Unit 4— Our Solar System & Earth

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# How Our Solar System Formed

A closer look at the planets that orbit our Sun.

### How Our Solar System Formed: A Close Look at the Planets Orbiting Our Sun (1110L)

By Cynthia Stokes Brown

Planets are born from the clouds of gas and dust that orbit new stars. Billions of years ago, circumstances were just right for Earth and the other planets in our Solar System to form.

The Solar System that we live in consists of a medium-size star (the Sun) with eight planets orbiting it. The planets are of two different types. The four inner planets, those closest to the Sun, are Mercury, Venus, Earth, and Mars. They are smaller and composed mainly of metals and rocks. The four outer planets — Jupiter, Saturn, Uranus, and Neptune — are larger and composed mostly of gases.

What are planets? Where did they come from? Why would some be rocky and some gaseous? What is our planet like? This essay will try to answer these questions.

#### The birth of the Sun

Let’s quickly review how our star came into being. Five billion years ago, a giant cloud floated in one of the spiral arms of the Milky Way galaxy. This cloud, called a nebula by astronomers, was made up of dust and gas, mostly hydrogen and helium, with a small percentage of heavier atoms. These heavier atoms had been formed earlier in the history of the Universe when other stars aged and died.

This cloud/nebula began to contract, collapsing in on itself. The atoms, once separated, began to jostle each other, generating heat. In the rising heat, the atoms collided more frequently and more violently. Eventually, they reached a temperature at which the protons at the centers of the atoms began to fuse, in a process called nuclear fusion. As they did, a tiny bit of matter transformed into a whole lot of energy, and a star was born. In this way, our Sun came into being.

#### The birth of the planets

The material in the nebula not absorbed into the Sun swirled around it into a flat disk of dust and gas, held in orbit by the Sun’s gravity. This disk is called an accretion disk. Material in the disk accumulated by further accretion — from sticking together.

Each planet began as microscopic grains of dust in the accretion disk. The atoms and molecules began to stick together, or accrete, into larger particles. By gentle collisions, some grains built up into balls and then into objects a mile in diameter, called planetesimals. These objects were big enough to attract others by gravity rather than by chance.

If the collisions of planetesimals occurred at high speeds, they could shatter the objects. But when impacts were gentle enough, the objects combined and grew. For some 10 to 100 million years these protoplanets orbited the Sun, some in egg-shaped circuits that resulted in more frequent collisions.

Worlds collided, combined, and evolved for a dramatic period of time. When it was over, there remained eight stable planets that had swept their orbits clean. A planet is defined as a body that orbits the Sun, is massive enough for its own gravity to make it spherical, and has cleaned its neighborhood of smaller objects.

In 2007, researchers at the University of California–Davis determined that our Solar System was fully formed at 4.568 billion years ago. They did this by determining the age of stony materials from the asteroid belt.

The Sun sent out energy and particles in a steady stream, called stellar winds. These winds proved so strong that they blew off the gases of the four planets closest to the Sun, leaving them smaller, with only their rocks and metals intact. That’s why they are called rocky, or terrestrial, planets. The four outer planets were so far from the Sun that its winds could not blow away their ice and gases. They remained gaseous, with only a small rocky core. They were made of more gas (namely hydrogen and helium) than the others to begin with, the Sun’s gravity having pulled closer the heavier materials in the original solar disk.

Between the inner and outer planets lies an area filled with millions of asteroids — small rocky, icy, and metallic bodies left over from the formation of the Solar System. No planet formed in this area. Astronomers theorize that Jupiter’s gravity influenced this region so much that no large planet could take shape. Jupiter is 11 times the size (in diameter) of Earth and more than twice as big as all the other planets combined. It is almost large enough to have become a star.

Of the four rocky planets, Mercury is the smallest, about two-fifths the size of Earth. Earth and Venus are almost the same size, while Mars is about half their size. Astronomers speculate that a smaller object must have hit Mercury, vaporizing its crust and leaving only the larger-than-usual iron core.

#### Conditions on Earth

When the rocky planets first formed, they were largely melted (molten) rock. Over hundreds of millions of years, they slowly cooled. Eventually Mercury and Mars, because they are small, solidified and became rigid all the way to their centers.

Only on Earth, and possibly on Venus, have conditions remained in an in-between state. Earth has stayed partially molten. Its crust is solid rock, and its mantle is rigid in short-term time. But over geologic time the mantle flows slowly. And the center of Earth consists of a solid iron core rotating in hot liquid called magma.

Some scientists and Big Historians use the term “Goldilocks Conditions” to describe conditions on Earth. This comes from an Anglo-Saxon children’s story, “Goldilocks and the Three Bears.” In the story, a young girl named Goldilocks wanders into the home of three bears, who are away. She tries out their porridge, their chairs, and their beds, finding some too hot or too cold, too hard or too soft, too large or too small, but one of each just right. Likewise, Earth is not too hot or too cold, not too big or too little, not too near the Sun or too far away, but just right for life to flourish.

#### Earth’s Moon

The rocky object nearest to us is the Moon. Where did it come from? Good question. The Moon orbits Earth, not the Sun, so it is not a planet. The Moon is about one-fourth the size of Earth. The origin of the Moon remains mysterious, but since astronauts walked on the Moon in 1969 and brought back rock and soil samples, we know more about it now than before.

The standard argument today holds that a small contending planet, about one-tenth the size of Earth, must have collided with Earth about 4.45 billion years ago. Earth was still red-hot beneath a possible thin new crust. Some of the material from the impact was absorbed into the liquefied Earth but some material ricocheted into space, where it settled into orbit and condensed as the Moon. At first the Moon orbited much closer to Earth. It is still moving away at a rate of almost two inches (four centimeters) per year.

The Moon significantly affects conditions on Earth. The impact that produced the Moon tilted Earth on its axis. This causes Earth’s seasonal variations in temperature, since the side tilted toward the Sun for one-half the year’s journey around the Sun receives more direct sunlight. Also, the Moon’s gravity causes the oceans’ tides, reduces the Earth’s wobble (which helps stabilize climate), and slows the spin of the Earth. The Earth used to complete a rotation on its axis in 12 hours, but now it takes 24.

#### Pluto and beyond

Before 2006, students learned that our Solar System had nine planets, not eight. The one counted as the ninth, Pluto, orbits out beyond Neptune. However, in 2006, the International Astronomical Union declared that Pluto does not count as a planet. It is smaller than Earth’s Moon. It orbits way out in a belt of asteroids beyond Neptune, and does not have enough gravity to clear the neighborhood around its path. Therefore, it was downgraded to a “dwarf planet,” or a planetesimal.

Astronomers feel confident that our Solar System formed by accretion because now they are able to glimpse a similar process occurring in part of the Orion Nebula. This planet-forming area is on the near side of a giant cloud complex that embraces much of the constellation Orion, 1,500 light-years from Earth. Since 1993, astronomers have discovered several hundred stars there in the process of formation, most of them surrounded by rings of dust in accretion disks, just like the one they believe produced the solar planets. These clouds of dust and gas around new stars in the Orion Nebula may develop into planetary systems similar to our own.

In 1995, astronomers in Switzerland found, for the first time, a planet beyond our Solar System orbiting an ordinary star. Such a planet is called an extrasolar planet, or an exoplanet. As of June 2012, more than 700 exoplanets had been discovered and confirmed. Most of them are giants, closer in size to Jupiter, as larger planets have proved easier to detect hundreds of light-years away. Most are detected not by direct imaging, but indirectly by measuring the effect of their gravity on their parent star or by observing how the light of the parent star dims as the planet passes in front of it.

In 2009, the National Aeronautics and Space Administration (NASA) sent a telescope into orbit around the Sun to hunt for habitable exoplanets in the region near the constellations Cygnus and Lyra. This telescope (actually a photometer), the centerpiece of what’s known as the Kepler mission, will monitor 100,000 stars a few hundred to a few thousand light-years away. (One light-year equals 6 trillion miles.) The mission will last three and a half to six years; in the first two years, it has found 17 planets with conditions thought to allow for the development of life.

In summary, planets are bodies orbiting a star. Planets form from particles in a disk of gas and dust, colliding and sticking together as they orbit the star. The planets nearest to the star tend to be rockier because the star’s wind blows away their gases and because they are made of heavier materials attracted by the star’s gravity. In the Sun’s system, Earth is one of four rocky planets, but a unique one, with rigid and molten layers.

### How Our Solar System Formed: A Close Look at the Planets Orbiting Our Sun (1020L)

By Cynthia Stokes Brown, adapted by Newsela

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The Solar System that we live in consists of a medium-size star (the Sun) with eight planets orbiting it. The planets are of two different types. The four inner planets, those closest to the Sun, are Mercury, Venus, Earth, and Mars. They are smaller and composed mainly of metals and rocks. The four outer planets — Jupiter, Saturn, Uranus, and Neptune — are larger and composed mostly of gases.

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This cloud/nebula began to contract, collapsing in on itself. The atoms, once separated, began to bump against each other, generating heat. In the rising heat, the atoms collided more frequently and more violently. Eventually, they reached a temperature at which the protons at the centers of the atoms began to fuse, in a process called nuclear fusion. As they did, a tiny bit of matter transformed into a whole lot of energy, and a star was born. In this way, our Sun came into being.

#### The birth of the planets

The material in the nebula that didn't absorb into the Sun swirled around it into a flat disk of dust and gas. The Sun’s gravity held this "accretion disk" in orbit. Material in the disk accumulated by further accretion — by sticking together.

Each planet began as microscopic grains of dust in the accretion disk. The atoms and molecules began to stick together, or accrete, into larger particles. By gentle collisions, some grains built up into balls. As they grew larger, they formed into objects a mile in diameter, called planetesimals. These objects were big enough to attract others by gravity rather than by chance.

If the collisions of planetesimals occurred at high speeds, they could shatter the objects. But when impacts were gentle enough, the objects combined and grew. For some 10 to 100 million years these protoplanets orbited the Sun. Some revolved around it in egg-shaped circuits that resulted in more frequent collisions.

Worlds collided, combined, and evolved for a dramatic period of time. When it was over, there remained eight stable planets that had swept their orbits clean. To be called a planet, it must orbit the Sun. It must also be massive enough for its own gravity to form it into a sphere, and has cleaned its neighborhood of smaller objects.

In 2007, researchers at the University of California–Davis determined that our Solar System was fully formed 4.568 billion years ago. Scientists did this by determining the age of rocky materials from the asteroid belt.

The Sun sent out energy and particles in a steady stream, called stellar winds. These winds proved so strong that they blew off the gases of the four planets closest to the Sun. The loss of their gasses left the planets smaller. Only their rocks and metals remained intact. That’s why they are called rocky, or terrestrial, planets. The four outer planets were so far from the Sun that its winds could not blow away their ice and gases. They stayed in a gas form, with only a small rocky core. These four were made of more gas (namely hydrogen and helium) than the others to begin with. Heavier materials had already pulled closer by the Sun’s gravity in the original solar disk.

Between the inner and outer planets lies an area filled with millions of asteroids — small rocky, icy, and metallic bodies left over from the formation of the Solar System. No planet formed in this area. Astronomers theorize that Jupiter’s gravity influenced this region so much that no large planet could take shape. Jupiter is 11 times the size (in diameter) of Earth and more than twice as big as all the other planets combined. It is almost large enough to have become a star.

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Only on Earth, and possibly on Venus, have conditions remained in an in-between state. Earth has stayed partially molten. Its crust is solid rock, and its mantle is rigid in short-term time. But over geologic time the mantle flows slowly. And the center of Earth consists of a solid iron core rotating in hot liquid called magma.

Some scientists and Big Historians use the term “Goldilocks Conditions” to describe conditions on Earth. In “Goldilocks and the Three Bears,” Goldilocks wanders into the home of three bears, who are away. She tries out their porridge, their chairs, and their beds, finding some too hot or too cold, too hard or too soft, too large or too small, but one of each just right. Likewise, Earth is not too hot or too cold, not too big or too little, not too near the Sun or too far away, but just right for life to flourish.

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The standard argument today holds that a small planet, about one-tenth the size of Earth, must have collided with Earth about 4.45 billion years ago. Earth was still red-hot beneath a thin new crust. Some of the material from the impact was absorbed into the liquefied Earth. However, some material ricocheted into space, where it settled into orbit and condensed as the Moon. At first, the Moon orbited much closer to Earth. It is still moving away at a rate of almost two inches (four centimeters) per year.

The Moon significantly affects conditions on Earth. The impact that produced the Moon tilted Earth on its axis. This causes Earth’s seasonal variations in temperature, since the side tilted toward the Sun for one-half the year’s journey around the Sun receives more direct sunlight. Also, the Moon’s gravity causes the oceans’ tides. Additionally, it reduces the Earth’s wobble (which helps stabilize climate), and slows the spin of the Earth. The Earth used to complete a rotation on its axis in 12 hours, but now it takes 24.

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Astronomers feel confident that our Solar System formed by accretion. They're sure in their belief because a similar process is occurring in part of the Orion Nebula. This planet-forming area is on the near side of a giant cloud complex that embraces much of the constellation Orion, 1,500 light-years from Earth. Since 1993, astronomers have discovered several hundred stars there in the process of formation. Most of them are surrounded by rings of dust in accretion disks, just like the one they believe produced the solar planets. These clouds of dust and gas around new stars in the Orion Nebula may develop into planetary systems similar to our own.

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In summary, planets are bodies orbiting a star. Planets form from particles in a disk of gas and dust, colliding and sticking together as they orbit the star. The planets nearest to the star tend to be rockier because the star’s wind blows away their gases and because they are made of heavier materials attracted by the star’s gravity. In the Sun’s system, Earth is one of four rocky planets, but a unique one, with rigid and molten layers.

### How Our Solar System Formed: A Close Look at the Planets Orbiting Our Sun (890L)

By Cynthia Stokes Brown, adapted by Newsela

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The Solar System that we live in consists of a medium-size star (the Sun) with eight planets orbiting it. The planets are of two different types. The four closest to the Sun are Mercury, Venus, Earth, and Mars. They are smaller and composed mainly of metals and rocks. The four outer planets — Jupiter, Saturn, Uranus, and Neptune — are larger and composed mostly of gases.

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This cloud/nebula began to contract, collapsing in on itself. The atoms separated. Loose, they began to bump against each other, generating heat. In the rising heat, the atoms collided more frequently and more violently. Eventually, they reached a temperature at which the protons at the centers of the atoms began to fuse, in a process called nuclear fusion. As they did, a tiny bit of matter transformed into a whole lot of energy. A star was born. In this way, our Sun came into being.

#### The birth of the planets

The material in the nebula that didn't absorb into the Sun swirled around it. It shaped into a flat disk of dust and gas. The Sun’s gravity held this "accretion disk" in orbit. Material in the disk accumulated by further accretion — by sticking together.

Each planet began as microscopic grains of dust in the accretion disk. The atoms and molecules began to stick together, or accrete, into larger particles. By gentle collisions, some grains built up into balls. As they grew larger they formed into objects a mile in diameter, called planetesimals. These objects were big enough to attract others by gravity.

If the collisions of planetesimals occurred at high speeds, they could shatter the objects. But when impacts were gentle enough, the objects combined and grew. For some 10 to 100 million years these protoplanets orbited the Sun. Some revolved around it in egg-shaped circuits that resulted in more frequent collisions.

Worlds collided, combined, and evolved for a dramatic period of time. When it was over, eight stable planets remained. Each of the planets had swept their orbits clean of smaller objects. To be called a planet, it must orbit the Sun. It must be massive enough for its own gravity to shape it into a sphere, and it has cleaned its neighborhood of smaller objects.

