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Present-day crustal motion in northeast China determined from GPS measurements

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GPS measurements carried out between 1997 and 2005 at 37 stations distributed throughout northeast China place indicate the presence of constraints on the present-day crustal motion in this region. Velocity vectors relative to Eurasia are very small, only 1.58 mm/yr on average, indicating that the region is generally stable. With the exception of five stations that show significant motion at the 95% confidence level, the insignificant motion of most stations precludes a clear association of their velocities with the rotation of a separate rigid microplate, suggesting that northeast China belongs to Eurasia plate. The velocities of several stations in the southwestern corner of the studied region consistently point to the southeast. This is most probably a distant effect of the eastward motion of northern Tibet. Small velocities of the stations of around the time of the 1999 $M_W = 7.1$ and 2002 $M_W = 7.3$ deep-focus earthquakes, which occurred in Wangqing county, suggest that these earthquakes did not cause wide-spread deformations to the shallow crust.

Key words: GPS, northeast China, crustal deformation, Eurasia plate.

1. Introduction

Northeast China is located between the Baikal Lake to the west and Sakhalin Island to the east, both of which are characterized by regional strong seismicity (Takahashi *et al.*, 1999; Calais *et al.*, 2002; Kogan *et al.*, 2003). The region comprises Helongjiang and Jilin provinces and most of Liaoning Province. Northeast China is generally considered to be a stable continental region, in contrast to other regions (for example, Tibet) of China. Six major faults are distributed throughout northeast China, of which the Yilan (YYF) and Dunhua Faults are the most active based on geological investigations and seismic studies (Yu, 1987). These two faults are assumed to be the northern segment of the great Tanlu Fault, which extends more than 1500 km throughout eastern China. Several small-scale faults are present in the southern corner of the study area, all of which are characterized by high activity (Deng *et al.*, 2002). A majority of earthquakes in the region have been shallow events, with the largest of these recorded in 1975, with a magnitude of $M_W = 7.5$ in Haicheng county, which is located near the south part of the study area. The most recent striking seismic events in this region are the two strong deep earthquakes that occurred in Wangqing county: one is the $M_W = 7.1$ earthquake, at a depth of 575.4 km in 1999, and the other one is the $M_W = 7.3$ earthquake that occurred in 2002 at a depth of 581.5 km (http://www.seismology.harvard.edu). Two volcano eruptions were recorded in Changbei mountain in 1771 and 1776, indicating that the Changbei mountainous region is tectonically active in a historical sense (Liu *et al.*, 2000).

Northeast China is assumed to be within the stable Amurian plate (AMU), which was proposed by Zonenshan and Savostin (1981) to explain the strong seismicity around the Baikal Lake as well as across the Stannovoy range (Fig. 1). No fewer than six different Euler rotation poles for the Amurian/Eurasia motion have been proposed to date (Wei and Seno, 1998, 2000; Heki *et al.*, 1999; Kogan *et al.*, 2000; Sella *et al.*, 2002; Calais *et al.*, 2003; Kreemer *et al.*, 2003), whereas the Amurian plate has been shown to have a different motion from that of the Eurasian plate (Petit and Fournier, 2005).

The goal of the present study was to characterize tectonic affection for northeast China and evaluate the evidence for independent motion of the AMU microplate based on an analysis of continuous and campaign mode GPS observations made in the period 1998–2005 in northeast China.

2. GPS Data and Analysis

GPS measurements were begun in August, 1998, in northeast China. As part of the Crustal Movement Observation Network of China (CMONOC), the network in northeast China consists of 37 sites, including four permanent sites—SUIY (Suiyang) and HLAR (Hailar), which have been operating since August, 1998, CHAN (Changchun), which operated continuously from 1998 to 2000 and has since been replaced by the station CHUN, and HRBN (Harbin), which was established in December, 2000. All of the campaign-based stations have been surveyed at least three times. The measurements were carried out with Ashtech Z12 or Trimble GPS receivers with choke ring an-

