Evaluation of Earthquake Potential in the Zagros Region (Iran) Using Seismic Strain and Seismicity Parameters

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ABSTRACT

To elucidate the details, the Zagros region was divided into 11 zones and seismic strain tensors in each zone were calculated in time interval between 1963 and 2016. The symmetric and anti-symmetric strain tensors are also calculated to investigate dilatation, shear and rotational strains individually. Seismic strain and b-value are used to quantify seismic potential in the Zagros region (Iran). Small to medium b-values (0.66, 0.72 and 0.80) are accompanied with medium to large strain rates (2.87×10^{-9}, 3.02×10^{-9} and 2.83×10^{-8}) in southeastern parts of the Zagros indicating more frequent moderate to large earthquakes. Medium b-values (0.72, 0.79 and 0.79) are accompanied with medium to large strain rates (2.52×10^{-9}, 4.33×10^{-9} and 9.20×10^{-9}) in central parts of the Zagros indicating more frequent moderate to large earthquakes. Medium to large b-values (0.74, 0.75, 0.76, 0.79 and 1.01) are accompanied with small to large strain rates (1.42×10^{-9}, 2.09×10^{-9}, 2.19×10^{-9}, 4.15×10^{-9} and 1.24×10^{-8}) in northwestern parts of Zagros indicating less frequent moderate to large earthquakes. Recurrence intervals of large earthquakes (M>6) in southeastern parts of Zagros (17, 43 and 48 years) and central parts of Zagros (24, 27 and 59 years) are shorter than northwestern parts (27, 51, 79 and 130 years).

Keywords:
Seismic strain; Moment tensor; Zagros; b-value; Recurrence interval

1. Introduction

The Zagros tectonic province is formed due to the continuous convergence between the continental Arabian plate and the continental microplate of Central Iran since 12 to 15 million years ago [1-2] (Figure 1). The present velocity of Arabian plate with respect to Eurasia increases from west to east along the Persian Gulf from 18 to 25 mm yr^{-1} [3-4]. Roughly half of this convergence between Arabian plate and Eurasian plate is accommodated by crustal shortening, thrusting and folding in the Zagros [5]. Earthquakes focal mechanism solutions demonstrate shortening and thickening through major thrust faults is responsible for deformation in Zagros [6-7]. Because of evaporate ductile layers in sedimentary part of the crust, no coseismic surface rupture is observed in this region [8]. In fact, there are several visible folds in Zagros [9-11].

On the basis of rate and state of deformation deduced from GPS surveys, Zagros has been divided into three parts: the Northwestern Zagros, the

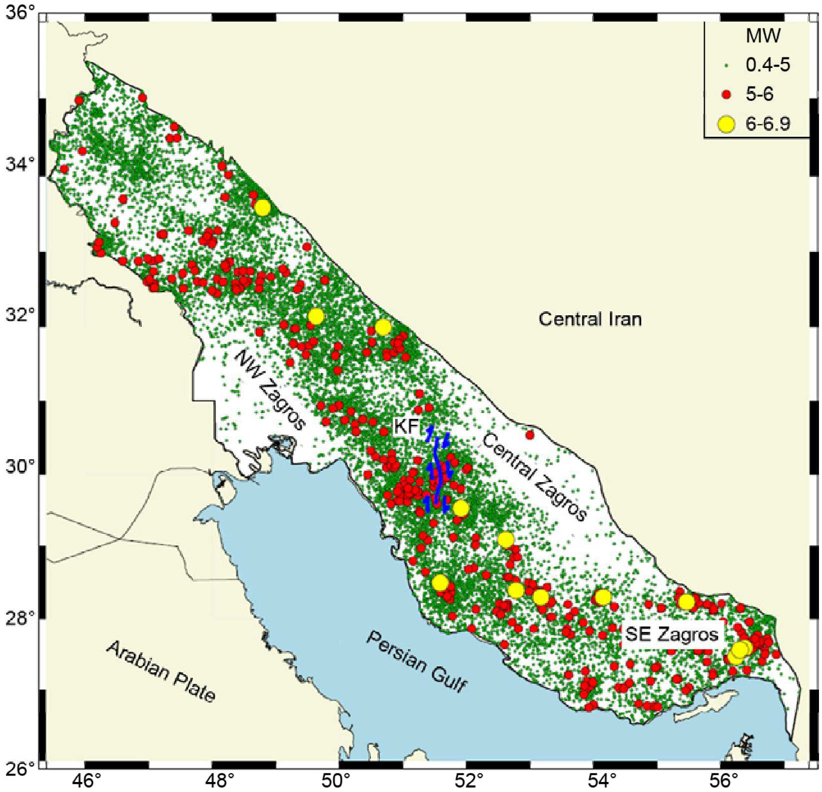

Figure 1. Seismicity map (Mw~0.4-6.9) of Zagros region for time period of 1963 to 2016 (ISC [27] and IRSC [28] bulletins). 'KF' is right-lateral strike-slip Kazerun Fault that is considered as the border between the Northwestern Zagros and the Central Zagros [4].

Central Zagros and the Southeastern Zagros [4] (Figure 1). Right lateral strike slip Kazerun Fault is considered as a border between the Northwestern Zagros and the Central Zagros [4, 5, 9]. In the Northwestern Zagros, present deformation is composed of a 3-6 mm yr^{-1} shortening perpendicular to the Zagros strike, and a 4-6 mm yr^{-1} strike slip motion parallel to the Zagros strike. In the Central Zagros and the Southeastern Zagros, the present deformation is 8 ± 2 mm yr^{-1} shortening perpendicular to the Zagros strike [4]. Large portion of the deformation is observed in southern part of Zagros, while seismicity is more widely spread all over the region. Accordingly, it is believed that evaporate ductile layers decouple the surface sedimentary layers from the seismogenic basement [11]. Therefore, the shallow deformation observed by GPS is related to the deformation of the sedimentary cover and does not represent the basement deformation [4]. Seismic strain of the Zagros has been investigated as well [12-15]. Jackson and McKenzie [12] used earthquakes with magnitudes $M_s \geq 6.0$ in Zagros in the time interval of 1908 to 1981. They estimated maximum velocity values 3.83 mm yr^{-1}, 1.34 mm yr^{-1}, 0.16 mm yr^{-1} in S40°E, N50°E and Up directions respectively. Most of the Zagros deformation is aseismic [14-15]. In fact, only 10 per cent of total deformation in Zagros is released by earthquakes [12].

Parameter b-value is the slope of frequency-magnitude distribution ($\log_{10}N = a - bM$), where b-value reveals the ratio of number of smaller to larger earthquakes [16]. 'N' is the number of events with magnitude larger or equal to M, and 'a' is a constant. The equation is applicable to a catalog in which magnitude of completeness is constant during time span of the catalog. Spatial distribution of b-values is very heterogeneous. The heterogeneity can be observed even in 1 to 30 km distances [17-18], which may be due to heterogeneity in material properties of the source region [19] and stress distribution [20]. The b-value often varies in the range of 0.60 to 1.30 in different areas with different tectonic regimes [21]. Higher b-values have been observed in areas which smaller earthquakes are more frequent than larger ones whereas lower b-values are estimated in areas which larger earthquakes are abundant [22]. Since a large number of small earthquakes is characteristic of regions of low strength and large heterogeneity in the crust materials, higher b-values are corresponded to this kind of regions. On the other hand, lower b-values are expected in homogeneous and resistant regions [19, 23]. High b-values are also observed in regions with decreased shear stress [24] and extensional stress [21]. In contrast, Low b-values are related to increased shear stress, and higher seismic moment release [20, 25]. Moreover, thrust zones have b-values smaller than 1, strike-slip zones have b-values around 1, and normal faulting is associated with b-values larger than 1 [26]. In this paper, seismic strain and b-value are studied during 1963-2016 in the Zagros region. Finally, earthquake potential in the Zagros region is evaluated by means of the seismic strain rates and b-values.

2. Data Set

To estimate b-value, a data set for Zagros is prepared consisting two parts. The first part was compiled from the International Seismological Center (ISC) bulletin [27] between January 1963 and January 2016 (hereafter called ISC part). The second part was compiled from the Iranian Seismological Center (IRSC) bulletin [28] from January 2006 to January 2016 (hereafter called IRSC part). IRSC has published local catalog of events, which have occurred since January 2006. Earthquakes from IRSC part which are reported in ISC part simultaneously were removed. Since for events with $M \leq 5$, the difference between various magnitude scales is not significant [29], magnitude scales of events with $M \leq 5$ were simply considered to be equal to moment magnitude Mw. For events with $M > 5$, special relations for Zagros [30] were applied to convert various magnitude scales to Mw. Therefore, magnitude scale of all events in our data set is homogenized to Mw. The final identical data set of Zagros contains 17009 earthquakes from 1963 to 2016 with magnitude range 0.4 to 6.9 (Figure 1).

Global Centroid Moment Tensor (GCMT) catalog data [31] for earthquakes with $M_w \geq 4.8$ in time interval of January 1976 to January 2016 (Figure 2 and Appendix 1) and those obtained by several authors for earthquakes with $M_w \geq 2.5$ in time interval of January 1963 to January 2016

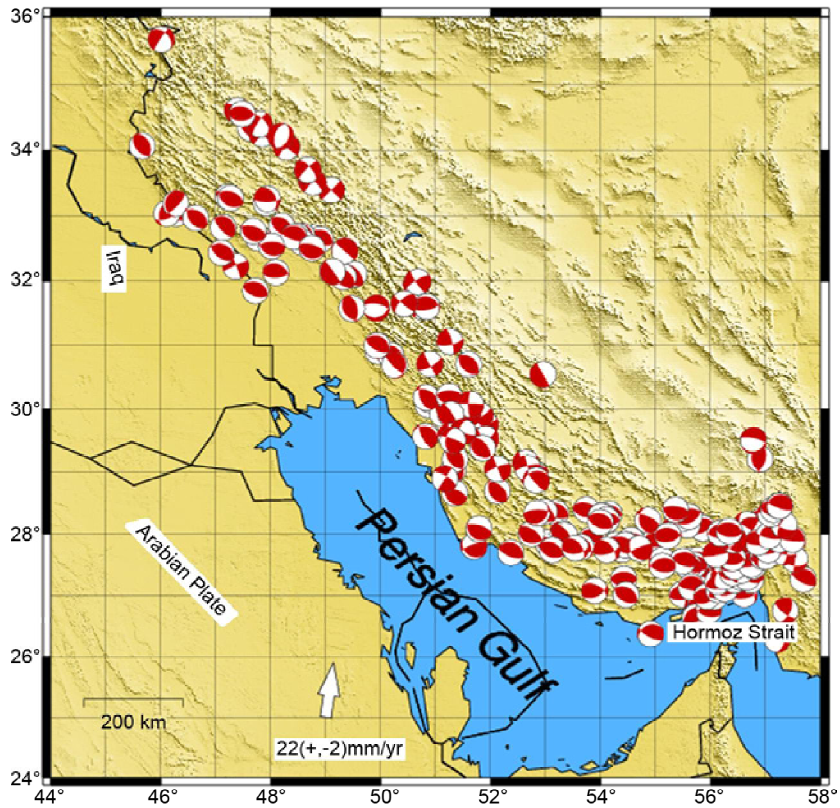

Figure 2. Focal mechanisms (GCMT catalog [31]) of earthquakes with M ≥ 4.8 occurred in time period 1976-2016, which have been used to estimate the strain tensors in the Zagros region. Thrust faulting is dominant in Zagros. Strike-slip faulting can also be observed in central and northwestern parts of the region.

(Appendix 1) are used to deduce seismic strain in the studied region.

3. Methods

3.1. Seismic Strain

Strain tensor in volume 'V' of crust is defined as [32]:

$$e_{ij} = \frac{1}{\mu V}\sum_{k=1}^{N} M_{ij}^{k} \tag{1}$$

where 'μ' stands for the shear modulus or rigidity of the crustal rock ($\mu=3\times10^{10}$N/m^2). 'N' is total number of events. 'M_{ij}' is the moment tensor of an earthquake:

$$M_{ij} = M_0(n_i.d_j) \tag{2}$$

where 'M_0' is scalar moment of the earthquake. n, d are respectively normal and slip vectors of corresponding fault plane defined as [33]:

$$n = \begin{pmatrix} \sin\delta\sin\varphi \\ \sin\delta\cos\varphi \\ \cos\delta \end{pmatrix} \tag{3}$$

$$d = \begin{pmatrix} -\cos\lambda\cos\varphi - \sin\lambda\cos\delta\sin\varphi \\ \cos\lambda\sin\varphi - \sin\lambda\cos\delta\cos\varphi \\ \sin\lambda\sin\delta \end{pmatrix} \tag{4}$$

where φ, δ, λ are strike, dip, and rake of the fault plane respectively.

