Determination of Seismic Lineaments by EGM2008 Data and Gravitational Facies in North of Qazvin, Iran

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Received: 26/04/2014
Accepted: 16/12/2015

ABSTRACT

This research is based on revealing hidden seismic lineaments by interpreting airborne gravimetric and magnetic gradients along with structural patterns [4] in north of Qazvin. IIEES Earthquake catalogue (M > 2 since 1962) has been plotted and analyzed for integrative geophysical purposes. Our research showed that hidden lineaments not only coincide with structural pattern, but spatially control the seismic behaviors in North Qazvin Fault (NQF) branches. The surveyed area is achieved by 56432 points with isometric grids. Besides, geological evidences have been used for facies changing and fault map verification according to seismic events. The facies' change is an innovative process for evaluating gravity lineaments related to NQF hidden lineaments. Such a pattern provides the spatial association of NQF seismic patterns with the revealed seismogenic lineaments of which evidences can be proved by airborne geophysical dataset. As a result, at least two hidden lineaments can be distinguished in north and eastern part of NQF according to geophysical evidences. Therefore, the east and north east of Qazvin have more seismic potentials than other regions because of an observed and meaningful variation of gravimetric facies next to NQF.

Keywords:
Airborne geophysics; Gravity facies; Hidden lineaments; North Qazvin fault

1. Introduction

Generally, interpreting and modeling the geophysical data are carried out in quantitative and qualitative manner. The increasing development of industries and extension vital currents in most places of Iran require the situation of subsurface lineaments to be considered in order to identify hidden faults and analyze hazards caused by them. In the previously performed researches on seismic faults, it was shown that discontinuities have influential role in systematic and dynamic of fault process, and recognizing these discontinuities is the most important factor in identification of fault range [1].

In the study area, lineaments and their relationship with faults and gravitational facies together with their role in seismic behavior of the area is of great importance. In this research, in addition to confirming the existing faults, hidden faults in the region are recognized. Besides, we will confirm the validity of gravity lineaments by checking if there is facies change in both sides of the region gravitational fabric.

2. Region and Tectonics

Located between 35.24 and 36.49 north latitude and 48.44 and 50.51 east longitude, Qazvin province has 15640 km^2 area and a population of 968000. Northern Faulted region of Qazvin is surrounded by Alborz Mountains. Geological phenomena of this region have experienced expanded magma differentiation with changes rending to hydrothermal systems due to abundance of igneous formation of Rhyolites, Rhyodacites and Trachy-Andesites [2]. The tectonic and geological history of the region is greatly different from that of other parts of Iran. From Cretaceous onwards, this region witnessed compress and tensile phases, which influenced tectonic structures preceding them and added the tectonic complexity in addition to vast volcanisms and intrusive units [3].

2.1. North Qazvin Fault (NQF)

This fault is located in Alborz- Azerbaijan zone, the mechanism of which had been reversed. The thrust NQF cuts across North Qazvin, 11km, in eastern-western trend at 60 km length, causing the Karaj formation to fault in Eocene and be driven on the quaternary and steeped destructive deposition to Neocene age [4].

This fault is the most important structural event correlated with large seismic events that possess long-term return due to Caspian compressive system. The height difference between Qazvin (1250 m above sea level) and its nearest peak at 30 km east-north of Qazvin, is one of the most remarkable topographical features of Qazvin range resulting in geodynamical movements in this fault. This faulted region has formed a border between plutonic- pyroclastic igneous units of Karaj and quaternary alluviums (south) in most of its length. This fault is active according to seismo-tectonics studies, and can be regarded as a seismic threatening factor for Qazvin urban and industrial centers [5].

In most of geological cross-sections of NQF in foothills, it is seen that horizontal or low slope alluvial deposits have had a rapid slope approaching the fault line under the effect of North Qazvin fault in alignment form. It seems that the historical earthquake of 1119 (M: 6.5) occurred due to this fault. The fault scarp, visible on satellite images SRTM (90 m resolution) of NQF represents an eastern-western trend in southern part of the main structures [6].

The mentioned fault was first studied in the proximity of Najmabad village (10 km north Qazvin), named after it. NQF is located on the southern part of central Alborz approaching Taleghan fault in the east. NQF was introduced as a thrusted fault system with a slope towards north according to geological researchers. There has been numerous historical earthquakes during which Qazvin city was destroyed many times [4].

In Figure (1), SRTM photomap from north faulted regions of Qazvin, Iran is shown. Events according to earthquake catalog North of Qazvin is shown in Table (1).