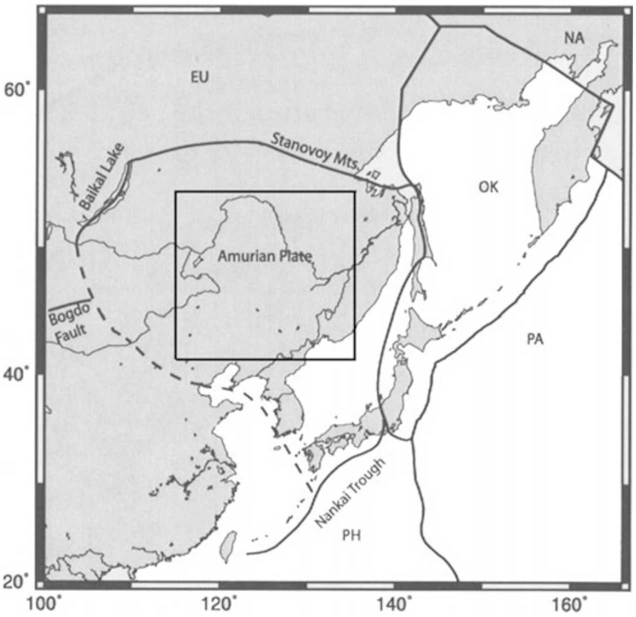

Fig. 1. Plate tectonic framework of the East Asia (after Wei and Seno, 1988). EU=Eurasian Plate, NA=North America Plate, OK=Okhotsk Plate, PA=Pacific Plate, PH=Philippine Sea Plate. The dashed lines are the southern boundary of AM-EU. The solid box shows the studied area.

tennas. During each campaign, each site was usually occupied for 22–24 hours a day for three consecutive days (Niu *et al.*, 2005).

GAMIT software is used to process GPS data for single-day solutions (King and Bock, 2003). Regional station coordinates, satellite state vectors, 11 tropospheric zenith delay parameters per site and day, and phase ambiguities were determined. IGS final orbits and IERS Earth Orientation Parameters were used, and elevation-depend antenna phase center corrections were made following the tables recommended by the IGS. Sixteen global IGS stations were used as ties with ITRF2000 (Altamimi *et al.*, 2002). The least square adjustment vector and the variance-covariance matrix for station positions and orbital elements estimated for each independent daily solution were then combined with global H-files from Scripps Institution of Oceanography (SIO) using GLOBK software (Herring, 2002). Common parameters in all solutions, such as the satellite orbit, polar motions, and tracking station positions, were solved with loose constraints on all the parameters. In the final step, station positions and velocities were estimated with QOCA software (Dong *et al.*, 1998). The QOCA modeling of the data was carried out by sequential Kalman filtering, which allowed adjustments to be made for global translation and rotation of each daily solution and minimized the positions and velocities of IGS core stations with respect to ITRF2000. We imposed the reference frame by minimizing the position and velocity deviations of 40 IGS core stations with respect to the ITRF2000 while estimating an orientation, translation, and scale transformation. Random walk perturbations were allowed for some parameters whose errors were found to be correlated with time. The height coordinates and vertical velocities were weighted by a factor of 10 less than the horizontal components.

