EVALUATION STRESS FIELD AND TECTONIC REGIME IN MID-EASTERN IRAQ-WESTERN IRAN FROM THE INVERSION OF MOMENT TENSOR FOCAL MECHANISM DATA

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ABSTRACT

The estimation of the stress-field direction from focal mechanism of an earthquake is a pertinent tool to understand crustal mechanics and earthquake habit. The main aim of this study is to infer the stress pattern of the mid-eastern Iraq - western Iran region. The study area is situated between latitudes 33.59°–34.93°N and longitudes 45.44°–46.39°E. Active stressed inversions of 102 moment tensor focal mechanisms data were used to rating the present day stress field. These data are subdivided into four regional subsets (circles) as a function of their geographical location and tectonic setting. The regional principal stress axes (σ_1 , σ_2 , and σ_3) were inferred using right dihedral and rotational optimization methods by the formal stress inversion method. The results showed that there are spatial differences in the tectonic stress field, proportionate with fault orientations and faulting mechanisms. Thus, five stress regime categories are presented for the study area. It turns out that the prevailing tectonic systems are thrust faulting (50.98 %), strike-slip faulting (29.40 %), and unknown or oblique faulting (13.70 %); while the rest of the tectonic systems are less present thrust with strike-slip faulting (4.90 %), and normal with strike-slip faulting (0.98 %). The orientation of the maximum horizontal stress has a general directional trend towards NW-SE and NE-SW with local deviations related to the main predominant geological structures. Quality stress classifications were determined for the four groups' areas and were of B and C quality. The local extensional tectonic environment between strike-slip fault systems possibly it's the reason there are some normal faults. Finally, we note that the spatial differences of the tectonic regime and the stress field are compatible with the neotectonic stress field that is identified from focal mechanism data.

Keywords: Focal mechanism solutions; Moment stress axes; Stress inversion; Stress regimes

INTRODUCTION

The analysis of the seismic source is one of the fundamental techniques in the study of active continental movements that can assist in determining the status and trends of tectonic movements and gives a better understanding of the current mode of tectonic deformation in the study region. It is possible to determine the stress that caused the faulting or seismic events through the classic stress inversion way, especially if there is a well-prepared homogeneous data (Angelier and Mechler, 1977; Angelier, 1984; Gephart and Forsyth, 1984).

The study area is located in the collision tectonics zones between the Arabian plate and the Iranian plate in the area between latitudes 33.59– 34.93°N and longitudes 45.44–46.39°E. The used data include earthquakes focal mechanisms with magnitudes $3.67 \leq MW \leq 6.11$ that occurred in a seismically active region at the beginning of January 2018 to the end of August 2019 (102 events). Most of the events are located in mid-eastern Iraq and the western part of Iran; near to the borders and have depth ranged between 8-2 km. The focal mechanisms data were taken from the study of Mohammed and Al-Rahim (2020) (Fig. 1). These data have chosen to assign the moment stress axes, horizontal stress axes and stress regimes (Table 1). The database available for the region of the study area was subdivided into four groups AA (Belula-Ezgeleh), BB (Khanaqin-Qasre Shirin-Sarpol Zahab), CC (Mandali-Samoor), and DD (Qolqoleh-Halol) according to the spatial distribution of the events, the city names and the surrounding geographical locations (Fig.1).

A few studies were done to represent the paleo stress system in Iraq and surrounding regions. Abdalnaby et al. (2014, 2016) applied two methods to assess the orientations of the principal stress axes in Northern Iraq and Diyala city, respectively by using the formal stress inversion of fault plane solutions. The aims of this work are to give a comprehensive picture of the tectonic regime and determine the probable local variations of stress axis orientation using focal mechanisms stress inversion database computed for the region.

TECTONIC FRAMEWORK

The Arabian-Eurasian plates are colliding from the Zagros suture region in western Iran to the Bitlis suture zone in southern Turkey. This collision occurred under the control of various tectonic forces that had a clear impact on the recent tectonic framework and structural geology of Iraq during the Phanerozoic period (Abdalnaby, 2018). In recent active tectonic areas; the topography of the land surface is an accurate reflection of the underlying structure and its interaction with surface processes (Jackson et al., 1996).

