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Davidson Seamount: A Volcano Slowly Built on an Abandoned Spreading Center

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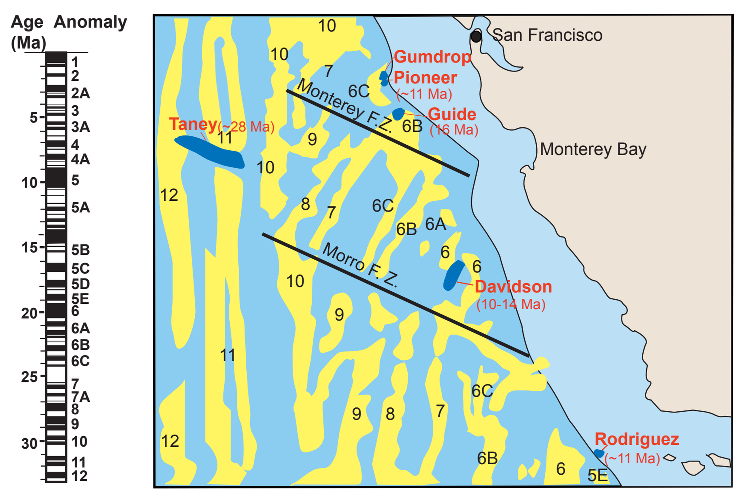
Introduction

Davidson Seamount is located 80 km off Big Sur, California, and rises from the 3500 m abyssal plain to 1254 m depth. The elongated volcanic edifice consists of a series of parallel ridges serrated with steep cones, built over at least 5 million years from 14.8 to 9.8 Ma above a spreading center abandoned at ~20 Ma. It has been explored and sampled with the ROV *Tiburon* and part of the summit has been mapped using the MBARI Mapping AUV. Lithologic distribution from video observations, glass chemistry, Ar-Ar ages of the lavas, and part of new high-resolution mapping data are presented here.

Davidson's steep, linear morphology, diverse chemistry and ages, and gassy, explosive eruptive character make it distinct from mid-ocean ridges or near-ridge volcanoes.

Geologic Setting

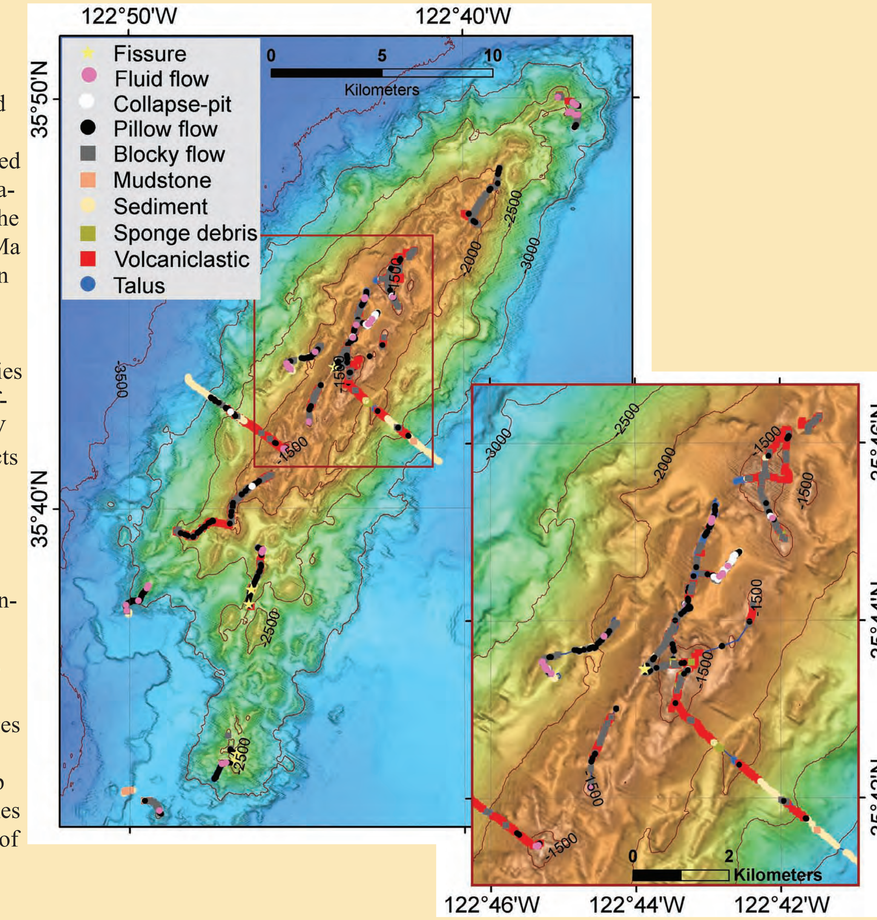


Map showing location of Davidson Seamount in the context of the magnetic anomaly pattern of the seafloor (Atwater and Severinghaus, 1989). Davidson and the other seamounts along the California continental margin are significantly younger than the crust beneath them. Davidson Seamount is flanked on both sides by magnetic anomaly 6, suggesting that it erupted at the site of an abandoned spreading center (Lonsdale, 1991).

