Journal of the Earth & Space Physics. Vol. 35, No. 3, 2009, P. 13-22

Modeling of bedrock topography in an urban area through micro-gravity data

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(Received: 6 Jan 2008 , Accepted: 24 Jan 2009)

Abstract

Micro gravity data was collected in a crowded street in Tehran where a subway terrain tunnel is to be excavated. The data is corrected for the gravity effects of the surrounding densely built up area with diverse buildings and the Bouguer gravity anomalies are computed. The residual gravity anomalies are prepared by removing a trend surface. Upward continuation is used to remove the gravity effects of shallow synthetic anomalies such as subsurface galleries and canals. Then the up-ward residual gravity anomalies are used to determine the depth of the bedrock (Hezar Darreh formation). A 2D inversion algorithm is applied on the data and the model is constrained based on prior geology information provided from the bore holes.

Key words: Microgravity, Bedrock topography, Urban area, 2-D inversion

مدل‌سازی سنگ کف در منطقه شهری با داده‌های میکروگرانی‌سنجی

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(دریافت: ۸۶/۱۰/۱۶، پذیرش نهایی: ۸۷/۱۱/۵)

چکیده

داده‌های میکروگرانی‌سنجی در یک خیابان شلوغ در تهران که در آینده تونل زیرزمینی مترو در زیر آن حفر خواهد شد برداشت شده است. بعد از اعمال تصحیحات اولیه که شامل حذف اثر ساختمان‌های مجاور خیابان نیز می‌شود، مقادیر بی‌هنجاری‌های بوگه محاسبه شده است. سپس با حذف اثر منطقه‌ای بی‌هنجاری‌های باقی‌مانده محاسبه شده‌اند. روش ادامه فراسو برای حذف نوفه‌های سطحی حاصل از تأسیسات زیرزمینی کم‌عمق به‌کار رفته است. داده‌های فراسوشده با استفاده از روش معکوس دوبعدی و اطلاعات اولیه زمین‌شناسی حاصل از گمانه‌ها برای مدل‌سازی سنگ کف به‌کار رفته و عمق سنگ کف (در بین آبرفت‌های سطحی تهران و کنگلومرای هزاردره) که در گمانه‌های حفر شده مشخص نشده ، تعیین شده است. باوجود تباین چگالی ضعیف بین آبرفت‌های سطحی و سنگ کف مرز مربوطه کاملاً مدل‌سازی شده است.

مدل‌سازی سنگ کف منجر به تعیین توپوگرافی آن می‌شود که به‌منظور حفر تونل مترو اطلاعات دقیق از این توپوگرافی کاملاً ضروری است.

واژه‌های کلیدی: میکروگرانی‌سنجی، توپوگرافی سنگ کف، منطقه شهری، معکوس دوبعدی

1 INTRODUCTIO

The determination of bedrock topography from the observed gravity anomalies is an important procedure in regional explorations. In small scale surveys particularly in urban

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areas the basement topography has rarely been investigated. Application of micro gravity data in urban areas is problematic due to the gravity effects of the buildings and man-made excavations.

From the first stage of micro gravity surveys these effects have been considered by several researchers such as Blizkovsky (1977) and Debeglia and Dupont. (2002). Blizkovsky (1977) presented diagrams for manual calculation of gravity effects of prismatic walls, vertical shafts and horizontal galleries. Debeglia and Dupont. (2002) also referred to the gravity effect of the buildings as a critical factor for engineering and environmental micro gravity investigations. However, the effect of man-made constructions could be calculated quite readily through the expressions for the gravity effect of a rectangular prism (Banerjee and Dupont. 1977) and cylinder (Belikov, 1987). These calculations could be quite time consuming and inaccurate when the number of these constructions is very high and they are diverse such as a street in a populous area. In these areas we have to be quite careful in dealing with the computation of these effects. Some of these man-made constructions may be under the ground surface which could be treated by smoothing the data although some short-wave length natural anomalies might be lost during the smoothing process. In the case of basement topography determination, this lack of short-wave length anomalies does not play a vital role. After treating the effects of buildings, the existing algorithms for basement determination in regional scales could be used in smaller scales and micro gravity data. Some of these algorithms are the stacked prism model of Bott (1960) and the polygonal model of Talwani et al. (1959). Most of the existing algorithms that employ either of these two methods, assume that the density above the basement interface is uniform and therefore a constant density is adopted in the modeling schemes (Battacharaya and Navolio, 1975). The reality of geology differential density values at different depths should be taken into consideration in modeling procedure (Chakravarti et al 2001 and Chakravarti and Rao, 1993).

