# Reworked K/Pg ejecta in early Paleocene deposits, Difunta Group, NE Mexico

## *Ejecta del K/Pg retrabajados en depósitos del Paleoceno temprano, Grupo Difunta, NE de México*

David **Cadena-González**[1], Ricardo **Barragán**[2], Francisco A. **Vega-Sandoval**[3], Criseida **Ruiz-Aguilar**[4], Francisco J. **Vega**[2,*]

[1] Posgrado en Ciencias Biológicas, Universidad Nacional Autónoma de México, Unidad de Posgrado, Edificio D primer piso, Ciudad Universitaria, 04510, CDMX, México.

[2] Instituto de Geología, Universidad Nacional Autónoma de México, Circuito de la Investigación Científica, Ciudad Universitaria, 04510, CDMX, México.

[3] Facultad de Ciencias, Universidad Nacional Autónoma de México, Circuito de la Investigación Científica, Ciudad Universitaria, 04510, CDMX, México.

[4] Escuela Nacional de Estudios Superiores, Unidad Juriquilla, Universidad Nacional Autónoma de México, Bulevar Juriquilla 3001, 76230, Juriquilla, Querétaro, México.

* Corresponding author:
(F.J. Vega) *vegver@unam.mx*

**How to cite this article:**
Cadena-González, D., Barragán, R., Vega-Sandoval, F.A., Ruiz-Aguilar, C., Vega F.J., 2025, Reworked K/Pg ejecta in early Paleocene deposits, Difunta Group, NE Mexico: Boletín de la Sociedad Geológica Mexicana, 77(2), A190625. http://dx.doi.org/10.18268/BSGM2025v77n2a190625

Manuscript received: June 9, 2025
Corrected manuscript received: June 11, 2025
Manuscript accepted;June 20, 2025

Peer Reviewing under the responsibility of Universidad Nacional Autónoma de México.



## ABSTRACT

The Chicxulub impact triggered massive sediment removal and deposit of ejecta around the world. The impact must also have triggered large tsunamis, whose geological record is nevertheless scarce. Some of the tsunamite backwash deposits were reworked during early Paleocene, and evidence of severe earthquakes and ejecta fall are preserved along the tsunamite deposits at top of Cretaceous and the base of lower Paleocene sediments in the Difunta Group, within Parras and La Popa basins, NE Mexico. Tsunamite backwash deposits were previously studied near El Papalote diapir (La Popa Basin, Nuevo León), where pseudotektites and bioclasts are ubiquitously abundant, along with diverse bioclasts and intraclasts of different lithologies that include igneous, metamorphic and sedimentary rocks from outcrops located to the N of the Difunta Group. We report here on three localities with lower Paleocene tempestites at La Popa Basin, all interpreted as storm deposits. These outcrops are found at the top of the K/Pg Delgado Sandstone Member and also include altered pseudotektites and bioclasts. Although ejecta and bioclasts were already reported from two localities (El Papalote and Amargos), we also illustrate deformed quartz and uncommon bioclasts such as crab cuticle, ammonite nuclei and shark teeth.

**Keywords: K/Pg, tsunamite, tempestites, ejecta, bioclasts, Difunta Group.**

## *RESUMEN*

*El impacto de Chicxulub disparó una remoción masiva de sedimentos y depósitos en todo el mundo. Seguramente, el impacto debió generar grandes terremotos y tsunamis cuyo registro geológico es escaso. Algunos de estos depósitos fueron retrabajados durante el Paleoceno temprano, posiblemente debido a intensas tormentas, consecuencia de alteraciones en la atmósfera, con evidencias de terremotos intensos y caída de eyecta preservadas a lo largo de depósitos de tsunamita que se encuentran entre la cima del Cretácico y la base del Paleoceno inferior en el Grupo Difunta, en las cuencas de Parras y La Popa, NE de México. Depósitos que representan el regreso de la tsunamita hacia la cuenca del golfo de México han sido estudiados cerca del diapiro El Papalote (Cuenca La Popa, Nuevo León), en donde pseudotectitas, bioclastos son localmente abundantes, junto con diversos bioclastos e intraclastos de diversas litologías que incluyen rocas ígneas, metamórficas y sedimentarias, acarreadas de afloramientos ubicados al N de la Cuenca La Popa. Previamente, dos localidades con eyecta han sido reportadas para las cuencas de Parras y La Popa. Aquí reportamos otras tres localidades con tempestitas del Paleoceno inferior, ubicadas en la Cuenca de La Popa. Estos afloramientos se encuentran en la porción superior de Miembro de Arenisca Delgado, cuya edad se estima alrededor del límite, incluyendo pseudotectitas. Eyecta y bioclastos han sido reportados previamente para dos afloramientos (El Papalote y Amargos). Adicionalmente, aquí reportamos cuarzo deformado y bioclastos como cutícula de cangrejo, núcleos de ammonite y dientes de tiburón.*

***Palabras clave: K/Pg, tsunamita, tempestitas, eyecta, bioclastos, Grupo Difunta.***

http://dx.doi.org/10.18268/BSGM2025v77n2a190625







## 1. Introduction

The Chicxulub impact on what is now the NE of the Yucatan Peninsula sent into the atmosphere large amounts of ejecta, among them as tektites whose composition, size, and shape are related to the distance from the crater, with localities distributed along the Caribbean, Central and South America, as well as the East coast of Mexico, and the SE of the USA. Other nearly immediate consequences of the impact included severe earthquakes, ejecta fall, large tsunami(s), an ignited atmosphere and subsequent ash and Iridium fall. The East coast of Mexico includes several KPB localities reported by several authors, mainly at relatively deep-water settings (Izett *et al.*, 1990; Sigurdsson *et al.*, 1991; Smit, 1999). Here, we reinforce the presence of lower Paleocene reworked ejecta-bearing deposits in the Difunta Group, NE Mexico.

The Difunta Group, located in NE Mexico in the S and SE of Coahuila (Parras Basin) and the E of Nuevo León (Figure 1), is a succession of mainly siliciclastic sedimentary rocks deposited in shallow marine and transitional environments during late Campanian to early Eocene time (McBride *et al.*, 1974; Vega *et al.*, 1989; Lawton *et al.*, 2001, 2009; Eberth *et al.*, 2004). Based on mollusk biostratigraphy, the K/Pg boundary was placed between the Middle Siltstone Member and the Upper Mudstone Member of the Potrerillos Formation in the La Popa Basin (Vega *et al.*, 1989; Vega and Perrilliat, 1995).

Most of the sedimentary history of lithostratigraphic units at La Popa Basin was controlled by salt tectonics, including 3 diapirs (El Papalote, El Gordo, La Popa) and a weld (La Popa weld; Giles and Lawton, 1999, 2002; Lawton *et al.*, 2001, 2021). To the SE of El Papalote diapir (Figures 2 and 4), ejecta-bearing deposits were first recognized in deposits of the Delgado Sandstone (Aschoff *et al.*, 2001; Aschoff, 2003; Shipley, 2004; Lawton *et al.*, 2005; Schulte *et al.*, 2010; Figure 3), formally described by Lawton *et al.* (2001) as a shoreface and shelfal 40-60 m thick sandstone deposit, lying erosively over the Middle Siltstone Member (upper Maastrichtian) and conformably underlying the Upper Mudstone Member of the


