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DISCOVERY AND GEOLOGY OF THE GUINNESS WORLD RECORD *LAKE COPPER, LAKE SUPERIOR, MICHIGAN*

by

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The Copper Pavilion at the A. E. Seaman Mineral Museum exhibits a 19-ton mass of native copper recovered on the bottomland of Lake Superior on permanent loan from the State of Michigan, Department of Natural Resources.

Discovery

This Guinness World Record holding tabular mass of native copper, weighing approximately 19 tons, was recovered from the bottomlands of Lake Superior and is now on exhibit in the Copper Pavilion at the A. E. Seaman Mineral Museum of Michigan Tech referred to here as the "*Lake Copper.*"

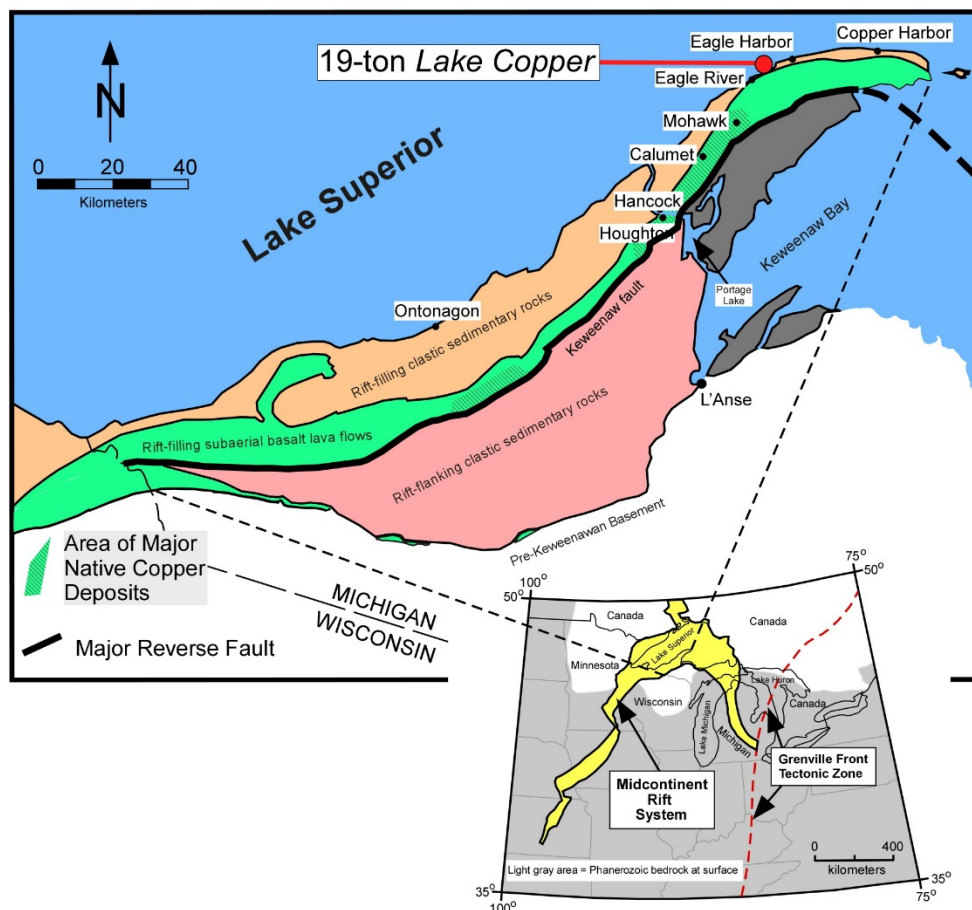


Figure 1: Location of the *Lake Copper* shown in context with the generalized bedrock geology along the flank of the Midcontinent rift system (after Bornhorst and Lankton, 2009).

