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SUPPLEMENTARY ONLINE MATERIAL FOR

New Palaeogene South American Native Ungulates from the Quebrada de los Colorados Formation at Los Cardones National Park, Salta Province (Argentina)

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Supplementary Online Material

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SOM 1. Geological Setting.

Los Cardones National Park is located in the Calchaquí Valleys, Salta Province, Northwestern Argentina (see SOM 2B). The fossil specimens studied here were collected from the lower levels of the Quebrada de Los Colorados Fm. (middle Eocene; Casamayoran SALMA) exposed along the Camino de los Colorados road, mostly at the Quebrada Grande locality. In this locality, the stratigraphic relationships of the Quebrada de Los Colorados Fm. are, at the base, with the Lumbrera Fm. (lower section), and, at the top, with the Angastaco Fm. (Del Papa et al. 2013a).

The Quebrada de Los Colorados Fm. comprises fluvial deposits widespread throughout western areas of the Salta Province, particularly along the Calchaquí and neighbouring valleys (Starck and Vergani 1996; Hongn et al. 2007; Payrola-Bosio et al. 2009; Aramayo 2015). The unit consists of an upward coarsening succession of sandstone and conglomeratic sandstone, with interbedded brick-red siltstone beds in the Calchaquí Valleys (DeCelles et al. 2011) (see SOM 2A). Del Papa et al. (2013a) and Chornogubsky et al. (2018) provided a detailed stratigraphic analysis of the Quebrada Grande locality, in which most studied specimens were collected. Del Papa et al. (2013a) divided the Quebrada de Los Colorados Fm. into three sequences, from the base to the top, LCI, LCII, and LCIII, which represent different depositional cycles (Del Papa et al. 2013a). The first sequence (LCI), about 230–300 m thick, is characterized by laterally extensive, red coloured clayey to sandy siltstones with local paedogenic calcretes, interbedded with sandstone beds (Del Papa et al. 2013b: fig. 4c). The facies association represents a wide floodplain in a context of meandering rivers environments. The specimens described here were recovered in association with several metatherian mammals from the LCI, around 10–15 m above the contact with the underlying Lumbrera Fm. The base of the Quebrada Los Colorados Fm.

has been dated to 40.6 Ma at 155 m above the contact with the Lumbrera Fm. at Monte Nieva (DeCelles et al. 2011; see below). Due to the fact that the LCI mammal-bearing levels at Quebrada Grande are 140 m below this dated horizon (see SOM 2A), an age older than 40.6 Ma (Lutetian–Bartonian, middle Eocene) is established for the SANU fauna presented here.

The fossil-bearing levels of Quebrada de Los Colorados Fm. have been correlated with those of the Casa Grande and Geste formations and the upper section of the Lumbrera Fm. (Deraco and Powell 2003; Hongn et al. 2007; Powell et al. 2011) on the basis of a partial faunistic similarity. However, Chornogubsky et al. (2018) proposed a correlation framework based on geochronological dates, which did not completely support this correlation. The mammal-bearing levels of the Geste Fm. are dated between 37–35 Ma (Priabonian) (DeCelles et al. 2007), being younger than those of the base of the Quebrada de Los Colorados (40 Ma; Carrapa et al. 2011) and the upper section of Lumbrera (39.9 Ma; Del Papa et al. 2010) formations. Following the current geochronological dates, the mammal-bearing levels of the lower section of the Quebrada de Los Colorados Fm. (LCI) and those of the upper section of Lumbrera Fm. are chronologically equivalent (SOM 3). At the moment, the Casa Grande Fm. has not yielded any geochronological date, thus, its equivalence with the Quebrada de Los Colorados Fm. needs to be taken with caution. In the South American biochronological context (Woodburne et al. 2014), the fauna of Quebrada de Los Colorados Fm. plus that of the upper section of Lumbrera Fm. have been correlated to the Casamayoran SALMA (García-López et al. 2019), whereas the fauna of the Geste Fm. is correlated to the Mustersan SALMA (Chornogubsky et al. 2018: fig. 7, and references therein).