Structure and geology

The structure of Davidson Seamount, based on hull-mounted 30 kHz multi-beam bathymetric data, is characterized by a series of parallel ridges and steep volcanic cones. These ridges are oriented NE-SW, parallel to the magnetic anomalies in the underlying ocean crust and the spreading center abandoned about 20 Ma (Davis et al., 2002). The data are shown gridded at 20m for the summit (inset map) and 40m for the entire seamount.

We have described the bottom lithologies with VARS (Video Annotation and Reference System) from videos of 18 ROV *Tiburon* dives to make geologic transects of the seamount. The inset map of the summit shows the density of observations and the variability of the bottom type. Visual interpretations were confirmed by rock samples collected at hundreds of sites.



The seamount is constructed of numerous lava flows as shown by the wide range of chemical compositions and ages (below) determined for the samples. Bulbous pillow lavas are common deep on the seamount, but the shallower cones and steep slopes are mainly composed of blocky, rubbly flows that provide substrate for large corals and sponges (Lundsten et al., 2006). On dive T1102, the entire spectrum of lava flow types was seen within one kilometer (photos at far right) on a single flow. The seamount is surrounded by thick pelagic sediments, eroded to the southwest by meanders of the Monterey Canyon. Pelagic sediment also fills depressions between the ridges and cones on the seamount.

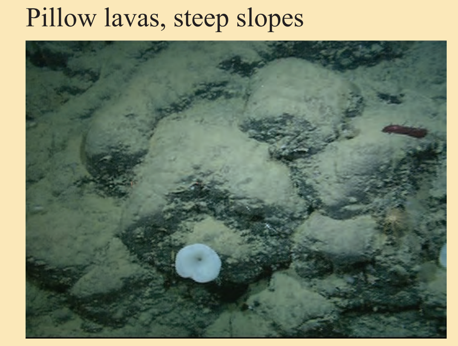
Volcaniclastic deposits are abundant on most cones, often as a thick, layered, eroded pavement draping underlying flows. The volcaniclastic rocks range from sandstone to breccia, contain glassy scoria and pumice fragments, and are evidence of explosive eruptions (Davis and Clague, 2003).

Fluid lavas

Fluid lava flow on ridge on flank of cone (T1102, 1366 m). Large *Paragorgia* grow out sideways from the ridge, catching plankton in the currents.

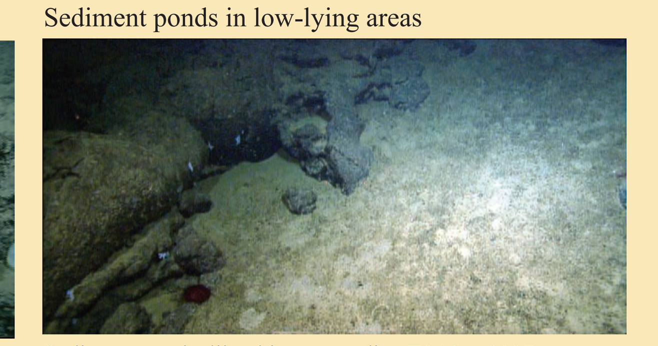
Drained pillow at 1728m on dive T430.

Pillow lavas, steep slopes



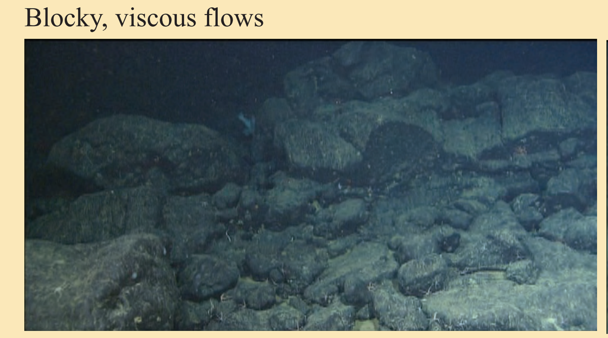
Steep slopes, sometimes as high as 400m, show truncated pillows and interiors of flows suggesting mass wasting or faulting events (T947, 2927 m).

Sediment ponds in low-lying areas

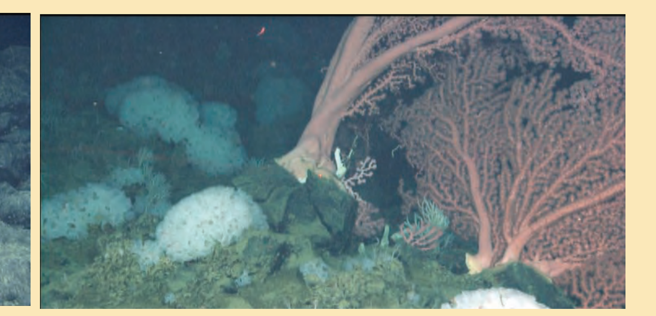


Sediment ponds, like this one on dive T946 at 2027 m, are found in saddles between cones. They often are surrounded by partially-buried pillow flows, suggesting that pillows often form the margins of flows, as they did at the lava flow observed on dive T1102 (to right).

