Dr. Maya Tolstoy

Nobel Conference 48

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Thank you very much for that nice introduction. Can I get my first slide. And speaking of jokes that only geologists get, I have the same slide that, that Dave used in his talk. [laughter]. We all love this one. Um, and I, I actually spend a lot of time thinking about why people should care about the bottom of the ocean, as you might guess. And there are many, many reasons why you should and that I could talk about today. But what I'm going to talk about is where my passion really lies, which is sea floor earthquakes and volcanoes. And I'm going to talk about all kinds of different earthquakes. I'm going to tell a story of earthquakes large and small and small from the, from the very large devasting earthquakes that you all have heard about in the news that take such a tremendous toll on human life, to the very tiny, tiny earthquakes that are occurring on our sea floor that nobody knows about except for a few geologists and geophysicists studying them because they're so tiny, that actually help life to thrive on the sea floor. So it's kind of the counterpart to these earthquakes that take so much life away from us.

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And so this is a picture of that illusive ocean bottom. And the colors here show you the sea floor, the symmetry. They show you the depth of the ocean. And what you see is the green colors down the center, the highest bathymetry actually the orangey color is the very shallowest, that's near the coast. But in the deep ocean you have these long chains of high mountains that Dave's already talked about that are the mid-ocean ridges. And this is where new surface of our planet is constantly forming. And then as it gets older and it moves away from the, from the mid-ocean ridge, it goes into these deeper basins that get as deep as 11 kilometers beneath the surface, the very deepest being the Mariana Trench.

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And so these mid-ocean ridges are places of constant renewal, constant change, sort of dynamic surface of our planet, and so are the edges where the plates dive down underneath the continents. Now this one I like to show just to remind everybody that going to sea isn't easy. And there are parts of the ocean that we understand better than other parts. And the parts that we understand the least are the parts where trying to study it involves going on seas such as this one. And so we deal with a lot of heavy equipment like Dave has shown. And there are some parts of the ocean where you just don't want to go and take that heavy equipment. And I've been through a few of them and I really don't want to go back, thank you very much. And so you'll notice that quite a bit of my work is focused in the Equatorial Pacific. [laughter] But take note potential students, choose your field area wisely.

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OK. So this is another map of the ocean floor, again with colors, but here the colors are crustal age. So the red represents the youngest crust. Some of it is what we call zero-age crust, it's just being born today, yesterday, within the last few years. There are constantly sea floor eruptions going on, some of which we know about, most of which we probably don't because we're not monitoring most of the ocean for this. And they don't produce terribly large earthquakes in many parts of the ocean. And then the deepest oldest crust is shown in blue, out as old as 200 million years. But as Julie said so nicely in the introduction, this whole area is just from 0 to 200 million years, that's very young on Earth's time scale. The continents which are in gray are more in the sort of 4 billion year time scale, or as old. Most of it's not that old. But the oceans are incredibly young. And constantly resurfacing and constantly moving.

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And this picture shows the plates that form the surface of our planet. The whole surface is made up of lots of individual surfaces that slide and crunch between each other. In some places they move apart from each other. That's at the mid-ocean ridges. Other places they slide under each other. And in other places they slide past each other like on the San Andreas Fault. But this solid Earth of ours is actually constantly moving and changing and deforming. It's very dynamic.

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And this shows the three different primary types of plate boundaries. We have mid-ocean ridges spreading boundaries where new crust is forming, moving apart. The subduction zones where one plate is diving under another, very often continental crust, and it's being recycled into the mantle. And then we have these strike slip boundaries where plates are sliding past each other. This happens at the oceanic spreading centers between spreading ridges and also on land.

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And so this is a little video of what's been going on for the last 180 million years. We think of our continents as pretty fixed, but in reality, they're moving all the time. Some are moving closer to each other. Some are moving further apart. In some cases, they're crashing into each other. This is the last major break-up of what was called a supercontinent, which was known as Pangaea, when all the continents were together about 180 million years ago. And then the Atlantic Ocean formed both in the north and the south and the land masses split apart. I particularly like to watch India, which suddenly takes off. It just goes washing up there and there's no wonder you get the Himalayas when it crashes into Asia. It's really the speedy one.

