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# NOTES AND CORRESPONDENCE

# Source Parameters of Regional Earthquakes in Taiwan: January–December, 1998

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## ABSTRACT

**We report source parameters of 49 earthquakes that occurred between January and December, 1998, in the Taiwan region. The improved CMT inversion algorithm by Kao et al. (1998) is used to overcome the generally higher background noise as well as the heterogeneous velocity structure resulted from the complex tectonic interactions near Taiwan. To make the results more accessible and useful to the academic community, both the table that summarizes the reported source parameters and the complete set of inversion results are available electronically from the BATS world-wide web site at**

**http://bats.earth.sinica.edu.tw/CMT_Solutions/cmtF1998.html.**

**(Key words: Broadband Array in Taiwan for Seismology, earthquake source parameters, waveform inversion, Taiwan)**

Successful development of the centroid-moment-tensor (CMT) inversion technique in the early 1980's has enabled the systematic determination of source parameters for global large and moderately-sized earthquakes (e.g., Dziewonski et al. 1981; Kawakatsu et al. 1995; Sipkin 1982). Later, the CMT inversion technique was successfully applied to regional earthquakes because of the increasing knowledge in detailed velocity structures on a regional scale and the establishment of regional broadband networks (e.g., Dreger and Helmberger 1993; Fan and Wallace 1995; Lay et al. 1994; Thio and Kanamori 1995; Zhao and Helmberger 1994). Consequently, routine report of CMT solutions for smaller, regional earthquakes becomes standard practice for many regional broadband seismographic networks (e.g., Zhu and Helmberger 1996; Pasysnos et al. 1996).

Establishment of the "Broadband Array in Taiwan for Seismology (BATS)" has enabled the systematic determination of reliable source parameters for regional earthquakes in Taiwan through CMT technique (Kao et al. 1998). The network began its test operation in late 1994 (Fig. 1). A brief description of BATS configuration and operation can be found in Kao et al.

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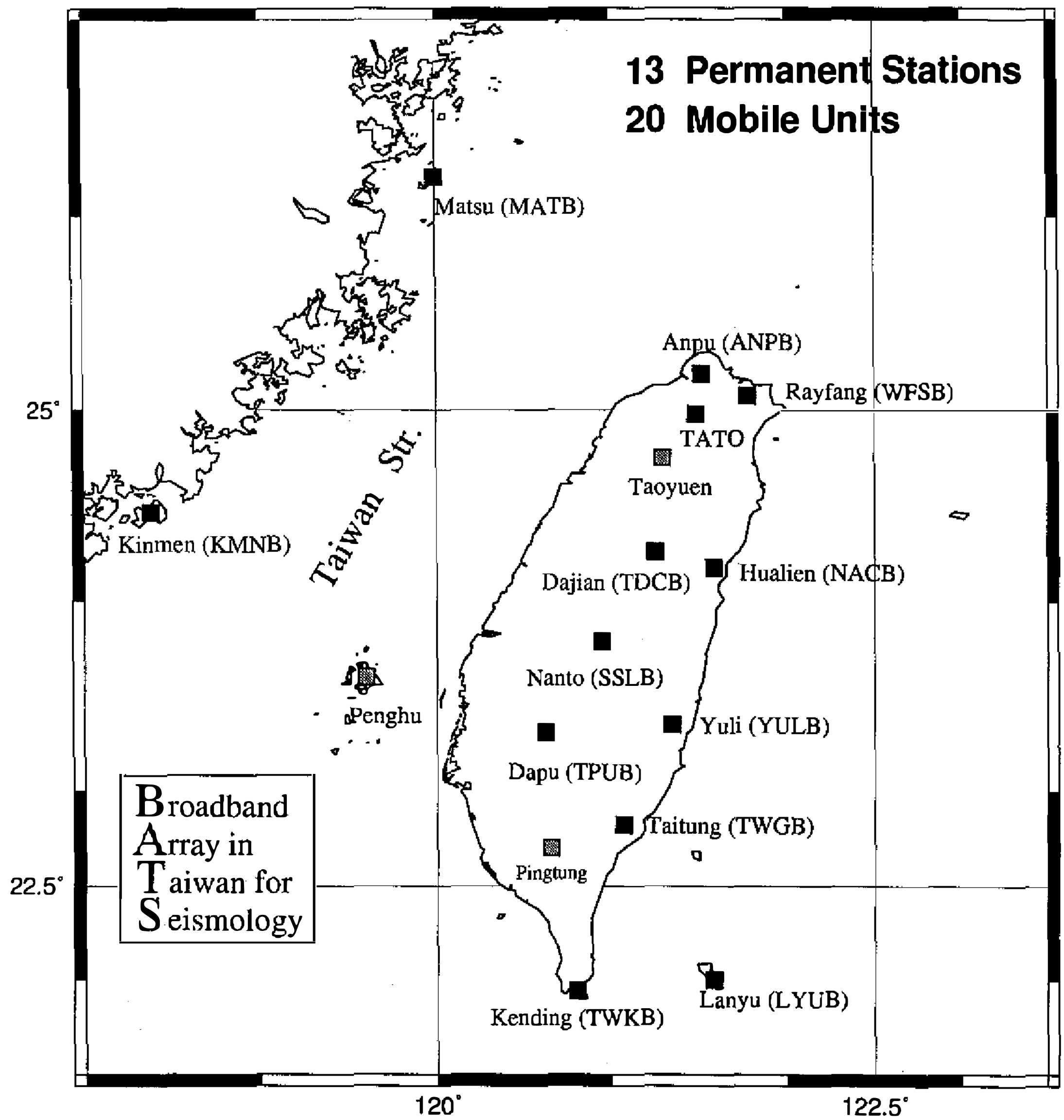


