Life Cycles

11

There is, in nature, perhaps nothing older than motion….
Galileo Galilei (1564–1642)

Recorded history, the period during which we have extant written records, spans less than 10,000 years on Earth. With very few exceptions, the Earth itself has been relatively unchanged during that span of time. However, if we could somehow speed up the clock and view a movie of the Earth over a much longer period of time, the Earth might indeed appear to be a living and breathing entity, as we will see in this chapter on life cycles.

The Big Bang

Scientists estimate that the Big Bang, originally proposed by Georges Lemaitre (1894–1966), occurred about 13.7 billion years ago. They estimate this by using mechanics—Albert Einstein's (1879–1955) general theory of relativity to be exact. Vesto Slipher (1875–1969) proposed that based on the red shift observed in the wavelengths received on Earth from stars throughout the galaxy it is possible to estimate the velocity that objects are moving away from one another. From these estimates one can extrapolate backwards in time and estimate the point in time at which all of these objects were at approximately the same location, ergo the Big Bang. Thus, we can infer that mechanics undoubtedly existed before the historical record began. In fact, mechanics was born the very moment that the Big Bang occurred.

By observing very remote objects in the universe it is possible to gather important information regarding the distant past. Using the Hubble telescope, astronomers have recently observed a quasar that is 13 billion light years from Earth. That means that the light from this star began its journey to Earth 13 billion years ago, when the universe was less than a billion years old, and interestingly, *almost nine billion years before the earth itself was formed!* The information that scientists have received from such distant objects thus far has confirmed that the mechanics principles that we are familiar with here on Earth not only seem to hold everywhere in the universe, but they also seem to have continued to apply throughout the history of the universe. For that reason, we call them "universal" laws (Fig. 11.1).

D. H. Allen, *How Mechanics Shaped the Modern World*,
DOI: 10.1007/978-3-319-01701-3_11,

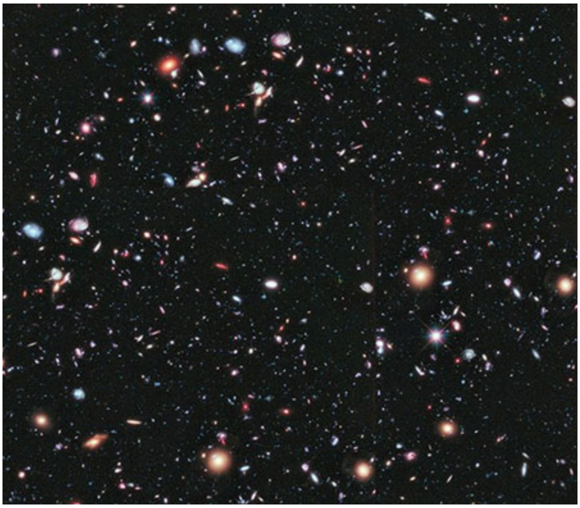


Fig. 11.1 Hubble telescope reveals the deepest view into the universe in a photograph that took 10 years to complete. Extreme deep field image captures thousands of galaxies billions of light years away

Scientists also tell us that there are four different kinds of forces (they actually call them “interactions”) in nature: gravitational forces, electromagnetic forces, strong atomic forces, and weak atomic forces. The weakest of all of these is the gravitational force, but despite this fact, by a quirk of nature, it is gravitational forces that govern our universe. Gravitational forces are inversely proportional to the square of the distance between the objects exerting the forces on one another (see Chap. 7), and because of this, gravitational forces act over very long distances, thus overtaking the other three forces in importance. Indeed, galaxies, solar systems, planets, moons, asteroids, comets,—all are formed by agglomeration resulting from gravitational forces. This is an example of mechanics on a truly enormous scale.

When the Big Bang occurred 13.7 billion years ago, the matter within the cosmos soon began interacting due to gravitational forces. And when our solar system was later formed, the planets evolved from countless impacts of bodies exerting gravitational forces on one another.

How do we know all of this today? The answer is that scientists study the motions of bodies in other solar systems across the universe. In other words, scientists use mechanics to measure the motions of objects that they observe through very sophisticated telescopes that are capable of distinguishing motions of stars and the objects orbiting them. For example, in most cases scientists don’t actually “see” a distant planet. Instead, they typically detect periodic motions of the star (or sometimes even two stars, called a binary system) that the planet of interest is orbiting, and from the frequency and amplitude of the motion of the parent star, scientists can utilize mechanics to estimate the mass and distance that the inferred planet is from the observed star. Armed with these two pieces of information, scientists can deduce additional information about the planet.

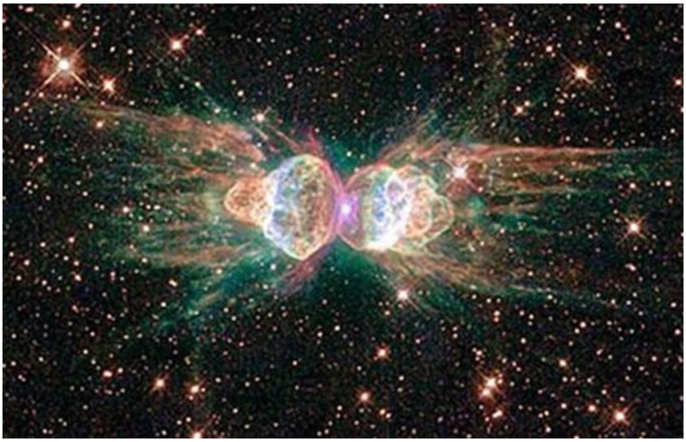


Fig. 11.2 The ant Nebula, a cloud of dust and gas whose technical name is Mz3, resembles an ant when observed using ground-based telescopes. The nebula lies within our galaxy between 3,000 and 6,000 light years from earth

Most of these stars are near to our planet on a cosmological time scale, meaning that they are a small number of light years away, so that the events that are being detected from these nearby solar systems have occurred in the very recent past (Fig. 11.2). But a few of them are also very far away (meaning that we are also looking into the distant past). By looking through this window into the past, it is possible to construe certain information regarding the historical nature of our universe. What we now know is that there are new solar systems being formed all the time. There are also old solar systems, some of which are in the process of dying (Fig. 11.3)

Fig. 11.3 Nebula NGC 2392, called Eskimo because it looks like a face surrounded by a furry hood. The hood is, in fact, a ring of *comet-shaped* objects flying away from a dying star. Eskimo is 5,000 light years from earth

Fig. 11.4 The trifid Nebula, 9,000 light years from earth, where new stars are being born

In fact, there is a broad distribution of ages of solar systems throughout the universe going right back to within a billion years after the Big Bang. It seems that galaxies, solar systems, and even planets are being formed all the time (Fig. 11.4). Just like humans, each one has a life span before they die, but their life span is usually much longer than that of any biological entities that we are aware of.

Our solar system appears to be almost middle aged, having been formed about 4.5 billion years ago, and with a total life expectancy of about 10 billion years. This last approximation is based on the amount of fuel scientists estimate is remaining for the sun to burn before it is extinguished.

Our solar system could perish at any time by a number of means that have low statistical probabilities, but that are nevertheless observed to occur elsewhere in the universe. Among these are strikes by asteroids large enough to upset the orbit of a planet sufficiently for that planet to impact another planet or even the Sun, thus causing the solar system to essentially become unstable and either explode or be cast off into space. Another possibility is that the large gas giants Saturn and Jupiter could exert gravitational forces on one or more other planets that are sufficiently large to upset the planetary orbits, thus causing them to change their orbits into an unstable configuration, thereby leading to the destruction of our solar system. Some scientists think that this jostling about of our planets may have already occurred at some point in the past, as it has been postulated that Uranus and Neptune may have interchanged their orbits.

