



Record of seismites linked to the Chicxulub impact in deep-water deposits: Evidence from western Cuba

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ABSTRACT

The Chicxulub asteroid impact (~66 Ma) marks the end of the Cretaceous period and represents the only asteroid impact on Earth with a global record. The planetary collision was accompanied by catastrophic events related to the release of vast amounts of energy. Although one of the predictable consequences of the Chicxulub event was the release of enormous amounts of seismic energy, its signature in the geological record remains poorly reported and documented. Here, we document exceptional soft-sediment deformation structures, interpreted as seismites, within the Upper Cretaceous (Campanian–Maastrichtian) Peñas Formation exposed at Arroyo Las Piedras, western Cuba. The rhythmically interbedded mudstone-chert sequence exhibits pervasive brittle and ductile deformations produced by liquefaction and fluidization processes. We identify faults, fractures, folds, and numerous soft sediment deformation structures (SSDS) across a thickness exceeding 70 m. These deformations are interpreted as seismic-induced structures (seismites), resulting from the Chicxulub impact event located <500 km west. Those seismites are interpreted to occur alongside massive mud-volcano-like extrusions that expelled liquefied material onto the seafloor, forming a resedimented deposit with a mixed microfossil assemblage of Late Cretaceous taxa. This K-Pg deposit is concordantly overlain by Paleocene calcilutite of the Ancón Formation. Our findings indicate that seismic shocks affected deep-ocean sediments and partially lithified rocks, triggering large-scale sediment remobilization. This site represents a unique record of K-Pg Chicxulub-derived seismic events in the Proto-Caribbean.

1. Introduction

The discovery of the Chicxulub crater (Hildebrand et al., 1991) and its connection to the mass extinction at the Cretaceous–Paleogene (K-Pg) boundary (Alvarez et al., 1980; Schulte et al., 2010; Morgan et al., 2022) marked a milestone in geological studies of the Caribbean region and the Americas. Numerous studies have been published on the Gulf of Mexico and northern Caribbean area (Bourgeois et al., 1988; Smit et al., 1996; Maurrasse and Sen, 1991; King Jr and Petruny, 2005; Yancey and Liu, 2013; Sanford et al., 2016; Kinsland et al., 2025), confirming the catastrophic consequences of the hypervelocity impact on the Yucatan

carbonate platform ~66 million years ago (Day and Maslin, 2005; Shonting and Ezrailson, 2017; Arbic et al., 2024; Gulick et al., 2019; Morgan et al., 2022; Range et al., 2022; Gulick, 2025). One of the immediate physical consequences of the impact was the release of vast amounts of energy, potentially triggering colossal earthquakes (Bermúdez et al., 2024, 2026). Models suggest that the Chicxulub impact released enough energy to induce massive seismicity in vast areas of the Western Hemisphere (Collins et al., 2005; Pierazzo and Artemieva, 2012; DePalma et al., 2019; Morgan et al., 2022). Seismically deformed sequences have been reported in Mexico (Alegret et al., 2001; Schulte et al., 2012; Bermúdez et al., 2026), the southern United

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States (Smit, 1999; Poag, 2017; Bermúdez et al., 2022; Irizarry et al., 2023), the Gulf of Mexico and the Caribbean (Grajales-Nishimura et al., 2000; Molina et al., 2009; Denne et al., 2013; Paull et al., 2014), western North Atlantic (Klaus et al., 2000; Norris et al., 2002), and even northern South America (Renne et al., 2018; Bermúdez et al., 2019, 2026).

Although several studies have reported on the stratigraphic and faunal characteristics of the K-Pg deposits in Cuba (Takayama et al., 2000; Tada et al., 2002; Goto et al., 2002, 2008; Alegret et al., 2005; Cobiella-Reguera et al., 2015; Arenillas et al., 2016; Arz et al., 2022), no work has described the stratigraphic signature of the potential seismicity triggered by the Chicxulub impact on what is now Cuban territory. Given the island's proximity to the impact site, it is hypothesized that the Upper Cretaceous successions should contain clear evidence of intense seismically induced deformation related to the impact. To test this hypothesis, we have described in detail the stratigraphic succession of the K-Pg transition exposed at the Arroyo Las Piedras, Pons Valley, western Cuba, following reports of distorted K-Pg beds (Pszczółkowski, 1987; Banzo-Morales, 2024; Banzo-Morales et al., 2025a, 2025b). Our work identifies deformation structures affecting the deep marine deposits of the Late Cretaceous and the earliest Danian. The nature and scale of the deformation suggest that the most likely trigger was the Chicxulub impact and indicate that the earthquakes and aftershocks resulting may have continued for years after the planetary event. Our findings contribute to understanding the stratigraphy and tectonics of western Cuba, one of the most complex geological contexts in the country and the Caribbean region, revealing the stratigraphic signature in this part of the Caribbean, of what has been called the Chicxulub Mega-earthquake (Bermúdez et al., 2022).

2. Location and geological setting

The study area is located in the Pons Valley, approximately 850 m southwest of the town of the same name, in the Pinar del Río Province, Western Cuba (Fig. 1). Geologically, the region is part of the Mogotes Belt (MB), Guaniguanico terrane, which includes carbonates deposited on the eastern continental margin of the Yucatan Block during the Late

Jurassic to the Cretaceous, and synorogenic deposits of Late Paleocene–Early Eocene age (Iturralde-Vinent, 1994; Pszczółkowski, 1999). By the end of the Cretaceous (~66 Ma), the area was located less than 500 km from the Chicxulub asteroid impact site (Kiyokawa et al., 2002; Schulte et al., 2010).