**Figure 1** Geographic location of the Difunta Group, Coahuila and Nuevo Leon.

http://dx.doi.org/10.18268/BSGM2025v77n2a190625







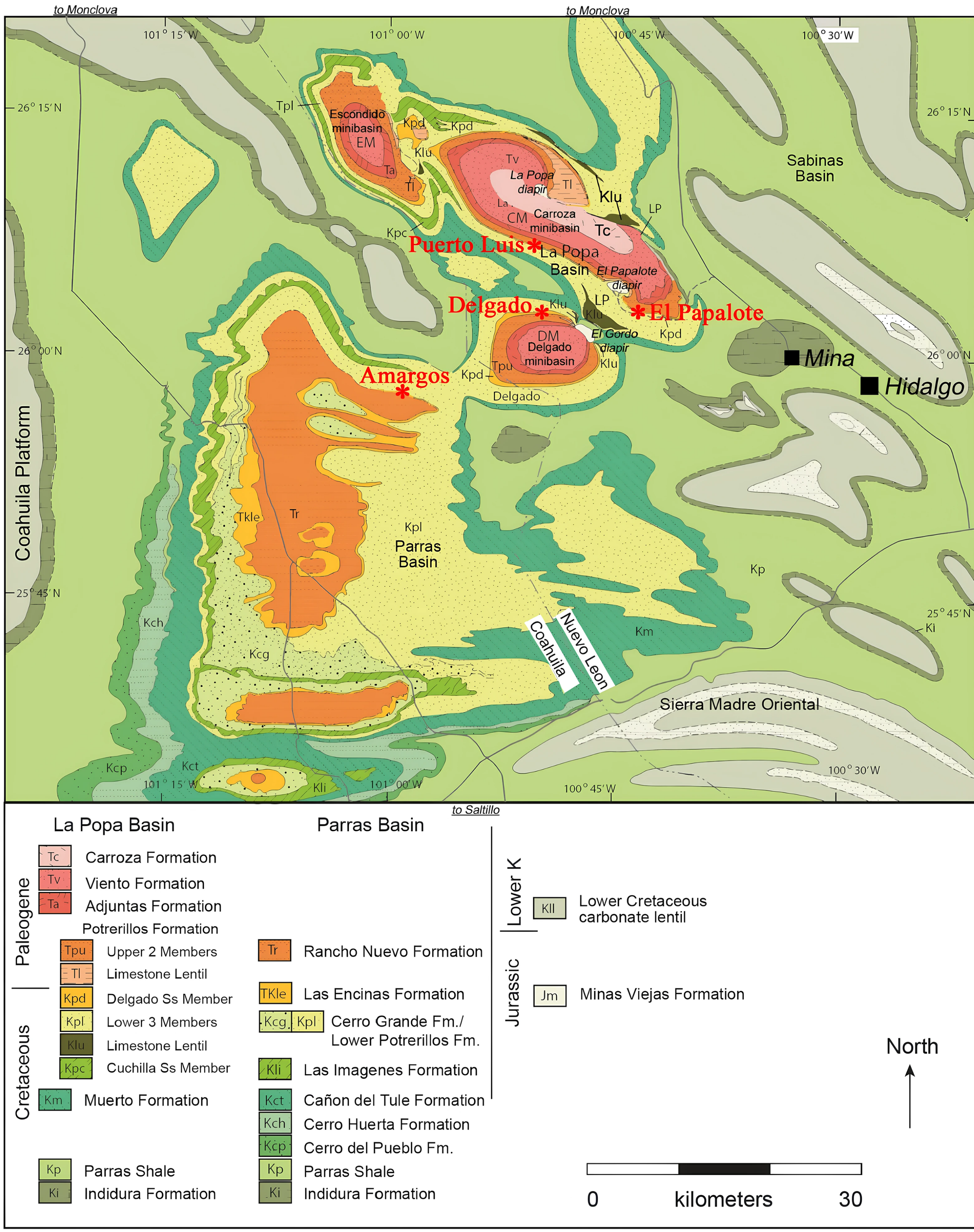


**Figure 2** Geologic map of lithostratigraphic units in the Difunta Group, NE Mexico, as well as the position of the localities here reported (modified after Lawton *et al.*, 2009).

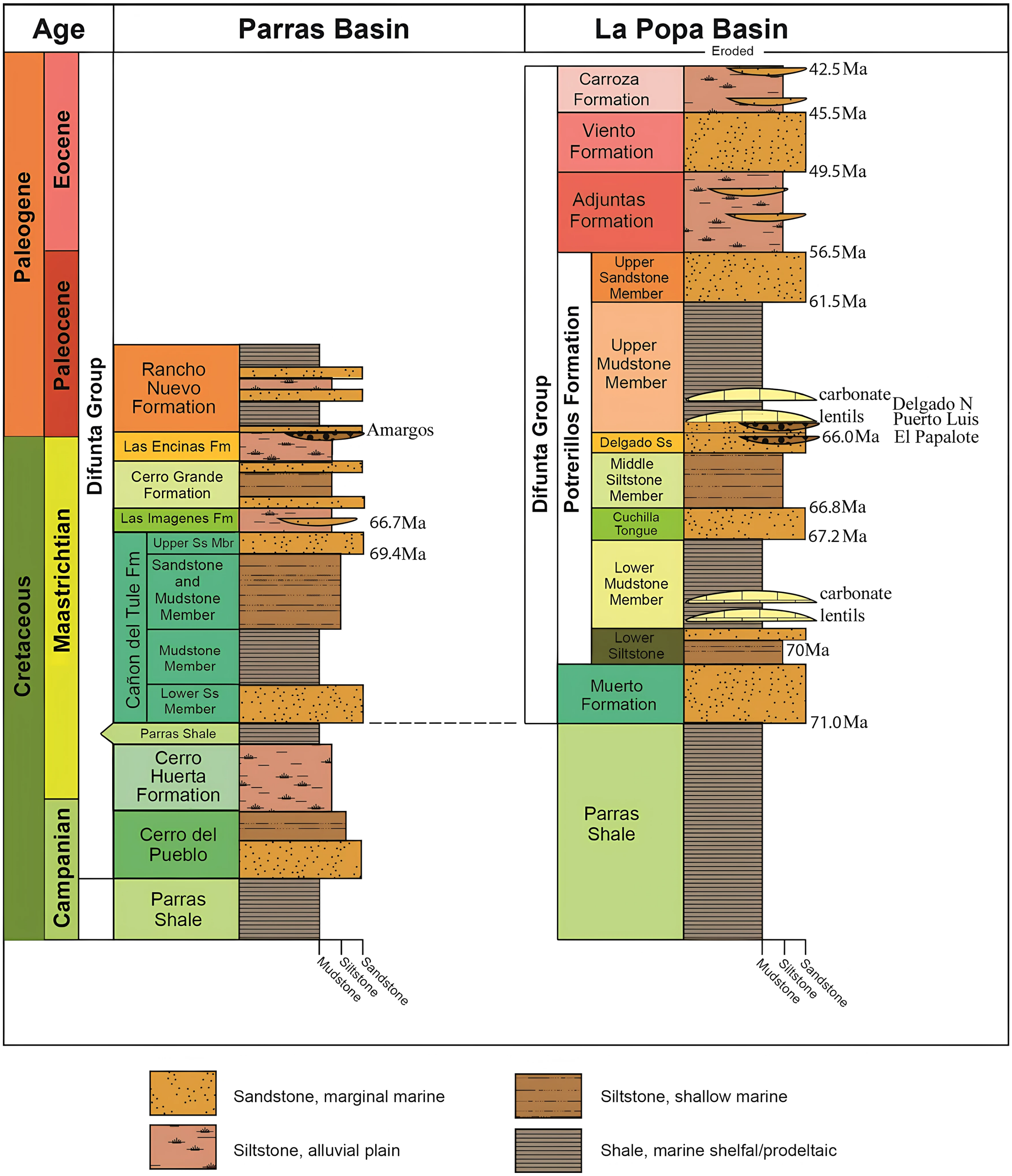


**Figure 3** Stratigraphy of the Parras and La Popa basins (Difunta Group), with relative positions of reworked tsunamite at basal Paleocene lithostratigraphic units (modified after Lawton *et al.*, 2009).

Potrerillos Formation (lower Paleocene). In this unit tsunamite backwash was deposited as valley-fill accumulations in a bathymetric break that separated Maastrichtian upper shoreface from lower shoreface and prodelta depositional settings (Lawton *et al.*, 2001; Aschoff and Giles, 2005).

