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1 **Evidence of a large «prehistorical» earthquake during Inca times? New insights**
2 **from an indigenous chronicle (Cusco, Peru).**
3

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17 **Keywords**

18 Oral Traditions, Historical earthquakes, Active Tectonics, Geomythology, Inca, Cusco
19

20 **Abstract**

21 A colonial chronicle written by the indigenous Peruvian author Pachacuti Yamqui
22 Salcamaygua ([1613?]) relates a legend of the sudden appearance of a huge animal –
23 kilometres in length and approximately 4 m in width – and described as the Andean snake-
24 like deity *amaru*. Pachacuti Yamqui alleged that this fantastic event occurred on the day that
25 the sovereign Pachacuti Inca Yupanqui's eldest son was born around 1440 CE, and was
26 named "Amaru". We suggest that the underlying event was an earthquake, and that the
27 propagation of the surface rupture across the landscape resembled a sudden appearance of a
28 snake-like being wriggling over the mountains and leaving an undulating surface trace. The
29 concordance between the snake's route and the layout of a major fault complex above Cusco,
30 as well as several ethnographic testimonies, support this hypothesis. Although little is known
31 about pre-1532 CE seismicity, the current tectonic settings of the Cusco area point to seismic
32 awareness of the Incas (ca.1300–1532 CE). Independent results from architectural and
33 paleoseismological fields in the Cusco area corroborate a significant impact of large
34 earthquakes on local societies. In Peru, without pre-Hispanic written sources, the oral folklore
35 and traditions preserved in Spanish chronicles offer a relevant, but still underexploited
36 resource for identifying paleo-extreme events. Combining multidisciplinary geomorphic
37 observations, archaeological evidence and historical sources, we revisit this legendary episode
38 and its possible implications.
39

40 **1. Introduction**

41 What could be the nature and degree of influence of thousands of years “long-term”
42 geological dynamics on decade-scale, “short-term”, human expansion and evolution? Without
43 considering and adopting a deterministic perspective, this question remains nevertheless
44 worthy of debate (Force and McFadgen, 2010; King and Bailey, 2006; Nomade et al., 2016).
45 Severely affected by floods, climate variations, volcanic eruptions, and earthquakes, the
46 Andes appear to be suited well for assessing the influence of natural phenomena on past
47 human societies. In Peru, particularly, numerous studies have demonstrated correlations
48 between climatic events and the emergence or demise of archaeological settlements (Binford
49 et al., 1997; Chepstow-Lusty et al., 2003, 2009; Christol et al., 2017; Sandweiss, 2003;
50 Sandweiss et al., 2009, 1996). Volcanoes and sudden eruptions have also had a great impact
51 on the worldview and organization of the pre-Columbian cultures (Bouysse-Cassagne, 2006;
52 Bouysse-Cassagne and Bouysse, 1984; Chávez Chávez, 2001; Reinhard, 1983). Few
53 academic investigations, however, seem to have focused on the impact of earthquake activity,
54 and almost exclusively in the Mesoamerican world (Garduño Monroy et al., 2020; Garduño-
55 Monroy, 2016). Although valuable work has been carried out in the aftermath of devastating
56 earthquakes that struck the Peruvian coast during colonial and modern times (D’Ercole et al.,
57 2007; Seiner Lizárraga, 2013; Walker, 2018, 1999), little has yet been done regarding pre-
58 Hispanic seismic risk management and perception. Beyond megathrust earthquakes that affect
59 mainly coastal areas, crustal faults within the Andes present a major threat for local
60 populations as demonstrated by the 1946 Ancash (Silgado Ferro, 1951) and 1950 Cusco
61 (Kubler, 1952) earthquakes. It therefore seems unlikely that earthquakes large enough to
62 rupture the earth’s surface did not affect local inhabitants before the Spanish Conquest (1532
63 CE).

64 In the absence of an intelligible pre-Columbian writing system, indigenous oral tradition and
65 folk tales preserved in colonial chronicles represent a particularly relevant source of
66 information for the identification and perception of past disastrous events. Often disregarded
67 for their lack of scientific rigor and chronological context, transgenerational oral memories
68 originate, however, from empirical environmental knowledge that may describe true natural
69 events in an alternative narrative system (Cohen et al., 2017; King et al., 2007; Masse and
70 Masse, 2007; McMillan and Hutchinson, 2002; Nunn, 2014; Troll et al., 2015). Through a
71 geological, archaeological and ethno-historical reading, we argue in this paper for a
72 reinterpretation of an extract from Pachacuti Yamqui Salcamaygua’s chronicle (Pachacuti

73 Yamqui Salcamaygua, 1993). Recounting seemingly a mythological event, a passage from the
74 *Relación de antigüedades deste reyno del Piru*, written in the mid-XVIIth century, alludes to
75 the activation of the major fault system crossing the Cusco Basin. Dated around 1440, it
76 might be the oldest seismic event reported by written sources in South America.

77

78 **2. Background**

79 2.1. Incas and ground motions

80 While earthquakes have frequently shaken the Cusco region (Peru) in the last 500 years,
81 Spanish chronicles are surprisingly quiet about the occurrence of any seismic event during
82 Inca times (ca. 1300–1532 CE). The only references to earthquakes before the Spaniards
83 arrived are imprecise and come from secondary sources (Garcilaso de la Vega, 1609, pp. 477-
84 Lib IX, CAP XIV; Silgado Ferro, 1978, p. 16). This situation is all the more striking because
85 Bernabé Cobo mentioned in his *Relación de las guacas del Cuzco* (1979, pp. 16-Ch-2:1) the
86 existence of a powerful Inca shrine, *Guaracince*, whose location was considered as the focal
87 point of ground shakings. Convinced of the occurrence of destructive “prehistorical
88 earthquakes” in the Cusco area, Bandelier (1906) was the first to address the issue of the
89 perception of natural hazards by pre-Columbian societies. He demonstrated the relevance of
90 examining and interpreting pre-Columbian legends and myths to assess the volcanic risk at
91 this period, for the Quinsachata and Misti eruptions.

92 In spite of abundant evidence of destruction (burnt daub, collapsed walls, smashed vessels)
93 registered in archaeological sites from the Late Intermediate Period (LIP: 1000–1400 CE) and
94 Late Horizon (LH: 1400–1532 CE) around Cusco (Covey, 2006; Kendall et al., 1992;
95 McEwan et al., 2005; Quave et al., 2018; Vargas P., 2007), very few were interpreted as
96 consequences of earthquakes (Fig.1 – note A). The extended layer showing collapsed
97 structures within the site of Warq’ana, near Huchuy Qosqo, constitutes unique evidence of a
98 hypothesized seismic event in the Cusco area (Kendall et al., 1992, p. 224). Even recognizing
99 that earthquakes do not provide the sole explanation of such types of evidence (instead, for
100 example, of war, raiding, or ritual behaviour), the small number of inferences of earthquakes
101 as the potential cause of destruction is particularly striking.

102 Recent paleoseismological and archaeoseismological research carried out within the Cusco
103 region may shed new light on this topic. The paleoseismological trenches excavated in only
104 two segments of the Cusco Fault System (Palomino Tacuri, 2020; Rosell Guevara, 2018 -
105 Fig.1) indicate at least four large and crustal seismic events ($M_w > 6$) during the last three

106 millennia, and argue for a reappraisal of the seismic impact on Cusquenian populations.
107 Although in its infancy, the results of an archaeoseismological survey in Machu Picchu attest
108 to the occurrence of at least one major and regional earthquake during the occupation phase
109 (Rodríguez-Pascua et al., 2019). Sudden and violent, this type of natural hazard may have
110 generated stress and panic in the population, leaving its imprint in the pre-Hispanic
111 worldview.

112

113 2.2. The *amaru* entity in the Andean worldview

114 In contrast to common snakes called *mach'aqway* in Quechua (Santo Tomás, 2003, p. 285),
115 *amaru* describes a mythological and chthonian serpent-like monster (likened to the European
116 dragon in the first Spanish description). Based on colonial definitions, the *amaru* was
117 associated with snakes of great dimension (González Holguín, 2007, p. 408) and coming from
118 the hot and humid Amazonian lowlands (Garcilaso de la Vega, 1609, pp. 196, 221; Huaman
119 Poma de Ayala, 1979, p. 190). This deity, particularly important in the Andean pantheon, and
120 having inspired names of Inca and indigenous leaders, as well as the appellation of the large
121 Inca compound of Cusco, the Amarukancha, seems to have covered a wide spectrum of
122 meanings and cosmologic notions. Urton (1981) described it as a double-headed and rainbow
123 serpent whose extremities are anchored in water sources. Its relation with meteorological
124 processes may have been much broader, such as associations of the *amaru* with the wet
125 season, with water streaming or lightning (Boelens, 2014). Finally, as Hocquenghem (1989,
126 pp. 212–213) explained, the rupture of equilibrium in the Andean conception of the world,
127 called a *pachacuti*, is often synonymous with the liberation of an *amaru* and its subsequent
128 petrification. Several phenomena could have triggered this disequilibrium: war, epidemics,
129 floods, and earthquakes.

130 Snakes and earthquakes are commonly linked in human folklore, all around the world. The
131 animal is often described as a reptile, a serpent, or even a dragon of great dimensions living
132 underground (Ludwin et al., 2007, p. 88). Ground shaking, as occurs during earthquakes, is
133 hence explained as the direct consequence of the movement of the serpent-like animal (Fig.2;
134 Kirikov, 1992). The Chumash Indians that inhabited the south coast of California believed in
135 the existence of two underground snakes that were responsible of the frequent ground shaking
136 produced by earthquakes on the San Andreas Fault (Fradkin, 1999, p. 70). Although less
137 common in Mediterranean legends, the snake or the dragon appears, nonetheless, as a
138 secondary character (Piccardi, 2007, 2005, pp. 98, 103). If this quick overview does not

139 demonstrate a widespread representation of earthquakes by serpent-like entities in past human
140 societies, it reveals at least a common association between this animal and the seismic
141 phenomenon, based probably on environmental and ecological observations. Several
142 references to the snake in the Andean mythology seem to endorse this assumption.

