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EARTH PHYSICS

NEW LOCAL MAGNITUDE CALIBRATION FOR VRANCEA (ROMANIA) INTERMEDIATE-DEPTH EARTHQUAKES

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Abstract. The purpose of this paper is to revise the local magnitude formula for the intermediate-depth Vrancea earthquakes. The new magnitude scale is based on the local magnitude scale defined by [9] and revised by [3]. The coefficients in the magnitude relation are determined through multiple regression method using as reference the duration magnitude scale previously used in routine magnitude estimation for the earthquakes occurred on the Romania territory. The amplitude (A) was measured on the horizontal components of broadband seismograms filtered to reproduce synthetic Wood-Anderson seismograms (in millimeters).

Key words: magnitude, Wood-Anderson amplitudes, earthquakes.

1. INTRODUCTION

The magnitude can be rapidly calculated from seismograms without detailed analysis. It was introduced as a simple and efficient way to define empirically the earthquake size, and not as a direct representation of a physical parameter.

To characterize the size of seismic events, one relative to the other, both empirical scales (such as magnitude scale) and physical model-based scales (such as seismic moment scale) are used. Choosing one or another of the procedures depends especially on the comparison purpose and on the data availability.

The magnitude problem becomes inevitably complex taking into account the dependence on type of waves (surface and body waves, coda waves etc.), focal depth (crustal, intermediate-depth or deep earthquakes), changes in seismic equipment, frequency content. It is very important to know that every magnitude scale has a private validity domain and different magnitude scales will give in general different values for the same event. These differences are an endless source of confusion for mass-media, who generally considers all magnitude scales together as the “Richter’s scale”.

The purpose of this paper is to revise the local magnitude formula for the intermediate-depth Vrancea earthquakes. The magnitude is a basic parameter to charactherize the seismotectonic of the Vrancea region, the seismic cycle evolution and early warning system [5, 6, 11, 10].

In order to calibrate and compare the magnitude scales used in the present work, we have to adopt a reference scale. For our study we have chosen the local magnitude scale defined by [9] and revised by [3].

Similar researches were made for Italian events [2] and Turkey earthquakes [1].

2. DATA SET

Romania seismicity can be divided into several epicentral areas such as: Vrancea, Fagaras-Campulung, Banat, Crisana, Maramures and Dobrogea. A cluster of intermediate-depth activity is located at the Carpathians Arc bend, while more diffuse seismicity in the crustal domain is spread along mountain belt and to the South-East of Vrancea (Fig. 1). Seismic activity at intermediate depth (60–180 km) in the Vrancea region is by far the most important as energy release and as effects. The earthquakes occur within a confined focal volume situated at the contact between three principal tectonic units: East-European Plate, Intra-Alpline subplate and Moesian subplate. Intense and still very dynamic processes at depth are releasing significant bursts of energy (a rate of 2–3 catastrophic earthquakes per century) which are felt over a very large and dense populated area.

For our analysis we selected a set of 467 intermediate-depth earthquakes from Vrancea seismic zone, recorded between 2007 and 2009, with duration magnitude M_D = 2.3–5.7. The events are located with HYPOPLUS software developed by [7]. The hypocenter depths are between 60 and 150 km.