The asymmetric second rank strain tensor e_{ij} can be written as sum of symmetric (ε_{ij}) and anti-symmetric (ω_{ij}) tensors as follows [33]:

$$e_{ij} = \varepsilon_{ij} + \omega_{ij} \tag{5}$$

where

$$\varepsilon_{ij} = \frac{1}{2}\left(e_{ij} + e_{ji}\right) \tag{6}$$

$$\omega_{ij} = \frac{1}{2}\left(e_{ij} - e_{ji}\right) \tag{7}$$

The ε_{ij} tensor contains dilatation and shear components of the strain while the ω_{ij} tensor involves rotation components of the strain.

3.2. b-Value

Assuming catalog can be divided into 's' subcatalogs with different magnitude of completeness, the likelihood function of seismicity parameters θ in the whole span of catalog is defined as the product of likelihood functions of seismicity parameters in 's' subcatalogs [34]:

$$L(\theta \mid X) = \prod_{i=0}^{s} L_i(\theta \mid X_i) \tag{8}$$

where $\theta = (\beta, \lambda)$, β is related to b-value as $b=\beta \log_e$, and 'e' is the Neperian number. λ is earthquake activity rate, and X_i are magnitudes in the i^{th} subcatalog. If the magnitude of earthquakes is independent from earthquakes number, the likelihood function of seismicity parameters θ in ith subcatalog can be written as the product of likelihood functions of parameters β and λ (i.e. $L_i(\theta \mid X_i) = L_{i\beta}.L_{i\lambda}$), hence, Eq. (8) can be rewritten as:

$$L(\theta \mid X) = \prod_{i=0}^{s} L_{i\beta}.L_{i\lambda} \tag{9}$$

Using maximum likelihood method, estimating parameter β is accompanied with putting first derivation of the likelihood function in terms of parameter β equal to zero:

$$\partial \ln L(\theta \mid X)/\partial\beta = 0 \tag{10}$$

3.3. Recurrence Interval

The recurrence interval for earthquakes larger than Mw can be estimated from the b-value and seismic moment rate as [35]:

$$T(M_W) = \left[\frac{b}{1.5+b}\right] \frac{10^{(1.5+b)M_{\max}+9.05}}{\dot{M}_{seismic}\left[10^{bM_{\max}} - 10^{bM_W}\right]} \tag{11}$$

'$M_{\max}$' stands for the maximum possible earthquake magnitude. '$\dot{M}_{seismic}$' represents seismic moment rate, which is defined as:

$$\dot{M}_{seismic} = 2\mu A H_s \dot{\varepsilon}_{\max} \tag{12}$$

where 'μ' is rigidity (3×10^{10} N/m^2), 'A' represents the surface area over which strain release is distributed, 'H_s' is thickness of the seismogenic layer. '$\dot{\varepsilon}_{\max}$' stands for the largest absolute eigenvalue of seismic strain rate tensor.

4. Results and Discussion

4.1. Seismic Strain

In order to estimate the seismic strain of Zagros in details, based on the density of earthquakes with $M \geq 5$, Zagros area was divided into 11 zones (Figure 3), coordinates of which are listed in Table (1). Thickness of seismogenic layer in Zagros is considered to be 20 km [36]. Therefore, the volume of each zone can be easily obtained via multiplying surface dimensions by the thickness of seismogenic layer (Table 1). Fault plane solution and scalar moment of earthquakes with $M_w \geq 2.5$ occurred during time period of 1963 to 2016 (Appendix 1) were employed to obtain moment tensor of earthquakes in each zone (Eqs. (2), (3), and (4)). The coordinate system has been considered such that 'X', 'Y', and 'Z' axes are respectively oriented in North, West, and Up directions. The asymmetric strain tensor e_{ij} was calculated for each zone from Eq. (1). The symmetric (ε_{ij}) and anti-symmetric (ω_{ij}) tensors were obtained using Eqs. (6) and (7). The resulted strain tensors for the 11 zones can be seen in Tables (2) and (4).

Table 1. Coordinate, thickness of seismogenic layer (Hs) and volume of 11 zones in Zagros (Figure 3).

Zone	Latitude Range (Degree)	Longitude Range (Degree)	Hs (Km)	Volume (Km^3)
1	27-28.5	53-54	20	369630
2	26.5-28.5	54-55	20	492840
3	26.8-28.5	55-56	20	418910
4	27-28.5	56-57	20	369630
5	28-29	51.2-53	20	443560
6	29-30	50.7-52.8	20	517480
7	30-31	49.5-51.5	20	492840
8	31.3-32.2	49-51.2	20	487910
9	32.4-33	46.5-48	20	221780
10	32.4-33	48-49	20	147850
11	33-34	47-49	20	492840

The symmetric (ε_{ij}) tensor has six independent elements. Three diagonal elements of the ε_{ij} tensor represent compression (for negative elements) or extension (for positive elements) of the crust in North, West, Up directions. The anti-symmetric (ω_{ij}) tensor has only three independent elements that represent clockwise rotation (for positive elements) or counterclockwise rotation (for negative elements) of the crust around Up, West and North axes. Eigenvalues and corresponding eigenvectors of the ε_{ij} tensor, which represent the amplitude and direction of the principal strains, are listed in Table (3). Rotation around Up, West, and North axes are deduced from three independent elements of the anti-symmetric (ω_{ij}) tensors (Table 4).

According to the sign of diagonal elements of ε_{ij}

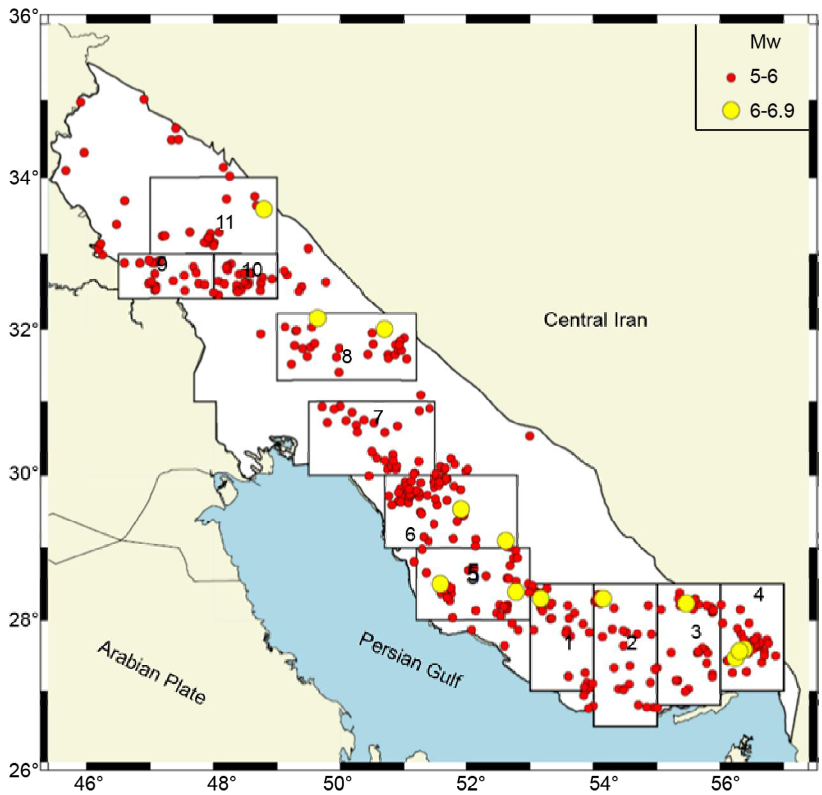

Figure 3. Dividing Zagros into 11 zones based on the density of earthquakes with $M \geq 5$ to estimate strain tensor in time interval of 1963 to 2016. Coordinate of the 11 zones are listed in Table (1).

Table 2. The asymmetric e_{ij} and symmetric ε_{ij} strain tensors of 11 zones in Zagros in time interval 1963-2016.

Zone	e_{ij}			ε_{ij}		
1	-7.7E-08	4.3E-08	1.1E-07	-7.7E-08	6.3E-08	3.2E-08
	8.3E-08	-2.0E-08	-1.3E-07	6.3E-08	-2.0E-08	-5.3E-08
	-5.4E-08	3.0E-08	8.1E-08	3.2E-08	-5.3E-08	8.1E-08
2	-1.0E-07	3.5E-08	1.1E-07	-1.0E-07	6.8E-08	1.8E-08
	1.0E-07	-2.0E-08	-1.6E-07	6.8E-08	-2.0E-08	-6.9E-08
	-7.8E-08	2.8E-08	1.0E-07	1.8E-08	-6.9E-08	1.0E-07
3	-5.0E-07	9.7E-11	7.9E-07	-5.0E-07	2.6E-07	2.2E-07
	5.2E-07	4.9E-08	-8.5E-07	2.6E-07	4.9E-08	-4.2E-07
	-3.3E-07	1.0E-08	5.2E-07	2.2E-07	-4.2E-07	5.2E-07
4	-9.0E-07	-5.4E-08	1.3E-06	-9.0E-07	2.6E-07	5.2E-07
	5.8E-07	9.5E-08	-1.7E-06	2.6E-07	9.5E-08	-8.7E-07
	-2.9E-07	-3.6E-08	9.0E-07	5.2E-07	-8.7E-07	9.0E-07
5	-4.4E-07	2.4E-07	4.5E-07	-4.4E-07	4.7E-07	-6.4E-08
	7.0E-07	-3.7E-07	-7.3E-07	4.7E-07	-3.7E-07	-2.1E-07
	-5.8E-07	3.0E-07	6.1E-07	-6.4E-08	-2.1E-07	6.1E-07
6	-1.5E-07	2.2E-07	7.1E-08	-1.5E-07	1.5E-07	8.7E-09
	8.1E-08	1.2E-07	-1.1E-07	1.5E-07	1.2E-07	-5.2E-08
	-5.3E-08	1.1E-08	2.1E-08	8.7E-09	-5.2E-08	2.1E-08
7	-5.6E-08	6.6E-08	7.7E-08	-5.6E-08	6.4E-08	7.6E-09
	6.1E-08	-4.6E-08	-8.1E-08	6.4E-08	-4.6E-08	-6.0E-09
	-6.2E-08	6.9E-08	7.8E-08	7.6E-09	-6.0E-09	7.8E-08
8	-7.7E-08	6.1E-08	-6.7E-08	-7.7E-08	-2.6E-08	-6.4E-09
	-1.1E-07	9.9E-08	-1.8E-07	-2.6E-08	9.9E-08	-1.1E-07
	5.4E-08	-5.1E-08	1.0E-07	-6.4E-09	-1.1E-07	1.0E-07
9	-3.2E-07	2.5E-07	6.6E-07	-3.2E-07	2.9E-07	2.2E-07
	3.3E-07	-1.7E-07	-5.9E-07	2.9E-07	-1.7E-07	-2.3E-07
	-2.1E-07	1.2E-07	4.0E-07	2.2E-07	-2.3E-07	4.0E-07
10	-2.9E-07	1.5E-07	4.6E-07	-2.9E-07	2.3E-07	1.1E-07
	3.2E-07	-1.4E-07	-4.9E-07	2.3E-07	-1.4E-07	-1.8E-07
	-2.3E-07	1.2E-07	3.3E-07	1.1E-07	-1.8E-07	3.3E-07
11	-7.2E-08	6.4E-08	3.1E-08	-7.2E-08	2.1E-09	1.5E-08
	-5.9E-08	6.4E-08	6.6E-09	2.1E-09	6.4E-08	7.1E-10
	-7.2E-10	-5.2E-09	8.6E-09	1.5E-08	7.1E-10	8.6E-09

tensors (Table 2), in zones 1, 2, 5, 7, 9, 10 the compression is observed in both North and West directions while the extension is observed in Up direction. In zones 3, 4, 6, 8 and 11, the compression is observed in North direction while the extension is observed in both West and Up directions. Large compression in North direction is accompanied by the small extension in West direction indicating a small strain partitioning in zones 3 and 4. Amplitude of compression in North direction is approximately equal to amplitude of extension in West direction in zones 6, 8 and 11 indicating a significant strain partitioning in these zones. The resulted significant strain partitioning in zones 6, 8 and 11 are also observed by geology [37] and geodesy [4] studies.

The first principal strains (ε_1) have N36°W, N32°E, N28°E, N25°E, N44°W, N24°W, N42°W, N14°W, N38°W, N38°W, N1°E azimuth in zones 1 to 11 respectively (Table 3 and Figure 4). In all zones, the first principal strains (ε_1) oriented in North direction have negative values (compression)

Table 3. Amplitude (Am), Azimuth (Az), and Plunge (Pl) of principal strains for 11 zones in Zagros in time interval of 1963 to 2016. Negative signs of 'Am' values indicate compression while positive signs demonstrate extension in the corresponding direction.