It was discovered in July of 1991 by local divers Bob Barron and Don Kauppi on the bottomlands of Lake Superior in about 30 feet of water northwest of Jacob's Creek, Great Sand Bay between Eagle River and Eagle Harbor (Figure 1 and 2). The tabular *Lake Copper* was horizontal when discovered rather than vertical in the vein as it had fallen over. It was not attached to the bedrock vein, but it visually lined up with the vein.

The bedrock beneath Lake Superior of Great Sand Bay consists of the Copper Harbor Formation composed of conglomerate and sandstone with an interlayered member termed the Lake Shore Traps consisting of multiple lava flows (Figure 2). The lava flows are more resistant to erosion and tend to outcrop along the north shore of the Keweenaw Peninsula from Eagle Harbor to the eastern tip of the peninsula where they result in several harbors. In Great Sand Bay, where the underlying bedrock is conglomerate and sandstone of the Copper Harbor Formation, the underwater surface is covered by sand. The bedrock is exposed at the underwater surface in the area of the Lake Shore Traps where it forms ridges.

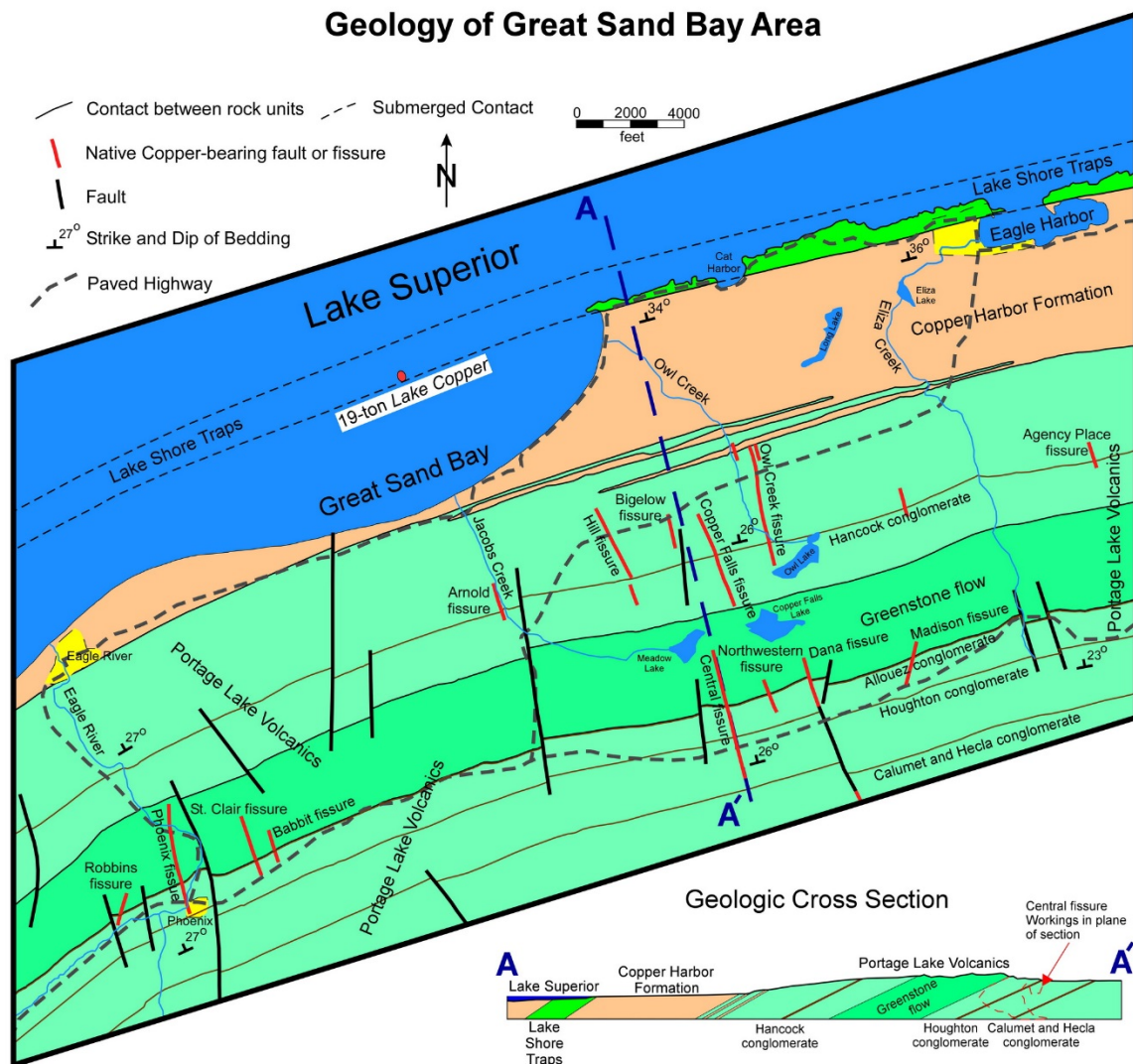


Figure 2: Location of the *Lake Copper* and relationship with the geology of the Great Sand Bay area, Keweenaw Peninsula, Michigan (geology after U.S. Geological Survey geologic quadrangle maps).

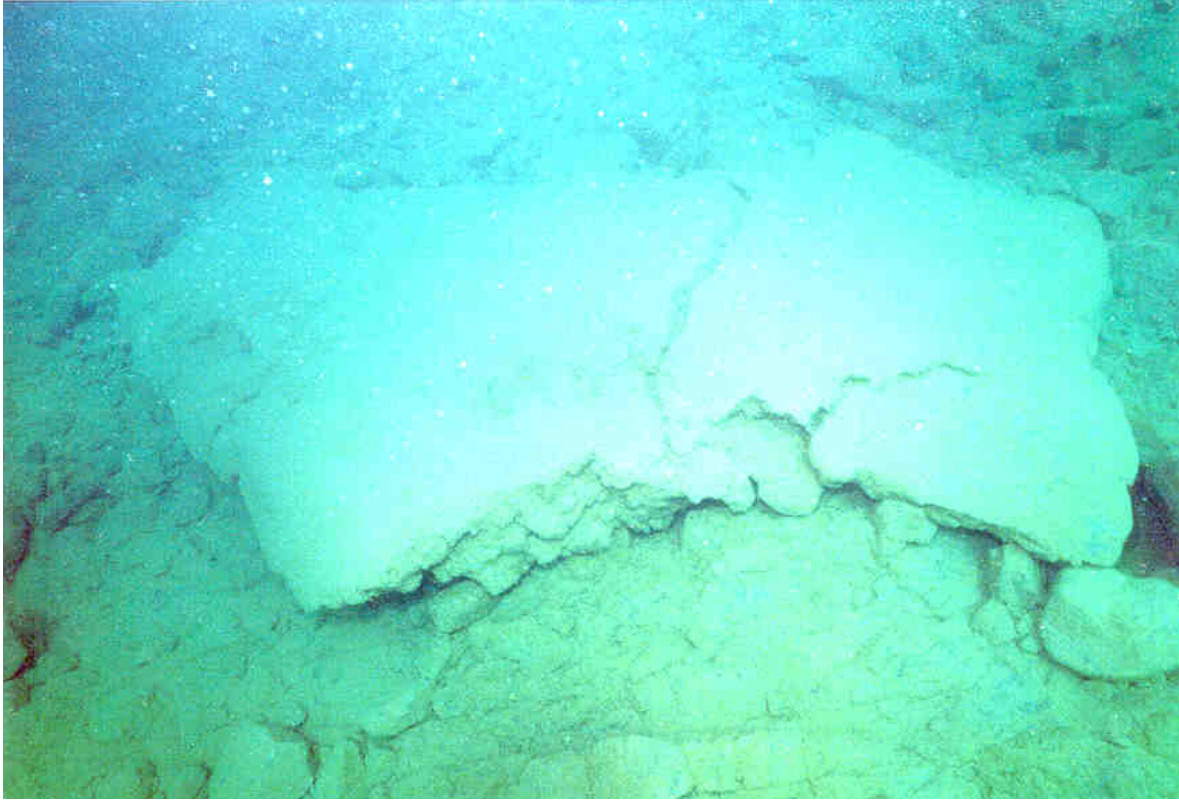


Figure 3: Nineteen ton *Lake Copper* lying on the bottomlands of Lake Superior in Great Sand Bay.

