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Fault Plane Solutions for the Recent Earthquakes in the Central Region of South Korea

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Abstract: We analyzed fault plane solutions of the recent twenty-two earthquakes which occurred from 2004 to 2006 in the central part of the Korean Peninsula by using P- and S-wave polarities along with SH/P amplitude ratios. The fault plane solution shows that strike-slip fault is dominant here, especially for the events with local magnitude equal to or greater than 3.0. However, some events with local magnitude less than 3.0 show normal fault or strike-slip fault with normal components. In the case of strike-slip fault, its orientation is almost in the direction of NNE-SSW to NE-SW almost parallel to the general trend of faults, while the compressional axis of the stress field trends ENE to E-W. The result is almost consistent with the stress field in and around the Korean peninsula, as reported previously. We cannot give any appropriate explanations to the normal faulting events along the western offshore and inland areas whether it is related to the local stress changes or tectonically unidentified extensional structures. Thus, an extension of investigations is desirable to clarify the cause of such phenomena.

Keywords: fault plane solution, strike-slip fault, polarity, amplitude ratio

Introduction

The Korean peninsula is a part of the Amurian plate and is an important link between the continental blocks of North and South China and the island arcs of Japan. This sector of the earth's crust is believed to have been stable and subject to only epeirogenic movements for over a billion years prior to the Mesozoic Era (Reedman and Um, 1975). Major orogenic events in the Korean peninsula occurred in Late Paleozoic and Mesozoic time (Songrim Disturbance in Triassic, Daebo Orogeny in Jurassic, Bulguksa Disturbance in Cretaceous). These activities severely disrupted the peninsula, creating a number of faults striking NE-SW or NNE-SSW (Chough et al., 2000). In Tertiary time, the southeastern margin of the Korean Peninsula experienced back-arc opening, resulting in deposition of Tertiary rocks in and around Pohang in association with back-arc opening in the East Sea (Sea of Japan) (Chough et al, 1990; Yoon and Chough, 1995).

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No prominent tectonic movements occurred during the Quaternary except for some isolated volcanic events. However, some faults such as the Yangsan and Ulsan faults were active in the Late Quaternary, although their slip rates are estimated to be less than 0.1 m/ka (Okada et al., 1994; Okada et al., 2001).

Intraplate stress field and crustal deformation have been considered to be controlled by the condition of plate boundaries and the heterogeneity of lithosphere. The seismogenic stress field in and around Korea may be formed under the common tectonic conditions of the regional tectonic forces originating from the collision between the Indo-Australian and the Eurasian plates in the west and the combined effects of subduction of the Pacific and Philippine plates around the Izu and Tokai area in the east (Kyung et al., 1996).

Seismicity of the Korean Peninsula shows a very irregular pattern of strain release, typical intraplate seismicity (Lee, 1987; Lee, 1998). Over the last two thousand years, the peninsula had been relatively quiet only with moderate activity, except for a period of unusually high seismicity from the fifteenth to eighteenth centuries (Lee, 1987). Since the installation of Omori's tremometer at Incheon in 1905, the seismic network in the Korean Peninsula gradually expanded to almost forty stations equiped with short and broadband seismograph at present. Recently, some institutes (e.g., Korea Meteorological Adminstration (KMA), Korea Institute of Geology and Materials (KIGAM), Korea Institute of Nuclear Safety (KINS), and Korea Electric Power Research Institute (KEPRI)), have been operating and expanding their own networks. With their help, the accuracy of earthquake parameters was greatly improved, especially for inland earthquakes.

Moderate-size earthquakes occur very scarcely in the Korean Peninsula. In order to calculate the fault plane solutions, we must include all possible waveform data of small earthquakes (3.0<M≤4.0) and micro-earthquakes (M≤3.0). In this case, there are some possibilities that the number of seismic stations detecting the microearthquakes decreases, and their space coverage becomes incomplete. Several years ago, we attempted to calculate the composite fault plane solutions due to the lack of the seismic stations and data in the central region of south Korea (Kyung et al., 2001). However, this method includes some weak points that closely located earthquakes are assumed to be occurred in the same fault. As time goes on, we could obtain more reliable data of many seismic stations.

The aim of this study is to re-calculate the fault plane solutions with greatly enhanced data set of several stations for the recent earthquakes and compare its result with other earlier results.

