Cretaceous-Paleogene boundary deposits at Loma Capiro, central Cuba: Evidence for the Chicxulub impact

Laia Alegret* Department of Earth Sciences, University College London, WC1E 6BT London, UK, and Departamento de Ciencias de la Tierra, Universidad de Zaragoza, 50009 Zaragoza, Spain
Ignacio Arenillas, José A. Arz — Departamento de Ciencias de la Tierra, Universidad de Zaragoza, 50009 Zaragoza, Spain
Consuelo Díaz Instituto de Geología y Paleontología, La Habana, Cuba
José M. Grajales-Nishimura Instituto Mexicano del Petróleo, 07730 Mexico D.F., Mexico
Alfonso Meléndez, Eustoquio Molina — Departamento de Ciencias de la Tierra, Universidad de Zaragoza, 50009 Zaragoza, Spain
Reinaldo Rojas Museo Nacional de Historia Natural, 10100 La Habana, Cuba
Ana R. Soria Departamento de Ciencias de la Tierra, Universidad de Zaragoza, 50009 Zaragoza, Spain

ABSTRACT

A newly discovered Upper Cretaceous to lower Paleogene section at Loma Capiro (central Cuba) has provided new evidence for a Cretaceous-Paleogene boundary age for the Chicxulub impact. The studied sediments at Loma Capiro consist of a foraminifera-rich marl and sandstone hemipelagic sequence, and a 9.6-m-thick intercalated clastic complex. Planktic foraminifera indicate an upper Maastrichtian age for the sediments below the clastic complex and a lowermost Danian age for those just above this complex. Small benthic foraminifera from below and above the clastic complex indicate deposition at middle to lower bathyal depths. The fining-upward clastic complex consists of a basal breccia that is overlain by microconglomerates and coarse- to fine-grained sandstones. The clastic complex contains reworked foraminifera from different ages and different paleoenvironments and, toward the top, impact material such as altered microtektites, shocked quartz, terrestrial chondrules, and accretionary lapilli. These microfacies suggest deposition from gravity flows that eroded sediments from upper-slope and shelf settings and redeposited them in deeper bathyal environments. We suggest that the origin of the clastic complex may be linked to the collapse of the Cuban platform, triggered by the Cretaceous-Paleogene impact at Chicxulub.

Keywords: Chicxulub impact, Cretaceous–Paleogene event, gravity flows, foraminifera, Cuba.

INTRODUCTION

The Cretaceous-Paleogene boundary event and the related catastrophic mass extinction are usually explained as the result of a large asteroid impact that occurred at Chicxulub in the Yucatan Peninsula, Mexico. The impact scenario is broadly accepted to account for the origin of the Cretaceous-Paleogene clastic deposits from the Gulf of Mexico, Caribbean, and North Atlantic (Smit et al., 1996; Grajales-Nishimura et al., 2000; Klaus et al., 2000; Soria et al., 2001; Tada et al., 2003). The Chicxulub impact caused the destabilization of the central and North American continental margins and megatsunamis, triggering the deposition of the so-called ''Cretaceous-Paleogene boundary cocktail'' unit in these areas (Bralower et al., 1998). This unit includes a mixture of reworked microfossils from different ages, impact-derived materials, and heterogeneous lithic fragments.

This single catastrophic scenario is not supported by a small group of scientists who argue that the Chicxulub crater was formed 300 k.y. earlier. This hypothesis is based on two main arguments. The first is the presence of several horizons of spherules found in the La Sierrita area (northeastern Mexico; Stinnesbeck et al., 2001), although the apparent multiple spherule horizons may be explained by slumping (Soria et al., 2001). The second is the presence of a 50-cm-thick layer of micritic limestone containing uppermost Maastrichtian planktic foraminiferal assemblages overlying the impact breccia in the Yaxcopoil-1 drill hole (Chicxulub crater; Keller et al., 2004). However, such a critical interval is not a micritic limestone, but it consists of a dolomitic calcareous sandstone with climbing ripples and scarce, reworked Albian to Maastrichtian planktic foraminifera, and it probably represents the infill of the crater due to the marine invasion into the cavity that occurred just after the Cretaceous-Paleogene boundary impact (Arz et al., 2004; Smit et al., 2004).

