A HIGH DENSITY SAMPLING SURVEY OF SHALLOW KARST FEATURES USING EM AND MAGNETIC PROFILING TECHNIQUES

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INTRODUCTION

During field experiments on high density sampling shallow EM (Geonics EM31) surveying near Moura, Portugal, it was found that a local shallow terrain depression showed enhanced rainwater infiltration and high apparent conductivity values (Sporry et. al. 1995). Other conductivity anomalies suggested a pattern correlating with the general geological strike direction (NW-SE). The depression was identified as the result of karst erosion of a dolomitic or marble formation. Similar depressions were identified in the close neighbourhood. A combined magnetic and VLF survey was also executed. The magnetic data showed small sized, but very strong anomalies. With ' the location belong part of the Moura-Ficalho Aquifer, the local major source for domestic water supply, it was realised that mapping karst features and fractures might contribute to a better understanding of the aquifer recharge mechanism. A survey was executed with EM, VLF and magnetics over a much larger area In order to establish a possible correlation between the geological trend, the pattern of depressions, apparent conductivity anomalies and magnetic anomalies and to study the cause and nature of magnetic anomalies. The survey location was named 'Calatroia', after the nearby farmhouse 'Monte da Calatrola'.

GEOLOGY AND GEOHYDROLOGY

The Moura region is situated within the Ossa-Morena Zone, which is described as a polyphase orogenic terrain, exhibiting a complex structure due to deformation and metamorphism during the late Precambrian and Palaeozoic. The region is characterised by intensive folding with a NW-SE strike direction, creating a landscape of prominent hard Cambrian dolomitic ridges and gentle valleys. The Calatroia survey area is situated in a valley which is associated with a NW-SE oriented synclinal axis and bordered by dolomitic ridges along anticlinal axes with the same direction. Marbles, sericite schists and metavolcanic intercalations as well as dolerite lntrusions occur within the dolomites. The valley surface consists of a thin cover of terra rossá, mixed with siliciferous fragments and rocks of marble and dolomite. The terrain has numerous smaller and larger shallow depressions with the typical nature of dolines. Directly below this surface cover, karst eroded marbles occur. Photo interpretation allows the identification of faults, fractures and karst

depressions.

The hydrogeology of the Moura area is characterised by a complex karstlc aquifer system between Ficalho and Moura (Da Costa, 1991). The system consists of basically five interconnected aquifer units, of which the Moura-Ficalho aquifer is the major one. Its karstlc nature has resulted in a complex groundwater flow through intricately weaving paths, generally developed along fault and fracture systems.

GEOPHYSICAL SURVEY PARAMETERS

The EM survey was executed with a Geonlcs EM3l instrument with data logger, mounted on

a non-conductive vehicle along profile lines in an E-W direction. Line spacing of 10 m and station intervals of I m were used, in order to allow highly detailed mapping of lateral conductivity variations.
To speed up the survey progress part of the area was surveyed with a second instrument at a sampling interval of 5 m. A total of 42 km was surveyed, of which 30 km with an interval of I m. The highest daily production using this technique was 8 km, unfortunately limited by the storage capacity of the available data logger.
Magnetic total field and VLF data were collected with an EDA Omni Plus instrument along the same grid, but with a N-S survey direction and a station interval of 10 m, resulting in a I O x l O m grid. A total of 24 line km of this data was surveyed.

DATA PROCESSING AND INTERPRETATION

EM3l survey

The raw apparent conductivity data were corrected for anomalous values (spikes). A level correction of 9 mS/m was applied to the data recorded with the digital instrument to remove negative apparent conductivities at locations with very low conductivities and to tie the levels of both instruments. After re-gridding to 2.5 m and smoothing with a 3*3 Hanning filter, the apparent conductivity contour map of Figure l was produced. The contour interval is 5 mS/m. Generally, the conductivity map suggests a shallow paleokarst topography covered and infilled with relative conductive (terra rossa) material. Such a paleokarst topography can be observed in an abandoned small open pit mine near Vila Ruiva, some 8 km SE from the Calatroia location. The results show variations from I to 60 mS/m or more, in places varying from 20 to 50 mS/m over a distance of 20 m. The highest conductivities are concentrated in the lower part of the valley. The pattern of apparent conductivity clearly demonstrates a NWSE trend, suggesting fracturing in this direction. Also lineaments in other directions can be recognised: a line-up of conductive lows can be observed between positions ON-4OOW and 25ON-2OOE with a WSW-ENE direction which -correlates with a pattern of shallow depressions. Another line-up is observed between l6ON-5OOW and 44ON-l2OW with a SWNE direction correlating with a lineament on the aerial photographs. Presentation of this data in greyshading with artificial illumination (not shown) enhances this pattern and also suggests horizontal displacement along these lineaments. In effect, it is surprising to see how many shallow structural features can be observed with this relative simple EM technique.
Statistically a large number of depressions coincide with relative high conductivities, but also depressions at or near locations with low conductivities can be noticed and an absolute unique relationship can not be established between depressions and apparent conductivity levels. This is not surprising, considering the nature of karst development, in which cavities can be infilled with erosion material or remain fairly 'clean' from infills.
At the scale of the conductivity map, the advantage of l m sampling can not be demonstrated and re-sampling the data at 5 m intervals does not produce significant differences In the mapping results. However, if the I m sampled data is mapped at a much smaller scale (IOO x 100 m), a high degree of detailing can be observed. Unfortunately, these results can not be presented within the context of this short note.

