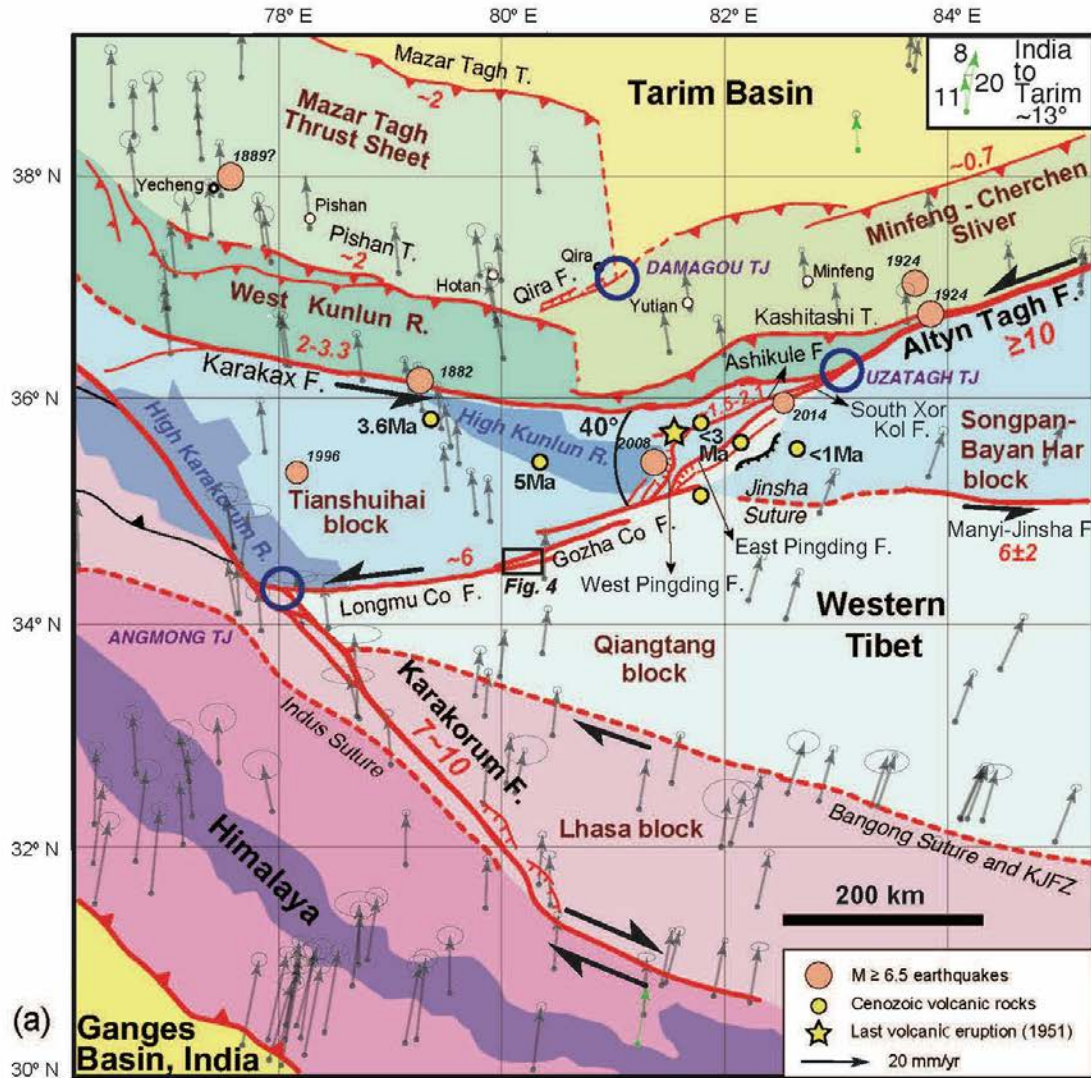
636 **5.6 Large-scale slip partitioning, triple junction kinematics and crustal** 637 **block tectonics across western Tibet**

