“Like It or Not, We Are Living on This Planet”

NASA’s Aqua satellite captured this dramatic image of thick ash pouring from Iceland’s Eyjafjallajökull Volcano on April 17, 2010. The plume reached heights of over nine kilometers and disrupted air traffic across Europe for weeks. Still, this eruption was demure compared to volcanic events that have occurred in Earth’s past history.

The number of large destructive earthquakes in this last year, plus a recent flurry of medium magnitude quakes in California, has led many people to ask, Are we in a period of heightened temblor activity, and is it likely to continue? It’s also raised questions among both scientists and laypeople about whether these events are related—and if so, how. The eruption this past spring of an Icelandic volcano, which disrupted air traffic in Europe for weeks, serves as an additional reminder that we live on a volatile planet. What, if anything, does this apparent uptick in geological activity portend, and how does it compare to events in Earth’s past history? E&S *sat down with Hiroo Kanamori, the Smits Professor of Geophysics, Emeritus, and Joe Kirschvink, the Van Wingen Professor of Geobiology, to hear their thoughts.*

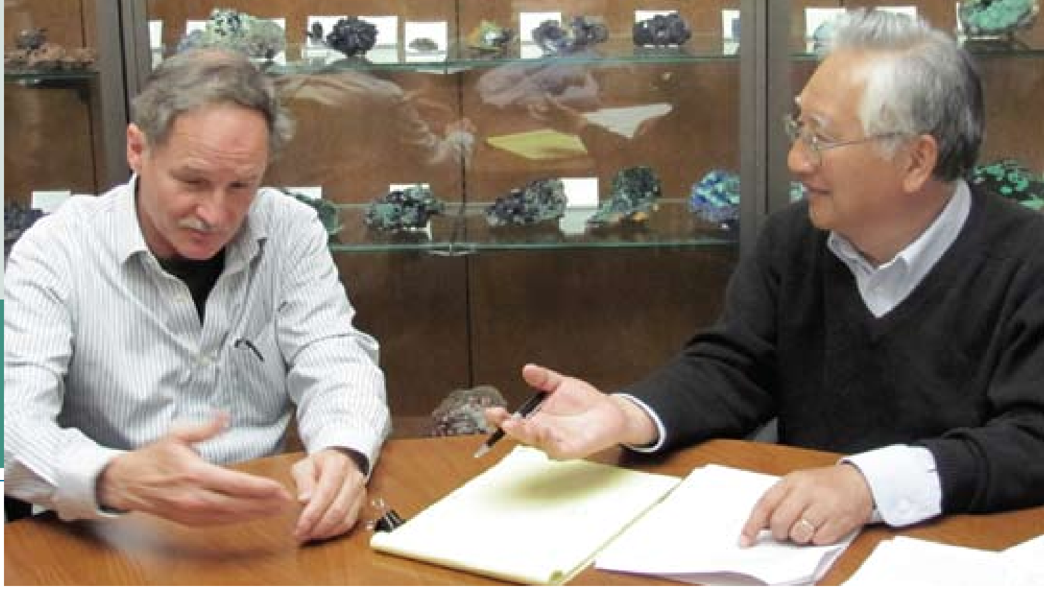
Between February and September this year, earthquakes ranging from magnitude 6.8 to 8.8 have occurred in regions as far-flung as Sumatra, China, Chile, New Zealand, and Baja, California. Are we in fact seeing more large quakes than usual?

Hiroo Kanamori: There are a couple of ways to answer this question. If you look at very major earthquakes, we are not seeing as much activity as between 1950 and 1965, when there were three events of magnitude 9 or greater in which an enormous amount of energy was released.

However, if we total up the number of quakes over magnitude 8 that have occurred since the first great Sumatran quake of 2004, we do find that these numbers really have increased. On average about

Geobiologist Joe Kirschvink (BS '75, MS '75) and geophysicist Hiroo Kanamori get together in the room housing Caltech's gem and rare-mineral collection to talk about earthquakes, volcanoes, and other past perils of life on Planet Earth.

By Heidi Aspaturian



one quake per year is magnitude 8 or larger. Since 2004, on average we have had two quakes of that size or more annually.

Is this statistically significant?