Any of these theorized scenarios for the possible destruction of our solar system involve mechanics—motions involving kinetic energy so large as to be capable of destroying our entire solar system. Scientists have observed just such events elsewhere in our own galaxy (Fig. 11.5). We have only recently been able to determine that such impact events are still occurring, albeit with decreasing regularity, in our now middle-aged solar system. Fortunately for us, events on this scale seem to occur rarely, as we will see in the next section.

Fig. 11.5 The glowering eyes from 114 million light years away are the swirling cores of two merging galaxies called NGC 2207 and IC 2163 in the distant canis major constellation

Meteors

Much of what we know about meteor strikes emanated from the diligent work of the geologist Eugene Shoemaker (1928–1997) (Fig. 11.6). For his Ph.D. thesis at Princeton University, Dr. Shoemaker studied the Barringer Meteor Crater near Winslow, Arizona. This crater, considered by many to be the most perfectly intact meteor crater on Earth, was created about 50,000 years ago by a meteorite about 50 m in diameter (Fig. 11.7).

In the 1960s Dr. Shoemaker hypothesized that those round shapes on the Moon were not heretofore suspected extinct volcanoes, but that they were instead the remnants of meteor strikes. Of course, if true his theory would have enormous

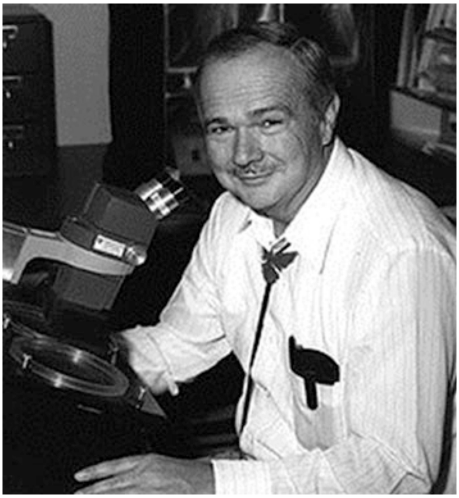


Fig. 11.6 Photograph of Dr. Eugene Shoemaker

Fig. 11.7 Photograph of Barringer Crater, Arizona

implications for the Earth as well. This is due to the fact that our planet exerts much larger gravitational forces than does the Moon, thus implying an even greater likelihood of meteor impacts on Earth.

Dr. Shoemaker's assertions were initially discounted by many people, but he was undaunted by their doubts. Instead, he went searching for meteor craters on Earth. Other than the obvious Barringer Crater, there wasn't much to go on. But he kept at it, and eventually he began to hit pay dirt (literally).

Dr. Shoemaker was the first person to notice that meteor craters display a unique ring of shocked quartz called coesite from the pressure wave caused by the impact of the meteorite. Such pressures created by meteor impacts are so incredibly large as to cause chemical changes in the adjacent geologic structure, an example of coupling between mechanics and chemistry.

The most interesting meteor crater to me that Dr. Shoemaker discovered is in Nördlingen, in south central Germany. At the time that he was seeking corroboration of his theories there was very little satellite photography to rely on, but he had some images of the countryside surrounding Nördlingen that looked suspiciously circular in shape. He thus travelled to Nördlingen with a colleague and they climbed the small cathedral in the center of town to get a better look at the skyline surrounding the town. Things looked about right, but he still didn't have proof.

Dr. Shoemaker's eureka moment came when he climbed back down to Earth from the bell tower in Nördlingen and examined the stones used to make the cathedral walls (Fig. 11.8). He chipped some pieces off, and sure enough, a scan showed high levels of coesite, thus proving that it was a crater created by a meteor strike, now called the Nördlinger Ries crater, which has a diameter of 24 km. It was formed about 14.5 million years ago, during the Miocene.

Fig. 11.8 St. Georges Church, Nördlingen

There is another crater located 42 km to the west-southwest of the Nördlinger Ries crater called the Steinheim crater, which has a diameter of 3.8 km. The two craters are believed by scientists to have formed together in what is termed a binary event. Apparently one meteor split into two objects on encountering the Earth's atmosphere. Stones from the area also contain large amounts of microscopic diamonds, which were formed when the impact pressure caused naturally occurring graphite to form into diamonds, another example of a chemical process induced by mechanics.

Chemists explain this phenomenon using something called a phase diagram, which is nothing more than a graph of temperature versus pressure for a given atom or molecule that distinguishes the various bonding structures that are possible as functions of temperature and pressure. What is not stated explicitly on a phase diagram is the fact that pressure (as well as temperature) changes can be induced by mechanics, as in the case of meteor strikes on Earth. Thus, chemistry and mechanics are innately connected.

Dr. Shoemaker slowly assembled a growing body of evidence to support his contentions, but he wasn't finished yet. In 1993, Dr. Shoemaker, his wife Carolyn, and David Levy discovered a comet that was heading for Jupiter. It was subsequently named Shoemaker-Levy, and in July of 1994, it broke up into several meteors just before striking Jupiter in a string of spectacular explosions (make sure that you watch the film clip on YouTube!) (Fig. 11.9).

There was much excitement in the astronomy community, for this was the smoking gun as it were—the proof that Dr. Shoemaker's assertions regarding meteors, comets, and asteroids were correct. As we now know, those rings on the surface of the Moon are craters from meteor strikes instead of extinct volcanoes. And sure enough, within a few years of these revelations we had plenty of popular disaster movies predicting a catastrophic meteor strike on Earth. I'll bet you've seen several of them.

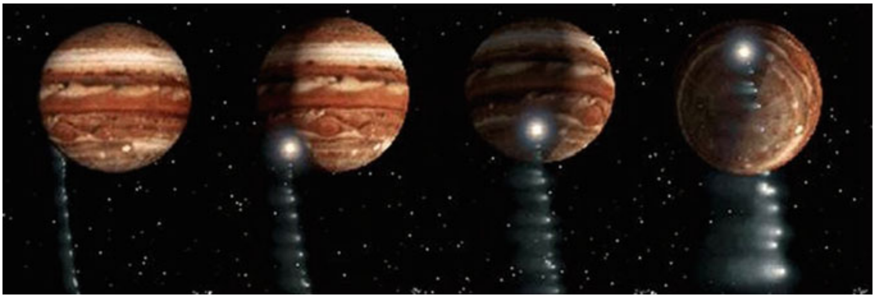
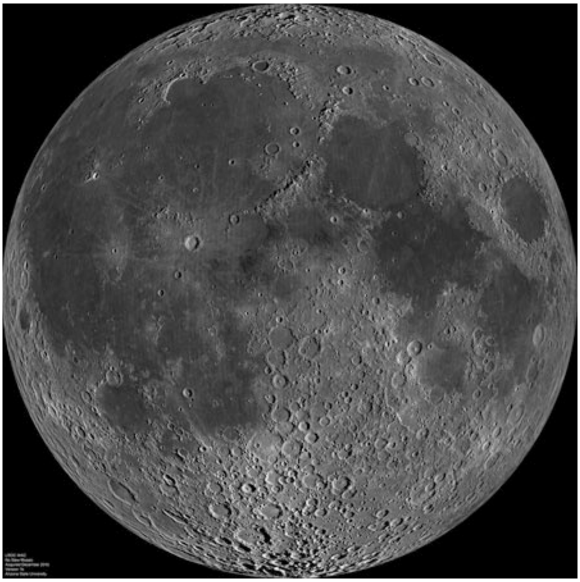


Fig. 11.9 Shoemaker-levy strikes Jupiter

Dr. Shoemaker was at one time in line to be one of the original astronauts in the 1960s, but he was excluded because he was diagnosed with Addison's disease. While that was surely not good for him, it may have been a good thing for the rest of the world. Otherwise, we might not have had all of these important discoveries regarding meteor strikes on Earth. And quite a few Hollywood movie employees would be out of work as well.