Fig.1. Colored map of focal mechanism for 102 events with main tectonic boundaries. Subdivided into four groups AA (Belula-Ezgeleh), BB (Khanaqin-Qasre Shirin-Sarpol Zahab), CC (Mandali-Samoor), and DD (Qolqoleh-Halol) according to (Mohammed and Al-Rahim, 2020)

Generally, the intensity of deformation, age of the sedimentary units and amount of shortening in the study region reduction from north and northeast (Zagros Suture Zone) in the direction of SW (Foreland region) (Fouad, 2014). Depending on the topography and deformational style, the northwestern and southeastern segments of the Zagros fold and thrust belt (including the study area) is one of the largest and most seismically active belts in the region, where it extends from eastern Turkey–Strait of Hormoz, (250-400) km wide (Khodaverdian et al., 2015). The topography of the high folded zone reflects high rugged “anticlinal” mountains discrete by deep and narrow “synclinal valleys because of the variation in resistance of diverse rock kinds to erosion and weathering (Fouad, 2014 and 2015; Sissakian et al., 2014). The seismicity of the area is due to the forces producing from movements of the Arabian plate to the north and northeast, which led to reactivation of the preexisting faults (Alridha et al., 2017).

The morphological units for the Zagros Fold–Thrust Belt is (i) Zagros suture zone, (ii) Imbricated zone, (iii) High folded zone, and (iv) Foothill zone (Fig. 2) (Jassim and Goff, 2006). The Zagros imbricate zone or known as the high Zagros zone in Iran is bounded by the main Zagros fault and main recent faults in the northeast and the high Zagros fault in the southwest

(Alavi, 2004; Farzipour et al., 2009). The Zagros Imbricate Zone represents both the thrust and imbricate zones in the previous tectonic divisions of Iraq. The high folded zone is located between the high Zagros fault in the northeast and the mountain front fault in the southwest. This zone is known as a part of the Zagros simply folded zone in Iran (Alavi, 2004; Farzipour et al., 2009). The Foothill Zone has been divided by the Kirkuk Fault into the Chemchamal and the Hemrin subzone (Jassim and Goff, 2006). This zone is part of the Zagros simply folded zone in Iran too and bounded by the Mountain front fault in the northeast and the Zagros foredeep fault in the southwest (Mobasher, 2007).

Fig. 2. Tectonic setting of mid-eastern Iraq - western part of Iran. Names within the parentheses are known in the Iranian part of Zagros (modified after Sissakian, 2000; Fouad, 2015; Zebari et al., 2019). The black rectangle represents the study area plotted in Fig.1 and the magnitude of the 102 earthquakes is indicated by the diameter of the colored circles

MATERIALS AND METHODS

Classification of Focal Mechanism Solutions

Due to fault plane ambiguity, it is not known prior which of the two nodal planes of the focal mechanism is the rupture plane, thus; the moment stress axes (P, T, and N) are used as a proxy for the orientation of the principal stress axes (Barth et al., 2008). The fault plane solutions of

the analyzed events are plotted using the (Frohlich, 1992) method and called Frohlich triangle diagram as in Fig. 3. The triangle diagram is generated using a computer code presented by (Hallo et al., 2019). The diagram uses the plunge of the P, T and N axes of the focal mechanisms to determine their kind as revers or thrust, normal and strike-slip mechanism. Detailed information is listed in (Table 1) on the resulting focal mechanisms includes the strike orientation, dip angle, rake angle of both nodal planes, the trend of slip and the directions of the moment stress axes. The Frohlich ternary diagram is used to plot the data for each group with color-coding according to the focal mechanism kind: red for normal or with strike slip faulting, green for strike slip, blue for reverse pure or with strike slip faulting, and gray color for unknown or oblique type. The oblique type (odd) indicates the maximum horizontal stress azimuth is not defined. (Figs. 1 and 3) show the groups AA, BB, CC with a dominance of reverse fault, while the group DD they have a relatively strike-slip fault.

Fig. 3. Representation of the focal mechanisms data into four groups for stress inversion based on the Frohlich triangle diagram

Moment Stress Axes

The moment stress axes (P, N, and T) are respectively, maximum shortening, neutral axes and maximum extension. These axes are perpendicular to each other from both the fault and the auxiliary planes. From focal mechanisms; the moment stress axes for the seismic events differ mostly and do not correspond with principal stress axes σ_1 , σ_2 and σ_3 . This is due to

earthquakes occurs on pre-existing faults (Scholtz, 2002; Stein and Wysession, 2003). Notwithstanding, σ_1 and σ_3 antipodalities are located within the same quadrants such as P and T respectively. To derive the orientation of the (σ_1 , σ_2 and σ_3) from (P, N, and T), a formal stress inversion way is needed to be performed (Delvaux and Sperner, 2003). The same is correct for principal stress axes σ_1 , σ_2 and σ_3 only in state of new fracture generation in a homogeneous isotropic medium (Vavryčuk, 2014). A preliminary analysis was performed using all the moment stress axes of the focal mechanisms data in each group. The P axis at 45 degrees from the compressional dihedron (bisecting both focal planes) (Anderson, 1951). Table (1) shows moment stress axes relying on their azimuth (dip direction) and plunge (dip angle).