Blocky, viscous flows

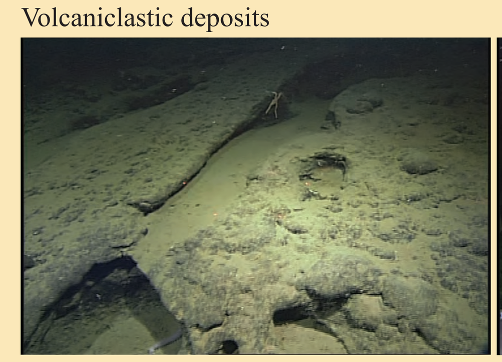


Blocky lava flow at the summit of a peak on the western side of the volcano (dive T946, 1728 m depth). Blocky or rubbly flows formed the bulk of the lava surfaces on the volcano, often draped with volcaniclastic deposits.

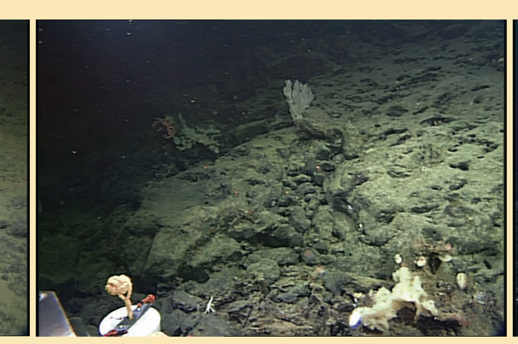


Trachyte was found at the summit of one cone on Davidson from 1316 to 1330 m. Here, an outcrop provides substrate for large *Paragorgia* and sponges. Trachyte, a viscous, highly fractionated lava, is unusual for spreading ridges but not uncommon in late stage eruptions at hot spot ocean islands.

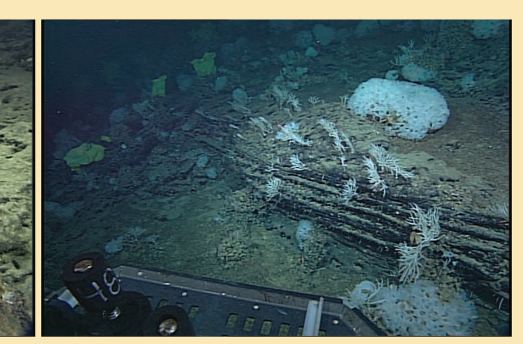
Volcaniclastic deposits



Volcaniclastic material drapes the flank of a cone on the western flank of the seamount at 2384 m depth. The pavement is eroded into small pits and grooves oriented downslope. A volcanic breccia, T426-R10, was collected here.



Volcaniclastic pavement eroded into small pits and large potholes filled with basalt and erratic cobbles (T428; 1413 m), reveal outcrops of the underlying flow.

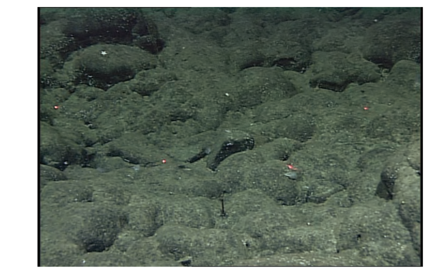


Bedded volcanic sandstone deposit at 1317 m on dive T147.

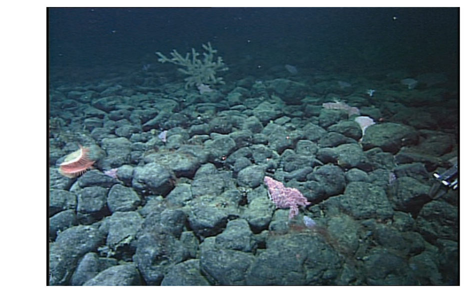
Why is mapping the seafloor so difficult?

Flow types on Davidson range widely over short distances, perhaps due to lava more viscous than at mid-ocean ridges.

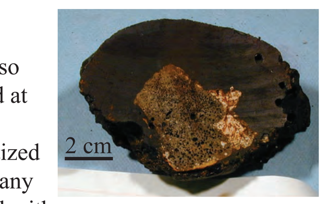
Age and the productive environment further complicated the mapping. The exact nature of the seafloor was often difficult to determine due to the lush animal growth, volcaniclastic drape, mass wasting, pelagic sediment deposition, manganese crust buildup, and the numerous erratics we collected, which provided no information about the lithology.



Thick manganese crusts precipitate slowly over time from seawater and cement and disguise the rocks of the seamount (T430, 2203 m). Is this a blocky flow, talus, or small pillows? A likely erratic in the center of the image would be the only rock that could be collected from this scene.

