Characteristics of global strong earthquakes and their implications for the present-day stress pattern

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MS received 15 June 2016; revised 4 April 2017; accepted 10 May 2017; published online 6 October 2017

Earthquakes occurred on the surface of the Earth contain comprehensive and abundant geodynamic connotations, and can serve as important sources for describing the present-day stress field and regime. An important advantage of the earthquake focal mechanism solution is the ability to obtain the stress pattern information at depth in the lithosphere. During the past several decades, an increasing number of focal mechanisms were available for estimating the present-day stress field and regime. In the present study, altogether 553 focal mechanism data ranging from the year 1976 to 2017 with $M_w \geq 7.0$ were compiled in the Global/Harvard centroid moment tensor (CMT) catalogue, the characteristics of global strong earthquakes and the present-day stress pattern were analyzed based on these data. The majority of global strong earthquakes are located around the plate boundaries, shallow-focus, and thrust faulting (TF) regime. We grouped 518 of them into 12 regions (Boxes) based on their geographical proximity and tectonic setting. For each box, the present-day stress field and regime were obtained by formal stress inversion. The results indicated that the maximum horizontal principal stress direction was $\sim$ N–S-trending in western North America continent and southwestern Indonesia, $\sim$ NNE–SSW-trending in western Middle America and central Asia, $\sim$ NE–SW in southeastern South America continent and northeastern Australia, $\sim$ NEE–SWW-trending in western South America continent and southeastern Asia, $\sim$ E–W-trending in southeastern Australia, and $\sim$ NW–SE-trending in eastern Asia. The results can provide additional constraints to the driving forces and geodynamic models, allowing them to explain the current plate interactions and crustal tectonic complexities better.

Keywords. Global strong earthquake; formal stress inversion; present-day stress pattern; focal mechanism solution.

1. Introduction

Generally, the lithospheric plates move towards and against each other with different velocities in different directions, and relative movements of these plates along the plate boundaries will induce

earthquakes. The gliding process between plates produces great but variable stress (Frisch *et al.* 2011). In recent years, the world has stepped into a natural disaster-prone period, and frequent natural disasters such as earthquakes pose a great threat to life and property safety around the world.

Tectonic stress is one of the fundamental datasets in Earth sciences compared to topography, gravity, heat flow and others (Sperner *et al.* 2003), which is released in catastrophic earthquakes (Fuchs and Muller 2001; Sperner *et al.* 2003). Knowledge of stress field in the hydrocarbon industry can be used to foresee borehole stability problems, optimize reservoir management through tectonic modeling in combination with other datasets, and predict tectonic fractures (Ding *et al.* 1998; Sperner *et al.* 2003; Smart *et al.* 2009; Ju *et al.* 2013b, 2014b, 2015; Ju and Sun 2016). Thus, investigation into the crustal tectonic stress is a key point in Earth geotectonic studies (Zoback 1992; Hou *et al.* 2006; Lunina and Gladkov 2007; Heidbach *et al.* 2010; Ju *et al.* 2012, 2013a, 2014a; Hussein *et al.* 2013).

Generally, formal inversion of focal mechanism data can reveal the present-day stress field and geodynamic regime (Zoback 1992; Fuchs and Muller 2001; Cortes and Angelier 2005; Delvaux and Barth 2010; Naimi-Ghassabian *et al.* 2015). Focal mechanism solutions are highly valuable as they can offer reliable stress information at different depths in the lithosphere (Tingay *et al.* 2010; Hussein *et al.* 2013). Observation of the present-day stress field and regime in the crust represents an important task for understanding the driving forces for the current deformation and the style of deformation itself (Hussein *et al.* 2013).

The purpose of this study is to analyze the characteristics of global strong earthquakes, estimate the orientations of the principal stress axes, and deduce the present-day stress pattern in the world. In the present study, it is considered that the strong earthquake is defined when its magnitude (M_w) is equal to or larger than 7.0. During 1976–2017, altogether 553 focal mechanism data with $M_w \geq 7.0$ were compiled from the Global/Harvard CMT catalogue, and the characteristics of global strong earthquakes were analyzed. Further, 518 of them were grouped into 12 regions (Boxes) based on their tectonic setting and geographical proximity. Formal inversions were performed to determine the present-day stress pattern globally based on these groups.

2. Data compilation

The Global CMT Project, formerly Harvard CMT, regularly determines focal mechanisms by moment tensor inversion of both long period body- and surface-waves to fit seismic waveforms calculated

for a reference earth model (Dziewonski *et al.* 1981, 1987; Zoback 1992). In this study, we combined 553 CMT solutions with $M_w \geq 7.0$ from the year 1976 to 2017 (table 1) to perform stress inversions for separate regions (figure 1).

Based on the compiled database, the individual focal mechanism was analyzed. The horizontal stress axes S_{Hmax} and S_{Hmin} , according to Lund and Townend (2007) and stress regime based on the World Stress Map (WSM) standard were calculated (table 1 and figure 2; NF: normal faulting, SS: strike-slip faulting, TF: thrust faulting, NS: intermediate between NF and SS, TS: intermediate between SS and TF, and UF: unknown or oblique faulting).

3. Characteristics of global strong earthquakes

3.1 Temporal characteristics

Based on the compiled database (table 1), the temporal characteristics of global strong earthquakes are analyzed. During 1976–2008, the number of strong earthquakes is generally less than 15 each year, whereas it increases greatly during 2009–2017 with a maximum of 23 in the year 2010 (figure 3a). The results indicate that the world has stepped into a natural disaster-prone period with frequent occurrence of strong earthquakes (figure 3a) in recent years. In addition, the earthquake magnitude becomes larger as well with several superstrong earthquakes (e.g., $M_w = 9.1$, 20110311, 05:47:33; figure 3b).

3.2 Spatial characteristics

Global strong earthquakes are not distributed randomly, but concentrated on a few worldwide seismic belts. Based on the distribution of global strong earthquakes, they are primarily located around plate boundaries (figure 1). Relative movements among plates will accumulate great energy, leading to strong earthquakes. In the latitudinal direction, global strong earthquakes are located between 70°S and 70°N with regions between 30°S and 60°N accounting for about 91.36% (figure 4a). In the longitudinal direction, global strong earthquakes are primarily located in three zones: 180°–170°W, 80°–70°W and 120°–170°E (figure 4b).

Table 1. *Compiled database of global focal mechanisms (1976 – 2017).*

Time	Location			Focal mechanism data				SH		Stress Regime
	Lat.	Long.	Depth	<i>M_w</i>	Strike	Dip	Slip	Max	Min	
19760101-012953	−29.25	−176.96	047.8	7.3	018	60	088	110	020	TF
19760114-155608	−29.69	−177.04	046.7	7.8	015	64	088	108	018	TF
19760114-164745	−28.72	−176.75	017.7	7.9	028	80	093	108	018	UF
19760121-100534	44.58	149.49	026.5	7.2	030	76	083	134	044	TF
19760204-090107	15.14	−089.78	016.3	7.5	347	80	−162	031	121	SS
19760324-044616	−29.99	−177.51	054.1	7.0	011	57	081	109	019	TF
19760505-045203	−29.84	−177.43	041.8	7.0	013	57	080	112	022	TF
19760603-164453	−04.75	153.47	085.9	7.1	331	59	094	057	147	TF
19760620-205324	03.18	096.24	019.1	7.0	147	62	085	063	153	TF
19760625-191813	−04.66	140.29	015.0	7.1	113	67	034	061	151	UF
19760711-204105	07.32	−078.11	015.0	7.3	176	72	024	127	037	SS
19760727-194211	39.52	118.03	015.0	7.6	126	79	−049	087	177	UF
19760728-104546	39.75	118.78	015.0	7.0	279	49	−071	086	176	NF
19760816-161159	07.07	123.75	033.0	8.0	158	55	089	069	159	TF
19760817-041940	07.14	123.01	015.0	7.1	120	83	−026	077	167	SS
19761124-122225	38.88	043.96	015.0	7.0	110	81	167	156	066	SS
19761130-004013	−20.54	−068.51	133.7	7.5	342	64	−099	172	082	NF
19770304-192211	45.23	026.17	083.6	7.5	235	62	092	143	053	TF
19770318-214407	16.38	122.59	035.0	7.2	007	65	081	108	018	TF
19770402-071538	−16.77	−171.91	050.3	7.3	190	62	122	073	163	TF
19770420-234304	−09.20	159.20	016.3	7.2	131	67	102	027	117	TF
19770420-234916	−09.33	159.79	016.4	7.1	122	72	077	050	140	TF
19770421-042423	−10.22	160.59	040.4	7.3	159	55	097	063	153	TF
19770622-120922	−22.86	−174.91	061.3	8.0	197	79	−089	014	104	NF
19770729-111549	−08.16	155.92	024.3	7.1	272	80	034	043	133	SS
19770819-060933	−11.14	118.23	023.3	8.3	061	67	−098	071	161	NF
19770826-195005	−59.60	−019.70	030.2	7.2	274	89	156	140	050	SS
19770827-071234	−07.92	125.72	032.3	7.0	038	49	068	144	054	TF
19771010-115403	−26.10	−174.88	023.4	7.3	170	55	−107	004	094	NF
19771017-172657	−27.93	173.88	017.4	7.0	348	90	−145	033	123	UF
19771123-092648	−31.22	−067.69	020.8	7.4	004	46	090	094	004	TF
19780209-213527	−30.60	−177.02	023.1	7.0	026	61	095	110	020	TF
19780307-024855	31.90	137.44	434.4	7.1	153	76	077	086	176	TF
19780323-003115	43.81	149.23	041.5	7.0	038	70	087	132	042	TF
19780323-031545	44.12	149.27	028.3	7.6	042	79	090	132	042	TF
19780324-194811	44.20	148.98	030.7	7.5	040	72	089	132	042	TF
19780612-081443	38.02	142.07	037.7	7.6	036	78	097	110	020	TF
19780723-144253	22.01	121.60	028.9	7.2	005	61	069	114	024	TF
19780916-153614	33.37	057.02	011.0	7.3	128	59	080	047	137	TF
19781104-221938	−11.16	161.82	033.3	7.0	161	73	119	040	130	TF
19781105-220213	−10.94	162.09	040.0	7.0	154	73	107	041	131	TF
19781129-195303	16.22	−096.56	016.1	7.7	127	84	094	020	110	UF
19781206-140236	44.74	145.82	181.0	7.8	330	83	−033	107	017	SS
19781223-112325	23.19	122.63	020.7	7.0	343	72	039	111	021	UF
19790216-100858	−16.88	−072.48	034.3	7.1	305	84	104	001	091	UF
19790228-212738	60.50	−141.39	018.8	7.4	084	77	089	176	086	TF
19790314-110731	17.78	−101.37	026.7	7.4	106	76	085	026	116	TF
19790410-014225	03.13	127.32	040.6	7.0	358	75	104	066	156	TF
19790501-130355	−21.27	169.97	073.4	7.4	281	83	−050	060	150	UF
19790724-193128	−11.26	107.68	020.0	7.0	334	90	−044	109	019	UF
19790912-051800	−01.78	136.06	016.3	7.5	008	85	161	054	144	SS
19791012-102530	−46.54	165.77	020.3	7.3	152	80	079	085	175	TF

