THE LAKE BOSUMTWI IMPACT STRUCTURE, GHANA

JHONNY E. CASAS
Escuela de Petróleo y Escuela de Geología, Minas y Geofísica, Universidad Central de Venezuela

https://iugs-geoheritage.org/geoheritage_sites/lake-bosumtwi-impact-crater/

INTRODUCTION

Lake Bosomtwi, sometimes spelled Bosomtwe, is a beautiful, round lake tucked away in Ghana's Ashanti Region (Africa). Scientists believe it was formed about a million years ago when a meteor crashed into the earth. The lake is surrounded by steep hills and covered in thick forests around its shores,

Central Ghana is underlain by the Proterozoic metavolcanic and metasedimentary rocks of the Birimian Supergroup, which are the host rocks for the extensive Ghanaian gold deposits. The elevated Obuom Range borders the southeast part of the Lake Bosumtwi drainage basin (Figure 1), and consists of uplifted metavolcanic rocks. Other than the Obuom Range, the topography of the Lake Bosumtwi drainage basin follows the Pleistocene relief produced by the impact structure. Lake morphometry is that of a simple bowl-shaped depression, which developed from the accumulation of post-impact lacustrine and alluvial sediments. The well-defined crater was initially characterized as a caldera (Smit, 1964) and has an average rim elevation of ~250 to ~300 m above the lake surface. At a radius of 8-10.5 km, an outer ring can be identified by low-relief topography and also by a halo-shaped magnetic anomaly observed in high-resolution aeromagnetic data.

Initial suggestions of a meteorite impact origin for the Bosumtwi crater came from MacLaren (1931), and later on publications by Smit (1964) and others, present abundant evidence of a meteorite impact origin. The 1 Ma Bosumtwi Crater in Ghana (Figure 1) is a complex impact structure with a rim-to-rim diameter of 10.5 km. The crater is associated with the Ivory Coast tektite strewn field (Figure 1), an expansive region of distal, molten ejecta deposition to the SW of Bosumtwi. The crater is almost completely filled by Lake Bosumtwi, which measures 8 km in diameter and has a current máximum depth of about 80 meters. The crater rim rises about 250–300 m above lake level. It is the youngest and best preserved of the 95 terrestrial impact structures with diameter larger than 6 km formed in a crystalline target.

Because the impacting body struck a subaerial site in the continental interior, rather than a submerged continental shelf, no profound backwash effects distorted the structure following the impact. Also, no postimpact tectonic deformation of the structure has been observed later. Consequently, the Bosumtwi crater is an excellent case study for investigating the impact process on Earth.

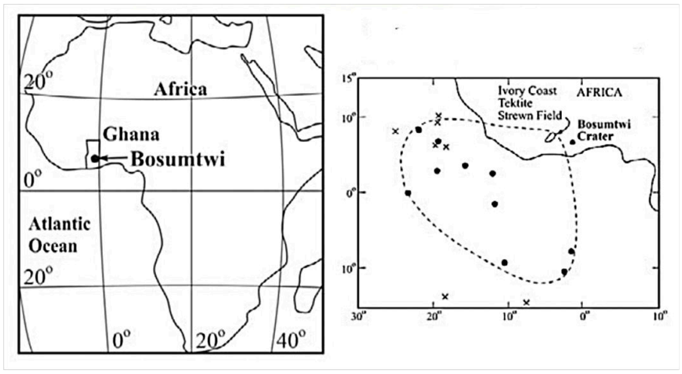


Figure 1. Location of the Bosumtwi crater in western Africa with the Ivory Coast tektite strewn field (right). Modified from Artemieva *et al.* (2004)

GEOLOGICAL SETTING

The Bosumtwi crater was dug out in lower greenschist-facies supracrustal rocks of the 2.1-2.2 Gyr old Birimian Supergroup, comprising mainly metasediments and metavolcanics (Figure 2). The Birimian target rocks are made up of mica schists and banded schists with both micaceous and quartz-feldspathic bands, phyllite, metagreywacke, quartzite and sandstone, shale and slate, as well as meta-tuffs. Birimian meta-volcanic rocks (altered basic intrusives intercalated with some metasediments) occur in the southeastern sector of the Bosumtwi area. Graywackes predominate the surface exposures and are the most important clast type in many suevite samples.