*Fig. 1.* Map of the "Broadband Array in Taiwan for Seismology (BATS)". Solid and gray squares show stations currently in operation and under construction, respectively. In addition to the permanent stations, BATS includes 17 portable stations that can be deployed for specific research tasks.

(1988, 2001) and Kao and Jian (1999, 2001). The Data Management Center of the Institute of Earth Sciences (IES-DMC), Academia Sinica is responsible for BATS data archiving and distribution. Meanwhile, one copy of BATS data is contributed to the Data Management Center of the Incorporated Research Institutions for Seismology (DMC, IRIS) for the same purpose. Interested readers can obtain updated information at BATS world-wide web site (http://bats.earth.sinica.edu.tw).

Our CMT algorithm begins with a background-noise evaluation that determines the frequency band used in the inversion. The cut-off frequency of the lower corner is usually at ~0. 02 Hz, which is determined by comparing the power spectra of waveform windows 300 s before and after the *P* first arrival (Kao et al. 1998). We also utilize a two-step procedure to allow different velocity models for different station-source pairs. This is to mimic the effect of heterogeneous velocity structures in the Taiwan region. For more technical details, readers are referred to our previous reports (Kao et al. 1998; Kao and Jian 1999).

To characterize the quality of inversion, each inversion result is classified by a combination of a letter (A–F) and a digit (1–4) depending on two parameters: the waveform misfit (E) and the amount of CLVD component ($\varepsilon$), respectively. The derivations of E and e are presented in our previous reports (Kao et al. 1998; Kao and Jian 1999) and listed in Table 1.

Following the criteria defined in Kao and Jian (1999), we report source parameters only if they meet the following criteria: (1) 3-component waveforms from at least three stations are used in the inversion, and (2) the quality of inversion must be higher than C4. A total of 49 earthquakes that satisfy these conditions are listed in Table 2. The corresponding best double-couple solutions and focal depths are plotted in Fig. 2.

