Built From the Crater Up – Chicxulub Science Museum, Geosciences Communication and Outreach

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Abstract

Natural history and geological museums have a rich tradition with major contributions in learning, outreach and educational programs. Natural parks and geological sites attract large numbers of visitors, scholars and students, offering interesting experiences. Here we examine the role and potential of the Chicxulub science museum, in relation to the Chicxulub impact and the Cretaceous/Paleogene boundary mass extinction. The impact ranks among the major single events shaping Earth's history, triggering global climatic change and wiping out ~76% of species. Chicxulub, with a ~200 km rim diameter, is the best preserved of the three large terrestrial multi-ring impact structures, being a natural laboratory for investigating impact dynamics, crater formation and planetary evolution. The structure and impact deposits are not exposed at the surface, being covered by carbonate sediments after its formation, which presents a challenge for outreach and education. The museum and research institute have a core mission to serve as a hub for multi- and interdisciplinary research on the impact, planetary sciences, climate change and life evolution, as well as educational, outreach and science communication programs, fulfilling a recognized task for dissemination and communication of geosciences. After decades of studies, Chicxulub impact remains under intense scrutiny and the new facilities built inside the crater, play a major role in expanding those efforts.

Keywords: Chicxulub Science Museum, Chicxulub impact, End-Cretaceous Mass Extinction, Geosciences Communication, Yucatan

Introduction

Here we address the potential of site museums with research capabilities, focusing on a museum and research center dedicated to the Chicxulub asteroid impact and the Cretaceous/Paleogene (K/Pg) boundary mass extinction. The impact and mass extinction, which includes the dinosaurs, ammonites, marine and flying reptiles among many other organisms, provide an interesting setting for education, outreach and science communication.

The Chicxulub Science Museum is integrated to the Institute for Research and Advanced Studies (CIRAS) - an inter- and multidisciplinary center equipped with research laboratories and a core repository, located in the Yucatan Science and Technology Park (PCYTY), Mexico (Figs. 1 and 2). The museum is uniquely placed to engage school children, students and visitors to the Earth´s and planetary processes and life evolution in a broad context.

Natural history and geological museums have a rich tradition, with collections of rocks, minerals, fossils and animals and plants. They play an important role in non-formal education, with high learning potential for students, museum-school synergies, science engagement, and teachers' professional development (Stevenson, 1991; Allen, 2004; Panda and Mohanty, 2010; Dahlstrom, 2014; Mujtaba et al., 2018). Museums with research departments allow integrating up to date science advances, taking advantage of thematic exhibits, interactive displays and virtual reality experiences (Collins and Lee, 2006; Panda and Mohanty, 2010; Louw and Crowley, 2013).

Geological museums play major roles in geosciences education and outreach. Field trips to geological sites are important components of the educational programs and in workshops, meetings and congresses. National parks, Geoparks and UNESCO heritage natural sites attract large numbers of scholars and students as well as visitors. Museums of natural history, geology and mineralogy present exhibits related to life evolution, fossil record, planetary exploration, plate tectonics and meteorite impacts (MacFadden et al., 2007; Koeberl et al., 2018). Some like the Smithsonian National Museum of Natural History, the British Museum, Geological Museum of China, Museum of Natural History of Paris, Natural History Museum in Vienna and Geological Museum of Barcelona, among many others, have rich fossil, meteorite and mineralogical collections (Komorowski, 2006; Koeberl et al., 2018). Geological site and impact crater museums are less numerous and include the Ries crater Museum in Nôrdlingen, the Meteor Crater Museum in Arizona, the Tswaing Crater Museum in South Africa, the Steinheim Crater Museum in Germany and the Meteorite Museum at Rochechouart (Pôsges, 2005; Buchner and Pôsges, 2011).

Climate change, growth of the global population, increased demand of energy and mineral resources, pollution, environmental deterioration and biodiversity loss present major pressing challenges to governments and society, which emphasize need for comprehensive structured educational, outreach and science communication programs (Stewart and Lewis, 2017).

Understanding Earth`s origin and evolution, geologic time, tectonic processes, rock and fossil record, life evolution and extinction presents challenges which have been considered in designing exhibits and activities in relation to ongoing research on Chicxulub impact. The link to research is strengthened being integrated to a research center, though facilities are yet limited compared to large natural history and geological museums. This connection facilitates participation of researchers and students with visitors through conferences, seminars and workshops, as well as allowing visits to the laboratories. How this translates in better appreciation and understanding and impact on science communication has been a major part of the planning. The impact and extinction of the dinosaurs provide an interesting and attractive context for educational, outreach and geosciences communication.

1. Chicxulub Impact and Mass Extinction

The Chicxulub impact is among the most important single events shaping life on Earth (Alvarez et al., 1980; Schulte et al., 2010). The impact marks the end of the Mesozoic Era, with the mass extinction wiping out ~76% of species including dinosaurs, ammonites, marine and flying reptiles, and the start of the Cenozoic that saw important radiations of many groups including mammals and birds. Chicxulub structure formed by an asteroid impact on the Yucatan carbonate platform in southern Gulf of Mexico (Fig. 3a,b) and was first identified in oil exploration surveys and drilling programs by Petroleos Mexicanos (Pemex) (Penfield and Camargo, 1981). It has a ~200 km rim diameter and a peak-ring and multi-ring morphology (Fig. 3c,d); the structure has been investigated by an array of geophysical/geological surveys and drilling programs (Figs. 4 and 5) (Hildebrand et al., 1991, 1998; Sharpton et al., 1992; Urrutia-Fucugauchi et al., 2011).

The K/Pg boundary is marked globally by the impact ejecta layer, characterized by the iridium and platinum group elements derived from the impacting body (Fig. 6; Schulte et al., 2010). The impact and its effects on Earth's climate and evolution of life have been intensively studied (Alvarez et al., 1980; Mukhopadhyay et al., 2001; Schulte et al., 2010; Urrutia-Fucugauchi et al., 2008, 2011; Lowery et al., 2018). Impact had massive short- and long-term global effects on the climate and environment, providing important lessons for understanding the impact of man-made greenhouse emissions. Although the mechanisms for the extinction and subsequent species diversification remain under scrutiny, studies of this mass extinction uncover general principles governing species/clade resilience and evolvability in response to rapid climate and environmental changes.

2. Background and Development of Chicxulub Museum

The CIRAS research and museum facilities are housed over an area of ~19 square kilometers located in the central sector of the Yucatan Science and Technology Park (Figs. 1 and 2). The CIRAS is a joint project between the National University of Mexico, the National Council of Science and Technology and the Ministry of Science and Higher Education of the Yucatan government that has developed over the course of a decade.

The project emerged with the aim to build a site museum dedicated to the Chicxulub impact and the effects on the planet and life evolution. The first phase was completed in 2011 with the Chicxulub Museum housed in the second and third floors of the PCYTY Central Library (Fig. 7). The second phase was the Chicxulub exhibition in the Meteorite Hall of the Grand Museum of the Maya World ("Gran Museo de Mundo Maya") in Merida City (Fig. 8), inaugurated in December 12, 2012.

The Chicxulub exhibition in the Grand Museum of the Maya World has attracted large number of visitors, students and researchers. The Chicxulub Impact and Extinction of Dinosaurs exhibition was planned at the time of the Mayan prophesy of the end of the world and included displays on historical accounts of catastrophic prophesies at various cultures. The exhibition presented and addressed beliefs on celestial phenomena such as comets and lunar and sun eclipses, which in some societies were associated with catastrophes, diseases, warfare and social unrest. The different contrasting views were presented in the framework of the Chicxulub impact, extinction of dinosaurs and other species and end of the Mesozoic Era.

Museum visits start with a video on the Chicxulub impact and the mass extinction, followed by an introduction to comets, asteroids and meteorites, the early observations, myths and interpretations of meteorite falls and cometary showers that later evolved as part of the studies of the planetary system. It includes exhibits of the fossil record, particularly during the Mesozoic and evolution of the dinosaurs, marine microorganisms, ammonites and flying and marine reptiles, which went extinct at the K/Pg boundary. The Chicxulub studies are presented within the context of the oil exploration in southern Mexico and the geological characteristics of the Yucatan peninsula (Urrutia-Fucugauchi et al., 2013). Exhibits display surface geological processes, including the groundwater flow and fracturing are influenced by the buried crater, which can be traced by the ring of cenotes and semicircular topographic depression over the crater rim. The Chicxulub exhibition was awarded the 2013 Miguel Covarrubias Prize from the National Institute of Anthropology and History. Related programs at the museum include conferences, seminars and symposia, including the progress reports of the research and drilling projects.

