Lava dome eruptions are often interspersed by vigorous explosions characterized by sequences of short-lived pulses. Such Vulcanian-type explosions represent a significant hazard, and an understanding of their dynamics is vital for risk mitigation. However, the causes for and the timing of the transition from effusive to explosive activity during dome formation are largely unknown. Here, we describe and interpret robust and unique multi-parameter data from seismic, strain, gravimetric and barometric records documenting the subsurface processes associated with Vulcanian-type explosions at Soufrière Hills Volcano, Montserrat. Geophysical signatures are distinct for two particular events in 2008, which are representative for the documented range of Vulcanian activity worldwide. We quantify explosion priming caused by processes in either the shallow (< 2km depth) or the deep magmatic system. One explosion has a signature related exclusively to shallow dynamics including conduit destabilisation, syn-eruptive decompression and magma fragmentation, conduit emptying and expulsion of juvenile pumice. In contrast, the second explosion was triggered by unprecedented sudden pressurisation of the entire plumbing system from depths of about 10 km (including the magma chambers) resulting in surficial dome carapace failure, a violent cannon-like explosion, propagation of a shock wave and pronounced ballistic ejection of dome fragments. With timescales for eruption priming on the order of few minutes, the precursory geophysical signatures are indicative of the nature of ensuing Vulcanian explosions. The short precursory phases characterise Vulcanian explosions as freak events triggered by abrupt rather than gradual changes in subsurface dynamics.