NATURAL HAZARDS

Humans have always had to deal with "unpredictable" **natural hazards**—earthquakes, volcanic eruptions, floods, avalanches, droughts, fires, tornadoes, hurricanes, and so forth. For most of human history such phenomena were beyond human control : they were neithere caused by humans, nor was there much humans could do to predict their consequences or mitigate (make less severe) their consequences.

Although many acts of nature still cannot be controlled, we have learned to better predict their occurrences and mitigate their effects. Furthermore, we have come to understand that some types of phenomena have a large anthropogenic (produced or caused by humans) component. Flash floods and avalanches may be caused, or at least exacerbated, by human deforestation in hilly regions. Abnormal droughts, storms, and other unusual weather phenomena may be caused or magnified by human interference with the atmosphere, such as the emission of high levels of greenhouse gases. Earthquakes, at least on a local level, may be caused by the pumping of fluid wastes into rocks lying deep below the surface.

As the Earth's human population increases, the damage done by naturally occurring, periodic "disasters" is magnified. A coastal area may be hit by a major storm once every century, a river may swell over its "normal" banks covering the flood- plain only once every few centuries, or a naturally set forest fire may periodically burn off dead underbrush and litter on the forest floor. Viewed on a temporal scale of millennia (thousands of years), such events form an integral part of the natural ecosystem cycle; from a natural, holistic perspective, they are not disasters at all. But when dense human populations inhabit a coastal area or a river's floodplain and depend on a forest for lumber products or for scenic beauty, these events are perceived as terrible disasters—and so they are from a human perspective. But they are disasters that, given a little knowledge of the natural, world, should have been easily anticipated. In this section, we briefly introduce some of the basic types of natural hazards that civilization must face as we continue to live in a natural environment.

Earthquakes and Volcanoes

Earthquakes and volcanic eruptions are geological phenomena that humans may be able to predict (though not always), but can virtually never control. With few exceptions, earthquakes and volcanoes are due to processes that take place deep within the crust and mantle. Volcanic eruptions are usually accompanied by at least minor to moderate earthquakes, but very large earthquakes can occur in the absence of volcanic activity. As we we have already discussed, earthquakes and volcanic activity are associated with the boundaries of the lithospheric plates, and can be explained in terms of moving and/or subducting plates. But earthquakes (and less commonly volcanoes) can also occur in the middle of plates; indeed, no place on the surface of Earth is immune to earthquake activity.

Earthquakes

Earthquakes are essentially shock waves that originate when large masses of rocks suddenly move relative to each other below the Earth's surface. For instance, along a plate boundary where two lithospheirc plates are sliding past each other, the plates my "hang up", allowing strain (frictional drag) to accumulate until it is finally relieved by rock movement—causing an earthquake. Earthquakes can originate up to 450 miles (700 km) below the surface. When the sudden rock movement occurs, various types of shock, or seismic, waves are transmitted through the Earth, causing the shaking or trembling felt by humans on the surface. A large earthquake may be detectable around the world.

Earthquakes are a constant threat to human life and well-being in some areas. Perhaps the most devastating set of earthquakes occurred near Shensi, China, in 1556 killing an estimated 830,000 people. A dozen earthquakes that caused the death of 100,000 people or more, have been recorded. Estimates are that, on average earthquakes kill at least 10,000 people a year and cause about $500 million in property damage. Japan, a nation always at risk for earthquakes, suffered devastating consequences in 1995 when a quake hit the Kobe area killing over 5000 people, injuring another 25,000 and initially leaving over 300, 000 homeless.

The intensity, magnitude, or strength of an earthquake is commonly measured either on the Richter scale (in North America) or the Mercalli scale (in Europe). The Richter scale is based on the amolitude of the seismic waves recorded by seismographs (instruments that record the motions of the Earth's surface) coming from a particular earthquake. The Ricther scale is a logarithmic scale so that every unity corresponds to a 10-fold increase in the amplitude of seismic waves. Thus a 7.0 earthquake is characterized by seismic waves with an amplitude of 100 times that seen in a 5.0 earthquake. Theoretically, the Richter scale has no upper limit, but some of the largest recorded earthquakes (such as the Lisbon earthquake of 1755 immortalized in Voltaire's *Candide*) have been ranked at about 8.9–9.0 (Table 1).

The Mercalli scale is more qualitative, based primarily on observations of the effects caused by an earthquake close to its origin. This scale classifies earthquakes into a dozen basic categories, from instrumental (earthquakes so small that they can be detected only on seismographs) to catastrophic (earthquakes where local destruction is virtually total). The Mercalli scale is easily related to the Richter scale in an approximate way.

Much research has recently gone into devising ways to predict earthquakes in both the long term and the short term. Some work has attempted to discover long-term earthquake cycles, based on the movements of the lithospheric plates and also perhaps correlated with such phenomena as meteoritic impacts, variations in the Earth's geomagnetic field, sunspot activity, and variations in the length of the day. Such work is very difficult pursue, and no method has been able to predict long-term earthquake events with any degree of accuracy.

