Chapter XX

מסכת ברכות פרק ט׳, משנה ב׳

... וְעַל הַזְּוָעוֹת ... אוֹמֵר ״בָּרוּךְ שֶׁכֹּחוֹ וּגְבוּרָתוֹ מָלֵא עוֹלָם.

"...and on earthquakes ... one says, 'Blessed [are You, Hashem, our G-d, King of the universe] whose power and might fills [the] world.'"

What are earthquakes and how do they happen?

Anyone who has felt an earthquake knows there is something extraordinary—and sometimes terrifying—about the experience. Without warning, the ground beneath your feet begins to shake, everything begins to creak and rattle, and items fall from walls and shelves. And that is just a moderate **tremor**! In larger quakes, buildings and bridges collapse and the ground tears open! Underground pipes and cables break, often causing power outages and fires. In 2010, an earthquake demolished much of the island country of Haiti, killing more than 200,000 people! Earthquakes beneath the ocean floor can also cause giant, destructive waves, known as tsunamis. An enormous earthquake off the coast of Indonesia in 2004 caused a tsunami that killed hundreds of thousands of people! Thankfully, most earthquakes are not dangerous. In fact, most are too gentle even to detect without sensitive scientific equipment, and of the fifty or so that are detected around the world every day, almost none cause any damage.

Strong earthquakes have played a significant role in Eretz Yisrael over the course of history. The earliest one recorded is in Zechariah 14:5, which is also referenced in Amos 1:1 and Isaiah 6:4. According to the Abarbanel, Amos 5:8 also makes a possible reference to tsunamis. The two most devastating earthquakes in Eretz Yisrael in recent years were in 1837 (the "Tzfat Earthquake") and in 1927 (the "Jericho Earthquake"), each of which caused the deaths of hundreds of people.

Fig XX.1. Damage in the Old City of Jerusalem from the 1927 Earthquake

Of course, even the most powerful earthquake imaginable is nothing compared to Hashem's power. However, when we experience something that gives even a glimpse of how powerful certain forces can be, it provides us with an opportunity to reflect on Hashem's greatness and just how powerful He is. That is the purpose of the blessing this Mishna instructs us to make upon experiencing an earthquake.

Plate Tectonics

While everything that happens in the universe is a direct expression of Hashem's will, Hashem typically chooses to express His will through the laws of nature. Until quite recently, scientists did not have a framework with which to understand the cause of earthquakes. In the 1960s, a revolutionary scientific theory called "**plate tectonics**" emerged to explain earthquakes, volcanoes, and many other features of our planet. The theory describes the Earth as comprising a series of layers—somewhat like an onion or a layer-cake—and describes how these layers interact. Since then, a vast body of evidence supporting this theory has accumulated, and most scientists now accept the theory is true. Be prepared to be surprised: After you learn about plate tectonics, you will never look at the ground beneath you the same way again!

The Earth primarily consists of three layers: the outermost layer—that is, the one closest to us—is called the **crust**. The innermost layer is called the Earth's **core**. And between the two is a section called the **mantle.**

The top-most layer of the Earth on which we all are standing is the crust. The name evokes the image of the thin, outer, and firmer layer surrounding a loaf of bread, which is called the bread's crust. The Earth's crust is made mostly of hard rock. It is about 5km (3 mi) thick under the oceans and can be as much as 100km (60 mi) thick under the big mountain ranges. This may sound very thick, but since the distance from the surface of the earth to its center is about 6400km (4000 mi), the crust is actually very thin compared to the other layers. To give you an idea, airplanes fly about 5-13km (3-8 miles) above the ground, so if you look down out of the window while you are flying in a plane, the distance between you and the ground is probably not so different than how far the crust extends into the Earth.

The mantle is the next layer. It counts for about 2/3 of the **mass** of the Earth and more than 4/5 of Earth's total **volume**. The mantle is mostly **solid**, but near where it meets the crust, there is a layer that is soft and can flow very slowly. You might imagine it as having the consistency of thick toothpaste or playdough. This soft layer in the mantle is called the **asthenosphere** and the soft rock is called **magma.**

The inner layer of the Earth is the core, and though it has never been seen directly, indirect measurements suggest that it can be divided into two parts: a **liquid** "**outer core**" and a solid "**inner core**". The outer core is believed to be made of very hot metal—mostly iron and some nickel—that circulates. This circulation is very important, as it creates the Earth's magnetic field. The Earth's magnetic field protects our **atmosphere** from being destroyed by the solar wind (see our chapter XY on meteors ברכות ט:ב about the solar wind.)