Zone		Am	Az	Pl
1	ε_1	-1.33E-07	324	15
	ε_2	1.23E-08	50	16
	ε_3	1.04E-07	360	68
2	ε_1	-1.52E-07	32	11
	ε_2	-2.83E-09	53	21
	ε_3	1.40E-07	173	65
3	ε_1	-7.25E-07	28	18
	ε_2	1.95E-08	54	23
	ε_3	7.75E-07	174	60
4	ε_1	-1.25E-06	25	21
	ε_2	-1.47E-07	55	22
	ε_3	1.50E-06	165	59
5	ε_1	-8.98E-07	316	4
	ε_2	1.75E-09	45	18
	ε_3	6.92E-07	148	72
6	ε_1	-2.29E-07	336	7
	ε_2	1.42E-08	40	74
	ε_3	2.03E-07	157	14
7	ε_1	-1.16E-07	318	3
	ε_2	1.27E-08	47	1
	ε_3	7.90E-08	30	87
8	ε_1	-1.65E-08	346	11
	ε_2	-1.75E-09	65	42
	ε_3	1.25E-07	176	45
9	ε_1	-6.58E-07	322	17
	ε_2	5.27E-08	49	5
	ε_3	5.05E-07	147	72
10	ε_1	-5.21E-07	322	14
	ε_2	6.59E-09	49	11
	ε_3	4.05E-07	78	72
11	ε_1	-7.54E-08	1	10
	ε_2	1.14E-08	354	79
	ε_3	6.44E-08	89	1

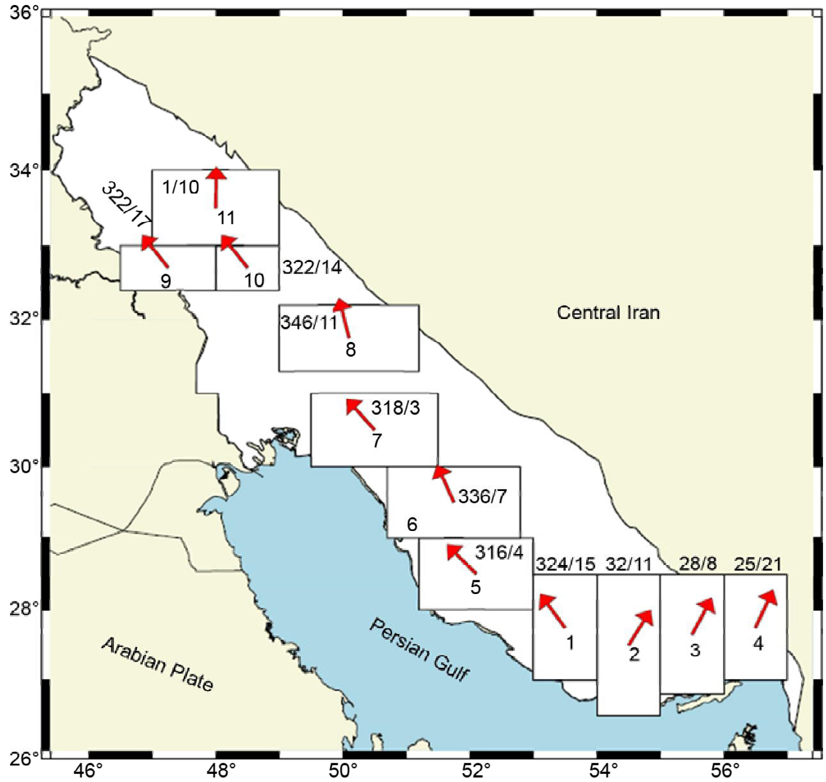

Figure 4. Azimuth/Plunge of first principal strain (ε_1) in 11 zones of the Zagros area.

Table 4. Anti-symmetric ω_{ij} strain tensors and rotational nanostrain around Up, West, North axes for 11 zones in Zagros in time interval of 1963 to 2016. Positive signs indicate clockwise rotation while negative signs demonstrate counterclockwise rotation around the corresponding axis.

Zone	ω_{ij}			Up	West	North
	0.0E+00	-1.9E-08	8.6E-08			
1	1.9E-08	0.0E+00	-8.3E-08	-19	+86	-83
	-8.6E-08	8.3E-08	0.0E+00			
	0.0E+00	-3.2E-08	9.6E-08			
2	3.2E-08	0.0E+00	-9.8E-08	-32	+96	-98
	-9.6E-08	9.8E-08	0.0E+00			
	0.0E+00	-2.6E-07	5.6E-07			
3	2.6E-07	0.0E+00	-4.3E-07	-262	+565	-434
	-5.6E-07	4.3E-07	0.0E+00			
	0.0E+00	-3.1E-07	8.2E-07			
4	3.1E-07	0.0E+00	-8.3E-07	-317	+825	-836
	-8.2E-07	8.3E-07	0.0E+00			
	0.0E+00	-2.2E-07	5.2E-07			
5	2.2E-07	0.0E+00	-5.1E-07	-228	+520	-518
	-5.2E-07	5.1E-07	0.0E+00			
	0.0E+00	7.2E-08	6.2E-08			
6	-7.2E-08	0.0E+00	-6.3E-08	+72	+62	-63
	-6.2E-08	6.3E-08	0.0E+00			
	0.0E+00	2.7E-09	7.0E-08			
7	-2.7E-09	0.0E+00	-7.5E-08	+2.7	+70	-75
	-7.0E-08	7.5E-08	0.0E+00			
	0.0E+00	8.7E-08	-6.1E-08			
8	-8.7E-08	0.0E+00	-6.5E-08	+87	-61	-65
	6.1E-08	6.5E-08	0.0E+00			
	0.0E+00	-3.8E-08	4.4E-07			
9	3.8E-08	0.0E+00	-3.6E-07	-38	+441	-362
	-4.4E-07	3.6E-07	0.0E+00			
	0.0E+00	-8.5E-08	3.4E-07			
10	8.5E-08	0.0E+00	-3.0E-07	-85	+348	-308
	-3.4E-07	3.0E-07	0.0E+00			
	0.0E+00	6.2E-08	1.6E-08			
11	-6.2E-08	0.0E+00	5.9E-09	+62	+16	+5.9
	-1.6E-08	-5.9E-09	0.0E+00			

(Table 3). Furthermore, according to plunge values (Table 3 and Figure 4), the first principal strains (ε_1) are sub-horizontal in all zones. Therefore, the first principal strains (ε_1) indicate thickening and shortening of the crust of the 11 zones. Zones 1, 2, 3, 4, 5, 9 and 10 are accompanied with counterclockwise rotation around Up axis (Table 4) indicating rotation to East direction. Zones 6, 7, 8 and 11 are accompanied by clockwise rotation around Up axis indicating rotation to West direction.

4.2. b-Value

Magnitude of completeness (Mc) for the Zagros data set is not constant with respect to the time showing a sudden drop in 2006 (Figure 5). In fact, the Zagros data set is composed of two subcatalogs with different Mc, one from 1963 to 2006 and another one from 2006 to 2016 (Figure 5). In cases such as the Zagros data set, when catalog is partitioned into more than one subcatalog with different Mc, Kijko-Sellevoll [34] method (section 3.2) can be employed to estimate b-value.

Before estimating b-values, catalog of Zagros (Section 2) was declustered using Reasenberg [38] method. Like section 4.1, Zagros was divided into 11 zones (Figure 3). Catalog of each zone is composed

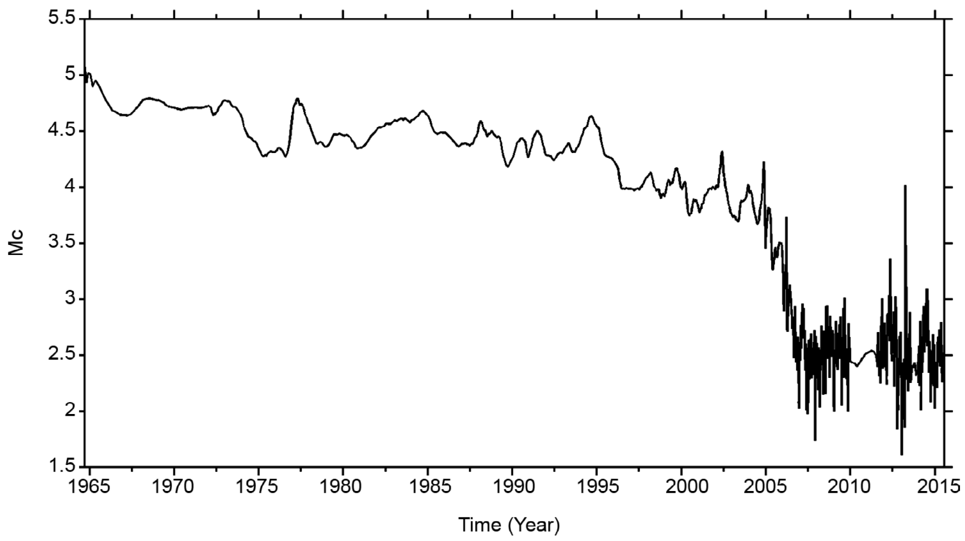

Figure 5. Variation of completeness magnitude (Mc) of the Zagros data set during 1963-2016. Completeness magnitude during 2006-2016 is lower than during 1963-2006.

of two subcatalogs with different Mc. Therefore, catalog of each zone was divided into two subcatalogs. The first subcatalog contains events occurred between 1963 and 2006, and the second subcatalog includes events occurred between 2006 and 2016 (Table 5). In Table (5), Mc of subcatalogs containing less than 500 events were obtained using the maximum curvature method, while Mc of subcatalogs containing more than 500 events were obtained using Entire-magnitude-range method [39]. After removing events smaller than Mc from all subcatalogs, b-value was estimated using Kijko-Sellevoll [34] method discussed in section 3.2. The resulted b-value and corresponding error of all zones for time period 1963-2016 are listed in Table (5).

Spatial distribution of b-values are very heterogeneous in Zagros, which may be due to heterogeneity in material properties of the source region [19] and stress distribution [20]. It is clear that b-value changes from 0.66 to 1.01 in Zagros (Table 5) is in agreement with Frohlich and Davis [21]. Lower b-values are estimated in areas in which larger earthquakes are abundant [22]. Lower b-values are expected in homogeneous and resistant regions [19, 23]. Moreover, thrust zones have b-values smaller than 1, strike-slip zones have b-values around 1 [26]. Several authors have discussed that thrust and strike-slip faulting are dominant in Zagros [6, 7, 9]. The b-values are smaller than or equal to 1 in Zagros (Table 5), which is in agreement with Schorlemmer et al [26].

4.3. Recurrence Interval of Large Earthquakes (M>6)

The strain rate tensor $(\dot{\varepsilon}_{ij})$ during time interval 'T' can be obtained through dividing strain tensor (ε_{ij}) by the time interval 'T' [32]. The dataset contains earthquakes occurred in time period 1963 to 2016.

Table 5. Number of earthquakes, Mc, b-value and corresponding error of 11 zones in Zagros.

Zone	N (1963-2006)	Mc (1963-2006)	N (2006-2016)	Mc (2006-2016)	b-Value	Error of b-Value
1	236	3.9	426	2.9	0.79	0.04
2	290	3.9	440	2.9	0.66	0.03
3	265	4.5	554	3.1	0.80	0.04
4	353	4.7	555	2.9	0.72	0.03
5	279	4.0	1333	2.7	0.72	0.02
6	495	4.1	1658	2.4	0.79	0.02
7	299	4.7	1083	2.3	0.74	0.02
8	296	4.1	1789	2.1	0.79	0.02
9	98	4.8	649	2.8	0.75	0.04
10	144	4.5	470	2.6	1.01	0.05
11	126	4.5	1250	2.3	0.76	0.03

Therefore, the strain rate tensors $(\dot{\varepsilon}_{ij})$ were obtained by dividing strain tensor (ε_{ij}) in each zone by $T = 53$ years (Table 6). Largest absolute eigenvalue of seismic strain rate tensor is considered as $\dot{\varepsilon}_{max}$ (Table 6). Thereafter, seismic moment rates $(\dot{M}_{seismic})$ were obtained from Eq. (12) (Table 7). As mentioned earlier, the thickness of seismogenic layer in Zagros is considered to be 20 km. Maximum possible earthquake magnitude (M_{max}) is estimated from frequency-magnitude plot for each zone (Figure 6 and Table 8). In fact, 'M_{max}' can be obtained from extrapolating the straight line fitted to the frequency-magnitude plot [16]. Recurrence interval of earthquakes with $M > 6$ for 11 zones are calculated using Eq. (11) (Table 8).