When it is preserved, the sedimentary record of the Cretaceous in the area includes the Pons and Peñas formations. The Pons Formation (Aptian-Turonian) contains black to gray limestones and some interbedded chert layers. At the top, an erosional hiatus, spanning the Late Turonian to the entire Santonian (Cobiella-Reguera, 2008; Pszczółkowski, 1999; Iturralde-Vinent, 2021), divides the Pons Formation from the Peñas Formation. The Peñas Formation (Hatten, 1957) is the only unit of this age preserved in the Cuban geological record and consists of a rhythmic intercalation of gray to black limestones and black chert (Linares-Cala and García-Delgado, 2021; Pszczółkowski, 1999). The unit contains abundant radiolarians and planktonic foraminifera, indicating a Campanian-Maastrichtian age (Grinán Ferrer et al., 2025a; Grinán Ferrer et al., 2025b). The studied sequence forms part of a monocline that partially outcrops along the bed of Las Piedras Creek, extending approximately 100 m in an E–W direction. Despite intense deformation, the strata generally dip toward the W–NW (azimuth 288°–294°). Dip angles vary from ~35° near the base of the section to ~85° (subvertical) near the top.

The stratigraphic record of the K-Pg event and the early Paleogene in westernmost Cuba shows notable lateral variations. In areas such as the Pons Valley (focus of this research), where the stratigraphic succession is more complete, lowermost Danian rocks overlie the Maastrichtian deposits of the Peñas Formation. In nearby areas, however, deposits linked to the Chicxulub impact rest unconformably on Early Cretaceous rocks (Tada et al., 2002; Arenillas et al., 2016). While in the Pons Valley, the Peña Formation is overlain K-Pg deposits of resedimented mud; in nearby areas, the K-Pg event is represented by ejecta-rich calcareous clastic deposits from the Moncada and Cacarajicara formations. The Moncada Formation corresponds to thin deposits (<10 m) representing Chicxulub-derived tsunami deposits (Tada et al., 2002; Goto et al., 2008; Arenillas et al., 2016; Arz et al., 2022). The Cacarajicara Formation

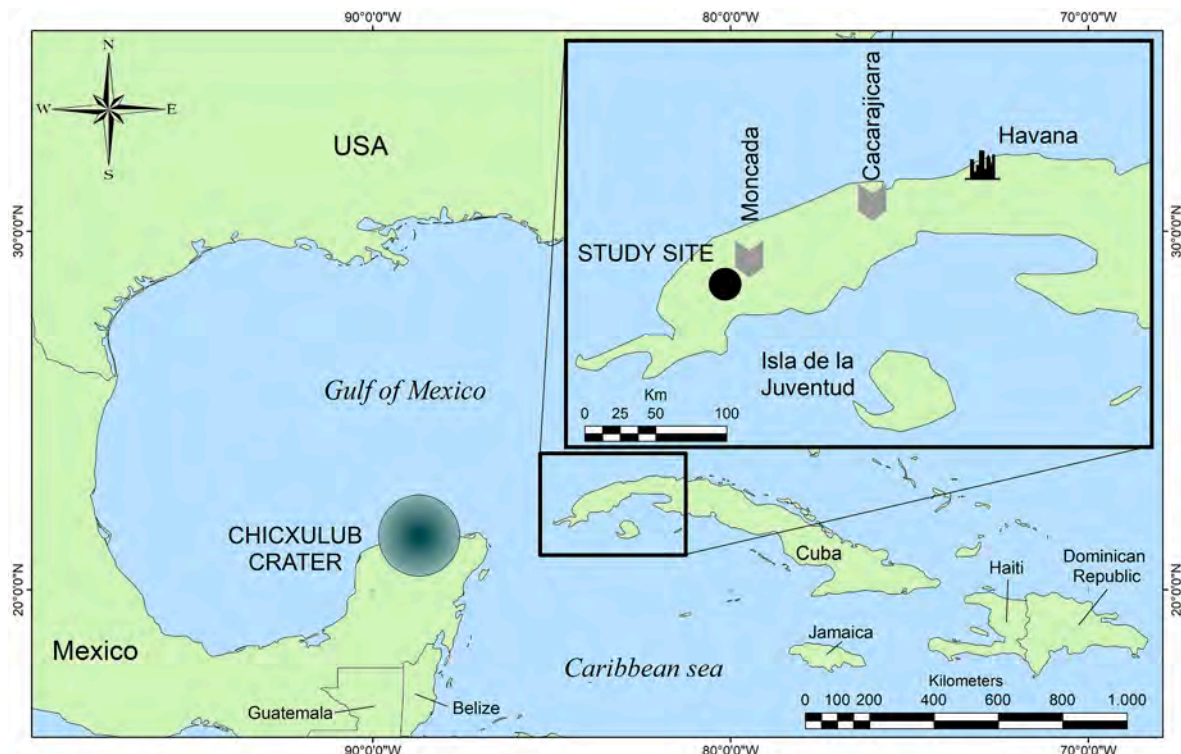


Fig. 1. Location map including other Cuban K/Pg boundary sections.

comprises thick deep-marine successions (>700 m) representing the collapse of the Yucatan platform margin as a consequence of the Chicxulub impact (Kiyokawa et al., 2002; Goto et al., 2008; Arz et al., 2022).

3. Materials and methods

For this research, the rocks representing the K-Pg transition outcropping in Las Piedras Creek, Pons Valley, western Cuba (22° 32.5346 N, 083° 54.3310 W), were described in detail. The studied section, from base to top, consists of a rhythmic sequence of medium to thick layers of mudstone and thin to very thin layers of chert from the Peñas Formation, overlaid by calcilutites from the Ancón Formation (Fig. 2).