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And so you can see that when we think about these things on geological time scales, our planet is very, very dynamic and active. And now this is one of my new favorite photographs. Can you raise your hand if you know where this picture is? Yeah, a few of you. So I love this picture for many reasons. It makes me want to go out for a walk in the desert. I love this when I'm in the desert Southwest and you can see the geology just exposed there in the rocks. This is something we can never do on the ocean floor because we, unless we're going to drain the oceans, we can't get this scale of lighting to go look at the geology. But this picture is actually the surface of Mars. This is one of the recent pictures returned by the Curiosity Rover. And it's just one of the most astonishing pictures I've seen in my life because it looks so, so Earthlike.

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But it reminds me of the challenge we have in looking at the deep-sea floor and how much harder it is to know our own planet. And then as Julie mentioned, we know more about the surface of other planets than we do our own because we're able to map them in very high resolution with radar systems. This is Venus here without its cloud cover. And this is the surface of Mars, but both of which have been mapped in great detail with radar emissions. Venus actually looks like this. Venus is covered in clouds of sulfuric acid and very, it's a very hostile environment for anything to survive on. But when you can look below those clouds with radar systems and map it and Mars of course is one of the best known, best mapped planets.

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So looking at Earth, Dave's already talked so eloquently about how we can explore the deep sea and one way to go and actually image the deep-sea floor is in submersibles. And I was lucky enough a few years ago to get to dive in the Russian Mir submersibles. And this was part of a documentary made by James Cameron on the deep-sea floor and the hydrothermal vent systems. And the Russians have an amazing operation with these two subs. And we went down into the mid-ocean ridge system. And I think this really illustrates that point that Dave was talking about about it, how it's like looking in the deep-sea floor when all you have is this one spotlight, it's like trying to map the Rockies with a flashlight at night. It's just really, really hard to do.

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And so what we see, this is where the sub landed. Maybe a few hundred meters or a thousand feet or so away from the ridge axis and what you see is a very barren landscape with these fresh lavas. So the crust is still very young. It hasn't had time for the sediments to accumulate because it's, you know, maybe a few hundred thousand years old. And there's very little down there. What is down there, the fish tend to move very slowly because it's a low-oxygen environment. But they do exist there. But mostly it's this barren field of lava and pillow lavas that was erupted at the ridge axis and has moved away. And this is where I always try and ask people to focus on the pillow lavas in the background. And it's obviously impossible to do. We seismologists love animals, too. This one is a dumbo octopus which is particularly stunning.

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But as you move in towards the ridge axis, as you get just a little bit closer, you start to see these concentrations of life. And you can see yellow staining on the rocks here that tell you something's coming out in the water. You see crabs. You see an anemones starting to gather in these little holes. And then you get right on the ridge axis and it's a very narrow band where you see this dense, dense life that Dave already discussed a little, that thrives at these systems. It's absolutely packed with life. You've got the crabs and the shells and tube worms. And then you have shrimp, here this is in the Atlantic, that swarm around these black smock areas and there are little bacteria that are eating the sulfur that's coming out of this hydrothermal system. And then the shrimp eat the bacteria and so it goes. You have a food chain there thriving without direct sunlight. And so as Dave had mentioned, nobody ever expected to find life down here so deep, so far away from sunlight. And what this black smoke is is it's the ocean water that has penetrated down into the crust, come near to the hot volcanic magma, gotten heated up in the rock, picked up minerals and nutrients, and then come gushing out at up to 700 degrees Celsius into the cold ocean water and as that very hot, super-heated water full of minerals and nutrients, hits the cold water, those minerals precipitate out and that's why you get that black smoke effect.

