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Detection and modelling of dolines by magnetic surveying in the central Ebro Basin (Spain).

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The development of alluvial dolines in the Ebro basin affects both to agricultural and urban areas. A great number of studies (geomorphological, geological, geotechnical...) and mapping of dolines and hazard areas have been developed during the last 30 years. Doline maps, based on the study of aerial photographs, allow detecting only a percentage of the total number of dolines, because time-spaced records of aerial photographs do not show their quick evolution. At present, the large increase in urbanized zones occupying old farming areas makes necessary the development of good prediction and detection methods to diminish the hazard associated to the doline genesis.

Although geophysical prospecting is of common use in the detection of voids and cavities in the subsoil, magnetic prospecting is not a widespread technique in analysing these problems. Magnetic prospecting is only applicable when there are contrasts of magnetic susceptibility between the media involved. In the surroundings of Saragossa dolines (developed mainly on Quaternary alluvial terraces covering a Tertiary gypsum substratum) are frequently filled with alluvial deposits, urban debris, etc. To check the possible contrast of properties, magnetic susceptibility was monitored in continuous-log cores (with a total length of more than 100 meters), drilled in the surroundings of Saragossa. More than 1000 measurements (in 10 cm steps) were taken by means of a KLY-3 susceptometer and by a SM-20 field susceptometer. The borehole cuts through all the rock-types present in the area and evinces remarkable magnetic contrasts; Miocene marls ($\approx$ 100 10^{-6}S.I.), gypsiferous marls ($\approx$ 30 10^{-6}S.I.) and pure gypsum ($\approx$ -10 10^{-6}S.I.), Quaternary alluvial and terrace deposits ($\approx$ 200 10^{-6} S.I.) and agricultural soils ($\approx$ 500 10^{-6}S.I.). This susceptibility contrast enables the suc-

cessful application of magnetic surveying to detect and to model those cases where the magnetic layering is disrupted (e.g. a karstic voids or collapses).

To check the validity of this assumption, a recently collapsed doline (October 2003), 16 meters deep and 10 meters in diameter, was selected. The doline was filled with urban debris. A square grid of 130 m side centred at the collapse was measured (up to 2 meters step). A proton magnetometer (PMG-1; GF Instruments) with gradiometer was utilized; more than 2500 surface measurements of total field intensity and the same number of gradient measurements were taken. The survey evinces a strong anomaly with a dipole defined by more than 650 nT and a gradient of about 100 nT. Surprisingly two other dolines were also detected during the survey; they do not show any clear surface-evidence but were characterized by dipole anomalies up to 400 nT (total intensity) and 60 nT (gradient). Interviews with local farmers confirmed the activity of both dolines, one of them formed more than 25 years ago. These results validate the starting hypothesis and open a new research approach to the problem.

The magnetic survey output allows constructing realistic geological predictions. The 2.5D forward modelling (with program Gravmag, British Geological Survey) fits with the known geometrical data. Magnetic prospecting is therefore a useful tool in the detection of subsoil cavities, provided that a minimum contrast of susceptibility exists between the media involved and the noise generated by surface or underground metallic objects is null.