We described, vertically and laterally, the exposed outcrops, recognizing thickness and nature of the beds, lithology, and sedimentary structures. Since our main goal was to identify evidence of seismically induced deformation, special attention was given to indications of liquefaction, describing soft sediment deformation structures (SSDS), folds, and faults. The stratigraphic columns were described following field standards, using Jacob's staff, Abney level, and compass. The location was monitored using GPS. Numerous photographs were acquired for structural and stratigraphic interpretation. For biostratigraphic control, particularly for the uppermost Cretaceous and the K-Pg transition interval, several rock samples were collected, expanding the available micropaleontological record (Banzo-Morales, 2024; Griñán Ferrer et al., 2025a; Griñán Ferrer et al., 2025b).

The analysis was performed on thin sections of the collected samples. Observations were made using a MELJI MT 5300 H binocular biological microscope. Sample preparation was based on the Branch Standard for the preparation of washed (LV) and thin-sectioned (SD) rock samples for paleontological or petrographic study, which has been in effect from 1979 to the present at the Sampling Group of the Biostratigraphy Department of the Petroleum Research Center (CEINPET).

The determination of planktonic foraminifera was based on the criteria of Premoli Silva et al. (2008). The updating of the systematics was carried out with the support of the Microtax website (Burkett et al., 2024).

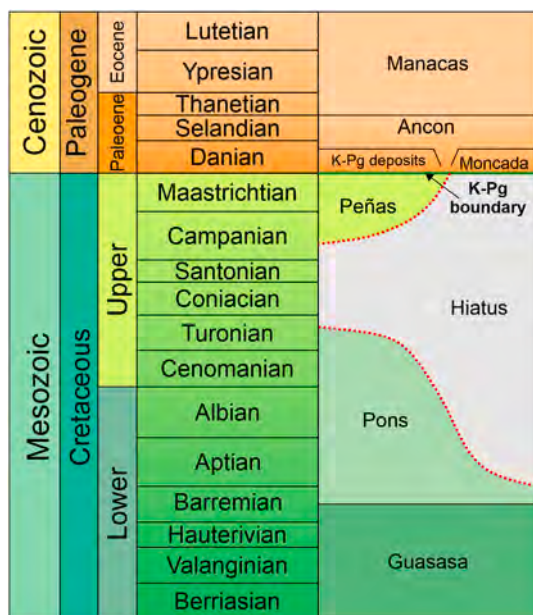


Fig. 2. Generalized stratigraphic succession of the K/Pg transition at the Mogotes Belt, Western Cuba.

4. Results

The stratigraphic section studied in this research includes, from base to top, rocks from the Pons (Aptian - Turonian), Peñas (Campanian - Maastrichtian), and Ancón (Early Paleocene - Early Eocene) formations. Our results suggest the presence of a new unit, located between the Peñas and Ancón formations, which, based on its age and stratigraphic relationships, we have informally named the “K-Pg deposits.” Due to poor exposure, descriptions of the Pons Formation are not included in this work (Fig. 3). Overall, the sedimentary record of the Upper Cretaceous and the K-Pg transition exposed at Arroyo Las Piedras, western Cuba, shows evidence of intense deformation extending ~70 m vertically from the K-Pg boundary.

4.1. Peñas Formation

The Peñas Formation consists of ~70 m of interbedded layers of gray mudstone and finely laminated black chert. Abundant planktonic foraminifera, including *Contusotruncana contusa*, *C. fornicata*, *C. walfschensis*, *Globotruncana bulloides*, *G. linneiana*, *Globotruncanella havanensis*, *Globotruncanella cf. elevata*, *Globotruncanella conica*, *G. stuarti*, *G. stuartiformis*, *Heterohelix* sp., *Laevella bentonensis*, *Laeviheterohelix* cf. *glabrans*, *Muricohedbergella planispira*, and *Rugoglobigerina rugosa*, suggest a Campanian-Maastrichtian age (Griñán Ferrer et al., 2025a; Griñán Ferrer et al., 2025b). Overall, the entire unit is intensely disturbed and shows the co-occurrence of brittle and ductile deformation structures (Figs. 4 and 5). Brittle deformation affects predominantly chert beds, while ductile deformation is ubiquitous and preferentially affects mudstone beds. At the base of the unit (lower 15 m), although both types of deformation coexist, brittle deformation is more pronounced (Fig. 4),

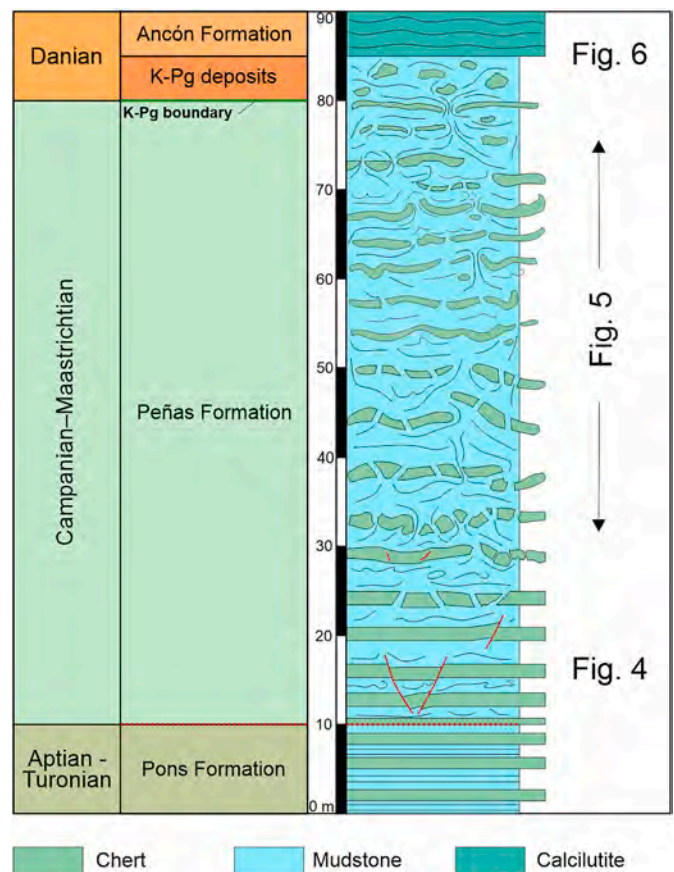


Fig. 3. Schematic stratigraphic section for the Upper Cretaceous and the Lower Paleogene at the Arroyo Las Piedras, western Cuba.