The Quebrada de Los Colorados, Lumbreira, and Geste formations are located in distinct physiographic provinces: the Puna Plateau (Geste), the Eastern Cordillera (Quebrada de Los Colorados), and the transition zone between the Eastern Cordillera and the Subandean Ranges (Lumbreira) (Payrola-Bosio et al. 2020; SOM 2B). The uprise of the Central Andes not only influenced the altitudinal profile of the area, but also the horizontal distance throughout its origin that accommodated a maximum of 150 km of shortening (Kley and Monaldi 1999). Each of these areas experienced different structural evolutions related to the eastward advance of fold-thrust deformation (Carrapa et al. 2011; Pearson et al. 2013; Payrola-Bosio et al. 2020), and the reactivation of several pre-Andean faults, resulting in a complex uprise pattern along the Puna Plateau and the Eastern Cordillera (Pearson et al. 2013). By the time of deposition of the Quebrada de Los Colorados and the upper section of the Lumbreira formations, the Puna Plateau approximately reached an altitude of more than 3000 m (Quade et al. 2015), constituting a conspicuous structural high in the region. At the same time, the Calchaquí Valleys were already elevated respect to the Lerma Valley, and formed the eastern deformation front (Payrola-Bosio et al. 2020). Unfortunately, there is no available paleoaltimetry data in order to evaluate the magnitude of the topographical change between the Calchaquí and Lerma valleys, and the presence of a geographical barrier. Regarding the Puna Plateau, stable isotope paleoaltimetry indicates that, by the time of Geste fauna (38–36 Ma), most of the Puna Plateau had attained an elevation of ~4 km (Canavan et al. 2014; Carrapa et al. 2014; Quade et al. 2015: 26). An alternative interpretation suggests a lower altitude (~2.5–3 km) during the Eocene, similar to the modern intermontane basins (Pingel et al. 2020: 11).

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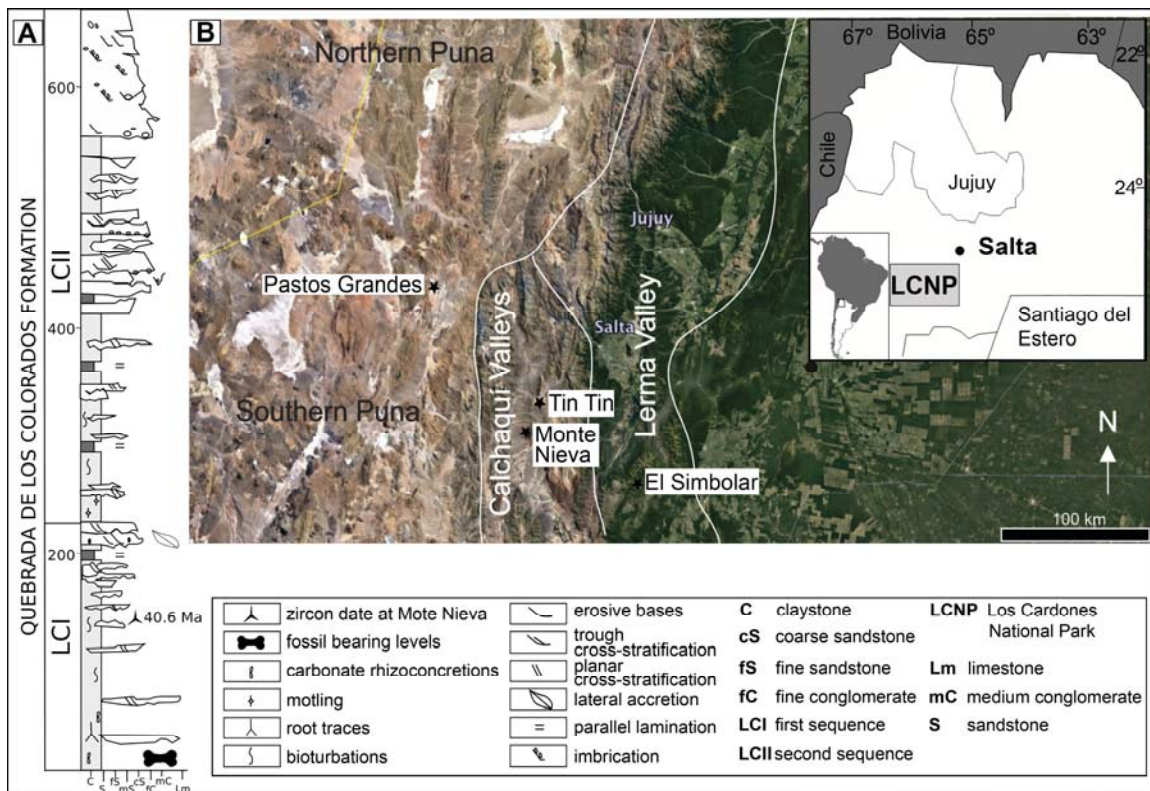
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SOM 2. Localities and stratigraphy of the studied area. **A.** Sedimentary log of the Quebrada de Los Colorados Formation at Quebrada Grande, Los Cardones National Park, Salta Province (modified from Del Papa et al. 2013a and Chornogubsky et al. 2018). **B.** Geographic location of the study area (taken from Google maps) with the main physiographic provinces discussed throughout the text. [intended width: 183 mm]