Formal Stress Inversion Methods

The determination directions of the faults must be accurate in a stress inversion step because using the wrong directions for the fault planes may output inexact results (Michael, 1984; Vavryčuk, 2014). The orientation of the three orthogonal principal stress axes σ_1 , σ_2 and σ_3 forms most compressional to most dilatational, respectively with $\sigma_1 \geq \sigma_2 \geq \sigma_3 \geq 0$. The ratio of principal stresses:

$$R = (\sigma_2 - \sigma_3) / (\sigma_1 - \sigma_3) \quad (1)$$

with $0 \leq R \leq 1$ is a measurement of the relative sizes of this principal stress. Wherefore, fault slip and focal mechanism data only constraint these four parameters that form the reduced stress tensor (Gephart and Forsyth., 1984; Angelier, 2002). In this research, two different formal stress inversion ways for the inversion of focal mechanisms are delineated using first: Right Dihedron method and second: Rotational Optimization Techniques (Delvaux and Sperner, 2003).

The Right Dihedron method

Right Dihedron method is utilized initially to process data, and this way was evolved by (Angelier and Mechler, 1977). The Rotational Optimization method uses the approximate and initial stress tensor as a starting point, which is an iterative process that aims to reduce the misfit function of each event.

Rotational Optimization method

This technique is the implementation of a new recurring inversion evolved by (Delvaux and Sperner, 2003). The purpose of this technique is to reduce a misfit function (using grid search) depending on the experiments for considerable number of different stress tensors. A statistical procedure is applied to compute (σ_1 , σ_2 and σ_3) for the trust areas to invents different sets of fault planes and to see the general probable stress tensor in the area. In each focal mechanism

two, nodal planes (fault and the auxiliary) are inverted to a stress tensor. Now, the factual fault plane will be based on the plane that has the least value of the misfit from both nodal planes. After this separation, only the selected fault planes will be inverted to calculate the (σ_1 , σ_2 , σ_3 and R) (Gephart and Forsyth, 1984). The consequences will be represented on an equal-area projection to assist with appraising the total quality of the outcome.

Horizontal stress axes method

The exact orientations of the horizontal stress are usually expressed the maximum (SH_{MAX}) and the minimum (SH_{min}) horizontal stress axis respectively. These are always perpendicular to each other. There are two ways to calculate, the first represented from the moment stress axes (Zoback, 1992a). While the second method is to compute the horizontal stress axes from the principal stress directions with a ratio of principal stresses (σ_1 , σ_2 and σ_3 and R) that are acquired from the inversion of fault plane solutions data (Lund and Townend., 2007) and applied in the windows-tensor program, in this study.

Evaluation of Stress Tensor Qualities

The Global Stress Map (WSM) is a global collection of data resources about the crustal present-day stress domain preserve. This map is utilized to assess the quality of our results in (GFZ) German Research Centre for Geosciences at the Helmholtz Potsdam Center. Heidbach et al. (2016) identified the quality ranking scheme for formal inversion of the focal mechanisms. The scheme is fundamentally based on the number, the precision, and the deep of the observation. The quality of each stress data record is set between A, and E, starting with higher quality A, and, lowest E. Quality A, intended that the orientation of SH_{MAX} is precise to within ± 15 , while, quality B, to within ± 20 . Whereas, the quality C to within the limits ± 25 , and finally D quality to within the limits ± 40 . Generally, most of the ways quality categories are determined via the standard deviation of SH_{MAX} . If the data records are of type (E) quality that has standard deviations greater than 40, then they do not provide sufficient information for those records. Heidbach (2016) considered the reliability of type A, B and C quality stress indexes to be utilized in the exegesis of geodynamic processes and in stress patterns resolving.

