Podcast interview: Mara Reed and Michael Manga

PNAS: Welcome to *Science Sessions*, the podcast of the *Proceedings of the National Academy of Sciences*, where we connect you with Academy members, researchers, and policymakers. Join us as we explore the stories behind the science. I'm Paul Gabrielsen, and I'm speaking with Mara Reed and Michael Manga of the University of California, Berkeley. In 2018, Steamboat Geyser in Yellowstone National Park, the world's tallest active geyser, began a series of eruptions after several quiet decades. In a recent PNAS study, Reed, Manga, and their colleagues investigated the source of the renewed activity, particularly exploring whether or not activity in the magma chamber beneath Yellowstone could have triggered the eruptions. They concluded that the geyser's reawakening was more likely hydrothermal than magmatic.

So Mara, what got you interested in Steamboat Geyser?

Reed: So, Steamboat is really a unique geyser. It's currently the tallest active geyser in the world. Eruptions can shoot water to 380 feet in the air, and it has these episodic active phases. So, it's not active all the time. We got interested in researching this geyser when it started one of these rare, active phases in March 2018.

PNAS: Michael, for those of us who have never witnessed a geyser erupt, what is it like?

Manga: I've never been lucky enough to see Steamboat erupt, but there's something about seeing a geyser erupt live that can't be replicated with video or a photograph. It's a very visceral experience. There's a lot of sound, the ground vibrates, and you get wet. And so all your senses are involved in the experience. There's even a smell, maybe it's the moisture in the air.

Reed: That's true. And with Steamboat, depending on the wind direction, you can get soaked. And at this point, the water's had plenty of time to cool. So you're not getting, you know, boiling water dumped on you, but you can get drenched. The water also has silica dissolved into it, and this geyser has a habit of wrecking car windshields. If the wind is blowing towards the parking lot, those water droplets will land on people's windshields and then evaporate and the silica's left behind. And then people will have these gunked up windshields.

I have seen a lot of geysers and nothing really compares to Steamboat. If you're trying to see it, you could be waiting there for anywhere from hours to days. And then the initiation of the eruption is something that has gotten me every time that I've seen it. I've seen it three times now. It has two vents. So the water splashing out of these two vents may be anywhere from 10 to 30 feet high, and then, sort of suddenly, just the intensity increases, the amount of water that gets discharged increases. And then there's just this wall of water in front of you that slowly builds higher and higher. And it's just an amazing, incredible experience to witness. It's very loud. If you have somebody standing right next to you, you need to shout to be able to hear them. It really sounds like a freight train going by or a jet engine.

PNAS: What is so significant about the series of geyser eruptions that began in 2018?

Reed: So this is the third active phase on record for this geyser. There was one from 1961 to 1969 and another from 1982 to 1984. What's special about this current active phase? Really for two reasons. One, there's so much monitoring equipment nearby that we actually have a good shot at studying it. And second, just the pace that it's been erupting. This active phase currently has the most eruptions out of all three of those active phases. It's just been erupting at a record pace.

Manga: Yeah, I think Mara captured it, but just the fact that Steamboat started to erupt is significant on its own. When something of this magnitude happens, there must be a reason, and all geysers are a surface manifestation of the earth transporting heat and fluids and that heat is coming from magmas underground. And so, when geysers start to erupt or we see changes at the surface, that might be foretelling that a volcanic eruption might be coming next. And so that was one of the reasons we started investigating; why did Steamboat start erupting?

PNAS: So, many people have heard about the magma chamber beneath Yellowstone. What's important to know about the magma chamber in context of this study?

Manga: Yeah. If Yellowstone were to have another super eruption, for sure, it would be devastating. Yellowstone is a little bit enigmatic as a geological feature. It's what we call a hotspot, so a location away from the boundaries of tectonic plates that has active volcanism. And at Yellowstone, this volcanism has manifested as some extremely large eruptions about 700,000 years ago, 1.3 million years ago, and 2.1 million years ago. The youngest large eruptions at Yellowstone are about 70,000 years ago. And since then, most of the manifestation of it being a geologically and volcanically active area has been what we call hydrothermal explosions, where heat from the magma creates explosions at the surface to make little craters or small lakes. And so at present, that's probably the largest volcanic hazard or natural hazard in Yellowstone National Park.

