Bollettino di Geofisica Teorica ed Applicata Vol. 56, n. 1, pp. 43-54; March 2015
DOI 10.4430/bgta0135

Investigation of the topography effect on the shape and polarity of the magnetic anomalies

M. Kangazian[1], B. Oskooi[1] and L. Namaki[2]

[1] *Institute of Geophysics, University of Tehran, Iran*
[2] *Islamic Azad University, Sanandaj Branch, Iran*

(Received: May 20, 2014; accepted: January 14, 2015)

ABSTRACT Ground magnetic surveys are frequently conducted in geophysical explorations. These surveys may be implemented in rough topographical conditions, but usually the altitude of the survey is considered to be flat while interpreting. In this study, we make a conceptual study on the physics of the magnetic problem considering different topography conditions for the survey, by the modelling of the 2D and 3D synthetic sources beneath gently to rugged ground topographies. The results show that the amplitude and polarity of the magnetic anomalies can be varying significantly, where the survey surface is not flat. Variations of the magnetic anomaly can be misinterpreted in determining the dip angle and magnetization of the source body. As a consequence, the topography of the survey surface should be considered during the interpretation. Such an effect is also studied on the Damavand volcano with a severe topography in northern Iran.

Key words: Damavand volcano, magnetic anomaly, topography effect, upward continuation.

1. Introduction

The magnetic anomalies are caused when there is a magnetic contrast between rock units. Magnetic contrasts might be produced by changes in the magnetic susceptibilities or due to magnetic remanence of the source bodies. The largest magnetic contrast occurs at the interface between the Earth's surface and air. The magnetic susceptibility of the air is 0.0 SI, while rock units where magnetic data are being collected show magnetic susceptibilities of 0.0-0.2 SI (Hunt *et al.*, 1995). Surface topography variations produce magnetic anomalies which are related to the air-ground surface magnetic contrasts, and not to buried magnetic bodies that are often the targets of the survey. Although early researchers recognized that magnetic surveys could be influenced by topographic effects, the phenomena have less been taken into consideration in their interpretation and the altitude of the survey areas have been regarded flat.

Naidu and Mathew (1994) introduced the correlation filtering and attempted to remove the component of the aeromagnetic field which is closely related to the topography. This method is applicable in situations where the direction of the magnetization is variable, for instance, where the remanent magnetization is dominant. Ugalde and Morris (2008) investigated the topographic effects on the airborne and ground magnetic data and showed that disregarding the topography effects could lead to wrong conclusions in magnetic data interpretations. They demonstrated that the results derived from different filter applications, such as reduction to the pole (RTP), calculating analytic signal (ASIG), and first vertical derivative (1VD), can be misleading indeed.

Some people believe in a misconception that flying on a drape-surface (parallel to the ground surface) will not include more topographic effects and any topographic effect on the magnetic data can be corrected by the upward continuation of the data to the surface parallel to the ground (Ugalde and Morris, 2008). Although the advantage of airborne magnetic surveys on a drape survey instead of a barometric one was recognized more than 30 years ago (Ugalde and Morris, 2008), upward continuation just attenuates high frequencies.

The details of this problem which occurs in different conditions have less been discussed in scientific literatures. In the current study, the theoretical basis of the magnetic anomalies generation is expanded and a conceptual study is made on the physics of the magnetic problem considering different topography for the survey. For this purpose, 2D and 3D synthetic models beneath gently to rugged ground topography are simulated in order to investigate variations caused in the amplitude and polarity of the magnetic anomalies.

2. Theory

Most of the conventional methods use simple initial models such as 2D bodies with polygonal cross section for simulating geological structures. 2D structures have been well studied and used by geophysicists because of their simplicity (Talwani, 1965; Ku and Sharp, 1983; Tsokas and Papazachos, 1992; Blakely, 1996). These types of modelling have become widespread and much software has been developed accordingly, but in most of them the altitude of the observation surface has not been regarded. In this paper, we considered this important factor in our MATLAB code in order to investigate the topographic effects on the magnetic data.

One of the most useful ways to approximate a geological 2D structure is simulating it with a bunch of long horizontal ribbons with the similar cross section. The total magnetic anomaly is then given as below (Blakely, 1996):

$$\Delta T = \sum_{m=1}^{M} \sum_{l=1}^{N} (\hat{F}_y B_{ly}^{m} + \hat{F}_z B_{lz}^{m}), \qquad (1)$$

where, M is the number of data points, $\boldsymbol{B}_{ly}^{m}$ and $\boldsymbol{B}_{lz}^{m}$ are the horizontal and vertical components of magnetic response of the side l at datum m and $\hat{\boldsymbol{F}}_y$ and $\hat{\boldsymbol{F}}_z$ are the horizontal and vertical components of the geomagnetic field.

In order to further extension of the topographic effects on the shape and polarity of the magnetic anomalies, 3D models were synthesized in different topography surfaces. A study of aeromagnetic contour maps suggests that most of the magnetic anomalies may be interpreted as a number of magnetized prismatic models (Rao and Babu, 1993). Hence, prisms could be used extensively for modelling and interpretation of 3D magnetic bodies.

