Transcript from Epic of Evolution: Life, the Earth and the Cosmos (BEP 210A)
March 24, 2000 - Lecture by Michael Wysession

Today I will wrap up rocks and the rock cycle, and spend some time at the end of the class talking about a particular set of materials that are economically important to us: in particular, metals, ores, oil and coal, and uranium. First, let me go back to where I had left off. I talked about having a set of mineral reaction processes by which certain materials would crystallize out first from a magma and certain materials would crystallize out last. Once you are done crystallizing out most of the mineral, I gave them names like olivine and pyroxene and feldspar, what you were left with was essentially the material that makes up granite, which exists in great abundance. There's a real problem with this, however. There is no way that this is how granite could have been formed. If you make granite by crystallizing out everything else first, there would just be a tiny little bit of granite left to form. But that's not the case. We see parts of the world that have huge amounts of granite. In fact, what I'm showing on this transparency is what we call batholiths. Batholiths are giant bodies of granite that form the cores of almost all big mountain chains. All along British Columbia, in Idaho, the Sierra Nevada Mountains down to Baja, all the Appalachian Mountains from Georgia to Maine, and so on, you find granite deep down inside these mountains. These represent huge amounts of granite, and there must be some other mechanism that could make such large, vast amounts of granite. As I mentioned, granite is primarily made of quartz, potassium feldspar, sodium feldspar and mica. It turns out that where you get the granite gives you the clue as to how it formed. The granite forms in the roots of mountains, and it turns out that granite forms from the reverse process of crystallization. Take any continental rock, or bunch of rocks, and push them down. You will heat them up and increase the pressure, and they will begin to metamorphose. Eventually they will melt, and the first stuff that melts is the material from which granite is formed. Imagine that a region of the crust is being squeezed on both sides in the middle of a continental plate collision. Some of the rock will be pushed downward. As it's going down and getting cooked, the first stuff that begins to melt off are these blobs of what will become granite, and they rise up as plumes right up through the overlying rock. They push their way up through, and as you continue to push the whole region down more and more, you will keep causing melting to occur, and this melt keeps rising up through the crust. But when it comes up, the melt passes into cooler rock above, so it doesn't make it to the surface. You are beneath a mountain, and it's a long way to the top of the mountain. And so the granite cools in these giant blobs that are called batholiths. Over time, erosion will wear away the mountains. Erosion in the form of water, glacial ice, and gravity, will scrape off the tops of the mountains. This will cause the crust to rebound upward, because just like sitting up on a mattress, once you remove the top part of the crust there's nothing holding down the rest of the crust. The crust starts to rise up, which allows more of it to erode away, and more comes up and more gets eroded away, and very quickly what were once these deep regions of granite are now exposed at the surface. As a result, if you hike through New England, you'll see a lot of granite there that was once 5-10 kilometers underground but is now exposed at the surface. But it was the result of the fact that granite was the first stuff that melted. This will be very important when I start talking about minerals like gold and silver and uranium and why we are actually able to dig these out of the ground in decent concentrations.

I want to just come back to one last question before I get into sedimentation and metamorphism, and that is the basic question of why rock melts in the first place. Why does the rock melt?

Well, we talked about part of this already for subduction zones. Rock melts in subduction zones because you add water to it. You can add water to hot rock that is solid and it will suddenly melt. I'm showing two curves on the same plot here. One is a plot called the geotherm (geo - Earth, therm - temperature). This is the actual temperature of the Earth as you go down, in this case to a depth of 150 kilometers. At the surface it is 0 degrees Centigrade, and as you go down the temperature rises. And by the time you are 100 kilometers down you're at 1,500 degrees Centigrade, perhaps even more. Some people put the temperature at about 1,600 degrees. This is really hot, and so if you ever wonder why we can't just drill down here there, this is the reason. Our metals typically melts at about 800 degrees, so all our drills would simply melt by the time we got far less than halfway down there. These blue and tan and green regions on the chart show the temperatures at which the material is either solid, liquid, or partially molten, which is a combination of solids and liquids - crystals existing simultaneously with liquids. The other curve is called the solidus. It is the temperature required at a particular depth to begin melting the rock. Notice that there are two different solidi. One is for a dry situation, and this is what we think normally applies to the interior of the Earth. In this case the solidus comes very close to the geotherm, and may actually cross it. We would expect the rock to become very soft there, and perhaps have a mall amount of partial melting (1-2%). This applies to most places in the Earth at a depth of about 100 to 150 kilometers. In a subduction zone, however, when you bring water down with the subducting lithosphere, you significantly change that curve. Now the geotherm crosses well beyond the melting temperature for the rock. The presence of water causes melting, and there is an active process of continuously taking the water and magma and spewing it out volcanoes.