Brecciated greywacke and phyllite dominate the geology immediately around the crater and locally intruded by small dikes and pods of granitic intrusives. Carbonates (previously unknown) were identified in high abundance in the analysis of drill cores and their origin is pre–impact (Aning *et al*, 2013). Other than the Obuom Range to the southeast of the crater, the topography of the Lake Bosumtwi drainage basin follows the Pleistocene relief produced by the impact structure. Lake morphometry is that of a simple bowl-shaped depression, which developed from the accumulation of post-impact lacustrine and alluvial sediments.

The well-defined crater was initially characterized as a caldera (Smit, 1964) and has an average rim elevation of ~250 to ~300 m above the lake surface which is about 80–100 m below the terrain outside of the rim. Except for the terrain of the Obuom mountain range, and locations along some stream channels in the environs of the crater, exposure is generally very poor. Recent rock formations include the lake beds and the products of weathering (laterites, soil) which can have thicknesses up to 10 m. Although no impact melt rock has been found around the crater, numerous breccia and suevite (Aning *et al*, 2013).

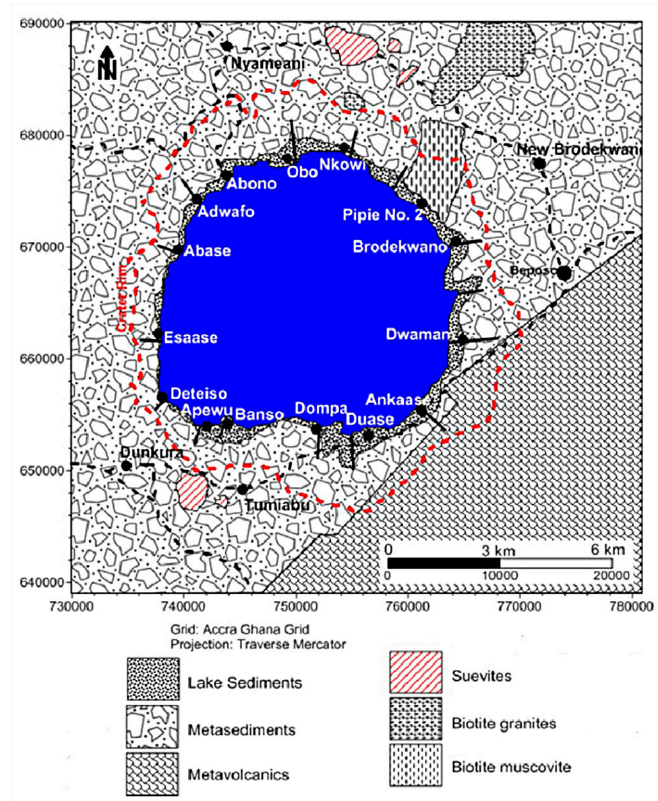


Figure 2. Geological map of the Bosumtwi crater area showing the different types of rocks. Modified from Aning *et Al.*, 2013

THE CRATER

This crater was created by approximately 500 m wide chondrite (stone) meteorite, which entered the atmosphere with a speed of some 20 km per second. It approached from the east and hit the 2 billion years old rocks (quartzite, phyllite, slate, and granite) with extraordinary force. The extreme kinetic energy of the meteorite caused an explosion which most certainly was felt on the whole of Earth.

It is presumed that in those times western Africa was covered with rainforest, so forest was eliminated in a huge area, millions of lives of animals were erased in a moment and many more perished in coming months. This explosion created a 10.5 km wide and some 750 m deep complex crater. The physics of the Earth's crust caused the upheaval of the central part in the crater. This upheaval is covered with lake sediments now but it is elevated some 130 m above the original bottom of the crater. Such a complex crater is classified as a medium-sized impact crater. Bosumtwi crater is the youngest and most likely the best-preserved medium-sized impact crater on Earth.