Bob and Don had been diving in Great Sand Bay for several years and had undertaken a systematic search of the area when they found an interesting vein northwest of the location of the tabular mass of native copper. The vein showed evidence of abundant native copper. Bob followed the trace of the vein and discovered a large horizontal slab of native copper lying on the bottom in the area of the lowermost part of the Lake Shore Traps (Figure 3).

The State of Michigan owns the bottomlands of Lake Superior around the Keweenaw Peninsula and a salvage permit from the Department of Natural Resources was required for extraction of the *Lake Copper*. Initial attempts at securing a permit were not successful until progress was made in 1996 after Bob became an employee of the A. E. Seaman Mineral Museum of Michigan Tech. The Department of Natural Resources was more willing to work with a state affiliated institution and an agreement was reached in December of 1999 between Michigan Tech and the State of Michigan. The State of Michigan retained ownership of the copper slab while agreeing to put it on permanent loan at the A. E. Seaman Mineral Museum of Michigan Tech. The *Lake Copper* was recovered by the H. J. Schwartz crane barge from Duluth, MN in July 2001 (Figure 4).

A.



B.



C.



D.



Figure 4: Recovery of the native copper vein by the US Army Corps of Engineers H. J. Schwartz crane barge. A. *Lake Copper* strapped and beginning to be lifted off of the bottomlands of Lake Superior. B. *Lake Copper* emerging from the surface of Lake Superior. C. *Lake Copper* continuing its ascent on to the barge. D. *Lake Copper* ready to be placed on the deck of the barge with diver Bob Barron in picture.

After its recovery, it was transported to the Quincy Mine Hoist Association hoist building for temporary exhibit from 2002 to 2014 on behalf of the museum. Relocation of the museum from its campus home to a more spacious site in 2011 provided an opportunity to incorporate the *Lake Copper* with exhibits of the Museum. In 2015 the *Lake Copper* was moved from the Quincy Mine Hoist Association building to the A. E. Seaman Mineral Museum through a generous donation from John and Jane Matz. The *Lake Copper* was placed on a custom engineered and constructed steel frame and subsequently a pavilion constructed on top of it (Figure 4).

The surface of the Lake copper is not shiny today. It is coated by secondary copper minerals, malachite (green-colored), cuprite (red-colored), and a very small amount of azurite (blue-colored). Hematite may also be in the secondary coating. These secondary copper minerals formed by chemical reactions with the surrounding lake waters.



Figure 5: *Lake Copper* covered by blue tarp placed on engineered stand with construction of pavilion underway.

Visitors are asked not to touch the large copper slab as oil from their skin can be left on the surface of the *Lake Copper* which over time can cause damage to the surface.

Visitors are welcome to touch the smaller mass adjacent to the large *Lake Copper* is a 250 lb mass of native copper recovered from Great Sand Bay about a quarter of a mile from shore. It too was horizontal when it was recovered but was attached to the tabular bedrock vein that was near vertical in orientation and this smaller mass of native copper had also fallen over. Like the larger mass, its top surface is smooth, due to erosive sculpturing, and has a red-brown color (cuprite (red, Cu_2O) and possibly hematite (brown, Fe_2O_3)) due to surface oxidation while in contact with lake waters. The bottom surface is irregular and pitted similar to the larger mass.

