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Magnetic and ground penetrating Radar methods to detect shallow ancient underground cavities at Ghasr-e-Shirin town in the southwest of Iran

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Abstract

Ground penetrating radar (GPR) and magnetic methods were used at Ghasr-e-Shirin town in Kermanshah province, southwest of Iran for detecting a series of large ancient (ca 1500 years) underground cavities (Tagh). The area of study is a historical monument which is named as Emarat e Khosro. Radar and total intensity magnetic field measurements have been done on the eastern part of the complex, where some underground man-made cavities are located. Radar and magnetic profiles indicate these cavities easily. Radargrams, total magnetic map, first horizontal derivative and first vertical derivative of total magnetic field indicate the location of the anomalies, which conform with the real situation. A comparison of results of 50 MHZ and 100 MHZ radargrams shows that the latter distinguishes the anomalies better. This work is completely experimental to indicate the effect of underground cavities on radar and magnetic data. It is concluded that a combination of these methods is a proper tool for delineating underground cavities.

Key words: Ground Penetrating Radar, Cavities, Total magnetic field

روش‌های مغناطیسی و رادار در تشخیص غارهای زیرزمینی در شهر قصرشیرین در ایران

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چکیده

عمق کم زیرزمین همیشه مورد توجه بشر بوده است. این محل، محل آب‌های زیرزمینی، مواد مورد مصرف در ساختمان سازی، محل دفن زباله‌ها و صدها کاربرد دیگر است. یافت حفرات و غارهای زیرزمینی هم از نظر باستان‌شناسی و هم از نظر آب‌های زیرزمینی از اهمیت ویژه‌ای برخوردار است (نیل، ۲۰۰۴). روش رادار یکی از روش‌های با قدرت تفکیک بالا در آشکارسازی بی‌هنجاری‌های زیرزمینی است. در عمارت خسرو در شهر قصر شیرین یک‌سری محل‌های غار مانند با سن حدود ۱۵۰۰ سال وجود دارد که می‌توان از آنها درحکم مدل برای تحقیق در مورد روش رادار و مقایسه آن با روش مغناطیسی استفاده کرد. اگرچه یکی از این ساختارها از دید عادی پنهان است. شهر قصر شیرین در جنوب غرب ایران در عرض جغرافیایی شمالی ۳۴/۵ درجه شمالی و در طول ۴۵/۶ درجه شرقی قرار دارد (شکل ۱). ساختارهای ساخته شده در رس قرمز رنگ واقع شده‌اند و از قسمت شرق قابل مشاهده و دسترسی هستند (شکل ۲).

روش رادار نفوذی زیرزمینی: این روش در مناطقی به‌کار می‌رود که ثابت دی الکتریک لایه‌ها اختلاف زیادی داشته باشند. در منطقه کاوش سه نیم‌رخ به طول‌های ۵۴ متر، ۳۵ متر و ۳۰ متر در جهت شمال و جنوب پیاده شد. دو مورد اول بر هم منطبق بوده

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ولی سومی ۸ متر در جهت شرق با نیم‌رخ اول فاصله دارد. سیستم مورد استفاده RAMAC GPR ساخت کشور سوئد است و از دو آنتن ۵۰ مگا هرتز و ۱۰۰ مگا هرتز پوششی استفاده شده است. در هر نقطه طبق تنظیم قبلی ۱۶ نگاشت بر روی هم جمع‌آوری می‌شود تا سیگنال به نوفه بهبود یابد.

پردازش داده‌های رادار: بسته نرم‌افزاری لرزه‌ای سندمیر (سندمیر، ۱۹۹۷) برای پردازش و تفسیر داده‌های رادار مورد استفاده قرار می‌گیرد. پردازش برای اجتناب از تفسیر غلط داده‌ها مورد نیاز است. از صافی میان گذر ۳۰ تا ۸۵ مگاهرتز برای صافی داده‌ها استفاده شد. از صافی بهره خودکار (AGC) برای تقویت داده‌های انتهای نگاشت‌ها استفاده شد. صافی مهاجرت برای حذف پراش‌ها و برگرداندن شیب‌ها به مقدار واقعی بهره می‌بریم.

نیم‌رخ اول: آنتن ۵۰ مگاهرتز غیر پوششی (unshielded) برای یافت بی‌هنجاری‌های این نیم‌رخ به‌کار گرفته شد. شکل ۳ رادارنگاشت خام این نیم‌رخ را نمایش می‌دهد. بی‌هنجاری‌های موجود با حروف لاتینی نمایش داده شده‌اند. سرعت موج در این نیم‌رخ با استفاده از روش نقطه میانی (CMP)m/ns ۰/۰۶۱ به‌دست آمده است که برای یافت عمق بی‌هنجاری استفاده می‌شود.

