Morpho-tectonics and geoelectric method applied to active faults characterization in South of Mashhad Plain, Northeast of Iran

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Abstract

Mashhad city, the second most populous metropolis of Iran, with a population of more than three million, lies between two seismically active regions of Binalood and Kopet-Dagh. In recent years, the city has grown around the South Mashhad (SM) fault zone in the south. Given the vital role of the SM fault in influencing the seismic risk of the city, this study is aimed at the evaluation of the fault's characteristics and activity. The overall trend of the fault and evidence of its activities are investigated by morphotectonic studies, and the situation of fault zone was explored by different geophysical methods including resistivity, magnetic and microtremor array. Morphology studies have shown that SM fault results in the deviation of the river channels, replacement, and deformation of alluvial fans. The geoelectric studies have shown three segments of the fault, F1, F2, and F3, with the notable normal displacement. Magnetometry and microtremor array studies across F1 confirmed the normal displacement of the fault. It is concluded that SM fault is an active right-lateral and normal fault system that had a significant role in the development of Mashhad Valley.

Keywords*: South Mashhad Fault, Active Fault, Geoelectric, Array Microtremor, Magnetometry, Morpho-Tectonic.*

Introduction

The effect of strong near-field motion was widely discussed in the recent years, in respect of the destructive earthquakes of 1992 Erzincan, 1992 Landers, 1994 Northridge, 1995 Kobe and 1999 Kocaeli and Düzce (Trifunac, 2009; Abrahamson, 1998; Birgoren & Tarhan, 2000). Abnormal strong ground motion, fault displacement, landslides, liquefaction and associated health problems are commonly mentioned as likely effects of active faulting in the urban area (Bostenaru Dan *et al.*, 2014). Among these, fault displacement hazard is the most destructive phenomena close to the active fault. Fault displacement resistant buildings are usually costly, and in some situations are non-applicable, so the first recommendation of seismic codes is to avoid development within the fault zones (Murbach *et al.*,1999; Hopkins, 1987; Bray,2009; PCE, 2001).

The South Mashhad Fault is a covered fault that passes from the borderline of Binaloud mountain to the Mashhad plain. In a few cases, the fault plane can be seen using aerial photograph, satellite images, and field studies. However, more precise and costly exploration approaches are necessary to determine the fault property (Wyatt *et al.*,1996; Wise *et al.*, 2003; Suski *et al.,* 2010; Demanet *et al.,* 2001b; Benson & Mustoe, 1995). In this study different methods of geomorphology, aeromagnetic, gravimetry, and microtremor array are applied to identify, establish and map the characteristics of the South Mashhad active fault.

Seismotectonic and Seismicity

Mashhad, the second-largest metropolis of Iran, is one of the holy cities of the Muslim world. It is located in the east of Mashhad plain between the two seismotectonic zones of Binalod and Kopet-Dagh in Northeast of Iran (Fig 1). The region of Binalod-Kopet-Dagh defines the tectonic boundary or transition suture zone of the Turanian Platform and the Iranian microcontinent (Berberian, 1981; Natal'in and Sengör, 2005; Nowroozi and Mohajer-Ashjai, 1985). The Kopet-Dagh folded Mountains extend from the eastern edge of the Caspian Sea to the Iran-Afghan border (Afshar Harb, 1979), and the Main Kopet-Dagh Fault marks the northeastern boundary of the belt (Maggi *et al.*, 2000). To the northwest and south belt bonded by the Apsheron-Balkan belt, are the north of the South Caspian Sea Basin (Brunet *et al.,* 2003) and the Binalud Mountains, which assumes as the Paleotethys suture zone (Wilmsen *et al.,* 2009; Sheikholeslami and Kouhpeym, 2012). Morphologically, the Binalud Mountains with NW-SE trend can be considered as the eastern prolongation of the Alborz (Nabavi, 1976; Lammerer *et al.,* 1983). Due to the similarity of sedimentary and structural features of Binaloud and Central Iran zones, the Binaloud zone is usually considered as a transitional zone between the Alborz and Central Iran (Nabavi, 1976). Binaloud region principally consists of sedimentary, metamorphic, ultrabasic and acidic rocks of different ages. The Neyshabour fault system and Fariman-Torbat Jam lineament (Eftekharnejad & Behroozi, 1991) are considered as the southern limit of the eastern Binalud (Fig. 2). The South Mashhad(SM) Fault or Sangbast-Shandiz(SS) fault is commonly assigned as the Northern border of the range. However, Mashhad plain is covered by thick Quaternary sediments, and the exact boundary between Kopet-Dagh and Binalod zones in about 20 km width of the plain is unclear.

The study area has experienced at least nine large earthquakes (M ≥ 7) during the last six centuries and is known as one of the seismically active regions of the Iran (Tchalenko, 1975; Berberian & Yeats, 1999; Ambraseys and Melville, 1982). The severe seismic activity of the area had been recorded in 1700-1800, but since that time a relatively quiet period has existed. SS fault system, SM fault, Tous Fault (North Mashhad fault) Kashafroud fault, and Kheyrababd fault are the most significant active faults around the area (Fig. 2). The SS fault system comprises a few parallel thrust-right lateral slip faults with the strike of NW–SE, a width of 3 km and length of about 100 km (Shabanian, 2009). The fault system will easily be recognized from aerial photographs and satellite imageries. Minor vertical displacement occurs across the fault segments, and the right lateral displacement of the fault in the ground surface suggests a steeply dipping fault plane (Hollingsworth *et al.*, 2008). The earthquake of 30 July 1673 with Magnitude of 6–7 has referred to this fault system. This earthquake haddestroyed two-thirds of Mashhad city, killing ~4000 people (Ambraseys & Melville, 1982). Up to now, SM fault has been introduced as an inactive thrust fault with a northwest-southeast trend which passed from Ultrabasic, Granite, Granodiorite, Splits and Metamorphic rocks of Paleozoic (Alavi, 1992; Berberian *et al.*, 2000).

Subsurface geology of Mashhad Plain

The available subsurface information of Mashhad plain include 1) geophysical studies (National Iranian Oil Company (NIOC) at Chenaran area); 2) geoelectric studies of the groundwater resources and 3) soil profiles of piezometric and drinking wells.