Tectonic stress regimes (R')

The basic concept of the stress regime index R' , as described by (Delvaux et al, 1997; Delvaux and Sperner, 2003) is used as a numerical expression of the stress regime, based on the value of the stress ratio (R), and known as follows:

$$R'_{NF} = R \text{ for extensional stress regime or normal faulting regimes (NF)}$$

$$R'_{SS} = (2 - R) \text{ for strike-slip regimes (SS)}$$

$R'_{TF} = (2 + R)$ for compressional stress regime or thrust faulting regimes (TF).

Tectonic stresses form a continual scale. In normal regimes, the value of the indicator R' ranges from 0 to 1, whereas for strike-slip regimes it is 1 to 2, and 2 to 3 for compression regimes (Delvaux et al., 1997), as well as their types according to the (WSM) project standard (NF, SS and TF refer to normal, strike-slip and thrust faulting, while NS: intermediate between NF and SS, TS: intermediate between SS and TF, UF: unknown or oblique (Zoback, 1992b; Heidbach et al., 2010).

RESULTS

Horizontal Stress Axes Results

The orientation of SH_{MAX} outcomes reveals a general trend of northwestern-southeastern to northeastern-southwestern with local perversions related to the big geological structures. Detailed results are obtained were identical in most cases using windows-tensor program to analyze the 102 focal mechanisms. The compression stress system at the Zagros fold and the thrust zone have a perpendicular direction near the Iraq-Iran border, as shown by the directions of the horizontal stress axes. Table (1) and Fig. 4 show the orientations of the horizontal stress axes.

Fig. 4. (Left) Rose diagrams show the direction of the maximum horizontal stress axis (SH_{MAX}) from the formal stress inversion methods in each group based on Table (2). (Right) SH_{MAX} from the focal mechanism database shown in Table (1) following the convention of Zoback (1992a). The lines colors indicate the type of faulting: red for normal; blue for thrust; and green for strike-slip

Tectonic Stress Regimes Results

Based on Zoback, (1992 a & b) it has been evaluated tectonic stress regime for each focal mechanism in the region (Table 1). Fig. 5 shows the distribution of five categories stress regimes existing in the current study. However, the TF (50.98 %), SS (29.40 %), and UF (13.70 %) are the most common tectonic systems, while, the less recurrent stress regimes in the region are TS (4.90 %) and NS (0.98 %).

Fig. 5. Apportionment categories of stress regimes from focal mechanism data existing in the study area

Formal Stress Inversion Results

The study area was divided into four regional subsets (circles). The stress inversion for all focal mechanism within each circle is studied separately using New Right Dihedron with Rotational Optimization ways. Fig. 6 represents the results of the stress inversion in the form of graphical outputs using Win-tensor. The projection of the σ_1 , σ_2 and σ_3 in a lower-hemisphere equal-area stereographic projection plot of the chosen focal planes as it is shown in cyclograph trace. If the normal faulting, it will be slip lines as a black dot with the external arrow, while reverse faulting is inside arrow, and strike-slip faulting is double semi-arrows. The orientation of the σ_1 is as a turquoise point encompassed by a circle, while σ_2 is as a triangle and a square for σ_3 . Large arrows outside the stereogram illustrate the related SH_{MAX} and SH_{min} orientations. The big blue arrow represents outside the stereogram is SH_{MAX} , while a red arrow for SH_{min} . The black bars on the periphery of the stereogram for the SH_{MAX} , while, white bars symbolize the directions of the horizontal stress axes for SH_{min} for unique focal mechanisms.

Table 1. Source parameters from (Iranian seismological center catalog), and focal mechanism solution of moment tensor inversion were taken (Mohammed and Al-Rahim, 2020) used for formal stress inversion in this study