The PCYTY Chicxulub Museum has attracted large number of visitors. Entrance is free and records are only for the guided tours and appointed visits of school children. In a four-year period, number of visitors is around seventeen thousand, including six thousand school students and one thousand pre-school children. Number of visitors to the Chicxulub Exhibition at the Grand Museum has been much larger, due to its association to the archaeological exhibits and easy access in Merida City. The comments and reactions to the PCYTY museum exhibits and outreach activities discussed below mainly come from the student groups and teachers, with additions from groups during conferences and seminars. The PCYTY guided tours for school groups offered the advantage of engaging with the teachers, which provided valuable interactions and feedback. In connection with the museum exhibits, conference series and workshops were held with participation of students and researchers. Among them, the workshops of the drilling and marine geophysics projects and on geosciences education.

Around the initial plan, research facilities expanded to include laboratories and the core repository built in the Yucatan Science Park, which houses academic and research institutions, start-ups and research-oriented firms, including Yucatan State University, UNAM, National Council of Science and Technology research centers and technology-oriented firms. CIRAS construction project took several years and the center was formally established on February 2th 2018, with the inauguration of the laboratories and core repository (Fig. 9). It has access to the National Hydrocarbon Core Repository, analytical laboratories and the apartment blocks to host visiting academics and students. The third phase started in 2016 with construction of the larger museum facility that started operating in the early 2019. The new museum aims to provide up to date information on the geophysical studies and drilling projects (Figs. 3, 4 and 5).

3. Chicxulub Institute and Science Museum

4.1 Science Museum

Studies on large meteorite impacts, dinosaurs, mass extinctions and life evolution attract the interest of wide audiences, opening interesting possibilities for science communication. The exhibits are organized around the studies of the Solar System, impact cratering, evolution of planetary surfaces, Chicxulub impact, crater formation, impact effects on climate and life-support systems, extinction of organisms, biotic turnover and life evolution. Exhibits aim to present, inform, engage and entertain visitors through studies on the Chicxulub impact, life evolution, K/Pg turnover and related inter- and multidisciplinary research (Figs. 10-12).

Exhibits on the Universe hall present an introduction to the origin and evolution of the Universe, formation of stars and galaxies, the Milky Way galaxy and the Solar System. The formation of planetary systems involves dynamic processes with collisions at different scales, with formation of first solids, planetesimals and large bodies. The origin and evolution of planetary systems are marked by collisions of bodies, which are the main process in the formation of planets, satellites, dwarf planets, asteroids and comets. Impact craters characterize the surfaces of solid planetary bodies and constitute the geological record of the dynamic evolution through time and space. Large-scale collisions resulted in construction and fragmentation of planetary bodies.

The hall on the Solar System and Impact Cratering presents an engaging introduction on the characteristics and evolution of planetary surfaces, impact dynamics, crater formation, impacts on time and space, comets, near-Earth asteroids and impact hazards. Hypervelocity impacts deliver high amounts of energy in short time scales; resulting in deep excavation cavities, material transport and deformation. Planetary surfaces preserve a record of impacts, with the magnitude and frequency of impacts higher in the early stages. Impact cratering is a major process in the evolution of planetary surfaces and the deep interiors. The terrestrial crater record has been erased and modified, with limited number of craters preserved in contrast to other bodies like the Moon, Mars, Venus and Mercury.

The exhibits on Chicxulub structure introduce the crater, impact and impact effects. It is the best preserved of the three large impact structures in the terrestrial record, being a natural laboratory for investigating impact dynamics, crater formation and planetary surface evolution in the Solar System (Urrutia-Fucugauchi and Perez-Cruz, 2009). The structure is located half on land and half offshore, with geometric center at Chicxulub Puerto on the coastline; it has a peak-ring and multi-ring morphology, which characterizes complex craters on the Moon and other Solar System bodies (Melosh, 1989).

The hall on the End-Cretaceous extinction and life evolution presents the effects of the meteorite impact on the life-support systems, linking the impact processes with the mass extinction. Exhibits introduce the fossil record, geological processes, the geological time scales and concepts of deep time and life evolution. The mass extinction marks a major boundary from the Mesozoic to the Cenozoic. In the geological record the boundary is marked by the Chicxulub ejecta layer. Interactive exhibits are used to introduce species communities and diversification after the impact and macro-evolutionary trends.

The exhibits include challenging themes on life evolution including extinctions, emergence of species, macroevolution and global climate change (Sepkoski, 1998; Jablonski, 2006, 2008). Experiences in science museums and museums of natural history emphasize roles of teachers and museum staff in interacting with visitors, particularly with school groups and students. The exhibits on the end Cretaceous mass extinction and the asteroid impact effects on the life support systems permit to address present day extinctions and global warming.

The Museum has a projection facility room, which is used to present videos and animations of the Chicxulub impact; plus, an auditorium, two meeting rooms and a child playing room. Independently managed souvenir shops complement the facilities. It has also space to host temporary exhibits on the Yucatan peninsula, Gulf of Mexico-Caribbean Sea, mineral and energy resources, global climate change and biodiversity. This is also part of the collaboration programs with other institutions. The space around the museum has outdoor exhibits (dinosaurs and marine and flying reptiles) that take advantage of the vegetation with endemic plants and large-size fossiliferous carbonate rock boulders (Fig. 12). Additionally, the PCYTY Botanical Garden is next to the museum facilities, which opens join activities.

4.2 Chicxulub Institute

The CIRAS Institute core repository and six laboratories have facilities for core description and sample preparation, core analysis, petrography, micropaleontology, geochemistry and physical properties. Laboratories are equipped with an array of analytical instruments, including core scanners, X-ray fluorescence system, gamma-ray core logging system, magnetic susceptibility meters, electrical resistivity meter, petrographic microscopes, laser particle analyser and an electronic scanning microscope (e.g., Fig. 9). The core repository has storage space for core samples and for conducting experiments, including low-speed impact experimental simulations. It has facilities for slim-core logging sensors and geophysical field instruments, including gravity and magnetic field meters.

Ongoing projects focus on studies of crater structure, dimensions, morphology, breccia deposits, melt sheet, deformation of target rocks, impact-induced hydrothermal system, pre-impact structures and post-impact processes. Chicxulub has been investigated with a wide array of geophysical methods, including gravity, magnetics, electromagnetics and seismic reflection (Hildebrand et al., 1998, Sharpton et al., 1993; Collins et al., 2008; Urrutia-Fucugauchi et al., 2011; Morgan et al., 2016).

The structure and ejecta are not exposed at the surface, making drilling an indispensable tool to sample the impact lithologies and pre- and post-impact sedimentary rocks (Fig. 3). Initial drilling was carried out by Pemex oil company, with intermittent core recovery providing samples of the carbonates, impact breccias and melt, which were key for confirming the age of the impact structure, corresponding to the K/Pg boundary (Hildebrand et al., 1991; Sharpton et al., 1992). Subsequent drilling programs incorporated continuous core recovery and geophysical logging (Urrutia-Fucugauchi et al., 2004, 2008) (Figs. 4, 5), with tens of thousands of core samples distributed to groups in different countries, which has allowed to expand the research on the crater and K/Pg boundary.

Impact resulted in global affectation of the climate and life support systems triggering a mass extinction in the marine and continental environments (Alvarez et al., 1980; Schulte et al., 2010; Urrutia-Fucugauchi and Perez-Cruz, 2016; Lowery et al., 2018), Recent studies are shedding light on factors determining the likelihood of taxa becoming extinct as in the case of arboreal birds after forests disappeared (Field et al. 2018). Mass extinction coinciding with the impact were followed by radiations in numerous taxa including mammals (Dos Reis et al. 2012), worm lizards (Longrich et al. 2015) and birds (Field et al., 2018). Further understanding of the factors driving species extinction and radiations is crucial to make predictions on the effects of man-made climate change.

CIRAS carries research relevant to the communities of Yucatan peninsula, which is characterized by karstic terrains with low elevation and smooth relief (Fig. 3). The city of Merida, located ~30 km away from the coastline, is just a few meters above sea level. The platform is an extensive low-inclination shallow ramp, which records the sea-level fluctuations during the Late Pleistocene glaciation and the Holocene. The peninsula is in the trajectory of hurricanes and tropical storms, with a thin soil cover and no surface waters. It is vulnerable to coastal erosion, marine intrusion, aquifer contamination and to global warming with changes of precipitation, sea level, cloud coverage and evaporation.