People then try to image the molten rock underneath Yellowstone caldera—the caldera's the surface collapse structure produced by these big eruptions—and it looks like magma is stored at several depths below the surface, at the bottom of the crust and then within the middle of the crust. Whether or not that magma is going to erupt is unclear. It will, eventually, presumably, but I'm not aware of anything that we can see or identify that says it's going to erupt, say, in our lifetime.

Reed: We'll be talking about ground deformation later. And so, this magma body that's beneath Yellowstone, because of where it's situated and when it cools and releases magmatic fluids and gases, these things can actually sort of percolate up through the surface and cause the ground to either uplift or deflate, depending on what's going on. So this is a thing that happens within the Yellowstone caldera, but also outside the Yellowstone caldera.

Manga: Yeah. Steamboat Geyser itself is located outside of the caldera.

PNAS: How did you investigate the cause of the eruptions?

Reed: We ended up using a wide variety of data sources. What's really neat, I think, about this study is that the central data set, which is the catalog of Steamboat eruptions, that is actually a crowdsourced data set. There's a website called Geyser Times and it's basically all geyser enthusiasts entering eruption times and observations that form the basis of the data set used in the paper. So it was really neat to sort of connect with community science in that way with this study. In addition to the interval data set, we used seismic data from nearby seismometers. We used GPS data. We used the stream flow measurements on a creek that runs through Norris Geyser Basin where Steamboat Geyser is located and Steamboat ejects water into it, so signals from the eruptions appear there. We ended up using MODIS satellite data to look at heat emissions from the geyser basin. We used geochemical data as well. So, there's just a whole, kind of, deluge of data sources that we're pulling from. I'm sure I missed something.

Manga: I was trying to pay attention, Mara, and I think that's pretty much everything. And weather data, too.

PNAS: What evidence would have suggested a magmatic cause, and what did you find?

Reed: So the big question is, okay, are these kind of deformation processes that are related to magmatic processes actually affecting the hydrothermal system? So with the influx of magmatic volatiles, you might expect to see some sort of temperature increase, whether that be in the reservoir supplying water to Steamboat Geyser or kind of from the geyser basin as a whole. So, we used the satellite data from MODIS to, kind of, see if we could figure out if more heat was being emitted into space from the geyser basin as a whole. And we did find, correlating also with the deformation trends, that since about 2012, 2013, there has been an increase of heat emissions into space from Norris Geyser Basin.

So that sort of tracks with the magmatic origins hypothesis. We also tried to look at the reservoir providing water to Steamboat. We did this by actually sampling a hot spring that's about 90 meters away from Steamboat, but it's hydraulically linked. And so, we analyzed the chemistry of those waters using things like silica geothermometers and other dissolved things in waters to sort of get an idea of the temperature of the reservoir. So, using new samples that we collected and historical samples, we didn't actually find any significant changes in that reservoir. So these two things, with the geyser basin heat emissions increasing and Cistern Spring's reservoir temperature not changing—these quantities aren't directly comparable, but they also sort of conflict. The geyser basin heat emissions, those increasing, that supported a magmatic hypothesis; but Cistern Spring's reservoir not increasing in temperature, you would expect to see that [increase], especially, if these processes were affecting Steamboat.

Manga: If this is a hypothesis that magma movement caused Steamboat to erupt, how would we test it? And as Mara said, the temperature of the water didn't change. The very subtle signal of heat we see is provocative. We also don't see a relationship between the earthquakes that accompany the ground deforming and the reactivation. So I guess, you know, if you view Steamboat as the patient, it shows some symptoms but not the key symptoms you would expect.

PNAS: So, if the source wasn't magma activity, what else could it have been?

Reed: So, like Michael said, we looked at earthquakes leading up to the reactivation, and we found that they didn't really shake the ground hard enough to cause the permeability changes that we would expect to maybe see to have a chance for that to affect geysers. We also looked at the stream flow measurements in the Yellowstone River as a proxy for precipitation. But, unfortunately, we didn't see either anomalously high or low periods correlate with anything, so we sort of ruled that out as well.

