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Compatible Flow and Transport Discretisations for Two-Phase Flow in Subduction Zones

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Subduction zones (SZs) are the crossroads of plate tectonics, where volatile-rich sediments, basalts, and lithosphere exchange mass and energy with the shallow and deep mantle. Solids descend while liquids ascend; temperatures vary by 800K; melting occurs by hydrous flux and decompression; liquids range from hydrous to silicic; energy is transported in every direction. This physical and chemical complexity means that our understanding of SZ magmatism lags behind other tectonic settings.

Progress in understanding such multi-phase, multi-component systems requires an accurate and efficient PDE modelling framework that consistently couples the essential physics. Developing methods for such geodynamic processes presents a number of crucial requirements including: (i) the discretisation used for the "flow" and "transport" problems should be selected such that they are compatible; (ii) the formulation of the governing equations for flow and transport permit an accurate representation of the velocity and pressure for both phases, and are amenable to efficient solvers; (iii) the transport discretisation should ideally be conservative and preserve physical bounds.

In this presentation, we discuss discretisations that satisfy the above requirements. With respect to the mechanics, we show that for a particular choice of the pressure variable, together with a suitable regularisation, high-order accuracy solutions can be obtained via the finite element method on unstructured meshes. This result applies to the velocity and pressure in each phase, even when the porosity is globally, or locally, identically zero. The efficient solution of this discrete formulation is achieved via a multi-level, auxiliary space preconditioner. Trade-offs and design choices associated with the compatibility of the discretisations used for the flow and transport problem will be discussed. Comparisons between continuous Galerkin finite element and finite volume based transport solvers will be presented.

The above techniques are brought together in our open-source framework ProjectMagmOx (https://bitbucket.org/dmay/projectmagmox). We will present the essential features of the framework required to enable multi-physics applications, together with examples of two-phase flow in an idealised subduction zone.