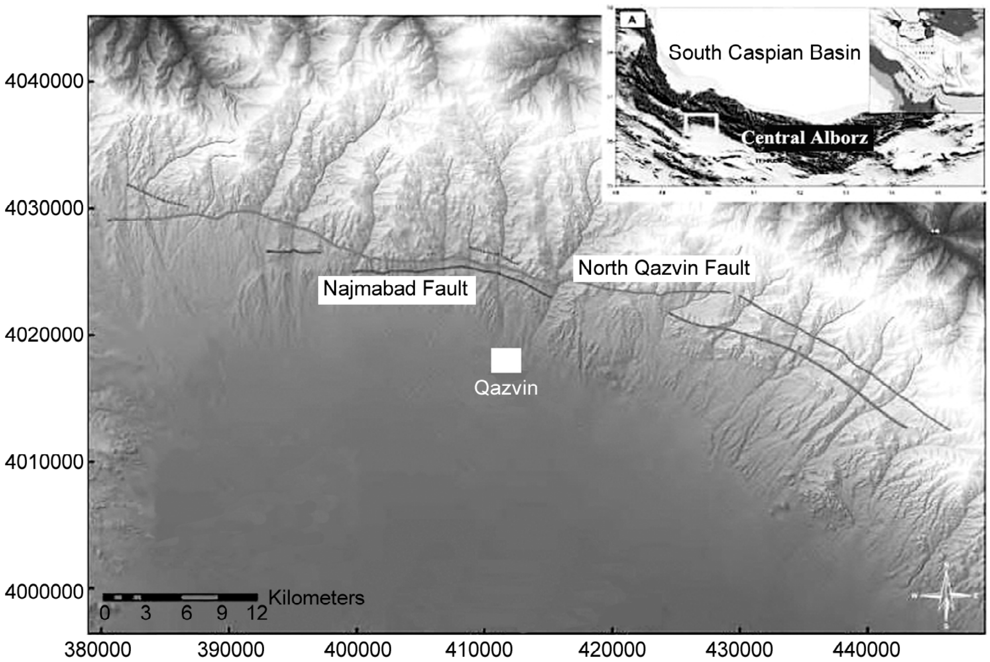

Figure 1. SRTM photomap from north faulted regions of Qazvin represents the situation of NQF and Najmabad faults. The small figure on the top shows the situation of case study [7].

Table 1. Seismic events according to earthquake catalog, North of Qazvin (www.iiees.ac.ir)

Reference	Magnitude	Depth	Longitude	Latitude	Time (UTC)	Date (yyyy/mm/dd)
MOS	mb:4.5	-	49.90	36	11:15:09.0	1962/09/11
ISC	mb:4	70	49.94	36.59	13:25:27.0	1992/06/12
EHB	mb:3.9	15	50.21	36.42	12:06:52.0	1999/03/26
EHB	Mw:5.2	29	49.75	36.52	13:46:51.0	2002/04/19
IIEES	Ml:3.2	14	50.36	36.46	19:13:23.0	2004/11/02
IIEES	Ml:2.6	14	50.26	36.40	23:35:14.6	2006/08/13
IIEES	Ml:3.1	14	49.71	36.09	23:40:09.1	2006/08/30
IIEES	Ml:2.7	27	50.38	36.31	14:28:08.0	2007/03/26
IIEES	Ml:3.1	15	49.88	36.54	20:17:56.9	2008/01/21
IIEES	Ml:2.5	15	49.99	36.49	18:16:44.9	2009/10/17
IIEES	Ml:2.5	15	50.04	36.34	23:57:11.7	2010/07/06
IIEES	Ml:2.6	18	49.77	36.38	03:59:17.1	2011/01/27

The plot of faulted zone has been adapted from Institute of Earthquake Engineering and Seismology (IIEES) in which the circles radius is proportional with its magnitude, Figure (2).

The seismic data was extracted of seismic catalog from IIEES with a radius of 40 km in Qazvin city center that limited between latitude (35.75 to 37.07) and in longitude (49.45 to 50.84). The near data to NQF was selected by counting of 12 seismic events. Seismic lineaments was extracted based on gradient changes of earthquake magnitude, over the past 51 years. Besides, in this study, gravity data of EGM2008 global geo-potential model with grid points 18900, airborne magnetic data with grid points 18760 and topography data of ETOPO1 global relief model with grid points 18760 were used.

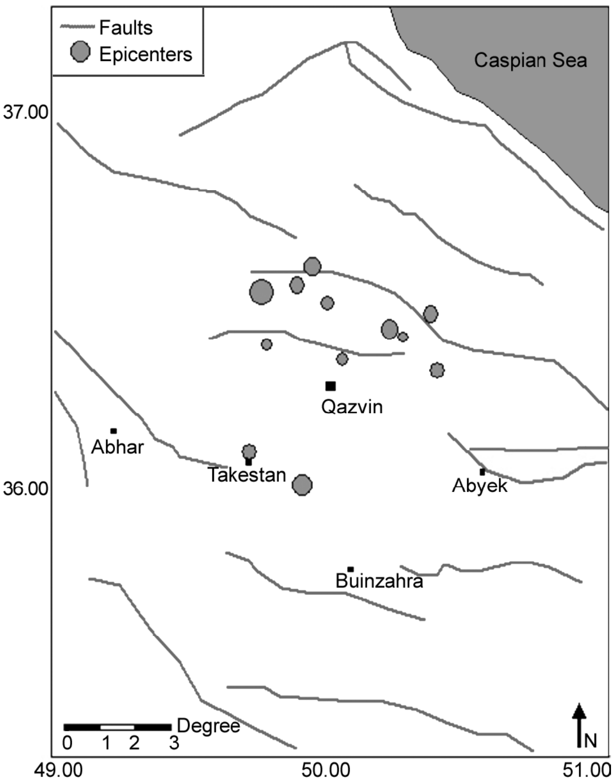

Figure 2. The plot of faults & structures by surfer software in north of Qazvin.

3. Methodology

This study has been done by using both airborne geophysical databases (magnetic and EGM2008 gravity) and satellite images based on decimal degree values. Besides, seismic information has been gathered from IIEES catalog within 40 km radius around Qazvin city according to 12 seismic events and regional geological considerations. We have used spatial analyst and surfer GIS software for geostatistical interpolation of databases (Kriging gridded maps) [13-14].

