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Cavity opening and amethyst geode formation in altered basaltic rocks of the Paraná province, South America, evaluated with the finite element method

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Giant amethyst geodes in altered volcanic rocks of the Paraná province, South America, can be formed by pressure exerted by water vapor (0.6 MPa), equivalent to a basalt cover of 20 m. The ballooning of the rock, the shape and size of the geodes are better understood with numerical simulations. The use of the finite element methods allow the determination of rock properties at the time of deformation in the Cretaceous (135 Ma). The presence of hot water in the rock causes a strong modification in the mechanical properties of the rock; the Young modulus E decreases from 50 GPa in average basalt to $\sim$1 GPa in the resultant claystone (altered basalt). In the studied problem, rocks with Young modulus E between 0.6-2.0 GPa can sustain ballooning. The size of the protogeode is dependant on the value of vapor pressure, which is directly related to thickness of the hangingwall basalt. The protogeode is smaller when E is higher (rock is less altered) or when vapor pressure is lower (smaller thickness of hangingwall). Permanent ballooning can only occur when the basalt becomes a plastic medium at the yield point due to progressive alteration of the initially elastic medium. The determining property for the final shape of the cavity is the yield point; a low transition point (lower than 0.1 MPa) leads to the formation of a prolate geode, whereas a high point (higher than 0.1 MPa) leads to the formation of an oblate geode. This study reproduces and explains a wide spectrum of observations made in the Paraná province amethyst and agate geodes, Brazil and Uruguay.