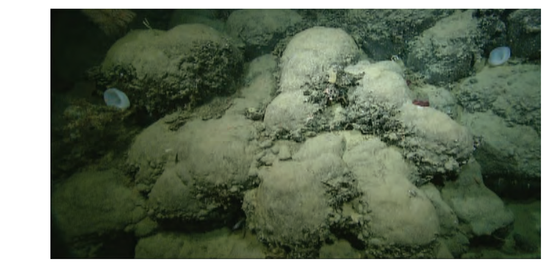


This appears to be talus, which is how we interpreted much of the loose broken rock that covers many of the steep slopes of the volcano. Yet this site was not below a cliff from which talus could have fallen, it was at the summit of a ridge at 1477 m. These blocky or `a`a-like flows can only be distinguished from talus by their setting.



T429-R12, shown in cross-section, from 1609m, is typical of so many rocks collected at Davidson: an altered basalt with palagonitized glass, clays filling many vesicles, and covered with a thick manganese crust.

Sponge reefs and debris cover large regions of the summits of cones and ridges, concealing the rocks underneath (T941, 1307 m).

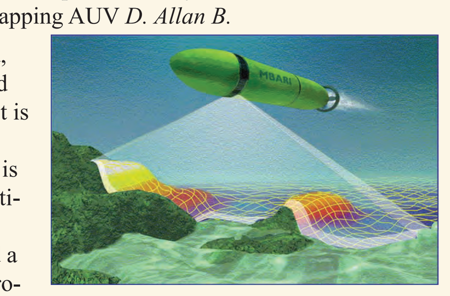


Heavily sedimented pillows on the extreme southwest edge of Davidson (T947, 2907 m). Rocks on the western side of the volcano were particularly heavily sedimented, obscuring the underlying lithologies.

Erratics are surprisingly common on the seamounts. These rocks, shown sawed open, were from one lag deposit at 1352 m; half are erratics. Erratics are rocks transported from the continent by kelp holdfasts, tree roots and sea lions (Paduan et al., 2007) and often easier to collect because they have thinner manganese crusts. On the ROV dives at Davidson Seamount, 28 erratic rocks and numerous pebbles in cores were collected along with the *in situ* basalt samples. Without a large suite of samples to identify which samples formed on the seamount, erratics might mistakenly be thought to belong there. (Scale in cm.)

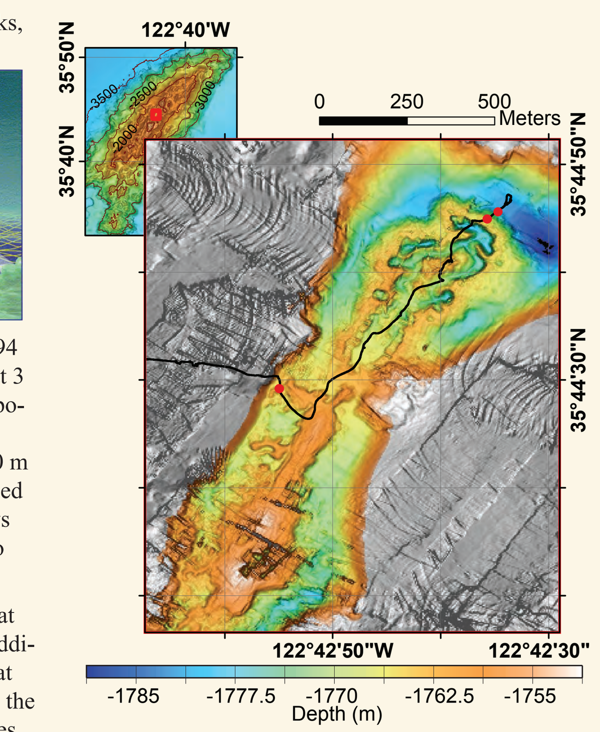
High-resolution mapping on Davidson

In order to extend our geologic interpretations beyond the ROV dive tracks, we ran 5 missions with the Mapping AUV *D. Allan B.*



The AUV is a torpedo-shaped, 6000 m rated vehicle designed and constructed by MBARI. It is 5.2m long and has an in-air weight of 662kg. The vehicle is equipped with a 200 kHz multi-beam sonar, 110 kHz and 410 kHz chirp sidescan sonar, and a 2-16 kHz chirp sub-bottom profiler. The multibeam provides a 120-degree swath with 0.94 degree by 0.94 degree beam resolution. The present endurance of the AUV is 8.5 hours at 3 knots. Navigation derives from an inertial navigation system (INS) incorporating a ring laser gyro aided by GPS at the surface and by velocity-over-ground observations from a Doppler velocity log (DVL) when within 130 m of the seafloor. A navigational precision of 0.05 percent of distance traveled is achieved with continuous DVL bottom lock. An acoustic modem allows surface aiding of navigation during deep descents, eliminating the need to deploy long baseline transponders.