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The Sun sent out energy and particles in a steady stream, called stellar winds. These winds proved so strong that they blew off the gases of the four planets closest to the Sun. The loss of their gasses left the planets smaller. Only their rocks and metals remained intact. That’s why they are called rocky, or terrestrial, planets. The four outer planets were so far from the Sun that its winds could not blow away their ice and gases. They stayed in a gas form, with only a small rocky core. These four were made of more hydrogen and helium gases than the others to begin with. Heavier materials had already pulled closer by the Sun’s gravity in the original solar disk.

Between the inner and outer planets lies an area filled with millions of asteroids. Asteroids are small rocky, icy, and metallic bodies left over from the formation of the Solar System. No planet formed in this area. Astronomers theorize that Jupiter’s gravity influenced this region so much that no large planet could take shape. Jupiter is 11 times the size (in diameter) of Earth. It's more than twice as big as all the other planets combined. Jupiter is so large it almost could have become a star.

Of the four rocky planets, Mercury is the smallest. It's about two-fifths the size of Earth. Earth and Venus are almost the same size, while Mars is about half their size. Astronomers speculate that a smaller object must have hit Mercury, vaporizing its crust. The impact left behind only its larger-than-usual iron core.

#### Conditions on Earth

When the rocky planets first formed, they were largely melted (molten) rock. Over hundreds of millions of years, they slowly cooled. Eventually, Mercury and Mars, because they are small, solidified. They hardened all the way to their centers.

Only on Earth, and possibly on Venus, have conditions remained in an in-between state. Earth has stayed partially molten. Its crust is solid rock. Beneath the crust is the mantle, which is rigid in short-term time. But over geologic time the mantle flows slowly. And the center of Earth consists of a solid iron core rotating in hot liquid called magma.

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The accepted theory today is that a small planet, about one-tenth the size of Earth, must have collided with Earth. This was about 4.45 billion years ago. Earth was still red-hot beneath a thin new crust. Some of the material from the impact was absorbed into the liquefied Earth. However, some material ricocheted into space, where it settled into orbit and condensed as the Moon. At first the Moon orbited much closer to Earth. It is still moving away at a rate of almost two inches (four centimeters) per year.

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### How Our Solar System Formed: A Close Look at the Planets Orbiting Our Sun (750L)

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The Solar System that we live in has a medium-size star at its center. It's better known as our Sun. Eight planets orbit it. The planets in our Solar System are of two different types. The four closest to the Sun are Mercury, Venus, Earth, and Mars. They are smaller and made mainly of metals and rocks. The four outer planets — Jupiter, Saturn, Uranus, and Neptune — are larger and made mostly of gases.

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Each planet began as microscopic grains of dust in the accretion disk. Atoms and molecules began to stick together, or accrete, into larger particles. By gentle collisions, some grains built up into balls. As they grew larger, they formed into objects a mile in diameter, called planetesimals. Now they were big enough to attract other planetesimals by gravity.

If planetesimals collided at high speeds, they could shatter. But gentle collisions helped the objects combine and grow. For some 10 to 100 million years, these protoplanets orbited the Sun and bumped into each other.

Worlds collided and combined. When it was over, eight planets remained. But there are rules about what makes a planet. To be called a planet, it must orbit the Sun. It must also be massive enough for its own gravity to shape it into a sphere. And a planet must have cleaned its orbit of smaller objects.

In 2007, scientists at the University of California determined the age of our Solar System. They concluded that it formed 4.568 billion years ago. The scientists discovered this by determining the age of rocky materials from the asteroid belt. The belt is an area filled with millions of asteroids. Asteroids are small, rocky, icy, and metallic bodies. They were left over from the formation of the Solar System.

As the Solar System formed, the Sun sent out energy and particles in a stream called the stellar winds. These powerful winds blew the gases off the four planets closest to the Sun. Without their gases, these planets became smaller. Only their rocks and metals were left. That’s why they are called rocky, or terrestrial, planets.

The four outer planets are much farther from the Sun. From such a distance, the winds could not blow away their ice and gases. These outer planets stayed in a gas form. Their only hard part was a small rocky core. However, these four were made of more hydrogen and helium gases than the others to begin with. Heavier materials had already been pulled closer to the Sun by the Sun's gravity when it formed.

Between the inner and outer planets lies the asteroid belt. No planet formed in the belt. Jupiter is incredibly large and therefore has a strong gravitational pull. Astronomers theorize that Jupiter’s gravity influenced this region so much that no planet could take shape. Jupiter is 11 times the size (in diameter) of Earth.

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#### Conditions on Earth

When the rocky planets first formed, they were largely melted (molten) rock. Over hundreds of millions of years they cooled. Eventually, Mercury and Mars, because they are small, solidified. They hardened all the way to their centers.

Only on Earth, and possibly on Venus, have conditions remained in an in-between state. Earth is partially molten. Its crust is solid rock. Beneath the crust is the mantle. It's the layer separating Earth's core from the crust. Over the short-term, the mantle seems solid. But the mantle's rock is hot and melts sometimes. It flows slowly over time. At the center of Earth is a solid iron core. It spins in hot liquid, called magma.

Some scientists and Big Historians use the term “Goldilocks Conditions” to describe conditions on Earth. This comes from “Goldilocks and the Three Bears.” In the story, Goldilocks wanders into the home of three bears. The bears are away. She tries out their porridge, their chairs, and their beds. She finds some too hot or too cold, too hard or too soft, too large or too small. But one of each is just right. Likewise, Earth is not too hot or too cold, not too big or too little, not too near the Sun or too far away. It's just right for life to grow.

#### Earth’s Moon

The rocky object nearest to us is the Moon. The Moon orbits Earth, not the Sun, so it is not a planet. The Moon is about one-fourth the size of Earth. Astronauts first walked on the Moon in 1969 and brought back rock and soil samples to study.

The origin of the Moon remains mysterious. Scientists today believe that a very small planet must have collided with Earth about 4.45 billion years ago. At the time, Earth was still red-hot. A thin crust had just formed on its surface. Some of the material from the impact was absorbed into the liquefied Earth. However, some material flew off into space. There it settled into orbit and came together as the Moon.

The Moon significantly affects conditions on Earth. The impact that produced the Moon tilted Earth on its axis. This causes Earth’s seasons. The side tilted toward the Sun for one-half the year’s journey around the Sun receives more direct sunlight. The Moon’s gravity is also responsible for the oceans’ tides.

#### Pluto and beyond

Before 2006, scientists said our Solar System had nine planets. Pluto was the ninth. However, in 2006, the International Astronomical Union declared that Pluto does not count as a planet. It doesn't meet the three requirements. Pluto is smaller than Earth’s Moon. It orbits way out in a belt of asteroids beyond Neptune. Finally, it does not have enough gravity to clear its orbit of rocky bodies. Therefore, Pluto was downgraded to a “dwarf planet.”

Astronomers feel confident that our Solar System formed by accretion. They're sure because a similar process is occurring in the Orion Nebula. This planet-forming area is in a giant cloud complex covering much of the Orion constellation. Orion's collection of stars is 1,500 light-years from Earth. Since 1993, astronomers have discovered several hundred stars forming there. Most of them are surrounded by rings of dust in accretion disks. These are just like the one they believe produced our solar system. These clouds of dust and gas around the new stars in the Orion Nebula may develop into planetary systems like our own.

In 1995 astronomers found a planet beyond our Solar System orbiting an ordinary star. Such a planet is called an exoplanet. More than 700 exoplanets have been discovered since. Most of them are giants, closer in size to Jupiter. Planets of that size are easier to detect hundreds of light-years away. One light-year equals 6 trillion miles.

Most exoplanets are not seen visually. They're typically spotted indirectly by measuring the effect of their gravity on their parent star. Or scientists can get a glimpse of changes in light. When a planet passes in front of its parent star, that star's light dims briefly.

In 2009, the National Aeronautics and Space Administration (NASA) sent a telescope into orbit around the Sun as part of the Kepler mission. Its goal is to hunt for planets outside our Solar System that could support life. Kepler's telescope will monitor 100,000 stars. They're a few hundred to a few thousand light-years away. In the first two years alone, it has found 17 planets that life could possibly survive on.

In summary, planets are bodies orbiting a star. Planets form from particles in a disk of gas and dust. The particles collide and stick together as they orbit the star. The planets nearest to the star tend to be rockier. Their heavier materials were attracted by the star’s gravity and stayed close to it. The star’s wind blows away their gases because they are so close. In the Sun’s system, Earth is one of four rocky planets. But it's a unique one, with rigid and molten layers.

# Why We're All Lava Surfers

Giant plates of the Earth's cooled crust float like rafts or islands over the molten ball of our planet's interior.

### Why We're All Lava Surfers: First-Hand Plate Tectonics (1160L)

By Peter Stark

I was squinting into the bright sunlight reflecting off the glacier, and my friend Ray, the photographer, walked a short ways ahead, a tall silhouette against the brilliant snow and ice.

The wind blew so hard it made us stagger and the gale’s force bowed the rope that linked the two of us and the guide ahead like a giant strand of spaghetti. A reddish ridge of earth protruded from the glacier and puffs of steam swirled and kicked from its far side. We were now nearing the place where fire mingled with ice.

All of sudden Ray disappeared. He vanished so quickly I couldn’t understand what had happened, as if a magician had touched him with a wand. Puzzled, I looked again ahead of me along the rope. I realized he hadn’t entirely disappeared. Rather, Ray had suddenly become really short. Only his head and shoulders poked above the glacier’s shimmering surface. I now understood that he’d fallen into a crevasse. His legs dangled underneath him in a deep crack in the glacier that probably dropped far down toward volcanic depths below.

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I’m an adventure writer. Magazines send me to wild and faraway places. When a magazine asked me to write an article about Iceland, I jumped at the chance and invited Ray along to take photos. While planning the trip, I learned that Iceland is known as the land of “fire and ice” because it’s dotted with big glaciers and live volcanoes. Far in the center of the island, the fire and ice — the glaciers and volcanoes — mix together in dramatic and sometimes explosive fashion. Getting to that spot became the goal of our trip. That journey would change the way I think about our planet Earth.

The Earth is a ball of hot, molten rock and minerals covered by the thin outer “crust” of cooled rock on which we live. Giant “plates” of this cooled crust float like rafts or islands over the molten ball of the Earth’s interior. In perpetual — but very slow — motion, most of the plates move only about one inch per year. In other words, we’re all lava surfing … very, very slowly. But where they meet along the plate edges, all sorts of crazy things occur. The huge plates scrape past each other sideways. They dive under each other. And in places, the constantly moving plates get snagged on each other, causing tremendous pressures to build. When this tension suddenly releases, things happen way, way, way faster than one inch per year.

My travels have led me to those plate edges in different parts of the world. Some of the bizarre phenomena I’ve witnessed are similar to what scientists observed and experienced during the last century in formulating the theory of plate tectonics.

#### A necklace of islands

Before going to Iceland, I’d spent some time in Indonesia. When I looked at a map of that country, I noticed its hundreds of islands strung out like a 3,000-mile-long necklace of pearls draped in the ocean below Asia. I wondered: “Why is it shaped in such a perfect arc?”

I hadn’t been there long when I started to get an answer. My wife, Amy, and her father, Rags, and I were staying in a little hotel on the Indonesian island of Bali. We were eating dinner one evening beside the small swimming pool. I looked up from my plate of rice and fish and my mango smoothie and noticed that the water in the swimming pool was sloshing back and forth, as it does when you slide around in a very full bathtub. But no one was in the pool!

“I think we’re having an earthquake,” I remarked.

“No we’re not,” they replied.

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Earthquakes strike that island necklace of Indonesia almost constantly — usually they are small and subtle. But occasionally huge quakes, including massive undersea tremors that trigger tsunamis, occur as well.

I found more evidence of what might be happening with that Indonesian island arc when we climbed a volcano, called Mount Marapi, on the island of Sumatra. Few people climb this volcano. It was difficult to see from below just how active it might be above. We hired a young man from a nearby village who could lead us to the top. Off we went in the rainy darkness before dawn, clambering for hours through dripping, misty rain forest. Finally, the green rain forest ended and we topped out at nearly 10,000 feet on the broad, ashy-gray summit that looked like the surface of the Moon and was scattered with big gray boulders.

The guide led us across the top, its flat, ashy surface gently pocked by that morning’s raindrops, until we reached the center.

“Take care,” the guide said, and pointed over an edge.

We inched closer and poked our heads over. There was the most incredible hole in the Earth I’d ever seen, as wide across as several soccer fields and impossibly deep, falling far away to a bottom I couldn’t see. Every 20 or 30 seconds a huge gray huffy blast of foul-smelling smoke and steam and ash came belching out of that rocky shaft and billowed past our faces into the sky. It made me dizzy to look over the rim.

Then I looked back around me at the big boulders lying on the summit plateau. I had assumed they’d lain there for years, if not centuries, since the last big eruption. I now noticed that they’d made craters in the ash, disturbing the rain-pocked surface. Right then I realized that the volcano had erupted just since that morning with its lava bombs falling out of the sky onto the summit. It was more than active — it was really active — and it felt like we were standing beside a direct hole down to the molten interior of the Earth.

“This thing could erupt again at any moment!” I said to Amy. “Let’s get out of here!”

#### Earth's often violent history

This got me interested in knowing more about plate tectonics, the theory that scientists developed after observing seismic events like volcanoes and earthquakes, studying data like the fossil record, and minutely examining maps. Maps tell amazing stories of the Earth’s dynamic and often violent history, and plate tectonics is a kind of language to read the stories hidden in maps.

When I studied a relief map of Indonesia that showed mountains and valleys on land and undersea, I noticed a huge ocean “trench” — the deepest underwater valley you can imagine, nearly five miles deep — running alongside the island necklace.

Why that arcing trench? Plate tectonics taught me that Indonesia’s necklace of islands traces a distinct seam in the Earth’s crust where two huge plates collide. The Australian Plate is shoving northward at two inches per year and diving beneath — subducting — the Eurasian Plate. This diving creates a deep crease in the Earth’s crust, the Sunda Trench. As the Australian Plate dives and melts into the Earth’s interior, it allows lava to well up to the surface in a necklace of active volcanoes along the seam, one of them the belching vent of our Mount Marapi. You can imagine how that the incredible pressure of two plates colliding shakes Indonesia with near-constant earthquakes, small and large, and occasional mega-quakes, like the 2004 undersea quake and tsunami off Sumatra.

Diving plates also shove up mountain ranges from below, like shoving a spatula under a sheet of raw pie dough, which is why Mount Everest, already at 29,035 feet the world’s tallest mountain, grows an inch or two taller every year.

Sometimes I try to imagine what the plates are doing directly under my feet. This is something you can do, wherever you live. Centers of continents, like the center of a raft, tend to be more stable than a subduction zone on a coast. But not always. I live with my family in the interior of the North American Plate, in Missoula, Montana. This is not so far from Yellowstone Park. All those famous geysers are actually boiling up from a “hot spot” where a massive bubble of lava pushes close to the Earth’s surface from deep beneath the crust and boils water that’s flowing underground. The North American Plate is sliding over that huge lava dome. (I’m lava surfing even while I’m writing this.) Over millions of years, as the Rocky Mountains slid over the Yellowstone Hot Spot, it melted and crumbled a wide channel right through the mountain ranges, like a hot pan melting lumps of butter, and snow and rain flowed off the Rockies into the channel to form a river.

