J. Earth & Space Physics. Vol. 28, No. 1 (2002) P. 1-6

Source parameters of the 1998 Fandoqa earthquake in Kerman Province, south -east Iran

Gheitanchi, M.R.*

*Institute of Geophysics, Tehran University, Tehran, Iran.

Abstract

In this study, the source parameters of the 1998 Fandoqa earthquake were investigated. The observed teleseismic bodywaves of mainshock were modeled in order to obtain the source process. The information from field investigations and the result of locally recorded aftershock activity were considered as supplementary data. The source process fitted with a single source model having a strike-slip mechanism very similar to the result of CMT solution. Rupture during this earthquake initiated in the epicentral area and extended in a bilateral manner. The seismic moment from bodywaves was calculated to be M_0=7.1 $\times 10^{25}$ dyne-cm and its effective stress drop was about 86 bar while its related dislocation was estimated to be 1.46 m.

Key words: Fandoqa earthquake, Seismicity of Kerman Province, Source parameters, Waveform modeling, Focal mechanism, Seismotectonics, Active Faults, Aftershock activity, Source Process

1. Introduction

On the 14th March 1998 at 19h 40m 31.8.s GMT, 23h 16m 31.8s local time, a strong earthquake occurred in the Fandoqa area not far from the epicenters of the recent destructive earthquakes that occurred in 1981 and 1989 in Kerman province southeast of Iran. The epicenter of the earthquake was computed as 30.05 N-57.E by ISC. The magnitude of the mainshock given by ISC, was mb=5.9, Ms=6.9 and the focal depth determination indicated a shallow depth of 9 kilometers. The earthquake killed five people and injured fifty others. It destroyed 2000 homes and left 10,000 homeless in the epicentral area (Mirzaei et al., 1998).
Shortly after the occurrence of the mainshock the Geophysics Institute of Tehran University deployed a temporary seismic network in the damaged area and carried on the monitoring aftershock activity for six weeks (Soltnian et al., 1998). This paper uses the results of the field and seismological investigations as well as the outcome of aftershock activity to analysis the source parameters. First the active fault system and the seismicity background are reviewed. Then, the source parameters of the mainshock and the result of aftershock activity are explained. In the last part, information from the field investigations and from the locally recorded aftershock activity is used to model the teleseismic bodywaves observed in GDSN stations. Finally, the results of this study are compared and discussed with the results of other studies.

2. Active fault system

The Kerman region is surrounded by the depressions of the Great Kavir desert in the north and Lut in the east, and the Zagros mountain ranges in the south and west. The major Quaternary faults in the area are the kuhbanan fault with northwest-southeast direction and the Nayband fault with a length of 400 km and a north-south trend. In contrast to the Zagros regions where no apparent surface fault trace is observable following even a powerful earth-quake, in this region strong earthquakes are often associated with well recognizable surface faulting. The main activated fault during the 1998 Fandoqa earthquake followed the existing traces of the Gowk fault system recognizable on satellite and air photographs and on the ground and joins several deep depressions from north to south with a total length of about 160 km (Berberian et al., 1984). The Gowk fault system roughly follows the Dasht-e-Lut boundary while at the northern and southern ends the reverse component is remarkable. Dominant right-lateral ground displacements that accompanied the mainshock coincided precisely with the pre-existing geological fault trace of high-angle reverse character (Ghorashi and Talebian, 1998). The mainshock produced 23 km of surface faulting with up to 3 m right-lateral strike- slip and 1 m vertical offsets (Berberian et al., 2001). The active faults as well as the instrumentally located epicenters of the destructive earthquakes in the Kerman region are given in figure 1.

3. Seismicity background

Our knowledge of the historical background of seismic activity in the Kerman region is very limited partially due to the low density of population (Ambraseys and Melville, 1982), and partially because of the low rate of