This bathymetric break might be a pre-existent feature, possibly emphasized by salt-withdraw triggered by the Chicxulub earthquake (Lawton *et al.*, 2005). The ejecta-bearing strata represent an S-SE tsunamite backflow which probably reached also deeper settings toward the Gulf of Mexico basin (Aschoff and Giles, 2005; Lawton *et al.*, 2005). Schulte *et al.* (2010) provided detailed study of the tsunamite backwash deposits at several outcrops S and SE El Papalote diapir found at the upper portion of the Delgado Sandstone of the Potrerillos Formation (between 26°02"44.95' N, 100°43"14.49' W and 26°03"05.64' N, 100°43"52.63' W; Figure 4). The light-gray tsunamite deposits are conformed by sandstone with hummocky cross-bedding at the base (Aschoff, 2003; Shipley, 2004; Lawton *et al.*, 2005; Schulte *et al.*, 2010). The El Papalote K/Pg ejecta-bearing deposits range in thickness from a few centimeters up to 4 m and include large reworked boulders with the same lithology as the basal sandstones of the Delgado Sandstone Member, interpreted as fragmented remains removed and transported basinward by the tsunami backwash (Lawton *et al.*, 2005; Schulte *et al.*, 2010). Tektite pseudomorphs are more abundant at the base of the tsunamite, becoming scarce toward the top of the deposit (Lawton *et al.*, 2005; Schulte *et al.*, 2010). Lawton *et al.* (2005) reported tektite pseudomorphs as composed mainly by Fe and Mg, ooids with quartz and calcite nuclei and other clasts represented by quartz, chert, micrite, calcareous siltstone, and very fine-grained sandstone (Figure 3C). Detailed compositional analyses of the pseudotektites are found in Schulte *et al.* (2010).

Previously reported bioclasts include foraminifera, corals, gastropods, ostreids, ammonites, bryozoa and echinoderms, most of them transported from shallow marine and estuarine environments to the N and NW of La Popa Basin (Lawton *et al.*, 2005). Schulte *et al.* (2010) also reported tektite pseudomorphs composed of calcite, Fe-Mg as well as Si-K and mention bioclasts as red algae, wood, foraminifera, gastropods, bivalves, bryozoa, brachiopods, echinoderms, and vertebrates.

To the W, at the NE portion of the Parras Basin, Stinnesbeck *et al.* (2016) reported an ejecta-bearing, channel-fill deposit found at the top of the Las Encinas Formation near Amargos, Coahuila (25°56"36.90' N, 101°01"28.64' W; Figures 2 and 5). The K/Pg boundary at the N and NE portion of the Parras Basin was previously placed within the upper third of the Las Encinas Formation, but no evidence of ejecta was found (Murray *et al.*, 1959; Hasseltine, 1968; Wolleben, 1977; Vega *et al.*, 2007). Pseudotektites are relatively ubiquitous at the Amargos locality, where light-gray sandstone-conglomeratic deposits are interpreted to be a tempestite deposit that occurred during early Paleocene storm events (Stinnesbeck *et al.*, 2016).

The presence of the early Paleocene (Danian) ostreoid *Gorizdrella gorizdroae* Vyalov, 1937 as a relatively abundant and well-preserved Paleocene mollusk included into the ejecta-bearing sediments, reinforces the interpretation of Paleocene storm deposits. Stinnesbeck *et al.* (2016) defined the Amargos reworked tsunamite as a bioclastic oligomict microconglomerate to contain devitrified, weathered tektite pseudomorphs. This 1 m thick channel-like structure is laterally continuous for about 100 m includes both late Maastrichtian and early Paleocene macrofossils such as the ammonite *Sphenodiscus pleurisepta* (Conrad, 1857) (phragmocone filled with spherules), the Maastrichtian echinoid *Hardouinia mortonis* (Michelin, 1850) and the early Paleocene (Danian) small ostreid *Gorizdrella gorizdroae* (Stinnesbeck *et al.*, 2016; Cadena-González *et al.*, 2023). The ammonite was interpreted to be carried along with the tsunamite, but the echinoids are thought to be eroded from the underlying upper Maastrichtian shallow marine beds of the

http://dx.doi.org/10.18268/BSGM2025v77n2a190625







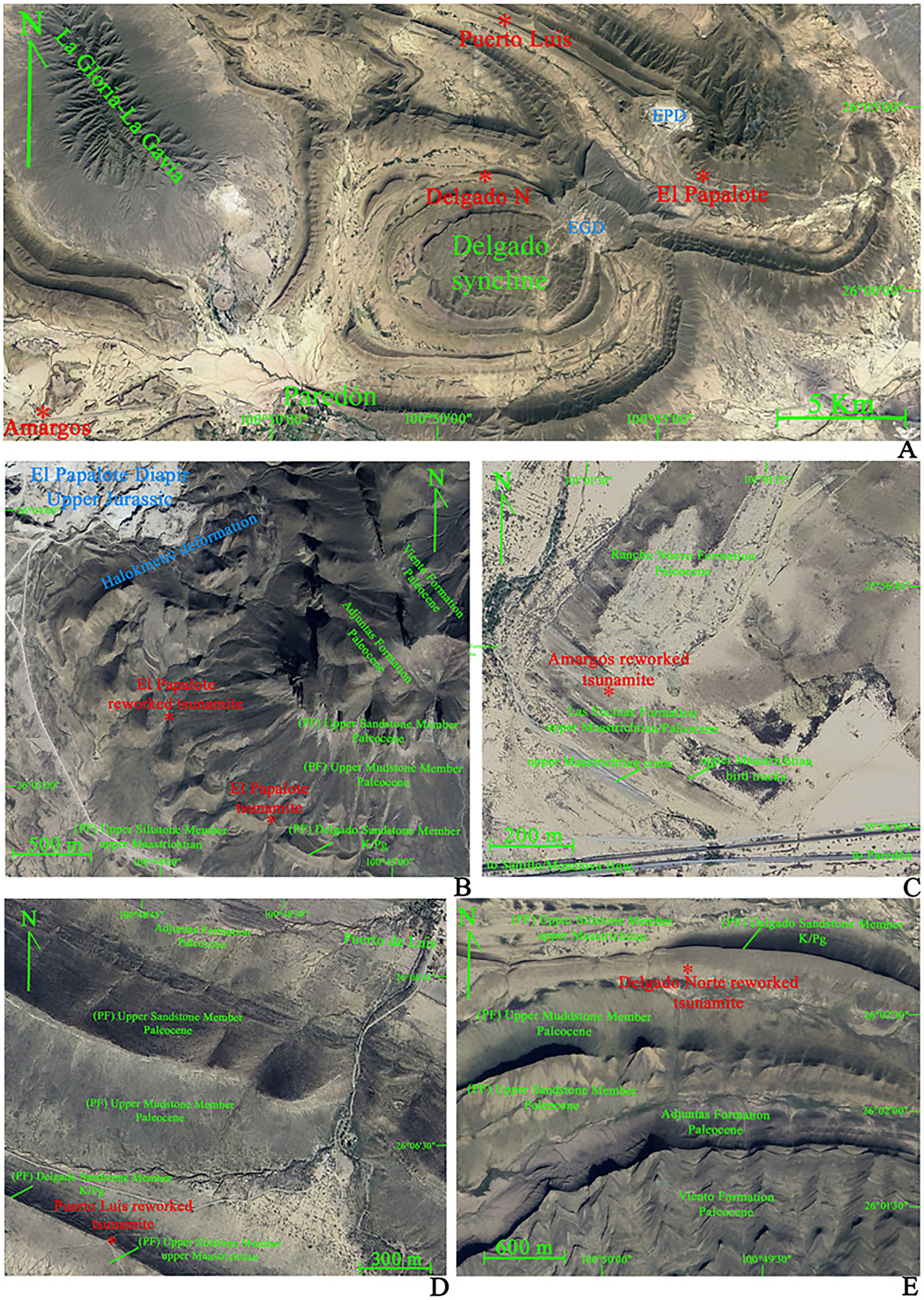


**Figure 4** A, location of El Papalote, Puerto de Luis and Delgado N, La Popa Basin, EPD = El Papalote Diapir, EGD = El Gordo diapir. B, location of El Papalote tsunamite and Paleocene reworked tsunamite, along with lithostratigraphic units nearby El Papalote diapir (La Popa Basin). C, location of Paleocene reworked tsunamite at Amargos, Parras Basin, Coahuila, with lithostratigraphic units. D, location of Puerto de Luis Paleocene reworked tsunamite, La Popa Basin and lithostratigraphic units. E, location of Delgado Norte reworked Paleocene tsunamite, La Popa Basin. All images taken from Google Earth.

lower Las Encinas Formation during the storm that deposited reworked tsunamite matter. The relatively small early Paleocene ostreids, although represented mostly by the left concave valve, preserve delicate fine ornamentation, suggesting low energy and/or protection by the fine sandstone matrix during transport in shallow marine settings.