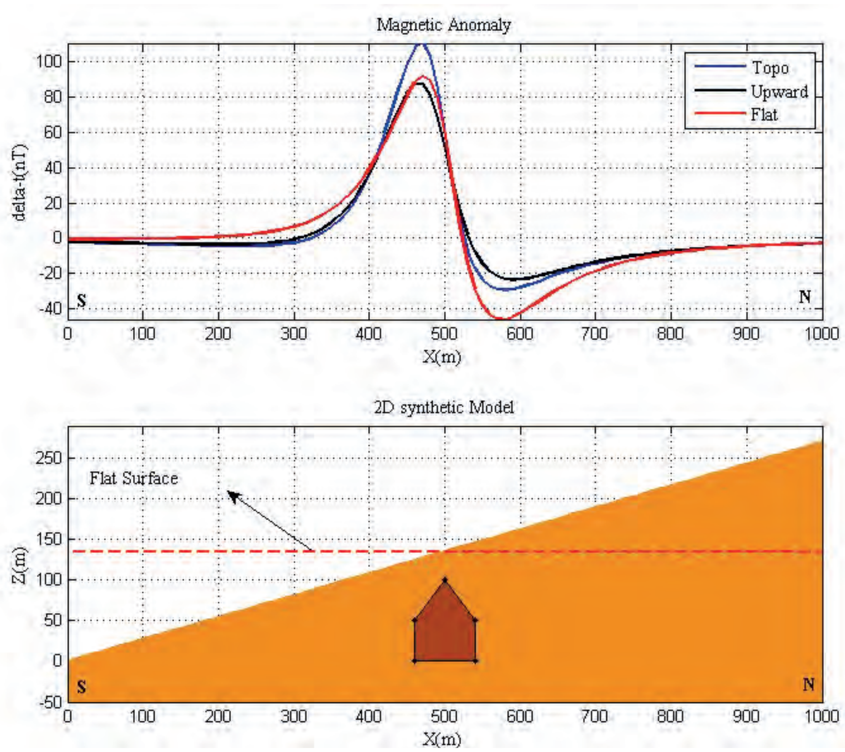

Fig. 1 - Magnetic anomalies of a 2D structure on a mild topography with southward slope 15° (blue), flat surface (red), and upward continuation of the data to 2 m level (black), magnetic parameters listed in Table 1.

3. Topographic effects on the synthetic magnetic anomalies

In order to investigate the topographic effects on the shape and polarity of the magnetic anomalies, an arbitrary 2D polygon was constructed with magnetic parameters presented in Table 1 under the various topographical conditions. The magnetization is assumed to be induced and there is no remnant magnetization, as well the topography does not have any magnetization. In Fig. 1, the 2D source is located beneath a southward gentle slope, mild topography, which we presume to be less than 15°. Data acquired on the slope shows a stronger intensity in the positive pole and a weaker intensity in the negative pole compared with the data obtained on a flat surface. In an induced magnetization situation we expect the positive pole to be generated in the south and the negative pole in the north in the stated geomagnetic field condition. Locating the source body beneath a southerly dipping surface (Fig. 1) will bring positive pole of the anomaly closer to the acquisition surface, while takes the negative one far away. In other words, potential fields change with the n power of inverse distance. Decrease of body's distance in the southern part from sloping surface in comparing with flat surface makes much flux to be distributed on the southern part of the topography surface. As a result it is observed more intensity in the positive pole. In this case, if survey altitude is considered to be flat in magnetic data analysis, variation of the magnetic poles of the anomaly may be misinterpreted as the variation of source geometry and lead to erroneously reconstructed body.

As referred before, there is an incorrect viewpoint that any topographic effect on the magnetic data can be corrected by upward continuation of the data to the surface parallel to the

