RELATION BETWEEN THE RUPTURE OF SEDIMENTARY ROCK AND THE RUPURE OF BASEMENT IN THE ZAGROS SIMPLY FOLDED BELT, IRAN

Farzane AZIZ-ZANJANI
Gratuate, IASBS, Zanjan, Iran
Farzaneh.aziz@yahoo.com

Abdolreza GHODS
Assistant professor, IASBS, Zanjan, Iran
aghods@iasbs.ac.ir

Keywords: Simply Folded Belt, Relocation, Focal Mechanism, Zagros

ABSTRACT

Zagros is a fold and thrust belt in the southwest of Iran and is also a very unique place on the earth that we can study a young continental collision zone. Different studies have been focussed on the deformation of the sedimentary cover and the basement. Yet the relation between the deformation at the surface and in the bedrock is a matter of debate. Earlier studies in the Zagros Simply Folded Belt (ZSFB) using local, teleseismic and Interferometric Synthetic Aperture Radar (INSAR) data have proposed that most of moderate earthquakes (Mw 5-6) occur in the lower sedimentary column while microseismicity is related to the basement. In this study, we have applied a multiple-event relocation analysis to a cluster of events in ZSFB. We also used S-P difference times of close BHRC accelerometer stations to have a proper control on the focal depths. Most of the focal depths illustrate that the beginning of rupture happens in the basement. In addition, we calculated moment tensor solution for some of large events using regional data obtained from the Iranian National Seismological Network (INSN), Iranian Seismological Center (IRSC) and Global Seismograph Network (GSN). These data provided the proper good azimuthal coverage for large events. Moment tensor inversion results are in consistency with previous results provided by body wave modelling and INSAR in which they show shallower centroid depths. Therefore, there is a discrepancy between the focal depth and the centroid depth that cannot be explained either by considering the error bars or the difference of two based on their definitions. We thereafter suggest that although the rupture begins at the basement, most of the moment release is in shallower depths and within the sedimentary column.

INTRODUCTION

Zagros is a young fold and thrust belt (ZFTB) in the southwest of Iran formed by the collision between Arabia and Eurasia plates (Berberian and King., 1981; Falcon., 1974). The ZFTB is subdivided into two main structural zones distinguished by different topographies and styles of deformation: the Zagros Simply Folded Belt (ZSFB) to the south west and the High Zagros Belt (HZB) to the north east. The High Zagros Fault (HZF) is the boundary between these two zones. The Hormoz salt layer as one of the detachment horizons is a lower incompetent layer between basement and crust that has an exposure in south east of Zagros as salt plugs and salt domes. The relation between the surface structures and basement is not crystal clear. Many people assume that the faulting in the basement occurs independently of the folding in the sedimentary cover because of the detachment horizons (Falcon., 1974; Jahani et al., 2009; Talbot and Alavi., 1996). Others have proposed that deformation started in a thin-skinned mode and continued as a thick-skinned deformation (Molinaro et al., 2004; Hatzfeld et al., 2010). Recent studies using local, teleseismic and INSAR data in ZSFB suggested that microseismicity is related to the basement but most of the moderate sized (Mw 5–6) earthquakes occur in the lower sedimentary cover (at depths of 5–10 km) and not in the basement which has previously been thought (Nissen et al., 2010; Nissen et al., 2011).

In this work, the depth of seismicity in a precisely relocated seismic cluster in ZSFB has been reassessed by the examination of a fully independent dataset, the dense accelerometer network of the Building and Housing Research Center (BHRC) in Iran. BHRC stations are strong motion seismometer which usually trigger for events larger than magnitude 4. Because BHRC stations do not have precise timing, we can only use Sg-Pg difference arrival times to estimate the depth of events. BHRC records show clear Pg and Sg phases for events in the magnitude range of 4 to 6. This makes them perfect for the depth evaluation in Zagros where the most of seismicity has a magnitude below 6. We also calculate moment tensor solution of eight earthquakes within this cluster both in frequency and time domain using regional data from Iranian National Seismological Network (INSN) and Iranian Seismological Center (IRSC) as well as Global Seismograph Network (GSN).

