Havre Trough and the "Rifting Phase" of Back-arc Basin Evolution

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The Havre Trough is ready for multi-disciplinary study of globally important processes including deformation of wet mantle and crust, magma genesis at the critical spatial and temporal boundary between flux- and decompression-melting, and accompanying submarine metallogenesis. Coordinated international marine geological, geophysical, and igneous geochemical studies within GeoPRISMS can result in breakthrough understanding of the "rifting phase" of the evolution of back-arc basins and the links to proto-continental crust growth and their ore deposits.

The formation of back-arc basins by the extensional breakup of volcanic arcs is an integral part of the subduction cycle. Recent studies of the Havre Trough back-arc basin have developed hypotheses of tectonomagmatic processes occurring in early stage backarcs with global implications (Figure 1). For example, estimates of back-arc melt productivity exceed that of the volcanic front by at least an order of magnitude (e.g., Wysoczanski et al., 2010; Todd et al., 2011), so magmas associated with back-arc volcanism are arguably the most volumetrically significant geochemical products of subduction zones, which is a key question of the GeoPRISMS SCD Initiative. Up to half of the volume of southern Havre Trough back-arc crust is newly accreted material following rifting of the proto-Havre volcanic arc (Wysoczanski et al., 2010) (Figure 1a). Fresh basaltic volcanism occurs on the seafloor across most of the width of the backarc, based on sampling by dredge and submersible, and inference from towed camera and acoustic backscatter. Ar-Ar ages of large interspersed seamount volcanoes are <1 Ma. Most back-arc volcanism is diffuse, contrasting with more axially focused volcanism at spreading ridges in more mature backarcs like the central and eastern Lau Basin to the north.

Havre Trough back-arc seafloor morphology is also distinct from mature spreading centers. Seafloor bathymetry at Havre is complex, with short-segment pillow basalt-floored rift grabens between chains of large-volume constructional volcanic edifices extending as much as 80 km behind the volcanic front (i.e., "hot fingers") (Figure 1b). The occurrence of each seems to be independent of the distance to the trench: some of the deepest Havre Trough rift grabens (~4000 mbsl) abut the volcanic front, whereas one of the best-preserved symmetrical stratovolcanoes (Gill Volcano) is in the westernmost backarc (Wysoczanski et al., 2010). The contrasting morphology indicates that most of the basin width is from disorganized spreading (i.e., “rifting”) that may result from extending wet asthenosphere, and the interplay of both flux and decompression melting in the evolving back-arc mantle (Figure 1a). For example, young volcanoes with arc-like chemistry (“arc regime”) are found far into the backarc, both as freestanding stratovolcanoes and as arc-perpendicular constructional volcanic chains (Wysoczanski et al., 2010; Todd et al., 2010). In contrast, volcanism in intervening rift basins (“rift regime”) is more MORB-like, similar to other BABB (Todd et al., 2011). Therefore, both decompression- and flux-melting can dominate at the same distance behind the volcanic front but in different tectonic settings at different distances along the arc (Figure 1b). Havre Trough is therefore an excellent site in which to study the three-dimensional aspects of back-arc deformation and magmatism.

For both arc and rift regimes, the widely distributed magmatic zone has two important consequences for interpretations of melting and material cycling at subduction zones. First, it samples a wide pressure range of slab-derived fluxes, and contains a larger mass-fraction of those fluxes than in the arc (e.g., Todd et al., 2011) (Figure 1b). Second, magmas across the back-arc are not aggregated, mingled and mixed in axial magma chambers, unlike during the spreading stage of more mature back-arc stages, so variations in both slab and mantle components are preserved. Therefore, the rifting stage of back-arc evolution is well-suited to monitoring the role of variable slab surface temperatures to depths of 6 GPa, and to evaluating its role in the evolution of the continental crust and upper mantle. In these respects, Havre is an analogue setting to the IODP Izu-Bonin-Mariana Rear Arc Expedition in March-May 2014.
Diffuse volcanism, diverse magma types, and complex morphology during the rifting phase of back-arc basin development may characterize many back-arc basins (e.g., western Lau Basin, northern Mariana Trough, both sides of the North Fiji Basin), as distinct from juvenile volcanic arcs and mature back-arc spreading ridges. Havre is the one place to study the processes within GeoPRISMS.