143 According to Martín de Murúa, a snake called *chipiroque* ou *pichiniqui* appeared to the
144 Indians some time before the Huaynaputina eruption (1600 CE) to warn them about this
145 subterranean punishment (Bouysse-Cassagne and Bouysse, 1984, p. 58). In the Huarochiri
146 manuscript (Ávila, 1980), the appearance of an *amaru*, created by the pre-Hispanic deity
147 *Huallalu Carhuinchu* during his legendary struggle with *Pariacaca*, is also accompanied by
148 intense ground shaking. Similarly, a Jesuit text of 1624 (Polia Meconi, 1999, sec. 37)
149 describes how the arrest of a sorceress that was breeding snakes in her house triggered
150 lightning strikes and tremors. As a chthonian creature, related to the underground world, the
151 serpent seems to be frequently related to earth motions in the Andean worldview (Gentile,
152 2017; Hocquenghem, 1989).

153

154 **3. The study area - The Cusco Valley and its seismic setting**

155 At an elevation of 3400 m, Cusco lies in the south-eastern part of Peru, in the Eastern
156 Cordillera. The region displays a long human occupation that dates back to, at least,
157 10,000BP. Characterized, until the end of the Middle Horizon (MH: 600–1000 CE) by small-
158 clustered polities, the Cusco Valley experienced then a gradual state formation process
159 throughout the LIP (Bauer, 2018; Covey, 2006) that turned it into the geographical centre and
160 political core of the Inca empire during the XVth century. Densely inhabited since the
161 Formative Period (~2000 BCE–400 CE), the Cusco Basin has resulted from the continuous
162 action of active tectonic processes, which probably foster human settlement.

163 The Cusco Basin is an intra-montane valley bounded along its northern margin by a complex
164 of active crustal faults. Trending mainly NW-SE, the Qoricocha, Tambomachay, Pachatusan
165 and Cusco normal faults control the subsidence and the filling of the basin (Benavente
166 Escobar et al., 2013; Cabrera, 1988; Cabrera and Sébrier, 1998 - Fig.1). Overlying the
167 Cenozoic and Mesozoic basement is a thick, extensive layer of unconsolidated lacustrine and
168 fluvial sediment of Quaternary age (Gregory, 1916; Marocco, 1978). Suitable for water
169 retention and farming activity that unconsolidated sandy sediment also amplifies seismic
170 waves, producing major site effects and making the area more sensitive to ground motions
171 than where rock is solid. Indeed, the lake deposits are ~300 m thick and show deformed

172 sedimentary structures (seismites), which are secondary effects of earthquakes (Benavente
173 Escobar et al., 2013, pp. 27–44).

174 The active tectonic structures crossing the Heartland of the Incas are part of the Cusco
175 Vilcanota fault zone (CVFZ) that generates frequent seismic activity (Fig.1). Historical
176 documents refer regularly to *temblores* (slight shakings) that cause stress and panic (Esquivel
177 y Navia, 1980; Gade, 1970; Palma and Biblioteca Nacional, 1901). Two violent *terremotos*
178 (devastating earthquakes) in 1650 (Julien, 1995; Villanueva Urteaga, 1970) and 1950
179 (Ericksen et al., 1954; Kubler, 1952) led to these acute reactions. In terms of structural
180 impacts, and despite their limited scope, both earthquakes destroyed buildings in the city of
181 Cusco, and the main colonial structures in particular. The high level of amplification of the
182 soft sediment lying in the Cusco valley-bottom explains a large part of the severity of the
183 damage.

184 In terms of cultural impact, the high frequency of ground shaking (Silgado Ferro, 1978) has
185 caused a persistent trauma in inhabitants' minds since the Spanish Conquest, while both
186 maintaining and fostering a collective seismic concern. The Lord of the Earthquakes (*Señor*
187 *de los Temblores*) cult, still celebrated each Holy Monday in Cusco, is one of the most salient
188 examples. The intense devotion attached to the patron saint originated in the 1650 earthquake,
189 but may have taken root in a pre-Columbian belief (Gade, 1970; Hajovsky, 2018; Rossano
190 Calvo, 1994).

191

192 **4. Methods**

193 4.1. Historical material

194 Juan de Santa Cruz Pachacuti Yamqui Salcamaygua was an indigenous chronicler living
195 during the XVIIth century. We know little about him, for his own writings constitute the only
196 source of information. Native of the Canas-Canchis region, approximately 130 km southeast
197 of Cusco, he claims a direct familial ascendancy in the local *curacas* of Guaygua Canchi,
198 which soon converted to Catholicism. Through his *Relación de antigüedades deste reyno del*
199 *Piru*, Pachacuti Yamqui (1993) claims to have written about the main events that shaped the
200 history of Peru. Imbued with catholic references (Duviols, 2017), his text is, arguably too
201 often, regarded exclusively as an early indigenous Christian worldview. Because of the direct
202 influence and contribution of the oral tradition in his work, we consider this source
203 particularly valuable for studying mythological stories coming from the local collective
204 memory. In his presentation of the Inca sovereign Pachacuti Inca Yupanqui, Pachacuti

205 Yamqui wrote about a fantastic event that allegedly occurred the day of birth of the eldest son
206 of the emperor.

207 “In that time, they say that news arrived of a miracle in Cuzco, consisting of something
208 like a *yauirca* or *amaru* [snake in Aymara or Quechua, respectively – note B] that had
209 emerged from the mountain of *Pachatusan*, a very fierce beast, half a league long and
210 thick, of two and a half fathoms in width, and with ears and fangs and whiskers. And it
211 came by *Yuncay Pampa* and *Sinca*, and from there it entered the lake of *Quibipay*, and
212 so, two *sacacas* of fire came out of *Aosancata*, and [one] passed *Pontina* of *Arequipa*;
213 and the other came down to and passed *Guamanca*, where there are three or four very
214 high mountains covered with snow, those in which they say that there are animals with
215 wings and ears, and tails and four feet, and on top of their backs many spines like a fish,
216 and from afar they say that it appeared to them [to be] all fire. (f.21-21v / Translation
217 modified from Bauer and Dearborn, 1995, p. 148 – note C)

218 The extract cited above reports the sudden appearance of a snake-like animal, commonly
219 called *amaru* in the Andean mythology. Due to the importance of the event, the Inca
220 Pachacuti decided to name his son Amaru Tupa Yupanqui. The supernatural entity had
221 impressive dimensions: 2.75 km long and almost 4.2 m thick (note D). The quoted text
222 describes the pathways of the snake to different key places along the traces of active faults
223 that define the geologic landscape of Cusco. The snake appeared at Pachatusan (point 1 on
224 Fig.3), the highest mountain in the Cusco valley and considered sacred by the Incas (Silva
225 Gonzales and Loza García, 2007). The animal continued westward along the ridge crest that
226 borders Cusco to the north. It crossed “Yuncay Pampa” known currently as Yuncaypata (point
227 2 on Fig.3), a small locality 4 km north of Cusco, and then passed through “Sinca” that
228 corresponds to the Sinqa Mountain (point 3 on Fig.3). It finally vanished in the Quibipay
229 lagoon (point 4 on Fig.3).

230 The exact location of the latter remains unknown, up to now. Mentioned a second time in the
231 book by Pachacuti Yamqui, the place was defined as a flat area where Atahualpa gathered the
232 main ethnic leaders of Cusco after the final battle against the Huascar’s army (Pachacuti
233 Yamqui Salcamaygua, 1993, p. 178 f.42). Others placed it one league, i.e. approximately 5
234 km, from Cusco (Mendiburu, 1902, p. 74), west of Cusco behind the Sinqa Mountain
235 (Zuidema, 1974, p. 215), or north-east of Cusco (Gentile, 2017, p. 310).

236

237 4.2. Geomorphological analysis

238 We combined the analysis of the historical source with a geomorphological and neotectonic
239 investigation. Topographical data from the Cusco Basin were processed using two Digital
240 Elevation Models (DEM). The creation of a high-resolution DEM (1.5m) based on Pleiades
241 images and covering the western part of the Cusco Basin allows us to relate the location of the
242 Quibipay lake with a classic feature of tectonic geomorphology. To this end, topographic
243 features were studied thanks to basic GIS analysis including a slope map, hill shadings, and
244 topographic profiles.

245 Based on a larger ASTER DEM (30m) we executed a “visibility analysis” from the
246 archaeological site of Amaru Marka Wasi, settled on a calcareous plateau above Cusco
247 (AMW on Fig.3). Composed mainly of rocky outcrops containing carvings this site was the
248 seventh shrine of the first *ceque* of the Antisuyu (An 1:7 in Bauer, 1998, p. 76). Considered to
249 be the former residence of the eldest son of the sovereign Pachacuti Inca Yupanqui, the site
250 most probably was dedicated to ceremonial activities. Due to its sacred character, its
251 geographic proximity with the localities mentioned in the story, and its direct relation with
252 Amaru Tupa Yupanqui, we considered it worth questioning the link that may have existed
253 between the outcrop and the Amaru story. The “visibility analysis” realized thanks to Global
254 Mapper software allows us to display the area visible from the summit of the outcrop. This
255 particular GIS analysis highlights the main features of the environment visible from the site
256 and provides some indications of its ceremonial purpose. We fixed as initial parameters an
257 observer of 1.65m tall and, a visibility radius from 20 km, and we kept the standard value of
258 atmospheric correction (1.333 - Brunner, 1984). Field reconnaissance carried out around the
259 archaeological site allowed to validate the region visible from the site. Finally, the GIS
260 platform enabled us to cross check the results with places mentioned in the text and
261 distribution of the main faults (Benavente Escobar et al., 2013).