Dr. Shoemaker was unfortunately killed in an automobile accident in Australia while searching for a meteor crater. For his lifetime of scientific achievements, a portion of his ashes were transported to the Moon by the Lunar Prospector space probe, making him (at the time of this writing) the only human buried on the Moon (Fig. 11.10).

Fig. 11.10 Photo of the near side of the moon showing meteor craters



Geologists like to talk about a “geologic time scale”. This is very interesting stuff. I don’t want to go into too much detail here, because you can find a summary of geology in Bill Bryson’s excellent book entitled *A Short History of Nearly Everything* [106]. Fortunately for me, he didn’t cover a whole lot of mechanics, which I suppose is why the word *nearly* is in the title of his book.

A big part of the reason that the geologic time scale became important in this century is a by-product of carbon dating. If you find a chunk of geologic material, and you find a piece of biological material within it, you can guess how old the geologic material is by utilizing carbon (or other elemental) dating. This technique was initially developed by Willard Libby and his colleagues at the University of Chicago in 1949, for which Dr. Libby received the Nobel Prize in 1960.

The reader can look elsewhere for the details regarding this technique, but suffice it to say that the technique involves the experimental capture of the *motions* of decaying radioactive isotopes of carbon-14. Since all atoms are not carbon-14 in a given sample of carbon, it is therefore possible to estimate the age of a sample of carbon by determining the portion that is carbon-14. Thus, the measurement of the age of biologic material is determined by using our new-found friend mechanics. This is possible only in samples containing carbon, and this element is usually found prodigiously in biologic media. Thus, scientists look for dead creatures in samples of specimens whose age they are attempting to determine.

Carbon dating isn’t always correct, because either older or newer carbon-laced materials can get into the geologic media and corrupt the estimate. Nevertheless, geologists have managed to utilize this technique to date most of the earth’s geologic formations accurately. I will discuss this in more detail later in this chapter, but for now suffice it to say this: our planet’s surface is constantly on the move, and this is inherently a problem in mechanics.

One thing you can do with carbon dating is to determine when all sorts of natural disasters occurred in the past. For example, we have the famous Chicxulub meteor strike in the Yucatan that may be responsible for wiping out the dinosaurs around 65 million years ago (Fig. 11.11). This strike was discovered by geologist Glen Penfield in the late 1970s. He found large amounts of coesite (as well as iridium, an element found in meteorites) in the region, thus confirming the strike. The crater is approximately 180 km in diameter, and is estimated to have been caused by a meteorite approximately 10 km in diameter, thus making it one of the largest known impact sites on Earth. The date of the impact is estimated by using carbon dating to determine the age of biologic materials found within the stones at the site.

On a geologic time scale, meteor strikes are pretty few and far between on Earth. The most recent event was in Siberia in 1908 (a meteorite also struck Russia during this writing in February of 2013). This impact, called the Tunguska event, is the largest in recorded history, resulting from a meteor estimated at approximately 100 m in diameter.

There have been approximately 50 other meteor craters discovered and confirmed on Earth to date. Unlike those on the Moon, they are difficult to spot because we have a tectonically active shifting crust, as well as an atmosphere that produces rain, wind and subsequent erosion (See Chap. 10).

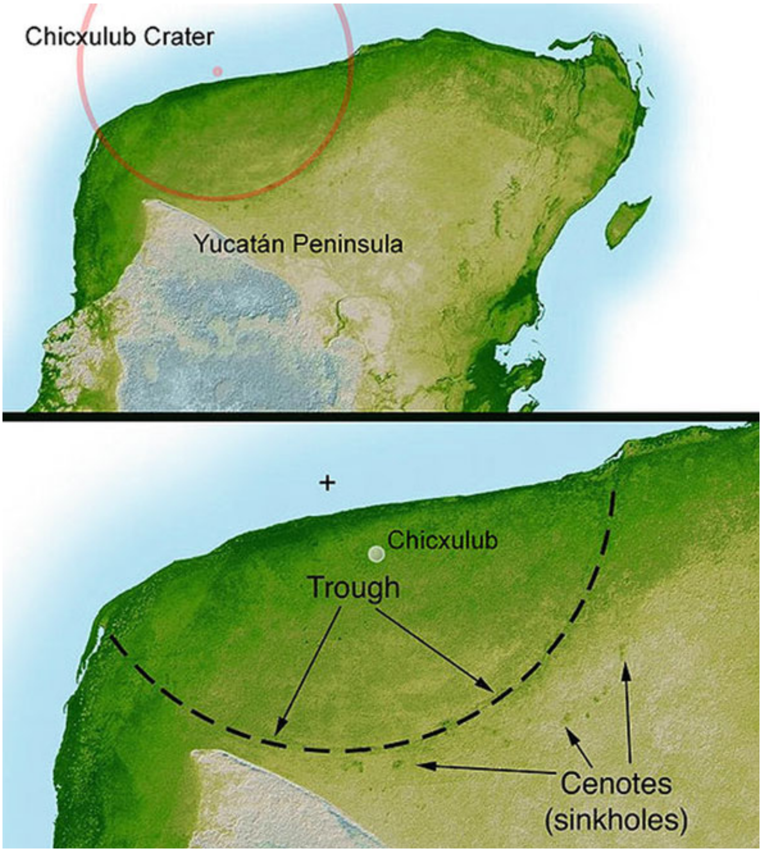


Fig. 11.11 Chicxulub crater

Of course, there have surely been a lot more than 50 meteor strikes on Earth in the past 4.5 billion years. After all, the Earth was formed early in our solar system's life due to the agglomeration of uncountable numbers of objects striking one another. But our geologically active planet has slowly wiped out the observable record of all save those that occurred since the Earth's geologic activity began to settle down, otherwise the surface of the Earth would look like the surface of the Moon. Thus, there are only a couple of known craters that are older than 2 billion years, and most are less than 500 million years in age.

Suffice it to say that the geologic record indicates that the probability of a large meteor strike on this planet on any given day is extremely remote. Furthermore, scientists nowadays have sophisticated mechanics-based tracking equipment that will give us plenty of advance warning if a large object heads our way. So don't pack up the car and start heading for the hills just yet. Still, should a kilometer (or greater)-sized object strike our planet, the kinetic energy contained within it will be sufficient to cause a global calamity that could wipe out most of the species on Earth, including our own (see Chap. 14).

Tectonic Plates

The current views of geologists were influenced by the meteorologist Alfred Wegner, who proposed the concept of continental drift in 1912. He noticed that the shape of the Eastern coast of South America bore a strong resemblance to the Western coast of Africa. Subsequent geologic examinations provided evidence that these two coastlines were at one time joined together.

While Wegner's views were initially discounted by the scientific community, he was eventually proven correct when it was discovered that the continents are drifting apart due to seafloor spreading. This is a fancy term that simply means that there are cracks on the sea floor out in the middle of the ocean that are slowly creating and spreading new surface material, and this is of course another example of global scale mechanics, this time involving long term flow of the Earth's crust.

The exterior of the Earth is composed of a series of tectonic plates that lie on the surface, called the lithosphere, which is about 200 km in thickness. These plates are relatively stiff and strong compared to the underlying layer, called the asthenosphere, which is viscoelastic (a combination of fluid- and solid-like), thus allowing the lithosphere to slowly slide over the asthenosphere. The plates slide due to a combination of gravitational forces, momentum induced by the Earth's spin, and most significantly by forces produced by convection of the underlying mantle. This produces a global scale problem in mechanics. These enormous forces slowly deform and translate the surface of the Earth over hundreds of millions of years.