2 SITE

The site under survey is along a north-south street about 5 km in length located in the center of Tehran. The orthometric heights of the street increase gently toward the north where it reaches the foot of the Alborz mountains. A variety of man-made features such as buildings and canals exist around and under the street.

3 GEOLOGY

In general, Tehran is underlain by several layers of heterogenous deposits. According to Rieben (1955) it is settled on Quaternary alluvial deposits which from surface to depth are as follows:

- Tehran alluvial formation(C) includes young alluvial fans that starts from the southern side of the Alborz mountains and extends towards the south and covers a wide part of Tehran. It has been formed by flood deposits with a thickness of up to 60 meters with distinct fan slope and converts to low slope silty layers towards the south. This formation is formed from cobble, gravel and coarse sand cemented by fine sand and silt in the form of heterogeneous sediments.
- The heterogeneous formation exposed north of Tehran (B) which was previously known as the Kahrizak formation is placed over the eroded and folded surface of Hezar Darreh alluvial (A formation). The B formation with high hills extends along Tehran's foothills.

Its depth at some points reaches 60 meters and is formed of a mixture of gravel, sand, cobble, clay and occasionally large pieces of rock. Hezar Darre alluvial conglomerate (A) is actually the bedrock

Several bore-holes have been excavated to study the geology of the site in detail One of them is illustrated in figure1 which shows the similarity of the deposits. The similarity of the deposits (B and C) and the basement (A) which is a loose conglomerate from a petrologic point of view is the main source of error in the determination of the basement topography. As is clear from bore-hole information there is no separation between the bedrock and overlain deposits. The depth of the bore hole (T1) is 42m. The main petrologic unit in the bore hole is a very dense light brown clayey sand with gravel (GC) which includes some lenses of very dense brown clayey sand with gravel (SC) and stiff, lean clay with brown sand (CL).

Actually GC represents B and C formations and we have to determine the contact interface between GC and A. Some characteristic of these units such as water content (W), cohesion, dry density and standard penetration test (SPT) are also shown in figure1.

The desired character which is dry density varies between 1.7 to 2 (gram per cubic meter) which is very close to the density of the basement conglomerate (1.8 to 2.2). Therefore we assume a maximum -0.4 density contrast between the bedrock which is called A and overlain deposits (GC) for the next procedures.

