of buoys moored in the open ocean. By placing GPS antennae on shore and on the buoys, the researchers are able to compare a buoy's "altitude" with that of a stable location on land. According to Teruyuki Kato, the project's leader, this arrangement can measure a buoy's vertical motion with an accuracy of a few centimetres, which will pick up dangerous tsunamis in the open ocean where they are mere ripples on the surface (they rear up into killer waves only when they reach the shallows). Dr Kato's team has already tested the system successfully in the sea off Ofunato, in the east of the country, and a new system will be placed off Muroto promontory, in the west, early next year.

Another line of research that holds promise is the analysis of a type of sound wave known as a T-phase wave. Rocks rumbling downhill produce T-phase waves that are carried by the ocean to both nearby and distant coastlines. Emile Okal of Northwestern University in Evanston, Illinois has observed that T-phase waves produced by landslides can be heard by hydrophones (underwater microphones) of the sort used to detect submarines. Dr Okal has used this technology to identify tsunamis caused by landslides (ie, the sort most likely to be dangerous, and thus require evacuations to be organised). He has also been able to process seismograms and identify differences between the seismic signals from earthquakes that produce tsunamis directly and those that trigger tsunami-producing landslides.

Merely detecting tsunamis, though, is not enough. Tsunamis must be classified to predict the level of danger. One way of doing that is by computer modelling. Models developed by Vasily Titov, at NOAA, and Costas Synolakis, at the University of Southern California, can predict the size and shape of the waves that will be generated by a particular tsunami, as well as the resulting coastal inundation. Knowing how far inland a tsunami will penetrate should help the authorities to evacuate the right areas.

Technology, though, can do only so much. The best protection, according to Dr Synolakis, is common sense. Coastal dwellers must be able to recognise the signs of a possible tsunami—such as strong, prolonged ground shaking—and seek higher ground at once. As with any hazard, the more informed the public are, the better their chances of survival. For instance, after the Papua New Guinea tsunami, an international team was dispatched to Vanuatu, a group of islands in the Pacific, where they showed videos of tsunamis to the villagers. When a tsunami struck Vanuatu in 1999, only five people died in it. The message is clear enough. There is no way to stop a tsunami once set in motion, but there is certainly a way to avoid getting killed by one. Run like hell. ■

Volcanoes

Plumbing the depths

A new understanding of what goes on under volcanoes

HOW is a volcano "plumbed in" to the Earth? Does Mount Pinatubo have any U-bends in its pipe-work and how many twists and turns are there in the conduits underlying Mount Etna's fireworks? The answer is fundamental to understanding how volcanoes work, and could be crucial to predicting when a particular volcano is next going to blow.

The traditional view is of a volcano being fed by a magma chamber that lies at the base of the Earth's crust. A few pipes lead up to the surface, each ending in a volcanic vent. Magma (as liquid rock is known before it erupts) periodically spurts out of these pipes. But that idea is being challenged by a group of geologists who argue for a more complex plumbing system of "magma-mush" columns—a network of magma-filled cracks that finger their way up through the crust. Among these geologists are Keith Putirka, of California State University, and Christopher Condit, of the University of Massachusetts, Amherst. And they think they have some evidence to back the idea up.

The answer lies in the magma itself. Dr Putirka and Dr Condit reckon that lava (as magma is called once it has erupted on to the surface) from a particular volcano will have been altered chemically by its journey through the crust in ways that betray the details of that journey. In a paper in this month's *Geology*, they apply their method to lava from the Springerville volcanic field in Arizona.


From the depths to the heights

Dr Putirka and Dr Condit are especially interested in the composition of a mineral called clinopyroxene. When magma pauses on its journey through the crust, it begins to cool. Crystals, including crystals of clinopyroxene, then start to form in it. The exact composition of the clinopyroxene, though, depends on the pressure under which it is forming. And that, in turn, depends on the depth. In particular, more pressure causes the mineral to be richer in sodium. So the sodium in clinopyroxene acts as a barometer that tells you at what pressure (and hence depth) the magma paused on its way to the surface.

At Springerville, Dr Putirka and Dr Condit discovered two levels in the crust where magma had paused and pooled before bursting through to the surface. The first was in the middle of the crust, at a depth of around 26km (16 miles), while the second was much nearer the surface—12km down. Crucially, they found no evidence for magma pooling at the base of the crust (a depth of around 40km at Springerville), suggesting the traditional model is plain wrong. And further support for the magma-mush-column idea has come from Bruce Marsh, of Johns Hopkins University in Baltimore, who has been studying an exposed section of Antarctic crust that reveals a cross section of pipes and pools within an ancient volcano.

Since the depths at which magma forms pools under a volcano are likely to influence the type of volcanic eruption at the surface, this information could help to predict a volcano's behaviour. Though little is known for sure, this being such a recent discovery, it seems likely that some plumbing structures will prove prone to producing infrequent, explosive eruptions, while others yield a steady trickle of lava at the surface.

That, of course, needs investigation. And Dr Putirka and Dr Condit are now doing so by studying other volcanically active areas. If they do uncover a relationship between a volcano's plumbing system and the size and timing of its eruption, it could lead to more accurate long-range forecasts for volcanoes. ■