The northern Yucatan peninsula is marked with sinkholes and dissolution structures and the buried structure exerts a strong influence in surface geological processes including subsidence, fracturing, groundwater flow, coastal and karst processes. The density and distribution of karstic structures relate to dissolution and in turn to fracturing, topography, rainfall and groundwater flow. The sinkhole distribution correlates with the buried structure, notably with the cenote ring located over the crater rim. Surface fracturing is related to the stress/strain state, with the regional tectonics, differential subsidence of the crater fractured breccias and carbonates surrounding the crater and rheological properties of the surface formations. Coastline morphology and processes are related to the buried structure, marked by the correlation at the intersections with the gravity anomaly rings. The thick carbonate cover has protected the structure and ejecta deposits from erosion, adding challenges for the studies. The structure, characterized on the surface by gravity and magnetic semi-circular concentric patterns (Fig. 3), is characterized by a gravity high and high-amplitude magnetic anomalies associated with the basement uplift, peak-ring and impactite deposits. The crater rim and terrace zone are marked on the surface by the cenote ring, fracturing and semi-circular topographic depression.

4. Discussion

The Chicxulub museum is designed in a broad context based on the Chicxulub impact and relation to life evolution, impact dynamics and cratering on planetary scales. The museum opens interesting opportunities and challenges. How is the museum addressing and developing opportunities for outreach, education and geoscience communication? How attractive is this unique geological site for engaging visitors? How are topics such the nature of geologic time, life evolution, fossil record, climate change introduced? How do visitors engage and respond to exhibits and related activities?

The mass extinction and K/Pg boundary provide an engaging start point and the context for addressing Earth´s evolution and how life evolves linked to geological processes, climate and environment. The exhibits allow introducing fundamental concepts on geological time, processes, life evolution, Earth System components and interconnections and role of sudden changes (Urrutia-Fucugauchi and Perez-Cruz, 2016).

5.1 Outreach and Education

Mujtaba et al. (2018) reviewed the learning potential of natural history museums, focusing on school students, interactions museum-schools, science engagement and teachers' professional development. Natural history museums have a rich tradition, with exhibits, interactive displays and collections of rocks, minerals, fossils and animals and plants. Museums play also important roles in conservation and preservation of fossils, minerals and geological sites (Lipps and Granier, 2009; Boonchai et al., 2009). Natural history exhibits and interactive displays on life evolution permit presenting and understanding difficult concepts in the life and geological sciences (Baum et al., 2005; Diamond and Scotchmoor, 2006; Spiegel et al., 2012; MacDonald and Wiley, 2012). They include the theory of evolution, natural selection, speciation, extinction, concepts of deep time, intense sudden high-amplitude events versus gradual incremental changes, global versus local processes and macroevolution. Visitors to natural history museums are in general more familiar with evolutionary concepts than those who do not have the experiences. Studies on how visitors view, approach and accept/reject/ignore evolution show that museum visitors accept and are more familiar with evolution than general public (Mujtaba et al., 2018). However, large sectors of the public face difficulties comprehending those concepts, including students and teachers, which is also the case with other topics such as climate change, sea level rise and cause of global warming.

Related activities include conferences, seminars, drawing contests for school children in primary schools, material/publications, interaction with teachers and schools and two GIFT (Geosciences Information for Teachers) Workshops of the European Geosciences Union (EGU) held in Merida in 2010 and 2016. The GIFT Workshops have been organized in collaboration with the Secretaries of Education and SIIES, Universities, Mexican Academy of Sciences and scientific societies. The Panamerican GIFT Workshop of the EGU capacity-building program scheduled for October 2020 in the Chicxulub Museum and PCYTY has been postponed for 2021. Other activities include the publication of the Chicxulub Newsletter with four issues per year starting in 2018 and the online outreach material.

Field experiences taking advantage of museum location are used to enhance learning experiences, from field observations of rocks, fossils and local flora and fauna. The close-by PCYTY Botanical Garden with marine fossil-rich outcrops permits to expand the visit experience. Additional activities can include microscopic observations for petrographic and microfossil analyses, complementing activities in the classrooms and museum visit. Novel avenues are being developed, using the internet, digital tools, apps and new spaces particularly for the natural and physical sciences (e.g. Braund and Reiss, 2004, 2006). Field trips to K/Pg boundary sites open opportunities to appreciate the impact effects and geological record (Fig. 6). Nearest K/Pg boundary sites are in Campeche, Quintana Roo and Belice are displayed in exhibits, maps, videos and images, which are complemented by animations illustrating how ejecta was emplaced proximal to impact site and at distant locations.

5.2 Challenges and Approaches

The structure and proximal ejecta deposits are not exposed at the surface, which is a challenge in comprehending the huge size and characteristics of the structure. We found that visitors have difficulties understanding how and why dinosaurs went extinct, dynamics of asteroid impacts and crater formation, sequence of events, other species affected, what happened with the mammals, why and how some mammal species did not go extinct, how some species went extinct while others do not. The Chicxulub size and relation of buried structure to the ring of cenotes are difficult to appreciate because of the large dimensions. Following the sequence of events and crater formation in a short time and with large energy release also generates questions. For instance, many visitors consider that impact formed the cenotes (particularly the cenote ring), though they acknowledge the crater lies deep beneath, covered by post-impact rocks and that the cenotes are recent surface features. The origin of Chicxulub structure also generates confusion, though there are exhibits on the impacts, craters on the Moon and other bodies, asteroids, etc., some visitors have difficulty understanding volcanic craters and volcanoes as different geological processes.

Presenting in an engaging way concepts on geological time, evolution, fossil record and geological processes is no easy task. Museums have developed and tested a wide range of approaches (Braund and Reiss, 2004, 2006; Allen and Gutwill, 2004; MacFadden et al., 2007; Mujtada et al., 2018). Results show mixed responses and the complex interactions, which have been discussed and evaluated in different contexts. Exhibits on dinosaurs attract more interest than displays on other groups. Widespread interest in dinosaurs comes from their large sizes and diversity, including predators like the T Rex and raptors as well as the feathered dinosaurs. The dinosaurs were a highly successful group during the Mesozoic, occupying the ecosystems in the continental land masses including the polar regions (Sereno, 1999; Barret et al., 2009).

Mammals are also attractive, particularly those on the Late Pleistocene megafauna from the Last Glacial age or the large land and marine mammals like whales and dolphins. Exhibits on human evolution and primates are more popular than similarly well-structured exhibits on other species. Chicxulub exhibits focus on relations and evolution of the various groups particularly the dinosaurs and mammals. Dinosaurs and mammals coexisted for a long time, with the different spatial distributions, habitats, body masses and lifestyles. What happened after dinosaurs, marine and flying reptiles, ammonites and many other groups went extinct helps to appreciate macro-evolutionary traits, species interdependency, how species evolve and interact, how ecosystems develop and function and how species relate and react to environmental and climatic conditions (Jablonski, 2005, 2008; Bambach, 2006; Barrett et al., 2009).

The End-Cretaceous mass extinction is the fifth and last large extinction event recognized in the geologic record (Emiliani et al., 1981; Bambach, 2006). Exhibits on the other major extinction events and the extinction rates for genera, families and species during the Phanerozoic in the marine and land realms allow to present macroevolution and changes through time (Sepkoski, 1998; Jablonski, 2005, 2008). Paleogeographic reconstructions document the evolving distribution of continents and oceans, with assemblage of the Pangea supercontinent and its breakup and drift apart. The changing ocean-continent distribution, ocean circulation, climate and landscapes form the backdrop for life evolution.

Impact affected the climate and environment at global scales, with a sharp sudden period of darkness and cooling caused by the fine dust ejecta in the stratosphere, which was followed by a global warming caused by the massive injection of carbon dioxide and other greenhouse gases

(Alvarez et al., 1980; Alvarez, 1997; Schulte et al., 2010). The deposition of the fine ejecta resulted in severe changes in the sea surface water chemistry, affecting the marine organisms. The warm climates of the Cretaceous were followed by a cooling trend during the Cenozoic, with the formation of the ice polar caps and the Late Pleistocene glaciation (Zachos et al., 2008). Evolution of the different genera, families and species correlates with the long-term climate evolution and changing paleogeographic and climate evolution during the Cenozoic.

