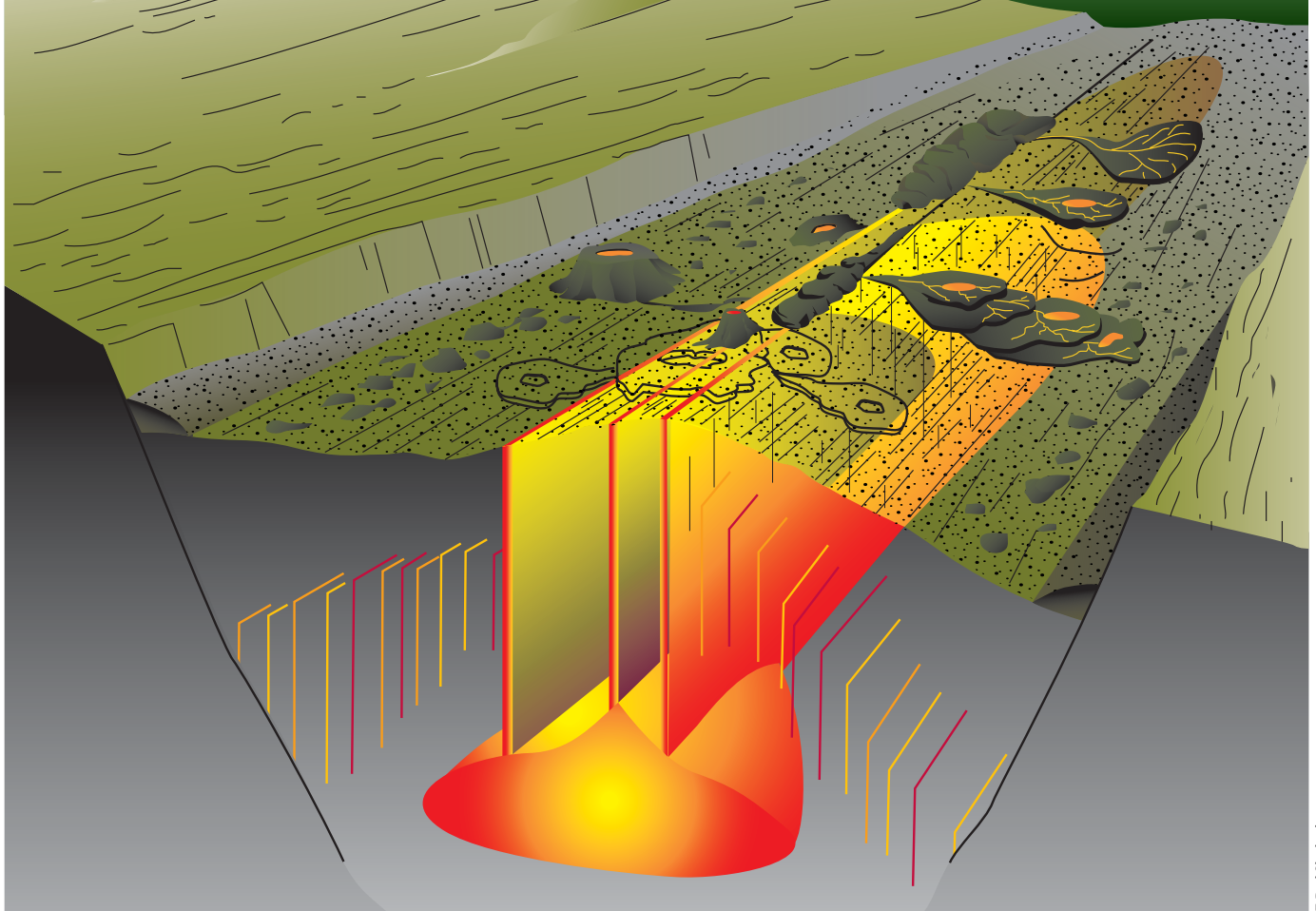


Mid-Atlantic Ridge Volcanic Processes

How Erupting Lava Forms Earth's Anatomy



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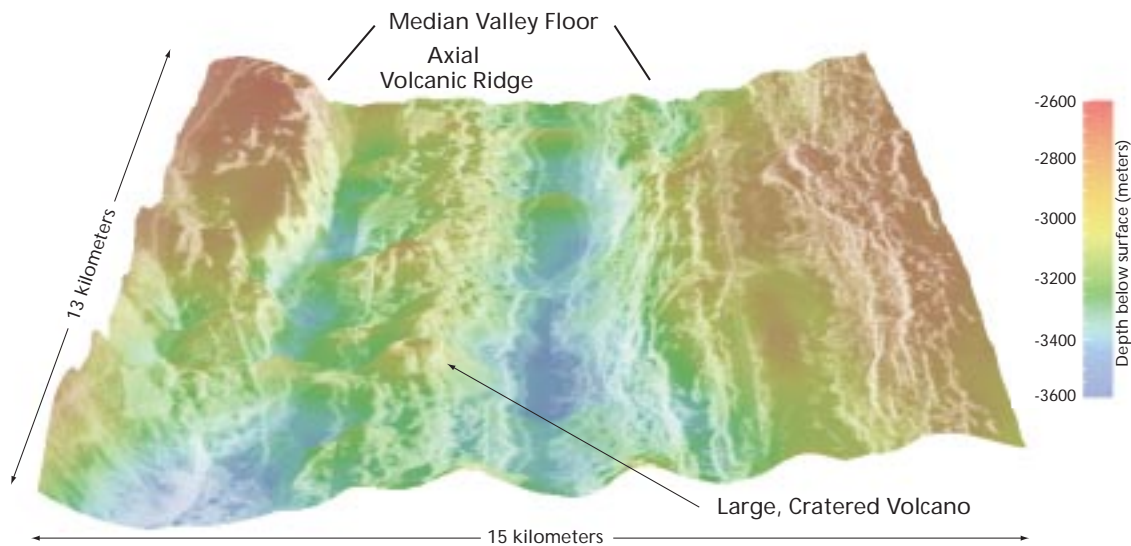
On the islands of Iceland and Hawaii, the location and distribution of eruptive fissures and vents, lava flows, and other volcanic features provide critical pieces of information for understanding how magma is supplied to the shallow crust and subsequently erupted at the surface. Mid-ocean ridge segments, which are in some ways single volcanoes—although long and narrow compared to subaerial (land) volcanoes—are not as well known, primarily because they lie at water depths of 2,500 meters or more. With advanced imaging techniques, we are, however, now obtaining data over relatively large areas of the mid-ocean ridges at the scales necessary to make the same kinds of observations and inferences about

magmatic and volcanic processes there as we do at subaerial volcanoes.

High-resolution side-scan sonar imagery combined with multibeam bathymetry is providing critical new views of the seafloor and changing our ideas about how the oceanic crust forms at the slow-spreading (25 millimeters per year, about the rate fingernails grow) Mid-Atlantic Ridge. These data also enable the design of future detailed geophysical and geochemical Mid-Atlantic Ridge studies at the same scale used to understand subaerial volcanic eruptions.

The Mid-Atlantic Ridge is composed of discrete spreading segments that are tens of kilometers long, and offset by transform faults and nontransform offsets. The axis of the Mid-Atlantic Ridge is marked by a major rift valley 1 to 1.5 kilometers deep, a central floor 4 to 15 kilometers across, and ranges of crestal mountains on each side of the valley separated by 20 to 40 kilometers. The median valley walls are composed of large faults that move the crust

Mid-Atlantic Ridge axis cross section. Beneath the surface, dikes (magma conduits) rise vertically and propagate along the axis from a magma body. Three dikes are shown in detail. The most recent is the one to the right, shaded yellow-orange. Where a dike breaches the surface, a fissure eruption occurs. Older flows are transparent. Hummocky ridges and seamounts are built along the axis. Seamounts and flat-topped highs on the flanks of the axial volcanic ridge are fed by lava tubes from the summit.