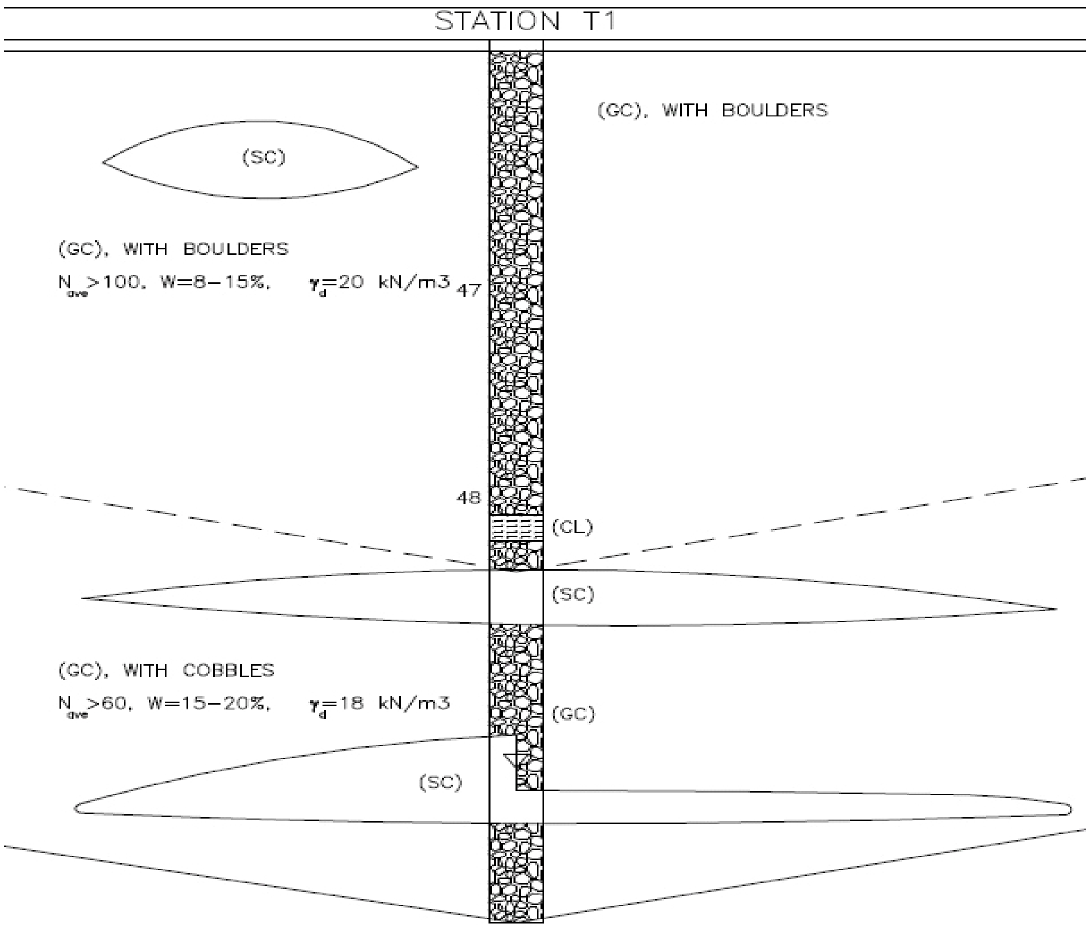

Figure 1. The bore-hole.

4 FIELD PROCEDURE

The gravity data is collected overnight by a

CG3M gravimeter along two profiles.

The long-term drift of the gravimeter was removed by using the cycling mode of the gravimeter during several days at the office at the Institute of Geophysics. For removing the short-term drift, gravity measurements at the base station were repeated several times during the working night. The maximum short-term drift during a night was 10 micro-Gal. The short term drift was computed and applied to the data using Geosoft software (Oasin montaj version 7).

These two profiles are called Left (L) and Right (R) when facing toward the north. The sampling interval along each profile is 15 m.

A base point is selected in the southern part of the street and at the lowest point of topography. All of the points were measured and corrected relative to this point.

5 DATA PROCESSING

The free-air and Bouguer corrections are computed through the classic expression,

$$\delta g_{(F+B)} = \left(0.3086 - 0.0419d\right)\Delta h, \qquad (1)$$

where d is the density and Δh is the relative height of the observation point.

Dealing with the terrain correction which is actually the gravity effect of man-made constructions around and under the site, the classic algorithms for computing the gravity effect of rectangular prism and cylinder are applied. The average effect of the building in the near-zone contribution (50 meters around the observation point) is first computed and treated as a terrain effect.

Applying the gravity corrections, the Bouguer anomalies are computed. Removing a trend surface of order 3 from the Bouguer gravity anomalies, the residual gravity anomalies are computed and shown in figure2 and 3 for profiles R and L respectively. The location of the bore-holes are marked on these figures. The residual and upward computed gravity anomalies for each profile are shown in figure4 and 5. As it is clear from these profiles the upwarded profiles are smoother. On these profiles different anomalies are distinguished based on their amplitudes and wavelengths.The most important negative anomaly can be seen on both of them toward the north in the area between the faults and we will get more information about the thickness of this zone by inverting the data.

