

The Moon is Not Made of Swiss Cheese

These days I begin almost every public lecture I give on human evolution showing one of the splendid images of Earth from space that are now available from NASA. This may seem odd to some, for what after all do images of Earth have to do with human evolution? I use them for two reasons. First, an image of Earth from space is extremely useful for illustrating the dominant and unique position of the continent of Africa on the planet, as Africa typically forms the jumping off point of my lectures since this is the jumping off point for hominin evolution. These images readily illustrate the huge size of Africa, which occupies about 1/3 of the habitable land surface of the planet*. At the same time one can see how Africa sits as the only continent that straddles the equator with substantial land surface running East, West, North and South along the equatorial line. Secondly, I perceive these images as symbols of human evolution. How better to demonstrate the remarkable adaptive abilities we inherited from Africa? With the morphology, behaviour, tools and skills honed in Africa over some 6 million years of human evolution, this small African ape that we are, was able to leave the physical borders of our planet and take such a photograph. Thus, largely for sentimental reasons, in my lectures I usually choose one of the images of Earth taken by the manned Apollo program rather than one by an un-manned Earth Orbiting Satellite. I think every one in my generation has some attachment to those manned missions. Despite only being three and half years old at the time and having only the vaguest of memories of day to day events, I remember vividly that July evening in 1969, when my parents roused me from slumber and sat me in front of the black and white television to watch the grainy picture of Neil Armstrong descend the ladder of the Eagle to be the first human to set foot on the Moon.

Beyond the obvious, and truly amazing technological achievement the moon landings represent, they highlight what a truly remarkable creature we humans are. You have probably never thought about it in this way, but that we humans are almost certainly the only animal that ponders and explores its own history. This is not intended as a “human-centric” statement, but a simple fact of coincident evolution of our species on this planet. Over the past several million years, we humans have acquired a remarkable, adaptable brain that allows us a great deal of mental freedom not possible in even our closest living relatives the African apes. The field of science that I participate in, paleoanthropology, is dedicated to nothing more than the examination of where we humans come from: physically, ecologically, behaviourally and culturally. What a tool this is, for we humans can learn from our history, not just through interaction with living persons that we meet during the course of our brief lifetime, or through the spoken and written word, where we literally interact with dozens, if not hundreds of generations of once living humans, sharing their experiences, good and bad, without having to necessarily experience them ourselves. Paleoanthropology delves beyond the written and spoken record into a deeper human history, going back thousands, if not tens of thousands of generations. Transgressing even the borders of our own species. More remarkable perhaps is the ability of modern humans to not only examine our own history but those of other animals, either living or extinct. This allows us not only a simple voyeuristic pleasure, a tyrannosaurus is after all inherently interesting to look at, but it also allows us to learn from the past history of other life forms, a tool that I would argue might one day save our species and the very biodiversity of this planet.

Living in South Africa we are surrounded by one of the richest paleontological and geological records on the Earth, and despite my chosen profession of paleoanthropology, I cannot escape from my academic roots in Georgia where I was also trained as a geologist. Besides the dolomitic region near Johannesburg that is the location of the caves that hold the fossils nearest and dearest to my heart, there are two other geological structures nearby that continuously distract me with their magnificence. The closest is the Tswaing meteor crater about forty kilometres North of Pretoria. Tswaing means “salt-pan” in the local seTswana language and this name derives from the small salty lake that fills the center of the crater. The crater was formed about 200,000 years ago when a stony meteorite estimated to be about sixty meters in diameter and travelling at around 60,000 kilometres per hour struck this spot, vaporizing on impact and producing an explosion estimated to be equal to around 10 million tons of plastic TNT (10 Megatons in modern nuclear war speak). The crater itself is still largely intact, the event having occurred such a geologically short time ago. When I’m working in nearby fossil deposits from that same time period I often imagine what it must have been like for animals and humans in the region far enough away from the impact zone not to have been vaporized when that object struck!

Slightly further afield, about 100 kilometres southwest of Johannesburg, is the site of a much larger and more ancient extraterrestrial impact known as the Vredefort dome. The Vredefort dome is the remnant of the central rebound peak of an impact crater estimated to have originally been between 250 and 300 kilometres in diameter. It was produced just after 2000 million years ago (2 billion years) by what was probably a chondritic meteorite greater than 10 kilometres in diameter. As a comparison, the *Chicxulub* crater in the Gulf of Mexico is estimated at approximately 180 kilometres in diameter and it was this impact that may have brought the 250 million year reign of the dinosaurs to an end. But when the Vredefort object struck, the only forms of life on the planet were single-celled organisms such as blue-green algae. Nevertheless, the Vredefort event must have been an enormous insult to the planet, creating shock and tidal waves that would have been felt around the world. The deformed rocks of the Vredefort bare mute testament to this.