The origin and model of deposition of the Cretaceous-Paleogene boundary deposits from the Gulf Coast and Caribbean are controversial issues that need more research. Studies performed in western Cuba have documented the presence of a clastic megabed, the origin of which has been related to the Chicxulub impact (e.g., Tada et al., 2003). Studies of Cretaceous-Paleogene boundary deposits from central Cuba are scarce, and the paleobathymetry and dating of these sediments, as well as the environmental consequences of such an impact, are not yet clear. In order to clarify these issues, we performed a multidisciplinary study of the new Loma Capiro section (central Cuba), including detailed stratigraphic, petrographic, and paleobathymetric analyses, and high-resolution foraminiferal biostratigraphy. In contrast to other Cretaceous-Paleogene boundary clastic deposits in sections and wells from Mexico, Guatemala, Belize, or from the crater itself, the newly discovered Loma Capiro section contains abundant microfossils, which provide some additional information on the origin and deposition of this unit, and on its relationship with the Chicxulub impact and the Cretaceous-Paleogene boundary event.

MATERIAL AND METHODS

The Loma Capiro section is located in central Cuba (Villa Clara Province; Fig. 1), on the

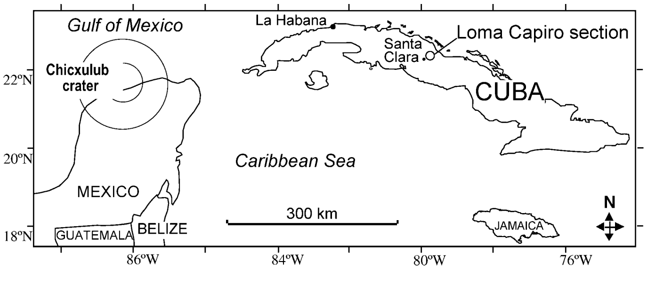

Figure 1. Location of Loma Capiro section.

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*Corresponding author e-mail: laia@unizar.es.

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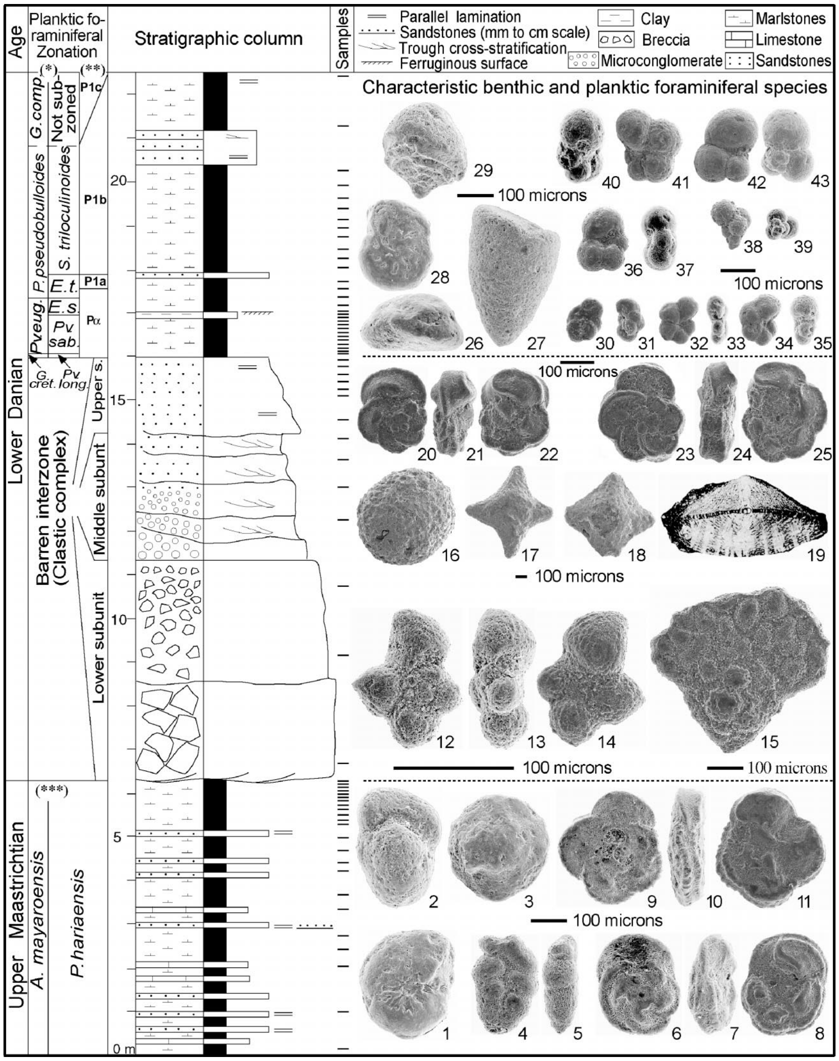

