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Improving groundwater vulnerability and risk assessments within karst aquifers using GPR

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Introduction

As a transboundary aquifer, the Classical Karst Region (grey area in Fig. 1A) represents an important water source for both Slovenia and Italy. However, due to extremely heterogenic subsurface settings and specific hydrogeological conditions of karst environments, the aquifer remains insufficiently protected (Turpaud et al., 2018). As agricultural activity represents one of the major sources of groundwater pollution in Slovenia (MOP, 2015), accurate groundwater vulnerability and risk assessments in agricultural environments are vital for a sustainable food production, especially in karst areas (Ravbar, 2007). By using the non-invasive ground penetrating radar (GPR) method, it is possible to both track the top soil thickness in a continuous way across the field (Kirsch, 2009) as well as detect the presence of karst features, which can contribute to the hydrogeological dynamics of the aquifer.

GPR Method

GPR is a geophysical method where electromagnetic waves are emitted from the transmitting antenna into the subsurface and detected by the receiving antenna after being reflected back to the surface from subsurface boundaries between materials and objects with different electromagnetic properties. It provides an efficient and non-destructive way of researching the shallow subsurface, therefore its use in geological studies has been increasing rapidly, e.g. for detecting faults and fractures, detecting karst features and cavities, mapping sediments and determining water table depths (Blindow et al., 2007). The penetration depth and resolution are mostly dependent on the frequency of the antenna used. Lower antenna frequencies enable greater penetration depths while higher antenna frequencies provide results with higher resolution (Jol, 2009). For the purpose of this study, the MALÅ ProEx recording unit was used together with two different antenna frequencies (250 and 500 MHz, Fig. 1B).

