UCSB Geology - Plate Tectonics Animation Downloads

Explanations to be used in conjunction with UCSB animations

Mesozoic Subduction

Section View of Subduction off Ca Coast, 01.mov

B.1. Mesozoic Subduction

Drawn and animated by Tanya Atwater using Photoshop and Morph.

Illustrates the geological processes commonly found at subduction zones. The Basement rocks of much of California were formed in this way.

Pangea

Pangea Breakup 01.mov

Flat world Continental Drift, Pangea to Present: Physical Puzzle

These are jpeg images from the movie Pangea.mov   They can be used to make a physical puzzle.

They include images of all the continents in
(1) Pangean configuration and
(2) present configuration, plus
(3ABC) individual continental pieces,.

My recommendation is to print out and laminate the (1) Pangea version and then cut the continents apart. This insures that they reconstruct well. Unfortunately this requires a large color printer.
The (2) Present version is for your information.

Note that there are two versions, each, of (1) and (2). The versions marked “sm” are shrunken to fit on a standard page - unfortunately quite small. Alternatively, the individual continents (3ABC) are page size sheets and not shrunken, so you can print them on a regular color printer and make the full sized puzzle using them.

Note that there are shape/space problems when Eurasia collides with India, Arabia, and Iberia forming the Himalayan and other mountain ranges. This can be solved by stacking the two versions of Eurasia in (1)* so that India, Arabia, and Iberia can be inserted between the two layers.

When I made this puzzle, I wrapped some thick, fuzzy blue cloth around a board to use as the background. (The fuzziness makes the pieces stay put better.)

* or print out two copies of 3B, cut away the indents from one, and stack them.

Breakup of Pangea and continental drift, 200 million years ago to present.
Drawn by Tanya Atwater and animated by Ian MacMillan using Flash, with additions by Grace Giles.

This is a special "flat earth" version of the drift of the continents, starting from the breakup of Super-continent Pangea about 200 million years ago. The continents were hand flattened by Atwater such that they are recognizable and they fit together in their Pangean and present-day configurations.

The motivation of this construction is to depict the breakup and drift of rigid pieces, while obviating common problems with other depictions. (In the most common depiction, the earth's surface is flattened via some projection such as the Mercator projection. Unfortunately, in these projections, drifting pieces artificially change size and shape. Other versions show rigid pieces moving around the surface of the globe, but since you can only see one side, they keep drifting out of view.)

India - Asia (Himalayan) Collision

India Asia Collision Section View.mov

India-Asia Continental Collision, 60 million years ago to present, cut-globe view.
Dedicated to Peter Molnar to honor his lifelong research on this spectacular continental collision, on the occasion of his 60th Birthday Symposium, Colorado, 2004. (Finally completed in 2007.)
Created by Tanya Atwater with extensive reviews and edits by Peter Molnar. Made using Photoshop and Morph, with original continental outlines on the globe from http://www.odsn.de/odsn/services/paleomap/

Twelve-second and four-second versions are offered. My recommendation: download both. The latter, speeded up version is just for fun, to emphasize the drama of the collision.

Spreading in the South Atlantic

Section View of SoAtlantic Divergence 120my to Present, 01.mov

Created by Tanya Atwater using Photoshop, Morph, and Final Cut Pro. Continental outlines on the globe surface from http://www.odsn.de/odsn/services/paleomap/. Earlier versions created by Carrie Glavich in Flash.

Shows a cut-globe view of the spreading of South America away from Africa to form the South Atlantic Ocean between about 130 million years ago and the present. Two versions are offered: simple plate motions and plate motions with a depiction of likely mantle convection patterns.

Some notes from Atwater about plate driving mechanisms and mantle convection.
In most elementary textbooks, the mantle is depicted as a boiling pot, with convecting fluid (the mantle) that carries the surface scum (the plates) around. The plates are depicted as passive floaters drifting on the underlying current. This is not a model believed by most experts in the field. Rather, they envision the geometry as follows.

The oceanic plates are mostly made of cooled mantle rocks (with a thin layer of crust painted on top). Thus they are the same as the adjacent hot mantle, but cooler and denser. Because of this, the motions of the plates are mostly driven by their own weight, slipping downhill off of the mid-ocean ridges and falling down through the mantle at the subduction zones. (Phase changes in the upper mantle and in the down-going slabs enhance these density differences.) Thus, for the most part, ***convection patterns in the upper mantle are driven by the motions of the plates, not vice-versa.***

The plates, themselves, are the tops and descending sides of the convection cells.