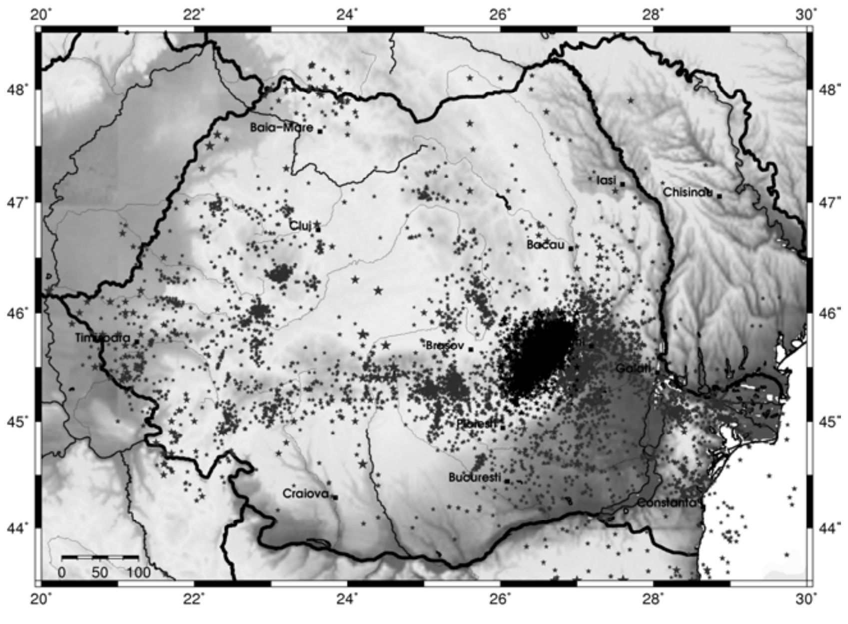

Fig. 1 – Romania seismicity between 984 and 2010. Black dots are epicenters of Vrancea intermediate-depth events; red dots are epicenters of crustal events.

We build a database of 2852 real Wood-Anderson amplitudes deduced from the available data. Maximum peak-to-peak amplitudes are measured on the horizontal components of the broadband sensors.

In this paper we used 33 broadband stations belonging to the National Seismic Network (Fig. 2). The amplitudes are automatically read for the first 3 seconds of the S-wave recording, using ANTELOPE 4.11 software.

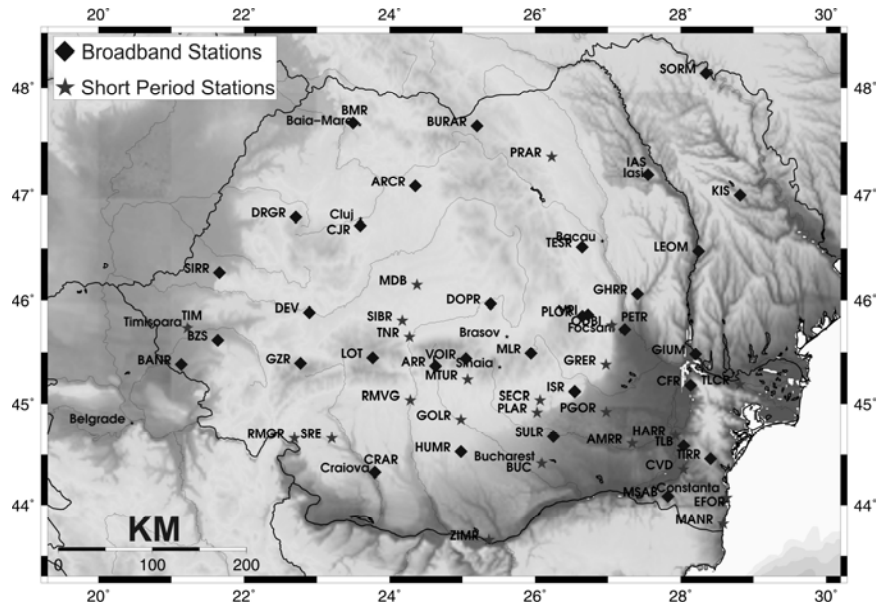

Fig. 2 – Distribution of the seismic stations used in this study.

3. METHOD

A new ANTELOPE real-time acquisition system has been implemented at the National Data Centre since 2002. In its original configuration, the system uses a unique magnitude formula for both crustal and subcrustal local events (independently of depth), of the form:

$$M_{\mathrm{Lant}} = C_0 + \log_{10}(A) + C_1 \log_{10}(\Delta) + C_2 \log_{10}(\Delta \cdot C_3 + C_4) + C_5\,, \qquad (1)$$

where: A is the maximum WA amplitude, Δ is the epicentral distance and C_0, C_1, C_2, C_3, C_4 and C_5 are coefficients.