This channel both helped and nearly killed early European explorers of the West. Trying to find a pass through the Rocky Mountains to reach the Pacific Ocean, they got funneled into this channel — today called the Snake River Valley — and paddled their canoes down its river. Too late, they discovered that the river eventually left the channel and flowed straight into an ancient ocean trench, now on dry land, created by the Pacific Plate diving under the North American Plate and then cut deeper by the river. Huge rapids smashed the explorers’ canoes and trapped them in the canyon bottom. Here they nearly starved to death.

#### Fire and ice

The explorers had stumbled into the deepest canyon in North America — a mile and a half deep, far deeper than the Grand Canyon — which they called “The Devil’s Scuttlehole” and today is known as Hells Canyon of the Snake River. The stunt rider Evel Knievel brought notoriety to a nearby section of the Snake River Canyon when he tried to jump it on his rocket-powered motorcycle, didn’t make the gap, fell out of the sky, and landed by parachute in the canyon bottom.

Iceland, where I traveled with Ray, is almost the opposite of a subduction zone of the type that formed Hells Canyon and the Rocky Mountains. I learned Iceland sits directly atop a giant seam where two plates are not colliding or diving but spreading apart. Known as the Mid-Atlantic Ridge, here lava wells between two plates, adding to their edges and creating a string of undersea volcanoes. Iceland is where some of the volcanoes rise above the Atlantic Ocean but it lies so near the North Pole that glaciers cover parts of it. Thus our goal: to reach a spot where volcanic fire mingled with glacial ice.

That’s where Ray was dangling in an icy crevasse. Fortunately, Ray carried a pair of skis in his arms. The skis and the rope tied to his waist snagged on the crevasse’s lip and prevented him from falling farther down into the crack. He quickly pulled himself out before the guide and I had to rescue him. We staggered onward into gale and into ice crystals pelting our faces.

Finally we stepped off the glacial ice and onto the reddish ridge. We clambered up it. From the top, there was a spectacular sight. It looked like another planet extending in the far distance — rippled plains of solidified lava, a strip of desert where sand and dust blew in the gale, huge glacial sheets, distant mountains. At our feet, below us, lay a small blue lake sparkling in the sun surrounded by hillsides of reddish earth and patches of glacial ice. Everywhere around the lake steam sprung from the Earth — from the hillsides, from the shores, from steaming vents in the glacier itself.

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Then I looked back around me at the big boulders lying on the summit plateau. I had assumed they’d lain there for years, if not centuries, since the last big eruption sent lava bombs falling out of the sky. I now noticed that they’d made craters in the ash, disturbing the rain-pocked surface. Right then I realized that the volcano had erupted just since that morning. It was more than active — it was really active. It felt like we were standing beside a direct hole down to the molten interior of the Earth.

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This got me interested in knowing more about plate tectonics. Scientists developed their theory about how plates work after observing seismic events like volcanoes and earthquakes and studying data like the fossil record. Closely examining maps tells amazing stories as well. The Earth’s constantly changing and often violent history can be understood through plate tectonics. It's a kind of language to read the stories hidden in maps.

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You can imagine how the incredible pressure of two plates colliding shakes Indonesia with near-constant earthquakes. Some are small, others are large, and occasionally they are huge, like the 2004 undersea mega-quake that triggered a tsunami off Sumatra.

Diving plates also shove up mountain ranges from below. It's like shoving a spatula under a sheet of raw pie dough, and explains why Mount Everest, already at 29,035 feet the world’s tallest mountain, grows an inch or two taller every year.

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The North American Plate is sliding over that huge lava dome. (I’m lava surfing even while I’m writing this.) Over millions of years, as the Rocky Mountains slid over the Yellowstone Hot Spot, it melted and crumbled a wide channel right through the mountain ranges, like a hot pan melting lumps of butter. Snow and rain flowed off the Rockies into the channel to form a river.

This channel is today called the Snake River Valley. The river eventually leaves the channel and flows straight into an ancient ocean trench created by the Pacific Plate diving under the North American Plate.

It is the deepest canyon in North America — a mile and a half deep, far deeper than the Grand Canyon. Today it's known as Hells Canyon of the Snake River. The stunt rider Evel Knievel brought notoriety to the Snake River Canyon when he tried to jump it on his rocket-powered motorcycle. He didn’t make it across the gap, fell out of the sky, and landed by parachute in the canyon bottom.

#### Fire and ice

Iceland, where I traveled with Ray, is almost the opposite of a subduction zone of the type that formed Hells Canyon and the Rocky Mountains. I learned Iceland sits directly atop a giant seam where two plates are not colliding or diving. Instead, they're spreading apart. Known as the Mid-Atlantic Ridge, here lava wells up between two plates that are adding to their edges. A string of undersea volcanoes results.

Iceland is where some of the volcanoes rise above the Atlantic Ocean. But, it lies so near the North Pole that glaciers cover parts of it. Thus our goal: to reach a spot where volcanic fire mingled with glacial ice.

That’s where Ray was dangling in an icy crevasse. Fortunately, Ray quickly pulled himself out before the guide and I had to rescue him.

Finally we stepped off the glacial ice and onto the reddish ridge. From the top, there was a spectacular sight. It looked like another planet. Extending into the distance were rippled plains of hardened lava, a strip of desert, huge glacial sheets, and mountains. At our feet, below us, lay a small blue lake sparkling in the sun. Everywhere around the lake steam sprung from the Earth.

We’d arrived at the spot where fire mixes with ice. We now stood directly atop the Mid-Atlantic Ridge. Here, the Earth was new.

### Why We're All Lava Surfers: First-Hand Plate Tectonics (780L)

By Peter Stark, adapted by Newsela

I was squinting into the bright sunlight reflecting off the glacier. My friend Ray, the photographer, walked a short ways ahead. We were surrounded by snow and ice.

The wind blew so hard it made us stagger. The two of us were linked by a rope to a guide who walked ahead of us. A reddish ridge of earth stuck out from the glacier. Puffs of steam shot out of it.

All of sudden, Ray disappeared. He’d fallen into a crevasse. Only his head and shoulders poked above the glacier’s surface. His legs dangled underneath him in a deep crack in the glacier.

“Ray!” I shouted. “Climb out!”

I’m an adventure writer. Magazines send me to wild and faraway places. When a magazine asked me to write an article about Iceland, I jumped at the chance. I invited Ray along to take photos.

Iceland is known as the land of “fire and ice” because it contains big glaciers and live volcanoes. Far in the center of the island, the glaciers and volcanoes mix together in sometimes explosive fashion. Getting to that spot became the goal of our trip. That journey would change the way I think about our planet Earth.

The Earth is a ball of hot, molten rock and minerals. At our planet's center is hot lava core. A thin outer “crust” of cooled rock covers the planet. We live on that surface. Giant “plates” of the crust float like islands over the molten ball inside the Earth. In very slow motion, most of the plates move. They slide beneath us about one inch per year. In other words, we’re all surfing on top of lava … just very, very slowly.

But where plates meet at their edges, all sorts of crazy things occur. The huge plates scrape past each other sideways. They dive under each other. And in some places, the plates get snagged on each other. When this happens, tremendous pressures build. Once this tension suddenly releases, things happen way faster than one inch per year.

I've been to plate edges in different parts of the world. Some of what I’ve witnessed is similar to what scientists observed during the last century.

#### A necklace of islands

Before going to Iceland, I’d spent some time in Indonesia. When I looked at a map of that country, I noticed its hundreds of islands strung out like a 3,000-mile-long necklace of pearls in the ocean. I wondered: “Why is it shaped in such a perfect arc?”

I hadn’t been there long when I started to get an answer. My wife Amy, her father, and I were staying on the Indonesian island of Bali. One night, we were sitting beside a small swimming pool. Suddenly, the water in the swimming pool sloshed back and forth, as it does when you slide around in a very full bathtub. But no one was in the pool!

It was a small earthquake. The motion was almost too subtle to feel.

I found more evidence of what might have made the arc on the island of Sumatra. There, we scaled a seldom-climbed volcano called Mount Marapi.

We hired a young man from a nearby village to lead us to the top. Off we went in the rainy darkness before dawn. For hours we climbed through misty rain forest. Finally, the green rain forest ended. We topped out at nearly 10,000 feet on the ashy-gray summit. It looked like the surface of the Moon and was scattered with big gray boulders.

The guide led us across the top. We reached the center.

“Take care,” the guide said, and pointed over the edge.

We inched closer and poked our heads over. There was the most incredible hole in the Earth I’d ever seen. It was as wide across as several soccer fields. I couldn’t see a bottom. Every 20 or 30 seconds, a huge gray blast of foul-smelling smoke and steam and ash blew out of that rocky shaft and past our faces. It made me dizzy to look over the rim.

Then I looked at the boulders lying around me. They had made craters in the ash. Right then, I realized that the volcano had erupted just since that morning and sent lava bombs falling out of the sky. This volcano was really active. It felt like we were standing beside a hole down to the molten interior of the Earth.

“This thing could erupt again at any moment!” I said to Amy. “Let’s get out of here!”

#### Earth's often violent history

This got me interested in knowing more about plate tectonics. The Earth’s ever-changing history can be understood through plate tectonics. Scientists learned how plates work by observing events like volcanoes and earthquakes, studying fossil records and examining maps.

When I studied a map of Indonesia that showed mountains and valleys on land and undersea, I noticed a huge ocean “trench.” It was the deepest underwater valley you can imagine, nearly five miles deep. And it was running alongside Indonesia's islands.

Why that arc-shaped trench? Plate tectonics taught me that Indonesia’s necklace of islands traces a seam in the Earth’s crust where two huge plates collide. The Australian Plate is shoving northward at two inches per year. The plate is sliding beneath — subducting — the Eurasian Plate. This creates a deep crease in the Earth’s crust, the Sunda Trench. As the Australian Plate dives and melts into the Earth’s interior, it allows lava to well up to the surface. It forms a string of active volcanoes. One of those is Mount Marapi.

The incredible pressure of two plates colliding shakes Indonesia with near-constant earthquakes. Occasionally there are mega-quakes. In 2004, an undersea quake caused giant tsunami waves off Sumatra.

Diving plates also push up mountain ranges from below. It's like shoving a spatula under a sheet of raw pie dough. The movement explains why the world’s tallest mountain, Mount Everest, is still growing. It stands already at 29,035 feet, but grows an inch or two taller each year.

Sometimes, I try to imagine what the plates are doing directly under my feet. This is something you can do too. Centers of continents, like the center of a raft, tend to be stable. Subduction zones on a coast tend to be less stable. But it doesn't always work that way.

I live with my family on top of the North American Plate, in Montana. We're not far from Yellowstone Park. The park is home to famous geysers — jet-like eruptions of steam that shoot straight up from the ground. Geysers actually boil up from a “hot spot” where a massive bubble of lava pushes close to the Earth’s surface. It starts from deep beneath the crust and boils water underground.

The North American Plate is sliding over that huge lava dome. I’m lava surfing even while I’m writing this. Over millions of years, the Rocky Mountains slid over the Yellowstone Hot Spot. It gradually melted and crumbled a wide channel right through the mountain ranges. Imagine a hot pan melting lumps of butter. Snow and rain flowed off the Rockies into the channel to form a river.

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# Alfred Wegener & Harry Hess

How a meteorologist and a geologist working 50 years apart brought forth the Theory of Plate Tectonics.

### Alfred Wegener and Harry Hess: Continents in Motion (1210L)

By Cynthia Stokes Brown

Alfred Wegener produced evidence in 1912 that the continents are in motion, but because he could not explain what forces could move them, geologists rejected his ideas. Almost 50 years later, Harry Hess confirmed Wegener’s ideas by using the evidence of seafloor spreading to explain what moved the continents.

#### Balloons and Arctic air

Alfred Lothar Wegener was born in Berlin, the son of a Protestant pastor. He received a PhD in astronomy from the University of Berlin in 1904, but his real love was air balloons. He and his brother, Kurt, set the world’s record in April 1906 for the longest time spent aloft in a balloon — 52 hours.

Later that year, Wegener joined an expedition to Greenland to track polar air circulation, which could be done with the help of air balloons. He had always dreamed of polar exploration too. In 1908, he began to teach at the University of Marburg, and in 1911 he co-wrote *The Thermodynamics of the Atmosphere*, a textbook that became popular; his fellow author, Vladimir Köppen, was a famous climatologist. Wegener married Köppen’s daughter Else two years later.

#### Continental drift

Wegener was making his mark as a meteorologist, or weatherman. Yet his mind seemed indifferent to the boundaries of academic disciplines. By 1910, he had noticed on a world map that the east coast of South America fits exactly against the west coast of Africa, as if they had once been joined. He looked for further evidence, found it, and, in 1915, published *The Origin of Continents and Oceans*. In it, he claimed that about 300 million years ago, the continents formed a single mass that he labeled “Pangaea,” a Greek word meaning “whole Earth.”

Wegener was not the first to present the idea of continental drift, as he called it, but he was the first to put together extensive evidence from several different scientific approaches. He used fossil evidence, such as that of tropical plants found on the Arctic island of Spitzbergen. He found large-scale geographic features that matched, like the Appalachian Mountains in the United States and the Scottish Highlands, as well as rock strata in South Africa that matched those in Brazil. He argued against the claim that earlier land bridges between the continents had sunk. He also disputed the theory that mountains formed like wrinkles on the skin of a drying apple, claiming instead that mountains formed when the edges of drifting continents crumpled and folded.

Geologists reacted to Wegener’s ideas with widespread scorn. They knew that his ideas, if accurate, would shake the foundations of their discipline. Wegener was not even a geologist — who was he to overturn their field?

Besides, he couldn’t explain what force could be immense enough to cause the continents to plow through the Earth’s crust like an icebreaker cutting through frozen sheets of ice. At a 1926 international conference in New York, many speakers were sarcastic to the point of insult; Wegener sat smoking his pipe, listening.

In 1924, Wegener accepted a professorship of meteorology and geophysics at the University of Graz in Austria. Six years later, he led another expedition to Greenland, this time with government backing, where he would set up yearlong weather-monitoring equipment at three stations on the glacier.

Drifting ice delayed the expedition and the Arctic weather proved a great hardship. In November 1930, Wegener led several dogsled teams carrying supplies to his colleagues at the isolated inland station, which did not have enough provisions. After celebrating his 50th birthday at the remote weather station, Wegener and his companion, Rasmus Villumsen, died on their return trip west to the coast.

#### Seafloor spreading

The idea of continental drift circulated in scientific circles until World War II, when sounding gear produced new evidence of what the seafloor looked like. The gear, developed in the 1930s, bounced sound waves off the seafloor to determine its depth and features.

It happened that the command of one attack transport ship, the USS Cape Johnson, was given to Harry Hammond Hess, a geologist from Princeton University. Hess, then in his late thirties, wanted to continue his scientific investigations even while at war. So he left his ship’s sounding gear on all of the time, not just when approaching port or navigating a difficult landing.

What Hess discovered was a big surprise. The bottom of the sea was not smooth as expected, but full of canyons, trenches, and volcanic sea mountains. Ocean floor exploration continued, and by the 1950s, other researchers had found that a huge rift ran along the top of the Mid-Atlantic Ridge. That enabled Hess to understand his ocean floor profiles in the Pacific. He realized that the Earth’s crust had been moving away on each side of oceanic ridges, down the Atlantic and Pacific oceans, that were long and volcanically active. He published his theory in *History of Ocean Basins* (1962), and it came to be called “seafloor spreading.”

In the early 1960s, dating of ocean-core samples showed that the ocean floor was younger at the Mid-Atlantic Ridge but progressively older in either direction, confirming the reality of seafloor spreading. Further evidence came along by 1963, as geophysicists realized that Earth’s magnetic field had reversed polarity many times, with each reversal lasting less than 200,000 years. Rocks of the same age in the seafloor crust would have taken on the magnetic polarity prevalent at the time that that part of the crust formed. Sure enough, surveys of either side of the Mid-Atlantic Ridge showed a symmetrical pattern of alternating polarity stripes. That clinched the argument for most geologists.

