Stratigraphic revision of *Coahuilaceratops magnacuera* as the first dinosaur from the Lower Maastrichtian Cerro Huerta Formation

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Introduction:

The Parras Basin in the southeastern part of Coahuila in northern Mexico has provided a substantial proportion of the known fossil record from the Late Cretaceous of Southern North America. Within the Parras Basin, the Difunta Group has produced a remarkable number of fossil discoveries, resulting in the description of several new taxa over the past two decades, including *Velafrons* and *Tlatolophus*. However, fundamental stratigraphic issues require resolution before the fossil assemblages of the Difunta Group can be properly compared and correlated within a global or North American stratigraphic framework.

In the early 2000s, international collaborations prospecting within the Difunta Group yielded rare ceratopsid remains, among them the chasmosaurine ceratopsid *Coahuilaceratops magnacuerna*, known from two individuals consisting of fragmentary skull remains[1]. Since then, various other chasmosaurine taxa such as *Navajoceratops* and *Terminocavus,* have been described from the southern portion of North America. These recent discoveries may prove to be important for our understanding of the evolution of the southern clade of ceratopsids through the late Campanian–early Maastrichtian.

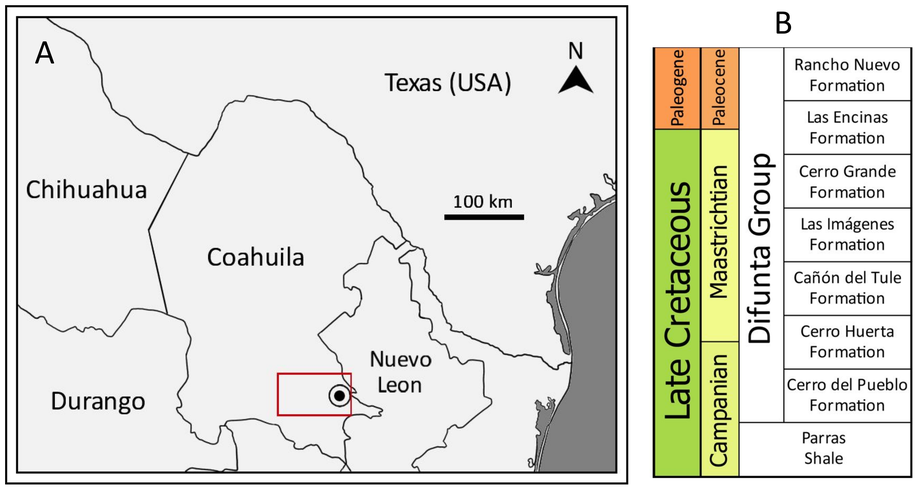

Fig. 1. (A) Geographical setting, map of northeastern Mexico; red rectangle indicates study area. (B) Stratigraphic chart showing the formational divisions and age of the Parras Basin.

Geological Framework:

The **Cerro del Pueblo Formation** (CdP) was deposited in a marginal marine setting, and is characterized by abundant thick gray mudstones and sandstones, interpreted as coastal plain, lagoonal and deltaic depositional settings with brackish, shallow marine environments that were developed along the eastern shore of Laramidia. The thickens of the CdP increases westward (Fig. 3). The CdP is posited to be Late Campanian in age, based on biostratigraphy[2], magnetostratigraphy[3] and isotopic analysis of strontium[4].

The **Cerro Huerta Formation** (CH) overlies the CdP and is characterized by red and green lithologies, with occasional interbedded gray strata. The CdP–CH contact is marked by "the base of the first red or green bed"[5]. The CdP–CH shift is marked by a transitional zone tens of meters thick, consisting of gray–green and red sediments, which show a gradual increase in the thickness of the red beds[3]. Currently, no age-diagnostic fossils have been recognized or described from the CH, limiting the biostratigraphic correlation. However, magnetostratigraphic analysis shows that the base of the CH spans the 32n.1r zone, while the overlaying Cañón del Tule Formation is correlated to near the boundary of the 31r.3r zone[3]. The CH has been interpreted as a more inland environment than the underlying CdP, comprising lacustrine and continental depositional environments with occasional marine-to-brackish ingress[2].