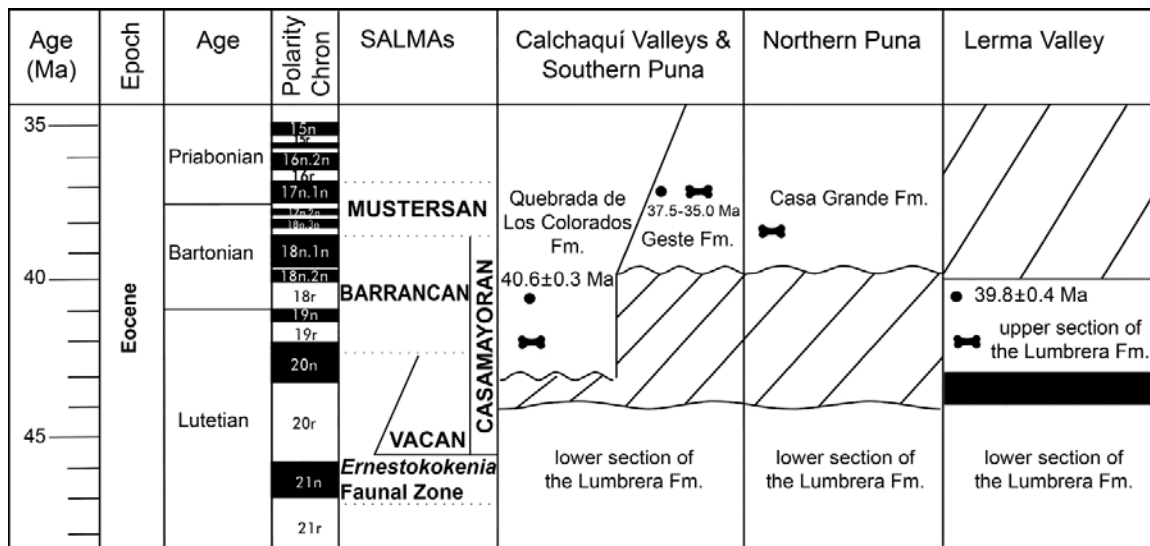


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SOM 3. Eocene chronostratigraphic chart of Northwestern Argentina. Black circles represent the known isotopic dates; bones drawings represent the mammal-bearing levels. Dates for: Quebrada de los Colorados Fm. after DeCelles et al. (2011); Geste Fm. after DeCelles et al. (2007); Lumbrera Fm. after Del Papa et al. (2010); global polarity time scale after Ogg (2012). South American Land Mammals ages after Woodburne et al. (2014) and Zimicz et al. (2020). [intended width: 183 mm]