Due to the practical concern, the inversion results are presented as an electronic appendix to this report. Interested readers can download the complete set from BATS world-wide web site at http://bats.earth.sinica.edu.tw/CMT_Solutions/cmtF1998.html. To make the results more accessible and useful to the academic community, Table 2 as well as the tables in our previous

Table 1. Quality classification of inversion results.

| Class | Criteria |
|---|---|
| | Average Waveform Misfit (E) |
| A | $0 \leq E < 0.3$ |
| B | $0.3 < E \leq 0.5$ |
| C | $0.5 < E \leq 0.7$ |
| D | $0.7 < E \leq 0.9$ |
| E | $0.9 < E \leq 1.1$ |
| F | $E > 1.1$ |
| | CLVD component ($\varepsilon$) |
| 1 | $\varepsilon \leq 0.1$ |
| 2 | $0.1 < \varepsilon \leq 0.25$ |
| 3 | $0.25 < \varepsilon \leq 0.4$ |
| 4 | $\varepsilon > 0.4$ |

Table 2. Source parameters of studied earthquakes.

| No | Origin Time[1] | Lat.[1] | Long.[1] | Dep. | $M_{xx}$[2] | $M_{yy}$[2] | $M_{zz}$[2] | $M_{xy}$[2] | $M_{xz}$[2] | $M_{yz}$[2] | $M_w$[2] | Strike[3] | Dip[3] | Rake[3] | E[4] | ε[4] | Class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 98/01/18/19:56:51.7 | 22.73 | 121.09 | 15 | -11.88 | -17.73 | 45.08 | 26.36 | 28.87 | -67.13 | 5.22 | 239.98 | 17.60 | 123.05 | 0.547 | 5.93 | C1 |
| 2 | 98/01/20/23:29:38.9 | 22.69 | 121.08 | 18 | -0.44 | -3.80 | 6.19 | 2.32 | 1.50 | -7.59 | 4.59 | 218.80 | 19.22 | 113.21 | 0.552 | 3.81 | C1 |
| 3 | 98/02/07/07:20:52.1 | 23.63 | 121.50 | 24 | 0.17 | -0.95 | 0.59 | 0.49 | -0.65 | 0.47 | 4.00 | 348.92 | 34.72 | 36.87 | 0.487 | 27.30 | B3 |
| 4 | 98/02/24/06:45:31.2 | 24.41 | 121.69 | 27 | -0.29 | -0.28 | 0.18 | 1.40 | -0.02 | -1.80 | 4.18 | 266.87 | 37.73 | 171.88 | 0.580 | 0.00 | C1 |
| 5 | 98/02/24/06:59:45.3 | 24.40 | 121.69 | 30 | -0.30 | 0.38 | -0.15 | 0.85 | 0.02 | -0.52 | 3.95 | 280.69 | 59.96 | -177.70 | 0.508 | 25.73 | C3 |
| 6 | 98/03/11/06:00:08.1 | 22.36 | 122.30 | 30 | 5.60 | -4.15 | -1.74 | -0.47 | 2.39 | -1.08 | 4.44 | 133.09 | 61.17 | -4.60 | 0.551 | 61.09 | C4 |
| 7 | 98/03/11/17:21:54.9 | 22.44 | 122.26 | 30 | 33.38 | -39.25 | -1.34 | 2.99 | 1.86 | 6.36 | 4.98 | 47.69 | 81.03 | -175.99 | 0.544 | 10.24 | C2 |
| 8 | 98/04/19/10:06:27.0 | 24.39 | 121.71 | 30 | -0.20 | 0.20 | -0.10 | 0.80 | 0.09 | -1.36 | 4.07 | 277.16 | 31.15 | -176.99 | 0.522 | 7.23 | C1 |
| 9 | 98/04/28/07:09:00.9 | 23.97 | 121.69 | 24 | -0.10 | 0.11 | 0.07 | 0.07 | 0.44 | -0.37 | 3.78 | 298.70 | 9.86 | 159.97 | 0.544 | 20.50 | C2 |