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But what's fueling that, what's driving this is ultimately the earthquakes. And the earthquakes that are allowing the cracks the open, that lets the sea water penetrate down. And hit the hot rock. And so if you look at a map of global earthquakes, this is about 35 years' worth of globally recorded earthquakes. The black dots show where we have well-located earthquakes. If you look in the deep ocean, the earthquakes essentially outline the mid-ocean ridge system. And so in this sense, earthquakes are almost like a life detection tool. So if you're in a very barren and hostile environment to life, one of the things you can look for, and I say this for looking at Mars as well. Mars is actually similar to the deep-sea floor. It's quite a hostile environment for life. It's quite barren. And so I would argue that if you want to know the best places to look for life, then that's almost definitely microbial life if it exists on Mars, you should put seismometers down there, and in fact, a mission has just been funded to put one seismometer on there, which is not enough but it's a start. You should put seismometers on there and find where the planet is still dynamic. If it's still dynamic. If there's still deformation going. Because when you have earthquakes, you have cracks that break and when you have cracks that break, you allow water to penetrate in there. And if it keeps breaking, that water can keep sucking fresh nutrients out of the rocks. And it's those nutrients that allow these amazing biological systems to thrive.

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So this hydrothermal circulation is a very, very important planetary process. It means that actually 1 to 2 percent of the whole ocean volume is stored inside the ocean crust at any one time and the entire volume of the ocean is cycled through in less than a million years. And so this cycling is important both for the chemistry of the ocean, you get all kinds of chemicals coming out from the sea floor that seep into the ocean. But it also, it supports this extensive ecosystem, both at these hydrothermal vent systems that are shown here and that we've talked about, but also in the subsurface. In fact, we know now that microbes are eating the rocks. They're living in this deep crustal environment where we never would've expected to find life. And you have this pillow lavas at the very surface and then something called sheeted dike basalts underneath them and then a melt supply so the magma chamber underneath that. And here in the crust there are actually microbes living and eating the rocks.

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And I'm going to divert for just a second here if I can get that video to show again. Now there are many, many important potential applications of studying hydrothermal vents and in basic research there's always applications you haven't foreseen and I think that sometimes the most interesting applications are the completely unexpected. And this is a picture here on this side of a hydrothermal vent system. On the other side here is the BP oil well from the 2010 Gulf of Mexico spill. And if you remember in the news when this first happened, the BP spokesmen were saying, 'There's no way we can possibly know the amount of oil that's coming out of this well.' And they were coming up with these wildly small estimates to start with. But my colleague at Lamont, Tim Crown, for his PhD thesis had actually developed an imaging technique that allows you to measure the flow rate of exactly this type of flow. It's called a turbulent buoyant jet. And he applied this same technique to the BP oil well and was one of the first people to come out with, and was the first to publish in a peer review journal, the estimate of the actual size of the spill and now the official estimates have come up to match that. But this basic research always has significant unintended applications.

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So back to sea floor earthquakes. This is a picture of one of the best ways of studying sea floor earthquakes except you don't want the instruments on the ship, you want them on the sea floor. But these are the instruments we use. They're called ocean bottom seismometers. And they're just like seismometers you use on land but they're obviously put on the ocean bottom. They have glass flotation spheres on the top. And then there's a data logger and a sensor and the battery case and acoustics case at the bottom. We have flashing lights and radio beacons and red flags to help us find them. And then anchors on the bottom.

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And the way that we deploy these is just to crane them over the side of the ship and drop them. And normally we don't get to see where they land. And if you knew how land seismologists do their work, you realize how astonishing that is because land seismologists go and find very nice quiet places and they dig a vault and they cement them in and they position it all very carefully. We just throw ours over the side of the ship and hope. [laughter] And most of the time it works. Sometimes it doesn't. Sometimes they never come back and we don't know why. Sometimes they never come back and we do know why. Most of the time they come back. So here you can see one deployed in a collapsed lava feature here. There's a lava pillow there. What we always hope is that they land close to horizontal. This is not always the case. But sometimes they'll land like that. And we probably will never know that's how they were sitting. We'll just notice that some of the data on the horizontal channels doesn't look very good. And so we'll have to speculate on why that was.