HK: We don't really know! Thanks to a study that's been going on for about the last 18 years, we do know a great deal more than we used to about triggering events in earthquakes. We now know that every large earthquake sends out seismic waves that can travel some distance and potentially activate seismic activity elsewhere. We saw this in a particularly spectacular way during California's 1992 Landers quake in the Mojave Desert, where earthquake activity affected areas as far away as Yellowstone National Park. In 2002, the Denali earthquake in Alaska touched off seismic activity in California, a considerable distance away.

So, as we look at the increase in major quake activity over the last six years, it is theoretically possible that the seismic waves generated in 2004 by the magnitude 9.3 Sumatran quake acted as a trigger for at least some of these events in other parts of the world. But it has not been confirmed.

How well do scientists understand the physical mechanisms that might touch off a quake cascade like this?

HK: We have several different models and theories. The most straightforward mechanism would be one in which the seismic waves increase stress on other faults that they're passing through. If those faults are already close to rupture, this seismic impact may be enough to push things over the edge.

There are also cases in which this activity is delayed. This appears to be what happened this summer when the magnitude 7.2 quake that had occurred in Baja California in April touched off two moderate quakes in June and July on the San Jacinto fault in Southern California.

Do seismologists have an explanation for this delayed activity?

HK: Again, several theories or models have been proposed. One possible scenario is that these delayed quakes occur on faults where the stress level is just below what is required to produce an earthquake. Seismic waves reaching the fault from another quake are not sufficient to generate an event immediately, but because faults are essentially in constant, incremental motion, the seismic waves may be enough to increase that speed of motion to the point where the fault accelerates toward the breakage threshold and then, after a time, you have a quake. Every fault contains a large number of nuclei—or potential sources of rupture—that are in a sense at different levels of maturity. Some are farther from failure, some are closer, but as the fault itself is shaken, every one of these nuclei moves closer to failure. In these models, shaking those sources won't produce a quake instantly, but it will accelerate motion along the fault sufficiently to eventually tip one or more of them over the failure threshold. In other words, instead of failing instantaneously, the movement increases over time until a failure threshold is reached, and then there's a quake.

Does what seismologists now know about the triggering effect give them any added ability to predict where the next quakes are likely to occur?

HK: Well, for the triggering mechanism to work, you must first have a region that is ready to go. If a stress wave travels through a region where there is no stress accumulation, nothing is going to happen. So, we cannot make these kinds of predictions unless we know how close particular areas are to failure.

In the Baja case, as with many others, there's a good deal of research and debate going on. In general, when you are dealing with earthquakes, it continues to be very difficult to demonstrate which mechanism accounts for a specific event. And that is in large part because you are investigating unique events that happen over very large timescales. You can't go into the laboratory and replicate the quake that just occurred. The bottom line in earthquake science is that nature does not give up her secrets easily.

Really, the fundamental need is still to study particular fault zones or volcanoes to see what the current stress conditions are. That is precisely what many seismologists are investigating now. They are making in-depth studies of exactly how stress is building up, what the background activity is, and

"We now know that every large earthquake sends out seismic waves that can travel some distance and potentially activate seismic activity elsewhere."

“The Icelandic eruption that we saw this spring was *tiny* compared to eruptions that have happened previously in Earth’s history.”

working to develop a more comprehensive picture of significant fault zones. Our technology, instrumentation, and field practices have improved quite a bit in the last decade, and we have been making good progress.