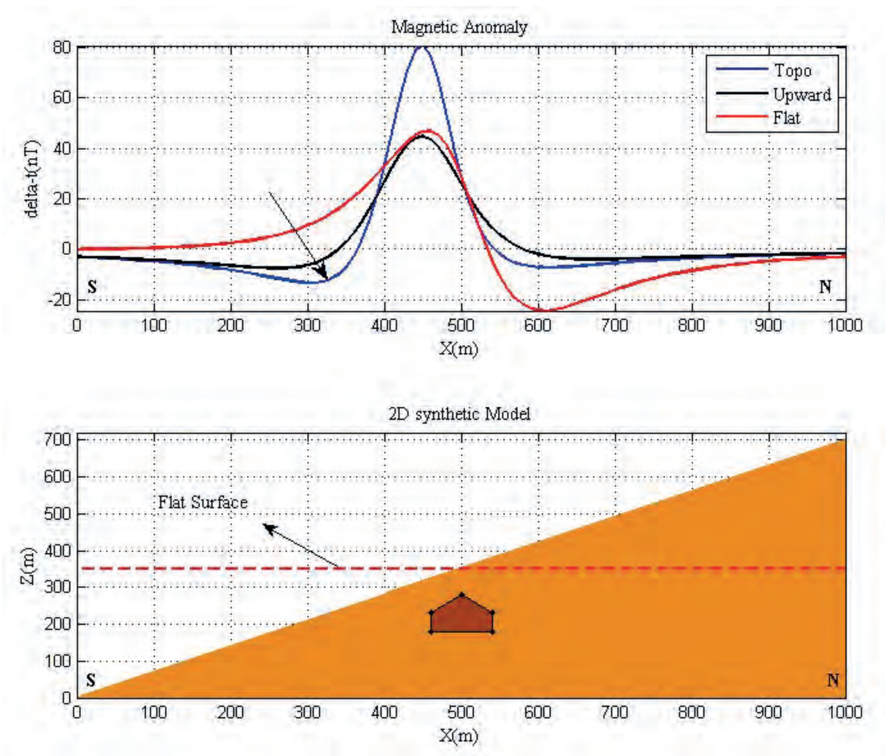

Fig. 2 - Magnetic anomalies of a 2D structure on a relatively severe topography with southern slope 30° (blue), flat surface (red), and upward continuation of the data to 6 m level (black), magnetic parameters listed in Table 1.

ground surface (Ugalde and Morris, 2008). The data collected under the topographic condition with 15° slope are transferred to 2 m elevation above the acquisition surface. It is shown in Fig. 1 that upward continuation cannot recover the negative high frequencies that topography has removed from data.

Table 1 - Synthetic models magnetic parameters.

Susceptibility	Inclination	Declination	Intensity
0.02 (SI)	60°	10°	50000 (nT)

In a rugged topographical condition with 30° slope toward the south (Fig. 2), a more severe variation in the magnetic anomaly is observable. The polarity of the anomaly can be reversed, a condition which occurred where a strong remanent magnetization component exists or the source body has been dislocated by tectonics.

In such topography conditions, if the survey altitude is considered to be flat, this anomaly can be misinterpreted to be a remanent magnetic body. In this case as it is observable in Fig. 2, upward continuation data, to 6 m elevation, is not reasonable due to the fact that the topography has changed the shape and polarity of the magnetic anomaly and this filter can solely decrease the intensity of the magnetic anomalies.

By switching the slope direction (Fig. 3a) the magnetic anomaly has been created with a