Figure (3) shows that a large earthquake ($M > 6$) occurred during 1963-2016 in zone 1. Resulted recurrence interval of large earthquakes ($M > 6$) for zone 1 is 59 years (Table 8). A large earthquake occurred during 1963-2016 in zone 2. Resulted recurrence interval of large earthquakes for zone 2 is 43 years. A large earthquake occurred during 1963-2016 in zone 3. Resulted recurrence interval of large earthquakes for zone 3 is 48 years. Three large earthquakes occurred during 1963-2016 in zone 4 (a 17-year average recurrence interval). Resulted recurrence interval of large earthquakes for zone 4

Table 6. The strain rate tensor $\dot{\varepsilon}_{ij}$ and corresponding eigenvalues (λ) of 11 zones in Zagros in time interval of 1963 to 2016. '$\dot{\varepsilon}_{max}$' is the largest absolute eigenvalue.

Zone	$\dot{\varepsilon}_{ij}$			λ	$\dot{\varepsilon}_{max}$
	-1.4E-09	1.1E-09	6.1E-10	-2.52E-09	
1	1.1E-09	-3.8E-10	-1.0E-09	2.32E-10	2.52E-09
	6.1E-10	-1.0E-09	1.5E-09	1.96E-09	
	-1.9E-09	1.2E-09	3.4E-10	-2.87E-09	
2	1.2E-09	-3.8E-10	-1.3E-09	-5.34E-11	2.87E-09
	3.4E-10	-1.3E-09	2.0E-09	2.65E-09	
	-9.4E-09	4.9E-09	4.2E-09	-3.02E-09	
3	4.9E-09	9.2E-10	-8.0E-09	3.69E-10	3.02E-09
	4.2E-09	-8.0E-09	9.8E-09	1.46E-09	
	-1.7E-08	4.9E-09	9.9E-09	-2.37E-08	
4	4.9E-09	1.8E-09	-1.6E-08	-2.77E-09	2.83E-08
	9.9E-09	-1.6E-08	1.7E-08	2.83E-08	
	-8.4E-09	9.0E-09	-1.2E-09	-9.20E-09	
5	9.0E-09	-7.1E-09	-4.1E-09	3.31E-11	9.20E-09
	-1.2E-09	-4.1E-09	1.1E-08	1.30E-09	
	-2.9E-09	2.9E-09	1.6E-10	-4.33E-09	
6	2.9E-09	2.3E-09	-9.8E-10	2.69E-10	4.33E-09
	1.6E-10	-9.8E-10	4.1E-10	3.84E-09	
	-1.0E-09	1.2E-09	1.4E-10	-2.19E-09	
7	1.2E-09	-8.6E-10	-1.1E-10	2.40E-10	2.19E-09
	1.4E-10	-1.1E-10	1.4E-09	1.49E-09	
	-1.4E-09	-4.9E-10	-1.2E-10	-1.61E-09	
8	-4.9E-10	1.8E-09	-2.2E-09	-1.26E-10	4.15E-09
	-1.2E-10	-2.2E-09	1.9E-09	4.15E-09	
	-6.1E-09	5.6E-09	4.2E-09	-1.24E-08	
9	5.6E-09	-3.2E-09	-4.4E-09	9.95E-10	1.24E-08
	4.2E-09	-4.4E-09	7.6E-09	9.94E-08	
	-5.6E-09	4.4E-09	2.2E-09	-2.09E-09	
10	4.4E-09	-2.8E-09	-3.5E-09	1.24E-10	2.09E-09
	2.2E-09	-3.5E-09	6.4E-09	1.65E-09	
	-1.3E-09	3.9E-11	2.9E-10	-1.42E-09	
11	3.9E-11	1.2E-09	1.3E-11	2.16E-10	1.42E-09
	2.9E-10	1.3E-11	1.6E-10	1.21E-09	

Table 7. Area (A), thickness of the seismogenic layer (Hs) and seismic moment rate $(\dot{M}_{seismic})$ of 11 zones in Zagros for time period 1963-2016. '$\dot{\varepsilon}_{max}$' is the largest absolute eigenvalue of the strain rate tensors $\dot{\varepsilon}_{ij}$ (See Table 6).

Zone	$\dot{\varepsilon}_{max}$	A (km^2)	Hs (km)	$\dot{M}_{seismic}$ (Nm/yr)
1	2.52E-09	18481	20	5.60E+16
2	2.87E-09	24642	20	8.48E+16
3	3.02E-09	20946	20	7.60E+16
4	2.83E-08	18481	20	6.28E+17
5	9.20E-09	22178	20	2.45E+17
6	4.33E-09	25874	20	1.34E+17
7	2.19E-09	24642	20	6.48E+16
8	4.15E-09	24395	20	1.21E+17
9	1.24E-08	11089	20	1.65E+17
10	2.09E-09	7392.7	20	1.86E+16
11	1.42E-09	24642	20	4.21E+16

Table 8. The seismic moment rate $(\dot{M}_{seismic})$, maximum earthquake magnitude from frequency-magnitude plot (M_{max} (Theoretical)), maximum earthquake magnitude from catalog (M_{max} (Observed)), maximum possible earthquake magnitude (M_{max}), b-value, and recurrence interval (T) for earthquakes larger than $M_w = 6$ for 11 zones in Zagros.

Zone	$\dot{M}_{seismic}$ (Nm/yr)	M_{max} (Theoretical)	M_{max} (Observed)	M_{max}	b-Value	T (Year)
1	5.60E+16	6.1	6.0	6.1	0.79	59
2	8.48E+16	6.5	6.0	6.5	0.66	43
3	7.60E+16	6.3	6.5	6.5	0.80	48
4	6.28E+17	6.6	6.9	6.9	0.72	17
5	2.45E+17	6.3	6.7	6.7	0.72	24
6	1.34E+17	6.5	6.1	6.5	0.79	27
7	6.61E+16	6.1	5.8	6.1	0.74	51
8	1.21E+17	6.1	6.1	6.1	0.79	27
9	1.65E+17	5.7	5.6	5.7	0.75	-
10	1.86E+16	6.2	5.8	6.2	1.01	130
11	4.21E+16	5.7	6.1	6.1	0.76	79

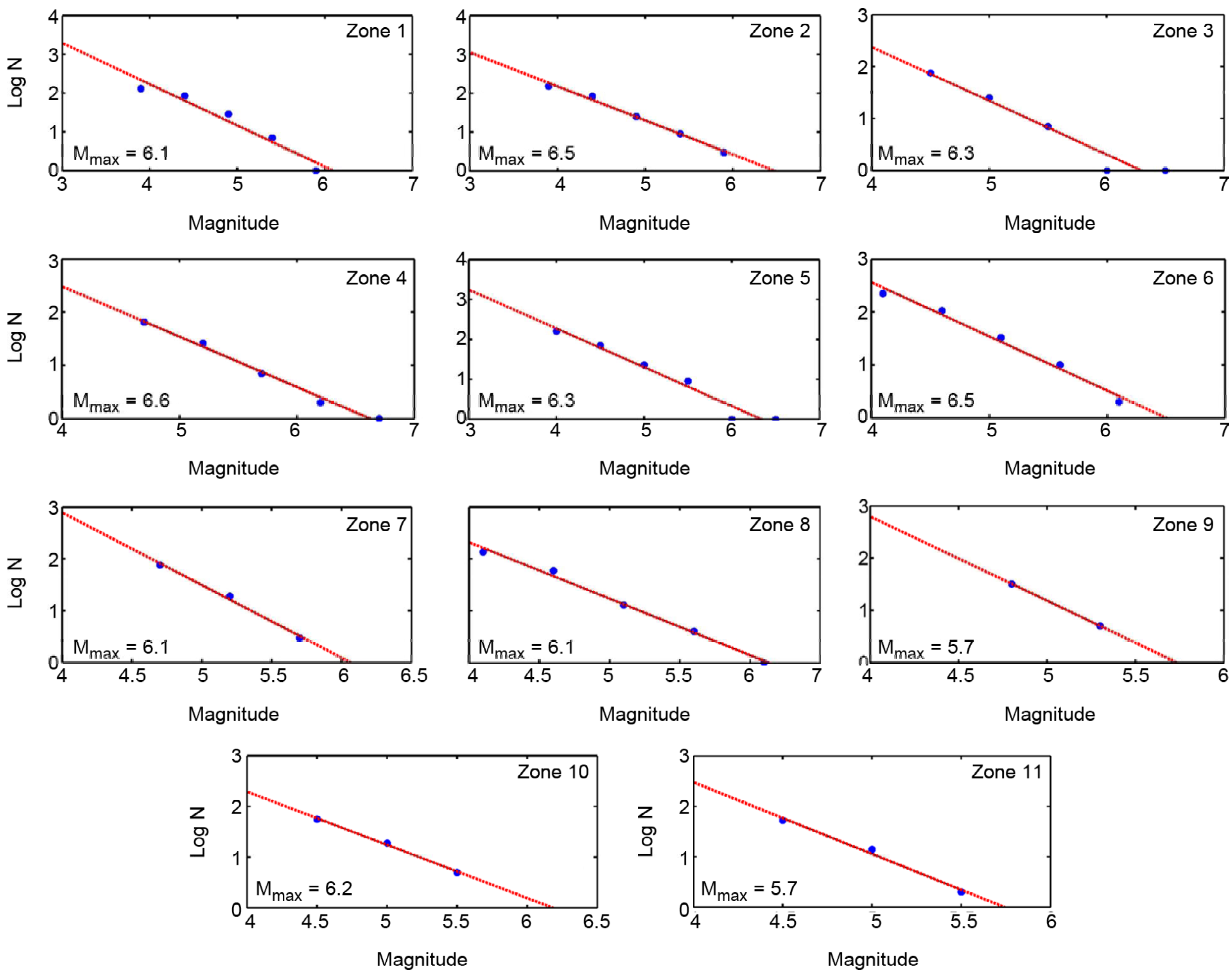

Figure 6. Frequency-magnitude plots of 11 zones in Zagros for time period 1963-2016. Theoretical maximum earthquake magnitude 'M_{max} (Theoretical)' can be obtained from the intercept of the best fitted line to magnitude axis..

is 17 years. Two large earthquakes occurred during 1963-2016 in zone 5 (26-year average recurrence interval). Resulted recurrence interval of large earthquakes for zone 5 is 24 years. Two large earthquakes occurred during 1963-2016 in zone 6 (26-year average recurrence interval). Resulted recurrence interval of large earthquakes for zone 6 is 27 years. No large earthquake occurred during 1963-2016 in zone 7. Resulted recurrence interval of large earthquakes for zone 7 is 51 years. Two large earthquakes occurred during 1963-2016 in zone 8 (26-year average recurrence interval). Resulted recurrence interval of large earthquakes for zone 8 is 27 years. No large earthquake occurred during 1963-2016 in zone 10. Resulted recurrence interval of large earthquakes for zone 10 is 130 years. A large earthquake occurred during 1963-2016 in zone 11. Resulted recurrence interval of large earthquakes for zone 11 is 79 years. Therefore, estimated recurrence intervals of large earthquakes in all zones are in agreement with recurrence intervals expected from seismicity behavior during 1963-2016.

Zones 2, 3 and 4 that are situated in the South-eastern Zagros (Figures 1 and 3) have small to medium b-values (0.66, 0.72 and 0.80) and medium to large strain rates (2.87×10^{-9}, 3.02×10^{-9} and 2.83×10^{-8}), which results in short recurrence intervals of large earthquakes ($M > 6$) in the Southeastern Zagros (17, 43 and 48 Years). Zones 1, 5 and 6 that are situated in the Central Zagros (Figures 1 and 3) have Medium b-values (0.72, 0.79 and 0.79) and medium to large strain rates (2.52×10^{-9}, 4.33×10^{-9} and 9.20×10^{-9}), which results in short recurrence intervals of large earthquakes ($M > 6$) in the Central Zagros (24, 27 and 59 Years). Zones 7, 8, 10 and 11 that are situated in the Northwestern Zagros (Figures 1 and 3) have Medium to large b-values (0.74, 0.76, 0.79 and 1.01) and small to medium strain rates (1.42×10^{-9}, 2.09×10^{-9}, 2.19×10^{-9} and 4.15×10^{-9}), which results in long recurrence intervals of large earthquakes

(M> 6) in the Northwestern Zagros (27, 51, 79 and 130 Years).

