Volcanologist Focuses on Reduction of Risk

John A. Lockwood

This edited transcript is based on John A. Lockwood's plenary presentation entitled "Volcanoes: The Ultimate Materials Source," given at the Materials Research Society 1998 Spring Meeting in San Francisco on April 13, 1998.

When Robert Hull, Immediate Past President of MRS, introduced volcanologist Jack Lockwood as the plenary speaker, he said, "We, all of us, as researchers have our tools or our experimental pieces of equipment. My piece of equipment is an electron microscope. Bob Nemanich's [1998 MRS President] might be a growth chamber. Jack's is a volcano, and his experimental tool is the volcano of Mauna Loa in Hawaii, which is the largest volcano in the world."

In response, Lockwood said, "I looked at the [MRS Meeting] list of papers and was struck by the fact that you have the potential of repeating experiments. You have some control; you can perhaps jiggle the voltages or something. We are totally helpless with our experiments."

Volcanologist John A. Lockwood measures the lava flow advance rate in Royal Gardens subdivision. United State Geological Survey photo by R.W. Decker.

We Don't Get to Repeat Our Experiments

A volcano does whatever it's going to do and we, the observers on the outside, try to figure out what's going on. While people like to think volcanologists really know what's going on, the truth is commonly we don't and we don't get to repeat our experiments.

My primary focus is the relationship of volcanoes to society. As materials researchers, you affect society through your technological findings and innovations. Society changes because of your work. In my particular case, it doesn't really make a difference what I do. The volcano will change society all by itself. There are two important terms to know and distinguish: *hazard* as in *volcanic hazard* and *risk* as in *volcanic risk*. The hazards are what volcanoes are going to do anyway. The risk is what happens when people are too close to the volcano.

Reduction of risk is really my focus. Reduction of risk would be easy if you could simply tell people not to build their structures too near the volcano, but the reality is that they have already built their cities in dangerous areas or they will build them for economic reasons. For example, in 1994 when refugees fled Rwanda, they set up homes in Zaire, which is a country fertile with farmland. Over half a million people camped on the barren slopes of Nyragongo Volcano, which then began to erupt after the refugees set up shelters in dangerous places.

I have to deal with volcanic risk by trying to reduce it. For example, the risk of eruptions can sometimes be reduced by diverting the flow of lava. Three items used to divert the flow are explosives, water, or new structures. I was involved with the U.S. Air Force in developing contingency plans to divert lava flows by detonating laser-controlled bombs (which we call "aerial displaced explosive devices" to avoid PR problems). In 1992, Italian volcanologists drilled a tunnel in a channel that was threatening a town called Zepherano. They detonated 7,000 kilos of explosives in the tunnel which changed the course of the channel and caused the flow to go in another direction, sparing the town.

In Iceland, volcanologists saved a harbor by spraying vast amounts of water to cool and thicken the flow of lava, making it form its own diversion. In Hawaii, a diversionary structure was built to protect the National Oceanic and Atmospheric Administration's Mauna Loa Observatory. The Observatory maintains the world's longest database for carbon dioxide build-up in the atmosphere and is a critical facility for global climatic change research. This structure now protects the area from future flows as (hopefully!) future lava flows will be diverted around the observatory.

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Examples of the Kinds of Volcanoes I've Worked With

I will talk briefly about some examples of the kinds of volcanoes I've worked with. In 1985, Ruiz Volcano erupted in Colombia. While the eruption itself was tiny, it melted a snowpack on the volcano, creating a larger and larger mud flow that, two hours later, reached the city of Armero, killing over 20,000 people, and another 5,000 people in neighboring areas. Until that catastrophe, I thought volcanoes were fun to work with, and that eruptions were pretty to watch. This was a case in which scientists failed their mission. The scientists did what they thought scientists should do: They issued warnings—but to the wrong people. They had about a year's warning about what could happen. They published a map showing that the city of Armero was in a very dangerous area. But then the scientists went home. They never met with the political leaders, the religious leaders, or other officials that could communicate with the people. So consequently, when the eruption came, nobody moved—nobody knew what to do.

With more and more sophisticated tools and a large amount of research on the process, we are getting better at our predictions. Still, the scale of the volcano is so grand compared to our instruments. In our predictions, for example, we're doing pretty well at saying the volcano is restless and something is going to happen. At Pinatubo Volcano in the Philippines, for example, we were extremely lucky that the volcano acted exactly as we hoped one would. We said that Pinatubo is giving all the signs that it is going to erupt and we recommended evacuation. Every time we issue an evacuation order, however, we hope we are correct because the economic costs of a failed prediction are high. However, we only get one shot at failing on a prediction. If we say the eruption won't happen and it does, or we say that it will happen and it doesn't, we've lost our credibility either way.

The last eruption I am going to talk about is fictional: I was the lead volcanology consultant in 1997 for a movie called *Dante's Peak,* which was produced by Universal Studios. Consultants to Hollywood have mixed experiences. Most of them are treated as wallpaper that are consulted: They speak when spoken to. In this particular case, however, director Roger Donaldson and producer Gale Anne Hurd were wonderful and committed to making the film as realistic as they could while still maintaining enough adventure to separate it from a documentary. After receiving the script from the director, my colleagues and I went over it, changing scenes and rewriting scenes that had a major impact on "getting it right."