At the spreading centers, as the plates slip downhill away from the mid-ocean ridges, they create a low pressure region beneath the center, drawing the underlying asthenosphere up into the widening crack. Thus, mantle upwelling beneath the center is both localized and driven by the departing plates. Beneath the moving surface plates, the plates drag the asthenosphere along. In models of the plate driving motions, the friction between the lithosphere and underlying asthenosphere is believed to resist the plate motion in most places, not to drive it.

At the subduction zones: the cold, down-going slabs entrain the surrounding mantle, dragging it downward. This, in turn pulls new asthenosphere toward the subduction zone tops, perhaps helping to move the overriding plates in these locales. The most dramatic mantle convection, called the “corner flow”, occurs where the slab separates from the bottom of the overriding plate, entraining and removing local asthenosphere that then must be replaced by inflow from the side. (Among other things, this process continually renews the heat and fertility of the mantle wedge beneath the arc magmatic belt.)

Comments? I'd love to hear them: atwater@geol.ucsb.edu

World Tectonics Map Exercise

World Tectonic Map Layers.psd

World Earthquakes and Volcanoes Map Exercise

The six maps are given as individual jpg files (and also as a layered Photoshop stack of maps).
Print out the six layers.

Xerox the instructions and Maps 2-6 onto paper, and xerox Map 1 onto a transparency. For best results do all the copying at the same time; machines tend to change scale from day to day. Make one set for each 3-4 students.

Supply each group with one red and one dark-colored WASHABLE transparency pen. (If they use permanent, you will have to throw the transparency away and do the copying all over again.)
The Exercise, below, is one I used on the first day in my Upper Division Plate Tectonics Class.
Feel free to alter it to suit your own purposes.
Isn’t plate tectonics great? Enjoy!

Seafloor Spreading and Magnetic Reversals

Sea Floor Spreading Section View 01.mov
Sea Floor Spreading Section View wArrows 02.mov
Sea Floor Spreading wMagStripes, 01.mov
SeaFloor Spreading Section View wArrows 01.mov

SeaFloorSpreading wPole Rev Scale & Strips, 01.mov

Sea floor spreading on three spreading centers connected by transform faults, with a front-cut cross section. Series of five animations demonstrating spreading, transform faulting, magnetic polarity reversals, and the Vine-Matthews hypothesis for the formation of seafloor magnetic stripes. These conceptual presentations are shown occurring at a gently rifted spreading center (i.e., a slow-medium spreading center).

Created by Tanya Atwater using Photoshop, Morph and Final Cut Pro with art help from John Iwerks and comments from Ken MacDonald and Doug Burbank.

Full Downloads Below:
Note: an earlier version had a mistake in the reversal time scale. If you downloaded those, please replace them with these.

Tuzo's Puzzle

Tuzo Diagram.jpg
Tuzo's Puzzle.jpg

This paper puzzle helps illustrate magnetic reversals, as well as the motions of transform faults located at spreading centers

Pacific Hemisphere Plate, 80 Ma to Present

Eastern Pacific Plate Motion 80my to Present.mov

Pacific Hemisphere Plate Tectonic History, 85 Ma to Present (stable North America held fixed).

Drawn and animated by Tanya Atwater using Photoshop and Morph. Thanks to Steve Cande and the POMP project for the original images and reconstructions.

Narrative below written to accompany the animation (each • represents one play-through of a given animation clip).

• Present Situation. At present the Pacific Plate fills most of the north Pacific Ocean basin. The various shades of blue show the ages of the sea floor, as deduced from marine magnetic anomalies. The Pacific plate is moving northwest toward the subduction zones of the Aleutians and the western Pacific island arcs. Along the rim of North America, it has captured some slivers of the continental edge and is carrying them northwestward toward Alaska. Thus, the present Pacific-North America plate boundary lies within the continent, the San Andreas and Queen Charlotte fault systems. This was not always the case......

• Late Cretaceous Situation, 85 Ma. In the late Cretaceous, 85 million years ago, there were several oceanic plates within the Pacific basin: the Pacific plate was a smallish southern plate with the Aluk, Farallon, and Kula plates spreading away from it.

• Oceanic Plate Evolution. Coming forward in time, the Pacific plate grew and grew and drifted north until it came to fill most of the north Pacific.

• East Pacific Rise Migration. Now watch the eastern edge of the Pacific plate. It moved steadily northeastward as new sea floor was accreted onto the edge by sea floor spreading between the Pacific and Farallon plates.

• Farallon Plate Disintegration. Now watch the demise of the mighty Farallon plate. It subducted beneath the Americas faster than it was being formed. As its surface area decreased, it broke into smaller plates then some of those subducted entirely, allowing a new boundary, the San Andreas, to form between the Pacific and North American plates.