262

263 5. Results and discussion

264 5.1. Archaeological places as “geolandmarks”?

265 The present analysis led us to identify a small community now belonging to the extended
266 agglomeration of Cusco, Cruz Verde de Quehuepay (Point 4 on Fig.3), as the former
267 Quibipay plain and lagoon mentioned in the text of Pachacuti Yamqui. As commented in 4.1.,
268 this place seems to have held a special significance for the inhabitants of the Cusco region,

269 since it is the place chosen by the sovereign Atahualpa and his court to speak to the main kin
270 groups and to request their obedience after he defeated his brother's army.

271 The etymological similarity of Quehuepay and Quibipay as well as its distance from the
272 Cusco historic centre (less than 4 km westward) strongly support the placement of the
273 Quibipay lagoon in Cruz Verde de Quehuepay. In spite of the present dense urbanization, the
274 new high-resolution DEM clearly highlights two important facts. First, Cruz Verde de
275 Quehuepay occupies the flattest part of the area (~2% of declivity) and lies against the Cusco
276 fault scarp (CVQ on Fig.4). Second, the small lagoon seems to have formed as a sag pond, a
277 classic feature of tectonic geomorphology (Burbank and Anderson, 2011) that develops where
278 ruptures bend or where fault segments are offset from one another; in either case the floor of
279 the pond drops with respect to surroundings during recurrent seismic rupturing (Fig.5).

280 Hence, the Quibipay plain, as well as the other toponyms mentioned in the legend, can be
281 associated directly with active tectonic structures and supports a seismic interpretation of the
282 Pachacuti Yamqui's extract. Three large fault segments run through the region where the
283 legend takes place (the Cusco, Tambomachay and Pachatusan faults) and match with the
284 Amaru's route (Fig.3).

285 The "visibility analysis" computed from the high-resolution DEM at Amaru Marka Wasi
286 enhanced the observation that standing atop the rocky promontory it is possible to see each of
287 the places mentioned by Pachacuti Yamqui (Fig.3). Instead of providing an overview on the
288 Cusco valley bottom and the Inca city, the archaeological site offers a wide panorama of the
289 mountain ridges bordering the northern part of the Cusco Basin. The Tambomachay fault,
290 which runs all along the mountainside, marks a clear topographic anomaly and forms the most
291 salient element of the landscape (Fig.6).

292 It is even more striking that all the sites mentioned in the legend and settled along the fault
293 segments contain important venerated places. Pachatusan, Picol and Sinqa were three of the
294 six most important sacred mountains in the Cusco region and hosted places of worship. Not
295 only was Paukarcancha (Pa in Fig.3), an important ceremonial and pilgrimage site displaying
296 Inca material, built on the top of Pachatusan (Bauer, 1998, p. 94; Silva Gonzales and Loza
297 García, 2007), but the Picol summit (Pi in Fig.3) and the Sinqa *waka* located on the southern
298 flank of the Sinqa Mountain (Si in Fig.3) were also significant places of offerings. We suggest
299 that just as ceremonial sites in the southern part of the Inca Empire are associated with
300 volcanoes (Chávez Chávez, 2001; Reinhard, 1983), the sacred dimension of some Inca
301 shrines of the Cusco Basin are related to this tectonic landform resulting from active faults.

302

303 5.2. A wavy fault scarp

304 Based on anthropological studies, Zuidema (1974, p. 215) interpreted the snake described in
305 the Pachacuti Yamqui story as a metaphor of a rainbow. Unable to verify the veracity of this
306 association, however, he simply offered a conceptual discussion about Andean mythological
307 representations. Nonetheless, Bandelier (1906) and Gentile (2017) have noticed the geological
308 interest of the passage, and postulated yet, without providing convincing arguments, the
309 hypothesis of a volcanic eruption or seismic event.

310 In the landscape above Cusco, anywhere fault scarps cut moraines as in Tambomachay,
311 Pachatusan or many other localities, a peculiar feature stands out: a serpent-like form of the
312 scarp (Fig.7). Moreover, in some interviews in the Huancavelica province (Zuidema, 1967, p.
313 49) as well as in our conversations in the southern part of the Cusco region (Sicuni), local
314 people have described openings in the ground or cracks as “amaru”. Cristóbal de Albornoz
315 (Duviols, 1967, p. 23) corroborates the frequent association of snakes and geological features
316 in the Andean mythology. The reader may notice that the little *quebrada* north of Picol
317 summit and driven by one Pachatusan fault segment is currently called Amaro (Fig.3). We
318 can easily suppose that pre-Hispanic populations observed the undulating form of the fault
319 trace in the landscape and tried to relate it to something familiar. It is noteworthy that the size
320 of the creature could be consistent with a segment of a surface rupture approximately 2.5
321 kilometres long and an opening of several meters in width. Relying on rupture of such
322 dimension and considering the seismic disaster of 1950 only associated with small-scale
323 surface rupturing (Cabrera, 1988; Ericksen et al., 1954), we postulate that this “prehistorical”
324 earthquake generated its highest intensities within the Cusco Basin.

325 Normal faults, which mark the fronts of many of the ridges in the Cusco region (Benavente
326 Escobar et al., 2013) differ from strike-slip faults, like the San Andreas Fault in California,
327 whose traces at the earth's surface are straight for tens of kilometres. Instead, normal faults,
328 commonly consist of short segments – a few kilometres long – that, when linked together,
329 form an escarpment that undulates across the landscape. Thus, whereas the trace of a strike-
330 slip fault bears little resemblance to a snake, linked normal-fault segments can easily
331 engender such an image, especially during trauma induced by severe ground shaking.
332 Moreover, when an earthquake occurs, slip does not suddenly, and simultaneously, occur on
333 all of the linked fault segments; rather, slip initiates at the epicentre, and the locus of slip
334 propagates away from it at a speed of ~1-3 km/s. Thus, for a fault that is, say, 30 km long and
335 visible to a single observer, approximately 10 to 30 seconds will elapse as the locus of slip

336 wriggles across the landscape from start to finish. As slip on faults during earthquakes
337 commonly occurs at ~1 m/s (Bizzarri, 2012; Brune, 1970), and total amounts of slip during
338 earthquakes of the magnitude that have caused damage in the Cusco region are commonly 1-2
339 m, slip at any point on the fault will last ~1-2 seconds. Thus, slip within a segment of the
340 rupture will occur concurrently, but segments several kilometres apart will not slip
341 simultaneously, enhancing the undulating and emerging serpent-like aspect of the landform
342 (Fig.7).

343 As explained in 2.2., the emergence of a chthonian creature within the world of the living was
344 understood in the Andean worldview as a *pachacuti*, a time and space upheaval, disturbing
345 the entire course of action (Bouysse-Cassagne and Bouysse, 1984, p. 57; Huaman Poma de
346 Ayala, 1979, p. 68). The *amaru* in Quechua and its rough translation *yauirca* in Aymara
347 (Bertonio, 1879, p. 396), correspond to one of these subterranean entities that may surge in
348 the context of destructive events such as landslides and earthquakes. The monstrous creature
349 remains then petrified and turns one landscape feature into the remnant of a geological
350 phenomenon (Hocquenghem, 1989, pp. 212–213). The landmark is thus the sign and
351 metonymy of the *pachacuti* and the restoration of order. A document from the *quipucamayocs*
352 seems to confirm the occurrence of a *pachacuti* in the region during Inca times and its close
353 relation with the Quibipay place, identified in this work. That document, indeed, quotes the
354 following words of the Atahualpa generals addressed to the ethnic leader in Quibipay after the
355 fratricidal war between Atahualpa and Huáscar: “**once again** should begin (a new world) of
356 Ticcicapac Inga” (Randall, 1987, p. 92). The Atahualpa generals consider their victory over
357 Huáscar as a new upheaval and seem to refer to a previous one that would have taken place in
358 Quibipay. Despite the less devastating impact of a tectonic event, we can easily consider a
359 large fault rupture affecting the capital of the Inca Empire as a tremendous turmoil.

360

361 5.3.“And so, two sacacas of fire came out...”

362 The second part of the extract from Pachacuti Yamqui Salcamaygua’s chronicle deals with the
363 simultaneous appearance of two balls of fire (*sacacas*). The meaning of this Aymara word is
364 not entirely clear, but could be defined as a fire emanating visibly in the sky, and different
365 from comets, which are called *wara-wara hali* by Aymara speakers (Bertonio, 1879, p. 304).
366 Previous studies did not establish a direct link between this celestial event and the occurrence
367 of the snake. These “fire exhalations” were understood as merely simple falling stars or
368 indirect evidences of the eruption of El Misti (hundreds of kilometres to the west near

369 Arequipa) dated between 1440 and 1470 CE (Bandelier, 1906; Thouret et al., 2001). We
370 suggest two new possible interpretations of this phenomenon.

371 During colonial times tremors in Cusco were frequently symbolically associated with celestial
372 events (Anónimo, 1819; Esquivel y Navia, 1980). Although we are not able to explain why
373 both phenomena are commonly linked, the appearance of a comet could be mentioned as a
374 divine sign after a catastrophe. The great influence of Christianity in the writings of Juan de
375 Santa Cruz (Duviols, 2017) would support that hypothesis. The second explanation is based
376 on the still poorly explained, but sometimes observed “earthquake lights” (EQL) that have
377 been reported before or during the ground shaking from major earthquakes (Fidani, 2010;
378 Stothers, 2004; Whitehead and Ulusoy, 2015). The *sacacas* could be an expression of fireball-
379 like lights described in various places such as in Lima during the 2007 Pisco earthquake
380 (Heraud and Lira, 2011) as well as in L’Aquila in 2009 (Fidani, 2010). Theriault *et al.* (2014)
381 noted that reports of earthquake lights seem to be more common in tectonic environments
382 with crustal extension such as the Cusco Basin.