Earthquake Data

Twenty-two earthquakes, which occurred from January 2004 to October 2006, were used for the fault plane solution in the central region of the Korean peninsula. During this period only the earthquakes less than M 3.6 occurred in this region. We analyzed the short-period and broadband vertical-component wave forms detected from the networks of KMA, KIGAM, and KINS. In case the station coverage is incomplete, we cannot obtain a reliable fault-plane solution using polarity information only. Thus we add SH-wave polarities and amplitude ratios of SH to P waves.

Figure 1 shows the location of seismic observation of KMA, KIGAMand KINS networks. KMA and

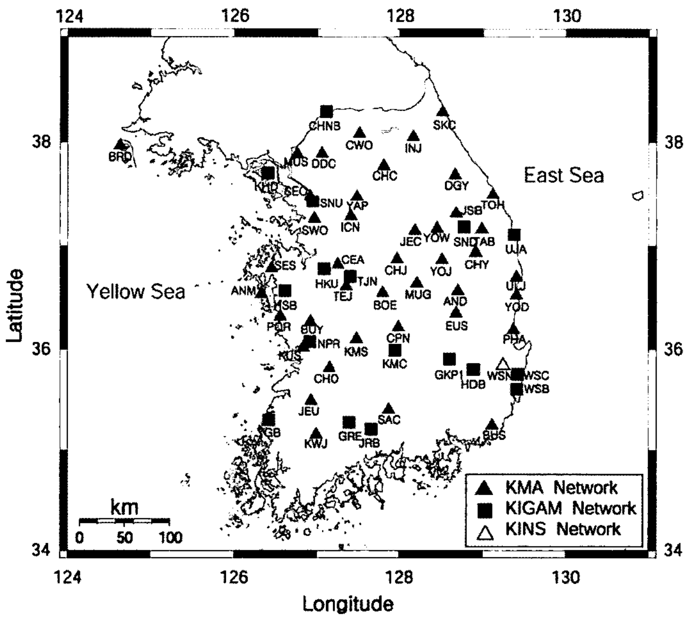

Fig. 1. The used seismic stations of KMA, KIGAM, and KINS.

Table 1. Source parameters of 22 earthquakes used in this study

No.	KIGAM					KMA				
	Origin time		Epicenter		Magnitude	Origin time		Epicenter		Magnitude
	yy/mm/dd	hh:mm:ss	Latitude (°N)	Longitude (°E)		yy/mm/dd	hh:mm:ss	Latitude (°N)	Longitude (°E)	
1	'04/01/05	06:11:51.60	36.1727	127.0093	3.2	'04/01/05	06:11:51.3	36.20	127.00	2.9
2	'04/02/26	05:51:16.30	37.1567	128.8822	2.4	'04/02/26	05:51:15.3	37.20	128.90	2.1
3	'04/05/30	21:45:55.00	36.9327	129.3177	2.6	'04/05/30	21:45:54.6	37.00	129.30	2.2
4	'04/06/11	16:25:40.97	37.2435	128.7278	2.6	'04/06/11	16:25:40.2	37.30	128.70	2.1
5	'04/07/13	20:37:55.65	36.4363	127.2910	2.6	'04/07/13	21:08:51.6	38.50	126.00	2.1
6	'04/08/13	22:42:02.09	37.5178	126.3464	3.3	'04/08/13	22:42:04.1	37.60	126.50	2.7
7	'04/09/15	07:47:33.72	37.4293	126.7870	2.9	'04/09/15	07:47:33.8	37.50	126.90	2.5
8	'04/11/05	01:25:46.31	37.0752	126.0445	2.6	'04/11/05	01:25:46.2	37.10	126.10	2.0
9	'05/06/10	12:49:55.28	36.7744	128.4802	2.3	'05/06/10	12:49:54	36.73	128.48	2.4
10	'05/06/10	21:14:36.70	36.7647	128.4785	2.5	'05/06/10	21:14:36	36.78	128.48	2.5
11	'05/08/25	19:33:47.32	36.7146	126.2188	2.3	'05/08/25	19:33:47	36.75	126.30	2.2
12	'05/09/07	17:11:11.56	37.0897	127.8549	.0	'05/09/07	17:11:10	37.09	127.86	2.1
13	'06/10/04	05:29;23.75	36.6827	127.6096	2.5	'06/10/04	05:29:22	36.67	127.67	2.2
14	'05/11/15	09:10:50.58	37.1881	128.7725	3.3	'05/11/15	09:10:49	37.20	128.79	3.0
15	'05/12/07	18:02:12.58	36.6144	127.7580	2.3	'05/12/07	18:02:11	36.63	127.77	2.2
16	'06/01/19	12:25:35.49	37.1988	128.7817	3.5	'06/01/19	12:35:34	37.21	128.80	3.2
17	'06/08/26	07:44:17.48	37.1845	128.7673	2.6	'06/08/26	07:44:16	37.21	128.81	2.2
18	'06/01/21	11:29:50.81	36.3337	127.2646	2.3	'06/01/21	11:29:49	36.33	127.26	2.1
19	'06/03/19	13:59:47.33	36.3131	127.3517	3.1	'06/03/19	13:59:47	36.34	127.36	2.9
20	'06/03/19	14:03:47.28	36.3108	127.3574	2.2	'06/03/19	14:03:46	36.33	127.34	2.0
21	'06/07/18	14:49:54.42	36.1052	126.6580	1.9	'06/07/18	14:49:53	36.13	126.65	2.0
22	'06/07/24	02:44:17.25	37.1620	126.3345	2.2	'06/07/24	02:44:17	37.17	126.32	2.0

