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THE DECAY OF AFTERSHOCK SEQUENCES FOR ALBANIA USING THE SEISMIC ACTIVITY DATA OF 1976-1990

Abstract. Using 14 cases of earthquakes followed by aftershocks for Albania during the period 1976-1990, the aftershock decay constants according to the Omori law, and some characteristics of the energy release, are found here. The magnitudes of analysed sequences are from 3.5 to 5.5. The values of p, which describes the aftershock decay, with the modified Omori law, in this study fall in the range between 0.84 and 1.49. There is a distinct difference observed between the value of this coefficient determined for the inner zone and that determined for the outer zone of Albania. The increase in coefficient p from the west to the east of the country shows that there is a faster decay of aftershocks in the inner part than in the outer part. It is shown that on average the energy released by aftershocks is about 8 percent of the energy released by the main shock. The results obtained are discussed in the light of the seismotectonics and stress regime.

INTRODUCTION

It is known that the immediate effect of earthquakes is to reduce stress in the focal region and redistribute it to adjacent areas, causing thereby aftershock sequences. From the physical point of view, it is clear that aftershock occurrences and the characteristics of their decay are strongly dependent on two main factors: stress concentration in the given zone and the features of the crustal rocks where this stress is applied.

Analysing the instrumental records of different earthquake series gives interesting information on the decay of the earthquake aftershocks, and throws light on the true nature of the physical processes due to release of earthquake energy. Moreover, this information gives a better understanding of the features of the crust where the earthquake is prepared and finally occurs.

THE MODEL USED AND THE RESULTS OBTAINED

The seismic activity of Albania, depending on the availability of data, is suitable for performing studies with different models of earthquake sequences. We believe that the heterogeneity of the Albanian geological structure is very important factor for the variation in the types of earthquake sequences one can distinguish there. A careful investigation of the seismic activity data recorded by the Albanian Seismological Network (ASN), from 1976 to 1990, testifies to the existence of the three types described by Mogi (1963). It is revealed that 70 percent of the earthquakes with local magnitude $M_L \geq 4.0$, recorded in the above mentioned period in Albania, belong to Mogi's first type; thus there are earthquakes without foreshocks but followed by aftershocks. Swarms are also frequent and are distributed mostly over the northern part of the country (Muço, 1992).

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Many authors have carried out detailed studies on the aftershock characteristics (Mogi, 1962; Utsu, 1969; Ranalli, 1969; Page, 1968; Drakopoulos and Ekonomides, 1972; etc.).

The generally accepted formulas describing aftershocks decay with time are

$$n\ (t)=K\ t^{-p}, \tag{1}$$

and

$$n\ (t)=K\ (t+c)^{-p}, \tag{2}$$

where K, c and p are constants.

Both the above functions express an inverse power law. Theoretically, they differ from each other because the first is shifted by c along the time axis. Thus it is evident that applied to the same decay process eqn. (2) would give a higher value of coefficient p, and so would describe a faster decay than eqn. (1).

Eqn. (1) was used by Mogi (1962), Ranalli (1969), Drakopoulos and Ekonomides (1972) and others. Utsu (1969) has applied eqn. (2), which he called "the modified Omori formula". In this study we used both formulas. The unit of time used is the day. As basis for discussion, eqn. (2), but with c=1, which is the formula recommended by Scholz (1990), is taken:

$$n\ (t)=K\ (t+1)^{-p}. \tag{2'}$$

If the coefficient p is very close to 1 (which is the case), this decay law is nearly hyperbolic.

To study the decay of aftershock sequences for Albania, the instrumental records of ASN for the period 1976-1990 were analysed. We employed the data from short period seismographs of DD-1 type. Considering the homogeneity of the used data, in our study 14 cases of earthquake sequences are included. Fig. 1 shows the epicentres of the main shocks for these series. The magnitudes of the main shocks are in the range 3.5-5.5. All these earthquakes belong to crustal activity. The main shocks of the considered sequences were relocated using an algorithm for hypocenter determination of near earthquakes (Herrman, 1979). The velocity model used was of linear form, where the velocity increases with depth (Crosson, 1972). All the earthquakes of Fig. 1 have epicenter determination errors less than 10 km. The aftershocks were counted in the records of the nearest seismological station to the epicentre of the main shock. The minimum threshold magnitude of these aftershocks is $M_L=1.0$. In all cases the epicentral distance of these stations does not exceed 50 km. All the seismographs of ASN are set on rock basements, mostly limestone, and their vertical component magnification normally is in the range 40,000-50,000.