Unlike Wegener, Hess lived to see his major theory confirmed and accepted. He helped to plan the U.S. space program and died of a heart attack on August 25, 1969, a month after Apollo 11’s successful mission to bring the first humans to the surface of the Moon.

#### Plate tectonics

By the 1970s, geologists had agreed to use the term “plate tectonics” for what has become the core paradigm of their discipline. They used the term “plates” because they had found evidence that not just continents move, but so do whole plates of the Earth’s crust. A plate might include a continent, parts of a continent, or undersea portions of the crust. Wegener’s idea of continental drift had been developed and refined.

Geologists today understand that the Earth’s surface, or crust, is broken up into eight to 12 large plates and 20 or so smaller ones. These plates move in different directions and at different speeds and are not directly related to the landmasses on them. For instance, the North American plate is much larger than the North American continent; the plate extends from the western coast of North America to the mid-Atlantic. Iceland is split down the middle, belonging to two different plates.

Over the last 500 million years, the continents have come together into one large mass, and then split apart again – possibly as many as three times. Scientists can only guess when the first plates formed and how they behaved further back than that.

The force that moves the plates is thought to be convection currents in the mantle under the Earth’s crust. The mantle is solid in the short term, but flows very slowly over geologic timescales. Pockets of hot liquid magma ooze up along extensive mountain ridges deep under the water, one running roughly north-south in the mid-Atlantic and another in the mid-Pacific. Along these ridges are found active volcanoes and hydrothermal (hot-water) vents, also known as “black smokers.” Through these vents pours very hot, mineral-rich water that supports astonishing ecosystems, the only ones on Earth whose immediate energy source is not sunlight. It’s possible that these “vent communities” are where the first living organisms on Earth developed.

Where the edges of the plates meet, several things may happen. If both plates carry continents, which are lighter than the ocean floor, they may clash head on, causing high mountains to rise. If one plate is heavier, it may go under the other, a process known as “subduction.” The material of the subducted plate returns to the mantle, recycling the Earth’s crust. Or the plates may move sideways, grinding against each other. This grinding produces cracks, or faults, in the plates, as along the California coast; these fractures are called “transform plate boundaries.” In whatever form the plate edges meet, earthquakes take place; on a global map of earthquake zones, the outlines of the plates are clearly visible.

The European and North American plates are moving apart at the speed a fingernail grows, about two meters (just over six feet) in a human lifetime. Millions of years in the future, parts of California and Mexico will probably drift off to become an island. Most of Africa is pushing northward toward Europe and will eventually squeeze out the Mediterranean Sea and cause high mountains to emerge along the whole southern coast of Europe. The eastern portion of Africa will split off at the Great Rift Valley and float off into the Indian Ocean. In geologic time, the Earth’s plates are always moving.

### Alfred Wegener and Harry Hess: Continents in Motion (1030L)

By Cynthia Stokes Brown, adapted by Newsela

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#### Balloons and Arctic air

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Later that year, Wegener joined an expedition to Greenland to track polar air circulation, which could be done with the help of air balloons. He had always dreamed of polar exploration too. In 1908, he began to teach at the University of Marburg. In 1911, he co-wrote *The Thermodynamics of the Atmosphere*, a textbook that became popular.

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Wegener was not the first to present the idea of continental drift, as he called it. But he beat everyone else in putting together extensive evidence from several different scientific approaches. He used fossil evidence, such as that of tropical plants found on the Arctic island of Spitzbergen. He found large-scale geographic features that matched, like the Appalachian Mountains in the United States and the Scottish Highlands. He located layers of rock called strata in South Africa that matched those in Brazil.

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#### Seafloor spreading

The idea of continental drift continued to circulate in scientific circles. During World War II, sounding gear produced new evidence of what the seafloor looked like. The gear, developed in the 1930s, bounced sound waves off the seafloor to determine its depth and features.

It happened that the command of an attack transport ship was given to Harry Hess, a geologist from Princeton University. Hess, then in his late thirties, wanted to continue his scientific investigations even while at war. So he left his ship’s sounding gear on all of the time, not just when approaching port or navigating a difficult landing.

What Hess discovered was a big surprise. The bottom of the sea was not smooth as expected. It was, in fact, full of canyons, trenches, and volcanic sea mountains. Ocean floor exploration continued. By the 1950s, other researchers had found that a huge rift ran along the top of the Mid-Atlantic Ridge. That enabled Hess to understand his ocean floor profiles in the Pacific. He realized that the Earth’s crust had been moving away on each side of oceanic ridges, down the Atlantic and Pacific oceans, that were long and volcanically active. He published his theory in *History of Ocean Basins* (1962), and it came to be called “seafloor spreading.”

In the early 1960s, dating of ocean-core samples showed that the ocean floor was younger at the Mid-Atlantic Ridge. It became progressively older in either direction. This confirmed that the seafloor was truly spreading. Further evidence came along by 1963, as geophysicists realized that Earth’s magnetic field had reversed polarity many times. Each reversal lasted fewer than 200,000 years.

Rocks of the same age in the seafloor crust would have taken on the magnetic polarity that was common at the time that that part of the crust formed. Sure enough, surveys of either side of the Mid-Atlantic Ridge found rocks with a symmetrical pattern of alternating polarity stripes. That clinched the argument for most geologists.

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#### Plate tectonics

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Geologists today understand that the Earth’s surface, or crust, is broken up into eight to 12 large plates and 20 or so smaller ones. These plates move in different directions and at different speeds. Their sizes don't correspond to the landmasses on top of them. For instance, the North American plate is much larger than the North American continent; the plate extends from the western coast of North America to the mid-Atlantic. Iceland is split down the middle, belonging to two different plates.

The continents have come together into one large mass, and then split apart again. Over the last 500 million years, this may have happened as many as three times. Scientists can only guess when the first plates formed and how they behaved further back than that.

The force that moves the plates is thought to be convection currents in the mantle under the Earth’s crust. The mantle is solid in the short term. But over longer geologic time, it does flow, though very slowly. Pockets of hot liquid magma ooze up along extensive mountain ridges deep under the water, one running roughly north-south in the mid-Atlantic and another in the mid-Pacific. Along these ridges are found active volcanoes and hydrothermal (hot-water) vents, also known as “black smokers.” Through these vents pours very hot, mineral-rich water that supports astonishing scenes of life. These ecosystems are the only ones on Earth whose immediate energy source is not sunlight. It’s possible that these “vent communities” are where the first living organisms on Earth developed.

Where the edges of the plates meet, several things may happen. If both plates carry continents, which are lighter than the ocean floor, they may clash head on, causing high mountains to rise. If one plate is heavier, it may go under the other, a process known as “subduction.” The material of the subducted plate returns to the mantle, recycling the Earth’s crust. Or the plates may move sideways, grinding against each other. This grinding produces cracks, or faults, in the plates, as along the California coast. In whatever form the plate edges meet, earthquakes take place; on a global map of earthquake zones, the outlines of the plates are clearly visible.

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#### Continental drift

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Scientists of the time believed that land bridges had once connected the continents, and later sunk into the ocean. Wegener wanted to demolish that claim. He also disputed the theory that mountains formed like wrinkles on the skin of a drying apple. Instead, he claimed that mountains formed when the edges of drifting continents collided and crumpled. For instance, scientists now believe India hit Asia, creating the Himalayas.

Geologists reacted to Wegener’s ideas with widespread scorn. Wegener was not even a geologist — who was he to try to overturn the basic knowledge of their own field? Besides, he couldn’t explain what force could be immense enough to cause the continents to plow through the Earth’s crust. At a 1926 international conference in New York, many speakers were sarcastic to the point of insult; Wegener sat smoking his pipe, listening.

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What Hess discovered was a big surprise. The bottom of the sea was not smooth as expected. It was, in fact, full of canyons, trenches, and volcanic sea mountains. Exploration of the ocean's floor continued.

By the 1950s, other researchers had found that a huge rift ran along the top of the Mid-Atlantic Ridge. That enabled Hess to understand what he'd discovered about the ocean floor of the Pacific. He realized that the Earth’s crust had been moving away on each side of oceanic ridges. The ridges ran down the Atlantic and Pacific oceans and were long and volcanically active. He published his theory in 1962, and it came to be called “seafloor spreading.”

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#### Plate tectonics

By the 1970s, geologists had agreed to use the term “plate tectonics.” They had evidence that continents move. But, they'd also found evidence that so do whole "plates" of the Earth’s crust. A plate might include a continent, parts of a continent, or undersea portions of the crust. Wegener’s idea of continental drift had been taken a step further.

Geologists today understand that the Earth’s surface, or crust, is broken up into eight to 12 large plates and 20 or so smaller ones. These plates move in different directions and at different speeds. Their sizes don't correspond to the landmasses on top of them. For instance, the North American plate is much larger than the North American continent; the plate extends from the western coast of North America to the mid-Atlantic. Iceland is split down the middle. It belongs to two different plates.

The continents have come together into one large mass — and then split apart again — more than once. Over the last 500 million years, this may have happened as many as three times.

The force that moves the plates is thought to be convection currents in the mantle under the Earth’s crust. The mantle is solid in the short term. But over longer geologic time, it does flow, though very slowly. Pockets of hot liquid magma ooze up along extensive mountain ridges deep under the water. One runs roughly north-south in the mid-Atlantic and another runs in the mid-Pacific.

Along these ridges are found active volcanoes and hot-water vents. Through these vents pours very hot, mineral-rich water. Astonishing forms of life are supported by the nutrients in the water. These ecosystems are the only ones on Earth who survive in the absence of sunlight. It’s possible that this is where the first living organisms on Earth developed.

Where the edges of the plates meet, several things may happen. If both plates carry continents, which are lighter than the ocean floor, they may clash head on, causing high mountains to rise. If one plate is heavier, it may go under the other, a process known as “subduction.” The material of the subducted plate returns to the mantle, recycling the Earth’s crust.

Or the plates may move sideways, grinding against each other. This grinding produces cracks, or faults, in the plates, as along the California coast. In whatever form the plate edges meet, earthquakes take place. On a global map of earthquake zones, the outlines of the plates are clearly visible.

The European and North American plates are moving apart at the speed a fingernail grows. In a human lifetime, this amounts to about two meters (just over six feet). Millions of years in the future, parts of California and Mexico will probably drift off to become an island. Most of Africa is pushing northward toward Europe. Eventually it will squeeze out the Mediterranean Sea. When it reaches Europe it will cause high mountains to emerge along the whole southern coast of Europe. The eastern portion of Africa will split off at the Great Rift Valley and float off into the Indian Ocean. In slow geologic time, the Earth’s plates are always moving.

### Alfred Wegener and Harry Hess: Continents in Motion (780L)

By Cynthia Stokes Brown, adapted by Newsela

Alfred Wegener showed evidence in 1912 that the continents are moving. But, geologists rejected his ideas at first, partly because Wegener wasn't a geologist. He also couldn't explain how the continents moved. Almost 50 years later, Wegener’s ideas were confirmed. Harry Hess proved Wegener right by using evidence that the ocean's floor spreads to explain what moved the continents.

#### Balloons and Arctic air

Alfred Wegener was born in Berlin, Germany. He received a PhD in astronomy from the University of Berlin in 1904. However, his real love was air balloons. He and his brother, Kurt, set the world’s record in 1906 for the longest time spent in a balloon — 52 hours.

Later that year, Wegener joined an expedition to Greenland. He would use his expertise with air balloons to track polar air circulation. Wegener had always dreamed of polar exploration.

#### Continental drift

Wegener studied the atmosphere as a meteorologist. He was earning recognition for his work. Yet his mind kept roaming. By 1910, he had noticed on a map that the east coast of South America fits exactly against the west coast of Africa. It appeared as if they had once been joined. He found evidence that it had and, in 1915, published *The Origin of Continents and Oceans*. In it, he claimed that about 300 million years ago, the continents formed a single mass. He labeled it “Pangaea,” a Greek word meaning “whole Earth.”

Wegener was not the first to present the idea of "continental drift." But he beat everyone else in putting together evidence from different scientific approaches. He found fossil evidence showing that the Earth was once one land mass. For instance, he located ancient tropical plants on the Arctic island of Spitzbergen. This is thousands of miles from where you would expect to find them.

Wegener also found rocks and mountains on different continents that were similar. He pointed out that the Appalachian Mountains in the U.S. are similar to the Scottish Highlands. He located rock layers called "strata" in South Africa that matched those in Brazil.

Scientists then believed that land bridges had once connected the continents. The theory was that they later sunk into the ocean. Wegener wanted to end that theory. He also disputed the theory of the time that mountains formed like wrinkles on the skin of a drying apple. Instead, he claimed that mountains formed when the edges of drifting continents collided and crumpled. Later studies backed up Wegener's research. Scientists now believe India hit Asia, creating the Himalayas.

Geologists mocked Wegener’s ideas. Wegener was not even a geologist. Who was he to try to overturn their beliefs?

Besides, he couldn’t explain what caused the continents to plow through the Earth’s crust. It would have required immense force. Picture ice-breaking ships cutting through frozen sheets of ice, just vastly more powerful.

In 1930, Wegener led another expedition to Greenland. He set up weather-monitoring equipment at stations on the glacier.

In November 1930, Wegener led dogsled teams carrying supplies to his colleagues at an isolated weather station. He celebrated his 50th birthday at the station. On his return trip back to the coast, Wegener died.

#### Seafloor spreading

Scientists kept talking about the idea of continental drift. During World War II, sounding gear produced new evidence of what the seafloor looked like. The gear, called sonar, was developed in the 1930s. It worked by bouncing sound waves off the seafloor. Sonar equipment on board received the waves and determined the seafloor's depth and features.

It happened that a geologist from Princeton University named Harry Hess was put in charge of a military ship. Hess wanted to continue his scientific investigations even while at war. Ship commanders usually turned on sounding gear to navigate when docking. Hess, however, left his ship’s gear on all of the time.

What Hess discovered was a big surprise. The bottom of the sea was not smooth as expected. It was, in fact, full of canyons, trenches, and volcanoes.

By the 1950s, other researchers had found that a huge rift ran along the top of the Mid-Atlantic Ridge. The discovery enabled Hess to understand what he'd learned about the ocean floor of the Pacific. He now knew that the Earth’s crust had been moving away on either side of oceanic ridges. The ridges ran down the Atlantic and Pacific oceans. They were long — and volcanically active. He published his theory in 1962. It came to be called “seafloor spreading.”

In the early 1960s, samples were taken from deep in the ocean's floor and dated. They showed that the ocean floor was younger at the Mid-Atlantic Ridge. It became older and older in either direction. This confirmed that the seafloor was truly spreading. Further evidence came along by 1963. Geophysicists realized that Earth’s magnetic field had reversed polarity many times. Each reversal lasted fewer than 200,000 years. When this happened, the North Pole and South Pole swapped magnetization.

Rocks on the seafloor would show the magnetic polarity at the time that that part of the crust formed. Sure enough, rocks were found in the Mid-Atlantic Ridge. They had a pattern of alternating stripes of polarity. It's almost like a zebra's coat. That clinched the argument for most geologists.

Unlike Wegener, Hess lived to see his major theory accepted. He helped to plan the U.S. space program. On August 25, 1969, he died of a heart attack. It was just a month after the Apollo 11 mission brought the first humans to the Moon.