Clearly, such a formula is not appropriate for intermediate-depth earthquakes, since focal depth parameter is not included. Therefore, we selected another type of magnitude formula:

$$M_L = C_1 \log_{10}(A) + C_2 \log_{10} R + \mathrm{C}_3 \cdot R - C_4, \qquad (2)$$

where: A – maximum amplitude, measured in mmwa; R – hypocentral distance (in km), $R^2 = \Delta^2 + h^2$; Δ – epicentral distance; h – focal depth, and C_1, C_2, C_3 and C_4 are coefficients to be determined by regression.

This is Richter's empirical relation (1958) revised by [3] and adopted by IASPEI working group.

The coefficients in equation (2) are estimated by multiple regression selecting as reference magnitude, the duration magnitude (M_D), calculated routinely with HYPOPLUS program [8] and adopted in the present Romania earthquake catalogue [7],

$$M_D = -C_1 + C_2 \log \tau + C_3\Delta + C_4 h, \tag{3}$$

where: τ – recording duration; Δ – epicentral distance; h – focal depth.

The application of the multiple linear regression analysis for the 2852 amplitudes measured by the selected stations for 467 events (each with 1 to 16 recordings for different seismic stations) let to the new magnitude calibration formula for Vrancea intermediate-depth events:

$$M_L = 0.5587 \log_{10}(A) + 1.7218 \log_{10}R + 0.0014 \cdot R - 0.2238. \tag{4}$$

4. RESULTS

We compare the new magnitude M_L values with the previous M_D values in Fig. 3. The regression line represented in Fig. 3 shows a good fit with the correlation coefficient of 94%. It is evident at the same time a tendency of the duration magnitude scale to overestimate the size of the larger earthquakes (the significant slope deviation from the first bisector).

The dependence of M_L magnitude as a function of amplitude is represented in Fig. 4 for the 467 selected events. As can be seen, the errors are larger at small magnitudes, as expected. We can conclude that the dispersion caused by the variation of hypocenter distance (R) is less important than dispersion caused by amplitude errors.

We test also the new magnitude relation with duration magnitude as obtained from duration measurement on analog seismograms at VRI and MLR stations (the stations of the Romanian seismic network with the longest time of operation). We selected to this aim 34 earthquakes recorded during 2007–2009 time interval with M_L = 3.5–5.3 magnitudes (Fig. 5). For the duration magnitude calibration a formula adopted after [4] was used:

$$M_{Dseis} = -0.87 + 2 \cdot \log \tau + 0.0035 \cdot A(\text{S-P}) \tag{5}$$

with S-P the difference between S-wave and P-wave travel times $A = 10.5$.

The comparison of the new magnitude relation with the previous formula from ANTELOPE software $M_{L\ ant}$ (Fig. 6) shows systematic differences especially below magnitude 4. The values become closer above this threshold. Up to this threshold, the magnitude values obtained with the old relation are much smaller than the values obtained now.

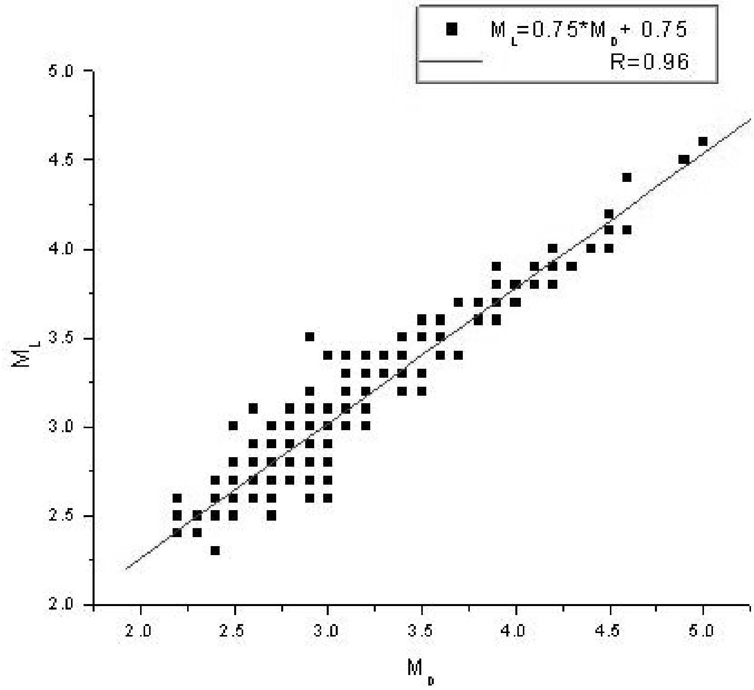

Fig. 3 – Linear fit between new magnitude M_L and duration magnitude M_D.