The purpose of this research is to report ejecta and bioclast contents of four ejecta-bearing localities (two of them new) in the La Popa Basin: El Papalote, Amargos, Puerto Luis and Delgado Norte. From these, only El Papalote includes K/Pg tsunamite backwash deposits *in situ*. The other three localities include reworked tsunamite deposited during early Paleocene storms, including tektite pseudomorphs, bioclasts and other microscopic grains of diverse lithology of igneous, metamorphic and sedimentary rocks. Bioclasts, ejecta and microclast contents are commented and illustrated for each locality, with emphasis on other bioclasts.

## 2. Material and method

The four outcrops—El Papalote (K/Pg boundary), Puerto Luis, Delgado Norte, and Amargos (Lower Paleocene tempestites)—were systematically sampled at 10 cm intervals from base to top in order to obtain a relatively uniform dataset. From each sampling point, rock fragments measuring approximately 5×5 cm were collected to ensure consistency in sample size and facilitate subsequent petrographic and microtextural analyses. These rock fragments were processed to obtain both polished surfaces and thin sections. Polished surfaces were prepared using progressively finer abrasives combined with diesel as a lubricant to achieve an optimal finish for macroscopic and mesoscopic observations. Thin sections were produced using an automated thin section machine to maintain uniform thickness and minimize preparation artifacts.

Microscopic observations and image acquisition were carried out using a Zeiss Axiozoom V.16 stereomicroscope equipped with a high-resolution Zeiss digital camera, which allowed for detailed documentation of textures, grain relationships, and sedimentary structures. For transmitted light petrography, a Zeiss polarizing microscope was employed, coupled with a Canon EOS camera to capture high-quality images. This combination facilitated both routine petrographic description and the documentation of key features relevant to the depositional and diagenetic history of the samples. All captured images were processed and edited using Adobe Photoshop Elements 2.0

## 3. K/Pg and lower Paleocene ejecta-bearing localities

### 3.1. EL PAPALOTE BACKWASH TSUNAMITE

In this study, we sampled the main outcrop at El Papalote, known as Hornet's Nest (26°02"14.50' N, 100°43"26.01' W; Figure 5A). At the base of the tsunamite deposit there is a layer of sandstone with numerous pseudotektites with no apparent intraclasts or bioclasts, this layer may represent the first pulse of ejecta out fall, or just the base of the tsunamite back deposit (Figures 5B and 5C). As reported by Lawton *et al.* (2005), other large sandstone boulders are found at the base and within the tsunamite backwash, with evidence of soft deformation (Figure 5E). Some gastropods include a slightly bended shell of the gastropod *Haustator trilira* (Conrad, 1860) (Figure 5F). Shark teeth and gastropods are embedded into the middle portion of the tsunamite backwash deposits (Figures 5G and 5H). Along with the bioclasts previously mentioned, olive-green, orange and black tektite pseudomorphs are found here (Figures 5I-5N). Bubbly calcite spherules along with altered glass are relatively abundant on the observed thin sections and are similar to those reported for the El Papalote tsunamite by Lawton *et al.* (2005) and Schultze *et al.* (2010). Red algae, foraminifera, ooids, echinoid plates and crustacean cuticles are also present (Figures 5O, 5P and 6A-6E).

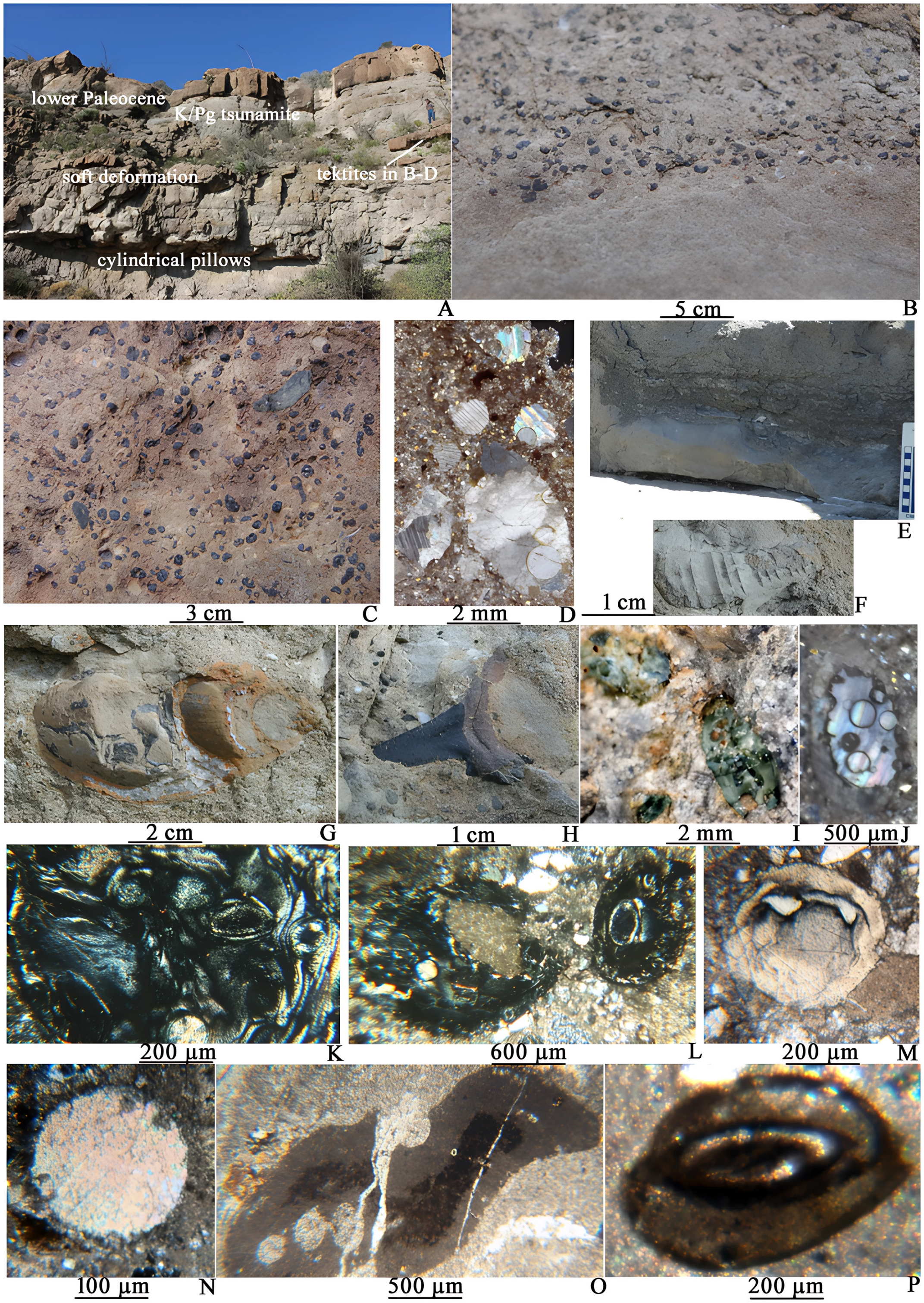


**Figure 5** A, “Hornets nest” tsunamite backwash outcrop to the SE of El Papalote diapir (Delgado Sandstone), showing deformed strata at the base (note person for scale). B, C, pseudotektites at the base of the tsunamite backwash deposit. D, pseudotektites in the sandstone layer at the base of tsunami backwash. E, base of tsunamite at “Hornets nest. F, slightly bended shell of Haustator trilira (Conrad, 1860) into light-gray sandstone of tsunami backwash deposits. G, unidentified gastropod with recrystallized shell into tsunamite backwash. H, shark teeth into tsunamite backwash. I-N, pseudotektites replaced by smectite and calcite from the base of ejecta-bearing hornest nest deposit. O, red algae fragment. P, alveolinid.

To the NW (1.6 Km) of the Hornets Nest outcrop, we also sampled a thin (30 cm) layer of light-gray conglomeratic sandstone (26°03"14.30' N, 100°43"58.25' W; Figures 6F and 6G), directly overlying the top of the Delgado Sandstone Member. This layer is here interpreted as a lower Paleocene tempestite that also includes diverse reworked clasts such as bryozoa, crustacean cuticle and microscopic shark teeth (Figures 6H-6K), along with bubbly pseudotektites (Figure 6L).

