YARRABUBBA CRATER, ONE OF THE WORLD'S OLDEST IMPACT CRATER

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Yarrabubba is a recentlyy discovered impact structure situated within the complex granite•greenstone terrain of the Yilgarn Craton. Shock-metamorphic effects including shatter cones, planar deformation features in quartz grains, and pseudotachylites, were found in deeply eroded Archean granites near Yarrabubba station, southeast of Meekatharra, Western Australia (Figure 1).

Figure 1. Location of Yarrabubba crater in Australia.

Aeromagnetic images reveal arcuate demagnetization features at diameters between 11 and 25 km, which roughly correspond to the outcropping of the Yarrabubba Granite, and are centered on a magnetic-high halo around the Barlangi Granophyre. Rapid-quench textures in the Barlangi Granophyre and its inter-fingering relationships with pseudotachylites suggest that it is an impact melt that was injected into the Yarrabubba Granite and spread along fault discontinuities. Both the potassic Yarrabubba Granite and the felsic Barlangi Granophyre are atypical in the northern Yilgarn, as are the abundant fracturing and frictional melting within the local granitoids. These anomalous geological features associated with shock-metamorphic effects are indicative of a hypervelocity-impact origin.

THE CRATER

Yarrabubba Crater is a massive impact structure located in the Yilgarn Craton of Western Australia (Figure 1). While it was known to be extremely old, its wasn't until 2020 that scientists were able to determine the precise age of this meteor crater and discover it was surprisingly old, making it one of the oldest known craters on earth, only preceded by a recently discovery in the centre of the East Pilbara Terrane, Western Australia, and dated as 3.74 Ga by Kirland *et al* (2025).

The rim of the original crater has been completely eroded and is not readily visible. It is estimated to have been ~70 Km across (dotted line in Figure 2), with its remnant today only being ~20 Km wide. The site no longer resembles a typical impact structure with a distinct rim and deep bowl. Instead, Yarrabubba's once-defining features have been eroded leaving only overgrown rocky outcrops and ridges

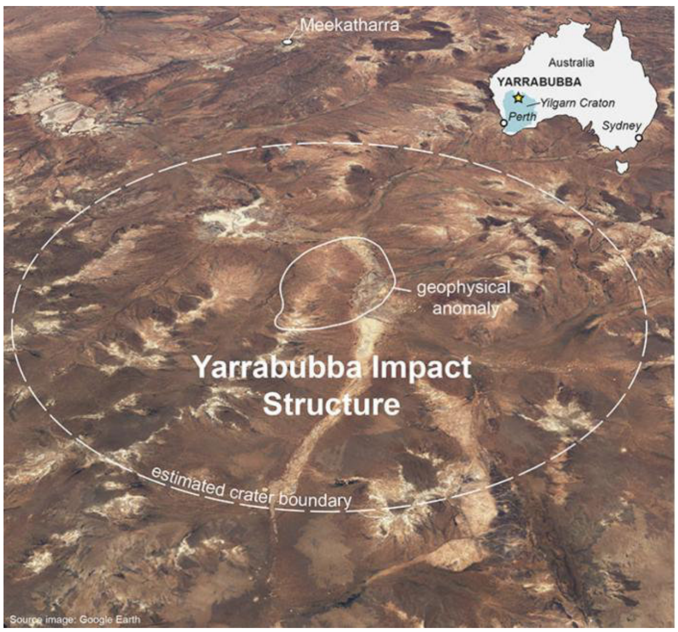

Figure 2. The 70km-wide Yarrabubba crater sits on top of an ancient piece of Earth's crust known as the Yilgarn Craton

THE AGE

The crater's age was determined by searching for rocks that showed signs of being subjected to the shock and extreme heat of a meteor strike. The impact zone is a monzogranite (about equal amounts orthoclase and plagioclase feldspar) that contains shocked quartz and shatter cones. Mineral samples were collected from a granophyre (sodic rhyolite) that formed as an impact generated melt within the monzogranite. Aboriginal people quarried this fine-grained rock to chisel it into sharp tools.