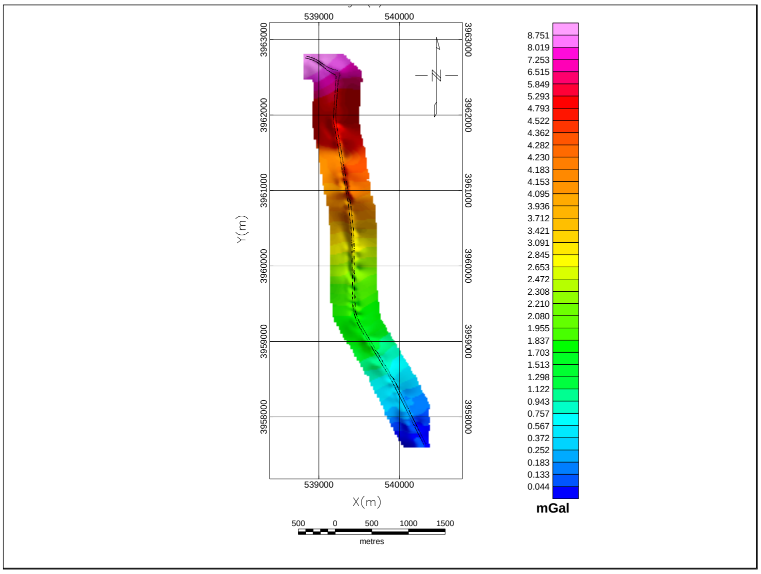

Figure 2. The Bouguer gravity anomalies.

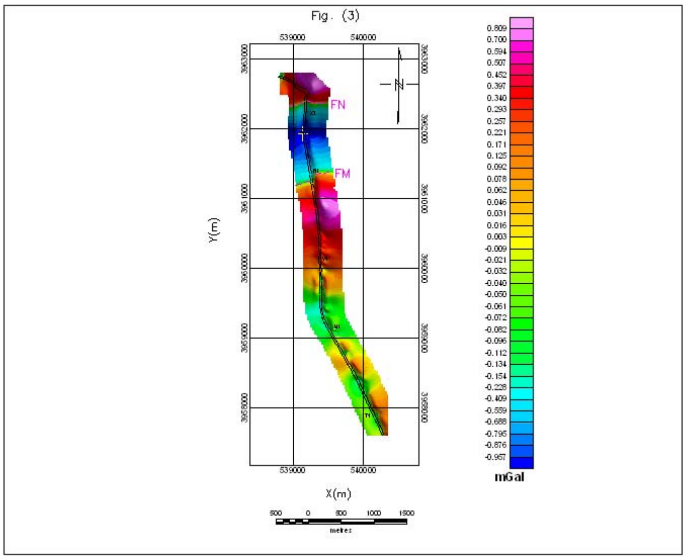

Figure 3. The residual gravity anomalies.

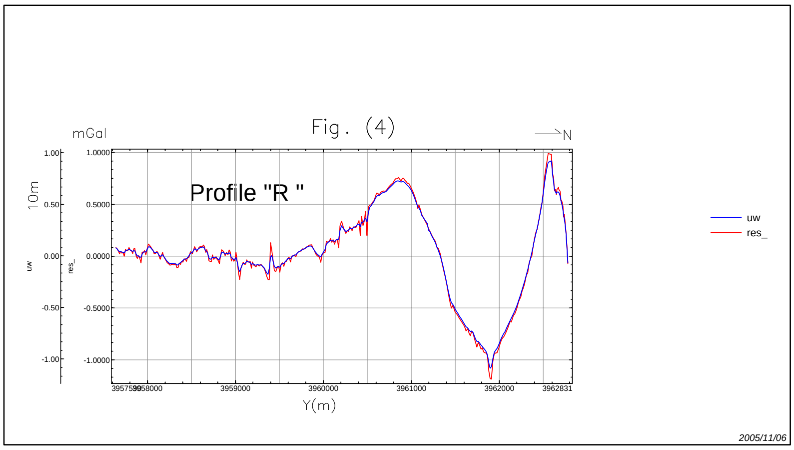

Figure 4. The residual and upward gravity anomalies for right (R) profile.

