Volcanoes and Permafrost in Bering Land Bridge National Preserve, Arctic Alaska

By James E. Beget and Jeffrey S. Kargel

Introduction

A famous early twentieth century geologist named William Morris Davis proclaimed that "volcanoes are accidents of nature." Morris believed that volcanic eruptions were anomalous and random events that could not be scientifically classified. Today, scientists know that volcanic eruptions involve a bewildering range of behavior and eruptive styles, resulting in numerous very different landforms that are all called volcanoes. So many different kinds of volcanic eruptive processes and different varieties of volcanoes have now been described that the confusion and consternation that William Morris Davis evinced at the beginning of the twentieth century over the nature of volcanism seems entirely understandable.

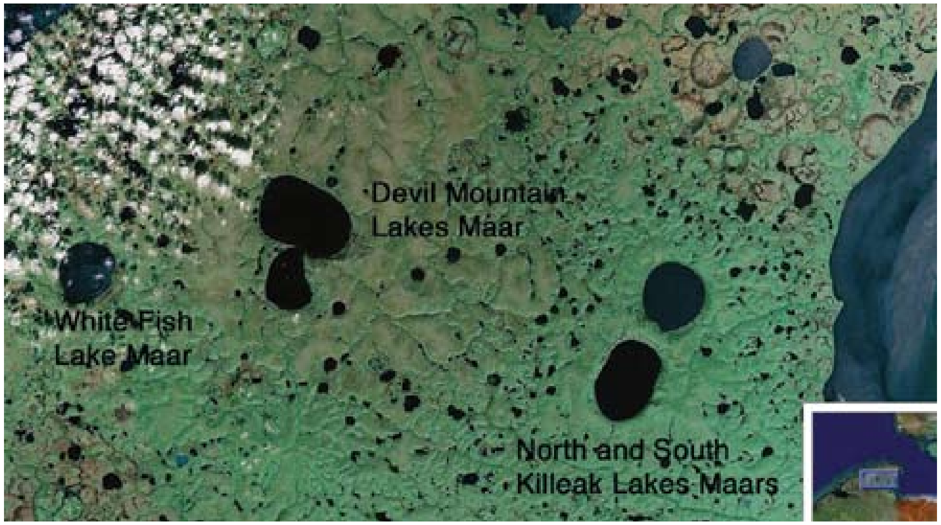
That various volcanic features are produced by different kinds of eruptions is well known even to non-scientists. For instance, the mostly gentle slopes of Kileaua Volcano in Volcanoes National Park in Hawaii were formed by lava flows while the deep crater at Mt. St. Helens in the Mt. St. Helens National Monument was created when the side of the mountain collapsed into the valley below. To complicate things further, volcanic processes can be strongly influenced by non-volcanic factors in the local environment. For instance, lava will erupt quite differently depending on whether it has been erupted on land, or on the sea floor, or under a glacier.

My colleagues and I have been investigating the processes and landforms produced by prehistoric volcanic eruptions through permafrost in the Bering Land Bridge National Preserve (BELA). BELA was not originally set aside to preserve its unique volcanoes, and it is not well known as a "volcano" park. However, scientific interest is growing in the unusual volcanoes found there, as they provide evidence of a new variety of volcanic eruption.

Volcanic eruptions through permafrost

The first scientist to work on the volcanoes of BELA was David Hopkins of the U.S. Geological Survey, who made annual expeditions to the Seward Peninsula during the 1950s and 1960s. Hopkins had a broad and eclectic range of both personal and scientific interests and made important scientific discoveries in biology, paleoecology and archeology, as well as geology (*O'Neill 2004*).

Hopkins mapped the extensive lava flows and volcanic craters of the Seward



The Devil Mountain Lakes Maar, North and South Killeak Lakes Maars, and the White Fish Lake Maar are larger then any other maar on earth. The Killeak Lake Maars, for example, are about 5 km in diameter.