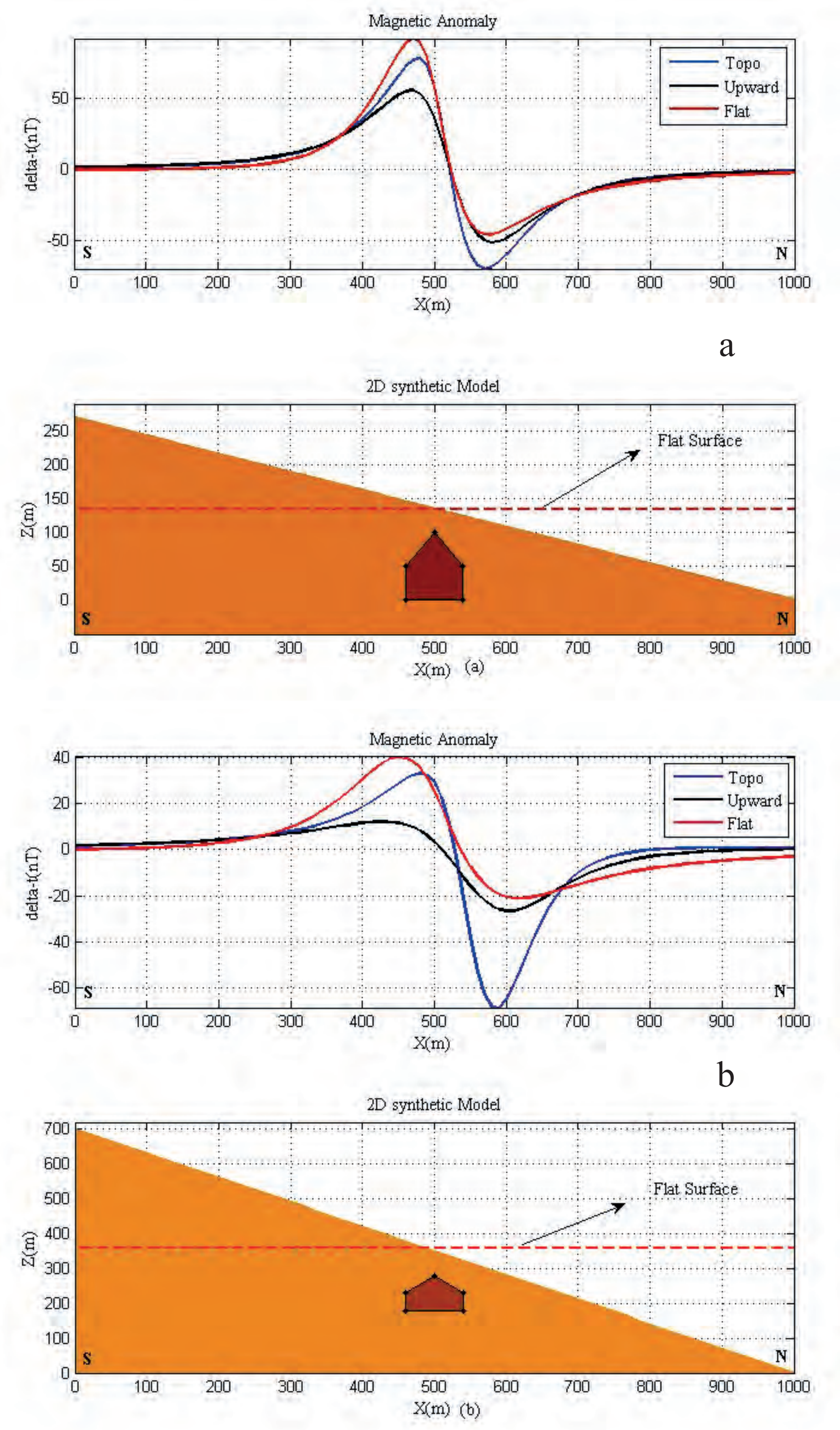

Fig. 3 - Magnetic anomalies of a 2D structure on topographic surface (blue), on flat surface (red), and transferring data to a surface parallel to the ground surface (black) in different slopes: a) a mild topography with northern slope 15°; b) a relatively severe topography surface with northern slope 30°, magnetic parameters presented in Table 1.

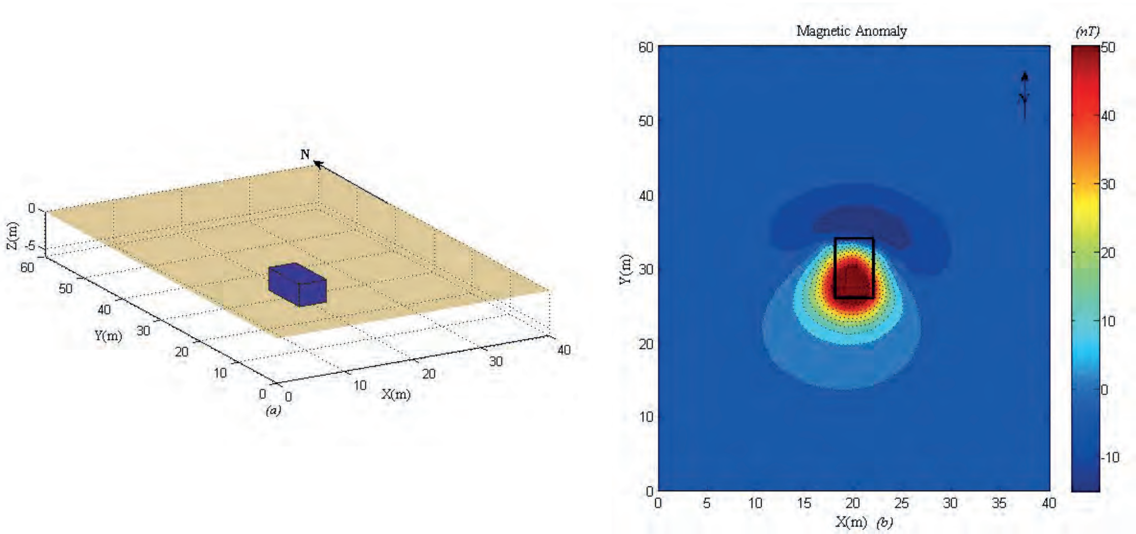

Fig. 4 – Location of the magnetic prism beneath a flat surface (a) and magnetic anomaly of the prism on the flat surface (b); geomagnetic field parameters listed in Table 1.

stronger intensity in the negative pole compared with the flat surface. In fact, the topography has caused the more magnetic flux distribution in the northern part. In severe case of topography with a dip of 30° (Fig. 3b), it is obvious that not only the negative pole intensity is increased, but also the peaks of the positive and negative poles have been moved. In both cases, mild and rugged topographies, upward continuation of the data could not restore the positive high frequencies that topography has omitted from the data.

If these data are interpreted without paying attention to the surface topography, increasing and decreasing magnetic poles would be attributed wrongly to the source slope. The shifting of maximum values would distort the results by applying the filters of ASIG and RTP, so it would influence both qualitative and quantities interpretations.

As it was observed, depending on the surface slope and source position, topography has different effects on the shape and polarity of the magnetic anomalies.

In order to further investigation on the topographic effects, a 3D model was synthesized in different topographic surfaces. A simple case of a magnetic prism is presented here. Fig. 4a shows a magnetized prism located at x_1=18 m, x_2=22 m, y_1=26 m, y_2=32 m, z_1=3 m, z_2=6 m, with magnetic parameters listed in the Table 1. The magnetic anomaly is seen in Fig. 4b.