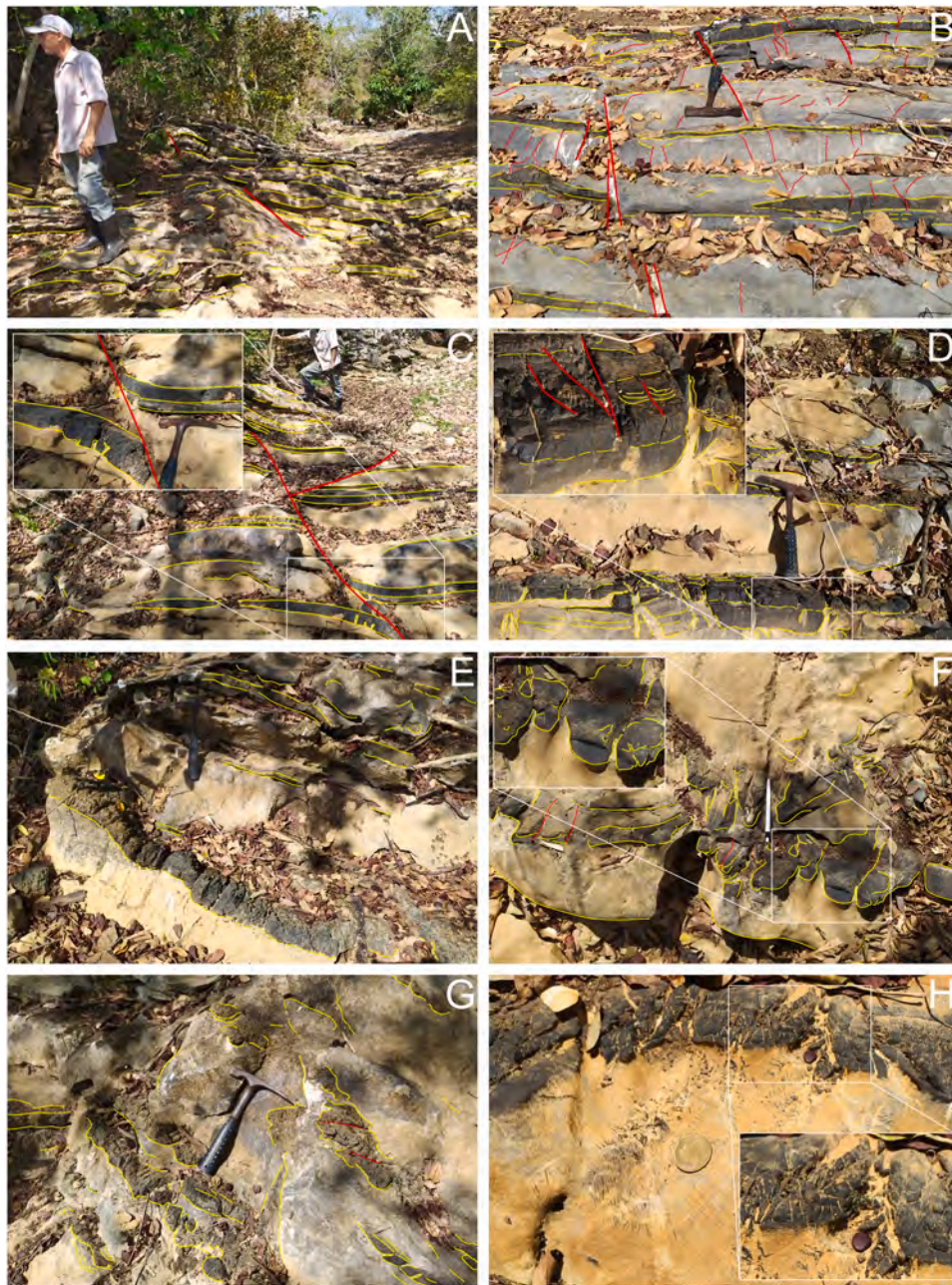


Fig. 4. Deformation structures at the base of the Peñas Formation. The dark layers correspond to black chert, while the light-colored rocks are mudstone. Yellow lines represent lithological boundaries and lamination. Red lines represent faults and fractures.

while in the middle and upper part of the Peñas Formation (upper 55 m), ductile deformation preponderates (Fig. 5).

At the base of the Peñas Formation, brittle deformation consists of fractures and normal and reverse faults with minor movement, oriented in different directions, and fractured and brecciated beds of chert (Fig. 4A–C). Ductile deformation consists of small folds and numerous centimeter-scale SSDS, including water escape structures, pillars, dikes, balls, pillows, pseudonodules, drops, disturbed lamination, flame structures, and convolute lamination. Locally, there are massive-looking mudstone sectors surrounding fractured and dislocated beds and floating chert fragments (Fig. 4D–H). In general, the chert beds are intensely fractured in several directions, sometimes appearing as breccias with no apparent movement. Locally, the fractures are filled with calcite or calcareous mud intruding from the underlying mudstone layers.