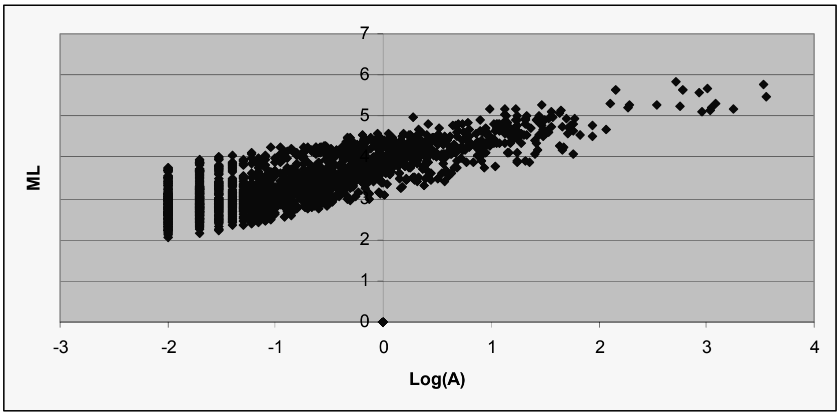

Fig. 4 – Dependence of M_L as a function of amplitude.

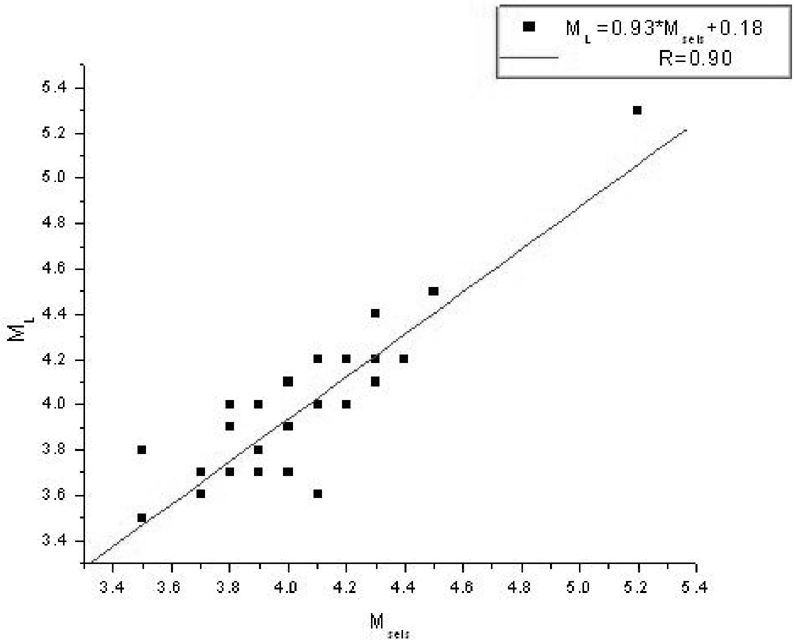

Fig. 5 – Linear fit between M_L and M_{seis} magnitude (M_L local magnitude obtained with the new coefficients, M_D – duration magnitude obtained from analog seismograms).