Table 1. (Continued.)

Time	Location			Focal mechanism data				SH		Stress Regime
	Lat.	Long.	Depth	Mw	Strike	Dip	Slip	Max	Min	
19791017-054313	18.54	145.30	583.8	7.0	140	55	−135	170	080	NF
19791023-095115	−10.58	161.35	031.3	7.0	158	62	097	061	151	TF
19791123-234026	05.18	−075.58	108.6	7.2	035	79	−051	177	087	UF
19791127-171044	34.45	059.58	025.0	7.0	358	73	−156	040	130	SS
19791212-080007	02.32	−078.81	019.7	8.1	181	76	083	105	015	TF
19800223-055112	43.21	146.91	033.6	7.1	034	75	090	124	034	TF
19800308-221220	−22.86	171.65	026.8	7.2	089	75	081	015	105	TF
19800413-180453	−23.74	−176.70	166.2	7.6	30	79	−067	177	087	UF
19800708-231941	−12.92	166.21	043.6	7.5	353	49	100	076	166	TF
19800716-195653	−04.68	143.18	081.9	7.3	085	68	086	00	090	TF
19800717-194303	−12.44	165.94	034.0	7.7	158	60	083	075	165	TF
19801010-122534	36.25	001.36	010.1	7.1	050	61	081	150	060	TF
19801024-145348	18.14	−097.86	063.4	7.1	105	66	−101	118	028	NF
19801025-070026	−22.16	169.83	011.0	7.1	124	65	081	045	135	TF
19801025-110025	−21.76	169.84	028.8	7.4	136	68	085	053	143	TF
19801108-102746	41.14	−124.36	015.0	7.3	051	89	27	005	095	SS
19810118-181736	38.15	143.04	020.0	7.0	027	76	095	107	017	TF
19810130-085250	51.52	176.10	020.0	7.0	070	70	081	172	082	TF
19810525-052538	−48.94	164.39	033.3	7.6	033	85	−173	078	168	SS
19810706-030852	−22.31	170.90	058.3	7.5	254	90	−060	30	120	UF
19810715-075925	−17.34	167.27	030.0	7.1	166	63	094	072	162	TF
19810728-172244	30.03	057.58	015.2	7.2	300	79	084	045	135	TF
19810901-092947	−15.02	−173.16	020.0	7.5	273	55	−103	104	014	NF
19811016-032548	−33.48	−073.15	040.4	7.1	006	56	086	100	010	TF
19811025-032234	18.28	−102.00	031.8	7.2	115	70	093	021	111	TF
19811226-170543	−29.86	−177.75	030.5	7.0	007	63	083	104	014	TF
19820103-141004	−00.96	−021.83	010.0	7.1	351	81	031	124	034	SS
19820111-061015	13.91	124.35	017.3	7.1	351	80	098	062	152	TF
19820507-053843	−60.96	−020.62	010.0	7.0	358	90	−143	043	133	UF
19820619-062202	12.65	−088.97	051.9	7.3	299	66	−083	111	021	NF
19820622-41853	07.28	125.99	473.4	7.4	232	65	−056	023	113	NF
19820630-015744	44.59	151.18	026.5	7.1	221	89	−118	084	174	UF
19820707-104315	−51.18	160.41	010.0	7.2	334	88	−028	110	020	SS
19820723-142410	35.98	141.91	027.0	7.0	027	76	091	115	025	TF
19821219-174422	−24.31	−175.10	029.2	7.5	006	68	086	101	011	TF
19830126-160229	−30.52	−179.21	224.1	7.0	086	83	−092	094	004	UF
19830318-090606	−04.86	153.34	069.9	7.7	308	49	060	059	149	TF
19830403-025021	08.85	−083.25	028.0	7.4	108	67	081	029	119	TF
19830404-025144	05.72	094.65	071.6	7.0	078	53	127	142	052	TF
19830412-120800	−04.92	−078.07	111.1	7.0	153	55	−093	155	065	NF
19830526-030018	40.44	138.87	012.6	7.7	200	63	092	108	018	TF
19830817-105606	55.30	161.75	077.2	7.0	073	55	114	144	054	TF
19831004-185238	−26.01	−070.56	038.7	7.6	168	71	083	089	179	TF
19831022-042149	−60.59	−024.19	010.1	7.0	042	56	−095	047	137	NF
19831124-053043	−07.44	128.32	157.1	7.4	291	57	113	002	092	TF
19831130-174629	−06.35	071.75	010.0	7.7	069	63	−113	091	001	NF
19831202-030911	13.86	−092.20	031.0	7.0	118	71	090	028	118	TF
19831230-235300	37.17	070.41	212.2	7.4	103	72	093	009	099	TF
19840101-090347	33.38	136.81	383.6	7.1	162	75	073	097	007	TF
19840207-213336	−09.81	160.42	021.9	7.5	182	72	124	059	149	UF
19840305-033358	08.26	123.86	644.1	7.2	038	58	−076	026	116	NF
19840306-021731	29.60	139.11	446.0	7.4	332	88	−070	110	020	UF

Table 1. (Continued.)

Time	Location			Focal mechanism data				SH		Stress Regime
	Lat.	Long.	Depth	Mw	Strike	Dip	Slip	Max	Min	
19840319-202848	40.59	063.24	015.0	7.0	041	69	091	129	039	TF
19840324-094416	44.17	148.62	030.6	7.1	030	74	085	129	039	TF
19840530-074955	-05.02	151.64	157.0	7.1	038	64	077	142	052	TF
19840806-120207	-00.29	122.38	252.8	7.4	230	75	-120	083	173	UF
19841015-102118	15.81	-173.40	119.7	7.1	161	89	-105	024	114	UF
19841101-044859	08.36	-038.82	010.0	7.0	183	88	-017	138	048	SS
19841115-024630	-22.10	170.67	098.6	7.0	093	86	063	044	134	UF
19841117-064939	-00.23	097.84	024.7	7.1	128	81	086	051	141	UF
19841120-081524	05.02	125.56	180.7	7.5	335	66	-097	163	073	NF
19850303-224740	-33.92	-071.71	040.7	7.9	169	66	081	090	00	TF
19850304-003253	-33.06	-071.79	033.0	7.3	346	77	060	110	020	UF
19850409-015708	-34.26	-071.86	046.6	7.1	170	69	086	085	175	TF
19850510-153601	-05.68	150.97	025.4	7.2	097	77	-023	055	145	SS
19850703-043707	-04.28	152.58	031.4	7.2	329	55	078	068	158	TF
19850729-075458	36.33	070.96	098.5	7.4	254	54	104	152	062	TF
19850919-131825	17.91	-101.99	021.3	8.0	106	73	085	024	114	TF
19850921-013732	17.57	101.42	020.8	7.5	121	73	091	029	119	TF
19851117-094036	-01.63	134.71	013.3	7.1	271	85	026	045	135	SS
19851128-035008	-13.76	166.08	044.4	7.0	167	78	158	035	125	SS
19851221-011333	-13.89	166.57	045.5	7.1	348	46	092	077	167	TF
19860115-201748	-21.26	169.91	121.0	7.0	122	83	063	071	161	UF
19860507-224745	51.33	-175.43	031.3	7.9	072	68	092	160	070	TF
19860526-190625	-20.24	179.03	567.5	7.1	103	89	069	056	146	UF
19860616-104836	-21.86	-178.87	564.8	7.0	040	72	-097	051	141	NF
19860624-031143	-04.42	143.64	099.7	7.2	115	73	082	039	129	TF
19860814-193929	02.08	126.89	020.2	7.5	224	81	104	106	016	UF
19860830-212851	45.76	026.53	132.7	7.2	240	72	097	138	048	TF
19861020-064623	-27.93	-176.07	050.4	7.7	013	71	036	142	052	SS
19861030-012905	-21.68	-176.45	196.3	7.1	020	85	-091	026	116	UF
19861114-212018	23.97	121.85	033.2	7.3	033	57	092	121	031	TF
19870208-183414	-05.90	147.72	015.0	7.3	352	87	173	037	127	SS
19870305-091721	-24.38	-070.93	041.9	7.5	175	68	083	094	004	TF
19870306-041055	-00.06	-077.84	015.0	7.1	007	64	086	102	012	TF
19870617-013301	-05.53	131.20	075.4	7.1	062	62	047	004	094	UF
19870808-154910	-18.96	-070.02	079.5	7.2	353	70	-091	175	085	NF
19870903-064036	-59.28	158.80	015.0	7.4	062	83	-021	019	109	SS
19871006-041915	-18.29	-171.93	015.0	7.2	203	52	-070	008	098	NF
19871012-135717	-07.12	154.05	018.2	7.0	114	51	-109	129	039	NF
19871016-204818	-06.22	149.44	047.8	7.3	086	58	090	176	086	TF
19871117-084705	58.87	-143.62	015.0	7.1	356	85	-147	040	130	SS
19871130-192340	58.17	-142.04	015.0	7.8	262	82	-020	038	128	SS
19880119-073046	-24.86	-070.55	031.0	7.0	177	73	091	085	175	TF
19880205-140117	-24.93	-070.56	017.2	7.1	181	73	092	087	177	TF
19880204-035214	13.42	125.03	034.7	7.2	343	70	094	067	157	TF
19880306-223552	57.37	-143.53	015.0	7.7	089	79	-015	046	136	SS
19880412-232007	-17.55	-072.83	015.0	7.1	145	79	091	052	142	TF
19880806-003638	25.19	094.89	100.5	7.2	148	54	120	036	126	TF
19880810-043844	-10.49	160.77	016.2	7.5	138	73	081	062	152	TF
19881008-044636	-18.82	-172.28	045.0	7.1	16	47	090	106	016	TF
19881106-130331	23.00	099.68	015.0	7.0	064	84	012	018	108	SS
19890210-111531	02.64	126.72	043.5	7.1	210	59	092	118	028	TF
19890505-182849	-08.05	-071.49	606.0	7.1	157	60	-093	160	070	NF