When I asked about obtaining real volcano footage for use in the film, I was told that virtual volcanoes will be used and field scenes mostly filmed in Wallace, Idaho, far from real volcanoes. I said, "This is whacko. Why would you do that?" I was told by the filmmakers that to make a good adventure film with a good script, it's much better to generate the volcano through special effects and digital techniques so that we have control over the volcano. That way we can make the volcano fit in the script rather than the other way around. If we're dealing with real footage, we have to bend the script to fit what we've got. They were right. To make the pyroclastic clouds [broken rock] look real, the filmmakers generated various kinds of explosions within the volcano they fabricated and threw in all kinds of materials. They filmed the eruption at extremely high speeds. What your eye sees is the very violent eruption.

The Connection Between Materials and Volcanoes

I studied physics in college until I reached the quantitative part, where I fell by the wayside quickly. Then I was fascinated by chemistry until I hit the realities of physical chemistry. I enjoyed biology because it took me outside. Then came the day when I took some classes competing with pre-med students and that was the end of that. I eventually moved to geology in which I received a PhD degree from Princeton University, then did a National Academy of Sciences postdoc in Russia. I spent 30 years working for the U.S. Geological Survey, eventually specializing in volcanology. I left the USGS in 1995 and began a private consulting business.

When asked to speak at the 1998 MRS Spring Meeting, I culled your Program book to obtain a summary of metals and materials that you are interested in. If you look at the distribution of elements in the earth, the major ones such as silicon, which many of you spend a lot of time with, comprises over a quarter of the earth's total mass. Other major elements include iron, titanium, and maganese. Minor elements in the earth's crust are Au, Co, Cr, Cu, Ni, and Zn.

The high-temperature gases coming out of volcanoes consist of elements like zinc, lead, arsenic, maganese, erbium, copper, indium, mercury, cadium, and a host of others, but their concentration is so low that you would never know they were there. So what actually concentrates these elements? In many cases the ultimate cause is volcanoes and their underlying molten rock systems. After a volcano has stopped erupting, it is still very hot. Consequently the circulation of rain water falling onto the flanks of the volcano penetrating downward is heated and raised back up. There is also a source of water in the cooling magma itself. As these volatiles move through the rocks, within and surrounding the volcano, elements which have become relatively unstable within some of the minerals can be precipitated out and highly concentrated.

At the base of the volcano, magma interacts with calcium carbonate deposits. Higher up, zinc and lead are deposited in the cooler zones. Silver and gold are found in upper parts of volcanoes and mercury is concentrated very near the surface—usually associated with hot spring deposits around volcanoes. Copper is usually formed at deeper levels, so that at copper mines, you usually won't find a volcano anymore because it will have eroded away before the copper deposits are exposed.

While materials research by G.L. Zhou at the University of Illinois involved the study of micro volcanoes at nanometer scales*, similar-looking volcanoes on Io, a moon of Jupiter, are 500 kilometers across! When I flew at night about 3,000 ft over a lava flow of a Mauna Loa eruption in 1975, I smelled something hot and was concerned. All of my instruments said everything was fine: The outside air temperature was -2°C. While the flow was 1000 K, Stefan's Law brought it up to the fourth power, causing high radiant heat energy. It had burned the dark colors on my airplane, but not the white paint. On earth, 70% of volcanoes are beneath the ocean. At the west coast of South America and the east coast of Eurasia, the Pacific plate is being subducted under the continent and materials are reaching high temperatures and melting, forming volcanoes at the margins. We measure the rates of subduction on the order of 5 to about 10 or 12 mm per year.

Volcanologists typically talk informally about two kinds of volcanoes. Red volcanoes are characterized by a lot of effusive activity, meaning the production of lava flows and molten lava. Gray volcanoes are highly explosive in nature and typically get covered with ash.

As to how volcanoes work, by measuring what is happening through the deformation of a volcano we know that a central magnetic storage chamber resides beneath the volcano. During eruptions fountains of lava up to 500 m high may develop, where molten glass is blown apart by hot gas. Lava may then flow downhill in underground lava tubes from the central vent. Eventually the lava may reach the sea where chemicals from the lava at about 1000°C react with sea water. The interactions cause benign explosive activity at the coast.

When asked whether I can control a lava flow by adding something to change the components, the problem is I am working with a lot of lava. While materials researchers can change the surface of a material by doping it with a few nanograms of another material, I am working with maybe 250 million cubic meters of lava.

Gray volcanoes, on the other hand, generate ash flow up into stratospheric height, causing problems for people. The extremely dangerous phenomena associated with these volcanoes are the pyroclastic flows. These are particular materials suspended in very, very hot, expanding gases. They will make the air so dark that you can't see your hand in front of your face.

To wrap up this talk, I want to leave you with this thought. When you are faced with working late at night, or on weekends, or maybe once in a while when your experiments are not going well and you need some mental diversion, look down your instruments at the very tiny amounts of materials you are studying, at the molecular levels, and think about where those metallic atoms come from. While you could say they come from a supplier or a purification lab, you can also consider the fire and fury they have known at their ultimate source: volcanoes. □

*This comment refers to work presented at the 1997 MRS Fall Meeting in Boston.