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Magnitude scale in the Tabriz seismic network

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Abstract

To record local earthquakes, the telemetric-digital seismic network of the Tabriz comprising of eight three component seismic stations was installed in the north-west of Iran. This array started operation at the end of 1995. Investigation of archived data in the Tabriz seismic network between 1999 to September 2004 shows that magnitude values in the database have not been determined using a single formula or a specific method. Comparison of magnitude values in the database with those values that have been published in the ISC/NEIC bulletin shows that magnitude values calculated in the Tabriz network are underestimated for events occurred in greater distances. By using magnitude values in the database and corresponding $m_b^{ISC/NEIC}$ (m_b^{ISC} or m_b^{NEIC}) values, a scale as M =log (v/4π)+2.6log (Δ)-2.2 is derived for determination of the magnitude in distance range of 170 to 1000 km, where v is peak-to-peak amplitude in micrometer/second and Δ is epicentral distance in kilometers. This formula gives a better estimate for the magnitude of events in comparison with the formula that is presently used in the Tabriz seismic network.

Keywords: Seismic network, Magnitude, Database, Tabriz

1 INTRODUCTION

Richter (1935) introduced the universally accepted basis of magnitude as proportional to log(amplitude). A large number of magnitude scales have been developed since then (e.g. Båth, 1981, Kanamori, 1983), most of them are similar to Richter's scale in the sense that they are based on the logarithm of some amplitude measurement. It is well known that earthquake-magnitude scales do not directly represent any physical parameters of the source. However, they represent the relative scale of earthquakes. During the last 50 years, many seismic networks have been installed. Most of the seismic networks or individual stations use their own formula for magnitude determination.

Earthquake magnitudes are both convenient and widely available, although the idea is based solely on an empirical relationship. Earthquake magnitude is routinely estimated by large data centers, such as the International Seismological Centre (ISC), the National Earthquake Information Center (NEIC) of the US Geological Survey, and by many national networks and at individual stations. Magnitude scales are normally estimated in two frequency bands: high-frequency body-waves with periods around one sec (for m_b and M_L) and low-frequency surface-waves with periods around 20 sec (for M_s).

In order to monitor seismic activity, the telemetric-digital seismic network of the Tabriz comprising of eight three-component seismic stations was installed in the central part of northwest Iran. The network stations have been selected to be in remote areas, away from noise and in good situation from a geological viewpoint and possibly to cover major faults in the area. The coordinates of seismic stations are given in Table 1, and in Figure 1 location of stations are shown on a shaded relief map of the region. This network started operation in late 1995.

The recorded waveforms in the Tabriz network are analyzed using Data Analysis Program (DAN), which has been produced by Nanometrics Company. It works under OS/2 in 32 bits or SUN workstations (DAN User's Guide, 1995). The method employed in this software for determining magnitudes is the use of maximum amplitude measurements from short-period stations, with no site correction. In this article, the bias in the magnitude values, which have been determined in this network is investigated, then a revised scale is derived for use in the Tabriz seismic network.

Table 1. Seismic stations of the Tabriz network.

Station Name	Station Code	Latitude N	Longitude E	Elevation M
Tabriz	TAB	38° 14′	46° 08′	1650
Heris	HRS	38° 20′	47° 03′	2100
Sarab	SRB	37° 50′	47° 40′	1950
Hashtrud	HSH	37° 18′	47° 16′	2100
Bostanabad	BST	37° 41′	46° 53′	2100
Azarshahr	AZR	37° 41′	45° 59′	2300
Shabestar	SHB	38° 14′	45° 37′	2150
Marand	MRD	38° 43′	45° 43′	2150