METHOD

The multiple-event relocation analysis named the hypocentroidal decomposition (HDC) algorithm (Jordan and Sverdrup, 1981) has been applied to a cluster of events in ZSFB. The HDC method is unique among multiple-event relocation methods because it can separate the location problem of a cluster of events into two parts, the relative locations of all events (known as cluster vectors) with respect to a reference point (the hypocentroid) in space and time, followed by the estimation of the location of the hypocentroid in absolute coordinates, which establishes the absolute locations of all events in the cluster by adding the cluster vectors to the hypocentroid. Using this method we calculated the location of earthquakes precisely. We used S-P difference times of close BHRC accelerometer stations to have proper control on focal depths. Although the S-P phases of BHRC stations are not included in the locating process, the depth is constrained by try and error method to fit better to these close S-P phases. We try to estimate focal depths after obtaining a precise location of epicenter for events that may be in error by the order of only 5km or less.

Focal mechanisms have been calculated using moment tensor inversion method. A detailed description of moment tensor theory is given by Aki and Richards (2002). Muller's reflection method has been used for construction of Green functions and synthetic seismogram (Muller 1985). After the calculation of Green function, Mtinvers program has been used for inversion (Dahm and Kruger., 1999). We separately did inversion in time and frequency domain using frequency range between 0.017 and 0.04 Hz. Moment tensor inversion in frequency domain is applicable to regions with less well-developed crustal velocity model and low signal-to-noise ratio (Herrmann 2011). To solve the ambiguity of the solution in frequency domain, we also retrieved solutions in time domain. Depth is not an unknown parameter in our inversion. However, the optimum solution is reached by minimizing *sc* parameter in equation 1 (Donner 2011).

$$sc = (1 - DC/100) + 1.5\,(res/res_{\max}) \quad (1)$$

The *res* value is the residue of the inversion for a given assumed depth, res_{max} is the maximum residual over all depths, and *DC* is the percentage of double couple for a given solution.

Dispersion curves derived from data shows that our velocity model is reliable at studied range of frequency. In fact, inversion is less sensitive to the deviation from exact earth structure in these frequencies. Later with sensitivity analysis we will show that changes in velocity structure have minor effects on solution for frequencies between 0.17 and 0.04 Hz. However, it changes the misfit between the data and synthetics. Also, Kagan angle was calculated after the Jacknife test for each event in order to do a sensitivity analysis respect to different stations and components.

RESULTS

Figure 1 shows result of relocation and moment tensor inversion in cluster within ZSFB region. The correlation between some epicentres and salt domes is clear. Furthermore, the most of focal depths after relocation illustrate that the beginning of rupture is within the basement (focal depths are larger than 15 km). However, the moment tensor inversion results for both waveform and spectrum data show shallower centroid depths that are in sediments. Table 1 shows different parameters such as latitude, longitude, focal depth, centroid depth, strike, dip and rake for 8 earthquakes in this cluster. The first three are based on the results of relocation and the rest based on the moment tensor inversions.