Table 1. (Continued.)

Time	Location			Focal mechanism data				SH		Stress Regime
	Lat.	Long.	Depth	Mw	Strike	Dip	Slip	Max	Min	
19890523-105512	−52.15	160.41	015.0	8.0	127	81	021	080	170	SS
19890904-131509	55.66	−157.23	025.7	7.0	062	82	089	156	066	UF
19891101-182542	39.95	143.08	024.0	7.4	025	77	095	104	014	TF
19891215-184408	07.88	126.96	036.9	7.5	025	59	106	100	010	TF
19900303-121644	−22.05	175.35	025.3	7.6	137	87	158	003	093	SS
19900305-163822	−18.35	168.04	036.9	7.0	153	63	083	070	160	TF
19900325-132308	09.95	−084.58	017.9	7.3	108	79	087	025	115	TF
19900405-211247	15.57	148.08	015.0	7.4	026	61	−080	016	106	NF
19900418-133936	01.31	123.35	033.2	7.6	257	64	073	005	95	TF
19900512-045017	48.94	041.38	612.5	7.2	056	76	−064	024	114	UF
19900520-022208	05.32	032.29	015.0	7.1	315	86	023	089	179	SS
19900524-200022	05.70	031.67	015.0	7.1	102	59	−059	077	167	NF
19900524-200931	−07.30	120.95	580.3	7.0	245	66	−082	056	146	NF
19900614-074108	11.70	121.86	015.0	7.0	132	79	−013	088	178	SS
19900620-210031	36.95	049.52	015.0	7.4	300	73	032	070	160	SS
19900716-072653	15.97	121.23	015.0	7.7	333	88	004	108	018	SS
19900727-123807	−15.50	167.26	129.0	7.2	194	59	115	082	172	TF
19900812-212535	−19.58	169.05	164.9	7.0	165	74	095	066	156	TF
19901106-201440	53.77	169.41	026.6	7.1	057	82	069	002	092	UF
19901230-191436	−05.23	150.73	204.8	7.4	102	80	127	153	063	UF
19910422-215712	10.10	−082.77	015.0	7.6	318	69	104	030	120	TF
19910620-051901	01.04	123.23	015.0	7.5	276	83	088	014	104	UF
19910623-212243	−27.23	−063.25	570.3	7.2	162	68	−104	179	089	NF
19910817-221721	41.71	−125.63	015.0	7.0	046	86	028	00	090	SS
19911014-155825	−09.17	158.36	030.3	7.2	163	68	109	052	142	TF
19911119-222901	04.80	−077.18	019.1	7.2	188	77	089	100	010	TF
19911222-084331	45.58	151.55	031.2	7.6	037	74	088	131	041	TF
19911227-040612	−55.91	−024.48	015.0	7.1	141	59	−090	141	051	NF
19920425-180612	40.25	−124.31	015.0	7.2	173	82	093	071	161	UF
19920515-070518	−06.35	147.59	039.8	7.2	104	56	091	013	103	TF
19920517-094930	07.27	126.96	034.0	7.1	034	67	109	103	013	TF
19920517-101542	07.33	127.18	024.5	7.2	020	67	100	099	009	TF
19920527-051346	−11.20	165.06	018.7	7.0	340	56	−094	164	074	NF
19920628-115753	34.65	−116.65	015.0	7.3	248	82	−020	024	114	SS
19920711-104433	−22.45	−177.96	393.8	7.2	029	77	−078	007	097	NF
19920819-020446	42.19	073.32	017.0	7.2	088	60	099	169	079	TF
19920902-001642	11.20	−087.81	015.0	7.6	122	78	090	032	122	TF
19921011-192438	−19.17	168.83	141.1	7.4	185	78	123	059	149	UF
19921018-151210	07.27	−076.34	015.0	7.1	009	81	046	139	049	UF
19921212-052950	−08.34	122.49	020.4	7.7	253	50	086	166	076	TF
19921220-205301	−06.60	130.52	069.7	7.2	335	61	137	032	122	TS
19930115-110616	43.06	144.29	100.0	7.6	259	86	−095	102	012	UF
19930306-030600	−10.73	164.02	015.0	7.1	158	84	145	025	115	SS
19930511-182700	07.07	127.00	046.5	7.0	031	51	114	103	013	TF
19930608-130357	51.36	158.75	045.9	7.5	039	61	096	123	033	TF
19930712-131737	42.71	139.28	016.5	7.7	179	55	090	089	179	TF
19930808-083449	13.06	145.31	059.3	7.7	075	80	075	014	104	TF
19930809-124258	36.48	070.47	213.7	7.0	109	67	098	009	099	TF
19930910-191303	14.41	−092.99	029.1	7.2	124	67	096	026	116	TF
19931113-011816	52.00	159.27	054.2	7.0	034	59	094	120	030	TF
19931229-074824	−20.39	169.94	015.0	7.0	302	73	−146	162	072	SS
19940309-232818	−17.69	−178.11	567.8	7.6	007	77	−114	039	129	UF

Table 1. (Continued.)

Time	Location			Focal mechanism data				SH		Stress Regime
	Lat.	Long.	Depth	Mw	Strike	Dip	Slip	Max	Min	
19940314-043033	−00.88	−023.03	015.0	7.0	171	88	−029	127	037	SS
19940602-181816	−11.03	113.04	015.0	7.8	099	83	090	009	099	UF
19940609-003345	−13.82	−067.25	647.1	8.2	092	81	−095	106	016	UF
19940713-023609	−16.50	167.35	025.0	7.1	181	89	132	047	137	UF
19940721-183640	42.30	133.04	489.1	7.3	155	89	056	110	020	UF
19940901-151601	40.59	−125.78	015.0	7.0	06	86	025	140	050	SS
19941004-132329	43.60	147.63	068.2	8.3	050	74	128	104	014	UF
19941009-075549	43.87	147.96	033.2	7.2	031	72	085	129	039	TF
19941114-191539	13.44	121.32	015.0	7.1	249	88	−020	025	115	SS
19941228-121959	40.56	142.99	027.7	7.7	022	79	95	100	010	TF
19950205-225113	−37.61	179.40	015.0	7.1	215	58	−090	035	125	NF
19950407-220714	−15.37	−173.15	087.9	7.3	298	84	073	064	154	UF
19950421-003500	12.27	125.69	021.7	7.1	003	71	101	077	167	TF
19950505-035359	12.67	125.30	018.3	7.0	351	76	097	67	157	TF
19950516-201302	−23.05	170.00	024.7	7.7	110	56	−084	105	015	NF
19950527-130403	53.03	142.65	023.6	7.0	196	82	169	062	152	SS
19950703-195103	−29.13	−177.22	044.7	7.1	011	62	087	104	014	TF
19950730-051157	−24.17	−070.74	028.7	8.0	177	68	091	085	175	TF
19950816-102801	−05.51	153.64	045.6	7.7	320	48	092	049	139	TF
19950816-231048	−06.08	154.19	045.0	7.2	311	45	089	042	132	TF
19950823-070609	18.88	145.30	599.2	7.0	351	53	−067	153	063	NF
19950914-140441	16.73	−098.54	021.8	7.3	115	75	091	023	113	TF
19951003-015137	−02.55	−077.53	025.0	7.0	018	57	068	127	037	TF
19951009-153629	19.34	−104.80	015.0	8.0	120	81	090	030	120	UF
19951018-103739	28.06	130.18	018.5	7.1	212	66	−076	016	106	NF
19951021-023909	16.67	−093.42	163.8	7.2	313	90	−104	178	088	UF
19951122-041526	29.07	034.73	018.4	7.2	294	77	−149	155	065	SS
19951203-180136	44.82	150.17	025.9	7.9	040	78	089	132	042	TF
19951225-044336	−06.93	129.65	160.7	7.0	033	64	049	155	065	UF
19960101-080523	00.74	119.93	015.0	7.9	252	85	094	145	055	UF
19960207-213657	45.29	150.45	048.7	7.1	030	64	078	133	043	TF
19960217-060003	−00.67	136.62	015.0	8.2	305	80	094	023	113	UF
19960221-125127	−09.95	−080.23	015.0	7.5	157	76	091	065	155	TF
19960225-030827	15.88	−097.98	015.0	7.1	117	74	095	018	108	TF
19960416-003105	−23.98	−176.47	116.2	7.1	311	75	123	007	097	UF
19960429-144051	−06.65	155.07	054.3	7.2	305	46	081	041	131	TF
19960610-040403	51.10	−177.41	029.0	7.9	074	74	092	160	070	TF
19960610-152509	51.38	−176.49	036.5	7.2	062	66	083	160	070	TF
19960611-182306	12.74	125.41	028.5	7.1	356	70	102	070	160	TF
19960617-112234	−07.38	123.02	584.2	7.8	098	54	−052	071	161	NF
19960722-141948	01.34	120.65	028.2	7.0	264	77	096	161	071	TF
19960805-223831	−20.72	−178.16	555.0	7.4	043	70	−087	039	129	NF
19961112-170016	−15.04	−075.37	037.4	7.7	172	64	110	062	152	TF
19970100-202840	18.34	−102.58	040.0	7.1	292	82	−106	145	055	UF
19970123-021532	−22.04	−065.92	281.6	7.1	351	90	−086	127	037	UF
19970227-210814	29.74	068.13	015.3	7.1	085	77	082	012	102	TF
19970421-120309	−13.21	166.20	051.2	7.7	178	66	122	059	149	TF
19970510-075750	33.58	060.02	015.0	7.2	338	90	−173	023	113	SS
19970525-232244	−32.02	−179.95	345.0	7.1	342	75	049	109	019	UF
19970920-161143	−28.83	−176.99	046.4	7.0	015	61	090	105	015	TF
19971014-095333	−21.94	−176.15	165.9	7.7	016	81	−105	046	136	UF