In the center of our planet is the inner core**.** It is very hot and seems to be made of metals similar to the outer core, but because it is under so much pressure, the inner core is solid.

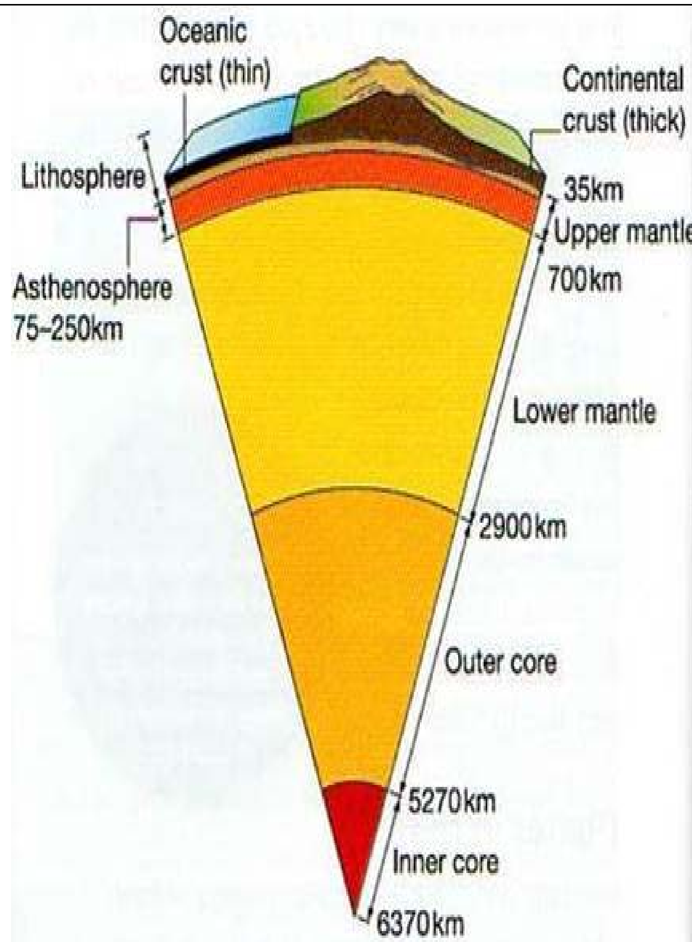


Fig XX.2. A diagram showing a slice of our planet from the surface to the center.

Replace Lower and Upper Mantle with Mantle. Remove Lithosphere.

So even though you might imagine the ground beneath your feet is solid "all the way down", in reality what you are standing on is a relatively thin firm layer of hard rock floating on a thicker melted layer! More amazing yet is that this floating layer is cracked into huge pieces called **plates** that are slowly moving around the planet in different directions!

Here is a diagram showing the plates. We will discuss the areas marked with colored stars and arrows below.