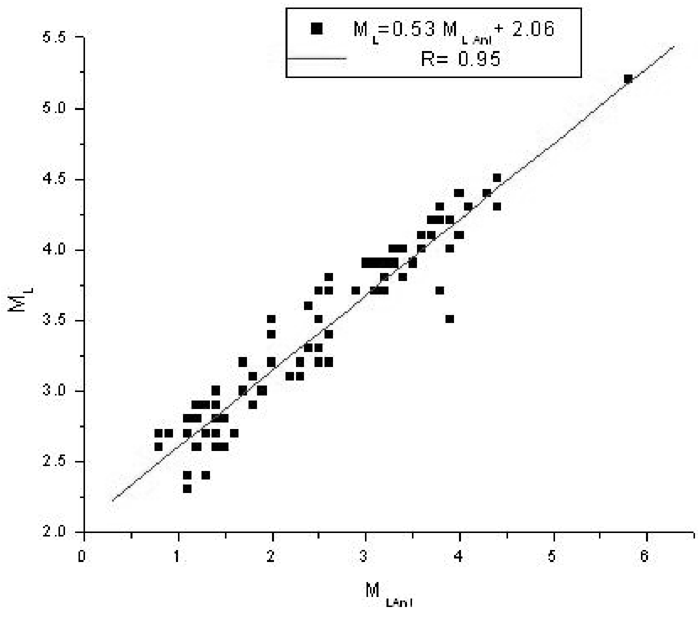

Fig. 6 – Comparison between local magnitude values obtained with the new coefficients and local magnitude values obtained with the old relation in ANTELOPE.

For a further test of the new magnitude formula we take into account a set of recent earthquakes occurred since November 2008 to January 2010 which is completely independent of the set used for calibration in (2). The results are summarized in Table 1 (a, b, c) for stations VRI and MLR. The duration is measured both on local analog seismograms at VRI and MLR and on the corresponding seismograms at the National Data Centre in Bucharest, after radio transmission of the signal.

Table 1

a) Analogical seismograms from stations around the country (empty spaces-lack of recordings)

Ev no.	DATA	Origin time	VRI			MLR		
			S-P	τ	M	S-P	τ	M
1	01.01.2010	13:11:46	16	73	3.4	16	90	3.6
2	02.01.2010	09:56:54	15	26	2.5	16	26	2.5
3	04.01.2010	19:55:21	14	110	3.8	14	100	3.6
4	06.01.2010	22:21:37	10	30	2.5	10	30	2.5
5	08.01.2010	10:07:20	12	65	3.3	13	70	3.3
6	09.01.2010	07:02:23	14	55	3.1	13.5	60	3.2
7	10.01.2010	01:44:14	11	23	2.4	13	30	2.6
8	12.01.2010	09:32:03	10	55	3	10	60	3.1
9	13.01.2010	05:29:06	15	40	2.9			
10	15.01.2010	00:19:02	14	45	3	16	60	3.1
11	15.01.2010	01:43:17	11	40	2.8	14	45	3.0
12	16.01.2010	06:16:08	10	27	2.5	10	20	2.1
13	21.01.2010	19:25:02	14	28	2.6	13	25	2.4
14	26.01.2010	17:55:30.	12	37	2.8	13	35	2.7
15	27.01.2010	04:42:21	14	90	3.6	14	83	3.5
16	30.01.2010	17:58:50				14	25	2.4
17	03.02.2010	10:32:55	12	40	2.8	13.5	35	2.7
18	04.02.2010	15:13:19	10	55	3	16	67	3.4
19	07.02.2010	13:27:15	15	70	3.4	16	65	3.3
20	25.02.2010	15:51:28	10	220	4.2	10	235	4.3
21	28.02.2010	18:55:12	15	98	3.7	16.5	120	3.9
22	03.03.2010	02:23:44						
23	13.03.2010	14:20:31	15	190	4.3	16	210	4.4
24	26.03.2010	18:36:48	10	380	4.7	10	410	4.7
25	05.04.2010	02:28:20	7.5	100	3.4	12	100	3.6
26	06.05.2010	04:50:58	11	110	3.7	12	125	3.8
27	08.06.2010	15:16:10	12	350	4.6	13	400	4.8
28	09.06.2010	03:42:59	17	100	3.8	16.5	150	4.1
29	25.04.2009	17:18:49	10	895	5.4			
30	27.05.2009	03:12:51	12	300	4.5			
31	12.04.2009	16:51:39	12	210	4.3	12	200	4.2
32	21.03.2009	22:08:58						
33	11.02.2009	03:02:56	10	105	3.6			
34	03.02.2009	02:57:07	15	50	3.1	15	55	3.1

Table 1 (continued)

