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Astronomy's Impact on Biology

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Fig.1. An image of the Organ Mountain fire forwarded to the ASLC list by Dave Dockery in late June. The Las Cruces Sun-News *suggested that the fire was ignited by a meteorite, but there is good reason to doubt that explanation.*

At the end of June, there was a discussion on the ASLC's listserver whether or not the fire at the base of the Organ Mountains (Fig. 1) was caused by a meteorite, as suggested by an article in the *Las Cruces Sun-News*. It was properly pointed out on the list that meteorites that strike the ground are often found not to be hot but cold. Their transit through the atmosphere is so brief that nothing but a millimeter or two of the meteorite's surface is heated to a molten temperature, and that thin veneer quickly cools in response to the much colder temperature of the space-borne rock beneath. But this isn't the first time that meteorites have been suspected of causing fires, and whether they do or not must depend on a number of factors, including their sizes, their entry angles and the condition of the dry vegetation on which they land.

Perhaps the most controversial episode occurred in 1871 when four large fires simultaneously erupted in the area of Lake Michigan, in the states of Michigan, Wisconsin and Illinois. The Chicago Fire, which was initially blamed on Mrs. O'Leary's cow, was a part of those fires. Michael Ahern, the *Chicago Republican* reporter who created the cow story, admitted in 1893 that he had made the story up because he thought it would make colorful copy, but he otherwise had no idea what the cause of the fire was. The Wisconsin portion of the fire is now called the Peshtigo Fire and is believed to be the deadliest in North American history, killing somewhere between 1,200 and 2,400 people. The Chicago Fire added several hundred more souls to that tally.

Meteor trails were observed in the sky that night. It was a windy night in October following an exceptionally dry summer. The fact that four very large fires all began simultaneously is certainly suspicious, but meteor-induced fires, although they've been repeatedly reported, have proven to be notoriously difficult to pin down as to the actual cause, and the fires of 1871 are no different.

But there's no doubt about the cause of the 1908 fires in Tunguska, Siberia. An airburst impactor set at least a small part of Siberia afire. The testimony of an observer who was 40 miles away the morning of the airburst was this:

“At breakfast time I was sitting by the house at Vanavara trading post. I suddenly saw that directly to the North, over Onkoul's Tunguska road, the sky split in two and fire appeared high and wide over the. The split in the sky grew larger, and the entire northern side was covered with fire. At that moment I became so hot that I couldn't bear it, as if my shirt was on fire; from the northern side, where the fire was, came strong heat. I wanted to tear off my shirt and throw it down, but then the sky shut closed, and a strong thump sounded, and I was thrown a few yards. I lost my senses for a moment, but then my wife ran out and led me to the house. After that such noise came, as if rocks were falling or cannons were firing, the earth shook, and when I was on the ground, I pressed my head down, fearing rocks would smash it. When the sky opened up, hot wind raced between the houses, like from cannons, which left traces in the ground like pathways, and it damaged some crops. Later we saw that many windows were shattered, and in the barn a part of the iron lock snapped.”

What effect did this impact have on life on Earth? Very little. It’s hard to make much of a dent in the history of life on this planet with an impactor. Life is resilient, and it’s best to think of an ecology as a stretchable web. Life recovers surprisingly quickly from disturbances, if they’re not too large.

Susceptibilities to extinction vary greatly among species. Species can be driven below their minimum viable population sizes for a raft of reasons. But even more importantly, species that occupy refugia less affected by the catastrophe will be the species that first rebound to repopulate the evacuated arena, while species that fall below their minimum viable population sizes everywhere are those that will be permanently extincted.

To some degree, permanent extinction is simply a matter of luck, but it is also highly correlated to body size and food chain considerations as well. Large-bodied animals are more susceptible to permanent extinction, as are top predators. Both require large areas and large prey populations to prosper, and if those conditions disappear, so do they. But the Tunguska event wasn’t large enough to do any harm to either, and thus life in Siberia rapidly recovered and filled the biological hole left by the bolide.