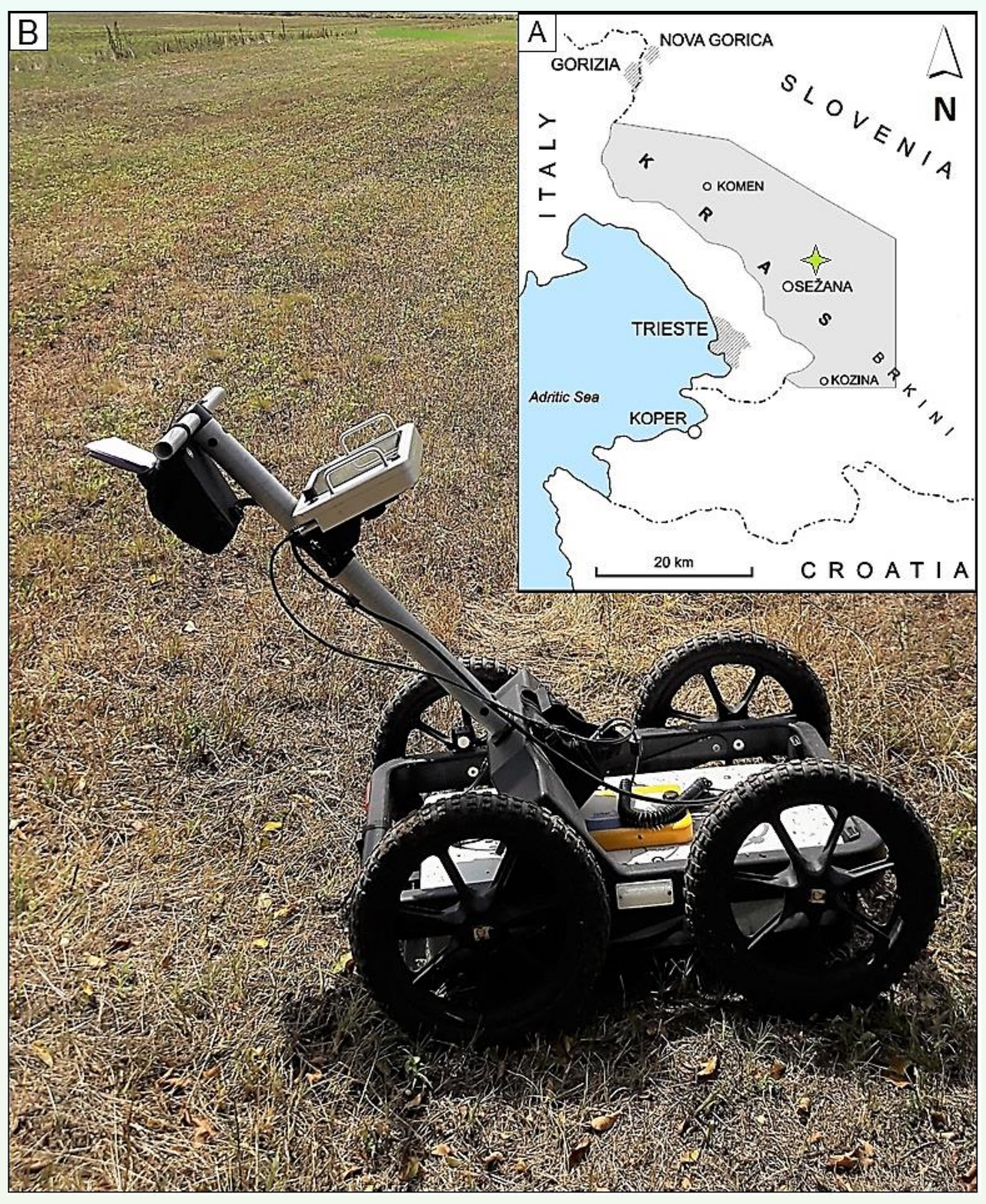

Figure 1: A – Geographical position (Jurkovšek, 2013) with marked research area (green star);
B – GPR cart with 250 MHz antenna.

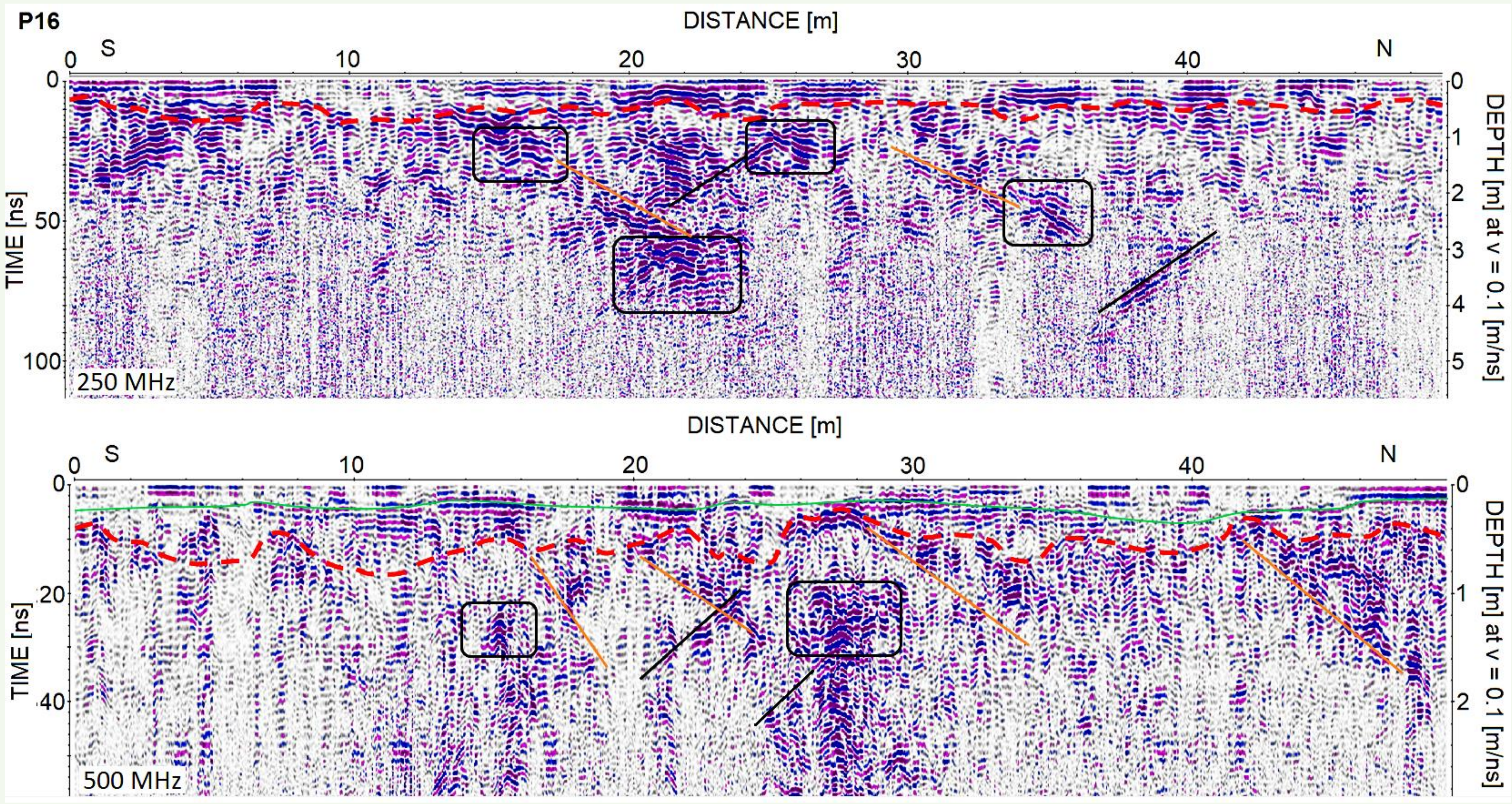

Figure 2: GPR profile P16 recorded with the 250 MHz (above) and 500 MHz (below) antenna. For interpretation and explanation of symbols, please see text.

