

Investigation and nomination of Gheysar blind fault focal mechanism by aftershocks' distribution and aeromagnetic data in Aryan-Shahr area, N-Birjand

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Abstract

In March 9th, 2008 an earthquake with $M_L=5.1$ occurred in Aryan-Shahr area, 55 km north of Birjand, East of Iran. More than 100 aftershocks were recorded within 8 days after the main shock. At first, the Sedeh fault with N76 trend was informed as source of this earthquake. But the distribution of aftershocks has been occurred in an ellipsoid district, that the long axe of this ellipsoid is not parallel with Sedeh Fault. The long axis of distribution ellipsoid of aftershocks (N120) is nearly perpendicular to the Sedeh fault trend.

Investigation of aftershock epicenter dispersal and the interpretation of aeromagnetic data make known the existence a blind fault parallel to long axis of distribution ellipsoid of aftershocks, which has been named Gheysar blind fault. The Gheysar blind fault with ~39 km length and trends of N126, appears to has a thrust component, and gently dipping (~20°SW).

Key words: Aryan-Shahr, Aeromagnetic data, Gheysar blind fault, Sedeh Fault

1. Introduction

The initial stages of fault development have been recognized in laboratory experiments, but not at seismogenic depths. To fully understand how faults initially develop and begin to evolve, one needs to first recognize and then observe the emerging structure. Recognizing the birth of a fault requires a priori knowledge of the regional tectonics, geologic structure, and seismic history. This information is needed to assess the likelihood that earthquake hypocenters that occur far from known faults represent new fault formation rather than slip at depth on existing structures. Furthermore, young faults may begin as blind structures, which make them difficult to recognize.

The 1994 Sefidabeh earthquake (berberian *et al.* 2000), 2003 Bam earthquake (Bihong and Xinglin 2007) revealed the significance of blind thrust faults in East IRAN. Dissimilar the expose active fault, blind faults are difficult to recognize because they aren't visible and haven't surface ruptures. Even after a blind fault is identified, it is difficult to determine whether the fault is active (Lettis *et al.*, 1997). We present evidence for an incipient, blind, thrust fault in southwestern Aryan-Shahr town that is associated with the March 9th, 2008 Aryan-Shahr earthquake.

As in Aryan-Shahr area, these active thrusts occur adjacent to active strike-slip faults, thus raising the question of how these fault types interact and contribute the regional deformation.

We use the techniques of Satellite Images process and Shuttle Radar Thematic Maps (SRTM) to examine small-scale features in the deformation field associated with the Aryan-Shahr earthquake. The study area is located in north part of Sistan suture zone and partial North Lut (Fig. 1a, b).

The fundamental premise of earthquake-hazard reduction in the U.S. is that most earthquakes take place along active faults that suddenly fail and slip. Large earthquakes take place along large faults, and large faults, it is widely held, cut the earth's surface. Geologists recognize faults that have displaced young surface deposits as having recently been active and deem them the most likely to rupture again.

This reasoning has yielded profound insights into earthquake behavior, making it possible to situate critical facilities-such as power plants and dams-away from active fault sites, to identify sites with high seismic potential and to make probabilistic forecasts of earthquake size and frequency.

Yet in March 9th, 2008 Aryan-Shahr most small earthquakes do not occur along faults that cut the earth's surface.

Previous seismicity studies (Berberian *et al.*, 1999, Walker and Khatib, 2006, Walker *et al.*, 2003, 2004) and geologic maps (Berthiaux, 1989, Eftekharneshad and Vahdati, 1992, Eftekharneshad and Valeh, 1997) of the area do not show a surface expression of a fault, geologic structure, or tectonic landform corresponding to the March 9th, 2008 Aryan-Shahr earthquake and aftershocks.

In this paper, Investigation of blind active fault by assimilates aftershock epicenter dispersal and the interpretation of aeromagnetic data.