In summary, we propose that future multi-disciplinary and international investigations of the Havre Trough backarc are well suited to address two outstanding problems in the GeoPRISMS Draft Implementation Plan for the New Zealand Primary Site: *How do rifting and spreading, and the spatial and temporal variation of magmatism, relate to the nature of slab-derived fluid-to-melt and the rheology of the mantle wedge?* and *What are the magma transport pathways through the crust, and respective contributions of subducted sediments and crustal assimilation along- and across-strike of the arc?*

Finally, studies of submarine exposures within short-segment basins within Havre Trough may also address another Key Question of the GeoPRISMS SCD Initiative: *What are the physical and chemical conditions that control subduction zone initiation and the development of mature arc systems?* Trenchward scarps of the deep (~4000 mbsl) grabens closest to the volcanic frontal ridge (e.g., Figure 1a) may expose the oldest part of the arc and thus contain evidence about the age and nature of early arc volcanic rocks to compare with Fiji-Tonga and IBM (e.g., Reagan et al., 2010; Todd et al., 2012).

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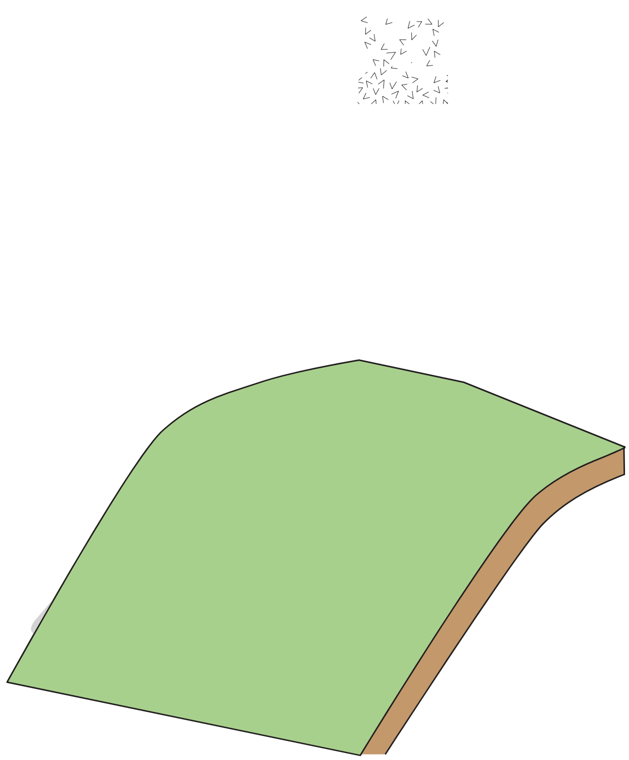

Figure 1a. Conceptual cross-sectional model of a backarc during the transitional rifting stage, showing intersection of flux- (blue lines indicate slab flux; yellow diapirs indicate flux melts) and decompression-melting (dashed triangle indicates decompression solidus) regimes and characterized by a broad zone of melt production. The relative contribution of slab flux with distance to the trench is indicated by the width of the blue lines. Patterned brown fill indicates remnant arc crust prior to back-arc extension, unpatterned brown fill represents rifted arc crust, and red fill indicates newly accreted oceanic crust, both within rift basins and as constructional volcanoes fed by intrusive dikes. Figure 1b. shows the model proposed by Todd et al. (2011) to explain along-arc changes in back-arc morphology and magma composition ("arc regime" vs. "rift regime"). Brown wavy lines represent slab isotherms (T1 and T2). Where the slab is hotter close the trench, slab flux is greater (shown here by more squiggly arrows), has a higher ratio of slab melt (orange) to aqueous fluid (blue), and yields greater melt productivity contributing to more constructional seafloor volcanism (i.e., "arc regime").