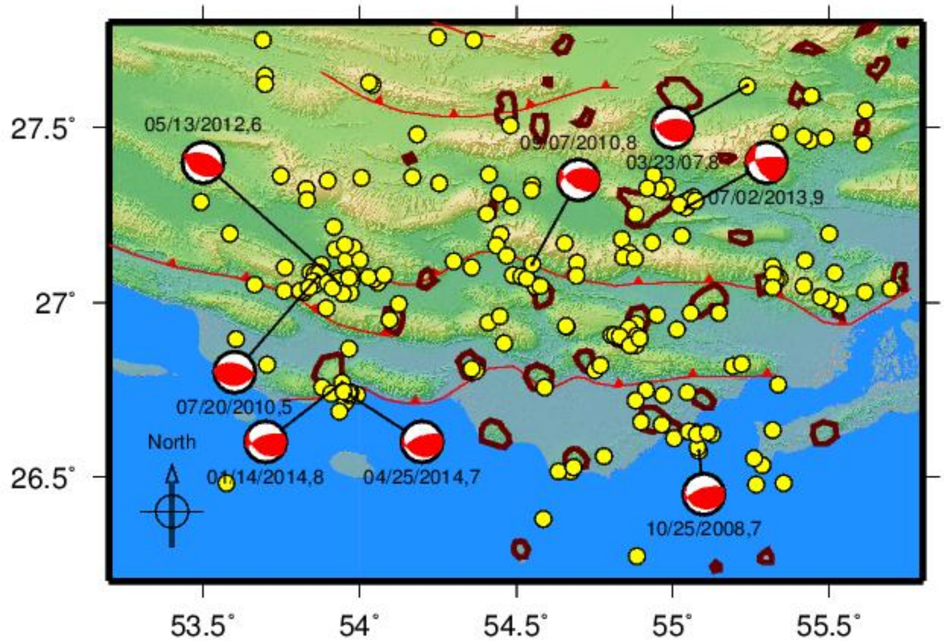
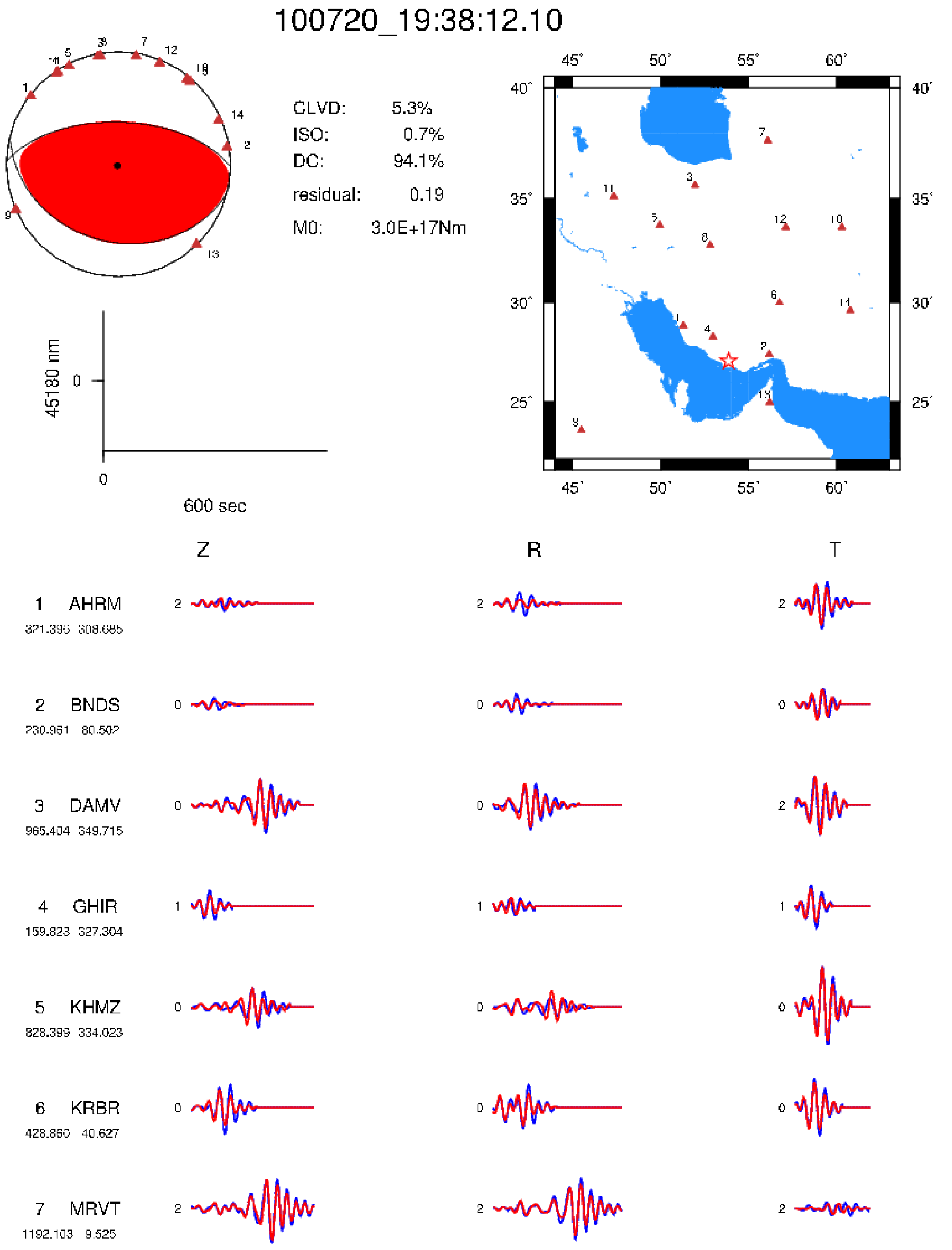