KIGAM networks cover most of the inland area. However, KINS network is limited to very local nuclear power plants. We used all possible waveform data of these three networks for the earthquakes listed in Table 1. There are a little difference in the value of source parameters between KIGAM and KMA. Our study for fault plane solutions is based on the parameters determined by KIGAM.

The epicentral location of these events are shown in Fig. 2. The epicenters are dominantly located along the offshore areas on the west and the NE-SW trending Okcheon fold belt.

Fault Plane Solution

Fault plane solution can be obtained from first P polarities, SH polarities, SH/P amplitude ratio, or wave form modeling. SV wave can be easily converted to P wave and complicated near the surface area. We didn't use the polarity and amplitude of SV wave. The study of fault plane solution for the Korean peninsula has been done by several researchers (eg., Jun, 1990, 1991; Kim, 1991; Baag et al.. 1998; Lee and Chung, 1999; Kyung et al. 2001; Kang and Baag, 2004; Park, 2005; Kang and Shin, 2006).

The dataset is inverted for the focal mechanism using the grid search algorithm (FOCMEC) of Snoke et al. (1984) and Snoke (2000). The focal depth was preliminary presumed to be 10 km. Most of the earthquakes are microearthquakes to small earthquakes whose magnitude range from 1.9 to 3.3. In order to reduce the error of fault plane solution, we selected only the inland and offshore earthquakes. The solutions are constrained within error range of 15 degrees by setting the 5 degree interval in grid search algorithm of FOCMEC.

The results are presented by equal area and lower hemisphere projections, as shown in Fig. 3. Table 2

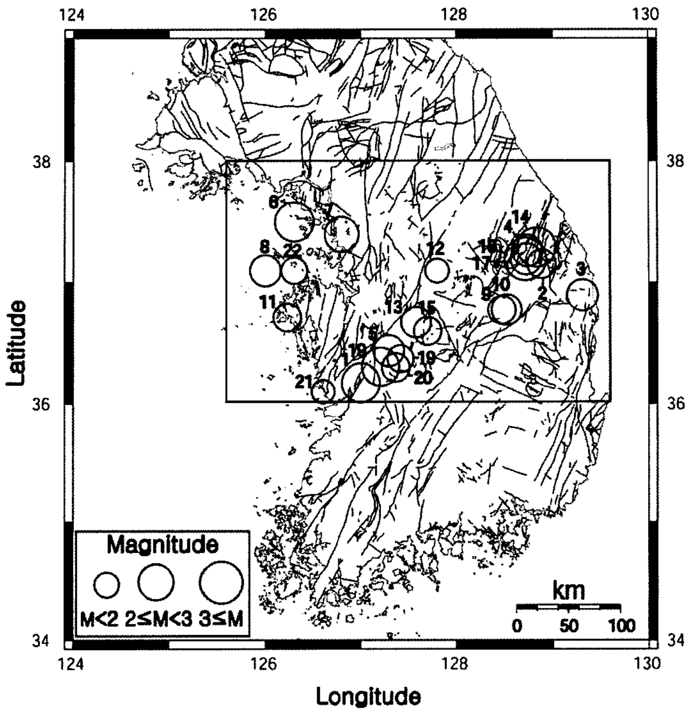

Fig. 2. Epicentral distribution of earthquakes occurring from January 2004 to October 2006 on the fault map (KIGAM, 1995) in the central region.

shows the parameters of focal mechanism solution of 22 earthquakes. The number of data for each event ranges from nine to twenty six. In order to improve the solutions of the focal mechanism caused by lack of P-wave polarity, SH/P amplitude ratios are included. Among 22 earthquakes, fault plane solutions of 16 earthquakes were obtained from only P-wave polarity. Fault plane solution of 6 earthquakes (No. 4, 5, 11, 14, 16, 19 in Table 2) were obtained from P- and S-wave polarities with amplitude ratios of SH to P waves.