We investigate the distribution of aftershock zones for large earthquakes scalar seismic moment magnitude main shocks and aftershocks are selected from the IRSC website (<http://www.irsc.ut.ac.ir>). One of preferences of remote sensing in geology is wide cover of study area that gives useful information of structural pattern. Faults and fractures are structures that were recognized by satellite images. For recognizing the liner structures and analyzing structure of Aryan Shah Region in the north west of Birjand use the digital data of TM sensor. By using Optimum Index Factor the most suitable false color combination was obtained. After that the spatial high pass filters and the effect of sun radiation angle and transportation in the data histogram were used. In the next stage the study area faults, mechanism and relation of them were recognized (Fig. 1b)

2. Geological and Geomorphologic overview

The Aryan-Shahr area is located in north of sistan suture zone in E-Iran (Fig. 1). This zone is separated from Afghan block, Lut block and Makran zone by these boundaries. N-S spreading of this zone is ~800 km and its width is 200 km. In fact, this zone has been formed from sediment of accretionary prisms between Lut and Afghan block by convergence phases at Senomanian-Oligomiocen time. Nevertheless abundance of calcalkalin volcanic rocks in northern part of the Lut block (Tirrul *et al.*, 1983) considered the sense of subduction toward to north and east, below the Lut block. Separation between Lut and Afghan block has created oceanic crust in Middle Cretaceous and flysch depositions formed simultaneously. Gradual convergence of Lut and Afghan at Middle-Late Oligocene time caused folding, fracturing and

uplifting in this area. Finally intense magmatic activation have appeared at Neogen time and concentrated in main fault margin.

Several present-day tectonic land forms have been used to indicate the activeness of crustal structures (Keller & and Pinter, 1996). These landforms of both primary and secondary features can be clearly seen by the uses of remote-sensing information. There are several tectonic landforms, such as offset streams, shutter ridges, and vine glass valleys, which are important for investigations of tectonic geomorphology. Recently with the application of ArcGIS and the DEM, several morphotectonic investigations can be easily evaluated with a very low cost and high quality results.

Most of Aryan-Shahr area is flat, one-third is covered by hills between 200 and 400m height from the plain and only a very small part of the points are rise above 400m.

Neotectonic evidences are shown that the study area is active. Even though the tectonic movements are very young, and the uplift rate is considerable. The observation data's shows the study areas have high potentials of tectonical activity. Field photographs of neotectonic evidence in Aryan-Shahr area shows in Fig. 2.

3. Aryan-Shahr earthquake

Tectonic deformation refers to regional deformation that may or may not be associated with moderate or large earthquakes. There are earthquake epicenters concentrated in the border active faults (Quaternary faulting), and all similar trending active fault with distributions of epicenter locations. Even though there are no mapped faults which these earthquakes easily can be tied to, there is morphological lineation in that direction.

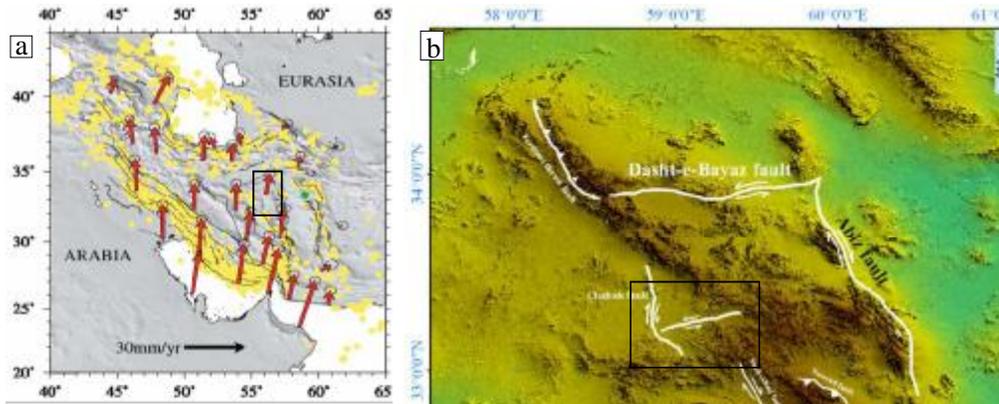


Figure 1. Geological location of Aryan-Shahr area.