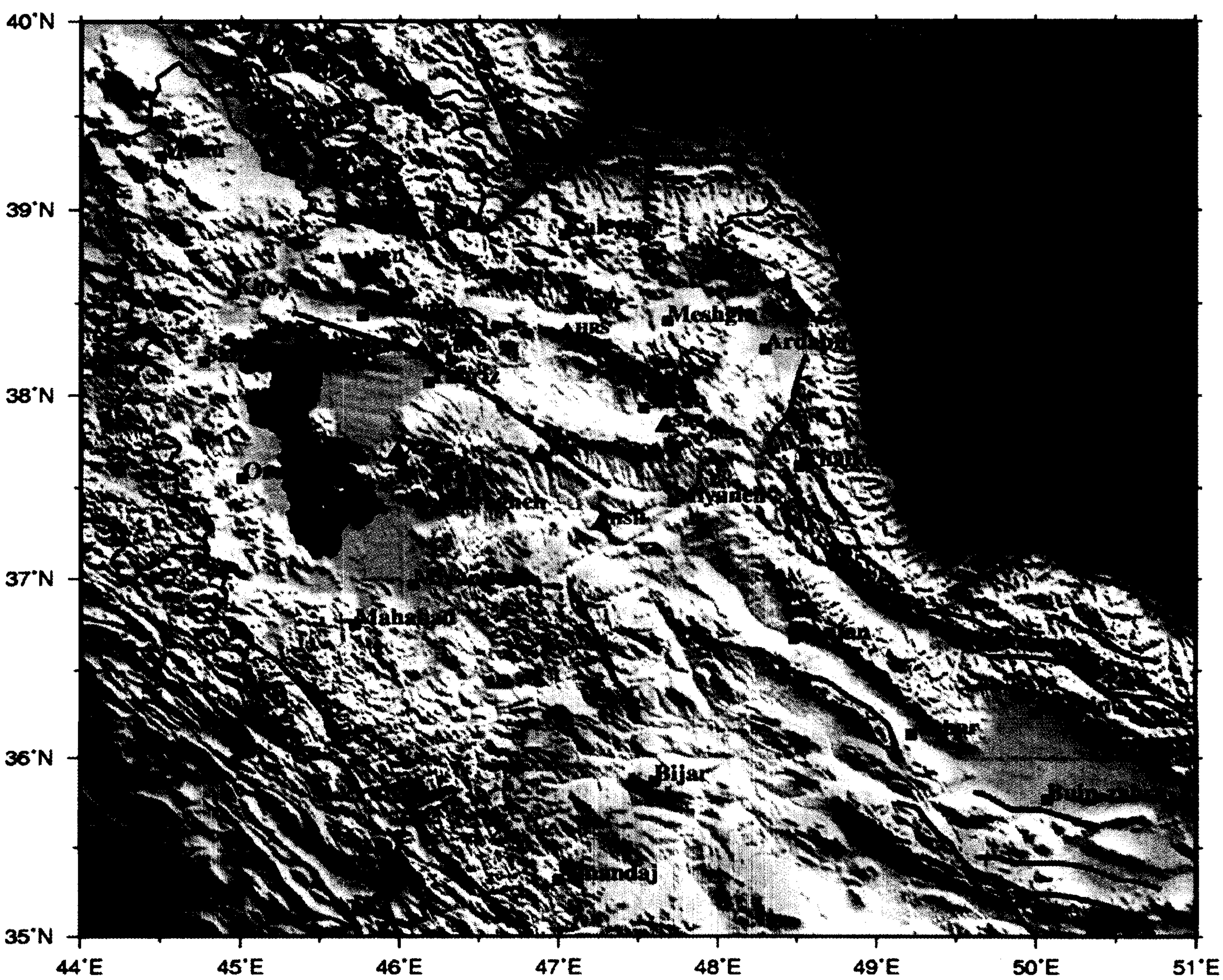

Figure 1. Shaded relief map of the north-western part of Iran. Triangles indicate the position of three component stations; squares show major towns; the major faults are also shown by color curves.

2 DATA

Recorded digital waveforms in the Tabriz network are analyzed using software which is based on two widely used earthquake location programs: a standard implementation program of Hypo71 (Lee et. al., 1972; Lee and Lahr, 1975) and LOC (a location program developed by the Geological Survey of Canada). In the center of the network the extracted catalogue data from waveforms such as event location, epicentral distance, arrival time of P and S phases, maximum amplitude, etc. are archived. Unfortunately, essential data such as phase-amplitude, epicentral distance, etc. have been not archived for some recorded events during 1995-1999. These data have been archived since late 1999. From 1999 to September 2004 more than 3379 events were recorded and analyzed, but no bulletin data from this seismic network has been published. In the database, amplitude values are available only for 2329 events. The histograms of a number of stations which contributed in locating of events and also a number of stations in which their amplitude values are archived in the database are shown in Figure 2a. As this figure shows for about one thousand events amplitude values of measured phase have not been archived, and for these events we cannot re-determine magnitude values, unless amplitude data for these events are extracted again from waveforms.

Magnitude-frequency of estimated values in the network is shown in Figure 2b. Distribution of events with magnitude equal and greater than 2.0 were plotted over the fault map of the region in Figure 3.