Figure 1. Result of relocation and moment tensor inversion in cluster within ZSFB region.Yellow circles show epicentres for cluster in SFB obtained by HDC method with focal depth larger than 15 km. Beach balls display calculated moment tensor solution with shallower and next to each beach ball the event time and depth are shown. Crimson polygons are the location of salt dome (Jahani et al., 2007) and fault data are from Hesami et al., 2001.

Table 1. Different parameters for 8 large earthquakes in figure 1.

Origin time	Latitude	Longitude	Focal depth	Centroid depth	Strike	dip	rake
2010/07/20_19:38:12.10	27.08529	53.84334	25	5	109.3	31.3	100.8
2012/05/13_18:21:14.98	27.06604	53.95179	18	6	104.4	39.9	77.5
2014/01/09_08:31:31.17	26.77024	53.94477	18	8	123.7	40.5	136.8
2014/04/25_20:59:50.16	26.73530	53.96916	18	7	113.6	31.1	129.7
2008/10/25_20:17:18.35	26.57480	55.08358	21	7	103.5	34.7	110
2010/09/07_02:11:5.72	27.11004	54.55164	16	8	270.7	36.1	72.7
2007/03/23_21:38:5.20	27.61775	55.23884	18	8	119.8	37.2	121.2
2013/07/02_11:18:34:69	27.27054	55.04171	18	9	154.1	40.5	139.4

Figure 2 shows the result of the inversion in the time domain and also the misfit between observation and synthetics for Koodian event (2010/07/20, also listed in table 1). Figure 3 shows the solutions for different depths in time domain. The similar results were obtained in frequency domain. Inversion in frequency domain is less sensitive to deviation from earth structure. So, moving towards the higher frequencies was applied to check sensitivity of solutions to variation of depth. Results obtained from all of these steps are in consistency with each other.