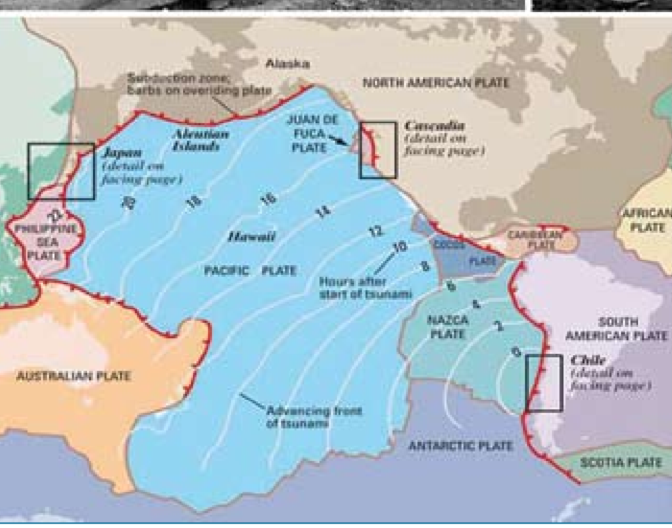
To give you one example, this year is the 50th anniversary of the biggest quake of the last century—the 1960 Chilean earthquake. Today we give it a magnitude of 9.5, but we still don’t really understand how big it was. This was a huge event. It caused widespread death and damage in Chile and sent a tsunami that struck the island of Hawaii without warning and killed dozens of people. Contrast this to the latest large Chilean quake in February, which was a magnitude 8.8. Within one hour of that quake, the U.S. Geological Survey had amassed a great deal of relevant information and sent it out. Almost everything that followed—hazard mitigation, tsunami warnings, and so forth—was based on the rapid-response and early-warning systems that have been developed over the last several years.

So it’s very clear that we can make a huge contribution to society by gaining a better understanding of the processes that underlie major quakes and then coming up with better tools for dealing with them. That’s been very exciting for us.

What do you each find most interesting about all this recent geologic activity?

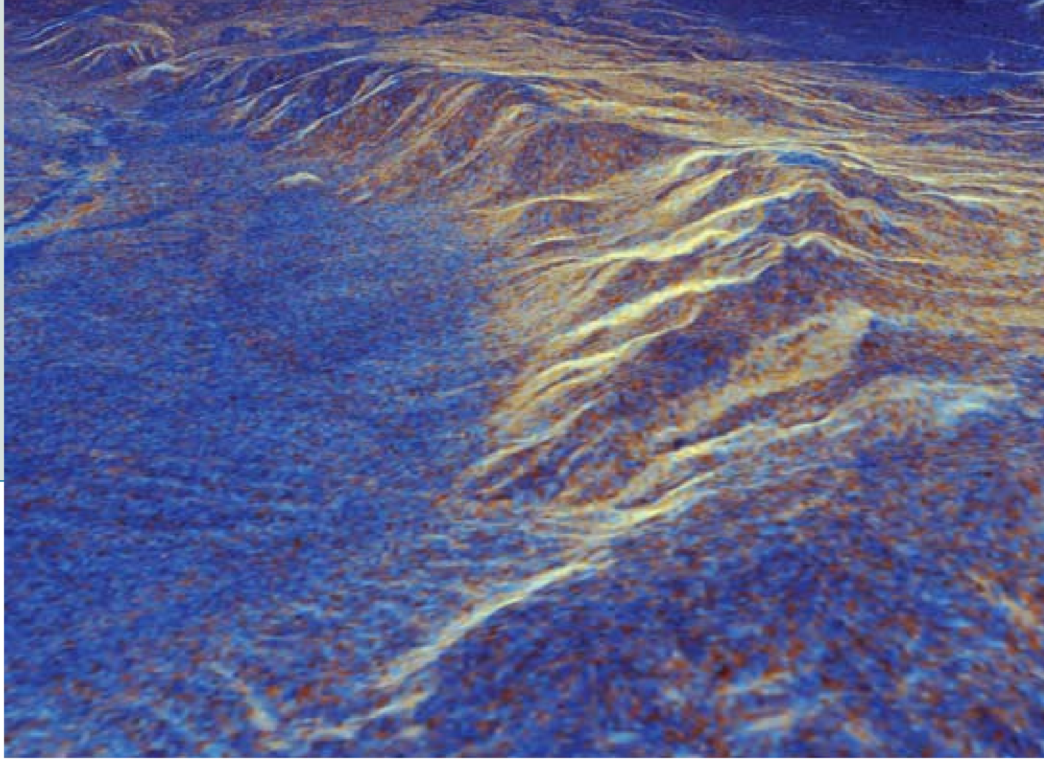
Joe Kirschvink: I don’t know if there’s any relation between Iceland’s volcanic eruption and this seismic activity. Most likely, it’s just a coincidence. But the Iceland volcano was definitely one of these things that was on the verge of eruption. It had to have a major magma chamber underneath it that was ready to go. It’s also interesting that the ash cloud that caused so much atmospheric havoc was partially due to the water that’s being melted away from the glacier overlying the volcano. If that enormous volume of water had not been there, it wouldn’t have been such a headache. Mixing water with hot, erupting magma leads to a particularly violent type of eruption. It’s called a “phreatic explosion”—the root word’s from the Greek, meaning “well”—and it is particularly good at producing fine-grained volcanic ash that can be carried long distances. So the troubles we saw were basically just a result of having a volcano at high latitudes under a substantial ice sheet.