(a) Yellow circles are earthquakes in the period 1964–2002 from the catalogue of Engdahl *et al.*, 1998 and subsequent updates. Red arrows are velocities (in mm/yr) of points in Iran relative to stable Eurasia, measured by GPS from Vernant *et al.* 2004). The green circle is the epicenter of the March 9th, 2008 Aryan-Shahr earthquake. Box shows the location of fig. 1b. (Jackson *et al.*, 2006)

(b) Shaded topographic image, from SRTM data, of the east Iran. Note the major faulting in eastern Iran. Box shows the location of fig. 3, 4.

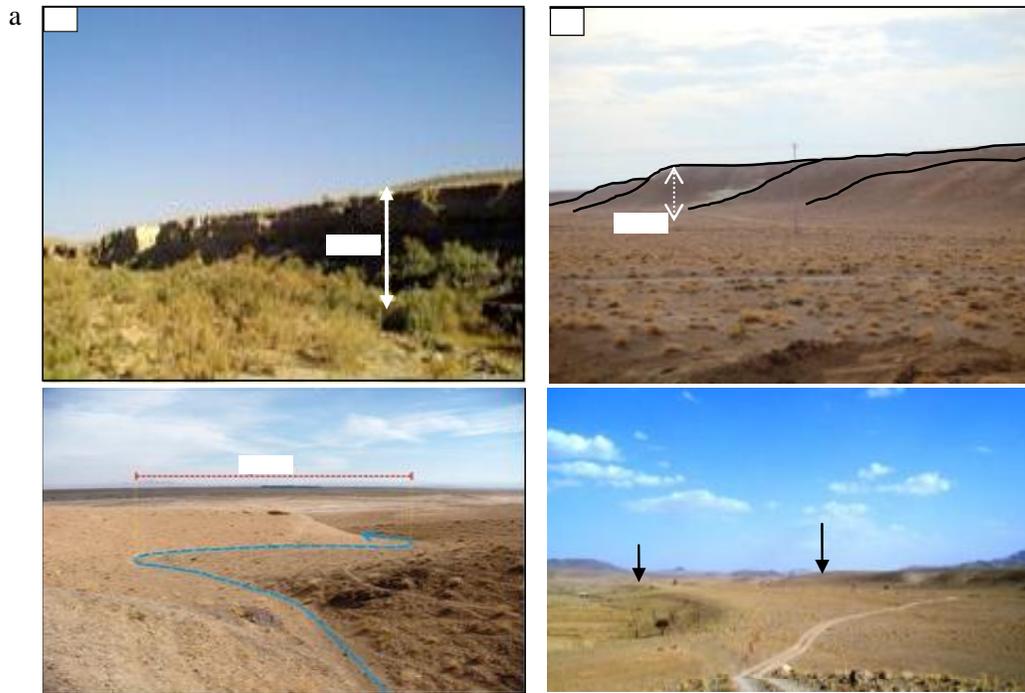


Figure 2. Field photographs of neotectonic evidence in Aryan-Shahr area. (a) A typical gully incised through the uplifted ridge, at 33° 17'N 59° 08'E, looking northeast. (b) View NW of the ~17 m high scarp (32° 25'N 59°E). (c) View E of a right-lateral offset of the river in Chahak fault trend (32° 20'N 58° 49'E). (d) View upstream (NE) at the village of Mahmooe (33° 19'N 59° 21'E), showing a river incised through the uplifted hanging wall, leaving behind abandoned fan surfaces as terraces.