383

384 **6. Conclusions**

385 In ancient and modern Peru, earthquakes frequently shook the ground, modified the
386 landscape, and devastated human settlements. In Cusco, time after time, people built and
387 rebuilt monumental architecture in the vicinity or even along seismically active faults.
388 Ongoing research indeed demonstrates the resilience of Inca buildings affected by past
389 earthquakes (Hinzen and Montabert, 2017; Rodríguez-Pascua et al., 2019).

390 How much the Incas knew about earthquakes and faults is unclear. Described as a small piece
391 of land where ground motions occurred, *Guaracince* (Ch. 2:1 - Cobo, 1979, p. 16) constitutes
392 a unique direct reference to an Inca worship site related to earthquakes. Our interpretation of
393 the latter myth suggests nonetheless that the relationship between ceremonial Inca sites and
394 regional faults may be much closer and that modern archaeology and anthropology may have
395 underappreciated the cultural significance of earthquakes for the Inca culture. This situation
396 echoes the well-established influence of the tectonic environment on the development of
397 sanctuaries in the Aegean area (De Boer and Hale, 2000; Partida, 2017; Stewart and Piccardi,
398 2017).

399 Historical and “prehistoric” seismicity must deal with large earthquakes that predate
400 instrumental seismology. Without an instrumental record, the identification and
401 characterization of ground-shaking episodes require a multi-proxy approach, combining

402 analyses not only of paleoseismological trenches and sediment cores, archaeological and
403 neotectonic observations but also interpretations of (ethno)historical sources.
404 Given that first generation accounts from Spanish chroniclers did not mention any major
405 ground-shaking episodes in the Cusco region during pre-Columbian times, the reader may
406 legitimately wonder why we have based our discussion on a later indigenous chronicler.
407 Although descendants of Inca people do not seem to have referred directly to such violent
408 natural phenomena, we argue that earthquake stories may still be “hidden” in mythological
409 episodes told to the first *conquistadores*. We consider thus the Amaru tale extracted from
410 Pachacuti Yamqui’s chronicle as a relevant example of a disastrous event preserved indirectly
411 in a legendary story and transmitted over several generations. The “seemingly mythological”
412 content of the *Relación de antigüedades deste reyno del Piru* does not preclude its analysis as
413 a valuable source of information. Moreover, it suggests that an earth science-based approach
414 can offer relevant insights regarding the nature and origin of myths in a given geodynamic
415 and cultural setting.

416 Thus, despite the metaphorical dimension, various elements make the seismological
417 interpretation of the legend plausible and worthy of consideration. We summarize again the
418 arguments, enounced above, in favour of our hypothesis:

- 419 - the similarity of the Amaru’s route to the layout of the main Cusco fault complex;
- 420 - in the south-eastern part of the Cusco region, indigenous people describe faults scarps
421 as “amaru”.
- 422 - the lake where the snake vanished might be interpreted as having been a sag pond.
423 Quibipay, known currently as Cruz Verde de Quehuepay, lies at the foot of the Cusco
424 fault scarp; the snake diving into the water would be therefore a metaphor for the
425 rupture ending in the lake.
- 426 - bright lights likened to fire described in the same extract by Pachacuti Yamqui might
427 be linked with earthquakes, given the recurrent association of comets with earthquakes
428 in colonial texts or as the occurrence of “earthquake lights”.

429 Following the traditional chronology of the Inca emperors made by John Rowe (1945, p.
430 277), we date the potential earthquake, which occurred apparently around the December
431 solstice (*Qhapaq Raymi*), between approximately 1438 CE (the beginning of Pachacuti’s
432 reign) and 1463 CE (when the second son of Pachacuti took command – note E).

433 Finally, this study highlights the relevant contribution that legends and myths in past risk
434 perception and management may bring. Due to the mythological content, inherent to this type

435 of source, geologic phenomena remain roughly constrained in terms of chronology. However,
436 folk tales and testimonies have yet proved their worth for describing pre-instrumental
437 earthquakes, in particular, in the San Andreas Fault region (MacLean, 1979; Meltzner and
438 Rockwell, 2004). A renewed paleoseismological and archaeoseismological effort is needed to
439 confirm the occurrence of such large seismic event during Inca times and affecting the Cusco
440 Basin. Improved characterization and mapping of the destructive evidence affecting the LIP
441 and LH settlements would provide useful complementary data.

442 According to the World Bank's Independent Evaluation Group, the number of events
443 considered as natural disasters grew by 200% between 1975 and 2015, which demonstrates
444 the increased threat for our modern societies (CRED, 2015; IEG, 2006). Increasing resilience
445 to future earthquakes in the Cusco area will require fostering innovative approaches to
446 address past human coping strategies. Cross-disciplinary interactions are shown here to be
447 necessary to study such an historic area, ranging from human and social sciences (e.g.
448 archaeology, history, anthropology, sociology...) to physical and natural disciplines (e.g.
449 geology, seismology, hydrology, and geography) and engineering (e.g. architecture), with
450 each, from its own perspective, providing new interpretations for improving hazard
451 assessment.

452

453 **Footnotes**

454 A) We are not claiming in any way that the earthquake occurrence may explain all the
455 evidence of destruction registered during the Killke (LIP) and Inca (LH) periods.
456 Bearing in mind the absence of consideration of earthquakes in almost all the
457 investigation interpretations, we may nonetheless wonder to what extent the current
458 lack of awareness of the seismic risk might have affected interpretations of the
459 archaeological records. We thus stress the need for future investigations to take into
460 account the impact of this natural hazard.

461 B) Juan de Santa Cruz Pachacuti Yamqui Salcamaygua came from an Aymara-speaking
462 area, but in process of "Quechuaisation" during Inca and colonial times (Itier,
463 pers.comm.). This particular situation explains the combined use of those two
464 languages in his chronicle.

465 C) "En este tiempo dizen que llegó la nueba como en el **Cuzco** ubo un milagro que como
466 un **yaurca** o **amaro** abía salido del serro de **Pachatusan** muy fiera bestia, media
467 legua de largo y grueso de dos bragas y medio de ancho, y con orejas y colmillos <y
468 barbas>¹. Y viene por **Yuncay Pampa** y **Sinca**, y de allí entra a la laguna de
469 **Quibipay**, y entonges salen de **Aosancata** dos **sacacas** de fuego, y passa a **Potina** <de
470 **Ariquipa**>, y otro viene para más abaxo de **Guamanca**, que está y tres o quatro serros
471 muy altos cubierto de niebes, los quales dizen que eran animales con alas y orejas y
472 colas y quatro pies, y ençima de las espaldas muchas espinas como de pescado, y
473 desde lejos dizen que les parecían todo fuego." (Pachacuti Yamqui Salcamaygua,
474 1993, p. 157-f.21-21v)

475 ¹ *Por caussa deste amaro puso por nombre a su hijo Amaro Yupangui* (A III).

476 D) We consider 1 league = ~ 5.5km and 1 fathom = ~ 1.6718m (Bauer, 2018, p. 47)
477 E) We base our chronological interpretation on the traditional Inca's chronology
478 elaborated by John Rowe. He considered that Pachacuti Inca Yupanqui ruled between
479 approximately 1438 CE and 1471 CE, based on colonial texts and calculations of the
480 number of years remaining until the Spanish Conquest. Since he died quite old (~70-
481 80) according to chronicles, it seems probable that Amaru Tupa was born around 1440
482 CE. Our assumed dating is, for sure, tentative due to the questions that still surround
483 Inca genealogy and succession (Duviols, 1979; Marsh et al., 2017; Meyers, 2019;
484 Ogburn, 2012), but should be regarded as a baseline for future paleo-and
485 archaeoseismological investigations. The assumed relation between the Amaru legend
486 and the name of the eldest son of the emperor Pachacuti justifies the dating attempt.