### 3.2. AMARGOS

The Amargos lower Paleocene reworked tsunamite is found in an approximately 100 m wide and up to 1 m thick channelized structure, erosively overlying the top of the Las Encinas Formation (Stinnesbeck *et al.*, 2016; Figures 2-4 and 7A). An ammonite shell, possibly *Sphenodiscus pleurisepta* (Conrad, 1857), includes numerous pseudotektites inside the phragmocone (Figure 7B), suggesting that the shell was empty and filled with fine-grain sediment that transported the ejecta. Although nearly as abundant as the ones found at El Papalote, tektite pseudomorphs are here replaced by calcite and/ or smectite (Figures 7F and 7G). The thin sections include ooids, fragments of gastropods, oysters, ammonites, crustaceans, bryozoa, echinoderms, and chert clasts (Figures 7B-7O). The small ostreids belong to the species *Gorizdrella gorizdroae*, which indicates an early Paleocene age for this deposit

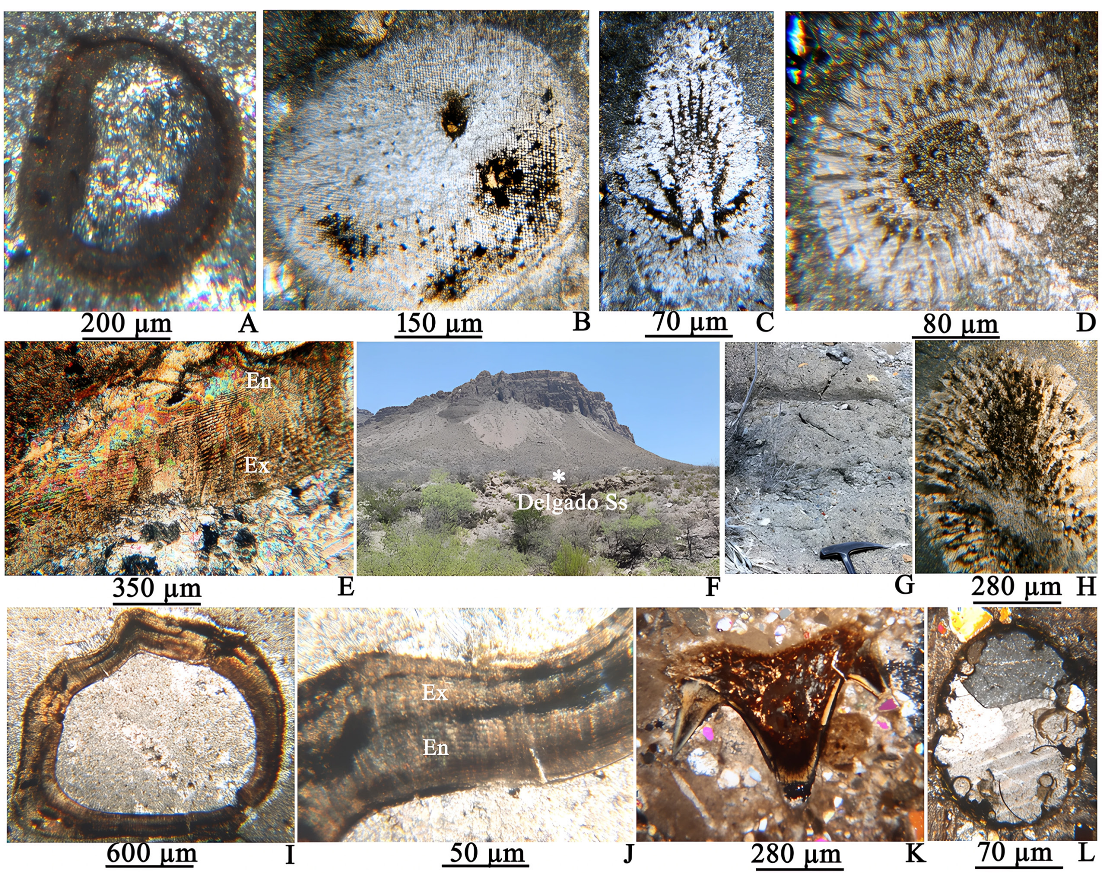


**Figure 6** "Hornets nest" tsunamite backwash clasts A-E: A, ooid with calcareos nucleus. B, echinoderm oscicle. C, solitary coral. D, echinoderm spine. E, crustacean cuticle, en = endocuticle, ex = exocuticle. F, position of reworked tsunamite in lower Paleocene tempestite, H-L, clasts. G, detail of lower Paleocene reworked tsunamite as conglomeratic calcareous sandstone with black chert clasts. H, ramose bryozoan. I, transverse section of crustacean pereiopod. J, detail of crustacean cuticle, en = endocuticle, ex = exocuticle. K, shark tooth. L, pseudotektite replaced by calcium carbonate.