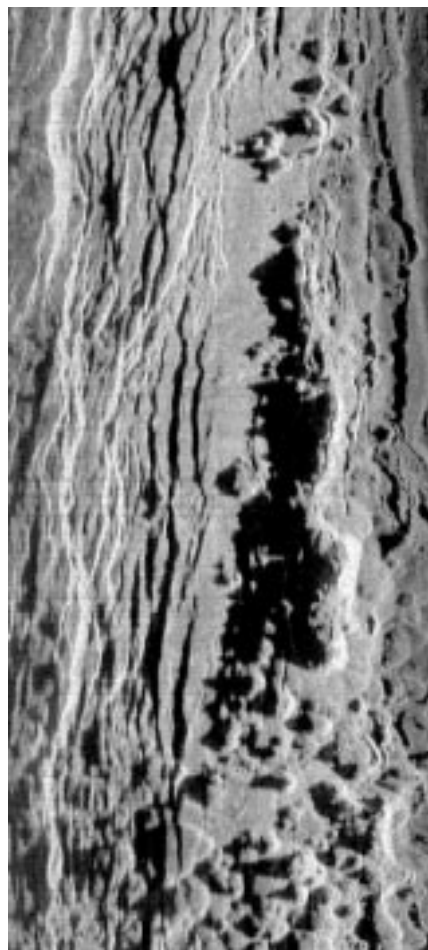


Three-dimensional perspective view of side-scan sonar data mapped onto the color bathymetric surface for a portion of the inner valley floor of a spreading segment near 29° N at the Mid-Atlantic Ridge. The area of the image is 15 kilometers east to west and 13 kilometers north to south. Several side-scan sonar swaths have been merged together across the image. Bright is a reflection, and dark is a shadow or attenuated return from sediment-covered terrain. The cratered seamount (volcano) marked on the image is about 220 meters in relief with a summit crater some 600 meters in diameter. A hummocky-textured axial volcanic ridge winds its way along the valley floor, and volcanic highs extend to the east and west from the axial volcanic ridge into its flanking deeps.

Side-scan sonar image of a small volcanic ridge that is located within the central low of a spreading segment near 25° N. Illumination is from the right. The ridge is about 3.3 kilometers long, 400 meters wide, and 30 meters high. The along-axis orientation of the ridge mimics neighboring faults and fissures, and it is inferred to have erupted from similar fissures. The smooth, unfaulted flows surrounding the ridge are interpreted to be part of the eruption that built the ridge. These flows cover pre-existing faults and fissures. Information about the small-scale volcanic products and faults gained from images such as these provide insight into the processes of magmatism and tectonism at the axis of the Mid-Atlantic Ridge.

upwards to form the crestral mountains. The central valley floor is the primary site of ocean crust construction, and most segments contain an axial volcanic ridge that runs down the center of the median valley floor. The axial volcanic ridges are themselves made up of smaller ridges, round domes, and a variety of topographic features that all amalgamate into a single larger ridge. Axial volcanic ridges may be 2 to 4 kilometers across and 100 to 600 meters high, and represent a very much larger scale of volcanic relief than found on fast-spreading ridges, which are characterized mainly by flat-lying flows.

Near-bottom sidescan sonar data collected at segments of the slow-spreading Mid-Atlantic Ridge are providing images that show volcanic structures on the floor of the median valley in unprecedented detail. At a small scale, there are two types of volcanic features: Some are composed of lava hummocks 50 to 200 meters in diameter and at most 10 to 20 meters high, while other features are coated with smooth lava flows, including one we've imaged that covers most of the median valley floor. The smooth flows are similar to those seen over



and across the surrounding seafloor, forming brims around the volcanoes. A range of other features are linear in plan, elongate parallel to the length of the segment, and probably represent eruptions along a fissure. Commonly seen in Hawaii and Iceland, these are often composed of a row of hummocks that resemble a caterpillar.