نیم‌رخ دوم: این نیم‌رخ در همان مکان و امتداد پروفیل ۱ ولی با طول ۳۳ متر پیاده شده است. آنتن مورد استفاده ۱۰۰ مگاهرتز غیر پوششی است و نگاشت حاصله در شکل ۴ آمده است. در این شکل مرزها واضح نیستند. برای وضوح بهتر از همه صافی‌ها به غیر از صافی میان گذر استفاده شده است. شکل ۵ نگاشت حاصل را نمایش می‌دهد که در آن بی‌هنجاری‌ها با حرف لاتینی آمده‌اند. پنج ساختار تو خالی در نگاشت دیده می‌شود ولی یک ساختار تو خالی در نگاشت هست که در مشاهدات صحرایی وجود ندارد ولی به‌نظر می‌رسد که عمداً پوشیده شده است (شکل ۲). ابعاد به‌دست آمده از نگاشت رادار در جدول ۱ آمده است.

نیم‌رخ سوم: این نیم‌رخ در ۸ متری غرب دو نیم‌رخ قبلی است و هیچ‌گونه به هنجاری در رادار نگاشت آن وجود ندارد (شکل ۶).

روش مغناطیس‌سنجی: جهت آشکارسازی بی‌هنجاری‌ها از روش اندازه‌گیری میدان کل مغناطیسی زمین در محل نیم‌رخ‌های رادار نیز استفاده شده است. پذیرفتای مغناطیسی خاک بستر ساختارها $5/90\times10^{-4}$ SI است در حالی که دیوارها و سقف آنها دارای مقدار $12/56\times10^{-6}$ SI هستند که دومی به‌علت ساختار رسوبی سنگ‌های به‌کار رفته است. پذیرفتای مغناطیسی با دستگاه بارتینگتون (Bartington MS2) ساخت کشور انگلستان اندازه‌گیری شده است. میدان کل مغناطیسی توسط مغناطیس‌سنج پروتون با دقت یک صدم نانو تسلا اندازه‌گیری شده است. فاصله قرائت‌ها پنج سانتی متر بوده است. نقشه میدان کل حاصل از سه نیم‌رخ در شکل ۷ آمده است که مکان اکثر بی‌هنجاری‌ها در آن مشخص است. نبود بعضی از بی‌هنجاری‌ها احتمالاً به‌علت عدم وجود تباین مغناطیسی بین تاق‌ها و بستر رسی است. شکل‌های ۸، ۹ و ۱۰ میدان کل، گرادیان افقی میدان و گرادیان عمودی نیم‌رخ اول را نمایش می‌دهند.

نتیجه‌گیری: روش رادار روش مفیدی برای تشخیص حفرات و ساختارهای تو خالی در تشکیلات مقاوم است. پارامترهای هندسی این بی‌هنجاریها به‌راحتی در صورت فراهم بودن شرایط فیزیکی و عمق کم قابل محاسبه و اندازه‌گیری است که با شرایط واقعی اختلاف چندانی ندارند. این تحقیق نشان می‌دهد که استفاده از آنتن بسامد زیادتر به افزایش قدرت تفکیک می‌انجامد. روش مغناطیس‌سنجی هم در صورت وجود تباین مغناطیسی بین بی‌هنجاری و بستر آنها به آشکارسازی بی‌هنجاری‌ها می‌انجامد ولی دقت روش رادار از مغناطیس بسیار بیشتر است. تنها محدودیت روش رادار عمق کم کاوش است.

واژه‌های کلیدی: رادار نفوذی زیرزمیی، غارها، میدان کل مغناطیسی

1 INTRODUCTION

Man always paid special attention to the shallow subsurface of the earth. This part of the earth is the place of constructional rocks and materials, underground water resources, storage of waste material and layers of sediments. In addition, the study of rocks and accumulation of shallow underground sediments gives information about the earth's history and the dynamical behavior of its surface (Neal, 2004). Most studies have been focused on determining the location and distribution of cavities in karst formations (Robert and Bosset, 1994; Holub and Dumitrescu, 1994; Beres et al., 2001; Al-fares et al, 2002). In our study the formation is a clayey soil than karstic. We locate the location of the anomalies and their dimensions. In our work, the underground structure (Tagh) which is visible naturally from one side (the eastern part) gives us enough information about the correctness of our interpretation. Due to the susceptibility and electrical contrast of the structure of the underground cavities with their adjacent layers, we are able to delineate the cavities by magnetic and GPR geophysical methods. The result of this work can be used for detecting hollow underground facility and subsurface cavities which are not visible at the surface. In Ghasr-e-Shirin and other parts of Iran there are many places, which can be a target for this method.

There are many ancient underground shallow water passages in Iran which have cannot be seen from the ground surface. Some of these places are now used for engineering purposes such as power plants, dams, airport landing strips and so on. The hollow structure which is investigated in this paper is similar to the above structures and can be used as a model for geophysical detection.

