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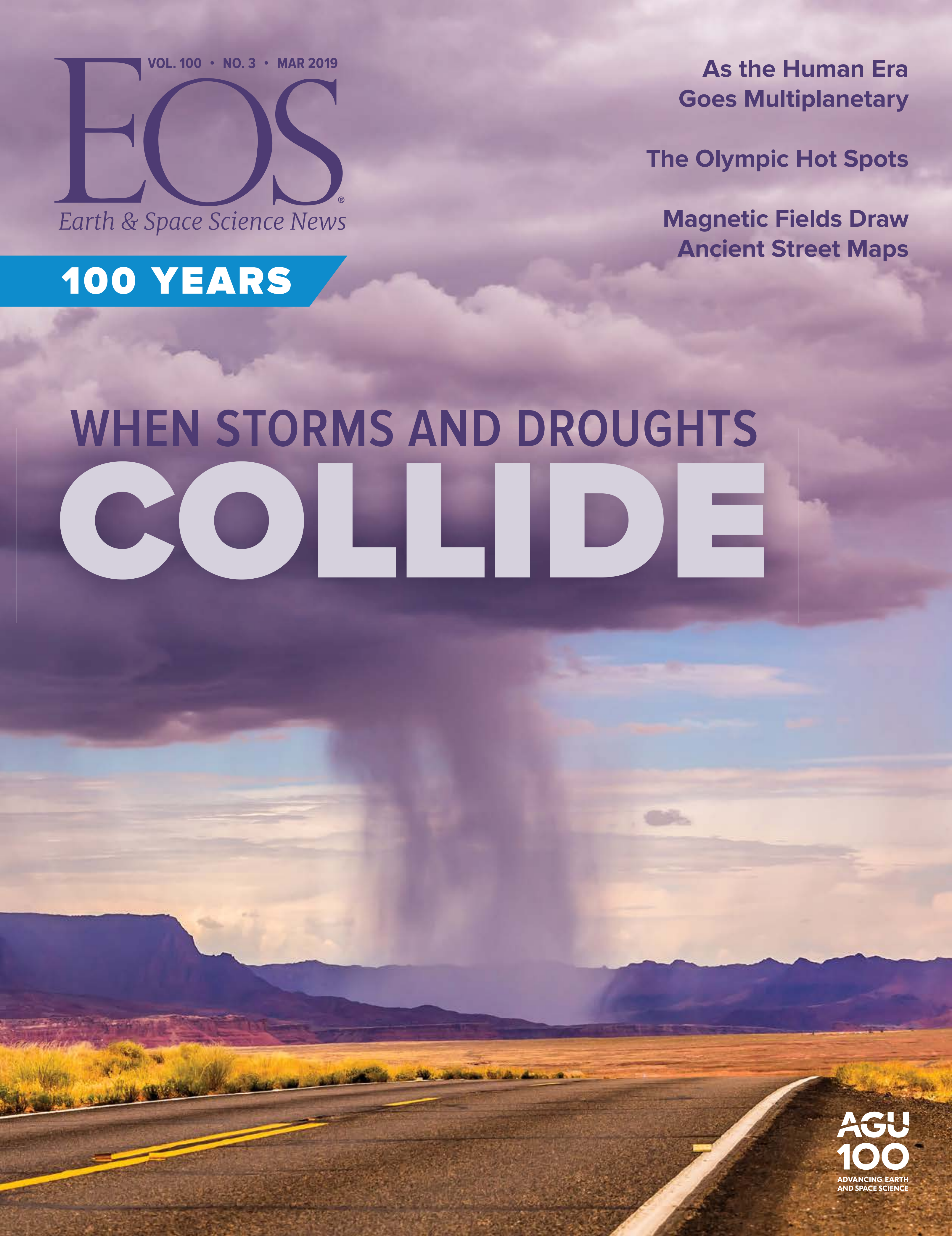

AGU 100
ADVANCING EARTH AND SPACE SCIENCE

The Mars Anthropocene

The impact of human activities on Earth serves as the basis for defining a new geological time interval on our planet: the Anthropocene. If the pace of current efforts to send humans to Mars is any indicator, the impact of human activities may soon be as quantifiable on Mars as it is on Earth, and the Anthropocene could soon make its debut as the first multiplanetary geological period.

The Anthropocene epoch, proposed as a new post-Holocene geological time interval beginning sometime in the mid-20th century, is not yet a formally defined geological unit within the terrestrial geological timescale. However, the term has seen widespread usage in the scientific and popular literature, as well as in the media, since it was popularized in 2000. It is characterized by the way in which human activities have profoundly altered many geologically significant conditions and processes, leaving characteristic evidence in the Earth's stratigraphic record (Table 1).