Some segments have a greater abundance of one type of feature than others. A segment near 29°N has a pronounced axial volcanic ridge primarily composed of hummocks and a few large circular volcanoes whose surfaces are covered with smooth flows. The axial volcanic ridge widens and narrows along its length, but is typically a few kilometers wide and about 150 meters high. In places, topographic highs that are flat-topped and covered with smooth-textured flows extend east and west from the base of the axial volcanic ridge.

By contrast, a segment at 25° N was flooded not long ago by smooth lava flows that are topped by a variety of small, more recently erupted features. It is intriguing that these two segments, which spread apart at the same rate, have dramatically different

most of the fast-spreading ridges (where spreading rates average 100 millimeters per year). These two types of small scale morphology are assembled into a great variety of larger forms. The round, domelike structures are small volcanoes composed sometimes of hummocks and sometimes of smooth flows. Some of them have flat tops with craters in the middle, some rise to sharp peaks. Lava flows run beyond the edges of the domes

volcanic styles: hummocky flows and the construction of an axial volcanic ridge at 29°N compared with flows that are flat-lying and spread away from their vents at 25°N. It is also interesting that the small-scale volcanic morphology at the center of the 25°N segment is similar to that observed commonly at fast-spreading ridges. This indicates that the correlation between style of eruption and variables such as volume of erupting magma and rates of effusion from the vent can blur the effects of spreading rate on eruptive styles—indeed eruptive styles can be similar at times between fast- and slow-spreading ridges and different between ridge segments with the same spreading rate.

How do the volcanic features we observe on the seafloor form? An eruption occurs when magma moves upwards and along the segment through a dike or vertical crack, intersects the seafloor, and flows onto the surface through a fissure. We know the characteristics of fissure eruptions on land, and envision that the same processes are at work on the seafloor. At the start of a fissure eruption the flows are vigorous, and tend to spread out rapidly. If the fissure eruption continues for some period of time, it will evolve first to several vents and then to a single vent, and with time the flow will decrease in vigor. Magma overflowing from the vent at low to moderate rates will tend to concentrate into channels. If the flow is steady, the channel may roof over to form a lava tube.

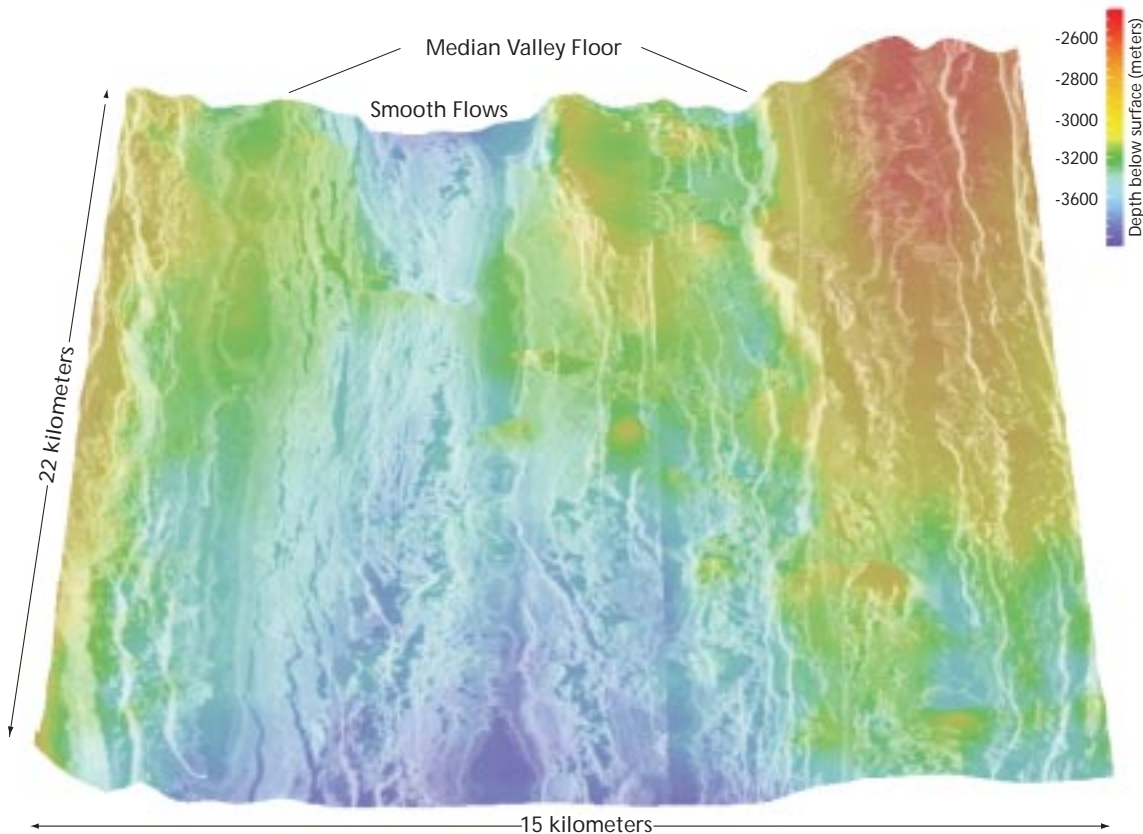
Low-relief flows are likely produced at the start of an eruption when the flows are fast and tend to spread out rapidly. Hummocky ridges are formed