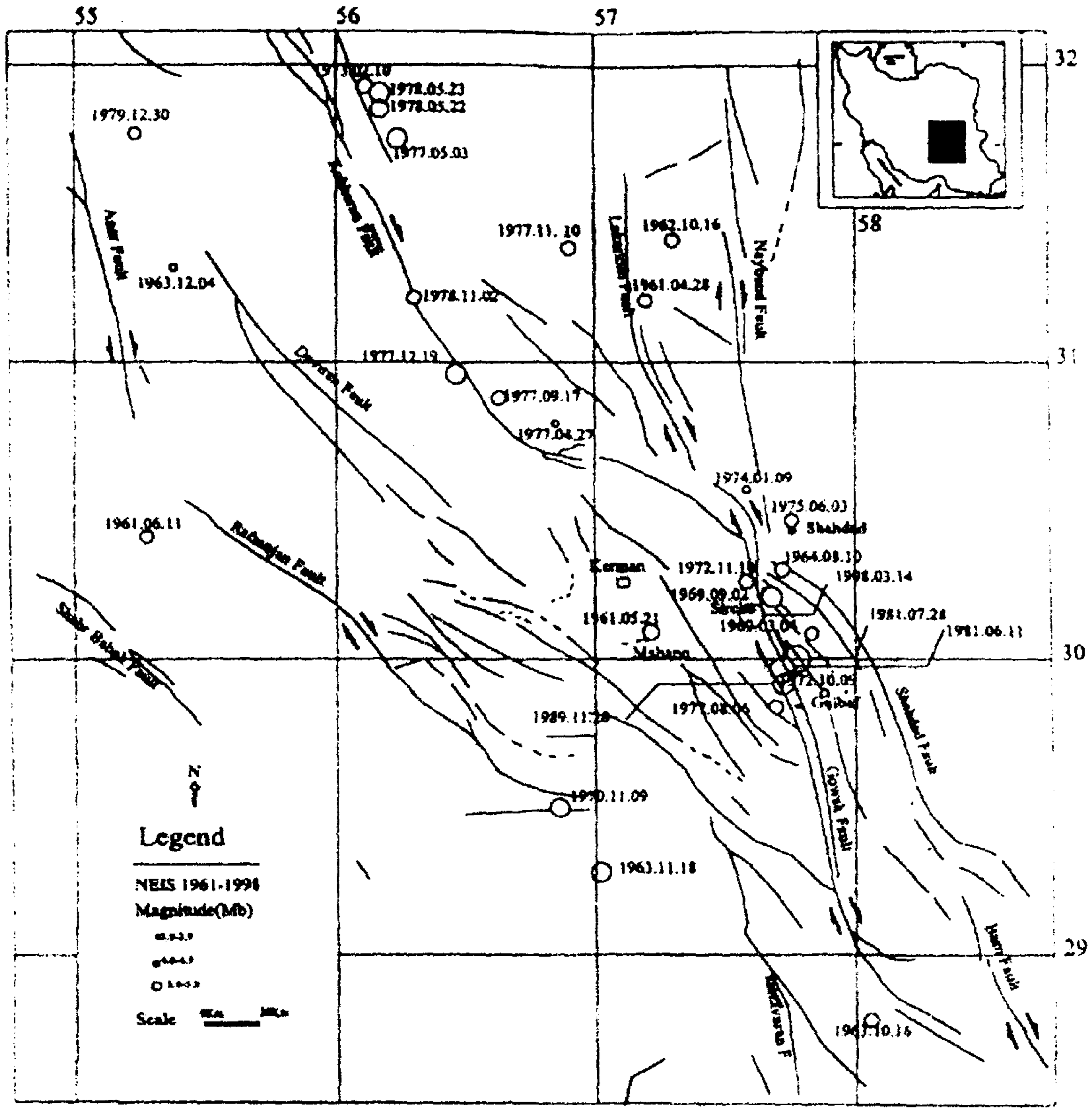

Figure 1. The major Quaternary and the recent active faults (reproduced from Berberian et al, 1984) as well as the instrumentally located epicenters of the destructive earthquakes in Kerman region.

seismic activity in the past centuries. On the other hand, the instrumentally recorded earthquakes and the existence of several active faults all indicate that the region has a high potential for seismic activity. Both the historical background and the instrumentally recorded earthquakes indicate that the seismicity of central Iran including Kerman province, does not follow a linear pattern. During 1977-1998, alone five strong earthquakes caused extensive damage and many human casualties in this region (Gheitanchi, 1999a). All earthquakes were associated with complicated surface ruptures showing a combination of dip-slip and strike-slip motions. The March 14th, 1998 earthquake occurred along a short segment of the Gowk Fault System, where the longer part had moved during the Golbaf-Sirch earthquake of 28, July 1981 (Berberian et al., 1984). The epicenters, the focal mechanisms and the causative faults of recent strong earthquakes in Kerman are given in figure 2.