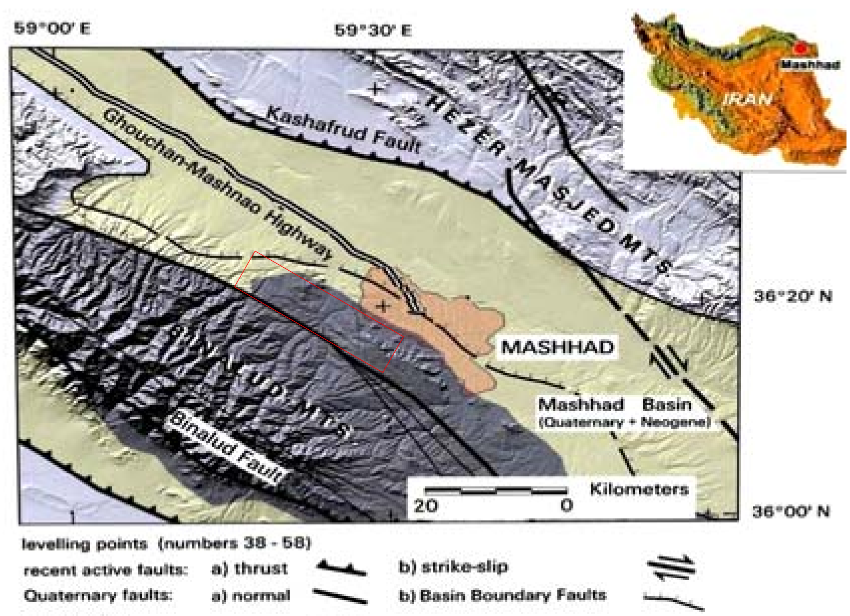

Figure 1. Study area.

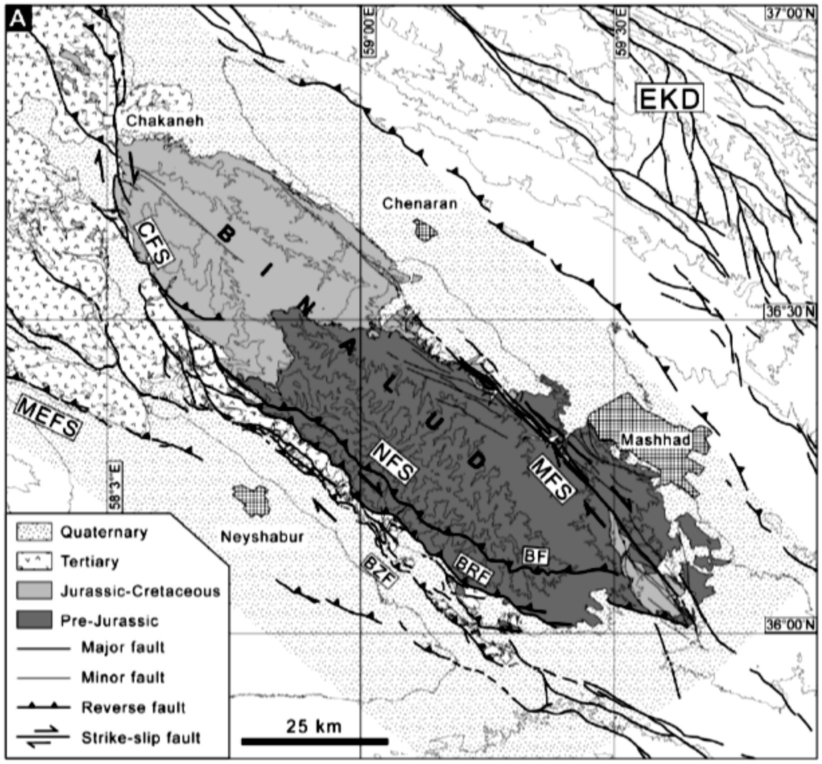

Figure 2. Simplified geological map of the area; Quadrangle shows the study area; dashed Red line is the general trend of SM fault; CFS, Chakaneh Fault System; MFS, Mashhad Fault System; NFS, Neyshabur Fault System; MEFS, Meshkan Fault System; BF, Binalud Fault; BRF, Barfriz Fault; BZF, Buzhan fault zone; QF, Qadamgah Fault; EKD, Eastern Kopet-Dagh. (Adopted from Shabanian, 2009 with some changes).

NIOC geophysical studies comprising aeromagnetic, gravimetric and seismic surface profiling, were carried out to survey the hydrocarbon potential in the Chenaran area (Alsoghe, 2002; Tabatabei, 1999; Khorasani, 1986). The aeromagnetic study showed that igneous outcrops in the south of Mashhad city were continued to the east and northeast and constitute the bedrock of the City. Also, a north-south fault trend cut the South Mashhad Ophiolite mass (Alsoghe, 2002). Seismic refractions are conducted in 4 lines around the Chenaran area (Khorasani, 1986). This study proposed a syncline shape for Mashhad plain which is cut by three northwest-southeast faults; two faults in the SW edge of the valley have a normal mechanism and results in fall of bedrock, and a reverse fault in the NE side of the valley contributes to the uplifting of the marly bedrock (Fig. 3).

The gravimetric study was conducted in the west of the plain in Golbahar area. This study proposed Mashhad plain is a double plunge syncline, the deepest part of syncline being close to the northern mountain, and three southwest-northeast faults pass from the center and two edges of the valley (Fig. 4) (Tabatabei, 1999). From the deep geophysical information, it may be concluded that both folding (synclinal) and faulting (Graben) processes affected formation of Mashhad valley.

The majority subsurface data of Mashhad plain comes from Geoelectric and groundwater exploration wells studies. Mashhad aquifer is the main water supply resource of the capital city of Mashhad and suburbs with a population of more than 4 million. The total capacity of non-renewable and renewable groundwater of the aquifer is about 5500 and 530 million cubic meters respectively (MCM) (KRWA, 1992). Annually 870 MCM groundwater is being extracted for different demands of household consumption, agriculture, and industrial uses, which is 340 MCM more than the renewable part. The groundwater extracted from this aquifer has lowered the water table (annual 1-meter) and caused ground subsidence. Already, the rate of land subsidence in some places has reached 80 cm per year (Motagh *et al.*, 2007).