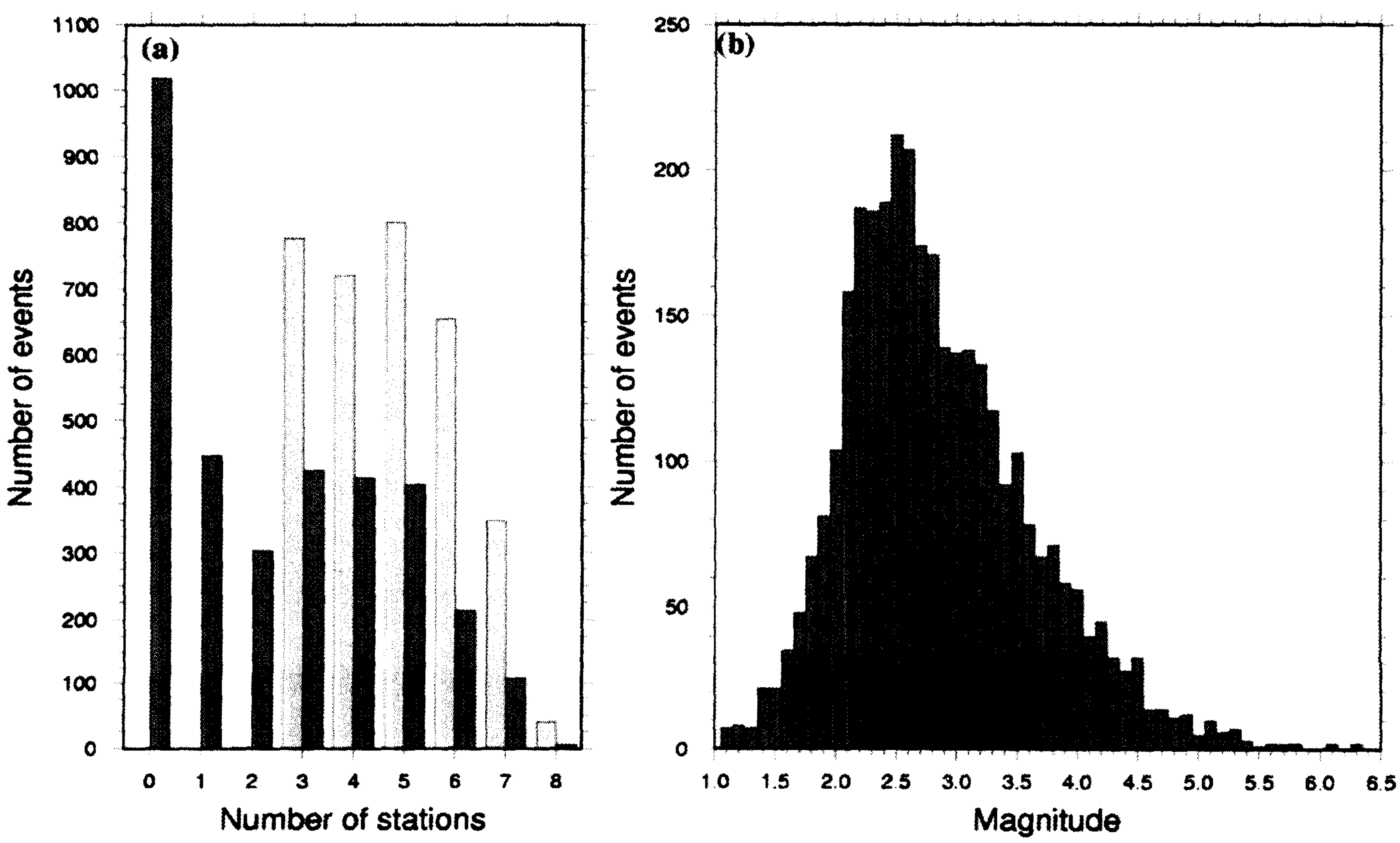

Figure 2. (a) Distribution of events versus number of stations. yellow and gray histograms are plotted respectively for located events in network and for available amplitude data. Histogram over station number zero means, in used dataset amplitude values in none of recorded stations for 1025 events have not been archived, however for these events magnitude values have been reported by network. (b) The magnitude-frequency histogram of recorded events since 1999 to September 2004.

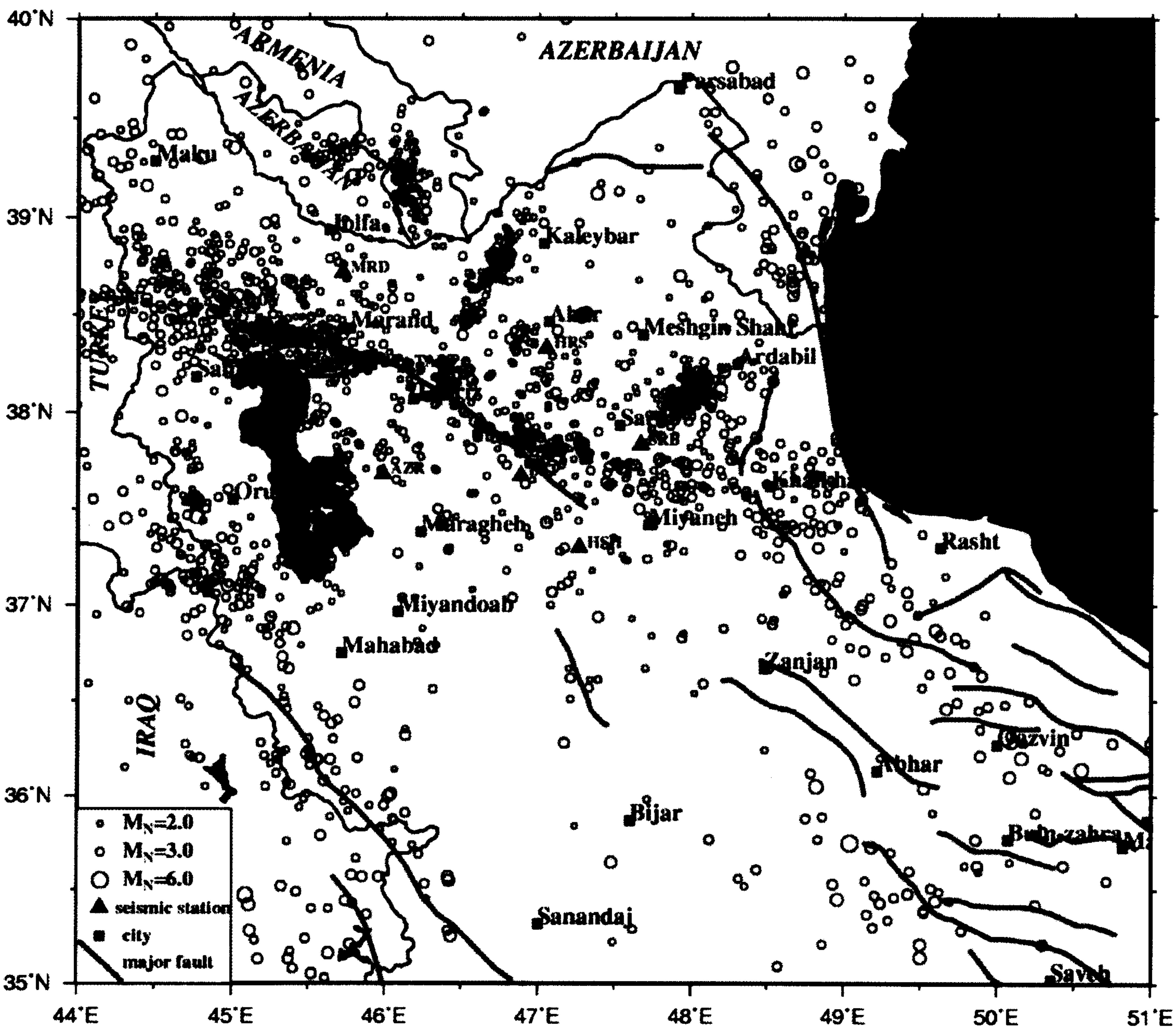

Figure 3. Distribution of 2503 events with $M_N \geq 2.0$ recorded from 1999 to September 2004, which occurred in area 35°N-40°N , 44°E-51°E, over the major fault map of region. The radius of circles is proportion to the magnitude values.

Figure 3 shows that concentration of events is large around the Tabriz fault, southeast of the volcanic Saballan mountain and western part of the Ahar. When events with magnitude $M_N \leq 2.5$ are excluded, concentration of data in some parts is significantly reduced.