Then seismicity, magnetic and gravity contour maps had been drawn, Figures (3) and (4).

It's necessary to say, seismic data interpolation is done by Inverse Distance Weighting (IDW) method with cell size of 0.001 decimal degree in a GIS environment. As seen on the maps, the location of lineaments are related with the place of the strongest seismic gradients that their fabric are linear. Moreover, the major plot of NQF retrieved from IIEES drawn on contour map shows that some of

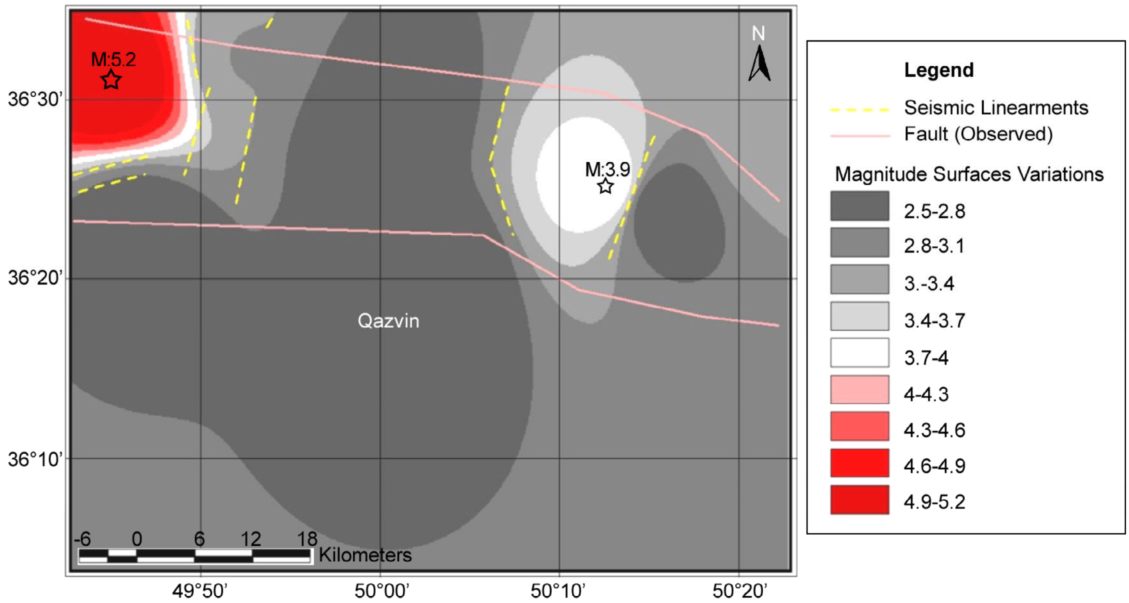

Figure 3. Contoured map of seismicity based on entities and the magnitude of earthquakes in north faulted region of Qazvin.