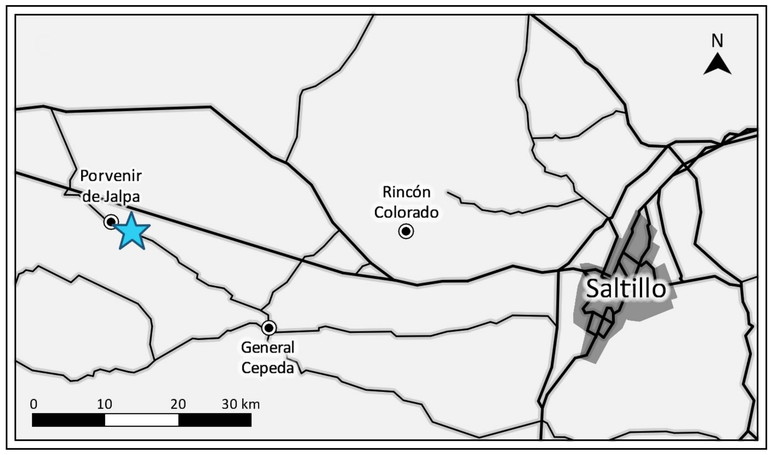

Fig. 2. Regional geographic map (for location in Mexico, see Figure 1); measured section marked with a blue star.

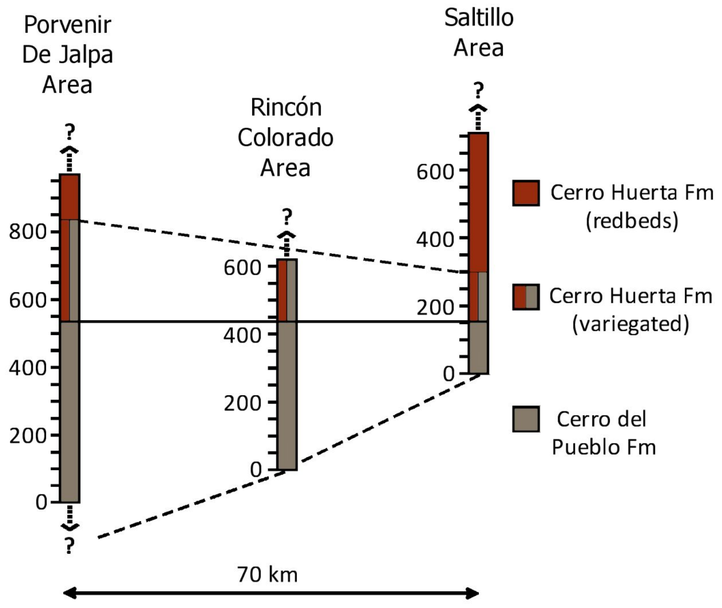

Fig. 3. West-East cross-sectional schematic of the CdP and CH; horizontal datum is the CdP - CH formational contact as indicated by the first occurrence of red beds, figure adapted from Eberth et al., 2004.

Measured Section:

The holotype *Coahuilaceratops* quarry was revisited with the original discoverer (C.L.D.) in order to compare its stratigraphy with newly discovered material within the Cerro del Pueblo Formation. It was then noticed by B.E.C. that the *Coahuilaceratops* quarry in fact occurs within the Cerro Huerta Formation and not the Cerro del Pueblo. A measured section was taken in the area immediately surrounding the sites, ~70 km west of Saltillo (Porvenir de Jalpa Area), in order to ascertain this with greater precision. Although the overall thickness of individual beds was measured, structural deformation could not be accurately determined within the section, likely having some repeating sections. Thus, although individual bed lithologies were reliably recorded, we advise caution regarding the total thickness of the units concerned and the precise stratigraphic position of formational boundaries and other sites of interest.

This formational reassignment makes *Coahuilaceratops* up to ~2 million years younger than previously thought. This is more consistent with its relatively derived phylogenetic position, with notable implications for paleobiological interpretation.