• Pacific Plate Motion. This time watch the motion of the Pacific plate, itself. It drifted northward or northwestward the whole time, toward the subduction zones of Japan and the Aleutian Islands. When its edge came in contact with North America it broke off continental slivers and carried them away to the northwest.

• Massive Subduction. This time watch and be impressed by the subduction; an astonishingly huge area of oceanic plate was subducted beneath North America. The Mesozoic and Cenozoic rocks of western North America are primarily a record of plate convergence in all its forms. The San Andreas fault is a very late complication superimposed on this rich history of subduction.

N.E. Pacific and W. North America Plate History, 38 Ma to Present.

Farallon Plate-NAmer Plate, 40my to Present.mov

Plate Tectonic History of the N.E. Pacific and W. North America, 38 Ma to Present (stable North America held fixed).

Drawn and animated by Tanya Atwater using Photoshop and Morph. Thanks to Bill Menard, Joann Stock, Jeff Severinghaus, Doug Wilson, Craig Nicholson, Gene Humphries, and many others. Reconstructions closely follow those presented in Atwater and Stock, 1998, Int. Geol. Rev., v. 40, p. 375.

Here are suggested narratives written to accompany the showing of the QuickTime animations (each * represents one play-through of a given animation clip)

Present Situation. At Present the Pacific Plate fills most of the northeast Pacific Ocean basin with only the small Juan de Fuca and Cocos plates remaining from the previous configuration. The various shades of blue show the ages of the sea floor, as deduced from marine magnetic anomalies. The Pacific plate is moving northwest past North America. It has captured some slivers of the continental edge and is carrying them northwestward toward Alaska. Thus, the present Pacific-NorthAmerica plate boundary lies withing the continent, along the San Andreas fault system. it is connected to othe plate boundaries at three-plate triple junctions, the so-called Mendocino and Rivera triple junctions; the locations and motions of these triple junctions help determine the on-shore geology in each time and place.

Early Cenozoic Situation 38 Ma. In the early Cenozoic, 50 Million Years Ago, other oceanic plates lay between the pacific and North American plates. They were spreading away from the pacific plate and subducting beneath the rim of the continent.

* East Pacific Rise Migration. Coming forward in time, the eastern edge of the Pacific plate moved steadily northeastward as new sea floor was accreted by sea floor spreading. Eventually, the spreading center itself reached the subduction zone and the intervening plate was destroyed. The Pacific plate

began to break off pieces of North America and carry them away, creating the San Andreas-Gulf of California plate boundary inside the continent.

* Triple Junction Evolution. Watch the motions of the triple junctions. The Mendocino triple junction migrated steadily up the coast, attached to the Mendocino fracture zone on the Pacific plate. The Rivera triple junction hovered near the southern California borderland then, about 12 million years ago, it jumped to its modern position when sea-floor spreading and subduction ceased off Baja California.

* San Andreas System Evolution. The evolution of the San Andreas system was essentially a two stage process. First the Salinian and borderland pieces of the continent were gradually transferred to the Pacific plate, later Baja California was transferred. A third stage has begun: the Sierra Nevada/Great Valley block is in the early stages of being transferred and carried away.

* Pacific Plate Motion. Watch the motion of the Pacific plate. It continually moved off to the northwest.

* Basin and Range Expansion. Now watch what happened to the interior of North America. In the early Cenozoic, western North America was much narrower. (Check out narrow Nevada!). During the late Cenozoic it expanded, forming the Basin and Range province. This occurred during the time that the Pacific plate was pulling the rim of the continent away to the northwest, perhaps causing the expansion or, more likely, just making room for it. (It was already elevated, hot and weak, ready to fall apart given the chance.)

Plate Tectonic History of Southern California, 20 Ma to Present (stable North America held fixed)

SoCal Plate Movement 20my to Present, 02.mov
SoCal Tectonics 20my to Present 01.mov
SoCal Cities wPlate Movement 20my to Present, 01.mov

Present Situation. At present, the primary Pacific-North American plate boundary runs from Cape Mendocino, along the San Andreas fault system and the Gulf of California spreading centers and transform faults. Notice that the Santa Ynez Mountains, Santa Barbara coast line, Channel Islands, and Santa Monica Mountains all run east-west, crosswise to most other features in the region. Paleomagnetic measurements show that this block, the Western Transverse Ranges Block has been rotated more than ninety degrees. Notice that the continental shelf off southern California and northern Baja California, the "California Borderland", is very wide and fragmented.

