Two-dimensional numerical modeling of ultramafic intrusion emplacement

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Intrusions of ultramafic bodies into the lower density crust are documented for a large variety of tectonic settings spanning continental shields, rift systems collision orogens and magmatic arcs. The intriguing point is that these intrusive bodies have a density higher by 300-500 kg/m^3 than host rocks. This paradox requires understanding of emplacement mechanism. We employed finite differences and marker-in-cell techniques to carry out a 2-D modeling study of intrusion of partly crystallized ultramafic magma from sub-lithospheric depth to the crust through a pre-existing magmatic channel. Systematically varying model parameters allows documenting variations in intrusion dynamics and geometry that range from funnel- and finger-shaped bodies (pipes, dikes) to deep seated balloon-shaped intrusions and flattened shallow magmatic sills. Emplacement of ultramafic bodies in the crust lasts for several kyr to several hundreds kyr depending mainly on the viscosity of the intruding magma. The positive buoyancy of the magma compared to the overriding colder mantle lithosphere drives intrusion while the crustal rheology controls the final location and the shape of the ultramafic body. Relatively cold elasto-plastic crust (T_{Moho}=400^{o}C) promotes strong upward propagation of magma due to the significant decrease of plastic strength of the crust with decreasing confining pressure. Emplacement is in this case controlled by crustal faulting and subsequent block displacements. Warmer crust (T_{Moho}=600^{o}C) triggers lateral spreading of magma above the Moho with emplacement being accommodated by coeval viscous deformation of the lower crust and fault tectonics in the upper crust. Strong effects of magma emplacement on the surface topography are also documented. Emplacement of high density, ultramafic magma into low-density rocks is a stable mechanism for a wide range of model parameters matching geological settings in which partially molten mafic-ultramafic rocks can be formed below the lithosphere. We expect this process to be particularly active below subduction-related magmatic arcs where huge volumes of partially molten rocks produced from hydrous cold plume activity accumulate below the overriding lithosphere.