HK: I think that what we need to realize is that this type of activity has gone on for a long time, and it will continue to go on. Basically, whether you like it or not, we are living on this planet. And it can be a perilous place.



Clockwise, from upper left: (1) The devastation wrought by the Great Chilean Quake of 1960, whose estimated magnitude of 9.5 ranks it as the largest temblor of the 20th century. (2) Residents of Hilo, Hawaii, survey the damage after a tsunami touched off by the quake struck the Big Island with little advance warning. (3) Several hours later, the tsunami flooded coastal regions of Japan, forcing residents to flee to higher ground. (4) A U.S. Geological Survey map traces the tsunami’s path across the Pacific from a subduction zone along the coast of Chile. Its waves reached Hawaii in 15 hours and Japan in 22.

Three quarters of a billion years ago, massive eruptions of eastern California's Long Valley Caldera (shown in a 3-D image produced by the NASA/JPL SIR-C Synthetic Aperture Radar aboard the Space Shuttle *Endeavour*) covered what is today the southwestern United States with a blanket of ash that extended as far east as the Mississippi. The region is still active, with the last sizable eruption occurring about 250 years ago. This view looks north, along the northeastern edge of the caldera.



Joe, you've made in-depth studies of ancient geological upheavals. Can you put these recent events in perspective for us?

JK: Just to take volcanoes, the Icelandic eruption that we saw this spring was *tiny* compared to eruptions that have happened previously in Earth's history. In California alone, about three-quarters of a million years ago—which geologically is nothing—the Long Valley Caldera, between Mono Lake and Mammoth, blew its top. The eruption covered the southwestern United States with a blanket of ash that extended all the way to the Mississippi. The sediments that washed off from the Mississippi delta produced deposits that in some places were hundreds of meters thick. That episode was far, far worse than anything in human memory. There was a similar eruption about two million years ago in what is today Yellowstone. The source was Huckleberry Ridge, and the ash, again, blanketed everywhere.

You know, as a geologist, I find these events useful because you can go to sediments of that age, and when you see evidence of the Huckleberry Ridge or the Long Valley Bishop Ash eruptions, you know exactly where you are chronologically. They are signature events that we can correlate and use to tell the age of the sediments that contain them. But it's sure not something that you would want to have happen anywhere near you today. There are volcanoes like this in other parts of the world. One of them, Mount Sakurajima, on the island of Kyushu in Japan, blows its top quite often—most recently, just last year. You wouldn't want to be anywhere nearby when that mountain decides to get really mad again.

Climatically the Icelandic eruption didn't do much of anything—the damage it caused was almost entirely economic. It was nothing like major episodes in Earth's history where we've had volcanic eruptions that have destabilized the climate to the point where they produced mass-extinction events.

The biggest of these events occurred at what we call the Permian-Triassic boundary, a little over 250 million years ago. It is sometimes referred to as the Great Dying, because such a significant percentage of life on Earth was wiped out over a period of some 15 million years. Today in the geologic record, we find evidence of flood basalts that covered Siberia and perhaps huge volumes of the surrounding ocean floor. The chemical reactions with the volcanic outflows and gases depleted the oceans so severely of oxygen that they basically went anoxic and marine life suffocated. You can see the fingerprints of that in the fossil record. And it's all linked to these enormous volcanic eruptions.

Hey—it's important to recognize that we're living on a dangerous planet. The one thing that you can say with near certainty is that if you go through the rock record and find evidence that something has occurred every 10 or 20 million years, it's going to happen again. It just happens that we're living in a very nice interval right now, and we wouldn't want to go back to any of these other periods.