In March 9th, 2008 partly violent earthquake of $M_L=5.1$ shook west of Aryan-Shahr city in the North of Birjand, East Iran. This earthquake not killed persons but destroyed some neighbor villages. Shortly after earthquake Tehran university institute of geophysics network installed in area recorded more than 100 aftershocks for three months. All data of 3 stations were processed, common aftershocks were separate, their parameters were determine and were drawn on fault map. Therefore distribution of aftershocks location and main shock geometry of causing fault is known. Results show that causing fault has 39 Km length, and average 6 Km depth. These results not confirm by geology data and Field investigation. Most major faults in Aryan-Shahr area reach, and thus intersect with, the surface of the earth. This intersection of the fault plane with the surface produces a linear feature called a fault trace. The active crustal faults include the Sedeh, Shah-Abad, Chahak, Dasht-e-Bayaz and Afriz faults, the not source of the damaging Aryan-Shahr earthquake (Fig. 1b, 3). Too some faults, do not reach the surface.

Aftershock pattern by the Gaussian distribution cannot be exact; some aftershocks occur at large distances from the main shock where not her traces of earthquake rupture can be found as the aftershock sequence. Also distribution of aftershocks location and main shock geometry of causing fault is known. For the 8 days after the earthquake 9th, March 2008 in Aryan-Shahr a dense seismic network of 3 stations was operated in the epicenter region to record aftershocks. The majority aftershock distribution delineates has been occurred in an ellipsoid district, that long axis of distribution ellipsoid of aftershocks an intense NW-SE zone of activity (Fig. 3).

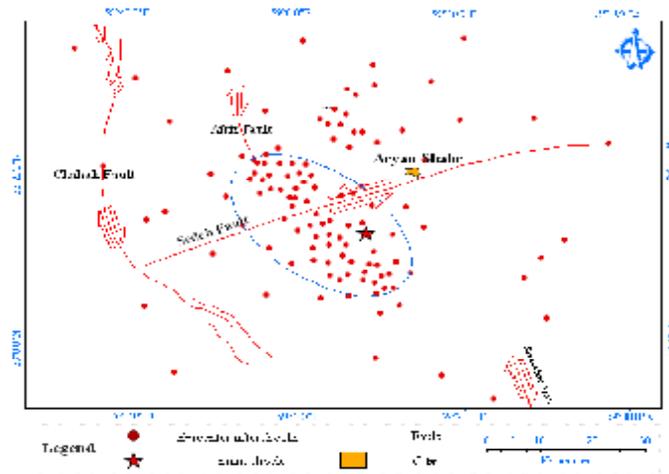


Figure 3. Aftershock locations for the March 9th, 2008 Aryan-Shahr earthquake. Locations of the best-located 106 aftershocks from March 9th, to March 17th, 2008. Note the distribution ellipsoid of aftershocks in Aryan-Shahr region.

4. Aeromagnetic evidence

This magnetic data on this paper were compiled from information recorded along the flight lines, which were flown at 7.5 km. spacing in a direction perpendicular to the primary geologic trend within each block. Tie lines were flown with a 40 km spacing perpendicular to the traverse lines. The regional gradient of the earth's field has been removed. Magnetic counters show total intensity field in gamma. Regional gradient has been removed as

explained elsewhere. If the fault plane terminates before it reaches the earth's surface, it is referred to as a blind thrust fault. Because of the lack of surface evidence, blind thrust faults are difficult to detect until they rupture. The March 9th, 2008 earthquake in Aryan-Shahr was caused by a previously-undiscovered blind thrust fault. In this study, Use of Aeromagnetic Data one technique is for recognition Blind fault.