Geologic History

The bedrock underlying Lake Superior and adjacent areas such as Michigan's Keweenaw Peninsula are composed of igneous and sedimentary rocks associated with the Midcontinent Rift System of North America (Figure 1; see Bornhorst and Lankton, 2009 for more details on the geologic history). These rocks were emplaced about 1100 million years ago. The rift was filled with a thick succession of subaerial basalt lava flow with minor interbedded conglomerate layers. In the Keweenaw Peninsula proper, these rift-filling volcanic rocks make up the geologic formation termed the Portage Lake Volcanics. Overlying the Portage Lake Volcanics north and east of Calumet, the rift-filling sedimentary rocks are composed of a thick succession of interlayered conglomerate and sandstone termed the Copper Harbor Formation. Along the north and west side of the Keweenaw Peninsula within the Copper Harbor Formation there is a sequence of lava flows termed the Lake Shore Traps (Figure 2). These lava flows are more resistant to erosion than surrounding sedimentary rocks and tend to form harbors in the Keweenaw Peninsula and are the host rocks that were surrounding the *Lake Copper*. After the rift was filled with lava flows, conglomerates, and sandstones, Himalayan-style continental collision along the Grenville front tectonic zone (Figure 1) compressed the rocks of the Keweenaw Peninsula. This compressional event fractured the rocks creating faults where rocks moved past one another and gently folded the rocks too. During compression, hydrothermal fluids (mineralizing hot waters) originating at depth within rift-filling volcanic rocks moved upward and resulted in filling the open spaces with native copper and other minerals. These open spaces consist of those that existed within the rocks when they were deposited, such as vesicles in volcanic rocks and pores between pebbles in conglomerates as well as secondary (later) open spaces, such as open fractures and faults produced by compression. The fractures and faults that cut across the predominantly east-west orientation of the volcanic and sedimentary rocks tend to be tabular and near vertical in orientation. If the fractures had sufficient open space within them, they acted as a conduits for hydrothermal fluids. The

mineralizing fluids moved along the open fractures (fissures) and outward into porous and permeable rocks adjacent to them. Over time the fractures were filled with minerals (native copper and others) precipitated from the mineral-laden hydrothermal fluids. These filled fractures or faults form veins and are locally referred to as fissure-type native copper mineralization.

This tabular *Lake Copper* was originally part of a steeply-dipping tabular vein. There have been 36 underwater copper veins discovered from the eastern tip of Great Sand Bay to Eagle River, about 3.2 km west, that cut across the Lake Shore Traps perpendicular to strike. They can be quite rich in native copper and can contain long continuous stringers protruding up to 1.5 m in height and extending almost 6 meters in length above the bottomland of Lake Superior. Most of veins are less than 50 cm in width and are primarily composed of quartz or calcite with minor amounts of laumontite, datolite, prehnite, and trace amounts of silver. Veins will locally contain clay pockets which can produce well defined copper crystal specimens such as the "Laker pocket" (Rosemeyer, 2009) Inland from Eagle River to Copper Harbor, there are frequent thin calcite-filled fractures (veins) that cut across the orientation of the Copper Harbor Formation perpendicular to strike. Some of these thin veins contain other minerals, especially laumontite, and rarely native copper.

In the Great Sand Bay area, on-land within the Portage Lake Volcanics there are a number of more prominent veins formed along faults or fissures (open fracture without offset) which cross cut orientation of the volcanic rocks (Figure 2). In the larger view, the orientation of the rift-filling rocks bend (change in orientation of the strike) from the Eagle River to Eagle Harbor area (Figure 1) and at the apex of this bend is where these more prominent veins are located. Some of these veins contained sufficient amounts of minable native copper and, consequently, mines were developed on those named in Figure 2, although only the Central and Phoenix fissures produced significant amounts of native copper. Cumulatively, the vein/fissure-type deposits only amounted to less than 2 % of copper produced from the mines of the Keweenaw Peninsula. The area of most copper production begins slightly south of Houghton and continues to Mohawk (Figure 1) and hence, these veins are on the fringe of the native copper producing area. The location of the vein which contained the *Lake Copper* housed in the Copper Pavilion as well as the numerous other underwater veins in Great Sand Bay are consistent with the higher frequency of on-land area of mineralized fissures/veins and thereby, suggests that it formed by processes similar to those within the Portage Lake Volcanics (Figure 2).

