After the GPR data processing procedures applied as mentioned previously, the interpretations of the 400 MHz profiles were carried out on the basis of horizontal variations and appearance of reflections. These variations and changes include: strength, continuousness, and attenuation and lateral relations. Each feature of the above-mentioned refers a special case. For example, the existence of a conductive zone such as sediment-filled cavity or water-saturated formation will be reflected as an attenuated area on the georadar section. The air-field cavities can be characterized on the georadar sections through following or tracing the laterally restricted series associated with large-amplitude pulses (Ulriksen 1982; Reynolds 2011). Losing of coherency or continuity, bending and scattering of reflections are also considered indicators for existence of karstic features. The vertical and sub-vertical fractured can be seen on the georadar sections as discontinuities or displacements of reflection events in the horizontal direction (Grandjean G and Gourry J-C 1996; Grasmueck 1996).

GPR profile Rufa 1

This profile (figure 9) was conducted along the ERT profile Rufa 1 taking the same direction from west to east. In this section, different karst features could be determined at different depths. A very clear uplift and break or cut off in reflection actions is detected between 110 and 125 m horizontal distance and extends to about 1.3 m in depth. This action refers to existence of a cavity. At about 90 m horizontal distance, a small diffraction hyperbola is detected and it may reveal the existence of a cavity. The same diffraction hyperbola is repeated at about 198 m horizontal distance but with increasing depth to about 8m. Distortion and absence of coherency which are index for existence karstic features such cavities or sinkholes could be mapped at a depth between 1 and 2 m along 325 and 348 m horizontal distance respectively. The intensity of strong reflection events is very clear in the section (black dashed rectangular). This zone of intensity is associated with a fracture (the black vertical dashed line) indicated from discontinuity and displacement of horizontal reflections. In addition to this, a another anomaly associated with a vertical open fracture is located between 1 and 2 m vertical depth and 150 to 160 m horizontal distance.

GPR profile Rufa 2

This profile was carried out along the same path of the ERT profile rufa 2 taking direction from south-west to north-east. This radiograms (figure 10) contains numerous karst features. In the first part (figure 10) of this section, a small diffraction hyperbola (its apex located at 68m horizontal distance) could be delineated begins at a depth more than 3 m and extend deeper to the end of the section. Another diffraction hyperbola could also be mapped in the shallow part of this section between 170 and 180 m horizontal distance and its apex starts at .3 m depth. Distortion, discontinuity and intensity of the reflection signal could be seen in this section between 1 and 2 m vertical depth at a horizontal distance 18-24, 45-52 and 64-74 m respectively. All these events can refer karst features occurrence. The heterogeneity of the subsurface in this profile can be inferred from the dipping reflections plotted as a solid line in the graph. In the other part of this radiogram at a horizontal distance of 250m, a small diffraction hyperbola could be interpreted as a small cavity placed near the surface. Another anomaly with nearly the same characteristics is located at a 252 m horizontal distance.

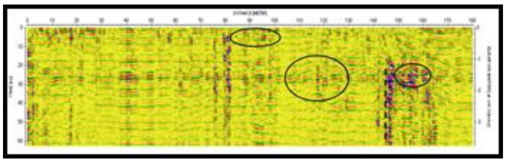
Figure 9: Part of GPR profile Rufa 1.

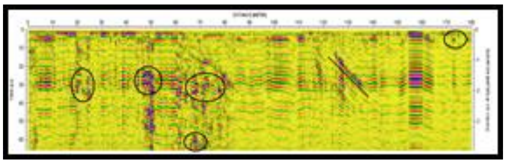
Figure 10: Part of GPR profile Rufa 2.

GPR profile Rufa 3

This radiogram is measured along the ERT profile Rufa 3 (figure 11). Generally speaking, this section is characterized with high amplitude reflection as it. The vertical and sub-vertical fractures are spread along the section. They can be delineated by tracing the discontinuity and displacement of reflection in the vertical and horizontal direction as it is shown in a black dashed line in the horizontal distances 18, 30, 157 m and 262 m. respectively. All these fractures are located very near from the surface and play as channels for water contributing finally in forming and developing the subsurface cavities.