Based on geoelectrical studies, Mashhad plain is a longitudinal asymmetrical valley filled by the alternation of gravel, sand, silt, and clay materials (Compagnie General de Geophysique, 1963). Grain size decreases from the west, southwest, and northeast toward the east and center of the plain. The alluvial fan deposits in the southern part are firmly coarser than of the north. Limestone outcrops in the west of Chenaran area result in coarser sediments deposits with respect to Schisty outcrops in the east of Chenaran and west of Mashhad city. The thickness of deposits is more than 350 meters in the west of Chenaran and the central of Valley (about the present-day location of Kashafrud river). The bedrock of the plain near the Southern slopes consist of Schist and Igneous rocks, but in the central and northern part of the plain, the bedrock comprises of colored, cohesive, Neogen Marl with alternation of sandstone and Gypsum. In the North edge of the plain (such as, Toos and Khaje-Rabie area), reverse faults lead to outcropping the Marly bedrock (CGG, 1963).

Figure 3. Seismic cross section of the Mashhad valley that shows at least three main faults in Northeast and Southwest edges. The fault mechanism in SW is normal and results in fall of the bedrock, but in the NE it is reversed consequently causing the uplifting of bedrock (Alsoghe, 2002).

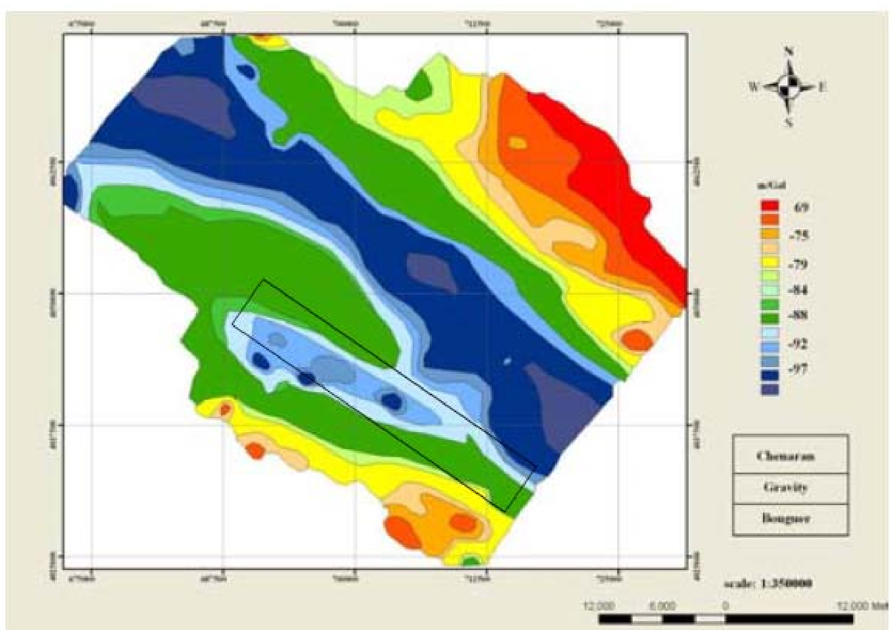

Figure 4. Burger anomaly map of the area, Blue Zone show low anomaly zone filled by Quaternary deposits. Brown color indicates the deepest part of Valley. This figure show two thalweg lines, near the northern mountain (main syncline) and close to the south edge (probably made by South Mashhad Fault) which is the interest of this study.

Morphotectonic study of the area

In an active tectonic area, alluvial fans conserve the history of activity for a long time. Parameters of lithology, climate, catchment characteristics, space to develop and tectonics are the primary controlling factors of alluvial fans (Bull, 2009), while the active tectonics is responsible for the subsequent changes (Hooke, 1968; Bull, 2007; Harvey et al., 2005). Mashhad plain is a longitudinal valley which is mainly filled by fan sediments originated from two mountain sides (Fig. 5). Some evidence of recent activity in Mashhad plain in the form of diversion of river trunk, increasing of sediment depth in front of the mountain, and deformation of fans are documented in some recent researches (Zamanian *et al*., 2010;Sajadian *et al*., 2015; Hafezi Moghaddas, 2008). Fig. 6 shows the geology map of the area prepared by interpretation of aerial photograph scales of 1:20000 and 1:50000.