MULTICHANNEL SEISMIC REFLECTION RESULTS

Airgun-sourced multichannel seismic reflection (MCS) data was acquired (Figure 3), and yield the most important results relevant to the morphology of the Bosumtwi impact structure. Significantly, none of the reflection data provide information below the contact between the post-impact sediments and the uppermost crater material. Additionally, considerable accumulation of biogenic gas in post-impact, organic-rich lacustrine sediments is evident on all vintages of data on the margins of the lake, which both obscures the near surface stratigraphy within sedimentary section in this area and induces numerous high amplitude water bottom multiples on all profiles, from the lakeshore to within ~2 km of the basin center. Whereas the imaging effectively failed on the edges of the lake, data acquired from the central basin of the lake are of excellent quality and both the lacustrine stratigraphy and impact material surface are well imaged in that locality (Scholz *et al,* 2007).

The most significant set of features revealed in the MCS data set define a distinctive central uplift situated just northwest of the center of the lake and crater, and is observed on four radial images that cross-cross the center of the basin (Figures 3, 4, 5). The feature is 1.9 km in diameter, with a maximum height of ~130 m above the adjacent circular moat that surrounds the uplift and forms the deepest part of the crater floor. Above the crater floor, Scholz *et al*, (2007) observed as much as ~310 m of post-impact lacustrine sediment, but the peak of the central uplift is within ~150 m of the lake bottom at one location. The maximum crater rim-to-floor height is 750 m, measured from the maximum elevation of the crater rim to the base of the post-impact lacustrine sediments. The sedimentary section in the basin center is well characterized with the lacustrine section observed as a set of continuous reflections.

The crater floor–post-impact sediment interface is easily identified on the MCS records as a moderate-low frequency, discontinuous, and high-amplitude package of irregular reflections, suggesting that the crater floor topography in the vicinity of the central uplift is broken and uneven (Figures 4, 5). At the peak of the central uplift, we observe a distinctive graben that has a maximum depth of over 50 m (Figure 4). Extending from the uplift surface into the sediment column we observe a series of faults that appear to have their origins on the graben boundary, and then extend upward 100 m or more into the sediment section that overlies the uplift. Other than the graben structure, the uplift is broadly symmetrical but with a broken second order relief indicative of fractured and deformed materials (Scholz *et al*, 2007).

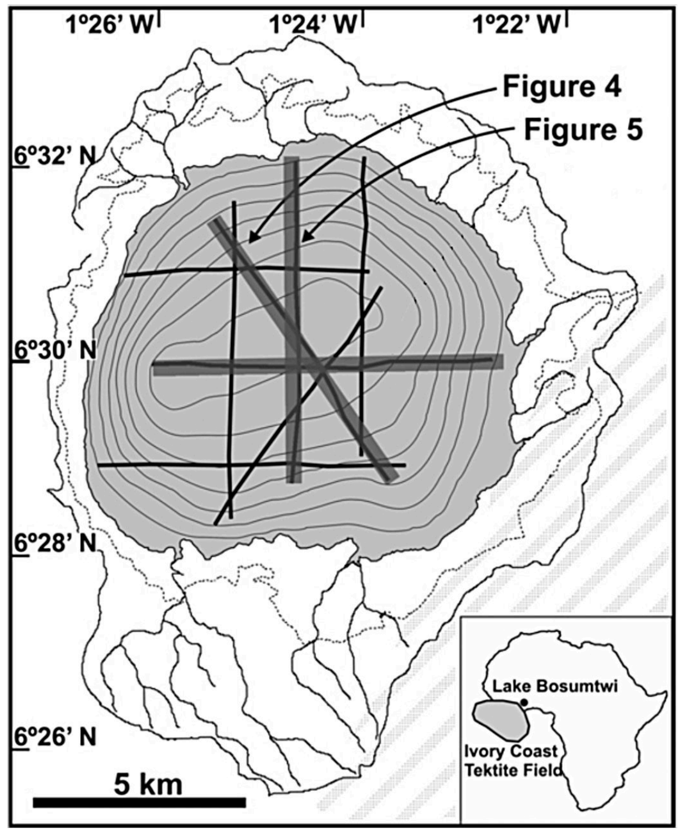


Figure 3. Bathymetry and drainage area of Lake Bosumtwi, with multichannel seismic reflection profile locations. Shaded lines (Figures 4 and 5) are presented below. Dotted line = overflow level. Shaded region in the lower right (southeast) part of the area shows the location of the Obuom Range. Inset shows the location of the Bosumtwi impact structure in Africa, along with the location of the Ivory Coast tektite field. Modified from Scholz *et al.* (2007).