638 Earlier studies along the ATF suggested Quaternary slip rates of up to 20-30 mm/yr (e.g.,
639 Molnar et al., 1987; Molnar and Lyon-Caen, 1989; Peltzer et al., 1989; Mériaux et al., 2004,
640 2005; Ryerson et al., 2006), the latter three at specific field sampling sites along the central and
641 eastern ATF. While local rates ≥ 20 mm/yr have been disputed, rates between ~10 and 15 mm/yr
642 along the fault from ~84 to 93°E are now well-established over different timescales (e.g., Gold et
643 al., 2011; Mériaux et al., 2012; Daout et al., 2018 and references therein). How rates ≥ 10 mm/yr
644 on the central ATF decrease to only 2-3 mm/yr in the Karakax valley must be accounted for. The
645 most plausible reason is the westward increasing complexity of the ATF system. While relatively
646 linear, although segmented into parallel strands by releasing and restraining bends east of 84°E,
647 the fault partitions westwards into distinct branches separating rising mountains from broad
648 basins (Figs. 1 a and 13a). Whereas it is essential to assess crustal kinematics across western

649 Tibet, such splitting into splays with strike-slip, thrust or normal components remains to be
650 accurately quantified.

651 The central ATF divides into two main faults (KXF and LGCF) at the Uzatagh triple junction
652 (83°E, Fig. 13a). Near that junction, where the strike of the KXF starts veering northwards by
653 ~40°, the sub-parallel Pishan-Kashitashi thrust, which raises the West Kunlun range to maximum
654 elevations of ~6000-6700 m, also terminates. A similar ~40° clockwise turn occurs near 81°E in
655 the Tarim foreland, between the emergent Minfeng-Cherchen sliver- and Mazar Tagh thrusts,
656 that parallel the ATF and KXF, respectively. We thus interpret the ~NE-striking, dominantly
657 normal, Qira fault zone (Avouac and Peltzer, 1993), to merge with both the Minfeng-Cherchen
658 sliver thrust and a ~NS-striking ramp bounding the eastern side of the Mazar Tagh thrust sheet.
659 Such a connection, near Qira, may be regarded as another triple junction (Damagou junction,
660 Fig. 13a). Southwest of Uzatagh, the ATF splits into a complex pull-apart system with oblique
661 sinistral/normal branches that merge back again southwestwards into the left-stepping LGCF
662 (Figs. 1 a and 13a). While the M~7, 2008 and 2014 Yutian earthquakes ruptured the
663 northwestern (West Pingding and Ashikule-Xor Kol) branches of that system, no large event has
664 been recorded yet along the southeastern branch, although it follows a deep, active rift between
665 the highest mountains (>6900-7100 m) of the West Kunlun range (Fig. 13a). Finally, farther SW,
666 the Longmu Co fault merges with the southern and northern Karakorum faults at the Angmong
667 triple junction, which also marks the southern termination of the high Karakorum range (Fig.
668 13a), where >40 km of post-Miocene crustal heave has occurred (Van Buer et al., 2015).

669



670

671 **Figure 13.** Block tectonics model consistent with updated fault slip rates across western Tibet. (a)

672 Summary of late Quaternary slip rates (numbers in red, in mm/yr) along main active faults (F.,

673 *red lines) and thrusts (T., red lines with teeth) separating crustal blocks between India and*
674 *Tarim (colored, after Wittlinger et al., 2004), with GPS vectors (small arrows) relative to stable*
675 *Eurasia (Wang and Shen, 2020). Large blue circles are three main triple junctions (TJ). Dark*
676 *blue/purple polygons highlight the highest topography along the Kunlun, Karakorum and*
677 *Himalayan ranges (R.). Small black box along LGCF indicates location of Figure 4. (b-e)*
678 *Triangular diagrams consistent with vector sums of late Quaternary slip rates along faults*
679 *separating blocks around triple junctions (red numbers are predicted rates; see discussion in*
680 *text). Top right inset is triangular diagram between current GPS vectors (green) just north of*
681 *Himalaya and in Tarim basin.*