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So those seismometers that you saw on the back of that ship and being dropped there were actually deployed at the East Pacific Rise back at my favorite east and Equatorial waters in the Eastern Pacific at the site referred to at 9 Degrees North, very imaginatively because it's at 9 degrees 50 minutes north. But this is one of the best studied sites on the planet in mid-ocean ridge sites and it's not just because the weather's good. It's a very, very interesting site at a fast-spreading ridge that spreads on the order of about 11 centimeters per year. That's about as fast as your fingernail grows. This is a more detailed bathymetric map done by ships' multibeam mapping systems. It shows the ridge axis coming down here. This is a fracture zone where the plates are siding next to each other. And then this is another ridge axis coming down here. My focus area is right there.

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And this shows a map of our ocean bottom seismometer, or OBS, array, how we deployed them. These blue dots are all where our ocean-bottom seismometers were deployed. And this is about 4 kilometers by 4 kilometers, a little more than 2 miles by 2 miles. It’s a very small array. And these red triangles here were all high temperature hydrothermal vents. So black smoker systems. And the black dots that you see are all tiny, tiny little earthquakes that we located with this seismic array.

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The largest one we saw was a magnitude one point five. If you were sitting right on top of it, you might feel it a little bit. But some of them are down. We managed to pick ones up as small as a magnitude minus one, which is really just a crack happening about on the scale of a person. It’s really quite tiny.

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And so this is a cross section through the sea floor. Along the X asis you have latitude so this is going along the ridge axis and from 9 degrees, 49 minutes to 9 degrees, 51 minutes. This is depth. And what I’ve shown here in red is where the magma chamber is. So where we’ve previously imaged it from different types of seismic data. And the gray dots are all tiny little earthquakes. And then the arrows are my interpretation of those tiny little earthquakes. And here you can see the vent sites that we have. The red triangles, again, are high-temperature vents. Yellow stars are these low-temperature diffuse vents. And so what we think is that the water is coming into the crust here in a very narrowly focused pipe. It churns around, hangs out here for a while, interacts with the rocks, picks up those nutrients, picks up the heat from the magma chamber. And then comes gushing back out at these black smokers. And so we have this sort of hydrothermal cell going here.

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And this is sort of a cartoon of how that works, where the sea water seeps in and we think it happens where there's a tiny little kink in the ridge axis. And that tiny little kink creates tectonic stresses that keeps cracks opening all the time so they don't clog up. So the water is gushing into the sea floor, interacting with these hot rocks and coming back out and putting all this interesting chemistry that Dave said you couldn't get a permit to dump in the ocean. And helping these biological systems thrive.

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So the other really interesting thing that we've learned about the sea floor earthquakes recently is that they're essentially pulsing with the tides. So they, the earthquakes are happening more commonly during increased tidal stresses. And this is a very complicated issue when you get into tidal stresses because there's different kinds of tides. There's actually the ocean tide that we all know about where the ocean goes up and down. But there's something called Earth tides, too, where the solid Earth that we're sitting on today is deforming in the same way that the ocean does with the passage of the moon and the sun. But it's deforming such a tiny amount that we can't feel it. Very sensitive instruments can measure it on land. But we can't actually feel it in our day-to-day lives. But the sea floor can feel it. And so there is this combination of effect of squeezing of the Earth and the pushing of the tides. But we have found that on the deep-sea floor, these tiny earthquakes will happen more commonly during the peak tidal stresses. Now it's not that the tides are causing the earthquakes. It's that you have a fault that's about to go. It's very close to breaking and that extra tiny little push from the tide is enough to put it over the edge. And so we see the sea floor very, very strongly pulsing with the tides. And tidal triggering of earthquakes is something that land seismologists had looked for for decades. And it'd been sort of people maybe vaguely saw a slight signal. And then somebody else would disprove it and then it would go away for 10 years and then somebody else would publish something where maybe there was a tiny signal there.

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And we use something called a Schuster Test. And it's this statistical test looking at the probability of non-randomness and I think it's above 95 percent confidence is considered evidence of tidal triggering. Well, when we ran the statistics on this, it was 99.99999999 percent and so we were pretty confident of it. And so what was nice about this is it sort of reinvigorated the field of tidal triggering a little bit and I'll get to that later. The other thing we saw in the earthquakes that was really interesting is this sort of steady increase in the rate of earthquakes. And this is over the course of three deployments from October 2003 until January 2006. And this is the number of events per day recorded on the array. And you can see this kind of gradual increase. It sort of pulses up and down through time. And then on January 22nd, it all went away and it collapsed. And so we are deploying these instruments on a yearly basis. We go out, we throw them over the side of the ship. We say, please land safely and come back when we call you. And a year later we go back and we call them and we say, please come back. And we'll send it this coded acoustic pulse and it will acknowledge the pulse and it will burn, something called a burn wire, drop its anchor and those floats, those yellow floats at the top will make it positively buoyant. It'll float back up and we'll go find it.

