EMPLACEMENT OF VOLCANIC DEPOSITS ON MID-OCEAN RIDGES: VENUS COMPARISONS;

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Introduction

Using recently available high resolution sidescan sonar data of the Mid-Atlantic Ridge we are investigating the morphology of the central axial ridge from 29° - 29°10'N in order to characterise the features observed and to better understand the mode of magma emplacement at the surface in an environment with surface pressures comparable to those on Venus [1]. As has previously been noted [2][3], some of these axial ridge features bear a strong resemblance to volcanic dome-like features observed on Venus. We believe that investigation of the relationship between mid-ocean ridge features and subsurface magma transport and storage systems will allow us a better understanding of extrusive volcanic features on both planets.

Observations and Characteristics

Figure 1 is a map of a ~3.5 km segment of the Mid-Atlantic Ridge (MAR) which shows a well-defined axial ridge. The most abundant features observable are small, spherical features which have a 'hummocky' texture. The smallest of these are seen at the limit of the sonar resolution (25 m) and they range up to hundreds of metres, although their characteristics change as they get larger. Although these features are seen as isolated mounds off to the side of the ridge, they are found to coalesce and form the first of two main seamount types observed along the mid-axial ridge, hummocky seamounts and flat-topped seamounts. Hummocky seamounts are conical in shape and appear to be a 'heap' of the hummocky flows [4]. The hummocky seamount in figure 1 is around 500 m in the along-strike direction. Hummocky features formed along the crest of the ridge may coalesce to form linear features. Some of these are comprised of hummocks which are barely touching and have only just merged at their adjacent surfaces; others are merged such that a single linear ridge is present, which may have a flattened top (Fig. 1). Other circular features are also observed; these tend to be smooth and flat or slightly domed and tend to be found adjacent to each other on the ridge forming beaded structures (Fig. 1). At their largest, these features form the flat-topped seamounts found on the axial ridge. The example in figure 1 is ~220 m high with a basal diameter of ~1500 m and summit diameter of ~600 m [4]. These seamounts tend to have smooth, flat tops, steep sides and may or may not have a summit crater. Features are observed which are attributable to both flood lavas and to debris flows from the nearby valley walls. Throughout, the ridge is cut by many faults and fissures of varying lengths and throws, resulting in many horst and graben features.

It is widely accepted that oceanic spreading centres are comprised of layered extruded volcanics underlain by a sheeted dyke complex [5]. However, the actual mode of magma transport through the dyke system and onto the surface is still not well understood. Bruce and Huppert [6] showed that magma flow through an elongate dyke-like structure would, depending on properties of the magma and the surrounding medium, result in parts of the dyke below a critical width closing up, while sections of the dyke wider than this value would remain open. This would result in a series of discrete eruption centres forming from an initial linear fissure eruption overlying a dyke.

Evidence for these features being emplaced through dykes also includes their linear array, surface graben, their parallelism to the spreading direction and the presence of dykes in ophiolites. Careful measurements have been made of smaller hummocky features in one section of the study area and it has been found that there is a small but distinct bias of elongation along the strike of the axial ridge. Across-strike measurements of features are an average of 93% of along-strike measurements. This is not believed to be an artifact of data collection but is believed to support the idea that these features are emplaced through elongate dykes. We are interested in the typical widths of dykes that might be feeding the eruptive vents described above. Preliminary data on dyke widths within the Troodos ophiolite [7], thought to be an analogue of a spreading centre, show width/frequency distributions and we use these as a guide to model the surface structures on the axial ridge.

