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Speleogenesis in hypogene settings: Development and validation of numerical models by field evidence

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The development of gypsum maze caves in hypogene settings is examined by process-based numerically modeling. The numerical model settings are largely based on field observations compiled from the karst terrain of the Western Ukraine and iteratively improved by comparing model outcome and field data. Conduit development in this type of setting is driven by artesian flow beneath topographical lows, where the vertical hydraulic gradient is maximized. The resulting cave-forming flow is directed transversely relative to bedding, laterally extensive stratiform fissure networks (often multi-storey) and the long dimensions of intrastratal fissures (transverse speleogenesis). In order to identify controlling processes and parameters of transverse speleogenesis, conduit development has been simulated using model scenarios that account for peculiarities of the Western Ukrainian setting. A coupled continuum-pipe flow model is employed for simulating conduit development within the soluble unit of a multi-layer aquifer system. Pathways that can potentially be enlarged (protoconduits), such as prominent joints and bedding planes, are represented by a pipe-network model while a continuum model represents the non-soluble aquifers and confining beds as well as the fractured porous rock of the soluble unit. In extension to earlier work that revealed the basic mechanisms of speleogenesis in generic settings, this work tries to come closer to the actual conditions found in field settings. To this end, a basic scenario that is believed to provide a simplified but still adequate representation of the Western Ukrainian karst settings is designed and subsequently modified by varying

parameters like permeability of the rock formation, chemical saturation of the inflowing aqueous solution, lateral extension of the discharge area, or structural conditions of the initial network of protoconduits. The discordance of fissure networks in various horizons of the soluble unit is represented in a two-dimensional vertical slice using various frequencies and various initial diameters to the network of protoconduits in the different horizons. This causes a limited vertical connectivity of protoconduits corresponding to the situation found in the Western Ukrainian settings. Larger initial apertures of the horizontal protoconduits in the middle levels account for the fact that fissure systems in certain horizons, most commonly in the middle ones, have good lateral connectivity, in contrast to other horizons where the lateral connectivity is poor. In addition to structural preferences, the hydraulic boundary conditions are found to be a controlling factor of the geometry of the evolving cave patterns. The spatial extension of the discharge area is found to influence the geometry of cave patterns evolving at the early stage of karstification. Under time-constant boundary conditions, however, differences in the geometry of the cave patterns in scenarios with localized or extended discharge area tend to disappear with ongoing simulation time. Earlier studies on conduit development suggest a positive feedback mechanism between increasing flow and dissolution rates and thus a speleogenetic competition of discrete pathways. This is also found in the hypogene setting examined here provided the permeability of the rock formation is sufficiently high. In low-permeability formations, however, the limitation of inflow to and outflow from the network of protoconduits causes conduit development to be less selective and a multiplicity of pathways can develop. Under these suppressed-flow conditions the frequency distribution of conduit apertures appears to be fairly uniform as opposed to the bimodal aperture distributions resulting from competitive conduit development under unlimited-flow conditions.