Taking the logs of both eqns. (1) and (2'), we transformed them into simple equations, and applying the least square method, the constants K and p could be found. In Fig. 2 the decays of these earthquake sequences are shown, while Table 1 gives the data on these sequences and the results obtained for the decay of their aftershocks.

Our approach was extended also to the study of some characteristics of seismic energy release during the main shock and aftershocks of each earthquake sequence considered. The energy was calculated according to the formula (Richter, 1958)

$$E=9.9+1.9\ M_L-0.024\ M_L^2\ . \tag{3}$$

The magnitude formula used is

$$M_L=\log\ (A/T)+a\ \log\ D+b\ D+c, \tag{4}$$

where A is amplitude in nm, T, period in sec., D, distance in km and a, b and c are constants found for each seismological station of ASN (Muço and Minga, 1991).

Table 2 gives the results obtained for the energy release.

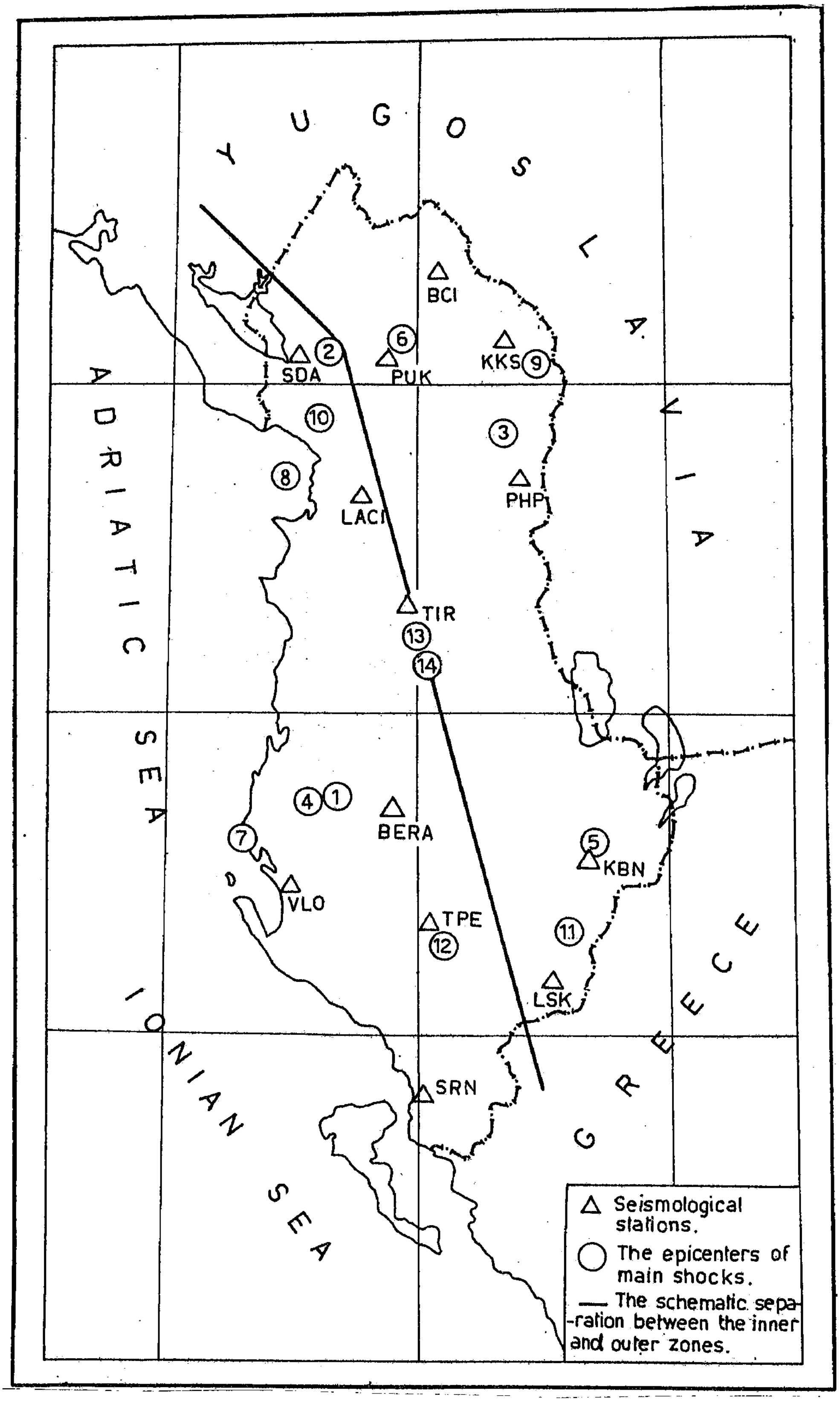

Fig. 1 — The Albanian Seismological Network (ASN) and the epicenters of the main shocks of the sequences considered in this study.