http://dx.doi.org/10.18268/BSGM2025v77n2a190625



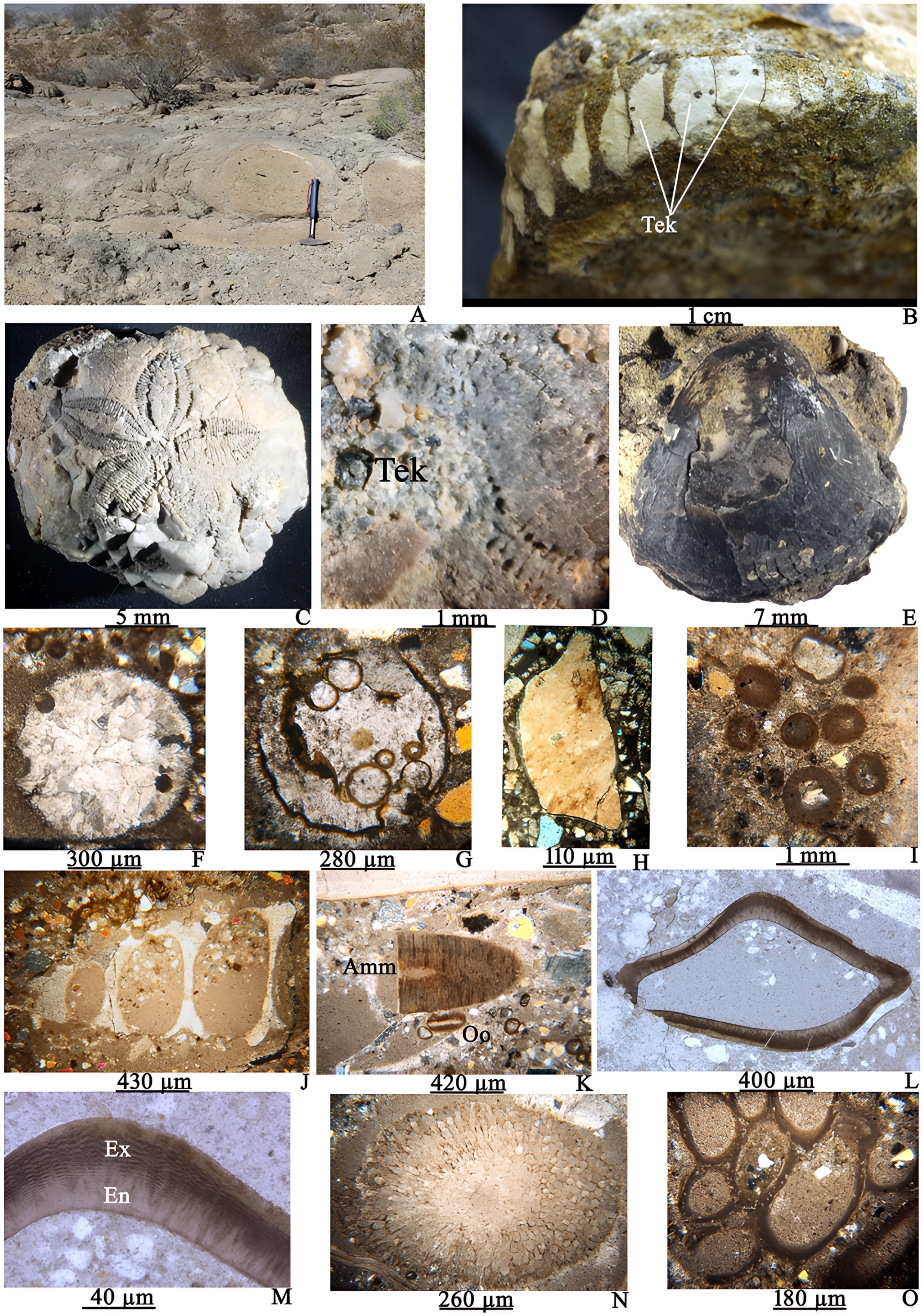


**Figure 7** A, Amargos lower Paleocene reworked tsunamite and some clasts. B, ammonite phragmocone with some pseudotektites inside chambers. C, the Maastrichtian echinoid *Hardouinia mortonis* reworked from upper Maastrichtian Las Encinas Formation. D, close-up to echinoid petaloid with pseudotektite nearby. E, left valve of the early Paleocene ostreoid *Gorizdrella gorizdroae*. F, G, pseudotektites. H, small chert clast with radiolarians. I, ooids. J, longitudinal section of turritellid gastropod. K, ammonite shell nucleus surrounded by ooids (Oo). L, M, crustacean cuticle with detail of endocutucle (En) and exocuticle (Ex). N, transverse section of ramose bryozoan. O, ovate chambers, possibly bryozoan.

http://dx.doi.org/10.18268/BSGM2025v77n2a190625





(Figure 7E). Cadena-González *et al.* (2023) also reported on the presence of numerous specimens of the Maastrichtian echinoid *Hardouinia mortonis* (Michelin, 1850) (Figures 7C and 7D), interpreted to be exhumed and carried along the Amargos area.

### 3.3. PUERTO DE LUIS

Located at 26°06"19.' N, 100°48"47.14' W, 800 m SW of Puerto de Luis ranch, there is an outcrop of lower Paleocene reworked tsunamite that erosively overlies the Delgado Sandstone, with an approximate thickness of 30 cm (Figures 8A and 8B). This outcrop appears to be equivalent to that observed near El Papalote diapir. Thin sections reveal a content of clasts similar to those observed at Amargos and El Papalote lower Paleocene reworked tsunamite (Figures 8C-8P).

### 3.4. DELGADO NORTE

The Delgado Sandstone type section is found near the Paleocene upper Gordo limestone lentil, NE of the Delgado syncline (26°02"09.48' N, 100°47"40.30' W; Lawton *et al.*, 2001, p. 231, fig. 12; Figure 9A). A small outcrop of a light-gray monomictic breccia that contains medium-sized sandstone clasts with angular edges (Figures 9B and 9C). Ammonites with pseudotektites inside the fragmocone are scarce but present in the lower Paleocene reworked tsunamite (Figure 9D).

It is interesting to note that the fragmocone of the ammonite found in this outcrop is unfilled also with diverse lithologies such as mudstone and coarse sandstone. This reveals that the ammonite shell was possibly empty by the time it was transported by the tsunami to be reworked along with tsunamite during an early Paleocene storm. The matrix includes pseudotektites replaced by calcite, some with bubbly internal structure (Figures 9E-9G).

Stratigraphically, this outcrop lies within the upper portion of the Delgado Sandstone, and includes scarce but recognizable left valves of the early Paleocene ostreoid *Gorizdrella gorizdroae*.

## 4. Discussion

Four ejecta-bearing localities have been recognized, two of them previously reported: El Papalote series of outcrops (Lawton *et al.*, 2005; Schulte *et al.*, 2010) and Amargos (Stinnesbeck *et al.*, 2016); two other ejecta-bearing localities are here reported (Puerto Luis and Delgado N). The El Papalote localities include *in situ* K/Pg tsunamite deposits in the most shallow K/Pg marine environmental settings found in NE Mexico (Smit, 1999), at an approximate distance of 800 km NE from the Chicxulub impact area.

Two new ejecta-bearing localities are here documented (Puerto de Luis and Delgado Norte), and along with the previously reported two localities (El Papalote and Amargos) include relatively abundant ejecta, igneous, metamorphic and sedimentary clasts, transported during the tsunami backwash from transitional and continental rock exposures located to the NW and N. The source of these microclasts is uncertain, but some can be compared with Cretaceous sedimentary units such as the Cenomanian-Turonian Eagle Ford Group, the Indidura Formation and upper Campanian Parras Shale, all cropping out to the NW and N of the study area. Bioclast diversity is illustrated, with some important additions to the previously mentioned bioclasts (Lawton *et al.*, 2005; Schulte *et al.*, 2010; Stinnesbeck *et al.*, 2016), such as ammonite nuclei, crustacean cuticle and shark teeth. Active since the early Cretaceous, salt-tectonics along with the initial pulses of the Laramide Orogeny might have created shallow marine and surficial topographic *traps* from where tsunami backwash deposits were reworked by early Paleocene strong storms that transported sediment basinward.

Comparison between morphology and composition of ejecta from La Popa Basin and that found in deeper marine K/Pg settings reported to the East in Nuevo León and Tamaulipas, might help understand if early Paleocene storms carried reworked tsunamite basinward, resulting in multiple ejecta-bearing strata.

