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ENORMOUS VOLCANIC ERUPTIONS

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Huge volcanic eruptions are the only one of two natural hazards that can cause global catastrophe, the other being the impact of an asteroid. In the very short history of civilisation, a few thousand years, there have been comparably few volcanic eruptions, which have been large enough to have global effects. Such events include very large explosive eruptions, such as Tambora, Indonesia in 1815. Much larger magnitude eruptions have happened regularly when time scales of millions of years are considered. Such extreme eruptions perturb global climate for several years and can have severe environmental impacts and consequences. The modern globalised world is arguably uniquely vulnerable to very large volcanic eruptions, making the study of their return periods, possible environmental effects and consequences a key goal of volcanology.

There are thousands of active volcanoes on the Earth, although many of them are located in the oceans. There are at least 1500 active volcanoes on land or on islands, but only 551 of them have had historic eruptions. Long dormant volcanoes therefore make up the majority and at least one volcano erupts on earth every 2 years that has no historical record. The local impacts of eruptions and include economic losses, loss of life and disruption of livelihoods. However, the largest explosive eruptions can have global reach with major changes to global climate and unusual weather for the few years that follow. Over 800 million people live within 100 kilometres of an active volcano. Exposure and vulnerability to major volcanic eruptions are increasing as a consequence of population growth, development and globalisation.

There are two measures of the size of an explosive eruption, namely magnitude and intensity. Magnitude is the total amount erupted and is measured either as the mass in kilograms or the volume of hot molten rock erupted in cubic kilometres for the largest eruptions. A widely used magnitude scale, comparable to that used for earthquakes, is used for volcanic eruptions based on erupted mass. On this scale the famous eruption of Vesuvius that destroyed Pompei is a magnitude 6.5 eruption as was the eruption of Mount Pinatubo, Philippines in 1991, the largest eruption of the 20th century. However, there have been much larger eruptions. The eruption of Tambora, Indonesia in 1815 of magnitude 7 is the greatest eruption on Earth in the last few hundred years, erupting a staggering 40 cubic kilometres of molten rock. Super-eruptions are defined as magnitude 8 or above, 10 times bigger than Tambora. One of the greatest eruptions of Earth's history with a magnitude exceeding 9 occurred at Toba 74,000 years ago to form the World' largest volcanic crater, measuring 100 km long by 30 km wide. The Toba eruption erupted about hundred times more molten rock than Vesuvius in AD79.

The intensity is the amount of molten rock erupted every second and so is a measure of the rate at which energy is released. Colloquially, intensity is sometimes considered a measure of violence. The rates are truly enormous in big explosive eruptions. By way of example in the 1980 eruption of Mount St Helens the intensity was ten thousand cubic metres per second, which is about the volume of the Tower of London erupted every 3 seconds! The most violent eruption yet known occurred in 180AD when 15 cubic kilometres of molten rock were erupted from the Lake Taupo volcano, New Zealand. That's enough to cover the whole of greater London in a layer 150 metres thick.

What happens in explosive eruptions? Magma (molten rock) accumulates several kilometres underground and pushes its way to the surface. Magma is so explosive because at depth where pressures are high volcanic gas (mainly water) is dissolved. However, at the Earth's surface the gas bubbles out violently expanding and creating high transient pressures which rip the magma apart mostly into tiny fragments called volcanic ash. The gas and ash jet out of the volcano at speeds of hundreds of kilometres per hour mixing with cold air. There are two basic phenomena that can happen. In one, so much air is heated by the jet that an enormous cloud of ash, gas and air rises up into the stratosphere often reaching heights of 20 to 50 kilometres above the Earth's surface. In other cases, the mixture of ash, gas and air is denser than the atmosphere and collapses onto the ground to form hot pyroclastic flows with temperatures of hundreds of degrees centigrade and speeds of many hundreds of kilometres per hour in the largest eruptions. In the AD 180 eruption of Lake Taupo, the flows easily flowed over mountains a kilometre high and spread to distances of almost 100 kilometres. Nothing can survive such flows.

The huge volcanic clouds spread out rapidly in the stratosphere to form gigantic clouds hundreds to thousands of kilometres in diameter when observed from space. Fine particles of volcanic dusts and volcanic gases spread quickly. In the case of the eruption of Mount Pinatubo the ash dust and gas encircled the earth around the equator within 3 weeks and the whole planet in a few months. In terms of affecting the Earth's atmosphere and climate the most important volcanic gas is sulphur dioxide, which reacts with water in the stratosphere to form tiny droplets of sulphuric acid. These droplets (known as aerosols) stay in the atmosphere for a few years but eventually the large-scale air currents move them to the poles where they gradually rain out and the Earth atmosphere clears. The first year is the worst with the Earth becoming shrouded in acid mist which reflects the suns energy back into space. Consequently, the climate cools resulting in what is known as a volcanic winter.