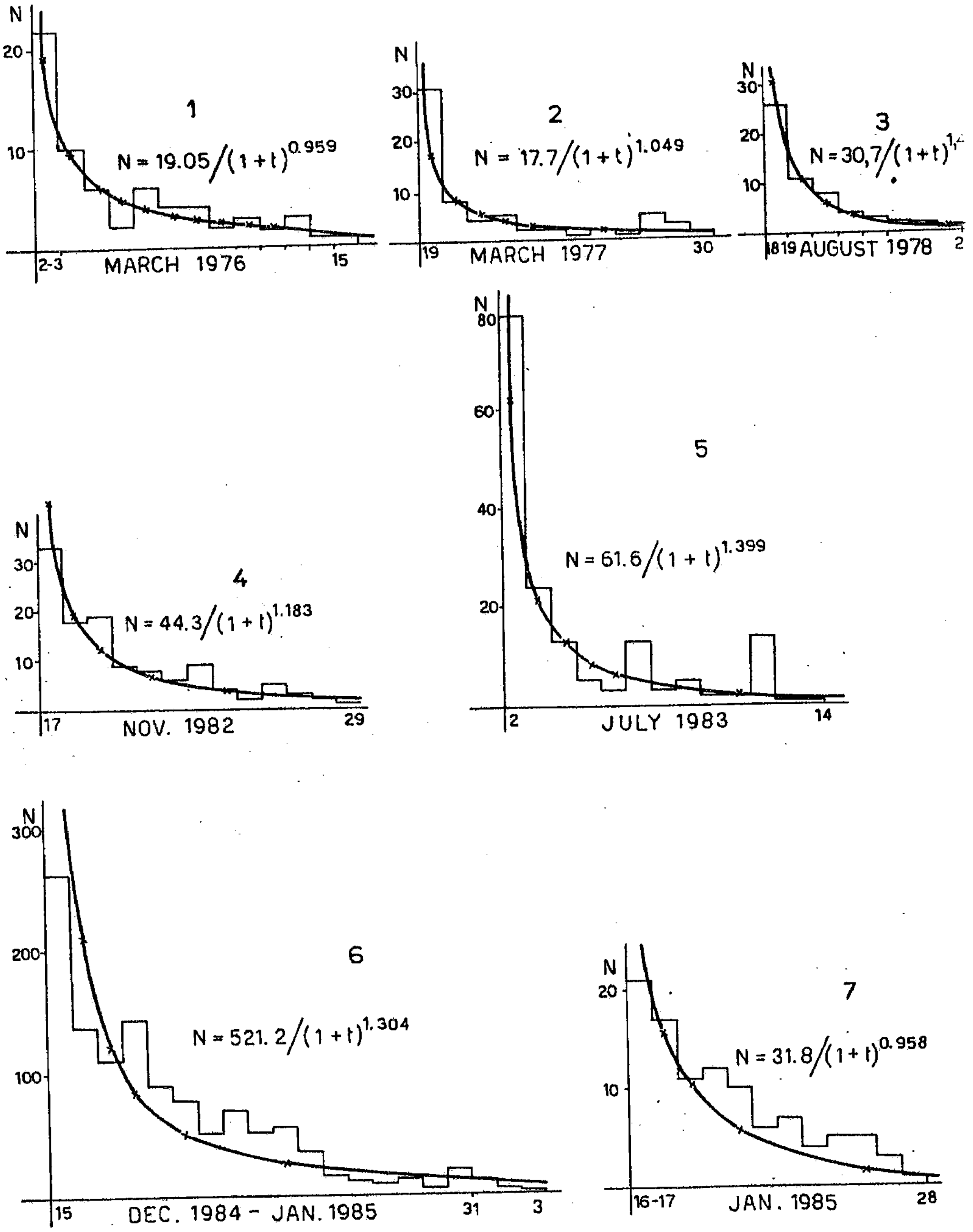

Fig. 2 — The decay of the aftershock sequences for different cases.