VLF survey

This method was applied to investigate the consistency of the conductive zones at larger depths than the EM3l (6.5 m) can offer. Data was collected using a 24 kHz transmitter (NAA, Maine USA). A six point Hjelt filter was applied to produce current density maps at 10 and 20 m 'depth' (depth of current distribution equal to sampling interval). The results again demonstrate a conductivity pattern with a main NW-SE orientation, correlating with the results of the EM3l survey. Generally the areas with high current density are smaller than for the EM3 I, but this is not surprising: conductive karst infill may vary at larger depths. Also it can be noticed that the areas of high current density (at larger depth) are slightly shifted with

respect to EM3l data, which is not contradictory to the apparent random distribution of karst erosion. An example of VLF data is not shown in this note.

Magnetic survey

After applying diurnal corrections, maps were generated to study the pattern of anomalous zones in the area. The total field intensity map (not shown) demonstrates a surprisingly large number of isolated and clustered anomalies, in patters confirming particularly those of the EM3l survey. Anomalies with amplitudes as high as 160 to 300 nT and with wave lengths of 50 to 140 m can be observed. A 3-D analytical signal map was generated to remove the ambiguous dipolar nature of the anomalies and to map the actual positions of magnetic contacts. The result is presented in Figure 2. The SW-NE striking lineament which could be observed In the EM3l data is also present in this data, as well as the WSW-ENE lineament. In the south-western part a NW-SE trend can be observed, which is shifted with respect to the earlier observed NW-SE conductivity trend. Generally a coincidence of low apparent conductivity zones and positions of magnetic contacts can be observed. Consistently, the correlation between depressions and magnetic anomalies is less obvious. Four depressions are located within the south-western cluster, one depression coincides directly with an anomaly, four depressions are located at the boundary of analytic signal anomalies and four depressions are located outside anomalies. This signifies by no means that there is no significant correlation: it is very well possible that dipping faults and fractures will offset the position of magnetic bodies with respect to the surface position of EM3l conductivities and the surface expression of lineaments from photo interpretation. Modelling of individual anomalies show for all of them generally a shallow depth of l to 6 m to the top of the body. However, some of them have a limited depth extension, while for others the depth extension can not be given (infinite depth). Although this may be consistent with the general geological situation, which allows for meta-volcanic intercalations as well as dolerite intrusions along zones of weakness, it delimits a conclusion which correlates unambiguously magnetic anomalies with lineaments as zones of weakness.

SUMMARY AND CONCLUSIONS

The combination of EM conductivity mapping, VLF and magnetic surveying has resulted in the identification of a number of lineaments in a karstic terrain, which could not be identified on the basis of photo interpretation and the mapping of dolines in the field. Generally the positions of dolines correlate with (much larger) zones of high apparent conductivities. The magnetic anomalies correlate very well with zones of low apparent conductivities, indicating a typical different lithological composition. The VLF method confirmed the continuation of the conductivity trend at larger depths.

Considering that karst erosion largely takes place along fractures and faults and that infiltration of precipitation will mostly be along these features, it can be concluded that the survey has made a significant contribution to the identification of major zones of aquifer recharge. Mapping of these zones at a larger scale could contribute to a better control in groundwater modelling.

REFERENCES

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2. Sporry, R.J. , Roy, J. , Hugens, W.A. and Sibhat, N., 1995. High Resolution Geophysical Sensing and Imaging: Proceedings of the EEGS, European Section, Sept. 1995, pp 312315.