But what of a larger event? It’s been recently proposed that the megafaunal extinctions of North America at the end of the last ice age, where we lost mammoths, camels, horses and lions, were caused by a similar but much larger airburst impactor over Canada 12,900 years ago. This hypothesis has certainly not been greeted with open arms. A review in January’s Geological Society of America’s *GSA Today* wrote: “The 12.9-ka impact story has struggled to bring its disparate evidence under a single umbrella. The impact story originated in Firestone and Topping (2001) and the Firestone et al. (2006) book, both of which contain observations and claims so wild that other work by these authors invites careful scrutiny.”

That's about as harsh a public rebuke as you’re ever likely to read in the scientific literature, and it’s almost certainly not warranted. A more recent press release just a few weeks ago from the University of Cincinnati was more positive in its assessment. They wrote:

“Geological evidence found in Ohio and Indiana in recent weeks is strengthening the case to attribute what happened 12,900 years ago in North America – when the end of the last Ice Age unexpectedly turned into a phase of extinction for animals and humans – to a cataclysmic comet or asteroid explosion over top of Canada.

“A comet/asteroid theory advanced by Arizona-based geophysicist Allen West in the past two years says that an object from space exploded just above the earth’s over modern-day Canada, sparking a massive shock wave and heat-generating event that set large parts of the northern hemisphere ablaze, setting the stage for the extinctions.”

Clearly, the final story hasn’t been told in regards to this latest hypothesis. Indeed, the discussions are just heating up. But there is little doubt now about the effects of life on this planet from the Chicxulub impact 65 million years ago, although that too wasn’t always the case. When the Alvarez-Alvarez hypothesis of an asteroidal impact being the cause of the Cretaceous/Tertiary (K/T) extinction event was first being argued, there was an exceptionally heated and prolonged argument about whether the hypothesis was true. The alternative idea was that the K/T boundary was actually due to the eruption of the Deccan Traps, an almost continental-sized lava flow half the size of modern India. Either event had the power to completely alter the Earth's biosphere, and the Deccan Traps hypothesis being the cause of the K/T extinction event had a fair number of supporters for quite a time.

Increasingly it appears that both events could be true, a double whammy, so to speak, and that the Chicxulub impact crater and the Deccan Traps are simply consequences of one another. There is good evidence to support the contention that the Deccan Traps are an antipodal ("opposite side of the earth") geological rebound event caused by the Chixculub impact. In this hypothesis, seismic waves created by the impact travel through the Earth and are intensely focussed at the antipode, producing a massive mantle plume that breaks through the skin of the Earth.

Originally the Deccan Traps lava flows had been thought to have occurred over a period of millions of years, but new evidence appearing just this summer strongly suggests that the flows appeared as “single eruptive events” over a short period of time, perhaps decades, precisely the behavior you would expect to see from a planetary impact rebound event.

Seventy percent of the species present on Earth at the time of the K/T event went extinct, but even it wasn’t the largest extinction event in the history of life on Earth. That happened 190 million years earlier. The “Great Dying” occurred at the Permian/Triassic (P/T) boundary 250 million years ago, where more than 90% of the species alive at the time disappeared. Of interest, another continental-sized lava flow also appeared at the same time, but five times larger than the Deccan Traps.

The Siberian Traps of the P/T boundary have been similarly linked to a putative asteroidal impact somewhere in the Antarctic/Australian/Japanese area (land masses which were contiguous at the time), although there is currently far less evidence for such an impact at this boundary, even though the effect on life on this planet was much greater.

While we only have these two possible major impacts on Earth during that period in which rebound events could even hoped to be measured before they would be erased by continental motions, the Earth is no longer the only planet that we available to us to look for these antipodal rebound effects.

Mars is now geologically dead, having had its molten interior core cool perhaps within the first billion years of its existence. As a consequence, Mars lost in turn its molten core, its magnetic dynamo, its magnetosphere, its protection against the solar wind, and ultimately its hydrogen, and thus its water. But what that means to us is that Mars' early geological history has been frozen in place in a manner that Earth long ago lost.