Now, let's look at this situation again. This is very interesting. Under normal conditions, even though rock is really solid here at the surface, 100 kilometers down you're on the verge of melting that rock or at least some degree of it. The normal geotherm may cross the solidus, causing the rock there to be slightly molten. This is very interesting, because now it makes sense why the plates can move around so easily at the surface. They are essentially skating over mush. They have a lubricated, soft, weak zone they more over, and we give this soft zone the name of the asthenosphere. It exists from about 100 to about 200 kilometers down, and it is very soft, and probably partially molten. It acts like a set of rollers. It offers almost no resistance to the plates and so the plates can really move across this soft, partially molten layer quite easily. It also gives us an interesting clue. If I go to the bottom of this picture, the two curves of the solidus and geotherm move apart again. The solidus keeps increasing, but the geotherm levels off. That means that below the asthenosphere rock gets stiff and hard again. This also explains why plates with continents have a hard time moving, because the continents have deep roots that extend right through the asthenosphere and drag against the bottom of the harder rock beneath. Rock of the asthenosphere must also flow around the roots of these continents, so as a continent plows across the surface, the asthenosphere rock that is in the way has to move around it. We actually see that happening in a variety of ways. One way is analogous to the wake of a boat. Imagine that you're in a speed boat, and you're zooming really fast across the surface of water. Does the water remain flat around the sides of your boat? No, not really. The water gets pushed up bit in front and around the sides, creating waves, and the water then drops down behind it. You get a wake in behind the boat because the water has to flow around the side of the boat to take the place of the gap created behind the boat when the boat moves forward. We see the exact same thing happen with India. India has been moving so fast northward that the asthenospheric rock has had to flow around it and there's actually a surface depression south of India of about 200 meters. India is leaving a wake behind it. The surface of the Earth south of is actually being sucked down. In other words, if you could measure your location relative to the rest of the Earth, you would see that your boat in the Indian Ocean is 200 meters closer to the center of the Earth south of India than it is most any other place around the world. Another way that we can see asthenospheric rock flow around the roots of continents is by the way they affect seismic waves from earthquakes. Seismic waves can detect the direction that mantle rock is flowing through something called seismic anisotropy.

The other reason that rock melts, in the case of mid-ocean ridges and hot spots, is something called pressure release. If you take rock at a point deep along the geotherm, and you suddenly bring it up to the surface, then it will end up crossing the solidus, and it will melt. That is what happens beneath mid-ocean ridges. As the diverging plates move apart, they leave a gap, and rock gets sucked up to fill the vacuum. As you bring the hot rock up to fill the void, you release the pressure, and it melts. In the case of hot spot plumes, the rock is already hotter than normal to begin with, so it begins to melt at a greater depth. But even in the case of mid-ocean ridge volcanism, the rock melts not because it is heated up, but because the pressure is lessened.

So now, what do we do with this igneous rock that cools from magma? We need to go back to the Rock Cycle diagram. The igneous rock can either get sent down into the Earth, and be subjected to high pressures and temperatures, where it becomes metamorphosed, or it can go to the surface and be weathered, eroded, transported, deposited and compacted into new sedimentary rocks. Well, let me talk briefly about this process of sedimentation.

[Q: You have granite that goes back down and melts and then it reforms again. At that point do you call it metamorphic?]

No, not if it melts. Once it melts, then it will crystallize into a brand new igneous rock. If it doesn't melt, if you just deform it, then it becomes a rock with a special name like a schist or gneiss. I'll show this in a moment.