2 STUDY AREA

Ghasre Shirin is located in the south west of Iran at 34.5ºN and 45.6ºE coordinates (figure 1). The underground man-made hollow structures (Tagh) were built in reddish argillites. On the top of the most of the cavities, there is a thin layer of soil. The width of each cavity is about 5.5m and 3.5m westward and eastward respectively and their height is about 2.5m. As we mentioned before, we can access the cavities easily from the eastern part (figure 2). The strike of the anomalies is approximately in an east-west direction. In figure 2 only a part of the hollow structures is seen.

Figure 1. The location of Ghasre Shirin.

Figure 2. A view of the investigated area. The circle shows the covered cavity.

3 GROUND PENERATING RADAR METHOD

Ground penetrating radar is applicable in this environment since a significant contrast in dielectric constant exists between the air and the surrounding soil.

The main aim of this research is to investigate whether we can use the GPR method for finding the geometrical parameters of a hollow man-made structures or not. Three north-south profiles with different lengths 54m, 35m and 30m have been used for this work. The first and second profiles only have different lengths but have the same position and strike (north-south direction) but the third one is in the same direction which is supposed to be far away from the anomalies. This profile is at 8m distance with the other ones westward. Ramac GPR™ system from Malå Geoscience, in Sweden was used for this investigation. 50MHZ and 100MHZ unshielded antenna, 2.0m and 1.0m antenna separation and a 0.2m trace spacing were employed to scan the underground anomalies. At each measuring point, 16 vertical stacks were sufficient to achieve the desired signal to noise ratio.

3.1 DATA OROCESSING

Reflex, a PC-based seismic package (Sandmeier, 1997), was used for the GPR data processing and interpretation. The processing is essential to avoid introducing any artifacts into the data. Initially horizontal scale normalization was done to correct any differences in the movement speed of the antennas during data collection. The data were then band-pass filtered (30-85 MHZ) to cut out very high and very low frequencies. Diffraction stack migration was then applied to the data to move steeply dipping reflections to their true subsurface positions and to remove hyperbolic diffractions. Finally, a slight automatic gain control (AGC) function was applied to compensate for the loss in amplitude at depth due to spherical divergences, scattering and dielectric loss, as well as amplitude loss during some data processing steps, such as migration. As the ground surface is approximately flat, no static correction is necessary.

The multi-offset profiles were used to perform velocity determination of the subsurface which is necessary for time-depth conversion.

3.2 PROFILE 1

50MHZ module was used initially on the first profile (54m length) to cover underground anomalies. This profile has a north south direction and its distance from the eastern edge of the structure is about 10 cm. Figure 3 shows the radargram along this profile without any filtering. Figure 4 depicts the radargram after data filtering in which the anomalies were marked a,b,c,d,e,f, and g.

A common midpoint (CMP) survey was conducted in the middle of profile 1, and subsequent velocity analysis yielded a velocity of 0.061 m/ns (figure 5) is used to estimate the thickness of the top of the cavities.

As the exact position of the cavities did not appear very clear on the first profile, we used a higher frequency radar module (100MHZ) to obtain a better image of the anomalies.

3.2 PROFILE 2

This profile is at the same position as the first one but with a shorter length (33m). 100MHZ unshielded antenna was used to scan the underground structures. The radargram is shown in figure 6. All the mentioned filters except the band-pass filter were applied on the radargram. We have found a clear image of the underground anomalies in this radargram (figure 7). Six hollow structures are recognized on the radargram of which only five are seen from field observation. Field observation showed that one of the cavities was covered (figure 2) which can be recognized on the radargram. The dimensions of the cavities are given in Table one. The anomalies are shown in letters on the radargram.

The overburden thickness, distance from the first point of measurement and horizontal extension of each anomaly are shown in table 1.

The third profile, which is in at a distance of 8m west of the first profile, is used to study whether the cavities extend toward the west or not. The radargram of this profile is shown in figure 8, which shows no trace of the underground cavity.

Table 1. The geometrical parameters of each anomaly.

	Overburden Thickness (m)	**The middle position from the first point of measurement (m)**	**Horizontal extension (m)**
Anomaly (a)	0.31	1.44	3.8
Anomaly (b)	0.31	6.80	5.31
Anomaly (c)	0.31	12.79	2.96
Anomaly (d)	0.31	18.02	1.90
Anomaly (e)	0.31	24.40	3.35
Anomaly (f)	0.31	30.55	4.24

4 MAGNETIC METHOD

The reddish soil has an average volume susceptibility of χ =5.90×10-4 SI while the wall and top of the cavities, which are open from the eastern part, have an average relatively low susceptibility of χ =12.56×10-6 SI due to small and medium sedimentary rocks 10 to 20cm of length in the host. Susceptibilities of the soil and the roof of the cavities were measured by the Bartington MS2 magnetic susceptibility system (Bartington operation manual). Therefore, in principle it is possible to detect these anomalies magnetically.