Figure 2. Stratigraphic column of Loma Capiro section, and scanning electron microscope photographs of most typical foraminiferal species. 1: *Stensioeina beccariiformis*; 2: *Gyroidinoides globosus*; 3: *Nuttallides truempyi*; 4–5: *Pseudoguembelina hariaensis*; 6–8: *Contusotruncana fornicata*; 9–11: *Abathomphalus mayaroensis*; 12–14: *Plummerita hantkeninoides*; 15: *Planoglobulina multicamerata*; 16: *Torreina torrei*; 17: *Asterorbis havanensis*; 18: *A. aguayoi*; 19: *Orbitoides apiculata apiculata*; 20–22: *C. plummerae*; 23–25: *Globotruncana linneiana*; 26: *Paralabamina hillebrandti*; 27: *Marssonella oxycona*; 28: *Cibicidoides hyphalus*; 29: *Aragonia ouezzanensis*; 30–31: *Parvularugoglobigerina sabina*; 32–33: *Pv. longiapertura*; 34–35: *Pv. eugubina*; 36–37: *Eoglobigerina simplicissima*; 38–39: *Guembelitria cretacea*; 40–41: *Parasubbotina pseudobulloides*; 42–43: *Subbotina triloculinoides*. *G. cret*—*G. cretacea*; *Pv. long*—*Pv. longiapertura*; *Pv. sab*—*Pv. sabina*; *E.s.*—*E. simplicissina*; *Pv. eug.*—*Pv. eugubina*; *G. comp.*—*G. compressa*. Biozonation by: (*) Arenillas et al. 2004; (**) Berggren et al. (1995); (***) Arz and Molina (2002).

northeastern side of the town of Santa Clara, ~1000 km east of the Chicxulub crater. The outcrop is situated at Loma Capiro (22°30′N, 79°50.5′W), and it provides an excellent exposure across more than 100 m. In this sector of central Cuba, the Cretaceous-Paleogene clastic complex is included in the Maastrichtian–Paleocene Santa Clara Formation. In addition to this complex, which is 9.6 m thick, we analyzed the upper 6 m of the underlying Maastrichtian marly sediments, and the lowermost 6.5 m of the overlying silty sediments.

We selected a total of 66 samples for micropaleontologic and petrographic studies (see Data Repository[1] and Fig. 2). At least 300 benthic foraminifera and 300 planktic foraminifera were picked from the >63 μm fraction from each sample. Thin sections and oriented thin sections of benthic macroforaminifera were analyzed. Petrographic examinations of polished thin sections from the clastic complex were carried out in order to document the presence of impact-related materials.

STRATIGRAPHY AND MINERALOGICAL IMPACT EVIDENCE

Sediments below the clastic complex consist of tabular bodies, as thick as 1 m, of foraminifera-rich massive gray marls with abundant intercalated white limestone, and ochre, fine- to medium-grained sandstone levels (Fig. 2). The limestones have a mudstone texture, and they are disposed in 10–30-cm-thick tabular levels with parallel lamination. The 2–15-cm-thick tabular sandstone bodies display an internal upward-fining evolution and parallel lamination.