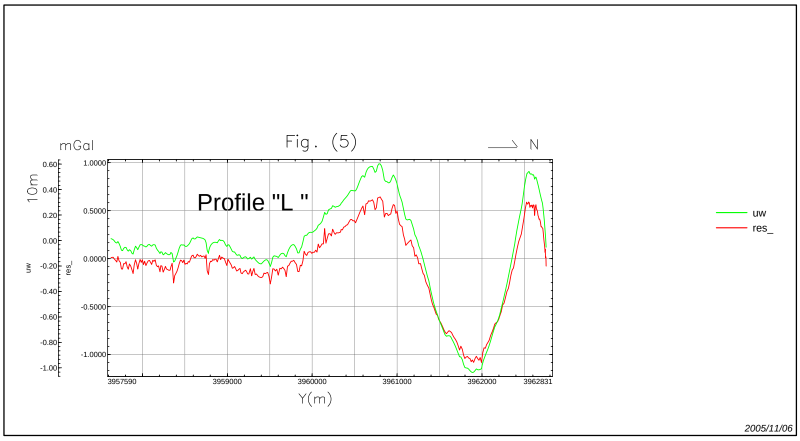

Figure 5. The residual and upward gravity anomalies for Left (L) profile.

6 INVERSION AND INTERPRETATION

The 2D gravity inversion algorithm described by Chakravarti et al (2001) is used to determine the topography of the basement (The contact between formation A with B). This algorithm uses a variable density contrast with depth and is based on the parabolic density function (Chakravarti and rao. 1993),

$$\Delta\rho(z) = \frac{\Delta\rho_0^3}{(\Delta\rho_0 - \alpha z)^2} \qquad (2)$$

where $\Delta\rho(z)$ is the density contrast observed at the ground surface and α is a constant.

In this algorithm the iteration process based on Marquardt's method (1963) continues until the following objective function becomes less than a criterion

$$\sum_{m=1}^{N} \left[g(x_m) - g_{cal}(x_m) \right]^2 < \varepsilon \qquad (3)$$

where g (x) is the observed gravity anomaly. To decrease the number of data (upward residual gravity anomalies) used in the numerical code the L and R profiles are divided into three parts. The input to the inversion algorithm are the constant α (0.1 here) and the contrast density at the ground surface (DEN, 0.4 here). The criterion for termination of iteration in the inversion procedure has been selected 0.0001 in all the cases. The process stops after a few iterations (less than 4 for all data sets) and the final objective

The results of inversion including the observed and calculated gravity anomalies and the topography of the basement are demonstrated in figures 6-11. The thickness of deposit GC (green area) in figures 6 and 9 for the parts R1 and L1 is less than 5 meters and in figures 7 and 10 for the parts R2 and L2 less than 10 meters which show the shallow depth of bedrock in these parts whereas the bore-holes T1 and V1 in these parts do not show any distinction between deposits GC and A. The deepest part of the bedrock is demonstrated in figures 8 and 11 (R3 and L3). This low gravity zone is also shown in figure 3 between faults FM and FN and is due to the thick part of the GC deposit. The maximum thickness of deposit (GC) is about 60 and 80 meters in R3 and L3 respectively.

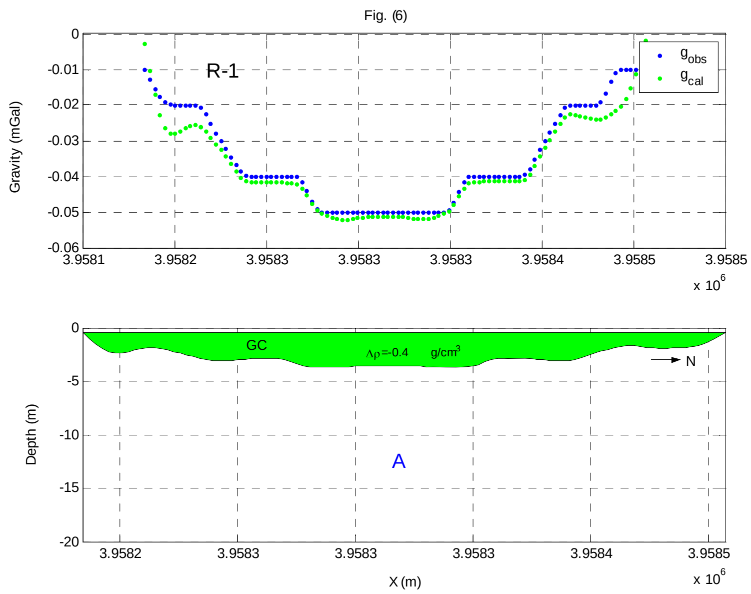

Figure 6. The residual and calculated gravity anomalies and bedrock (A) interface for R1.