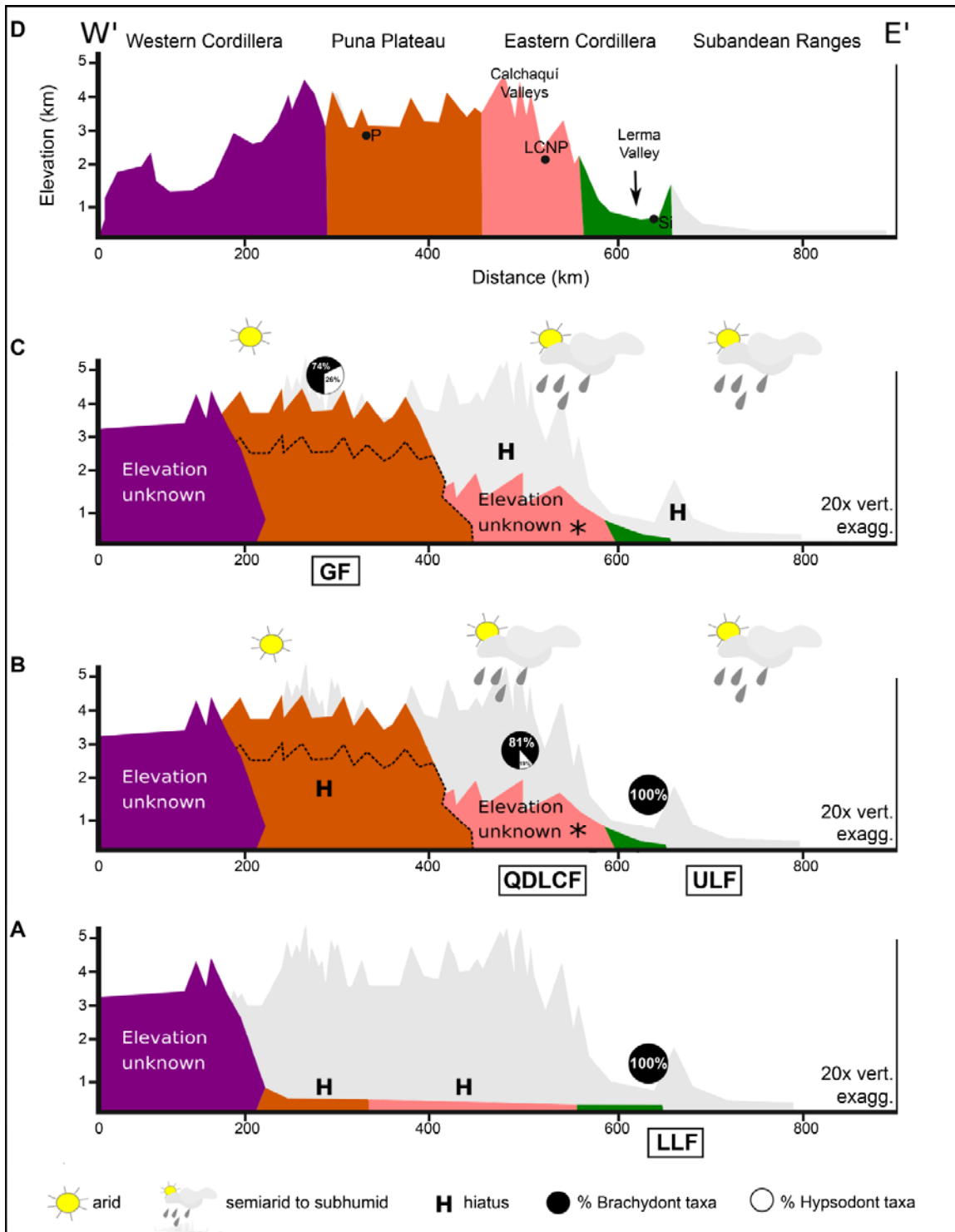
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SOM 4. Stratigraphic and chronological distribution of the taxa of South American Native Ungulates recognized in the Palaeogene of Northwestern Argentina. * indicates the genera also present in Patagonia (Argentina). Abbreviations: Ind, Indaleciidae; “Arch”, “Archaeohyracidae”; Ast, Astrapotheria; Astr, Astrapotheriidae; “Camp”, “Campanorcidae”; Didol, Didolodontidae; EFZ, *Ernestokokenia* Faunal Zone; H, hiatus; Inter, Interatheriidae; “Isot”, “Isotemnidae”; Leont, Leontiniidae; Lito, Litopterna; Noto, Notoungulata; “Notoh”, “Notohippidae”; “Notos”, “Notostylopidae”; “Oldf”, “Oldfieldthomasiidae”; Pyr, Pyrotheria; Pyro, Pyrotheriidae; Tox, Toxodontia; Typ, Typotheria. [intended width: 183 mm]