Debbie Smith explores volcanic terrain in Iceland.

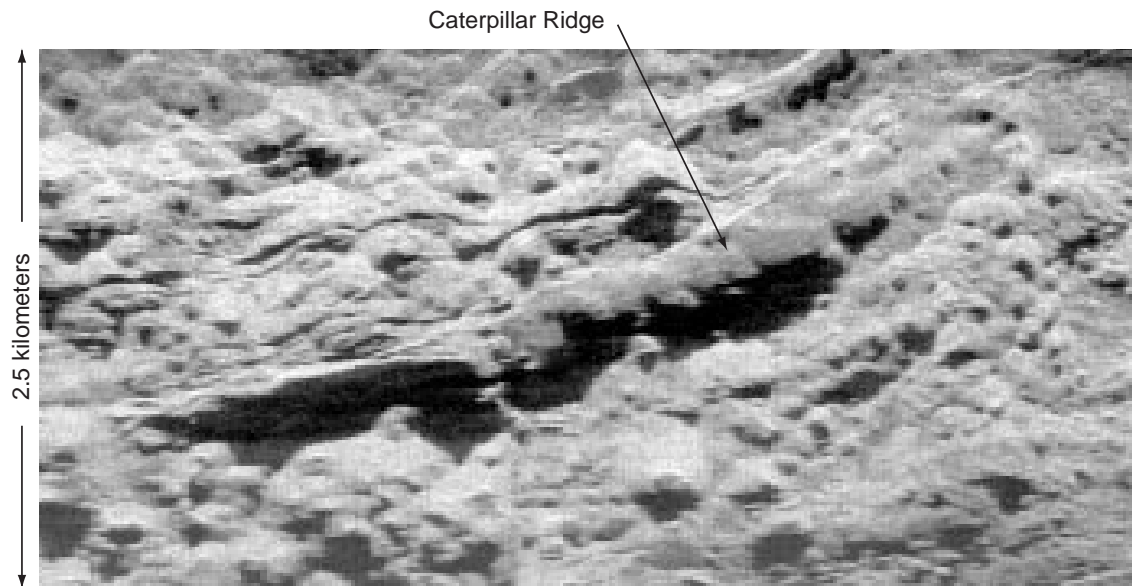
when the fissure eruption becomes confined to several vents along its length, similar to spatter cones or spatter ramparts that form along fissures in Iceland and Hawaii. A large circular volcano (seamount) is constructed when the lava flows from a single opening, much like the flow from the Pu'u 'O'o cone that marks the current vent on the East Rift Zone of Kilauea Volcano in Hawaii. Surface flows, hummocky ridges, and seamounts are, therefore, constructional products of a fissure eruption. At larger scales, axial volcanic ridges are built from many eruptions that are focused within a relatively narrow region of the central valley floor.