5. Conclusions

The predominant state of deformation in most parts is shortening of the basement. On average, the Southeastern Zagros and the Central Zagros have higher seismic strain than the Northwestern Zagros. In the Southeastern Zagros, the main principal strain axes have sub-horizontal plunge with Northeast-Southwest direction, upright to strike of the tectonic structures. The Southeastern Zagros is accompanied by motions perpendicular to tectonic structures and pure thickening. The results obtained from this study indicate that the Southeastern Zagros is under-thrusting beneath the Central Iran at a sub-horizontal angle. On the other hand, in the Central Zagros and the Northwestern Zagros, the main principal strain axes have sub-horizontal plunge with Northwest-Southeast direction. Deformation state of the Central Zagros and the Northwestern Zagros is composed of both thickening perpendicular to tectonic structures and extension along the strike of the Zagros. It is concluded that the significant strain partitioning is occurred in the Central Zagros and the Northwestern Zagros, which indicates that central parts (zone 6) and northwestern parts (zones 8 and 11) of Zagros are rotating to west.

The b-value was also investigated in the Zagros region in time interval 1963-2016. The b-values in the Southeastern Zagros and the Central Zagros are lower than the Northwestern Zagros. Seismic moment rate variations in the Southeastern Zagros and the Central Zagros are similar to the Northwestern Zagros. However, Lower b-values is responsible for more frequent large earthquakes in the Southeastern Zagros and the Central Zagros. Recurrence intervals of large earthquakes (M> 6) confirm this conclusion. The recurrence intervals in the Southeastern Zagros and the Central Zagros are shorter than the Northwestern Zagros.

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Appendix 1

Zagros earthquakes with $M_w \geq 2.5$ occurred between 1963 and 2016. Coordinates of the 11 zones are listed in Table (1) and Figure (3). Columns indicate date, latitude, longitude, strike, dip, rake (Fault plane), strike, dip, rake (Auxiliary plane), depth, scalar moment, and Mw. References are: TJ=[7], BJP=[9], EE=[13], H=[31], MJPB=[36], B=[40], THG=[41], YHT=[42], YHFP=[43], AM=[44], GYH=[45], YHG=[46], SYT=[47]. Single stars indicate that latitude and longitude are reported from ISC catalog [27]. Double stars indicate that latitude and longitude are reported from IIEES catalog [48]. 'S' in Mw column indicates that the original magnitude scale (M_L) is converted to Mw using $M_w = 0.701\times M_L + 1.656$ [30]. 'HK' in M_0 column indicates that scalar moment is obtained from corresponding M_w using $M_w = \frac{2}{3}\log M_0 - 10.7$ [49].

Date	Lat. (°N)	Long. (°E)	s_1	d_1	r_1	s_2	d_2	r_2	Depth (km)	$M_0(\times10^{18})$	M_w	Ref.
Zone 1												
1968/9/14	28.43	53.18	288	30	90	108	60	90	7	0.562(HK)	5.8	TJ
1983/ 2/18	27.95	53.85	272	20	94				15	0.0688	5.2(H)	EE
1985/ 8/ 7	27.86*	53.05*	303	39	116	91	55	70	15	0.256	5.5	H
1986/ 5/ 2	28.03	53.02	331	52	121	107	47	57	15	0.239	5.5	H
1986/ 5/ 3	28.02*	53.34*	325	62	108	111	33	60	15	0.0755	5.2	H
1996/ 5/24	27.74	53.12	289	68	91	107	22	88	15	0.0775	5.2	H
1997/ 5/ 5	27.16	53.42	296	52	128	64	52	52	15	0.0467	5.0	H
1997/11/14	27.90	53.15	295	65	81	135	26	108	18	0.0005(HK)	3.8(S)	THG
1997/11/16	28.32	53.28	129	80	85	335	11	115	12.8	0.0005(HK)	3.8(S)	THG
1997/11/16	28.37	53.10	165	65	-168	70	79	-25	10.7	0.00005(HK)	3.1(S)	THG
1997/11/19	28.28	53.57	350	80	-153	255	63	-11	18.0	0.00005(HK)	3.1(S)	THG
1997/11/19	28.29	53.56	350	80	-153	255	63	-11	12.5	0.0001(HK)	3.3(S)	THG
1997/11/21	27.93	53.14	105	40	90	285	50	90	9.1	0.00005(HK)	3.1(S)	THG
1997/11/22	28.31	53.30	325	75	0	55	89	179	12.5	0.00003(HK)	3.0(S)	THG
1997/11/26	28.41	53.08	320	35	110	115	57	76	13.8	0.00001(HK)	2.8(S)	THG
1997/11/27	28.41	53.08	320	35	110	115	57	76	13.9	0.00001(HK)	2.8(S)	THG
1997/11/28	28.08	53.27	110	70	86	300	20	99	13.6	0.0001(HK)	3.4(S)	THG
1997/11/30	28.03	53.04	110	50	103	270	41	74	10.1	0.00001(HK)	2.8(S)	THG
1997/11/30	28.24	53.26	120	65	101	275	27	67	15.8	0.0001(HK)	3.5(S)	THG
1997/12/1	28.02	53.05	85	50	41	325	59	131	11.8	0.0001(HK)	3.3(S)	THG
1997/12/3	28.29	53.31	250	65	-11	345	79	-154	12.7	0.00005(HK)	3.1(S)	THG
1997/12/4	28.27	53.35	335	75	161	70	72	15	15.0	0.0002(HK)	3.6(S)	THG
1997/12/10	28.17	53.16	285	45	86	110	45	93	12.3	0.00007(HK)	3.2(S)	THG
1997/12/11	28.14	53.04	145	75	75	10	20	133	13.2	0.00007(HK)	3.2(S)	THG
1997/12/11	28.15	53.04	145	75	75	10	20	133	13.8	0.00005(HK)	3.1(S)	THG
1997/12/14	28.46	53.19	100	40	68	307	53	107	13.9	0.0022(HK)	4.2(S)	THG
1997/12/14	28.29	53.57	290	75	0	20	89	179	18.0	0.0001(HK)	3.5(S)	THG
1997/12/15	28.28	53.61	70	65	11	335	79	154	19.0	0.0001(HK)	3.3(S)	THG
1997/12/18	28.33	53.25	70	60	54	305	45	135	14.0	0.00007(HK)	3.2(S)	THG
1997/12/21	28.37	53.18	330	60	-137	215	53	-38	11.4	0.0002(HK)	3.6(S)	THG
1997/12/21	28.35	53.27	265	55	55	135	47	128	15.2	0.00005(HK)	3.1(S)	THG
1997/12/22	28.11	53.46	340	75	161	75	72	15	8.3	0.00002(HK)	2.9(S)	THG
1997/12/22	28.12	53.46	340	75	179	250	89	0	10.5	0.0001(HK)	3.3(S)	THG
1997/12/22	28.11	53.46	340	80	153	75	63	11	9.5	0.00003(HK)	3.0(S)	THG
1997/12/22	28.12	53.45	340	80	153	75	63	11	8.6	0.00001(HK)	2.8(S)	THG
1997/12/22	28.12	53.46	345	80	179	255	89	0	10.6	0.00005(HK)	3.1(S)	THG
1997/12/23	28.12	53.45	350	80	-153	255	63	-11	15.2	0.0007(HK)	3.9(S)	THG
1997/12/24	28.13	53.47	260	85	179	350	89	0	10.5	0.00005(HK)	3.1(S)	THG
1997/12/25	28.35	53.06	240	50	36	125	63	134	12.2	0.00005(HK)	3.1(S)	THG
1997/12/25	28.13	53.47	350	80	-153	255	63	-11	10.2	0.00007(HK)	3.2(S)	THG
1997/12/26	28.10	53.46	360	70	179	90	89	0	12.7	0.0063(HK)	4.5(S)	THG
1997/12/26	28.09	53.46	345	80	179	255	89	0	9.6	0.00007(HK)	3.2(S)	THG
1997/12/26	28.08	53.45	345	80	179	255	89	0	8.6	0.0003(HK)	3.7(S)	THG
1997/12/26	28.09	53.47	340	80	0	250	89	179	13.9	0.0007(HK)	3.9(S)	THG
1997/12/26	28.09	53.45	345	80	179	255	89	0	9.2	0.0001(HK)	3.3(S)	THG
1997/12/26	28.09	53.45	345	80	0	75	89	179	10.2	0.0001(HK)	3.3(S)	THG
1997/12/26	28.08	53.46	345	80	179	255	89	0	15.0	0.0063(HK)	4.5(S)	THG
1997/12/26	28.08	53.45	340	75	0	250	89	179	9.6	0.0001(HK)	3.3(S)	THG
1997/12/26	28.08	53.46	345	80	-153	250	63	-11	14.1	0.0002(HK)	3.6(S)	THG
1997/12/26	28.10	53.46	340	80	-153	245	63	-11	12.7	0.0001(HK)	3.5(S)	THG
1997/12/26	28.08	53.47	90	75	18	355	72	164	15.6	0.0011(HK)	4.0(S)	THG
1997/12/26	28.10	53.46	90	75	18	355	72	164	14.1	0.0011(HK)	4.0(S)	THG
1997/12/26	28.08	53.46	90	75	18	355	72	164	12.0	0.0005(HK)	3.8(S)	THG
1997/12/26	28.10	53.46	345	80	179	255	89	0	14.4	0.0002(HK)	3.6(S)	THG
1997/12/26	28.11	53.46	345	80	179	255	89	0	13.0	0.0007(HK)	3.9(S)	THG
1997/12/26	28.11	53.47	350	80	0	260	89	179	10.1	0.0001(HK)	3.3(S)	THG