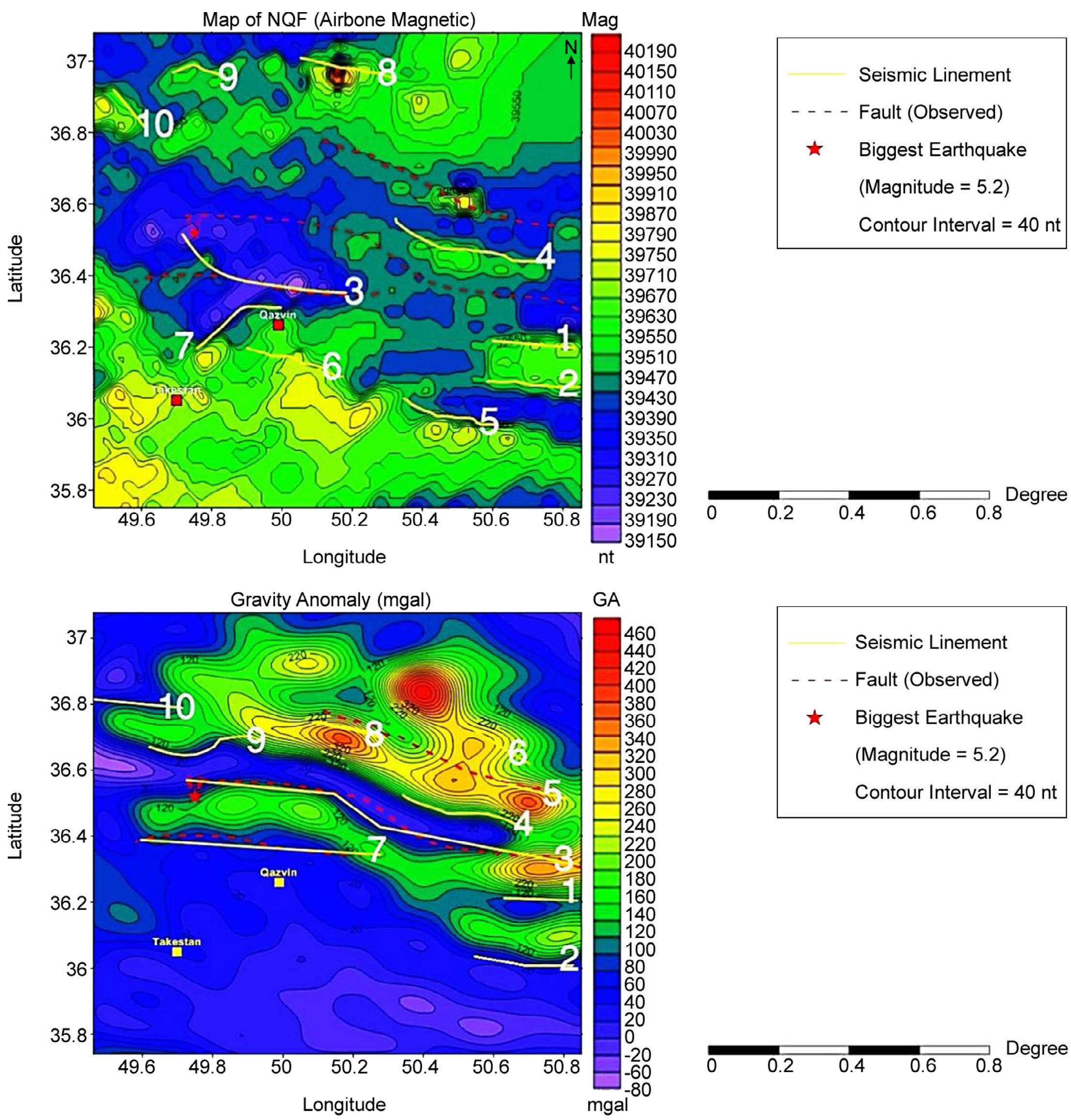

Figure 4. The counter maps of the airborne magnetic (scale: 1/200000).

the lineaments are on the field of NQF and some of them are not. Then a solution was found between this framework that if we have had regional magnetic and gravity data and draw the contour map of data, then we extract and specify magnetic lineament and seismic gravity, it can be concluded after modulation of two or three cases that which one of lineaments in seismic catolog is realy representative of seismic lineament and which one is not. During the exploration, the existence or nonexistence of a fault or buried influent mass is more important than determination of form or depth of burial. In a magnetic plot, there are some parts with large and significant magnetic changes that represent rocks with high magnetic susceptibility and low burial depth. On the magnetic plot, a sedimentary basin is shown that is caused by monotonous counter lines, low intensity of the field, little changes of the gradient and numerous space between lines. On a magnetic map, in many cases, the existence of border with high gradient between zones with low gradient difference indicates the existence of fault. Geophysical contoured maps not only realised NQF lineaments but also correlated with observed structures [4] for verification. In these maps, yellow lines indicate both seismic, magnetic and gravity lineaments and red dotted lines are observed faults by Berberian et al. [4]. In magnetic plot, the interruption of contour process and divergence of counter lines is a symbol of lateral movement by faults [8].

The hidden faults often cannot be seen through the sedimentary cover and just apparent by magnetic maps. According to magnetic gradients, the lineament number 3 is correlated with real fault branches while other lineaments probably suggested the number of hidden fault locations. In magnetic plot, yellow and green areas have high susceptibility. When the ratio of magnetic susceptibility of subsurface mass is increased, the intensity of magnetic anomaly will be increased too; therefore, with increasing the magnetic susceptibility, the range of anomaly will be increased.

Obtaining useful information about subsurface structures by corrected information of gravity is the final and important step in functions of gravity. In the exploration of gravity, the changes in rock density are made division in gravity of potential field; thus, density contrast have fundamental importance in gravimetric interpretation. From geological point of view, the existence of fault in an area is caused by fracture and replacement of geological layers in vertical and horizontal directions. In this situation, the same kind of geological layers are placed on both sides of a fault at different depth from the surface, so that sediments usually placed on the deep layers. Therefore, because of density difference between sedimentary and fault layers, their gravity effect will be different. This difference is clearly shown at contour lines. We can identify the existence of fault in a region with proper interpretation on counter lines of gravity. On EGM2008 gravity plot, the regions are without quiet contour lines and gravity changes means that area has a monotonous geology structure. On the other hand, convergence of the contour lines indicate the zones with intensive gravity gradient changes. The more the convergence of lines, the more the possibility of fault will be. On the gravity maps, convergence and length route of convergence of the contour lines are two factors in recognition of faults [8]. It is evident that using the geology information of the area and gravity data can help to more efficient interpretation. In gravity contour map, violet and blue areas have low gravity changes, and red and orange areas have high gravity changes. Wherever anomaly is deeper and gradient positive, gravity data indicate a more specific range. Based on gravity contours, a corridor within north faulted region of Qazvin can be seen. In the view of gravity, the top of this area is high and the down is low. Therefore, the facies changes will be appeared gradually. This map can be used for the changes of gravity facies of area. We see that gravity lineaments No. 1 and No. 4 confirmed magnetic lineaments No.1 and No. 4. Besides, gravity lineaments No. 3, No. 5 and No. 7 confirmed existing faults in Seismic Catalog map. Thus, lineaments that are approved with two or three of geophysical layers can be considered as new but hidden structures. In Figure (4), the observed faults are shown with red dotted lines, and hidden lineaments are shown in yellow. As it is clear from Figures (4a) and (4b), in many cases, lineaments and observed fault systems confirm each other, but in some cases, they are not correlated together. Lineaments can be interpreted as subsurface hidden structures according to instrumental located epicenters and their spatial associations with magnetic and gravity lineaments. Such hidden structures usually covered by young alluvial formations and therefore have no traces in the ground surfaces. For instance, a 3D image of EGM2008 gravity gridded data is shown in Figure (5) in which there is a prominent section of maximum gravity changes with convergent contours next to gravimetric lineaments.

