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# GPR, seismic and geo-electric investigation of a paleokarst breccia pipe field, Svalbard

Walter Wheeler (1), Björn Heincke (2,3), Giuliana Rossi (4), and Niklas Allroggen (5)

(1) Centre for Integrated Petroleum Research, Bergen, Norway (walter.wheeler@uib.no), (2) Geological Survey of Norway, Trondheim, Norway, (3) IFM-GEOMAR, Kiel, Germany (bheincke@ifm-geomar.de), (4) OGS, Trieste, Italy (grossi@ogs.trieste.it), (5) Bremen University, Bremen, Germany (niklas.allroggen@uni-bremen.de)

A kilometer-scale field of karst breccia pipes was investigated using georadar (GPR), seismic, geo-electric and geologic techniques, with the goal of documenting 3D facies architectures. Studies at this scale are fundamental for understanding karst and collapse processes, and yield petrophysical models that can be applied to groundwater or hydrocarbon exploitation in paleokarst settings. At the kilometer scale geological exposure is typically incomplete; even 3D oil-industry seismic reflection data over buried examples do not give sufficient resolution to visualize critical details. Shallow-geophysical techniques bridge this resolution gap and add the third dimension to otherwise largely 2D exposures, allowing the building of realistic 3D reservoir-analogue models.

The study site is the mesa-like Wordiekammen plateau in the Carboniferous Billefjorden half-graben basin on Spitsbergen. Cliffs along the plateau margin expose gently-dipping Late Carboniferous syn- to post-rift platform carbonate strata, punctuated by 60-m-diameter breccia pipes that appear to cut through 100- to 200 m thickness of strata. Karstification and collapse are inferred to have occurred in the latest Carboniferous to Early Permian, with the breccia pipes nucleating in underlying gypsiferous strata. The strata are also cut by small-offset (<10m) faults related to collapse processes and regional extension. Breccia pipes form strong vertical heterogeneities in rock properties affecting fluid-flow characteristics on a meter to hundred-meter scale.

The km-scale architecture of the pipe field was established by systematically surveying the plateau with a 25-m-spaced grid of 2D GPR lines (50 MHz antennas, penetration 30-40 m). Breccia bodies were identified by steep-sided zones of complex diffraction patterns interrupting bedding-related continuous reflections. Two of the identified pipes were studied in detail using high-resolution 3D GPR surveys (field size: 150 x 100 m, 40 cm midpoint spacing) and seismic tomography. One pipe was further studied using 3D resistivity tomography. Images from migrated 3D GPR surveys enabled us to determine the breccia-pipe shape and structure with a resolution of some decimetres in the upper 30 m meters. Strata around the pipe margins are seen to vary from undeformed to locally downfaulted.

Seismic acquisition was optimized through modeling then followed by tomographic simultaneous inversion of refracted and reflected waves. Penetration was hindered by scattering and the wave-guide-like effect of a shallow topography-following very-high-impedance contrast attributed to top permafrost. Long offsets were used to recognize underlying reflections. P-wave velocities range from about 2.7 km/s to 4.5 km/s, with the lower velocities corresponding to a pipe mapped using GPR. Chaotic patches interrupt the reflection layering, also consistent with breccias. Multichannel analysis of surface waves on a line crossing two pipes shows phase velocities of 2.0-3.0 km/s; dispersion curves between 10-80Hz constrain the upper 80-100 m. The pipes are characterized by homogeneous modelled Vs whereas the surrounding layered bedrock shows heterogeneous Vs.

A grid of 2D resistivity profiles (5 m electrode spacing, max. spread 400 m, Wenner and Dipole-Dipole) with 3D inversion show that the breccia pipes are typically characterized by low resistivity (<6k ohm m) from the surface to over 40 meters depth compared to high resistivity (>20 k ohm m) outside the pipes. The plateau is characterized by permafrost to several hundred meters depth, hence the high resistivity is attributed to carbonate with air or ice in the porosity. The low resistivity values are provisionally attributed to gypsum-related brine in the high-porosity breccias, where the gypsum is related to collapse of overlying gypsiferous strata and/or pre-permafrost groundwater flow in the pipes. This is consistent with outcrop relations, which indicate the breccias are permeable and associated with gypsum veins.