682

683 While few long-term slip rates are well-constrained except along the ATF-KXF and
684 Karakorum faults, InSAR measurements now reveal ~ 0.7 mm/yr of \sim NS shortening across the
685 Minfeng-Cherchen thrust and 6 ± 2 mm/yr of \sim EW sinistral motion along the western Manyi-
686 Jinsha fault (Daout et al., 2018) (Fig. 13a). Field studies imply \sim NS shortening rates of ~ 2 - 2.5
687 and ~ 1.5 - 2.5 mm/yr across the Pishan and Mazar Tagh thrusts, respectively (Guilbaud et al.,
688 2017; Laborde et al., 2019). If assumed constant since shortening began in the West Kunlun
689 range (~ 24 Ma), the sum of the latter rates (~ 3.5 - 5 mm/yr) would be consistent with subduction
690 of the Tarim lithospheric mantle to a depth of ~ 200 km (88-125 km beneath the ~ 90 km depth of
691 the west Tibetan Moho) (Lyon-Caen and Molnar, 1984; Wittlinger et al., 2004), in classic plate
692 tectonic behavior, coherent with young volcanism south of the West Kunlun range (small yellow
693 circles in Fig. 13a). Lastly, along the Ashikule fault, cosmogenic dating of terrace offsets
694 suggests rates of ~ 1.5 - 2.1 mm/yr (Pan et al., 2015) (Fig. 13a).

695 Kinematic triangular diagrams (Fig. 13b-e) fitting the vector sums of rates along the faults
696 that separate the seven west-Tibetan blocks (Tarim, Mazar, Minfeng, Qiangtang, West Kunlun,
697 Tianshuihai, Ladakh-Himalaya; color-coded in Fig. 13a), which appear to take up much more
698 seismic strain than does internal deformation, clearly support block tectonics (e.g., Meyer et al.,

699 1998; Raterman et al., 2007). Specifically, at the Damagou junction, divergent thrusting on the
700 Mazar Tagh and Minfeng thrusts results in ~ 1.1 mm/yr of \sim NNE extension along the Qira fault
701 zone (Fig. 13b). The decrease in sinistral rate between the ATF and KXF is consistent with
702 transfer, at the Uzatagh junction, of ~ 6 mm/yr of slip along the LGCF (Fig. 13c) in a direction
703 enabling extension along the eastern boundary of the West Kunlun range. That rate is consistent
704 with both the 32 ± 4 m offset of the Sumxi-Longmu Lake topmost shoreline, abandoned ~ 6 -5.5 ka
705 ago (Gasse et al., 1991; Avouac et al., 1996) and the larger offsets (950 ± 50 m) of Eemian (123 ± 5
706 ka, Amidon et al., 2013) glacial valleys (Fig. 4). Finally, the vector sum of rates along the
707 southern Karakorum (~ 10 mm/yr, Chevalier et al., 2005) and LGCF (~ 6 mm/yr) predicts ~ 11
708 mm/yr of \sim NS shortening west of the Angmong junction (Fig. 13d). This may be further
709 decomposed into ~ 4.5 -7.5 mm/yr of dextral motion along the northern Karakorum fault and ~ 5.5
710 mm/yr of shortening across the high Karakorum range (Fig. 13e). Note that a faster dextral slip
711 rate along the central Karakorum fault is consistent with very short-term InSAR geodetic
712 observation (Wang and Wright, 2012). Most importantly, the kinematics of the latter, Angmong
713 junction, would thus account for the rise of the second highest mountain range in Asia after the
714 central Himalayas. The dextral rate decrease and the glaciated, high topography past that
715 junction would explain why the active Karakorum fault was mistakenly inferred by some (e.g.,
716 Robinson, 2009) to terminate north of $\sim 34^\circ$ N.