3.1. Filtering Operations

The situation of magnetic and gravity lineaments are surveyed by applying different filters. In this procedure, the active tectonic of the area and hidden fault branches have been studied and shown in Figure (6). By applying upward transformation filters, Figure (6a), the surfacing above the product level (330 m) and related shallow anomalies will be wiped off the map. In downward transformation filter, selective depth is 330 m, Figure (6b). Applying this filter has removed noises from surfaces and therefore realized more hidden lineaments theoretically. Downward continuation results have meaningful differences with upward results and seem to be useful for structural interpretations. Besides, for correcting the regional effect of the magnetic anomalies, we have used a Reduction To Pole (RTP) filter. By applying this filter, the magnetic contours have been slightly changed and displaced in north direction. There are various methods for detecting the border of anomalies. For example, a local phase filter uses gravity gradients for producing new contours to show enhanced corners effectively. One of these filters is the Tilt Angle (*TA*). This filter can be obtained by the following equation: Eq. (1) [9].

$$Tilt\ Angle = \tan^{-1}\left[\frac{\frac{\partial g}{\partial z}}{\sqrt{\left[\frac{\partial g}{\partial x}\right]^2+\left[\frac{\partial g}{\partial y}\right]^2}}\right] \quad (1)$$

In the above equation, Eq. (1), g is gravity field. In fact, it is inverse tangent of the vertical to horizontal derivative of gravity field $\left(\sqrt{\left[\frac{\partial g}{\partial x}\right]^2+\left[\frac{\partial g}{\partial y}\right]^2}\right)$. *TA* filter can be used as a method for locating gravity corners related to lineaments. The vertical gradient value at the edge of the anomaly is zero, and the horizontal gradients are maximum; therefore, the value of *TA* in the corners is zero and the rest of the amount will be negative. This angle usually ranges in ±90 degrees and represent to corners of the anomalies better than the analytical signals [9]. Figure (6c) shows the gravimetric grids after *TA* applied. In this figure, dark blue areas indicate minimum value of the local phase with slowly changes in the gravity fields. On the other hand, the white color areas indicate maximum value of the local phase with intense and sharp gravity changes at the edge of anomalies. Analytical signal is a combination of horizontal and vertical gradients of potential field data, the maximum amount of

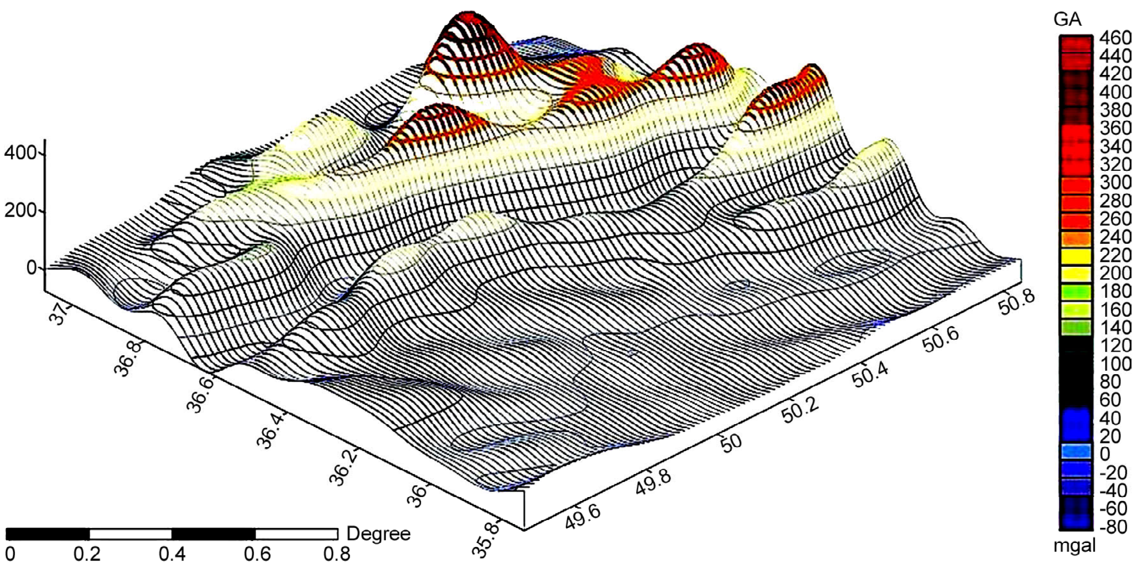

Figure 5. The 3D image related to EGM2008 gravity grid in north of Qazvin.