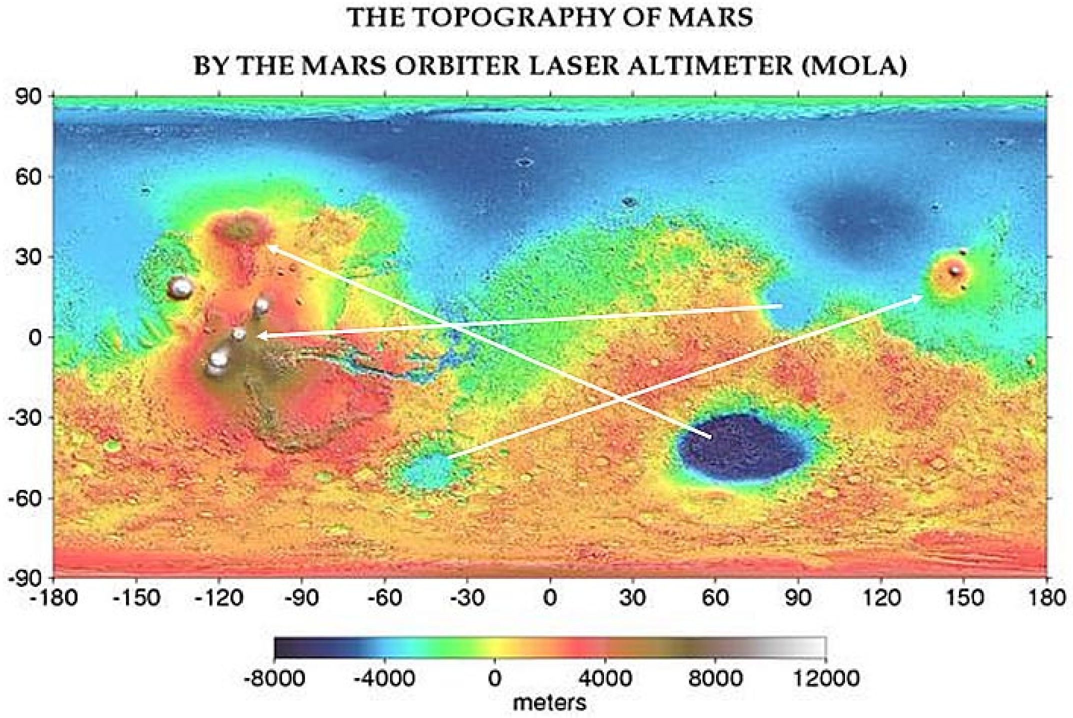

Fig. 2. The elevational topography of Mars as recorded by NASA's Mars Orbital Laser Altimeter (MOLA). Elevations are shown in color, with yellow being defined as the mean elevation of Mars. One half of Mars is intensely cratered, but that cratering appears only in the highland regions. The other half of Mars, the Borealis Basin, has been swept clean of its craters.

Figure 2 is a recent MOLA topographic map of Mars. The deep purple circular region in the lower righthand portion of the image is the Hellas Basin, the deepest depression on the Martian surface. It is almost certainly an impact crater, likely created by a glancing impactor. Of great interest, there is also a sizable elevated plateau precisely at the antipode to the Hellas Basin, Alba Patera. Indeed, there are a number of such elevated areas that are antipodal to matching depressions on Mars, and I’ve indicated some of them by the white arrows.

Mars is an odd planet. Half of its surface retains the ancient cratering events following the initial sweep of the protoplanetary disc debris from which the planets evolved. The other half of Mars is almost completely devoid of impact craters, colored in ocean blue in the image. More odd yet, the ocean blue part of Mars lies in a 4 km deep depression that is otherwise completely discontinuous with the remainder of the Martian surface.

Twenty years ago, Don Wilhelms and Steven Squyres, the current principal investigator for the two rovers that are now walking across the surface of Mars, proposed that the Martian surface discontinuity was the result of a major impact, following the time of primary cratering. The only problem with the hypothesis was that it is very hard to imagine how such an impact could have occurred without melting both planetary bodies.