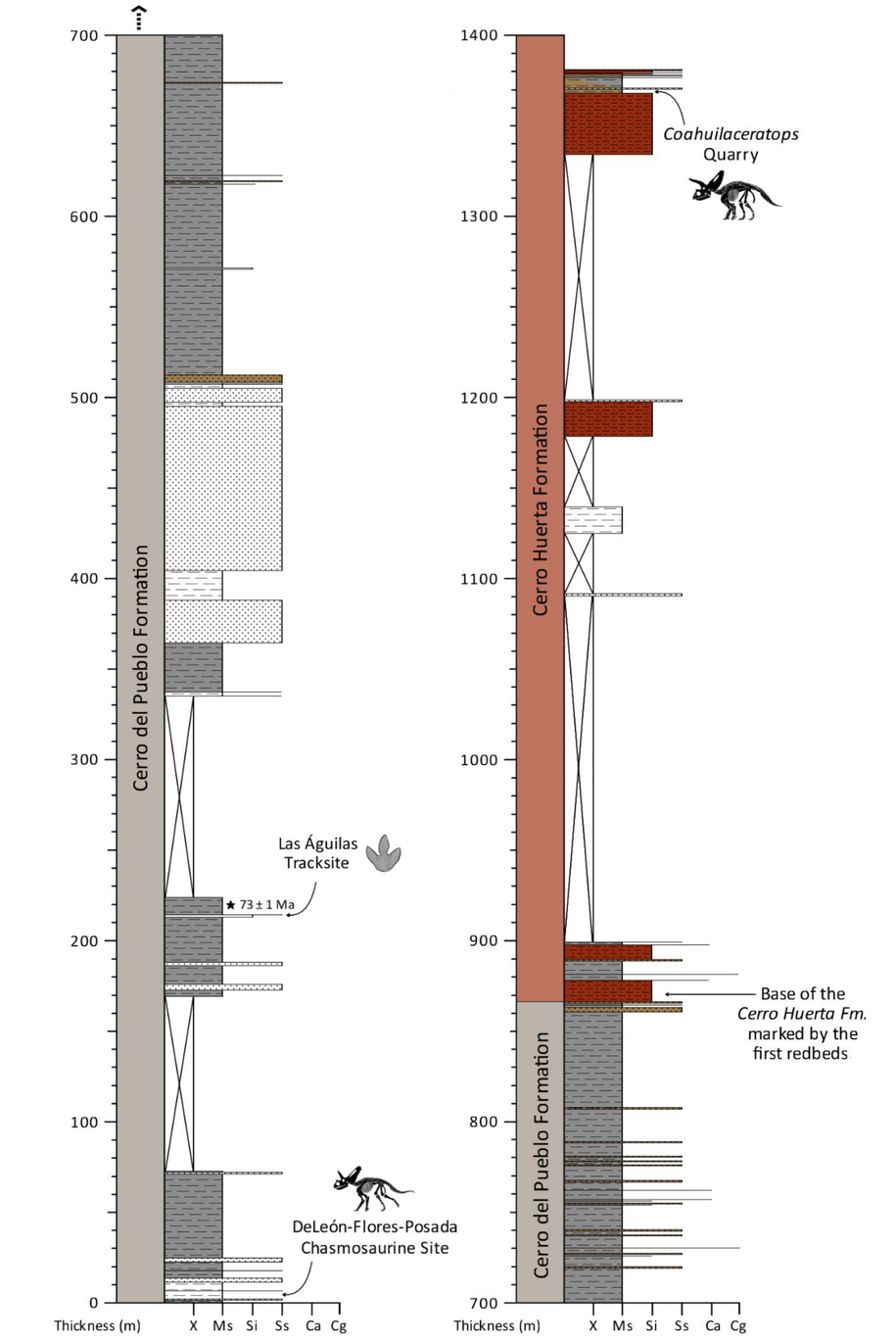

Fig. 4. Stratigraphic column of the measured section. Abbreviations: X, unexposed; Ms, mudstone; Si, siltstone; Ss, sandstone; Ca, calcite; Cg, conglomerate. Note the shift to redbed intervals, marking the Cerro del Pueblo–Cerro Huerta contact, revealing the Coahuilaceratops quarry nested in between redbeds, belonging to the Cerro Huerta Formation. Star indicates Strontium isotopic dating of oysters overlaying the Las Águilas Tracksite (Vogt et al., 2016).