717 Detailed field studies are still lacking in the region separating the Himalayas from the Tarim
718 basin. Active faults that might bound the steep SW and NE faces of the West Kunlun and
719 Karakorum ranges (dark blue patches in Fig. 13a), contributing to the deformation budget across
720 the plateau, remain unexplored. This notwithstanding, however, a pattern of regional
721 deformation dominated by block faulting seems to be inescapable. Triple junction-governed slip-

722 partitioning, similar to that long-successful in plate tectonics (e.g., McKenzie and Morgan,
723 1969), appears to account best for changes in slip rates at the merging points between the central
724 ATF, KXF and LGCF, southern and northern Karakorum and Longmu Co faults, and between
725 the Qira fault, Mingfeng-Cherchen and Mazar Tagh thrusts (Fig. 13a). Likewise, the fact that the
726 highest mountains in western Tibet abruptly terminate near two of these junctions is best
727 explained by triple junction kinematics. Stronger crustal shortening, accounting for both the
728 maximum elevations of the Karakorum range and northwestward right-lateral slip decrease along
729 the eponymous fault (Chevalier et al., 2016), may just be interpreted as a simple consequence of
730 such kinematics. While the current, local geodetic dataset remains insufficient, both space- and
731 time-wise, to fully corroborate block tectonics, the main amplitude and directional changes of
732 extant GPS vectors (a total of $\sim 13^\circ$ anticlockwise, top right inset in Fig. 13a, Wang and Shen,
733 2020) between the Himalaya and the Tarim tend to coincide with the positions of the main active
734 faults. That several of the largest faults follow ancient, likely weak, crustal/lithospheric divides
735 between the main terranes of the Tibetan collage (e.g., Oytog, Jinsha and Bangong sutures, Matte
736 et al., 1996; Wittlinger et al., 2004), mechanically justifies the observed behavior. Crucially,
737 while complex, the late Quaternary kinematics across western Tibet strongly support simple
738 block tectonics rather than broadly diffuse deformation (Peltzer and Tapponnier, 1988; Meyer et
739 al., 1998; Tapponnier et al., 2001; Loveless and Meade, 2011).

740

741 **6 Conclusion**

742 New slip rate measurements along the Karakax and Longmu Co faults, westernmost
743 branches of the Altyn Tagh fault, help understand broad-scale block kinematics across the
744 western tip of the Tibetan Plateau, between the Ganges plain and the Tarim basin. Over the last

745 ~210 ka (age of the oldest alluvial surface dated thus far in northwestern Tibet), and possibly
746 since ~24 Ma, the slip rate along the Karakax fault seems to have remained constant, between 2
747 and 3 mm/yr, as recently shown by Peltzer et al. (2020) since ~115 ka. Since the beginning of the
748 Holocene, great earthquakes ($M \sim 7.6$) appear to have ruptured at least ~150 km of the fault with
749 fairly regular, if long ($\sim 2500 \pm 500$ years) return times, and with characteristic co-seismic slip
750 amounts on order of 6 m - as was the case for the last, likely 1882 AD event - for four such
751 events. These conclusions are based on the combination of high-resolution digital elevation
752 surveys and dating of alluvial fan and terrace offsets at Taersa in the Karakax valley, and of lake
753 shoreline and glacial valley offsets by the Longmu Co fault south of Sumxi Lake. Along the
754 Karakax fault, the well-known, ~80 km offset of the Karakax river may have accrued since uplift
755 of the West Kunlun range started in the early Miocene (~24 Ma). The sum of the slip rates on the
756 Longmu Co fault (~6 mm/yr) with those on the Karakax fault (~2-3 mm/yr) and on the active
757 thrusts ($2 \times \sim 2$ mm/yr = ~ 4 mm/yr) along the Tarim foreland of the Kunlun, yields a total of ≥ 12
758 mm/yr along the central Altyn Tagh fault, between central Tibet and the Tarim, in keeping with
759 the modern InSAR rate (≥ 10.5 mm/yr) obtained by Daout et al. (2018). To a first order, at the
760 scale of the entire western plateau, block tectonics and triple junction kinematics appear to
761 account for the recent and late Tertiary continental deformation, even though the seven blocks
762 involved, particularly the Tianshuihai block, may not be torsionally rigid. Specifically, the
763 junction between the conjugate Longmu Co and Karakorum strike-slip faults may be key to
764 explain the rise and abrupt southern termination of the high Karakorum range, second highest in
765 the world. Our results bridge the gaps between present and long-term geological history, and
766 between broad-scale geodesy and local field evidence.
767

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789 **References**

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