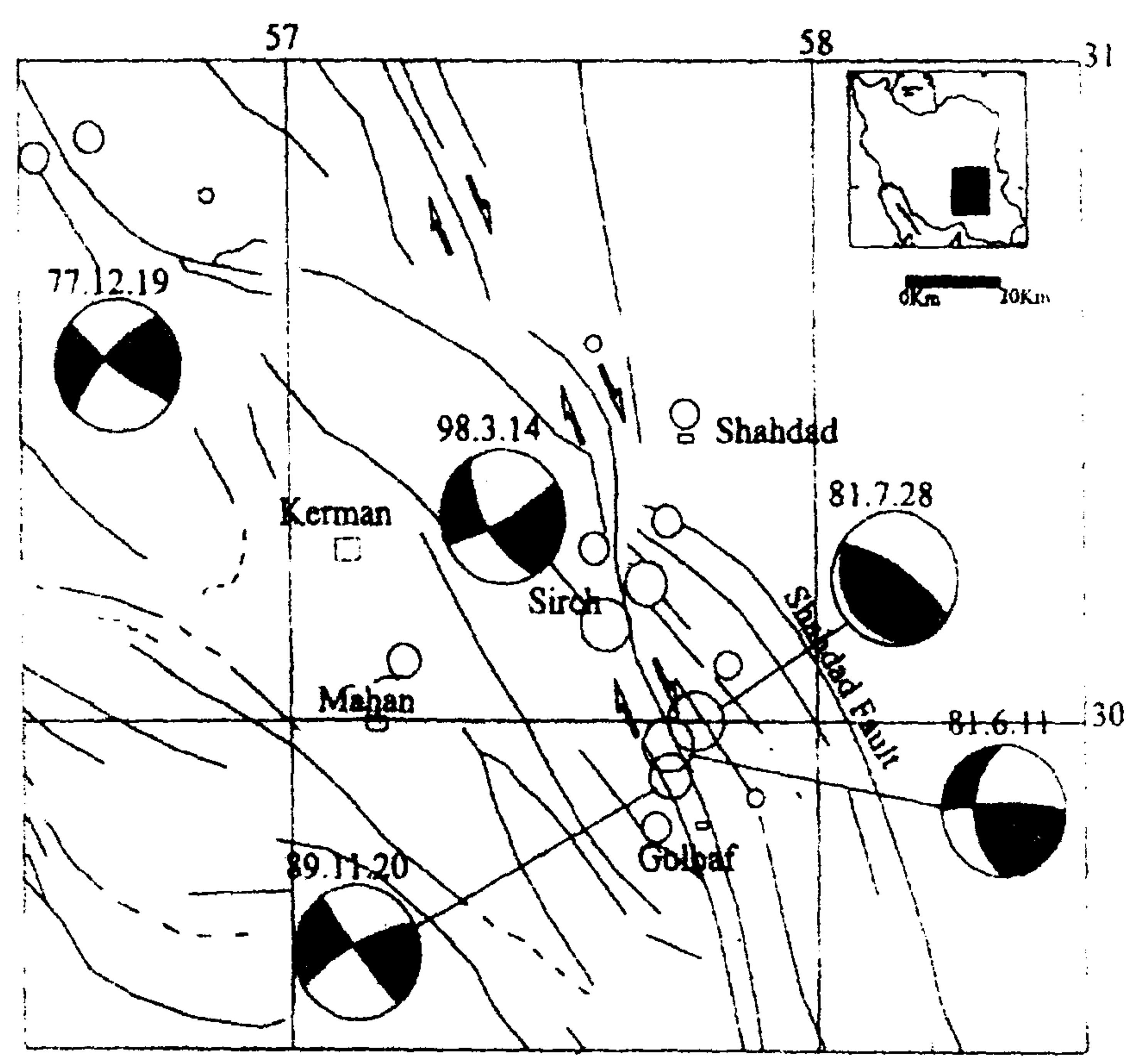

Figure 2. Epicenters and mechanisms of strong earthquakes and their causative faults in Kerman region (reproduced from Gheitanchi, 1999a).

4. Source parameters of mainshock

The magnitude, origin time and the hypocentral location were given by several agencies for the mainshock. This information is summarized in table 1. Among these agencies, USGS and Harvard University as their routine work published the source mechanism immediately after the occurrence of the mainshock. The centroid moment tensor solution for a best double couple point source given by USGS shows two nodal planes striking N56E (dipping 89 SE) and N146E (dipping 58). Another solution was given by Harvard University indicating two nodal planes striking N61E (dipping 85 SE) and N154E (dipping 57). Both solutions indicate predominantly strike-slip mechanisms and are in agreement with the mechanism of other earthquakes in this region. The seismic moment calculated by USGS (M_0 =7.7 $\times 10^{25}$ dyne-cm) is smaller than evaluated by HRVD (M_0 =9.4$\times 10^{25}$ dyne-cm). To provide better constraints on the source parameters of the mainshock, we analyzed the combined body and surface waves from 18 GDSN stations which are in a good azimuthal coverage and used a modified version of the centroid moment tensor solution (Kawakatsu, 1995). The best double couple for final solution showed two nodal planes striking N61.8E (dipping 63.28 SE) and N 158.9E (dipping 76.2 SW). The seismic moment was calculated to be M_0=1.02$\times 10^{26}$ dyne-cm and the moment magnitude was Mw=6. The source parameters obtained by USGS, the University of Harvard and Berberian et al (2001) as well as the result of this study are given in table 2.

The mainshock was followed by several moderate aftershocks which caused minor damage in the affected area. The strongest of them, with mb=5.2, occurred on the 18th November 1998 and damaged houses at Chahar Farsakh, 45 km north of the mainshock region and was associated with surface cracking near the north end of the Gowk fault system (Berberian et al., 2001). In order to study the aftershock activity, a temporary seismic network was deployed within the meizoseismic area one week after the occurrence of the mainshock by the Institute of Geophysics in Tehran University and the seismic activity was monitored for forty-five days. The network included five portable digital system PDAS and four analog PS2. More details such as the location of seismic stations and the process of data as well as the source parameters of aftershocks were given in a preliminary report (Soltanian et al, 1998). About 1595 aftershocks were recorded by the local seismic network during forty-five days. Out of this number, 680 were located. The analysis of these aftershocks indicated that the seismicity appears to be more scattered than along a fault zone. Aftershocks extended over an approximately 40 km long zone with a general NW-ES elongation following the trend of main fault system. The depth of aftershocks extended down to 20 km but the high concentration seemed to be down to 15 km. The epicentral distribution and the cross sections of aftershocks along and across the main fault are given in figure 3 and figure 4.

5. Teleseismic bodywave modeling

To obtain more details of the source process of the mainshock we modeled the P and S digital waveforms observed at thirty GDSN stations within the epicentral distance from 30 to 90 degrees. The S-waves were rotated in order to obtain the transverse component for the SH analysis. The records with a duration of 60

Table 1. The magnitude, origin time and the hypocentral location given by several agencies for the mainshock.

Name	Date	Origin time	Lat.	Long.	Dep.	Mb	Ms	Mw
MOS	1998 03 14	19h 40m 30.4s	30.117	57.618	33.0	6.6	6.5	--
EID	1998 03 14	19h 40m 28.0s	30.101	57.503	00.0	5.3	6.8	--
BJI	1998 03 14	19h 40m 27.1s	30.320	57.520	10.0	5.7	7.3	--
NEI	1998 03 14	19h 40m 27.0s	30.154	57.605	09.0	5.9	6.9	6.6
ISC	1998 03 14	19h 40m 31.8s	30.161	57.612	43.5	5.8	6.7	--
HRV	1998 03 14	19h 40m 34.2s	30.950	57.600	15.0	--	--	6.6

Table 2. The source parameters obtained by USGS, the University of Harvard and Berberian et al (2001) as well as the result of this study.