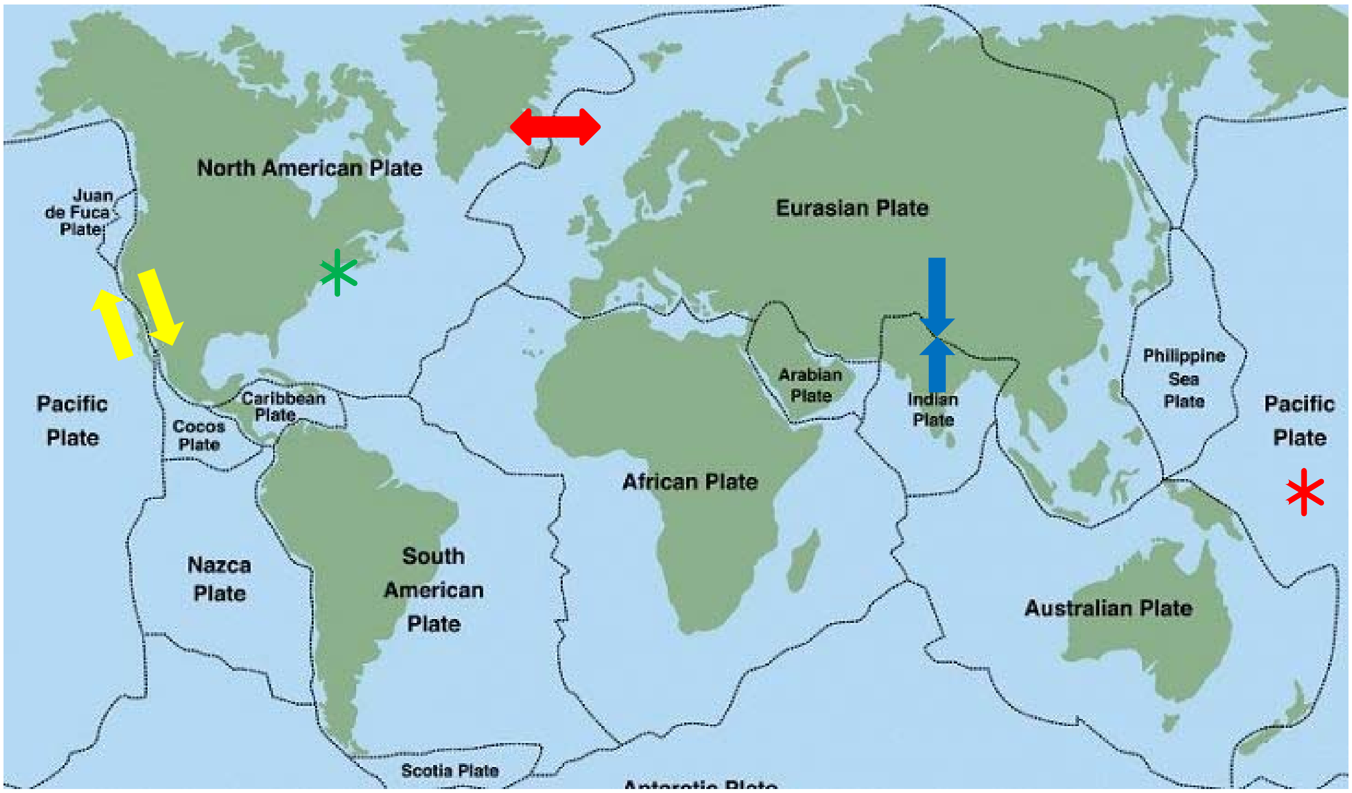


Fig XX.3: A diagram showing the plates that float on the asthenosphere.

Let's say you are standing in New York (indicated by the green star in figure XX.3). As you can see, this is in the middle of the North American Plate. The solid ground that you are standing on is actually only about 35km (20 mi) thick, slowly drifting over a very thick layer of **molten** rock. Scientists have measured your speed, and you're moving roughly 3 cm (1 inch) south every year. Some plates travel faster than this. For instance, if you lived on an island on the Pacific plate (see the red star), then you would be traveling at about 10cm (4 inch) a year--high speed for a plate! That might not sound like much, but over long periods of time it certainly adds up.

All the plates are moving in different directions, so what is happening at the boundaries where they meet?

There are three types of boundaries (see Fig XX.3 for arrows):

1. Some plates are sliding past each other (yellow arrows). This causes earthquakes.
2. Some plates are moving away from each other (see red arrows). This makes volcanoes.
3. Some plates are moving directly towards each other (blue arrows). This creates mountains, earthquakes, and volcanoes.

Let's look at each one of these in detail.

1. The type of boundary at which plates are sliding past one another is called a "**transform plate boundary**" or more commonly a "fault" (see the yellow arrows in Fig XX.3). One might think that when plates slide past each other nothing much would happen. However, the edges of these plates are thousands of miles long and made of uneven, jagged rock, so they do not slide past each other smoothly! In fact, they usually get stuck as they scrape together. Then the forces pushing them in opposite directions build up until they overcome the obstacles in one area, and then that area suddenly jerks forward. This sudden movement can be many meters in just a few seconds. Since we're talking about billions of tons of rock moving very suddenly, the event sends **shock waves** through the surrounding rocks, pushing and pulling them back and forth. That's an earthquake!

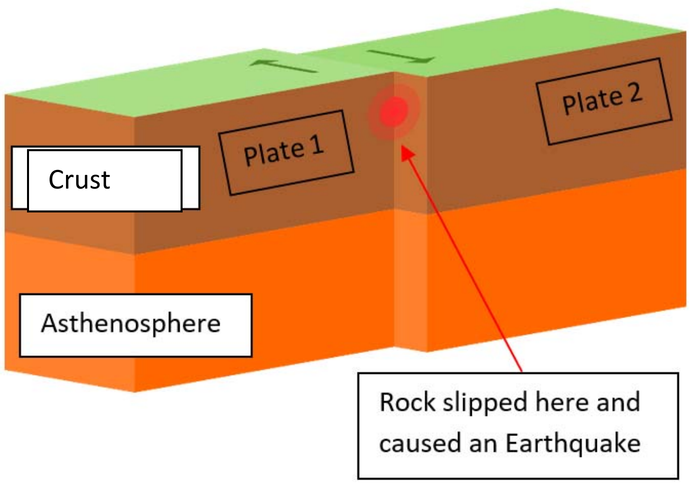


Fig XX.4. A transform plate boundary, where the plates are grinding past each other.	Fig XX.5. These orange trees in California were originally planted in straight lines across the San Andreas Fault – a transform plate boundary in California. The picture was taken 30 years after they were planted.