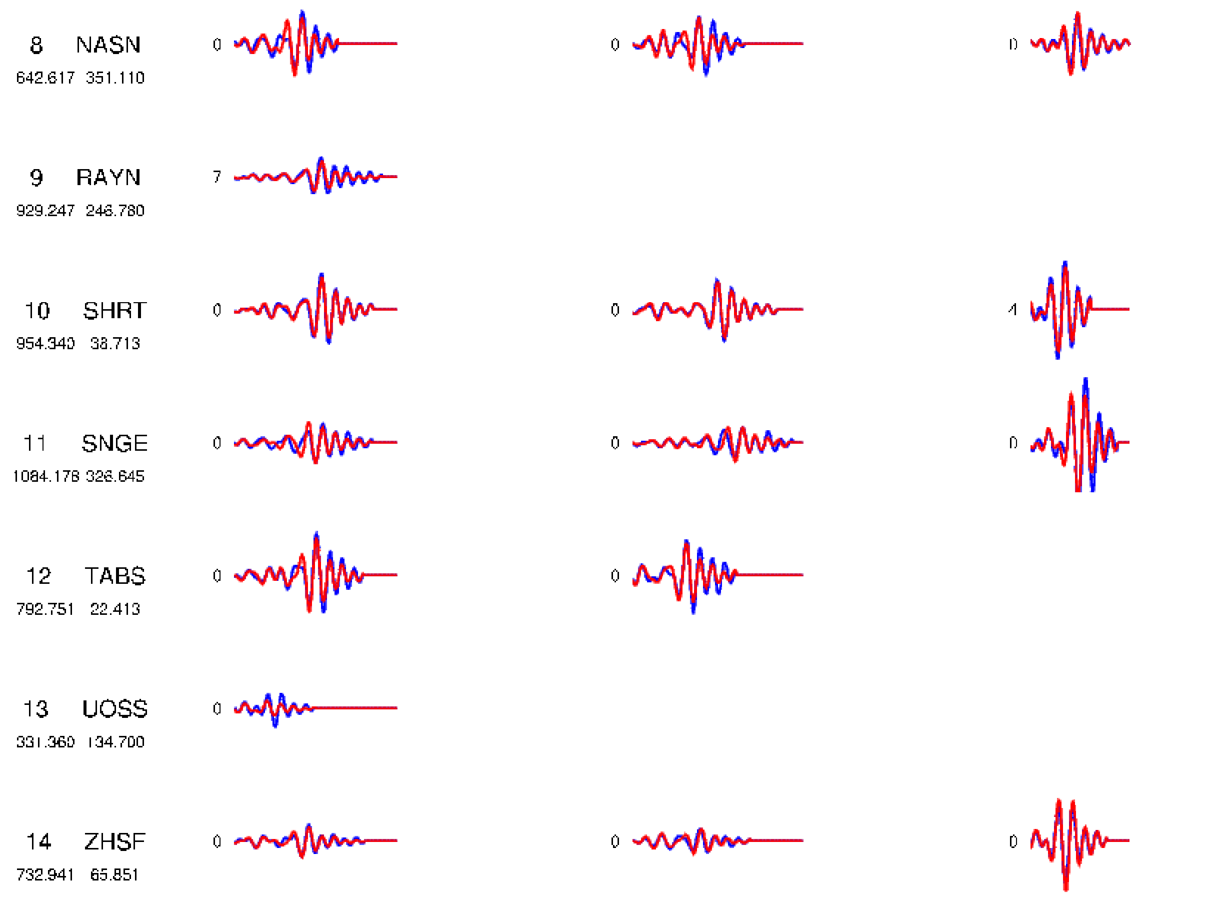


Figure 2. Inversion result for Koodian event (2010/07/20). Centroid depth is 6 km. Blue and red lines are observations and synthetics, respectively. Number beside each waveform is the value of time shifts. Numbers below the name of stations are focal distance and their azimuth from epicenter, respectively.

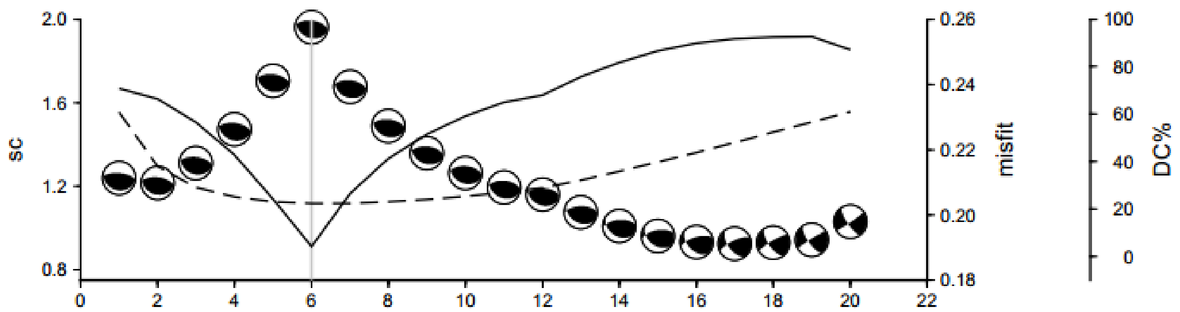


Figure 3. Inversion results for different focal depths for Koodian event. Beach balls are DC part of solutions. Dotted line shows misfit between observation and synthetics. Solid line shows sc value for each depth (sc value give us depth with minimum misfit and maximum Dc). Grey line indicates the depth with minimum sc.

Moment tensor inversion is sensitive to uncertainties in epicenter, focal depth, earth model and azimuthal coverage of seismic stations. We have used epicenters and focal depths calculated from HDC multiple event relocation that considerably are more accurate. However, the instability of the solution might be partially associated to poor azimuthal coverage. Most of the recording stations are in the north of epicenter. The Jacknife test was performed for the analysis of the sencitivity of the solution to different components at different stations In this test, 20 percent of waveforms has been disregarded from inversion iteratively. Then Kagan angles have been calculated. Figure 4-a shows the result of the test that gives the maximum Kagan angle of 17 degree for this event. This indicates the stability of presented solution with respect to using different combination of stations and components.