In 2014, Dr. Timmons Erickson collected roughly 90 Kg of granitic rocks from Yarrabubba. Back in the laboratory, he and his colleagues placed the rocks in water and added 120,000 volts of electricity. That jolt broke the rocks into sand-size grains. These scientists were looking for grains of zircon and monazite, tough minerals that survive for billions of years and, crucially, incorporate uranium and thorium atoms into their crystalline structure.

Erickson *et al* (2020) were able to pinpoint the timeline by extracting samples of these grains 0f zircon and monazite from the base of Yarrabubba crater. These robust minerals were shocked into a crystallized form by the sheer energy of the impact with the space rock, which the team estimates was several miles in diameter. Erickson *et al* (2020) used uranium-lead dating to estimate the age of the crystals, which turned out to be hundreds of millions of years older than other ancient craters such as Vredefort Dome in South Africa or the Sudbury structure in Canada.

As mentioned, the minerals zircon and monazite were used to date the impact using the U/Pb dating method. Zircon is an ideal 'isotopic clock' because the crystal structure can incorporate uranium but not lead. The lower photo (Figure 3) shows a shocked zircon crystal used to date the Yarrabubba impact. The margin of the grain (pink) recrystallized during impact, leaving the inner core (blue) intact. The length of the crystal is ~200 microns (millionths of a meter), about the size of a dust mite.

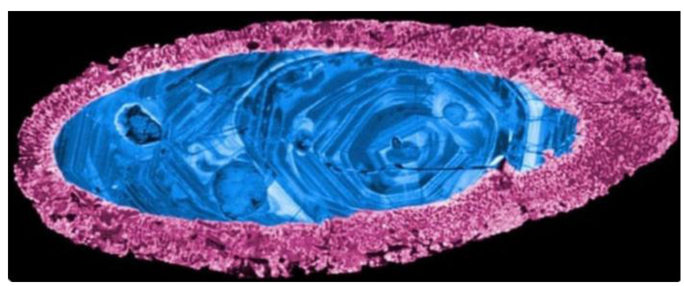

Figure 3. Close-up of a zircon crystal showing the original structure (blue) surrounded by the area snap heated by the meteorite strike.

Based on measurements of 39 zircon and monazite crystals, Erickson *et al* (2020) calculated that the Yarrabubba impact occurred 2.229 billion years ago, with an uncertainty of plus or minus 5 Ma. The next-oldest impact structure, the 200 Km wide Vredefort Dome in South Africa, is over 200 Ma younger.

Impact craters that date back billions of years are relatively rare on Earth because our planet is so geologically active, that processes such as plate tectonics and volcanism are constantly eroding and erasing (Figure 4), the record of Earth's past collisions with random space rocks.

Figure 4. An outcrop of impact melt rock on Barlangi Hill in the Yarrabubba crater in Western Australia, the site of an asteroid collision more than 2 billion years old.

THE SNOWBALL EARTH SPECULATION

The dating of the crystals places the impact right towards the end of the very first "snowball Earth" known as the Huronian glaciation. Also, deposits in the youngest remnants of ancient crust such as in South Africa that are the same age as Yarrabubba indicate glaciers extended across much of the Earth.

Yarrabubba was at the right time to possible trigger the end of a global ice age and to warm the planet. Computer simulations by Erickson *et al* (2020) using a 6.5 Km diameter meteor crashing into a ~5 Km thick ice sheet covering granitic bedrock, generated a crater with a diameter comparable to Yarrabubba. The impact would have released up to 200 billion tonnes of water vapor into the atmosphere, which could have rapidly warmed the planet and melted ice sheets. To further test that hypothesis, Erickson et al (2020) modeled the effects of a roughly 6.5 Km wide impact object striking ice sheets of different thicknesses. They found that in all scenarios, more than 100 billion tons of water vapor would have been jetted into the upper atmosphere.

Water vapor is a potent greenhouse gas, responsible for about half of the heat absorption from solar radiation today, so suddenly having much more of it aloft could have triggered a warming that ended an ice age, Erickson *et al* (2020) suggested. That idea still needs to be tested with more climate models; the researchers noted. Pointing out that it is necessary to think about these extreme events where we might have had some extraterrestrial bodies making big changes to our Earth system. Potential links between major extraterrestrial collisions and worldwide climate changes, is a subject that has to be investigated more in detail..

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