Geo- and biological sciences scholars and students often have problems grasping details of evolutionary processes (MacFadden et al., 2007; Mujtada et al., 2018). This illustrates the challenges particularly for non-formal curricula and learning outside the classroom. Also highlighting importance of formal and informal comprehensive education and outreach programs, science museums and supplementary activities directed to inform and engage the public on what science is and what represents (Stevenson, 1991; Allen, 2004; Allen and Gutwill, 2004). What is the scientific method and what makes it unique in understanding the natural world? In recent years with the development of molecular biology, with genetics, molecular clocks and metagenomics, evolutionary studies entered a new field (Chen et al., 2014). Introducing new developments and findings present opportunities and challenges. Recent discoveries provide unprecedented detail into the events before, during and after the impact and mass extinction, which allow for a narrative of events, integrating evidence in a multidisciplinary approach.

5.3 Outreach and Science Communication

Museum programs integrate research components, displaying up to date developments and challenges, reflected in the exhibits, interactive displays and virtual reality experiences (Louw and Crowley, 2013). Exhibits cover a large multidisciplinary range of topics, moving from the physics of hypervelocity impacts, high pressure/temperature processes and rheological properties to the delicate balance of geological processes and life evolution. The museum provides a forum for outreach, educational and science communication; although its potential needs to be further developed. In addition, it needs to address topics and matters relevant for policy making and the society. Needed is a closer and better structured relationship with other components of the science park. Programs for visiting researchers and postgraduate students are needed to expand the lecture and seminar program focusing on science communication. In this context, a strategic program for science communication with wider scope and well-defined priorities is required (Stewart and Nield, 2013: Stewart and Lewis, 2017).

Key aspects for science communication include climate change and effects on biodiversity and global warming and environmental affectation caused by human activity. A recognized task in science communication is "effective dissemination and communication of the geosciences to decision makers and society" (Arattano et al., 2018; Stewart and Lewis, 2017; Illingworth et al., 2018). The global changes present severe effects on the biodiversity, with the loss of species that are being interpreted as the sixth mass extinction. Displays showing examples of how studies connect to life evolution can be used with reference to familiar groups of organisms, connecting the K/Pg extinction, evolution of species and present situation (e.g., Field et al., 2018). Recent developments, relating studies on the fossil record and molecular phylogenies are also displayed that show the intricate interconnections and complex responses during biotic transitions and pre- and post-extinction processes.

5. Conclusions

The museums of science and technology are linked to the development of modern societies, with science and technology being the driving forces for the transformation of societies. The Chicxulub complex is part of a multidisciplinary project integrating research laboratories and museum exhibits. The museum provides an attractive space for learning, exploring and experimenting aimed to engage the interest of children, youngsters and adults. Museums are key elements for science communication and engaging on the discovery process. In this context, integrating and housing research laboratories enhances the capacities, making them more inviting to learn, wonder and experiment.

With the 40th anniversary of the impact theory and discovery of Chicxulub structure, research on the impact and mass extinction has intensified. Anthropogenic activities are a major force for climate and environmental change and species extinction. Enhanced understanding of the Earth System, processes, life evolution and extinctions and impact of human activities is critical to address the geo-environmental hazards. The CIRAS aims to provide scientific and technical information and advice to society and decision-makers and to construct a wide collaboration network.

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List of Figures

Fig. 1. Chicxulub Center for Scientific Research and Advanced Studies in the Yucatan Science City of the Parque Cientifico y Tecnologico de Yucatan. Views of the Chicxulub research complex, with the museum, laboratories and core repository (photos J Martinez, Z Mendoza).

Fig. 2. View of the Yucatan Science City (Parque Cientifico y Tecnologico de Yucatan, PCYTY) in Sierra Papacal, Yucatan, Mexico. View to the south of the central PCYTY sector, with the Central Library Building (Drone image, www.pcty.com.mx; Parque Cientifico y Tecnologico de Yucatan).

Fig. 3. Chicxulub crater. (a) Map of Gulf of Mexico and Yucatan peninsula, showing location of the Chicxulub crater. (b) Satellite interferometry radar image of the northern Yucatan peninsula (image courtesy NASA Jet Propulsion Laboratory), showing the surface topographic semi-circular depression above the buried Chicxulub crater rim. The location of the Chicxulub CIRAS center is shown by the star and arrow. Also marked for reference the location of Merida City and Chicxulub Puerto. (c) Chicxulub crater Bouguer gravity anomaly (Sharpton et al., 1993), showing the concentric semi-circular pattern, with the central gravity high and gravity rings marking the peak-ring and multi-ring morphology. (d) Schematic structural model of Chicxulub crater, showing the basin, central uplift, terrace zone, melt sheet, breccias and target Cretaceous sediments (Collins et al., 2008).

Fig. 4. Chicxulub drilling programs. View of the drill rig for the Yaxcopoil-1 borehole, core samples for the impact breccias-Paleocene carbonates contact and core repository (Urrutia-Fucugauchi et al., 2004, 2011).

Fig. 5. View of drilling platform for the Chicxulub IODP-ICDP Expedition 364 drilling project over the peak-ring zone. Marine geophysical surveys, view of the UNAM R/V Justo Sierra.

Fig. 6. The Cretaceous/Paleogene (K/Pg) boundary is marked globally by the ejecta layer (Schulte et al., 2010). K/Pg boundary sites are interesting geological sites, marking a major event in life evolution. In the Gulf of Mexico-Caribbean Sea area the boundary is characterized by the presence of high energy sediments that lie in between the basal spherules and clay layers.

Fig. 7. Chicxulub Science Museum in the Yucatan Science City PCYTY. Views of the Central Library building that houses the museum in the second and third floors and views of the exhibits (Perez-Cruz and Urrutia-Fucugauchi, 2015).

Fig. 8. Partial view of displays of the exhibition on Chicxulub and the extinction of dinosaurs in the Gran Museo Mundo Maya in Merida, Yucatan.

Fig. 9. Chicxulub laboratories, with view of the six laboratory facilities and some of the instrumental facilities.

Fig. 10. Chicxulub Science Museum. Partial views of exhibits in the Universe and Solar System.

Fig. 11. Chicxulub Science Museum. Partial views of exhibits in the Chicxulub crater and impacts.

Fig. 12. Chicxulub Science Museum. Partial views of exhibits on life evolution and mass extinctions. Exhibits on dinosaurs and other flying and marine reptiles are arranged inside and in the museum surroundings.

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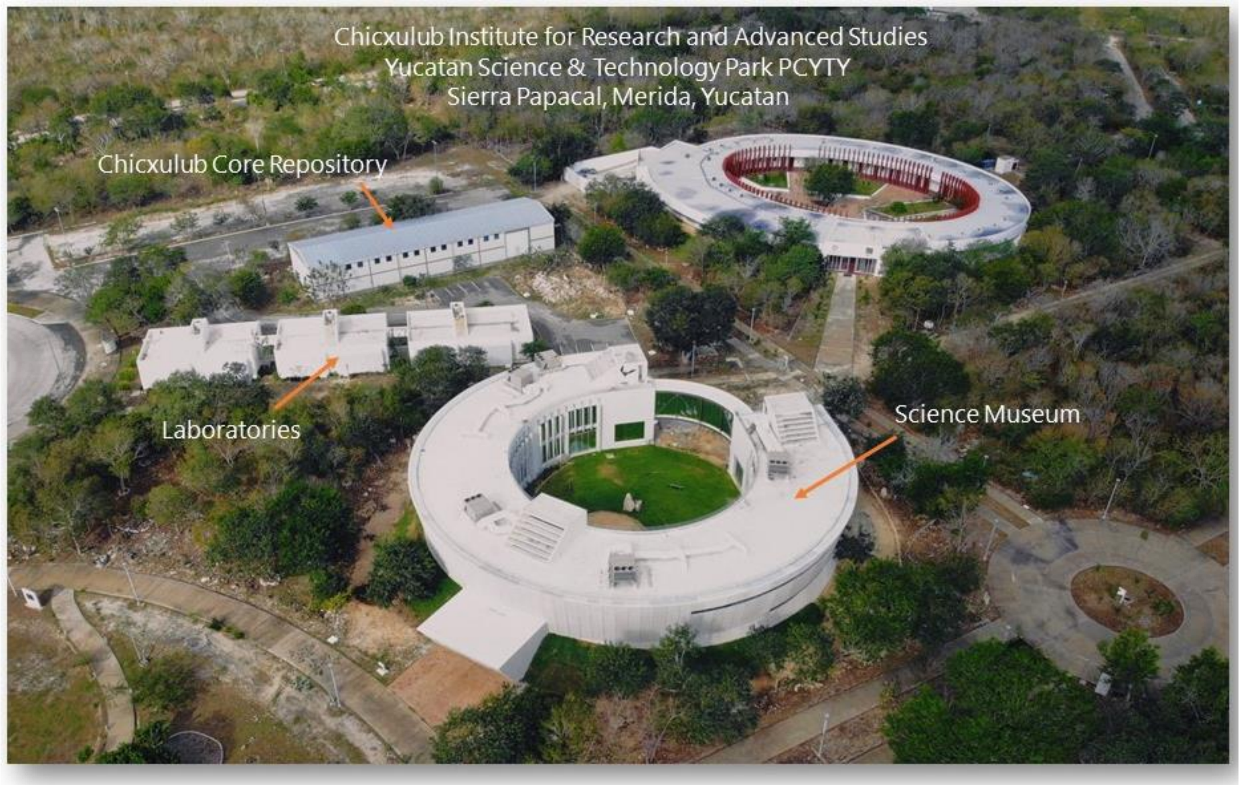
Chicxulub Institute for Research and Advanced Studies
Yucatan Science & Technology Park PCYTY
Sierra Papacal, Merida, Yucatan
Chicxulub Core Repository
Laboratories
Science Museum