During the next few decades and for the first time in history, the impact of human activities and technologies not only on Earth but also on other planetary bodies could be analyzed and quantified. It is probably still too soon to propose a new epoch defining the geology of other planets based on the impact of human activities, but we may start considering the case of Mars.

So far, exploration of Mars has been carried out by robotic explorers, which have likely left little lasting impact, and this impact has not been on a global scale. But a fundamental change is already in motion: NASA has been officially commissioned to send humans to Mars. Other national and private-sector space programs have launched their own efforts, so it is entirely possible that one of these other organizations may precede NASA in completing manned missions to Mars.

Explorers on Mars extract water from subsurface ice deposits in this artist's rendering. Credit: NASA Langley Advanced Concepts Lab/Analytical Mechanics Associates

Table 1. Signs of Human Impact on Earth and Potential Impacts on Mars

PARAMETER	EARTH (OBSERVED)[a]	MARS (FORECASTED)
Uniqueness	Human impact signatures are sufficiently different from the natural features of the Holocene to constitute a new unit of geological time.	Humans will leave stratigraphic signatures (buildings, evidence of atmospheric changes, biomass) in sediments and ice never seen before on Mars. Except for ice ages, human colonization will be the first global change on Mars since the atmospheric loss billions of years ago.
Global extent	Human signatures show excellent global or near-global correlation in a wide variety of marine and terrestrial sedimentary bodies.	In situ resource utilization and microbial dispersion will be global because raw materials (potentially mined) and ice (potentially biocontaminated) are globally distributed.
Preservation potential	The archaeological record registers new patterns within the Earth system.	There will be higher preservation potential than on Earth because the thinner atmosphere and lack of an active microbiota retard alterations to the record of human effects.
Synchronous base	All the above effects are globally synchronous stratigraphic markers for the Anthropocene, starting in the mid-20th century.	All the stratigraphic markers will develop at the same time, once humans begin settling bases on Mars.

[a]Earth parameters are after *Waters et al.* [2016]

Therefore, it is possible that human activities will soon inaugurate an Anthropocene on Mars. Like the Anthropocene on Earth, this new era would be distinguishable by markers in the planet's stratigraphic record.

Planning Our Arrival

The coming era of space entrepreneurship will determine the timeline of human activity on Mars, especially since NASA adopted a decentralized market approach in 2005, awarding contracts to private players. Since 2005, three quarters of the growth in the global space economy has come from commercial endeavors. The company SpaceX has stated that it could land humans on Mars in the next 10–12 years, and it has partnered with NASA in the landing site selection process through the Space Act Agreements.

Plans are also on the table to start revisiting the Outer Space Treaty, an agreement put forth 50 years ago and signed by all the current and aspiring spacefaring nation-states and many others, which provides the basic framework for international space law. An updated treaty should help to lay the basis for human settlement on Mars and to expand commerce in the age of space entrepreneurs. The human presence on Mars is likely to be a reality all too soon, despite the lengthy list of knowledge gaps that we need to address to start understanding the anthropogenic impact on Mars's geologically significant conditions and processes.

Microbial Hitchhikers

What we already know is that the moment astronauts set foot on Mars, microbial contamination will be inescapable and irreversible. Astronauts staying there for the long term would require some means of transporting and storing water and food, a continuous air supply, and the containment and management of secretions and human waste, among other requirements.

> All the anticipated impacts derived from human exploration will happen long before we begin to alter Mars on a planetary scale.

These activities would create an unavoidable risk of microbial leaks from spacecraft, space suits, and waste disposal systems. The microbial leaks and species invasions could spread far enough to produce a global impact on Mars, eventually creating identifiable sediments.

Human habitat modules and rovers would continuously release microbes into the environment. Furthermore, astronaut bases established in the planet's subsurface to protect their human occupants against radiation and extreme temperature fluctuations would also shield their microbial occupants from the naturally sterilizing conditions of the surface radiation and oxidative environment.

Human Activities' Mark on the Martian Landscape

Searching for resources on Mars—and using those resources in situ—would also add to the human effects on Mars. Extracting and processing Martian raw materials to obtain life-supporting consumables and propellants would transform the Martian surface and subsurface and imprint a permanent mark. Human topographic signatures would start to accumulate, beginning with such small-scale effects as regolith erosion, landslides, and terrain collapse and eventually extending to larger areas: flattening mountains, piling hills, or excavating major open-pit mines.

Some of these human activities would potentially generate new zones where terrestrial organisms are likely to replicate and where any extant Martian life could flourish. Life as we know it requires water, so these zones could appear, for example, after drilling to explore a subsurface aquifer.