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Well, we went back in 2006 and only four of our 12 instruments came back and that's very unusual. And some of them were still talking to us and saying, 'We can hear you. 'We've released our anchor.' But they weren't coming up to the surface. And so we immediately for numerous reasons suspected an eruption and then we went back with the camera system and this here is actually one of those ocean bottom seismometers buried in lava. You can actually only see about a third of it or so. The rest is completely covered in lava flow. And what's astonishing is that this instrument was still talking to us. The acoustics were still working. And this is one of the ones that said, 'I've released my anchor.' And it wasn't coming back.

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So what do you do when your instrument doesn't come back? This was, in this corner here you'll actually see a hooked, a sort of grappling hook that was hung on the bottom of this camera sled in a fit of optimism that we might be able to pull it out. But this one was not coming out with the little hook like that. So we called on the ROV Jason from Woods Hole. And this is a picture of Jason actually this summer. And I like that picture because that's my son in front of it and he's also called Jason. And so he really likes it. When he saw it, he said to me, 'Mom, am I named after Jason.' And I said, no. And then he said, 'Well, can I be?' And I said, sure. [laughs]

OK. So we call on Jason. And Jason did manage to dig out one of our OBS's and you can see a little bit of footage of that here. They had to work really hard. This was my colleague Dan Fenari [SP] at Woods Hole who is really, the spearhead of this and was the hero on this. And, uh, you can see it pulling off lumps of lava to, so that it will float back up. And there you can see where it was actually scalded by the lava where the plastic was melted. But remarkably most of it was still intact and we were able to get the instrument back to the surface.

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So this site had erupted before in 1991 and this is video from just a fortuitus Alvin dive that occurred at that site in 1991 that actually helped make this site such a focal point. Wasn’t just the good weather, as I said. But one of the things that they found when the stumbled across this recent eruption was all this white snow in the seawater and people didn't understand at first, you know, what exactly this was. But it turns out to be bacterial mats. And this is bacteria that’s been blown up from within the, within the sea floor. And this helped lead to this concept of the subsurface biosphere. The fact that there are these microbes living deep in the rock and feeding off the rock. So these eruptions have really been illuminating in terms of understanding not just our geological processes but the biological processes. And we don't have any footage of the eruption from the East Pacific Rise but this is some footage collected, I think couple years ago, in the Western Pacific by Joe Resing and others, of a volcano called West Mata, that’s in a, what’s called bac-arc spreading center. And this is, again, footage from Jason and you can see how close Jason was bravely willing to get. But the water’s really not a very good conductor of heat. So you can get reasonably close and still be safe. As long as the eruption doesn’t go in an unexpected direction.

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But this is our first real footage of deep-sea underwater eruptions. We also have a little footage of off Hawaii from a diver actually that shows pillow basalts forming. And there you can see how those strange pillow structures that we saw frozen in the older crust as the submarine moved and how they form as the magma basically oozes out and as it hits the cold sea water, that surface, that black surface cools almost instantly, or the red, the red cools instantly and becomes this black glossy basalt.

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I'm going to tell you about one other sea floor eruption just because it's one of my favorites which is up in the Gakkel Ridge. And the Gakkel Ridge is one of our least studied mid-ocean ridges because it's covered by ice most of the year. And that's getting unfortunately less, less true. But the Gakkel Ridge is one of the slowest spreading ridges on the planet. It spreads at maybe one to two centimeters per year. We have never put ocean bottom seismometers up there. I wish we had. But because it's so slow spreading, it means that it's actually very cold and brittle in the crust. And when the Gakkel Ridge erupts, it produces big earthquakes. It produces earthquakes big enough for us to record them on the global seismic network.