As for the short term, researchers have identified several precursors that often signal the probability of a major earthquake in earthquake prone areas. The most commonly utilized precursors are unusual land deformation. Seismic activity, geomagnetic and geo-electric activity, groundwater fluctuations, and natural phenomena such as animal behaviour and unusual weather conditions.

Although we usually do not think of earthquakes as being caused by human activity, some earthquakes are indeed anthropogenically induced (caused by humans). Earthquakes have been induced by nuclear blasts, conventional blasting, mining activities, fluid injection and extraction from rocks deep underground, and the building of dams and reservoirs. A now classic example of human-induced faulting and seismic activity occurred near Denver in the early 1960s, when nerve-gas waste was disposed of by pumping it down a well to great depths where it would be below groundwater supplies. Pumping the waste down the well at high pressures triggered a series of earthquakes. Since then it has been verified experimentally in oil fields that puming fluids into the ground (and in some cases extracting them, such as the pumping out of oil) can induce seismic activity.

The most important cause of human-induced earthquakes seems to be the construction of large dams and reservoirs. In the case of at least six major dams around the world, including Hoover Dam on the Colorado River, earthquakes of a magnitude greater than 5 on the Richter scale (moderately strong earthquakes, capable of minor damage) have apparently been induced by the impounding of water in large reservoirs. Over 1000 earthquakes of various magnitudes have been felt since Hoover Dam was constructed in 1935; before 1935 the area was not known for earthquake activity. Worldwide dozens of dams have been associated with seismic phenomena. It is thought that water in the reservoir may penetrate the underlying bedrock and cause rock slippage that generates earthquakes. The huge mass of water in the reservoir also exerts tremendous pressures on the underlying rocks, and this can cause downwarping and subsidence of the land's surface.

TABLE 1

Some of the Largest Earthquakes, by Magnitude on the Richter Scale

Year	Location	Magnitude
1755	Lisbon, Portugal	9.0
1906	Andes (Colombia)	8.6
1906	Valparaiso, Chile	8.4
1906	San Francisco, United States	8.25
1911	Tienshan, China	8.4
1920	Kansu, China	8.5
1923	Tokyo, Japan	8.2
1933	Japanese trench	8.5
1950	North Asom, India	8.6
1960	Chile	8.3-8.9
1964	Alaska	8.6
1976	Tangashan, China	8.2
1977	Sumba, Indonesia	8.9
1977	Argentina	8.2
1979	Indonesia	8.1
1985	Mexico City, Mexico	8.1
1994	Bolivia	8.2
2000	Bhuj, India	8.0
2001	Near Coast of Peru	8.4
2004	Northern Sumatra	9.1
2005	Indonesia	8.6
2006	Kuril Islands, Russia	8.3
2010	Chile	8.8
2011	Honshu, Japan	9.0
2012	Northern, Sumatra	10.0
2015	Illapel, Chile	8.3

Given that humans have inadvertently caused earthquakes, some people suggest that in the future we might be able to intervene to control natural earthquake activity. Perhaps, in an active earthquake zone, we could selectively induce a series of small earthquakes by either injecting or extracting fluids from the rocks. The small, relatively harmless earthquakes might relieve the strain on the rocks and thus allow us to avoid a single large, very destructive earthquake.

Volcanoes

Volcanoes are basically spots in the Earth's crust where hot, molten rock (magma) wells up to the surface. Active volcanoes are found almost exclusively in three geological settings : at convergent plate margins where one lithospheric plate subducts under another, melting the rock which rises to the surface as volcanoes (for instance, in Indonesia and elsewhere along the Pacific rim); at divergent plate margins where magma wells up to the surface as two lithospheric plates pull apart from each other, forming a rift (as in the middle of the Atlantic Ocean); and over mantle hot spots, areas that lie over a hot mantle plume that breaks through the crust and spews molten rock onto the Earth's surface (as in the Hawaiian Isands).