35	30.01.2009	14:43:42	15	40	2.9	16	40	2.9
36	27.01.2009	07:23:51	13	30	2.6	13	35	2.7
37	13.01.2009	05:50:32	14	45	3.0			
38	04.01.2009	10:02:44	15	40	2.9			
39	19.11.2008	01:05:09	14	70	3.3	15	70	3.4
40	17.11.2008	04:45:28	15	80	3.5			

b) Analogical seismograms from Bucharest (empty spaces-lack of recordings)

Ev no.	DATA	Origin time	BUC					
			MLR			VRI		
			S-P	τ	M	S-P	τ	M
1	01.01.2010	13:11:46	15.5	90	3.6	16	70	3.4
2	02.01.2010	09:56:54	15.5	26	2.5			
3	04.01.2010	19:55:21	14	100	3.6			
4	06.01.2010	22:21:37				10	20	2.2
5	08.01.2010	10:07:20	13	70	3.3	12	50	3.0
6	09.01.2010	07:02:23	14	55	3.1	13	35	2.7
7	10.01.2010	01:44:14	14	27	2.6	14.5	23	2.4
8	12.01.2010	09:32:03	10	60	3.1	10	45	2.8
9	13.01.2010	05:29:06	14	36	2.7			
10	15.01.2010	00:19:02	16	55	3.1			3.1
11	15.01.2010	01:43:17	14	43	3.0			
12	16.01.2010	06:16:08						
13	21.01.2010	19:25:02	13	22	2.2			
14	26.01.2010	17:55:30	13.5	33	2.7			
15	27.01.2010	04:42:21	13.5	85	3.6			
16	30.01.2010	17:58:50	15	30	2.6			
17	03.02.2010	10:32:55	14	40	2.8			
18	04.02.2010	15:13:19	15	63	3.3	10	45	2.8
19	07.02.2010	13:27:15	16	100	3.7			
20	25.02.2010	15:51:28	10	230	4.3			
21	28.02.2010	18:55:12	10	130	3.7			
22	03.03.2010	02:23:44						
23	13.03.2010	14:20:31	16	205	4.3	15	183	4.2
24	26.03.2010	18:36:48		410		10.5	390	4.7
25	05.04.2010	02:28:20	12	98	3.6	8	97	3.4
26	06.05.2010	04:50:58	12	130	3.8	12	110	3.8
27	08.06.2010	15:16:10	13	400	4.8	12	340	4.6
28	09.06.2010	03:42:59	16	150	4.1	17	140	4.1
29	25.04.2009	17:18:49	10	560	4.9			
30	27.05.2009	03:12:51	13	300	4.6			
31	12.04.2009	16:51:39	11.5	183	4.1			
32	21.03.2009	22:08:58						
33	11.02.2009	03:02:56	12.5	105	3.6	9.5	100	3.5
34	03.02.2009	02:57:07						
35	30.01.2009	14:43:42	16	37	2.9			
36	27.01.2009	07:23:51	13	35	2.7			

Table 1 (continued)

37	13.01.2009	05:50:32						
38	04.01.2009	10:02:44	16	60	3.3	15	57	3.2
39	19.11.2008	01:05:09	16	70	3.4	15	70	3.4
40	17.11.2008	04:45:28	15	75	3.5	15	75	3.5