Name	Strike	Dip	Rake	Strike	Dip	Rake	M0 (dyne-cm)
USGS	149	66	-179.0	58.0	89	-24.0	7.7*10**25
HRVD	153	65	-176.0	61.0	86.0	-25.0	9.6*10**25
Berberian et al	156	54	-165.0	--	--	--	9.1*10**25
This study	158.9	76.2	-152.4	61.8	63.2	-15.5	1.02*10**26

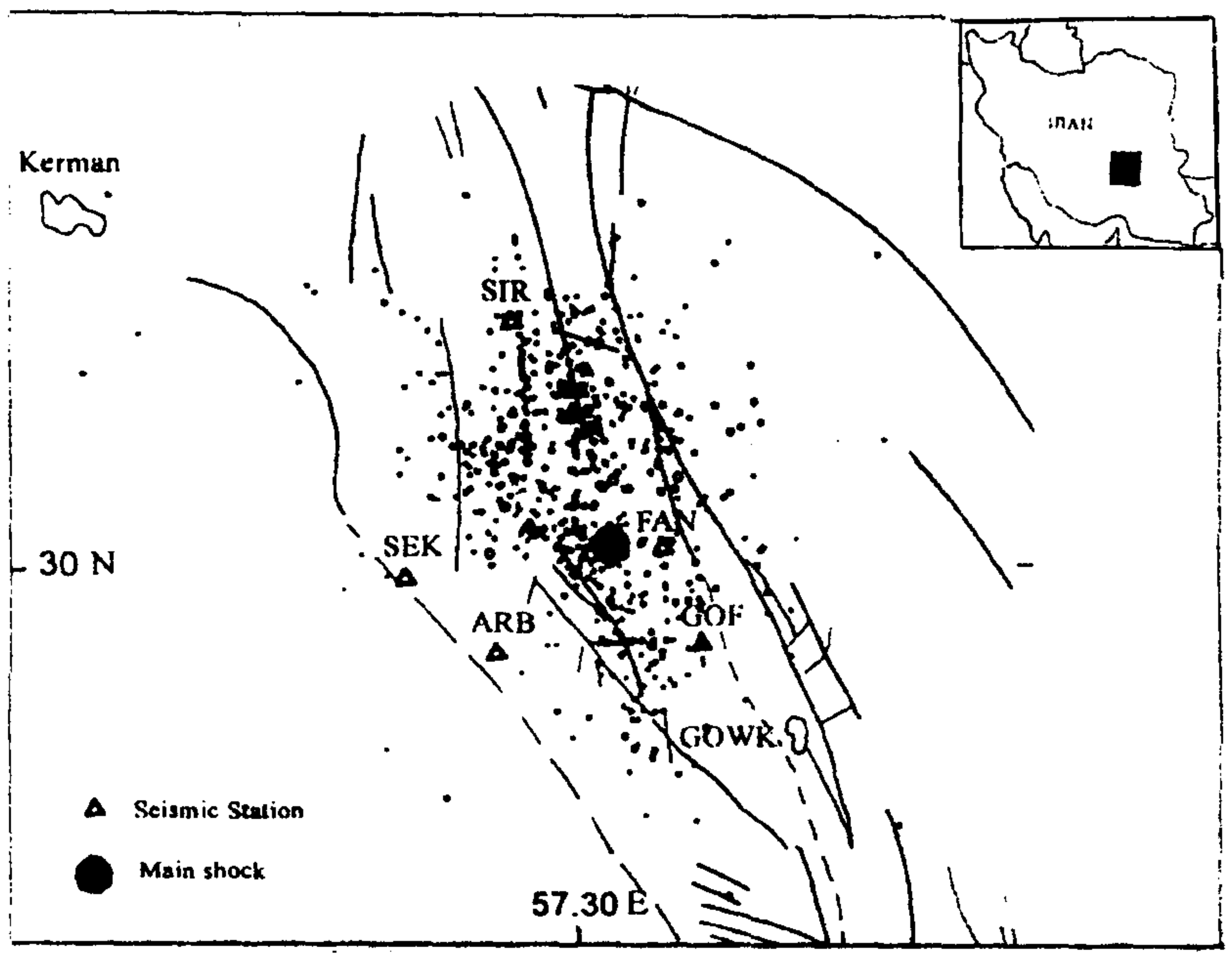

Figure 3. The surface faulting and the location of temporary seismic stations as well as the epicenteral distribution of locally recorded aftershocks (reproduced from Soltanian, et al, 1998). The instruments were installed in Golbaf (GOF), Fandoqa (FAN), Sirch (SIR), Sekonj (SEK), and Arab-Abad (ARB).