Table 1. (Continued.)

Time	Location			Focal mechanism data				SH		Stress Regime
	Lat.	Long.	Depth	Mw	Strike	Dip	Slip	Max	Min	
19971015-010343	-31.06	-071.42	069.8	7.1	173	80	-083	156	066	UF
19971028-061528	-04.44	-076.55	118.9	7.2	158	52	-091	159	069	NF
19971108-100303	35.33	086.96	016.4	7.5	348	88	159	033	123	SS
19971115-185933	-14.92	167.21	121.8	7.0	197	50	103	097	007	TF
19971125-121443	01.37	122.71	029.4	7.0	275	69	089	007	097	TF
19971205-112721	54.31	161.91	033.6	7.8	039	68	097	120	030	TF
19971222-020602	-05.56	148.05	196.5	7.1	221	75	-024	180	090	SS
19980104-061226	-22.31	171.08	114.3	7.4	092	76	045	040	130	TS
19980130-121620	-24.02	-070.62	041.0	7.0	172	74	086	088	178	TF
19980325-031303	-62.99	148.64	028.8	8.1	281	84	017	055	145	SS
19980329-194823	-17.57	-178.85	553.7	7.1	104	71	040	052	142	TS
19980503-233038	22.37	125.53	022.9	7.4	049	89	172	094	004	SS
19980716-115642	-10.91	166.09	100.3	7.0	198	54	078	118	028	TF
19980717-084933	-02.50	142.07	015.0	7.0	287	75	078	037	127	TF
19980804-185929	-00.57	-080.48	025.6	7.1	172	78	082	100	010	TF
19980820-064111	28.99	139.47	425.5	7.0	337	82	-064	120	030	UF
19981109-053849	-06.94	128.95	024.6	7.0	084	56	075	007	097	TF
19981129-141045	-02.03	125.00	016.4	7.7	196	65	-150	054	144	SS
19990119-033543	-04.72	153.66	087.5	7.0	326	59	092	054	144	TF
19990206-214809	-12.78	166.58	098.2	7.3	178	69	116	061	151	TF
19990304-085211	05.38	122.03	018.0	7.1	167	54	094	073	163	TF
19990405-110817	-05.65	149.71	149.4	7.4	094	75	097	171	081	TF
19990408-131040	43.66	130.47	575.4	7.1	189	82	067	135	045	UF
19990510-203310	-05.38	150.97	144.6	7.0	069	54	-058	046	136	NF
19990516-005132	-04.99	152.76	042.0	7.0	075	62	087	168	078	TF
19990817-000150	41.01	029.97	017.0	7.6	091	87	164	137	047	SS
19990920-174735	24.15	120.80	021.2	7.6	211	65	087	124	034	TF
19990930-163123	16.20	-096.96	046.8	7.4	300	49	-078	112	022	NF
19991016-094659	34.71	-116.27	015.0	7.1	067	85	010	021	111	SS
19991112-165728	40.93	031.25	018.0	7.1	170	80	-036	129	039	SS
19991119-135702	-06.49	148.98	033.0	7.0	084	66	085	00	090	TF
19991126-132145	-16.08	168.31	015.0	7.4	020	62	103	096	006	TF
19991206-231240	57.35	-154.35	054.1	7.0	267	90	-027	042	132	SS
19991211-180346	15.87	119.64	035.1	7.2	011	88	-077	152	062	UF
20000108-164730	-16.84	-173.81	162.4	7.2	182	88	-098	041	131	UF
20000225-014405	-19.55	174.17	016.8	7.1	047	80	016	001	091	SS
20000328-110031	22.32	143.76	099.7	7.6	112	85	-086	095	005	UF
20000504-042133	-01.29	123.59	018.6	7.5	319	83	026	093	003	SS
20000512-184329	-23.72	-066.85	226.6	7.1	005	80	-096	020	110	UF
20000604-162847	-04.73	101.94	043.9	7.8	199	67	038	145	055	TS
20000618-144428	-13.47	097.17	015.0	7.9	254	85	-153	118	028	SS
20000806-072724	28.89	139.68	411.3	7.3	344	74	-068	137	047	NF
20001116-045537	-04.56	152.79	024.0	8.0	236	88	133	102	012	UF
20001116-074245	-05.03	153.17	031.2	7.8	070	75	089	162	072	TF
20001117-210220	-05.26	152.34	017.0	7.8	078	68	101	155	065	TF
20001206-171115	39.60	054.87	033.0	7.0	089	68	065	024	114	TF
20010101-065724	06.73	127.07	044.0	7.4	030	52	117	100	010	TF
20010109-164938	-14.90	167.11	114.4	7.0	288	76	047	056	146	TS
20010113-173346	12.97	-089.13	056.0	7.7	307	56	-086	123	033	NF
20010126-031655	23.63	070.24	019.8	7.6	066	64	060	002	092	TF
20010213-192845	-05.40	102.36	021.2	7.3	121	74	086	038	128	TF
20010224-072358	01.55	126.42	042.8	7.0	032	49	100	114	024	TF

Table 1. (Continued.)

Time	Location			Focal mechanism data				SH		Stress Regime
	Lat.	Long.	Depth	Mw	Strike	Dip	Slip	Max	Min	
20010603-024210	−29.37	−178.23	199.3	7.1	351	64	057	109	019	TF
20010623-203423	−17.28	−072.71	029.6	8.4	159	74	098	056	146	TF
20010707-093902	−17.45	−072.45	025.0	7.6	165	79	099	055	145	TF
20010821-065214	−36.70	−179.08	059.0	7.1	202	53	068	129	039	TF
20011012-150223	12.88	145.08	042.0	7.0	013	75	116	072	162	TF
20011019-032858	−04.31	124.11	018.8	7.4	089	86	013	044	134	SS
20011114-092716	35.80	092.91	015.0	7.8	190	80	−150	052	142	SS
20011212-140250	−42.69	124.67	016.0	7.1	259	85	172	125	035	SS
20020102-172306	−17.78	167.85	040.0	7.2	189	84	106	064	154	UF
20020303-120824	36.57	070.42	228.5	7.3	108	68	092	016	106	TF
20020305-211623	05.92	124.25	028.7	7.5	156	67	099	055	145	TF
20020331-065300	24.19	121.96	039.0	7.1	077	63	072	005	095	TF
20020426-160614	13.15	144.67	069.1	7.0	071	89	093	124	034	UF
20020628-171940	43.74	130.45	581.5	7.3	192	77	086	110	020	TF
20020819-110115	−21.74	−179.08	630.9	7.6	022	76	−072	175	085	NF
20020819-110835	−24.16	178.49	699.3	7.7	237	87	090	147	057	UF
20020908-184438	−03.27	143.38	019.5	7.6	339	68	116	043	133	TF
20021010-105042	−01.79	134.30	015.0	7.5	329	86	173	014	104	SS
20021102-012626	02.65	095.99	023.0	7.2	135	75	095	036	126	TF
20021103-221328	63.23	−144.89	015.0	7.8	029	82	019	162	072	SS
20021117-045400	47.81	146.45	479.8	7.3	197	86	098	075	165	UF
20030120-084316	−10.43	160.63	031.0	7.2	293	58	041	055	145	TS
20030122-020649	18.86	−103.90	026.0	7.5	108	79	086	027	117	TF
20030317-163627	51.33	177.58	027.0	7.0	060	75	073	175	085	TF
20030526-092439	38.94	141.57	061.0	7.0	193	72	097	091	001	TF
20030620-061947	−07.37	−071.89	556.2	7.0	139	49	−114	156	066	NF
20030715-202838	−01.42	069.47	015.0	7.5	216	89	159	081	171	SS
20030804-043743	−60.80	−043.21	015.0	7.6	210	76	−124	065	155	UF
20030821-121300	−45.01	166.87	031.8	7.2	209	67	088	121	031	TF
20030925-195038	42.21	143.84	028.2	8.3	028	82	083	139	049	UF
20030925-210820	41.75	143.62	047.3	7.3	033	72	091	121	031	TF
20030927-113336	50.02	087.86	015.0	7.2	131	71	158	180	090	SS
20031031-010641	37.89	142.68	015.0	7.0	026	81	092	110	020	UF
20031117-064331	51.14	177.86	021.7	7.7	067	74	080	173	083	TF
20031227-160122	−21.99	169.81	023.0	7.3	139	61	087	052	142	TF
20040103-162331	−22.41	169.72	015.0	7.1	117	52	−100	125	035	NF
20040205-210513	−03.62	135.53	013.0	7.0	044	43	−010	002	092	UF
20040207-024244	−04.03	134.78	012.0	7.3	261	68	−007	038	128	SS
20040715-042720	−17.68	−178.52	577.2	7.1	345	44	137	047	137	TF
20040725-143525	−02.68	104.38	600.5	7.3	108	45	−129	133	043	NF
20040905-100716	32.94	137.00	016.0	7.2	277	38	100	001	091	TF
20040905-145743	33.13	137.22	012.0	7.4	079	46	072	002	092	TF
20041111-212658	−07.87	125.12	017.0	7.5	067	27	072	167	077	TF
20041115-090702	04.72	−077.57	016.0	7.2	021	11	114	099	009	UF
20041122-202635	−46.36	164.91	040.0	7.1	043	36	103	125	035	TF
20041126-022512	−03.55	135.54	012.0	7.1	005	34	00	140	050	UF
20041128-183219	42.88	145.36	047.0	7.0	242	26	122	134	044	TF
20041223-145931	−49.91	161.25	027.5	8.1	069	74	167	116	026	SS
20041226-010109	03.09	094.26	028.6	9.0	329	08	110	047	137	UF
20041226-042137	06.61	092.79	013.6	7.2	351	27	121	064	154	TF
20050205-122324	05.47	123.67	530.6	7.1	158	14	−114	171	081	NF
20050302-104217	−06.54	129.99	196.1	7.1	041	88	055	175	085	UF

