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Percolative flow of melt through suprasolidus crust, melt extraction, and magma ascent and emplacement in large hot orogens

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Melting of lower continental crust (LCC) is an integral part of orogeny, and active orogenic plateaux are underlain by a layer of low seismic velocity and high electrical conductivity, interpreted as due to melt. In Tibet, LCC flows from beneath the thick, elevated plateau between areas where crust is strong; weakening is inferred to be due to partial melting, based on multiple geophysical datasets. In exposed LCC, a variety of microstructures is preserved that indicate the former presence of melt, from those specific to the reactant phases (rounded grains and cuspate pores between corroded grains) to those involving the products of melting reactions (rational faces on peritectic crystals, thin quartz/feldspar films along grain boundaries, overgrowths on residual phases, and pore-filling shapes for late-crystallized melt). Melt extraction pathways are recorded by leucosome traces in residual rocks. Strain and anisotropy of permeability control the form of melt channels, and strong anisotropy promotes high fluid focusing. Melt extraction comprises three stages. In hydrate-breakdown melting, the early stage of melt accumulation is diffusion-controlled and melt accumulates around peritectic phases in the fabric or in low-pressure sites. A melt-bearing rock is defined as porous when melt volume reaches the melt wetting transition, which is also where a large decrease in strength occurs, initiating a porous flow regime, in which melt flow in channels to lower pressure sites is controlled by the anisotropy of permeability. As melt flow becomes progressively more focused in the source, these channels form networks, analogous to ductile deformation band networks; they allow accumulation of melt and form the link for melt flow from grain boundary accumulations to ascent conduits. In the transfer stage, melt moves through discordant fractures, which enable it to move shallower in the crust. Dike growth is governed primarily by the ratio of

elastic to viscous response of the host rock, so that as viscosity contrast is reduced with increasing T and melt volume, the viscous response dominates, although the resulting intrusions are dike-like. In many examples, dike emplacement occurred along a preferred direction independent of anisotropy, which suggests the orientation is controlled by stress, and together with the macroscopic fracture-like discontinuity filled by granite, characterizes the process of dike formation as a fracture phenomenon. For dikes $>$ 10cm wide, the thickness commonly shows a power law distribution, which suggests the dikes may be scale invariant. Features of fracturing in ductile crust include blunt tips, zig-zag geometry close to the fracture tips and petrographic continuity between leucosome in the host and granite in the dike. Following an approach in which soil mechanics is applied to deformation of porous (melt-bearing) rock, the type of localization and ductile fracture depend upon porosity, grain packing, melt pressure, effective mean stress, differential stress, and stress path (loading vs. unloading – compactive plastic flow vs. dilatant plastic flow). In suprasolidus LCC, fracture propagation takes place by development and coalescence of melt-filled pores ahead of the fracture tip, with fracture opening involving extensive inelastic deformation and diffusive mass transfer. Here, differential stresses are low, effective mean stress is low, the cohesive strength is low (relative to the strength of the grains) at melt fractions greater than $\sim$7-8 vol.%, and during rapid exhumation the loading rate is fast, which are the conditions necessary for ductile failure. Melt extraction requires a high melt focusing factor (L/H) – favored by high intrinsic anisotropy of permeability in the lower crustal source and a short ascent path, such as is commonly found during exhumation by doming. Granites commonly occur associated with major transtensional fault systems or in extensional detachments close to the base of the upper crust, which was likely close to the brittle – ductile transition during emplacement; this strength peak is a natural magma trap.