Mid-Cenozoic Situation, 20 Ma. This is a likely reconstruction of the continental rim before it was shifted and reorganized by the evolving plate boundary. The inner Borderland has been collapsed and the Western Transverse Ranges Block has been rotated back in order to place the Channel Islands beside San Diego. The Los Angeles Basin does not yet exist.

* Rotation of the Western Transverse Ranges. The Western Transverse Ranges Block started out with its southern rim, the Channel Islands, lying near San Diego. During the extensional shear of the borderland, the block was torn away and rotated out to its present east-west orientation. The gaps that opened up on both sides of the rotating beam are postulated to have been filled from below by core complex-like emplacement of underplated Franciscan materials.

* San Andreas System Evolution. As the contact zone between the Pacific and North American plates grew and solidified, the rim of North America fragmented. Pieces were transferred to the Pacific plate, establishing the San Andreas plate boundary inside the continent.

* Two stage transfer. The continental transfers occurred in two steps: 1. During the Miocene, coastal California fragments were gradually transferred. 2. Later, about five million years ago, Baja California was transferred as one relatively coherent piece.

* Southern California Tectonic Stages. The transfer of Baja California to the Pacific plate profoundly changed the tectonic situation in southern California. Before the Baja transfer, the plate boundary bent outward from the northern San Andreas to the Pacific rim - an oblique-extension configuration, and thus the California borderland was extended and sheared. After the Baja transfer, the plate boundary bent inland into the Gulf, an oblique-compression configuration, and the San Andreas "Big Bend" and the present mountains were created.

Southern California, 20 Ma to Present

SoCal Plate Movement 20my to Present, 02.mov
SoCal Tectonics 20my to Present 01.mov
SoCal Cities wPlate Movement 20my to Present, 01.mov

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Southern California Paleomagnetic Vectors

xxx.mov

Drawn and animated by Tanya Atwater using Photoshop and Morph. After Hornefius 1985. Journal of Geophysical Research, v. 90, p 12503-12522. Dark blue = vectors measured in samples aged 29-14 Ma. Medium blue = vectors measured in samples aged 14-11 Ma. Dark blue = vectors measured in samples aged 11-5 Ma.

This is the primary data set that convinced most geologists the western Transverse Ranges block has rotated clockwise about 90o.

Southern California, Origin and Dispersal of the Poway Conglomerate

SoCal Plate Motion wPoway Conglomerate.mov

Southern California: Southern California, Origin and Dispersal of the Poway Conglomerate

Drawn and animated by Tanya Atwater using Photoshop and Morph. After Pat Abbott, 1999. The Rise and Fall of San Diego, 231 pp.

This illustrates a likely three step scenario for the dispersal of these distinctive rocks. The present day outcrop patterns are strong geological support for the Transverse Ranges rotation.

Southern California Puzzle

SoCal Puzzle Base.jpg
SoCal Puzzle Pieces.jpg
SoCal Puzzle Instructions & Activities.pdf

This puzzle, when cut out and pinned together with brads, supplies an approximate physical model clarifying how the rotating Transverse Ranges are part of the larger Pacific-North American plate boundary (San Andreas system). Puzzle sheets are offered in color, and xeroxable black and white. Accompanying text supplies construction instructions, a description of the history being depicted, and related paleo-magnetic and Poway conglomerate stories.

Plio-Pleistocene Oblique Shortening against the San Andreas fault

Section View of Crustal Shortening, 01.mov

B.3. Plio-Pleistocene: Oblique Shortening against the "Big Bend"

Drawn and animated by Tanya Atwater using Photoshop and Morph.

Since Baja California began to move and collide with southern California, the land has been shortened. The layer cake was faulted and folded and portions of the block were uplifted to form dry land. The dramatic mountainous landscapes that we enjoy today have all been pushed up by this collision and shortening of the land. This collision continues today, uplifting the land, one earthquake at a time

Miocene: Rifting and rotation, volcanism, crustal upwelling and deposition in marine basins

SoCal Plate Movement 20my to Present, 02.mov
Small Plate being Twisted, 01.mov

B.2. Miocene: Rifting and rotation, volcanism, crustal upwelling and deposition in marine basins

Drawn and animated by Tanya Atwater using Photoshop and Morph.