c) All four values of magnitudes

Ev no.	DATA	Origin time	M_D seis	M_L ant	M_D	M_L
1	01.01.2010	13:11:46	**3.5**	2.7	3.9	**3.5**
2	02.01.2010	09:56:54	**2.5**	1.2	3.2	**2.9**
3	04.01.2010	19:55:21	**3.7**	2.9	4.0	**3.6**
4	06.01.2010	22:21:37	**2.4**	1.5	2.6	**2.6**
5	08.01.2010	10:07:20	**3.2**	2.1	3.3	**3.2**
6	09.01.2010	07:02:23	**3**	1.8	3.1	**3.2**
7	10.01.2010	01:44:14	**2.5**	1.7	3.0	**3.0**
8	12.01.2010	09:32:03	**3**	2.1	3.1	**3.1**
9	13.01.2010	05:29:06	**2.8**	1.9	3.4	**3.2**
10	15.01.2010	00:19:02	**3.3**	1.6	3.3	**3.1**
11	15.01.2010	01:43:17	**3**	2	3.3	**3.1**
12	16.01.2010	06:16:08	**2.3**	1.1	2.7	**2.4**
13	21.01.2010	19:25:02	**2.4**	1.3	3.0	**2.8**
14	26.01.2010	17:55:30.	**2.7**	1.8	2.9	**3.1**
15	27.01.2010	04:42:21	**3.6**	2.6	3.6	**3.7**
16	30.01.2010	17:58:50	**2.5**	1.1	3.1	**2.9**
17	03.02.2010	10:32:55	**2.8**	1.8	3.0	**2.9**
18	04.02.2010	15:13:19	**3.1**	2.7	3.3	**3.3**
19	07.02.2010	13:27:15	**3.5**	2.2	3.4	**3.6**
20	25.02.2010	15:51:28	**4.3**	3.8	4.2	**4.2**
21	28.02.2010	18:55:12	**3.8**	2.8	3.8	**3.8**
22	03.03.2010	02:23:44		0.8	2.5	**3**
23	13.03.2010	14:20:31	**4.3**	3.5	4.2	**4.2**
24	26.03.2010	18:36:48		2.8	3.6	**3.6**
25	05.04.2010	02:28:20	**3.5**	2.5	3.1	**3.5**
26	06.05.2010	04:50:58	**3.7**	3.1	3.9	**3.9**
27	08.06.2010	15:16:10	**4.7**	4.5	4.7	**4.7**
28	09.06.2010	03:42:59	**4**	3	4.2	**4**
29	25.04.2009	17:18:49	**5.2**	5.3	5.7	**5.2**
30	27.05.2009	03:12:51	**4.5**	4.4	4.9	**4.5**
31	12.04.2009	16:51:39	**4.2**	3.9	4.5	**4.2**
32	21.03.2009	22:08:58		3.2	4.3	**3.9**
33	11.02.2009	03:02:56	**3.6**	3	3.9	**3.7**
34	03.02.2009	02:57:07	**3.1**	2.7	3.7	**3.6**
35	30.01.2009	14:43:42	**2.9**	2.3	3.3	**3.2**
36	27.01.2009	07:23:51	**2.7**	2.1	?	**3.1**
37	13.01.2009	05:50:32	**3.0**	2.3	3.5	**3.3**
38	04.01.2009	10:02:44	**3.1**	2.4	3.6	**3.3**
39	19.11.2008	01:05:09	**3.4**	2.4	3.6	**3.5**
40	17.11.2008	04:45:28	**3.5**	2.8	3.7	**3.7**

After analyzing the analogical seismograms, we made a comparison between the four magnitude estimations (M_L – magnitude obtained with the new coefficients, M_D – duration magnitude obtained with HYPO, $M_{L\ \mathrm{ant}}$ – local magnitude obtained with Antelope old relation, $M_{D\ \mathrm{seis}}$ – duration magnitude obtained from analogical seismograms). The distribution of the four magnitude estimations for the analyzed events plotted in Fig. 7 shows well-correlated values for the new magnitude scale and duration magnitude scales, while the old formula in Antelope leads to significantly lower values for smaller events. For magnitudes greater than all of these four relations have close values.