487

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499

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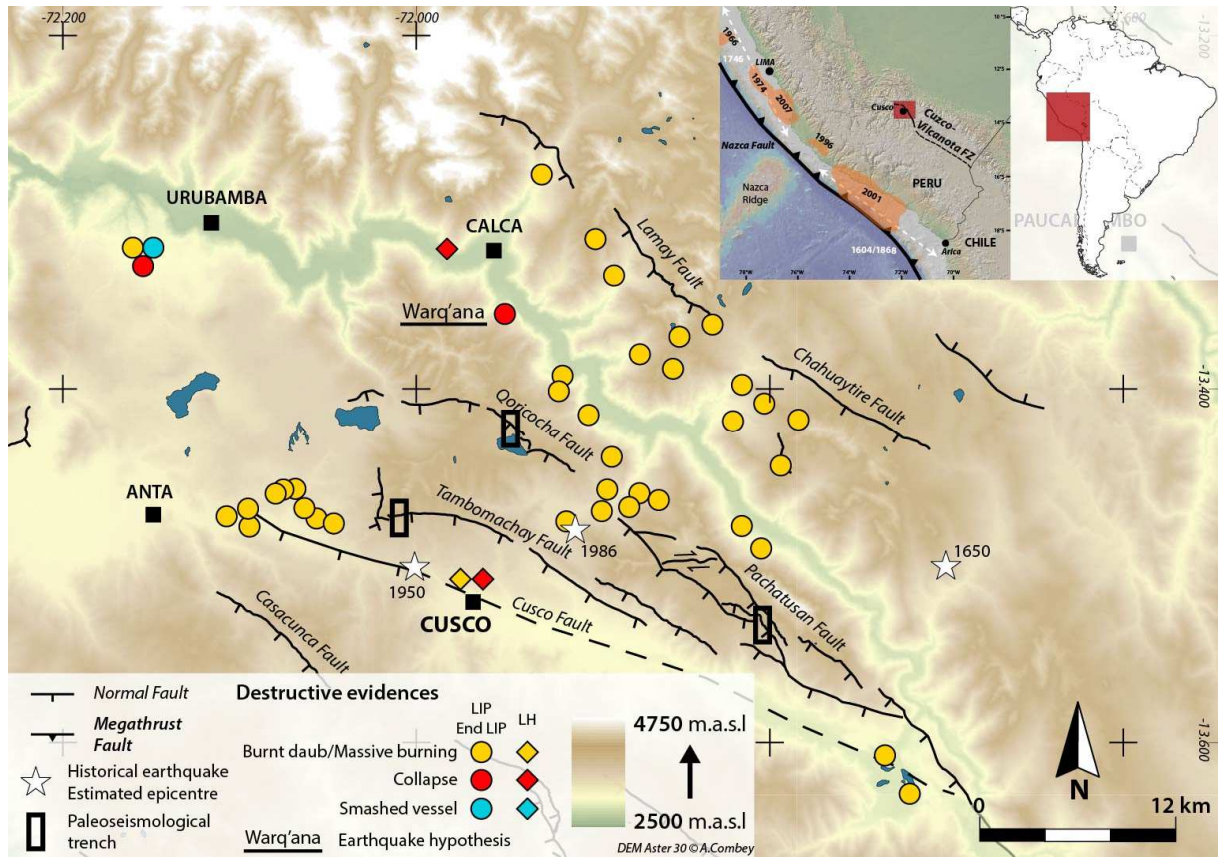


Fig.1. Map listing the archaeological evidence of destructive events (without a determined origin) dated from the Late Intermediate Period and the Late Horizon in the Cusco area (Covey, 2006; Kendall et al., 1992; McEwan et al., 2005; Quave et al., 2018; Vargas P., 2007). The earthquake hypothesis was only alleged in one case.

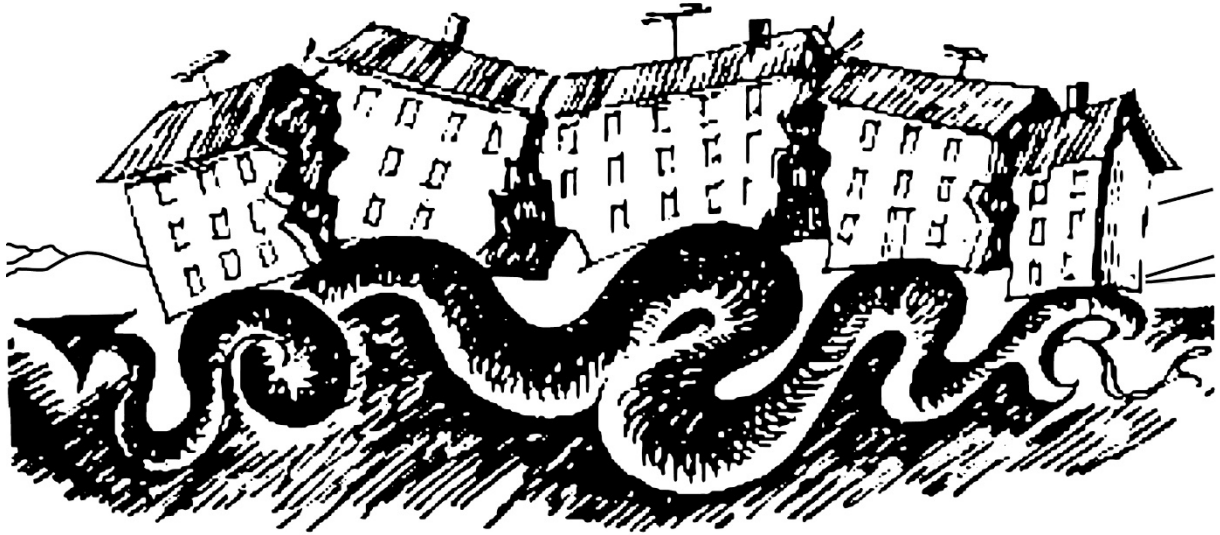


Fig.2. Wiggling of a Dragon-like creature as a metaphor of the ground motion during an earthquake: “let us resort to some imagination to fancy the picture of ground motion under a structure during an earthquake. In my opinion, it can be best illustrated by an image of a gigantic snake-like dragon moving under the building by throwing its body into vertical loops” (Kirikov, 1992, p. 11).

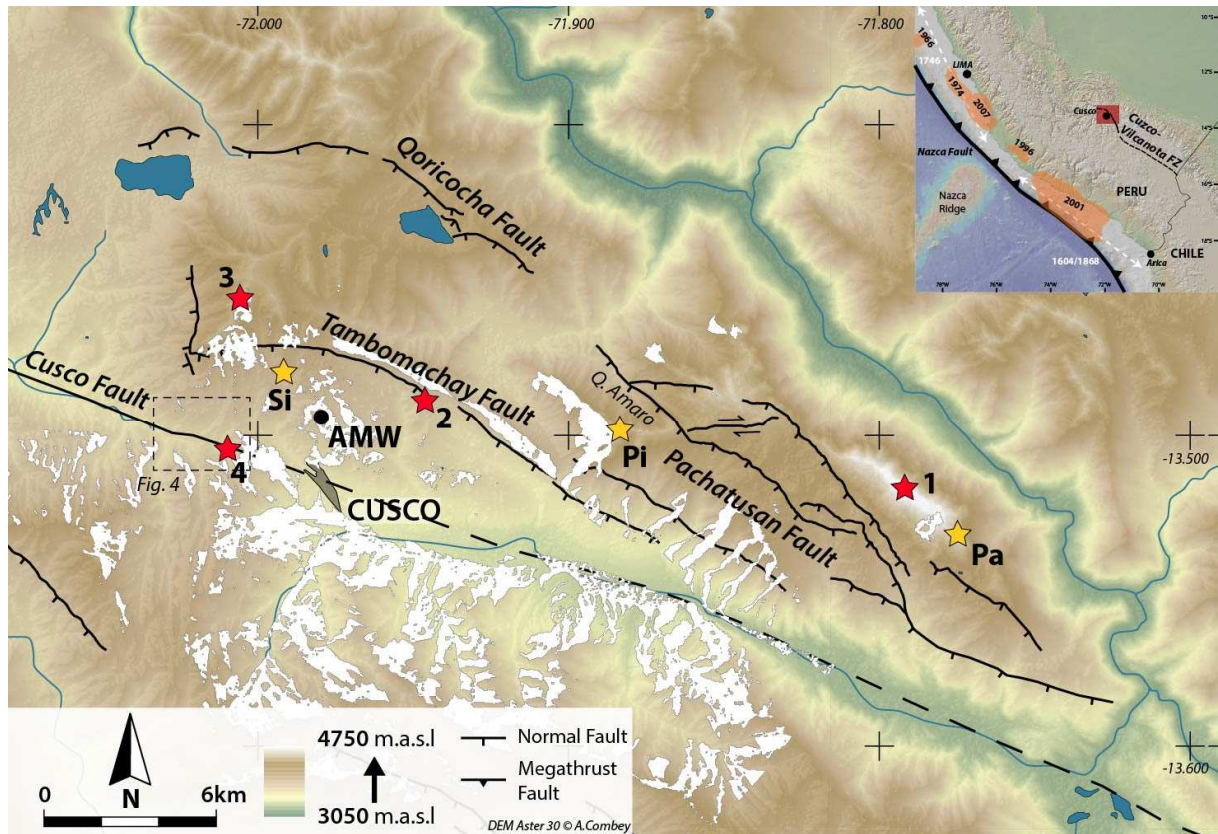


Fig.3. Map of the Cusco valley showing the layout of the Pachatusan-Tambomachay-Cusco Fault System as well as the geographical places (red stars) mentioned in the Pachacuti Yamqui's text. 1- Pachatusan; 2- Yuncaypata; 3- Sinqa summit 4- Cruz Verde de Quehuepay. "Pa" refers to the Paukarcancha site, "Pi" to the Picol summit and "Si" to the Sinca huaca. White areas show what can be seen from the Amaru Marca Wasi site (black point, AMW) and therefore highlight that large segments of the fault system are visible from that spot.