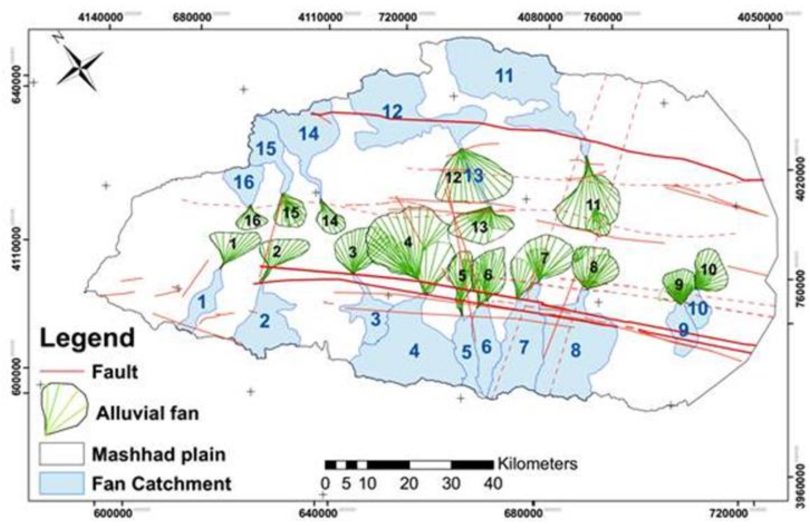

Figure 5. Alluvial fans in southwest and northeast of Mashhad Plain

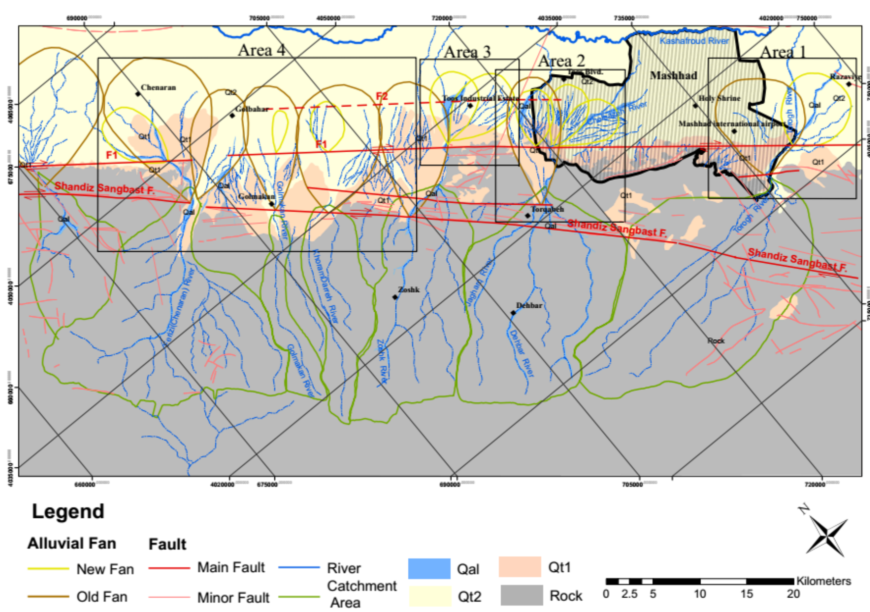

Figure 6. Large-scale geomorphology map of study area, the general trend of F1 fault which is determined by aerial photograph, coincides with the location of recent changes in river and fans. F2 fault is recognized based on a geophysical study which is discussed in section 6.

The old fans of Chehlbazeh, Zoshk, Torogh, Kahu, Golmakan, and Golbahar are situated along the SS fault, while in the middle of old fans, along with the F1 fault, new fans are created, and river trunks show right-lateral displacements. It is assumed that the vertical displacement was responsible for the generation of new fans.

Fig. 7 demonstrates the Geology map of Torogh (area1). As it can be seen, the main trunk of Torogh River turn to the right with an apparent displacement more than 1.3 km, and the new fans are formed along the F1. The best recent activity evidence of F1 can be seen in the Chelbazeh fan (Figs 8-9).

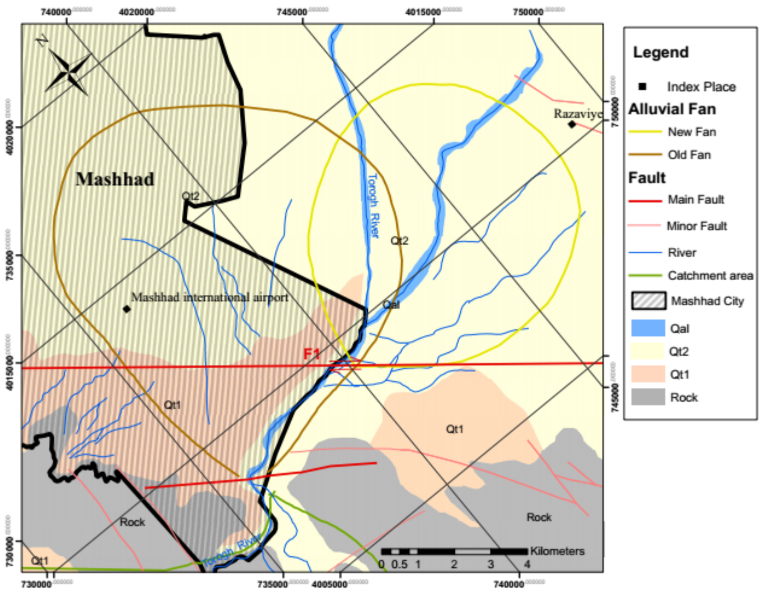

Figure 7. Geology map of Torogh (area1), Brown and Yellow lines show the old and new fans, respectively.

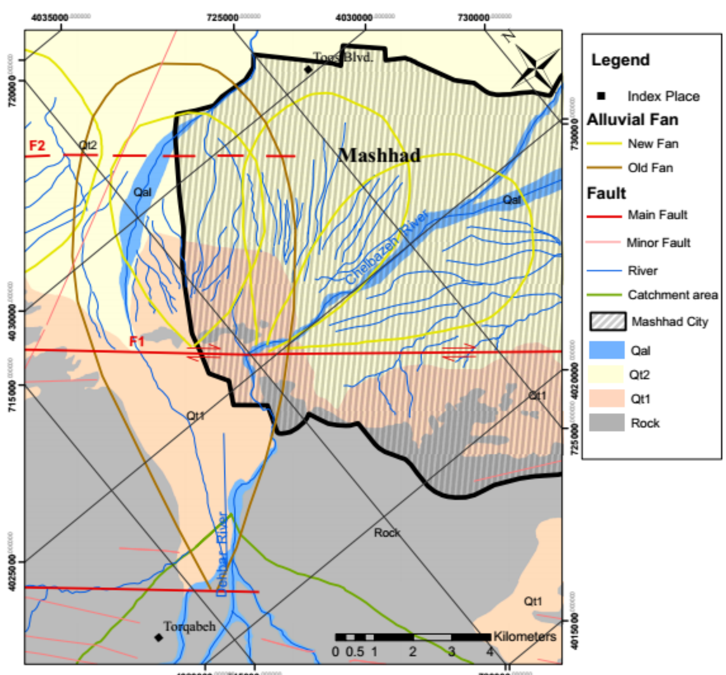

Figure 8. Geology map of Chehlbazeh fans (Area 2)

Right lateral displacement, separation from the mountain, and gradual displacement from west to east of this fan are quite visible in the aerial photographs. The apparent horizontal displacement of this river is measured to be about 1.0 km. As with the last river, Zoshk river similarly shows the right-lateral displacement along the F1 fault, and newly generated fans turn to the east. The apparent displacement is about 0.6 km which is less than Chehlbazeh and Torogh area (Fig. 10). The generation of new fans along the F1 and right-lateral displacement for two others fan of Khoram-Dareh and Golmakan in the west of Zoshk are also evident. However, it may be concluded that from east to the west, apparent horizontal displacement and the dimensions of new fans decrease. In contrast to other fans, the new fan of Chenaran moved to the left (Fig. 11).