#### Plate tectonics

By the 1970s, geologists had agreed to use the term “plate tectonics.” They already knew that the continents move. But, they'd also found evidence that so do whole "plates" of the Earth’s crust. A plate might include a continent or parts of a continent. Even portions of the Earth's crust now underwater can form plates. Wegener’s idea of continental drift had been taken a step further.

Geologists today understand that the Earth’s crust is broken up into eight to 12 large plates and 20 or so smaller ones. These plates move in different directions and at different speeds. Their sizes don't match the landmasses on top of them. For instance, the North American plate is much larger than the North American continent. The plate starts at the western coast of North America. Yet, it extends into the middle of the Atlantic Ocean. Iceland is split down the middle. It belongs to two different plates.

The continents have come together into one large mass — and then split apart again — more than once. Over the last 500 million years, this may have happened as many as three times.

The force that moves the plates is thought to be convection currents in the Earth's mantle. The mantle is the area below the Earth’s crust. It separates the earth's core from the crust. The mantle is solid in the short term.

But over longer geologic time, the mantle does flow, though very slowly. And plates float on top of the mantle. Pockets of hot liquid magma in the mantle ooze up along mountain ridges deep under the water. One runs north-south in the middle of the Atlantic Ocean. Another runs in the mid-Pacific Ocean.

Along these ridges are active volcanoes and hot-water vents. Very hot, mineral-rich water pours through these vents. The water nourishes amazing forms of life. These ecosystems are the only ones on Earth that live without sunlight. It’s possible that the first living things on Earth developed in such vents.

Where the edges of the plates meet, several things may happen. Continents are lighter than the ocean floor. So, if both plates carry continents, they may clash head on. Mountains rise up at the point of collision. If one plate is heavier, it may go under the other, a process known as “subduction.” The part of the plate that gets subducted becomes part of the mantle.

Or the plates may grind against each other. As they grind together, cracks, or faults, appear in the plates. However plate edges meet, earthquakes take place. If you look at a global map of earthquake zones, the outlines of the plates are clearly visible.

The European and North American plates are moving apart at the speed a fingernail grows. In a human lifetime, this amounts to about two meters (just over six feet). Millions of years in the future, parts of California and Mexico will probably drift off. They'll separate from North America and become an island.

Most of Africa is pushing toward Europe. Eventually, it will squeeze out the Mediterranean Sea. When it reaches Europe, it will cause high mountains to form along the southern coast. The eastern portion of Africa will split off at the Great Rift Valley. It will then float off into the Indian Ocean. In slow geologic time, the Earth’s plates are always moving.

# Eratosthenes

More than 2,000 years ago, Eratosthenes compared the position of the Sun’s rays in two locations to calculate the spherical size of the Earth with reasonable accuracy.

### Eratosthenes of Cyrene: Measuring the Circumference of the Earth (1180L)

By Cynthia Stokes Brown

More than 2,000 years ago Eratosthenes compared the position of the Sun’s rays in two locations to calculate the spherical size of the Earth with reasonable accuracy.

Eratosthenes was born in the Greek colony of Cyrene, now the city of Shahhat, Libya. As a young man, he traveled to Athens to pursue his studies. He returned to Cyrene and made such a name for himself in scholarly endeavors that the Greek ruler of Egypt brought him to Alexandria to tutor his son. When the chief librarian of the famous Library of Alexandria died in 236 BCE, Eratosthenes was appointed to the prominent position around the age of 40.

A man of many talents, Eratosthenes was a librarian, geographer, mathematician, astronomer, historian, and poet. His friends at the library nicknamed him Pentathlos, or athlete who competes in five different events. The name seemed to fit a scholar who excelled in many fields of study. Most of Eratosthenes’s writings have been lost, but other scholars reported his work and findings — which were extensive.

#### Studying the Earth

Eratosthenes may have been the first to use the word geography. He invented a system of longitude and latitude and made a map of the known world. He also designed a system for finding prime numbers — whole numbers that can only be divided by themselves or by the number 1. This method, still in use today, is called the “Sieve of Eratosthenes.”

Eratosthenes was also the first to calculate the tilt of the Earth’s axis, which he figured with remarkable accuracy; the finding was reported by Ptolemy (85-165 CE). Eratosthenes also calculated the distance from the Earth to the Moon and to the Sun, but with less accuracy. He made a catalog of 675 stars. He made a calendar with leap years and laid the foundation of chronology in the Western world by organizing the dates of literary and political events from the siege of Troy (about 1194–1184 BCE) to his own time.

Yet his most lasting achievement was his remarkably accurate calculation of the Earth’s circumference, the distance around a circle or sphere. He computed this by using simple geometry and trigonometry and by recognizing Earth as a sphere in space. Most Greek scholars by the time of Aristotle (384–322 BCE) agreed that Earth was a sphere, but none knew how big it was.

How did Greek scholars know the Earth was a sphere? They observed that ships disappeared over the horizon while their masts were still visible. They saw the curved shadow of the Earth on the Moon during lunar eclipses. And they noticed the changing positions of the stars in the sky.

#### Measuring the Earth

Eratosthenes heard about a famous well in the Egyptian city of Swenet (Syene in Greek, and now known as Aswan), on the Nile River. At noon one day each year — the summer solstice (between June 20 and 22) — the Sun’s rays shone straight down into the deep pit. They illuminated only the water at the bottom, not the sides of the well as on other days, proving that the Sun was directly overhead. Syene was located very close to what we call the Tropic of Cancer, ~23.5 degrees north, the northernmost latitude at which the Sun is ever directly overhead at noon.

Eratosthenes erected a pole in Alexandria, and on the summer solstice he observed that it cast a shadow, proving that the Sun was not directly overhead but slightly south. Recognizing the curvature of the Earth and knowing the distance between the two cities enabled Eratosthenes to calculate the planet’s circumference.

Eratosthenes could measure the angle of the Sun’s rays off the vertical by dividing the length of the leg opposite the angle (the length of the shadow) by the leg adjacent to the angle (the height of the pole). This gave him an angle of 7.12 degrees. He knew that the circumference of Earth constituted a circle of 360 degrees, so 7.12 (or 7.2, to divide 360 evenly by 50) degrees would be about one-fiftieth of the circumference. He also knew the approximate distance between Alexandria and Syene, so he could set up this equation:

*360 degrees / 7.2 degrees  =   circumference of the Earth /distance from Alexandria to Syene*

Eratosthenes estimated the distance from Alexandria to Syene as 5,000 "stadia," or about 500 miles (800 kilometers). He made this estimation from the time it took walkers, who were trained to measure distances by taking regular strides, to trek between the cities. By solving the equation, he calculated a circumference of 250,000 stadia, or 25,000 miles (40,000 kilometers).

Several sources of error crept into Eratosthenes’s calculations and our interpretation of them. For one thing, he was using as his unit of measure the Greek unit “stadion,” or the length of an athletic stadium. But not all stadiums were built the same length. In Greece, a stadion equaled roughly 185 meters (607 feet), while in Egypt the stadion was about 157.5 meters (517 feet). We don’t know which unit Eratosthenes used. If he used the Greek measure, his calculation would have been off by about 16 percent. If he used the Egyptian one, his error would have been less than 2 percent off the actual Earth’s circumference of 24,860 miles (40,008 kilometers).

A century after Eratosthenes, the Greek astronomer Posidonius of Rhodes (c. 135–51 BCE) calculated the Earth’s circumference. Posidonius used the star Canopus as a frame of reference: when the star is visible at the horizon in Rhodes, it is 7.5 degrees above the horizon in Alexandria. His first calculations came out almost exactly correct, but he revised the distance between Rhodes and Alexandria, which resulted in a number comparable to about 18,000 miles (about 29,000 kilometers), about 28 percent smaller than the actual circumference. Ptolemy reported the calculations of Posidonius instead of those of Eratosthenes, and it was Ptolemy’s writings that found their way to Christopher Columbus. If Ptolemy had used Eratosthenes’s larger, more accurate figure for Earth’s circumference, Columbus might never have sailed west.

Eratosthenes lived to be about 82 years old, when he starved himself to death because he feared the onset of blindness.

### Eratosthenes of Cyrene: Measuring the Circumference of the Earth (990L)

By Cynthia Stokes Brown, adapted by Newsela

More than 2,000 years ago Eratosthenes calculated the size of the Earth with reasonable accuracy just by measuring the Sun's rays.

Eratosthenes was born in the Greek colony of Cyrene, now part of Libya. As a young man, he traveled to Athens to study. He returned to Cyrene and made such a name for himself as a scholar that the Greek ruler of Egypt brought him to Alexandria to tutor his son. When the chief librarian of the famous Library of Alexandria died in 236 BCE, Eratosthenes was appointed to the prominent position around the age of 40.

A man of many talents, Eratosthenes was a librarian, geographer, mathematician, astronomer, historian, and poet. His friends at the library nicknamed him Pentathlos, or athlete who competes in five different events. The name seemed to fit a scholar who excelled in many fields of study. Most of Eratosthenes’s writings have been lost, but other scholars reported his extensive work.

#### Studying the Earth

Eratosthenes may have been the first to use the word geography. Some call him the father of geography. He invented a system of longitude and latitude and made a map of the known world. He also designed a system for finding prime numbers — whole numbers that can only be divided by themselves or by the number 1. This method, still in use today, is called the “Sieve of Eratosthenes.”

Eratosthenes was also the first to calculate the tilt of the Earth’s axis, which he figured with remarkable accuracy; the finding was reported by the writer Ptolemy (85-165 CE).

Eratosthenes also calculated the distance from the Earth to the Moon and to the Sun, but with less accuracy. He cataloged 675 stars. He made a calendar with leap years and organized the dates of literary and political events from the siege of Troy (about 1194–1184 BCE) to his own time. His work laid the foundation of chronology in the Western world.

Yet his most lasting achievement was his remarkably accurate calculation of the Earth’s circumference, the distance around a circle or sphere. He computed this by using simple geometry and trigonometry and by recognizing Earth as a sphere in space. Most Greek scholars by the time of Aristotle (384–322 BCE) agreed that Earth was a sphere. None, however, knew how big it was.

How did Greek scholars know the Earth was a sphere? They observed that ships disappeared over the horizon while their masts were still visible. They saw the curved shadow of the Earth on the Moon during lunar eclipses. And they noticed the changing positions of the stars in the sky.

#### Measuring the Earth

Eratosthenes heard about a famous well in the Egyptian city of Syene, now known as Aswan, on the Nile River. At noon one day each year — the summer solstice (between June 20 and 22) — the Sun’s rays shone straight down into the well's deep pit. They illuminated only the water at the bottom, not the sides of the well, as on other days. This proved that the Sun was directly overhead.

Back in Alexandria, Eratosthenes erected a pole. On the summer solstice, he observed that it cast a shadow, proving that the Sun was not directly overhead there. Instead, it was slightly south. Eratosthenes knew that the Earth was curved. By also knowing the distance between the two cities, Eratosthenes could calculate the planet’s circumference.

Eratosthenes measured the angle of the Sun’s rays off the vertical. He divided the length of the leg opposite the angle (the length of the shadow) by the leg adjacent to the angle (the height of the pole). This gave him an angle of 7.12 degrees. He knew that the circumference of Earth constituted a circle of 360 degrees. So 7.12 (or 7.2, to divide 360 evenly by 50) degrees would be about one-fiftieth of the circumference. He also knew the approximate distance between Alexandria and Syene, so he could set up this equation:

*360 degrees / 7.2 degrees  =   circumference of the Earth /distance from Alexandria to Syene*

Eratosthenes estimated the distance from Alexandria to Syene as 5,000 "stadia," or about 500 miles (800 kilometers). He made this estimation from the time it took walkers, who were trained to measure distances by taking regular strides, to trek between the cities. By solving the equation, he calculated a circumference of 250,000 stadia, or 25,000 miles (40,000 kilometers).

Yet, errors crept into Eratosthenes’s calculations. For one thing, he was using as his unit of measure the Greek unit “stadion,” or the length of an athletic stadium. But not all stadiums were built the same length. In Greece, a stadion equaled roughly 185 meters (607 feet), while in Egypt, the stadion was about 157.5 meters (517 feet). We don’t know which unit Eratosthenes used.

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By Cynthia Stokes Brown, adapted by Newsela

More than 2,000 years ago Eratosthenes calculated the size of the Earth with great accuracy just by measuring the Sun's rays.

Eratosthenes was born in the Greek colony of Cyrene, now part of Libya. As a young man, he traveled to Athens to study. He returned to Cyrene and made such a name for himself as a scholar that the Greek ruler of Egypt brought him to Alexandria to tutor his son. When the chief librarian of the famous Library of Alexandria died in 236 BCE, Eratosthenes got the job around the age of 40.

Eratosthenes was a man of many talents. He was a librarian, geographer, mathematician, astronomer, historian, and poet. His friends at the library nicknamed him Pentathlos, or athlete who competes in five different events. The name seemed to fit a scholar who excelled in many fields of study. Most of Eratosthenes’s writings have been lost, but other scholars reported his wide range of work.

#### Studying the Earth

Eratosthenes may have been the first to use the word geography. Some call him the father of geography. He invented a system of longitude and latitude and made a map of the known world. He also designed a system for finding prime numbers — whole numbers that can only be divided by themselves or by the number 1. This method is still in use today.

Eratosthenes was also the first to calculate the tilt of the Earth’s axis, which he figured with remarkable accuracy; the finding was reported by the writer Ptolemy (85-165 CE).

Eratosthenes also calculated the distance from the Earth to the Moon and to the Sun, but with less accuracy. He cataloged 675 stars. He made a calendar with leap years and laid the foundation of chronology in the Western world. He organized the dates of literary and political events from the siege of Troy (about 1194–1184 BCE) to his own time.

Yet he is best known for his remarkably accurate calculation of the Earth’s circumference. He was able to do that because he recognized Earth as a sphere. He then computed the distance by using simple geometry and trigonometry. Most Greek scholars by the time of Aristotle (384–322 BCE) agreed that Earth was a sphere. None, however, knew how big it was.

How did Greek scholars know the Earth was a sphere? They observed that ships disappeared over the horizon while their masts were still visible. They saw the curved shadow of the Earth on the Moon during lunar eclipses, when the moon passes directly behind the Earth and into its shadow. And they noticed the changing positions of the stars in the sky.

#### Measuring the Earth

Eratosthenes heard about a famous well in the Egyptian city of Syene, which is now known as Aswan, on the Nile River. At noon one day each year — the summer solstice (between June 20 and 22) — the Sun’s rays shone straight down into the well's deep pit. They lit up only the water at the bottom, not the sides of the well, as on other days. This proved that the Sun was directly overhead.

Back in Alexandria, Eratosthenes erected a pole. On the summer solstice, he observed that it cast a shadow. This proved that the Sun was not directly overhead there. Instead, it was slightly south. Eratosthenes knew that the Earth was curved. By also knowing the distance between the two cities, Eratosthenes could calculate the planet’s circumference.

Eratosthenes measured the angle of the Sun’s rays off the vertical. He divided the length of the leg opposite the angle (the length of the shadow) by the leg adjacent to the angle (the height of the pole). This gave him an angle of about 7.2 degrees. He knew that the Earth was a 360-degree circle. He also knew the approximate distance between Alexandria and Syene, so he could set up this equation:

*360 degrees / 7.2 degrees  =   circumference of the Earth /distance from Alexandria to Syene*

Eratosthenes estimated Alexandria was 5,000 "stadia" away from Syene, equal to about 500 miles (800 kilometers). He could estimate the stadia because walkers were trained to measure distances by taking regular strides. So, he used the amount of time it took walkers to trek between the cities. By solving the equation, he calculated the Earth's circumference at 250,000 stadia, or 25,000 miles (40,000 kilometers).