The epicentral location and origin time of recorded events in the Tabriz network from 1999 to September 2004 were compared with those in ISC/NEIC bulletin. Those epicentral estimates whose absolute value of differences are ≤ 0.5 degree in both latitude and longitude and absolute value of differences in origin times are ≤ 10 seconds were assumed to be the same event. 82 events with available $m_b^{ISC/NEIC}$ and M_N were selected in this way, then listed in table 2. Data in ISC bulletin is available to April 2003. So, in table 2 data since April 2003 was extracted from NEIC bulletin. For m_b determination in both ISC and NEIC agencies (m_b^{ISC} or m_b^{NEIC}) the same formula and depth-distance calibration terms $Q(\Delta,h)$ of Gutenberg and Richter (1956) are used.

Table 2. List of 82 selected events in this study.

Data from Seismic Network of the Tabriz								Data from ISC or NEIC Bulletin							
Date	Origin-t	LAT	LONG	M_N	RMS	ERLAT	ERLONG	Origin-t	LAT	LONG	mb	RMS	SMAJ	SMIN	AZ
19990219	180008.4	38.52	44.68	4.5	.00	.005	.014	180015.7	38.81	44.51	4.3	1.24	6.7	3.9	0
19990904	204549.5	40.07	50.82	4.0	.04	.021	.029	204550.0	40.26	50.84	4.5	.92	5.1	2.6	0
20000226	104132.6	37.55	44.77	4.1	.06	.015	.039	104139.4	37.34	44.53	3.9	1.43	8.3	8.4	90
20000308	014551.7	40.60	52.31	4.2	.04			014554.4	40.68	51.95	4.5	.85	6.2	3.2	0
20000309	142936.3	41.18	47.59	3.8	.07			142942.6	41.01	47.65	3.8	1.33	16.4	10.6	0
20000321	140741.9	40.04	48.20	5.1	.01			140743.3	40.05	48.20	5.0	1.07	3.8	2.0	0
20000410	034236.2	38.12	48.19	4.5	.04	.018	.064	034240.4	38.07	48.11	3.9	1.27	10.5	6.2	0
20000507	231053.4	37.95	38.49	4.0	.02			231053.3	38.15	38.85	4.4	1.16	2.4	2.8	90
20000609	161055.7	41.89	49.20	3.8	.03	.144	.109	161059.2	41.87	49.63	3.8	1.32	6.9	7.4	90
20000624	005541.2	31.54	50.65	3.2	.03	.004	.005	005544.5	31.81	50.85	4.2	1.12	5.9	4.3	0
20000703	050816.9	36.07	54.85	3.5	.05	.063	.040	050816.5	35.94	54.79	4.1	.73	21.5	11.3	0
20000822	165518.0	37.75	57.10	4.8	.07	.048	.016	165514.7	38.13	57.39	5.1	1.10	3.3	1.7	0
20000907	073231.9	38.44	44.99	4.3	.00	.000	.001	073233.7	38.47	45.08	3.9	.98	10.8	12.0	90
20000911	165448.0	35.39	44.90	4.7	.09	.043	.032	165455.5	35.67	45.18	4.5	1.05	4.0	2.8	0
20000927	034358.1	41.08	49.69	3.9	.03	.011	.012	034358.5	41.09	49.59	4.6	1.08	4.4	3.0	0
20001006	062014.0	37.10	44.97	4.5	.01	.003	.004	062022.0	37.10	45.23	4.1	.99	8.7	5.0	0
20001125	180905.0	40.24	50.37	5.4	.08	.018	.034	180911.5	40.22	49.94	5.7	1.04	2.3	1.4	0
20001125	184913.0	40.11	50.26	4.2	.05	.011	.028	184913.2	40.09	50.12	4.4	.95	6.9	3.5	0
20001125	202536.4	40.17	50.26	2.9	.00	.010	.018	202533.8	40.14	50.14	3.7	1.11	13.7	8.1	0
20001125	210108.7	40.06	50.13	2.7	.01	.020	.039	210105.5	40.12	50.09	3.6	1.10	14.9	9.7	0
20001125	221507.1	40.32	50.03	3.1	.01	.016	.027	221504.7	40.22	49.95	3.8	1.12	11.1	7.1	0
20001126	001821.1	40.10	50.00	2.8	.00	.016	.033	001820.8	40.08	50.12	4.0	.95	11.1	5.7	0
20001201	140825.4	40.45	50.18	3.4	.01	.020	.033	140827.2	40.27	50.03	4.0	1.17	9.5	12.1	90
20001202	154259.4	40.12	50.46	3.4	.04	.018	.013	154300.3	40.14	50.20	3.9	.79	13.0	14.4	90
20001206	171104.1	39.60	54.82	6.0	.01	.045	.274	171106.6	39.49	54.81	6.7	1.01	2.1	1.2	0
20001224	163019.7	40.23	50.29	3.5	.02	.006	.008	163022.5	40.17	50.06	3.5	1.16	13.7	8.5	0
20001225	030014.5	40.48	50.33	3.4	.00	.000	.000	030017.0	40.25	50.08	4.2	.88	10.7	5.0	0
20010115	161246.1	39.67	55.03	4.0	.08	.057	.124	161253.2	39.40	54.74	4.0	1.31	7.2	3.4	0
20010121	171022.5	40.21	50.36	2.9	.02	.009	.014	171027.1	40.63	50.00	3.8	1.26	10.3	5.4	0
20010201	024251.7	38.77	44.54	4.2	.13	.050	.035	024253.9	38.66	44.60	4.0	1.29	4.8	5.1	90
20010323	052412.9	32.89	46.42	4.9	.01	.000	.000	052412.0	32.88	46.60	5.1	1.25	2.7	1.8	0
20010329	063250.2	32.99	46.45	3.5	.02	.574	.018	063252.2	33.07	46.65	4.4	.90	5.8	5.0	90
20010403	173641.4	32.84	47.97	4.9	.08			173633.7	32.48	48.00	5.0	1.00	3.0	1.8	0
20010429	163407.2	40.13	48.75	3.9	.00	.000	.000	163409.4	40.04	48.52	4.0	1.14	6.8	4.4	0
20010528	085652.6	35.57	45.96	3.9	.01	.035	.011	085701.2	35.75	46.06	3.8	1.19	12.4	7.0	90
20010612	014648.4	39.12	47.38	4.7	.06	.014	.012	014652.2	38.99	47.26	4.6	1.21	4.8	3.6	0
20010617	112211.1	39.21	45.78	4.5	.00	.001	.001	112215.1	39.04	45.81	4.1	1.45	3.9	4.9	90
20010811	144501.6	37.34	43.87	4.1	.03	.005	.010	144510.9	37.19	44.30	3.8	1.43	10.8	8.2	90
20010812	004205.0	37.45	44.31	4.1	.02	.003	.009	004208.7	37.23	44.17	4.2	1.26	3.0	3.4	90
20010813	020520.2	35.13	45.37	3.9	.01	.029	.012	020524.7	35.23	45.43	4.2	.92	11.2	6.7	90
20010912	145206.8	37.92	43.03	3.5	.02	.016	.132	145202.9	37.91	42.74	4.0	1.41	5.4	5.4	90
20011029	100448.1	38.84	48.92	4.4	.04	.046	.114	100451.1	38.79	48.60	4.5	.86	3.0	3.9	90
20020105	144343.5	37.41	48.92	4.6	.03	.022	.018	144342.7	37.67	49.00	4.4	1.09	3.8	4.8	90
20020106	062225.1	37.87	48.95	4.3	.00	.001	.001	062226.8	38.24	48.95	4.2	.89	7.3	4.2	0
20020124	072356.0	38.92	48.72	3.9	.00	.003	.006	072400.0	38.76	48.46	3.7	1.33	13.1	8.6	0
20020204	015326.4	41.42	43.92	4.0	.02	.014	.030	015330.3	41.11	44.10	4.0	1.39	4.1	4.3	90
20020305	065419.6	38.39	45.40	4.2	.06	.007	.038	065426.8	38.33	45.24	4.3	1.44	6.1	7.2	90
20020306	191302.1	38.58	44.44	3.8	.00	.001	.003	191301.6	38.53	44.36	4.1	1.45	8.0	4.3	0
20020314	083044.9	38.94	44.38	3.8	.00	.001	.001	083042.6	39.34	44.61	3.8	.98	8.2	8.8	90
20020314	125705.5	39.16	44.44	4.2	.01	.008	.020	125659.3	39.34	44.18	4.3	1.30	4.2	4.6	90
20020407	225021.9	38.35	45.07	4.6	.00	.000	.000	225030.6	38.40	45.25	4.5	1.21	4.9	3.0	0
20020424	201003.6	34.90	47.61	4.1	.00	.024	.007	201000.4	34.49	47.34	4.8	1.17	3.1	2.4	0
20020622	025824.1	35.75	49.04	5.7	.00	.000	.000	025821.5	35.59	49.02	6.2	1.18	1.8	1.2	0
20020622	033156.7	35.45	48.96	4.3	.07	.000	.000	033201.6	35.59	49.01	4.4	1.22	6.0	5.4	90
20021019	155708.0	39.17	55.42	4.4	.06	.033	.024	155709.8	39.09	54.97	5.0	1.04	5.1	2.4	20
20021110	232451.3	35.74	44.71	3.5	.00	.012	.009	232442.2	35.38	44.73	4.0	1.01	16.5	9.0	41
20021209	075057.8	36.88	45.40	4.6	.00	.000	.000	075058.4	36.46	45.09	4.7	1.25	4.6	3.0	6
20021224	170309.2	34.86	47.37	4.5	.13			170303.9	34.49	47.45	5.1	1.17	3.5	2.3	35
20021224	221721.6	34.84	47.41	4.0	.08	.031	.032	221716.9	34.44	47.36	4.6	1.08	5.3	3.9	29
20030111	174524.9	29.62	51.79	4.1	.07	.058	.062	174528.3	29.67	51.51	5.2	1.17	4.7	2.3	14
20030220	142300.2	38.58	45.11	3.7	.00	.000	.000	142306.7	38.35	45.01	4.2	.99	17.7	10.4	110
20030227	223639.2	38.36	44.01	4.0	.08	.016	.048	223643.8	38.34	44.15	4.3	1.18	9.0	7.9	18
20030605	171401.8	38.42	45.14	4.2	.01	.001	.004	171405.0	38.59	45.12	4.3				
20030811	201209.7	38.67	45.24	4.7	.08	.028	.062	201208.9	38.83	44.88	4.7				
20031020	062654.3	38.60	45.03	4.7	.02	.002	.002	062651.0	38.65	44.57	4.8				
20040208	125404.1	41.68	47.40	3.9	.01	.019	.005	125401.1	41.31	47.40	4.1				
20040519	004711.0	39.79	53.61	3.1	.01	.006	.004	004717.7	40.10	53.31	4.0				
20040523	024907.2	40.83	48.77	3.2	.00	.024	.028	024913.0	40.77	48.56	4.1				