By putting the source body beneath topographic surface with 15° slope towards the south (Fig. 5), it is seen in Fig. 6a that some negative high frequencies are removed in comparing with the case of flat surface. The reverse situation occurs for the positive pole, i.e., it becomes stronger as discussed for the 2D models. In this case, upward continuation of the data to 2 m above the acquisition surface (Fig. 6b) is not able to recover negative high frequencies that topography has removed from the data.

Magnetic anomaly in Fig. 6c belongs to the magnetic prism located beneath southward severe topography with 30° slope. Similar to the 2D structure case the polarity of the positive and negative poles of the anomaly is completely reversed, that is quite different from what we can see in the flat surface case (Fig. 4b). This phenomenon is usually misinterpreted as remanent

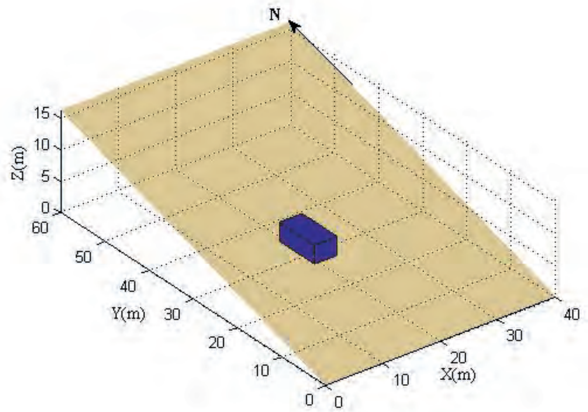

Fig. 5 - Situation of a magnetic prism beneath southward slope surface.

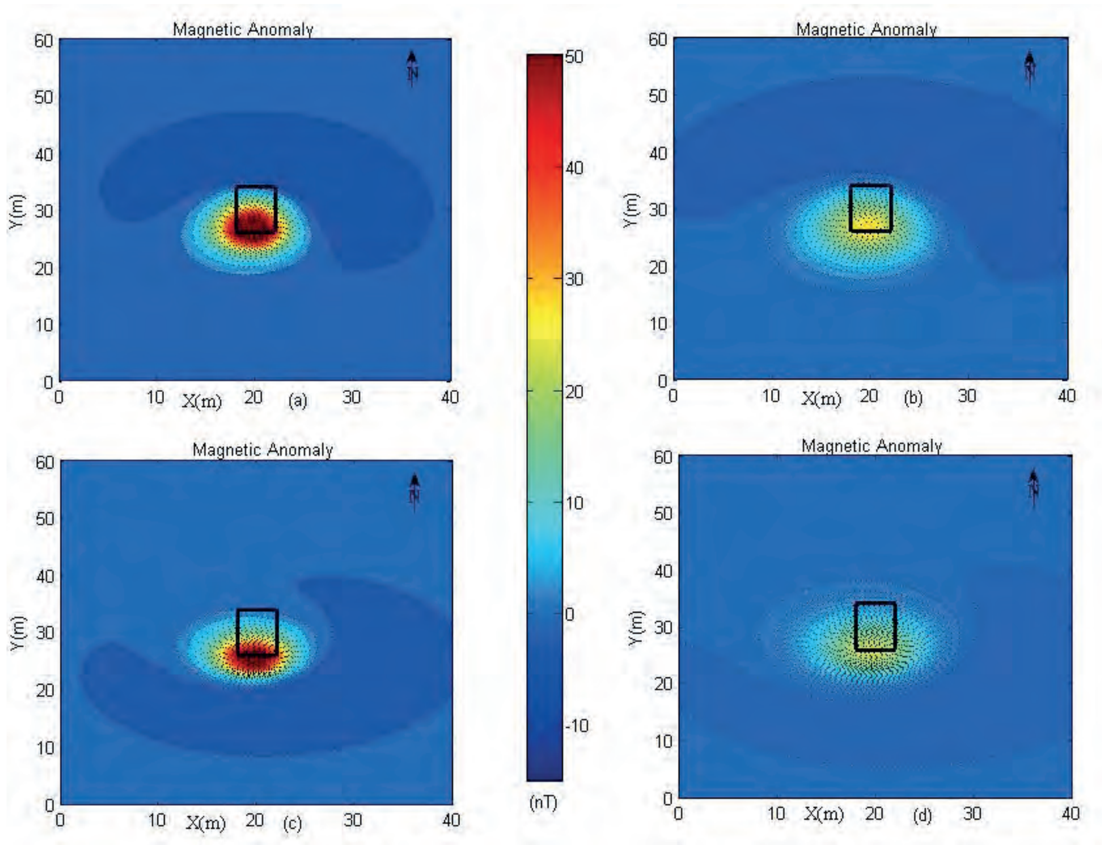

Fig. 6 - Magnetic responses of the magnetic prism: a) on the southward gently slope about 15°; b) upward continuation of the data to 2 m above observation surface; c) on the severe topography with southward slope 30°; d) upward continuation of the data to 2 m above acquisition surface.

magnetization, if survey altitude is considered to be flat. Fig. 6d shows the magnetic anomaly after upward continuation of the data to 2 m above the survey surface. It is seen that upward continuation just attenuates the magnetic anomaly intensity and it is not able to reshape the magnetic anomalies in order to correct the topographic effects. In these cases, the obtained results will be unreliable and data should be analyzed carefully. All magnetic anomalies in Fig. 6 were made from a source body with different observation surfaces. The results show that it is reasonable to consider the data acquisition surface topography when interpreting the magnetic data.