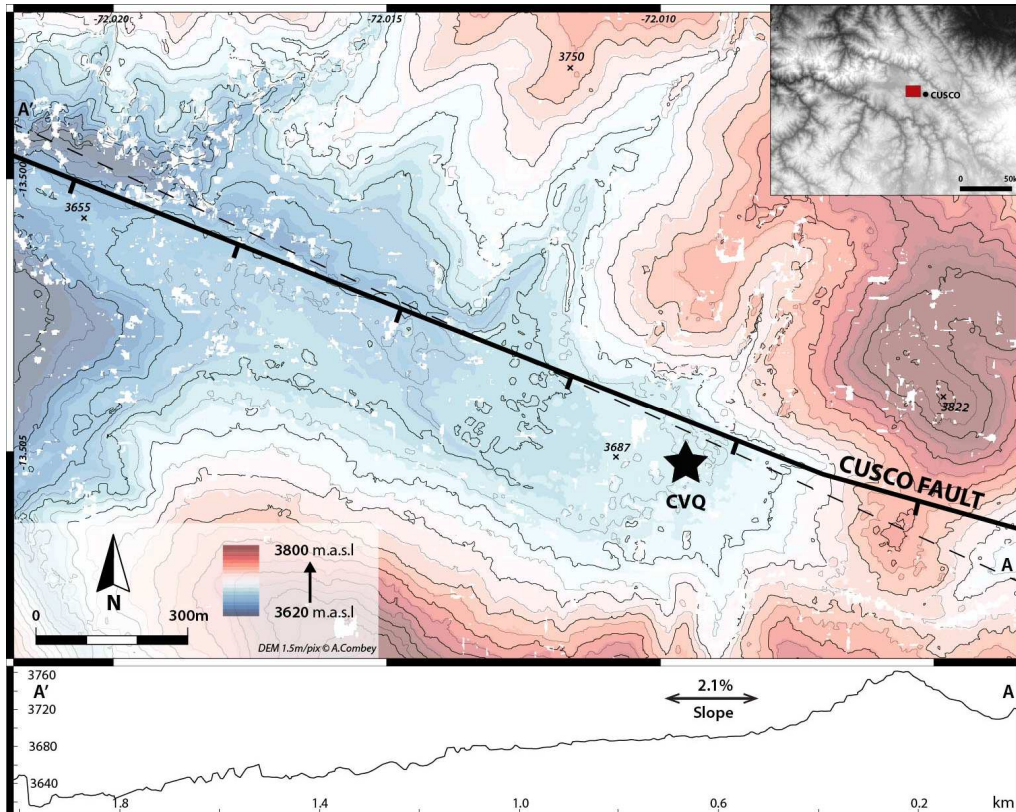


Fig.4. Topographic map of the Quehuepay area. The black star marks the location of Cruz Verde de Quehuepay (CVQ). The gentle slope illustrated in the topographic profile (AA') explains easily the former name Quibipay *pampa* and its ability to retain water.

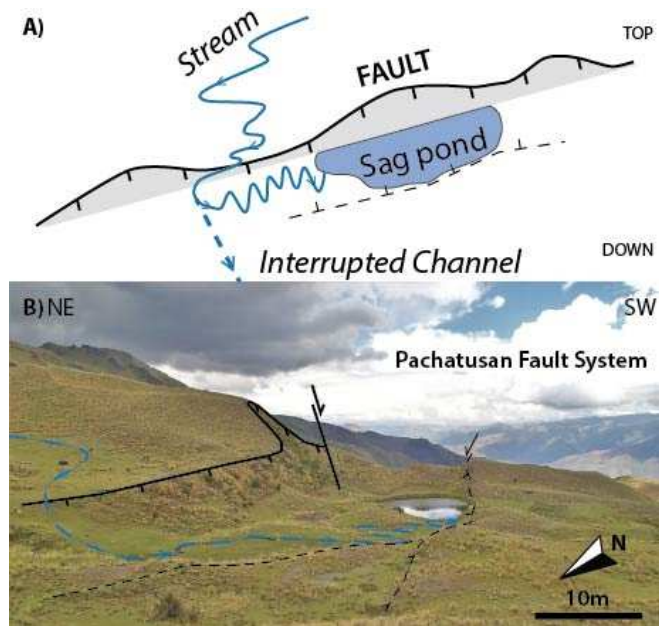


Fig.5. A) Sketch of a “sag pond”. A depression develops in the shear zone of the fault and interrupts the drainage. The subsequent lakes accommodate along this tectonic landform and highlight the fault trace even in steep landscapes. B) Example of sag pond at the foot of a Pachatusan fault segment.

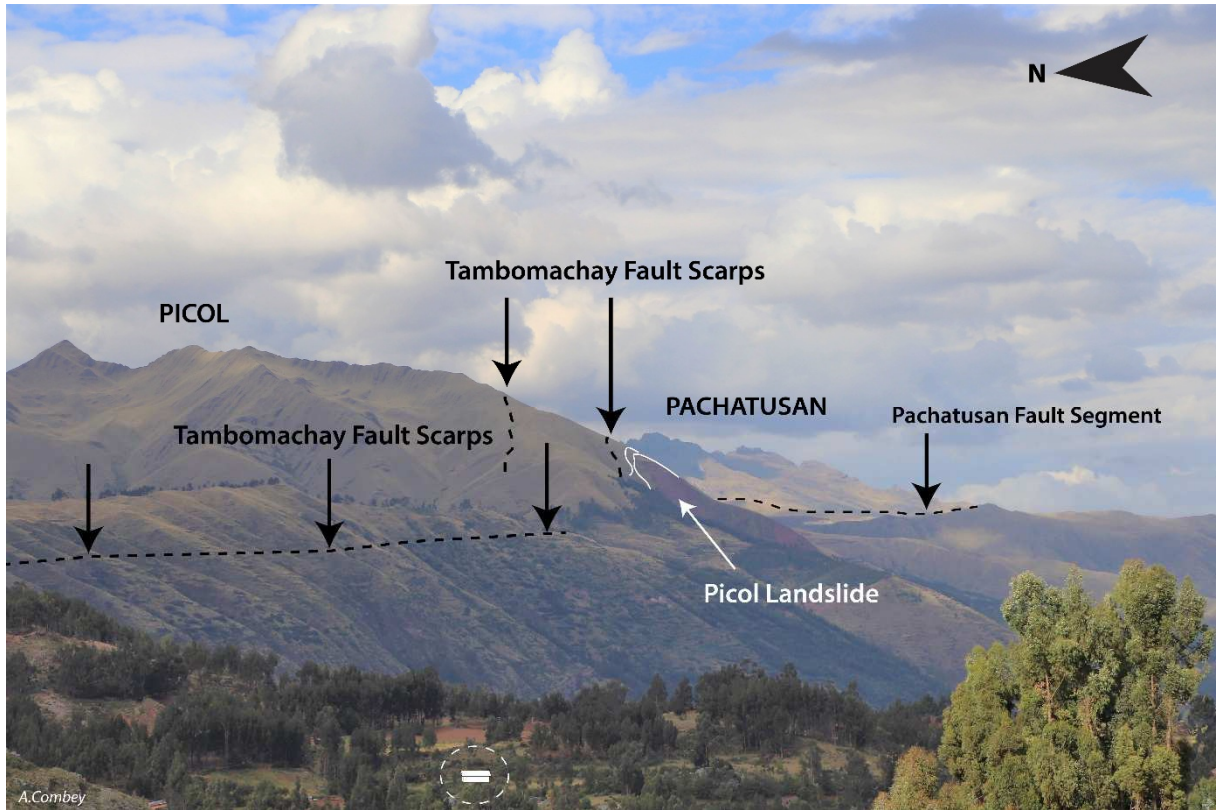


Fig.6. Panorama from the Amaru Marca Wasi archaeological site. The Tambomachay Fault Segment and the Picol landslide represent the most salient features in the landscape visible from that location. Note that the Pachatusan Fault segment is also visible in the background, forming a comprehensive panorama of the “snake like” scarps.