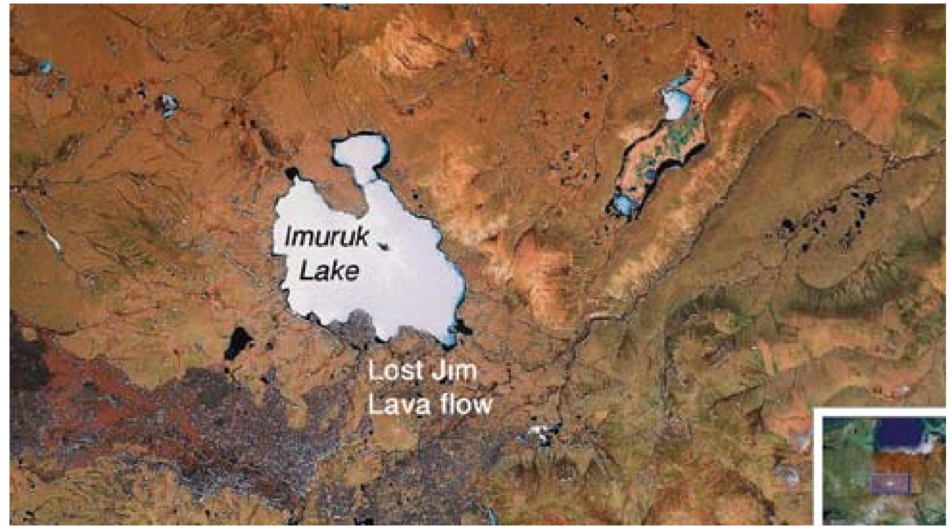


Figure 1. The Lost Jim lava flow is the youngest lava flow on the Seward Peninsula. It flowed northward over permafrost into Imuruk Lake and constructed a large delta on the south side of the lake.

Peninsula and recognized that some of the volcanic features were only a few thousand years old (*Hopkins 1959, 1967*). In the 1980s, David Hopkins took a position as a Professor at the University of Alaska Fairbanks, and the National Park Service sponsored a research program that allowed Hopkins to continue his research with a group of young faculty and graduate students. I was one of the young professors fortunate enough to accompany David Hopkins.

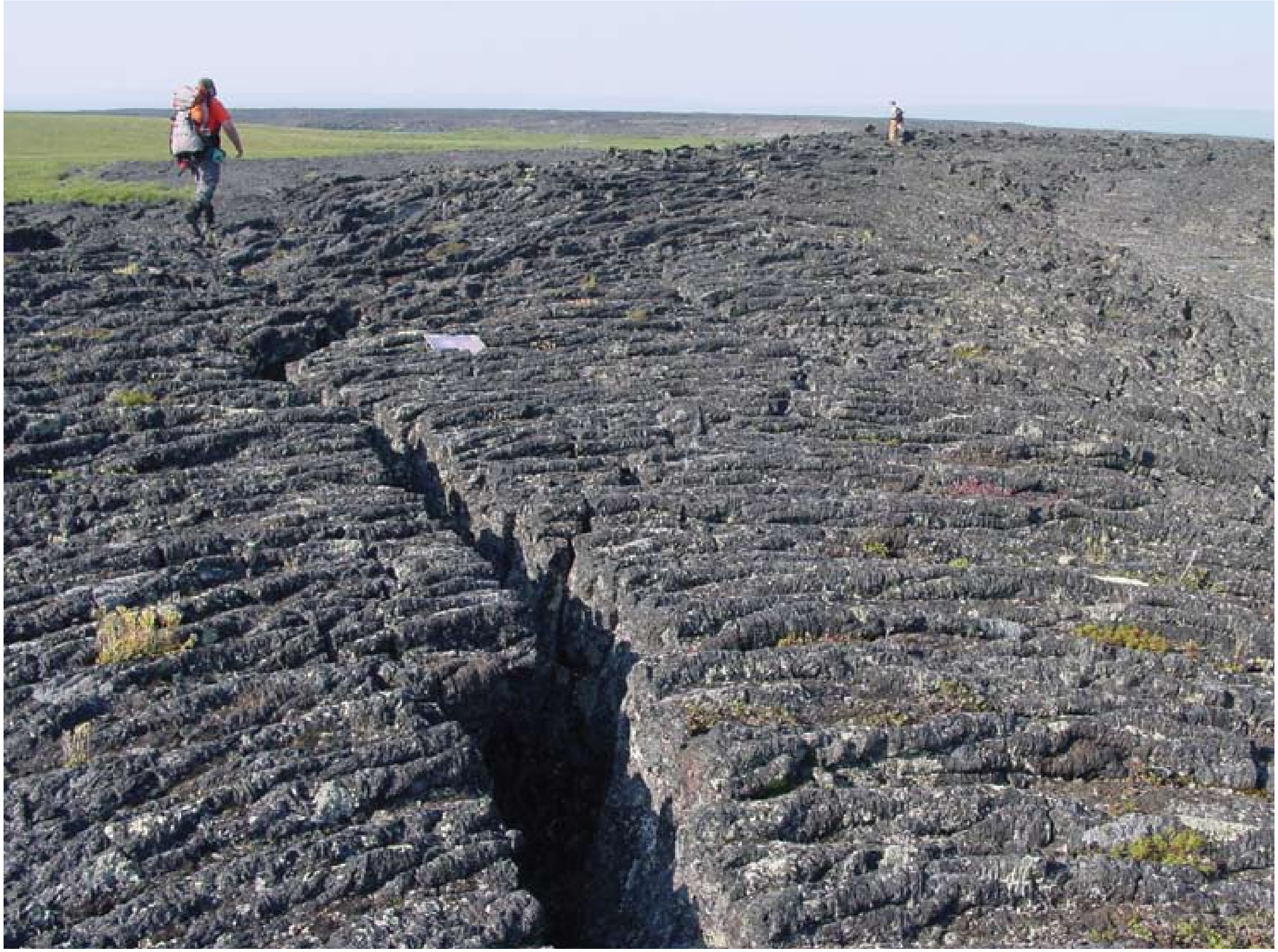
It soon became apparent that some of the volcanoes on the Seward Peninsula were quite unusual. Maar craters are common volcanic features created when volcanic explosions excavate a circular depression into the earth, which often fills with water. However, maars in the rest of the world are usually less than a thousand feet across, and rarely are more than 1.2 miles (2 km) in diameter. In contrast, each of the four maar craters on the Seward Peninsula was at least 3 miles (5 km) across, and the largest was more than 5 miles (8 km) across (*Figure 1*). The maar craters in BELA were the largest maars on earth…but why were they so large?