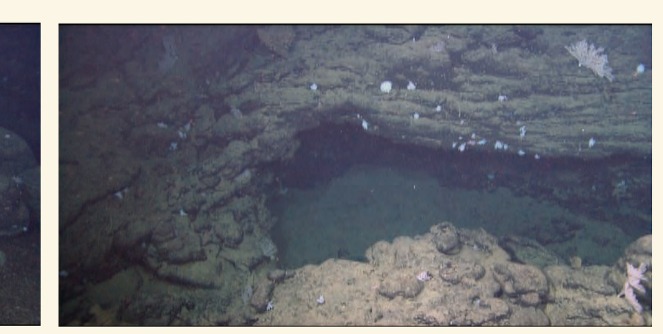
The missions proved very difficult as the ridges and cones are so steep that the AUV lost DVL bottom lock and navigational continuity at times. In addition, the steep slopes forced the vehicle into steep climbs and descents that create difficulties locating the pixels along track. Despite these problems, the surveys discovered an usual lava flow in a depression between steep ridges to the NW and SE.



Map of an inflated and drained lava flow on Davidson Seamount (its location is outlined in red on the small map of the seamount). Nothing like it has been found elsewhere on Davidson or the other seamounts off the California continental margin. The bathymetric data is gridded here at 3 meter resolution. The flow is all but invisible in hull-mounted multibeam sonar bathymetry. The color ramp of the map was chosen to highlight the relief of the flow; the gray areas are shallower ridges on either side. Despite the noise in the data, a variety of volcanic features are evident. We then explored this flow using the ROV *Tiburon* during dive T1102 (track is black line, and the locations of the images below are red dots in sequence from NE to SW).

The flow lies between high ridges near the summit of the seamount. The SW half of the flow is inflated and marked by a shallow fissure parallel to the old spreading ridge. The NE half of the flow drained and the crust collapsed up to 13 m, leaving veneers on interior walls and broken crusts on floors of the collapses. The flow is bounded by a pillowed margin and surrounded and draped by accumulated pelagic and volcanic sediment. The flow is 24m thick at its SW end, and 16-19m thick at its NE end, is 1.3 to 1.4 km long, and ranges from 80m to 300m wide. The lava is a mugearite, one of the more fractionated lavas on Davidson. The origin of the collapse is uncertain, as lava did not drain out from the collapsed pond. Either the lava drained back down the underlying eruptive fissure or loss of exsolved gas bubbles from the gas-rich mugearite led to the collapse.

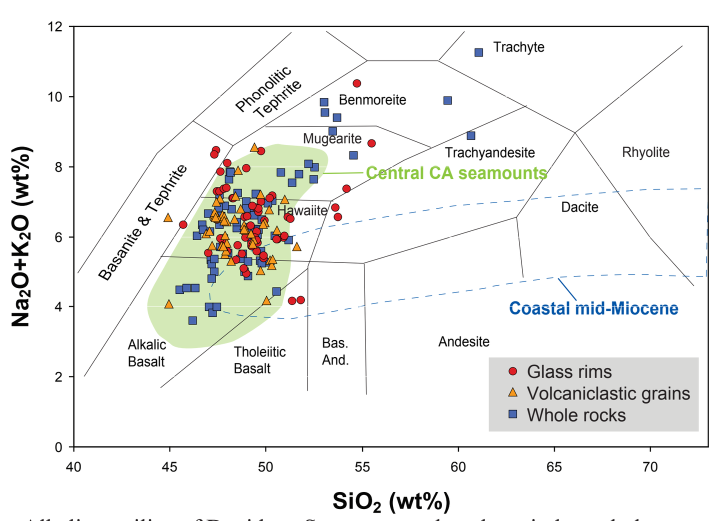
Elongate pillows (1780m depth) cascade down flanks of the inflated, drained lava flow Locations of this and the photos to the right are the red dots on the map above.



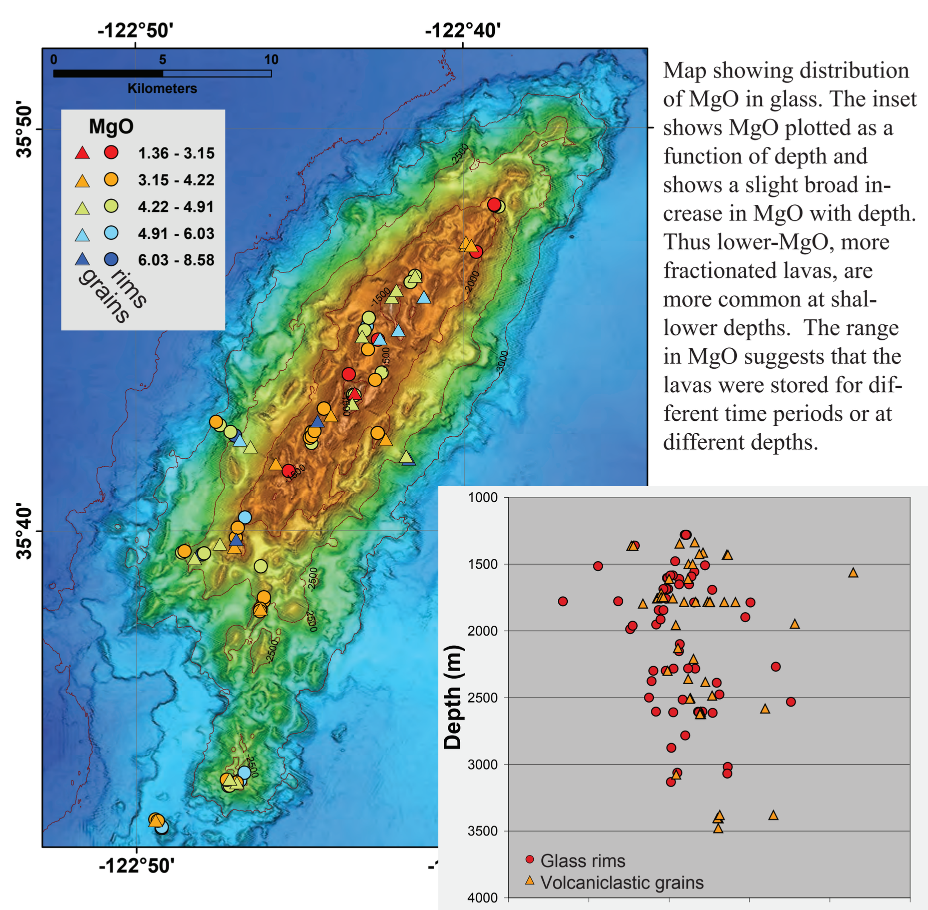
Collapse pit in surface of lava flow explored on T1102 (1778m). Drainback veneer is visible as bathtub rings on the walls of the pit.