The 9.6-m-thick clastic complex consists of an upward-fining sequence in which three subunits were identified. (1) The lowest subunit corresponds to a 5-m-thick upward-fining breccia with a clayey-lutitic matrix and angular to subrounded clasts that are 2–40 cm in diameter, among which igneous clasts dominate. The fabric ranges from grain supported at the base to matrix supported toward the upper part of this body. Lithologies typical of an ophiolitic complex make up 64% of the lithoclastic composition of the basal breccia, whereas volcaniclastic sediments make up 30% of the assemblage. Slumps locally affecting the basal part of the breccia and the underlying Cretaceous marls and limestones were identified (Fig. 3A). (2) Higher in the section, a 3-m-thick, upward-fining subunit of microconglomerates and coarse-grained sandstones was identified. It contains volcanic and carbonate clasts as much as 1 cm long, and it shows internal erosive scours and 20–30-cm-thick sets displaying parallel and cross-lamination. (3) The uppermost subunit consists of a 1.8-m-thick sequence of coarse- to fine-grained sandstones displaying parallel lamination and an upward-fining internal evolution.

The uppermost subunit contains impact material (Figs. 3B–3D) such as shocked quartz, terrestrial chondrules, and abundant accretionary lapilli and calcified glass microspherules (altered microtektites). Shocked quartz grains are scarce, although grains of quartz with a structure that resembles one set of planar deformation features were found. Accretionary lapilli are spherules formed by the accretion of mineral and lithic fragments and consist of a very fine grained outer crust and a coarser-grained core. The chondrules have spherical, droplet-like, and dumbbell shapes. The glass

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[1] GSA Data Repository item 2005131, Tables DR1 and DR2, distribution charts of benthic and planktic foraminiferal species at Loma Capiro section, Cuba, is available online at www.geosociety.org/pubs/ft2005.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

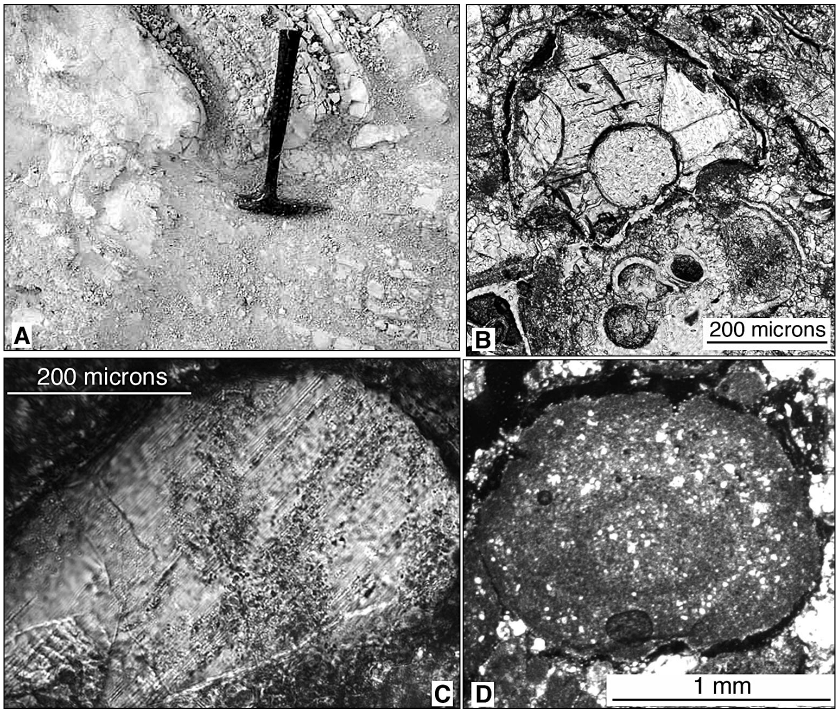

Figure 3. A: Slumps affecting Cretaceous sediments at Loma Capiro. B: Calcified broken vesiculated spherule. C: Shocked quartz grain with one set of planar deformation features. D: Accretionary lapilli, showing concentric structures and core lined by dark rim, and outer dark gray band.

spherules have been altered to calcite; they are spherical and normally vesicular.

The clastic complex is overlain by a Danian sequence of tabular bodies, as much as 2 m thick, of ochre and gray massive to occasionally laminated silts, intercalated with 0.25–0.8-m-thick tabular sandstone levels. The sandstones are fine grained and display parallel lamination and low-angle cross-lamination.