About 200 million years ago the continents were all joined together (the last time) in a single super continent called Pangaea (from the Greek 'pan', meaning entire, and 'Gaia' meaning earth) by geologists. This term was apparently coined during a discussion on Wegner's theory in 1927. I will refrain from showing an image of Pangaea for the simple reason that through the miracle of the internet you can (and should) view a movie of the evolution of Pangaea on YouTube.

There are currently eight major plates covering the Earth's surface, as well as a number of smaller ones (Fig. 11.12). Because the continents are spreading apart in some places, it stands to reason that there must also be some places where the continents are coming together, since the surface area of the Earth is not changing. This is accomplished via plate subduction, which is another fancy term that simply means that one plate rides up over another. In other places the plates simply slide laterally with respect to one another (Fig. 11.13).

Relative motions between tectonic plates results in what we call earthquakes. The plates normally get stuck relative to one another for a period of time, but as the forces build up between the two plates attempting to slide relative to each other, eventually the forces will overcome the shearing load carrying capability of the two plates, and they will slip more or less instantaneously with respect to one another, thus producing an earthquake, which is nothing more than a mechanical wave passing through the Earth's crust.

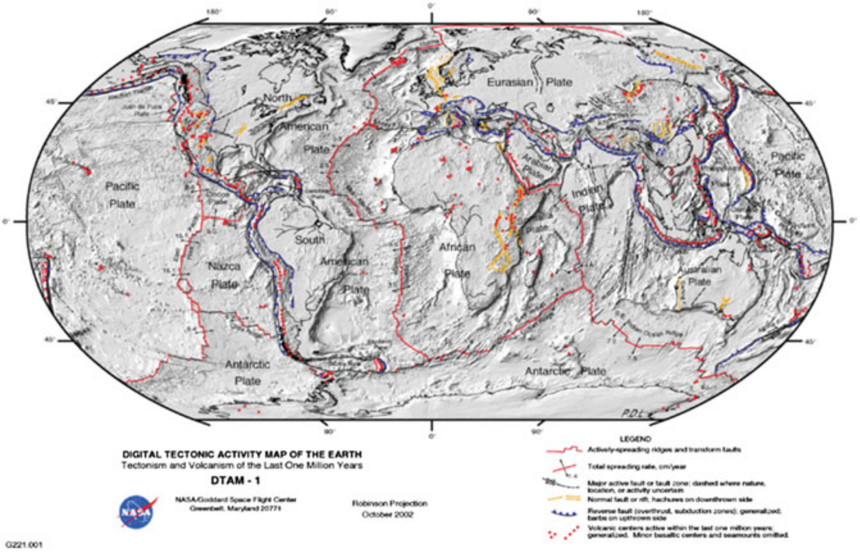


Fig. 11.12 The Earth's tectonic plates

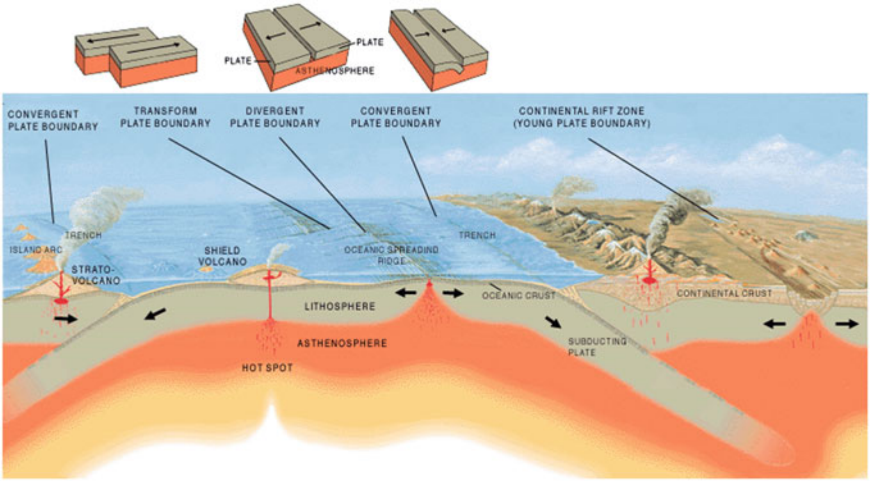


Fig. 11.13 Three types of tectonic plate boundaries

As described above, earthquakes can be caused by lateral sliding between two plates, or they can also be caused by one plate sliding on top of the other (subduction). This latter type can be particularly damaging when the two plates are in the ocean, because this type of earthquake produces a mechanical wave which may lead to a tsunami.

Water is a liquid. Liquids are viscous in shear, and elastic in compression. What this means is that they store energy extremely well in compression, but they dissipate it rather quickly in shear. So when a subduction zone produces an earthquake, the ocean wave that is produced is a compression wave, and this type of wave stores energy so well that it can cross an entire ocean without dissipating very much energy. This type of earthquake is capable of producing tsunamis thousands of miles from the quake site.

The wave is normally not very tall in the deep waters of the ocean, but as the wave moves through shallower and shallower water as it approaches the shoreline the wave is forced skywards as it seeks a means of propagating ahead. Normally the wave propagates *through* the ocean, without actually displacing the molecules. However, when the wave approaches the shoreline the water molecules are actually transported forward. The top part of the wave, near the surface of the water propagates forward faster than the water below, forcing the wave higher and higher above sea level as it races to shore. Eventually, the wave becomes unstable as the tip of the wave outraces the lower part, crashing on the shore with enormous energy. For example, a subduction earthquake occurred on December 26, 2004 off the coast of Sumatra, Indonesia. The resulting tsunamis struck the coast of virtually every land mass surrounding the Indian Ocean, sending thirty foot waves ashore, killing 230,000 people. This is a big problem in mechanics.

Scientists still cannot accurately predict when and where an earthquake will occur. However, fortunately for us, scientists now understand the mechanics of earthquakes sufficiently well that they can predict with some accuracy when and where a tsunami will strike the shore once an earthquake has occurred. For example, when the earthquake struck off the coast of Tōhoku, Japan on March 11, 2011, scientists issued tsunami warnings that saved countless lives.

Perhaps someday in the not-too-distant future scientists will be able to predict when and where earthquakes will occur. The logical succession of events would therefore be to utilize this information not just to forewarn the populace in the area affected, but perhaps even someday to undertake preventive measures to prevent both the earthquake and resulting tsunamis altogether. This solution, if it is ever to be realized, will doubtless involve the use of mechanics.

Volcanoes

Tectonic plate boundaries can also have imperfect contact with their neighboring plate, thereby producing gaps in the Earth's crust that allow magma to escape to the Earth's surface. Where this occurs violently, we call it a volcano. Most volcanoes occur along tectonic plate boundaries.

When one plate is riding over another, the lower plate is slowly pushed lower and lower beneath the plate on top. The plate on top is pushed upwards, thus producing the shoreline of land masses.

The lower plate has typically come from the ocean floor, so that it is saturated with water. As this water is pushed downward beneath the shoreline within the subducted plate, it can sometimes reduce the melting temperature of the overlying mantle, thus creating magma. Sometimes this magma cools before it reaches the surface, but occasionally the magma will boil upwards to the surface, thereby creating a volcano.

On other occasions the subducted plate induces cracks in the layer above, thereby allowing the magma to reach the surface, again causing a volcano to form. In either case the zone where the volcano is created is typically a few to a few hundred kilometers inland from a coastal area where the subduction is occurring, and this is why for example the volcanoes along the Pacific plate form the "Ring of Fire" somewhat inland from the plate subduction zone, which is in the seabed just off the coast.