Date	Lat. (°N)	Long. (°E)	s1	d1	r1	s2	d2	r2	Depth (km)	M0(×1018)	Mw	Ref.
1997/12/27	28.10	53.48	340	85	179	250	89	0	14.2	0.0003(HK)	3.7(S)	THG
1997/12/27	28.09	53.47	345	80	-153	250	63	-11	15.3	0.0005(HK)	3.8(S)	THG
1997/12/27	28.10	53.47	335	80	0	245	89	179	12.5	0.0003(HK)	3.7(S)	THG
1997/12/27	28.06	53.49	340	80	153	75	63	11	13.5	0.0011(HK)	4.0(S)	THG
1997/12/27	28.31	53.30	250	55	-17	350	76	-143	13.6	0.00002(HK)	2.9(S)	THG
1997/12/27	28.09	53.46	335	80	0	245	89	179	11.0	0.0001(HK)	3.5(S)	THG
1997/12/28	28.12	53.45	340	80	179	250	89	0	12.1	0.0005(HK)	3.8(S)	THG
1997/12/28	28.12	53.45	335	80	179	245	89	0	13.8	0.0011(HK)	4.0(S)	THG
1997/12/28	28.12	53.45	335	80	-153	240	63	-11	12.4	0.0011(HK)	4.0(S)	THG
1997/12/28	28.09	53.46	335	85	0	265	89	179	13.1	0.0016(HK)	4.1(S)	THG
1997/12/28	28.11	53.46	320	80	153	55	63	11	11.1	0.0007(HK)	3.9(S)	THG
1997/12/28	28.10	53.46	335	75	161	70	72	15	11.1	0.0001(HK)	3.5(S)	THG
1997/12/28	28.13	53.47	325	80	0	235	89	179	11.5	0.0002(HK)	3.6(S)	THG
1997/12/29	28.10	53.47	335	75	161	70	72	15	14.7	0.0022(HK)	4.2(S)	THG
1997/12/29	28.10	53.47	320	65	168	55	79	25	12.6	0.0011(HK)	4.0(S)	THG
1998/11/13	27.76	53.62	318	32	120	104	63	73	7	0.16(H)	5.4	TJ
1999/ 4/30	27.81*	53.56*	321	53	134	82	55	47	44.9	0.0597	5.1	H
2010/ 7/20	27.03*	53.89*	269	33	59	124	62	109	12	0.574	5.8	H
2012/ 5/13	27.06*	53.95*	306	34	112	100	58	76	12	0.0619	5.1	H
2012/ 9/ 6	27.11*	53.99*	146	73	175	237	85	17	12	0.0862	5.2	H
2015/ 4/29	27.15	53.34	290	28	95	104	63	87	17	0.026	4.9	H
Zone 2												
1966/9/18	27.82	54.27	269	34	96	82	56	86	12	0.794(HK)	5.9	TJ
1970/2/23	27.82	54.47	286	44	90	106	46	90	9	0.281(HK)	5.6	TJ
1971/11/8	27.01	54.46	300	42	90	120	48	90	9	0.794(HK)	5.9	TJ
1977/10/19	27.79	54.88	117	41	120				15	0.216	5.5(H)	EE
1984/12/22	27.83	54.44	116	41	84				49	0.054	5.1(H)	EE
1997/10/ 3	27.79	54.73	281	9	102	89	81	88	4	0.101(H)	5.3	TJ
2001/ 4/13	28.20*	54.86*	295	67	64	166	34	135	26.1	0.0551	5.1	H
2003/ 7/10	28.35	54.10	277	33	93	93	57	88	15	0.479	5.7	H
2003/ 7/10	28.26	54.05	310	65	114	83	34	49	15	0.359	5.6	H
2003/10/24	28.25*	54.03*	128	39	70	333	54	105	33	0.0401	5.0	H
2003/11/28	28.26*	54.02*	255	74	100	43	19	60	33	0.0378	5.0	H
2003/12/15	28.25*	54.12*	272	43	90	92	47	90	15	0.0485	5.1	H
2006/ 9/10	27.54	54.29	321	52	147	73	65	43	23.1	0.0367	5.0	H
2008/ 5/ 5	28.36*	54.08*	290	36	88	113	54	92	12.4	0.07	5.2	H
2008/10/25	26.63**	54.89**	249	31	45	119	69	113	12	0.154	5.4	H
2010/ 4/27	27.09	54.80	156	76	-175	64	86	-15	20	0.0374	5.0	H
2011/10/19	27.92	54.31	282	51	87	107	39	94	15.5	0.0722	5.2	H
2013/ 7/ 2	27.10	54.92	286	49	79	122	42	102	22.8	0.0291	4.9	H
2014/ 1/ 2	26.95	54.36	329	54	141	85	59	43	12	0.113	5.3	H
Zone 3												
1965/6/21	28.10	55.84	313	60	110	97	36	59	8	1.122(HK)	6.0	TJ
1971/4/12	28.26	55.61	261	35	90	81	55	90	10	0.794(HK)	5.9	TJ
1974/12/2	28.09	55.86	268	27	110	65	65	80	7	0.09	5.2	B
1975/12/24	27.02	55.48	260	34	90	80	56	90	8	0.199(HK)	5.5	TJ
1976/3/16	27.33*	55.00*	253	40	90	73	50	90	9	0.070(HK)	5.2	TJ
1987/ 5/12	27.95	55.32	278	34	104	80	57	80	15	0.175	5.4	H
1990/11/ 6	28.32	55.46	275	30	101				7	7.1	6.5	MJPB
1991/ 5/22	27.38	55.77	288	18	80	118	72	93	13	0.12(H)	5.4	TJ
1992/ 5/19	28.05	55.35	254	40	99	63	51	83	15	0.294	5.6	H
1993/ 7/ 9	28.39	55.33	277	69	83	115	22	107	16	0.0742(H)	5.1	TJ
1995/ 1/24	27.64	55.65	217	31	56	75	64	109	15	0.0312	4.9	H
2005/11/27	26.80*	55.77*	257	39	83	86	51	96	12	1.03	5.9	H
2005/11/27	26.83**	55.82**	124	53	126	254	49	52	14.6	0.0351	5.0	H
2005/11/27	27.00**	55.79**	308	88	-177	218	87	-2	12	0.213	5.5	H
2005/11/30	26.81	55.58	258	62	62	127	39	132	21.9	0.012	4.7	H
2006/ 3/25	27.57	55.76	308	30	95	113	60	100	17	0.672	5.9(H)	AM
2006/ 3/25	27.48	55.68	276	35	89	98	55	91	12	0.214	5.5	H
2006/ 3/25	27.41	55.66	267	30	70	110	62	101	12	0.081	5.2	H
2006/ 3/25	27.53	55.62	261	33	59	116	62	108	12	0.0357	5.0	H
2006/ 3/25	27.44	55.36	256	34	57	114	62	110	19.3	0.0269	4.9	H
2006/ 6/ 3	26.91**	55.91**	260	49	69	111	45	112	12	0.0651	5.1	H
2006/ 6/28	26.86*	55.82*	247	33	96	59	57	86	12	0.642	5.8	H
2007/ 2/27	27.97	55.23	280	42	108	76	50	74	22.8	0.0344	5.0	H
2007/ 3/23	27.48	55.12	265	42	69	113	51	108	12	0.0347	5.0	H
2007/ 7/24	27.14	55.65	270	21	81	100	69	94	20.5	0.0336	5.0	H
2008/ 9/10	26.93**	55.73**	234	33	76	71	58	99	12	1.74	6.1	H
2008/ 9/17	27.20**	55.94**	245	45	59	106	53	117	12	0.0944	5.2	H
2008/12/ 7	26.82	55.74	217	53	69	69	41	115	12	0.154	5.4	H

Date	Lat. (°N)	Long. (°E)	s1	d1	r1	s2	d2	r2	Depth (km)	M0(×1018)	Mw	Ref.
2008/12/ 8	26.83	55.76	238	49	59	100	50	120	12	0.0597	5.1	H
2008/12/ 9	26.81*	55.82*	241	33	73	81	59	101	14	0.0432	5.0	H
2012/ 1/ 9	26.86	55.65	242	45	36	125	66	129	17.2	0.0288	4.9	H
2014/11/10	27.75	55.71	79	90	49	349	41	80	15	0.0838	5.2	H
2014/11/15	28.04	55.13	247	41	66	97	53	109	22.2	0.0203	4.8	H
Zone 4												
1964/12/22	28.16	56.89	272	14	90	92	76	90	18	0.199(HK)	5.5	TJ
1970/2/28	27.83	56.31	264	40	90	84	50	90	-	0.199(HK)	5.5	TJ
1971/12/9	27.29	56.37	276	40	55	138	58	116		0.562(HK)	5.8	TJ
1975/3/7	27.48	56.23	90	60	90	270	30	90	11	1.584(HK)	6.1	TJ
1977/ 1/ 5	27.46	56.20	204	43	40				29	0.052	5.1(H)	EE
1977/ 3/21	27.61	56.39	267	27	98				18.8	14	6.7(H)	EE
1977/ 3/21	27.60	56.52	241	26	77				19.3	1.81	6.1(H)	EE
1977/ 3/22	27.60	56.42	77	34	112				12	1.5	6.0	MJPB
1977/ 3/23	27.62	56.59	260	41	92				10	0.228	5.5(H)	EE
1977/3/24	27.66	56.60	302	30	90	122	60	90	-	0.10(HK)	5.3	TJ
1977/ 4/ 1	27.55	56.33	262	44	90				10	0.956	5.9(H)	EE
1977/12/10	27.68	56.60	291	28	138				18	0.29	5.6	MJPB
1980/11/17	27.36	56.08	251	30	87				15	0.0867	5.2(H)	EE
1980/11/28	27.59	56.50	311	37	134				15	0.136	5.4(H)	EE
1981/ 4/16	27.73	56.35	221	42	8				15	0.0524	5.1(H)	EE
1983/ 7/12	27.61	56.40	227	50	75				17	1.00	5.9	MJPB
1987/ 4/29	27.42	56.11	265	41	112				10	0.37	5.6	MJPB
1987/12/18	28.15	56.66	160	44	-145	43	67	-52	10	0.672(H)	5.8	B
1988/ 6/ 9	27.67	56.10	310	11	139	81	83	82	15	0.0806	5.2	H
1997/4/19	28.00	56.87	219	47	13				19	0.21	5.5	MJPB
1997/ 7/27	27.41	56.56	108	76	175	199	85	15	33	0.0582	5.1	H
1998/ 8/ 1	27.74	56.51	280	52	93	95	38	86	9	0.0637(H)	5.1	TJ
1999/ 12/ 7	27.83	56.45	90	70	90	270	20	90	15.0	0.000006(HK)	2.5(S)	YHFP
1999/ 12/ 11	27.45	56.86	250	75	-7	342	82	-184	38.0	0.0016(HK)	4.1(S)	YHFP
2000/ 3/ 5	27.95	56.47	313	44	101	117	47	80	12	0.163(H)	5.4	TJ
2002/ 4/17	27.30	56.66	117	68	123	237	39	36	33	0.0911	5.2	H
2003/ 2/14	27.48	56.77	288	18	97	100	73	88	25	0.292	5.6	H
2003/11/ 5	27.09	56.15	231	52	78	70	39	105	33	0.0266	4.9	H
2005/12/27	28.01	56.18	257	32	76	94	59	99	18.3	0.0196	4.8	H
2006/ 2/28	27.86	56.87	302	19	118	93	73	81	25.4	1.37	6.0	H
2006/ 3/ 5	27.90	56.47	192	50	69	43	44	113	12.0	0.0022(HK)	4.2(S)	YHG
2006/ 3/ 5	28.17	56.92	88	90	60	358	30	-180	19.6	0.0045(HK)	4.4(S)	GYH
2006/ 3/ 6	28.14	56.90	205	43	-49	335	58	-122	18.7	0.0126(HK)	4.7(S)	GYH
2006/ 3/ 7	28.11	56.86	104	90	70	14	20	180	18.9	0.0011(HK)	4.0(S)	GYH
2006/ 3/ 7	28.12	57.00	76	71	68	306	27	136	18.1	0.0005(HK)	3.8(S)	GYH
2006/ 3/ 8	28.15	56.92	220	17	55	76	75	100	19.0	0.0178(HK)	4.8(S)	GYH
2006/ 3/ 9	28.08	56.90	54	79	44	314	46	165	16.8	0.0011(HK)	4.0(S)	GYH
2006/ 3/ 9	28.09	56.94	178	61	-11	274	80	-151	18.1	0.0001(HK)	3.3(S)	GYH
2006/ 3/ 10	28.09	56.91	141	60	42	26	54	142	18.6	0.0003(HK)	3.7(S)	GYH
2006/ 3/ 10	28.04	56.82	254	48	48	127	56	127	14.7	0.0003(HK)	3.7(S)	GYH
2006/ 3/ 11	28.09	56.94	147	74	48	41	43	157	17.0	0.0001(HK)	3.5(S)	GYH
2006/ 3/ 11	28.08	56.93	102	84	90	282	6	90	21.6	0.0355(HK)	5.0(S)	GYH
2006/ 3/ 14	27.89	56.51	133	34	-42	260	67	-117	18.3	0.0001(HK)	3.5(S)	GYH
2006/ 3/ 18	28.10	56.94	189	71	-23	287	67	-159	18.0	0.0005(HK)	3.8(S)	GYH
2006/ 3/ 20	28.07	56.88	98	70	90	278	20	90	16.1	0.0001(HK)	3.5(S)	GYH
2006/ 3/ 21	27.55	56.54	29	48	-31	140	67	-134	9.0	0.0005(HK)	3.8(S)	YHG
2006/ 3/ 21	27.95	56.70	70	54	37	315	61	138	9.0	0.0011(HK)	4.0(S)	YHG
2006/ 3/ 23	27.95	56.74	63	81	60	319	31	163	23.0	0.0022(HK)	4.2(S)	YHG
2006/ 3/ 24	27.96	56.74	245	28	-43	14	71	-111	22.0	0.0011(HK)	4.0(S)	YHG
2006/ 3/ 24	28.16	56.96	70	90	60	340	30	-180	20.2	0.0089(HK)	4.6(S)	GYH
2006/ 3/ 25	28.08	56.96	91	56	53	324	48	131	21.7	0.0001(HK)	3.5(S)	GYH
2006/ 3/ 25	27.95	56.75	204	65	-2	295	88	-155	19.0	0.0001(HK)	3.5(S)	YHG
2006/ 3/ 25	28.09	56.96	264	82	29	170	61	171	20.4	0.0001(HK)	3.5(S)	GYH
2006/ 3/ 25	28.09	56.96	67	64	16	329	75	153	23.4	0.0003(HK)	3.7(S)	GYH
2006/ 3/ 25	28.10	56.96	25	35	30	270	72	121	20.8	0.0003(HK)	3.7(S)	GYH
2006/ 3/ 25	28.06	56.96	19	38	20	273	77	127	20.2	0.0003(HK)	3.7(S)	GYH
2006/ 3/ 25	28.09	56.96	55	72	-16	150	74	-161	23.1	0.0063(HK)	4.5(S)	GYH
2006/ 3/ 25	28.10	56.96	19	39	23	271	75	127	21.6	0.0054(HK)	4.4(S)	GYH
2006/ 3/ 25	28.08	56.96	77	61	8	171	82	-150	21.2	0.0003(HK)	3.7(S)	GYH
2006/ 3/ 25	28.09	56.95	260	83	13	169	76	173	21.1	0.0003(HK)	3.7(S)	GYH
2006/ 3/ 25	28.10	56.96	265	75	26	167	64	163	21.3	0.0001(HK)	3.3(S)	GYH
2006/ 3/ 25	28.08	56.96	76	69	-22	174	69	-157	22.5	0.0011(HK)	4.0(S)	GYH
2006/ 3/ 25	28.09	56.96	85	84	-17	177	72	-174	21.6	0.0005(HK)	3.8(S)	GYH
2006/ 3/ 25	28.09	56.95	260	83	13	169	76	173	21.5	0.0011(HK)	4.0(S)	GYH