| 10 | 98/05/02/00:05:53.0 | 21.72 | 121.10 | 24 | 2.07 | -11.42 | 6.20 | -0.42 | 3.49 | 0.30 | 4.60 | 24.66 | 50.81 | 129.61 | 0.629 | 22.24 | C2 |
| 11 | 98/05/02/05:37:42.4 | 24.56 | 122.56 | 84 | -7.85 | 1.62 | 6.46 | 4.19 | 17.12 | 6.90 | 4.81 | 221.42 | 20.03 | 26.23 | 0.467 | 16.84 | B2 |
| 12 | 98/05/09/20:53:39.0 | 24.82 | 121.91 | 72 | 0.63 | -6.18 | 5.01 | -3.09 | 11.05 | 6.02 | 4.70 | 5.75 | 21.12 | 149.56 | 0.434 | 14.93 | B2 |
| 13 | 98/05/15/08:50:28.5 | 23.96 | 121.72 | 39 | 1.60 | -0.95 | -0.74 | -1.16 | -0.87 | 1.34 | 4.19 | 290.74 | 43.45 | -15.53 | 0.475 | 32.96 | B3 |
| 14 | 98/05/17/16:36:01.2 | 24.08 | 121.53 | 27 | -0.59 | -0.34 | 0.80 | 0.76 | 0.04 | 0.49 | 3.98 | 75.95 | 43.91 | 131.69 | 0.529 | 22.97 | C2 |
| 15 | 98/05/30/06:22:38.3 | 24.27 | 122.13 | 57 | 2.01 | -8.81 | 6.33 | 3.00 | 3.99 | 4.75 | 4.62 | 43.77 | 41.63 | 141.27 | 0.429 | 4.02 | B1 |
| 16 | 98/07/06/11:33:54.2 | 24.35 | 122.87 | 39 | -1.69 | 1.37 | 0.26 | 0.13 | 1.43 | -1.23 | 4.20 | 312.14 | 38.38 | 173.64 | 0.489 | 18.81 | B2 |
| 17 | 98/07/11/18:23:14.9 | 24.37 | 122.04 | 21 | -0.04 | 0.02 | 0.16 | -0.62 | 0.13 | -0.47 | 3.87 | 92.98 | 54.04 | 11.56 | 0.483 | 21.31 | B2 |
| 18 | 98/07/17/04:51:15.0 | 23.50 | 120.66 | 12 | 79.84 | -318.13 | 169.46 | 82.57 | -193.35 | 197.70 | 5.66 | 339.58 | 32.00 | 35.57 | 0.559 | 21.23 | C2 |
| 19 | 98/07/17/18:44:39.9 | 24.06 | 121.69 | 15 | -1.56 | -5.04 | 5.03 | 2.30 | 3.64 | -4.09 | 4.53 | 196.26 | 24.02 | 70.96 | 0.495 | 2.09 | B1 |
| 20 | 98/07/18/17:02:39.7 | 23.51 | 120.69 | 12 | 1.33 | -0.75 | -0.22 | 1.09 | -2.43 | 1.92 | 4.30 | 327.57 | 25.73 | -3.64 | 0.503 | 40.84 | C4 |
| 21 | 98/07/19/17:58:31.9 | 23.53 | 121.67 | 36 | 0.17 | -3.38 | 3.07 | 1.04 | 0.07 | -1.46 | 4.32 | 201.78 | 33.89 | 100.27 | 0.453 | 24.12 | B2 |
| 22 | 98/07/20/16:35:24.9 | 24.08 | 122.10 | 21 | -3.35 | -1.79 | 6.49 | 2.72 | 2.56 | -4.16 | 4.53 | 243.97 | 27.18 | 111.43 | 0.581 | 12.33 | C2 |
| 23 | 98/07/24/18:44:03.0 | 21.63 | 121.84 | 12 | 467.62 | -994.06 | 360.10 | 46.15 | -409.80 | -468.71 | 5.94 | 220.10 | 44.59 | 157.02 | 0.557 | 25.66 | C3 |
| 24 | 98/07/30/08:15:41.1 | 22.93 | 121.41 | 15 | 0.16 | -0.58 | 0.49 | 0.18 | -0.32 | 0.13 | 3.82 | 345.61 | 42.72 | 44.42 | 0.487 | 4.75 | B1 |
| 25 | 98/07/31/09:23:26.3 | 24.76 | 122.87 | 111 | 3.65 | -2.67 | -0.78 | 9.69 | -5.13 | 1.12 | 4.64 | 350.24 | 62.60 | -3.79 | 0.495 | 5.82 | B1 |
| 26 | 98/08/11/02:07:49.8 | 24.85 | 123.34 | 129 | -15.65 | 9.09 | 7.09 | 48.06 | -58.38 | -6.51 | 5.19 | 8.73 | 40.01 | 5.07 | 0.464 | 4.38 | B1 |