A third possible aspect of the Mars Anthropocene, beyond the release of microbes and land surface changes in the course of in situ resource use, is the creation and wide distribution of novel materials, including pollutants. A Martian field station with a four-person crew, for example, would require significantly more electrical power than our current robotic missions. Using nuclear power to meet these needs could create long-lived radioactive waste. Also, if a reactor were to explode while operating or be destroyed during a failed atmospheric entry, it could disperse a radioisotope signature over a wide area.

Making human life possible on Mars will require significant and unprecedented modification of the Martian landscape and skyline (Table 1). Predicting and understanding how these changes may occur on Mars—and gaining insights into the dynamics and sensitivity of landscapes and their responses to human forcing at global scale—will be central to interpreting and mitigating our impact on the planet.

Table 2. Arguments for the Existence of an Earth Anthropocene Compared with Projected Human-Generated Changes to Mars

PARAMETER	EARTH (OBSERVED)	MARS (FORECASTED)
	Atmospheric Changes	
Composition	black carbon, inorganic ash spheres, and spherical carbonaceous particles from fossil fuel combustion; elevated carbon dioxide and methane concentrations	rocket fuel emissions that will include aluminum oxide particles and gaseous chlorine species; residues from life sustainment systems, human bases, and greenhouses
Temperature	average global temperature increase of 0.6°C–0.9°C from 1900 to the present	local hot spots, eventually transitioning to global effects if terraforming starts
	Geological Changes	
In situ resource use	mining, industrial activity	mining
Distribution of novel materials	“technofossils”: elemental aluminum, concrete, plastics	“technofossils”: elemental aluminum, concrete, plastics
Pollutants	polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pesticides, leaded gasoline; artificial radionuclides from thermonuclear weapons tests	residues from human bases and vehicles, long-lived nuclear wastes; widely dispersed radioisotope signatures from reactor failures
	Biological Changes	
Extinction of species	extinction rates far above background rates since 1500; deforestation	risk of extinction of any extant microbiota on Mars
Species invasions	human-triggered transglobal species invasions	microbial leakage from astronauts and human bases (if Mars has always been lifeless, these would be the first organisms on the planet)
Farming	changes associated with agriculture and fishing	first greenhouses on Mars

Building Colonies Increases the Impact

A variety of human activities define the Anthropocene on Earth. Such activities include changes in erosion and sediment transport and alterations in the chemical composition of soils and the atmosphere associated with colonization, agriculture, and urbanization. Human activities alter Earth’s carbon cycle and the cycles of various metals through the environment. Humans also introduce nonnative and invasive species into new habitats.

As humans begin to colonize Mars, similar changes can reasonably be anticipated to occur there at a rapid pace (Table 2). These changes are likely to produce a stratigraphic signature in sediments and ice that will be distinct from that of the Late Amazonian, the current time period on Mars (Figure 1).

We have already witnessed a similar process in Antarctica, where analogue studies make use of the continent’s climate, terrain, and isolation to simulate conditions and processes that humans will likely face on missions to Mars. Although humans in Antarctica are mainly devoted to scientific research and they must follow a determined policy for environmental conservation, the effect of the “age of humans” is already visible on the continent, creating a pressing concern.

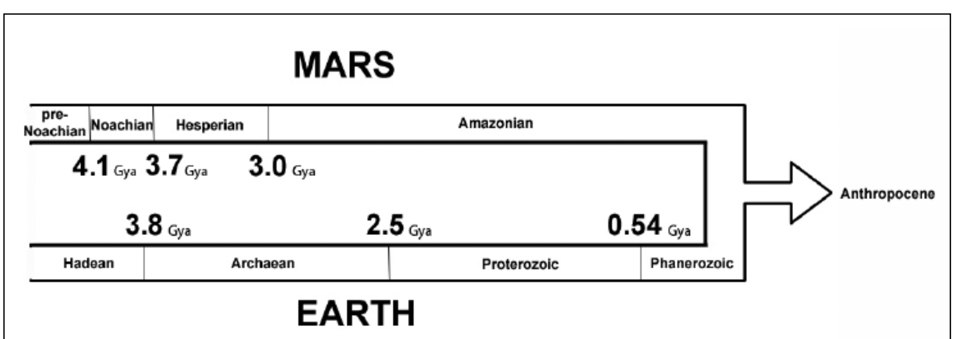

Fig. 1. Could geological timescales on Earth and Mars converge into one common Anthropocene future?

Effects Begin on Day One

Given that humans have yet to set foot on Mars, it seems like we have plenty of time to think about ways to manage our impact on the planet. However, all the anticipated impacts derived from human exploration will happen long before we begin to alter Mars on a planetary scale.

At our current rate of progress, these large-scale endeavors are just one step above science fiction. Today’s reality is that our children or grandchildren will see astronaut footprints on the red sands of Mars. And when that happens, the Mars Anthropocene will begin.

Acknowledgments

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