Let me talk for a moment about sedimentary rocks. 75% of our continents are covered with sedimentary rocks, and they comprise much of the material we make our houses and other buildings out of: like limestone and marble. Sedimentary rocks form through a variety of different processes that we can divide into three categories. These processes are clastic, chemical and organic. A sedimentary rock is just a rock that is created from previous rocks. A clast is a little bit of something, like a pebble or grain of sand. So clastic sedimentary rocks are made from pieces of other rocks. Sand becomes sandstone. Mud becomes mudstone, or, more commonly, a sedimentary rock called shale. Chemical sedimentary rocks form when the rock precipitates directly out of a liquid solution. One example is salt. When the concentration of salt in the oceans exceeds a certain limit, salt will precipitate directly out onto the seafloor. This especially occurs in warm regions with high rates of evaporation like the Gulf of Mexico or the Mediterranean Sea. The most common chemical sedimentary rock is the one that I showed last month with the fossils in it: it is called limestone. Limestone is primarily calcium carbonate, the principle ingredient in toothpaste, or Tums. Limestone forms when the concentration of calcium carbonate in the water becomes too great. Limestone, however, can also form through an organic process – the third type of sedimentary rock. Corals and clamshells are made of calcium carbonate, and when they get buried, they become limestone. Another example of a sedimentary rock is coal, which is essentially fossilized swamp.

As I mentioned, 75 percent of the continents are covered with sedimentary rocks, and sedimentary rocks can form in lakes, glaciers, deserts, and in fact, any environment, but they mostly form in the oceans. The implication of this is very interesting. Most of the continents have been covered by the ocean at one time or another, because most of the continents are covered with sedimentary rocks, and most sedimentary rocks are formed in oceans. How does this happen? I have tried to draw a simple diagram to demonstrate this. Imagine that you are standing on the shoreline looking out at the ocean. A lot is actually going on right there. You've got waves crashing up against the shore, and those waves carry a tremendous amount of energy. They pummel the rock, and grind it to pieces. Where do those pieces go? They get carried out to sea for the most part, and if they are very fine, they get settle out as mud, which will eventually become shale. What's left is sand, however, and sand is made of only the very toughest, hardest minerals, and for the most part, that means they are made of quartz. So when you walk on the beach, you are usually walking on 95 to 99% quartz grains. The sand will eventually become sandstone. In between the sand and the mud, at a slightly shallow depth, but a little ways away from the shore, you've got a lot of life going on. This is where the shells, crabs, clams, and coral live, and this stuff is all calcium carbonate. This all will eventually become limestone. Let's imagine a situation, however, where the sea level changes. Imagine that the sea level is rising, so the shoreline is moving to the left. My cartoon man is running away from the advancing ocean shoreline, but it really takes a lot longer for this to happen. We keep dumping new sediments on top of the old ones, so now the sand beach has moved up and over to the left, and the coral and mud have done the same. You still have sand, coral, and mud being deposited, but they are being put down in different places. Remember, as new sediment gets packed on top, the sand, coral, and mud are being compacted to form sandstone, limestone, and shale. Now let us reverse the sea level change, and start to lower the sea level, driving the shoreline back to the right. My cartoon man is now chasing after the water. We still have our sand, coral and mud being deposited, but we can see that the result of our raising and lowering of the sea level has resulted in alternating layers of different sedimentary rocks that would be observed at a single location. Go straight down at any point along here and you would see the alternating sequences of rocks: sandstone, limestone, shale, limestone, sandstone, limestone, and so on. Because the shoreline can advance and retreat thousands of miles when the sea level changes, we see these alternating sedimentary layers over most of the continents. This figure is a slice through the Grand Canyon, which is one of the most glorious big holes on Earth. What's wonderful about it is that we see down through giant horizontal layers of rock going down about a mile. The Colorado River cuts right through this repeated sequence of sedimentary rocks. The layers are abbreviated: SS is sandstone, SH is shale, and LS is limestone. These layers are repeated going down to up, they way they were laid down: sandstones, shales, limestones. These sequences occur over and over, so the shoreline must have been passing back and forth over this region many times. The Cambrian layers at the bottom are over 500 million years old, and the Permian layers go up to 250 million years ago, so we've got over 250 million years of time represented here. But not all of this time is represented. Notice that there are lines here called *unconformities*. These are gaps in time of rock that is missing. Unconformities occur at the times that the land is raised above the sea level, and the rock at the surface begins to erode. There is no way to tell what rocks use to exist there. They were eroded and washed to the sea, to make new rock somewhere else.

So even though my cartoon of the deposition of sediments was overly simple, it applies to most of the continents, as sandstone, limestone, and shale make up almost all sedimentary rocks. Loose sand gets squeezed together, chemical precipitation fills in the little gaps between the grains, and the result is sandstone. The corals and shells get squeezed together, and they become limestone.

