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Speleogenesis in cratonic multi-storey artesian systems: conceptual and numerical models

A. Klimchouk (1), **S. Birk** (2)

(1) Institute of Geological Sciences, National Academy of Science of Ukraine, Kiev, Ukraine,
(2) Institut für Erdwissenschaften, Karl-Franzens-Universität Graz, Austria
(steffen.birk@uni-graz.at)

Conceptual and respective quantitative models of speleogenesis/karstification developed for unconfined aquifers cannot be directly applied for explaining speleogenesis in confined settings. A conceptual model for speleogenesis in multi-storey artesian settings has been developed, based on views about hydraulic continuity in artesian basins and close cross-formational communication between aquifers in multi-storey artesian systems. Model settings, best exemplified by the gypsum karst in the Western Ukraine (although being common throughout many cratonic artesian basins) include a soluble layer, initially of low permeability, that separates "normal" porous/fissured aquifers in a system, confined by a clay sequence. Transverse speleogenesis denotes conduit development driven by the upward head gradient across a soluble layer, maximized below river valleys, so that the cave-forming flow is directed transversely relative to bedding, laterally extensive stratiform fissure networks (often multi-storey) and the long dimensions of intrastratal fissures. Fissure networks in the soluble bed receive uniform and aggressive recharge from the lower aquifer, and flow distances through the soluble unit are generally short. The conceptual model inferred a specific hydrogeologic mechanism inherent in artesian transverse speleogenesis (restricted input/output), that suppresses the positive flow-dissolution feedback and hence speleogenetic competition in fissure networks and accounts for the development of more pervasive channelling in artesian settings, of maze patterns where appropriate structural prerequisites exist. In order to identify controlling processes and parameters, basic mechanisms of transverse speleogenesis have been simulated using a numerical model. The model simulations show that the evolution of maze caves in artesian settings requires structural preferences such as laterally extended fissure networks in

the gypsum layer. It is favoured by the presence of systematic heterogeneities in vertical conductivity of a fissure network, which is represented in the Western Ukraine by discordance in the permeability structure between fissure networks at various intervals of the gypsum bed, and hence by the limited vertical connectivity of networks. The effect of such discordance is somewhat similar to that of the presence of low permeable intercalations. In addition to structural preferences, the variation of boundary conditions in time, e.g. increasing hydraulic gradient across the soluble unit due to river incision into the upper confining bed, further influences the development of maze patterns. The most important stage for the development of maze caves under artesian conditions is found to be the initial karstification period, i.e. before a highly conductive pathway connecting the aquifers overlying and underlying the soluble unit has been established. During this period the structure of the mature conduit system is established, the solutional enlargement of conduits is spatially extended, and total dissolution rates are higher than the later ones.