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Architecture of a paleokarst breccia-pipe field, Carboniferous, Svalbard

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Upwards-propagating collapse pipes typically form sinkholes where they meet the land surface. Renewed dissolution of breccia in ancient pipes can have a similar effect. For these cases, probability-based models of sinkhole hazard are closely related to the expected mature architecture of the collapse-pipe field. We present a case study of the architecture of a square-kilometre field of collapse-pipes from the Carboniferous-Permian in which the pipes are documented in outcrop and using shallow geophysical methods.

The study site is located on the Wordiekammen plateau in the Carboniferous Billefjorden half-graben basin on Spitsbergen. Cliffs bounding the plateau expose breccia pipes cutting a gently-dipping 200-m-thick series of platform carbonates, in turn underlain by stratiform breccias and residual pods of gypsum. Many of the breccia pipes are tall (>250 m) and postdate several shallow karstification episodes. Most pipes are inferred not to have reached the surface based on a lack of terrigenous material and fluvial structure, although several pipes show indications of such surface communication. Although the pipes are generally attributed to gypsum dissolution, a deep carbonate karstification event is inferred based on high temperature calcite cement, and burial dehydration of gypsum, may also have contributed to void formation.

On the plateau top the collapse pipes are obscured by thick scree, thus km-scale size and spacing data for the pipes and faults was collected by mapping the bedrock with 2D ground-penetrating radar (GPR). GPR profiles were acquired on a grid with 25-meter line spacing, using 50 MHz antennas and achieving 30-40 m penetration. Breccia bodies were identified by steep-sided zones of complex diffraction patterns interrupting bedding-related continuous reflections. Two pipes were further studied in 3D using high-resolution GPR, tomographic seismic and geo-electric. These geophysical data were merged into a comprehensive 3D framework including helicopter-borne lidar and photo scans of the plateau rim geology, thus allowing an integrated visualization and interpretation of the different datasets. The GPR data show the breccia pipes to be slightly oblate with diameters ranging from 20 to over 100 m; 60 meters is a typical value. Approximately 10 pipes are identified in cliff-side outcrops bordering the GPR area, whereas 30 more are identified within the plateau by the GPR data. The GPR volume lies about 200 m above the pipe base, hence the pipe-length frequency-distribution data are incomplete. The strata are cut by small-offset (<5m) faults related to collapse processes and larger-offset faults related to regional basin extension. The breccia pipe field appears to be delimited by these more regional faults, in turn inferred to control the thickness of syn-rift gypsum and/or the hydrology of its dissolution.

Collapse breccia pipes form strong vertical heterogeneities in rock properties such as porosity and permeability, matrix density, cement, mechanical strength and lithology, affecting fluid-flow characteristics on a meter to hundred-meter scale. It is rare that pipe fields are well exposed at the kilometre scale. Although some scaling data can be obtained from 3D oil-industry seismic reflection data but the resolution insufficient to visualize critical details. The outcrop combination of seismic, electric and geologic techniques facilitates the interpretation of 3D facies architectures and by proxy porosity-permeability relationships. Studies at the km scale are fundamental for understanding basic karst and collapse processes, and yield petrophysical models that can be applied predictively to natural hazards and groundwater or hydrocarbon exploitation in paleokarst settings.