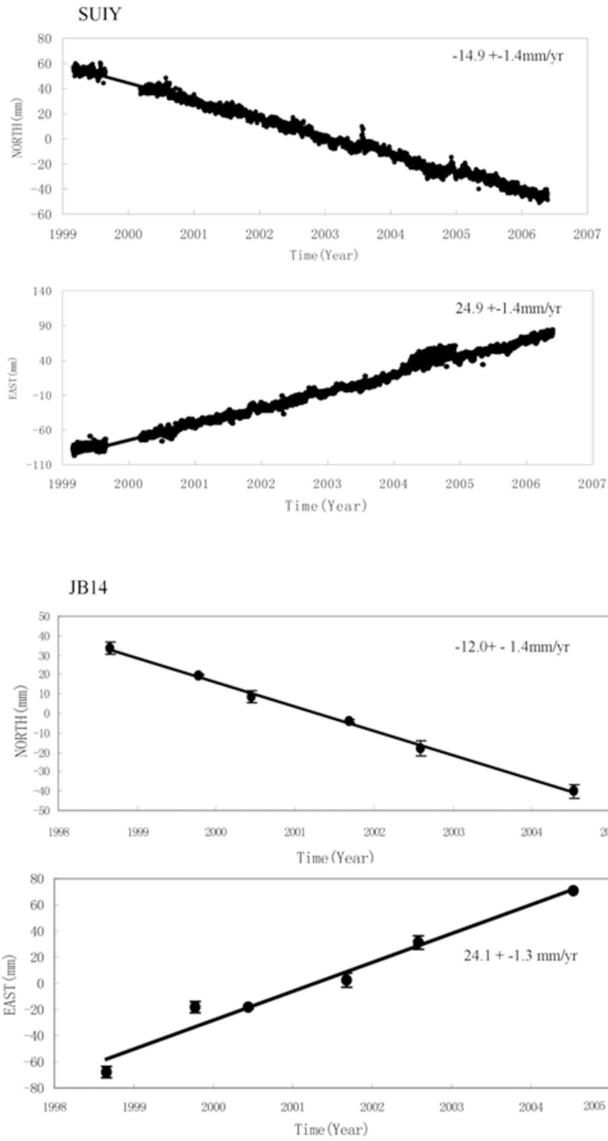

Fig. 2. Time series of horizontal coordinates at SUIY and JB14 in ITRF2000. Solid lines are the best fit lines for temporal changes of the east and north components.

For ease of interpretation, we express velocities relative to the Eurasia stable plate. The Eurasia reference frame is realized by subtracting the rotation of the Eurasian plate from that of the ITRF2000. The definition of a Eurasia-fixed reference frame used to be notably difficult, although several plate motion models provide the motion of Eurasia plate (DeMets *et al.*, 1994; Sella *et al.*, 2002; Kreemer *et al.*, 2003). Investigators generally define the Eurasia stable plate by inverting GPS velocities of a group of sites that are assumed to be on the stable interior across the Eurasia plate (Wang *et al.*, 2001; Shen *et al.*, 2005). In order to study deformation in a boundary region that is wide and distant from the stable region of either adjoining plate, a more robust approach is to determine the frame using stations within the stable interiors of the adjoining plates, thereby minimizing the velocities within each plate (Steblov *et al.*, 2003). From this viewpoint and considering that northeast China lies in the border region of the Eurasia, Okhotsk, and Philippe sea plates as well as for the ease of combining our

Table 1. Velocities in ITRF2000-NNR Reference Frame and their Standard Deviations (σ).

Site	Longitude	Latitude	V_e mm yr^{-1}	Vn mm yr^{-1}	σ_e mm yr^{-1}	σ_n mm yr^{-1}	Correlation
CHUN	125.44	43.79	24.8	−12.7	1.6	1.6	0.0006
E001	134.29	48.28	21.2	−12.4	1.6	1.5	0.0010
E003	133.95	46.79	23.6	−19.9	1.6	1.5	0.0006
E005	126.67	51.70	22.2	−11.4	1.6	1.5	0.0016
E006	127.41	50.25	22.8	−12.4	1.6	1.6	−0.0009
E007	129.63	49.27	20.5	−13.9	1.5	1.5	0.0009
E008	128.93	47.75	24.0	−10.9	1.5	1.5	0.0003
E009	126.14	48.50	23.5	−13.7	1.5	1.5	0.0006
E012	127.35	43.74	22.7	−12.9	1.6	1.5	0.0002
E014	125.14	42.84	24.8	−12.5	1.6	1.6	−0.0010
E016	128.10	42.42	24.1	−12.6	1.6	1.5	−0.0008
E018	122.34	53.48	22.1	−11.9	1.6	1.5	0.0009
E020	121.46	50.77	22.9	−10.1	1.6	1.5	−0.0006
E021	121.91	48.75	22.7	−12.7	1.6	1.6	0.0006
E022	124.00	47.39	23.9	−11.5	1.6	1.5	0.0006
E025	120.87	44.56	25.6	−11.5	1.6	1.6	−0.0004
E028	123.42	42.54	25.6	−11.3	1.6	1.6	0.0001
E029	122.85	42.06	25.3	−12.2	1.6	1.6	−0.0002
E030	121.61	42.05	24.8	−12.8	1.6	1.6	−0.0018
E040	124.90	42.08	24.9	−14.3	1.6	1.6	−0.0006
E054	117.43	49.60	24.2	−11.4	1.5	1.5	0.0007
E056	116.78	48.65	24.4	−11.1	1.5	1.5	0.0005
E057	118.25	48.03	24.0	−11.2	1.5	1.5	0.0006
E058	119.94	47.16	23.9	−11.8	1.5	1.5	0.0008
E059	116.94	45.51	25.2	−11.6	1.6	1.6	0.0006
E062	119.02	42.28	25.6	−12.1	1.6	1.6	0.0002
E064	111.97	43.65	25.7	−12.3	1.6	1.6	0.0007
HLAR	119.74	49.27	25.0	−12.6	1.4	1.4	0.0005
HRBN	126.62	45.70	22.5	−12.3	2.4	2.4	0.0002
JB10	131.17	46.65	21.9	−13.7	1.4	1.4	0.0005
JB11	126.96	46.65	19.0	−13.7	1.4	1.4	−0.0001
JB12	129.48	43.00	23.4	−13.2	1.5	1.5	−0.0002
JB13	124.10	50.39	22.9	−11.5	1.4	1.4	0.0000
JB14	122.17	46.06	24.2	−12.0	1.4	1.4	0.0007
JB15	121.76	42.75	25.6	−12.1	1.5	1.4	0.0005
JB17	116.10	43.90	27.4	−13.7	1.5	1.5	0.0007
SUIY	130.90	44.43	24.9	−14.9	1.4	1.3	−0.0007