His calculations were incredibly close. The Earth’s actual circumference is 24,860 miles (40,008 kilometers).

Yet, errors crept into Eratosthenes’s calculations. For one thing, he was using as his unit of measure the Greek unit “stadion,” or the length of an athletic stadium. But stadiums were different lengths in Egypt and Greece. We don’t know which unit Eratosthenes used.

If he used the Egyptian measure, he would have been nearly spot on. However, if he used the Greek one, his calculation would have been off by about 16 percent.

A century after Eratosthenes, the Greek astronomer Posidonius of Rhodes (c. 135–51 BCE) calculated the Earth’s circumference. Instead of using the Sun, Posidonius used the star Canopus as a point of reference. When the star is visible at the horizon in Rhodes, it is 7.5 degrees above the horizon in Alexandria. His first calculations came out almost exactly correct. But then he revised the distance between Rhodes and Alexandria, which resulted in a calculation of 18,000 miles (about 29,000 kilometers). His new calculation was about 28 percent smaller than the actual circumference of 24,860 miles.

Ptolemy reported the calculations of Posidonius, instead of those of Eratosthenes.  Christopher Columbus read Ptolemy’s writings. If Ptolemy had used Eratosthenes’s larger, more accurate figure for Earth’s circumference, Columbus might never have sailed west.

Eratosthenes lived to be about 82 years old. He starved himself to death because he feared going blind.

### Eratosthenes of Cyrene: Measuring the Circumference of the Earth (770L)

By Cynthia Stokes Brown, adapted by Newsela

More than 2,000 years ago Eratosthenes figured out the size of the Earth with great accuracy. His tools: a stick, the Sun's rays, and simple math.

Eratosthenes was born in the Greek colony of Cyrene, now Libya. In Cyrene, he made a name for himself as a great scholar. The Greek ruler of Egypt decided to bring him to Alexandria to tutor his son. In 236 BCE, the chief librarian of the famous Library of Alexandria in Egypt died. Eratosthenes was given the job around age 40.

Eratosthenes was a man of many talents. He was a librarian, geographer, mathematician, astronomer, historian, and poet. Most of Eratosthenes’s writings have been lost. Luckily, other scholars have recorded his wide-ranging work.

#### Studying the Earth

Eratosthenes was the father of geography. He invented a system of longitude and latitude. He made a map of the world as it was known at the time. He also designed a system for finding prime numbers — whole numbers that can only be divided by themselves or by the number 1. His system is still in use today.

Eratosthenes was also the first to figure the tilt of the Earth’s axis. His calculation was impressively close to being correct.

Eratosthenes also calculated the distance from the Earth to the Moon and to the Sun, but with less accuracy. He cataloged 675 stars. He made a calendar with leap years. He laid the foundation of chronology, the science of arranging historical events in order by when they happened. He organized the dates of events from the siege of Troy (about 1194–1184 BCE) to his own time.

But he is best known for figuring the distance around the Earth. His calculation was not correct, but it was impressively close. He computed the circumference by using simple geometry and trigonometry. Most Greek scholars by the time of Aristotle (384–322 BCE) agreed that Earth was a sphere. None, however, knew how big it was.

How did Greek scholars know the Earth was a sphere? They noticed that when ships disappeared over the horizon, their masts were still visible for a few extra moments. They also saw that the Earth made a curved shadow on the Moon during lunar eclipses. This happens a couple times each year when the moon passes directly behind the Earth and into its shadow. The Greeks had also noticed the changing positions of the stars in the sky.

#### Measuring the Earth

Eratosthenes heard about a famous well in the Egyptian city of Syene, now known as Aswan, on the Nile River. The summer solstice falls one day each year between June 20 and 22. At noon on that day, the Sun’s rays shone straight down into the well's deep pit. On other days, the sides of the well would be lit. But not on this day. On the Solstice, the rays lit up only the water at the bottom. This proved that the Sun was directly overhead.

Back in Alexandria, Eratosthenes erected a pole. On the summer solstice, he observed that it cast a shadow. The Sun was not directly overhead there. Instead, it was slightly south. Eratosthenes knew that the Earth was curved. By also knowing the distance between the two cities, Eratosthenes could calculate the planet’s circumference.

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Eratosthenes knew the distance from Alexandria to Syene was about 5,000 "stadia." To us, that distance would equal about 500 miles (800 kilometers). By solving the equation, he calculated the Earth's circumference at 250,000 stadia, or 25,000 miles (40,000 kilometers).

His calculations were incredibly close. The Earth’s actual circumference is 24,860 miles (40,008 kilometers).

Yet, Eratosthenes’s calculations had errors. For one thing, he was using the "stadion" as his unit of measure. A stadion was the length of an athletic stadium. But stadiums were different lengths in Egypt and Greece. We don’t know which unit Eratosthenes used.

If he used the Egyptian measure, he would have been nearly spot on. However, if he used the Greek one, his calculation would have been off by about 16 percent.

A century after Eratosthenes, the Greek astronomer Posidonius of Rhodes (c. 135–51 BCE) calculated the Earth’s circumference. Instead of using the Sun, Posidonius used the star Canopus as point of reference. When the star is visible at the horizon in Rhodes, it is 7.5 degrees above the horizon in Alexandria. He was very close to Eratosthenes’s calculation of 7.2 degrees. Posidonius's calculations came out almost exactly correct.

But then he changed the distance between Rhodes and Alexandria. This resulted in a calculation of 18,000 miles (about 29,000 kilometers). His new calculation was about 28 percent smaller than the actual circumference of 24,860 miles.

The writer Ptolemy reported the calculations of Posidonius, instead of those of Eratosthenes. Christopher Columbus read Ptolemy’s writings. If Ptolemy had used Eratosthenes’s larger, closer figure for Earth’s circumference, history might have had a different outcome. Columbus might never have sailed west. The Americas might not have been reached by Europeans until much later.

Eratosthenes died around the age of 82. He starved himself to death because he feared going blind.

# Principles of Geology

Excerpts from Chapter One of Lyell's *Principles of Geology*.

### In Their Own Words: Charles Lyell (1530L)

By Charles Lyell

*Charles Lyell (1797–1875) was a British lawyer and the foremost geologist of his day. He is best known as the author of "Principles of Geology," which popularized geologist James Hutton’s concept of “uniformitarianism”— the idea that the Earth was shaped by slow-moving forces still in operation today. Uniformitarian ideas opposed the common belief among many geologists that unique catastrophes or supernatural events, like the biblical flood in the story of Noah, shaped Earth’s surface. The motto of uniformitarianism was “the present is the key to the past,” an idea that Lyell’s friend, Charles Darwin, extended to biology. In fact, Lyell’s "Principles of Geology" was one of the few books that Darwin carried on his famous voyage on the HMS Beagle — a voyage that led him to write "The Origin of the Species."*

#### Geology defined — Compared to History — Its relation to other Physical Sciences

Geology is the science which investigates the successive changes that have taken place in the organic and inorganic kingdoms of nature; it inquires into the causes of these changes, and the influence which they have exerted in modifying the surface and external structure of our planet.

By these researches into the state of the Earth and its inhabitants at former periods, we acquire a more perfect knowledge of its present condition, and more comprehensive views concerning the laws now governing its animate and inanimate productions. When we study history, we obtain a more profound insight into human nature, by instituting a comparison between the present and former states of society. We trace the long series of events which have gradually led to the actual posture of affairs; and by connecting effects with their causes, we are enabled to classify and retain in the memory a multitude of complicated relations — the various peculiarities of national character — the different degrees of moral and intellectual refinement, and numerous other circumstances, which, without historical associations, would be uninteresting or imperfectly understood. As the present condition of nations is the result of many antecedent  changes, some extremely remote, and others recent, some gradual, others sudden and violent; so the state of the natural world is the result of a long succession of events; and if we would enlarge our experience of the present economy of nature, we must investigate the effects of her operations in former epochs .

We often discover with surprise, on looking back into the chronicles of nations, how the fortune of some battle has influenced the fate of millions of our contemporaries, when it has long been forgotten by the mass of the population. With this remote event we may find inseparably connected the geographical boundaries of a great state, the language now spoken by the inhabitants, their peculiar manners, laws, and religious opinions. But far more astonishing and unexpected are the connections brought to light, when we carry back our researches into the history of nature. The form of a coast, the configuration of the interior of a country, the existence and extent of lakes, valleys, and mountains, can often be traced to the former prevalence of earthquakes and volcanoes in regions which have long been undisturbed. To these remote convulsions  the present fertility of some districts, the sterile character of others, the elevation of land above the sea, the climate, and various peculiarities , may be distinctly referred. On the other hand, many distinguishing features of the surface may often be ascribed to the operation, at a remote era, of slow and tranquil  causes — to the gradual deposition of sediment in a lake or in the ocean, or to the prolific  increase of testacea and corals.

To select another example, we find in certain localities subterranean deposits of coal, consisting of vegetable matter, formerly drifted into seas and lakes. These seas and lakes have since been filled up, the lands whereon the forests grew have disappeared or changed their form, the rivers and currents which floated the vegetable masses can no longer be traced, and the plants belonged to species which for ages have passed away from the surface of our planet. Yet the commercial prosperity, and numerical strength of a nation, may now be mainly dependent on the local distribution of fuel determined by that ancient state of things.

Geology is intimately related to almost all the physical sciences, as history is to the moral. An historian should, if possible, be at once profoundly acquainted with ethics, politics, jurisprudence, the military art, theology; in a word, with all branches of knowledge by which any insight into human affairs, or into the moral and intellectual nature of man, can be obtained. It would be no less desirable that a geologist should be well versed in chemistry, natural philosophy, mineralogy, zoology, comparative anatomy, botany; in short, in every science relating to organic and inorganic nature. With these accomplishments, the historian and geologist would rarely fail to draw correct and philosophical conclusions from the various monuments transmitted to them of former occurrences. They would know to what combination of causes analogous effects were referable, and they would often be enabled to supply, by inference, information concerning many events unrecorded in the defective archives of former ages. But as such extensive acquisitions are scarcely within the reach of any individual, it is necessary that men who have devoted their lives to different departments should unite their efforts; and as the historian receives assistance from the antiquary, and from those who have cultivated different branches of moral and political science, so the geologist should avail himself of the aid of many naturalists, and particularly of those who have studied the fossil remains of lost species of animals and plants.

The analogy, however, of the monuments consulted in geology, and those available in history, extends no farther than to one class of historical monuments — those which may be said to be undesignedly commemorative of former events. The canoes, for example, and stone hatchets found in our peat bogs, afford an insight into the rude arts and manners of the earliest inhabitants of our island; the buried coin fixes the date of the reign of some Roman emperor; the ancient encampment indicates the districts once occupied by invading armies, and the former method of constructing military defenses; the Egyptian mummies throw light on the art of embalming, the rites of sepulture, or the average stature of the human race in ancient Egypt. This class of memorials yields to no other in authenticity, but it constitutes a small part only of the resources on which the historian relies, whereas in geology it forms the only kind of evidence which is at our command. For this reason we must not expect to obtain a full and connected account of any series of events beyond the reach of history. But the testimony of geological monuments, if frequently imperfect, possesses at least the advantage of being free from all intentional misrepresentation. We may be deceived in the inferences which we draw, in the same manner as we often mistake the nature and import of phenomena observed in the daily course of nature; but our liability to err is confined to the interpretation, and, if this be correct, our information is certain.

### In Their Own Words: Charles Lyell (1210L)

By Charles Lyell, adapted by Newsela

Charles Lyell (1797–1875) was a British lawyer and the foremost geologist of his day. He is best known as the author of *Principles of Geology*. It popularized geologist James Hutton’s concept of “uniformitarianism” —  the idea that the Earth was shaped by slow-moving forces still in operation today. Uniformitarian ideas opposed the common belief among many geologists that unique catastrophes or supernatural events, like the biblical flood in the story of Noah, shaped Earth’s surface. The motto of uniformitarianism was “the present is the key to the past.” Lyell’s friend, Charles Darwin, took that idea and extended it to biology.

In fact, Lyell’s *Principles of Geology* was one of the few books that Darwin carried on his famous voyage on the HMS Beagle — a voyage that led him to write *The Origin of the Species*. What follows is a summarized version of the original text.

#### Geology defined — Compared to History — Its relation to other Physical Sciences

Geology is the science which investigates the successive changes that have taken place in the organic and inorganic kingdoms of nature. It inquires into the causes of these changes. And it describes the influence which they have exerted in modifying the surface and external structure of our planet.

By this research into the state of the Earth and its inhabitants at former periods, we acquire a more perfect knowledge of its present condition. Our views concerning the laws governing its animate and inanimate productions become more comprehensive. When we study history, we obtain a more profound insight into human nature. We can draw comparisons between the present and former states of society. We trace the long series of events which have gradually led to the current state of affairs.

By connecting effects with their causes, we are enabled to classify and retain in the memory a multitude of complicated relations — the various peculiarities of national character. More deeply can we understand the different degrees of moral and intellectual refinement, and numerous other circumstances. Without historical associations, these would be uninteresting or imperfectly understood.

The present condition of nations is the result of many previous changes. Some are extremely remote, and others recent, some gradual, others sudden and violent. In a similar way, the state of the natural world is the result of a long succession of events. If we seek to enlarge our experience of the present inner workings of nature, we must investigate the effects of her operations in past eras.

On looking back into the history of nations, we often discover with surprise how the outcome of some battle has influenced the fate of millions today. This remote event may be connected to the current geographical boundaries of a great state, the language now spoken by the inhabitants, their peculiar manners, laws, and religious opinions. But far more astonishing and unexpected are the connections brought to light when we dig deeper into the history of nature.

The form of a coast, the layout of the interior of a country, the existence and extent of lakes, valleys, and mountains, can often be traced to earthquakes and volcanoes in regions which are now tranquil. These ancient upheavals are the reason why some lands are fertile, and others are sterile. They determine the elevation of land above the sea, the climate, and various peculiarities.

On the other hand, much of the Earth's surface was formed by slow operations such as the the gradual depositing of sediment in a lake or in the ocean, or to a great increase of testacea and corals.

To select another example, we find in certain areas underground deposits of coal, consisting of vegetable matter which drifted into what were formerly seas and lakes. These seas and lakes have since been filled up. The lands the forests once grew upon have disappeared or changed their form, the rivers and currents which floated the vegetable masses can no longer be traced. And the plants belonged to species which have passed away from the surface of our planet ages ago. Yet the wealth and numerical strength of a nation may now be mainly dependent on the distribution of fuel determined by that ancient state of things.

Geology is closely related to almost all the physical sciences, as history is to the moral. A historian should, if possible, be at once profoundly acquainted with ethics, politics, jurisprudence, the military art, theology; in a word, with all branches of knowledge by which any insight into human affairs, or into the moral and intellectual nature of man, can be obtained. Likewise, a geologist should be well versed in chemistry, natural philosophy, mineralogy, zoology, comparative anatomy, botany; in short, in every science relating to organic and inorganic nature.

With these accomplishments, the historian and geologist would rarely fail to draw correct and philosophical conclusions from the various monuments brought to them by former events. They would know what combination of causes similar effects were relatable to. And they would often be enabled infer information concerning many events unrecorded in the archives of former ages.

But since no one individual can be expert in so many subjects, it is necessary that men who have devoted their lives to different departments should unite their efforts. The historian receives assistance from experts on ancient times and from scholars of moral and political science. In the same way, the geologist should avail himself of the aid of many naturalists. He should particularly gain the help of those who have studied the fossil remains of lost species of animals and plants.