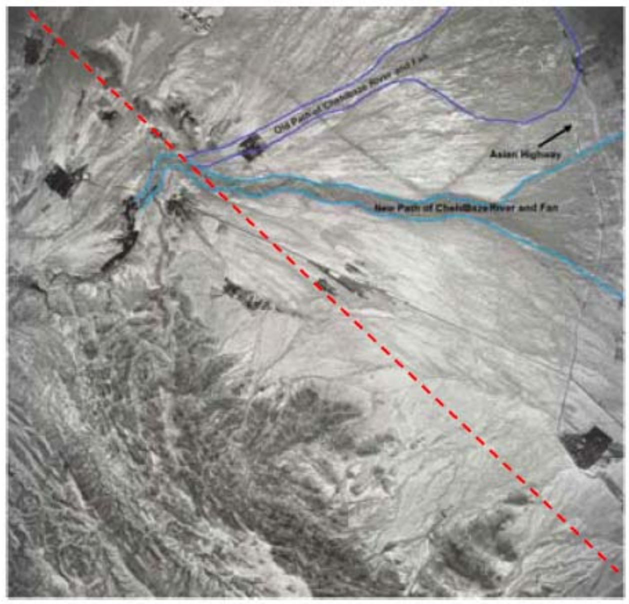

Figure 9. Arial Photograph of Chehlbazeh fan, displacement to the east, run away from the mountain, and right lateral deviation of the main river are obviously evident in this photo.

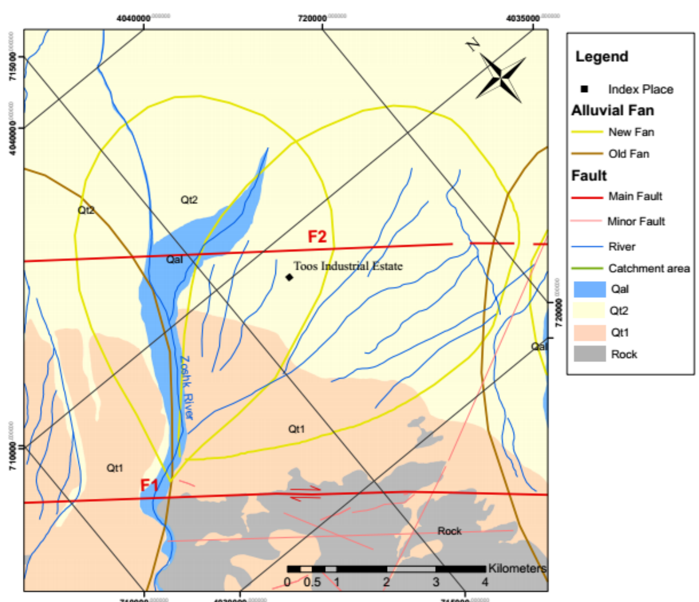

Figure 10. Geology map of Zoshk fan (Area 3)

Geoelectric Study

Geoelectrical Studies in Mashhad plain has been conducted at different periods of 1963, 1969, 1970, 1973 & 1978 by Khorasan Razavi Regional Water Authority (KRWA, 1992, 2002; SAPC 1999). In this research, raw geoelectrical data of 1978 including 23 geoelectric prospecting sections with a maximum current electrodes distance of 3000 meters, are reinterpreted using IPI2win software (Fig. 12) (Bobachow, 2002). The criteria used for separation of the different lithologies is represented in Table 1. Figs 13-17 show examples of apparent and actual resistivity profiles.

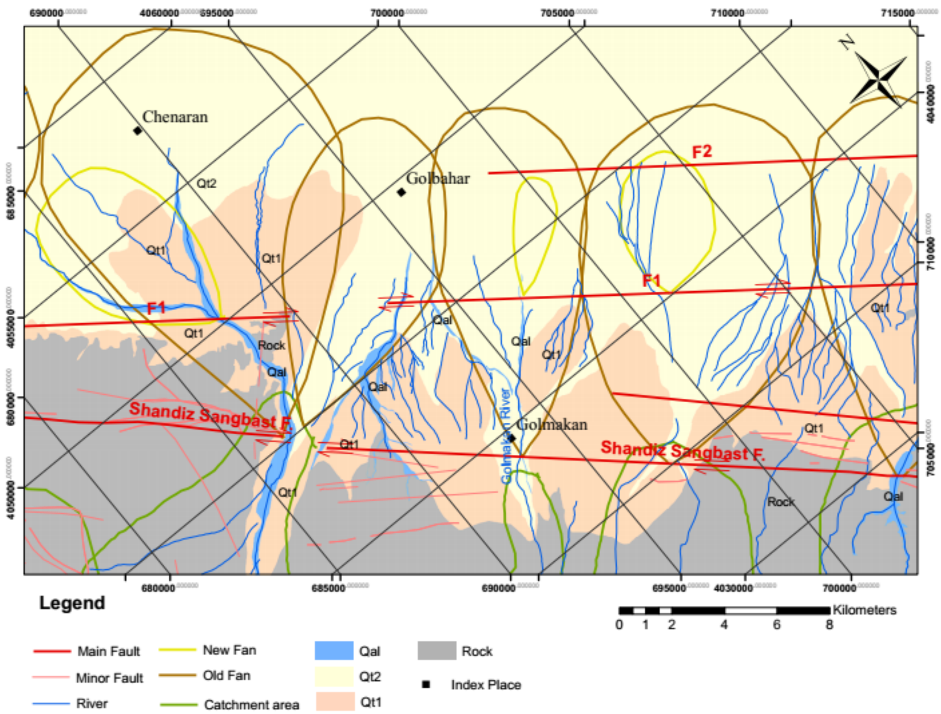

Figure 11. Geomorphology map of Zoshk-Feriz area (area 4).