20040528	131504.5	36.40	51.65	3.7	.02	.019	.009	131506.3	36.37	51.50	4.4
20040528	194701.1	36.36	51.53	4.2	.05	.035	.019	194702.7	36.44	51.41	4.5
20040529	041240.0	36.61	51.56	3.1	.08	.089	.072	041234.7	36.38	51.64	4.4
20040529	045302.4	36.32	51.54	3.5	.04	.052	.026	045300.4	36.51	51.19	3.9
20040529	092348.2	36.37	51.54	4.3	.02	.009	.007	092347.7	36.40	51.37	4.7
20040529	183801.3	36.21	51.66	4.3	.05	.027	.015	183805.8	36.46	51.32	4.3
20040529	225518.2	36.59	51.57	3.4	.01	.011	.004	225516.7	36.47	51.43	4.3
20040530	014239.6	36.15	51.58	3.8	.03	.078	.048	014238.7	36.40	51.51	4.3
20040530	130954.1	36.47	51.42	3.9	.08	.040	.023	130952.4	36.53	51.36	4.2
20040607	040123.0	36.59	51.47	3.7	.05	.056	.026	040120.1	36.44	51.34	4.3
20040701	223008.3	39.69	43.64	4.7	.00	.023	.038	223009.3	39.77	43.98	5.4
20040702	125634.4	35.53	48.93	3.6	.00			125644.3	35.57	48.91	4.0
20040730	071400.4	39.89	43.69	4.6	.02	.007	.005	071407.8	39.63	43.97	4.8
20040810	081742.5	40.18	44.12	3.9	.03	.265	.262	081748.3	39.80	43.93	4.4