Event Date	O. Time (UTC)	Lat. E	Log. N	CD	MW	Plane 1			Plane 2			Moment Stress Axes						SH _{MAX}	SH _{min}	R'	SR
						S	D	R	S	D	R	P		N		T					
												PL	AZ	PL	AZ	PL	AZ				
2018/01/05	6:32:57	34.530	45.698	19	4.00	181	78	99	325	15	55	32	264	9	359	56	102	74	164	2.5	TF
2018/01/06	15:22:08	34.471	45.759	17	5.02	360	80	75	237	18	146	33	103	15	3	53	252	119	29	2.5	TF
2018/01/11	6:59:29	33.712	45.693	20	5.63	135	65	70	356	32	126	18	240	18	144	64	11	66	156	2.5	TF
2018/01/11	7:00:53	33.667	45.714	16	5.28	166	54	110	315	40	65	07	243	16	335	72	128	61	151	2.5	TF
2018/01/11	7:14:15	33.722	45.709	18	5.28	160	65	90	340	25	90	20	250	00	340	70	70	70	160	2.5	TF
2018/01/11	7:21:33	33.700	45.719	19	5.27	315	75	75	181	21	134	28	57	14	319	57	205	68	158	2.5	TF
2018/01/11	7:37:09	33.762	45.731	21	4.02	310	60	60	179	41	131	10	61	26	326	62	171	64	154	2.5	TF
2018/01/11	7:52:47	33.815	45.747	17	4.11	177	57	130	300	50	45	4	240	33	333	57	144	59	149	2.5	TF
2018/01/11	7:55:00	33.733	45.703	18	4.80	150	80	70	34	22	153	32	257	20	154	51	37	93	3	2.5	UF
2018/01/11	8:00:39	33.724	45.686	18	5.28	167	67	99	325	25	70	21	250	08	343	67	94	66	156	2.5	TF
2018/01/11	8:17:55	33.641	45.622	17	3.98	150	50	90	330	40	90	5	240	0	150	85	60	60	150	2.5	TF
2018/01/11	8:29:03	33.804	45.659	18	3.82	330	80	50	228	41	165	24	90	39	338	41	165	84	174	1.5	UF
2018/01/11	9:23:55	33.677	45.706	19	3.90	130	65	65	358	35	132	16	238	23	141	62	1	64	154	2.5	TF
2018/01/11	9:32:24	33.706	45.653	18	4.12	155	55	100	318	36	76	9	238	8	329	77	99	57	147	2.5	TF
2018/01/11	13:16:43	33.724	45.735	18	4.21	145	65	80	348	27	110	19	242	9	149	68	35	66	156	2.5	TF
2018/01/11	13:30:46	33.740	45.654	17	3.91	165	60	109	310	35	60	13	241	17	335	69	115	57	147	2.5	TF
2018/01/11	14:47:17	33.723	45.699	20	4.01	330	80	55	226	36	163	27	87	34	337	44	206	98	8	2.5	UF
2018/01/11	20:19:40	33.653	45.697	18	3.81	168	62	101	325	30	70	16	250	10	342	71	102	67	157	2.5	TF
2018/01/11	21:50:44	33.775	45.685	19	4.31	140	70	30	39	62	157	5	268	54	171	35	2	89	179	1.5	SS
2018/01/11	21:52:22	33.779	45.648	20	3.77	330	80	80	195	14	135	34	69	10	332	54	228	83	173	2.5	TF
2018/01/12	17:50:40	33.645	45.671	16	3.88	285	65	35	179	59	150	4	50	48	316	42	144	51	141	1.5	TS
2018/01/13	0:33:26	33.660	45.708	19	4.27	140	50	60	2	48	121	1	251	23	160	67	343	71	161	2.5	TF
2018/01/13	6:30:30	33.671	45.707	17	3.81	332	66	123	95	40	40	14	39	29	137	56	286	34	124	2.5	TF
2018/01/13	9:24:19	33.718	45.699	19	4.21	140	50	65	356	46	117	2	247	19	157	71	343	68	158	2.5	TF
2018/01/14	19:45:47	34.396	45.851	17	4.11	260	85	15	169	75	175	7	33	74	278	14	125	34	124	1.5	SS
2018/01/18	16:48:42	34.556	45.669	15	3.92	192	82	114	300	25	20	33	262	23	8	48	127	66	156	2.5	UF
2018/01/19	22:17:56	33.709	45.699	16	4.91	333	61	118	105	40	50	11	43	24	138	63	290	39	129	2.5	TF
2018/01/21	2:19:37	34.528	45.547	14	4.03	2	76	104	135	20	45	30	80	14	178	57	290	68	158	2.5	TF
2018/01/21	5:45:39	34.548	45.586	16	4.05	177	74	102	320	20	55	28	257	11	353	60	103	68	158	2.5	TF
2018/01/26	20:17:34	33.675	45.611	13	4.09	163	54	127	290	50	50	2	227	29	318	60	133	46	136	2.5	UF
2018/02/02	9:42:57	34.798	45.757	8	4.16	145	80	45	45	46	166	22	358	44	245	38	106	6	96	1.5	UF
2018/02/16	18:22:00	33.634	45.699	18	3.97	155	89	95	255	5	10	44	240	5	335	46	70	24	114	2.5	TF
2018/03/28	0:27:05	34.491	45.497	19	3.95	161	78	99	305	15	55	32	244	9	339	56	82	54	144	2.5	TF
2018/04/01	8:35:25	34.434	45.786	15	5.13	08	69	-148	265	60	-25	38	229	52	38	05	135	47	137	1.5	SS
2018/04/02	3:03:22	34.388	45.821	14	4.01	7	73	132	115	45	25	17	157	40	262	45	49	151	61	2.5	TF
2018/04/30	22:14:49	34.861	45.821	18	4.15	140	55	60	5	45	126	6	296	24	203	65	38	118	28	2.5	SS
2018/05/22	0:31:53	34.830	45.879	16	4.35	94	85	170	185	80	5	4	140	79	248	11	49	140	50	1.5	TF
2018/06/26	17:57:03	34.618	46.268	15	4.54	255	85	15	164	75	175	7	298	74	183	14	30	119	29	1.5	SS
2018/06/26	22:13:05	34.546	45.641	14	3.77	146	71	95	310	20	75	26	232	5	324	64	65	48	138	2.5	SS
2018/07/15	7:10:59	34.614	46.278	17	4.32	245	90	20	155	70	180	14	288	70	155	14	22	110	20	1.5	SS
2018/07/16	5:33:53	34.625	46.289	14	4.16	133	81	-160	40	70	-10	21	268	68	67	7	175	86	176	1.5	TF
2018/07/22	10:07:25	34.630	46.255	15	5.52	343	80	-165	250	75	-10	18	117	72	284	4	26	116	26	1.5	SS
2018/07/22	16:48:47	34.585	46.296	13	3.98	337	86	-150	245	60	-5	24	115	60	255	17	17	111	21	1.5	TF
2018/07/23	0:59:47	34.606	46.303	16	4.37	156	85	-170	65	80	-5	11	21	79	182	4	290	21	111	1.5	SS
2018/07/24	8:46:11	34.643	46.312	16	4.29	158	80	170	250	80	10	0	114	76	205	14	24	114	24	1.5	SS
2018/07/24	19:58:29	34.794	45.816	14	4.50	355	50	75	197	42	107	4	6	11	275	78	114	7	97	2.5	UF
2018/07/25	1:47:47	34.634	46.315	17	4.02	147	80	165	240	75	10	4	104	72	206	18	13	103	13	1.5	SS
2018/07/26	15:51:19	34.317	45.622	17	4.15	331	76	96	125	15	65	31	55	6	149	58	249	48	138	2.5	SS
2018/08/04	17:02:04	34.620	46.354	12	3.75	344	76	-164	250	75	-15	21	117	69	296	0	27	117	27	1.5	SS
2018/08/25	22:13:25	34.622	46.233	13	5.82	250	75	-30	348	61	-162	45	185	38	43	20	296	19	109	0.5	SS
2018/08/26	5:18:28	34.622	46.231	16	4.05	147	83	-135	50	45	-10	36	289	44	64	24	180	98	8	1.5	TF
2018/08/26	8:25:03	34.620	46.259	11	3.67	153	77	-149	55	60	-15	31	288	57	83	11	191	104	14	1.5	TF
2018/08/26	9:23:33	34.608	46.202	12	3.67	159	76	154	255	65	15	8	299	61	43	28	205	117	27	1.5	SS
2018/08/29	5:34:35	34.613	46.291	11	4.12	164	76	-164	70	75	-15	21	27	69	206	0	297	27	117	1.5	TF
2018/08/31	21:05:43																				