Date	Lat. (°N)	Long. (°E)	s1	d1	r1	s2	d2	r2	Depth (km)	M0(×1018)	Mw	Ref.
2006/ 3/ 25	28.10	56.96	251	83	-39	346	50	-171	21.3	0.0016(HK)	4.1(S)	GYH
2006/ 3/ 26	28.10	56.96	276	90	25	186	65	180	21.4	0.0005(HK)	3.8(S)	GYH
2006/ 3/ 27	28.10	56.91	52	86	44	319	45	175	18.7	0.0054(HK)	4.4(S)	GYH
2006/ 3/ 28	28.08	56.96	64	71	-23	162	67	-159	21.9	0.0007(HK)	3.9(S)	GYH
2006/ 3/ 29	28.09	56.96	72	64	16	334	75	153	21.6	0.0007(HK)	3.9(S)	GYH
2006/ 3/ 29	27.96	56.87	239	80	-28	334	62	-169	25.0	0.0022(HK)	4.2(S)	YHG
2006/ 3/ 29	28.09	56.96	81	86	-14	172	75	-176	20.8	0.0007(HK)	3.9(S)	GYH
2006/ 3/ 29	27.79	56.72	30	48	31	279	68	134	17.0	0.0007(HK)	3.9(S)	YHG
2006/ 3/ 30	28.09	56.95	258	74	-13	352	77	-164	21.6	0.0063(HK)	4.5(S)	GYH
2006/ 4/ 23	27.62	56.62	62	41	41	299	64	124	12.0	0.0022(HK)	4.2(S)	YHG
2006/ 5/ 17	27.60	56.47	251	55	84	82	35	99	14.0	0.00003(HK)	3.0(S)	YHG
2006/ 6/ 3	27.64	56.60	8	44	49	239	58	122	13.0	0.0022(HK)	4.2(S)	YHG
2007/ 4/25	28.04	56.34	282	34	94	98	56	87	18.6	0.0892	5.2	H
2007/ 8/25	28.05	56.74	314	85	-178	224	88	-5	23.5	0.0444	5.0	H
2009/11/ 3	27.04	56.16	246	30	63	96	64	105	13.2	0.0387	5.0	H
2015/ 1/25	27.27	56.14	299	36	112	92	57	75	12.6	0.0292	4.9	H
2015/ 3/ 5	27.82	56.66	260	27	91	79	63	90	31.1	0.0289	4.9	H
Zone 5												
1972/4/10	28.43	52.82	288	49	99				9	8.44	6.6	BJP
1972/4/10	28.43	52.82	322	40	98				10	3.69	6.7	BJP
1976/ 4/22	28.71	52.12	312	52	80				7	0.38	5.7	BJP
1985/ 2/ 2	28.22	53.48	284	58	-95	114	32	-81	21.6	0.183	5.4	H
1990/12/16	29.05	51.31	144	67	87	332	23	97	15	0.411	5.7	H
1993/ 3/29	28.00**	52.74**	305	64	99	104	28	72	40	0.0733	5.2	H
1994/ 3/30	28.96	52.60	148	71	177	239	87	19	33	0.158	5.4	H
1994/ 4/ 3	29.01	52.72	142	79	-159	47	69	-11	33	0.0807	5.2	H
1997/11/16	28.58	52.98	115	65	70	335	31	125	15.8	0.00005 (HK)	3.1(S)	THG
1997/11/17	28.05	52.96	300	20	99	110	70	86	12.8	0.00007 (HK)	3.2(S)	THG
1997/11/17	28.04	52.96	300	20	99	110	70	86	12.3	0.00002 (HK)	2.9(S)	THG
1997/11/17	28.04	52.97	140	45	116	285	50	66	16.8	0.00003 (HK)	3.0(S)	THG
1997/11/17	28.05	52.97	150	50	132	275	55	51	14.5	0.00005 (HK)	3.1(S)	THG
1997/11/17	28.05	52.97	155	60	143	265	59	35	12.2	0.0001(HK)	3.5(S)	THG
1997/11/20	28.33	52.96	315	30	121	100	64	73	14.6	0.00003 (HK)	3.0(S)	THG
1997/11/22	28.22	52.97	330	65	147	75	61	28	15.1	0.00005 (HK)	3.1(S)	THG
1997/12/2	28.22	52.96	310	75	-161	215	72	-15	13.7	0.0001(HK)	3.3(S)	THG
1999/ 9/24	28.49	51.06	294	65	74	148	29	121	33	0.0927	5.2	H
2000/ 3/ 1	28.40	52.85	267	69	106	49	26	55	15	0.0403	5.0	H
2002/ 2/17	28.00	51.68	288	68	83	126	23	106	33	0.116	5.3	H
2004/ 3/ 2	28.90**	51.17**	33	90	-161	303	71	0	16.1	0.0548	5.1	H
2005/ 8/ 9	28.90	52.52	139	75	117	257	30	31	16.1	0.055	5.1	H
2010/11/26	27.94	52.47	281	42	70	128	51	107	12	0.204	5.5	H
2012/ 2/ 5	28.53	51.32	312	42	75	152	50	103	18.2	0.0254	4.9	H
2013/ 4/ 9	28.27	51.62	303	54	69	157	41	117	12	3.5	6.3	H
2013/ 4/10	28.24	51.65	289	62	61	159	39	133	12	0.195	5.5	H
2013/ 4/10	28.11	51.73	324	59	112	106	37	58	12	0.0562	5.1	H
2013/ 4/10	28.39	51.51	318	45	76	156	47	103	13.3	0.0813	5.2	H
2013/ 4/10	28.24	51.65	289	62	61	159	39	133	12	0.195	5.5	H
2013/ 4/10	28.11	51.73	324	59	112	106	37	58	12	0.0562	5.1	H
2013/ 4/11	28.28	51.62	338	54	105	134	39	71	20	0.0423	5.0	H
2013/ 5/ 1	28.07	51.78	327	58	130	90	49	45	12	0.0347	5.0	H
2013/ 5/ 6	28.33	51.55	324	37	93	140	53	88	17.9	0.039	5.0	H
2014/ 4/16	28.48	51.50	102	86	-11	193	79	-176	19.1	0.0254	4.9	H
2014/10/28	28.32	52.91	325	53	135	86	56	47	18.9	0.0395	5.0	H
2014/12/30	28.54	51.88	230	36	-173	134	86	-54	17	0.0477	5.1	H
2015/ 1/10	28.64	51.85	311	87	25	219	65	177	21.8	0.0202	4.8	H
Zone 6												
1968/6/23	29.81	51.16	136	45	88				9	0.22	5.5	BJP
1971/4/6	29.80	51.88	62	79	2				6	0.072	5.3	BJP
1981/ 4/ 1	28.85	51.50	351	34	144				15	0.0777	5.2(H)	EE
1986/ 7/12	29.96	51.58	4	73	-159				4	0.26	5.5	BJP
1986/12/20	29.98	51.62	344	65	163				8	0.11	5.3	BJP
1988/ 8/11	29.97	51.57	3	69	-175				7	0.24	5.5	BJP
1988/ 8/11	29.97	51.67	350	82	-166				9	0.65	5.8	BJP
1988/ 8/30	29.96**	51.72**	337	83	-147	242	57	-9	15	0.0612	5.1	H

Date	Lat. (°N)	Long. (°E)	s1	d1	r1	s2	d2	r2	Depth (km)	M0(×1018)	Mw	Ref.
1988/12/ 6	29.94	51.65	357	74	198				10	0.32	5.6	BJP
1989/ 5/ 3	29.64	51.42	153	55	-166	55	78	-36	15	0.0814	5.2	H
1992/ 9/11	29.96	51.11	302	33	67	148	60	104	15	0.121	5.3	H
1993/ 1/ 6	29.31	52.02	339	90	-166	248	76	0	15	0.149	5.4	H
1994/ 3/ 1	29.14	52.63	239	87	15	149	75	177	13	1.37(H)	5.9	TJ
1994/ 3/29	29.20	51.36	334	40	104	136	52	79	7	0.0535(H)	5.1	TJ
1994/ 6/20	29.05	52.67	255	74	-3				7	0.60	5.8	MJPB
1996/11/18	29.76	51.12	177	62	-177	85	87	-28	33	0.085	5.2	H
1999/ 5/ 6	29.50	51.88	142	78	-167	49	77	-12	7	2.80(H)	6.1	TJ
1999/10/31	29.36	51.48	324	58	105	117	34	67	33	0.0688	5.2	H
2000/ 5/ 3	29.57	50.18	277	77	45	174	47	162	33	0.0448	5.0	H
2000/ 6/23	29.93	51.25	180	75	175	272	85	15	33	0.0612	5.1	H
2001/ 3/28	30.20	50.43	327	80	97	113	12	56	15	0.113	5.3	H
2002/ 6/ 1	29.57	51.23	170	88	148	261	58	2	33	0.0378	5.0	H
2003/ 1/11	29.17	50.94	104	83	-31	199	60	-171	33	0.0713	5.2	H
2003/ 5/27	29.45	51.50	290	79	45	189	46	165	33	0.0973	5.3	H
2010/ 9/27	29.56	51.62	309	6	100	119	85	89	17.1	0.938	5.9	H
2011/ 1/ 7	30.03	51.64	343	84	-164	252	74	-6	23.6	0.043	5.0	H
2012/ 6/ 8	29.69	50.62	315	36	87	139	54	92	13.3	0.0369	5.0	H
2012/10/10	29.11	52.56	316	52	120	93	47	57	14.9	0.0258	4.9	H
2013/11/28	29.22	51.09	2	50	151	112	68	44	13.1	0.334	5.6	H
2014/ 5/21	29.58**	50.88**	303	35	94	118	56	87	14.5	0.0965	5.3	H
2014/ 5/21	29.51	50.88	315	38	118	101	57	70	18.6	0.0405	5.0	H
Zone 7												
1979/ 3/28	30.49	49.48	317	42	92	135	48	89	15	0.0745	5.2	H
1988/ 3/30	30.29	49.84	296	32	90	116	58	90	15	0.744	5.8	H
1989/ 5/27	29.86	50.69	332	57	122	103	45	51	15	1.25	6.0	H
1991/11/ 4	30.06	49.71	314	49	84	143	41	97	21.7	0.311	5.6	H
1993/ 3/26	30.54	50.65	152	88	-164	61	74	-3	33	0.0518	5.1	H
1993/ 6/22	30.01	50.40	278	70	85	112	21	104	15	0.126	5.3	H
1993/10/21	30.36	50.95	271	50	80	105	41	101	15	0.0359	5.0	H
1995/ 4/22	30.87	49.46	318	60	101	117	32	72	39.5	0.0975	5.3	H
1998/ 9/21	30.90	51.07	343	78	160	78	71	12	33	0.0496	5.1	H
2011/ 3/ 5	29.99	51.05	302	49	87	126	41	93	12	0.102	5.3	H
Zone 8												
1977/ 4/ 6	31.96	50.67	112	64	132	228	48	36	6	1.3(H)	5.9	B
1978/12/14	32.14	49.65	150	34	100				15	1.95	6.1(H)	EE
1985/ 3/27	31.66	49.94	71	31	-116				83.8	0.0593	5.1(H)	EE
1985/ 9/18	31.59	49.44	143	36	74				11	0.110	5.3(H)	EE
1992/ 3/ 4	31.64	50.71	122	79	173	213	83	12	33	0.0572	5.1	H
1998/ 6/15	31.71	50.77	294	26	123	78	68	75	5	0.0797(H)	5.0	TJ
2002/ 4/23	31.66	51.21	65	85	90	245	5	90	13.9	0.00005(HK)	3.1(S)	YHT
2002/ 4/23	31.66	51.20	90	85	90	270	5	90	13.9	0.00001(HK)	2.8(S)	YHT
2002/ 5/1	31.83	50.90	75	83	35	340	54	171	6.0	0.00002(HK)	2.9(S)	YHT
2002/ 5/3	31.97	50.67	45	75	18	310	72	164	12.8	0.0001(HK)	3.3(S)	YHT
2002/ 5/5	31.73	51.12	70	75	7	338	82	164	8.9	0.0005(HK)	3.8(S)	YHT
2002/ 5/7	31.71	51.10	80	65	22	340	69	153	10.1	0.0001(HK)	3.3(S)	YHT
2002/ 5/10	31.62	51.09	95	45	90	275	45	90	10.4	0.000008(HK)	2.6(S)	YHT
2002/ 5/11	31.79	50.95	60	75	34	320	57	162	11.9	0.00002(HK)	2.9(S)	YHT
2002/ 5/17	31.90	50.92	30	65	-168	295	79	-25	11.5	0.00002(HK)	2.9(S)	YHT
2002/ 5/22	32.04	50.64	30	75	-18	125	72	-164	7.1	0.0001(HK)	3.5(S)	YHT
2002/ 5/26	31.68	51.10	35	65	11	300	79	154	11.5	0.00001(HK)	2.8(S)	YHT
2002/ 5/26	31.76	50.87	210	80	-153	115	63	-11	5.5	0.00003(HK)	3.0(S)	YHT
2002/ 5/27	31.69	51.10	140	75	145	240	57	18	6.0	0.00001(HK)	2.8(S)	YHT
2002/ 5/27	32.17	50.82	100	75	90	280	15	90	6.6	0.0001(HK)	3.3(S)	YHT
2002/ 5/27	31.80	51.16	80	65	22	340	69	153	10.5	0.0001(HK)	3.4(S)	YHT
2002/ 5/30	31.74	50.90	70	75	18	335	72	164	13.1	0.00003(HK)	3.0(S)	YHT
2002/ 6/1	31.74	51.04	45	65	11	310	79	154	10.8	0.000006(HK)	2.5(S)	YHT
2002/ 6/4	31.90	50.83	90	65	90	270	25	90	13.5	0.0022(HK)	4.2(S)	YHT
2002/ 6/9	31.98	50.58	55	80	26	320	63	168	20.1	0.0001(HK)	3.3(S)	YHT
2002/ 9/25	32.04	49.10	303	46	78	141	45	103	15	0.302	5.6	H
2005/10/20	31.77	50.47	131	83	152	224	62	8	29.1	0.0444	5.0	H
2005/12/26	32.33	49.12	323	85	88	169	5	115	12	0.0468	5.0	H
2006/ 9/26	32.01	50.72	147	79	168	239	78	11	24.8	0.026	4.9	H
2012/ 7/ 1	31.67	50.90	254	58	73	103	35	115	16.8	0.0519	5.1	H
2012/ 7/24	31.72	50.92	253	57	72	104	37	115	17.8	0.0346	5.0	H
2013/ 1/12	31.75	50.95	247	61	40	135	56	144	21.2	0.033	4.9	H
2013/ 1/25	31.71	51.03	295	44	110	87	50	71	20.9	0.0385	5.0	H
Zone 9												
1988/ 1/26	32.33	46.85	306	20	79	137	70	94	19.9	0.262	5.5	H