Discussion:

Fowler and Freedman Fowler (2020) hypothesized that in the Middle to Late Campanian, the North American subcontinent of Laramidia was inhabited by two chasmosaurine clades (a northern "*Chasmosaurus* lineage" and a southern "*Pentaceratops* lineage"). These were created by vicariance in the Early or Middle Campanian during a period of high sea level, which partitioned the Laramidian lowlands into northern and southern regions, separating ancestral subpopulations. The *Chasmosaurus* lineage originated in northern Laramidia and later extended its range south as far as Utah, evolving into *Kosmoceratops* in the Late Campanian, after which there is no further record. The *Pentaceratops* lineage originated in southern Laramidia, but after regression of the Western Interior Seaway in the Middle Campanian, its descendants eventually moved north, evolving into *Anchiceratops*.

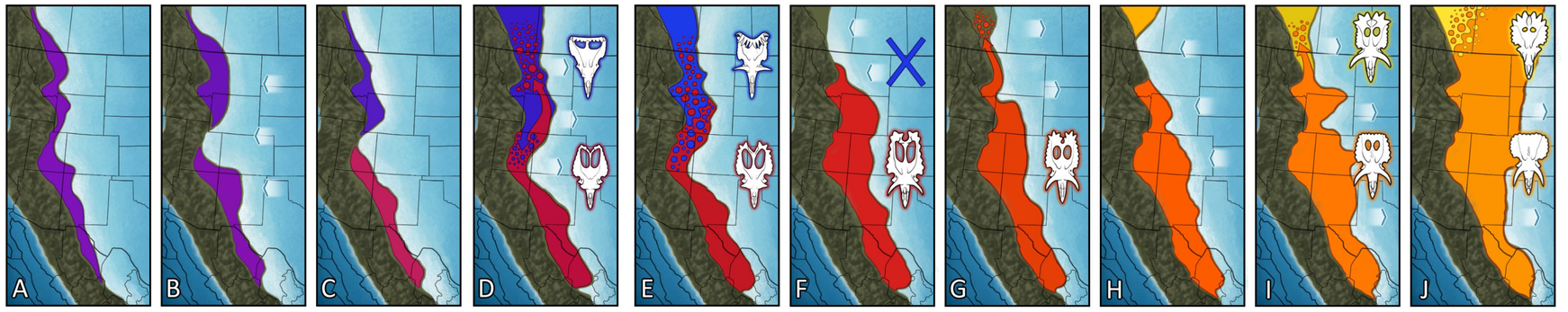

Fig. 5. Latitudinal biogeographic vicariance hypothesis in chasmosaurines: maps based on Lillegraven & Ostresh, 1990. (A) Ancestral population of basal chasmosaurines in Laramidia. (B) Marine transgression divides ancestral chasmosaurines. (C) Allopatric speciation occurs amongst chasmosaurines, evolving into a northern *Chasmosaurus* lineage (in blue) and a southern *Pentaceratops* lineage (in red). (D) Marine regression occurs, reuniting both lineages, resulting in faunal exchange. *Chasmosaurus* lineage, *Vagaceratops irvinensis*. *Pentaceratops* lineage, CMN 8800. (E) Lineages further evolve. *Chasmosaurus* lineage, *Kosmoceratops richardsoni*. *Pentaceratops* lineage, *Utahceratops gettyi*. (F) Marine transgression occurs, *Chasmosaurus* lineage becomes extinct, leaving no further record after *Kosmoceratops*. *Pentaceratops* lineage becomes cosmopolitan along Laramidian lowlands. (G) Marine regression occurs, a *Pentaceratops* lineage subpopulation moves north. (H) Marine transgression occurs, producing second latitudinal biogeographic vicariance event, resulting in allopatric speciation between the northern *Pentaceratops* lineage (in yellow) and southern *Pentaceratops* lineage (in orange). (I) Northern *Pentaceratops* lineage, *Anchiceratops ornatus*. Southern *Pentaceratops* lineage, *Arrhinoceratops brachyops*. Marine regression occurs, which reunites both lineages. (J) Further marine transgression expands the Laramidian lowlands. Lineages further evolve. Southern *Pentaceratops* lineage, *Triceratops*. This lineage becomes cosmopolitan along the subcontinent. Northern *Pentaceratops* lineage, *Regaliceratops peterhewsi*.