velocity field with the velocities at VLAD and KHAJ of Steblov *et al*. (2003), we employed the IGS site velocities derived by Steblov *et al*. (2003) at 18 sites (ARTU, BOR1, BRUS, GRAZ, IRKT, KIRU, KOSG, KSTU, METS, NRIL, NYAL, ONSA, POTS, VILL, VLAD, WTZR, YAKT, and ZWEN). These sites are believed to be located in the stable Eurasian interior, distributed across the Eurasian plate, and to define the Eurasia stable frame. This site distribution is similar to the one used by Wang *et al*. (2001) but cover a broader region. The estimated Eurasian plate rotates at $0.2502 \pm 0.0025°$/myr with a pole at $55.2 \pm 0.4°$N, $-103.8 \pm 0.7°$E. The weighted root mean square (rms) of velocity for these 18 stations is 0.7 mm/yr, with the most contributions coming from KIRU, IRKT, and KSTU (1.8, 1.1, and 1.2 mm/yr, respectively). This angular velocity is slightly different from the estimate by Wang *et al*. (2001), but for sites in northeast China the velocities relative to Eurasia differ by no more than 0.9 mm/yr when angular velocity is used. We subtracted the Eurasia-ITRF2000 rotation from the ITRF2000 velocities to map our results in a Eurasia-fixed frame.

3. Result and Discussion

The site velocities in ITRF2000 over the period of 1998–2005 are listed in Table 1. Examples of time series of horizontal coordinates are shown in Fig. 2. The standard deviations were computed by scaling the formal 1-sigma uncertainties of the final adjustment by the overall chi-square per degree of freedom. 1-Sigma uncertainties for their velocity components are less than 1.7 mm/yr at all sites except HRBN and CHAN, which has a short time span of less than 3 years or low data quality due to operation problems. We integrated our site velocities with those for VLAD and KHAJ of Steblov *et al*. (2003) and derived a consistent velocity field with respect to the stable Eurasia continent. Velocities and their error ellipses at the 95% confidence level are shown in Fig. 3. Despite uncertainties, we believe that the GPS velocities may indicate the possibility of tectonic implications. For most sites, the velocities are relatively small, ranging from 0.1 to 3.5 mm/yr for both the NS and EW components, respectively, thereby reflecting the relatively high stability of northeast China relative to other Chinese regions, such as Tibet, and other countries in East Asia,