When the Pacific Plate began scraping against North America, the Transverse Ranges block broke off and twirled around. The stretching thinned the crust, drawing lavas and lower crustal rocks up to fill the gap. The Santa Monica mountains and parts of the offshore Channel Islands are made of the lavas from these volcanoes. Conejo Mountain, near Oxnard is the throat of an old volcano. The stretching broke the continental shelf into many marine basins, very rich living places for marine life. These basins formed excellent habitats for microscopic floating plants called diatoms,.and the diatoms were food for swarms of tiny shrimp, and these, in turn, were scooped up by whales The pastey looking rocks that form many of our sea cliffs started out as a pile of microscopic skeletons from these diatoms. The organic parts of the diatoms slowly decayed to form natural gas, oil and tar. Fossil whale bones form the stones on some of our beaches.

Santa Barbara Channel Oil: Structural Evolution

Section View of Oil in Anticlines wOil Rig, 01.mov
Section View of Oil Seeps, 01.mov
Section View of Crustal Shortening, 01.mov

Structural Evolution: During the last few million years, the sedimentary layers under the Santa Barbara Channel have been shortened, folded, and faulted.

Migration of oil into anticlines: Tar, oil, and gas rise through the pores in the rocks and collect in "traps" under the anticlinal folds in the clay layers. Oil wells extract the oil from these traps.

Natural Oil seeps: Where the layers have been broken by faulting or breached by erosion, hydrocarbons escape to the surface, releasing the gases and forming oil and tar seeps.

Santa Barbara Channel Oil: Migration of oil into anticlines

Section View of Oil in Anticlines wOil Rig, 01.mov

Structural Evolution: During the last few million years, the sedimentary layers under the Santa Barbara Channel have been shortened, folded, and faulted.

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Natural Oil seeps: Where the layers have been broken by faulting or breached by erosion, hydrocarbons escape to the surface, releasing the gases and forming oil and tar seeps.

Santa Barbara Channel Oil: Oil seeps on ocean floor

Section View of Oil Seeps, 01.mov

Structural Evolution: During the last few million years, the sedimentary layers under the Santa Barbara Channel have been shortened, folded, and faulted.

Migration of oil into anticlines: Tar, oil, and gas rise through the pores in the rocks and collect in "traps" under the anticlinal folds in the clay layers. Oil wells extract the oil from these traps.

Natural Oil seeps: Where the layers have been broken by faulting or breached by erosion, hydrocarbons escape to the surface, releasing the gases and forming oil and tar seeps.

Bay Area Sea Level Change: SF Bay formation

SF Bay Sea Level Rise 18ky to PresentFlood.mov

Wave Cut Terraces - Formation

Coastal Terrace Formation, 01.mov

Small Waves

Side View of Small Waves on Beach, 01.mov

Erosion by Large Storm Waves

Side View of Large Waves Eroding Shore.mov

Ice Ages

NAmer Deglaciation 21Ky to 6ky.mov

Pygmy Mammoths

xxx.mov

Deglaciation of North America

xxx.mov

The Last Deglaciation of North America - 21,400 to 5700 years ago

The last Ice Age began about 120,000 years ago, and gradually intensified with lots of variations over the next 100,000 years, reaching its maximum about 18,000 years ago. The melt-back, between 18,000 and about 6000 years ago, was relatively rapid.

This movie shows how the great Canadian Ice Sheet melted away at the end of that last Ice Age.

Credits
The Last Deglaciation of North America movie was created by Professor Tanya Atwater, U.C.S.B., and Professor Stephen Porter, U. Washington using Photoshop and Morph.
Glacier reconstructions are based on Dyke, A. S. (2004), "An outline of North American Deglaciation with emphasis on central and northern Canada" in Quaternary Glaciations-Extent and Chronology, Part II, p. 373-424, J Ehlers and P. L. Gibbard, ed, Elsevier; with additional data from Denton, G. H. and Hughes, T. J. (eds) 1981, The last great ice sheets, p. 263-317. J. Wiley & Sons, New York, 484 p.
Coastlines and C14 calibration were estimated using the Barbados sea level curve of Bard E, Hamelin BJ, Fairbanks RG, Zindler A (1990) "Calibration of the 14C timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals", Nature 345. p. 405–410.
Extent and variations of Great Basin lakes is from D. R. Curry, G. Atwood, and D. Mabey, 1983, Major Levels of Great Salt Lake and Lake Bonneville, Map 73, Utah Geological Survey: and from Morrison, R. D. (1965) "Quaternary geology of the Great Basin", in The Quaternary of the United States, H. Wright and D. Frey (eds), Princeton University Press , and R. D. Morrison (1964) Lake Lahontan: Geology of the Carson Desert, Prof. Paper 40 United States GeologicalSurvey..
Artist J. Iwerks assisted in rendering the glacial topography of the ice sheets.
Prof. J. Severinghaus provided helpful scientific critiques and suggestions.