At the top of the Peñas Formation, brittle deformation is almost entirely concentrated in the chert and consists predominantly of fractured, dislocated, isolated, and brecciated chert beds. Ductile deformation includes folds of varying height and amplitude and occasional centimeter-sized SSDS, including water escape structures, disturbed lamination, balls, pillows, drops, plastic intrusions, and pseudonodules (Fig. 5A and B). However, the main feature of the ductile deformation corresponds to (especially at the top of the unit) massive or pseudo-laminated mudstone embedding centimetric to decimetric-sized black chert fragments (Fig. 5C–H).

4.2. “K-Pg deposits”

Immediately above the rocks of the Peñas Formation, there is a level of variable thickness (5 to 10 m) of chaotic mudstone with fragments of

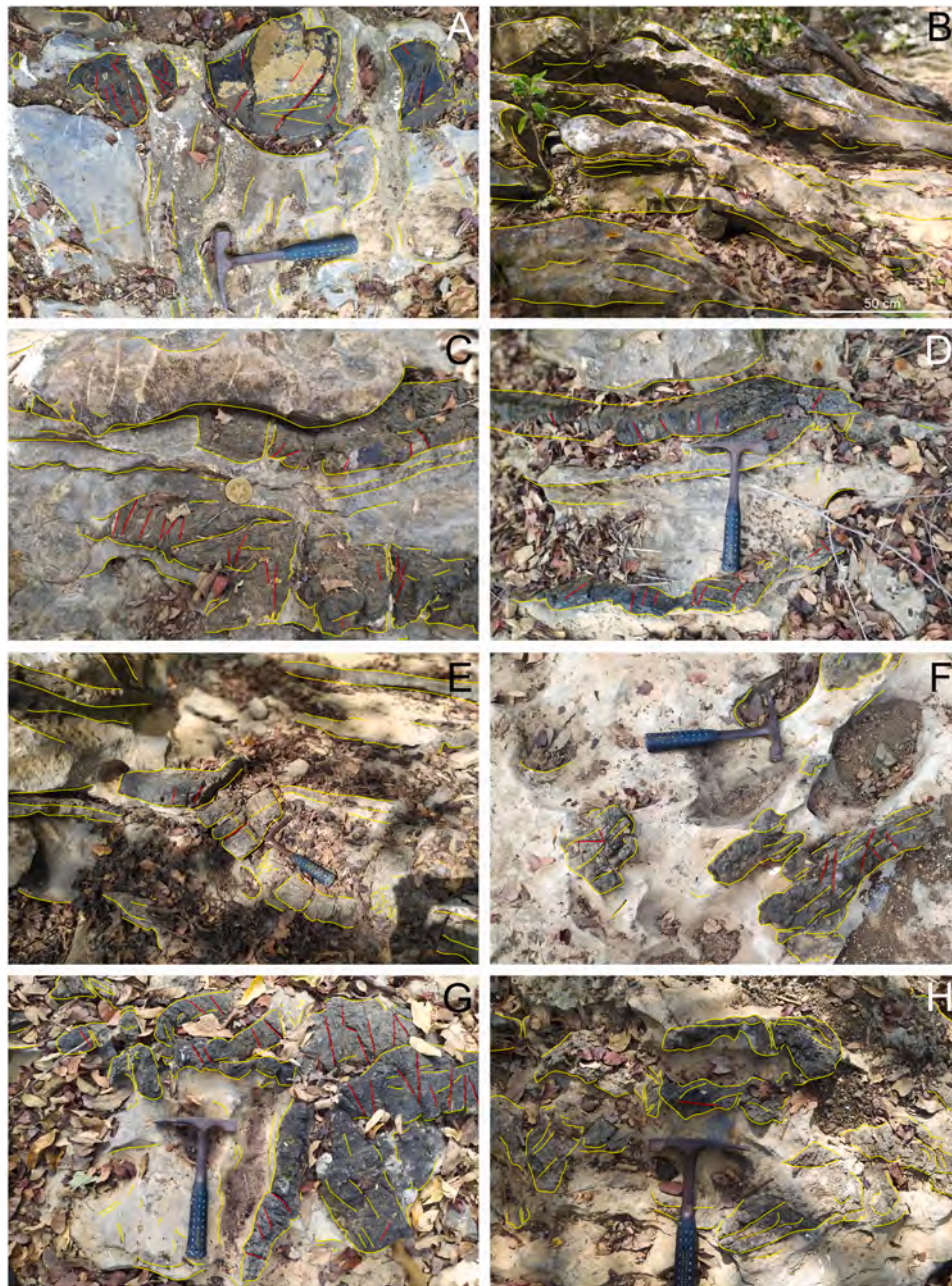


Fig. 5. Deformation structures at the top of the Peñas Formation. The dark layers correspond to black chert, while the light-colored rocks are mudstone. Yellow lines represent lithological boundaries and lamination. Red lines represent faults and fractures.

black chert, similar to those described previously (Fig. 6A–C). The micropaleontological content suggests a mixture of Cretaceous faunas. Planktonic foraminifera such as *Globotruncana linneiana*, *Radotruncana calcarata*, *Globotruncanella angulata*, *Planoheterohelix* sp., *Muricohedbergella holmdelensis*, *Globotruncanella conica*, *Globotruncana ventricosa*, *Globotruncanella havanensis*, *Globotruncana rosetta*, *Globotruncana aegyptiaca*, *Claviohedbergella* cf. *C. simplex*, *Globotruncanella* sp., *Contusotruncana* sp., *Heterohelix* sp., *Globigerinelloides* cf. *G. ultramicrus*, *Claviohedbergella* sp., *Globotruncanella* sp., *Pseudotextularia* sp., *Laeviheterohelix* sp., *Globigerinelloides* sp., *Globotruncana* sp., and *Rugoglobigerina* sp., suggest a Campanian–Maastrichtian age. At the same time, *Globotruncanella elevata*, *Contusotruncana fornicata*, and *Muricohedbergella planispira* and *Laevella bentonensis* indicate reworking of the Santonian–Campanian, Turonian–Maastrichtian, and Albian–Turonian records, respectively. The deposit varies between areas that preserve lamination and sectors of massive mudstone containing fragments of intensely

fractured chert of varying sizes. The sectors that preserve the internal structure include examples of convolute lamination, disturbed lamination, and occasional pseudonodules and water escape structures. During the petrographic study of these mudstones, some devitrified impact spherules and shock quartz were observed.