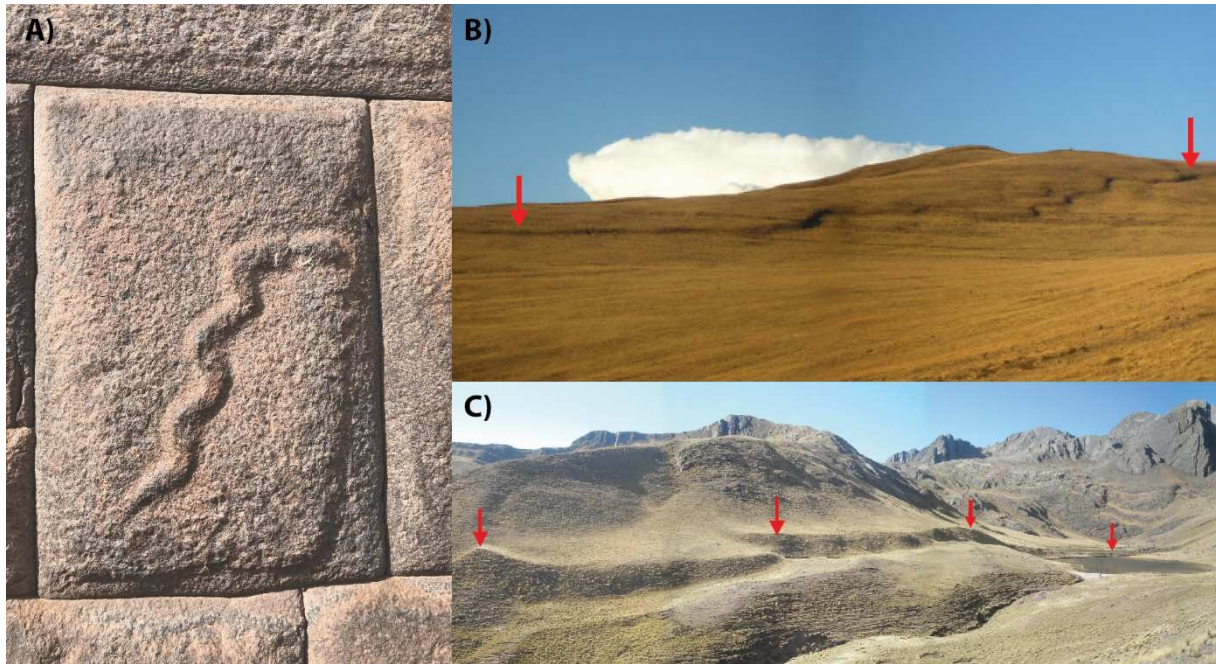
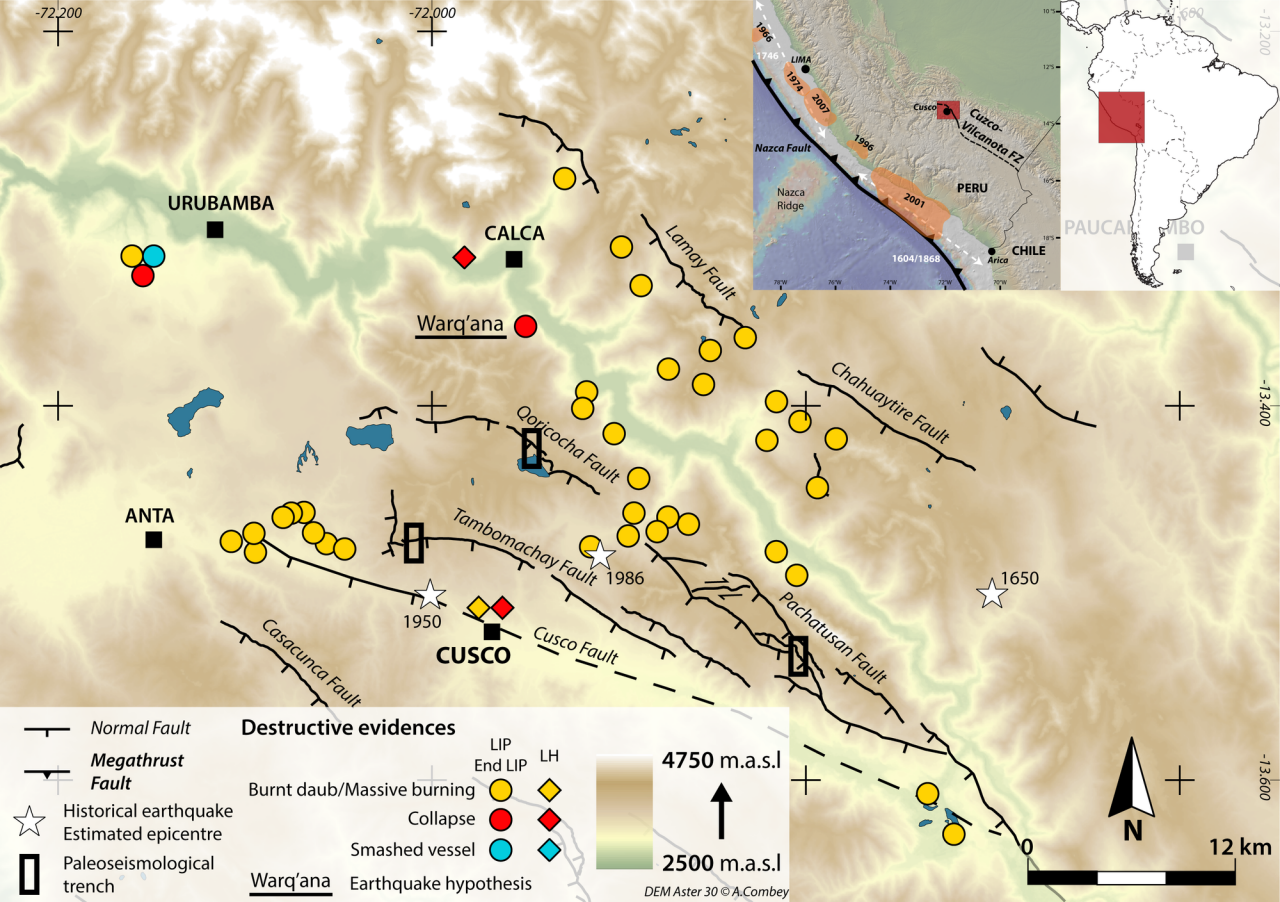


Fig.7. A) Apotropaic figure in architectural elements, the serpent carved motif is a common representation in Inca/colonial walls of Cusco (photograph: Beaterio de las Nazarenas – Siete Culebras). B) Qoricocha fault scarp and C) Langui Layo fault segment. In a similar fashion to modern observers, people during pre-Columbian times might have easily perceived these landforms as a serpent making its way underground.



- Normal Fault
- Megathrust Fault

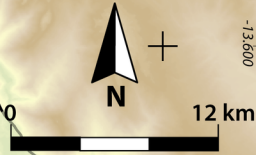
Destructive evidences

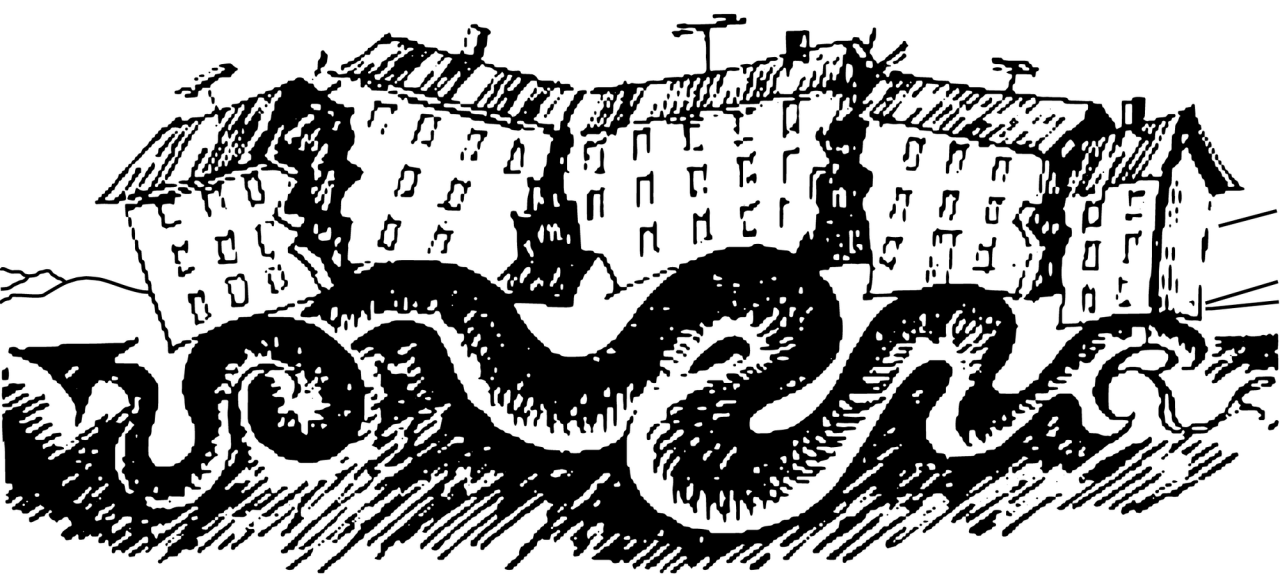
- ☆ Historical earthquake
- ☆ Estimated epicentre
- ▭ Paleoseismological trench

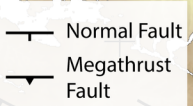
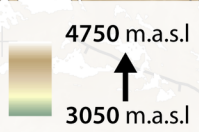
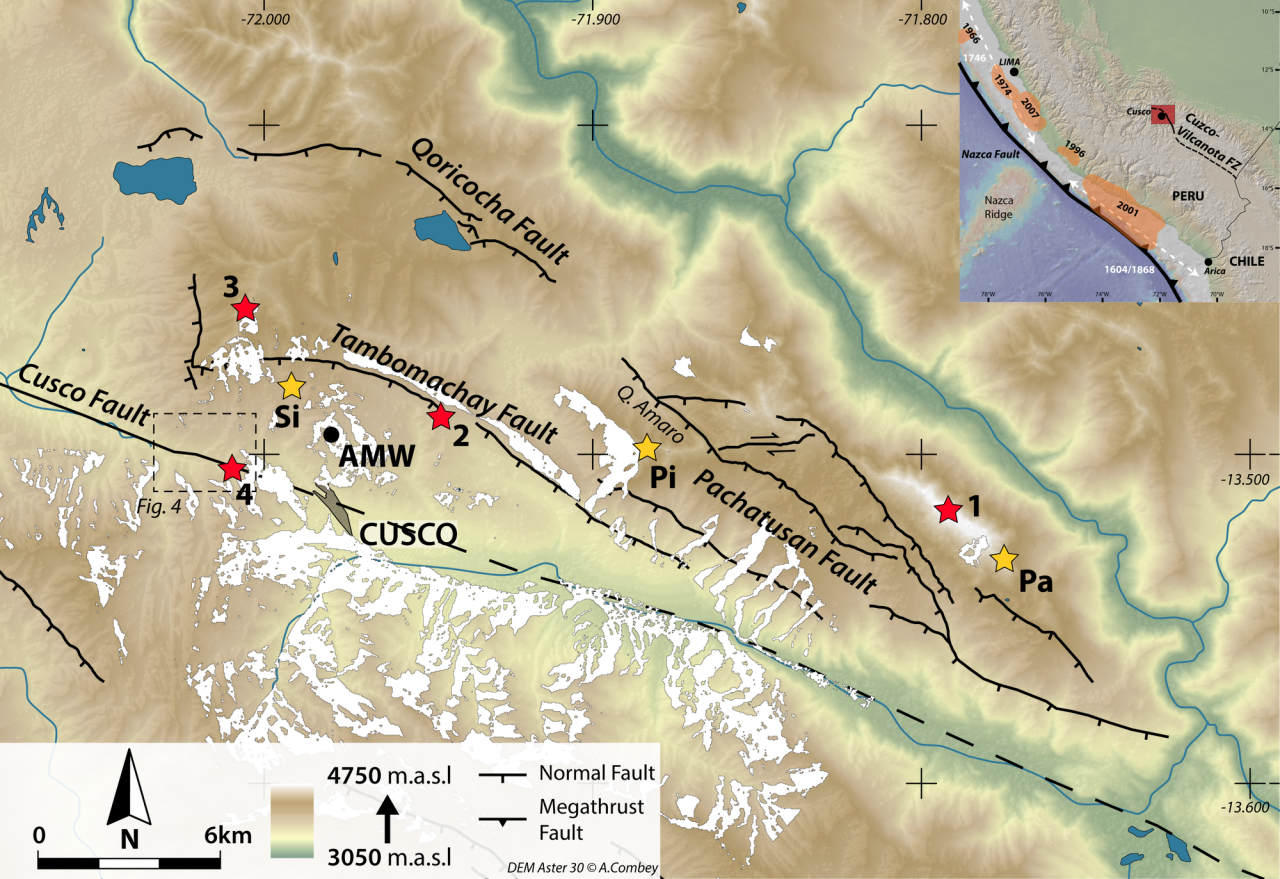
- | | | |
|----------------------------|-----|----|
| | LIP | LH |
| Burnt daub/Massive burning | ● | ◆ |
| Collapse | ● | ◆ |
| Smashed vessel | ● | ◆ |
| Earthquake hypothesis | — | — |