SOM 5. Hypothetical model of the distribution of brachydont and hypsodont taxa along the topographical gradient through the early to late Eocene. Lower section of the Lumbreira fauna (**D**), upper section of the Lumbreira and Quebrada de Los Colorados faunas (**C**), Geste fauna (**B**), and recent altitudinal profile of the studied area (**A**) in a west-east transect at 24–25°S with the main physiographic areas discussed in the paper. The physiographic areas are indicated in different colors; light grey (in B–D) indicates the modern altitudinal profile. Topographic and climatic models were modified after Quade et al. (2015), except for the Calchaquí Valleys during the time deposition of the Quebrada de Los Colorados Formation (*) that follows Payrola-Bosio et al. (2020). Broken line in the Puna Plateau indicates the topographical range suggested by Pingel et al. (2020). Abbreviations: GF, Geste Formation; H, geographical hiatus in the fossil record; LCNP, Los Cardones National Park; LLF, lower section of the Lumbreira Formation; P, Pastos Grandes; QDLCF, Quebrada de Los Colorados Formation; Si, El Simbolar; ULF, upper section of the Lumbreira Formation. [intended width: 183 mm]



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SOM 6. Discussion of the Northwestern faunas along the topographical gradient.

During the Eocene, the Central Andes uplift controlled landscape evolution in the Northwestern Argentina (Canavan et al. 2014; Quade et al. 2015; Payrola-Bosio et al. 2020) (see SOM 6), a fact that could have had an important role in the faunistic differences mentioned in the text regarding the number of foreign genera registered in each stratigraphic unit. Additional differences concerning the presence of hypsodont taxa emerge when the faunas are analyzed along the topographical cline (see SOM 6). The ancient Eocene fauna of the lower section of the Lumbrera Fm. has been mostly recovered from El Simbolar, at the eastern margin of the Lerma Valley (Si, see SOM 6), and adjacent localities (e.g. Pampa Grande). If the levels with the didolodontid *Saltaodus* (Gelfo et al. 2020) that outcrop at the Puna plateau correspond to the lower section of the Lumbrera Fm. (see SOM 6), this would mean that the fauna (or at least some faunistic elements) occupied the whole territory along the west-east transect. All ungulates that have been recovered from the lower section of the Lumbrera Fm. are brachydont taxa. During the late middle Eocene (40 Ma), the ungulate faunas were distributed in the Calchaquí and Lerma valleys (see SOM 6), as well as in the Puna Plateau, but only if the levels with *Saltaodus* correspond to the upper section of Lumbrera Fm. instead of the lower one (see SOM 6). The fauna of the Calchaquí Valleys (Quebrada de Los Colorados Fm.) shows the first record (in a temporal context) of hypsodont ungulates (García-López et al. 2020), whereas these are absent in the eastern fauna of the Lerma Valley (upper section of the Lumbrera Fm.) (see SOM 6). In this sense, the fauna of the Quebrada de los Colorados Fm. could be characterized as a mixed fauna composed by brachydont and hypsodont ungulates (see SOM 8). In addition, this unit has delivered the first record of marsupials with hypsodont incisors (see Chornogubsky et al. 2018), a fact that reinforces the presence of more