Table 1. (Continued.)

Time	Location			Focal mechanism data				SH		Stress Regime
	Lat.	Long.	Depth	Mw	Strike	Dip	Slip	Max	Min	
20050328-161032	01.67	097.07	025.8	8.6	125	83	086	051	141	UF
20050613-224440	-20.02	-069.23	094.5	7.8	352	67	-094	177	087	NF
20050615-025105	41.15	-126.42	020.4	7.2	047	85	007	001	091	SS
20050724-154216	07.92	091.88	012.0	7.2	120	89	-158	165	075	SS
20050816-024640	38.24	142.05	037.0	7.2	024	74	093	109	019	TF
20050909-072713	-05.20	153.95	083.6	7.6	319	60	089	050	140	TF
20050926-015544	-05.60	-076.20	108.1	7.5	169	51	-088	168	078	NF
20051008-035052	34.38	073.47	012.0	7.6	114	57	065	045	135	TF
20051114-213859	38.22	144.97	018.0	7.0	019	49	-078	011	101	NF
20060102-061103	-61.12	-021.39	020.2	7.4	265	78	-013	041	131	SS
20060102-221345	-19.80	-177.72	589.5	7.2	049	76	-107	075	165	NF
20060127-165905	-05.61	128.20	397.4	7.6	169	63	-123	016	106	NF
20060222-221915	-21.20	033.33	012.0	7.0	172	65	-078	158	068	NF
20060420-232518	60.89	167.05	012.0	7.6	044	51	101	125	035	TF
20060503-152704	-20.39	-173.47	067.8	8.0	011	72	078	119	029	TF
20060516-103936	-31.41	-178.91	151.1	7.4	342	74	100	056	146	TF
20060717-082038	-10.28	107.78	020.0	7.7	098	80	088	014	104	UF
20060820-034156	-61.27	-034.52	017.2	7.0	273	86	-008	048	138	SS
20061115-111508	13.50	154.33	013.5	8.3	033	75	089	125	035	TF
20061226-122629	21.81	120.52	019.6	7.0	329	61	-098	157	067	NF
20070113-042348	46.17	154.80	012.0	8.1	266	39	-054	064	154	NF
20070121-112801	01.10	126.21	022.2	7.5	034	35	108	113	023	TF
20070325-004013	-20.60	169.12	041.2	7.1	333	36	089	064	154	TF
20070401-204039	-07.79	156.34	014.1	8.1	333	37	121	044	134	TF
20070801-170904	-15.41	167.41	126.0	7.2	356	29	079	092	002	TF
20070808-170511	-06.03	107.58	304.8	7.5	330	30	155	027	117	UF
20070815-234158	-13.73	-077.04	033.8	8.0	321	28	063	066	156	TF
20070902-010529	-11.74	165.68	018.3	7.2	338	23	101	063	153	TF
20070912-111116	-03.78	100.99	024.4	8.5	328	09	114	046	136	UF
20070912-234935	-02.46	100.13	043.1	7.9	317	19	102	040	130	TF
20070913-033537	-02.31	099.39	017.0	7.0	312	10	090	042	132	UF
20070928-133904	21.94	143.07	275.8	7.5	073	49	050	009	099	TF
20070930-052352	-49.26	164.10	012.6	7.4	029	36	123	100	010	TF
20071031-033026	18.83	145.59	211.0	7.2	196	60	152	068	158	UF
20071114-154111	-22.64	-070.62	037.6	7.7	358	20	098	083	173	TF
20071129-190033	15.06	-061.41	147.9	7.4	109	58	032	055	145	TS
20071209-072838	-25.75	-177.22	149.9	7.8	034	25	038	152	062	TF
20071219-093037	51.02	-179.27	027.6	7.2	274	21	118	169	079	TF
20080220-080845	02.69	095.98	014.9	7.3	299	11	080	034	124	TF
20080225-083642	-02.66	099.95	014.4	7.2	317	06	102	040	130	UF
20080320-223312	35.43	081.37	012.0	7.1	358	41	-110	011	101	NF
20080409-124624	-20.12	168.80	035.2	7.3	340	30	101	064	154	TF
20080412-003021	-55.56	158.49	022.0	7.1	003	43	102	085	175	TF
20080512-062840	31.44	104.10	012.8	7.9	231	35	138	114	024	TF
20080630-061752	-58.33	-021.77	026.0	7.0	143	83	-179	008	098	SS
20080705-021214	54.12	153.37	610.8	7.7	143	48	-134	170	080	NF
20080929-151943	-29.85	-177.46	051.1	7.0	197	32	092	106	016	TF
20081116-170244	01.50	122.05	029.2	7.3	092	20	084	005	095	TF
20081124-090310	54.27	154.71	502.3	7.3	276	19	-029	065	155	UF
20090103-194409	-00.38	132.83	015.2	7.7	099	23	047	032	122	TF
20090103-223345	-00.58	133.48	018.2	7.4	101	26	072	022	112	TF
20090115-174948	46.97	155.39	045.2	7.4	011	44	084	105	015	TF

Table 1. (Continued.)

Time	Location			Focal mechanism data				SH		Stress Regime
	Lat.	Long.	Depth	Mw	Strike	Dip	Slip	Max	Min	
20090211-173501	03.92	126.81	023.9	7.1	117	38	083	032	122	TF
20090218-215350	-27.27	-175.90	036.5	7.0	274	38	179	139	049	UF
20090319-181753	-23.08	-174.23	049.1	7.6	205	44	098	109	019	TF
20090528-082505	16.50	-087.17	012.0	7.3	063	60	-007	020	110	SS
20090715-092250	-45.85	166.26	023.5	7.8	025	26	138	089	179	TF
20090809-105559	33.05	138.19	301.8	7.1	086	17	168	137	047	UF
20090810-195605	14.16	092.94	022.0	7.5	039	36	-092	040	130	NF
20090902-075508	-08.12	107.33	053.2	7.0	054	46	117	126	036	TF
20090929-174827	-15.13	-171.97	012.0	8.1	119	38	-131	144	054	NF
20090930-101617	-00.79	099.67	077.8	7.6	074	52	139	133	043	TF
20091007-220329	-12.59	166.27	044.2	7.6	344	41	087	076	166	TF
20091007-221915	-11.86	166.01	041.7	7.8	337	36	082	072	162	TF
20091007-231400	-13.12	166.37	042.5	7.4	341	43	083	076	166	TF
20091109-104503	-17.11	178.53	603.9	7.3	172	42	033	114	024	TS
20100103-223642	-08.88	157.21	012.0	7.1	321	21	102	045	135	TF
20100112-215317	18.61	-072.62	012.0	7.0	152	69	159	021	111	SS
20100226-203130	25.86	128.61	018.0	7.0	091	80	009	045	135	SS
20100227-063515	-35.98	-073.15	023.2	8.8	019	18	116	095	005	TF
20100227-080130	-38.09	-075.41	019.9	7.4	003	46	-102	011	101	NF
20100311-145536	-34.53	-072.13	016.3	7.0	016	06	-053	176	086	UF
20100404-224109	32.31	-115.39	012.8	7.2	223	84	-002	178	088	SS
20100406-221519	02.07	096.74	017.6	7.8	307	07	88	039	129	UF
20100509-055951	03.36	095.78	037.2	7.2	308	15	088	040	130	TF
20100527-171455	-13.81	166.65	042.9	7.2	347	44	096	073	163	TF
20100612-192700	07.85	091.65	033.1	7.5	220	63	031	168	078	UF
20100616-031639	-01.87	136.36	012.0	7.0	332	80	-172	016	106	SS
20100718-133513	-06.22	150.33	036.7	7.3	257	30	082	172	082	TF
20100723-220820	06.54	123.59	596.8	7.3	263	19	-031	053	143	UF
20100723-225121	06.62	123.90	576.9	7.6	233	18	-038	026	116	NF
20100723-231516	06.83	123.48	641.4	7.4	254	22	-052	054	144	NF
20100810-052354	-17.57	167.81	031.9	7.3	353	33	126	062	152	TF
20100812-115121	-01.51	-077.51	197.8	7.1	153	21	-068	142	052	NF
20100903-163558	-43.56	172.12	012.0	7.0	178	82	001	133	043	SS
20100929-171132	-04.92	133.78	017.7	7.0	185	43	-075	175	085	NF
20101025-144300	-03.71	099.32	012.0	7.8	316	08	096	044	134	UF
20101221-171954	27.10	015.60	015.6	7.4	110	40	-137	137	047	NF
20101225-131651	-19.67	168.04	016.6	7.3	001	48	-061	161	071	NF
20110101-095704	-27.02	-063.21	586.0	7.0	360	20	-064	166	076	NF
20110102-202027	-38.71	-073.84	019.4	7.1	005	13	097	091	001	TF
20110118-202332	28.61	063.90	052.3	7.2	077	31	-060	060	150	NF
20110309-024532	38.56	142.78	014.1	7.3	189	12	078	105	015	TF
20110311-054733	37.52	143.05	020.0	9.1	203	10	088	115	025	UF
20110311-061559	35.92	141.38	029.0	7.9	199	17	084	112	022	TF
20110311-062613	38.27	144.63	021.1	7.6	182	42	-100	009	099	NF
20110407-143251	38.32	141.85	053.5	7.1	019	37	083	113	023	TF
20110624-030952	52.09	-171.77	074.2	7.3	015	10	-160	048	138	UF
20110706-190333	-29.22	-175.83	022.3	7.6	163	36	-114	177	087	NF
20110710-005716	37.98	143.33	022.0	7.0	065	74	016	018	108	SS
20110820-165513	-18.52	167.94	033.5	7.1	342	29	093	070	160	TF
20110820-181935	-18.26	167.94	036.0	7.0	343	33	094	070	160	TF
20110824-174616	-07.68	-074.66	144.4	7.0	197	40	-057	177	087	NF
20110903-225546	-20.79	169.72	151.6	7.0	019	29	160	073	163	UF