Results

Fig. 4 shows the epicentral distribution and focal mechanism solutions of 22 earthquakes on the fault map (KIGAM, 1995). In the western part of Kyonggi massif the earthquakes occurred on the offshore areas around Taean-Dangjin (No. 8, 11, and 22), Kanghwa (No. 6), and Seoul (No. 7). The focal mechanism solution reveal one strike-slip fault, three normal fault, and one strike-slip fault with normal component. The P- and T-axes of strike-slip fault are ENE-WSW and NNW-SSE. The directions of nodal planes are NNE-SSW or NE-SW, almost coinciding with the general trend of lineament in this area. However, we cannot clearly explain why the normal faults are dominant in this area.

There occurred many earthquakes in the NE-SW trending Okcheon fold belt. In the northeastern part of Okcheon fold belt, especially in the vicinity of Taebaek-Jeongseon areas, the fault plane solutions show almost strike-slip fault (No. 2, 14, 16) with P-axis of ENE-WSW or E-W directions. The directions of nodal planes are NNE-SSW, almost coinciding with the general trend of faults in this area. However, microearthquake (less than 2.6) shows normal fault (No. 4, 17) with T-axis of N-S direction.

The earthquakes in the vicinity of Daejeon (No. 18, 19, 20), Seocheon (No. 21) and Nonsan (No. 1) areas show almost strike-slip faults with P-axis of NE-SW to ENE-WSW direction in the southwestern part of