Continental Map templates were constructed and down loaded from the ODSN Plate Tectonic Reconstruction Service at
http://www.odsn.de/odsn/services/paleomap/paleomap.html

Black Sea Flood

Black Sea Flood.mov

Formation of Big Southern Butte, eastern Snake River Plain, Idaho

xxx.mov

Big Southern Butte is a rhyolite dome complex which formed about 300,000 years ago. The rhyolite magma forming Big Southern Butte fractionated from an olivine tholeiite parent magma. This rhyolite magma was ~5% less dense than surrounding rocks and rose through a fracture in the Tertiary rhyolite. Since the SRP basalts are highly fractured and are overall less dense than the ascending rhyolite magma, the magma stalled out at a depth of ~900 m and ponded at the interface between the Tertiary rhyolite and the Quaternary basalt to form a sill. Continued supply of magma inflated the sill into a laccolith, pushing up the ~900 m of basalt cover rock. Inflation progressed until the basalt cover rock fractured. As rhyolite extrusion began, the basalt cover on the south side of the laccolith began to sink either as a flap or broke into several large pieces and sank. A dome began to form from endogenous growth. The basalt cover on the north side of the dome remained intact and on top of the rhyolite. A massive white crust formed below a crumble breccia on the surface of the slowly growing dome. Later, rapid endogenous growth broke up the white crust, forming an autoclastic breccia. Minor extrusions of rhyolite reached the surface and chilled as obsidian. Small explosions produced a graded explosion breccia and lapilli tuffs near the top of Big Southern Butte. Near the end of the growth of the southeast dome, the intrusive center shifted slightly to the northwest forming another dome. Cessation of the magma supply during the final growth stages of this second dome resulted in a small depression near its summit.

For more information see:
Spear, D. B., and King, J. S., 1982, The geology of Big Southern Butte, Idaho, in Bonnichsen, B., and Breckenridge, R.M., eds., Cenozoic geology of Idaho, Idaho Bureau of Mines and Geology Bulletin, p. 395-403.
McCurry, M., Hackett, W. R., and Hayden, K., 1999, Cedar Butte and Cogenetic Quaternary Rhyolite Domes of the Eastern Snake River Plain, Guidebook to the Geology of Eastern Idaho: Pocatello, Idaho, Idaho Museum of Natural History, p. 169-179.

Tree Molds at Craters of the Moon National Monument

Tree Molds in Lava Explanation, 01.mov

Volcanic tree molds form when hot, fluid lava surrounds a tree and the tree either decays or burns away after the lava cools and hardens. Since a'a lava is very blocky, the more fluid type of lava, pahoehoe lava, generally forms the best tree molds. As lava advances and surrounds the tree, it usually lights the tree on fire.

Here are some pictures taken in Hawaii by staff at the Hawaiian Volcano Observatory that show how advancing lava sets trees on fire.

As advancing lava surrounds the tree, the thin, partially cooled crust of the pahoehoe lava may stack up against the tree trunk in rope-like forms. These ropes often accumulate on the upstream end making the tree mold larger on that side. Often, tree molds are vertical. However, trees may fall over and leave behind horizontal molds too. The height of the tree mold indicates the maximum height of the lava flow. Sometimes geologists can tell which direction the lava was flowing long after it cooled and hardened by examining how the ropes of pahoehoe wrapped around the tree. These tree molds show how pahoehoe ropes stacked up against the tree.

Notice how the pahoehoe ropes wrap around and adhere to the tree.

A rectangular pattern resembling a tire tread may form as the tree cooks to charcoal. Lava may enter the cracks in the charcoal exterior of the tree and after the tree decomposes or burns completely, "tire tracks" are left in the lava.

Dike Emplacement at Craters of the Moon National Monument

Dike Emplacement at Crater of the Moon.mov

The Craters of the Moon lava field spreads across 618 square miles and is the largest young basaltic lava field in the lower 48 states. The area contains more than 25 volcanic cones including outstanding examples of spatter cones. Sixty distinct lava flows form the Craters of the Moon lava field ranging in age from 15,000 to just 2,000 years old.

The Great Rift, the pathway that allowed molten rock to come to the surface runs from north of the visitor center, through this area, and to the SE, a distance of about 60 miles. A portions of the rift were forced open by rising magma, huge amounts of molten rock were spewed out onto the surface of Craters of the Moon.