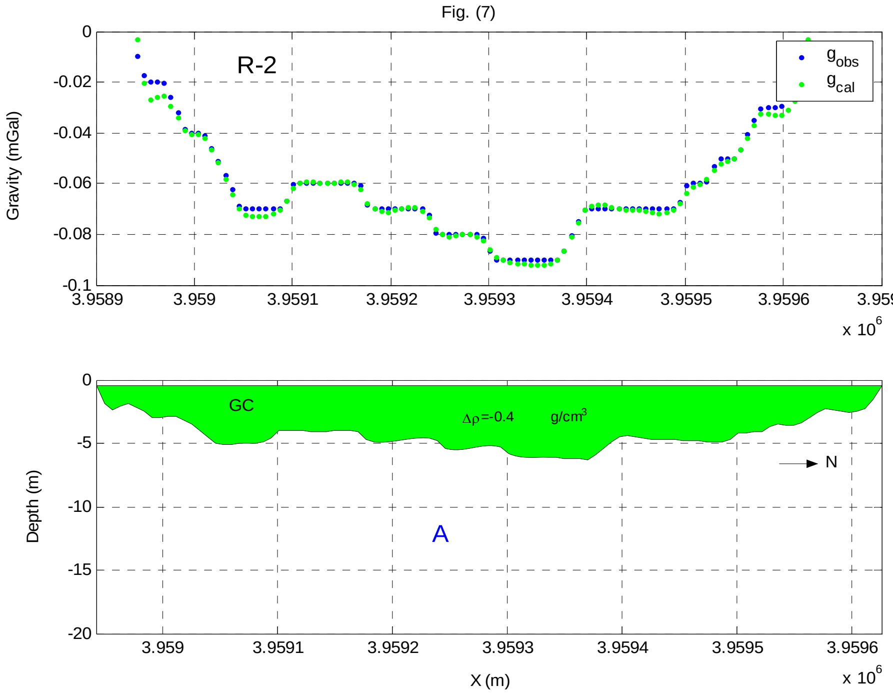

Figure7. The residual and calculated gravity anomalies and bedrock (A) interface for R2.

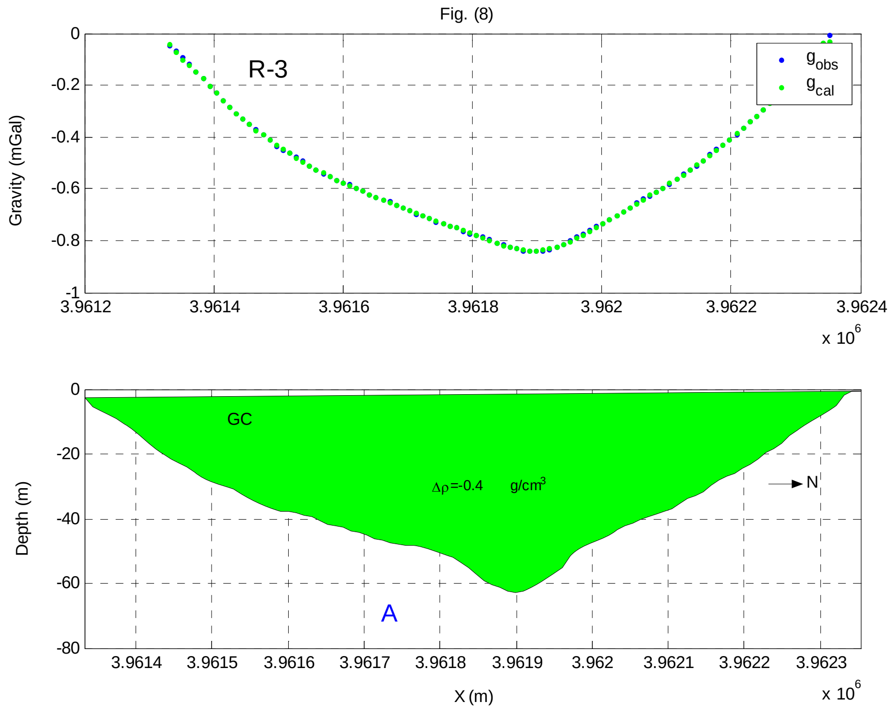

Figure 8. The residual and calculated gravity anomalies and bedrock (A) interface for R3.