4.3. Ancón Formation

In the study area, the Ancón Formation (Early Paleocene–Early Eocene) abruptly overlies the K–Pg deposits (with possible local irregular erosion; Fig. 6A–C). The base of the unit includes planktonic foraminifera such as *Globanomalina compressa*, *Eoglobigerina* sp., *Morozovella velascoensis*, *Subbotina velascoensis*, *Chiloguembelina* sp., and *Acarinina* sp. The presence of *G. compressa* suggests a Danian age, while *M. velascoensis* and *S. velascoensis* indicate the Selandian. Furthermore, a late Paleocene–early Eocene interval is recorded, marked by a faunal association



Fig. 6. Deformation structures at the “K-Pg deposits” and the base of the Ancón Formation. White lines represent formational boundaries. Yellow lines represent lithological boundaries and lamination. Red lines represent faults and fractures.

consisting of *Planorotalites* sp., *Acarinina* sp., *Morozovella* sp., *Morozovella acuta*, *Subbotina* sp., *Morozovella velascoensis*, and *Igorina* sp., along with planktonic foraminiferal chambers. Redeposition of Late Cretaceous taxa is also recorded.

Unlike the underlying deposits, the first strata of the Ancón Formation are finely laminated and show no evidence of brittle deformation. The calcilutites at the base of the unit show mild deformation, represented by some millimeter-scale SSDS, including pseudonodules, water escape structures, and convolute lamination and predominantly gentle folds, simulating ripple lamination, slightly deforming the original planar parallel lamination (Fig. 6B–E).

5. Discussion

The deformed deposits from the Cretaceous–Paleogene transition in the Pons Valley region, western Cuba, are complex and varied. The disturbed sequence extends from the base of the Peñas Formation to the base of the Ancón Formation. Here, the most intensely deformed

deposits are located around the K-Pg boundary (i.e., the top of the Peñas Formation and the beds we have named the “K-Pg deposits”, which includes Chicxulub impact-derived ejecta). We propose that sediments and unconsolidated rocks in this region of the western Caribbean by the time of the K-Pg boundary (~66 Ma) were affected by seismically-induced deformation processes triggered by colossal earthquakes resulting from the Chicxulub asteroid impact. Several arguments support our interpretation: 1) The Chicxulub impact coincides with the K-Pg boundary (Arenillas et al., 2006, 2016; Renne et al., 2013; Sprain et al., 2015). 2) The study area was located less than 500 km from the impact site (Kiyokawa et al., 2002; Tada et al., 2003; Schulte et al., 2010). 3) The collision released vast amounts of energy (Collins et al., 2005; Morgan et al., 2022; Gulick, 2025). 4) Numerous lines of evidence suggest that the Chicxulub asteroid impact could have triggered earthquakes with a magnitude $M_w > 10$ (Boslough et al., 1994; Day and Maslin, 2005; DePalma et al., 2019; Bermúdez et al., 2024, 2026). Our findings would represent the thickest record (>70 m) of seismites reported to date, exposing the catastrophic nature of the seismicity

triggered by the Chicxulub impact.

Our findings show that brittle and ductile deformation structures coexist in the Peñas Formation (Campanian–Maastrichtian). Brittle deformation is indicated by faults and fractures, predominantly affecting chert beds towards the base of the unit, while ductile deformation is ubiquitous and preferentially affects mudstone beds. Ductile deformation is marked by the co-occurrence of abundant and diverse SSDS and massive mud sequences with flow structures, suggesting liquefaction and fluidization processes (Lowe, 1975; Rodríguez-Pascua et al., 2000; Berra and Felletti, 2011). Although liquefaction generally occurs in saturated sandy sediments (Obermeier, 1996; Gibert et al., 2011), liquefaction of muddy sediments has been reported during recent seismic events, such as those in the 1964 Niigata earthquake (Towhata, 2024), 1997 Cariaco earthquake (González et al., 2004), and the Christchurch earthquake (Maurer et al., 2014), laboratory experiments (Tian et al., 2016), or paleo earthquakes (Su et al., 2014), demonstrating that under critical conditions, liquefaction of muddy sediments is possible. Variations in the type of deformation according to lithology, and concurrent occurrence of several SSDS, imply different stages of lithification (Mazumder et al., 2006; Berra and Felletti, 2011), and varied responses to a shared deformation process (McLaughlin and Brett, 2004). In particular, SSDS in sequences affected by seismically-induced liquefaction constitute what is commonly known as seismites (Seilacher, 1969; Montenat et al., 2007).