Earthquakes in Israel are caused by a transform fault. The Dead Sea Transform is a fault between the African and Arabian Plates that runs from the Red Sea to the Dead Sea, and up the Jordan River Valley to Syria and Turkey.

2. When plates move apart from each other it is called a "**divergent plate boundary**" or commonly a "rift valley" if it is on land (see the red arrows in Fig XX.3). As plates move apart, magma from the mantle beneath them flows up to fill the gap between them. See figure XX.6. When magma comes to the surface of the earth, it is called **lava**. The lava cools down to form solid rock, which becomes new crust. Usually the new crust build-up is not very thick, and typically exists on the ocean floors. You can see in figure XX.3 that there are many plate boundaries down the middle of the oceans where more ocean crust is forming, and the oceans are getting bigger. Occasionally, a lot of lava is released and piles up to become a **volcano** above the water level, which forms a new island.

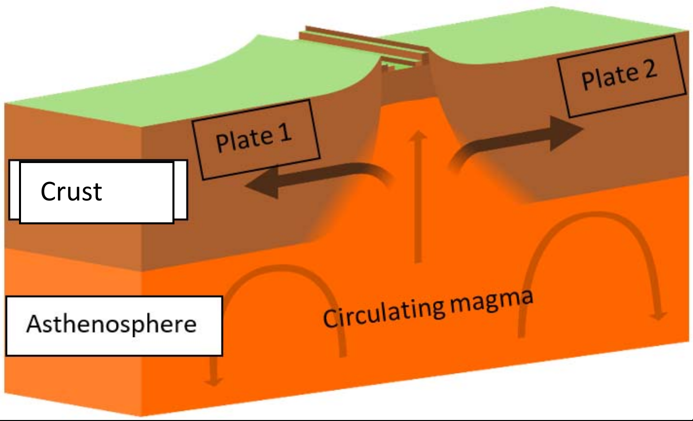


Fig XX.6. A divergent plate boundary, where tectonic plates are moving away from each other. Note the arrows in the asthenosphere indicating the circulating magma that is pushing the plates apart.

Fig XX.7. Lava coming up the cracks in a divergent plate boundary in Iceland.

3. Where tectonic plates push into each other is called a "**convergent plate boundary**." The effects of tectonic plates colliding directly are usually dramatic. Over very long periods of time, one plate is pushed up as it crumples, forming mountains, while the other gets pushed down into the mantle as the upper plate rides on top of it. For instance, the collision between the Australian plate and Eurasian plate has pushed up the Himalaya mountains (see Fig. XX.9) —the highest mountain range in the world (see the blue arrows in Fig XX.3). This process is ongoing, and the Himalayas continue to rise at a rate of about 5 cm (2 inches) every year! As the two plates press against each other, they don't move smoothly. Instead, the movement goes in fits and starts, with pressure building up until there is a sudden release and the rocks burst forward—again causing an earthquake. There are other complicated processes that can also create volcanoes in the mountain ranges.

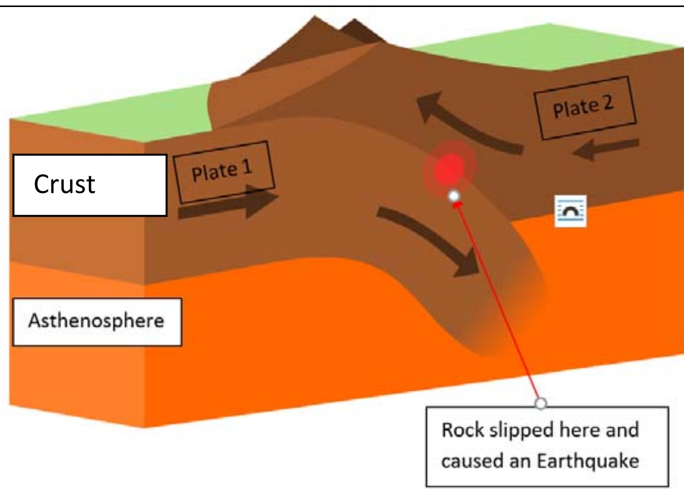


Fig XX.8. A convergent plate boundary, where the plates are sliding into each other. Plate 2 is pushing Plate 1 down, while Plate 1 pushes Plate 2 up. As Plate 1 moves into the asthenosphere, it slowly melts into the mantle.

