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Crust rheology controls morphology of ultramafic intrusions: numerical investigation

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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 question we address is how magma can ascend and settle in host crustal rocks whose density is 300-500 kg/m^3 lower than that of intrusive rocks. To answer this paradox, we employed finite differences and marker-in-cell techniques in two-dimension to model intrusion of partly crystallized ultramafic magma from sub-lithospheric depth up to the upper crust through a magmatic channel in the lithospheric mantle. Systematically varying model parameters such as magma driving pressure and the physical properties of both intruding and intruded materials allows documenting variations in intrusion dynamics and geometry. 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. Two-dimensional geometries are classified into five major types: funnel-, finger-, sickle-, nappe- and balloon-shaped. Relatively cold elasto-plastic crust (T_{Moho} = 400˚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. The most common intrusion shapes are funnel-shaped; nappe (sill) – shaped bodies are characteristic for low viscosity magma. A warm crust (T_{Moho} = 600˚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. Balloon-shaped intrusions typify a ductile lower crust with low viscosity. Our results indicate that 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. Viscous and plastic strain of both the lithosphere and the crust takes an active role and makes an important contribution in injecting high-density magma into lower density rocks. These new conclusions indicate that the shape and depth of mafic–ultramafic intrusions bear important significance in terms of lithospheric rheology and magma viscosity.