Further along on dive T1102, blocky and fluid textures coexist on the same lava flow. The surfaces of this flow changed radically, as seen during many of the video transects elsewhere on the seamount.

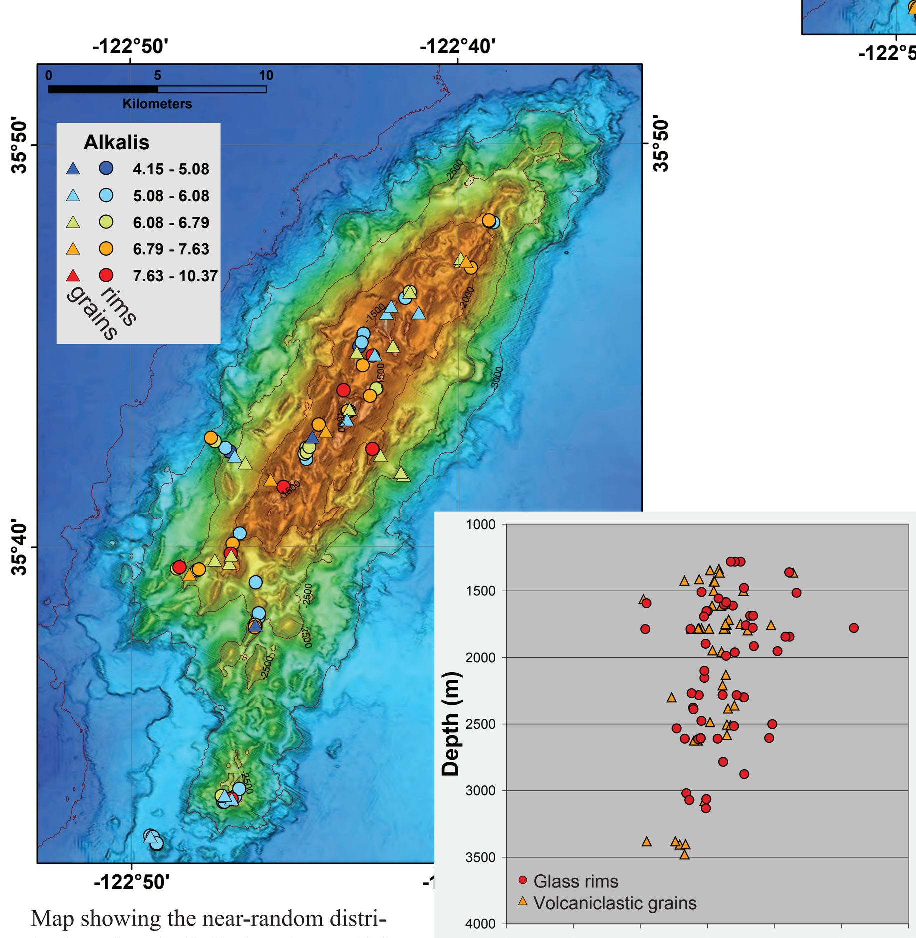
Glass chemistry



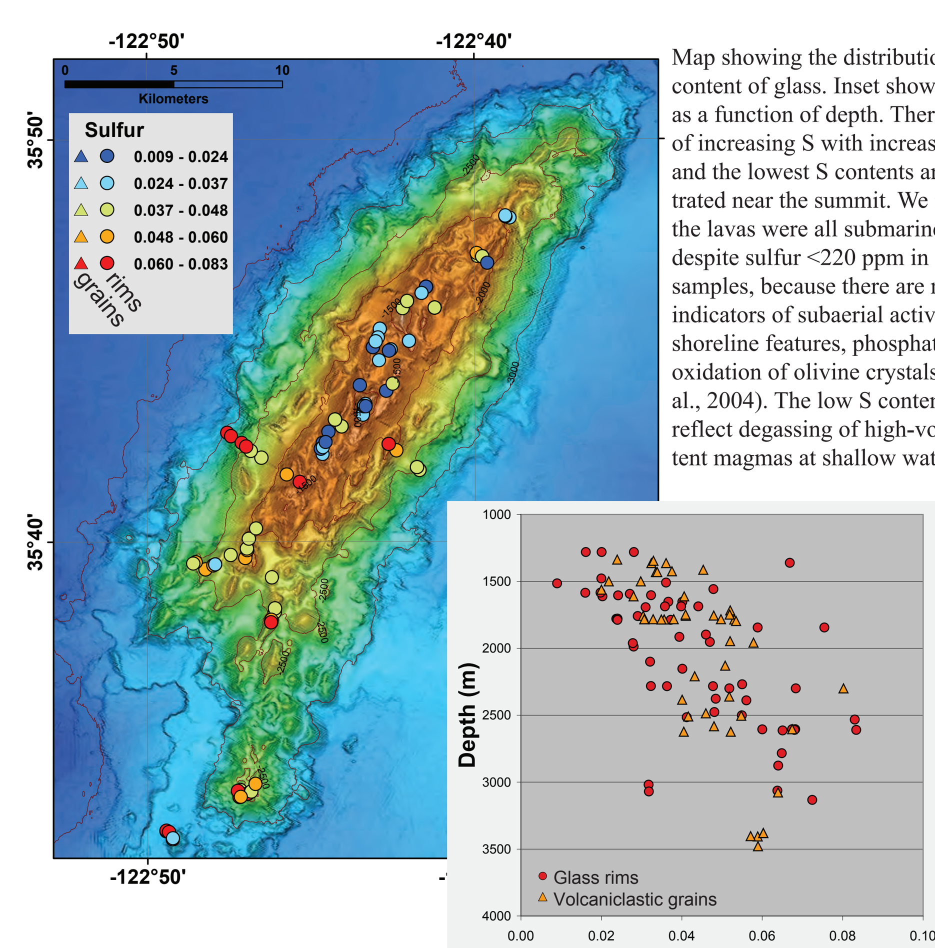
Alkalis vs silica of Davidson Seamount rocks, glass rims, and glass fragments, portrayed over compositional fields. Glass rims and volcaniclastic grains were analyzed by electron microprobe and whole rocks by XRF. Fields of published data are indicated for dredged samples from other seamounts off central CA and for on-land coastal CA mid-Miocene volcanics (from Davis et al., 2002). Most samples are hawaiite, but lavas also include tholeiitic basalt, alkalic basalt, basanite, mugearite, benmoreite, and trachyte. Many of these lavas contain mantle and crustal xenoliths (Davis et al., 2007).