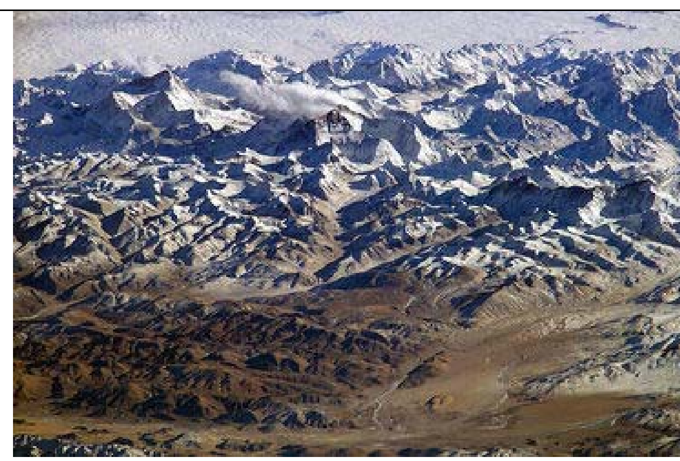


Fig. XX.9. The Himalayas. The picture was taken from the International Space Station.

When an earthquake happens under the ocean, the sudden jump forward of the ocean floor over hundreds of kilometers can give a very fast push to all the water above it, as in figure XX.10. This is one way a giant wave or **tsunami** is made.

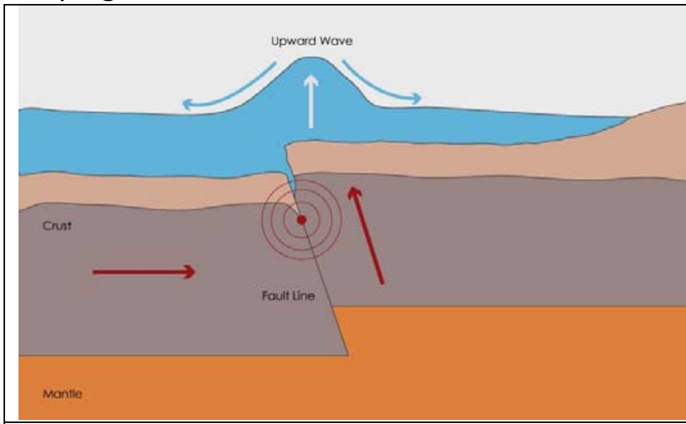


Fig XX.10 How a tsunami is made from an earthquake. The right-hand plate was suddenly pushed up by the left-hand plate, creating a giant wave.

Fig XX.11. The 2011 tsunami in Japan. The sea has risen several meters (!) and is crashing over a tsunami barrier.

We will never understand all of Hashem's ways, but understanding the awesome forces that shape our world will enable you to invest much more into the next blessing you recite over an earthquake!

Sources
https://www.geolsoc.org.uk/Plate-Tectonics/Chap2-What-is-a-Plate/Mechanical-properties-lithosphere-and-asthenosphere
https://www.texasgateway.org/resource/introduction-plate-tectonics
https://www.quora.com/What-is-the-speed-of-tectonic-plates
http://www.soufangroup.com/tsg-intelbrief-major-earthquakes-and-disaster-preparedness-in-the-levant/
https://en.wikipedia.org/wiki/Rare_Earth_hypothesis#With_plate_tectonics

Picture Sources
Plates: https://www.bucknell.edu/academics/arts-and-sciences-college-of/academic-departments-and-programs/geology-and-environmental-geosciences/location/geologic-history-of-central-pennsylvania/plate-tectonics
San Andrea orange groves: http://www.indiana.edu/~g105lab/images/gaia_chapter_13/SanAndFOrgTr.jpg
Jerusalem 1927: https://en.wikipedia.org/wiki/Timeline_of_the_history_of_the_region_of_Palestine

Chapter XX - Mountains, Hills, Seas, and Rivers

מסכת ברכות פרק ט׳, משנה ב׳

עַל הֶהָרִים, וְעַל הַגְּבָעוֹת, וְעַל הַיַּמִּים, וְעַל הַנְּהָרוֹת, וְעַל הַמִּדְבָּרוֹת, אוֹמֵר ״בָּרוּךְ עוֹשֶׂה מַעֲשֵׂה בְרֵאשִׁית״

"On [seeing] the mountains, hills, seas, rivers, and deserts one says, 'Blessed [are You, Hashem, our G-d, King of the universe] who makes the works of Creation.'"