Data Acquisition

Parallel GPR profiles were recorded with both antennas along an entire agricultural field with reduced crop growth, located in Štorje within the Classical Karst aquifer (green star in Fig. 1A). For validation purposes, the thickness of the top soil was measured at five points along the field by small excavations. GPR results were also correlated with existing borehole and geological mapping data.

Results

As seen in Fig. 2, in addition to tracking the top soil thickness (green line), which is thinner than expected (17 – 32 cm), we were also able to detect the lower boundary of the weathered limestone (red line) as well as identify discontinuities representing limestone bedding (black lines), fractures (orange lines) and karst features (black frames). The 500 MHz profile provides more precise information on the top soil thickness, while the 250 MHz profile enables deeper penetration. The north-dipping discontinuities most likely represent solutionally enlarged fractures, while the south-dipping discontinuities probably represent the limestone bedding (Jurkovšek, 2013). The presence and spatial orientation of both types of discontinuities, as well as the presence of karst cavities, were confirmed by borehole televiewer data (Fig. 3).

Discussion and Conclusions

In order to avoid additional irrigation and fertilization that could lead to a potential increase of pollutants reaching the groundwater, the top soil thickness as well as the presence of subsurface discontinuities and karst features were investigated on a problematic agricultural field. The results provided information on both lateral and vertical variations of the subsurface features. Therefore, GPR could contribute to more accurate groundwater vulnerability assessments. It could also be used for defining the most representative positions of soil moisture tracking probes for irrigation optimization purposes in precision agriculture and play an important role in sustainable food production.

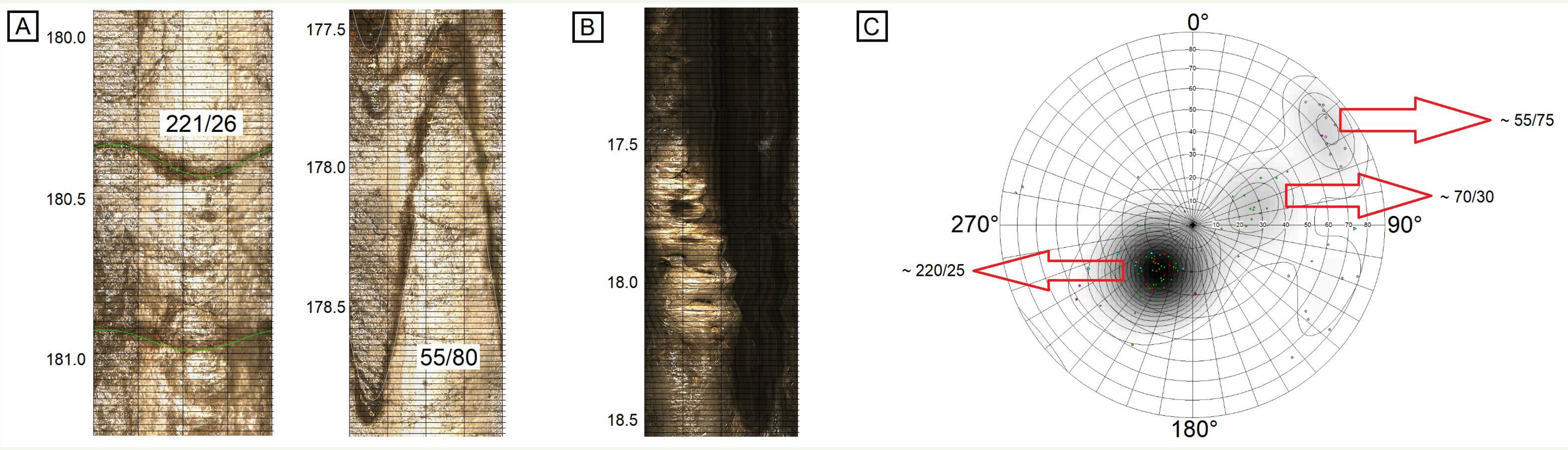

Figure 3: Data from near-by Štorje-1/12 borehole televiewer measurements. A – examples of discontinuities with different azimuths and dips; B – part of a karst cavitiy located at 13 – 17 m depth; C – Schmidt plot of defined discontinuities in the borehole, showing three main areas with average azimuths and dips.

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