And it leaves us with a hypothesis that we haven't been able to test yet. So, all these hydrothermal fluids coming up through the ground, they have silica dissolved in them. That's kind of what the linings of geyser plumbing systems are made of. So, the silica precipitates and dissolves, and the rate at which those two things happen depends on heat and some other chemistry things in the subsurface. So, we're thinking right now that maybe subtle shifts in the rates of those processes could actually cause this episodic active–dormant activity in Steamboat and maybe other geysers.

So, one other question we asked is, okay, again, if we're assuming there might be this connection between the magmatic processes directly affecting the hydrothermal system, why would Steamboat be the only geyser that reactivated? And we didn't see any other of the significant geysers in Norris Geyser Basin reactivate.

PNAS: What else did your study teach you about the plumbing of Steamboat Geyser?

Manga: One of the outstanding questions about Steamboat Geyser is why is it so tall? And it is at present the tallest geyser eruption on earth. And we compiled observations from geysers around the world—how high they erupt and where the water is stored underground before the eruption—and it seems that at Steamboat Geyser the water's stored deeper than all the other geysers. And you might want to ask, well, why does that matter? But the deeper you go below the surface of the earth, the higher the pressure, the hotter water needs to get to boil. And the hotter water is, the more energy it has. More energy means a taller eruption.

Reed: One other thing we did was calculate eruption volumes because we had the fortuitous stream gauge that had already been installed for other monitoring purposes on this hydrothermally derived creek in Norris Geyser Basin. So calculating those, we found volumes ranging from 134 to 538 cubic meters. And just for reference, 250 cubic meters is about the size of an Olympic-sized swimming pool. So these are pretty big eruptions. What was a little surprising was that we did not find a correlation between the volume of water erupted and the interval either before or after the eruption, possibly suggesting that the geyser is not in steady state.

Manga: Yeah. Steamboat is not just tall. The amount of water that erupts is huge. It's a big geyser.

PNAS: How did your work advance understanding of the hydrothermal features at Yellowstone?

Manga: I think Steamboat is a window into the amounts of fluid moving through the crust, how much mass and energy it's transporting, and the timescales over which that mass and energy are being transported. And Steamboat is actually an interesting geyser; it may not have been born until 1873 or 1878.

Reed: 1878 was the first reported [eruption], or at least it either came into being in 1878 or had a really large hydrothermal explosion in 1878 that sort of kicked off its status as a large geyser.

Manga: And for many listeners, 1878 may seem like a long time ago, but many of the other iconic geysers in Yellowstone are much older. They probably date to when the glaciers retreated from Yellowstone, say, 14,000 years ago, and the hydrothermal system was able to be exposed to the surface and the eruptions began. And so, Old Faithful, Grand Geyser, Castle Geyser, they may be over 10,000 years old.

PNAS: Was the study well-received? Can you talk about the response to the study?

Reed: Well, my parents certainly think I've made it because my work has appeared in *The New York Times*. It's just been really nice to see actually how much interest there is. A lot of these stories about this work took our ambiguous findings about the reactivation of Steamboat, but also kind of ran with it. There wasn't a lot of hyperbole surrounding the volcano, which was really nice to see.

Manga: When we write papers, publish papers about geysers, they do get picked up by the press. It is a chance to convey and help people understand how science is done and the scientific method, from having a hypothesis to how we test that hypothesis with data. It's a chance to highlight how many great data sets are out there to answer these types of questions and the monitoring that's being actively carried out.

There are probably about 500 or so geysers in Yellowstone, and there's only a very small number for which we have any quantitative data. And so, our ability to learn about geysers and understand them is severely hampered by the lack of data. Steamboat is special because we have so much more data than most geysers, in part because it's so big and impressive, but looking forwards, hopefully we will get more data and more will be monitored. And the geyser enthusiasts will continue to make observations and share those observations. So, I suspect we will learn a lot more over the coming years to decades.

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