Why do we make a blessing on mountains, hills, seas, and rivers?

When we are moved or inspired by Hashem's works, it is proper to direct those emotions to the One who made them, which is why our Rabbis instituted a special *beracha* to be said upon seeing these wonders of Creation. In that spirit, surely we will be even more inspired when we understand how extraordinarily these things work together to mold our beautiful planet.

The War

Our planet is a battleground between two incredibly strong forces that have been in continuous conflict since Creation. On one side of the battle is **erosion**, the forces that wear away the surface of the Earth. Its agents are wind and rain, snow and ice, rivers and glaciers, waves and ocean currents. Left unchallenged, these would slowly wear down the tallest mountains and fill in the deepest **oceanic trenches**. Opposing erosion is **plate tectonics** and the movement of the surface of the earth itself. These forces push up new hills and mountains and make new oceans and seas. The balance between these two opposing forces is truly one of Hashem's many wonders. This war has carved all the **landscape** that you see around you and has created the many beautiful, awe-inspiring, and strange places in our world. Most importantly, it is their interactions that make our planet suitable for life. Let us look a little closer at how it all works.

Plate Tectonics

In Chapter XY on earthquakes, we learned how our planet's surface is made up of gigantic **continent**-sized plates of rock that slowly move around the planet. Where these plates are moving away from each other, a new ocean is formed. Where these plates are moving towards each other, new hills and mountains are formed. It would be very worthwhile to read that chapter before reading this one.

Erosion

Do you remember the story of how Akiva the shepherd started on his path to becoming the great Rabbi Akiva[1]? He was watching drops of water falling into a hole in a rock when he realized that it was the soft water that had very slowly, drop by drop, worn away the hard rock to make the hole. He reasoned to himself, that if something as soft as water can carve a stone, the powerful words of Torah could pierce his heart of flesh and blood, and so began his journey to greatness. The process of water wearing away that stone is an example of erosion – the breaking down and removal of rock and soil by wind, rain, ice, snow, rivers, glaciers and waves.

[1] Avos D'Rabbi Natan 6:2

Figure XX.1 Mount Ararat in Turkey

This is Mount Ararat in Turkey. There is a legend (not based on Chazal) that this is the same Mount Ararat upon which Noah's Ark came to rest. Mount Ararat is an old **volcano** that was formed from two tectonic plates (the Arabian plate and the Eurasian plate) crashing into each other. You can see a map of these two plates in the chapter on earthquakes (see Fig XY.2.) As these two plates move into each other, they push up mountains, form volcanoes, and cause earthquakes. Now that plate tectonics has pushed up this mountain, what might bring it down? There are a few possibilities.

<u>Wind:</u> When the wind blows from the deserts to the south-east of Mount Ararat, it brings with it countless tiny bits of sand. The wind blasts these particles against the mountain. Each grain of sand can knock off a tiny bit of rock from the mountain, making yet more sand.

Fig XX.2. An example of wind erosion: the "Mushroom" rock formation in Timna National Park, Israel.

Wind erosion has worn away the softer rock beneath the head of the Mushroom, to carve this natural sculpture.

Rain: When the wind blows from the North or West of Mount Ararat it often brings with it rain. Each drop of rain that hits the rock will remove a tiny bit of the rock (just as Rabbi Akiva figured out). Maybe only a few **atoms** are removed by each drop, but billions of drops every year add up!

Figure XX.3 These hills in Iran are made of very soft rock that rain can easily erode. The extraordinary formation left behind is an extreme example of erosion from rain.

Snow: As you can see, there is plenty of snow on top of Mount Ararat. How can soft, fluffy snow cause erosion? Snowflakes tend to stick together, so a thick layer of snow can build up even on a steep mountain slope. Sometimes, an enormous layer of snow can become unstable, after being shaken by an earthquake or a strong wind, and then suddenly slide down the mountainside, picking up even more snow on the way. This icy chain reaction is called an **avalanche**. Avalanches are incredibly powerful: they can include as much as 10 million tons of snow moving at 300 kilometers per hour (190 mph)! As you can imagine, anything in the way of an avalanche will get flattened or carried away. Large rocks smash against each other, trees are uprooted, and houses are flattened. That's a lot of erosion in just a few minutes!

Figure XX.4 An avalanche in the Himalaya mountains near Mount Everest.

On the right of the picture you can see another buildup of snow that looks ready to collapse in a second avalanche.