(Table 2. continued)

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | 98/08/13/01:05:31.3 | 24.47 | 122.97 | 81 | -0.63 | 0.66 | -0.08 | 0.20 | 0.58 | 0.43 | 3.93 | 215.64 | 42.96 | -3.45 | 0.396 | 3.59 | B1 |
| 28 | 98/08/15/00:15:43.3 | 24.39 | 122.77 | 24 | -0.76 | 0.07 | 0.92 | 0.27 | 0.57 | -0.31 | 3.96 | 262.10 | 27.57 | 104.25 | 0.488 | 9.91 | B1 |
| 29 | 98/08/16/11:13:03.8 | 23.20 | 120.53 | 12 | 2.09 | -3.79 | 2.85 | 0.84 | -1.99 | 0.14 | 4.36 | 335.00 | 54.01 | 37.45 | 0.494 | 8.76 | B1 |
| 30 | 98/08/25/02:49:31.2 | 24.60 | 122.53 | 15 | 5.64 | -6.86 | -0.02 | 2.77 | -1.24 | -0.55 | 4.50 | 236.42 | 80.32 | 173.37 | 0.590 | 3.91 | C1 |
| 31 | 98/09/04/10:40:50.6 | 23.91 | 121.58 | 18 | -2.99 | 0.30 | 2.03 | 4.77 | 2.69 | 1.64 | 4.47 | 195.57 | 57.28 | 22.28 | 0.509 | 7.03 | C1 |
| 32 | 98/09/09/17:54:00.8 | 23.10 | 121.53 | 36 | 0.66 | -0.47 | -0.16 | 0.21 | 0.20 | -0.21 | 3.83 | 142.63 | 62.44 | -13.07 | 0.435 | 19.60 | B2 |
| 33 | 98/09/10/06:46:06.4 | 22.64 | 120.66 | 15 | 0.21 | -3.06 | 2.68 | -0.32 | -1.31 | 0.93 | 4.28 | 333.02 | 41.66 | 54.04 | 0.484 | 17.21 | B2 |
| 34 | 98/09/12/06:53:08.5 | 24.43 | 122.61 | 42 | 0.79 | -1.63 | 0.86 | -0.14 | -0.92 | -0.27 | 4.09 | 211.30 | 52.28 | 148.71 | 0.478 | 5.91 | B1 |
| 35 | 98/09/13/05:34:48.3 | 24.24 | 123.01 | 33 | 31.67 | -46.79 | 21.57 | -10.96 | -28.91 | -1.92 | 5.09 | 209.81 | 58.94 | 153.61 | 0.474 | 12.20 | B2 |
| 36 | 98/09/16/04:56:11.2 | 23.84 | 120.84 | 27 | -0.11 | -0.34 | 0.43 | 0.40 | -0.23 | -0.32 | 3.83 | 246.78 | 48.40 | 139.69 | 0.368 | 19.27 | B2 |
| 37 | 98/09/21/16:29:37.3 | 23.94 | 121.55 | 15 | -0.76 | -0.26 | 0.68 | 0.98 | 0.52 | 0.58 | 4.05 | 198.58 | 56.82 | 37.31 | 0.477 | 10.87 | B2 |