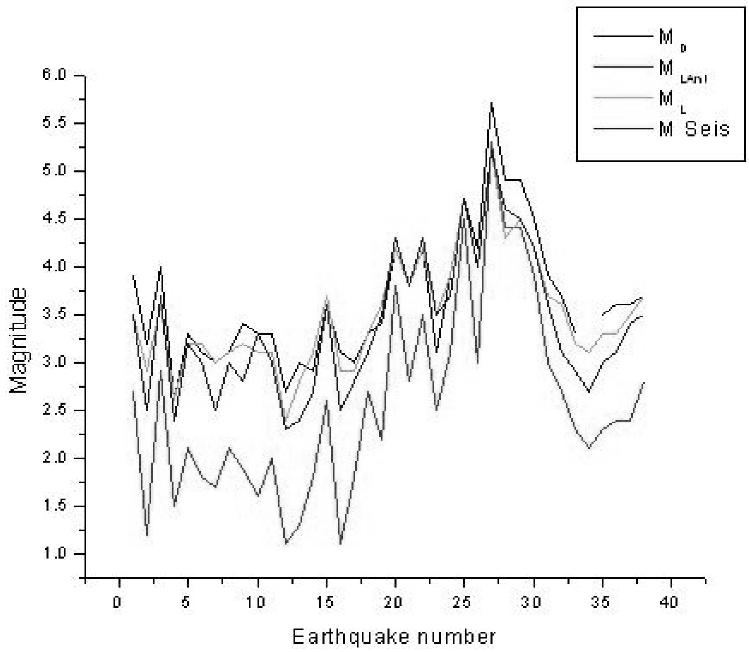

Fig. 7 – Comparison of the new relation with the results obtained by the 3 existing relations used by NIEP (M_L – new-local magnitude obtained with the new coefficients, M_D – HYPO-duration magnitude obtained with HYPO, M_L – antelope-local magnitude obtained with Antelope, M_D – seis-duration magnitudes obtained from analogical seismograms.

Starting with September 2010 the new relation was implemented in the real time acquisition and data processing system of NIEP (ANTELOPE 4.11). Since 24 September until July 2011 there were recorded on-line 143 intermediate-depth seismic events in Vrancea zone with magnitude values between 2.1 and 4.7. Again the new magnitude calibration fits well the duration magnitude values, as shown in Fig. 8.

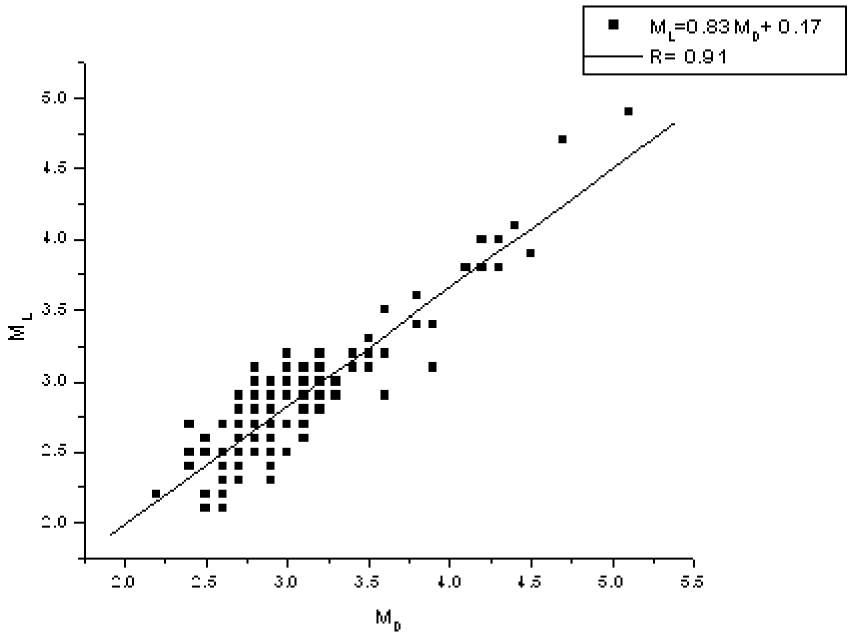

Fig. 8 – New magnitude calibration scale compared with previous duration magnitude scale for the most recent events in the Vrancea region.

5. CONCLUSIONS

A new magnitude relation is obtained for Vrancea intermediate-depth earthquakes using Wood Anderson amplitudes as measured on horizontal components (S waves) of the broadband stations of the Romania seismic network. The new relation is calibrated with duration magnitudes and takes into account the depth values. Also, it provides better estimations for the smaller magnitudes, since duration magnitudes saturate below magnitude around 2, in case of Vrancea intermediate-depth earthquakes.

The tests carried out on different data sets show a good accuracy and stability for magnitudes below 6. As a consequence of this work, the new magnitude scale has been implemented in the earthquake monitoring system of the National Institute for Earth Physics in Bucharest.

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