Models of Emplacement

Head et al [8] have shown that the morphological features observed along the Mid-Atlantic axial ridge are consistent with the emplacement of dykes having widths similar to those observed in ophiolites. For a magma filled crack showing these widths and approaching the surface, theory predicts that very low effusion rates will characterise the narrowest (<0.5 m) parts of the dyke, resulting in relatively short (~50 m) thin (<0.3 m) flows. These narrow parts of the dyke will cool first producing perhaps small hummocky edifices less than 100 m in diameter and only a few metres high. Intermediate dyke widths (~0.5 - 0.7 m) will produce low effusion rate flows of up to ~250 m long and <0.4 m thick, producing edifices of varying height and depending on duration and accumulation of flow units, up to ~500 m wide. Longer dyke segments are favoured by intermediate dyke widths and will lead to adjacent eruptions with similar characteristics producing elongate linear ridges and overlapping edifices. These ridges are up to 50 m high. Where the dyke is at its widest (~0.7 - 1.0 m), higher volume fluxes and flows result, leading to long flows (250 - 1000 m) up to 0.6 m thick.

Cooling behaviour, magma supply and overall dyke geometry lead to the eruptions becoming centralised to locations characterised by wider dykes. Continued eruption from these centralised locations should build edifices with heights and shapes dependent on accumulated flows, up to ~3 km in diameter. Flat-topped seamounts are likely to be dominated by relatively long flows while hummocky seamounts by shorter flows. The formation of many of the features observed on the Mid-Atlantic ridge can be explained using this model. For even the largest seamounts, only a wide portion of the dyke is required, rather than a shallow subsurface magma chamber.

We conclude that the range of morphologic features observed along the axis of the Mid-Atlantic Ridge is consistent with the emplacement of dykes with widths similar to those observed in ophiolite complexes. The consequent range of eruption conditions along a single dyke and the behaviour of the dyke as the eruption evolves predict features which are similar in morphology and dimensions to observed hummocky mounds, hummocky ridges, bulbous and flat topped seamounts, and smooth flows (Fig. 1). On the basis of the size of the axial volcanic ridge and the observed often parallel hummocky ridges, each axial volcanic ridge (AVR) is almost certainly the product of multiple dyke intrusion and eruption events. With spreading rates typical of the MAR, about one dyke emplacement event would be expected every 100 years. Thus, given the cooling time for dykes in the submarine environment, MAR dykes should solidify between average dyke emplacement events, with new events typically producing a separate dyke and extrusive ridge on the larger axial volcanic ridge.

Typically, the morphology of rise crests differs between the MAR and the faster spreading East Pacific Rise, which is characterised by an abundance of smooth sheet flows, many fewer hummocky ridges and only very rarely, small central seamounts. This may be relatively easily explained by the faster spreading rates, anticipated wider, more continuous shallow reservoirs, wider dykes, and consequent higher effusion rate eruptions that would be typical of the EPR. In addition, the faster spreading rate of the EPR means that subsequent overpressurization events leading to dyke emplacement are more common and thus are more likely to reoccupy the sites of incompletely solidified dykes, rather than producing a new dyke and new eruptive ridge each time. Together, these characteristics favour the development of accumulations of extensive smooth sheet flows, rather than the development of a distinctive series of hummocky ridges and seamounts as appears to be typical of the Mid-Atlantic Ridge.

Completion of the mapping of these segments of the Mid-Atlantic ridge will permit us to determine correlations between the geometries of the observed features with those of the predicted dykes feeding the axial ridge. In particular we are looking for relationships between larger and smaller features in linear formation, which should allow us to determine narrower and wider segments of the underlying dyke system.

Venusian Analogues

A wide range of volcanic features has been observed on Venus [9][10][11][12] primarily in the extensive volcanic plains. Although the general tectonic environment is thought to differ because of the lack of plate tectonics at present on Venus, nonetheless, abundant evidence exists for the presence of dykes on Venus and their importance in transport of magma to the surface. We have identified a series of features with broadly similar characteristics in the venusian plains; these include small shields, bulbous ridges, flat-topped shields, small shields with hummocky rims, small shields with elongate summit pits, and elongated shields with radiating flows. Mapping is presently underway to formulate morphologic and morphometric comparisons between these and the terrestrial submarine analogues.

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Figure 1: Axial Ridge Features at 29°N