Discovery of a pristine Chicxulub impact glass spherule deposit on Gorgonilla Island, Colombia

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Abstract

The discovery of a new Cretaceous/Palaeogene (K/Pg) bathyal marine sequence on Gorgonilla Island, SW Colombia, extends the presence of Chicxulub impact spherule deposits to the Pacific region of northern South America and to the Eastern Pacific Ocean.

The Gorgonilla spherule layer is approximately 20 mm thick and consists of extraordinarily well-preserved glass spherules up to 1.1 mm in diameter. The size, morphology and chemical composition of these spherules are similar to Chicxulub spherule ejecta from U.S., Mexico, North and Central America, and the Caribbean, but differ in their unrivaled excellent preservation. About 70-90% of the spherules are unaltered or only partly altered consisting of colorless or faintly green to yellow glass, and their chemical composition is consistent with other occurrences, e.g. Beloc glasses.

Normal size-grading, delicate spherule textures, welded melt components and an absence of bioturbation or traction transport suggest that the Gorgonilla spherule layer represents an almost undisturbed settling deposit.

Introducction

Ever since the discovery of the Chicxulub impact crater in the subsurface of Yucatan, Mexico, in the early 1990's, a spherulitic unit containing melt droplets in the form of tiny glass spherules (microtektites) with similar chemical composition as glass from the Yucatan impact breccia has been documented throughout Central and North America and the Caribbean (e.g., Keller *et al.* 2003a, b; 2011, 2013; Norris *et al.* 1999; Schulte *et al.* 2010). Recent high-resolution stratigraphy and geological mapping of sedimentary sequences at Gorgonilla Island, Southwest Colombia (Project "Stratigraphy and Paleontology of Colombian Pacific area" of Grupo de Investigación Paleoexplorer) now extends the occurrence of the Chicxulub spherule deposit to the Pacific Ocean of NW South America and represents the first K/Pg section of Colombia, South America and the Eastern Pacific Ocean (Bermúdez *et al.* 2016)

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The outstanding preservation of the deposit will allow us to go further in the knowledge of the consequences of the Chicxulub impact and its role in the mass extinction.

Materials and Methods.

Gorgonilla section was measured and examined for lithological changes, sedimentologic structures, trace fossils, erosion surfaces and deformation. Sediments were sampled at close intervals for microfossils, and mineralogical and geochemical analyses. To investigate shapes and surface structures, spherules were hand-picked from gently disintegrated samples. Imaging, chemical analysis, electron microprobe analyses and mapping of spherules were performed at the Institut für Geowissenschaften of Ruprecht-Karls-Universität, Heidelberg, Germany by Drs. Michael Hanel, Jens Hopp, Winfried H. Schwarz and Mario Trieloff. Planktic foraminiferal biostratigraphy was determined from washed residues and thin sections in Princeton University, EEUU, by Dr. Gerta Keller.

Location and geological setting.

Gorgonilla Island is located within the Gorgona National Natural Park, twenty miles off the Colombian Pacific coast. This is a marvelous park dedicated to the conservation and study of national treasures of this part of Colombia. Gorgona island was a former top security prison until 1984 when was declared as a National Natural Reserve. At present, the island is on the process to become a UNESCO's World Heritage site.

The Gorgonilla K/Pg section is located on the SW coast of Gorgonilla Island, approximately 35 kilometer off the Colombian coast to the West, at 2°56´ N and 78°12´ W (Figure 1). The island is 0.5 to 1 km in diameter and located about 500 m SW of the larger Gorgona Island. Both islands are covered by dense pluvial forest and deep lateritic soil. Rock units only crop out along the coast. Currently, the access to the island is closed to the public. Only research-related-activities are allowed.

Gorgona and Gorgonilla Islands are among the less deformed and last accreted pieces of the Caribbean plateau and expose a mafic and ultramafic magmatic sequence of Late Cretaceous to Early Paleocene age (98.7±7.7 to 64.4±5 Ma), including basalts, gabbros and peridotites intercalated with basaltic komatiites and microgabbroic intrusions. Pyroclastic sediments of Paleocene age overlie this sequence (Serrano *et al.* 2011). At the time of the Chicxulub impact, the Gorgonilla site was thus located approximately 2700-3000 km southwest of the impact site in northern Yucatan. Today a 70 m thick sequence containing the K/Pg boundary is exposed along the beach of Gorgonilla Island.