In adition, we don't have a precise earth model for the Zagros region and it is very unlikely to develop a proper 1-D model for the study area because the earthquakes struck the region that its geology significantly changesin different directions. The crustal rocks of Zagros changes from the west of the range to the east (Makran subduction zone) and from the south of the range towards the north (the zone of Central Iran). The Arabian plate is located in the south of the earthquake's epicenter. So, the range of frequency that is less sensitive to the velocity structure was selected. First, the dispersion curves for data and presented model were calculated which were similar in period between 25 and 60 seconds. Then, the sensitivity of solutions to using different models was examined. Figure 4-b shows velocities models and corresponding calculated solutions that give maximum Kagan angle of 22 degree that again shows the stability of our solution to the velocity model.

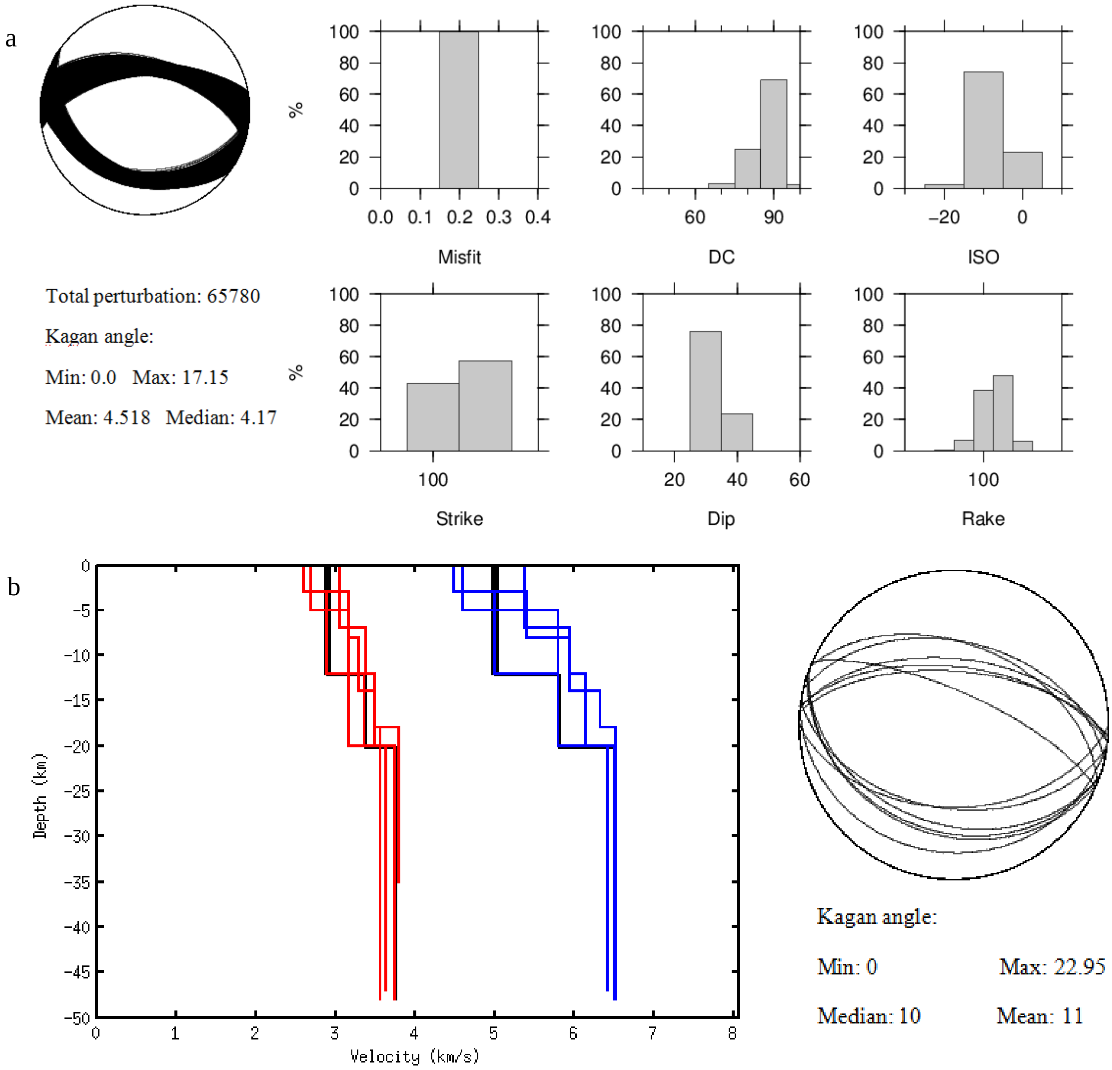


Figure 4. The sensitivity analysis for Koodian event in time domain: a) The Jacknife test and the corresponding Kagan angle. b) (Left) Different velocity models for S and P waves (red and blue lines respectively), black solid lines show the main velocity models. (Right) Solutions for different models and the related Kagan angle.

CONCLUSIONS

We used both regional data and BHRC accelerometer data for studying the deformation of the ZSFB. Result of the moment tensor inversion both in the frequency and time domain shows shallow centroid depth (5-8 km) with predominant reverse mechanism. This observation is in consistency with the result of previous body wave modelling and INSAR data presented for the same region (Nissen et al 2011). However, the results of relocation using HDC method and assigned focal depths using close BHRC stations show deeper depths for events (15-25 km). These results suggest that also rupture begins at the basement, most of the moment release happens in shallower depths within the sedimentary column. Further investigations are needed to explain relationship between the rupture of the sedimentary cover and the rupture in the basement in ZSFB and for the probable role of salt domes. That itself would clarify the large difference between the calculated focal depths and the centroid depths.