We looked at the lava chemistry and volume of the erupted material, but these weren't unusual in any way. We finally concluded that the BELA maars were formed by a previously unknown eruptive process—the interaction of magma and permafrost (*Beget et al. 1996*). At the Espenberg maars, the thermodynamic properties of ice played a key role in triggering large explosive steam eruptions. Radiocarbon dating indicated these eruptions occurred about 18,000 radiocarbon years ago. The explosive eruptions produced ash that fell many miles from the volcanoes and deeply buried the land surface around the volcanoes, preserving ice-age plants that were growing in this area when the eruptions occurred (*Hoeffle et al. 1999*). When magma at 1000-1100°C contacted permafrost, the result was large steam explosions. The frozen ground contained a large supply of water at the time of the eruptions, allowing numerous large steam explosions to occur and excavate the large craters

The Devil Mountain Lakes, Whitefish Lake and North and South Killeak Lakes on the northern Seward Peninsula were all recognized as giant volcanic maar craters created by eruptions through permafrost (*Figure 1*). Each crater was excavated by hundreds of steam explosions, and surrounding these craters were deposits of pyroclastic density currents and poorly sorted ejecta that had been blasted out of the frozen ground during the hundreds of phreato-magmatic explosions (*Beget et al. 1996*).

Martian Environments, Martian Volcanism and volcanoes in the Bering Land Bridge National Preserve

The discovery of the giant maar craters in BELA at first seemed to be merely a volcanologic curiosity without any wider signficance. There were apparently no other examples of these features anywhere on earth. Areas with active volcanism like Iceland or Kamchatka had little permafrost, and areas like Siberia and Tibet with signficant permafrost had little active volcanism. However, the possibility arose of



Left:
Figure 2. We traversed the Lost Jim lava flow on foot. The surface of the flow showed beautiful pahoehoe texture, consistent with a tube-fed origin.

Top:
Figure 3. We used an air taxi to get to Imuruk Lake. All our field equipment, scientific instruments and supplies were tightly packed into the floatplane.

looking for landforms similar to those in the Bering Land Bridge National Preserve in a surprising place…on the planet Mars.