Table 1. (Continued.)

Time	Location			Focal mechanism data				SH		Stress Regime
	Lat.	Long.	Depth	Mw	Strike	Dip	Slip	Max	Min	
20110915-193111	-21.61	-179.21	624.9	7.3	312	38	-007	091	001	UF
20111021-175728	-28.83	-175.72	048.4	7.4	202	37	083	116	026	TF
20111023-104128	38.64	043.40	012.0	7.1	246	38	060	174	084	TF
20111214-050505	-07.49	146.83	132.9	7.1	067	24	-004	024	114	UF
20120110-183713	02.59	092.98	023.7	7.2	103	81	-173	147	057	SS
20120202-133449	-17.69	167.11	020.5	7.0	051	51	-043	021	111	NF
20120320-180255	16.60	-098.39	015.4	7.5	296	10	095	024	114	UF
20120325-223721	-35.31	-072.41	033.8	7.1	020	16	112	099	009	TF
20120411-083931	02.35	092.82	045.6	8.6	020	76	005	154	064	SS
20120411-104338	00.90	092.31	054.7	8.2	107	83	-177	152	062	SS
20120412-071605	28.57	-112.76	015.8	7.0	131	74	-177	175	085	SS
20120814-025951	49.97	145.70	598.2	7.7	243	63	108	135	045	TF
20120827-043740	12.02	-089.17	012.0	7.3	117	76	093	022	112	TF
20120831-124744	10.85	126.97	045.2	7.6	197	51	110	092	002	TF
20120905-144223	10.00	-085.64	029.7	7.6	115	73	086	032	122	TF
20120930-163145	01.89	-076.22	159.1	7.2	080	54	-073	066	156	NF
20121028-030437	52.61	-132.06	012.0	7.8	122	66	083	040	130	TF
20121107-163556	14.11	-092.43	021.3	7.4	121	65	094	026	116	TF
20121207-081835	38.01	144.09	057.8	7.2	158	59	048	098	008	TF
20121207-081847	37.77	143.83	019.5	7.2	198	50	-090	018	108	NF
20121210-165315	-06.65	129.83	159.2	7.1	048	80	043	179	089	UF
20130105-085832	55.69	-134.97	013.8	7.5	064	89	030	018	108	UF
20130206-011255	-11.18	165.21	020.2	7.9	142	70	090	052	142	TF
20130206-012330	22.50	008.60	022.5	7.1	166	52	-085	162	072	NF
20130206-015423	-10.44	165.56	014.1	7.0	160	88	007	115	025	SS
20130208-152654	-10.72	165.92	023.6	7.0	358	85	008	132	042	SS
20130209-141615	01.16	-077.40	152.3	7.0	265	78	015	038	128	SS
20130406-044242	-03.33	138.49	073.6	7.0	222	56	-043	011	101	NS
20130416-104432	27.89	062.21	050.8	7.7	238	56	-102	069	159	NF
20130419-030605	46.00	150.92	104.5	7.3	244	83	-109	099	009	UF
20130523-171913	-23.19	-176.88	188.1	7.4	015	82	-085	000	090	UF
20130524-054508	54.61	153.77	611.0	8.3	012	79	-089	009	099	NF
20130707-183542	-04.10	153.98	382.9	7.3	167	47	-070	153	063	NF
20130715-140407	-61.05	-023.51	021.5	7.3	271	85	-018	047	137	SS
20130830-162510	51.44	-175.12	026.7	7.0	064	67	086	159	069	TF
20130924-113008	26.70	065.04	012.0	7.8	130	87	129	177	087	UF
20130925-164252	-16.03	-074.81	046.1	7.0	133	59	093	040	130	TF
20131015-001250	09.84	123.96	012.0	7.1	235	50	098	138	048	TF
20131025-171025	37.17	144.66	024.9	7.1	171	43	-107	002	092	NF
20131117-090541	-60.49	-045.32	023.8	7.8	102	44	003	056	146	UF
20140401-234732	-19.70	-070.81	021.6	8.1	355	15	106	077	167	TF
20140401-235811	-19.85	-071.39	020.6	7.0	177	65	094	082	172	TF
20140403-024336	-20.43	-070.60	028.7	7.7	165	76	087	080	170	TF
20140411-070734	-06.78	155.09	044.1	7.1	134	48	093	042	132	TF
20140412-201450	-11.35	162.24	027.3	7.6	117	71	028	067	157	SS
20140413-123628	-11.45	161.97	037.5	7.4	289	49	102	010	100	TF
20140418-142736	17.55	-101.25	018.9	7.3	115	72	087	029	119	TF
20140419-132813	-06.64	154.67	036.0	7.5	135	55	092	044	134	TF
20140623-205334	52.00	178.43	104.3	7.9	309	84	-117	169	079	UF
20141014-035144	12.33	-088.45	040.8	7.3	309	67	-088	127	037	NF
20141101-185730	-19.76	-177.61	445.4	7.1	252	80	074	012	102	UF

Table 1. (Continued.)

Time	Location			Focal mechanism data				SH		Stress Regime
	Lat.	Long.	Depth	M_w	Strike	Dip	Slip	Max	Min	
20150213-185928	52.70	-032.74	025.2	7.1	277	88	-170	142	052	SS
20150227-134509	-07.35	122.50	551.5	7.0	137	79	-141	178	088	SS
20150329-234855	-05.18	152.59	037.6	7.5	081	61	90	171	081	TF
20150425-061159	27.91	085.33	012.0	7.9	101	84	089	016	106	UF
20150505-014427	-05.32	152.10	038.3	7.5	080	58	098	162	072	TF
20150507-071034	-07.36	154.49	012.0	7.0	132	51	-077	122	032	NF
20150512-070528	27.67	086.08	012.0	7.2	307	11	117	023	113	UF
20150522-214527	-10.90	163.54	015.3	7.0	252	58	-005	028	118	SS
20150530-112311	27.94	140.56	680.7	7.9	036	25	-039	010	100	NF
20150727-214131	-02.53	138.44	040.6	7.0	327	42	117	040	130	TF
20150916-225523	-31.13	-072.09	017.4	8.3	007	19	109	087	177	TF
20150916-231852	-31.79	-071.95	035.7	7.1	349	30	087	081	171	TF
20151020-215208	-14.88	167.19	140.9	7.1	189	58	147	064	154	TS
20151026-090947	36.55	070.42	209.4	7.5	279	21	085	012	102	TF
20151124-224547	-10.73	-071.12	610.7	7.5	350	39	-080	164	074	NF
20151124-225101	-10.11	-071.28	627.3	7.6	350	30	-081	164	074	NF
20151204-222507	-47.81	085.14	028.4	7.1	044	47	-054	020	110	NF
20151207-075015	38.35	072.88	012.0	7.2	303	75	180	168	078	SS
20160124-103037	59.75	-153.27	110.7	7.1	313	59	152	005	095	TS
20160130-032520	53.86	158.73	168.1	7.2	324	39	-029	111	021	NS
20160302-125005	-04.75	094.22	037.2	7.8	275	87	180	140	050	SS
20160415-162516	32.84	130.77	012.9	7.0	128	71	-014	085	175	SS
20160416-235857	-00.12	-080.25	022.3	7.8	027	21	124	100	010	TF
20160428-193334	-16.05	167.26	033.5	7.0	328	36	084	061	151	TF
20160528-094708	-56.24	-026.50	068.7	7.2	223	38	-142	071	161	NF
20160729-211834	18.50	145.70	208.9	7.7	192	34	132	079	169	TF
20160812-012645	-22.56	173.07	021.8	7.2	288	75	176	154	064	SS
20160819-073238	-55.16	-031.41	022.1	7.5	116	24	070	037	127	TF
20160829-043018	00.13	-017.72	026.8	7.1	079	77	176	125	035	SS
20160901-163816	-37.19	179.03	027.8	7.1	354	20	-134	017	107	NF
20161113-110353	-42.03	173.85	018.8	7.8	226	33	141	108	018	TF
20161208-173858	-10.48	161.14	046.3	7.8	151	49	123	038	128	TF
20161217-105155	-05.56	153.83	053.3	7.9	141	36	096	048	138	TF
20161225-142237	-43.54	-074.57	034.2	7.5	007	21	100	091	001	TF

Note: The format of time is year/month/day-hour/minute/second. It is considered that positive values indicate north latitude and negative values indicate east longitude respectively in the present study, NF: normal faulting, SS: strike-slip faulting, TF: thrust faulting, NS: intermediate between NF and SS, TS: intermediate between SS and TF and UF: unknown or oblique faulting.