REFERENCES

Berberian M and King GCP (1981) Towards a paleogeography and tectonic evolution of Iran, *J Earth Sci*, 18: 210-265

Dahm T and Kruger F (1999) Higher degree moment tensor inversion using far-field broadband readings: Theory and elvauation of the method with application to the 1994 bolivia deep earthquake, *Geophysical Journal*, 137: 35 – 50

Donner S, Robler D, Kruger F, Ghods A and Strecker M R (2013) Segmented seismicity of the Mw 62 Baladeh earthquake sequence(Alborz Mountains, Iran) revealed from regional *Journal of seismology*, 17:925-959

Falcon NL (1974) Southern Iran: Zagros Mountains In: A Spencer (Ed), Mesozoic Cenozoic orogeny Belts, *Special Publication*, 4: 199-211

Hatzfeld D, Authemayou P, Van der Beek O, Bellier Lavé J, Oveisi B, Tatar, M, Tavakoli F, Walpersdorf A, Yamini Fard F (2010) The kinematics of the Zagros Mountains (Iran), in Tectonic and Stratigraphic Evolution of Zagros and Makran During the Mesozoic-Cenozoic, edited by P Leturmy and C *Robin, Geol Soc Spec Publ*, 330, 19–42

Herrman RB, Benz H and Ammon CJ (2011) Monitoring the earthquake source process in north America, *BSSA*, 101: 2609-2625

Hessami K, Koyi HA and Talbot CJ (2001a) The significance of strike-slip faulting in the basement of the Zagros fold and thrust belt, *J Pet Geol*, 24: 5–28

Jahani S, Callot J, Frizon D, Letouzey J and Leturmy P (2007) The salt diapirs of the eastern fars province (Zagros, IRAN): A brief outline of their past and present, *Springer*, 287-306

Jahani S, Callot JP, Letouzey J and Frizon De Lamotte (2009) The eastern termination of the Zagros Fold and Thrust Belt, Iran: Structures, evolution, and relationship between salt plugs, folding, and faulting, *Tectonics*, 28, TC6009

Jordan TH, Sverdrup KA (1981) Teleseismic location techniques and their application to earthquake clusters in the south-central Pacific, *Bull Seism Soc Am* 71: 1105–1130

Molinaro M, Leturmy P, Guezou JC and Frizon Delamotte D (2005) The structure and kinematics of the south-eastern Zagros fold –thrust belt, Iran: from thin-skinned to thick-skinned tectonics *Tectonics*, 24, NIL42–NIL6

Talbot C J and M Alavi (1996) The past of a future syntaxis across the Zagros, in Salt Tectonics, edited by G I Alsop, D J Blundell, and I Davison, *Geol Soc Spec Publ*, 100, 89-110