Multiple glaciations within the past 2.6 million years ago have eroded away the bedrock of the Great Lakes region. Phanerozoic bedrock capping Precambrian basement was largely removed in the northern areas including completely removed in almost all of the western side of the Upper Peninsula of Michigan. The bedrock exposed by glaciation in the far western side of the Upper Peninsula of Michigan consists of rocks of the Midcontinent rift system (Figure 1 and 2). Each subsequent episode of glacial advance lead to more and more erosion. Prior to the last Wisconsin Glacial Stage but after the previous stage, the tabular mass of native copper within the vein must have been exposed above the surface of the hosting Lake Shore Traps. When it formed, the surface of this *Lake Copper* was highly likely to have been irregular and pitted on all sides. Minerals other than native copper were precipitated in the vein at the same time as the native copper and these competed for space. The irregular and pitted surfaces of this *Lake Copper* were once filled by these other minerals. Observations of minerals in veins in this area indicate that these minerals are mostly calcite and laumontite. Being readily vulnerable to weathering, the calcite and laumontite are relatively easily removed in the weathering environment from the surrounding the native copper. The surfaces on both sides of the 19-ton mass of native copper, and the smaller 250-lb mass, in the near vertical tabular veins were likely exposed prior to the last stage of glaciation and the attached minerals were removed leaving irregular and pitted surfaces.

The 19-ton *Lake Copper* was oriented in a horizontal position when it was discovered rather than the near vertical position it was in the vein after it formed. The *Lake Copper* had fallen over and while not attached to the

bedrock vein, it visually lined up with the vein. By simply standing it up it would have been in the correct lateral position and orientation hence, there was no movement other than falling over. The smaller adjacent 250-lb *Lake Copper* was also horizontal but was attached. Glacially transported masses of native copper tend to be smooth on both the top and bottom surfaces due to abrasion by other rocks carried in the ice along with the masses of native copper; glacially transported native copper is locally termed "float" copper as it once "floated" in glacial ice. The underside of the *Lake Copper* masses in the Copper Pavilion copper slab have an irregular and pitted character indicated that they were not abraded. The pitted underside is consistent from it being protected from glacial scouring/abrasion because after it fell over between the last and previous stages of glaciation. In addition, the irregular and pitted underside further demonstrates that the 19-ton tabular mass of native copper was not glacially transported and it is not float copper. The top side of both *Lake Copper* masses are smooth and were subjected to abrasion by rocks and fine particles carried by the glacier during the Wisconsin glacial stage. The top of the 19-ton *Lake Copper* is also grooved (striated) which caused by larger rocks scrapping the surface. Additional study of the *Lake Copper* is likely to reveal more about its geologic history.

The top surface of the mass of native copper from the vein was almost certainly clean "shiny" copper after the retreat of the last glacier from Lake Superior. The *Lake Copper* has been continuously submerged under lake waters since the retreat. Today the surface is not "shiny" copper today because chemical reactions between the native copper and surrounding lake waters have resulted in the formation of secondary copper minerals. Based on the adjacent 250 lb red-brown colored *Lake Copper* recovered from underwater in Great Sand Bay near the *Lake Copper* and many other small masses of native copper recovered from Great Sand Bay, the top glacially polished surface of the 19-ton *Lake Copper* was likely coated with cuprite (red, Cu_2O) and perhaps hematite (brown, Fe_2O_3). On the 19-ton *Lake Copper*, the cuprite was in turn coated by or replaced by a thin veneer of malachite (green-colored, $\text{Cu}_2\text{CO}_3(\text{OH})_2$) which is now the dominant greenish color of the glacially polished surface. If heavily cleaned as was the case for the 250-lb *Lake Copper*, the malachite would be removed and only the cuprite-dominated coating would remain. On the pitted bottom side there is a small patch of azurite (blue-colored, $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$) which is formed under restricted environmental conditions.