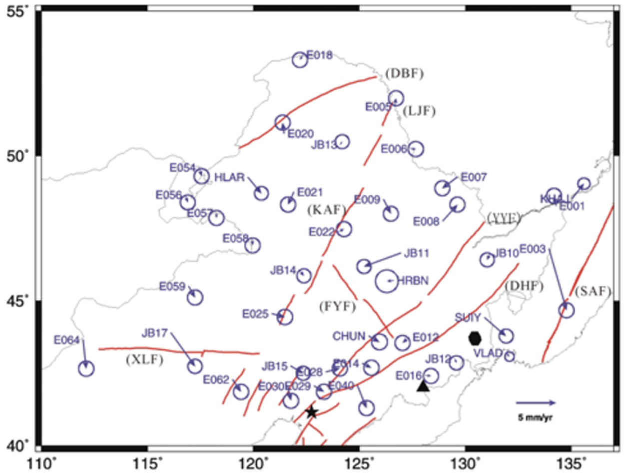

Fig. 3. Map showing the observed velocity field with respect to Eurasia in Northeast China. The error ellips show with 95% confidence limits. Solid red lines show quaternary faults. Abbreviations are DBF: Der Bugan Fault, LJF: Len Jiang Fault, YYF: Yi Lan Fault, DHF: Dun Hua Fault, SAF: Sikhot-Alin Fault, KAF: Keshan Daan Fault, FYF: Fu Yu Fault, XLF: Xila Mulun Fault. The star indicates the location of 1975 Haicheng Earthquake (M7.5). The triangle indicates Changbei volcano. The hexagon indicates the epicenters of 1999 M_W 7.1 and 2002 M_W 7.3 earthquakes.

such as Japan (Kato *et al.*, 1998; Shen *et al.*, 2000; England and Molnar, 2005; Shen *et al.*, 2005). The stability of northeast China is comparable with that South Korea (Hamdy *et al.*, 2005). With the exception of five stations (JB11, E003, E040, JB17, SUIY), all stations show insignificant motion at the 95% confidence level, precluding a clear association of their velocities with the rotation of a separate rigid plate (AMU plate). This suggests that northeast China is on the Eurasia plate. Velocities at the two sites located in and around the Changbei volcano (JB12, E016) are approximately 1 mm/yr, implying that the Changbei volcano has not been active in recent years. SUIY shows significant motion and its velocity vector points in the southeast direction. Although SUIY is not far from the epicenters of the 1999 $M_W = 7.1$ and 2002 $M_W = 7.3$ deep-focus earthquakes (approx. 200 km), we were unable to find convincing evidence indicating that this site was affected by these earthquakes. Insignificant velocities at JB12, E016, and VLAD, which are more than 200 km distant from the epicenters, reaffirm the observations that these two deep earthquakes did not cause wide-spread motion to the shallow crust. The velocity vector at JB11 seems to be clearly anomalous, since it is quite different from the southeastern motion recorded at most stations. We checked all of the surveying documents from the Research National Earthquake Infrastructure Service, China Earthquake Administration, but were unable to find any problem with the surveying procedure and other factors that could have influenced the observations. Therefore, we believe the southwestward motion of JB11 is real. The motion of JB11 can be confirmed by the velocity vector of the continuously observed station HRBN, although the latter has a relatively large uncertainty (Table 1 and Fig. 3). The motions at E040, which is close to the southern end of DHF, SUIY, which is near the central part of the fault, and E003, which is located in the northeastern extending direction of the fault, were all significant. The southwestward motion of JB11 and the southeastward motion of E040, SUIY, and E003 as a whole indicate a tensional strain zone to the west of DHF. Moreover, the velocity of JB17 shows a southeastward motion at the 95% confidence level. Since this velocity is in good agreement with directions of the two neighboring sites, E059 and E062, we believe the southeastward motion of JB17 is a reliable measurement. When the velocity fields of all stations were monitored closely, we found that the velocities of more than eight stations in the southwestern corner of the region point to the southeast. This is most probably a distant effect of the eastward motion of northern Tibet (Chen *et al.*, 2004).

