Conceptual and numerical models of karst genesis in artesian systems

Steffen Birk[1] & Alexander Klimchouk[2]

1 Institut für Erdwissenschaften, Karl-Franzens-Universität Graz, Austria (steffen.birk@uni-graz.at)
2 Ukrainian Institute of Speleology and Karstology, Ministry of Education and Science and National Academy of Science of Ukraine

Conceptual and respective quantitative models of karst genesis developed for unconfined aquifers cannot be directly applied for explaining karst genesis in confined settings. A conceptual model of transverse 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. Model settings include a soluble layer, initially of low permeability, that separates insoluble porous or fissured aquifers in a system confined by a clay sequence. This type of setting is common throughout many cratonic artesian basins, but best exemplified by the gypsum karst in the Western Ukraine. 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, to laterally extensive stratiform fissure networks, and to 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 infers a specific hydrogeologic mechanism inherent in artesian transverse speleogenesis, i.e. restricted input and output, which suppresses to some extent the positive flow-dissolution feedback found in unconfined settings. In order to identify controlling processes and parameters, basic mechanisms of transverse speleogenesis have been simulated using a numerical model. The numerical model combines a coupled continuum-pipe flow model, representing both diffuse-flow and conduit-flow components of karst aquifers, with a dissolution-transport model calculating dissolution rates and corresponding widening of karst conduits. The model simulations show that the evolution of maze caves in artesian settings requires structural preferences such as laterally extended fissure networks in the soluble bed. Maze cave development 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 can be higher than the later ones.