BIOSTRATIGRAPHY

For biostratigraphic determinations (Fig. 2), we used the planktic foraminiferal zonations by Arz and Molina (2002) and Arenillas et al. (2004). We recognized 67 planktic foraminiferal species in the lowermost 6 m of the section (Cretaceous autochthonous sediments not affected by slumping), which belong to the *Pseudoguembelina hariaensis* subzone (*Abathomphalus mayaroensis* zone). The uppermost Maastrichtian *Plummerita hantkeninoides* subzone, and probably most of the *Pseudoguembelina hariaensis* subzone, are absent. The coexistence of *P. hariaensis*, *Globotruncana bulloides*, and *Contusotruncana fornicata* in this interval indicates a stratigraphic gap that affects the last ~1500 k.y. of the upper Maastrichtian (Arz and Molina, 2002).

Above the clastic complex, the *Guembelitria cretacea*, *Parvularugoglobigerina* (*Pv.*) *eugubina*, *Parasubbotina pseudobulloides*, and *Globanomalina compressa* zones were identified. Since the clastic complex only contains reworked microfossils, we have included it in a barren interzone between the *Abathomphalus mayaroensis* zone and the *Guembelitria cretacea* zone. A short hiatus comprising the *Hedbergella holmdelensis* subzone (= P0 by Beggren et al., 1995) and most of the *Pv. longiapertura* subzone affects the lowermost part of the Paleocene (i.e., the first 15–20 k.y. of the Danian; Arenillas et al., 2004). Therefore, the *G. cretacea* zone is practically absent at Loma Capiro, and it is only represented by 4 cm identified between the clastic complex (barren interzone) and the *Pv. eugubina* zone.

PALEOBATHYMETRY

Benthic foraminiferal assemblages at Loma Capiro contain abundant representatives of the bathyal to abyssal Velasco-type fauna, such as *Aragonia velascoensis*, *Gaudryina pyramidata*, *Gyroidinoides globosus*, *Nuttallides truempyi*, *Nuttallinella florealis*, or *Stensioeina beccariiformis*, as well as other taxa typical of middle bathyal to abyssal depths, namely *A. ouezzanensis*, *Gyroidinoides* spp., *Marssonella oxycona*, *Nt. coronula*, *Oridorsalis umbonatus*, *Paralabamina hillebrandti*, and *Spiroplectammina spectabilis* (e.g., Alegret et al., 2001, 2003). Species with an upper depth limit of ~500–700 m (e.g., *Bulimina trinitatensis*, *N. truempyi*, *Nt. florealis*, *S. beccariiformis*, *Sp. spectabilis*; Alegret et al., 2003) are most abundant at Loma Capiro. These data indicate that sediments below (Maastrichtian) and above (Danian) the clastic complex were deposited at middle to lower bathyal depths.

AGE AND EMPLACEMENT OF THE CLASTIC COMPLEX

Abundant reworked foraminifera, including nearly all planktic foraminiferal species identified in the Maastrichtian marls, were found in the clastic complex. Specimens of *Globotruncana linneiana* and *Contusotruncana plummerae* (upper Santonian–lower Maastrichtian), as well as *P. hantkeninoides* and *Ps. hariaensis* (uppermost Maastrichtian), were also found. These species do not coincide in age, suggesting the presence of reworked mixed Upper Cretaceous assemblages in this unit. The presence of reworked specimens of *P. hantkeninoides* in the clastic complex at Loma Capiro indicates that the stratigraphic interval that belonged to the *P. hantkeninoides* subzone (i.e., the uppermost 300 k.y. of the Maastrichtian; Keller et al., 2004) was present in this area, and that it was probably eroded during the Cretaceous-Paleogene event. According to these data, the Chicxulub impact event cannot have taken place 300 k.y. before the Cretaceous-Paleogene boundary, as suggested by Stinnesbeck et al. (2001) and Keller et al. (2004). On the contrary, these data strongly support the Cretaceous-Paleogene boundary age of the Chicxulub impact.

Accordingly, benthic macroforaminiferal assemblages from the clastic complex consist of a mixture of species from different ages, such as *Asterorbis aguayoi* (Campanian–lower Maastrichtian), *A. macei*, *A. rooki*, *Pseudorbitoides trechmani*, *Sulcoperculina globosa*, *Torreina torrei* (Maastrichtian), and *A. havanensis*, *A. cubensis*, and *Orbitoides apiculata apiculata* (upper Maastrichtian).