GPR profile Rufa 4

This profile (figure 12) was conducted along the ERT profile Rufa4 but in an opposite direction. In this section, the karstic features can be noticed from discontinuity and lateral variations in reflection events. In the horizontal distance 10 m a depth ranges from 1 to 2.2 m, an uplift and lateral discontinuity could be interpreted as a cavity. The same feature is repeated within the horizontal distance 25-64 m and a depth extends from 1.2 to 2.3 m figure 18. Another karstic feature can be inferred from the intensity of the strong signal of the reflections located between 250-260 m and a depth extension equal to 1.2 m.

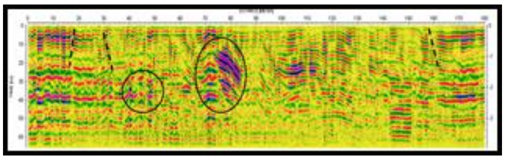

Figure 11: Part of GPR profile Rufa 3.

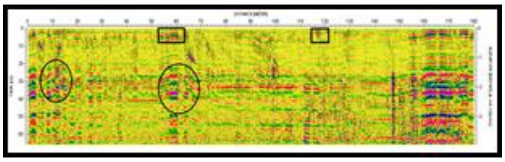

Figure 12: Part of GPR profile Rufa 4.

GPR profile Rufa 5

This GPR data section (figure 13) was measured in the same direction of resistivity line RUFA5 Figure 20 and 21. Most of the karstic features in this radiogram are in relation with the intensity of the strong signal of the reflection events as it can be seen in the horizontal distances 18-24, 46-62, and 95-108 m which agreed in depth between 0.9-1.6, 0.6-1.8, and 1-2.8 m respectively. A discontinuity in the horizontal direction associated with a displacement is mapped in the horizontal distance 80 m at depth starts at 1 m and extends to the end of the section. This may be interpreted as a fracture zone figure 20. After the horizontal distance 110 m, the section seems to be attenuated as a result of the high moisture in this part of the section which weakens the radar signal.

GPR profile Rufa 6

This profile (figure 14) was measured in the direction from west to east in agreement with ERT Rufa6. The karstic features in this profile appear nearly in the first two meters of the subsurface while the other part is attenuated. At the beginning of this radiogram, definitely at horizontal distance 9 m depth 1-1.8 m, hyperbola diffraction is located referring to a cavity occurrence. Intensity in reflection amplitude is located along the horizontal distance 24-54 and 65-80 m in a depth range from 0.6 to 1.8 m. In the second part of the section, two sub-vertical parallel fracture zones are delineated at 214 and 236 m horizontal distance respectively. A distinct uplift and discontinuity zone could be documented in horizontal distance 320 m starting at 0.9m depth and extends to nearly 2 m down.

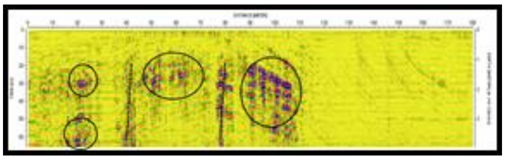

Figure 13: Part of GPR profile Rufa 5.

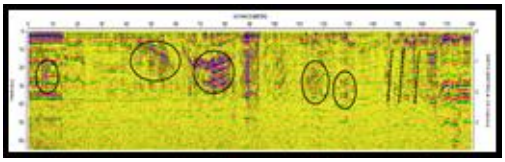

Figure 14: Part of GPR profile Rufa 6.

4. Conclusions - Electrical resistivity tomography and ground penetrating radar used in this work could be applied successfully to delineate and map the subsurface karstic features like cavities and fractured zones over the Sulaiy Formation in the Eastern Rufa Graben. Those karstic features show various sizes and located generally in the shallower part of the profiles sections. The air-filled cavities could be detected and delineated in the interpreted profiles sections were characterized with high resistive values in consideration to the whole profile. On the other hand, the non-air-filled cavities which were rare and encountered in Rufa-1 profile and Rufa-5 profile have a low resistivity value. These distinctive high and low resistive values referring to the air-filled and water-filled cavities respectively spreading through the study area agreed with relative resistivity values of many published studies around the world such as the studies achieved by [6, 7, 8]. The cavities and fractures which were appeared as a hyperbola in all the six GPR data sections or as amplification associated with uplift or discontinuity of reflection events and linear interface are similar to those documented by [8, 9].

5. References

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Scientific CV (optional)

Please write your brief Scientific CV on the back of the abstract (maximum 20 lines) and insert your picture on it too.