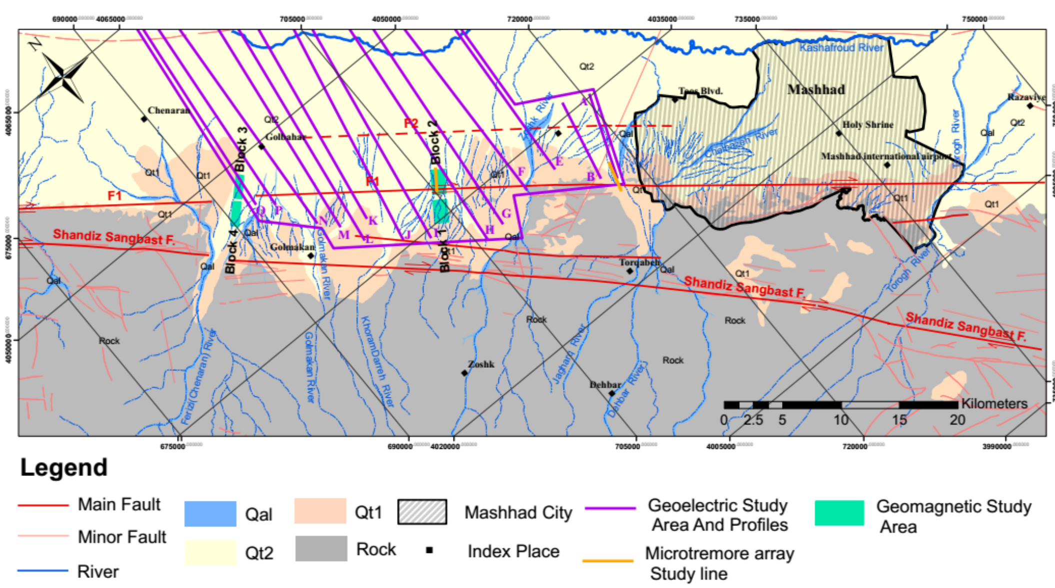

Figure 12. Location of geoelectrical section in west of Mashhad city

Table 1-The range of electrical resistivity used for identification of the geological units

No	Actual electrical resistivity (Ωm)	Marerial	No	Actual electrical resistivity(Ωm)	Marerial
1	>150	Dry alluvial	4	30-150	Alternation of fine and carse grain sediments
2	>150	Hard sedimentary rock	5	>30	Marl-saturated fine grain material
3	200-800	Metamorphic	6	>50	Soft sedimentary rocks(Shale and Marl)

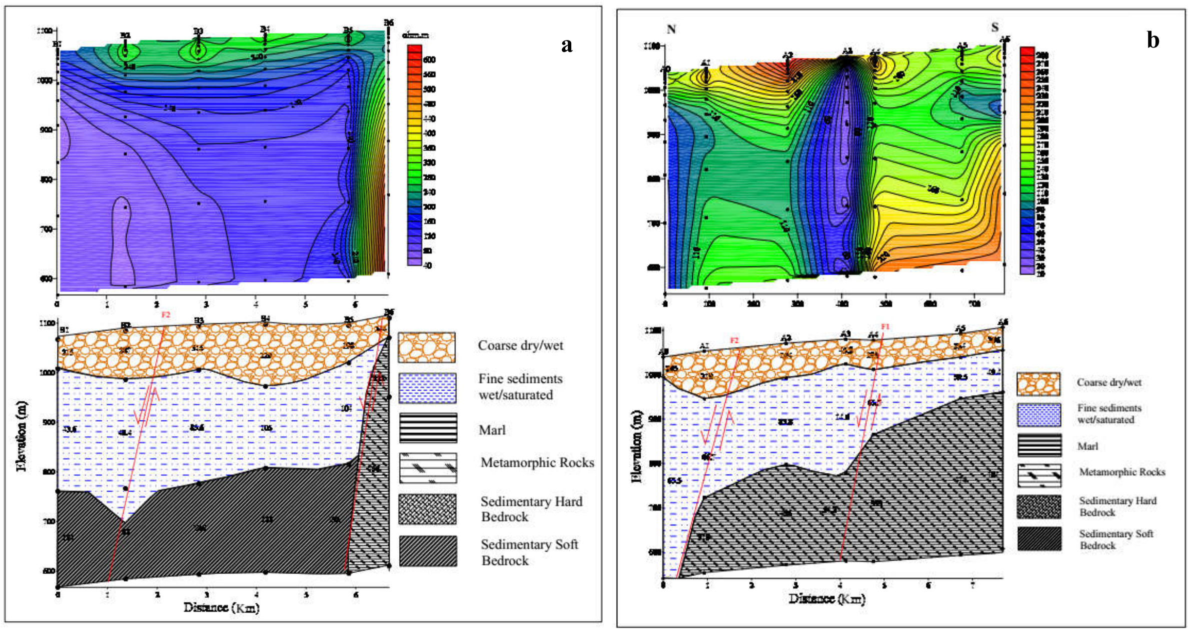

Figure 13. (a) Apparent and actual electrical resistance of profile A; (b) Apparent and actual electrical resistance profile B. A crushed zone with low resistivity is composed along a nearly vertical faults in both sections.

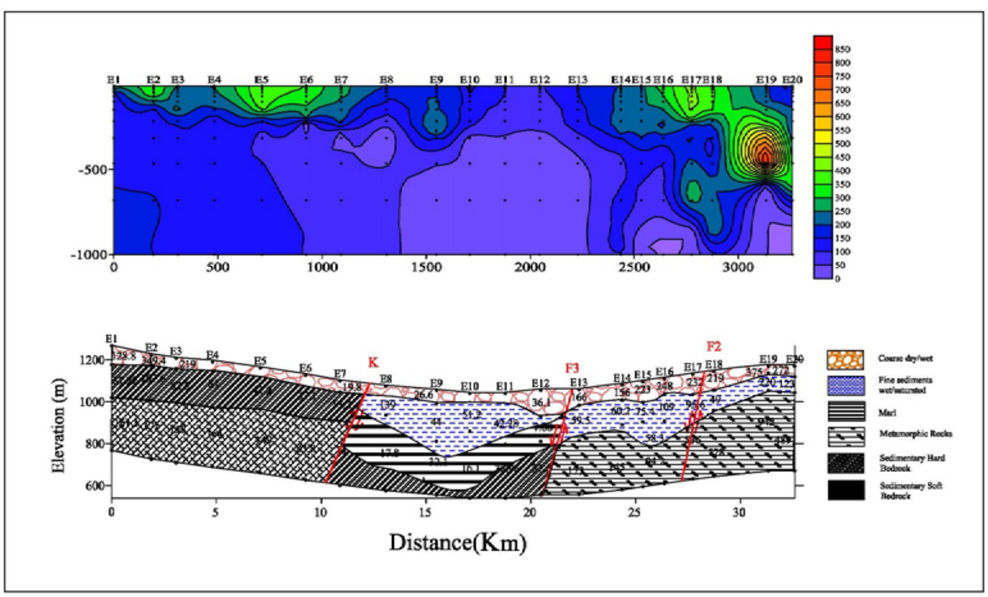

Figure 14. Apparent and actual electrical resistance profile E; Trend faults F2, F3 and the reverse fault of Kashafroud are observed in this section. Marley rocks constitute a low resistivity area in the middle of the section and F2 lies in the border of marl and metamorphic rocks.