Ice: Have a close look at a typical rock on Mount Ararat (or anywhere else for that matter) and you will usually see tiny cracks. When it rains on a rock, rainwater can seep into these tiny cracks. If the temperature then falls enough, the water in the cracks freezes into ice. What happens when water freezes? It expands! But inside a crack there is no space for the water to expand, so the ice widens the crack and can even break the rock apart! The next day the ice thaws (melts) leaving a bigger crack in the rock for more water to freeze in the next night. This is called freeze-thaw weathering. Strictly speaking this is called weathering and not erosion as the rocks aren’t moved from place to place, but as you can imagine, it makes erosion much easier.

Fig XX.5 A rock split apart by freeze-thaw weathering. This may have started with a microscopic crack that was slowly widened each freeze-thaw cycle. At some point the whole rock just cracked apart from the pressure caused by the ice’s expansion.

Rivers: Rain falls on Mount Ararat and then the rainwater runs down the steepest slopes to form small streams. As they flow down, they meet other streams becoming a small river and then flow into the valley below. Other small rivers from other mountains connect to the growing stream, and eventually it grows into a mighty river. The streams that flow down the slopes of Mount Ararat join the river Aras and eventually end up in the Caspian Sea. Here is what it looks like as it flows down from the mountains to the sea:

Fig XX.6 A stream meets the Aras as a waterfall, near the beginning of the Aras river

Fig. XX.7 The Aras river further down has grown in size. Note the flat areas the river has made on its sides between the mountains.

Fig XX.8 The now large Aras river near its end. There are no more hills around – just a flat plain.

Wherever water flows, it can pick up sand, pebbles, and even rocks. As these stones tumble down stream, they grind against the **riverbank** or **riverbed,** causing erosion. In Fig XX.6 and Fig XX.7, it is the force of the river’s water and **sediment** that has slowly cut through the mountains, forming the valleys you see. In Fig XX.8 it is the river that has flattened all the hills and mountains around it, making a flat

plain. Rivers can make plains because they don't just move downhill, they also move sideways, back and forth across the plain, cutting away at any hills or mountains they meet.

Glaciers: A **glacier** is a river of ice that forms on frigid mountains[2]. There is a small glacier near the top of Mount Ararat. How do glaciers form? When snow accumulates faster than it can melt, it builds an ever-thickening layer of frozen water. The weight of snow slowly compresses lower layers of snow into ice. When the ice is at least 15 meters (50 feet) thick, then it starts to slide down the slope of the mountain. Glaciers move slowly – typically 25cm (10 inches) a day. Glaciers are the most powerful force of erosion of all. On the sides and bottom of a glacier the hard ice rubs against the rock, wearing deep U-shaped valleys into the mountain and carrying away loosened rock.

Fig XX.9 A large glacier in the Himalaya Mountains. It looks like a brown and white striped **solid** river. The white stripes are ice, and the brown stripes are rocks that have been eroded off the sides of the mountains and fallen into the river of ice.

Fig.XX. 10. This picture was taken standing on the surface of the same glacier pictured in XX.9. You can see the ice under and behind the big rock.

Just look at the sizes of the rocks that the glacier has knocked of the sides of the mountains!

So now we can answer our question: what might bring down Mount Ararat? Even though the glacier on Mount Ararat is the strongest force of erosion, it only covers a small part of the mountain, so that isn't the whole answer. The wind, rain, ice and snow will play their part in wearing it down. But the streams and rivers on and around the mountain will do most of the work. Across the world, rivers cause more erosion than all the other forces of erosion combined. Given enough time, rivers could wear away all

[2] Glaciers also form in the Arctic and Antarctica in non-mountainous regions because it is so cold everywhere.

the mountains and hills in the world, including Mount Ararat, until there is nothing left other than a flat plain covered by the sea. The reason this doesn't happen is because plate tectonics continues to lift up new hills and mountains!

There is no war

So now we understand that what plate tectonics builds, erosion destroys. Why did Hashem make this perpetual battle? The continuous rebuilding of the Earth's surface appears to be essential for life on Earth. Here are some examples why. Wind and rain would eventually erode all land until everything was covered by the oceans. Plate tectonics ensures land is pushed back above sea level. Plant life would remove all **carbon dioxide** from the **atmosphere**, converting it into coal and oil and turning the planet into an ice world, but volcanic activity burns the coal and oil back to carbon dioxide, releasing it into the atmosphere, and ensuring Earth's surface temperatures stay warm.