A nice example of the power of carbon dating is illustrated by the photograph of Capo la Gala, shown below. Capo la Gala is located on the Sorrentino side of the Amalfi Peninsula, adjacent to the Bay of Naples in Southern Italy. More importantly, it is located about ten miles from Mt. Vesuvius (Fig. 11.14).

We all know about Mt. Vesuvius—that's the volcano that erupted in 79 AD, thereby inundating Pompeii (with volcanic ash) and Herculaneum (with lava) [107]. If you haven't been to either of these places, I strongly advise you to start making travel plans. I've been there quite a few times, and I've not even begun to tire of the treasure trove of information that was buried by this most famous of all volcanic eruptions in recorded history.

The reason that the 79 AD eruption is still so famous is multifold, but let's start with the photo shown in Fig. 11.14. One can readily see that the large stones thrusting downwards into the Bay of Naples are layered. Those are in fact layers of lava flows from eruptions of Mt. Vesuvius! By carbon dating biologic material contained in these layers, scientists have been able to determine that Mt. Vesuvius undergoes an enormous eruption about once every 2,000 years. The clock is

Fig. 11.14 Photograph of Capo la Gala on the Bay of Naples

Fig. 11.15 Street scene in Pompeii

ticking, folks. We are due for another major eruption of Mt. Vesuvius in the not-too-distant future. And we know this because we can carbon date geologic media using mechanics.

Scientists are preparing for the next eruption in a variety of ways. Archeologists studying Pompeii today have determined that the city suffered a major earthquake a few years before the last major eruption of Vesuvius in 79 AD [2] (Fig. 11.15). After the earthquake (and before the fatal eruption), locals began rebuilding the city, using bricks in many places to support the partially destroyed stone columns, similar to that shown below. It is also interesting to note that the Romans cut the lateral beams on an angle in order to provide added friction against failure, a problem in mechanics, as shown in the photo (Fig. 11.16).

Fig. 11.16 Reconstruction of columns in the forum at Pompeii. *Note* the angular cuts in the beams mounted above the columns

The area around the Bay of Naples is today equipped with seismometers, mechanics devices that measure large and rapid motions of the Earth's surface. Thus, assuming that earthquakes will precede the next eruption, we appear to be well equipped to receive plenty of advance warning before the next major eruption of Mt. Vesuvius. The real challenge will be to convince the approximately three million people who are in the predicted path of destruction of the volcano to evacuate before it erupts, because we may not be able to predict with precise accuracy exactly when the next eruption will occur.

There is an interesting footnote to this story. The Mt. Vesuvius eruption in 79 AD was described by Pliny the Younger (his uncle, Pliny the Elder, was killed when he attempted to rescue persons fleeing the eruption), and his description is still extant today. It reads as follows:

> The carts that we had ordered brought were moving in opposite directions, though the ground was perfectly flat, and they wouldn't stay in place even with their wheels blocked by stones. In addition, it seemed as though the sea was being sucked backwards, as if it were being pushed back by the shaking of the land. Certainly the shoreline moved outwards, and many sea creatures were left on dry sand. Behind us were frightening dark clouds, rent by lightning twisted and hurled, opening to reveal huge figures of flame. These were like lightning, but bigger. At that point the Spanish friend urged us strongly: "If your brother and uncle is alive, he wants you to be safe. If he has perished, he wanted you to survive him. So why are you reluctant to escape?" We responded that we would not look to our own safety as long as we were uncertain about his. Waiting no longer, he took himself off from the danger at a mad pace. It wasn't long thereafter that the cloud stretched down to the ground and covered the sea. It girdled Capri and made it vanish, it hid Misenum's promontory. Then my mother began to beg and urge and order me to flee however I might, saying that a young man could make it, that she, weighed down in years and body, would die happy if she escaped being the cause of my death. I replied that I wouldn't save myself without her, and then I took her hand and made her walk a little faster. She obeyed with difficulty, and blamed herself for delaying me.
>
> Now came the dust, though still thinly. I look back: a dense cloud looms behind us, following us like a flood poured across the land. "Let us turn aside while we can still see, lest we be knocked over in the street and crushed by the crowd of our companions". We had scarcely sat down when a darkness came that was not like a moonless or cloudy night, but more like the black of closed and unlighted rooms. You could hear women lamenting, children crying, men shouting. Some were calling for parents, others for children or spouses; they could only recognize them by their voices. Some bemoaned their own lot, other that of their near and dear. There were some so afraid of death that they prayed for death. Many raised their hands to the gods, and even more believed that there were no gods any longer and that this was one last unending night for the world. Nor were we without people who magnified real dangers with fictitious horrors. Some announced that one or another part of Misenum had collapsed or burned; lies, but they found believers. It grew lighter, though that seemed not a return of day, but a sign that the fire was approaching. The fire itself actually stopped some distance away, but darkness and ashes came again, a great weight of them. We stood up and shook the ash off again and again, otherwise we would have been covered with it and crushed by the weight. I might boast that no groan escaped me in such perils, no cowardly word, but that I believed that I was perishing with the world, and the world with me, which was a great consolation for death.
>
> At last the cloud thinned out and dwindled to no more than smoke or fog. Soon there was real daylight. The sun was even shining, though with the lurid glow it has after an eclipse. The sight that met our still terrified eyes was a changed world, buried in ash like

> snow. We returned to Misenum and took care of our bodily needs, but spent the night dangling between hope and fear. Fear was the stronger, for the earth was still quaking and a number of people who had gone mad were mocking the evils that had happened to them and others with terrifying prognostications. We still refused to go until we heard news of my uncle, although we had felt danger and expected more.
>
> You will read what I have written, but will not take up your pen, as the material is not the stuff of history. You have only yourself to blame if it seems not even proper stuff for a letter. Farewell [108].

For those who do not know, Misenum is the ancient name for modern day Miseno, a port on the opposite side of the Bay of Naples from Mt. Vesuvius, about 30 km from the crater. That's quite a large distance for the amount of destruction described above by Pliny.

Pliny's description of the eruption is so inconceivable that it was actually discounted by most credible sources until recently, when Mt. St. Helens erupted in 1980 and demonstrated to the modern world the power of volcanoes. The next eruption of Mt. Vesuvius thus looms large (Fig. 11.17).

Fig. 11.17 Mt. St. Helens eruption on May 18, 1980

As mentioned above, volcanoes are caused by mechanically induced tears or imperfections in the Earth's crust, thereby allowing magma, ash, and noxious gases to escape to the Earth's surface. Most volcanoes can be found along the boundaries of tectonic plates that are either converging or diverging. Thus, volcanic eruptions are a result of deformable body mechanics. These eruptions can spew out incredible amounts of magma, which subsequently hardens and causes major changes in the landscape. In addition, the enormous ash plume spewed out from some volcanoes is sufficient to blot out the Sun and cause global climate change for years to come.

There have been some spectacular volcanic eruptions down through the history of our planet. Of course, really old ones are difficult to study due to erosion of the Earth's surface with time, another mechanics issue. Within the span of recorded history, the most famous eruptions are in chronological order: Santorini (c. 1600 BCE), Vesuvius (79 AD), mentioned above, and Krakatoa (1883). But there are less famous volcanoes erupting quite often all over the Earth.

The Santorini eruption, sometimes called by its ancient name of Thera, occurred about 3,600 years ago on the Greek island of Santorini, blowing the entire center of the island away, and with it virtually the entire Minoan civilization (Fig. 11.18). The resulting tsunami apparently also destroyed the main portion of the Minoan civilization on the island of Crete, a 100 km to the south. Some believe that this eruption, perhaps the largest in recorded history, is the source of the legend of Atlantis, the lost continent [109]. There is a fabulous archeological dig at Akrotiri on the south side of Santorini, demonstrating the city as it appeared before the eruption.