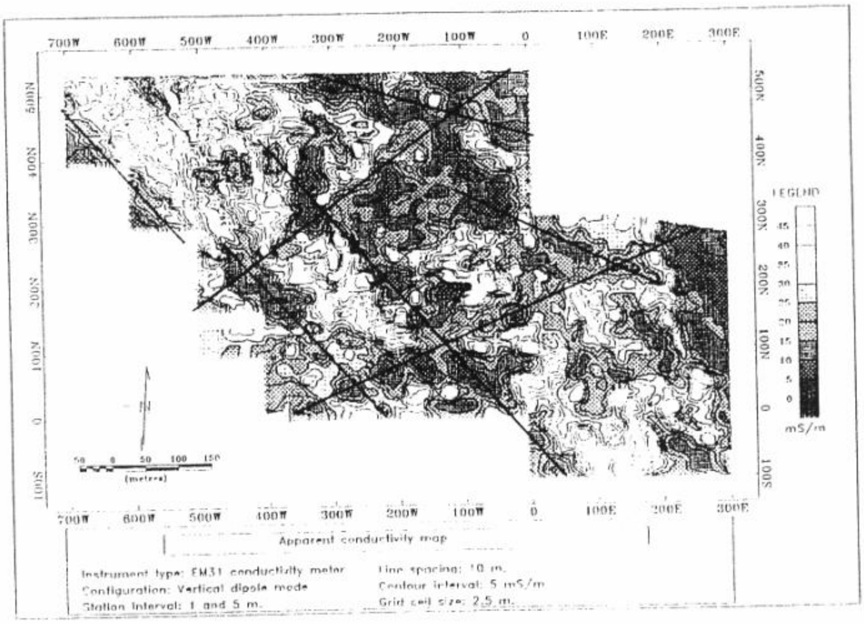


Figure 1: Apparent conductivity contour map. Solid lines represent interpreted lineaments.