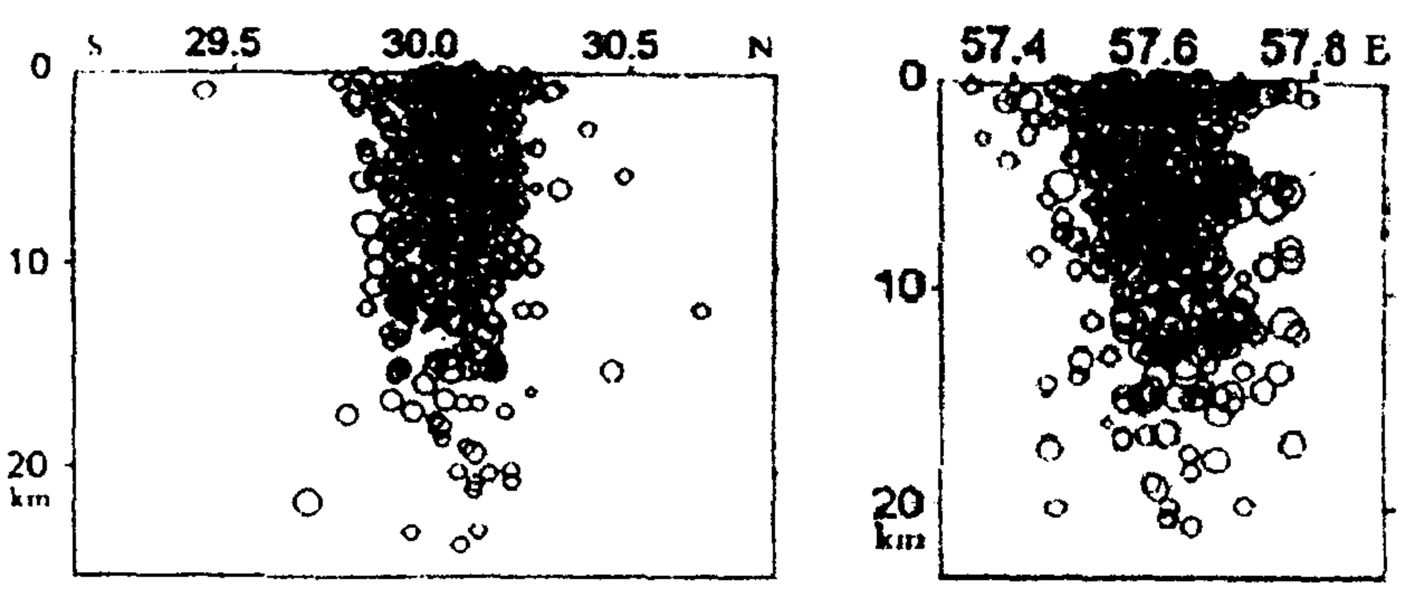

Figure 4. Cross section of aftershocks along the fault in north-south direction is shown in left figure. Cross section across the fault in east-west direction is shown in right figure. The location of mainshock is indicated by a star in both figures.

seconds and a sampling interval of 1 second after P and SH arrival times were converted to the ground displacement and were inverted to their sources to investigate the rupture process. The double-couple point source, represented by moment tensor was determined iteratively by matching the observed with the synthetic ones (Kikuchi and Kanamori, 1991). In calculating the synthetic wavelet for a point dislocation we used the Jeffreys-Bullen model (Jeffreys and Bullen, 1958). We assumed a singlet and obtained the pulse width of a source time function from the initial part of the recorded waveforms. The source time function of triangular shape having a rise and process time of 6 seconds (3 seconds each) was best fitted. Then, with fixed source time function, the data was inverted for the depths fixed at 5, 10 and 15 km. The focal depth of 10 km, indicated the best fit of the synthetic waveforms to the observed waveforms and minimized the residual error, while the sP phase as well as the P and pP phases were included in producing synthetic waveforms. We performed one iteration because the residual error did not decrease remarkably for more than one iteration and a single source model could describe the initial 60 seconds of recorded waveforms. By examining several crustal models, a three layer structure with crustal thickness of 42 km was found to have a minimum approximation error and best fit. The seismic moment was calculated to be $M_0 = 7.1 \times 10^{25}$ dyne-cm. Rupture during this earthquake initiated in the epicentral area and extended in a bilateral manner. This result could be understood from the contour lines of the correlation function for the final solution which is shown in figure 5. The selected examples of