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And in 1999 we saw a swarm of earthquakes. And this is a map of the Gakkel Ridge. This is, these are the normal faults bounding the ridge valley. This is the ridge axis going up here. And these stars and the beach balls are all earthquakes that were recorded as part of this swarm. And so we have this very basic bathymetry of the area and we saw the earthquake swarm in 1999 and it looked for all the world like an eruption. The character of the earthquakes were not like a main shock, after shock swarm. It was just sort of ongoing. And so I was looking around for data that might confirm this. And it turned out that right in the middle sort of toward the end of this, there was a U.S. nuclear submarine transiting over the area with some scientists on board with some scientific mapping equipment mounted to the hull of the submarine. This is incredibly fortuitus. And they were mapping this area both for the bathymetry and something called side scan, which looks at the reflectivity of the return. And what they saw is this very dark patch that basically indicates high reflectivity. And this is thought to be a fresh lava flow.

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Am I doing something wrong here with the speaker? I'm not sure what that is.

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So what they saw is this what appears to be a fresh lava flow with tendrils of lava running off around a central volcanic system. So we have these eruptions going on all over the planet. And this is just a cartoon that was actually made when we got all our OBS's stuck in lava that shows these sensors right along the ridge axis where this new crust is forming. But now I'm going to shift gears slightly and I'm going to move away from this creation of crust to the destruction of crust. And we're going to go down into the subduction zone. We're moving away from those tiny earthquakes that give life to these larger, devastating earthquakes that take life.

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And so here's a very simple cartoon of what happens at those subduction zones. You have one plate diving underneath another like this. And here you get what's called a locked fault. So this is the fault that's going to break but it's locked. And as the pressure builds up of this plate pulling down, this overriding plate gets pulled down with it. And then what happens when this fault here finally breaks, this plate jumps up and it gets pushed up like that. So it jumps up with an enormous flick as the stress is released. And the ocean that's above it gets pushed up. And that's what causes these enormous tsunamis to happen at this particular type of faults.

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And this is a picture and some data from the Tohoku earthquake that occurred last year in March, magnitude nine point zero with over 20,000 fatalities. And you've all seen videos of that, of the devasting tsunami and also of course the awful aftermath. And what this map here shows is the displacement field. So how much the earth actually moved. And this scale here from purple to red is in meters so that's 0 to 21 meters. That's over 60 feet. So at the rupture points, at the main epicenter of the earthquake, the earth actually moved in a matter of tens of seconds it moved 60 feet in one jump.

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And it's almost unimaginable that kind of a leap in the earth. And then you start to understand how that kind of leap can cause such a massive wall of water. And if we look at a model of the tsunami as it happened and propagated across the Pacific, it covered all the way across the Pacific in about 20 hours and then even bounced back and came back again. There's actually satellite data from NASA of once the tsunami hit Antarctica, it even caused icebergs to break off of Antarctica. And that's how powerful it was 20 hours later still, all the way across the Pacific.

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So the other really devasting earthquake in the last decade that was devastating because of a tsunami was the Sumatra-Andaman earthquake in December 26, 2004. That's officially given the magnitude of nine point one, though some people argue it should be a nine point three. When you get to these very large ones, how the magnitude is determined is sometimes controversial. But this shows the area of maximum energy release here in Sumatra. And this earthquake was 1200 kilometers long, that's about 800 miles long was the rupture zone. It ruptured for 8 minutes. We're used to thinking of earthquakes, at least for those of you who've lived in California that sort of last a few seconds or, you know, then the rolling will last, you know, maybe tens of seconds at most. This thing, the rupture itself, before you even get to just the rolling, continued for 8 minutes. And the area that slipped is basically about the area the size of the state of California. That is just almost unimaginably large.