To be fair, we can only compare one class of historical monuments to the records studied in geology — those which unintentionally mark past events. The canoes, for example, and stone hatchets found in our peat bogs, inform us about the arts and manners of the earliest inhabitants of our island; the buried coin fixes the date of the reign of some Roman emperor; the ancient military camp indicates the districts once occupied by invading armies, and the former method of constructing military defenses; the Egyptian mummies throw light on the art of embalming, burial customs, or the height of humans in ancient Egypt.

No other class of artifacts is more authentic. But it's just one of the resources on which the historian relies. In geology, however, it is the only evidence we can draw from. For this reason, we must not expect to obtain a full and connected account of any series of events beyond the reach of history.

Geological monuments are frequently imperfect recorders of the past. Yet, at least their clues can't be intentionally misrepresented. We may be deceived in the inferences which we draw, in the same manner as we often mistake the nature and significance of phenomena observed in nature. Yet, our risk of making an error is confined to the interpretation, and, if this be correct, our information is certain.

### In Their Own Words: Charles Lyell (1070L)

By Charles Lyell, adapted by Newsela

*Charles Lyell (1797–1875) was a British lawyer and the leading geologist of his day. He is best known as the author of*Principles of Geology*. It popularized geologist James Hutton’s concept of “uniformitarianism”— the idea that the Earth was shaped by slow-moving forces still in operation today. Uniformitarian ideas opposed the common belief among many geologists that unique catastrophes or supernatural events, like the biblical flood in the story of Noah, shaped Earth’s surface. The motto of uniformitarianism was “the present is the key to the past.” Lyell’s friend, Charles Darwin, took that idea and extended it to biology.*

*In fact, Lyell’s*Principles of Geology*was one of the few books that Darwin carried on his famous voyage on the HMS Beagle. That voyage to far-flung areas of the world led him to write*The Origin of the Species*. What follows is a summarized version of Lyell's original text.*

#### Geology defined — Compared to History — Its relation to other Physical Sciences

Geology is the science which investigates the successive changes that have taken place in the organic and inorganic kingdoms of nature. It inquires into the causes of these changes. And it describes their influence in modifying the surface of our planet.

By studying the past state of the Earth and its former inhabitants, we acquire a more perfect knowledge of its present condition. Our understanding of the laws governing its living and nonliving productions become more complete. When we study history, we gather deeper insights into human nature. We can draw comparisons between the present and former states of society. We trace the long series of events which have gradually led to the current state of affairs.

By connecting effects with their causes, we are can organize and retain in the collective memory a number of complicated relations. Together this helps shed light on what makes a certain nation unique. We can understand more deeply the different degrees of moral and intellectual refinement. Without historical associations, these would be uninteresting or imperfectly understood.

The present condition of nations is the result of many previous changes. Some are extremely remote, and others recent. Some are gradual, others sudden and violent. In a similar way, the state of the natural world is the result of a long succession of events. If we seek to enlarge our experience of today's inner workings of nature, we must investigate the effects of her operations in past eras.

It is surprising how often the outcome of some battle in history affects the fate of millions today. An event long ago may be connected to the current borders of a great state. The battle's result may be what language is spoken there today. It can determine the manners of the inhabitants, the laws that govern them, and the religion they follow. But far more surprising are the connections we find when we dig deeper into the history of nature.

The coastlines, lakes, valleys, and mountains, can often be traced to earthquakes and volcanoes in regions which are now tranquil. These ancient disasters may have caused some lands to be fertile today and others to be sterile.

On the other hand, much of the Earth's surface may have been formed by slow and tranquil causes. Sediment in a lake or in the ocean may have deposited gradually over time, for instance.

To select another example, we find underground deposits of coal, made originally of vegetable matter, which drifted into what were formerly seas and lakes. These seas and lakes have since been filled up. The lands the forests once grew upon have disappeared. Others changed their form. The rivers and currents which floated the vegetable masses can no longer be traced. And the plants belonged to species which have left our planet ages ago. Yet the wealth and population of a nation may now be mainly dependent on the fuel created by that ancient state of things.

Geology is closely related to almost all the physical sciences. It's just as history is to moral subjects. A historian should be profoundly acquainted with ethics, politics, jurisprudence, the military, and religion. In essence, the historian should grasp all branches of knowledge which give insight into human affairs, or into the moral and intellectual nature of man. Likewise, a geologist should be well versed in chemistry, natural philosophy, mineralogy, zoology, anatomy and botany. In short, geologists should be familiar with every science relating to organic and inorganic nature.

With these accomplishments, the historian and geologist would draw correct conclusions from the records left behind by former events. They would know what combination of causes similar effects now were relatable to. And they would often be able to infer information concerning many events of former ages that were never recorded.

But such extensive understanding of different fields of study is out of reach of any individual. It is therefore necessary that men who have devoted their lives to different branches should unite their efforts. The historian receives assistance from experts on ancient times and politics. In the same way, the geologist should ask the aid of naturalists. He should particularly gain the help of those who have studied the fossil remains of lost species of animals and plants.

To be fair, we can only compare one class of historical monuments to the records studied in geology — those that unintentionally leave clues about the past. The canoes, for example, and stone hatchets found in our peat bogs, offer an insight into the arts and manners of the earliest people who lived there; the buried coin fixes the date of the reign of some Roman emperor; the ancient military camp shows where invading armies once occupied ground, and the former method of constructing military defenses; the Egyptian mummies throw light on the art of embalming, burials, or how tall humans in ancient Egypt were.

No other class of artifacts is more authentic. But it's just one of the resources on which the historian relies. In geology, however, it is the only evidence we can draw from. For this reason, we must not expect to obtain a full and connected account of any series of events beyond the reach of history.

Geological monuments are frequently imperfect recorders of the past. Yet, at least their clues can't be misrepresented on purpose. Our inferences may be wrong, in the same manner as we often mistake the nature and significance of phenomena observed in nature. Yet, our risk of making an error is confined to the interpretation, and, if this be correct, our information is certain.

### In Their Own Words: Charles Lyell (950L)

By Charles Lyell, adapted by Newsela

*Charles Lyell (1797–1875) was a British lawyer and the leading geologist of his day. He is best known for writing*Principles of Geology*. The book spread the idea of “uniformitarianism,” which was developed by James Hutton, a geologist. Hutton proposed that the earth was shaped by slow-moving forces still at work today. Uniformitarian ideas went against what many geologists believed: that unique catastrophes or supernatural events, like the biblical flood, shaped Earth’s surface. The motto of uniformitarianism was “the present is the key to the past.” Lyell’s friend, Charles Darwin, took that idea and extended it to biology.*

*In fact, Lyell’s*Principles of Geology*was one of the few books that Darwin carried on his famous voyage on the HMS Beagle. That voyage to far-flung areas of the world led him to write*The Origin of the Species*. What follows is a summarized version of Lyell's original text.*

#### Geology defined — Compared to History — Its relation to other Physical Sciences

Geology investigates the changes that have taken place one after another in the kingdom of nature. It inquires into the causes of these changes. And it describes their influence in modifying the surface of our planet.

By studying the state of the Earth and its former inhabitants, we get more perfect knowledge of its present condition. Our views about the laws governing nature become more complete. Likewise, when we study history, we get better insight into human nature. We can draw comparisons between the present and former states of society. We trace the long series of events which have gradually led to the current state of affairs.

By connecting effects with their causes, we can organize and retain a number of complicated relations in the collective memory we all share. Together this helps shed light on what makes a nation unique. Without historical associations, these would be uninteresting or imperfectly understood.

The present condition of nations is the result of many previous changes. Some are ancient, and others recent. Some are gradual, others sudden and violent. In a similar way, the state of the natural world is the result of a long series of events. If we seek to understand today's inner workings of nature, we must investigate the effects of her operations in past eras.

Look back into the history of nations. When we do, we often discover with surprise how the outcome of some battle has affected the fate of millions today. It can determine a nation's borders. The battle's result may have shaped the language now spoken by the people who live there. Their manners, laws, and religion may have been formed by that battle's outcome. But when we dig deeper into the history of nature, the connections we find are even more astonishing.

In lands that are calm today, the geography can be traced back to a time of violent disasters. The coastlines, lakes, valleys, and mountains may be the result of earthquakes and volcanoes. Such ancient disasters may explain why some lands have rich, productive soil and others fail to grow crops.

On the other hand, much of the Earth's surface may have been formed by slow causes. Sediment in a lake or in the ocean may have deposited gradually and gently over time.

Deposits of coal underground are another example. Originally these were made of vegetable matter, and drifted into what were formerly seas and lakes. These seas and lakes have since been filled up. The lands the forests once grew upon have disappeared. Others changed their form. The rivers and currents which floated the vegetable masses are gone. And the plants belonged to species which have left our planet ages ago. Yet the wealth and population of a nation may now be dependent on the fuel created by ancient nature.

Geology is closely related to nearly all the physical sciences. History is linked to other social studies in the same way. A historian should closely study ethics, politics, law, military, and religion. In essence, the historian should grasp all branches of knowledge which give insight into the moral and intellectual nature of man. Likewise, a geologist should be well versed in chemistry, mineralogy, zoology, anatomy, and botany. In short, geologists should be familiar with every science relating to nature.

Armed with all this knowledge, historians and geologists would draw correct conclusions from the records left behind by former events. They would know what combination of causes similar effects relate to. And they would often be able to piece together events not recorded during former ages.

But such a deep understanding of so many different fields of study is impossible for any one person. Therefore, scholars of different branches must share their knowledge. The historian receives assistance from experts on ancient times and politics. In the same way, the geologist should ask the aid of naturalists. He should particularly get help from those who have studied the fossil remains of lost species of animals and plants.

The ordinary objects that leave clues about past history are like the records we study in geology. The canoes, for example, and stone hatchets found in our peat bogs, inform us about the arts and manners of the earliest people who lived there; the buried coin fixes the date of the reign of some Roman emperor; the ancient military camp shows where invading armies once occupied land; the Egyptian mummies throw light on the art of embalming, burials, or how tall humans in ancient Egypt were.

No other type of artifact is more true to fact. But it's just one of the resources on which the historian relies. In geology, however, it is the only evidence we can draw from. For this reason we must not expect to obtain a full and connected account of any series of events beyond the reach of history.

Geological monuments often leave behind an imperfect record of the past. Yet, it at least can't be misrepresented on purpose. We may draw false conclusions from them, in the same way we often mistake the importance of phenomena we observe in nature. Yet, our mistakes would just be in the interpretation. However, if our conclusions are correct, our information is certain.

### In Their Own Words: Charles Lyell (770L)

By Charles Lyell, adapted by Newsela

*Charles Lyell (1797–1875) was a British lawyer and the top geologist of his day. He is best known for writing*Principles of Geology*. It made geologist James Hutton’s idea of “uniformitarianism” popular. Uniformitarianism is the belief that the Earth was shaped by slow-moving forces. And those forces are still at work today.*

*Uniformitarian ideas opposed the old belief that unique catastrophes or supernatural events shaped Earth’s surface. The Great Flood from the Bible is one example of such an old belief. The motto of uniformitarianism was “the present is the key to the past.” Lyell’s friend, Charles Darwin, extended that idea to biology.*

*In fact, Lyell’s*Principles of Geology*was one of the few books that Darwin carried on his famous voyage on the HMS Beagle. That voyage to far-flung areas of the world led him to write*The Origin of the Species*. What follows is a summarized version of Lyell's original text.*

#### Geology defined — Compared to History — Its relation to other Physical Sciences

Geology investigates the changes that have taken place in the kingdom of nature. It looks into the causes of these changes. Then it describes how they have helped form the surface of our planet.

By studying the state of the Earth and its past inhabitants, we better understand its present condition. Our views on the laws of nature become more complete. When we study history, we get a better understanding of human nature. We can draw comparisons between society now and in the past. We trace long series of events. We see how they gradually led to things as they are today.

By connecting effects with their causes, we are able to classify events. Then we can remember them. We can store them in the collective memory of humankind. Together this helps shed light on a nation's character. We can more deeply understand a nation's moral and intellectual state.

The way nations are today is the result of many changes in the past. Some are ancient. Others are more recent. Some came about gradually. Others arose suddenly and violently. In a similar way, the natural world was caused by a long series of events. To understand today's nature, we must investigate the effects of nature through history.

Look back at the history of nations. When we do, we often discover with surprise how the outcome of some battle has affected the fate of millions today. This ancient event may have created the current borders of a nation. The battle's result may have shaped the language now spoken by people who live there. Their manners, laws, and religion were set by that battle's outcome. But dig deeper into the history of nature. The connections we find there are more astonishing.

In calm places, the shape of the land today can be traced back to disasters in the past. Earthquakes and volcanoes may have formed the coastlines, lakes, and mountains. Such violent disasters may explain why some lands have rich soil and others fail to grow anything.

On the other hand, much of the Earth's surface may have been formed by slow-moving force. Sediment at the bottom of a lake may have gradually built up over time.

Underground deposits of coal are another example. Originally these were made of vegetable matter. Then they drifted into what were once seas and lakes. These seas and lakes have since been filled up. The lands the forests once grew upon have disappeared. Others changed their form. The plants species are long extinct. Yet the wealth and population of a nation may now depend on the coal created by ancient nature.

Geology is closely related to other sciences. History is linked to other subjects in the same way. A historian should be acquainted with politics, law, military, and religion. The historian should closely study all branches of knowledge concerning human affairs. Likewise, geologists should know chemistry, mineralogy, zoology, and botany. In short, geologists should be familiar with every science relating to nature.

If this happened, historians and geologists would be right in their theories. They would draw the correct conclusions from the records left behind by former events. They would understand combinations of causes. And they could relate similar effects to the past. And they would often be able to piece together events never recorded.

Deeply understanding so many fields of study is impossible for any one person. So scholars must work together. The historian consults experts on ancient times and politics. In the same way, the geologist should ask for help. He should particularly gain the aid of those who have studied the fossils of extinct species.

The comparison between geology and history isn't perfect. It only applies to artifacts left behind. For example, we've discovered ancient canoes and stone hatchets found on our land. These artifacts tell us something about the arts and customs of early peoples. Buried coins help us know when some Roman emperor ruled. An ancient military camp shows where invading armies once occupied land. Mummies tell us something about humans in ancient Egypt. We can examine the mummies to understand embalming, burials, or how tall the Egyptians were.

Artifacts are physical evidence. Historians study artifacts. But they have other resources they can use. In geology, however, physical remains are all we have. That's why we must not expect to get such a full account of any series of events.

What we discover from geological monuments is rarely perfect. Yet, it at least can't be faked. We may draw false conclusions from them. But it's in the same manner we make mistakes in observing nature today. So, our mistakes would just be in the interpretation. But if our conclusions are correct, our information is certain.

# Codex Leicester - Fossils/Mountains, Moon/Tides

Excerpts from da Vinci's handwritten journal show the creative thinking process of one of the world's most influential scientists.

### In their own words: Leonardo da Vinci's Codex Leicester (1830L)

Leonardo da Vinci (1452-1519) was a multi-talented Italian scholar who gave meaning to the term “Renaissance man.” He was a painter, architect, mathematician, inventor, engineer, and more. The Codex Leicester is one of da Vinci’s 30 scientific journals and takes the form of 18 sheets of paper, folded in half with writing on both sides — 72 pages of writing in total. The Codex is named for the Earl of Leicester, Thomas Coke, who acquired it in 1717. In the Codex, da Vinci notes his observations about astronomy, the movement of water, light, fossils, and geologic formations. The creative thinking process of a scientist is on display as da Vinci argues, probes, and accumulates information on which to base claims.