Fig. 1


Yucatan Science & Technology Park (PCYTY)
Sierra Papacal, Merida, Yucatan

Fig. 2

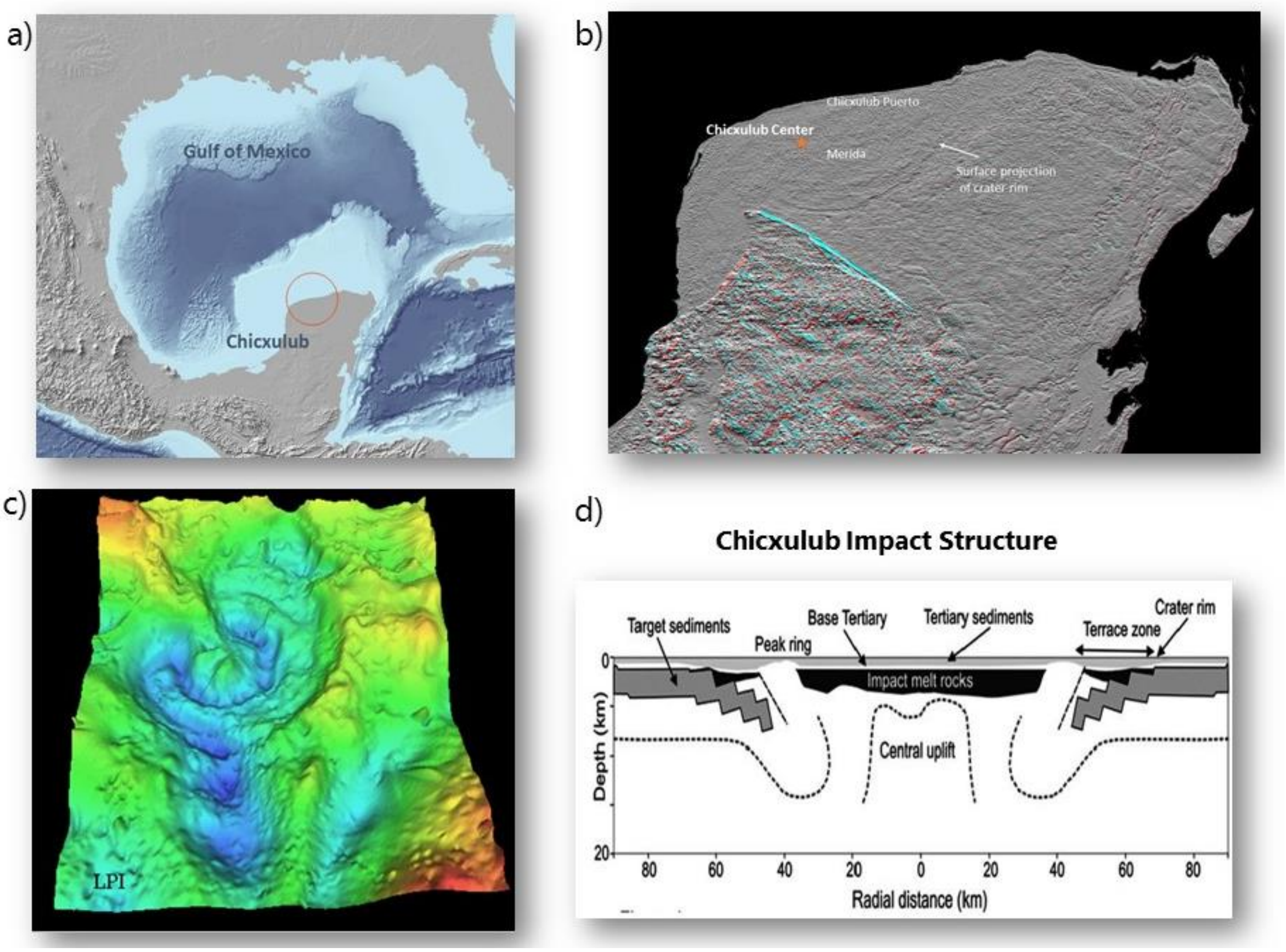
a)
Gulf of Mexico
Chicxulub
b)
Chicxulub Puerto
Chicxulub Center
Merida
Surface projection of crater rim
c)
LPI
d)
Chicxulub Impact Structure
Target sediments
Peak ring
Base Tertiary
Tertiary sediments
Terrace zone
Crater rim
Impact melt rocks
Central uplift
Depth (km)
0
20
80
60
40
20
0
20
40
60
80
Radial distance (km)

Fig. 3

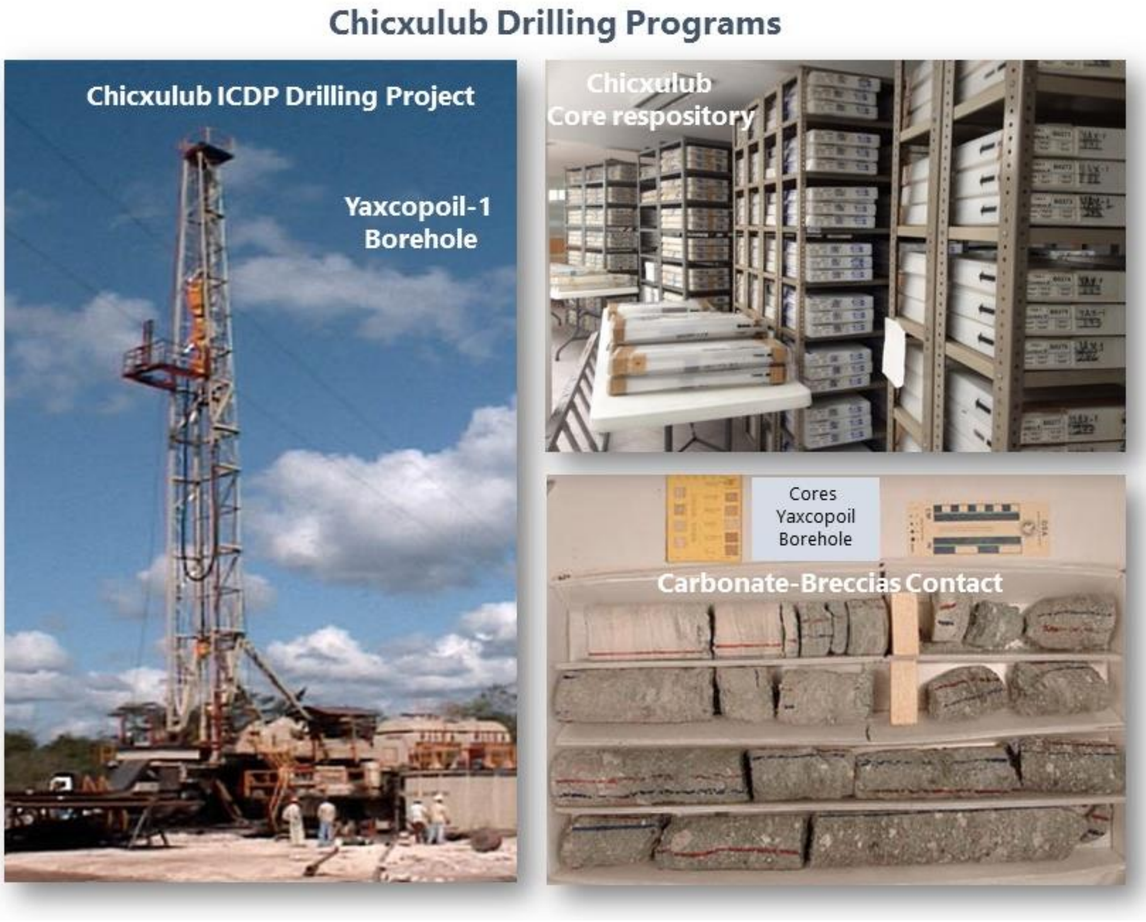
Chicxulub Drilling Programs
Chicxulub ICDP Drilling Project
Yaxcopoil-1
Borehole
Chicxulub
Core respository
Cores
Yaxcopoil
Borehole
Carbonate-Breccias Contact