Stages of Eruptions: Great Rift

- Magma comes from great depths rather than having intruded almost exclusively by lateral motion from a high, crustal-level magma reservoir. The magma is tapped directly from a partially melted lithospheric mantle.
- In the ESRP, dikes rise along a pathway aligned with Basin and Range faulting (northwest trend)
- Dikes are blade-like in shape
    - Tens of km long
    - Few km high
- Dikes have a critical depth of ~ 750-1000 m in the ESRP
- As a dike rises to the surface, 2 maxima oriented on each side of dike equally spaced by a distance roughly equal to twice the depth to the crack-rift center
    - Tension cracks
    - Faults in alignment- do not exist in ESRP

North Crater Rafted Blocks at Craters of the Moon National Monument

Craters of the Moon, rafted blocks.mov

North Crater cinder cone has of the more unique histories of the more than 25 cinder cones of the Craters of the Moon Lava Field. Five lava flows erupted from or near its base. Three of those flows tore apart North Crater and carried pieces of the cone more than 11 kilometers (nearly 7 miles) to the northeast.

Cinder cones form when loose rock fragments erupt from a central vent and pile up to create small, often circular, volcanoes. Some rock fragments are so hot they weld together when they land. Rock fragments called cinders make up most of North Crater, but ash, volcanic bombs, and taffy-like spatter are also common. Cinders and ash form when hot magma, highly charged with dissolved gas, rises to the surface and erupts explosively, shooting magma into the air. The sudden release in pressure allows gases in the magma to expand, creating tiny gas bubbles in the rock called vesicles. Not as highly charged with gas, spatter did not expand as it boiled from the vent. Flying through the air and crashing to the ground often gives large volcanic bombs weird and contorted shapes. The very light and loose cinders on North Crater contrast with the heavy and solid accumulations of taffy-like spatter and volcanic bombs also present.

In one explanation for the large hole in the northwest side of North Crater, the Great Rift cracked open the cone. Thick, pasty magma then easily pushed apart the weakened cone walls and floated away large pieces of the cone just like rafts floating down rivers. As these rafted blocks floated away, they shed loose, unconsolidated cinders and ash into the lava flow transporting them. Tremendous stresses caused the rafted blocks to break up into smaller pieces and mix into the upper portions of the transporting flow. Later, more lava flows buried many of the rafted blocks. Today, some of the large resistant blocks that did not break apart as they rafted, poke up through the younger flows. Enough unburied rafted blocks exist to suggest North Crater may have been 40 m (131 ft) taller and 200 m (656 ft) wider at the base before rafting events carried away portions of the cone. This North Crater would include the existing North Crater and occupy the area between the current North Crater and the highway, visitor center, and campground. Alternatively, several smaller North Craters, or cousins of North Crater, may have also existed throughout time and been partially rafted away and later rebuilt. For further information on rafted blocks and cinder cones see:
http://volcanoes.usgs.gov/Products/Pglossary/pglossary.html (A photo glossary of volcanic terms compiled by the USGS.)

Foshag, W.F., and Gonazalez, J.R., 1956, Birth and Development of Parícutin Volcano, Mexico: U.S. Geological Survey Bulletin 965-D, p. 355-489.
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Natural Attenuation of a Trichloroethylene Plume in a Basalt Aquifer

TCE Natural Attenuation, 01.mov

This simulation depicts the natural attenuation of a contaminant plume in a basalt aquifer. The broad, volcanic Snake River Plain in the western U.S. possesses one of the largest most productive aquifers in the country drawing its water from surrounding mountain ranges. The aquifer, consisting mainly of fractured basalts, is at least 60 meters below land surface. The Idaho National Laboratory, built on the Snake River Plain, is remediating portions of the aquifer that are contaminated from past waste disposal practices. One such location, Test Area North, has an aquifer plume containing trichloroethylene or TCE. The rapid movement of groundwater in the fractured basalts of the aquifer caused TCE to spread into a two-mile long plume.

As in other locations of the Earth's subsurface, this aquifer is home to a diverse community of microbes adapted to survive in this austere environment. These cells exist where the aquifer chemistry permits their energy needs to be met. Among these cells are methanogens that survive by using hydrogen to reduce dissolved inorganic carbon where oxygen is absent. In the process they produce methane that dissolves into the aquifer. Elsewhere in the aquifer, where oxygen is abundant, cells called methanotrophs derive their energy from the methane produced by methanogens reducing oxygen in the process. To derive energy from methane, these methanotrophs use a unique enzyme called methane monooxygenase. As it turns out, methane monooxygenase can co-metabolize TCE. In other words, using this enzyme these methanotrophs inadvertently remove TCE from the aquifer through their metabolic activity.