Figure 1. Location of the Gorgonilla K/Pg section, Colombia, South America.

Stratigraphy

The Gorgonilla K/Pg section is composed of thin-medium bedded light olive gray tuffaceous sandstone, rhythmically alternating with massive gray-yellow tuffaceous siltstone and claystone (Figure 2). Deposition of individual sandstone beds as turbidites is likely, based on faint normal grain size gradation in these layers. The mudstone units contain coccolithes, planktic and benthic foraminifers, radiolarians (*Spumellaria* and *Nasselaria*), sponge spicules and rare poorly preserved benthonic foraminifers, these assemblage and sediments are interpreted to represent pelagic bathyal deposition. This is a simple stratigraphy that is not alike whatsoever to the famous yet complex sequences with multiple levels of spherules from North-East of Mexico or Haiti. Gorgonilla spherule layer appears to have remained unaffected from tsunami-reworking or backwash and may thus represent the first parauchtochthonous primary fallout deposit of the Chicxulub impact known to date.

The Gorgonilla spherule-rich layer is easily identified in the outcrop at 19.70 m of the section by its gray-green to dark green color and abundance of spherules visible by eye or hand lens. The unit is approximately 20 mm thick and characterized by an undulating lower contact and gradual upper transition. This spherule layer is traceable over about 1 meters laterally without significant changes in thickness or lithology. Synsedimentary bed disruption, small shear zones and contortion are present and are likely responsible for local duplication of the spherule layer (Figure 3).

Slump and other soft-sediment deformation features are ubiquitous at Gorgonilla in the sedimentary unit underlying the spherule layer, leading to uneven surfaces and disrupted bedding. Upsection from the spherule layer, soft sediment deformation is also occasionally present, but markedly rarer and restricted to small-scale slumps and contortion of individual thin sediment units, while other units appear to be unaffected.

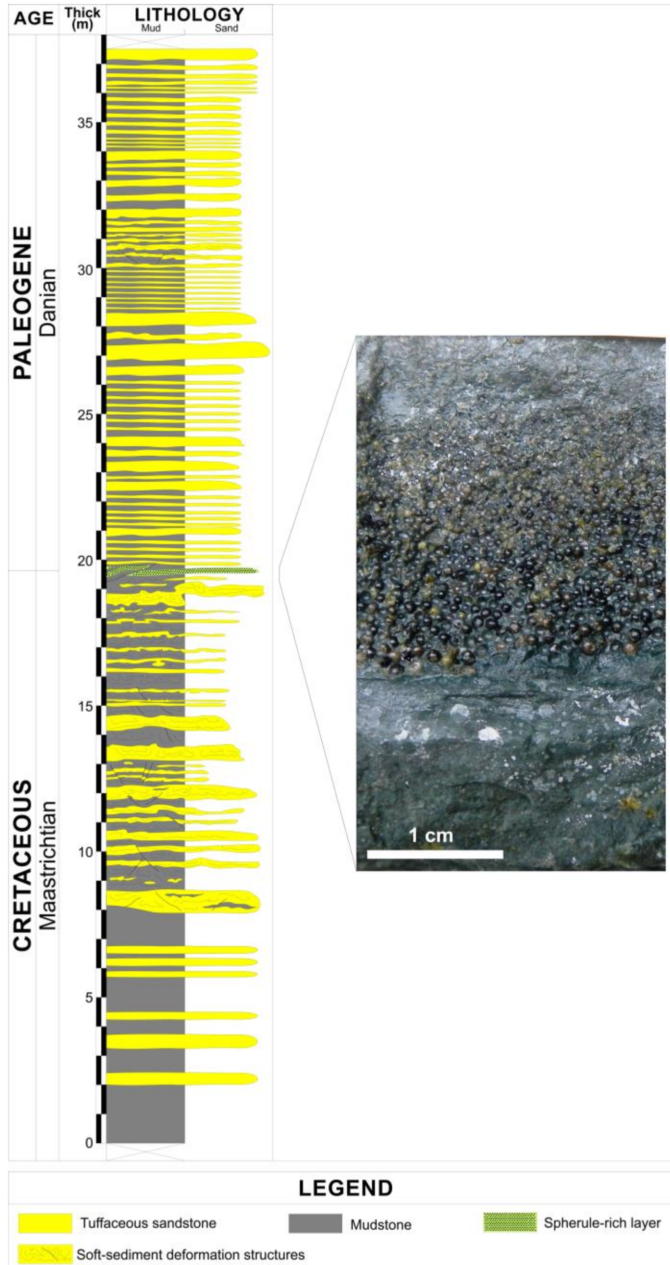

Figure 2. Gorgonilla K/Pg section illustrating a detail of spherule-rich layer (K/Pg boundary).