4. Conclusion

On the basis of the measurements and discussion reported here, we conclude that the velocities of GPS sites in northeast China are approximately 1.58 mm/yr, on average, relative to Eurasia stable plate, suggesting that this region is generally stationary with respect to Eurasia plat;. Five stations show a significant motion relative to the Eurasia plate at the 95% confidence level, but the small number and limited geographic distribution of these stations preclude a clear association of their velocities with the rotation of a separate rigid plate (AMU), suggesting that northeast China belongs to Eurasia plate. The velocities of several stations in the southwestern corner point to southeast. This is most probably a distant effect of the eastward motion of northern Tibet. The small velocities at the sites around the epicenters of the two recent strong deep-focus earthquakes with a magnitude of $M_W = 7.1$ and $M_W = 7.3$, respectively, indicate that these seismic events did not cause broad deformation to the shallow crust.

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References

Altamimi, Z., P. Sillard, and C. Boucher, ITRF2000: a new release of the International Terrestrial Reference Frame for earth science applications, *J. Geophys. Res.*, **107**(B10), 2214, doi:1.1029/2001JB000561, 2002.

Calais, E., M. Vergonolle, J. Deverchere, V. San'kov, A. Lukhnev, and S. Amarjargal, Are post-seismic effects of the $M = 8.4$ Bolnay earthquake (1905 July 23) still influencing GPS velocities in the Mongolia-Baikal area?, *Geophys. J. Int.*, **149**, 157–168, 2002.

Calais, E., M. Vergnolle, V. San'kov, A. Lukhnev, A. Miroshinitchenko, S. Amarjargal, and J. Déverchère, GPS measurements of crustal deformation in the Baikal-Mongolia area (1994–2002): Implication for current kinematics of Asia, *J. Geophys. Res.*, **108**(B10), 2501, doi:10.1029/2002JB0002373, 2003.

Chen, Q., J. Freymueller, Q. Wang, Z. Yang, C. Xu, and J. Liu, A deforming block model for the present-day tectonics of Tibet, *J. Geophys. Res.*, **109**, B01403, doi:10.1029/2002JB0002151, 2004.

DeMets, C., R. G. Gordon, D. F. Argus, and S. Stein, Effect of recent revisions to the geomagnetic time scale on estimates of current plate motions, *Geophys. Res. Lett.*, **21**, 2191–2194, 1994.

Deng, Q., P.-Z. Zhang, R.-K. Ran, X.-P. Yang, W. Min, and Q.-Z. Chu, Characteristics of Chinese active tectonic units, *Science in China (Series D)*, **32**(12), 1020–1030, 2002 (in Chinese).

Dong, D., T. A. Herring, and R. W. King, Estimating regional deformation from a combination of space and terrestrial geodetic data, *J. Geodesy*, **72**, 200–214, 1998.

England, P. and P. Molar, Late Quaternary to decadal velocity fields in Asia, *J. Geophys. Res.*, **110**, B12401, doi:10.1029/2004JB0003541, 2005.

Hamdy, A. M., P.-H. Park, and H.-C. Lim, Horizontal deformation in South Korea from permanent GPS network data, 2000–2003, *Earth Planets Space*, **57**, 77–82, 2005.

Heki, K., S. Miyazaki, H. Takahashi, M. Kasahara, F. Kimata, S. Miura, N. F. Vasilenko, A. Ivashchenko, and K.-D. An, The Amurian plate motion and current plate kinematics in eastern Asia, *J. Geophys. Res.*, **104**(B12), 2501, 29147–29155, 1999.

Herring, T. A., GLOBK, Global Kalman filter VLBI and GPS analysis software, Mass. Inst. Technol., February 15, 2002.

Kato, T., G. S. Ell-Fiky, E. N. Oware, and S. Miyazaki, Crustal strains in the Japanese islands as deduced from dense GPS array, *Geophys. Res. Lett.*, **25**(18), 3345–3348, 1998.

King, R. W. and Y. Bock, Documentation for the GAMIT GPS Analysis software, Mass. Inst. Technol., Scripps Inst. Occeangr., Release 10.1, November 11, 2003.

Kreemer, C., W. E. Holt, and A. J. Haines, An integrated global model of present-day plate motions and plate boundary deformation, *Geophys. J. Int.*, **154**, 8–34, 2003.