The portable overhauser magnetometer system GSM-19 V6.0, (GEM System Inc.) manufactured in Canada was used for magnetic investigation with accuracy of 0.01nT. This system is equipped with GPS and is able to measure the total magnetic field and field gradient. Data collection was done on three profiles, 35m in length, and the distance between profiles is 1m. The distance between data reading on each profile is 0.5m. A base station was established near the profiles for secular variation measurements and the collected data were corrected with the information from the base station using GEMLinkw3.0 software from GEM company.

The total field magnetic map of the three profiles (figure 9) shows the anomalies at about 8m, 13m, 20m and 30m which are the same as the radar results. Some of the anomalies are not recognized on this map due to lack of contrast in magnetic susceptibility of the anomalies with the surrounding bed. Now each magnetic profile is explained individually. Reduction to pole is the first filter that must be applied to the data before any processing. This filter moves the anomalies to their correct position. The dipolar nature of the magnetic field causes the anomalies to displace horizontally from their initial position (Baranov, 1957). Due to lack of space, only for profile 1, the total field, the horizontal gradient and the vertical gradient of the anomaly are shown. For profiles 2 and 3 only the total magnetic anomaly is shown.

4.1 PROFILE 1

The total magnetic anomaly of this profile shows two anomalies at 8.5m and 19.5m in which at the first one the magnetic field variation is stronger than the second one (figure 10, letters a and b). The first vertical derivative and the first horizontal derivative of the total field give the same results (figures 11 and 12). In this profile only two anomalies are recognized.

4.2 PROFILE 2

The total magnetic anomaly of this profile shows the first anomaly at 1.5m while the second one is at 13m (figure 13). The first horizontal derivative and the first vertical derivative of the total field give the same results as the total magnetic field.

4.3 PROFILE 3

The total magnetic anomaly of this profile shows the anomalies at 3.45m, 7.50m and 20m (figure 14). Again the first horizontal derivative and the first vertical derivative of the total field give the same results as the total magnetic field.

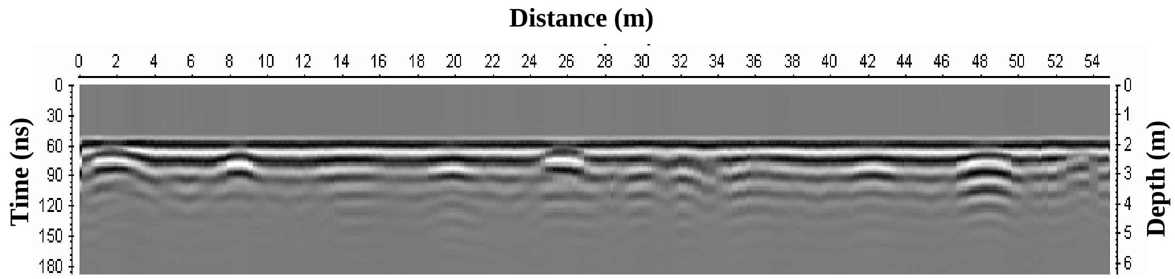

Figure 3. Radargram of 50MHZ unshielded antenna on profile 1. The horizontal axis (m) is the profile direction and the right vertical axis is the depth (m) while the left one is the time (ns) axis. In all the shown radargrams this notation is valid.

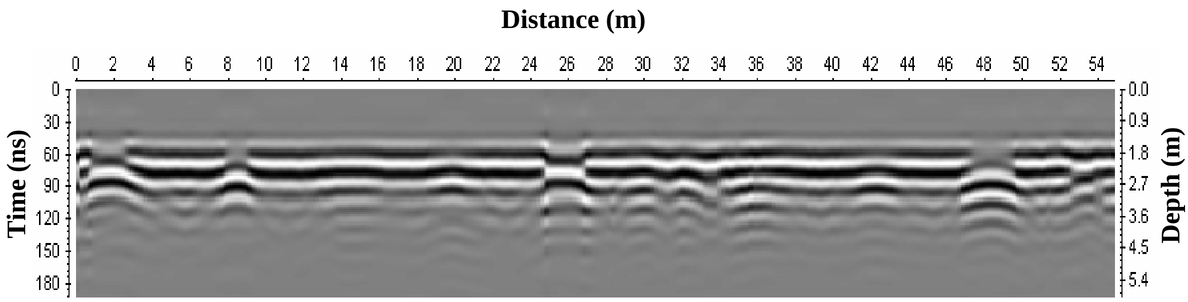

Figure 4. Radargram of 50MHZ unshielded antenna on profile 1 after required filtering.