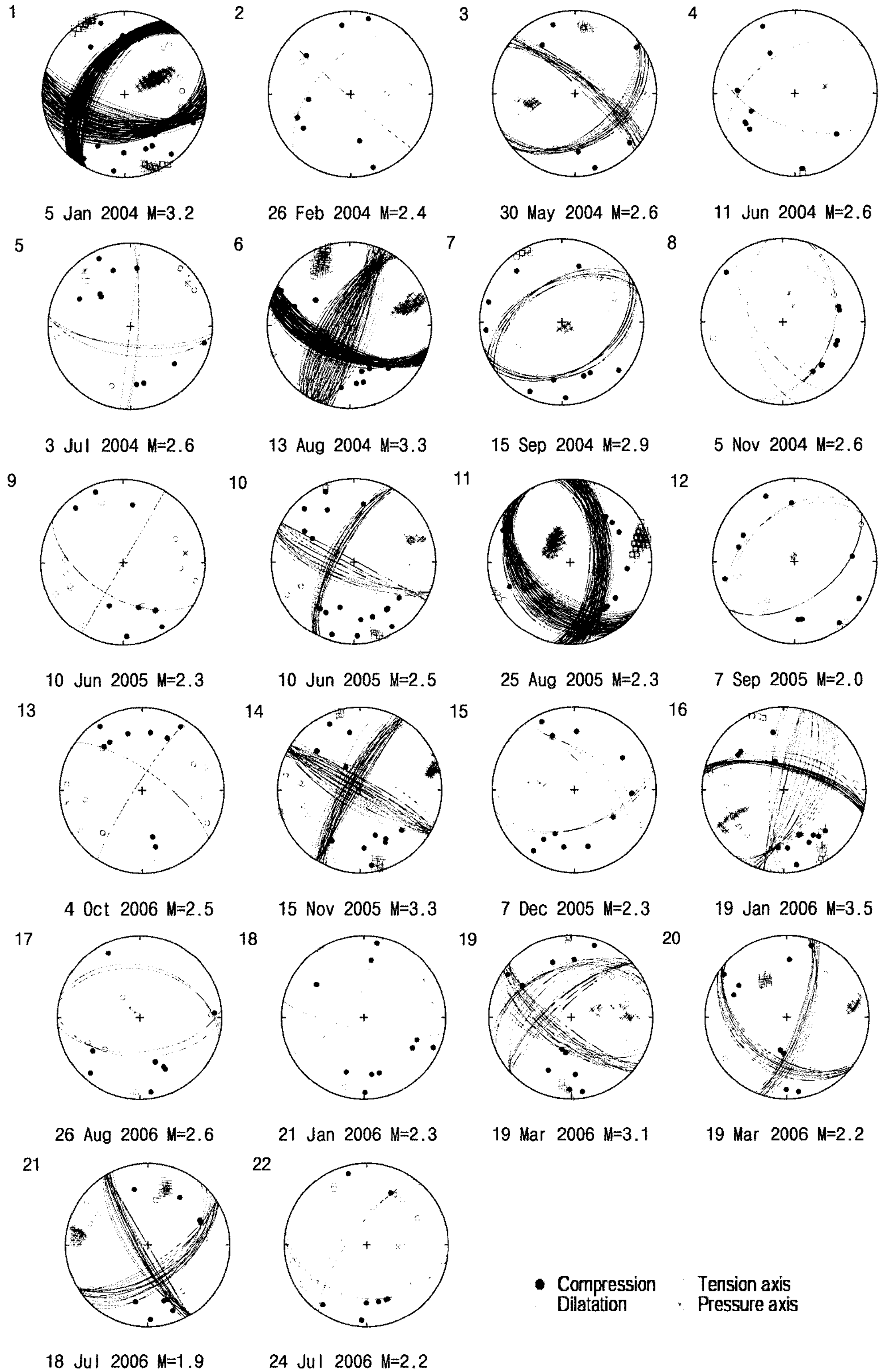

Fig. 3. Fault plane solutions of earthquakes obtained from P, S polarities and SH/P amplitude ratio. The number is the same as that in Fig. 1 and Table 2.

Table 2. Parameters for focal mechanism solution of 22 earthquakes

No	Plane 1			Plane 2			P-axis		T-axis		Data
	Strike	dip	rake	strike	dip	rake	azimuth	dip	azimuth	dip	
1	128	51	34	14	64	136	74	8	335	49	20
2	131	87	-35	223	55	-177	82	26	83	22	13
3	308	74	-53	58	40	-154	257	48	11	20	13
4	110	56	-53	236	48	-132	77	60	175	4	9
5	95	72	9	2	82	162	50	7	317	19	15
6	113	61	-9	207	83	-151	73	28	338	10	18
7	245	55	-90	65	35	-90	155	80	335	10	18
8	20	38	-65	170	56	108	34	72	273	10	16
9	121	55	0	31	90	145	81	24	340	24	20
10	114	73	-18	210	73	-162	72	25	162	0	26
11	6	70	-79	157	22	-117	293	63	88	25	12
12	54	50	-83	224	40	-98	5	83	140	5	17
13	306	71	7	213	83	161	261	8	168	18	20
14	303	85	14	211	76	75	76	6	168	14	19
15	316	58	-48	75	51	-137	281	55	17	4	14
16	281	66	-18	19	73	-155	242	30	149	5	26
17	280	40	-82	91	50	-97	320	83	185	5	15
18	101	78	-9	193	81	-168	58	15	327	3	15
19	126	58	-26	230	68	-146	91	39	356	6	18
20	128	51	34	14	64	136	74	8	335	49	13
21	150	79	33	53	57	167	278	14	16	31	16
22	100	36	-31	216	73	-122	90	52	330	21	21

Okcheon fold belt. In central region one earthquake (No. 13) shows strike-slip fault and another (No. 15) normal fault with strike-slip component in Koesan, Chungbuk province, and the other (No. 12) normal fault in Wonju, Kangwon province with different directions of pressure or tension axis.

Finally, in Yeongnam massif two earthquakes occurred in Youngju (No. 9, 10) show almost the same strike-slip faults with pressure axis of E-W direction. One earthquake in Uljin (No. 3) shows strike-slip fault with normal component.

The results show that the fault plane solution of strike-slip fault predominate in the central region, especially, for events with local magnitude equal to or greater than 3.0 (No. 1, 6, 14, 16, 19). However, some events with local magnitude less than 3.0 show normal fault or strike-slip fault with normal component.

Our results using the earthquakes occurring from 2004 to 2006 were compared with those (Park, 2005) from 1999 to 2004. The general pattern of fault plane solution is almost similar but locally there is a little difference. Especially, in and around the northeastern part of Okcheon fold belt this study shows dominantly strike slip fault with P-axis trending to ENE-WSW or E-W directions, compared to thrust fault with P-axis trending to E-W by former study (Park, 2005). Here the focal mechanism of the Yeongweol earthquake(M_L 4.5) in 1996 shows strike-slip fault with thrust component and P-axis trending ENE-WSW (Baag et al., 1998). It seems that focal mechanism of microearthquakes does not always follow that of medium size earthquake. It may depend on the local conditions or small scale geological structures within the upper crust.