Soft-sediment deformation structures include syndepositional faulting and fault-grading, hydroplastic mixed layers, pillar and flame structures, small and medium-scale slumps with internal folding and associated thrusting, contorted laminae, small-scale convolution, abundant sand injections, and convolute structures. These features indicate that sediment was relatively unconsolidated when liquefaction or sediment dewatering occurred and caused contortion, probably due to seismic shock. Injectites are abundant and include bedding-normal lenses of structureless sandstone (sills) enclosed in laminated mudstones and vertical dikes, or Q fissures filled with sandstone. These dikes formed rapidly by fluidized injection.

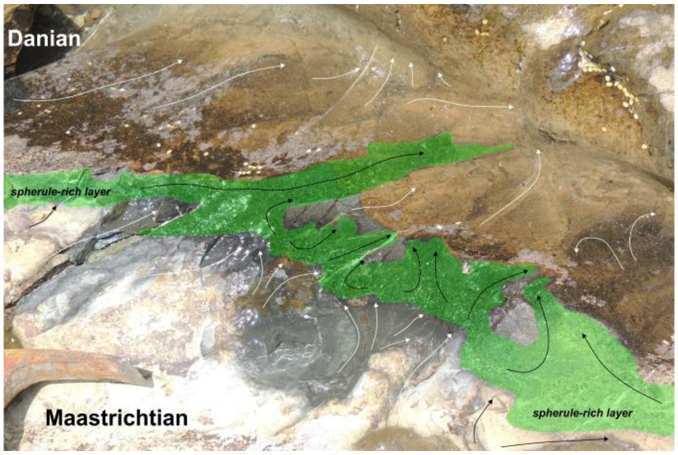

Figure 3. Intense ductile and brittle deformation reaches up to 12 m below the spherule layer, but did not disrupt the stratigraphic succession, which appears structurally intact. Detail on spherule-rich layer level.

The spherule deposit is well cemented in the basal millimeters and nearly devoid of clastic sediments (Figure 4), whereas in the upper part spherules are less cemented and more friable with increasing detrital content. The maximum size of spherules is between 1.0 to 1.1 mm in diameter and was detected near the base of the layer. Spherules gradually decrease in diameter with the smallest present near the top of the layer (Figure 2), thus indicating a normally size-graded deposit. Apart from size grading, there are no morphological differences between large spherules at the base and smaller spherules at the top of the unit. The spherule deposit lacks sedimentary structures suggestive of traction or mass flow transport.

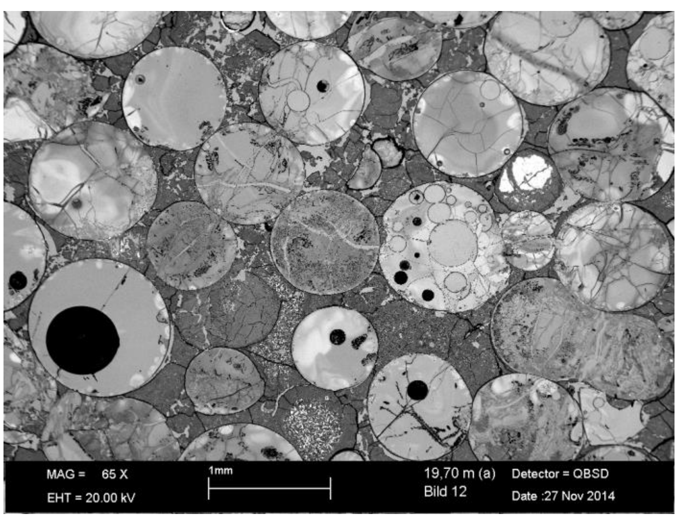

Figure 4. SEM photomicrograph of bottom of spherule-rich layer, with a matrix composed by calcite cement with absence of clastic grains and round and compressed spherules of pristine solid glass.