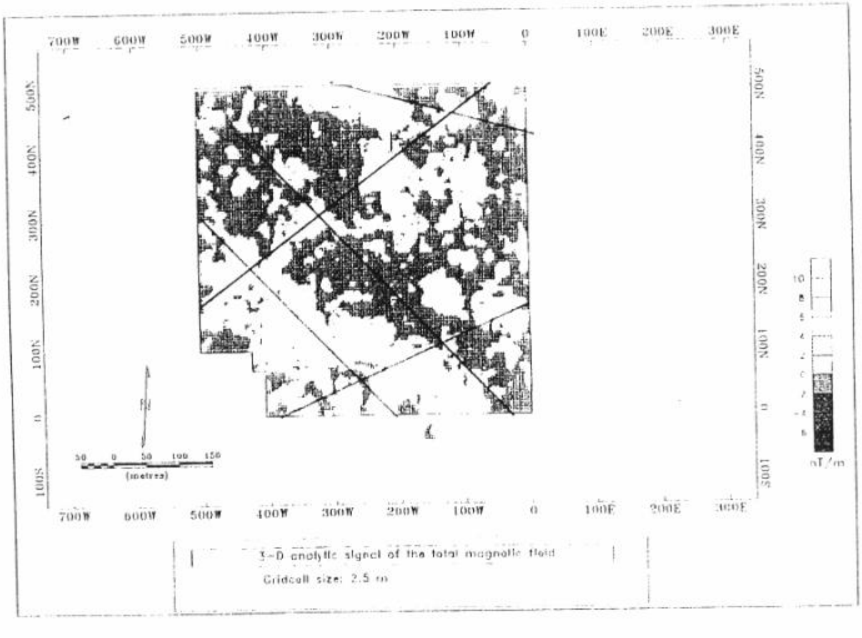
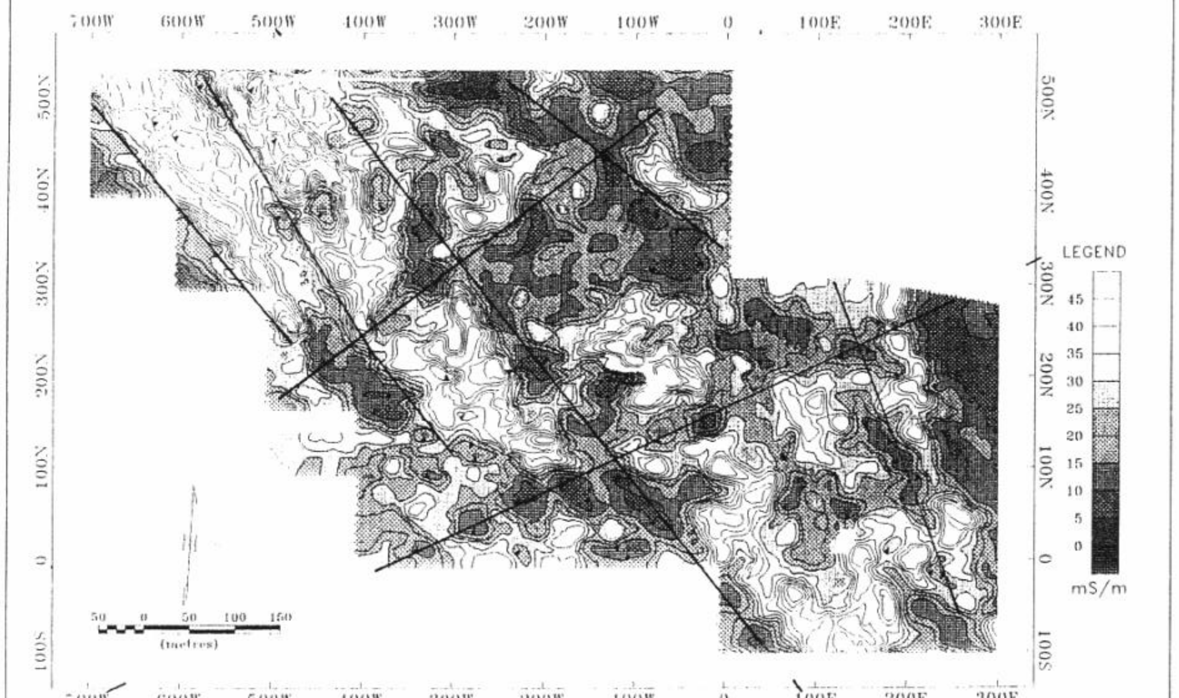
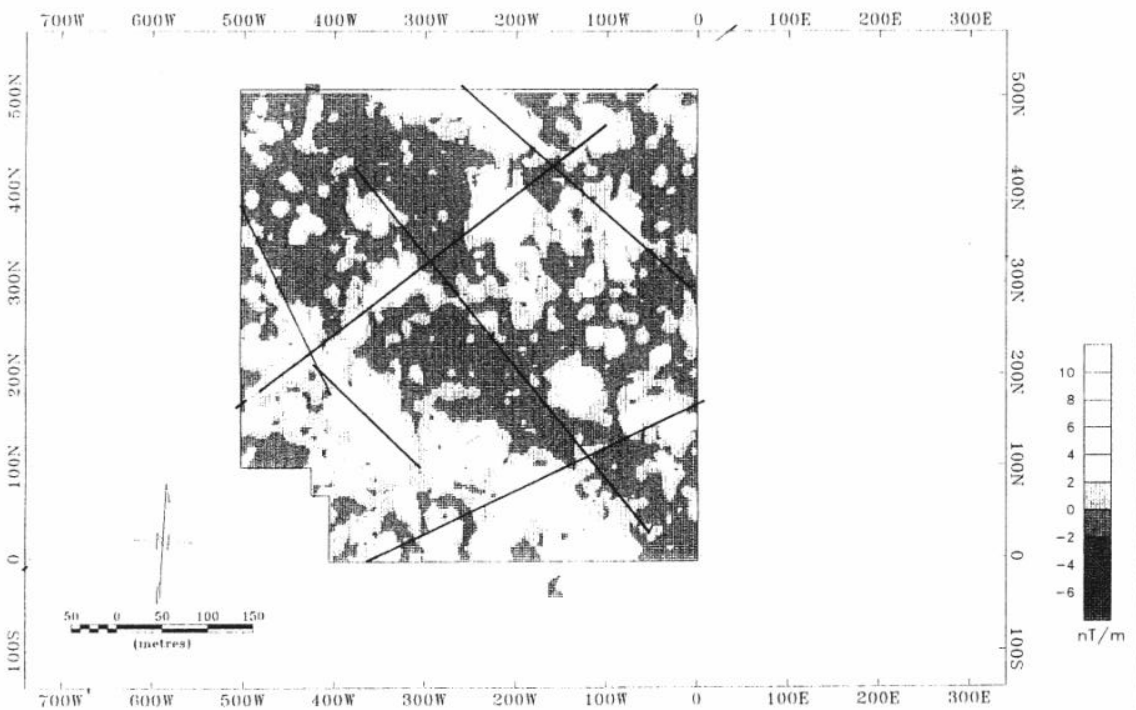


Figure 2: 3-D analytic signal map of the total magnetic field. Lineaments correlate particularly with low conductive zones.