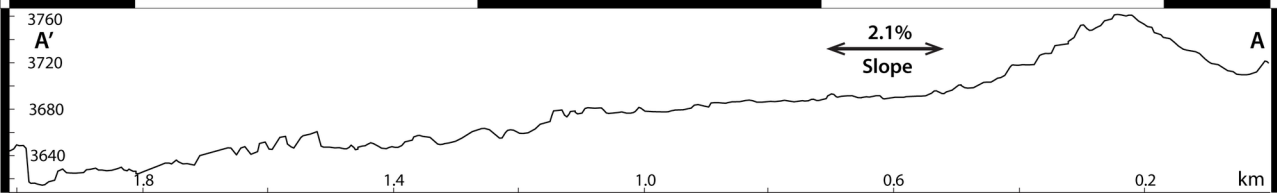
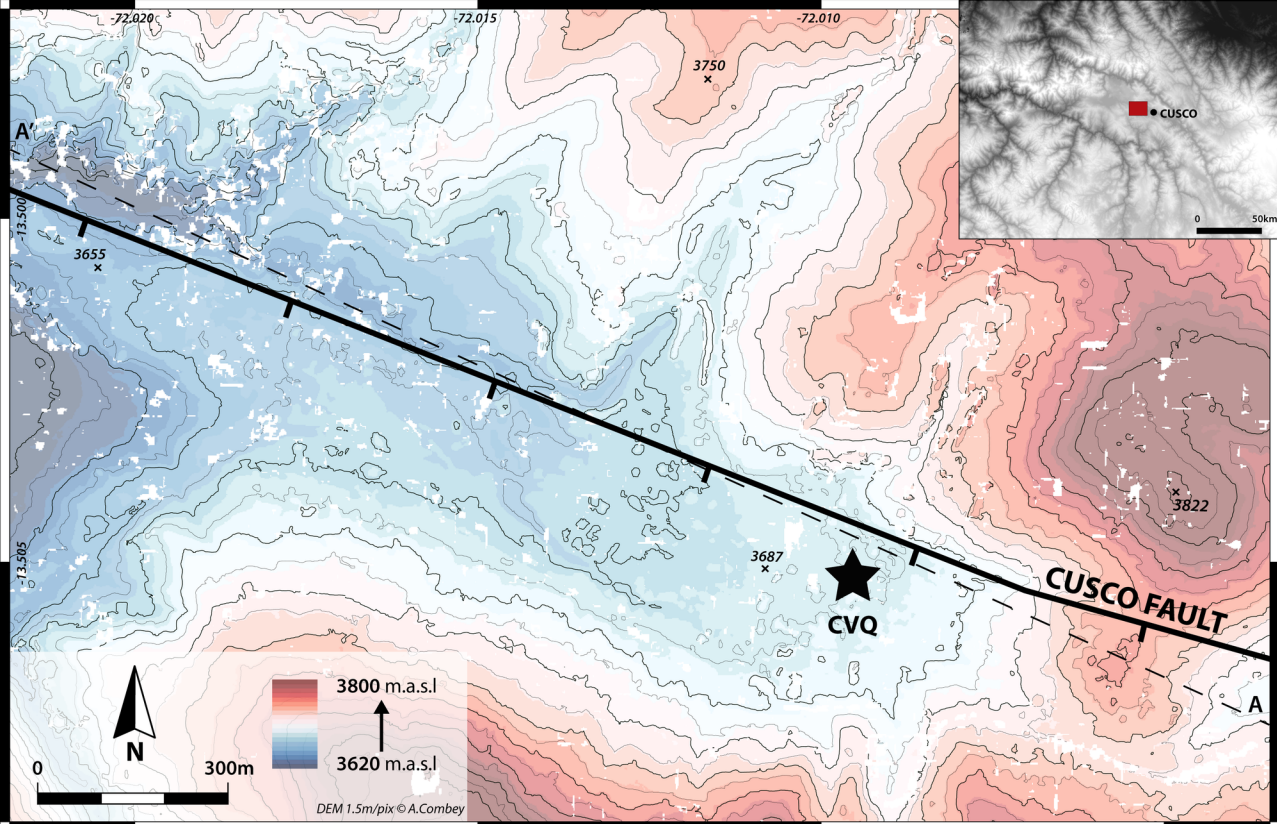
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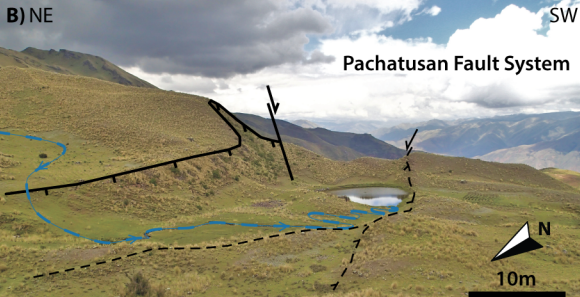
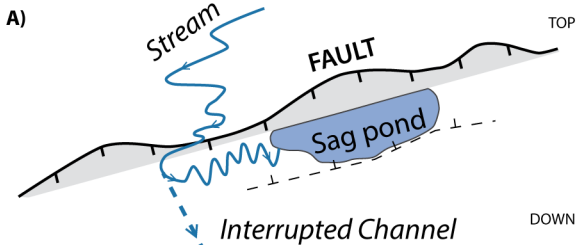


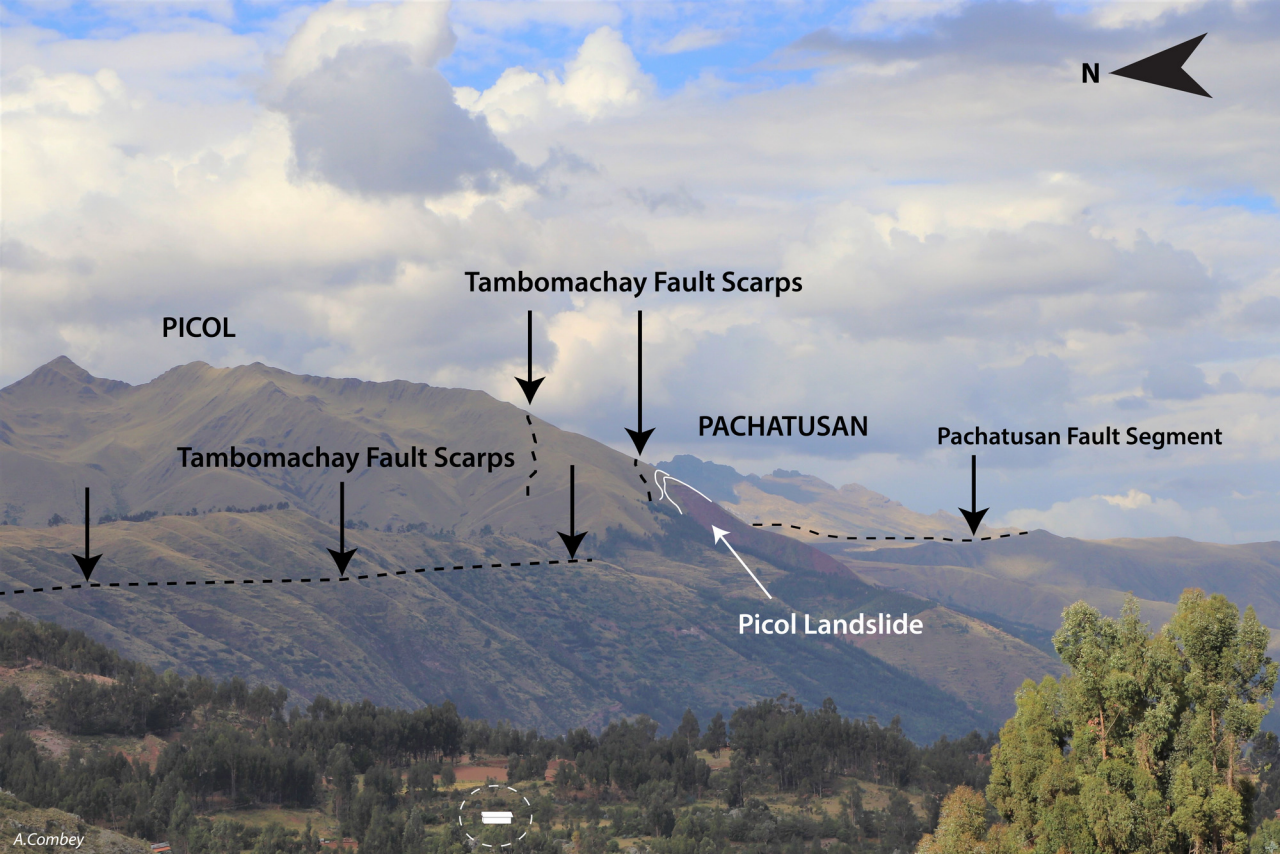




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PICOL

Tambomachay Fault Scarps

Tambomachay Fault Scarps

PACHATUSAN

Pachatusan Fault Segment

Picol Landslide