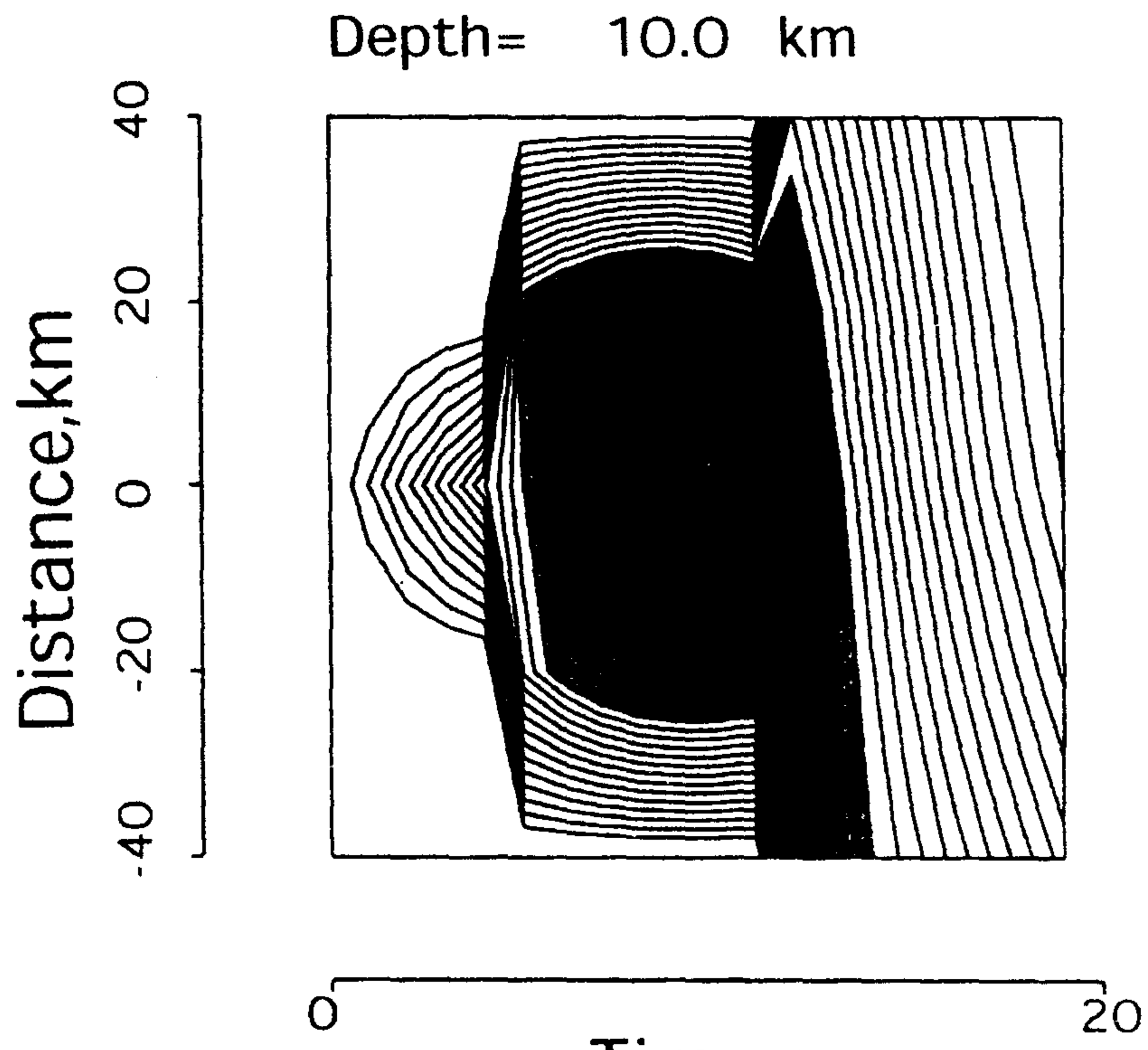

Figure 5. Contour lines of the correlation function for the final solution.

6. Discussions and Conclusion

The waveform modeling indicated that the 1998 Fandoqa earthquake was a single source with a right-lateral strike-slip mechanism having a small normal component very similar to the result of the CMT solution. This mechanism is consistent with the geological and seismological observations and the investigation carried out by Berberian et al (2001). In our previous study of the two destructive earthquakes, which occurred within 47 day in 1981 devastating the towns of Golbaf, Sirch and Chaharfarsakh, we calculated the shear strains produced by the first earthquake around its activated fault and indicated that significant accumulation of shear strain (or earthquake-generating stress) preceded the occurrence of the second earthquake. It was concluded that this fact should have had an appreciable effect on the mechanical state in the focal region and played some role in the occurrence of the following earthquakes. Now, the 1998 March 14 Fandoqa earthquake occurred in the area where the stress field was increased by the previous earthquakes. Moreover, as inferred from our waveform modeling in the previous study, the 1981 July 27 Sirch earthquake was a multiple source having two major subevents. The first subevent had a pure reverse mechanism but the second subevent had a large strike-slip component which was consistent with observed severe destruction as well as maximum displacements and could explain the sense of rupture (Gheitanchi, 1999b). The mechanism of the second subevent of the 1981 Sirch earthquake is very similar to the 1998 Fandoqa earthquake suggesting that these two events should correspond to the same fault system. This was confirmed by the field report indicating that the 1998 ruptures closely followed the trace of the surface faulting in the 1981 July 27 Sirch earthquake (Berberian et al., 2001). The triangular source time function having a rise and process time of 6 seconds, which was best fitted for this study, agrees well with the results given by Berberian et al. (2001) who indicated that about 80 per cent of the moment was released in the first 6 seconds. The seismic moment obtained from bodywaves, in this study, was $M_0 = 7.1 \times 10^{25}$ dyne-cm at a depth of 10 km for the centroid. Berberian et al. (2001) got the seismic moment 9.1×10^{25} dyne-cm at a depth of 5 km for the centroid. This tradeoff is entirely expected as at a shallower depth greater moment is needed.

The distribution of locally recorded aftershocks generally followed the trend of the fault system but had a diffused pattern suggesting that the nearby faults were activated so as to readjust the stress field around the epicentral area that had been perturbed by the occurrence of the mainshock. This phenomena was observed in the case of the 1981 earthquakes in this region by computation of the shear strains produced by the first earthquake in 1981 around its activated fault (Gheitanchi, 1999b).