| 38 | 98/09/27/17:02:22.0 | 24.48 | 122.42 | 51 | -0.23 | -0.77 | 1.22 | 0.88 | 0.08 | 0.57 | 4.05 | 57.93 | 40.46 | 123.59 | 0.370 | 24.87 | B2 |
| 39 | 98/09/28/08:57:19.9 | 21.09 | 122.11 | 36 | -5.71 | -0.10 | 3.80 | -3.67 | -5.91 | -12.64 | 4.73 | 86.75 | 18.85 | 26.91 | 0.619 | 9.16 | C1 |
| 40 | 98/10/09/12:52:51.5 | 22.12 | 121.65 | 27 | 5.10 | -22.81 | 16.20 | 4.48 | 4.12 | 3.52 | 4.82 | 28.85 | 44.60 | 119.75 | 0.397 | 39.52 | B3 |
| 41 | 98/10/11/04:56:34.8 | 23.89 | 121.71 | 45 | 0.44 | -0.31 | -0.15 | 0.23 | -0.26 | 0.21 | 3.77 | 326.25 | 51.75 | -14.70 | 0.463 | 3.35 | B1 |
| 42 | 98/10/13/16:54:18.0 | 21.86 | 121.50 | 24 | 1.42 | -0.16 | -0.97 | 0.70 | -0.22 | -1.01 | 4.10 | 260.85 | 42.88 | -142.39 | 0.477 | 4.43 | B1 |
| 43 | 98/10/17/23:11:09.7 | 24.82 | 122.01 | 27 | 2.10 | -4.02 | 2.79 | -2.06 | 3.14 | -3.20 | 4.47 | 129.76 | 42.64 | 24.74 | 0.536 | 28.46 | C3 |
| 44 | 98/11/03/07:06:37.5 | 22.15 | 121.15 | 36 | 1.40 | -4.84 | -0.35 | -13.40 | -5.74 | 2.97 | 4.73 | 184.14 | 70.21 | 167.02 | 0.361 | 20.66 | B2 |
| 45 | 98/11/17/22:27:32.5 | 22.83 | 120.79 | 24 | 8.63 | -68.10 | 68.44 | -33.69 | -52.29 | -10.69 | 5.25 | 185.50 | 41.42 | 135.71 | 0.338 | 13.39 | B2 |
| 46 | 98/11/19/10:30:02.2 | 23.79 | 121.77 | 48 | -2.07 | 1.18 | 0.58 | 2.53 | -1.15 | -1.38 | 4.30 | 20.65 | 64.78 | 18.69 | 0.377 | 17.37 | B2 |
| 47 | 98/11/26/22:12:19.3 | 25.06 | 122.51 | 159 | -0.09 | 10.05 | -9.99 | 3.49 | -2.50 | 3.60 | 4.64 | 144.99 | 40.72 | -118.32 | 0.318 | 0.63 | B1 |
| 48 | 98/12/14/00:59:03.3 | 24.29 | 122.16 | 48 | 0.57 | -4.37 | 3.26 | 1.95 | 1.41 | 3.07 | 4.43 | 47.24 | 37.19 | 138.90 | 0.351 | 6.78 | B1 |
| 49 | 98/12/22/01:49:06.9 | 24.25 | 122.58 | 60 | 2.19 | -1.73 | -0.75 | 2.89 | 0.91 | 5.99 | 4.50 | 79.08 | 30.37 | -174.79 | 0.366 | 23.08 | B2 |