Now, the process doesn't stop here, however. We are now going to venture into the last part of the Rock Cycle, called *metamorphism*. Imagine that we continue to compress these sedimentary rocks some more. We heat it and press it, applying pressure and temperature. This sandstone is now going to become a new rock called a *quartzite*, in which all the individual sand grains become totally welded together. There is no more pore space between the tiny sand grains. The grains themselves deform to fill in all the gaps. It doesn't look at all like sand anymore. We do the same thing to limestone, and it becomes a new rock called *marble*. Any original signature that we had of the coral and the shells gets totally obliterated. The chemicals get melded together, and become twisted and contorted. When subjected to high temperatures and pressures, shale becomes *slate*, which is even flatter and stiffer than shale. Many of you may have slate roofs or slate patios at your houses. The slate is very hard and flat. We have started with mud, squeezed out all the water, and squeezed all the flat mica grains together, first created shale, and then created slate. All of these processes, involving taking one rock and altering it to another, are part of the process of metamorphism. But we don't have to stop with the slate. We can continue to squeeze this stuff and continue to alter is. You can continue to deform the quartzite, but because it is just one material (SiO_2 – quartz from the sand grains), we still call it quartzite. We don't give it a new name, we just refer to it has having undergone a higher *grade* of metamorphism. The greater the deformation of the original sand grains, the higher the grade of metamorphism it underwent, which usually means the higher the temperature and pressure it was subjected to. The same goes for limestone and marble. Both are just calcium carbonate ($CaCO_3$), so a greater amount of deformation of the original limestone signifies a higher grade of metamorphism. At some point, take a moment and look at our collection of marbles halfway up in the front entryway of Wilson Hall. There is a remarkable variety of textures and colors. All the swirls in there are little bits of chemical imperfections within the limestone that have been twisted and contorted like taffy over great periods of time as the rock was deformed deep underground by tectonic processes like plate collisions. The situation for shale and slate is different, however. Mud contains a lot of different minerals, a whole variety of compositions, and so we get strange things happening to a slate as we continue to heat it and press it. The results are unusual rocks called *schists* and *gneisses*. In the case of a, schist we actually begin to grow new crystals that prefer high pressures. I'm going to hand around a sample of a schist that is filled with little garnet crystals. Now, these garnet crystals were not there in the initial mud, but as the rock got squeezed at higher and higher pressures, the garnet crystals, which are stable at higher pressures, begin to grow at the expense of other materials. The shininess of the schist is due to the presence of mica crystals, which also like high pressures because they are flat, and they also begin to grow at the expense of other minerals. The situation becomes even more extreme in the case of a gneiss. The original minerals and textures of the rock become totally obliterated. Totally new minerals have grown at the expense of the original minerals, which are not stable at the high temperatures and pressures of the deep Earth. In this sample, the material was stretched along one direction, but the white and black bands were not initially there. They have grown at high pressures, and then stretched and twisted out.

[Q: Is there a limit to the highest grade of matamorphism?]

Yes, because if you go too high, you melt the rock. Once you melt it, it recrystallizes into an igneous rock, so you reset the clock on it.

This sample rock is a gneiss from Amitsoq, Greenland. It's cut in half. The other half of this rock is on display in the Smithsonian Institution. One of the faculty members in our department, Bob Dymek, lugged this back from Greenland. It's one of the oldest rocks ever found in the world – almost 4 billion years old. We have no idea what the initial rock was, or what it looked like, or what kind of minerals were initially there. They have all been transformed into new minerals by the high temperatures and pressures. They've all been twisted and contorted and stretched like taffy into these long lines and we can get the bulk composition (how many silicon atoms, how many magnesium atoms, etc.) but we don't know the initial appearance that that rock took when it first formed. A lot can happen to a rock over 4 billions years.

This diagram is a graphic representation of what I just said. We start with mud at the surface. As we push it down into the Earth, we increase the temperature and the pressure, and we go from mud to mudstone, shale, slate (mica crystals begin to form), schist (more mica crystals are growing), gneiss (banding of new minerals forming), and lastly, a migmatite. A migmatite is a rock that has just begun to melt, and these little white lines that run through it are lines of melt that have cracked their way into the rock. The white veins are made of quartz, which is the first material to melt. These rocks are rare, because they need to be brought back up to the surface after melting begins, but before the whole rock melts to become magma.