With the constant supply of methane methanotroph communities can heal the damage caused by the TCE. Naturally occurring microbes in the aquifer other than methanotrophs may be removing TCE by their own enzymes.

Research over the past 10 years indicates that the TCE is gradually disappearing from the aquifer near Test Area North by this biologically driven natural attenuation. TCE is estimated to have a 13-year half-life in the aquifer so that by late this century it will have practically disappeared. Research continues to investigate the rates at which these cells degrade TCE, the effects that TCE co-metabolism has on the cells, and how our knowledge of natural attenuation at Test Area North can be transferred to other contaminated sites.

Microbial Activity In Sediments At An Active Margin; Control By Fluid Flux

Microbes During Sedimentation.mov

This simulation is a depiction of a convergent margin showing the subduction of one tectonic plate beneath another, the associated scraping of the accretionary prism, the forearc basin, and distant volcanic activity.

Closer view of prism showing movement of subducting plate, resistance of overlying plate, discontinuous nature of scraped sediments on prism (folding, buckling), and relatively laminar sediments of forearc basin.

Microbes are left in place in sediments through sedimentation of particles as "marine snow" or are mobilized in the sediments by fluid movement controlled by any of the processes that are depicted in this simulation. Microbial activity in the sediments is controlled by the flux of chemical energy proximal to the cells. Cells require some minimal inputs of energy (e.g., acetate, H_2) and oxidants (e.g., CO_2, sulfate) as well as removal of wastes (e.g., methane, sulfide). This mechanical flux on an active margin may be driven by regional- or global-scale processes such as:
- Compaction and fluid expulsion
- Hydrate instability
- Seafloor slumping
- Tidal forces
- Tectonism

COMPACTION
The mass of overlying sediments gradually packs sediment particles thereby squeezing water and gases out during the compaction process.
Cells attached to the sediment particles benefit from fluid flux past them. Coarse grained strata are likely to be especially prone to high flux rates and may be habitats where high microbial biomass and activities would be expected.

HYDRATE INSTABILITY
Changes in the gas hydrate stability zone (GHSZ) may occur as a result of temperature or pressure changes in the sediments. The example shows a gradual warming of bottom waters near the seafloor which would cause hydrates in the sediments to decompose. When hydrate forms or decomposes there

are associated changes in the gas phase, that is, methane may change from existing as a free gas, as a dissolved gas, or as a hydrated (solid) gas. Changes in hydrate stability are reversible.

Cells that remain attached to the sediments may be alternately exposed to dissolved, free or hydrated methane, depending on the location of GHSZ. The formation of each phase is likely to cause local, micro-scale flux of porewater. These phase changes are likely to be gradual, tempered by sediment thickness and the rapidity of pressure and temperature changes which lead to change in gas hydrate stability.

SEAFLOOR SLUMPING

Hydrates that form on a slope act to hold the sediments together. However, following events that might destabilize the hydrates (e.g., bottom-water warming or seismic events) the hydrate dissociates, gas is released, and a seafloor slump may occur.

Initially, cells are surrounded by the hydrate and are relatively quiescent. The destabilization of the hydrate causes both the aforementioned changes in gas phase and a massive disruption of the sediments as they move down slope. Sediments and the attached microbes are dramatically resorted and mixed. Cells are exposed to the rapidly mixed porewater and porewater constituents.

TIDAL FORCES

The diurnal, monthly, and seasonal effects of tides have a measurable impact on hydrostatic pressure in sediments. The resulting cyclic change in hydrostatic pressure influences the rate of flux of fluids out of sediments and, by inference, the movement of these fluids within the sediments. Open sediment systems (i.e., subject to the hydrostatic pumping of tides) are exposed to relatively low hydrostatic pressure during low tides and release more pore fluids from the sediments compared to when they are exposed to high hydrostatic pressure during high tides.

Cells that are attached to sediments in open systems experience higher flux rates of fluids during low tides than at high tides. Such cells may be metabolically adapted to tidal cycling.

TECTONIC EVENTS

Tectonic events along plate boundaries increase or change fluid movement in the overlying sediments. Porewaters and their constituents are relatively static under pre-event conditions in shallow sediments. The seismic event mediates shock waves that create large as well as localized (pore-scale) mixing and potentially significant fluid flow through fissures and fractures. Preferred flowpaths for fluids may be newly opened as a result of such an event.

Between events, microbial cells may be relatively inactive due to depletion of electron donors and electron acceptors in their immediate surroundings. The pressure wave exerted by the seismic event may redistribute these microbial energy sources and sinks in a manner that exceeds normal diffusion in the sediments.