Fissure control on volcanic action in the Pacific

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ABSTRACT

Many modern linear volcanic chains on the Pacific plate can be backtracked to the general region of large Mesozoic seamount provinces in the far western Pacific, but those provinces differ in many ways from their younger counterparts in volcano arrangement, spacing, linearity, and age progression. Over the past 165 m.y., regions of volcanism have become narrower, more linear, and more consistently age-progressive. Rather than viewing this trend as a consequence of changes in the number, location, duration, and intensity of mantle plumes, we propose instead that five sets of stresses in the upper mantle combine to produce the patterns of great fissures and systems of fissures through the lithosphere along which seamount provinces and linear chains form. These are (1) lateral lithospheric contraction; (2) subduction-driven flow of the asthenosphere, which presently is antiparallel to Pacific plate motion, but which can be uneven in velocity and somewhat divergent in direction; (3) stresses in the plate produced by changes in patterns, relative orientations, and rates of subduction; (4) accumulation of low-density material and melt at places of lateral heterogeneity of density, viscosity, and composition in the asthenosphere; and (5) volcanic loading and redistribution of mass during differentiation at volcanic centers. Of these, the present direction of propagation of linear volcanic chains is most strongly controlled by contractive stresses and the pattern of subduction-driven asthenospheric counterflow, with volcanic spacing and volume arising from different combinations of the other stresses.

Eruption of midplate seamounts results from buoyancy contrasts in the uppermost asthenosphere stemming from mantle heterogeneity, slightly variable temperature gradients, and the ponding of melt. Melt generally present in the low-velocity zone flows into shear gashes and then pools in traps beneath permeability barriers at the base of the lithosphere, with higher melt concentrations occurring above regions of greater mantle fertility and/or higher temperature. The lithospheric stress regime coupled with magma overpressure then induces lithospheric fracturing and eruption. Eruption, even above fertile mantle, may be stifled when the combination of lithospheric stresses is compressive, and fairly voluminous, even above refractory asthenosphere, when lithospheric stresses are extensional. Extremely voluminous volcanism occurs when a strongly extensional regime and/or a lithospheric thin spot coincides with asthenosphere having both high mantle fertility and higher temperature (e.g., oceanic plateaus at triple junctions).

The relative importance of the five sets of stresses has varied in the past. Assuming that linear island chains propagate mainly in the local direction of least principal stress in the underlying lithosphere, the changes in fissure patterns through time are probably related to the increasing proportion and distribution of subduction boundaries on the northern and western margins of the plate as it grew in size to become the largest on Earth. This initiated counterflow in the asthenosphere and caused changes in the orientations of spreading ridges, the number and pattern of transform faults, the existence and distribution of microplates, and the magnitudes and orientations of the stress fields. Stress concentrations in the plate were far from uniform. Stress differences led to varieties of fracture patterns, which prompted the release of magma along volcanic ridges of varied morphology, size, and distribution of volcanic centers. The orientation and magnitude of counterflow in the asthenosphere and stress contrasts across the plate increased with the growth of subduction boundaries. Fissure patterns accordingly became more consistently oriented. Important events at the boundaries of the plate, such as the Australian-Asian collision and the demise of the Kula ridge in the northern Pacific changed the direction of asthenospheric counterflow, midplate stress orientations, and the patterns of stress concentration, and these conditions—rather than shifts in plate motions over fixed hotspots—resulted in changes in directions of volcanic chains.