3.3 Depth

In seismology, the depth of focus or focal depth refers to the depth at which an earthquake occurs. Earthquakes occurring at a depth of <70 km and >300 km are classified as shallow-focus and deep-focus earthquakes, respectively, while those with a focal depth between 70 and 300 km are commonly termed mid-focus earthquakes or intermediate earthquakes (Li 1983; Armstrong *et al.* 2008). Based on the data in table 1, about 75.8% of global strong earthquakes are shallow-focus earthquakes (figure 5). Mid- and deep-focus earthquakes

only account for 14.7% and 9.5%, respectively (figure 5).

3.4 Stress regime

In the compiled database (table 1), the horizontal stress axes S_{Hmax} and S_{Hmin} according to Lund and Townend (2007) and stress regime based on the WSM standard were calculated for individual mechanism (figure 2). Generally, the most common stress regime of global strong earthquakes is TF (47.7%) (figure 6).

Figure 1. The distribution of global strong earthquakes with focal mechanisms of superstrong earthquakes ($M_w \geq 8.0$)(1976–2017). Plate boundaries are from Bird (2003).

Figure 2. Focal mechanism data of global strong earthquakes (1976–2017) represented as $S_{H\max}$ axes. The extending directions of lines indicate the $S_{H\max}$ axes. NF: normal faulting, SS: strike-slip faulting, TF: thrust faulting, NS: intermediate between NF and SS, TS: intermediate between SS and TF, and UF: unknown or oblique faulting. Plate boundaries are from Bird (2003).

Figure 3. The temporal characteristics of global strong earthquakes (1976–2017). (a) The number of strong earthquakes with time and (b) the magnitude of strong earthquakes with time.

4. Present-day stress pattern

4.1 Zonation

Since the focal mechanism data are not consistent in terms of stress regime and orientation in the whole world, thus they cannot be inverted altogether (Barth 2007; Delvaux and Barth 2010). Inverting such data together without considering regional deformation characteristics leads to mean deviatoric stresses, which are not representative of the geological reality (Barth 2007; Naimi-Ghassabian *et al.* 2015). Therefore, in the present study, from a total of 553 data, 518 of them were assembled into 12 sub-areas (Boxes) on the

basis of their geographical proximity and tectonic setting to study regional stress regime and changes in stress orientation (figure 7).

Strong earthquakes in western North America continent, resulting from relative movements between Pacific plate and North America plate, are grouped in Box 01. Box 02 is located in the Middle America region, formal stress inversion of strong earthquakes in Box 02 can reveal the relationship among Cocos plate, Caribbean plate, Pacific plate, North America plate and Nazca plate. The dominant NF- and TF-regime strong earthquakes in western South America continent are grouped in Box 03 and Box 04, respectively, which indicate relative movements between Nazca plate and

Figure 4. The spatial characteristics of global strong earthquakes (1976–2017) (a) distribution along latitude and (b) distribution along longitude.

Figure 5. The depths of global strong earthquakes (1976–2017).

Figure 6. The stress regimes of global strong earthquakes (1976–2017). NF: normal faulting, SS: strike-slip faulting, TF: thrust faulting, NS: intermediate between NF and SS, TS: intermediate between SS and TF, and UF: unknown or oblique faulting.

South America plate. Formal stress inversion of strong earthquakes in Box 05 can reveal the relationship among South America plate, Antarctica plate, Sandwich plate and Scotia plate. Boxes 06, 07 and 08 are located in eastern Australia continent, strong earthquakes happened there will

indicate relative movements between Pacific plate and Australia plate. Inversion of strong earthquakes in Box 09 indicate the stress state caused by Pacific plate, Okhotsk plate and Philippine Sea plate. Strong earthquakes happened in southeastern Asia are grouped in Box 10, which result from

Figure 7. Focal mechanism data of global strong earthquakes (1976–2017) assembled into Boxes for stress inversion. Plate boundaries are from Bird (2003). The main global plates are shown and listed with two-letter plate identifiers – AF: Africa plate, AM: Amur plate, AN: Antarctica plate, AR: Arabia plate, AU: Australia plate, CA: Caribbean plate, CL: Caroline plate, CO: Cocos plate, EU: Eurasia plate, IN: India plate, NA: North America plate, NZ: Nazca plate, OK: Okhotsk plate, PA: Pacific plate, PS: Philippine Sea plate, SA: South America plate, SC: Scotia plate, SO: Somalia plate, SU: Sunda plate, SW: Sandwich plate, and YA: Yangtze plate.

relative movements among Amur plate, Philippine Sea plate and Yangtze plate. Box 11 is located in northwestern Australia continent, inversion of strong earthquakes in Box 11 can reveal the relationship between Sunda plate and Australia plate. Box 12 is located in the Eurasia continent, strong earthquakes in Box 12 mainly result from relative movements between India plate and Eurasia plate (figure 7).

4.2 Methodology

Many researchers have attempted to estimate tectonic stresses using a wide variety of direct inversion, iterative and grid search methods adapted for the reconstruction of past and present-day stresses from fault kinematics and/or earthquake focal mechanical data (e.g., Angelier 1979, 1994; Etchecopar *et al.* 1981; Gephart and Forsyth 1984; Delvaux *et al.* 1995, 1997; Delvaux and Barth 2010; Ju *et al.* 2012; Hussein *et al.* 2013; Naimi-Ghassabian *et al.* 2015).

Generally, formal stress inversion of focal mechanism data is based on two assumptions (Bott 1959; Carey-Gailhardis and Vergely 1992; Delvaux *et al.*

1997; Delvaux and Barth 2010): (a) the stress field is uniform and invariant in space and time, and (b) earthquake slip occurs in the direction of maximum shear stress (Wallace-Bott hypothesis).

In the present study, formal stress inversions were performed to study the global present-day stress field with the Rotational Optimization Method (ROM) (Delvaux and Sperner 2003), which can give four parameters of the reduced stress tensor that best model the stress state in a given region: the orientation of three principal stress axes (σ_1 , σ_2 and σ_3 ; $\sigma_1 \geq \sigma_2 \geq \sigma_3$) and the stress ratio R , which shows the magnitude of σ_2 relative to the magnitudes of σ_1 and σ_3 (Delvaux and Sperner 2003; Cortes and Angelier 2005; Delvaux and Barth 2010).

$$R = \frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3}. \quad (1)$$

The ROM is a new iterative inversion procedure presented by Delvaux and Sperner (2003). In this method, both nodal planes of each focal mechanism are compared to a stress tensor, and the plane that has the smaller value of the misfit will be considered as the actual fault plane. The selected fault

Table 2. Stress inversion results for the 12 Boxes (parameters for stress map).

Box definition		Reduced stress tensor parameters							SH		Misfit, regime and quality rank			
No.	Data	$\sigma_1\text{pl}$	$\sigma_1\text{az}$	$\sigma_2\text{pl}$	$\sigma_2\text{az}$	$\sigma_3\text{pl}$	$\sigma_3\text{az}$	R	Max	Min	Misfit(avg.)	R'	Regime	Q
01	025	15	187	17	092	67	317	0.17	008	098	14.7	2.17	TF	B
02	032	41	207	48	012	08	111	0.14	026	116	05.6	1.86	NS	A
03	018	65	255	11	010	22	105	0.03	071	161	07.8	0.03	NF	A
04	025	10	083	03	174	79	278	0.83	080	170	13.2	2.83	TF	A
05	012	84	224	06	050	01	320	0.90	050	140	15.7	0.90	NF	B
06	047	23	099	30	355	51	220	0.17	101	191	09.3	2.17	UF	B
07	011	12	277	03	186	78	084	0.36	097	187	13.0	2.36	TF	B
08	129	06	217	02	127	83	019	0.69	038	128	14.0	2.69	TF	B
09	080	14	143	09	235	73	357	0.80	133	223	15.3	2.80	TF	B
10	058	02	259	22	350	68	164	0.71	078	168	15.0	2.71	TF	B
11	055	13	190	07	282	76	041	0.61	007	097	16.4	2.61	TF	B
12	026	28	197	21	095	53	333	0.14	019	109	09.6	2.14	TF	B

Note: (1) box definition: Box number and the number of data in the Box. (2) Reduced stress tensor parameters: plunge (pl) and azimuth (az) of the principal stress axes (σ_1 , σ_2 and σ_3) and stress ratio R . (3) SH: $S_{H\max}$ and $S_{H\min}$. (4) Misfit, regime and quality rank: average misfit angle, stress regime index, regime based on the WSM standard, and quality rank (Q). NF: normal faulting, SS: strike-slip faulting, TF: thrust faulting, NS: intermediate between NF and SS, TS: intermediate between SS and TF, and UF: unknown or oblique faulting.

planes are then inverted to calculate the principal stress axes and stress ratio (Gephart and Forsyth 1984; Delvaux and Barth 2010; Naimi-Ghassabian *et al.* 2015).

To perform the inversion, the Win-Tensor program (Delvaux and Sperner 2003) was used. First, the range of possible orientations σ_1 and σ_3 was determined based on the “Right Dihedron Method (RDM)”, which is independent from the choice of the nodal planes (Angelier 1979, 1994) and can make a rough estimation of the four parameters of the reduced stress tensor. It allows us not only to obtain the first estimation of the stress ratio, but also to filter out the focal mechanisms that are not compatible with the dominant dataset (Hussein *et al.* 2013). The initial result is used as a starting point for the ROM using the misfit function F5 in the program. The function F5 varies from 0 (perfect fit) to 360 (perfect misfit) and is independent from the dimensions of the stress ellipsoid.