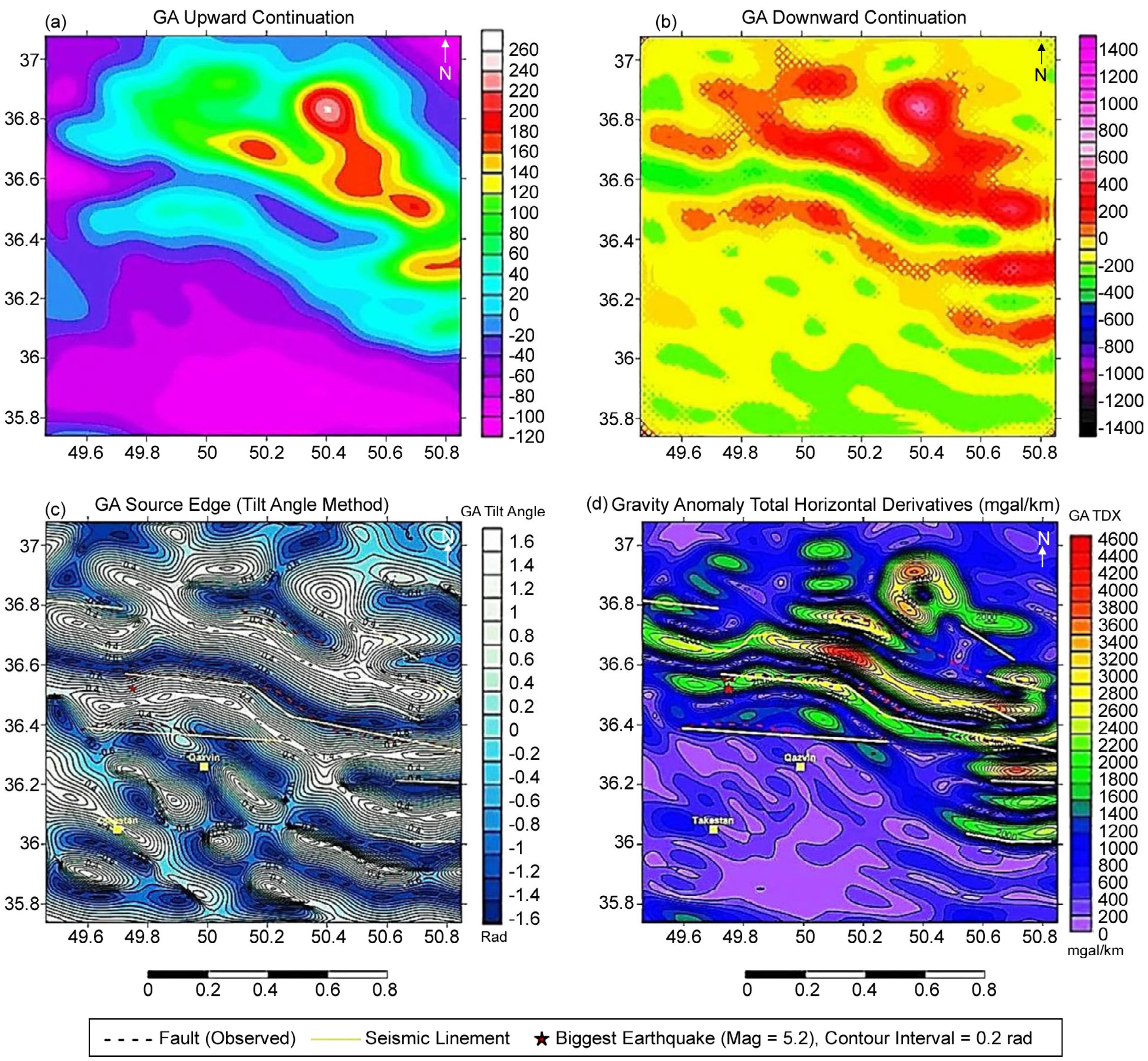

Figure 6. Upward continuation (a), Downward continuation (b), TA filtering (c) and Analytical signal filtering (TDX) by Matlab and Surfer software based on EGM2008 gravity data processing in north of Qazvin (scale: 1/200000).

which is placed on the mass edges. Independence analytical signal measure on the characteristics of the magnetization vector of mass disruption and the vector of magnetic field is an advantage of this method [11].

Analytic signal was first defined for two-dimensional objects as the following equations, Eqs. (2) and (3) [11].

$$A(x,y)=\frac{\partial g}{\partial x}\hat{i}+\frac{\partial g}{\partial y}\hat{j} \tag{2}$$

$$|A(x,y)|=\sqrt{\left(\frac{\partial g}{\partial x}\right)^2+\left(\frac{\partial g}{\partial y}\right)^2} \tag{3}$$

In Eq. 3, $|A(x,y)|$ is two-dimensional analytical signal amplitude in position (x,y) and g is gravity field measurements in position (x,y). This method is based on taking the derivative in different directions and then vector sum of the derivatives, that the edges of the anomaly will be clearly better [12].

With the help of the TDX filter position of faults outcrop is estimated more accurately that, correspond with the evidence in the geological map of the area, Figure (d6).

As a result, several hidden fault branches have been identified around NQF and confirmed by overlapping the airborne geophysical contours with the observed fault systems [4], Figure (7). It' notable that gravitational facies is the changes of the stratigraphic units along with density variations.

To analyze and correlate the gravity changes with geological patterns, we have used a geo-referred database under the license of GIS. Gravity changes plot is drawn to check fabrics that are between formations or not, Figure (8).