Brittle deformation occurs throughout the Peñas Formation, but it is primarily concentrated in the lower part of the unit (Fig. 7). Minor fractures and normal and reverse faults, oriented in different directions, indicate synchronous compressional and extensional processes occurring in various directions (Rodríguez-Pascua et al., 2000; Kahle, 2002). Concurrent ductile deformation structures affecting the mudstones suggest seismic shaking and that the early lithified chert beds were unsuitable for fluidization (Seilacher, 1969; Alfaro García et al., 1995; Montenat et al., 2007). Similarly, fractured and brecciated beds of chert, embedded in massive mudstone, are similar to *in situ* fragmented breccias (autoclastic breccias) associated with seismites (Spalletta and Vai, 1984; Montenat et al., 2007; Su et al., 2014). Overall, the structures and relationships observed are similar to those present in the so-called Rubble Zone defined for seismites (Seilacher, 1969).

Present in the entire succession, but mainly in the upper 55 m of the

Peñas Formation (Fig. 7), the ductile deformation consists of a rich and diverse group of SSDS and massive or pseudo-laminated (flow structures?) mud sequences including chert fragments. The ductile deformation includes folds of variable size and amplitude, and SSDS such as pillows, pseudonodules, balls, drops, hydroplastic intrusions, water escape structures, pillars, dikes, disturbed lamination, convoluted lamination, and flame structures. Combined, flame structures, drops, pseudonodules, ball and pillow structures, and plastic intrusions are considered evidence of gravitational collapse of the competent bodies into the muddy sediments due to liquefaction and fluidization during seismic events (Alfaro et al., 1997; Obermeier, 1996; Moretti and Sabato, 2007). Liquefaction and fluidization processes can also generate vertical shear stress, forming SSDS such as clastic dikes, liquefied breccia, and water-escape structures (Bezerra et al., 2001; Berra and Felletti, 2011; Cui et al., 2022).

We suggest a connection between the massive or pseudo-laminated (flow structures?) mudstones that include chert fragments from the Peñas Formation and the overlying calcilutites from the “K-Pg deposits” (Fig. 7). Firstly, the massive mudstone seems to correspond to liquefied and fluidized sediments that deformed layers and dragged chert fragments during their ascending movement. Secondly, the finely laminated calcareous muds from the “K-Pg deposits” contain a mixture of Cretaceous foraminifera that might represent the expulsion to the seafloor surface of the liquefied and remobilized muddy materials from underlying rocks. Although scarce, the presence of altered spherules and impact quartz may be related to materials ejected during the formation of the Chicxulub crater, incorporated during the deposition of the expelled muds on the marine surface. We suggest that seismically induced processes, similar to mud diapirism, may explain those processes. Even though to date no similar scenario has been reported in other K-Pg locations, diapiric-like structures associated with the K-Pg boundary have been reported in several areas of the Gulf of Mexico and have been linked to seismicity resulting from the Chicxulub impact. However, in El Mimbrel and Rancho Nuevo (Mexico) and Moscow Landing (the United States), the diapiric-like structures involving Maastrichtian shales are dissected by tsunami-backwash Chicxulub-derived deposits (Alvarez et al., 1992; Smit et al., 1996; Schulte, 2003; Hart et al., 2013). Nonetheless, the bathymetric position of the Cuban deposits, located at a depth of more than 4000 m (Pszczółkowski, 1999),

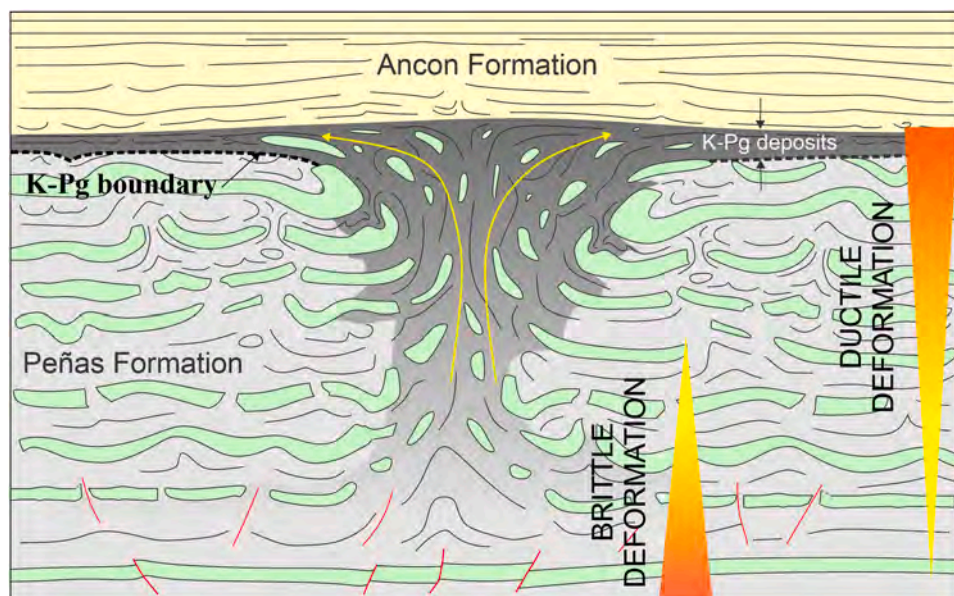


Fig. 7. Conceptual model, not to scale, of the deposits associated with the K-Pg boundary in the study area. The deformation observed in the rocks of the Peñas Formation corresponds to seismites resulting from the liquefaction and fluidization of unconsolidated calcareous mud (gray) and the folding and fracturing of the chert layers (light green) as a consequence of the Chicxulub impact. The ascent to the sea floor of the liquefied and fluidized muds, dragging fragments of the chert layers, is similar to mud volcanoes and corresponds to the “K-Pg deposits” (dark gray).

would protect these diapirs from the effects of tsunamis, preserving the expelled materials. Diapiric structures resulting from earthquakes are common and have been reported extensively (Dimitrov, 2002; Kopf, 2002; Mazzini and Etiope, 2017), especially as a result of earthquakes with a magnitude $M_w > 5$ (Mellors et al., 2007; Manga et al., 2009).