[1] Origin time (Year/Month/Day/hr:min:sec) and epicentral locations (°N, °E) are reported by the Seismology Center, Central Weather Bureau, Taiwan.

[2] X, Y, Z point to north, east, and vertically down, respectively. All are in the unit of $1 \times 10^{15}$ Nt m.

[3] Estimated best double-couple solutions in degrees.

[4] E and ε are defined by equations (2) and (1), respectively. ε is expressed in percent (%).

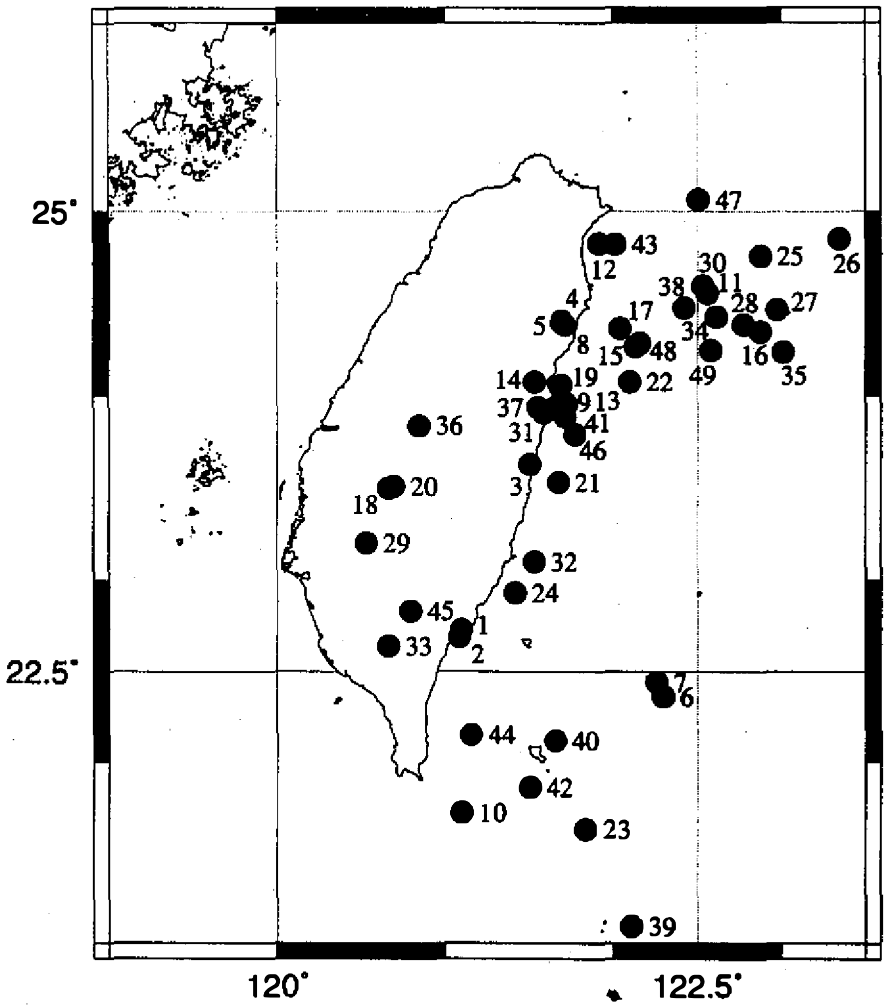


*Fig. 2.* Moment-tensor inversion results. (a) Map shows the epicenters of 49 earthquakes presented in this study. Numbers are according to Table 2. (b) Corresponding best double-couple solutions. The first number above each fault plane solution is the event number. The number in parenthesis is the best focal depth.

reports showing source parameters of earthquakes between 1995 and 1997 are also available in our web site (http://bats.earth.sinica.edu.tw/CMT_Solutions).

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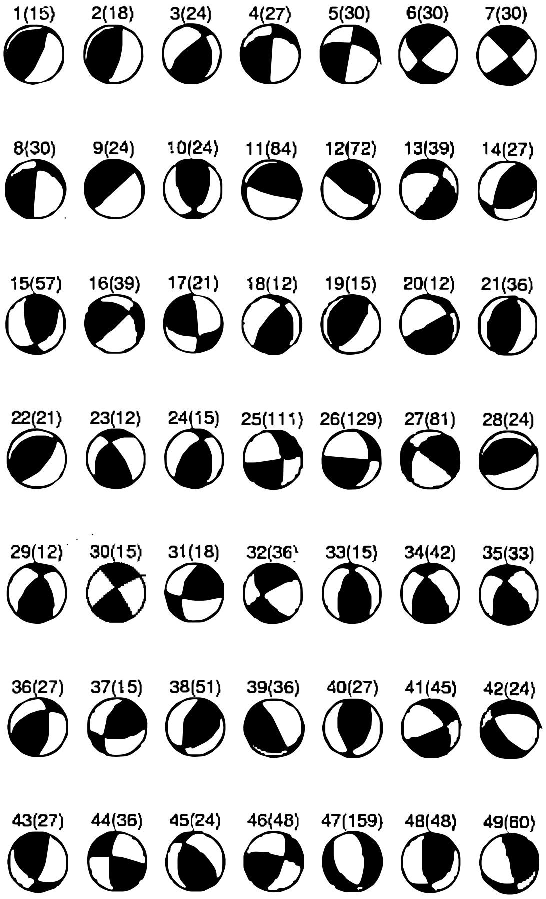


(*Fig. 2.* continued)

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