Here are translated excerpts of the Codex that provide a look at da Vinci’s experiments and observations.

*Note: Headings have been inserted by the editors.*

#### Observing light and waves

“Here it is demonstrated how the Moon, not having any light of its own but the light which it takes from the Sun, could not take nor reflect it if it had not a dense and lustrous surface like surfaces of mirrors and liquids; but were it of the nature of dense and lustrous mirror, it would give us only part of all the light, as if the eye which looks at it were situated in the point a, and such a thing would make very small light. But if its lustre originates from a liquid body, the reflected rays would not lose their character nor their great brightness; but if it is wavy, as we see for ourselves happening in the marine waters, then the brightness will convey itself to each single wave on its own account, and then all together will cause a great quantity of brightness, but not so powerfully as originally, on account of the shady parts that the waves possess.” (Codex Leicester, Folio 1 R)

#### Shells in the mountains

“If you will say that the shells, which are visible in our times within the borders of Italy, far from the seas, at such a great height, were caused by the Deluge, which left them there, I reply that if you believe that the Deluge was 7 cubits higher than the highest mountain, as he who measured it wrote, these shells, which always reside near to the sea shores, ought to remain on those mountains, and not so low as the feet of the mountains, every one at the same height, stratum by stratum. And if you will say that these shells are inclined to stay near the sea shores, and that, as the water rises at such a height, the shells depart from their first location and follow the increase of the waters up to their greatest height, here it is replied that, since the shell, an animal, has no faster motion than the land snail when it is out of the water, it will be even slower, since it does not swim but rather it makes a furrow in the sand and by means of the sides of this furrow, on which it leans, it will walk between 3 to 4 braccia a day; thus, with this motion, it could not walk from the Adriatic Sea to the Monferrato in Lombardy, which is a distance of 250 miles, in 40 days, as he, who kept a calculation of this time, said. And if you say that the waves carried the shells there, because of their weight they cannot be supported except on the sea bed; and if you do not grant me this, at least acknowledge that they had to remain on the tops of the highest mountains, and in the lakes that are shut among the mountains, such as the lake of Lario, and the Maggiore and of Como, and of Fiesole, and of Perugia and similar.” (Codex Leicester, Folio 8 V)

#### Underground water and a moving Earth

“The heat of the fire burning within the center of the Earth warms the waters which are enclosed within the great caverns and other concavities; and this heat causes the aforesaid waters to be warmed and evaporated, and they raise themselves up to the roofs of the aforesaid concavities, and penetrate through the fissures of the mountains, up to their greatest heights, where, as it finds the cold, it suddenly changes back into water, as it is seen happen in the still, and it falls down and forms the beginning of the rivers, which are subsequently seen descending from there. But when great coldness pushes back the heat toward the center of the world, this heat becomes more powerful and gives rise to greater evaporation of the aforesaid waters; and these evaporations, heating the caverns in which they circulate, cannot produce the waters as they used to, as it is seen in the making of aqua vitae, for if the passage for the evaporation of wine did not pass through cool water, the said evaporation would never change into aqua vitae, but would return and finally it would condense to such an extent that it would break every obstacle. We will say the same of water heated in the bowels of the earth, which not finding in its passage places of such coolness as are adapted for it, does not form itself into water as it did before, but it condenses and congeals like the fire multiplied and condensed within a bombard, which makes itself harder and more powerful than the matter that receives it, and so, unless it has a sudden exhalation, it immediately proceeds to break and destroy that which opposes its growth; so does the aforesaid evaporation of water, and it bursts within the bowels of the earth in different places, revolving and rumbling with great tumult; it finally reaches the surface of the Earth, which with a great earthquake shakes the regions and often ruins the mountains and collapses the cities and intervening lands in various parts, and it emerges with great wind through the breaks previously made in the earth; and so, by this exhalation, it consumes its own power.” (Codex Leicester, Folio 28 R)

### In their own words: Leonardo da Vinci's Codex Leicester (1310L)

By Leonardo da Vinci, adapted by Newsela

Leonardo da Vinci (1452-1519) was a multi-talented Italian scholar who gave meaning to the term “Renaissance man.” He was a painter, architect, mathematician, inventor, engineer, and more. The Codex Leicester is a 72-page scientific journal handwritten by da Vinci. The Codex is named for the Earl of Leicester, Thomas Coke, who bought it in 1717. In the Codex, da Vinci notes his observations about astronomy, the movement of water, light, fossils, and geology. The creative thinking process of a scientist is on display as da Vinci argues, probes, and accumulates information on which to base claims.

Here are selections of the Codex that have been translated and adapted to provide a simplified look at da Vinci’s experiments and observations.

*Note: Headings have been inserted by the editors.*

#### Observing light and waves

“The Moon, not having any light of its own but the light which it takes from the Sun, could not take nor reflect that light if it had not a dense and shining surface like a mirror or liquid. But, if it were like a dense and shining mirror, it would give us only some of the light, as if the eye which looks at it were situated in the point a, and such a thing would make very small light. However, maybe the Moon contains oceans. If its glow comes from a liquid body, the reflected rays would not lose their character nor their great brightness. But if it is wavy, as we see in the oceans, then the brightness will convey itself to each single wave on its own account, and then all together will cause a great quantity of brightness. However, the shady parts of the waves mean the brightness will not be as powerful as it was originally.” (Codex Leicester, Folio 1 R)

#### Shells in the mountains

“Shells can be seen today in Italy, far from the seas, at great heights. You say they were brought by the Great Flood described in the Bible, which was higher than the highest mountain. My reply is that these shells, which always reside near sea shores, ought to remain on those mountains, and not so low as the feet of the mountains, every one at the same height, layer by layer. If you say that these shells are inclined to stay near the sea shores, and that, as the water rises at such a height, the shells follow the rising water up to their greatest height, I reply that since the shell, an animal, is no faster than the land snail when it is out of the water, it will be even slower. The shell does not swim but rather it makes a trail in the sand and will walk less than 2.5 meters a day. At this rate, the shell could not walk from the Adriatic Sea to the Monferrato in Northern Italy, which is a distance of 400 kilometers, in 40 days, as the Bible said. And if you say that the waves carried the shells there, I reply because of their weight they cannot be supported except on the sea bed. If you do not accept this, at least acknowledge that they had to remain on the tops of the highest mountains, and in the lakes that are enclosed among the mountains." (Codex Leicester, Folio 8 V)

#### Underground water and a moving Earth

“The heat of the fire burning within the center of the Earth warms the waters which are enclosed within the great caverns. This heat causes the waters to be warmed and evaporated, and they raise themselves up to the roofs of the caverns, and climb through cracks in the mountains. They climb higher still, until it finds the cold, and suddenly changes back into water. It falls down and forms the beginning of the rivers, which are then seen descending from there. But when great coldness pushes back the heat toward the center of the world, this heat becomes more powerful and gives rise to greater evaporation of the waters. These evaporations, heating the caverns in which they circulate, cannot produce the waters as they used to. Just as it is seen in the making of alcohol, if the evaporation of wine did not pass through cool water, it would never change into alcohol, but would return and finally it would condense to such an extent that it would break through its confines. We will say the same of water heated in the depths of the earth. If the water cannot find the coolness it needs, it does not form itself into water as it did before, but it condenses and congeals like the fire multiplied and condensed within a bomb. It makes itself harder and more powerful than the matter that receives it, and so, unless it has a sudden exhalation, it immediately proceeds to break and destroy that which confines it. The evaporation of water bursts within the depths of the earth in different places, revolving and rumbling with great commotion. Finally, it reaches the surface of the Earth as an earthquake, ruining mountains and collapsing cities. It emerges with great wind through the breaks previously made in the earth; and so, by this exhalation, it consumes its own power.” (Codex Leicester, Folio 28 R)

### In their own words: Leonardo da Vinci's Codex Leicester (950L)

By Leonardo da Vinci, adapted by Newsela

Leonardo da Vinci (1452-1519) was a multi-talented Italian scholar who gave meaning to the term “Renaissance man.” He was a painter, architect, mathematician, inventor, engineer, and more. The Codex Leicester is a 72-page scientific journal handwritten by da Vinci. The Codex is named for the Earl of Leicester, Thomas Coke, who bought it in 1717. In the Codex, da Vinci notes his observations about astronomy, the movement of water, light, fossils, and geology. The creative thinking process of a scientist is on display. We can see how da Vinci argues, probes, and gathers information on which to base claims.

Here are selections of Codex. They have been translated and adapted to provide a simplified look at da Vinci’s experiments and observations.

*Note: Headings have been inserted by the editors.*

#### Observing light and waves

“The Moon is without any light of its own. It has only the light which it takes from the Sun. But it could not take nor reflect that light if its surface was not dense and shining like either a mirror or liquid. But, if it were like a shining mirror, it would give us only some of the light. It would reflect at an angle that would make very little light. But maybe the Moon contains oceans. If its glow comes from a liquid body, the reflected rays would not lose their character. Nor would they lose their great brightness. But if it is wavy, as we see in the oceans, then the brightness will convey itself to each single wave on its own account. Then all together will cause a great quantity of brightness. However, the shady parts of the waves mean the brightness will not be as powerful as it was originally.” (Codex Leicester, Folio 1 R)

#### Shells in the mountains

“Shells can be seen today in Italy, far from the seas, at great heights in the mountains. You say they were brought by the Great Flood described in the Bible, which was higher than the highest mountain. My reply is that these shells, which always reside near sea shores, ought to have remained on those mountains. They should not be found so low as the feet of the mountains, every one at the same height, layer by layer.

You might then say that these shells are inclined to stay near the sea shores. And you say, as the water rises at such a height, the shells follow the rising water up to their greatest height. I would reply that a sea snail is no faster than the land snail when it is out of the water. In fact it will be even slower. The snail does not swim. Rather it makes a trail in the sand and will walk less than 2.5 meters (8 feet) a day. At this rate, the shell could not walk from the Adriatic Sea to the Monferrato in Northern Italy in 40 days, as the Bible said. The snails could not have walked that distance of 400 kilometers (249 miles).

And you might say that the waves carried the shells there. I would reply that because of their weight they cannot be supported except on the sea bed. Things that are heavier than water do not float on water. You may not accept this. But, at least acknowledge that they had to remain on the tops of the highest mountains, and in the lakes that are enclosed among the mountains. (Codex Leicester, Folio 8 V)

#### Underground water and a moving Earth

“The heat of the fire burning within the center of the Earth warms the waters which are enclosed within the great caverns. This heat causes the waters to be warmed and evaporated. They raise themselves up to the roofs of the caverns, and climb through cracks in the mountains. They climb higher still, until it finds the cold, and suddenly changes back into water. It falls down and forms the beginning of the rivers. But when great coldness pushes back the heat toward the center of the world, this heat becomes more powerful. It gives rise to greater evaporation of the waters. These evaporations heat the caverns in which they circulate.

Yet they cannot produce the waters as they used to. Just as it is seen in the making of alcohol, if the evaporation of wine did not pass through cool water, it would never change into alcohol. It would instead return to vapor and finally it would condense to such an extent that it would break through whatever holds it.

We will say the same of water heated in the depths of the earth. If the water cannot find the coolness it needs, it does not form itself into water as it did before. Instead it condenses and congeals like the fire multiplied and condensed within a bomb. It makes itself harder and more powerful than the matter that receives it.

And so, unless it has a sudden release, it immediately proceeds to break and destroy whatever holds it. The evaporation of water bursts within the depths of the Earth in different places, revolving and rumbling with great commotion. Finally, it reaches the surface of the earth as an earthquake. The power ruins mountains and collapses cities. It emerges with great wind through the breaks previously made in the Earth; and so, by this exhalation, it consumes its own power.” (Codex Leicester, Folio 28 R)

### In their own words: Leonardo da Vinci's Codex Leicester (740L)

By Leonardo da Vinci, adapted by Newsela

Leonardo da Vinci (1452-1519) was a talented Italian scholar. He was a painter, architect, mathematician, inventor, engineer, and more. The Codex Leicester is a 72-page scientific journal handwritten by da Vinci. The Codex is named for the Earl of Leicester, who bought it in 1717. In the Codex, da Vinci notes his scientific observations. He inquires into astronomy, the movement of water, light, fossils, and geology. The creative thinking process of a scientist is on display. We can see how da Vinci argues, probes and gathers information.

Here are selections of Codex. They have been translated and adapted to provide a simplified look at da Vinci’s experiments and observations.

*Note: Headings have been inserted by the editors.*

#### Observing light and waves

“The Moon cannot make light of its own. It only has the light which it gets from the Sun. But it could not take nor reflect that light if its surface was not dense and shining. It must be like either a mirror or liquid. But, if it were like a mirror, it would give us only some of the light. It would reflect at an angle that would make very little light.

So maybe its surface contains water. If its glow comes from a body of liquid, the reflected rays would not lose their character. Nor would they lose their great brightness. But if it is wavy, like an ocean is, then each wave will reflect in its own way. Then all together will cause a great amount of brightness. However, the shady parts of the waves could cause some dimness. It means the brightness will not be as powerful as the Sun's light was originally.” (Codex Leicester, Folio 1 R)

#### Shells in the mountains

“Shells can be seen today in Italy, far from the seas. They can be found high up in the mountains. You say they were brought by the Great Flood described in the Bible. When the flood rose up you say it was higher than the highest mountain. My reply is that these shells, which always reside near sea shores, ought to have remained on those mountains. They should not be found as low as the base of the mountains. But they are found there. They can be seen layer by layer. You might say instead that these snails start out near the sea shores. And then you say that the water rises up high. And the shells, you say, follow the rising water up to their greatest height. I would reply that the sea snail is no faster than a land snail when it is out of the water. In fact it will be even slower. The snail does not swim. Rather it makes a trail in the sand. It will walk less than 2.5 meters (8 feet) a day.

At this rate, the snail could not walk from the Adriatic Sea to the Monferrato in Northern Italy. It most certainly couldn't walk there in 40 days, as the Bible said. The snails could not have walked that distance of 400 kilometers (249 miles). And you might say that the waves carried the shells there. I would reply that because of their weight they cannot have. Things that are heavier than water do not float on water. You may not accept this. But, at least acknowledge that they had to remain on the tops of the highest mountains and in the lakes between the mountains. (Codex Leicester, Folio 8 V)

#### Underground water and a moving Earth

“The heat of the fire burning within the center of the Earth warms the waters inside the great caverns. The fire's heat warms the waters until evaporation. The evaporated waters rise to the roofs of the caverns. They climb through cracks in the mountains. They climb higher still, until they find the cold. Suddenly the steam changes back into water. It falls down and forms the beginning of the rivers.

But great coldness can push back the heat toward the center of the world. When this occurs this heat becomes more powerful. It gives rise to greater evaporation of the waters. These evaporations heat the caverns in which they circulate. Yet they cannot produce the waters as they used to. It is just as seen in the making of alcohol. If the evaporation of wine did not pass through cool water, it would never change into alcohol. It would instead return to its evaporated state. And finally it would condense to such an extent that it would break through whatever holds it.

We can say the same of water heated in the depths of the Earth. The water needs coolness. If it cannot cool it does not form itself into water as it did before. Instead it condenses and congeals. The vapor then becomes like the fire multiplied and condensed within a bomb. It makes itself harder and more powerful than its container. And so, unless it can escape, it immediately proceeds to break and destroy that whatever holds it. The evaporation of water bursts within the depths of the earth in different places. It revolves and rumbles with great commotion. Finally, it reaches the surface of the Earth as an earthquake. The power ruins mountains and collapses cities. It emerges with great wind through cracks in the Earth. By this release of steam, it consumes its own power.” (Codex Leicester, Folio 28 R)