THE IMPACT OBLIQUITY

Most of the numerical results done were obtained for a vertical impact, although Artemieva *et al*, (2004) believed that the Bosumtwi structure was produced by an asteroid impact with substantially shallower impact angle (probably in the interval 30-45°). The main indication of the obliquity is the ejecta distribution. The spatial distribution of distal ejecta formed at the beginning of the excavation stage is the most asymmetrical feature and is commonly used to determine an impact angle and direction. However, the distal ejecta are the most short-lived feature (because of a small total thickness, a small fragment size distribution and a quick degradation due to weathering). Fortunate the Ivory Coast tektite strewn field aid in the reconstruction of the Bosumtwi impact event.

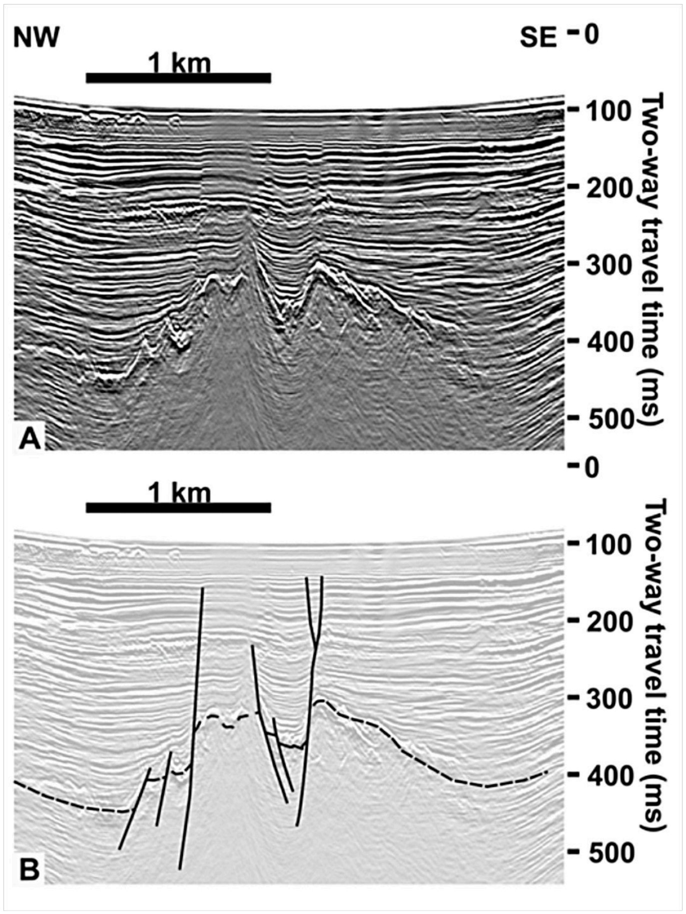


Figure 4. a) Uninterpreted and (b) interpreted MCS profile extending across the lake from northwest to southeast (central part of profile is shown). Note the pronounced crestal graben on the central uplift. The zone immediately beneath the central uplift is largely reflection-free, and is interpreted as mainly impact breccia. Several normal faults extend from the central uplift into the sediment section, and are interpreted as associated with post-impact compaction. The sediment-breccia interface is well imaged over most of the profile, and is characterized by a high-amplitude two-cycle reflection. Lower amplitude reflections observed beneath the sediment-breccia contact on the basin margins are mainly reverberations.
Modified from Scholz *et al.* (2007).