M_N = Calculated magnitude using equation (2)
ERLAT = Error of latitude in degrees.
ERLONG = Error of longitude in degrees.
RMS = Root Mean Square of time residuals in seconds.
m_b = Body wave magnitude in ISC/NEIC Bulletin.
SMAJ = Semi-major axis of 90% ellipse in km.
SMIN = Semi-minor axis of 90% ellipse in km.
AZ = Azimuth of Semi-major axis of ellipse.

3 MAGNITUDE DETERMINATION

Nuttli (1973) introduced an m_{bLg} magnitude scale specifically designed for Eastern United States earthquakes using 1-sec period L_g amplitudes recorded on narrow-band short-period vertical component, WWSSN (World Wide Standardized Seismographic Network) seismograms. The use of the short-period vertical component L_g arrival to determine magnitude has been adopted by many of the local and regional networks. In a number of network bulletins including the Tabriz network this magnitude is known as M_N, where the N denotes Nuttli. In some networks M_N is applied to situations outside its definition, e.g., to instruments other than WWSSN short-period and to waves with much greater than 1-sec period.

Understanding the procedure of magnitude determination and formula used as a scale has an important role in investigation of capability of formula used or method. We should be able to obtain the same magnitude values by using the same formula and the same data that have been used while extracting bulletin data from waveforms.

Investigation of the database shows that determination of magnitude values in the whole database is not uniform. For some events recalculated magnitudes values using amplitude data of recorded stations are different from those values archived in the dataset.

There is no a clear documented reference for magnitude formula which has been used in DAN software. (The source codes of DAN are not accessible). It seems that in the Tabriz seismic network most magnitude values have been determined using a modified form of the m_{bLg} scale (Nuttli, 1973) as

$$M_N = \log(\frac{A}{2}) + 1.66\log(\Delta) - \log(T) - 0.1 \qquad (1)$$

where A is peak-to-peak amplitude of wave which has the largest amplitude (maximum to minimum) whatever it is Lg or S phases on vertical component seismograms in microns, Δ is the epicentral distance in kilometers, and T is the period of measured phase in seconds. The L_g wave travels with group velocities of 3.3 to 3.5 km/sec and is the largest arrival on the seismogram. Although L_g is a surface wave, comparing its level of excitation with the level of the short-period P waves and the long-period surface waves suggests that it is more closely related to m_b than to M_S. The value of 1.66 in equation (1) has been obtained by making the m_b values from the 1-sec L_g waves equal to those found from telesesimic P or P_n waves (Nuttli, 1973). In the Tabriz network, the stations are equipped with short period SS-1 seismometers, which is a velocity meter. So in the database instead of displacement (A), velocity of ground (v) have been archived in micrometer/second, the equation (1) after replacing A by v ($A=v/2\pi = vT/2\pi$) and omitting log (T) term becomes

$$M_N = \log(\frac{v}{2\times 2\pi}\times T) + 1.66\log(\Delta) - \log(T) - 0.1 = \log(\frac{v}{4\pi}) + 1.66\log(\Delta) - 0.1 \qquad (2)$$

The $m_b^{ISC/NEIC}$ (m_b^{ISC} or m_b^{NEIC}) versus M_N values for selected data, is plotted in Figure 4. This Figure shows that magnitude values of M_N are smaller than $m_b^{ISC/NEIC}$ values. The regression line was plotted assuming the same variance in $m_b^{ISC/NEIC}$ and M_N using the York method (1966), to account uncertainties in both abscissa and ordinate. The equation of regression line is

$$m_b^{ISC/NEIC} = (0.83825 \log \pm 0.13183) M_N + (0.96445 \pm 0.53079) \quad (3)$$