The preservation of the glass is simply otstanding, perhaps the best of the world to date, where about 70% of the spherules are massive glass (microtektites); the other 30% contain single, or more rarely two or more vesicles. These are either completely hollow or totally to partly filled with secondary calcite or brown-colored smectite. The size of vesicles reaches up to ~30% of the spherule volume; vesicles are usually round, isolated from each other, or connected by secondary cracks which are filled with calcite. 70-90% of the glass spherules are unaltered or only partly altered. In thin sections the glass is usually colorless; some spherules are faintly green or yellow-colored. Schlieren textures are frequent and expressed by differences in refraction indices and chemical composition of the individual schlieren.

The spherule layer grades into a 0.1 m thick brown siltstone rich in radiolaria and other microfossils as well as rare isolated spherules. Spherules are black to olive or translucent honey colored. The majority is round, but oval, teardrop and dumbbell shaped morphologies are also frequent, in addition to irregular grape-like clusters of two, three, four or even more spherules; when broken apart, convex-concave contacts are observed in the connecting area of graped spherules (Figure 5).

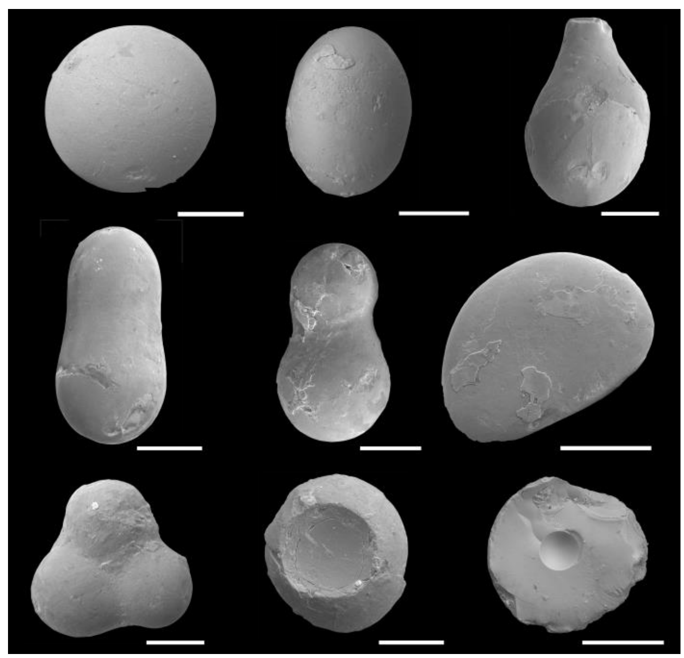

Figure 5. SEM photomicrograph of selected Gorgonilla´s glass spherules illustrating the main morphologies of the spherules. Scale bar = 500 l µm.

Backscattered electron images occasionally reveal the presence of tiny dendritic and/or fibrous crystals of primary microlites (the mafic composition of the crystals, including calcium, magnesium, iron and titanium, suggests these are clinopiroxenes), which suggests that some Gorgonilla spherules are microkrystites (Glass and Burns, 1988) that formed as droplets condensed from vaporized target rock and the impactor (Figure 6).

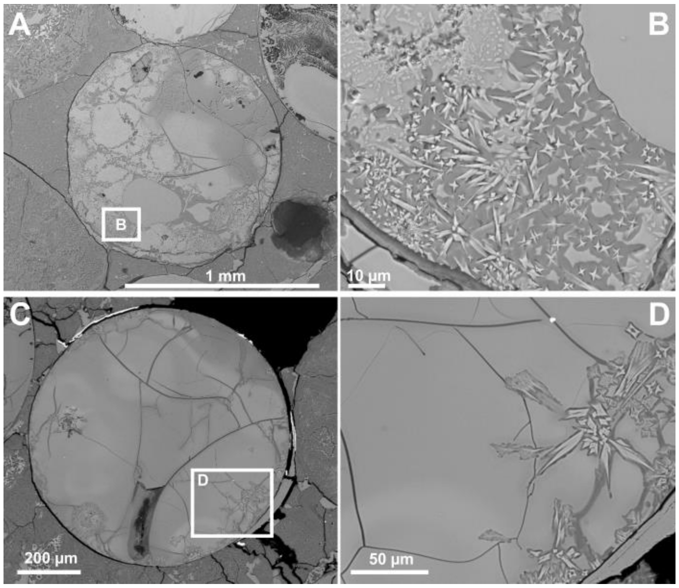

Figure 6. Microkrystites of the Gorgonilla K/Pg section. (A and C) Backscattered electron microscope images of glass spherules. (B and D) Details, illustrating primary microlites.