Finally, the deformation observed in the “K-Pg deposits” and the first layers of the Ancón Formation suggests the persistence of seismic activity for some time after the Chicxulub impact. The disturbed lamination and the presence of convolute lamination, pseudonodules, and water escape structures imply that the deformation processes observed in the upper part of the Peñas Formation continued to operate in the earliest Danian. The phenomenon has been observed in other K-Pg locations, and although its duration is still uncertain, it is estimated to be between a few months and a few years (Berry, 2023; Bermúdez et al., 2024, 2026). The observed SSDS suggest deformation of unconsolidated sediments affected by liquefaction and fluidization (Rodríguez-Pascua et al., 2000; Berra and Felletti, 2011; Etensohn et al., 2011). While flow patterns and pseudonodules indicate *in situ* repeated changes in the direction of force, by irregular rotational or oscillatory movement (Matsuda, 2000), water escape structures point to vertical shear stress and fluidization phenomena (Obermeier, 1996; Bezerra et al., 2001). Overall, the structures and relationships observed in the upper part of the Peñas Formation, the “K-Pg deposits”, and the first layers of the Ancón Formation are similar to those present in the so-called Soupy Zone defined for seismites (Seilacher, 1969).

6. Conclusions

The outcrops studied in western Cuba reveal evidence of seismically induced deformation that can be attributed to the Chicxulub impact. The disturbed sequence extends from the base of the Peñas Formation (Campanian–Maastrichtian) to the base of the Ancón Formation (Early Paleogene). Our findings indicate that the seismicity derived from the Chicxulub impact affected tens of meters of the marine substrate. There is evidence that the deformation involved sediments and partially lithified rocks of the Peñas Formation and the lowermost Paleogene deposits, suggesting that the seismic activity extended to the earliest Danian. The deformation is similar to that reported in the Soupy and Rubble zones defined in the concept of seismites (Seilacher, 1969). Given that the outcrops of the Pons Formation (Aptian–Turonian) were not studied, the so-called Segmented Zone may be present in the rocks of that unit. Nevertheless, our findings would constitute the thickest record of seismites reported to date, revealing the catastrophic nature of the seismicity associated with the Chicxulub impact.

The deformed sequence of the Peñas Formation has a thickness of ~70 m and is interpreted as seismites resulting from seismic deformation triggered by the Chicxulub impact. The evidence shows the simultaneous occurrence of brittle and ductile deformation. Ductile deformation structures develop preferentially near the K-Pg boundary, while brittle deformation structures are more abundant as we descend stratigraphically, suggesting different stages of lithification.

Brittle deformation structures are preferentially located in the base of the Peñas Formation (lower 15 m); here, fractures and faults are preferentially concentrated in the chert beds, while fluidization is concentrated in the mudstone beds. Ductile deformation, represented by liquefaction-folding structures, occurs preferentially in the middle part of the unit and differentially affects the mudstone and chert beds. While the chert beds are preferentially folded (and typically fractured), ductile deformation resulting from liquefaction predominates in the mudstone bed, including abundant evidence of plastic intrusions affecting the chert. At the top of the Peñas Formation, chert beds were generally dislocated and commonly appeared as floating blocks in intensely deformed, chaotic-looking mudstone beds, suggesting upward mudflows carrying chert fragments.

The deposits associated with the Chicxulub impact contain some ejecta elements and consist predominantly of calcareous muds. These

muds contain a faunal mixture that accumulated immediately above the Peñas Formation. We interpret these rocks as representing the K-Pg event in this area of western Cuba, formed by the re-accumulation of liquefied sediments from the Campanian and Maastrichtian. Micropaleontological evidence indicates that this material originated from the Peñas and Pons formations. It was injected into the deformed substrate and expelled onto the ocean floor, forming mud volcanoes. These flows occurred in bathyal environments at depths exceeding 4000 m and may constitute a new type of K-Pg deposit not previously identified.

The basal deposits of the Ancón Formation (early Danian) correspond to finely laminated, slightly deformed calcilutite, suggesting that seismic activity, although on a smaller scale, extended into the early Danian.

Further work is needed in nearby locations to clearly define the extent and characteristics of the deformed areas within the Peñas Formation, as well as in the so-called “K-Pg deposits” representing the Chicxulub event. It is also suggested that the study be extended to the rocks of the Pons Formation to establish clearly the extent and characteristics of seismicity within the rocks that formed the ocean floor at the time of the collision. Additionally, it will be necessary to formally define the stratigraphy of the K-Pg deposits in the Pons Valley and their relationship with the tsunamites and deposits that represent the collapse of the continental platform in other areas of Cuba and the Caribbean as a result of the collision. These studies will provide a better understanding of the sedimentological signature and the processes involved in the formation of seismites associated with mega-earthquakes such as the one triggered by the Chicxulub asteroid impact.

CRedit authorship contribution statement

Reinaldo Rojas Consuegra: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Esther María Cruz Gámez:** Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Wilmer Pérez Gil:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Siylvia Teresita Blanco Bustamante:** Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Isabel Beatriz Grinán Ferrer:** Data curation, Formal analysis, Investigation, Writing – original draft. **Mercedes Torres La Rosa:** Data curation, Formal analysis, Supervision, Writing – original draft. **Rogelio Agüero López:** Investigation, Visualization, Writing – review & editing. **Sujai Banzo Morales:** Data curation, Investigation, Writing – original draft. **Dámaso Cáceres Govea:** Formal analysis, Investigation, Writing – original draft. **Kenya Elvira Núñez Cambra:** Formal analysis, Methodology, Writing – original draft. **Hermann D. Bermúdez:** Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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