Geoelectrical sections show four fault trends across the Mashhad plain which are named here as F1, F2, F3, and K(Kashafroud). The F1 with the same trend proposed by geomorphology study is traceable in all sections (Figs 13-17). In the majority of sections, F2 formed the border of metamorphic and Pleistocene Marl. The total vertical displacement of bedrock across the F1 and F2 reached up to 300 meters. In the north of all long sections, reverse Fault of Kashafroud is evident(Fig. 14-17).

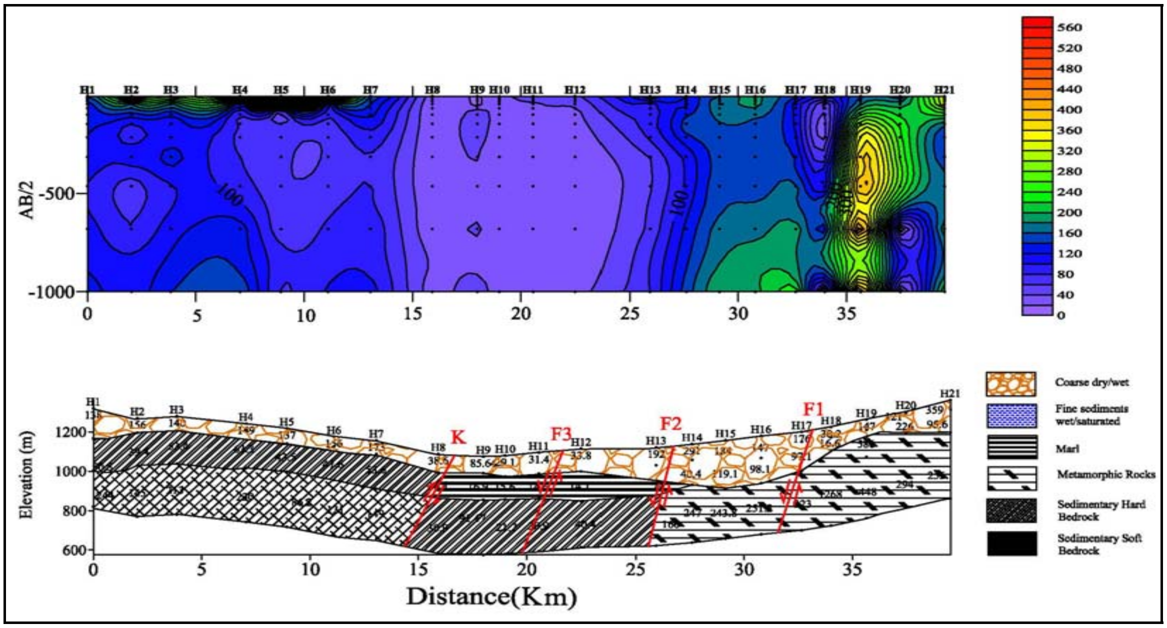

Figure 15. Apparent and actual electrical resistance profile H. The four trend faults are also seen in this section.

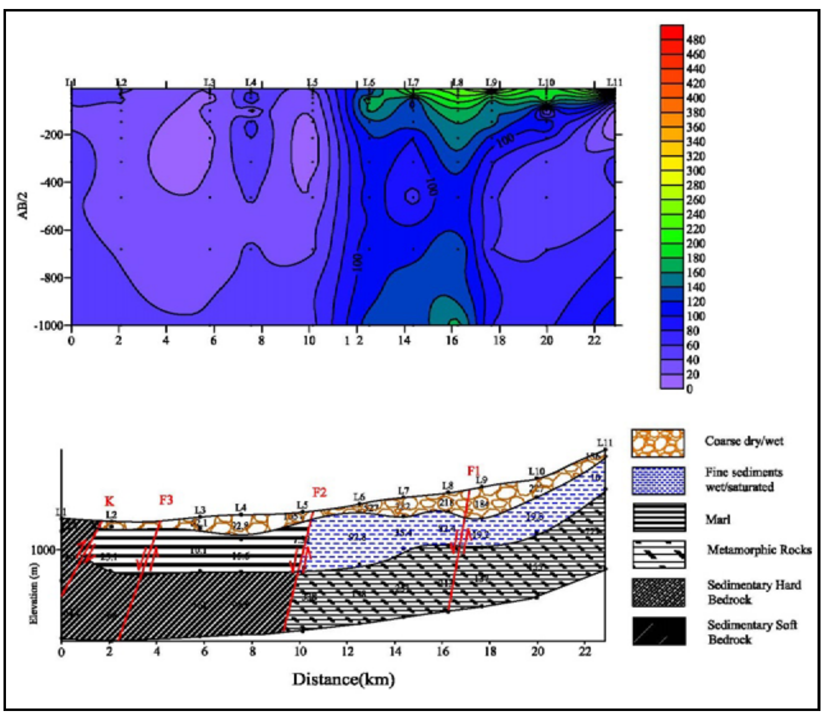

Figure 16. Apparent and actual electrical resistance profile L. As in other sections, Neogen marl between the two faults of Kashafroud and F2 existed and F1 results in crushing of bedrock and thicknessing of alluvial deposits.

Discussion

The geomorphology and geology studies confirmed the recent activity of the SM fault. The geoelectric research introduced the three Quaternary faults of F1, F2, and F3 that have a similar trend to the SS and SM fault (Fig 18).