Because lava tubes and channels are common on



Three-dimensional perspective view of side-scan sonar data mapped on to a color bathymetric surface for a portion of the inner valley floor of a spreading segment near 25°N at the Mid-Atlantic Ridge. The area of the image is 15 kilometers east to west and 22 kilometers north to south. The morphological center of this segment is a topographic low filled with smooth-textured flows that are extensively fissured and faulted. Isolated volcanic features sit stratigraphically on top of the smooth flows.

Side-scan sonar image of a volcanic ridge made up of small individual hummocks. This segmentation causes the ridge to look like a caterpillar. Illumination is from the top. The ridge is about 1 kilometer long and 20 meters high. Initially, surface flows erupt along the length of the fissure. Eruption conditions rapidly evolve, however, and individual hummocks form when lava begins to erupt from discrete vents.



subaerial volcanoes, they are likely to be common at mid-ocean ridges as well. Lava tubes probably feed the flows that regularly coat the flanks of the axial volcanic ridges, and are likely the sources of the lava that built the semicircular topographic highs extending east and west from the base of the axial volcanic ridge in the segment near 29°N. The fields of hummocks observed on the surface of the majority of Mid-Atlantic Ridge flows may be equivalent to the fields of "tumuli" that are common in Iceland and Hawaii. Tumuli form where fluid pressure within a lava tube or lava flow increases sufficiently to cause the basaltic rock that forms the surface to swell and crack. Tumuli are typically a few meters high but can reach heights of 10 meters, and they are elongate to near-circular in plan shape. Lava can squeeze out of the cracked surface, covering a tumulus and giving it the appearance of a small vent.

Determining the importance of tubes and channels in transporting lava away from the site of eruption, and determining whether or not the hummocky surface textures observed in the seafloor imagery are tumuli or not, awaits more detailed imaging and sampling such as that done on Serocki Volcano located near 22° N on the Mid-Atlantic Ridge. Geochemical evidence suggests that this flat-topped volcano is fed by lava that erupted initially at the summit of the axial volcanic ridge and flowed through a tube about a distance of a kilometer before the tube became blocked, broke, and allowed lava to pour out and form the volcano.

What do we know about the difference in eruptive style between fast- and slow-spreading mid-ocean ridge segments? Because fast-spreading ridges are characterized primarily by low-relief flows, we think that eruptions there are typically vigorous and last only a short time. Hummocky ridges are built at fast-spreading ridges, however, so that at times fissure eruptions must continue and become restricted to a few vents that build these

features. Seamounts are rare at the axis of fast-spreading ridges. By contrast, the domelike volcanoes, common hummocks, and generally complex volcanic topography of the Mid-Atlantic Ridge would arise from eruptions that start out vigorously to produce low-relief flows and evolve to form hummocky ridges and seamounts. As the eruption continues at a moderate rate, tubes develop that transport lava to the flanks of the axial volcanic ridges and coat their surfaces with a variety of volcanic features, some of which generate fields of tumuli.

Recent enhancements to the capabilities of near-bottom side-scan sonar systems are now making it possible to obtain co-registered, fine-scale bathymetry in conjunction with high-resolution, side-scan imagery. As more of these data are collected, we will be able to constrain the sizes and shapes of the small-scale volcanic features, and make more rigorous comparisons to subaerial features. Within the context of these data, it will be possible to design future geophysical and geochemical experiments on the same scale as those currently conducted at subaerial volcanoes. Studies such as these, in combination with existing data, will rapidly advance our understanding of the volcanic processes associated with the construction of oceanic crust at the Mid-Atlantic Ridge.

Debbie Smith travels to the far reaches of land and sea to investigate volcanic features. She recently received a grant from the National Science Foundation to "take" the public and school children to sea aboard R/V Thompson (University of Washington) via the Internet during an October 1998 cruise (www.punaridge.org). For a change of pace, she dons her soccer boots to join the noon pickup games on WHOI's McKee ballfield.

Joe Cann says he is old enough to remember before there were any plate tectonics, but still young enough to enjoy research on mid-ocean ridges. He visits Woods Hole out of season, when the rents on the Cape are lower, from his base in the UK at the University of Leeds.