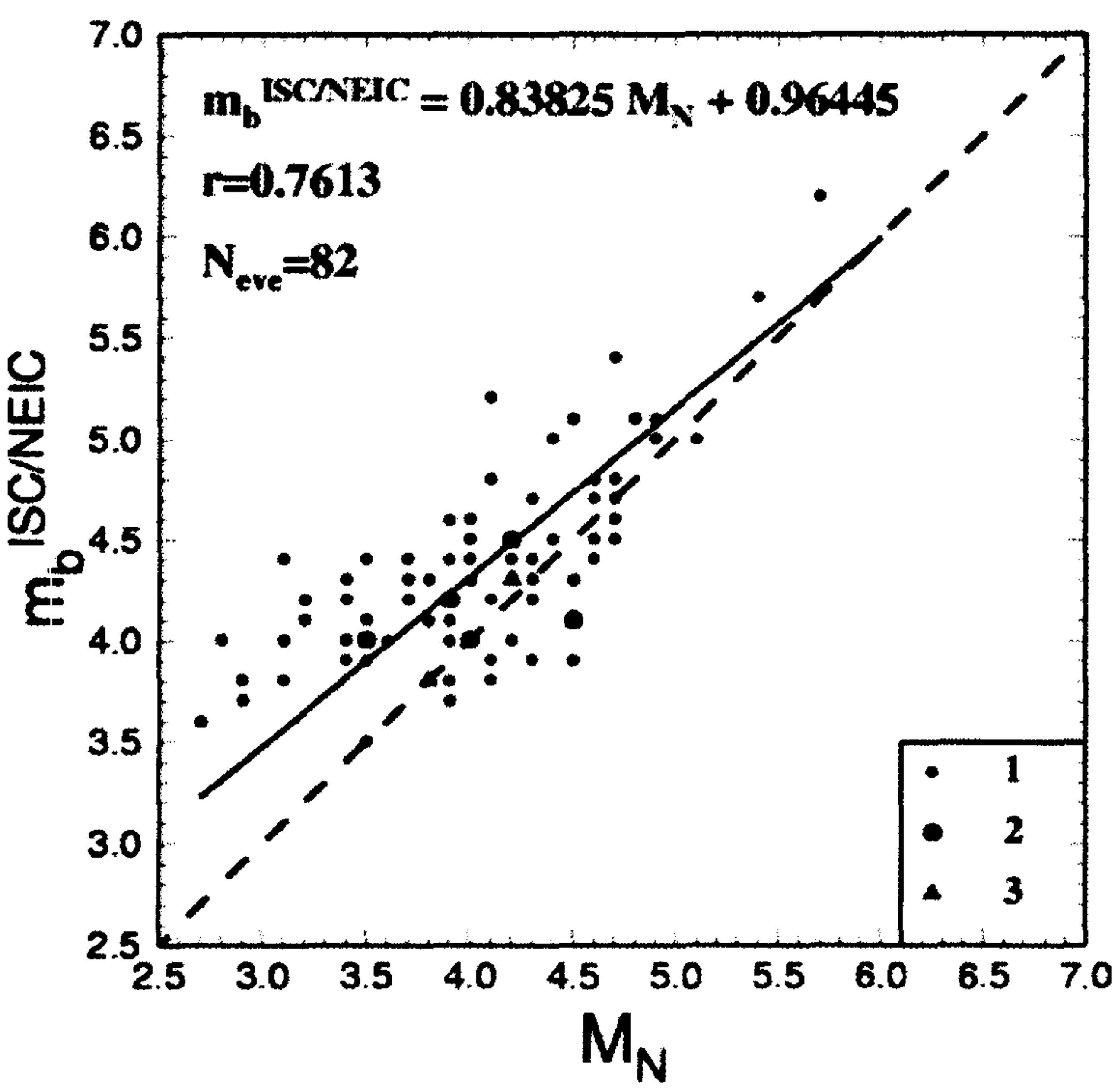

Figure 4. $m_b^{ISC/NEIC}$ versus M_N for 82 events. The dashed line shows the locus of equality, and the regression line is shown by a solid line. Symbols indicate the number of data points as shown. r=correlation coefficient, N_{data}= number of station data, and N_{eve} = number of events.

Substituting equation (2) into equation (3) gives

$$m_b^{ISC/NEIC} = 0.8383 \log(\frac{V}{4\pi}) + 1.3915 \log(\Delta) + 0.8806 \quad (4)$$

Replacing first side of this equation by M_L gives a scale as

$$M_L = 0.84 \log(\frac{V}{4\pi}) + 1.4 \log(\Delta) + 0.88 \quad (5)$$

The M_L scale should be tied to the Richter (1935) M_L scale for southern California. Since here the M_N values are used, then M_N values are calibrated with $m_b^{ISC/NEIC}$ scale, and the obtained magnitude formula is expressed by M.

By using $m_b^{ISC/NEIC}$ values of selected events, we can obtain an empirical formula for M determination in the Tabriz network. However, researches have shown that the published magnitude values in the ISC and NEIC bulletins for small events ($m_b^{ISC} \leq 4.8$) due to used depth-distance correction terms are underestimated (e. g., Rezapour, 2003). To approach this purpose, a formula is assumed as

$$M = \log(\frac{A}{2}) + C_1 \log(\Delta) + C_2 - 0.1 \log(T) = \log(\frac{V}{4\pi}) + C_1 \log(\Delta) + C_2 \quad (6)$$

where its form is similar to the general form of most magnitude formulae. To obtain constants of C_1 and C_2 , $m_b^{ISC/NEIC}$ is replaced with M, then $m_b^{ISC/NEIC}$-log(v/4π) values are plotted against log(Δ) for 385 individual data in Figure 5a. It is well known that the result of linear regression analysis is affected by concentration of data. To remove concentration of data effect, the individual $m_b^{ISC/NEIC}$-log(v/4π) values were averaged over log(Δ)=0.05 intervals. The averaged data are plotted in Figure 5b with error bars.

As figure 5a shows the data point at distances about Δ<100 km are insufficient. These data were excluded in regression analysis. A linear regression for these averaged data gives

$$m_b^{ISC/NEIC} = \log(\frac{V}{4\pi}) = (2.5991 \pm 0.0972) \log(\Delta) - (2.1996 \pm 0.2449) \quad (7)$$

The coefficients of C_1 and C_2 in equation (6) are equaled to 2.6 and – 2.2 respectively, and the simple form of equation (6) becomes

$$M = \log(\frac{V}{4\pi}) + 2.6 \log(\Delta) - 2.2 \quad (8)$$

Therefore, the following formula is suggested for use in magnitude determination in the Tabriz seismic network.