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And again, it slipped maybe tens of feet when it did slip. And the tsunami that was spawned by that one also found its way all across the Indian Ocean, caused deaths along the east coast of Africa, as well as of course the hundreds of thousands of deaths in Sumatra and in Thailand. It was a truly devasting event. And this is my little, this is a very technical slide. But it's my little slide of hope. It's one of the most optimistic things that I've seen in a long time and this is coming from a scientist in Japan, Sachiko Tanaka. And what she has found, and this ties back to the mid-ocean ridges a little bit, what she has found is that in the years proceeding these very large and devasting earthquakes, there was actually a change in the strength of the tidal triggering. And that's what both of these plots, this is for Sumatra, this is for Tohoku. And this shows something called the P value, it's basically related to the randomness of distribution. And as this number down, it means that the strength of tidal triggering is getting stronger. It's getting, the tidal triggering is getting stronger.

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Up here there really isn't a good correlation with the tides. As you get closer to the main rupture, there becomes a stronger correlation with the tides, particularly if you look at the earthquakes, the smaller earthquakes that were happening right around the rupture point. And then she's just seeing the same thing in Tohoku. This paper just came out a few months ago where there's really not much correlation with tides. Remember I talked to about how back decades ago when the whole earth seismologists would look at this, they would see nothing. But then when she looked at the earthquakes right near the point of breakage in the years proceeding, again, you get this increased strength of tidal triggering. And so this is one of the most optimistic things that I've seen in a long time in terms of our ability to potentially forecast where the most hazardous areas are.

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What you do with that information is another matter and I think that we all, anybody living in earthquake areas always have to be prepared for the worst because it will happen. And then of course you can ask will it happen here? And here being in the continental U.S. or in North America and the answer is absolutely yes. It will. It's not a question of if. It's a question of when. And probably the biggest seismic hazard in the 48 continuous states is the Cascadia subduction zone. And this is up off the coast of Oregon and Washington. It's where this Juan de Fuca Plate, which is a very small plate that's next to the Pacific plate, where this one is being subducted underneath Oregon and Washington.

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And we know this area has produced magnitude nine earthquakes in the historical past. In fact, we know it produces them about every three to five hundred years, you get these magnitude nine earthquakes with very large tsunamis. The last one is actually very well documented because of tsunami records in Japan where they recorded a tsunami hitting about 300 years ago. So you could certainly argue that we're due for a very large one here but it may not be for another couple hundred years. We don't know.

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And this is what's going on there specifically. So you have this Juan de Fuca Plate subducting underneath the North American Plate and this is the locked zone where it's going to rupture. Another very interesting thing to come out of seismology in the last decade is evidence for what's called slow slip earthquakes. It turns out we can actually record motions on this section of the fault where it's moving over the course of a week or 2 weeks. And it’s moving the amount that it would move in a regular earthquake but of course we don't feel it because it happens so gradually. So those sound like really good things. Those sound like earthquakes that, yeah, they’re relieving the stress on the fault. But they’re relieving it slowly so it’s not causing this devastation. But unfortunately what we now think is happening is that these slow slip events, which are happening very periodically, about every 14 months in the Pacific Northwest. They are actually increasing the stress on this locked zone. And so we’re trying to understand whether or not these slow slip events can tell us anything about the increasing hazard on this locked zone.

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And one of the things that’s ongoing at the moment is sometimes called the Cascadia Initiative. This is funded by the National Science Foundation. And it’s a huge experiment initially started with stimulus funding to monitor this area, to cover it with both seismic and geodetic sensors so we’re deploying seismometers all along the offshore area, out to the edge of the Juan de Fuca Plate and then increasing the seismic coverage on land and also putting GPS stations. This is a four-year program. We just deployed the second year of the ocean bottom seismometers. And it’s unusual in that it’s a community experiment. Normally as scientists we’re used to we go out and do our own little thing and then we come back and keep our data and work on it. This is an open access experiment. Anybody, you can go download the data from this experiment as soon as it becomes available, which the first data should actually be coming available this week sometime.

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And so there’s a team of us that are going out and deploying these instruments. And, in fact, we’ve had to develop a new type of instrument. A new type of ocean bottom seismometer to deploy in this very shallow water area because we don't usually deploy in those shallow waters because it’s heavily fished. So our very expensive, you know, 50 to 100 thousand dollar ocean bottom seismometers get dragged up by fisherman and we don't get data and the fisherman aren’t happy. It’s bad new all around. But it’s really critical for the science questions that we understand what’s going on in this shallow area where we’re near the locked zone and near that slow slip zone.