hypsodont taxa in this unit. Strikingly, aff. *Eohyrax*, one of the three hypsodont ungulates that have been recovered from the Quebrada de los Colorados Fm. (see above), has affinities with the Patagonian *Eohyrax* (García-López et al. 2020). The presence of Patagonian elements in this unit is also reinforced by the record of the didolodontid *Ernestokokenia* and the notostylopid *Homalostylops*. On the contrary, the upper section of the Lumbrera Fm. is composed exclusively by brachydont taxa (see SOM 8), which are all endemic elements of Northwestern Argentina. By the late Eocene (ca. 37 Ma), the fauna of the Geste Fm., which occurs at the western end of the cline in the Puna Plateau (see SOM 6), is also a mixed assemblage. The presence of hypsodont tyotheres (i.e., “archaeohyracids”) and some Patagonian elements (i.e., *Pseudhyrax*, *Propyrotherium*, and *Ernestokokenia*) in this unit is a feature shared with the Quebrada de los Colorados Fm. In addition, in the Geste fauna, the interatheriids, “archaeohyracids”, and “oldfieldthomasiids” are the most abundant groups within the SANUs.

In general terms, the appearance of hypsodont taxa in Northwestern Argentina is chronologically coincident with the pattern observed in the well-studied outcrops of Patagonia (Madden 2014). In regional terms, it is interesting to note that the distribution of hypsodont taxa during the middle Eocene is coincident with the eastward advance of fold-thrust deformation (see SOM 6). As mentioned earlier, around 40 Ma, the orogenic front was located at the Tonco Valley (Payrola-Bosio et al. 2020), while the Lerma Valley, especially its eastern margin (El Simbolar locality), was not deformed by that time. García-López et al. (2020) postulated that the high diversity of hypsodont taxa (i.e., “Archaeohyracidae”) in Northwestern Argentina during the middle late Eocene indicates an early diversification of the group in this area. This suggests that in the lower levels of the Lumbrera Fm., the “archaeohyracids” should be present, but have not been identified yet.

However, the paraphyletic condition of this group (e.g., Reguero and Prevosti 2010; Billet 2011) and the exclusive brachydont composition of the lower Lumbreira fauna do not support this hypothesis. In addition, the sudden appearance of additional Patagonian elements in the Calchaquí Valleys (Quebrada de los Colorados Fm.) during the Casamayoran and, later, during the Mustersan (Geste Fm.) in the Puna Plateau allows postulating a migration event of the SANUs from Patagonia to the intraorogen faunas of Northwestern Argentina. In fact, the differences between the Quebrada de los Colorados plus Geste and the lower and upper Lumbreira faunas correspond to taxonomic novelties (e.g., “Archaeohyracidae” and Interatheriidae) occurring in the Puna and Calchaquí Valleys, and not in the lower and upper Lumbreira faunas (see SOM 6). In this sense, it is possible that the landscapes that developed along the intraorogen basins during the Eocene could be the connection path with Patagonia that was used by ungulates to reach the Calchaquí Valleys and the Puna Plateau some time during the Eocene. As suggested by García-López (2020), the absence of these taxa in the Lerma valley could be the result of topographical barriers and/or environmental differences that would have established an oriental endemism and a circulation area in the center and west, where non-endemic hypsodont taxa are registered.

The different faunal contents for the Lumbreira (lower and upper sections), Quebrada de Los Colorados, and Geste formations could be associated to a differential sampling effort or taphonomic biases. However, both the Geste and Lumbreira formations have been extensively explored, even with sorting techniques (Babot et al. 2019), and have produced abundant and well-preserved specimens throughout the years (see Powell et al. 2011). In this sense, although the taphonomic biases and the sampling effort could play a role in the recorded faunal disparity, the effect of orogeny as a factor regulating the

dynamics of the ungulate faunas in Northwestern Argentina should not be discarded, although, this variable should be carefully (and more deeply) assessed.

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SOM 7. Hypsodonty categorization of the genera identified in the Quebrada de Los Colorados, Geste, Casa Grande, and Lumbreira (upper and lower levels) formations. **A.** Hypsodont genera. **B.** Brachydont genera. [intended width: 183 mm]