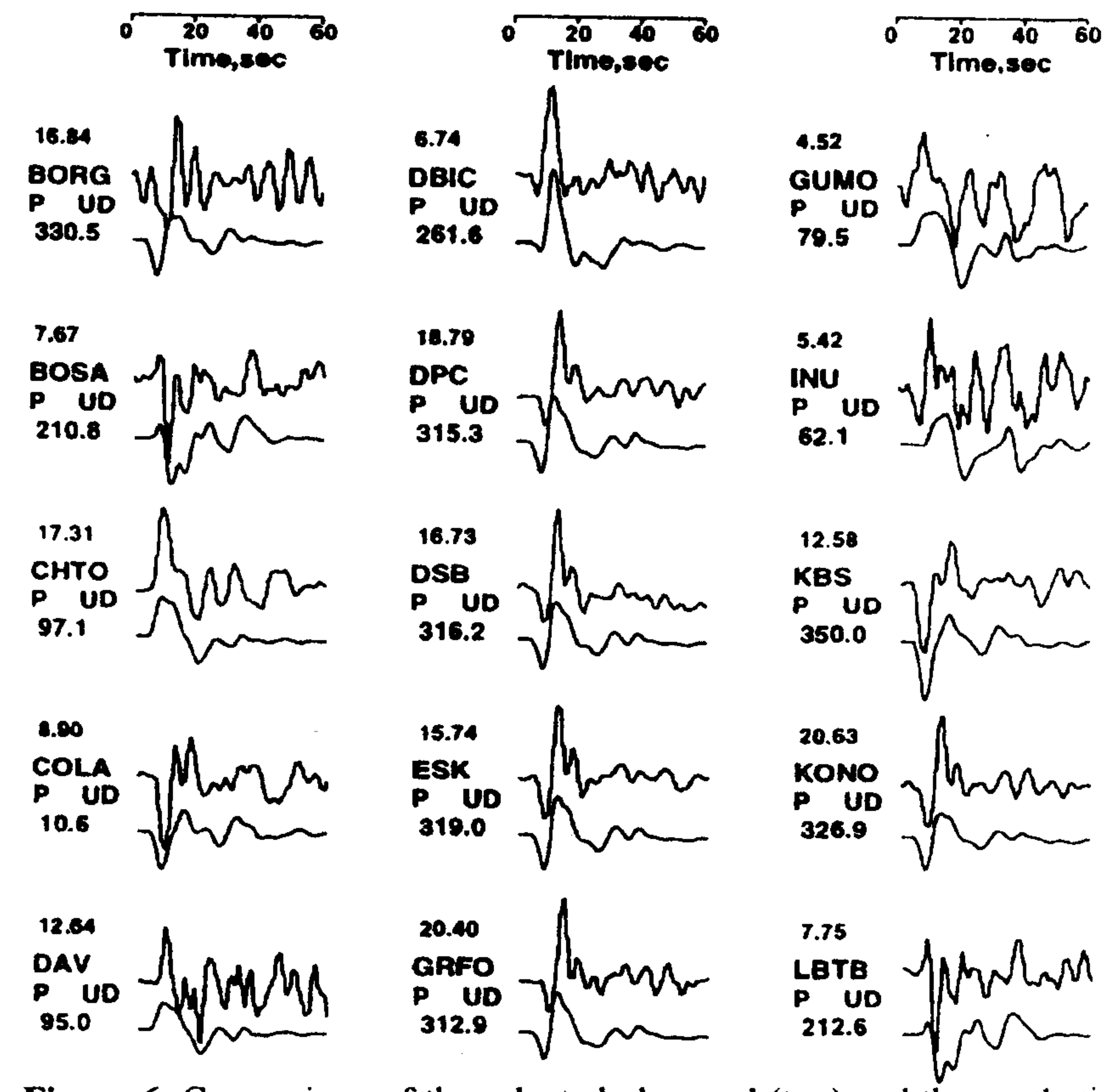

Figure 6. Comparison of the selected observed (top) and the synthetic (bottom) P-waveforms for the final solutions of the 1998 Fandoqa mainshock. The correlation coefficient, the name, component and azimuth of station are given on the left side of each waveform.