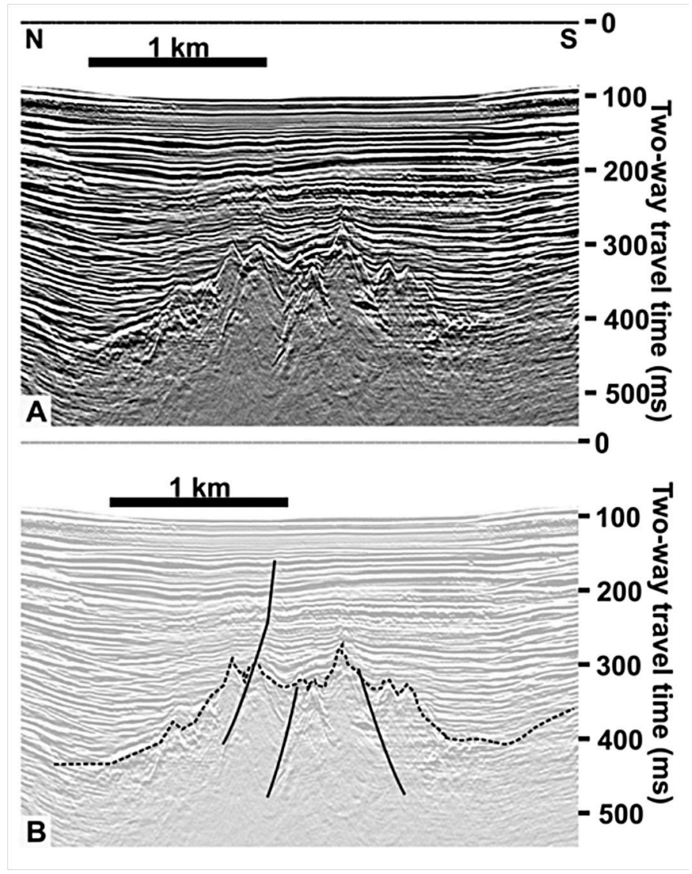


Figure 5. a) Uninterpreted and (b) interpreted profile extending across the central part of the lake from north to south. The crestal graben is not observed on this profile. Note several normal faults that extend up into the sediment section. The uppermost ~40 ms (TWTT) of sediment section contains distinctly lower amplitudes than the deeper sediment section reflections. This sequence is composed of high-water content lacustrine muds, sitting on top of a desiccation surface. The edge of the annular moat is observed on the margins of this profile. Modified from Scholz *et al.* (2007).

TEKTITES

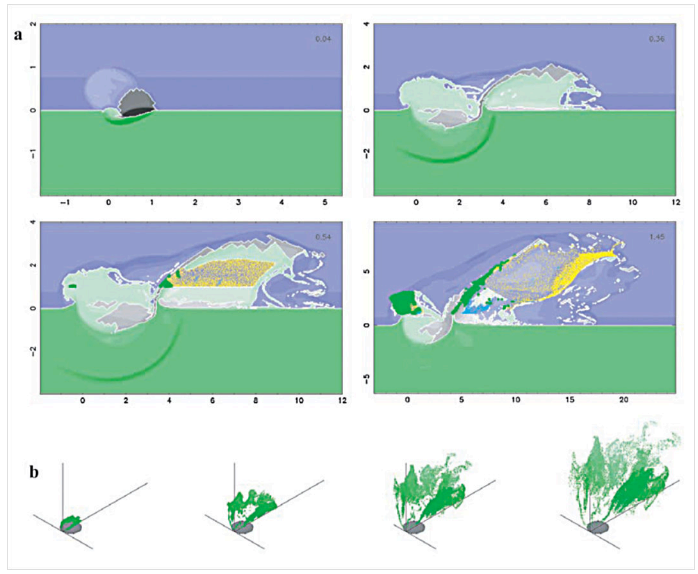
Bosumtwi Lake is surrounded by rainforest. In such conditions the soil erosion is faster than, for example, in dry deserts, and due to this crater has eroded and is covered with soil, there are no cliffs exposed. Due to this, the research of this impact crater is not that easy. To constrain the direction and angle of impact for the Bosumtwi crater, Artemieva *et al*, (2004) monitored the fate of the distal ejecta in different oblique numerical model runs. This allows the authors to compare the model results with observational data from the tektite strewn field in the Ivory Coast. Ivory Coast tektites were first reported in 1934. The tektites were found in a region with a radius of about 40 km around the town of Qualle. Additional collections were made later, but the total number collected remains small (about 200).