Sediment changes have seen in geological map, usually range between positive and negative gradient. Therefore, in other words, between both

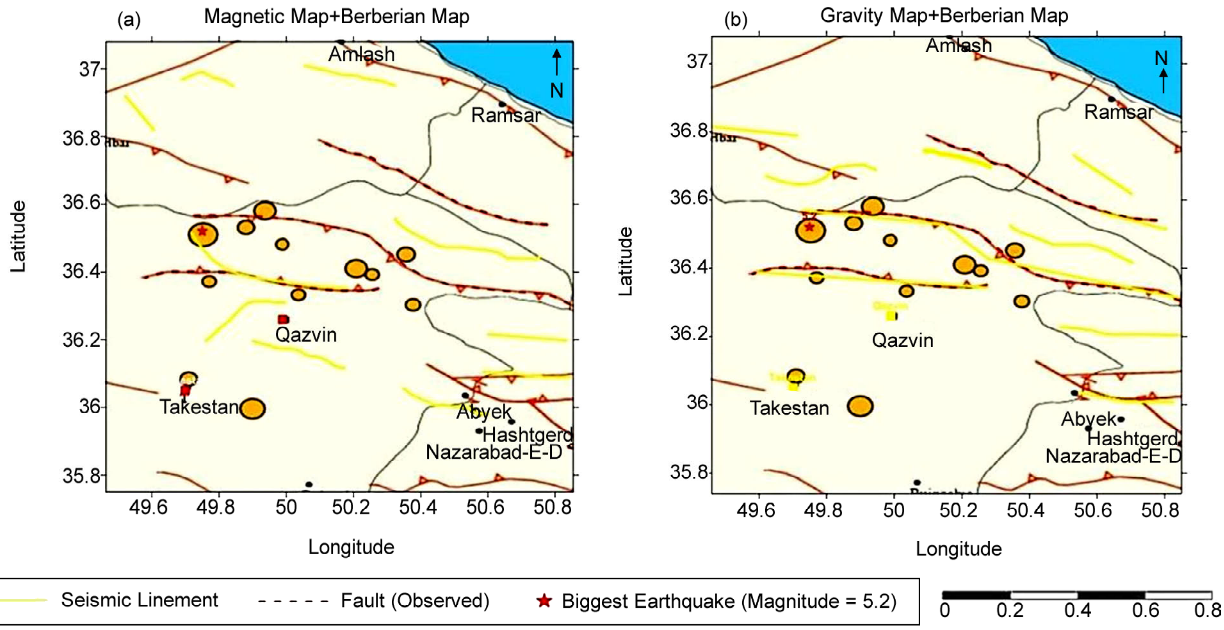

Figure 7. The overlap map of airborne magnetic contours (a) and EGM2008 gravity contours (b) with Berberian observed fault system (1999) (scale: 1/200000).

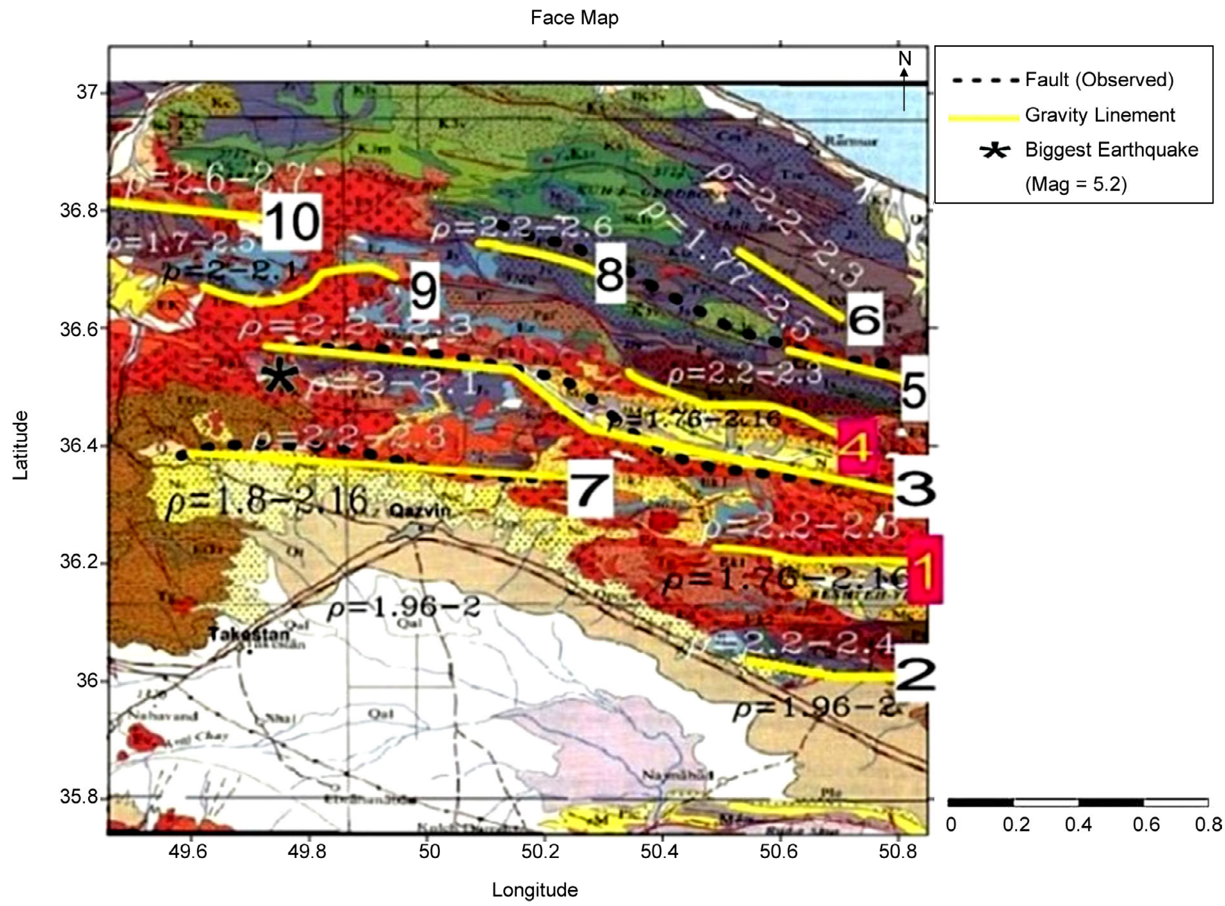

Figure 8. The plot of gravitational facies based on geological map of Qazvin (scale: 1/20000).

sides of the seismic lineaments deference in formation is seen. Therefore, in geological map, there are seismic lineament where deference in formation is seen. Gravitational facies is a reliable criteria to identify faulted regions based on gravity values [13]. In territory of this study, the hidden lineaments and their relationships with NQF branches in addition to the role of gravitational facies in seismicity of the area has high importance.