Fig. 11.18 Satellite view of Santorini, showing the part of the Island destroyed in the eruption. *Note* the re-emerging cone in the center of the bay

Fig. 11.19 Photograph of the Volcanic Island recently formed by the Santorini Caldera. *Note* the cliffs of the island inundated by the eruption in the background

The lava dome at Santorini has grown back to the surface of the sea, so that you can take a tour out to the recently formed island, where you will find plenty of solidified lava, along with vents of noxious gases. This is a must see for anyone who travels to Santorini on vacation (Fig. 11.19).

Krakatoa is situated between the islands of Java and Sumatra in the Dutch East Indies. The Krakatoa eruption of 1883 is the largest recorded volcanic event on Earth since the eruption at Santorini. It is estimated that the eruption had a total energy equivalent to about 13,000 times the energy of the atomic bomb that was dropped on Hiroshima in 1945. The eruption was so loud that it was heard at a distance of 5,000 km. Krakatoa is a very active volcano, having erupted several times recently. In addition, the terrain around the volcano is punching through the surface of the ocean quite rapidly, suggesting that other eruptions may be due soon (Fig. 11.20).

Perhaps the most dangerous of all the volcanoes on Earth is the supervolcano at Yellowstone. It is called a supervolcano because of the enormous size of the magma bubble beneath the surface of the Earth in Yellowstone. There have been 142 caldera forming events caused by the Yellowstone hotspot in the past 17 million years. The last super-eruption occurred about 640,000 years ago, ejecting about 1,000 km^3 of rock and ash into the atmosphere. The next time this volcano erupts, and it most certainly will someday, it will wipe out perhaps as

Fig. 11.20 Satellite photo of Anakrakatoa taken in 2007

much as half of North America. Since the last major eruption prior to the latest one was about 1.3 million years ago, we could be due for another one at any time (Fig. 11.21).

My favorite volcano is actually a field of volcanoes that created the Hawaiian Islands. These are the gentlest type of volcanoes that we know of. The Hawaiian Islands were formed entirely by magma seeping through a tear called a hotspot in the Hawaii-Seamount Chain in the mid-Pacific Ocean. These islands are actually part of an extended chain of volcanoes that are continuously being formed by the slow southeastward sliding of this hotspot (5–10 cm per year) on the ocean seafloor (Fig. 11.22).

The Midway Island Atoll, nearly a thousand miles to the northwest of the state of Hawaii is at 28 million years the oldest portion of the Hawaii-Seamount chain. At 800,000 years of age Hawaii is the newest and farthest southeast, and is also the largest island in the chain. The other islands in the chain grow progressively older as one scans northwest along the chain (Fig. 11.23).

Since the volcanoes Mauna Loa and Kilauea are still active on the Big Island of Hawaii, this island is still growing and thus exhibits cone-like orography. In fact, one can see the effects of recent lava flows on the geography of the island by traveling along the southern part of the island. The most recent flow fields display little erosion and have very little vegetation, whereas progressively older flow fields show increasing erosion and vegetation. It only takes a few years for marked changes to be readily apparent. Thus, this island is a living laboratory of the effects of nature on very young lava fields (Fig. 11.24).

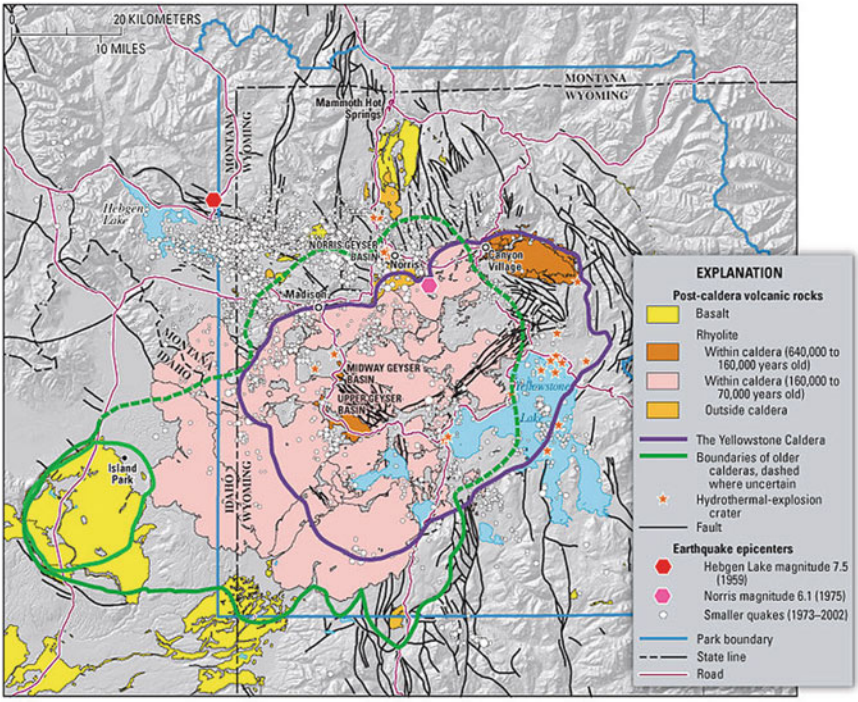


Fig. 11.21 The yellowstone calderas

Mauna Loa rises nearly 14,000 ft (4,169 m) above sea level on the Big Island of Hawaii. Since the floor of the ocean is 20,000 feet below sea level in this part of the Pacific, this would be the tallest (and most massive) mountain on Earth if it were measured from its base. When it snows on top of this massive mountain as well as its sister Mauna Kea, locals are known to take up skiing until the snow melts (Fig. 11.25).

As one moves to the northwest from Hawaii to Maui (Fig. 11.26), it is apparent that this island is in reality two separate islands that joined together due to erosion of the mountains created by two separate volcanoes (Fig. 11.27). On this island one sees more of the effects of erosion with time, especially on the older northwestern portion of the island, near the ‘Iao Needle (Fig. 11.28).

This erosion is caused by the uplifting of air currents as they move over the mountainous volcanoes, thus causing adiabatic (constant energy) cooling, and resulting rain that leads to erosion (see Chap. 10), thereby creating the gorgeous valleys that dot the older of the Hawaiian Islands.

The southern portion of Maui contains the volcano Haleakala, which is classified as dormant. Although it last erupted in 1790, don’t count it as extinct just yet. There may be more to come from this massive volcano (Fig. 11.29).