Age data, isotope studies and compositional data analyzed by Artemieva *et al,* (2004), confirmed the tektites' origin from the Bosumtwi crater. Glass spherules and microtektites were found in deep-sea deposits from the equatorial Atlantic in 1967 (Glass et al, 1991). The strewn field does not extend below 12°S and north of 9°N; the Eastern and western limits are not well defined. In total, the strewn field lies in the quadrant SW of the crater, showing preferable direction of the impact from ENE. Additional cores from the Atlantic must be studied before the shape and extent of the strewn field can be determined with any confidence. Previous modeling work suggests that the most suitable conditions for the tektites' origin arise in the case of high-velocity impact (20 km/s or higher) with impact angle in the range from 30° to 50° (Artemieva *et al,* 2004).

Figures 6a and 6b by Artemieva et al, (2004), show the early stage of a Bosumtwi-type impact at 30 and 20 km/s, including ejection of solid and molten materials, their disruption into particles, and the particles motion in the atmosphere. Only solid and molten particles larger than 1 cm in diameter are shown so as not to overload the figures. Molten particles from the target (i.e., potential tektites and microtektites) are shown in yellow, solid fragments are in green, and molten projectile is in cyan. One second after the impact, almost all of the molten and solid high-velocity material is ejected and broken into the particles, while intensive ejection of (either molten or solid) material from deeper layers continues for much longer (Artemieva *et al,* 2004).

The initial ejection velocities of material are high, up to 10 km/s, which is close to the velocity of the expanding gas. As a result, the particles are not subjected to high dynamic pressures that otherwise would disrupt them into a fine dust immediately after ejection. The temperature of the entraining gas is rather high, in the range of 1000–2000 °K, so the particles do not cool quickly during the flight, allowing enough time to have them aerodynamically shaped (which is typical for tektites), and to lose volatiles like water (Artemieva *et al*, 2004).

The Bosumtwi structure is not large enough to create worldwide ejecta; all of the ejected material is decelerated in atmosphere and deposited on the surface at the distances up to 2000 km from the crater. The majority of this material (80–85%), however, is deposited in the vicinity of the crater, probably as a molten component of suevite (Figure 7). The rest may be identified as a tektite strewn field (Artemieva *et al*, 2004).



Figures 6a and 6b. Early stage of a Bosumtwi-type impact at 30 and 20 km/s, including ejection of solid and molten materials, their disruption into particles, and the particles motion in the atmosphere. Molten particles from the target are shown in yellow, solid fragments are in green, and molten projectile is in cyan. Modified from Artemieva et al. (2004).

Figure 7. Outcrop of polymict impact breccia (suevite) north of crater rim at Bosumtwi. Modified from International Commision of Geoheritage (IUGS).

THE LAKE AND THE CLIMATIC RECORD

The bottom of the crater has been filled by a lake. Currently, Bosumtwi Lake has a diameter of some 8 km, it is up to 80 m deep. At the depth of some 15 meters, the water becomes anoxic. Bosumtwi Lake currently does not have any inlets or outlets – it is fed only by rain. Due to isolation here have developed endemic species of fish, a cichlid Hemichromis frempongi and subspecies of cichlids Tilapia busumana and Tilapia discolor. The bottom of the lake is covered with up to 310 m thick layer of sediments. Those sediments provide very important data about climate history in this part of Africa.

The analysis shows that this part of Africa on a regular basis experiences approximately 30-40 years-long droughts. The level of the lake falls per some 10-30 meters in such times. These droughts are caused by the changes in temperatures in the Atlantic (Atlantic Multidecadal Oscillation). During the droughts the bed of the crater is covered with forest, only in the central part remains a smaller lake. Sometimes though water filled the crater and was flowing out of it.

Climatic record of Lake Bosumtwi shows that approximately 70,000 years ago Africa experienced extreme drought and disappeared almost totally. It is speculated that because this extreme drought, just a handful of humans survived and in a search of a better environment they left Africa and spread in Eurasia.