2019/01/06	14:29:24	34.114	45.597	19	3.92	155	80	70	39	22	153	32	262	20	159	51	42	98	8	2.5	TF
2019/01/14	18:17:59	34.112	45.618	15	4.40	336	72	88	344	18	96	05	27	58	124	31	294	26	116	1.5	TF
2019/01/15	0:56:21	34.107	45.629	14	3.76	135	75	30	36	61	163	09	263	57	159	32	337	76	166	1.5	TF
2019/01/15	17:07:01	34.123	45.626	14	3.71	188	71	137	295	50	25	13	246	44	349	43	144	62	152	1.5	TF
2019/03/12	12:06:06	34.243	45.580	15	4.51	155	59	106	305	35	65	12	323	14	56	71	193	140	50	2.5	NS
2019/04/01	10:07:24	33.717	45.697	19	4.83	347	68	125	105	40	35	16	52	32	153	53	299	46	136	2.5	SS
2019/04/01	10:16:14	33.704	45.713	19	4.63	324	60	87	150	30	95	15	56	02	326	75	226	57	147	2.5	TF
2019/04/01	10:53:36	33.702	45.799	17	4.20	340	60	125	105	45	45	08	45	30	140	59	301	42	132	2.5	TF
2019/04/15	6:34:31	34.507	45.731	17	4.08	340	80	80	205	14	135	34	79	10	342	54	238	93	3	2.5	TF
2019/05/11	10:28:58	34.870	45.755	13	4.92	12	73	132	120	45	25	17	72	40	177	45	324	66	156	2.5	TF
2019/05/25	10:20:44	34.634	46.359	19	4.35	305	75	-50	52	42	-157	45	255	38	113	20	06	89	179	0.5	SS
2019/05/25	18:26:42	34.863	45.837	18	4.01	40	78	144	140	55	15	05	52	115	34	265	1	91	1.5	TF	
2019/06/05	3:33:05	34.419	45.603	18	4.54	160	70	90	340	20	90	25	250	0	340	65	70	70	160	2.5	TF
2019/06/05	3:36:16	34.447	45.636	14	4.61	172	57	130	295	50	45	04	145	33	238	57	49	144	54	2.5	TF
2019/06/23	16:51:59	34.451	45.626	18	4.43	176	62	112	315	35	55	14	250	19	345	66	125	66	156	2.5	TF
2019/07/17	15:19:33	34.452	45.614	16	4.18	290	60	45	173	52	141	05	50	38	317	52	146	52	142	2.5	TF
2019/07/29	20:47:10	34.483	45.617	14	4.20	335	50	90	155	40	90	05	65	0	155	85	245	65	155	2.5	TF
2019/08/03	00:26:06	34.590	46.223	17	4.02	330	79	139	70	50	15	18	296	48	47	36	142	93	3	2.5	TF

