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Why you should or should not use stabilised low-order elements for geodynamical modelling

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Despite well-documented drawbacks, the bi-tri-linear velocity - constant pressure (Q1P0) element is still the workhorse of many Finite Element geodynamics codes. With the advent of modern parallel iterative solvers and ever more powerful high performance computers, a new generation of codes now relies on quadratic elements, which are stable and yield better accuracy. However, two exceptions come to mind in the past decade: the Rhea code (Burstedde et al., GJI 2013) and the GALE code (https://geodynamics.org/) which both rely (or relied, in the second case) on the stabilised low-order element Q1Q1 element. This element is linear for both velocity and pressure. While Rhea was very successful for large-scale adaptive mantle convection simulation (Stadler et al, Science 2010), the GALE manual states: "[Like the Q1P0 element,] this formulation has its own instability that is fixed by adding an artificial compressibility. In principle, this artificial compressibility should be small and get smaller as resolution increases. In practice, for realistic geologic problems, the artificial compressibility was far too large and dramatically altered the dynamics." I have implemented the Q1Q1 element in my code ELEFANT and will document when and how this element can be used and how it compares with other elements for a variety of geodynamical benchmarks and test cases.