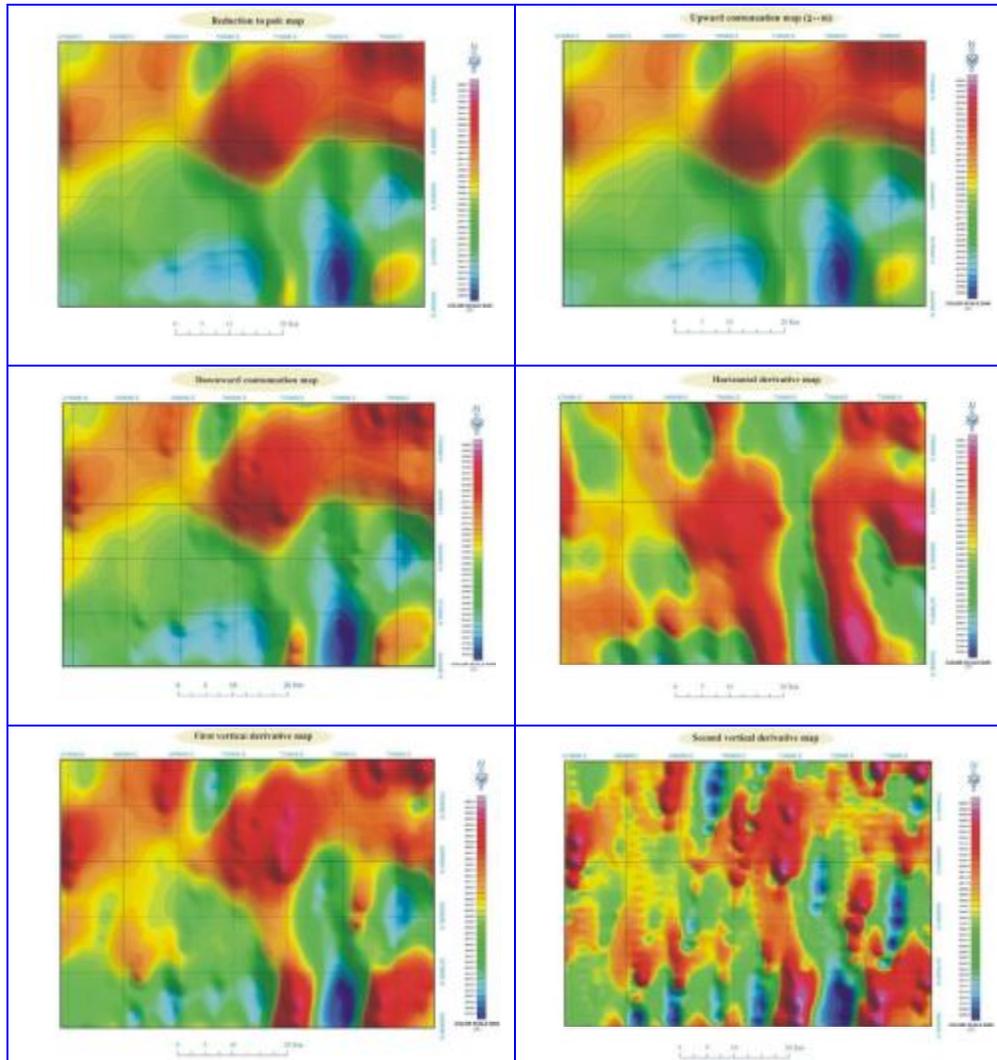


Figure 4. Applied filter by Geosoft software for aeromagnetic data processing in Aryan-Shahr area. (a) Reduction to the pole filtering. (b) Upward continuation filtering. (c) Downward continuation filtering.(d) Horizontal derivative filtering. (e) First derivative filtering. (f) Second vertical derivative filtering.

By Reduction to the pole, Upward and Downward continuation, Horizontal, First and Second vertical derivative filtering in Geosoft software recognize blind fault in Aryan-Shahr area (Fig. 4). So, we identify four blind faults in study area, and named Gheysar, Room-Chelunak, Shushood and Gazar blind faults (Fig. 5).