O. Time (UTC) original time in UTC, Lat latitude in degree, Log longitude in degree, CD calculated depth in km, MW moment magnitude, S strike, D dip, R rake angle, P, N, and T compressional, normal, and tensional moment stress axes respectively, PL plunge angle, AZ azimuth. SH_{MAX} and SH_{min} respectively, maximum and minimum horizontal principal stress directions, SR stress regime according to the WSM standard. R', stress regime index. NS normal faulting with strike-slip component, SS strike-slip faulting, TS thrust faulting with strike slip component, TF thrust faulting, UF unknown or oblique faulting

The small circle on the upper left nook of each panel exhibits the orientation and kind of the horizontal stress axes. The histograms to the lower-left nook of the stereograms portray the rating of the misfit angle F5 in Win-tensor program weighted mathematically in relation to the magnitude for each status. Note that the stress field changes gradually from the compression in the group's AA, BB and CC thrust belt to transpression while, strike slip in group DD respectively, where preexisting NW-SE to NE-SW deep faults system framework is reactivated.

Quality Ranking Scheme Results

Zoback (1992) has mentioned that the precision of the results increases (higher quality rankings) as the magnitude of the earthquake increase but in the single focal mechanism quality, A or B cannot be given even if the solution is well constrained and the earthquake is large. In this study, we compiled the stress data and it includes 94 data records. Indexes of stress inversion with the quality ranking scheme outcomes for the four sub-regions as in (Table 2). These were specified to be of B and C quality for the four groups in the study region.

Table 2. Stress inversion for the four sub-regions (parameters of the stress tensor)

Circle definition		Reduced stress tensor parameters						stress ratio (R)	Horizontal stress axes		Quality Rank (Q.R)	Stress regime index (R')	Stress regime
Group	No. of Data	σ1		σ 2		σ 3			SH _{MAX}	SH _{min}			
		PL	AZ	PL	AZ	PL	AZ						
AA	9	01	089	33	180	57	358	0.44	089	179	B	2.44	TF
BB	50	24	244	14	340	62	098	0.26	059	149	B	2.4	TF
CC	13	08	240	36	336	53	139	0.1	065	155	C	2.47	TF
DD	22	07	289	83	090	02	199	0.54	106	016	B	1.47	SS

Fig. 6. Formal stress inversion of the focal mechanisms data based on Table (1) and Fig. 1 Results are given in Table (2). The New Right Dihedron method (left panels) and the Rotational Optimization method (right panels)