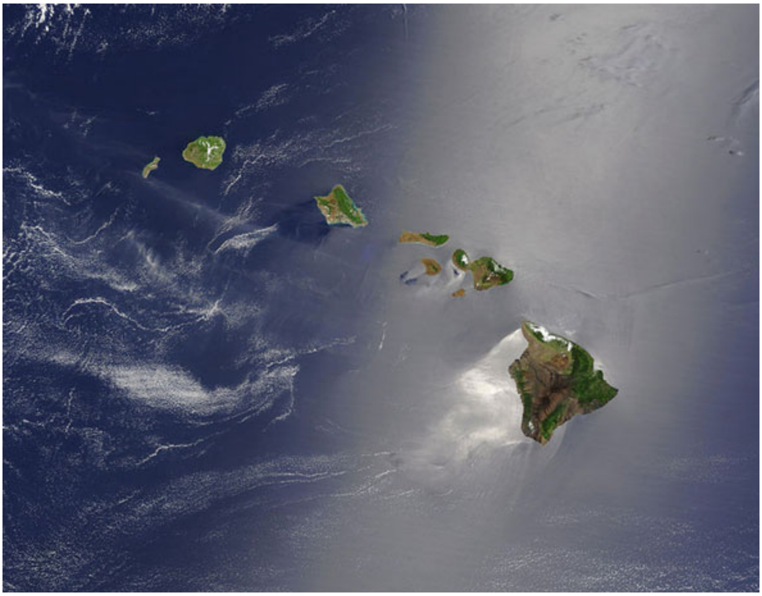


Fig. 11.22 Satellite photo of the Hawaiian Islands, showing from *top left* Niihau, Kauai, Oahu, Molokai, Lanai, Maui, Kahoolawe and Hawaii

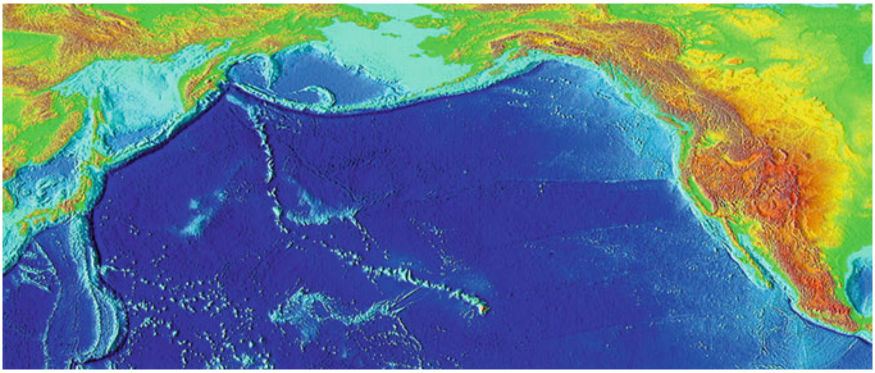


Fig. 11.23 The Hawaii-seamount chain

Near the northwest end of the Hawaiian chain one finds Kauai. At 6 million years in age, it is the oldest of the large Hawaiian Islands. Volcanoes on this island stopped erupting several million years ago. Today it is a contender for the wettest place on Earth, producing 12 m (40 ft!) of rainfall annually on Mount Wai-‘ale-‘ale, in the Alaka’i swamp, the highest swamp on Earth.

Fig. 11.24 Hotspot drift slowly shifts the active volcanoes southeast

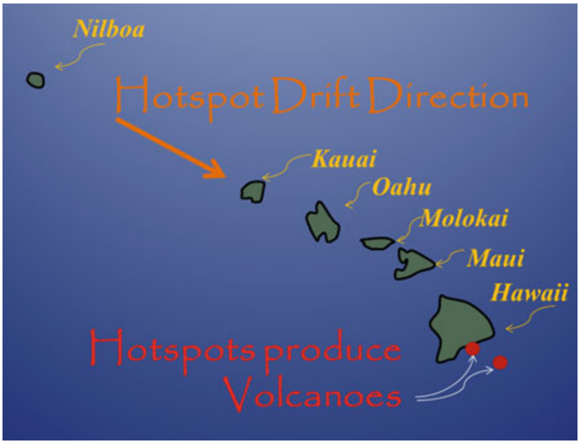
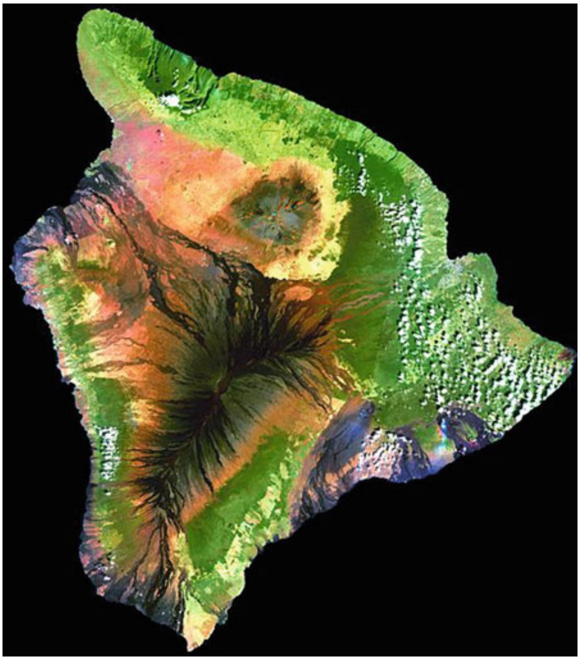


Fig. 11.25 Satellite photo of the big island



For sheer beauty caused by erosion, Kauai is the best of the Hawaiian Islands to visit. Waimea Canyon (Fig. 11.30) and the Na Pali Coast (Fig. 11.31) are quite spectacular, having been carved out by all that rain rushing down from the Alaka'i Swamp for millions of years.

Someday all of this erosion will cause Kauai to look like the now-nearly flat Wake Island. And someday Wake Island, on the northwest end of the Hawaiian Island Chain, will disappear beneath the waves of the Pacific Ocean. On the other end of the chain, 35 km to the southeast of Hawaii, the newest island is forming,

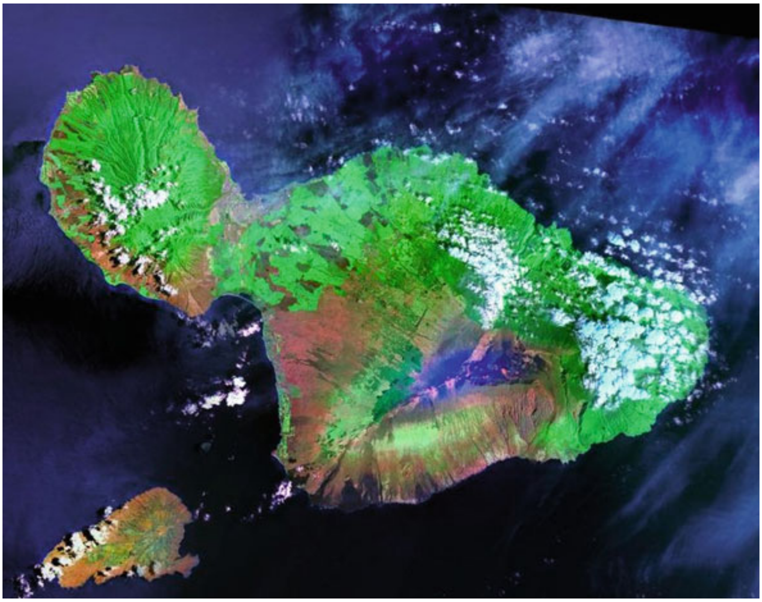
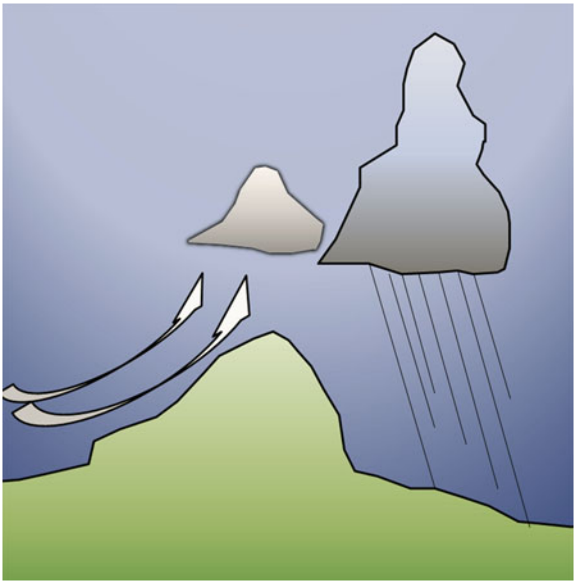


Fig. 11.26 Satellite photo of Maui

Fig. 11.27 How adiabatic uplifting of air over mountains produces clouds and subsequent rainfall



and though it is still about 975 m beneath the surface of the ocean, Hawaiians have already named it Lo'ihi. It is expected to make its first appearance above sea level in 1–100,000 years.