Our results were compared with the former result by composite fault plane solution in and around the Chungnam province (Kyung et al., 2001). They show almost the same strike slip fault movement with P-axis trending to ENE-WSW or E-W directions.

The P- or T-axes of focal mechanisms, although they are not the exact principal stress directions, are

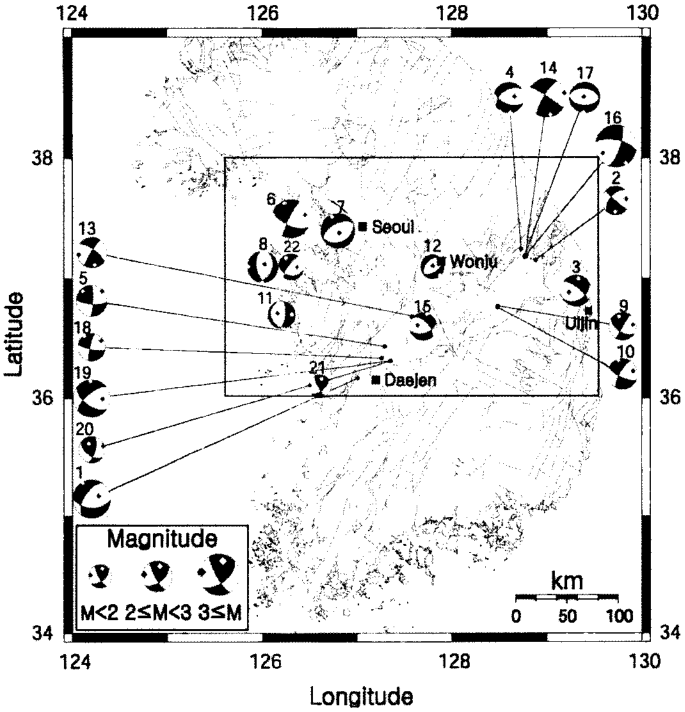

Fig. 4. Epicentral distribution and focal mechanism solutions of 22 earthquakes on the fault map (KIGAM, 1995). Beach balls represent the lower hemisphere projection of nodal planes of each event. Shaded and open quadrants denote compressional and tensional motions for P wave, respectively.

useful first-order approximations to the tectonic stress regime (Zoback, 1992). The orientations of the compressional stresses from P-axis in the central region range from NE-SW to E-W. However, the predominant trend is ENE-WSW, which agree well with the results from previous studies (Baag et al., 1998; Chung and Kim, 2000; Kang and Baag, 2004).

Discussion and Conclusion

We obtained fault plane solutions of the recent 22 earthquakes occurring in the central region of south Korea (36°N-38°N). They were obtained from P- and S-wave polarities along with SH/P amplitude ratios of the data.

1. The fault plane solution of strike-slip fault predominate in the central region, especially for events with local magnitude equal to or greater than 3.0. However, some events with local magnitude less than 3.0 show normal fault or strike-slip fault with normal components. The T-axis trends NW-SE to E-W on the west coastal area and N-S in the inland area.

2. In the case of strike-slip fault, its orientation is almost in the direction of NNE-SSW to NE-SW almost parallel to the general trend of faults, and the compressional axis of the stress field trends ENE to E-W. The result is almost consistent with the stress field in and around the Korean Peninsula, as reported previously.

3. It seems that focal mechanism of micro-earthquakes does not always follow that of medium-size earthquake. It may depend on the local conditions or small scale geological structures within the upper crust.

The trend of the regional stress field from north-eastern China and the Korean Peninsula to the inner zone of southwest Japan exhibits mainly ENE-WSW or E-W compression and NNW-SSE extension, and the focal mechanisms show almost strike-slip fault (e.g., Shiono, 1977; Tsukahara and Kobayashi, 1991;

Xu, 1994). Our results in the central region of south Korea also support the general trend of regional stress field. However, we cannot give any clear explanations for the normal faulting events along the western offshore and inland areas whether it is related to the local stress changes or tectonically unidentified extensional structures. Normal fault movements have almost no relations with the main compressional stress field in the Korean Peninsula. Therefore, an extension of investigations is desirable to clarify the cause of such phenomena.

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