Fig. 4

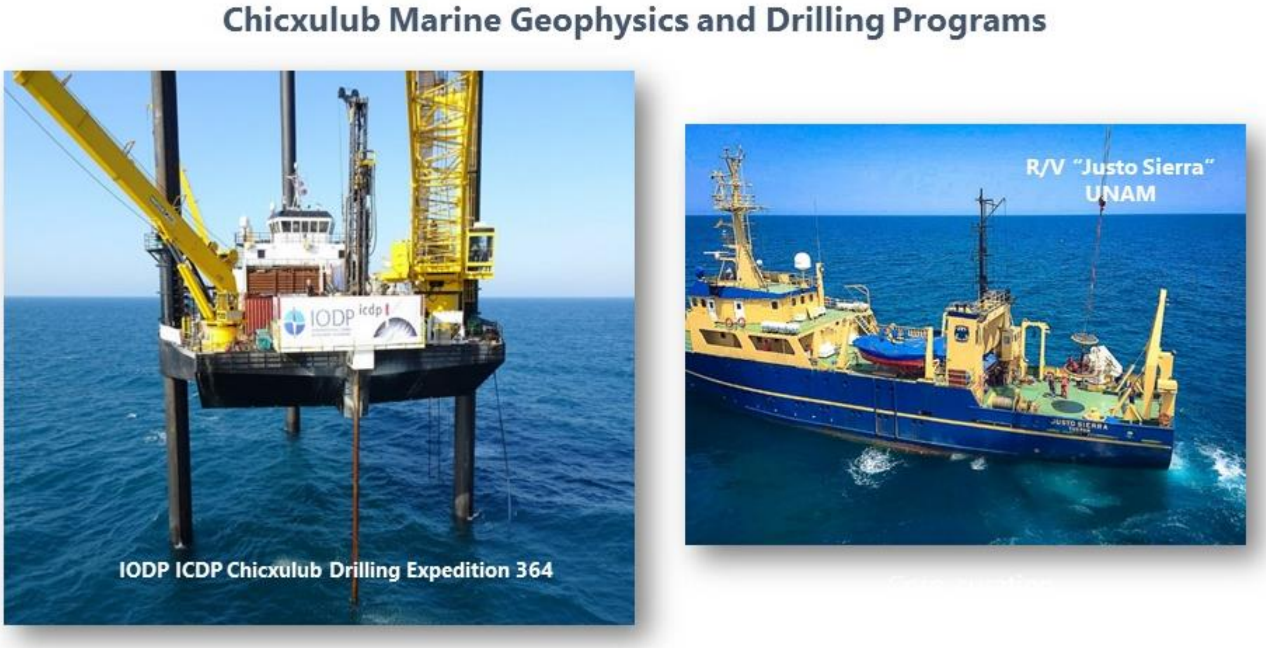
Chicxulub Marine Geophysics and Drilling Programs
IODP icdp
IODP ICDP Chicxulub Drilling Expedition 364
R/V "Justo Sierra"
UNAM

Fig. 5

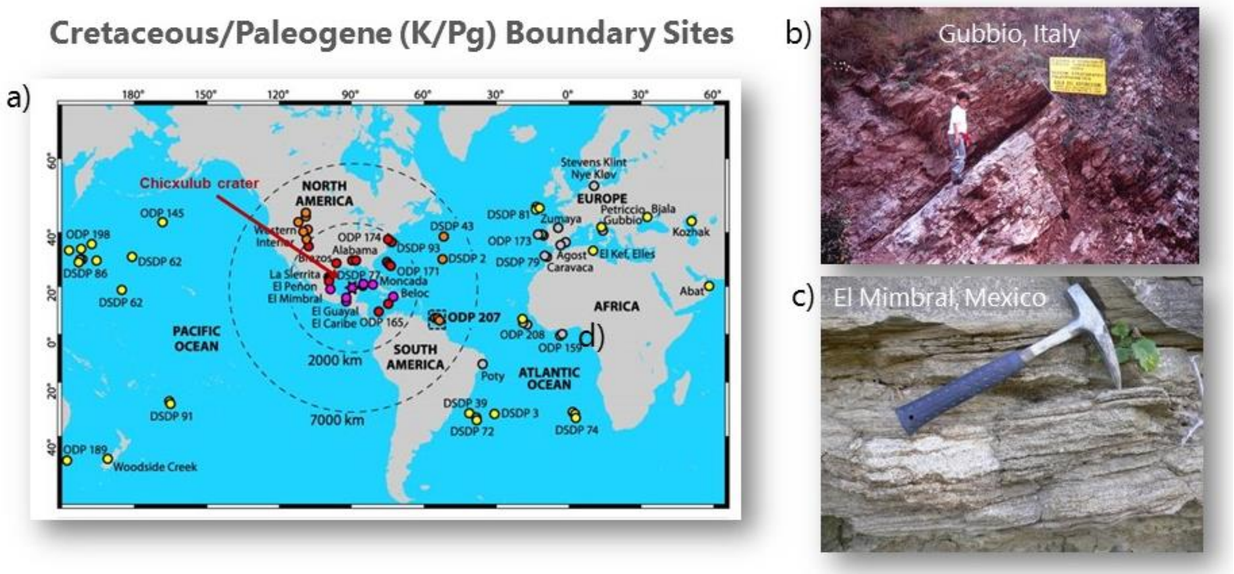
Cretaceous/Paleogene (K/Pg) Boundary Sites
a)
180°
150°
120°
90°
60°
30°
0°
30°
60°
60°
40°
20°
0°
20°
40°
Chicxulub crater
NORTH AMERICA
Western Interior
Brazos
Alabama
ODP 174
DSDP 93
DSDP 43
DSDP 2
ODP 171
La Sierrita
El Peñon
El Mimbral
DSDP 77
Moncada
Beloc
El Guayal
El Caribe
ODP 165
ODP 207
2000 km
7000 km
SOUTH AMERICA
PACIFIC OCEAN
ODP 145
ODP 198
DSDP 62
DSDP 86
DSDP 62
DSDP 91
ODP 189
Woodside Creek
Stevens Klint
Nye Kløv
EUROPE
DSDP 81
Zumaya
ODP 173
DSDP 79
Agost
Caravaca
Petriccio
Bjala
Gubbio
Kozhak
El Kef, Elles
Abat
AFRICA
ODP 208
ODP 159
d)
Poty
ATLANTIC OCEAN
DSDP 39
DSDP 3
DSDP 72
DSDP 74
b)
Gubbio, Italy
c)
El Mimbral, Mexico