NASA started sending satellite orbiters and landers to Mars with the Mariner missons in the 1960s and the Viking missions of the 1970s. The Soviet Union also sent missions to Mars in the early 1970s. After a 20-year-long hiatus, NASA returned to Mars with the Pathfinder Missions in the 1990s, and NASA, the Japanese Space Agency and the European Space Agency have all since sent missions to Mars since then. From the time the earliest photographs from these Martian space probes were sent back, it was apparent that Mars combined volcanoes and permafrost. Mars was the perfect environment to search for the products of volcano-permafrost interactions similar to those found in Bering Land Bridge National Preserve.

Mars, with a mean average air temperature of -81°F (-63° C), has surface temperatures not that dissimilar to winter temperatures in Alaska, and the pictures sent from landers that successfully reached the Martian surface showed polygonal patterns and cracks that indicated the presence of permafrost and ice wedges, similar to ground ice features found in Alaska (*Mustard et al. 2001*). It is

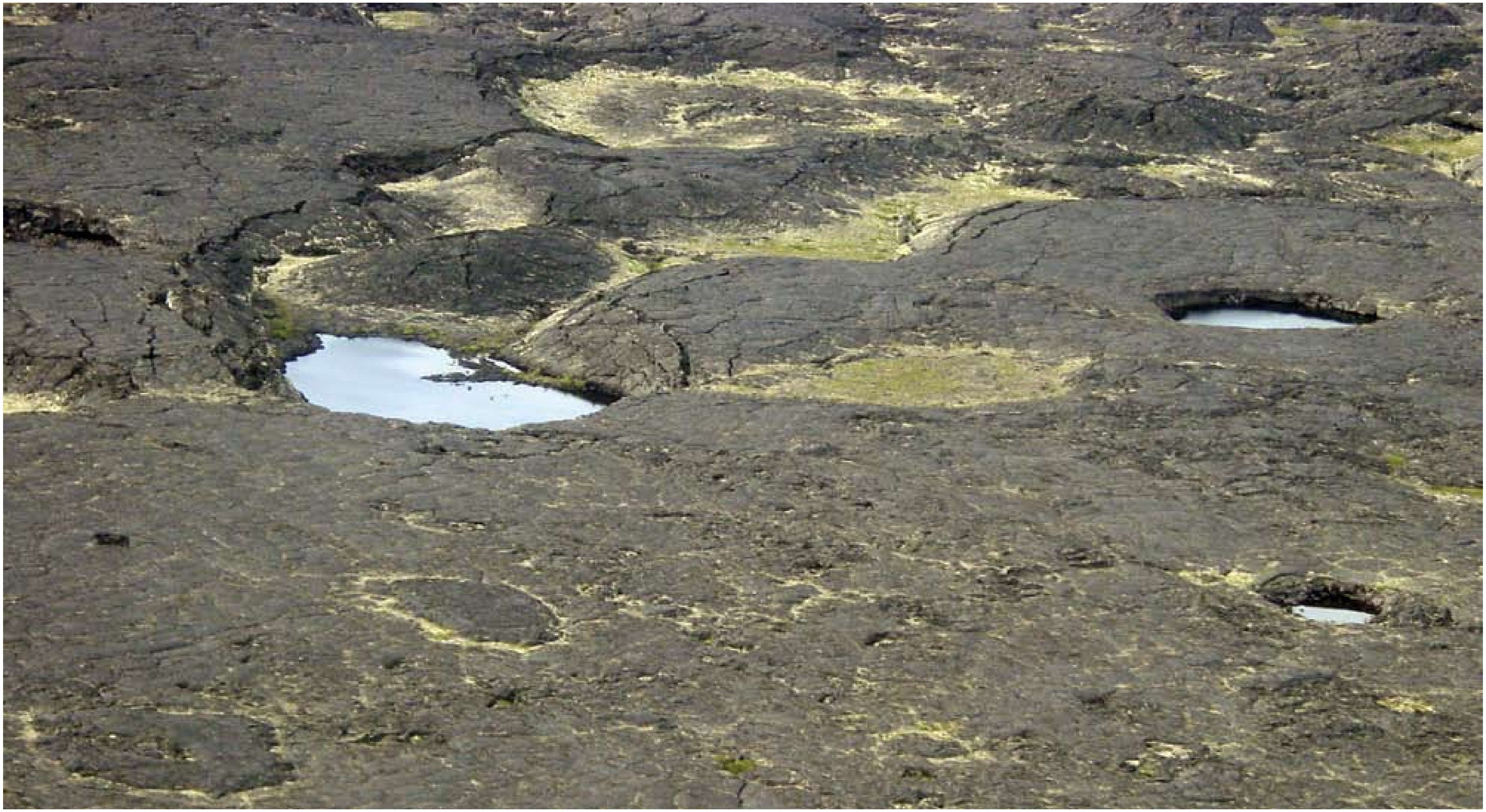


Figure 5. There are numerous collapse features and pits within the Lost Jim lava flow. These features are interpreted as thermokarst produced when permafrost under the lava flow thawed due to the heat released by the active lava flow.

highly likely that Mars has been the site of magma-permafrost interactions.

New models of volcano-permafrost interactions on Earth and Mars

In 2003, NASA provided a research grant that allowed me to return to the Bering Land Bridge National Preserve in company with two new colleagues: Dr. Rick Wessels of the Alaska Volcano Observatory and Dr. Jeff Kargel, a longtime NASA researcher and expert on all things to do with Mars. Our goal was to discover new distinctive landforms and geologic deposits recording magma-permafrost interactions. There are many lava flows visible on Mars, and we began a study of lava flows in BELA that we knew had been erupted through permafrost.

David Hopkins had identified the "Lost Jim" lava flow in the Imuruk Lake area as the youngest and best preserved lava flow on the Seward Peninsula (*Hopkins 1959*). We studied satellite images of the Lost

Jim lava flow from BELA and other lava flows, looking for differences between the Alaskan lava flows and Martian lava flows that we knew erupted through permafrost, and lava flows found in Hawaii and elsewhere on earth that didn't travel across permafrost. We then traveled to Imuruk Lake (*Figure 2*) from Kotzebue by float plane piloted by Buck Maxon. Buck had been our pilot when David Hopkins and I worked in BELA in the early 1990s. Buck flew us to a good campsite on the shoreline of Imuruk Lake only a couple of miles from the Lost Jim lava flow (*Figure 3*). After setting up camp, we took advantage of the midnight sun to hike across the tussocks and permafrost to start our study of the lava flow.