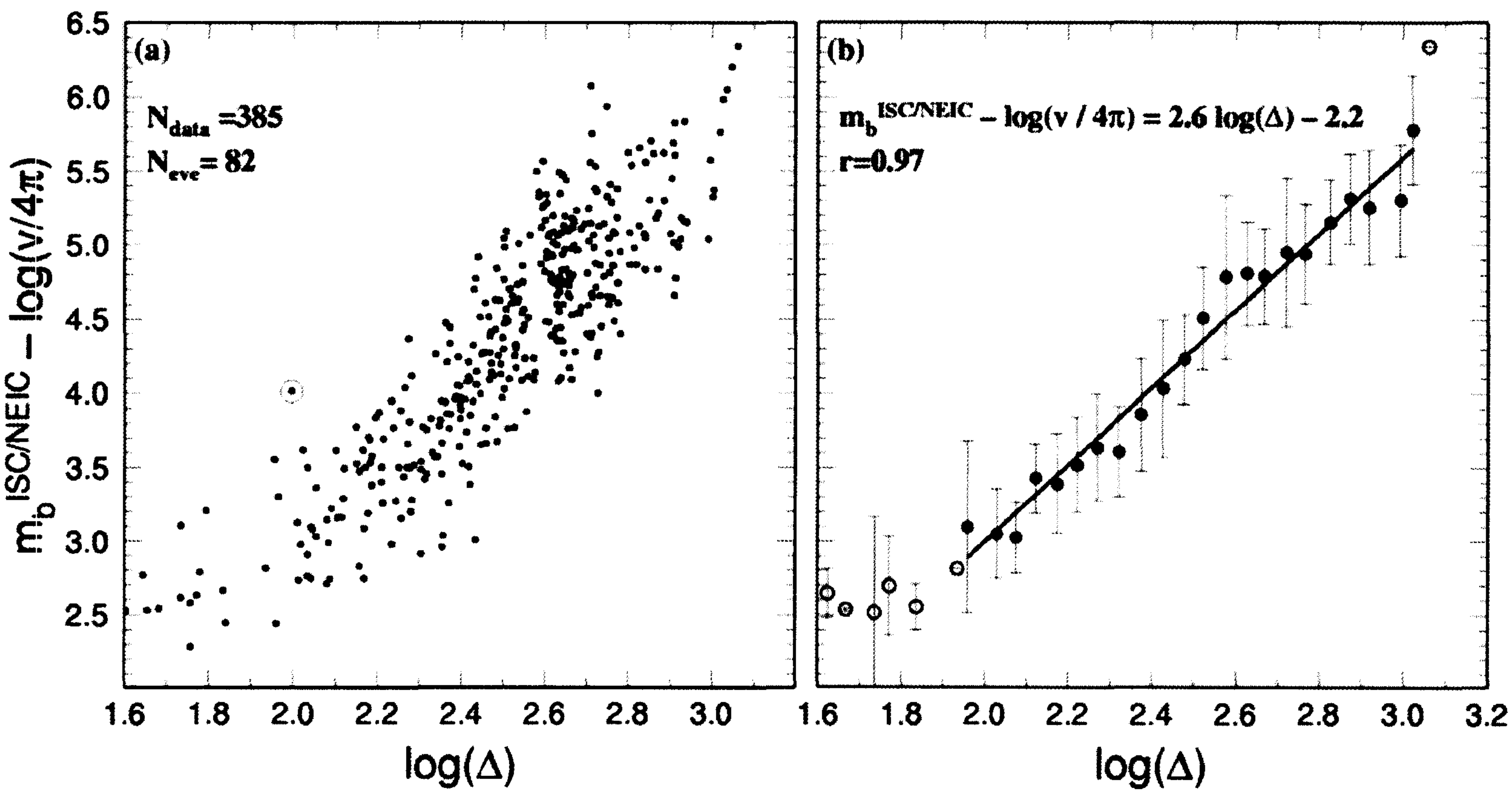

Figure 4. (a) $m_b^{ISC/NEIC}$-log (v/4π) versus log (Δ) for 385 individual data points. (b) Averaged $m_b^{ISC/NEIC}$- log (v/4π) values over 0.05 interval of log (Δ) with standard deviations. The circled event in (a) was thought to be in error and was not used in the averaging process. The solid line represents a linear regression fitted to the data as $m_b^{ISC/NEIC}$-log (v/4π)=2.6log (Δ)-2.2. The data points, which were used in regression analysis, are shown by filled circles. r = correlation coefficient, N_{data}= number of station data, and N_{eve} = number of events.

$$M = \begin{cases} \log(\frac{v}{4\pi}) + 1.66\log(\Delta) - 0.1 & \text{for } \Delta \le 170 \\ \log(\frac{v}{4\pi}) + 2.6\log(\Delta) - 2.2 & \text{for} \\ 170 < \Delta \le 1000 & \end{cases} \quad (9)$$

where v is ground velocity in micron per seconds, and Δ is epicentral distance in kilometers.

Magnitudes of events in the database were recalculated using equation (9). Comparison of these values with archived magnitude values in the database shows that equation (9) gives a better estimate of event size than equation (2), which is presently used in the Tabriz seismic network.

Theoretical attenuation curves for Airy phase (including the effects of spreading over a spherical surface and anelastic attenuation) versus log Δ are not linear. Thus, magnitude formulae of the form of equation (6) are valid only over a limited range of epicentral distance, for which the curve can be approximated by a straight line.

4 CONCLUSIONS

Investigation of the database used in this study shows that in the Tabriz network magnitude values have not been determined uniformly and have been determined using different formulae. Comparison of M_N values in the database with $m_b^{ISC/NEIC}$ values shows that estimated magnitude values at greater distances have been underestimated.

The M_N scale, which is presently, used in the Tabriz network is essentially designed for eastern North American earthquakes. The deviation of M_N from corresponding $m_b^{ISC/NEIC}$ values can be due to a difference in attenuation coefficients between the two regions in the distance range of 170 to 1000 km, although Nuttli (1973) tied it to the teleseismic m_b values. Nuttli (1980) showed that for 1-sec period P_g , S_n and L_g , the coefficient of anelastic attenuation has an average value of 0.0045 km^{-1}, which is greater than that

for eastern North America. In addition, M_N is applied to situations outside its definition, e.g., to instruments other than WWSSN short-period and to waves with much greater than 1-sec period.

For magnitude determination in the Tabriz network an empirical formula was derived by using published m_b values in ISC or NEIC bulletin. Application of this formula (eq. 9) to the database provides unbiased estimates of magnitude in comparison with equation (2) that is presently used.

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