http://dx.doi.org/10.18268/BSGM2025v77n2a190625







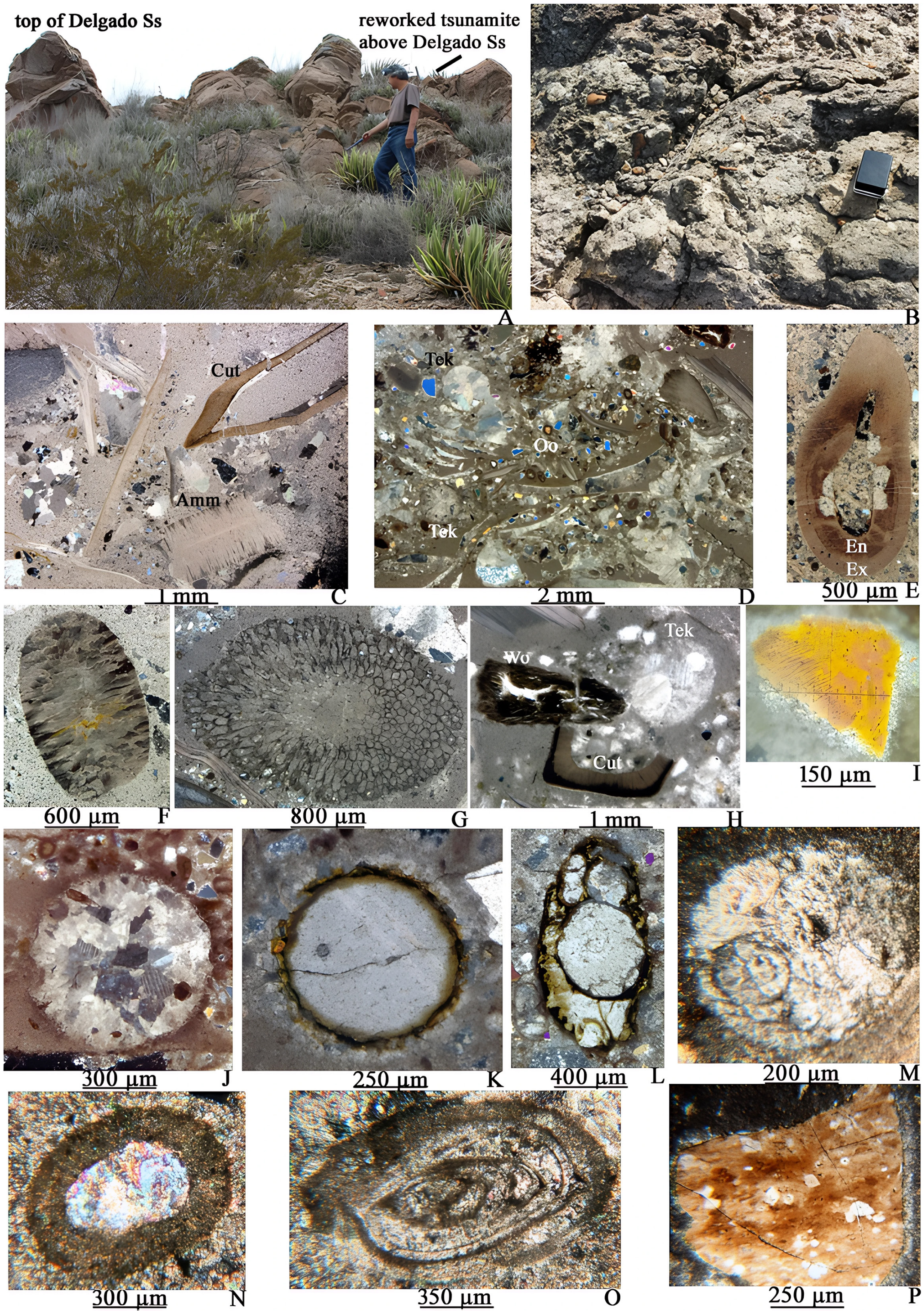


**Figure 8** Puerto de Luis reworked tsunamite and clasts. A, Delgado Sandstone (Ss) with lower Paleocene reworked stunamite at the top. B, reworked tsunamite as conglomeratic calcareous sandstone. C, fragment of ammonite shell nucleus (Amm) and crustacean cuticle (cut). D, pseudotektites (Tek), ooids (Oo), ostreid shell fragments and other intraclasts. E, transverse section of crustacean fragment showing cuticular structure (En = endocuticle, Ex = exocuticle). F, possible reworked ammonite shell nucleus. G, transverse section of bryozoan ramose colony. H, crustacean cuticle (Cut), wood (Wo) and pseudotektite (Tek). I, shock quartz. J-M, pseudotektites. N, ooids with calcareous nucleus. O, alveolinid. P, chert clast with radiolarians.

## 5. Conclusion

New outcrops of reworked ejecta are reported from the lower Paleocene Difunta Group, La Popa Bain, Nuevo León. Two previously reported localities (one NW of Parras Basin, Coahuila) were sampled and interpretations of reworked Chicxulub ejecta are confirmed. Although it is not possible for the moment to state if the reworked ejecta were accumulated by a single storm during the early Paleocene, differential contents in fossils, bioclasts and ejecta might suggest either different depositional scenarios or/and different storm events. In all sections, ejecta-bearing deposits are found just above the K/Pg Delgado Sandstone Member of the Potrerillos Formation (La Popa Basin). Some interesting and relatively abundant microscopic bioclasts include crustacean cuticle, ammonite shell fragments and shark teeth. Further fieldwork and sampling is still necessary in order to evaluate if the reworked ejecta layers are part of a discrete, continuous layer across the base of the lower Paleocene Upper Mudstone Member of the Potrerillos Formation, including a detailed map of outcrops. Most of the K/Pg localities reported from the Caribbean and Gulf of Mexico belong to relatively deep marine and continental deposits, the ejecta-bearing localities here mentioned belong to shallow marine environments.

## Contributions of authors

DCG: field work, images and final manuscript review; RBM: interpretation of microclasts and some illustrations; FAVS: field work, polished samples and thin sections; CRA: laboratory experiments; FJV: field work, structure of manuscript, location figures.

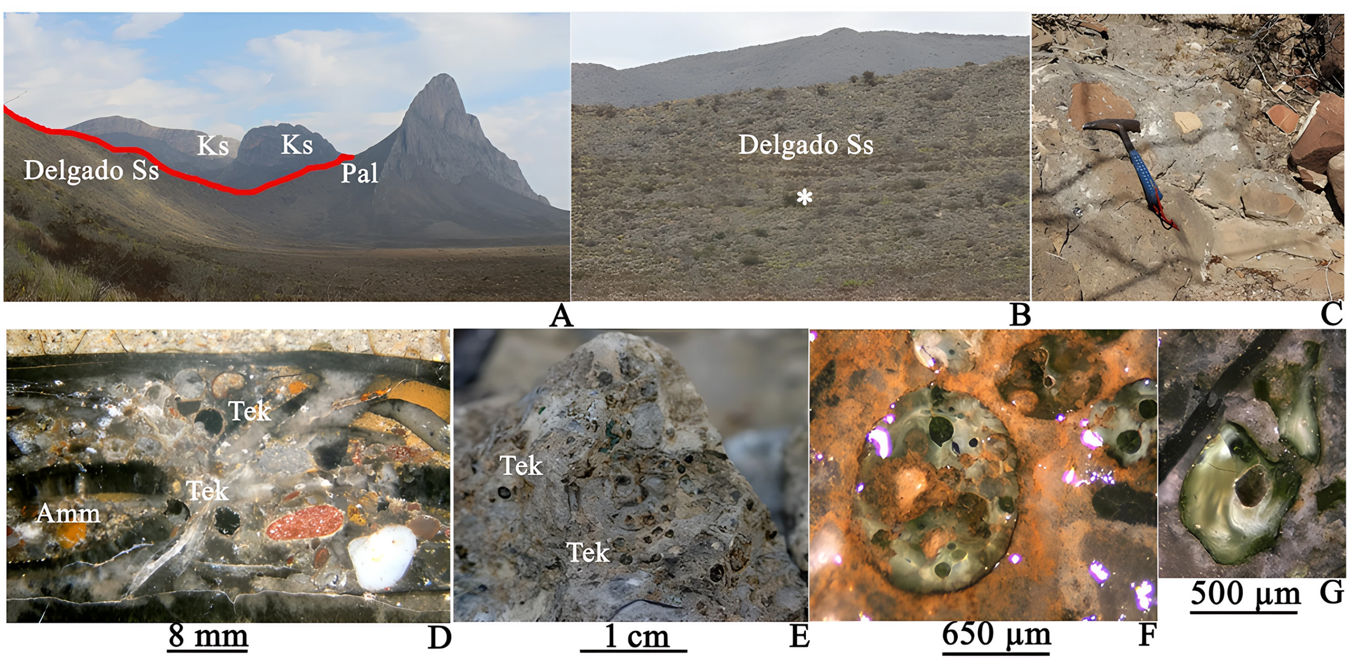


**Figure 9** Delgado Norte lower Paleocene reworked tsunamite deposits (above Delgado Sandstone). A, approximate position of K/Pg (red line) along the north side of the Delgado syncline (Ks = Upper Cretaceous, Pal = lower Paleocene. B, approximate position of reworked tsunamite discontinuos sandstone layer with position of outcrop in C. C, outcrop with sandstone clasts and pseudotektites in matrix. D, ammonite transversal section showing pseudotektites and other clasts inside shell phragmocone (Tek = pseudotektites). E-G, pseudotektites from reworked tsunamite at Delgado Norte next to outcrop in C.

## Financing

DGAPA, UNAM for the economic support from PAPIIT project IN109424.

## Acknowledgements

Our sincere gratitude to Dirección General de Asuntos del Personal Académico (DGAPA, Universidad Nacional Autónoma de México) for the economic support from PAPIIT project IN109424 to FJV. Aid of Fernando Núñez-Useche in recognizing bioclasts is much appreciated. José Flores-Ventura (Museo del Desierto, Saltillo, Coahuila) offered assistence during fielwork. Field observations and advice was given by Hermann D. Bermúdez (Department of Earth and Environmental Studies, Montclair State University, Montclair, New Jersey 07043, USA). Advise and fieldwork support by Michelangelo Martini, Hermann Bermúdez and Fernando Núñez-Useche was very important and so we thank these specialists. Comments and suggestions of two anonymous reviewers are highly appreciated.

## Conflicts of interest

We declare no conflict of interest in this contribution.

## Handling editor

Antoni Camprubí

## References

Aschoff, J.L., 2003, Sedimentation patterns within a salt-diapir influenced foreland basin: Upper Cretaceous to lower Paleogene Delgado Sandstone Tongue, Potrerillos Formation, La Popa basin, Nuevo Leon, Mexico: Las Cruces, U.S.A., New Mexico State University, master thesis, 259 p.