4. Real topography

We extracted the topography of Mt. Damavand from Digital Elevation Model (DEM) data along a S-N profile and regarded it as a real topography. Mt. Damavand is located approximately 50 km NE of Tehran, Iran. It is the highest summit in the Alborz ridge, which is one of the branches of Alpine and Anatolyan range. It is a young volcano that has formed mostly during the Holocene Epoch (approximately more than 10,000 years). It is the highest peak in Iran and the highest volcano in the Middle East (Davidson *et al.*, 2004). It has an altitudinal gradient with 21° slope so could become an appropriate choice for topographic effect investigation.

There are documents that a hot magma body exists beneath the volcano with continuing activity, although minor. This activity indicates a dormant rather than extinct volcano (Davidson *et al.*, 2004). Therefore, a synthetic model of the magma chamber and intrusive bodies were synthesized beneath Damavand's topography by considering geological observations.

In the 2D case, 80 data points with 200 m spacing were considered along a profile (Fig. 7), and a synthetic model was simulated by magnetic parameters listed in Table 2. A comparison between the synthetic magnetic anomalies caused by magma chamber and intrusive bodies under the topographic and flat surfaces (Fig. 8) depicts that topography has influenced intensity of the anomaly. In other words, both negative and positive poles intensity were increased. In addition, the peak of the positive pole has been moved aside. If survey altitude is considered to be flat this variations could be regarded due to a higher susceptibility and could distort the results of filter applications such as ASIG, RTP, and so on.

In this case, chosen profile is symmetric in shape and source bodies were located approximately in the centre of the topography. As a result the magnetic flux is distributed along the profile similarly and transferring data to the level of 350 m to some extent has reduced the magnetic intensity but it has not been able to correct the relocation of the positive pole.

In order to analyze Damavand's topography in 3D situation, more profiles were considered from south to north, each with 11 km long and 500 m distance in between (Kangazian, 2012). The magma chamber and intrusive bodies were simulated by a magnetic sphere and prisms with magnetic parameters presented in Table 2. Fig. 9 shows the magnetic responses of the synthetic source body under the topographic and flat surfaces.

Table 2 - Synthetic models magnetic parameters.

Susceptibility	Inc	Dec	Intensity
0.1 (SI)	55°	4.5°	48000 (nT)

The positive poles have the same intensity for the magnetic anomaly simulated under the flat surface (Fig. 9b) while being asymmetric the Damavand's cone by considering Damavand's topography contour lines, valley in the east and lava in the west (Davidson *et al.*, 2004), has

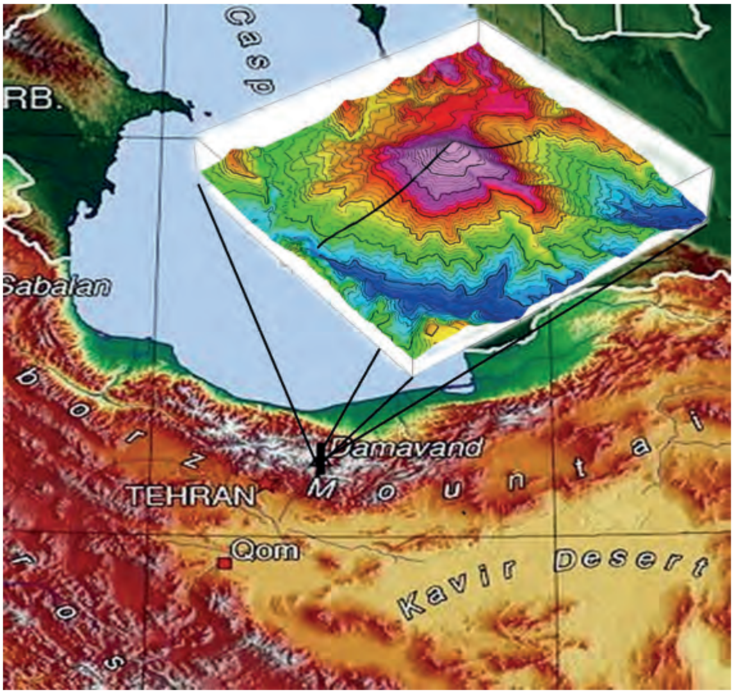

Fig. 7 - Location map of the profile across Damavand.