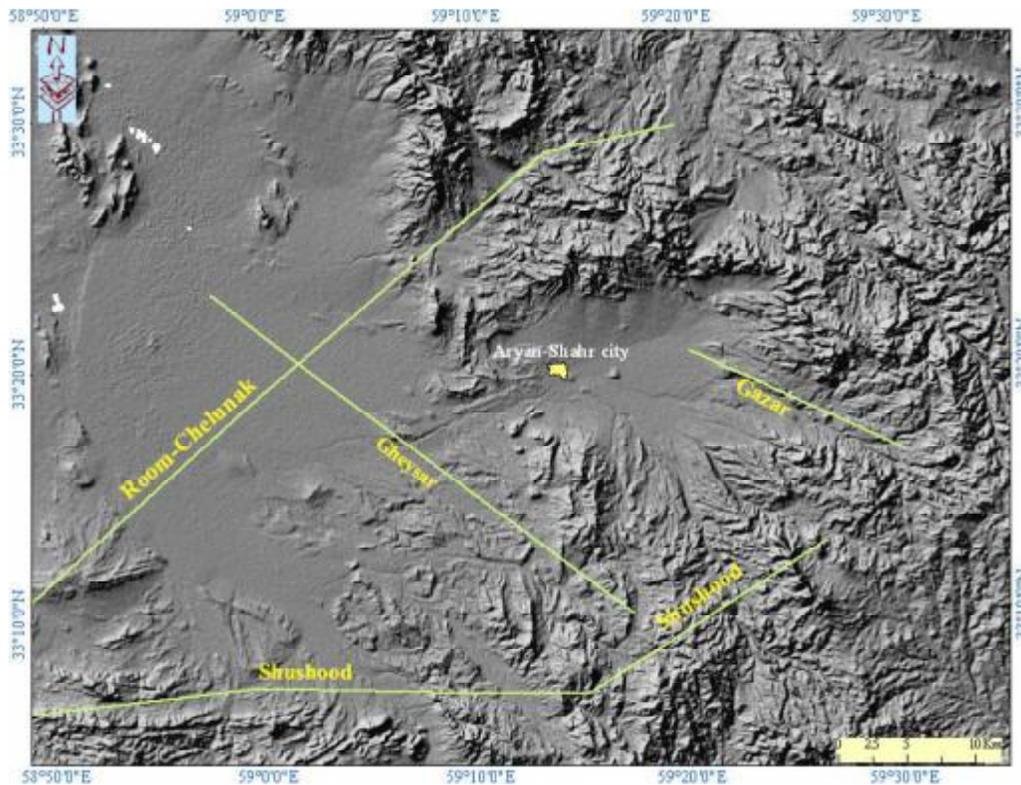


Figure 5. Blind fault identified by aeromagnetic data process.

5. Aftershock locations and Gheysar blind fault mechanism

Focal mechanism solutions of the area's earthquakes have been displayed to reveal mechanisms of seismically active fault zones. These solutions indicate dominance of thrust faults in a compressive regime for vast majority of earthquake of Aryan-Shahr. Active fault in Aryan-Shahr area are blind and the focal mechanism solution of the earthquakes of the region points to the presence of thrust faulting in its basement. The aftershock zone is sub vertical beneath the Gheysar blind fault trace, broadening with depth (Fig. 6a, b, c). In this study, we suggest that the aftershock zone has a steep ($\sim 20^\circ$) Southwestward dip. Nearly all the best-determined locations lie in the range 1–9 km, and thus almost entirely below the 2–8 km depth range in which most of the slip occurred in the main shock, and which produced the subsurface deformation revealed in the Gheysar blind fault (Fig. 6d). The depth range of maximum slip in the main shock is nearly completely free of aftershocks in the Fig. 6d. This is a very significant observation as it suggests that the thickness of the seismogenic zone in the region is about 30 km, and that not ruptured in the Aryan-Shahr main shock. An important question is whether the unruptured may still fail seismically in a future event. Their results were much the same, demonstrating a thickness to the seismogenic layer of ~ 30 km, and a relative lack of surface rupture above the Gheysar blind fault.

