README

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Jagert, F., Güldenhaupt, J., & Chatziliadou, M.:

Wireline logging and video data of a 224 m deep exploration well in a carbonate karst in Hagen, North Rhine-Westphalia, Germany

(Finalised data of: Optical Borehole Imager, Acoustic Borehole Imager, Calliper, Downhole Video)

The investigation of karst aquifers is inherently challenging due to their heterogeneous nature. A new borehole, measuring 224 metres in depth, was drilled into the 'Massenkalk' formation in the Steltenberg quarry at Hagen, North Rhine-Westphalia, Germany, with the objective of investigating its potential as a geothermal reservoir analogue (Coordinates of well R1: 401398 / 5690212 UTM 32N). Geophysical logging and camera runs revealed the presence of highly permeable karst structures, which visually displayed vuggy porosity. The permeability of the aquifer seems largely dominated by karst structures, specifically fractures that have been widened by dissolution. Instead of intense fracturing, the rock mass generally appears to be characterised by karstification and secondary porosity.

The logging and mapping data were finalised in PDF, TXT and AVI formats as supplementary material of DOI: 10.1127/zdgg/2025/0450

To enable borehole imaging, the Quick Link (QL40) downhole geophysical logging system from Advanced Logic Technology (ALT) was employed. Making structural mapping within WellCAD possible, this data provided greater insight into the fracture and karst system. The interpretation of the gamma ray, deviation, and full waveform sonic probes is discussed in the associated article (Jagert et al. 2025). The following probes are particularly important for this dataset:

- Optical Borehole Imager (QL40 OBI-2G) – operational only in water-filled or dry boreholes,
- Acoustic Borehole Imager (QL40 ABI-1G) – operational only in water or drilling mud,
- 3-Arm Calliper (QL40 CAL) – a mechanical calliper, suitable for dry borehole sections.

1) Wireline logging data analysed using WellCAD:

Optical Borehole Imager (OBI):

The Optical Borehole Imager (QL40 OBI, 2G: 2nd generation) generates high-resolution true-colour images of the borehole wall with a selected azimuthal resolution of 1800 pixels. The system employs a high-resolution digital CMOS image sensor in combination with a fisheye lens, producing a 360° continuous digital image of the borehole wall, either in air or clear water. The OBI simultaneously generates a real-time processed image, enhanced by a filtering algorithm that optimizes luminance distribution. An integrated orientation sensor determines the azimuth and inclination of the borehole, allowing for image orientation with respect to a global reference. This is achieved using a three-axis magnetometer in combination with three accelerometers.

Image Correction & Limitations:

- Image distortions caused by probe rotation during movement are automatically corrected.
- However, strong movements (e.g., gliding over cavities) or magnetic anomalies (e.g. iron) are difficult or impossible to correct.
- Manual azimuth correction was necessary in the upper borehole section (first metre of open hole) due to magnetic distortion from the iron conductor housing between 0 – 11 metres.

The OBI successfully generated a high-resolution image log down to 81.6 metres, with a pixel resolution of approximately 0.3 mm. The visible structures indicate the presence of karstic cavities and secondary porosity, extending deep into the bedrock.

Acoustic Borehole Imager (ABI):

The Acoustic Borehole Imager (QL40 ABI, 1G: 1st generation) utilizes a rotating mirror and a 1.2 MHz sound pulse to generate an unrolled 360° acoustic image of the borehole wall. Identical in construction to the OBI, an integrated orientation sensor determines the azimuth and inclination of the borehole, allowing for image orientation with respect to a global reference.

Resolution & Data Processing:

- The amplitude channel was contrast-adjusted using histogram equalization, applied uniformly across the log. The value range spans the total minimum to maximum of the log.
- The selected resolution was 288 points per revolution, with a vertical resolution of approximately 3 mm per pixel.
- Calliper data and radius image channels were derived from travel-time measurements, providing minimum, average, and maximum borehole diameter values.

Data Interpretation & Limitations:

- Erroneous points occur in areas where vuggy porosity, open fractures, or karstic cavities prevent the acoustic beam from being reflected. These non-reflective areas are color-coded: dark blue (amplitude) and black (radius).
- As a result, the calculated borehole diameter (calliper) is unreliable or absent in these zones.

The ABI successfully generated an image log between 37.1 – 133.6 metres with a resolution of approximately 3 mm per pixel.

3-Arm Calliper Probe (CAL):

The QL40 CAL records a continuous borehole diameter log using three mechanically coupled arms that maintain direct contact with the borehole wall. This tool is particularly suitable for sections above the water table. In contrast, the ABI probe is better suited for submerged sections, as its acoustic calliper method provides higher resolution and, consequently, more comprehensive borehole wall coverage.

For structural mapping, a known calliper value must be selected, as estimated dip values depend on the borehole diameter.