Paleontology and age.

Age control based on planktic foraminifera indicate a diverse latest Maastrichtian *Plummerita hantkeninoides* zone CF1 assemblage below the glass spherule layer and an early Danian *Parvularugoglobigerina eugubina* zone P1a(2) assemblage above including *Parasubbotina pseudobulloides and Subbotina triloculinoides*, which evolved in the uppermost part of C29r. Maastrichtian planktic foraminifera are present in the spherule layer and clasts with earliest Danian species are present above it marking erosion. These data indicate that spherule deposition could have occurred anytime between the latest Maastrichtian zone CF1 and the early Danian P1a(2), an interval spanning about 200 ky across the K/Pg (Bermúdez *et al.* 2016)

Disscusion

The presence of a 2 cm thick normally graded spherule layer at Gorgonilla Island, SW Colombia, extends the presence of a Chicxulub impact deposit to the Pacific region of northern South America and, for the first time, to the Eastern Pacific Ocean.

Intense soft-sediment deformation and bed disruption affected only Maastrichtian sediments, suggests that bed-disruption processes followed emplacement of the ejecta deposit. The ubiquitous deformation of Maastrichtian sediments at Gorgonilla does not appear to be related to lithology, local tectonic activity or paleogeographic setting, but could have resulted from seismic activity, which we assume was caused by the single very-high-energy Chicxulub impact (e.g. Schoemaker *et al.* 1990; Boslough *et al.* 1996). Deformation of Maastrichtian but not Paleocene sediments suggests seismic activity was restricted to K/Pg or pre-K/Pg time correlative with the Chicxulub impact, but did not cause large-scale slope failure and platform collapse, or chaotic reworking of fossils and lithologies.

Spherule size, morphology, internal features (e.g. vesicles) and chemical composition are similar to Chicxulub spherule ejecta from US, Mexico, North and Central America, and the Caribbean (Bermúdez *et al.* 2016). However, unlike those deposits, the Gorgonilla spherules are unrivaled in their excellent preservation including a unique abundance of unaltered or only partly altered glass, which will allow for a more precise evaluation of Chicxulub target lithologies.

The absence of detritus and presence of delicate convex-concave contacts and agglutinated spherules suggest that the basal portion of the spherule layer represents a parauchtochthonous deposit, and thus a very rare primary undisturbed settling deposit of the Chicxulub impact. Further research is in progress to evaluate the age and mode of deposition and geochemical properties of this remarkable deposit.

Conclusions

The discovery of a new K/Pg bathyal marine sequence on Gorgonilla Island, extends the presence of Chicxulub spherule deposits to the Pacific region of northern South America and to the Eastern Pacific Ocean.

About 70 to 90% of the spherules (microtektites and microkrystites) are vitrified, which is also unique among Chicxulub ejecta deposits known to date. The range of main element compositions and the oxide variation are compatible with those from Beloc and Mimbral.

Their fluidal-shaped forms, smooth surfaces, and internal textures, such as vesicles and streaked schlieren are indicative of an origin as molten droplets from a highly fluid melt with subsequent exsolution of a gas phase due to pressure release and cooling.

Normal size-grading, delicate spherule textures, welded melt components, and absence of bioturbation or traction transport indicate that the Gorgonilla spherule layer represents an almost unaltered primary suspension settling deposit.

Gorgonilla site was close enough, 2700 to 3000 Km to the impact site to receive 20 mm of ejecta, yet was located far enough away from the shelf edge to be affected by a destabilization and collapse of the continental margin. Its pelagic position in deep water of the tropical western Pacific likely protected the Gorgonilla spherule layer from reworking by impact-induced tsunami waves.

The detailed study of this deposit, still in progress, will provide key data about the effects of the Chicxulub impact and its role in the mass extinction that took place around the end of the Cretaceous.

Acknowledgements

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