Kogan, M. G., G. M. Steblov, R. W. King, T. A. Herring, D. I. Frolov, S. G. Egorov, V. Y. Levin, A. Lerner-Lam, and A. Jones, Geodetic constraints on the relative motion and rigidity of Eurasia and North America, *Geophys. Res. Lett.*, **27**(14), 2041–2044, 2000.

Kogan, M. G., R. Bürgmann, N. F. Vasilenko, C. H. Scholz, R. W. King, A. I. Ivashchenko, D. I. Frolov, G. M. Steblov, Ch. U. Kim, and S. G. Egorov, The 2000 Mw 6.8 Uglegorsk earthquake and regional plate boundary deformation of Sakalin from geodetic data, *Geophys. Res. Lett.*, **30**(3), 1102, doi:10.1029/2002GL016399, 2003.

Liu, R.-X., *Active Volcanoes in China*, Seismological Publishing House, Beijing, 2000.

Niu, Z.-J., M. Wang, H.-R. Sun, J.-Z. Sun, X.-Z. You, W. Gan, G. Xue, J. Hao, S. Xin, Y. Wang, Y. Wang, and B. Li, Contemporary velocity field of crustal movement of Chinese mainland from Global Positioning System measurements, *China Sci. Bull.*, **50**(9), 939–941, 2005.

Petit, C. and M. Fournier, Present-day velocity and stress fields of the Amurian Plate from thin-shell finite-element modeling, *Geophys. J. Int.*, **160**, 357–369, 2005.

Sella, G. F., T. H. Dixon, and A. Mao, REVEL: A model for recent plate velocities from space geodesy, *J. Geophys. Res.*, **107**(B4), 2081, 10.1029/2000JB000033, 2002.

Shen, Z.-K., C. Zhao, A. Yin, Y. Li, D. D. Jackson, P. Fang, and D. Dong, Contemporary crustal deformation in east Asia constrained by Global Positioning System measurements, *J. Geophys. Res.*, **105**(B3), 5721–5734, 2000.

Shen, Z.-K., J. Lü, M. Wang, and R. Bürgmann, Contemporary crustal deformation around the southeast borderland of the Tibetan Plateau, *J. Geophys. Res.*, **110**, B11409, doi:10.1029/2004JB003421, 2005.

Steblov, G. M., M. G. Kogan, R. W. King, C. H. Scholz, R. Bürgmann, and D. I. Frolov, Imprint of the North American plate in Siberia revealed by GPS, *Geophys. Res. Lett.*, **30**, 2041–2044, 2003.

Takahashi, H., M. Kasahara, F. Kimata, S. Miura, K. Heki, T. Seno, T. Kato, N. Vasilenko, A. Ivashchenko, V. Bahtiarov, V. Levin, E. Gordeev, F. Korchagin, and M. Gerasimenko, Velocity field of around the sea Okhotsk and Sea of Japan region determined from a new continuous GPS network, *Geophys. Res. Lett.*, **26**(16), 2533–2536, 1999.

Wang, Q., P.-Z. Zhang, J. T. Freymuller, R. Biham, K. M. Larson, X. Lai, X. You, Z. Niu, J. Wu, Y. Li, J. Liu, Z. Yang, and Q. Chen, Present-day crustal deformation in China constrained by global positioning system measurements, *Science*, **294**, 574–577, 2001.

Wei, D. and T. Seno, Determination of the Amurian plate motion, in *Mantle Dynamics and Plate Interactions in East Asia*, Geodynam. Series, edited by M. Flower *et al.*, Am. Geophys. Union, 27, pp. 337–346, 1998.

Wei, D.-P. and T. Seno, Kinematical analysis of plate tectonics model in northeastern Asia, *Chinese J. Geophys*, **43**(1), 53–63, 2000 (in Chinese with English abstract).

Yu, L.-W., Spatio-temporal distribution of moderate-strong and strong earthquakes in the Northeastern China, *Northeastern Seismological Research*, **3**(1), 11–22, 1987 (in Chinese with English abstract).

Zonenshain, L. P. and L. A. Savostin, Geodynamics of the Baikal rift zone and plate tectonics of Asia, *Tectonophysics*, **76**, 1–45, 1981.

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