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Rising buoyancy of viscous fluids and exhumation of high-temperature metamorphic belt

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We performed numerical simulations for the evolution of crustal scale patterns of rising buoyancy of viscous fluids. The system consists of a high-viscosity (10^{18}–10^{21} Pa s) matrix and a low-viscosity buoyant material (10^{8}–10^{18} Pa s). The system size is 36 km (vertical thickness) x 90 km (horizontal width) with periodic boundary condition. The upper 3 km and lower 3km are assumed to be ridged plates. The lower ridged plate is assumed to move to left side with 1 cm/yr. The lower-right corner is a source region of low-viscosity buoyant materials, whose dimensions are 3 km (vertical thickness) and 30 km (lateral width) at 30–33 km depth.

The results show that patterns of rising buoyant viscous fluids transform from diapirs to branching dike-like patterns with increasing viscosity contrast. A blo-dike pattern appears in transitional conditions between diapir and dike-like patterns. The blob-dike pattern is similar to a stock or batholith of plutonic rocks. Laterally elongated patterns appear with low-density contrast and low-viscosity contrast in the diapiric regime. This pattern resembles large-scale plutono-metamorphic complexes (high-temperature metamorphic belts). This pattern is formed when the exhumation rate of diapirs due to buoyancy becomes comparable to the lateral velocity of the lower ridged plate.

We compare the numerical results with the time and space distributions of mid Cretaceous high-temperature plutono-metamorphic complexes (high-temperature metamorphic belts) in northern Kyushu, Japan, where a large amount of felsic plutonic rocks (batholith) and a smaller amount of high-temperature metamorphic rocks exist. The comparison shows that scare distribution of high-temperature metamorphic rocks on the southern side of northern Kyushu, Japan, is well explained by slowly rising buoyancy of viscous fluid with low-viscosity contrast and low-density contrast associated with lateral movement of ridged mantle. On the other hand, the widespread distribution of batholiths of felsic rocks should be explained by rising buoyancy viscous fluids with relatively higher-viscosity contrast and higher-density contrast. The coexistence of these two different modes of rising buoyancy of viscous fluids may be attributed to differences in the degree of separation of melt from solid residue. The results of the simulation suggest that the slightly lower-viscosity and lower-density of partially melted metamorphic rocks compared with those of surrounding rocks at low to middle crustal depths, and the lateral movement of ridged mantle are critical for exhumation of high-temperature metamorphic complexes in northern Kyushu, Japan.