Although this hypothesis well-explains the geographic occurrences and systematics of Campanian chasmosaurines, it does not explain the close relationship of the contemporaneous *Arrhinoceratops* and *Anchiceratops*. Here, we hypothesize that a second vicariant event may have occurred within the *Pentaceratops* lineage in which a subpopulation stayed in southern Laramidia and evolved independently of the northern *Pentaceratops–Anchiceratops* lineage, giving rise to *Arrhinoceratops* and the Triceratopsini which would later move northward after a marine regression reunited the Laramidian lowlands. *Coahuilaceratops* would therefore be an early representative of this southern lineage, which would be consistent with systematic analyses that place *Coahuilaceratops* as a relatively derived chasmosaurine exhibiting a number of characteristics also seen in the Triceratopsini (e.g., more anteriorly positioned nasal horn, relatively massive postorbital horns, retention later into ontogeny of raised bumps on the anterior end of the midline parietal bar), and may include other enigmatic taxa, including "*Bravoceratops*", *Sierraceratops turneri*, and the Almond Formation chasmosaurine. Unfortunately, *Coahuilaceratops* is missing the diagnostic posterior portion of the parietal, so it is difficult to address the absence or presence of a median embayment or to establish any further relationships until more complete material of this enigmatic taxon is recovered.

Figure 7. Select cranial elements of *Coahuilaceratops magnacuerna* (CPC 276). Parietal: (A) dorsal view, (B) ventral view and (C) left lateral view . Supraorbital horncores: (D) left horncore and (E) right horncore. Fused nasals: (F) right lateral view, (G) left lateral view, and (H) anterior view. Right squamosal in (D) dorsal view; and (E) ventral view. Select elements in dark gray.