THE ASHANTI LEGEND

In some places trunks of giant trees stick out from the lake. This is a testimony of rather recent droughts when the site of the current lake was covered with a forest. Local legends have recorded these observations. There is a tale that Ashanti hunter Akora Bompe in the 17th century was chasing a wounded antelope in the forest (where the lake is now). Antelope jumped in the small pool in the center of the crater as if the lake wanted to save the antelope. Since then the lake is named Bosomtwe (antelope god).

Indigenous people consider that this is a sacred lake where souls of the dead come to bid a farewell to the god Twi. Due to local beliefs, it is allowed to fish only from wooden planks (padua) here – it is taboo to touch the water with iron. The most sacred place, a spiritual center of the lake is Abrodwum Stone. When the fish in the lake is scarce, a cow is sacrificed next to the stone and the body of the animal is thrown in the lake. Locals then rush into the lake to get a piece of the meat. Lately this does not help anymore. Due to overpopulation and overfishing, fish is scarce in the lake.

REMARKS

At about 1 Ma old, Bosumtwi it is one of the best-preserved impact craters in the world and certainly the most recent of its size. For the better understanding of the cratering process and to verify numerical and geophysical models, it is necessary to drill the crater center and the deepest site of the crater. In the case of more than one borehole at the periphery, interesting information concerning asymmetric deposition of melt and projectile material may also be obtained. This information will give additional constraints of this kind of impact obliquity for future comparison with other impacts.

REFERENCES

Aning, A., Tucholka, P. & Danour, S. (2013). The Bosumtwi meteorite impact crater, Ghana: New Results on the impact direction of the meteorite from 2D Electrical Resistivity Tomography (ERT) Survey. International Research Journal of Geology and Mining (IRJGM), 3(4): 147-157.

Artemieva, N., Karp, T. & Milkereit, B. (2004). Investigating the Lake Bosumtwi impact structure: Insight from numerical modeling, *Geochem. Geophys. Geosyst.,* 5(11): 1-20. doi:10.1029/2004GC000733

MacLaren M. (1931). Lake Bosumtwi, Ashanti. *Geographical Journal*, 78:270-276. https://www.jstor.org/stable/1784899?origin=crossref

Scholz, C., Karp, T. & Lyons, R. (2007). Structure and morphology of the Bosumtwi impact structure from seismic reflection data. Meteoritics & Planetary Science 42, 4(5): 549-560.

Smit, A. (1964). Origin of Lake Bosumtwi (Ghana). Nature. 203:179-180. https://www.nature.com/articles/203179a0

jcasas@geologist.com

Jhonny E. Casas es Ingeniero Geólogo graduado de la Universidad Central de Venezuela, y con una maestría en Sedimentología, obtenida en McMaster University, Canadá. Tiene 38 años de experiencia en geología de producción y exploración, modelos estratigráficos y secuenciales, caracterización de yacimientos y estudios integrados para diferentes cuencas en Canadá, Venezuela, Colombia, Bolivia, Ecuador y Perú.

Autor/Co-autor en 61 publicaciones para diferentes boletines y revistas técnicas, como: Bulletin of Canadian Petroleum Geology, Geophysics, The Leading Edge, Asociación Paleontológica Argentina, Paleontology, Journal of Petroleum Geology, Academia de Ciencias, Academia de Ingeniería y Caribbean Journal of Earth Sciences; incluyendo presentaciones en eventos técnicos: AAPG, SPE, CSPG-SEPM y Congresos Geológicos en Venezuela y Colombia, así como artículos históricos en el boletín AAPG Explorer. Autor de mas de 40 artículos de divulgación científica.

Profesor de Geología del Petróleo (1996-2004). Profesor de materias de postgrado tales como: Estratigrafía Secuencial, Modelos de Facies y Análogos de afloramiento para la caracterización de yacimientos (2003-2025), en la Universidad Central de Venezuela. Mentor en 12 tesis de maestría. Representante regional para la International Association of Sedimentologist (2020-2026) y ExDirector de Educación en la American Association of Petroleum Geologists (AAPG) para la región de Latinoamérica y del Caribe (2021-2023). Advisory Counselor para AAPG LACR (2023-2026).