Fig. 6

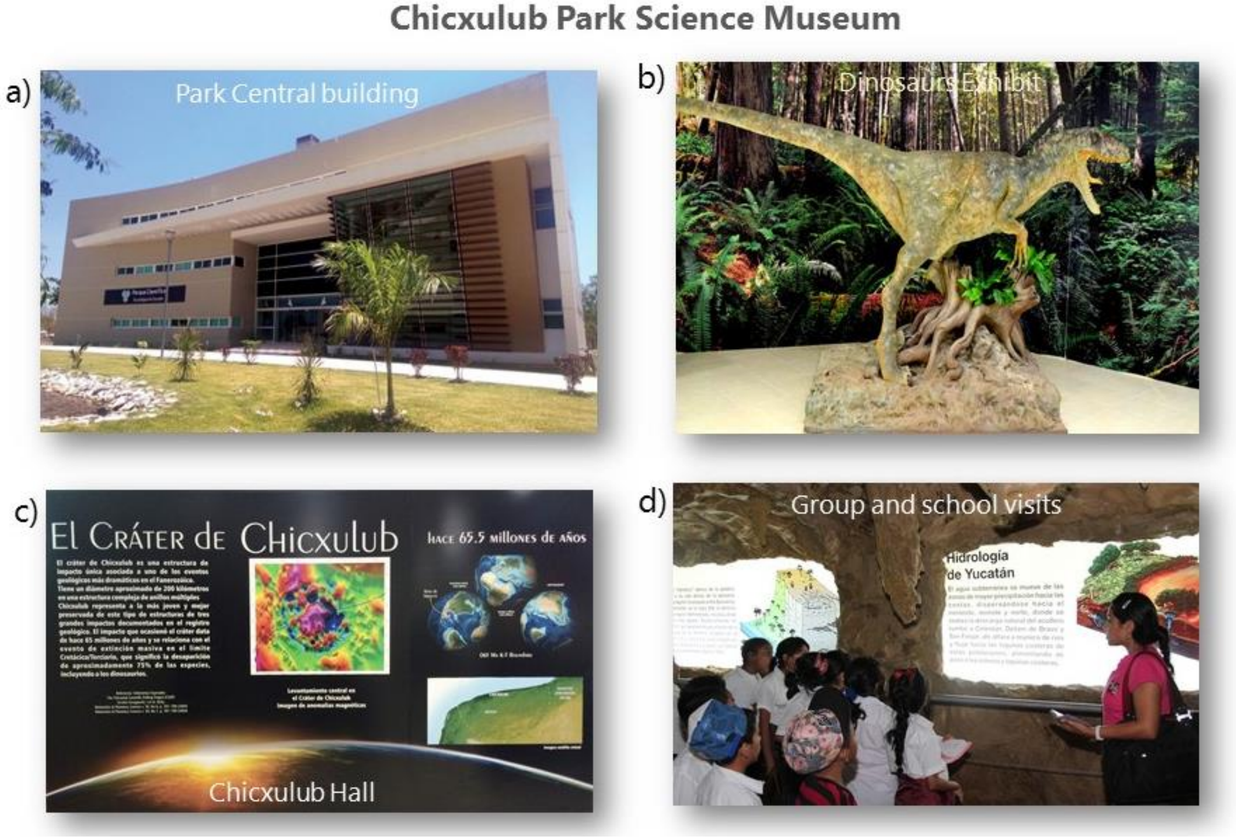
Chicxulub Park Science Museum
a)
Park Central building
b)
Dinosaurs Exhibit
c)
El Cráter de Chicxulub
Hace 65.5 millones de años
Chicxulub Hall
d)
Group and school visits
Hidrología de Yucatán

Fig. 7


Chicxulub and the Extinction of Dinosaurs
Grand Museum of Maya World

Fig. 8

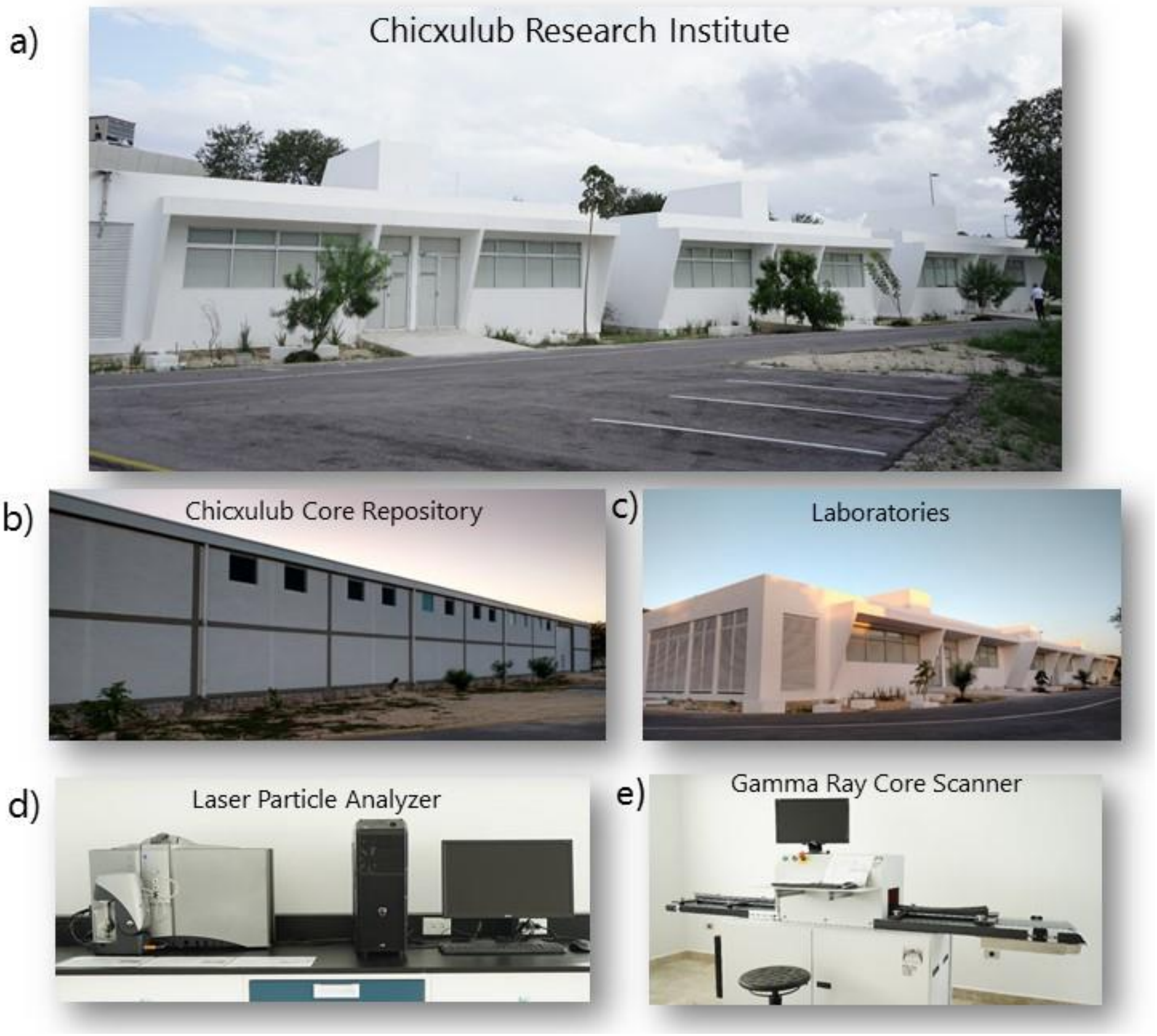
a)
Chicxulub Research Institute
b)
Chicxulub Core Repository
c)
Laboratories
d)
Laser Particle Analyzer
e)
Gamma Ray Core Scanner

Fig. 9

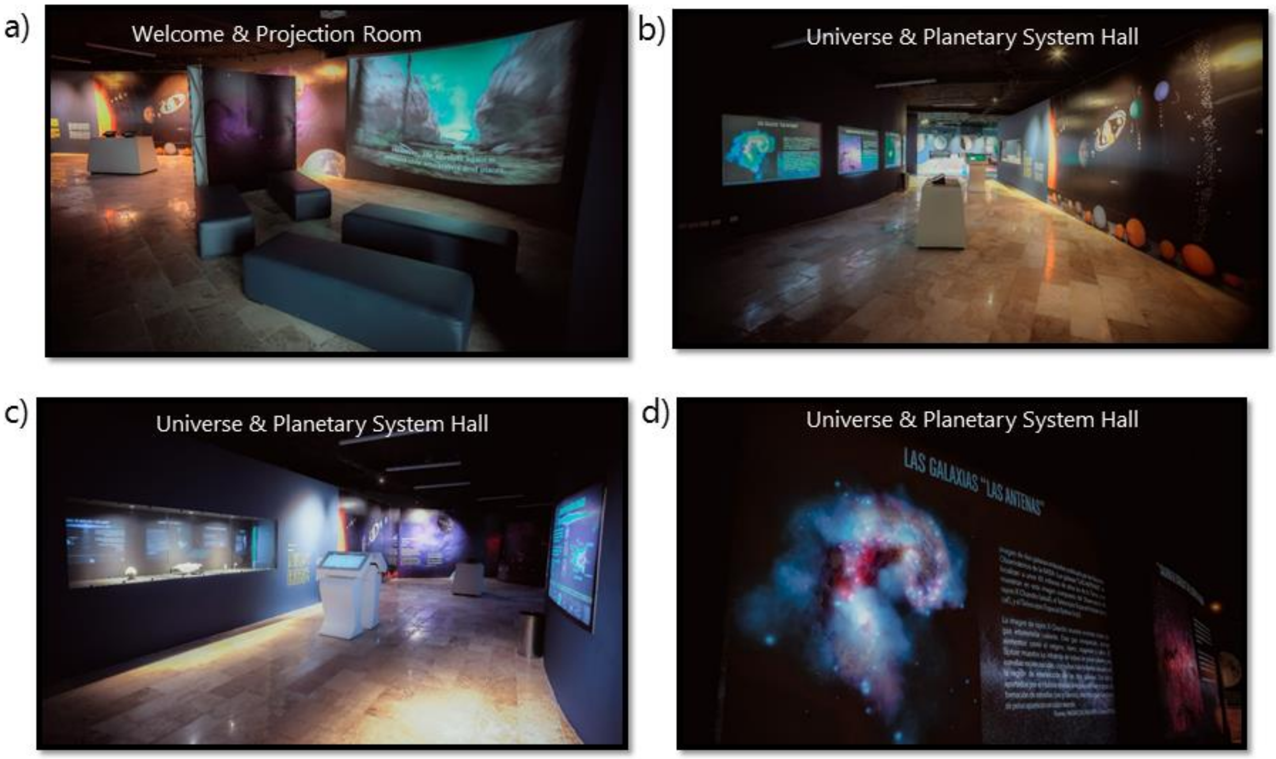
a)
Welcome & Projection Room
b)
Universe & Planetary System Hall
c)
Universe & Planetary System Hall
d)
Universe & Planetary System Hall
LAS GALAXIAS "LAS ANTENAS"