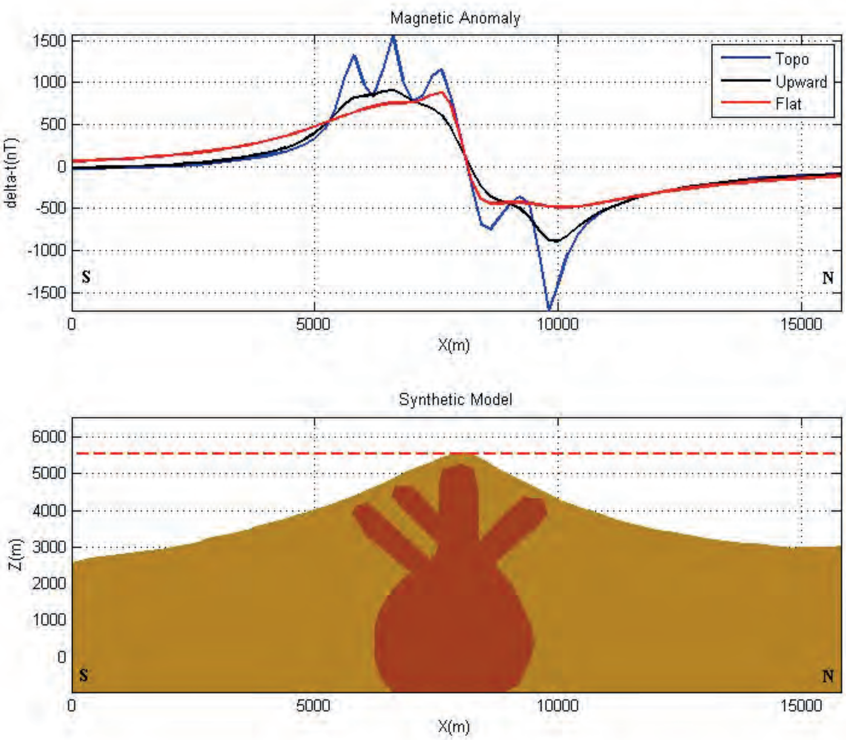

Fig. 8 - Synthesized anomalies of a hypothetical magmatic complex. The main chamber and dipping tabular intrusive bodies beneath Damavand.

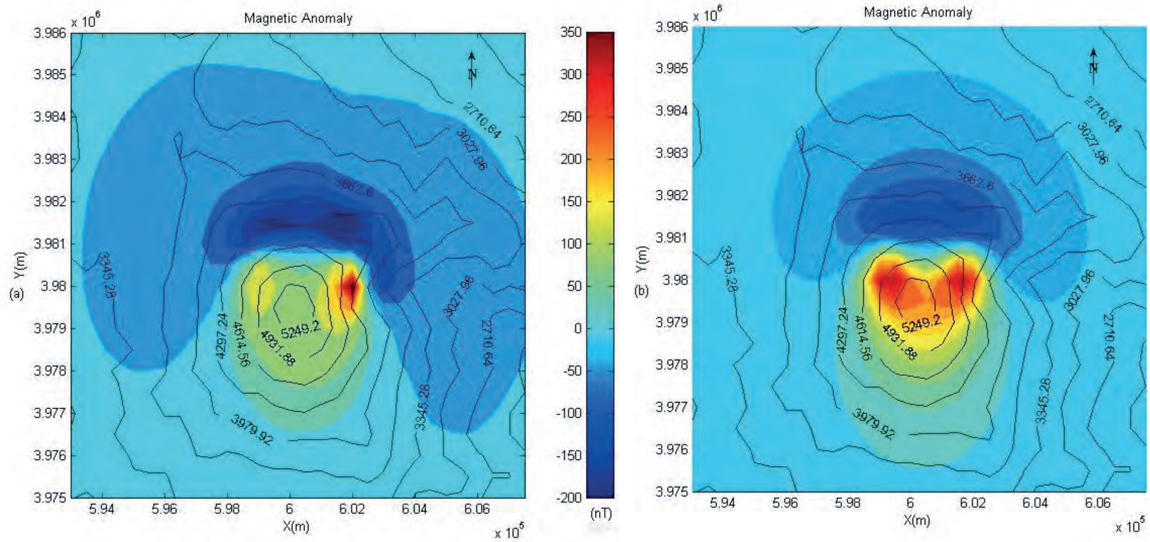

Fig. 9 - Synthetic magnetic anomaly of magma chamber and intrusive bodies: a) under Damavand's topography; b) under flat surface, contour lines show Damavand's topography.

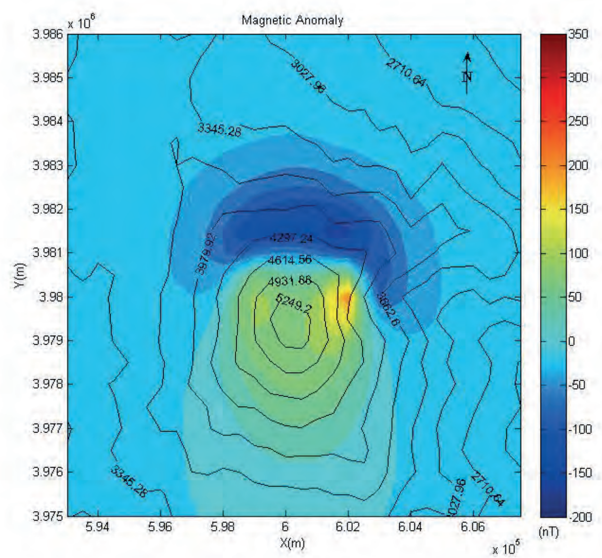

Fig. 10 - Upward continuation of the data acquired on the topographic surface to 200 m elevation.

strengthened the positive pole in the east and has weakened the western counterpart (Fig. 9a). In addition, the topography has led to greater intensity in the negative pole than the flat surface.