In general, the stress regime can be expressed with the Stress Regime Index (SRI, R'), which is calculated from the stress ratio (R , equation 1). The R' is defined as (Delvaux *et al.* 1995, 1997; Delvaux and Barth 2010):

$$\begin{aligned} (R' = R) & \text{ for normal faulting regimes (NF),} \\ (R' = 2 - R) & \text{ for strike-slip regimes (SS), and} \\ (R' = 2 + R) & \text{ for thrust faulting regimes (TF).} \end{aligned}$$

Based on the definition of R' , a continuous scale is formed: 0 to 1 for NF, 1 to 2 for SS, and 2 to 3 for TF.

The quality evaluation was based on the updated quality ranking system of the WSM (Heidbach *et al.* 2010). Each stress data record is assigned a quality between A and E with A being the highest quality. A-quality means that the orientation of the maximum horizontal compressional stress S_H is accurate to within $\pm 15^\circ$, B-quality to within $\pm 15^\circ$ – 20° , C-quality to within $\pm 20^\circ$ – 25° , D-quality to within $\pm 20^\circ$ – 40° , and E-quality data records have standard deviations greater than 40° or do not provide sufficient information. In general, A-, B- and C-quality stress indicators are considered reliable for the use in analyzing stress patterns and the interpretation of geodynamic processes (Delvaux and Barth 2010; Naimi-Ghassabian *et al.* 2015; Soumaya *et al.* 2015).

In the present study, the best-fit stress tensor on both nodal planes was determined with the ROM first, and was then applied on all focal planes and considered as the actual fault plane. The data were filtered in order to obtain good quality tensors, to keep the most compatible focal plane for each mechanism and eventually to remove those mechanisms for which both focal planes gave a larger angular misfit until all misfit angles fall below 30° – 40° .

Figure 8. Stress inversion and focal plane selection results. Lower-hemisphere equal-area stereo-plots of the selected focal planes and associated slip lines. The related S_{Hmax} and S_{Hmin} orientations are represented by large arrows outside the stereogram. Their length and colour symbolize the horizontal deviatoric stress magnitude. Red outward arrows: σ_3 stress axis, green arrows: σ_2 stress axis and blue inward arrows: σ_1 stress axis. The vertical stress is symbolized in the small circle on the upper left corner by a solid circle, red for compressional regimes, green for strike-slip regimes and blue for extensional regimes. Stress inversion results are represented by the orientation of the three principal stress axes (a dot surrounded by a circle for σ_1 , a triangle for σ_2 , and a square for σ_3). The histogram on the lower left corner of the figures represents the distribution of the misfit angle, weighted arithmetically based on the magnitude.

4.3 Results

The stress regime in western North America continent is TF ($R' = 2.17$, Box 01) with a $\sim$ N-S-trending (N008°E) S_{Hmax} axis. The stress tensor in

western Middle America region is NS ($R' = 1.86$, Box 02) regime with a NNE-SSW-trending (N026°E) S_{Hmax} axis. The northwestern and southwestern South America continent indicate a NF ($R' = 0.03$, Box 03) and TF ($R' = 2.83$, Box 04)

Figure 9. Tectonic maps showing the velocities for major plates in the no-net-rotation reference frame (after [Kreemer et al. 2003](#)). Plate boundaries are from [Bird \(2003\)](#).

regime, respectively. The S_{Hmax} axis of Box 03 is NEE–SWW-trending (N071°E) and NEE–SWW-trending (N080°E) in Box 04. The stress regime in southeastern South America continent is NF with a R' of 0.90 (Box 05), and its S_{Hmax} axis is NE–SW-trending (N040°E) (table 2 and figure 8).

Boxes 06–08 are located in the east of Australia continent (figure 7). The stress tensor indicate a UF ($R' = 2.17$, Box 06; eastern Australia), TF ($R' = 2.36$, Box 07; southeastern Australia), and TF ($R' = 2.69$, Box 08; northeastern Australia) regime, respectively. The S_{Hmax} axis is in the NWW–SEE (S101°E), NWW–SEE (S097°E), and NE–SW (N038°E) direction, respectively (table 2 and figure 8).

All the stress regimes in eastern, southeastern, southern and central Asia indicate TF ($R' = 2.80$, Box 09; $R' = 2.71$, Box 10; $R' = 2.61$, Box 11 and $R' = 2.14$, Box 12). The S_{Hmax} axis is NW–SE-trending (S133°E) for eastern Asia, NEE–SWW-trending (N078°E) for southeastern Asia, ~N–S-trending (N007°E) for southern Asia, and NNE–SSW-trending (N019°E) for central Asia (table 2 and figure 8).

5. Discussions

Plate motions provide first order insights into the interplay between the lithosphere and the mantle, which can be determined using seafloor

magnetic anomalies, fracture zones and transform fault strikes and earthquakes slip vectors ([Coltice et al. 2017](#)). Therefore, the present study results combined with the velocities of major global plates (in the no-net-rotation reference frame; [Kreemer et al. 2003](#)) provided new insights into global tectonics and stress pattern (figure 9). The North American and Eurasian plate move to west and east, respectively, with the North Atlantic Ridge as their boundary. The African plate moves towards northeast with an average velocity of about 3.0 m/yr. The movements of the Australian and Pacific plate point to north and northwest, respectively, with an average velocity of about 6.0 cm/yr and 7.0 cm/yr. Different velocities of global plates and their movement directions cause the difference in stress pattern and tectonics. [Heidbach et al. \(2010\)](#) suggest that tectonic stress field can be classified as a function of the spatial scale of investigation. The 1st order stress field is of continental scale and from the results of forces generated at plate boundaries, most importantly mid-ocean ridge ‘push’, subduction slab ‘pull’, trench ‘suction’ and resistance due to continental collision ([Zoback 1992](#); [Reynolds et al. 2002](#); [Delvaux and Barth 2010](#); [Tingay et al. 2010](#)). Plates bordered by oceanic trenches move ~8 times faster than those bordered by spreading ridges, which supports the process of subduction largely dominates others in its ability to move the plates ([Coltice et al. 2017](#)).

As global strong earthquakes are primarily located in regions of plate boundaries (figure 1), the stress inversion in the present study reveals the present-day 1st order stress field and regime. In addition, the results suggest that different regions (Boxes) have different tectonic stress regimes (figure 8 and table 2), which agree well with the present global tectonic framework. The distribution of global strong earthquakes also suggests that it has a relationship with the earth rotation rate. Larger rotation rate indicates more strong earthquakes (Tang 1997). Besides, Ma *et al.* (2007) indicated that the number of strong earthquakes (especially the shallow-focus ones) is highly related to the Earth variable rotation rate.

Modeling of present-day plate motions indicated that the ratio between toroidal and poloidal velocity was about 0.32 (Lithgow-Bertelloni and Richards 1998), which suggests that more TF- and NF-type earthquakes happened in the lithosphere (Yu *et al.* 2003). In fact, most of the seismic energy was released by TF- and NF-type earthquakes resulting from plate movements (Yu *et al.* 2003), especially the TF-type. Generally, the TF-type strong earthquakes are mainly distributed on the circum-pacific seismic belt and the Himalaya collision boundary as shown in Boxes of 01, 04, 06–12 (figures 2, 8 and table 2). The NF-type strong earthquakes occurred in zones of the ocean ridge and continental rift valleys (figures 2 and 8). The toroidal to poloidal ratio of mantle convection determines the release of seismic energy, and the heterogeneous mantle motion act as an important factor for the distribution of different types of strong earthquakes in the world (Yu *et al.* 2003; Martin *et al.* 2008; Hong *et al.* 2009).

6. Conclusions

Earthquakes occurred on the Earth can serve as important sources for describing the present-day tectonic stress field and regime. In the present study, altogether 553 focal mechanism data from the year 1976 to 2017 with $M_w \geq 7.0$ were compiled in the Global/Harvard CMT catalogue. The characteristics of global strong earthquakes and present-day stress pattern were analyzed based on the database. The world has stepped into a natural disaster-prone period with frequent strong earthquakes, revealing the temporal and spatial changes in stress field and geodynamic regime. Global strong earthquakes are primarily distributed

around plate boundaries, and 75.8% of them are shallow-focus earthquakes. The most common stress regime of global strong earthquakes is thrust faulting (TF). We grouped 518 of global strong earthquakes into 12 regions (Boxes) based on their geographical proximity and tectonic setting. For each box, the present-day stress field and regime have been obtained by formal stress inversion. Generally, the maximum horizontal principal stress direction was $\sim$ N–S-trending in western North America and southwestern Indonesia, $\sim$ NNE–SSW-trending in western Middle America and central Asia, $\sim$ NE–SW in southeastern South America and northeastern Australia, $\sim$ NEE–SWW-trending in western South America and southeastern Asia, $\sim$ E–W-trending in southeastern Australia, and $\sim$ NW–SE-trending in eastern Asia. The division and distribution of global plates, the Earth's rotation rate and the toroidal to poloidal ratio of mantle convection influence the global present-day stress pattern.

Acknowledgements

We would like to express our gratitude to the anonymous reviewers for giving constructive suggestions and comments which improved this manuscript in many aspects. Many thanks to the Global CMT Project for the earthquake data. The work was financially supported by the Key Laboratory of Coal-based CO₂ Capture and Geological Storage, Jiangsu Province (China University of Mining and Technology 2016B04), China Postdoctoral Science Foundation (2015M581891), Postdoctoral Science Foundation of Jiangsu Province (1501059A) and the Priority Academic Program Development of Jiangsu Higher Education Institutions.

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Corresponding editor: N PURNACHANDRA RAO