We quickly determined that the Lost Jim lava flow had been a "tube-fed" flow, constructed of multiple lobes and thin sheets of lava that traveled away from the source vent in small tunnels within the lava flow. The recognition that the Lost Jim flow was tube-fed raised concerns that hot lava traveling within the tubes might have been insulated from the underlying frozen ground.

We spent the next week walking for miles over the lava flows and the surrounding tussocks, surveying the lava's surface morphology and describing various characteristics of the flow (*Figure 4*). Eventually we collected enough data to determine that the Lost Jim lava flow did display a marked difference from a typical tube-fed flow. The surface of the flow is pockmarked with large collapse pits as much as 330 feet (100 m) across and tens of feet deep (*Figure 5*). Examination of the lava flow exposed at the edge of the collapse pits showed the presence of tunnels related to tube flow. The collapse pits apparently formed when the flow was active, rather then being a feature formed long after the flow had cooled.

We developed a hypothesis that the collapse pits are evidence of a sub-lava thermokarst field. Thermokarsts are forming in many areas of the Arctic today where permafrost is thawing due to global warming. Thermokarsts have also formed in the geologic past during unusually warm intervals (*Beget et al. 2008*). The discovery of thermokarst underneath the lava flow is consistent with the high temperatures (ca. 950-1100°C) associated with eruptions of lava like that of the Lost Jim flow. Even though the lava in the tube-fed Lost Jim flow never came into direct contact with permafrost, the heat of the lava was sufficient to thaw the underlying permafrost beneath the tube-fed lava flow.

The discovery of a second unusual geologic feature recording interactions of volcanism and permafrost is very exciting and scientifically important. These unique features, to our knowledge, have only be found on earth within BELA. We anticipate similar features will be seen in satellite imagery of Martian volcanoes. I am confident that new discoveries of this kind will continue to be made, as much remains to be learned about the history and processes of past volcano-permafrost interactions within the boundaries of the Bering Land Bridge National Preserve in Alaska's Arctic.

Acknowledgements

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