Apparent conductivity map

Instrument type: EM31 conductivity meter
Configuration: Vertical dipole mode
Station interval: 1 and 5 m.
Line spacing: 10 m.
Contour interval: 5 mS/m
Grid cell size: 2.5 m.



3-D analytic signal of the total magnetic field

Gridcell size: 2.5 m

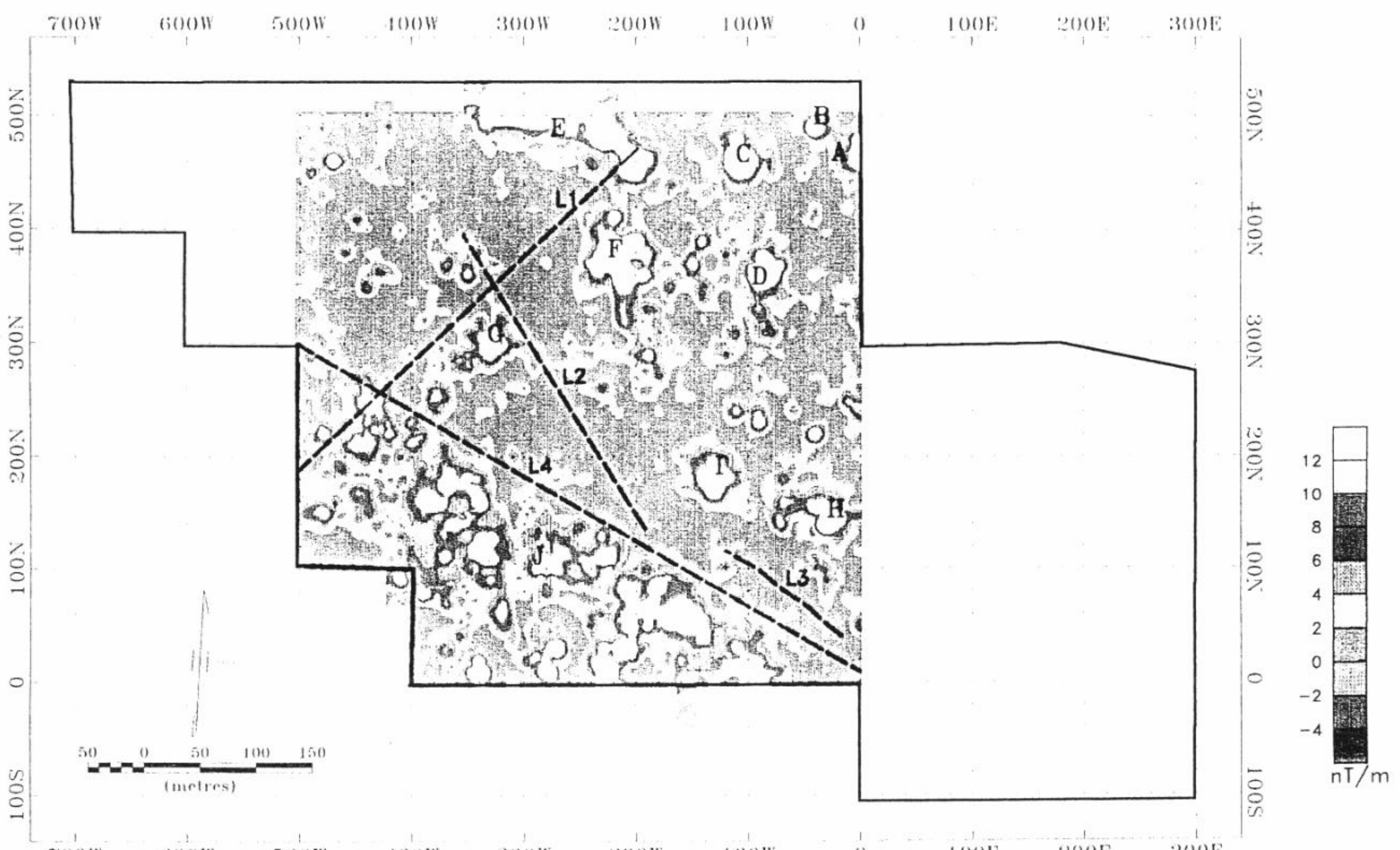


Fig.5.4 3-D analytic signal of the total magnetic field

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