If we step back for a minute, now that we have touched upon sedimentary and metamorphic rocks, as well as igneous rocks, we can look at the structural differences between oceanic and continental crust. They are sort of like the odd couple: like Felix and Oscar. The ocean crust is very neat, very nicely structured and well-mannered. Top to bottom, there are sediments, pillow basalts, vertical basaltic dikes, and gabbro. Beneath the gabbro, which extends to the bottom of the oceanic crust, is a well-defined boundary with the mantle called the "Moho." The Moho was named after Andrija Mohorovicic, who is a Croatian seismologist who discovered the boundary in 1909. But the term came into use in the '60s when words like "mojo" were the fad, and since no one could pronounce "Mohorovicic," everybody just called it the "Moho." Anyway, oceanic crust is built like a nice layer cake and anywhere in the ocean you go you see the same structure. Go over to the continents, however, and you see something totally different. You get every possible combination of igneous rocks and metamorphic rocks deep within the crust. At the surface, you get sedimentary rocks at some locations and not others. The whole thing has been tremendously twisted and altered over 4 billion years of stretching and compressing due to numerous plate collisions. It is a real mess, and has taken centuries of geological observations to try to sort out.

I would like to end by talking about a particular set of sedimentary rocks and processes that are of particular importance to us for economic reasons. Coal, for example, is a sedimentary rock. It originally begins as swamps like the Everglades (Florida). A lot of organic matter sinks into water that is anaerobic where it doesn't get full decayed, and more organic matter (dead trees, leaves) keeps piling on top of it. This organic material gets removed from the life cycle at the surface and becomes buried. If it is pushed down thousands of meters below the surface, it will eventually become lignite or bituminous coal, which is a low-grade coal. And as you go to even deeper layers (and therefore pressures), the coal takes the form of anthracite, which is a shiny, dark, heavy coal that's very concentrated in organic material (i.e., fuel). Coal is found in lots of places that we used to have swamps. Essentially, when you look at the map of coal reserves for the world, you are looking at a map of where all the swamps were 150-300 million years ago. And the U.S. happened to have a lot of swamps, and so we have very large coal reserves. When all our oil runs out we're, going to go back to burning coal again. We hopefully will find cleaner sources of energy, it but it hard to imagine that we won't need our coal resources. In terms of fossil fuels and non-renewable fuels, our picture looks something like this. We have natural gas, crude oil, tar sands and shale oil (this is oil trapped within layers of shale). The amount of oil and natural gas is miniscule compared to the amount of energy that can be gotten from the coal that we know exists. Our coal resources are at about the same level as the energy we can hope to get from the nuclear fission of uranium oxides. Energy from nuclear fission is not unlimited. We have to go and get the uranium first before we can go and split it, and uranium is a very rare element. This brings up a very interesting question. How do we find the uranium? Wouldn't we have to grind up the entire continental crust to extract the tiny amounts of uranium that exists within it?

This chart shows the natural concentrations of many economically important elements: aluminum, iron, magnesium, potassium, phosphorus, nickel, copper, lead, tin, uranium, silver, mercury, platinum, gold, and so on. We use these materials for a wide variety of purposes: industry, finance, luring mates, etc. These are given as percentages of the crust, by weight. Gold is .000000002 of 1 percent of the crust. It is totally insignificant in terms of volume. If gold were evenly distributed throughout the crust, we would have to grind up billions of tons of crust just to extract tiny amounts of gold. We could never do it. It would never be possible. If uranium were evenly scattered throughout the crust, it would be impossible for us to ever extract enough of it to use for nuclear power. Fortunately, we don't have to tear up the entire continents, and there is a reason for this. Plate tectonics does it for us. This maps shows he locations of some of the mineral deposits that are economically important to us. Notice that these locations almost exactly correlate with the locations of subduction zones. The message here is very clear. The process of plate tectonics somehow concentrates minerals and ores. How might this happen? Think for a moment about my discussion of the stability of mineral structures. I said that you had to get ions fitting nicely together in an atomic structure for that material to be stable. Now, bring along a big, bulky uranium atom, and try to fit that into your mineral structure. You can't do it very well. It doesn't really fit in any of these silicate structures. As a result, the heavy metals are the first materials to dissolve and the first to melt. If you destabilize the mineral by heating it up or bringing some water into it and trying to dissolve it, these gold and uranium atoms are the first ones that will come out of the mineral structure. The minerals are happy to be rid of them, and these bulky atoms travel off with the migrating fluid, to wherever it is going.