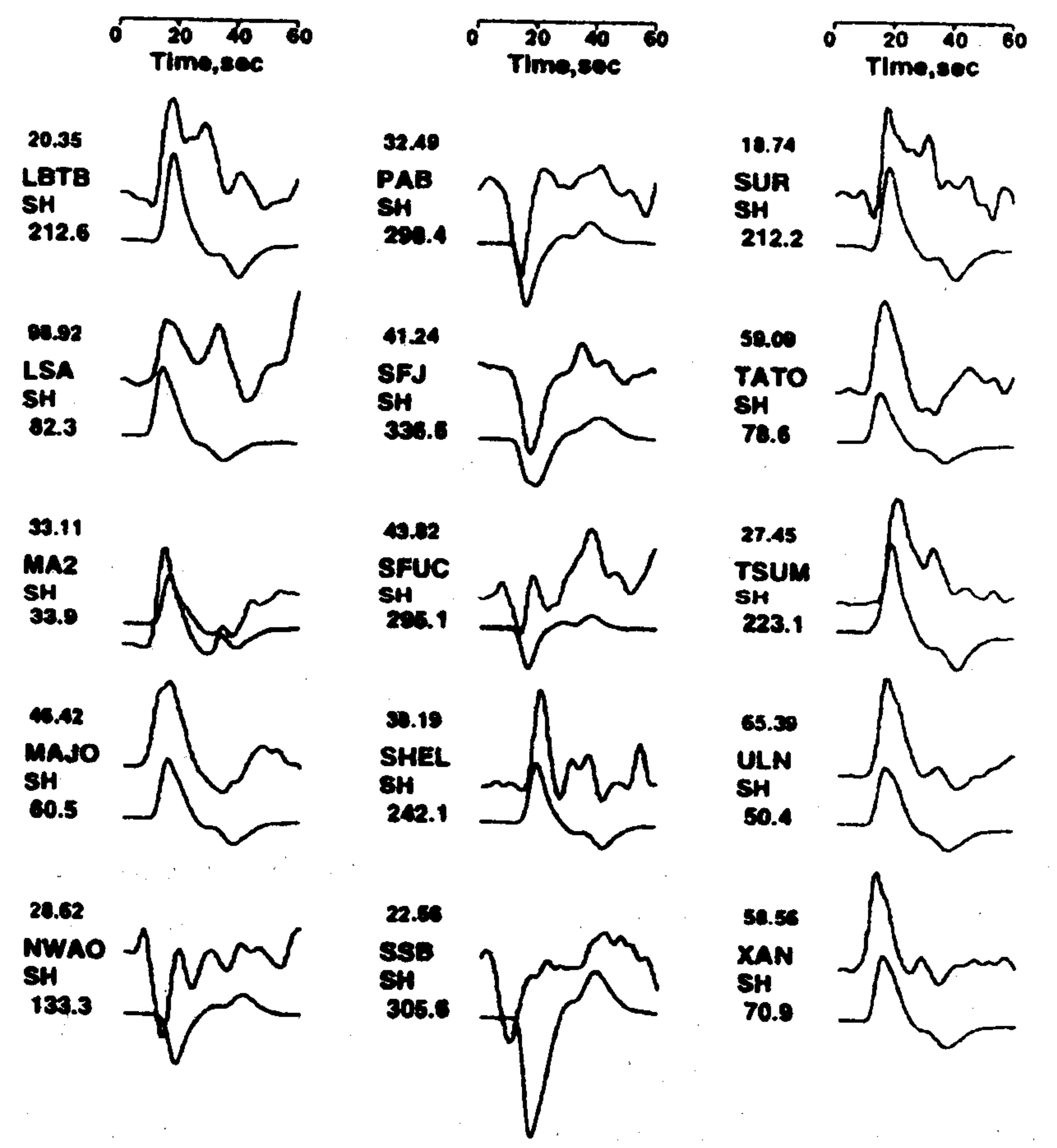

Figure 7. Comparison of the selected observed (top) and the synthetic (bottom) SH-waveforms for the final solutions of the 1998 Fandoqa mainshock. The correlation coefficient, the name, component and azimuth of station are given on the left side of each waveform.

Acknowledgements

The author would like to thank Prof. Kawakatsu for offering his program to perform the centroid-moment tensor solution. He also appreciates the critical review and helpful comments he received from Prof. J. Jackson and Prof. M. Ghorashi. The digital waveforms of GDSN were copied from IRIS in the computer Centre of Earthquake Research Institute of Tokyo University. The author is also grateful to Prof. M.Kikuchi for useful discussions and reviewing the manuscript. This work was partially supported by the research project No. 652/1/501 from the Institute of Geophysics and the office of the vice chancellor for research. I would like to extend my thanks to Prof. K. Shimazaki of the Earthquake Reseach Institute at the university of Tokyo for his logical support during my short stay in Tokyo for this work.

Reference

Ambraseys, M. M., and Melville, C. P., 1982, A history of Persian earthquakes: Cambridge University Press, P.219.

Berberian, M., Jackson, J. A., Fielding, E., Parsons, B. E., Priestley, K., Ghorashi, M., Talebian, M., Walker, R., Wright, T. J., and Baker, C., 2001, The 1998 March 14 Fandoqa earthquake (Mw 6.6) in Kerman province, southeast Iran: re-rupture of the 1981 Sirch earthquake fault, triggering of slip on adjacent thrusts and the active tectonics of the Gowk fault zone: Geophys. Jour. Int., **146**, 371-398.

Berberian, M., Jackson, J. A., Ghorashi, M., and Kadjar, M. H., 1984, Field and teleseismic observation of the 1981 Golbaf-Sirch earthquake in SE Iran: Geophys. J.R. Astr. Soc., 77, 809-838.

Gheitanchi, M. R., 1999a, Strong earthquakes in Kerman Province, south-east Iran: Proceedings of the third international conference on seismology and earthquake engineering, Tehran, I.R. Iran, IIEES.

Gheitanchi, M. R., 1999b, Characteristics of the Golbaf and Chaharfarsang-Sirch, South-East Iran, Earthquakes: Jour. Earth & Space Phys., **25**, 1-9.

Gheitanchi, M. R., Kikuchi, M., and Mizoue, M., 1993, Teleseismic interpretation of the 1968 Dasht-e Bayaz, NE Iran, earthquake: Geophys. Res. Lett., **20**, 245-248.

Ghorashi, M., and Talebian, M., 1998, Golbaf (Iran) earthquake of 14 March 1998 A Preliminary Field Report: First Iran-Japan Workshop on Recent Earthquakes in Iran and Japan Workshop on Recent Earthquakes in Iran and Japan, May 16-18, 1998, Tehran, I.R.Iran.

Jeffreys, H., and Bullen, K. E., 1958, Seismological tables: Office of the British Association, Burlington House, London.

Kawakatsu, H., 1995, Automated near-realtime CMT inversion: Geophys. Res. Lett., **22**, 2569-2572.

Kikuchi, M., and Kanamori, H., 1991, Inversion of complex body waves-III: Bull. Seis. Soc. Am., **81**, 2335-2350.

Mirzaei Alaviyeh, H., Farzanegan, E., and Rahimian, M., 1998, *A* Preliminary Report on the earthquake of Golbaf – 14 March 1998: Building and Housing Research Center, Report No. 284.

Soltanian, S, Ghasemi, H, Sharif, M., Haj-Moradkhany, M., and Kosrovieny, M., 1998, A Preliminary Report on the aftershock activity of the March 14 1998 Golbaf, Kerman Earthquake: Inst. Geophys., Tehran Unv., Int. Rep., Tehran.