In addition, life on our planet needs certain **elements** to survive, such as carbon, **sulfur**, iron, iodine and about another 20 elements. Many of these elements, such as Iodine, are rare. Plate tectonics brings rocks containing all these elements from deep inside our planet to its surface. Then, erosion breaks down the rocks to dust. **Bacteria**, **fungi**, and plants then extract from the crumbled rocks the elements they need to live and grow. We then get the elements we need to live and grow by eating these **organisms** (or eating the animals that eat them.)

So really, erosion and plate tectonics are not at war, rather they are a partnership set up by Hashem to ensure all life on Earth, including us, has a place to live and an ongoing supply of the essential elements we need. Now that is *nifla'ot haBorei*!

Maybe next time you say the blessing, "*Blessed are You, Hashem, our G-d, King of the universe who makes the works of Creation."* you can have in mind to thank Hashem not just for the mountain, hill, sea, or river in front of you, but also for all incredible system Hashem has established on our wonderful planet that allows us to live here and enjoy it!

Berachos 9:2 - What are זיקין?

According to the Bartenura's second explanation, זיקין are comets.

A comet is relatively small (0.1km – 40km) planet-like body that orbits the sun. Comets contain frozen gas, ice, dust and rocky particles. One might think of a comet as a huge, dirty snowball.

Comet Hale-Bopp, as seen in Croatia in 1997

As a comet approaches the Sun, solar radiation causes the frozen materials in the comet's nucleus (core) to vaporize. Gas and dust are released forming a huge, "fuzzy" atmosphere around the comet called the *coma*. The force exerted on the coma by the sun's radiation cause an enormous *tail* to form in the direction opposite the Sun. Both the coma and tail are illuminated by the Sun and may become visible from Earth when a comet passes close by.

The solid nucleus of a comet is generally less than 50 km across and is irregularly shaped; however, the round coma may be larger than the Sun, and comet tails have been observed to extend 150 million km or more!

As of May 2009, there are a reported 3,648 known comets; however, this represents only a tiny fraction of the total unseen comet population, which may number one trillion! About every decade or so, a comet will become bright enough to be noticed by a casual observer. Recent great comets have included Hyakutake in 1996, Hale-Bopp in 1997, and McNaught in 2007.

Comet Hyakutake

Comet McNaught

Berachos 8:2 - What are זיקין?

זיקין according to the Bartenura's first pshat, are meteors.

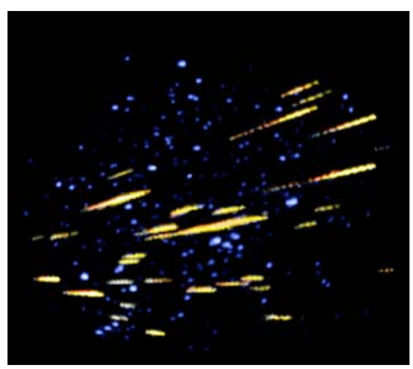
A meteor is the visible streak of light that occurs when a meteoroid enters Earth's atmosphere. People often call this a falling star or a shooting star.

Meteors typically occur 50 to 85 kilometers (30 to 50 miles) above the Earth's surface. Millions of meteors occur in the Earth's atmosphere every day. Most meteoroids that cause meteors are about the size of a pebble. They become visible between 65 and 120 kilometers (40 and 75 miles) above the earth. They disintegrate at altitudes of 50 to 95 kilometers (30 to 60 miles). Meteors have roughly a fifty percent chance of a daylight collision with the Earth as the Earth orbits in the direction of roughly west at noon. Most meteors are, however, observed at night as low light conditions allow fainter meteors to be observed.

The visibility is due to the air friction that heats the meteoroid so that it glows and creates a shining trail of gases and melted meteoroid particles. The gases include vaporized meteoroid material and atmospheric gases that heat up when the meteoroid passes through the atmosphere. Most meteors glow for about a second. A relatively small percentage of meteoroids hit the Earth's atmosphere and then pass out again: these are termed Earth-grazing fireballs.

Meteors may occur in showers, which arise when the Earth passes through a trail of debris, meteoroids, left by a comet, or as "random" or "sporadic" meteors, not associated with a specific single cause. The meteoroids are entering Earth's atmosphere at extremely high speeds on parallel trajectories and appear to radiate from one point in the night sky. Most are smaller than a grain of sand, so almost all meteoroids disintegrate and never hit the Earth's surface. Fragments which do contact Earth's surface are called meteorites. In 1902, the Willamette Meteorite was found. It is the largest meteorite ever to be found in the United States and the sixth largest in the world.

The Willamette Meteorite



Part of the sky during a meteor shower, the meteors have actually occurred several seconds to several minutes apart.