It is seen in Fig. 10 that transferring the data to the level of 200 m above the highest topography cannot recover the high frequencies in the positive pole that Damavand's topography has removed from the data, therefore topographic effects cannot be corrected.

5. Conclusions

The data acquisition surface geometry can have a complex but predictable effect on the generated magnetic anomaly. It is called "topography effect". In this study, 2D and 3D synthetic models were examined in different topographical conditions by generating corresponding magnetic responses. In each case, magnetic field variations were investigated to see the changes in the intensity and shape of the positive and negative poles of the anomalies (anomaly waveform). The results show that although this effect is negligible in mild topographical situations, it can be more prominent by increasing the topography gradient. Eliminating this effect in magnetic data interpretations may result in erroneously determination of source parameters, especially the source magnetization.

It was observed in this study that in some situations the polarity of the positive and negative poles of the anomaly is completely reversed, a phenomenon which usually is misinterpreted as remanent magnetization. The shape and wavelength of the positive and negative poles are also changed in some topographical conditions, which can be corresponded to shape, susceptibility, and dips of the causative body. In fact, inclined magnetic field relative to the topographic slopes creates an undesired element in the data. So to achieve a reasonable level of accuracy in magnetic data interpretation, topography effects should be considered. Moreover the upward continuation of the data to a surface parallel to the survey surface for correcting the topographic effect is not rational. It should be mentioned that the upward continuation just attenuates high frequencies and it is not able to recover high frequencies that topography remove from the data or change the shape of the anomalies. Therefore, the only way to remove the topography effects is topography corrections. Forward modelling of a real topography case on Mt. Damavand as well as a hypothetic magma chamber and its hypabyssal and volcanic branches beneath, has released important consequences of this phenomenon, which can be used on the ground and airborne modelling of the real case anomalies.

Acknowledgments. The research council of the University of Tehran and the Institute of Geophysics are acknowledged for the financial support of the first author's attendance at the International Geophysical Conference and Oil and Gas Exhibition, Istanbul, 2012. We also thank the Associated Editor Iginio Marson, University of Trieste, and the reviewers for their precious comments which improved our paper.

REFERENCES

Blakely R.J.; 1996: *Potential theory in gravity and magnetic applications*. Cambridge University Press, Cambridge, U.K., 441 pp.

Davidson J., Hassanzadeh J., Berzins R., Stockli D.F., Bashukooh B., Turrin B. and Pandamouz A.; 2004: *The geology of Damavand volcano, Alborz Mountains, northern Iran*. Geol. Soc. Am. Bull., **116**, 16-29.

Hunt C.P., Moskowitz B.M. and Banerjee S.K.; 1995: *Magnetic properties of rocks and minerals*. In: Ahrens T.J. (ed), Rock physics and phase relations: a handbook of physical constants, American Geophysical Union, Washington DC, U.S.A., pp. 189–204, doi: 10.1029/RF003p0189.

Kangazian M.; 2012: *Investigation of the topographic effect on synthetic magnetic data at different latitudes in Iran*. M. Sc. Thesis, University of Tehran, Iran, 124 pp. (in Persian).

Ku C.C. and Sharp J.A.; 1983: *Werner deconvolution for automated magnetic interpretation and its refinement using Marquardt inverse modeling*. Geophys., **48**, 754-774.

Naidu P.S. and Mathew M.P.; 1994: *Correlation filtering: a terrain correction method for aeromagnetic maps with application*. Appl. Geophys., **32**, 269-277.

Rao D.B. and Babu N.R.; 1993: *A Fortran-77 computer program for three-dimensional inversion of magnetic anomalies resulting from multiple prismatic bodies*. Comput. Geosci., **19**, 781-801.

Talwani M.; 1965: *Computation with the help of computers of magnetic anomalies caused by bodies of arbitrary shape*. Geophys., **30**, 797-817.

Tsokas G.N. and Papazachos C.B.; 1992: *Two-dimensional inversion filters in magnetic prospecting: application to the exploration for buried antiquities*. Geophys., **57**, 1004-1013.

Ugalde H. and Morris B.; 2008: *An assessment of topographic effects on airborne and ground magnetic data*. The Leading Edge, **27**, 76-79.

Corresponding author: Behrooz Oskooi
Dept. of Geomagnetism, Inst. of Geophysics, University of Tehran
Kargar shomali, Tehran, Iran
Phone: +98 21 88630470, fax: +98 21 88009560, e-mail: boskooi@ut.ac.ir