DISCUSSION

Different structural frameworks may be presently undergoing the selfsame stress regime but displaying differences in their focal mechanisms. Defining a small group might produce a spurious impression of stress field variation due to it might also reflect the heterogeneity of the reactivated structures. Results obtained in the present research reveals the spatial distribution of focal mechanisms, the orientation of the SH_{MAX} and SH_{min} axes, the focal mechanism types and compare for the homogeneity with lateral differences. Tectonic stress regimes, styles of faulting and tectonic stress fields in each sub region is debated as follow:

1. Belula-Ezgeleh (Group AA)

The Northern part of the study region is located on the border of Iraq-Iran within what has known the Zagros fold and thrust belt, which delimits the continental collision zone between the Arabian and Eurasian Plates. There are six events only for this set. The stress tensor indicates that compressive is identical in a nearly horizontal southwestern -northeastern direction ($N89 \pm 14.4E$), and the collection of thrust with strike-slip faulting is the expression by the comparatively high stress ratio R' (2.44 ± 0.30) (Table 2) (Fig. 6), while the axis of the SH_{min} is in a nearly vertical direction.

2. Khanaqin-Qasre Shirin-Sarpol Zahab (Group Bb)

This group represents the largest number of events (45 events), most of them are inside Iran and a few are on the Iraq-Iran border, located within the Zagros fold, thrust belt that is a very seismically active region. A tectonically effective zone that accommodates crustal shortening resulting from the collision between the Arabian and the Eurasian Plates (Berberian and King, 1981) and observes that tectonic movement is divided between various kinds of faults. Due to local structural intricacies, which may demonstrate, why the Qasre Shirin concatenation broke in earthquakes sequence of moderate events Instead of being than as a single thoroughgoing larger rupture with NW striking segments, which parallel the regional orientation in fold axes (Nissen et al., 2019). Reverse faulting with almost all compression axes in the northeastern to southwest orientations characterizes the solutions. The inverted stress field has a SH_{MAX} orientation ($N59 \pm 20E$), and stress ratio R' (2.4 ± 0.3) (Table 2) (Fig. 6),

3. Mandali-Samoor (Group CC)

Most of the events in this group are distributed between Iraq and Iran on the border, and few kilometers northeast of the Iranian town of Naft Shahr (Fig.1). The orientation of the direction

of maximum compressive stress and the prevailing pattern of faulting is northeast-southwest. Thus, the Outputting stress tensor indicates that compression in a northeastern-southwestern orientation ($N80 \pm 18.3E$). The comparatively high-stress ratio R' (2.47 ± 0.24) with a compressive tectonic system (Table 2) (Fig. 6).

4. Qolqoleh-Halol (Group DD)

The Qolqoleh-Halol located in the western part of the study region. Twenty-two seismic events are located inside Iran between high Zagros fault, and main recent fault, which is a major northwestern-southeastern, 800km long right lateral strike-slip fault that accommodates some of the strain (Tchalenko and Braud, 1974) (Fig. 2). The strike-slip components in faulting mechanisms can be seen all over the region. All of mechanisms show and reveal a general trend of the SH_{MAX} orientation is nearly a NW-SE orientation ($N106 \pm 8.6E$) and the relatively stress ratio R' (1.47 ± 0.11) (Table 2) (Fig. 6).

CONCLUSIONS

The general direction of the (SH_{MAX}) is northwestern-southeastern to northeastern-southwestern with the presence of local deviations that are associated with the major geological structures in the region. The compression stress system at the Zagros fold and the thrust zone have a perpendicular direction near the Iraq-Iran border, as shown by the directions of the horizontal stress axes. The presence of five categories of stress regimes are determined by focal mechanisms inversion of the recorded events. The prevailing tectonic systems are TF (50.98 %), SS (29.40 %), and UF (13.70 %); while the rest of the tectonic systems are less present TS (4.90 %), and NS (0.98 %). We note the gradual changes in the stress field, wherein groups AA, BB and CC is compression in thrust belt, while, in group DD there is transpression and strike-slip. These changes cause reactivation of the preexisting northwestern-southeastern to northeastern-southwestern deep faults system.

Results obtained in the present research has a good harmony with both seismic trends concluded from earthquake locations and mapped faults and corresponding with the tectonic framework of the Arabian–Eurasian continental collision region. The strike-slip movement on the surfaces of faults appears to be the result of the rotation of the Arabic plate counter-clockwise. The spatial differences of the tectonic setting and the stress field are compatible with the neotectonic stress field that is identified from focal mechanism data. The relation obtained between moment and local magnitude was suitable for the researched area within the magnitude range.

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