Aschoff, J.L., Giles, K.A., 2005, Salt diapir-influenced, shallow-marine sediment dispersal patterns: Insights from outcrop analogs: American Association of Petroleum Geologists Bulletin, 89(4), 447–469. https://doi.org/10.1306/10260404016

Aschoff, J.L., Giles, K.A., Lawton, T.F., 2001, Origin of Upper Cretaceous (latest Maastrichtian) massive boulder-cobble conglomerates, Potrerillos Formation, La Popa basin, northeastern Mexico: Incised valley fill or mega-tsunamite?: Geological Society of America, Abstracts with Programs, 33(6), A202.

Cadena-González, D., Flores-Ventura, J., Vega-Sandoval, F.A., Vega, F.J., 2023, Cretaceous echinoids in Paleocene reworked tsunamite from Coahuila, NE Mexico: Journal of South American Earth Sciences, 109, 104504. https://doi.org/10.1016/j.jsames.2023.104504

Conrad, T.A., 1857, Descriptions of Cretaceous and Tertiary fossils, in Emery, W.H. (ed.), Report on the United States and Mexican Boundary Survey: U.S.A., 34th Congress, 1st Session, Senate Ex Document 108 and House Ex Document 135, vol. 1, 140–174.

Conrad, T.A., 1860, Descriptions of new species of Cretaceous and Eocene fossils of Mississippi and Alabama: Journal of the Academy of Natural Sciences of Philadelphia, 4, 275–298.

Eberth, D.A., Delgado-de Jesús, C.R., Lerbekmo, J.F., Brinkman, D.B., Rodríguez-de la Rosa, R.A., Sampson, S.D., 2004, Cerro del Pueblo Formation (Difunta Group, Upper Cretaceous), Parras Basin, southern Coahuila, Mexico: Reference sections, age, and correlation: Revista Mexicana de Ciencias Geológicas, 21, 335–352.

Giles, K.A., Lawton, T.F., 1999, Attributes and evolution of an exhumed salt Weld, La Popa Basin, Northeastern Mexico: Geology, 27, 323–326. https://doi.org/10.1130/0091-7613(1999)027%3C0323:aaeoae%3E2.3.co;2

Giles, K.A., Lawton, T.F., 2002, Halokinetic sequence stratigraphy adjacent to El Papalote diapir, La Popa Basin, Northeastern Mexico: American Association of Petroleum Geologists, Bulletin, 86, 823–841. https://doi.org/10.1306/61eedbac-173e-11d7-8645000102c1865d

Hasseltine, G.H., 1968, Geology of the San Miguel syncline, Coahuila, Mexico: U.S.A., University of Missouri at Columbia, master thesis, 44 p.

Izett, G.A., 1990, The Cretaceous/Tertiary boundary interval, Raton Basin, Colorado and New Mexico, and its content of shock-metamorphosed minerals; Evidence relevant to the K/T boundary impact-extinction theory: U.S.A., Geological Society of America, Special Paper, 249, 1-100.

Lawton, T.F., Vega, F.J., Giles, K.A., Rosales-Domínguez, C., 2001, Stratigraphy and origin of the La Popa Basin, Nuevo León and Coahuila, Mexico, in Bartolini, C., Buffler, R.T., Cantú-Chapa, A. (eds.), Mesozoic and Cenozoic Evolution of the Western Gulf of Mexico Basin: Tectonics, Sedimentary Basins and Petroleum Systems: American Association of Petroleum Geologists, Memoir, 75, 219–240. https://doi.org/10.1306/m75768c9

Lawton, T.F., Shipley, K.W., Aschoff, J.L., Giles, K.A., Vega, F.J., 2005, Basinward transport of Chicxulub ejecta by tsunami-induced backflow, La Popa basin, northeastern Mexico, and its implications for distribution of impact-related deposits flanking the Gulf of Mexico: Geology, 33(2), 81–84. https://doi.org/10.1130/g21057.1

Lawton, T.F., Bradford, I.A., Vega, F.J., Gehrels, G.E., Amato, J.M., 2009, Provenance of Upper Cretaceous-Paleogene sandstones in the foreland basin system of the Sierra Madre Oriental, northeastern Mexico, and its bearing on fluvial dispersal systems of the Mexican Laramide Province: Geological Society of America, Bulletin, 121(5/6), 820–836. https://doi.org/10.1130/b26450.1

Lawton, T.F., Giles, K.A., Rowan, M., 2021, La Popa Basin, Nuevo León and Coahuila, Mexico: Halokinetic Sequences and Diapiric Structural Kinematics in the Field: Switzerland, Springer Geology Fieldguides, Springer, 98 p. https://doi.org/10.1007/978-3-030-79397-5

McBride, E.F., Weidie, A.E., Wolleben, J.A., Laudon, R.C., 1974, Stratigraphy and structure of the Parras and La Popa basins, northeastern Mexico: Geological Society of America, Bulletin, 84, 1603–1622. https://doi.org/10.1130/0016-7606(1974)85%3C1603:sasotp%3E2.0.co;2

Michelin, H., 1850, Notice sur deux espèces d'Échinides fossiles: Revue et Magasin de Zoologie Pure et Appliquée, 2(141), 240.

Murray, G.E., Wolleben, J.A., Boyd, D.R., 1959, Difunta strada of Tertiary age: American Association of Petroleum Geologists Bulletin, 43, 2493–2495.

Schulte, P., Smit, J., Deutsch, A., Salge, T., Friese, A., Beichel, K., 2010, Tsunami backwash deposits with Chicxulub impact ejecta and dinosaur remains from the Cretaceous–Palaeogene boundary in the La Popa Basin, Mexico: Sedimentology 59, 737–765. https://doi.org/10.1111/j.1365-3091.2011.01274.x

Shipley, K.W., 2004, Ejecta-bearing deposits at the K/T boundary and their implications for timing of Laramide folding, La Popa basin, Mexico: U.S.A., Las Cruces, New Mexico State University, master thesis, 143 p.

Sigurdsson, H., Carey, S., Mandeville, C., Bronto, S., 1991, Pyroclastic flows of the 1883 Krakatau eruption: Eos, 72(36), 377-381. https://doi.org/10.1029/90EO00286

Smit, J., 1999, The global stratigraphy of the Cretaceous-Tertiary boundary impact ejecta: Annual Review of Earth and Planetary Sciences, 27, 75–113. https://doi.org/10.1146/annurev.earth.27.1.75

Stinnesbeck, W., Frey, E., Espinoza-Chávez, B., Zell, P., Flores-Ventura, J., Rivera-Sylva, H.E., González-González, A.H., Padilla-Gutiérrez, J.M., Vega, F.J., 2016, Theropod, avian, pterosaur, and arthropod tracks from the uppermost Cretaceous Las Encinas Formation, Coahuila, northeastern Mexico, and their significance for the end-Cretaceous mass extinction: Geological Society of America Bulletin, 129(3/4), 331–348. https://doi.org/10.1130/b31554.1

Vega, F.J., Perrilliat, M.C., 1995, On some Paleocene invertebrates from the Potrerillos Formation (Difunta Group), northeastern Mexico: Journal of Paleontology, 69, 862–869. https://doi.org/10.1017/s0022336000035538

Vega, F.J., Mitre-Salazar, L.M., Martínez-Hernández, E., 1989, Contribución al conocimiento de la estratigrafía del Grupo Difunta (Cretácico Superior-Terciario) en el noreste de México: Revista Mexicana de Ciencias Geológicas, 8(2), 179–187.

Vega, F.J., Nyborg, T., Fraaye, R.H.B., Espinosa, B., 2007, Paleocene decapod Crustacea from the Rancho Nuevo Formation (Parras Basin-Difunta Group), Northeastern Mexico: Journal of Paleontology, 81(6), 1432–1441. https://doi.org/10.1666/06-018r.1

Vyalov, O.S., 1937, Index Oysters of the Paleogene of Fergana: Geologiya I Razvedka Sluzhby Tresta “Sredazneft,” Trudy, Vypuschen Pervyy Tashkent: Zapiski. Izdatel’stevo Komitet Nauk Uzbekistan, SSR, 48 p.

Wolleben, J.A., 1977, Paleontology of the Difunta Group (Upper Cretaceous.Tertiary) in Northeastern Mexico: Journal of Paleontology, 51(2), 373–398.