The solution of course was to have the impact be a glancing blow, but even that didn't explain everything. The Tharsis Ridge is in the wrong place. It shouldn’t be where it is. In the News & Views section of the April 11, 2008 issue of *Science,* Richard Kerr wrote the following about recent studies of the Martian discontinuity:

“Last month, planetary geophysicist Jeffrey Andrews-Hanna of the Massachusetts Institute of Technology in Cambridge and colleagues presented their test of the giant-impact hypothesis at the Lunar and Planetary Science Conference (LPSC) in Houston, Texas. In 1984, planetary scientists Donald Wilhelms, now retired from the U.S. Geological Survey, and Steven Squyres of Cornell University first proposed that a huge impactor had blasted out the Borealis basin. Fitting a circle to the ‘dichotomy boundary’ between the basin and the highlands, they suggested that the circle could mark the outer edge of a huge crater. But the fit was too rough to win many converts.

“So Andrews-Hanna and his colleagues looked for a better way to trace out the dichotomy boundary. The great Tharsis volcanic complex had obscured much of the boundary when it smothered one-quarter of the planet with lava hundreds of millions of years after the lowlands formed. To ‘remove’ Tharsis, they drew on measurements of martian gravity and surface height from the past decade of Mars orbiters. Subtle variations in the pull of gravity – evidenced in variations of a spacecraft's orbit – reflect the added mass of Tharsis lavas as well as the extent of the deep, less-dense crustal rock buoying up the highlands. The height of the surface constrains the volume of added lavas.

“By combining the data in a model, the researchers erased Tharsis's contribution to the present surface and traced the topographic edge of the Borealis basin right under Tharsis. Rather than a circle, the best shape for the basin turns out to be a 10,650-kilometer-long ellipse, they reported at the LPSC meeting. That's a familiar look for big impact basins. The 2300-kilometer Hellas impact basin in the southern highlands, for example, is also elliptical and also underlain by a uniformly thin crust. And there's no particular reason, Andrews-Hanna said, why the giant-impact theory's only serious rival – a peculiar sort of churning deep within the planet – would produce an elliptical basin or the observed sharp boundary between thin and thick crust.”

The rebound hypothesis remains controversial for the Chicxulub/Deccan Traps pair, and is even more debated for the P/T-impactor/Siberian Traps event among Earthly geologists, but surprisingly perhaps, the antipodal rebound hypothesis is relatively well accepted by astronomers as an explanation for the topography of Mars.

The sequence of the evolution of the Martian surface is thus believed to be this: intensive cratering over the entirety of its surface for the first half billion years of its existence, just as it was for the Earth, Moon, Venus and Mercury. The Moon, Mercury and Mars however retain that evidence due to the absence of further geological activity. Some short time later, Mars was whacked by the glancing blow of a very large impactor, creating the hemispheric discontinuity of the Borealis Basin. Some time later yet, Mars was hit again by the smaller Hellas Basin impactor, creating the Alba Patera plateau as a rebound event.

We can’t see a similar depth in time on Earth with accuracy. But we can look back across the span of time that encompassed fossilized life. On Earth, the Age of the Dinosaurs was apparently ushered into existence following the P/T event 250 million years ago, and their dominance was extinguished by a bookend event at the K/T boundary, 65 million years ago.

Because of the knowledge we’ve been retrieving from Earth and Mars over the last several decades, the argument that both events were caused by asteroidal impacts has been substantially strengthened (but in the minds of many, still jumping the gun a bit). Nonetheless, because of this, the geological history of both Earth and Mars is beginning to make more sense and tell a more consistent story than we’ve previously understood, particularly in regards to the evolution of life on this planet. But the most extraordinary consequence is yet to be discussed. We may well owe a good portion of our intelligence to these impacts.

Next month: How Astronomy Changed My Life, and Millions of Other Species as Well