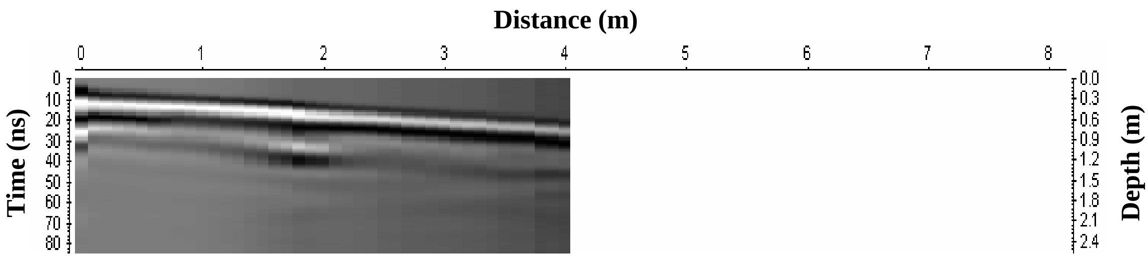

Figure 5. CMP survey to calculate formation velocity.

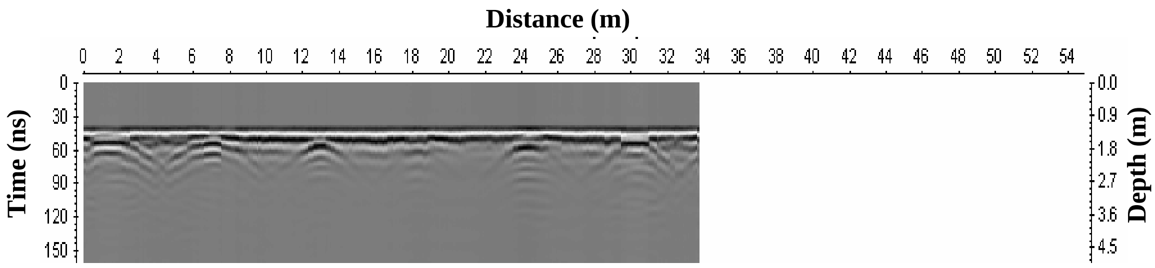

Figure 6. 100MHZ unshielded antenna on profile 1.

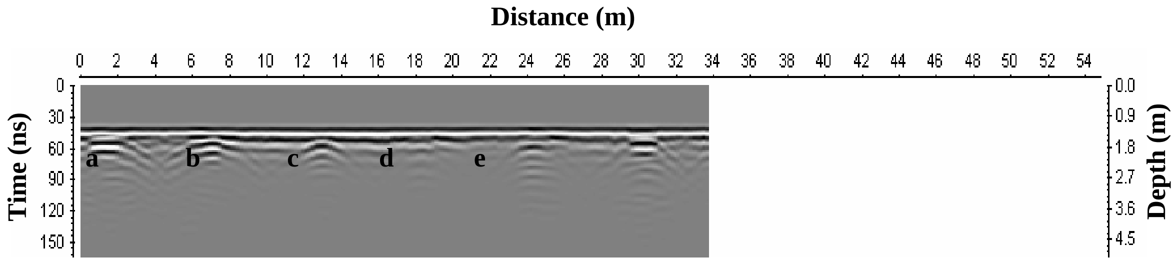

Figure 7. 100MHZ unshielded antenna on profile 1 after filtering.

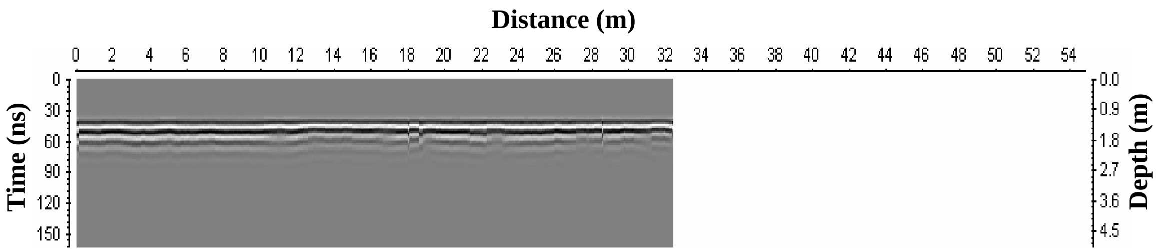

Figure 8. Radargram of profile 3.

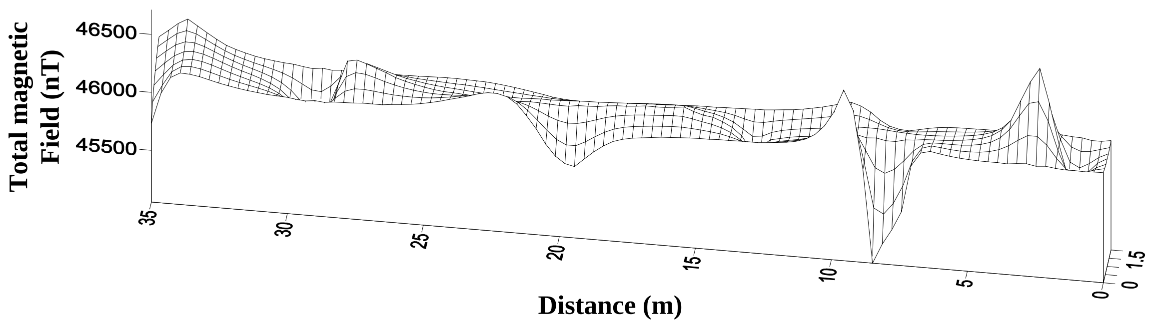

Figure 9. Total magnetic map of the investigated area.