4. Discussion

In this paper, with diagnosing around the gravity fabric of the area we check that if changes of geology facies exist or not, and if this changes of facies is consonant with changes of slate density (for example, dolomite conversion to limestone in the vicinity of a fabric). We found that geological facies change has occurred actually. However, we will not have gravity because the density changes are not visible. According to achieved results, there is a direct relation between Faults and compression of lineaments. Most of the compression of lineaments is near the faults. It is necessary to say, for drawing and synthesis of the data and production gravitational facies map is used from ArcGIS, Surfer11 and Excel software facilities. Analysis of lineaments on facies map and determination of seismic hidden faults in North of Qazvin is shown in Table (2). Record of recent seismic events (Ms: 2.7 in 38 km north of Qazvin and Ms: 2.9 in 20 km Razmian city, 2013 AD), along with new fault branch (lineament No. 4) is a confirmation for this truth; hence, new seismic lineaments and events of 40 km Qazvin city center are shown in Figure (9).

Table 2. Analysis of lineaments according to facies map in North of Qazvin.

Possible Hidden Fault	Direction	Facies Change	Lineament Length (km)	Lineament Number
Violent	E-W	Existent	38.5	1
Weak	E-W	-	33	2
Violent	NW-SE	Existent	126.5	3
Violent	NW-SE	Existent	44	4
Weak	NW-SE	-	22	5
Weak	NW-SE	Existent	22	6
Violent	E-W	Existent	77	7
Weak	NW-SE	-	22	8
Weak	SW-NE	-	33	9
Violent	E-W	Existent	33	10

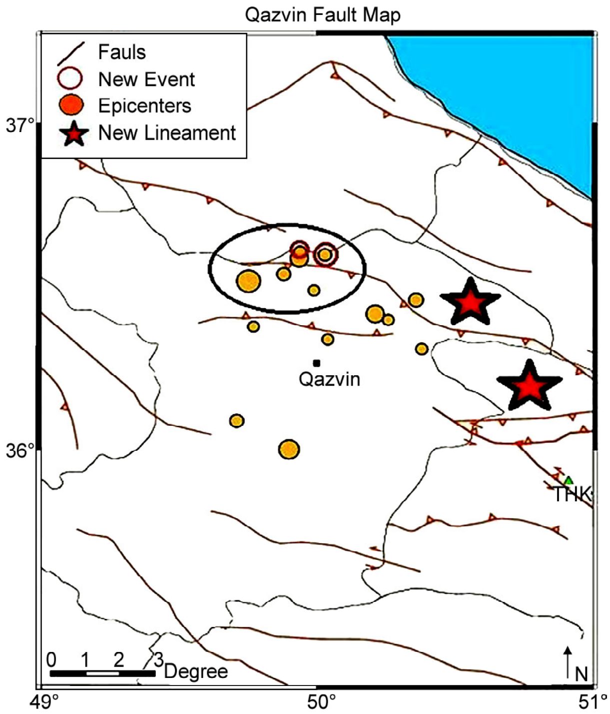

Figure 9. The plot of new lineaments and events in radius 40 km of Qazvin city center (www.IIEES.ac.ir).

5. Conclusions and Suggestion

- In this study, by combining neo-tectonic evidence, aeromagnetic data, EGM2008 gravity data and seismic data, we can better quantify the seismic potential of regions where strain rates are high, and identify blind faults mechanisms.
- Gravitational facies match with geological facies often; therefore, we usually see density changes with a change of geological formation, and gravitational fabrics will be a separator line of two gravitational facies.
- Gravitational fabric has often got a faulted mechanism; therefore, as a fault has been acted and two geological formations with different density have been put together.
- Based on the result of this research, the specified lineaments No. 1 and No. 4, which extended in the eastern-northern areas, are new faulted branches which confirmed by aeromagnetic, EGM2008 gravity and geological plots. Although these lineaments have been covered by young alluvials (Quaternary sediments) and deep weathered by climate changes, most of them can be

distinguished by geophysical interpretations. It means that we have new faulted branches and new cases of seismic activities for hazard analysis of NQF earthquakes.

- In fact, with argument about gravitational facies changes beside gravity data, we can prove better the existence of fault in the view of gravity and as a criterion have been used to recognition and determination hidden lineaments with seismic mechanism.
- This research method has included the exploitation of seismic lineaments and a new step in connection with the confirmation tectonic patterns around seismic epicenters by combining EGM2008 satellite data and gravitational facies changes.
- It is suggested that with drawing lateral sections of the gravity and magnetic changes and its comparison with formation changes of area, forthcoming studies should be focused on realizing the hidden fault seismicity and their focal mechanisms related to future earthquakes in north of Qazvin.

Acknowledgments

The authors would like to thank engineer Fayyaz for his kind cooperation and careful comments.

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