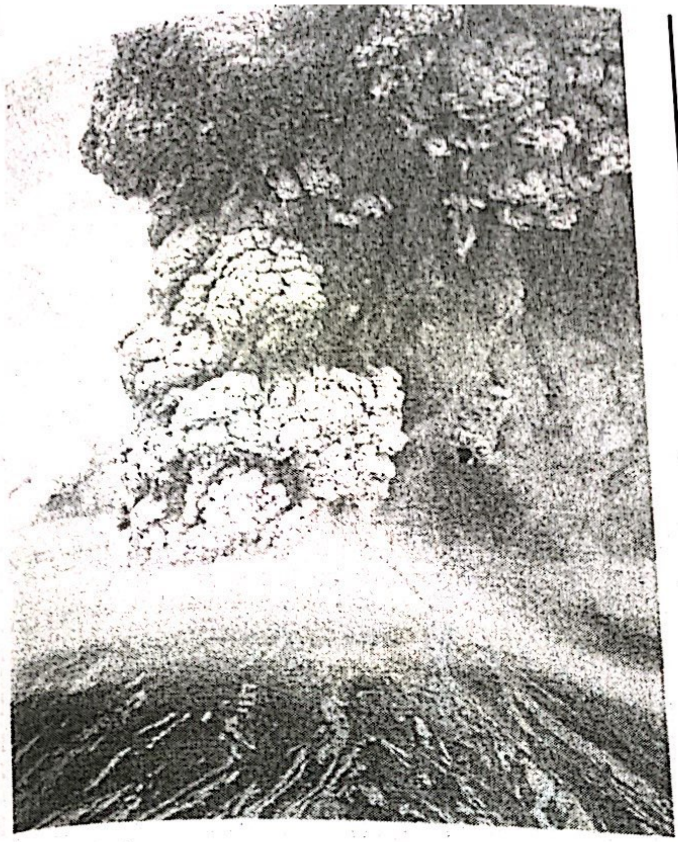
TABLE 2

The Mercalli Scale of Earthquake Intensity

Scale	Intensity	Description of Effect	Maximum Acceleration (MM SEC^{-2})	Corresponding Richter Scale
I.	Instrumental	Not felt except by a very few under especially favourable circumstances.	< 10	
II.	Feeble	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.	< 25	

III.	Slight	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like a passing truck.	< 50	< 4.2
IV.	Moderate	During the day felt indoors by many outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing automobiles rock noticeably.	< 100	
V.	Slightly strong	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.	< 250	< 4.8
VI.	Strong	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage sight.	< 500	< 5.4
VII.	Very strong	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving automobiles.	< 1000	< 6.1
VIII.	Destructive	Damage slight in specially designed structures; considerable in ordinary substantial buildings,	< 2500	

	with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns monuments, walls. Heavey furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving automobiles dirsturbed.		
IX. Ruinous	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.	< 5000	< 6.9
X. Disastrous	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations destroyed; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over river banks.	< 7500	< 7.3
XI. Very Disastrous	Few, if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.	< 9800	<8.1
XII. Catastrophic	Damage total. Practically all works of constryction are damaged greatly or destroyed. Waves seen on ground surface. Objects are thrown upwards into the air.	< 9800	> 8.1



Volcanoes can be classified according to whether they extrude predominantly basaltic or andesitic magma. Volcanoes at divergent plate boundaries and hot spots tend to produce basaltic magma which is relatively silica-poor and originates from the mantle. Andesitic magma contains a higher percentage of silica and is generally formed from the remelting, differentiation, and recrystallization of previously existing crustal or mantle material. Thus andesitic volcanoes are commonly found in subduction zones where rock is remelted.

Basaltic magmas are hotter and much less viscous than andesitic magmas, which tend to contain a much higher percentage of gases (often predominantly water vapour). Consequently, whereas lava may flow smoothly out of the crater of a basaltic volcano, andesitic volcanoes tend to be much more explosive, shooting out steam and other gases, rock fragments of various sizes, and volcanic ash.

Volcanic eruptions can affect humans on both a local and global scale. On a local level, volcanic eruptions can destroy local towns and cities. As we have seen, large volcanic eruptions can have worldwide effects by spewing dust, ash, and gases (including material that can form acid rain) into the atmosphere, affecting global weather patterns. For example, the 1883 eruption of Krakatoa, a volcano in the Sunda Straits between Sumatra and Java, spewed 4 cubic miles (18 km^3) of rock, ash, and other debris into the atmosphere to heights of 50 miles (80 km). The materials initially reduced the amount of incoming solar radiation reaching the Earth's surface by an estimated 13%. Even two years later, the amount of incoming slolar radiation over France was still 10% below normal.

The eruption of Krakatoa also set off tsunami that caused damage throughout the Pacific basin. Tsunami (Japanese for ''harbour wave'') are huge waves, sometimes caused by explosive volcanic activity in or near the oceans or by large undersea earthquakes (usually registering higher than 6.5 on the Richter scale) or landslides. Fortunately, tsunami are relatively rare; however, they can be extremely destructive. The waves can range in height from less than 3 feet (1m) to nearly 200 feet (60 m).

Even with modern technology and knowledge, predicting future volcanic activity is extremely difficult. Although we know where to expect active volcanoes relative to lithospheric plates and can determine if a volcano is active or dormant (based on the time since its last eruption), we cannot predict exactly the timing and intensity of future eruptions. Researchers use many of the same techniques used for predicting earthquakes. Seismic activity, land deformation, geomagnetic and geo-electric parameters can be monitored. Any anomalous behaviour, like a change in seismic activity or active deformation of the sides of a volcano, can herald an imminent eruption. But estimating the strength and type of eruption that will occur is difficult. The analysis of gases given off by volcanoes holds some promise for predicting volcanic activity, at least in the short term. But sampling gases being vented from an active volcano that may be near eruption can be very difficult and dangerous.