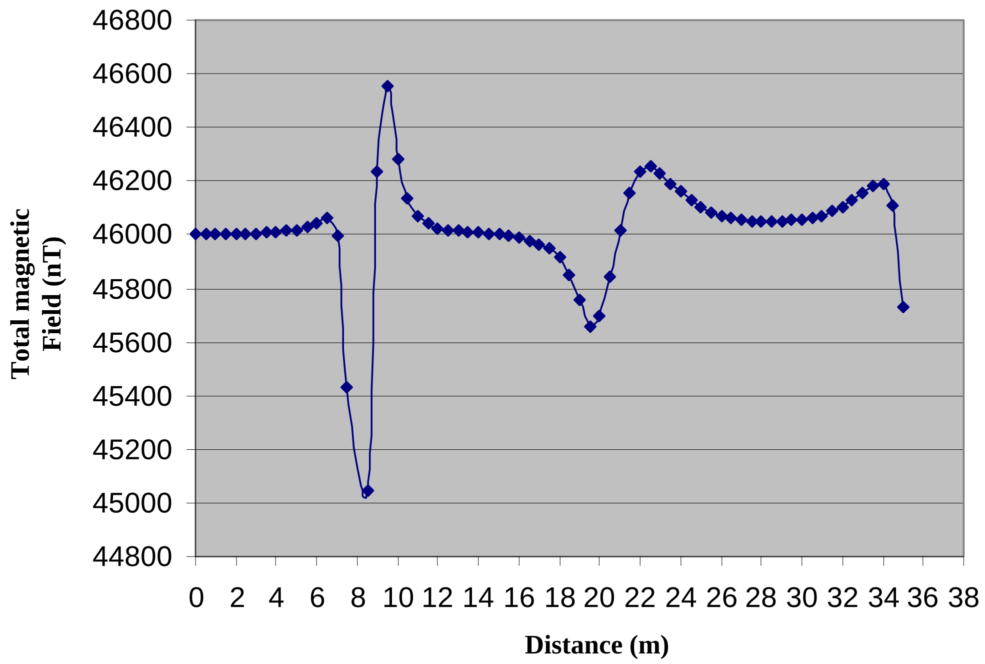

Figure 10. Total magnetic field of profile1. The solid squares are the data point positions.

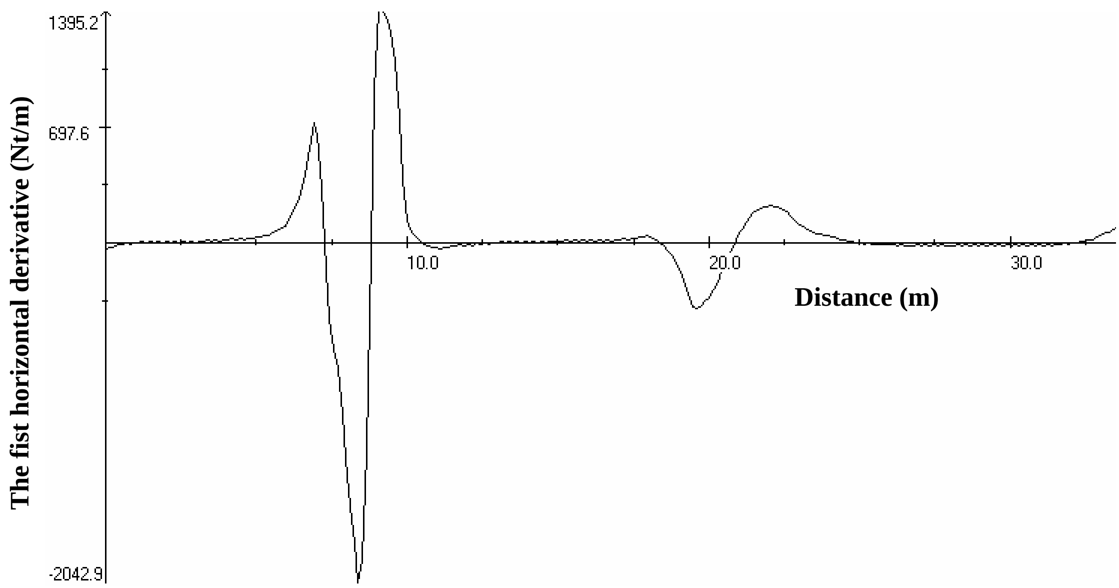

Figure 11. The first vertical derivative of the total magnetic field of profile 1.