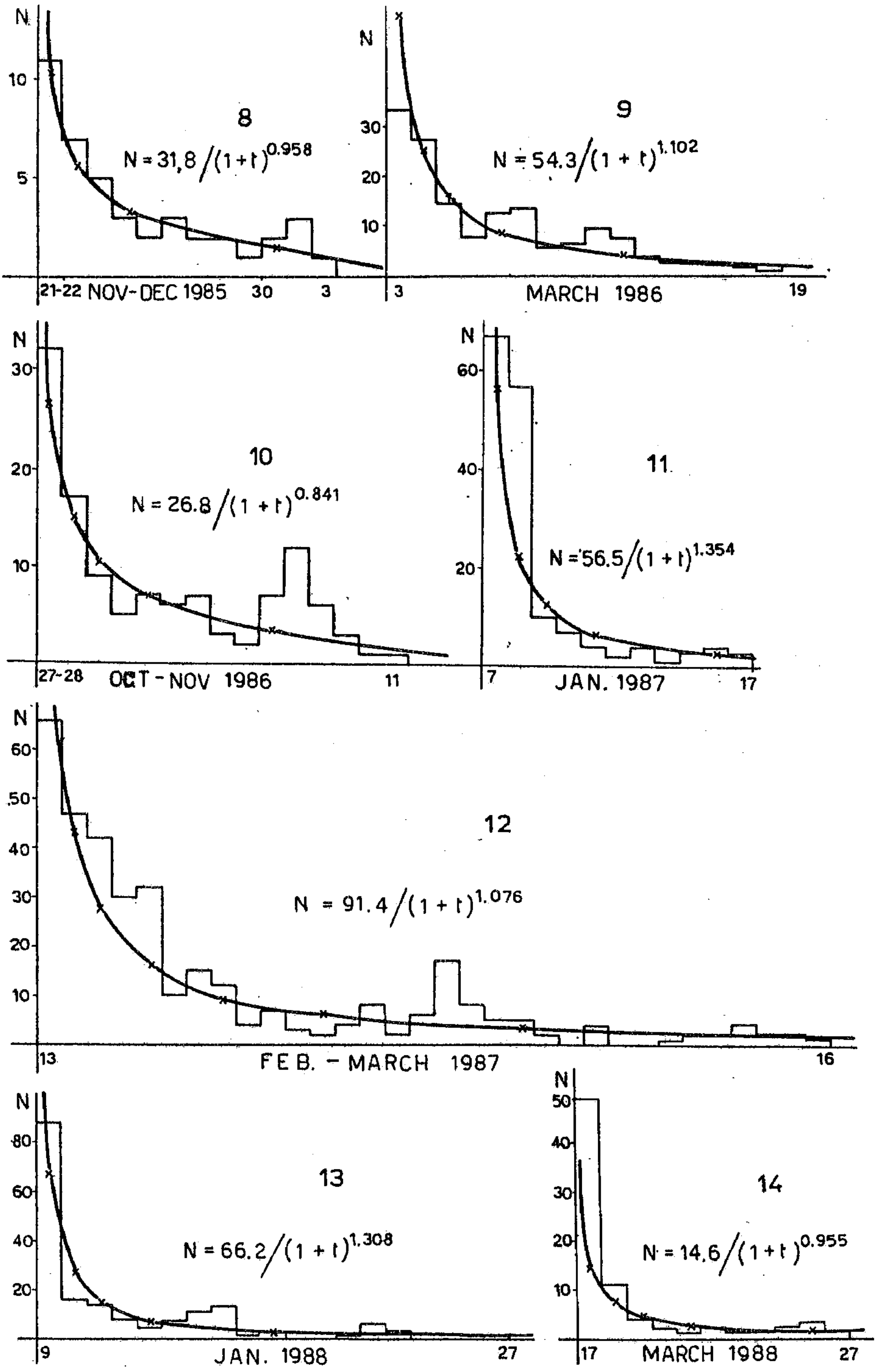

Fig. 2 — Continued.

Table 1 — The aftershock sequences and their decay parameters.