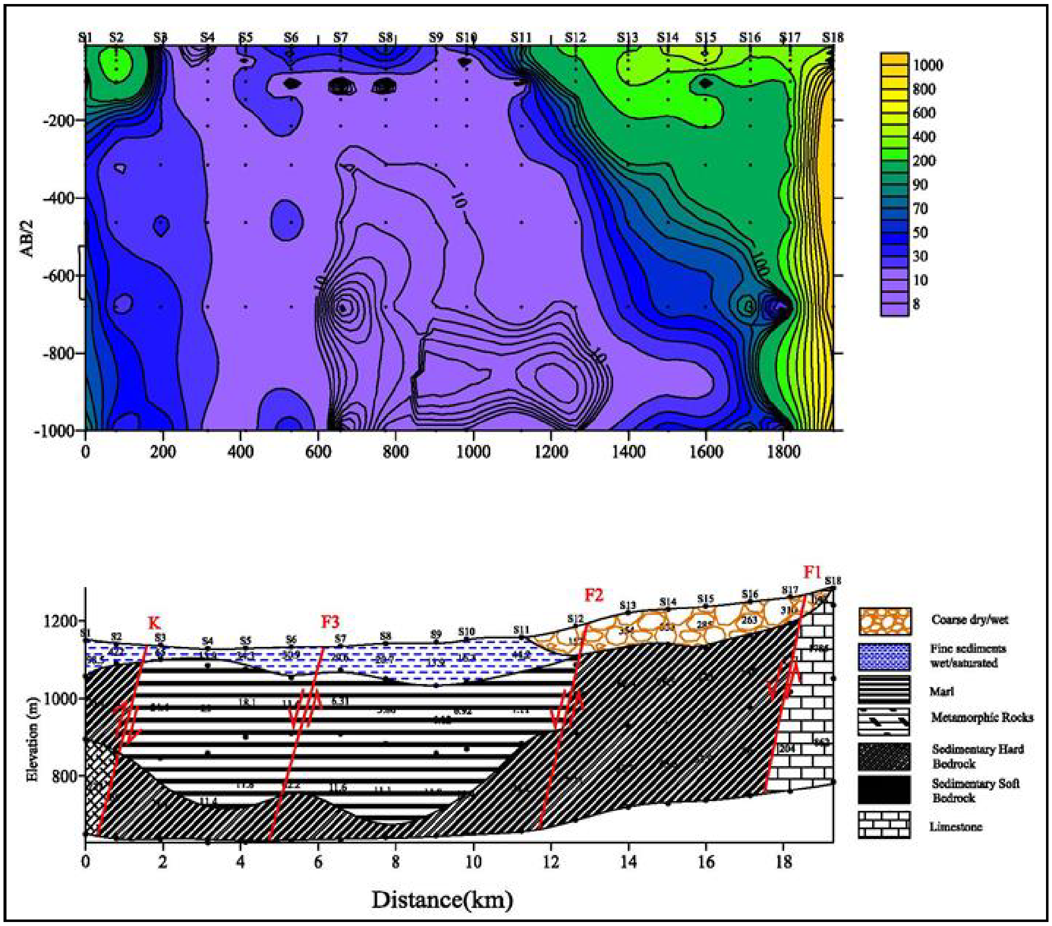

Figure 17. Apparent and actual electrical resistance profile S, the final section. In the south of this section limestone and alternation of shale and sandstone are detectable. As the previous sections, Neogen Marl existed in the middle of the section.

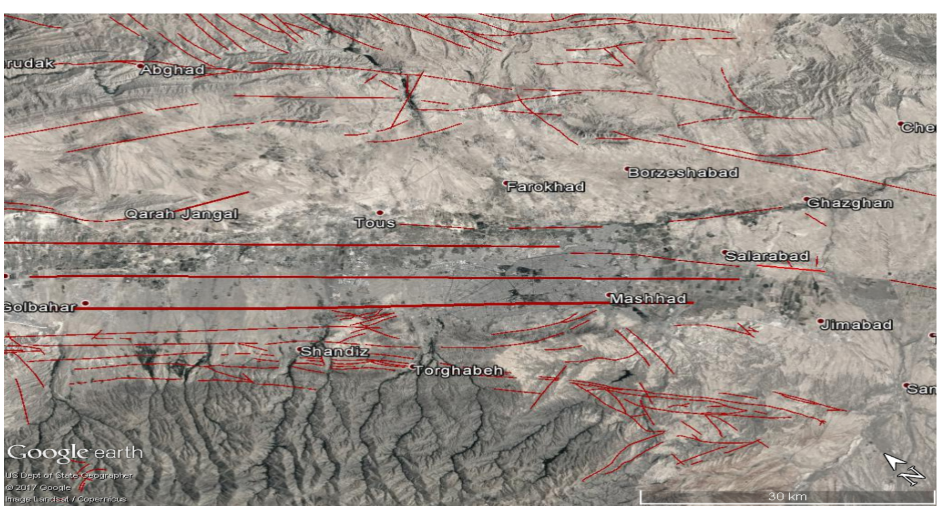

Figure 18. Three fault hidden fault trend in Mashhad Plain.

The generation of new fans along the F1 has suggested the existence of a vertical component for this fault.

F2 in some sections lies in the border of the Metamorphics rocks of Binalod and the Sedimentary rocks of Kopet-Dagh. In contrast to F1, no geomorphology evidence of F2 and F3 is recognized in the aerial photograph; therefore it may be concluded that F2 and F3 are older than F1. According to similar trends and also the proximity of F1 to the SM fault, it is thought that F1, F2, and F3 belong to South Mashhad fault system (SMFS). Also, it is possible that other hidden faults existed in the center of the plain. Shabanian et al. (2009) have reported that the new stress between the Binaloud and Kopet-Dagh turn to the right lateral strike-slip mechanism of SS Fault. This study also proposed the strike-slip mechanism for SM fault but with the significant normal component. The total vertical displacement of F1 and F2 are measured to be more than 300 meters. This study confirmed that the present situation of Mashhad Valley is affected by both syncline and Graben mechanisms.

Conclusion

This study shows the SM fault system comprised three subparallel segments of F1, F2, and F3 that result in the fall of bedrock and formation of a graben valley in the collision zone of Binaloud and Kopet-Dagh in the northeast of Iran. The geomorphology features along with F1 fault, which pass from mountain front, support a strike-slip and normal mechanism. F2 and F3 are identifiable by geoelectrical sections. F2 lies in the interface of metamorphic and sedimentary rocks of Binaloud and Kopet-Dagh. The F1 fault can be classified as an active fault which has a vital role in the seismic risk evaluation of Mashhad city.

Acknowledgments

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