> "The one thing that you can say with near certainty is that if you go through the rock record and find evidence that something has occurred every 10 or 20 million years, it's going to happen again."

One question we often hear from both the public and the media is, will we ever be able to predict earthquakes the way we can—more or less—forecast the weather? What are your views?

HK: There are such fundamental differences between weather forecasting and earthquake prediction. With weather, the situation basically changes on an almost daily basis. With quakes, we are dealing with long-term processes in which the timescale for stress buildup and release is very long—100 to 1,000 years or more—while the length of time in which quakes occur is very short.

As I said earlier, we have made major advances in our understanding of how these seismic processes operate over these lengthy timescales. But to be able to say there's a strong likelihood that a magnitude

"Why are we supporting this thing called the geological survey to study volcanoes?"

8 earthquake will occur in some specific area within the next hundred years or so is not necessarily very useful for the average layperson. You simply can't handle it like a weather forecast. If the forecast says, "rain tomorrow," you may take your umbrella, and either it rains or it doesn't. However, in the case of earthquakes, if you say that something big is going to happen tomorrow and nothing happens, that can be a problem. And that's really a key difference between climatology and seismology.

JK: I agree with Hiroo. If you want to see how completely distinct the two areas are, just turn the analogy around. Certainly, meteorology averaged over a very long period of time gives you climate. Or, to put it another way, climate is just long-term weather. But I certainly wouldn't advocate analyzing ancient climates to determine whether you'll have a thunderstorm next Tuesday.

HK: The fact is that it will be a long time, if ever, before we can accurately predict when and where major earthquakes will occur. So the real question is, if we are becoming more adept at gathering and interpreting information about long-term seismic conditions and so forth, how can we make the best use of it?

What we really need to emphasize are rapid-response systems and structural-control systems, so that when significant earthquakes happen and these large seismic waves are generated, we are able to capture that activity, analyze it, and prepare structures that are better able to withstand shaking. You cannot make very precise, short-term predictions, but there are certainly more effective and efficient ways to capitalize on the information we do have.

It's so important to have scientists working directly with engineers on these issues so that we can give them a good idea of what to expect over the long term. Then they can apply that knowledge to come up with better ways to deal with natural hazards and their potentially damaging impacts. We have made a great deal of progress in civil and structural engineering, and it's exciting to see that our scientific product can be effectively used for the public benefit. But there is a great deal more we can and should be doing.

JK: We also need to do more to raise public awareness and understanding of why it is so essential to invest in this research and these technologies. Earlier this year we had some politician stand up and ask indignantly, "Why are we supporting this thing called the geological survey to study volcanoes?" Then, of course, boom! Iceland goes off and you disrupt the entire economy of Europe. Maybe that makes the reasons even more obvious, but we shouldn't have to rely on these kinds of wake-up calls to make the point that the planet's seismic and climatic activity merits serious study, and must be supported by both public and private sources. A system in which science is left to wither and die is not a way of maintaining your civilization. I may be a geologist, but I don't want to go back to the Stone Age, thank you. E&S

***Hiroo Kanamori*, the Smits Professor of Geophysics, Emeritus, was the director of Caltech's seismo lab from 1990 to 1998. Born in 1936, just 13 years after the magnitude 7.9 Great Kanto Earthquake that devastated the Tokyo-Yokohama area and killed some 140,000 people, Kanamori earned his PhD at the University of Tokyo in 1964. He then came to Caltech as a research fellow for a year, returning as a full professor in 1972. He became professor emeritus in 2005.**

***Joseph Kirschvink*, the Van Wingen Professor of Geobiology, studies biomagnetism, paleomagnetism, and Earth's climatic history. He earned both a BS in biology and an MS in geology from Caltech in 1975, and a PhD in geobiology from Princeton in 1979. He returned to his alma mater as an assistant professor in 1981.**

Heidi Aspaturian, associate editor of* On Campus *and media relations writer from 1985 to 1992, editor of* On Campus *from 1993 to 2001, and editor of* Caltech News *from 1992 to 2009, recently retired from the Caltech Office of Marketing and Communications.

From glaciers at the equators to dinosaurs near the poles, listen to Joe Kirschvink discuss Earth's ancient climates in an exclusive E&S podcast.