No	Earthquake				M_L	Aftershocks		Stc.	K*	K	p*	p	Corr. coeff.
	Date	Origin time	Coordinates			Days	Numb.						
1	1976 03 02	19 41 37.1	40.70; 19.63;	10	5.3	13	66	TIR	15.2	19.0	0.682	0.959	0.85
2	1977 03 19	19 18 21.0	41.92; 19.68;	16	3.5	11	63	SDA	11.5	17.7	0.832	1.049	0.78
3	1978 08 18	20 53 19.6	41.79; 20.37;	17	4.7	8	58	KKS	3.9	30.7	1.182	1.490	0.98
4	1982 11 16	23 41 19.9	40.82; 19.61;	21	5.1	13	119	VLO	25.2	44.3	1.051	1.183	0.91
5	1983 07 02	16 16 44.0	40.80; 20.87;	9	4.5	13	165	KBN	36.7	61.6	0.994	1.399	0.82
6	1984 12 15	08 20 23.6	41.99; 19.69;	1	4.1	20	1210	PUK	265.3	521.2	1.205	1.304	0.89
7	1985 01 16	23 35 58.0	40.71; 19.27;	2	4.8	12	102	VLO	18.7	31.8	0.884	0.953	0.80
8	1985 11 21	21 57 14.0	41.71; 19.48;	0	5.1	12	43	TIR	7.2	11.5	0.652	0.863	0.89
9	1986 03 03	01 24 05.1	41.94; 20.42;	2	4.6	17	161	KKS	32.3	54.3	1.001	1.102	0.89
10	1986 10 27	22 32 23.0	41.90; 19.74;	5	4.5	14	117	SDA	16.5	26.8	0.742	0.841	0.74
11	1987 01 07	00 39 28.6	40.47; 20.71;	0	4.6	14	171	LSK	33.6	56.5	1.059	1.354	0.86
12	1987 02 13	13 58 10.1	40.32; 20.01;	2	4.6	34	345	TPE	57.8	91.4	0.963	1.076	0.82
13	1988 01 09	01 02 46.6	41.29; 19.83;	1	5.3	23	187	TIR	39.7	66.2	1.012	1.308	0.84
14	1989 03 17	00 50 51.3	41.23; 20.00;	24	4.6	11	77	TIR	8.2	14.6	0.842	0.955	0.63

Note: K*, p* are the decay coefficients calculated by eqn. (1)
K, p are the decay coefficients calculated by eqn. (2')

Table 2 — Some characteristics of the energy release of aftershock sequences.

No	Date	M_L	M_L*	E (erg)	E* (erg)	E*/E (%)
1	1976 03 02	5.3	4.0	$2.138*10^{19}$	$2.547*10^{17}$	1.19
2	1977 03 19	3.5	2.9	$2.269*10^{16}$	$1.922*10^{15}$	8.45
3	1978 08 18	4.7	3.8	$1.995*10^{18}$	$6.538*10^{16}$	3.28
4	1982 11 16	5.1	4.4	$9.332*10^{18}$	$9.429*10^{17}$	10.13
5	1983 07 02	4.5	3.4	$0.920*10^{18}$	$5.346*10^{16}$	5.80
6	1984 12 15	4.1	3.2	$1.950*10^{17}$	$5.463*10^{16}$	28.21
7	1985 01 16	4.8	3.9	$2.951*10^{18}$	$9.982*10^{16}$	3.36
8	1985 11 21	5.1	4.6	$9.332*10^{18}$	$1.375*10^{18}$	15.20
9	1986 03 03	4.6	4.2	$1.358*10^{18}$	$3.028*10^{17}$	23.30
10	1986 10 27	4.5	3.8	$0.920*10^{18}$	$7.050*10^{16}$	7.66
11	1987 01 07	4.6	3.6	$1.358*10^{18}$	$4.161*10^{16}$	3.06
12	1987 02 13	4.6	3.4	$1.358*10^{18}$	$2.338*10^{16}$	1.72
13	1988 01 09	5.3	3.5	$2.138*10^{19}$	$2.586*10^{16}$	0.13
14	1989 03 17	4.6	3.5	$1.358*10^{18}$	$2.648*10^{16}$	1.95

Note: M_L and E are the local magnitude and the energy released by the main shock;
M_L* and E* are the local magnitude of the largest aftershock of the series and the energy released by all the series (except main shock).

ANALYSIS AND DISCUSSION OF THE RESULTS

As one can see from Table 1, for all the cases taken into consideration for the period 1976-1990, the values of the decay parameter p of the earthquake sequences vary from 0.84 to 1.49. It was found that the p value is higher for the earthquake sequences of the inner zone of Albania than for those of the outer zone. This means that generally the series of aftershocks have a tendency to decay faster in the inner zone than in the outer. The lesser values of p may be connected with the higher degree of fracturing of the rocks (Mogi, 1963; Bottari and Caccamo, 1981), which probably results from the contact of the Adria microplate with the Balkan orogen, part of the Eurasian lithospheric plate.