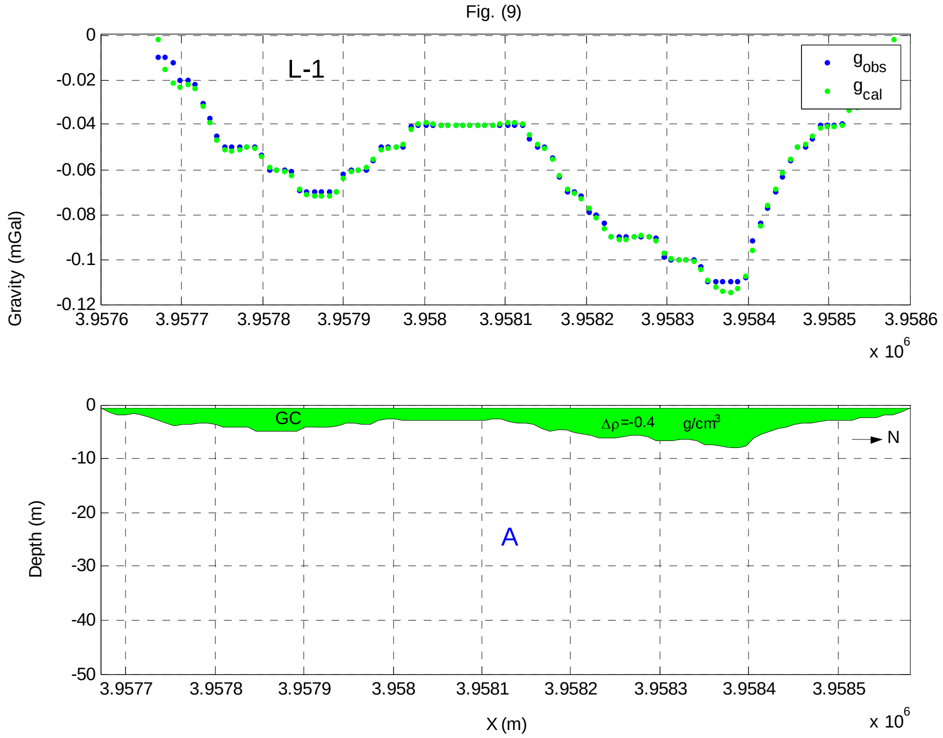

Figure 9. The residual and calculated gravity anomalies and bedrock (A) interface for L1.