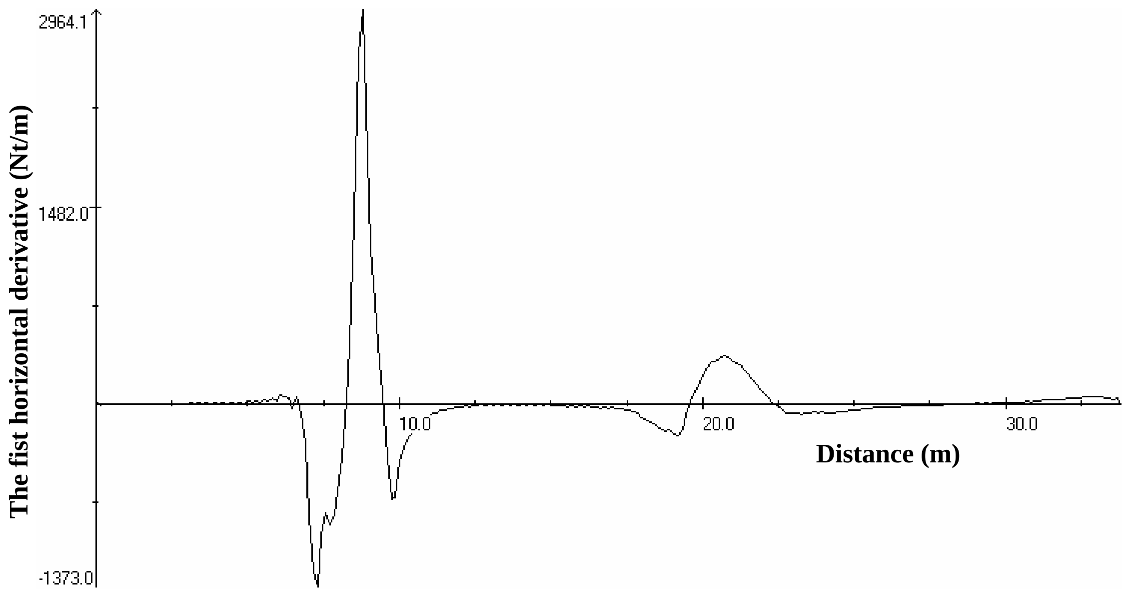

Figure 12. The first horizontal derivative of the total magnetic field of profile 1.

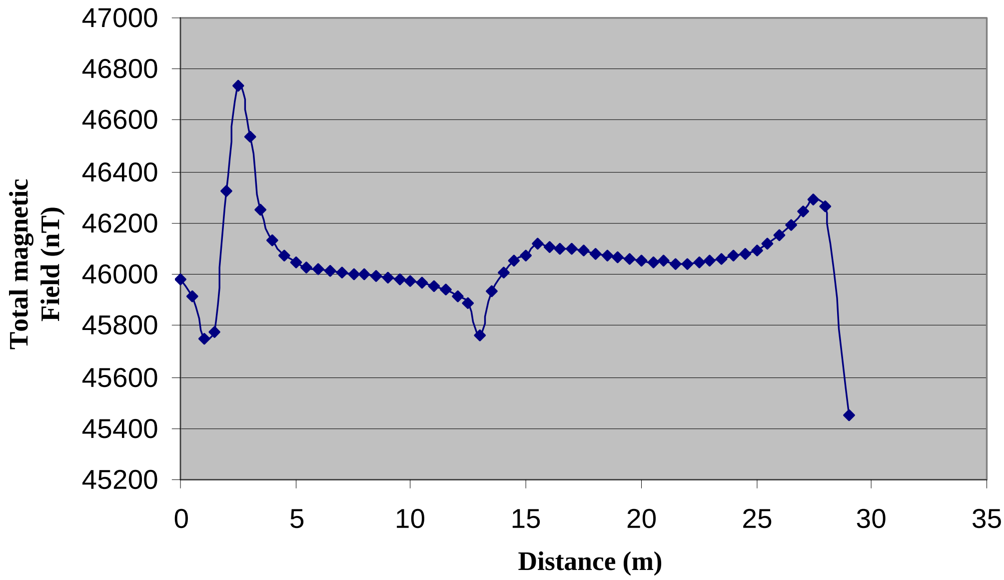

Figure 13. Total magnetic field of profile 2. The solid squares are as figure 1.