Let’s look at an example of this at a mid-ocean ridge. At a mid-ocean ridge we have these chimneys that spout hot water up out of the sea floor. Where does the water come from? It gets sucked in from the ocean at distances that are away from the ridge, it heats up in contact with the hot rock of the ridge, and rises up out of the ridge floor as smoking chimneys. The water is black because it is filled with dissolved minerals and metals. How did these get in there? As the cold water within the crust passes into hot-rock regions, it begins to heat up. Increased temperature raises the dissolution reaction rates. The hot water becomes much more efficient at dissolving materials out the rock that it passes through. And what materials are going to get dissolved? The heavy metals. When the hot water, rich in minerals and metals, erupts at the bottom of the ocean floor, it gets instantly chilled through contact with ocean water, which is just above 0 degrees Centigrade. Chilling the water reduces its ability to carry dissolved solids, and all this metal-rich stuff blankets down on top of the crust. The result is a very metal-rich layer sitting on top of the ocean seafloor. This mid-ocean ridge water circulation cycle is an incredibly efficient machine at pulling out minerals and metals from ocean crust and then dumping them back onto the ocean floor. Once the ocean crust is made at the ridge, it slowly chugs its way across the ocean floor, usually reaching a subduction zone within 100-150 million years. The crust has a rich layer of minerals and metals at its top, but this layer gets increasingly covered by ocean sediments. By the time the ocean plate reaches a subduction zone, there may be several kilometers of sediments at the top of it. When the plate sinks into the subduction zone, much of those sediments are scraped off by the over-riding plate, but not all of them. This means that the metal-rich layer usually makes it into the subduction zone. As the plate sinks, it begins to heat up again. The presence of water keeps the solidus low, which means that melting occurs more easily. Once again, the heavy metals are some the first materials to melt, and so they become part of the forming magma, and they get whisked away and travel up toward the surface, where they comes up to a volcanic region like Mount St. Helens. Some of the magma freezes underground as intrusive igneous rocks. The whole subduction zone region ends up being very rich in metals and ores. Where have the gold rushes been? Have they been in St. Louis? No, they’ve been in places like California, the Yukon, and Alaska. Well, California, the Yukon, and Alaska are places that have had subduction occur for a very long amount of time along the Western Coast of North America. The metals got sucked out of the rock of the ocean crust by flowing water, dumped on top of the crust at mid-ocean ridges, carried across the ocean floor on the moving oceanic plate, pulled down underneath the continents in subduction zones, and then dissolved into melt that travels back up to the crust that overlies the subduction. A lot of the gold and uranium and silver and mercury and lead and titanium and tungsten that was in the ocean crust got removed, and got concentrated in above subduction zones. This makes them much more easily mined. There is no way that we would ever be able to do all this on our own, but plate tectonics has done it for us.

Petroleum is another byproduct of metamorphic processes. Oil and natural gas are fossilized ancient organic muck from the ocean sea floor. Take all the dead fish, plants, seaweed, worms, bacteria, etc., dump sand and shale and mud and limestone on it, push it down into the earth where temperatures are high, and it eventually cooks. When it cooks, what you get is liquid oil and natural gas, which will rise up to the surface because they are lighter than the surrounding rock. Most of the oil that’s has ever been created has come right back up to the surface and put back into the ecosystem, to be chewed up and eaten by bacteria and brought back into the life cycle. Some of it, however, gets trapped down deep beneath layers of impermeable rock. How does this happen? You need to be in a place where you can create big arches of rock that can trap the oil as it rises upward. This happens when plates collide. Plate tectonics again. More than half of all the world’s oil is in the Middle East. The tiny little country of Kuwait, a speck on the map, has 11 percent of all the world’s oil, which is why we are such good friends with them. And Saudi Arabia, our good buddy in the Middle East, has over a quarter of the world’s oil. Saudi Arabia, Kuwait, Iran, Iraq, United Emirates, are all in this one region. How did this happen? How did this area get so much oil? Luck. It has been subjected to just the perfect plate tectonic conditions where the ocean that did exist (called the Tethys Sea) between Arabia and Eurasia had just enough sediment and just enough compression to bury the organic material to just the right depth to cook out the oil. This occurred because Africa decided to rotate into Eurasia, causing the crust in between to buckle and fold. That folding became the Zagros Mountain Belt that cuts right across the Middle East. The arched layers of rock have trapped the oil and prevented it from rising to the surface. So it sits there in these large arches, waiting to be drilled into and pumped up. Too deep, and you destroy the oil with temperatures that are too high. Too much plate collision, and you create giant faults that allow the oil to leak up to the surface. You have to have just the right circumstances, and the Middle East area happens to have had just those right plate tectonic circumstances, so they got the oil.