The clastic complex contains a mixture of deep-water benthic foraminiferal species (e.g., *A. velascoensis*, *B. trinitatensis*, *G. pyramidata*, *Gy. globosus*, *N. truempyi*, *Nt. coronula*, *Nt. florealis*, *P. hillebrandti*, *Osangularia velascoensis*, *S. beccariiformis*) and shallow-water species (e.g., *Anomalinoides praeacutus*, *Coryphostoma incrassata* forma *gigantea*, *Oridorsalis plummerae*) that are common in sublittoral to upper bathyal environments (e.g., Alegret et al., 2003). Moreover, assemblages from the second and third subunits contain bryozoans and abundant macroforaminifera from sublittoral environments. These data suggest that allochthonous Upper Cretaceous material coming from the shelf and the upper part of the slope was transported and redeposited at middle-lower bathyal depths during the deposition of the clastic complex.

Diverse impact material was found toward the top of the clastic complex. The chondrule-like particles and the accretionary lapilli are similar to those reported from the Miocene Ries Crater in Germany and from the Cretaceous-

Paleogene boundary El Guayal section in Mexico, which were interpreted as having been generated by impact mechanisms (Graup, 1981; Grajales-Nishimura et al., 2003). The calcified glass spherules have been interpreted as altered tektites and have been reported from many Cretaceous-Paleogene boundary localities in Mexico (e.g., Smit et al., 1996). Altered microtektites have also been documented from the Cretaceous-Paleogene fireball layer in North America, Canada, the Atlantic Ocean, Southern Ocean, and Mediterranean Domain, as well as in Boreal Paratethys (Ortega-Huertas et al., 2002).

The aforementioned characteristics of the clastic complex indicate that it is equivalent to the Cretaceous-Paleogene boundary cocktail unit defined by Bralower et al. (1998), which has been identified in sections and wells from the Chicxulub crater and the Gulf Coast margins, and is commonly related to the Chicxulub impact event (Smit et al., 1996; Grajales-Nishimura et al., 2000; Arz et al., 2004).

The sedimentologic features and the micropaleontologic and mineralogic content of the Cretaceous-Paleogene clastic complex allowed us to infer that it corresponds to a mass flow, which includes (1) coarse-grained debris flows that led to the deposition of the breccia, which also contains clasts from multiple sources; and (2) slumping processes that locally affected both the breccia and the underlying Cretaceous marly sediments. Similar coarse breccia units have been reported from around the Chicxulub impact crater (Grajales-Nishimura et al., 2003; Tada et al., 2003), and have been related to the collapse of the Mexican and Cuban platforms, and to the large-scale gravity flows triggered by the seismic waves originated by the Cretaceous-Paleogene impact at Chicxulub.

We interpret the upper subunit as due to the settling of a resuspended sediment cloud produced by the entrainment into the basin of fine material from the mass flow. This model also accounts for the concentration of impact evidence toward the top of the clastic complex. Alternatively, the upper subunit might correspond to the homogenite unit documented by Tada et al. (2003) from western Cuba. According to their model, the homogenite unit was deposited in a few weeks after the Chicxulub impact, from a resuspended sediment cloud that was generated in shallower areas by large tsunamis.

CONCLUSIONS

Sedimentological features and paleobathymetrical data inferred from benthic foraminifera from below and above the clastic complex indicate hemipelagic sedimentation at middle to lower bathyal depths. Biostratigraphic inferences based on planktic foraminifera indicate a late Maastrichtian age (*Pseudoguembelina hariaensis* subzone) for the autochthonous sediments below the clastic complex, and an earliest Paleogene age (*Guembelitria cretacea* to *Globanomalina compressa* zones) for those just above this complex.

The presence of impact material and reworked uppermost Maastrichtian foraminifera in the clastic complex supports the relationship between the Chicxulub impact and the Cretaceous-Paleogene boundary event. We suggest that the uppermost Maastrichtian gap was caused by erosion associated with the gravity flows and slumping processes that originated during the Cretaceous-Paleogene impact event. We conclude that the deposition of the clastic complex was geologically instantaneous and linked to a rapid and catastrophic event (Chicxulub impact) at the Cretaceous-Paleogene boundary.

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