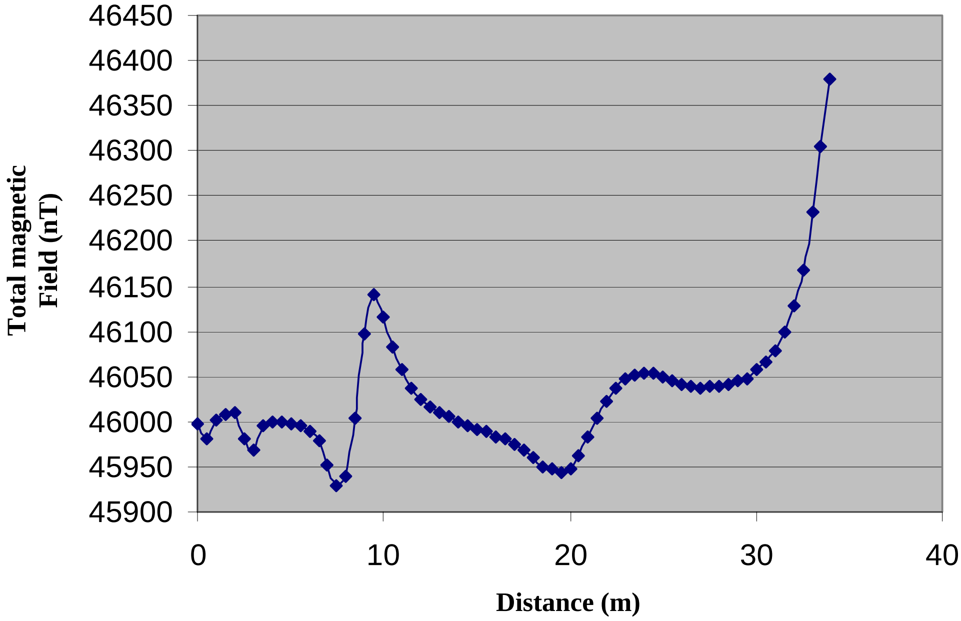

Figure 14. Total magnetic field of profile 3. The solid squares are as figure 1.

DISCUSSION

When we compare figure 6 (100 MHZ radargram) with figure 4 (50 MHZ radargram), a tagh is seen on the former while nothing appears on the latter. There is an anomaly on the radargram of figure 6 at 13m horizontal position while on the radargram of 50MHZ this anomaly does not appear. On the radargram of figure 4 at horizontal positions 24m and 30m it seems that the two anomalies are adjacent to each other while on figure 6 they are completely separated. Therefore, it is obvious that the 100 MHZ unshielded antenna reveals the anomalies better than the 50 MHZ one. This conclusion is physically reasonable as the 100 MHZ antenna has a shorter wavelength than the 50 MHZ antenna which gives the higher resolution.

As is seen from the results, profile 1 and 3 of magnetic data give the same position of anomalies but profile2 does not have any result in common with the other two. We concluded that each magnetic profile only detects some of the anomalies and a combination of the results of the profiles gives a picture of the subsurface. However, the radar method reveals the caves better than the magnetic method. At least in this research work, the magnetic method does not give any additional information. Both of the radar antennas which were used on the anomalies revealed them clearly but the 100 MHZ module gives better results than the 50 MHZ one.

5 CONCLUSIONS

The radar method is a useful method for recognizing shallow underground cavities. The geometrical parameters of the anomalies at the study area can be obtained easily by the radar method (Table 1). GPR radargrams with proper frequency give the anomalies parameters which are not different from the real situation. This work reveals that the unshielded antenna with 100 MHZ frequency is better than the 50 MHZ module from viewpoint of resolution due to the shorter wavelength of the module. The magnetic method also used for detecting the underground anomalies but it is not as effective as the radar method. This method only reveals some of the anomalies. The reason is probably due to the lack of susceptibility contrast of the taghs with the adjacent environment.

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REFERENCES

Al-fares, W., Bakalowicz, M., Guérin, R., and Dukhan, M., 2002, Analysis of the karst structure of the Lamalou area (Hérault, France) with ground penetrating radar. J. Appl. Geophys., **51**, 97-106.

Baranov, V., 1957, A new method for interpretation of aeromagnetic map: Pseudo-Gravimetric anomaly: Geophysics, **22**, 359-383.

Bartington Instrument LTD, Operation manual for MS2 magnetic susceptibility system, England, Internet: http://www.bartington.com.

Beres, M., Luetscher M., and Olivier, R., 2001, Integration of ground penetrating radar and microgravimetric methods to map shallow caves, J. Appl. Geophys., **46**, 249-262.

GEM Systems Inc. 52 West Beaver Creek Rd. Unit 14, Richmond Hill, Ontario, Canada, L4B 1 L9.

Holub, P., and Dumitrescu, T., 1994, Détection des cavités á l' aide de mesures électriques et du géoradar dans une galerie d' amenée d' eau. J. Appl. Geophys., **3**, 185-195.

Robert, A., and de Bosset, C., 1994, Application du géoradar á la location de cavités, de nids de gravier et de zones karstiques. J. Appl. Geophys., **31**, 197-204.

Neal, A., 2004, Ground-penetrating radar and its use in sedimentology: principles, problems and progress, Earth Sci. Rev., **66**, iss. 3-4, p. 261-330.

Sandmeier, K. J., 1997, REFLEX Version 4 program for processing and interpretation of Reflection and Transmission Data, Karlsruhe, Geophysical Institute, University of Karlsruhe, Germany, 265 pp. Enviromental and Engineering Geophysical Society, 10200 W. 44th Ave., #304 Wheat Ridge, CO, USA 80033.