The mean value of the exponential coefficient p is 1.020 ± 0.05 for the outer zone of Albania, and $p = 1.329 \pm 0.03$ for the inner zone. Analysing the decay of the aftershock sequences of Albania for the considered period, a generalised value of $p = 1.131 \pm 0.08$ is revealed. Fig. 3 expresses the theoretical aftershock decay inferred from the above analysis for both the inner and outer zones of Albania. The relatively broad range in the values of p shows that even inside a small territory there can be variability in the aftershock decay. This is not in agreement with

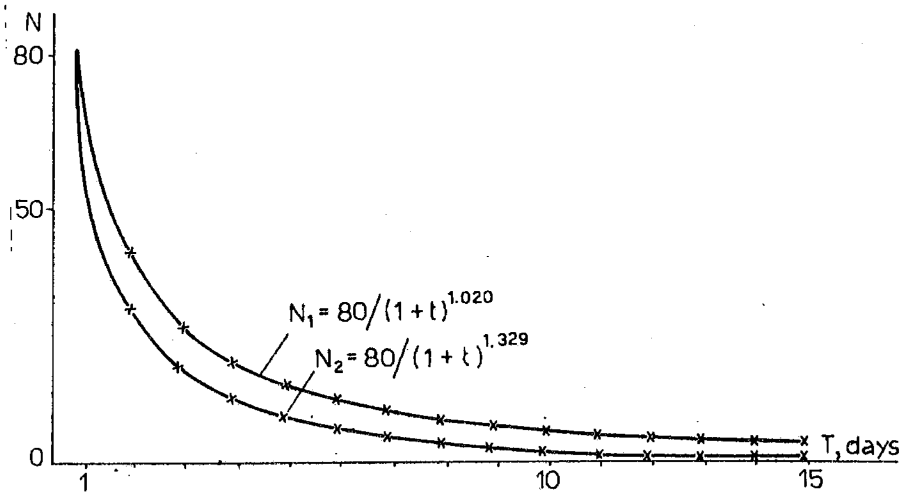

Fig. 3 — The theoretical curves of the aftershock decay constructed for the inner and outer zones of Albania.

the opinion that there is no evidence that p values vary significantly from one aftershock sequence to another and from one tectonic region to another (Page, 1968).

Our p valaues are close to those obtained for other earthquakes around Albania. Pasquale (1985) found p=1.011 for the Irpinia earthquake (1980), and p=0.853 and 0.985 for the two Friuli earthquake sequences (1976). He used the same eqn. (2'). Lesser values of p result for the Montenegro earthquake of April 15, 1979: p=0.64 and p=0.58, for two phases of the aftershocks of this earthquake (Sulstarova and Lubonja, 1983). These authors used eqn. (1).

From Table 2, one can see that the ratio E*/E, which is the energy released by aftershocks versus that released by the main shock of the same series, is from 0.13 to 28.2 percent. The mean value is about 8 percent. This rate depends mostly on the difference between the magnitude of the main shock and that of the largest aftershock. This mean difference is about 0.9 magnitude units. Judging by the energy release of the considered earthquake sequences, no distinction between the outer and inner zones of the country is revealed.

The decay of the aftershock activity with time reflects a decrease of stress in the aftershock region. On this basis, the stress situation in a given zone should directly affect the aftershock decay of an earthquake sequence. Such is evident also in the conclusions of our study. As is known, the stress field in Albania changes strongly from a predominance of compression in the outer zone, to extension in the inner zone (Muço, 1992).

Of course, other factors besides the stress field and the degree of fracturing of the zone influence the decay of aftershock sequences. For example, the activation of shear or longitudinal faults, the depth of the activated zone etc., whose clarification requires more detailed studies.

CONCLUSIONS

Analysing the aftershock activity of Albanian earthquakes for the period 1976-1990, some characteristics of their decay were found for the Albanian territory. The mean value of the decay coefficient is p=1.131. The aftershocks of the inner zone of the country tend to decay faster than those of the outer zone. The theoretical curves of the aftershock decay were constructed.

Evaluating the energy release during the main shock and the aftershock activity, it is found that the energy released by the whole aftershock sequence is on average 8 percent of the energy released by the main shock of the sequence.

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