Map showing distribution of MgO in glass. The inset shows MgO plotted as a function of depth and shows a slight broad increase in MgO with depth. Thus lower-MgO, more fractionated lavas, are more common at shallower depths. The range in MgO suggests that the lavas were stored for different time periods or at different depths.



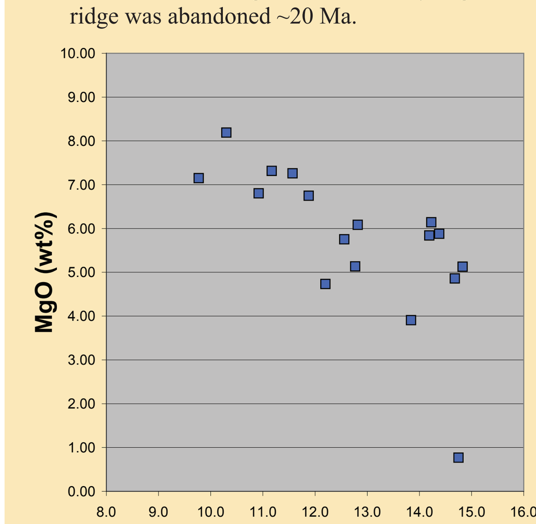
Map showing the near-random distribution of total alkalis ($Na_2O + K_2O$) in glass. Inset to right shows total alkalis in glass as a function of depth. There is a broad general trend to more alkali-rich lavas at shallower depths. The more fractionated lavas are more viscous, consistent with the blocky, pasty flows and explosive deposits observed near the summit.