Fig. 10

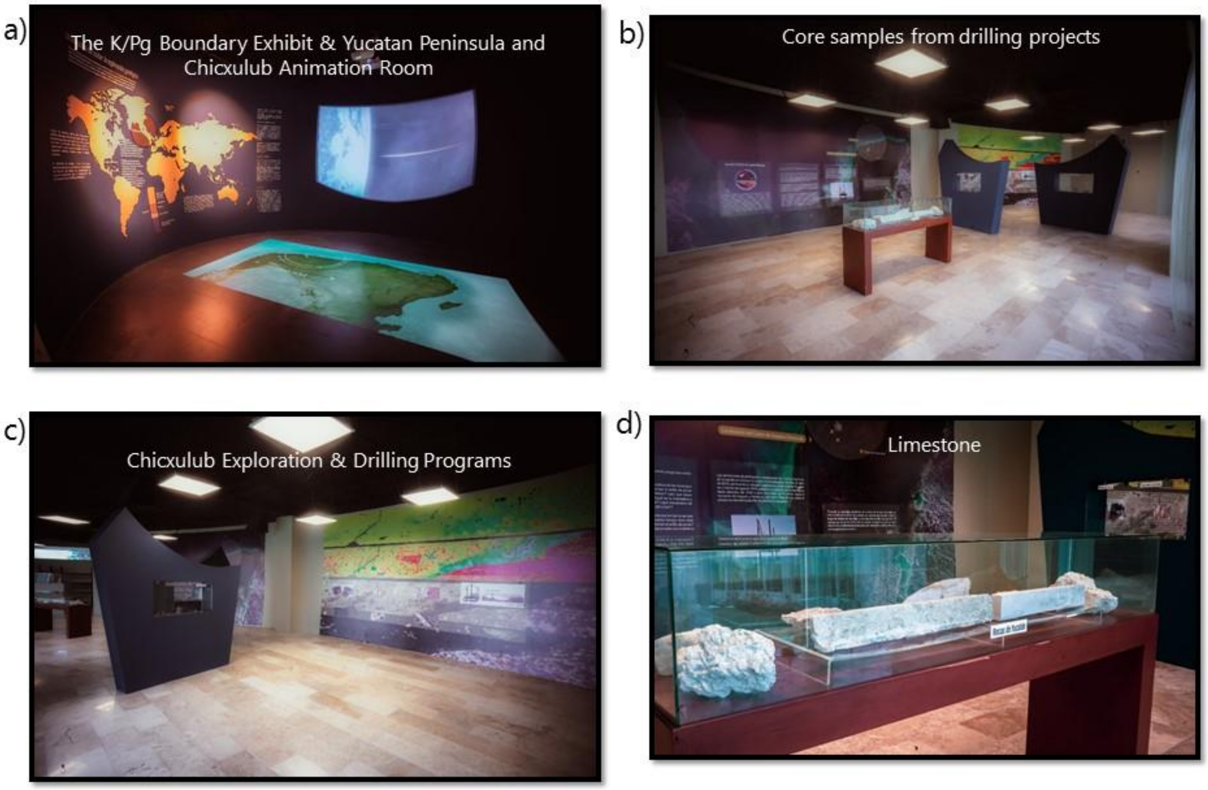
a)
The K/Pg Boundary Exhibit & Yucatan Peninsula and Chicxulub Animation Room
b)
Core samples from drilling projects
c)
Chicxulub Exploration & Drilling Programs
d)
Limestone

Fig. 11

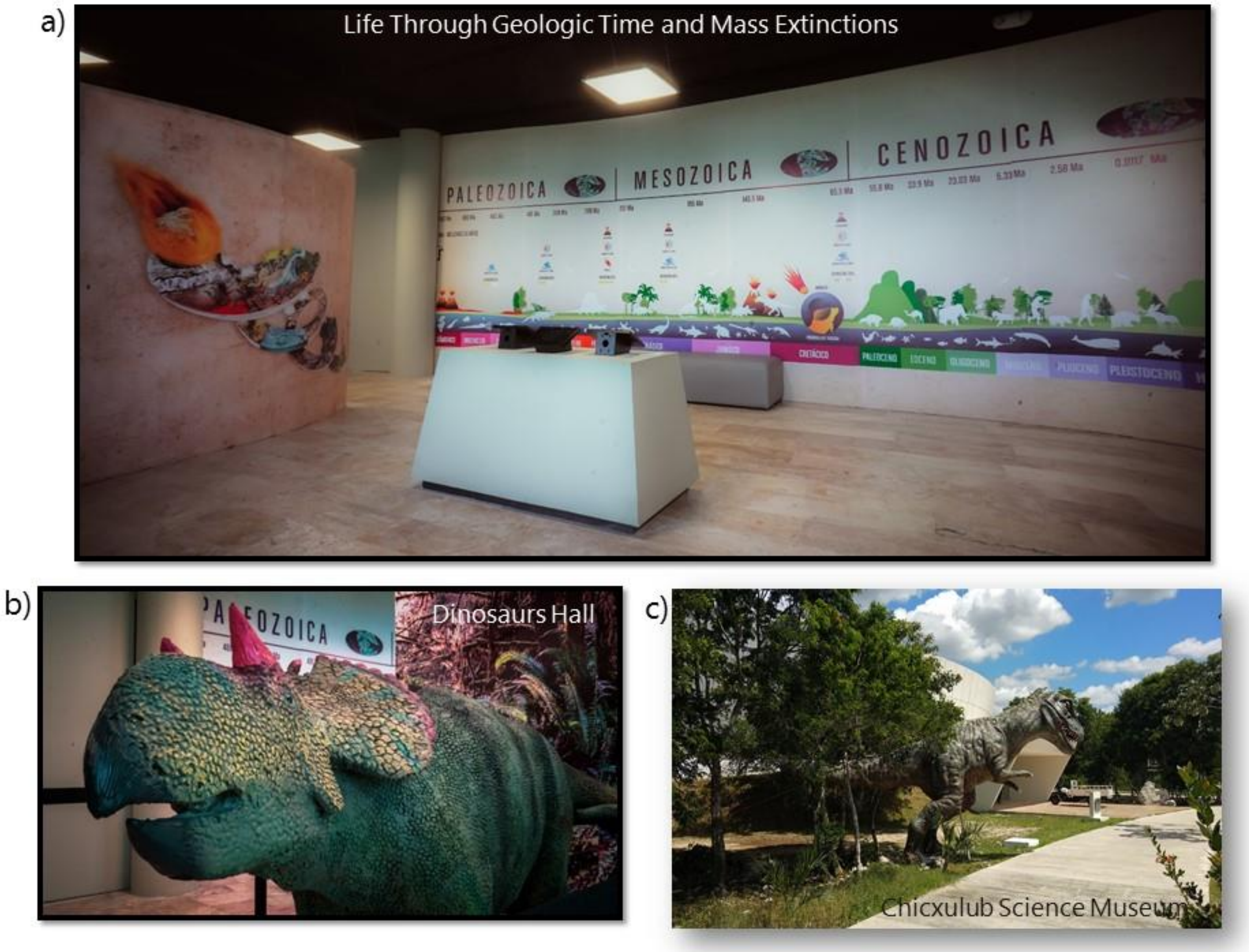
a)
Life Through Geologic Time and Mass Extinctions
PALEOZOICA
MESOZOICA
CENOZOICA
CRETÁCICO
PALEOCENO
EOCENO
OLIGOCENO
PLIOCENO
PLEISTOCENO
b)
Dinosaurs Hall
PALEOZOICA
c)
Chicxulub Science Museum

Fig. 12