Structural Mapping Log:

The structural log was used to manually acquire geological structure data by fitting a sinusoid to features visible in an unrolled image, such as fractures, bedding planes, and occasionally karst structures (Fig. 1). The recorded data include depth, dip direction, dip angle, and structure classification attributes. Image logs from the ABI (amplitude and radius from travel-time measurements) and the OBI (true-colour and contrast-enhanced processed images) were used for mapping. The dip value depends on the borehole diameter, which was obtained from the recorded calliper log of the 3-arm mechanical calliper and the acoustic calliper.

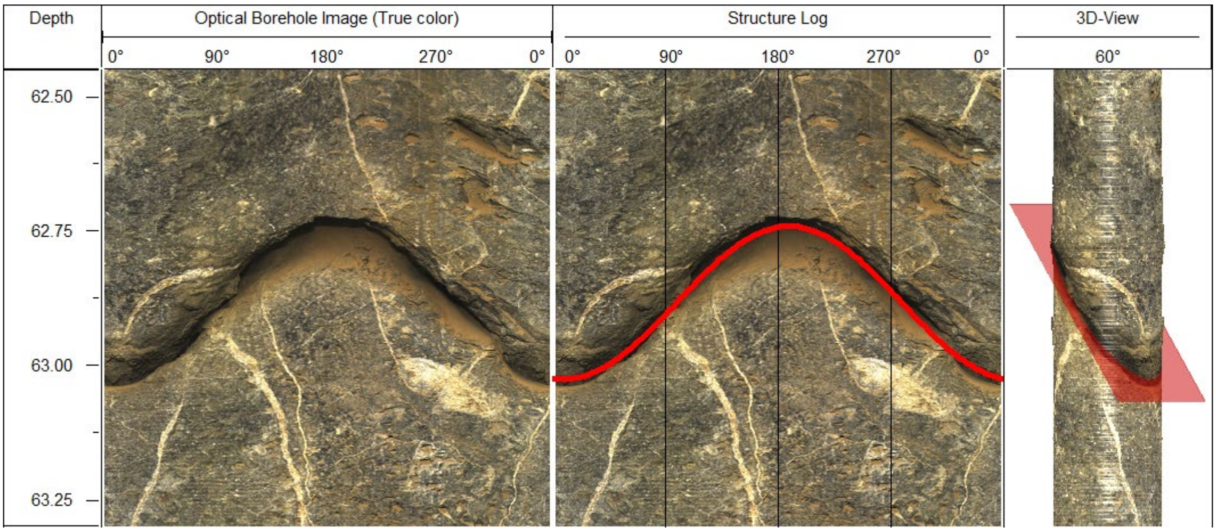

Fig. 1: Example of a mapped structure. Left: original image, centre: mapped sinusoid, right: 3D visualisation.

Since structural dips are derived from an image captured in an inclined borehole, they require correction for the inclination and azimuth of the borehole axis. In this study, structural data were adjusted to reflect true dips. The 'Apparent to True Azimuth and Dip' method in WellCAD was applied using dip and azimuth logs from the ABI and OBI deviation sensors.

2) Downhole video data:

The downhole video was captured using a sliding, wired camera equipped with a fixed-focus wide-angle lens and an integrated ring light. The camera head, measuring 23 mm in diameter and 35 mm in length, was centralised along the borehole axis and lowered at a relatively constant speed.

The video was recorded at a resolution of 1280 × 720 pixels, and the data was retrieved directly from the camera without post-processing (AVI format).

The first recording documents the descent into the borehole down to the water level at approximately 37.8 metres. To ensure optimal image clarity, a second descent was performed after cleaning the camera lens. The video reveals both turbid and relatively clear sections. The turbidity results from water movement caused by the previous day's borehole activities, whereas the clear sections — flushed in less than 17 hours — indicate rapid groundwater flow.

The descent continued to a depth of about 133 metres, where the centraliser encountered a huge karst void, preventing further advancement.

Recommended Literature:

Jagert, F., Kruszewski, M., Mueller, M., Wohnlich, S., & Immenhauser, A. (2025). Aquifer characterisation of the karstified Massenkalk carbonates as potential geothermal reservoir: Implications from borehole logging and hydraulic testing (Hagen, Germany). Z. Dt. Ges. Geowiss. (J. Appl. Reg. Geol.), 176/1, 1-20. https://doi.org/10.1127/zdgg/2025/0450

Advanced Logic Technology (ALT) & Mount Sopris Instruments (2012a): User Guide. QL40 ABI and ABI40 Acoustical Borehole Imager. v12.01.30. Luxembourg / USA.

Advanced Logic Technology (ALT) & Mount Sopris Instruments (2012b): User Guide. QL40 CAL – 3 Arm Caliper. v12.12.13. Luxembourg / USA.

Advanced Logic Technology (ALT) & Mount Sopris Instruments (2021): User Guide. QL40 OBI-2G – Optical Borehole Imager. V21.09.15. Luxembourg / USA.