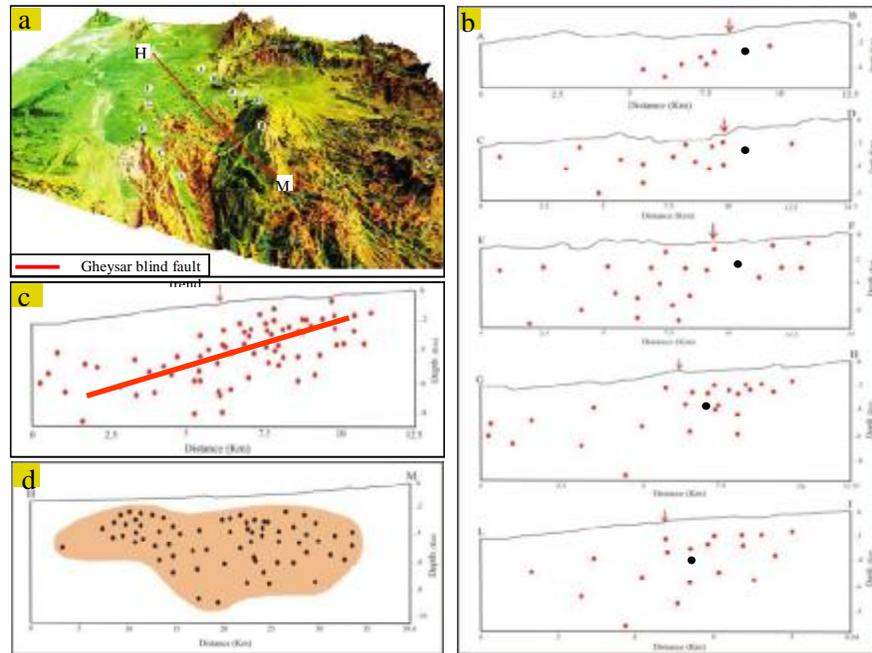


Figure 6. (a) 3D perspective image of the Aryan-Shahr area. Open box A-B up to L-I is location of cross section in fig. 6b. (b) Cross section along axis of distribution ellipsoid of aftershocks. Black points are main shock, and red points are aftershocks. Red arrows are projection Gheysar blind fault in surface. (c) In total cross-section fig. 6b, Gheysar blind fault trace is well-defined steeply dipping fault. Since cross section is perpendicular to Gheysar blind fault, not to fault splay, distribution about fault splay is artificially widened. (d) A northwest-southeast section along the line of the Gheysar blind fault, showing the 106 high-quality aftershock locations of author. The depth range of maximum slip in the main shock is nearly completely free of aftershocks.

On the basis of the seismicity pattern and focal mechanisms, we infer that the Gheysar blind fault is likely a small displacement strike-slip fault zones. This could be consistent with an incipient fault, and the clear activity at both ends should evolve, with time, toward a connected through going fault. The lack of a surface expression associated with the seismic lineament may be because it is a young fault that has had little throw.

In numerous examples around the world, active strike-slip faults appear to end in dip-slip faults, with displacements that die away from the junction between the two [e.g., Bayasgalan *et al.*, 1999; Berberian *et al.*, 1999b, 2000; Meyer *et al.*, 1998; Parsons *et al.*, 2006]. The Nauzad thrust along the northern margin of Kuh-e Mo'inabad is an example of this type of structure with the thrust linking at its eastern end to the Purang strike-slip fault [see Berberian *et al.*, 2000, Figure 14].

6. Conclusion

The close proximity and orientations of the Gheysar seismic lineament and the Shah-Abad fault suggest that these two structures are related. The seismic lineament may represent an extension or propagation of the Shah-Abad fault towards the northwest. In this study, by combining neotectonic evidence, aftershocks' distribution and aeromagnetic data, one can better quantify the seismic potential of regions where strain rates are high, and identify

Gheysar blind fault mechanisms. Also, with the attention of the importance of basement faults without any surface fault in data base of earthquake source and the importance of basement depth & sediment coverage thickness research in the investigation of damage intensity in other regions. The Gheysar blind fault with ~39 km length with a near N126 trend which appears to has a thrust component, and gently dipping (~20°SW), perform important role in the seismicity analysis of Aryan-Shahr area. Our conclusion is that in regions where blind faults are present, the cumulative surface deformation from many repeated earthquakes will leave surface diagnostic of active faulting in the landscape, such as the diversion or abandonment of river channels, abrupt changes from river incision to deposition and abandoned terrace surfaces that can be identified in satellite imagery and the field.

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