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And so we developed this new type of seismometer. This is one that was developed at Lamont with the Lamont OBS group that's, by the way, available for anybody who wants to write a National Science Foundation proposal. So what you see here is what's called a troll-resistant OBS. So it's the same electronics as you saw being deployed previously but it's got this huge stainless steel heavy case over the top of it that's designed to allow the troll nets to basically just roll over it. That was our hope anyway. And so far it looks like it worked.

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This is from the deployment last summer, summer of 2011 off the coast of Oregon when we were still learning how to deploy these very heavy and very cumbersome things. And you'll see this is the very technical part of it. We do literally kick them overboard sometimes. [laughter] And we had all kinds of challenges with these things because they turn out not to be very aerodynamic. We were actually lowering them on the wire. They were too heavy to just drop to the sea floor the way we do with our other instruments. So we had to lower them on a wire. But even the small heave that you can see here in the very slight oceans we had were a problem. We had wires break where they went tumbling down to the bottom and all kinds of bad things happened. But we learned a lot.

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And then for this year when we had to do the first recovery, we again called upon Jason. And I just want to show you a little video of what it's like inside Jason's control van. And I apologize, this is shot on my iPhone. It's not the best video. But it's really amazing. They have these two containers that they put back to back. And it's full of monitors and there's navigation equipment and there's cameras showing different views, different angles. This is the sonar system that helps us, here actually you can see our OBS being picked up on the sonar system.

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And it's really a little bit like a space mission. It's a lot of fun. And there's a great camaraderie in this van and it's so exciting even when you're just looking at mud. [laughter] You're like, wow, that's the bottom of the ocean. And here's one of our troll-resistant OBS's that landed upside down because the line broke so we called on Jason to save it and now it does something very sinister. Watch this. It's not what you expect from a robot but it pulls out a knife. [laughter] I couldn't tell you how sort of weird it is to be sitting there in the van and see this robotic arm pull out a knife, even though it's what you want it to do and somebody in the van is controlling it. You can see there's also some cool fish down there. And so they had to cut off the lines that were tied to it. I think this was an old tag line from when it had dropped off or something. And so we had all kinds of things we had to clean up with Jason. And Jason did a marvelous job. And then they hooked into it. And recovered the instrument for us.

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This is how they're supposed to look on the sea floor. So this is one that had been sitting there for a year that had built up quite a bit of sediment around it, um, around the base. But was very successful [inaudible] resisting trollers. You can see the upside down shape would not be as good at it. And what was interesting is there was also a lot of life around these things. It turned out in this shallow water that they really attracted all kinds of critters. We had big fish, little fish. We had these enormous crabs that made their home there. I kinda felt bad sometimes pulling up their homes because they're like little artificial reefs that farm on the sea floor.

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And then we saw these amazing, amazing krill swarms that clouded our view and it was also fun to watch because, you know, we'd be there, a bunch of seismologists in the van and we were just all so awestruck by this and these cut little krill that just came and stared at our cameras. And you can see our seismometer's completely disappeared but nobody cares. [laughter] I just thought like, wow, that's so cool.

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So I hope that I've been able to convey to you a few more things about why you should care about the bottom of the ocean. It really is a tremendously exciting place and I sort of want to go back to one of the questions on the panel about this, the counter play between wonder and knowledge. And I really feel like at some level we don't lose wonder with knowledge. In fact, we almost get more of it. Because the more we discover that's down there that surprises us, the more wondrous it is.

It really is an amazing, an amazing planet and an amazing deep ocean. And I just want to end quickly by saying thank you to a lot of people and there's just a few names listed here but science at its best is always a collaborative effort and seagoing science absolutely is always a team effort. It has to be a team effort. And there are many, many colleagues that have helped me with the work I've shown here or that have led the work shown here. And I just want to briefly acknowledge them by name. I also want to thank James Cameron for allowing me to use the video footage from his film, and the National Science Foundation which really funded most of the research that I talked about and that you saw here. And I'll leave you with the video of the krill.