But even these impacts pale in comparison to the granddaddy of all extraterrestrial Earth impacts: the so-called Giant Impact or Theia event. From data collected by the Apollo and Luna manned missions and by the Clementine and Lunar Prospector unmanned missions, researchers have now demonstrated that the Moon itself is a product of an impact with the Earth of a Mars-sized asteroid or proto-planet (named Theia) in the earliest days of Earths formation. The Clementine mission demonstrated that the whole of the Moons surface was once covered with a “magma ocean”. This was shown by establishing that the whole surface of the moon is dominated by an aluminium rich rock called anorthosite, which forms when molten rock crystallizes, slowly allowing aluminium rich low-density minerals to “float” to the top of magma, while high density metals like iron “sink” in this heated liquid rock. The idea of a giant impact was further substantiated by observing such craters as the South Pole-Aitken basin, a 2600 km wide impact structure whose floor is iron rich. Thus, when the huge impact of the Aitken event occurred, the overlying aluminium rich rock was stripped away, revealing the deeper iron rich rocks. Most of the craters on the moon are thought to have been formed by impact of a variety of different sized meteorites

and comets. Because there is no “weather” on the moon, the evidence of these extraterrestrial impacts remains effectively forever unchanged, giving the moon its Swiss cheese-like appearance. This is in sharp contrast to Earth, where smaller impact craters are generally wiped away “quickly” (in a geological sense), by the actions of erosion or plate tectonics, or from the simple fact that they struck the deep water of the oceans instead of land. Isotopic studies of the anorthosite of the Moon** suggest that the magma ocean occurred at the earliest stages of Moon formation around 4.4 to 4.5 billion years ago, linking this magma ocean event directly to the origin of the Moon. The only known way to achieve such temperatures that would produce these molten Moon-wide phenomena is if the Moon was formed by a giant impact between Earth and a huge extraterrestrial object, knocking away the Moon-sized ejecta into orbit around Earth. Recent analysis suggest that something less than 65% of its mass is made up of the original impactor and more precise dating has suggested that the giant impact occurred around 4.553 billion years ago.

But why, beyond hind-sight spectator value, is all of this knowledge about extraterrestrial impact important to humans? As I began this essay I commented on the remarkable ability of humans to learn not only from their own history but that of other animals and in fact the history of the Earth itself. With the capabilities we now have, only some 150,000 years into the evolutionary history of our species *Homo sapiens*, we can see the fate that has befallen other life forms due to these catastrophic events and learn from them. We know what happened to the dinosaurs. Their reign was ended in a flash and a bang by a relatively tiny object flying through space that Earth had the misfortune of getting in the way of. We know that that while such an event is literally a “one in a million” chance occurrence, such events do repeatedly occur, and in a geological sense, relatively frequently, in our Earth's history. But unlike the dinosaurs, or even those humans sitting on the Witwatersrand just watching the Tswana object fall from the sky 200,000 years ago, we modern humans, because of the forewarning given to us by palaeontology and geology, literally by studying the history of other animals, have at least a fighting chance of preventing such an impact from sending us the way of the dinosaurs. Of course Hollywood has recently capitalized on the potential horror of these extraterrestrial extinction causing events. However, they didn't highlight that it is the uniqueness of humans and our never-ending search to understand the past that might just give us, and the present biological diversity of this planet, a chance sometime in the future when misfortune dictates that Earth's path intersects with one of these deadly space wanderers.

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* I often find people are surprised at this fact as they are either fooled by two-dimensional Mercator conformal projection maps which expand and distort the size of areas away from the equator in order to project the land surface of the Earth onto a piece of paper or, conversely, they just don't believe it. The key to the statement is the term “habitable” and it is strictly considered from a human perspective. I define this as the removal of Alpine regions, deserts, tundra and water covered areas where humans really haven't lived in any significant densities until very recently. Thus areas such as the Himalayas, Andes, Siberia, the central Sahara and Antarctica are “uninhabitable” by this definition, with apologies to the people that live in these places.

** The Clementine and Luna missions also, remarkably, demonstrated the presence of water ice in the permanently shadowed regions of the poles, possibly originating from the impact of water bearing meteorites and comets.