Fig. 11.28 Photograph of the ‘Iao Needle

Fig. 11.29 Haleakala crater

Thus, volcanoes are born, and they live long and constantly varying lives, and then one day they die, and in the case of the Hawaiian Islands, they are buried at sea. The Hawaiian Islands are in my view the best place on Earth to see the effects of the mechanics of volcanoes.

Fig. 11.30 Photo of Waimea Canyon

Fig. 11.31 The Na Pali Coast of Kauai

Glaciers

At various times in history, glaciers have played a profound role in the geography of our planet. When the climate on Earth cools, glaciers advance from polar and elevated regions, and the results can be quite impressive.

Glaciers are formed by precipitation occurring at elevations sufficiently high that the precipitation is frozen (usually in the form of snow). This solid form of water normally falls on mountains, and gravitational forces cause it to congregate in the valleys beneath the mountain peaks. If the accumulating snow is not heated sufficiently for it to melt, then the accumulation of more and more snow causes the layers near the bottom of the heap to be compacted by the snow above, thus gradually converting the snow to much denser ice. The ice grows into a field that we call a glacier, and this is all caused by mechanics (Fig. 11.32).

Fig. 11.32 The black rapids glacier, Alaska

I've visited several glaciers in my lifetime. Most of them are enormous and overwhelming in their size and power. My favorite is the Mer de Glace (meaning sea of ice) in Chamonix, France. It's not the biggest, but it's one of the most accessible in the world, and that alone makes it a hit with me (Fig. 11.33).

But there is much more to see when you visit this glacier. First of all, there is the famous Montenvers train, completed in 1909 (Fig. 11.34). The train is in and of itself a marvel of the power of modern mechanics. It was one of the first trains ever built that could traverse steep inclines, and this was accomplished by constructing a geared drive system beneath the train, a challenging problem in mechanics.

But wait, there is still more! When the visitor arrives aboard the train at the Montenvers station from Chamonix, he/she is treated to a fabulous view of the glacier from above. The glacier itself looks very much like the surface of a sea that is covered with debris. The first impression is not of ice, but more like lots of dirt with ripples on the surface.

The visitor can go *inside* the Mer de Glace. This is a fracture mechanist's dream world (see Chap. 13). The ice inside this magnificent glacier, unlike that on the surface above, is clear and pristine. Thus, one can actually see crystalline grain boundaries, and even more impressive, the interfaces of enormous cracks inside the glacier (Fig. 11.35).

In the eighteenth and nineteenth centuries the Mer de Glace extended right down into the edge of Chamonix, at the base of the valley beneath Mont Blanc, the tallest mountain in Europe. Due to climate change, the foot of the glacier began to recede in the mid-nineteenth century, and it is now no longer visible from the city below.

Fig. 11.33 The Mer de Glace

The surface of the glacier has also dropped several hundred feet just in the past 40 years (my first visit there was in 1971, and my most recent was in 2012). Despite this, the man-made grotto that one can enter to see the inside of the glacier continues to slide down the valley at a rate of about 90 m per year. Thus, the grotto has to be constantly reconstructed for the burgeoning flow of tourists who visit the glacier every year. If you've never seen a glacier, the Mer de Glace should be your first one to visit.

Like other natural physical phenomena on our planet, glaciers have life spans. They grow in colder times, and they recede in warmer ones. The last Ice Age on Earth ended about 13,000 years ago, but before it ended, there were lots of interesting differences from today.

Because there was so much ice on Earth, the sea level was much lower then. For example, there was a land bridge that connected Asia to Alaska, and scientists think that is how people first populated the Americas. The British Isles were also connected to Europe, thus allowing easy access for indigenous peoples to Britain,

Fig. 11.34 Chamonix-Montenvers train

Fig. 11.35 Entrance to the grotto inside the Mer de Glace

but later on they found it difficult to depart when the ice receded and the sea level rose, cutting them off from mainland Europe.

If the valley that the glacier rests in is in a polar region, then it may undergo little change over a long period of time. On the other hand, if the glacier is in a region that experiences some melting, then the coefficient of friction between the glacier and the valley floor may be reduced sufficiently for the glacier to actually travel down the valley, and depending on the slope and the roughness of the valley, at varying speeds. This sliding of the glacier over the surface of the Earth can cause all sorts of interesting things to happen, all of them resulting from mechanics.

Fig. 11.36 Moraine in the foreground at Lake Louise, Canada

There are lots of remnants of the mechanical effects of massive glaciers from the previous ice age. For example, there was a field of glaciers in Canada that were so massive that they pushed the Earth's crust downwards, perhaps partially creating the Hudson Bay, which is shallow in depth, but enormous in breadth. The Great Lakes developed when receding glaciers carved out valleys that subsequently filled with fresh water.

Fig. 11.37 Cape Cod viewed from space

Fig. 11.38 Photograph of Half Dome at Yosemite National Park

As the ice age took hold in the recent past, the glaciers pushed further and further southwards, reaching well into what is now the United States. Most of Canada was under ice. As the glaciers slowly extended southwards, they pushed enormous mounds of dirt ahead of them, but when the climate began to warm again, they receded, and the mounds of dirt were left stranded. We call these mounds of dirt and debris moraines, and today we can tell how far south the glaciers advanced from the remnants of these moraines (Fig. 11.36). There are moraines all across the U.S. Midwest, thus demonstrating the southernmost extent of the last ice age. For example, Cape Cod is the remnant of a moraine (Fig. 11.37).

Due to their enormous mass and size, glaciers can have great destructive power. Imagine if you will making a time lapse movie of a glacier over a span of perhaps a 100,000 years, and then running that movie fast forward in just a few minutes. You would see the glacier carving out valleys, and defacing mountains as it plowed its way down the valley, and then leaving the remnants of its destruction behind as it receded.

A great place to go and see the remains of such destructive power of glaciers is Yosemite National Park. There is so much to see there that it is almost beyond comprehension. The glaciers have receded now, but when they plowed down through the main valley, they gouged out now jaw-dropping scenery everywhere one looks. My favorite is Half Dome, an enormous granite monolith formed by a volcanic magma bubble ten million years ago (Fig. 11.38). When the glaciers came to the valley later, the front face of the previously formed dome was sheared off, thereby creating one of the tallest vertical faces on Earth. All of this was created by

Entity	Life Span	Ratio to the Universe Life Span
Universe	10^{12} years	
Galaxies	10^{11} years	1/10
Our solar System	10^{10} years	1/100
Pangaea	10^{8} years	1/10,000
Volcano	10^{7} years	1/100,000
Glacier	10^{5} years	1/10,000,000
Humans control Earth	10^{4} years	1/100,000,000
Roman Empire	10^{3} years	1/1,000,000,000
Human	10^{2} years	1/10,000,000,000
Hurricane	0.1 year	1/10,000,000,000,000
Tornado	0.01 year	1/100,000,000,000,000

Fig. 11.39 Average lifespans of various entities within the cosmos

mechanics. You simply cannot understand how enormous Half Dome is without visiting Yosemite. And if you go there, starting preparing now to climb to the top of Half Dome. It can be reached without climbing gear from the smaller mound on the east side called Quarter Dome.

So we have now seen that the universe, galaxies, solar systems, volcanoes, glaciers, and people all have their own life cycles. There are lots of theories about how long the universe will last. Above is one guess compared to other life spans (Fig. 11.39).