Small Masses of *Lake Copper* Recovered from Linear Depressions

Many smaller masses of *Lake Copper* (native copper recovered from bottomlands of Lake Superior) from less than ¼ inch across to 1 ft. across have been recovered in Great Sand Bay. These smaller masses are exclusively found in thin linear depressions. We have developed a hypothesis on their geologic history as described below.

Underwater in Great Sand Bay, the near vertical tabular veins are readily recognized as long thin linear depressions up to 3 feet in width. The dominant minerals in the veins are calcite, laumontite, and clay minerals. These minerals are much more easily weathered than the host basalt or conglomerate and will ultimately break down into small sized (sand to clay size) particles. The surface weathering and erosion by moving water likely resulted removal of the dominant minerals in the veins as well as any contained native copper. However, the native copper is resistive to erosion making their final size appear not very different from their original form except for smoothing and rounding. We suspect that these small native copper masses were widely scattered throughout and moved about the Great Sand Bay bottom prior to the latest glacial stage and after the previous one, a timing similar to exposure and collapse of the 19-ton *Lake Copper*. As weathering and erosion progressed the linear depressions formed and became a trap for the masses of native copper on the bottomlands as they were moved around the Great Sand Bay area. The density of the native copper is about 8.4 gm/cm^3 which is roughly 3 times the density of normal rock and once the native copper masses were trapped in the linear depression they remained there towards the bottom. During the last glacial advance the ice "slid" over the depressions allowing the native copper to remain accumulated in them. Since these smaller masses of *Lake Copper* were tumbled around, they are smoothed on all sides instead of one side as is the case for the 19-ton

Lake Copper and the 250-lb *Lake Copper*. Just like the larger *Lake Copper* masses, the surface of the smaller ones from the linear depressions are altered on their surface to secondary copper minerals, red-brown cuprite-dominated (red, Cu_2O) coating and malachite (green-colored, $\text{Cu}_2\text{CO}_3(\text{OH})_2$).

Weight of the Large *Lake Copper*

When the large *Lake Copper* mass was lifted by the US Army Corps of Engineers crane on to the barge, the crane strain gauge recorded a weight of approximately 17 tons. This was the weight reported for the Guinness World Record. In the summer of 2016, a better estimate of the mass of the *Lake Copper* was made by using volumetric estimates of the *Lake Copper* itself and compared to density measurements of actual small copper masses from around the vicinity of the large *Lake Copper*. The density of smaller native copper masses collected underwater in Great Sand Bay were measured using the water immersion method. The density of pure copper is 8.96 gm/cm^3 with an expected density of the native copper slab to be less. The smaller masses of native copper were selected to minimize the amount of attached rock since there is only a very small amount attached to the *Lake Copper*. The density of attached rock or non-copper mineral ($\sim 2.7 \text{ gm/cm}^3$) will substantially lower the density. The average of the best 3 measurements with the least amount of attached surface material was 8.4 gm/cm^3 . The estimate of the error in the density, based on 8 measurements, is likely plus/minus 0.2 gm/cm^3 . A scaled surface digital image was generated from several photographs. Two independent measurements of the volume of the *Lake Copper* were obtained using visual estimates of thickness as applicable to a certain part of the surface. The surface was divided into 7 to 8 different areas for each estimate. The surface area for each applicable thickness was generated via computer, multiplied by the thickness, and summed to obtain the volume of the *Lake Copper*. The volume was multiplied by the measured density of 8.4 gm/cm^3 and the high and low density to obtain multiple estimates. In conclusion, the *Lake Copper* has been estimated to weigh between 18.5 to 20 short tons with a probable weight of 19 tons.

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