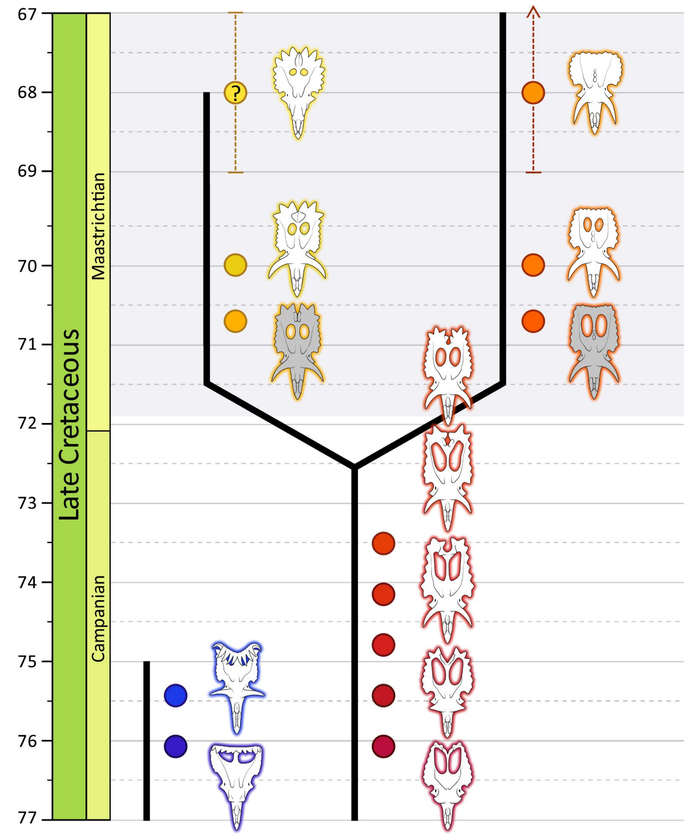

Fig. 6. Hypothetical phylogenetic relationship of Upper Campanian and Maastrichtian chasmosaurines. Hypothetical skulls in gray. *Chasmosaurus* lineage in blue (skulls bottom to top: *Vagaceratops*, *Kosmoceratops*); *Pentaceratops* lineage in red (skulls bottom to top: CMN 8800, *Utahceratops*, *Pentaceratops*, *Navajoceratops*, *Terminocavus*); Northern *Pentaceratops* lineage in yellow (skulls bottom to top: *Anchiceratops* ancestor, *Anchiceratops*, *Regaliceratops*); Southern *Pentaceratops* lineage in orange (skulls bottom to top: *Coahuilaceratops*, *Arrhinoceratops*, *Triceratops*).

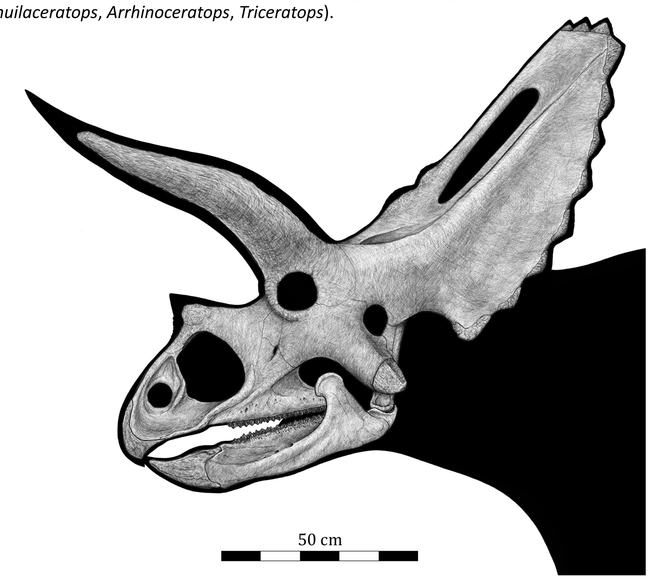

Figure 8. Skull reconstruction of *Coahuilaceratops magnacuerna*.

Conclusions:

- *Coahuilaceratops magnacuerna* is here reported to derive from the Cerro Huerta Formation rather than the previously reported underlying Cerro del Pueblo Formation. As a consequence, *Coahuilaceratops* is ~2 million years younger than previously stated and the first dinosaur taxon known from the Cerro Huerta Formation.
- Due to the thickness, high sediment accumulation rates, and large amount of fossil material, these formations thus could represent an ideal opportunity to assess the fossil record of Southernmost Laramidia with high-resolution stratigraphic data.
- Due to *Coahuilaceratops* exhibiting some craniofacial features also seen in the Triceratopsini, it is here hypothesized that it may represent the earliest member of this clade/lineage, lending credence to the southern Laramidia hypothesis concerning the origin of the Triceratopsini.
- The recognition that *Coahuilaceratops* derives from the Cerro Huerta demonstrates the utility of accurate stratigraphic data in enhancing paleobiological analysis. We suggest that in light of the complex stratigraphic relationships of the lower Difunta Group, other fossil specimens purportedly reported from the Cerro del Pueblo Formation be reassessed in their stratigraphic position. For example, the lambeosaurine hadrosaurid, *Tlatolophus galorum*. Which is described as having originated from a "layer of dark greenish mudstone interbedded with reddish sandstones" within the Cerro del Pueblo Formation[8], but this facies description does not correspond to the Cerro del Pueblo Formation
- Finally, this demonstrates the great potential for further discoveries of important southern Laramidia dinosaur fossils in Mexico. Most notably, due to its probable early Maastrichtian age, the hitherto unknown Cerro Huerta fauna may prove to be of great importance in understanding the evolution of North America's final dinosaur fauna immediately preceding the K–Pg boundary mass extinction.

Acknowledgments and Literature Cited:

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