The global effects of huge explosive eruptions are quite dramatic. 1816 was known as the "year without a summer" and followed the 1815 eruption of Tambora in Indonesia. Overall there was an estimated 1.5^{o}C cooling of the Earth's atmosphere in 1816. This does not sound very much, but it only takes a cooling of 4^{o}C for a full-blown Ice Age. The climate effects though are more complicated than a simple cooling everywhere. The aerosol mist also absorbs heat coming in from the sun and changes the global patterns of air movements so that some areas get much colder than average and some places actually get hotter than usual. The climate impact is illustrated by the weird weather in New England in the summer of 1816. Farmers sowed their crops in the spring by snow and frosts occurred in June, so they sowed again but more snow and frosts in July and then August destroyed most of the crops and wheat prices in the USA tripled. It was just as bad in Europe and there was widespread food shortages and starvation set in.

Understanding of the climate effects of huge eruptions advanced greatly in 1991 when Mount Pinatubo erupted. In the modern era of satellites, the change in climate was documented in detail. Furthermore, climate scientists were able to compare the observations of these changes favourably with models of the Earth's climate. Such models are the same ones used to forecast global warming. There were other effects. The eruption of volcanic chlorine in 1991 led to an ozone hole appearing over northern Europe in 1992. Another strange outcome was that for a few years the rate of increase of greenhouse gas carbon dioxide decreased. This phenomenon has not been fully explained but one possibility is that very fine volcanic dust can fertilise plankton in the oceans which then extracts carbon dioxide from the atmosphere and thus counteracts the input of CO_2 from fossil fuels.

Of course, Pinatubo, although one of the largest eruptions of the 20th century is still only 1% or less of the energy output of a super-eruption. What happened to the Earth's climate when there is an eruption like Toba? We don't yet have a very good answer to this question. Climate models can be run with much larger loadings of sulphur dioxide. The Met Office has made such studies and finds global cooling can be 10 to 15^{o}C and the deep freeze can last at least a decade. However, the predictions of these models are very uncertain partly because we do not have very good estimates of how much sulphur was erupted by the Toba volcano. It was certainly much more than Pinatubo or Tambora but likely not 100 times more. Also, the effects of climate may not be proportional to the amount of sulphur in a simple way.

How often do huge eruptions occur? In order to answer this key question a global database of large explosive eruptions of magnitude 4 or greater has been developed at University of Bristol from historical and geological records of eruptions. We can apply statistical analysis to this database and find that magnitude 7 eruptions happen every few hundred years while super-eruptions of magnitude 8 or more happen every 17,000 years. However, these estimates are rather uncertain. One place to obtain another record of global volcanism is Antarctica. Every time there is a major eruption the aerosol droplets of sulphuric acid deposit in Antarctica and get frozen into the ice. They are easily identified as the acid causes a large increase in the electrical conductivity of the ice. Thus, the record of the hundreds of thousands of years of major explosive eruptions is preserved in the ice which can be recovered by drilling. Many eruptions larger than magnitude 7 have been found. The observations are consistent with a super-eruption every 20,000 years or so.

Where will future huge explosive eruptions be located? Perhaps less likely are volcanoes which have had recent eruptions of this kind, so Krakatoa, Pinatubo and Tambora are not high on the list. These volcanoes may have exhausted much of the molten rock stored underground and need building up again. We might look then at volcanoes with calderas that have not erupted for a long time or earmark volcanoes which have features characteristic of volcanoes before they formed a caldera. At least some such volcanoes build up large volcanic cones from numerous eruptions and then become dormant for many thousands of years before the big one. A team at Bristol University are engaged in a collaborative project with Turkish geologists and we think that we have identified a volcano called Erciyes Dag in Central Anatolia which has the hallmarks of a volcano with these characteristics. The volcano is close to the City of Kayseri with 1.3 million inhabitants and a dramatic population growth of 5% per year. New apartments and industrial complexes are being constructed on top of pyroclastic flows erupted about 8,000 years ago. Our project is aimed at evaluating the hazards and risks to help Turkish colleagues develop a programme of research and monitoring with the aim at protecting people. There is a good case to be made that an international programme of work should begin to identify locations for future huge eruptions and help prepare for globally significant event that is inevitable.