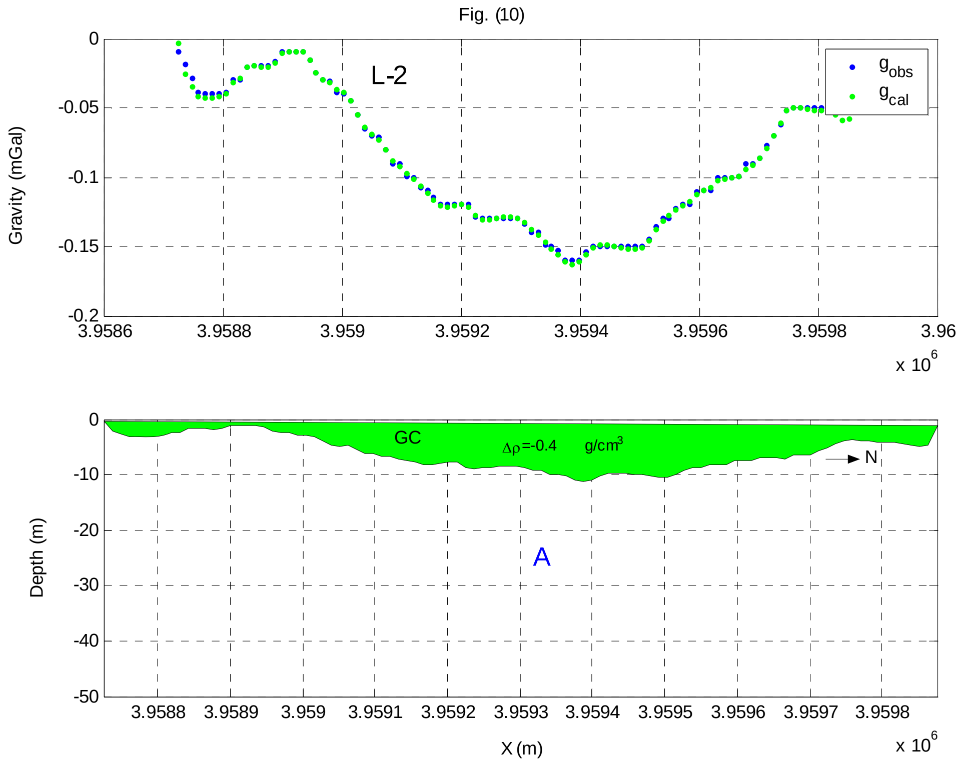

Figure 10. The residual and calculated gravity anomalies and bedrock (A) interface for L2.

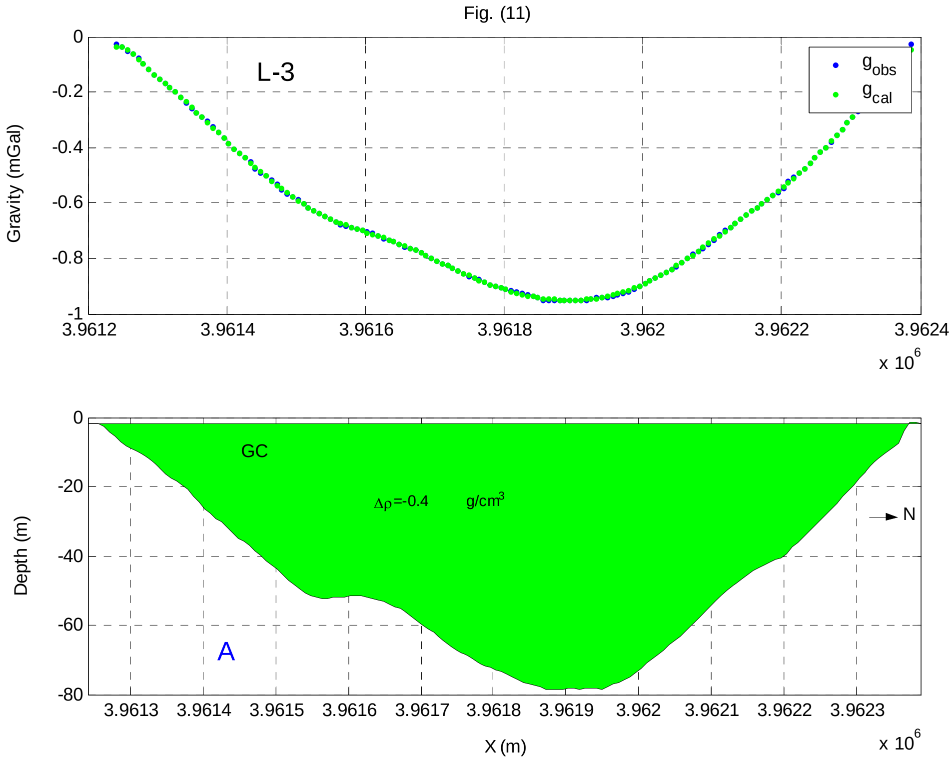

Figure 11. The residual and calculated gravity anomalies and bedrock (A) interface for L3.

7 CONCLUSION

The inversion algorithm seems to work efficiently and is capable of delimiting the bedrock interface even though there is a small density contrast between the bedrock and overlaying deposits in all areas. The real depth of the basement which is not distinguishable in bore-holes could be determined accurately. For example in bore-hole T1 all units are named as GC but the modeling results (L1, R1, L2 and R2) show a shallow distinct density contrast between the bedrock and overlain deposits (GC). A thick part of GC is determined at the north of the site and can be seen along both profiles (R3 and L3). In addition to the bedrock topography the exact position of the known faults (FM and FN) under the site are determined.

ACKNOWLEDGEMENT

The author is grateful to the authorities of Metro and Zamin Ab Pey (Zap) Company for providing the opportunity to carry out the work and Eng. Salimi and Nasooti for collecting the data and to the authorities of the Institute of Geophysics and the University of Tehran for all their support.

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