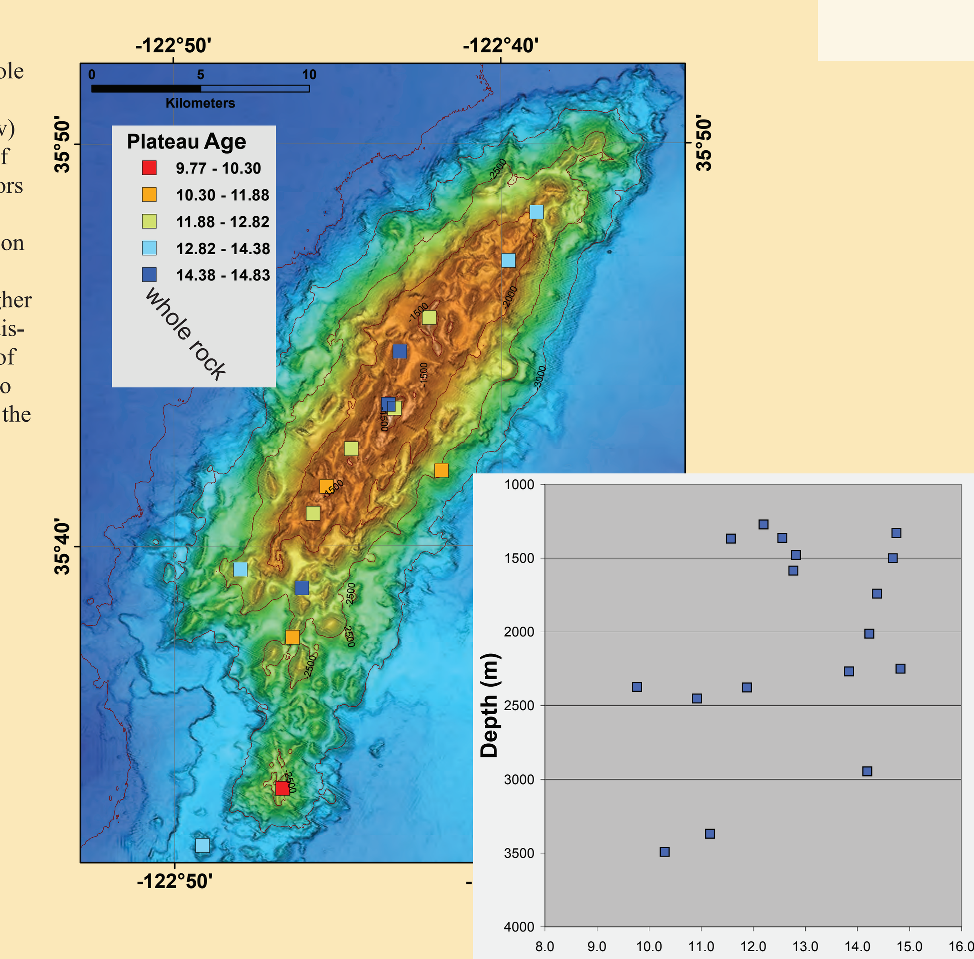


Map showing the distribution of sulfur content of glass. Inset shows S content as a function of depth. There is a trend of increasing S with increasing depth and the lowest S contents are concentrated near the summit. We infer that the lavas were all submarine erupted, despite sulfur <220 ppm in some samples, because there are no other indicators of subaerial activity such as shoreline features, phosphatization, or oxidation of olivine crystals (Paduan et al., 2004). The low S contents probably reflect degassing of high-volatile content magmas at shallow water depths.

$^{40}Ar/^{39}Ar$ age data

Map showing distribution of incremental heating Ar-Ar ages determined on plagioclase and amphibole separates from seventeen lavas. The inset (lower right) shows age as a function of depth. Plot (below) shows MgO content of whole rocks as a function of age. The ages range from 9.8 to 14.8 Ma, with errors of +/- 0.13 to 0.27 Ma. The oldest rocks are high along the central ridge, and the youngest rocks are on the deeper flanks and southern end of the edifice. There is a trend that the less fractionated lavas (higher MgO) are younger. The numerous small cones of disparate chemistry and age suggest episodic growth of the volcano for at least 5 million years, from 14.8 to 9.8 Ma. Seamount growth most likely began when the ridge was abandoned ~20 Ma.





Conclusions

- Davidson Seamount is located on an abandoned spreading center.
- Davidson experienced prolonged and sporadic activity from 14.8 to 9.8 Ma, and probably since the spreading center was abandoned at 20 Ma.
- Lava chemistry is highly varied, and includes tholeiitic basalt, alkalic basalt, basanite, hawaiite, mugearite, benmoreite, and trachyte.
- Compositions of the volcaniclastic (explosive) deposits and lava flows are similar.
- Lava chemistry becomes less fractionated and younger at the periphery of the seamount. This implies deepening of the magma source as the lithosphere thickened, and migration outward of the magma's path of ascent as the seamount built.
- Visual mapping of surface lithologies shows high variability on small scales.
- Pillow lavas are not the dominant flow type, but are more common at greater depths.
- Blocky or `a`a-like flows dominate, especially at shallower depths.
- Most cones have both lava flows and volcaniclastic deposits.
- No pit craters or calderas are present. This implies no crustal magma chambers, which agrees with the infrequent, small-volume eruptions indicated by the Ar-Ar ages.
- Difficulties with the visual and the high-resolution multibeam mapping processes are exacerbated by the age and steep topography of the seamount.

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