Date	Lat. (°N)	Long. (°E)	s1	d1	r1	s2	d2	r2	Depth (km)	M0(×1018)	Mw	Ref.
1989/ 4/ 2	32.89	47.62	351	85	-130	256	40	-7	15	0.142	5.4	H
2001/ 3/23	32.78	46.29	301	42	74	142	50	104	15	0.145	5.4	H
2001/ 4/ 3	32.58	47.80	270	62	77	116	31	113	30.7	0.0746	5.2	H
2001/ 9/ 1	32.81	47.58	288	60	83	121	31	101	15	0.0413	5.0	H
2008/ 9/ 3	32.44	47.10	294	34	78	128	57	98	12	0.057	5.1	H
2012/ 2/28	32.58	46.81	298	45	78	134	46	101	12	0.0359	5.0	H
2012/ 3/ 8	32.79	46.73	294	30	81	125	61	95	15.6	0.0428	5.0	H
2012/ 4/18	32.54	46.85	301	43	84	129	47	95	12	0.0405	5.0	H
2012/ 4/18	32.52	46.93	328	47	129	98	55	56	12	0.0275	4.9	H
2012/ 4/20	32.53	46.83	298	37	85	124	53	93	12	0.0813	5.2	H
2012/ 4/20	32.63	46.73	292	42	73	135	50	105	12	0.0873	5.2	H
2012/ 4/20	32.50	46.90	292	34	78	127	57	98	12	0.0436	5.0	H
2012/ 4/20	32.53	46.83	298	37	85	124	53	93	12	0.0813	5.2	H
2012/ 4/21	32.54	46.75	285	31	43	156	69	114	18.9	0.0753	5.2	H
2012/ 5/ 3	32.66	47.60	303	40	101	109	51	81	21.1	0.161	5.4	H
2014/ 8/17	32.62	47.34	311	30	107	111	62	80	20.2	0.0178	4.8	H
2014/ 8/18	32.59	47.53	317	27	111	114	65	80	12	2.57	6.2	H
2014/ 8/18	32.59	47.60	331	38	137	98	65	60	18	0.595	5.8	H
2014/ 8/18	32.56	47.45	274	32	78	109	59	97	12	0.0737	5.2	H
2014/ 8/18	32.68	47.38	70	83	31	336	59	171	16.5	0.183	5.4	H
2014/ 8/18	32.50	47.57	300	30	108	99	62	80	12	1.06	6.0	H
2014/ 8/19	32.63	47.32	289	29	84	116	61	93	12	0.0954	5.3	H
2014/ 8/20	32.51	47.62	310	22	109	109	69	82	13.9	0.32	5.6	H
2014/ 8/22	32.68	47.54	293	44	98	101	46	82	28.7	0.0262	4.9	H
2014/ 8/23	32.57	47.64	347	52	149	98	66	43	18.9	0.14	5.4	H
2014/ 8/24	32.61	47.76	328	90	156	58	66	0	24.7	0.0493	5.1	H
2014/10/15	32.45	47.87	272	53	92	89	37	88	12	0.628	5.8	H
2015/ 2/15	32.74	46.65	310	23	100	119	68	86	17.3	0.0263	4.9	H
Zone 10												
1977/ 4/26	32.10	48.63	293	29	93	110	61	88	19.6	0.197	5.5	H
1977/ 6/ 5	31.85	47.72	293	34	91	111	56	89	10	1.55	6.1	H
1977/ 6/ 5	32.13	48.09	289	33	91	108	57	89	10	0.129	5.3	H
1980/10/19	32.16	48.13	293	36	106	94	56	78	15	0.55	5.8	H
1981/ 1/ 2	32.22	47.82	277	24	95	92	66	88	15	0.0981	5.3	H
1983/ 5/28	32.45	48.36	314	38	113	106	56	73	27.3	0.253	5.5	H
1990/ 8/ 3	32.80	48.24	318	64	111	96	33	53	15	0.11	5.3	H
1990/10/11	32.41	47.89	308	45	90	128	45	90	15	0.0355	5.0	H
1994/ 7/31	32.53	48.00	309	41	114	99	53	71	18	0.249	5.5	H
1994/ 9/20	32.18	48.60	286	65	91	103	25	87	15	0.0786	5.2	H
2010/ 2/23	32.52	48.18	286	33	72	127	59	101	16.6	0.0288	4.9	H
2010/ 2/23	32.60	48.21	307	55	111	93	40	62	15.5	0.0697	5.2	H
Zone 11												
1987/ 5/29	33.54	47.76	128	88	170	218	80	2	15	0.10	5.3	H
1998/10/ 4	33.32	47.26	288	53	88	111	37	92	9	0.115(H)	5.2	TJ
1998/10/ 5	33.26	47.26	290	51	84	119	39	97	7	0.137(H)	5.3	TJ
2004/11/21	33.23	47.75	310	26	112	106	66	80	12	0.0681	5.2	H
2004/11/22	33.21	47.82	308	29	111	105	63	79	12.1	0.0371	5.0	H
2004/11/27	33.18	47.80	330	38	145	89	69	57	20.3	0.0244	4.9	H
2005/ 5/ 3	33.73	48.64	316	74	-161	220	71	-17	21.6	0.0316	4.9	H
2006/ 3/30	33.65	48.78	321	70	-167	226	77	-20	19.5	0.0621	5.1	H
2006/ 3/31	33.74	48.73	313	78	-174	222	84	-12	17	1.71	6.1	H
2006/ 3/31	33.73	48.75	319	67	-168	224	79	-24	25.7	0.0538	5.1	H
2006/ 4/8	33.80	48.71	332	65	-90	152	25	-90	5.4	0.0011(HK)	4.0(S)	SYT
2006/ 4/29	33.78	48.85	206	13	-90	26	77	-90	2.3	0.0001(HK)	3.3(S)	SYT
2007/ 6/27	33.57	48.92	17	38	41	252	66	120	6.4	0.00002(HK)	2.9(S)	SYT
2007/ 6/29	33.96	48.59	237	23	44	105	75	107	10.8	0.0005(HK)	3.8(S)	SYT
2007/ 6/30	33.88	48.74	261	90	18	171	72	-180	8.9	0.00003(HK)	3.0(S)	SYT
2007/ 6/30	33.88	48.74	83	47	15	343	80	136	9.4	0.00003(HK)	3.0(S)	SYT
2007/ 6/30	33.88	48.75	69	64	-16	166	76	-153	10.0	0.0001(HK)	3.4(S)	SYT
2007/ 6/30	33.87	48.74	44	40	0	314	90	130	8.8	0.00003(HK)	3.0(S)	SYT
2007/ 7/1	33.88	48.74	58	40	0	328	90	130	9.6	0.00003(HK)	3.0(S)	SYT
2007/ 7/1	33.88	48.74	58	40	0	328	90	130	9.5	0.0003(HK)	3.7(S)	SYT
2007/ 7/1	33.88	48.74	81	75	-33	181	58	-162	10.0	0.0007(HK)	3.9(S)	SYT
2007/ 7/1	33.88	48.74	64	71	-24	162	68	-160	10.0	0.0007(HK)	3.9(S)	SYT
2007/ 7/1	33.88	48.75	55	54	-38	169	61	-138	9.7	0.0007(HK)	3.9(S)	SYT
2007/ 7/1	33.89	48.74	250	90	30	160	60	-180	10.3	0.0002(HK)	3.6(S)	SYT
2007/ 7/1	33.88	48.75	223	86	22	131	68	176	9.4	0.00001(HK)	2.8(S)	SYT
2007/ 7/1	33.88	48.74	250	90	30	160	60	-180	9.8	0.00005(HK)	3.1(S)	SYT
2007/ 7/1	33.88	48.73	50	44	-22	156	75	-132	10.0	0.0001(HK)	3.4(S)	SYT
2007/ 7/1	33.79	48.80	58	52	27	311	69	139	6.0	0.0001(HK)	3.5(S)	SYT

Date	Lat. (°N)	Long. (°E)	s1	d1	r1	s2	d2	r2	Depth (km)	M0(×1018)	Mw	Ref.
2007/ 7/2	33.87	48.74	256	40	-90	76	50	-90	8.8	0.0002(HK)	3.6(S)	SYT
2007/ 7/2	33.87	48.73	247	90	30	157	60	-180	8.0	0.0005(HK)	3.8(S)	SYT
2007/ 7/2	33.88	48.74	217	62	-11	312	80	-151	11.4	0.0001(HK)	3.4(S)	SYT
2007/ 7/2	33.87	48.74	71	40	0	341	90	130	10.6	0.00003(HK)	3.0(S)	SYT
2007/ 7/11	33.97	48.56	251	86	-15	342	76	-176	9.8	0.0001(HK)	3.5(S)	SYT
2007/ 7/15	33.64	48.99	31	89	-30	122	60	-178	8.4	0.0001(HK)	3.5(S)	SYT
2007/ 7/17	33.63	48.94	48	33	-13	149	83	-122	4.9	0.0003(HK)	3.7(S)	SYT
2007/ 7/18	33.76	49.00	222	59	-30	329	65	-145	14.8	0.0005(HK)	3.8(S)	SYT
2007/ 7/18	33.76	49.00	85	36	37	324	69	120	15.7	0.00007(HK)	3.2(S)	SYT
2007/ 7/18	33.76	49.00	219	72	-21	315	70	-161	15.7	0.0001(HK)	3.4(S)	SYT
2007/ 7/19	33.90	48.64	97	58	90	277	32	90	5.2	0.00007(HK)	3.2(S)	SYT
2007/ 7/24	33.70	48.91	251	73	-6	343	85	-163	6.8	0.0007(HK)	3.9(S)	SYT
2007/ 7/25	33.78	48.82	64	64	56	300	41	139	8.4	0.00005(HK)	3.1(S)	SYT
2007/ 7/25	33.79	48.83	193	75	-48	299	44	-158	9.2	0.0001(HK)	3.3(S)	SYT
2007/ 7/27	33.73	48.87	172	58	-81	334	33	-105	6.6	0.00007(HK)	3.2(S)	SYT
2007/ 7/29	33.91	48.67	69	77	83	279	15	119	5.1	0.0001(HK)	3.5(S)	SYT
2007/ 7/30	33.80	48.78	119	49	90	299	41	90	4.6	0.0002(HK)	3.6(S)	SYT
2007/ 7/30	33.65	48.93	218	60	0	128	90	150	5.4	0.0001(HK)	3.5(S)	SYT
2007/ 7/31	33.90	48.65	233	74	-12	327	79	-163	5.6	0.0011(HK)	4.0(S)	SYT
2007/ 8/1	33.72	48.80	77	60	0	347	90	150	4.0	0.00007(HK)	3.2(S)	SYT
2013/ 1/22	33.07	48.60	323	44	134	90	60	56	21.2	0.0219	4.8	H