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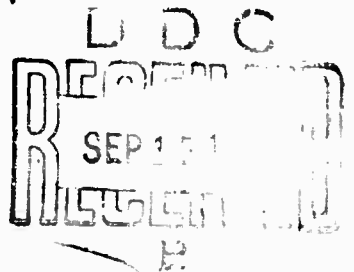
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PRELIMINARY STUDY OF THE AFTERSHOCKS IN THE CENTRAL ANDES

by Ramón Cabré S.J.

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ABSTRACT

The aftershocks located in the Central Andes between January 1950 and June 1963 are considered. It appears that data in that period were too scarce to obtain a number of locations sufficient to give satisfactory results by this method; this region has most of earthquakes deeper than normal, which prevents a fuller use of the method; nevertheless it may give acceptable results if applied to the last years.

INTRODUCTION

The study of the sequences of aftershocks is one of the tools used to investigate regional seismicities.

The main goal of this paper is to prepare a deeper study, excluding the possibility of anomalous response of the region, considering if data available will support a satisfactory study and obtaining a provisory knowledge of the regional behavior in relation to the aftershocks sequences.

EVENTS CONSIDERED

The area covered by this study extends from Latitude 0° to 30° and from 60° W to 81.5° W. The selection of these limits in Longitude is quite natural, since the seismic activity diminishes on both sides of the Andes and apparently it disappears completely in the aseismical regions of Eastern South America and of the Pacific Ocean.

The earthquakes between January 1950 and June 1963 are considered; they are taken from a compilation of locations prepared by the U.S. Coast and Geodetic Survey (Reference 1). During these 13 and a half years seismological stations were so

scarce in South America that a location of low magnitude seisms was impossible.

In total 793 earthquakes were located in the Central Andes, among them 91 of magnitude 6 or more; these 91 and their aftershocks have been examined; see table 1. Table 2 and fig. 1 show the distribution of these 91 earthquakes according to their magnitude.

In many instances it is impossible to know if an earthquake is related to another as an aftershock or not; to prevent any arbitrary selection of aftershocks, only events during the 48 hours after the main shock and not further than 5 degrees (550 Km.) are considered aftershocks. The possibility of dependence of some events much later and much further is acknowledged, but it is well known that most of the remaining strain is released shortly after the main shock and not too far from it; so the probability of a large aftershock beyond these limits is negligible for a statistical study as the present.

Among the 91 earthquakes of large magnitude we find 22 followed by aftershocks, the aftershocks total being 32.

COMPARISON WITH BATH'S LAWS

Bath has noted that for shallow shocks the highest magnitude of an aftershock as an average is 1.2 smaller than the magnitude of the main shock; this statement is known as "Bath's law" (2).

It is not very useful in our case since only 35 shocks were shallow (even including in this figure all the 20 for which depth was not given, which on the other hand seems correct, since generally depth was not mentioned in sources when it was supposed normal).

More recently Bath has studied special cases trying to include them in generalized rules(3). He proposes a tentative rule for the case of several shocks of the same magnitude:

$$M - M_1 = 1.2 + \frac{\log(N_1/N)}{1.2^2}$$

where M = magnitude of the main shocks, M_1 = magnitude of the largest aftershocks, N = number of equally large main shocks, N_1 = number of largest aftershocks.

Finally, if the main shock is deep, Bath's theory gives a difference between the main shock and the largest aftershock greater than for a surface focus; he proposes as a very tentative rule:

$$M - M_1 = \frac{2}{3}h + 1$$

the depth h being measured in units of 100 Km; in our study 55 events of magnitude 6 or more are 100 deep (or more).

Combining the three Bath's propositions, we obtain the formula:

$$M - M_1 = \frac{2}{3}h + \frac{\log(N_1/N)}{(\frac{2}{3}h + 1)^2} + 1$$

In table 1 there are four couples of similar magnitude earthquakes which now have to be considered as single events; thus the number of large earthquakes is reduced to 87, and 20 of them are followed by aftershocks.

The Bath's laws only state the maximum magnitude expected for the largest aftershock, but a major difficulty appears to apply to them: the magnitudes in the interval considered in this study were calculated only for large shocks. Therefore it is necessary to find a minimum magnitude permitting for an event to be located; then if the theoretical maximum is larger than this minimum calculated for a given earthquake, we shall say that this earthquake would have some aftershock determined.

Actually the minimum magnitude is not a naturally fixed limit. The author(4) has defined a "minimum compensated magnitude" derived from the statistical law applying to the number N of events of magnitude M or larger:

$$\log N = A - BM$$

After calculating $A = 8.25$, $B = 1.0$ for the interval of this study, the minimum compensated magnitude is obtained by changing

N by its value 793 in the above formula. M is found to be 5.35. Statistically it may be considered as a limit of magnitude over which any event should be located.

According to table 1, we should find located aftershocks for 22 earthquakes. The 20 cases observed yield a good agreement with these 22 expected as an average, but evidently these figures are much too small to support any definitive conclusion.

The correspondence between the actual single aftershocks and those expected is really poor, as it may be realized in fig. 2; deficiencies in locations and consequently in the application of the minimum compensated magnitude could be responsible of this lack of correspondence.

PREVISION FOR FUTURE STUDIES

Nowadays the conditions for the Central Andes are much improved for any seismological work, mainly because of the installation of new seismological stations, specifically those VELA Standard of U.S. Coast and Geodetic Survey and DTM of the Carnegie Institution of Washington.

Calculating the minimum compensated magnitude from June 1965 through May 1966, the author found the value 4.50, which means that the number of events expected to be located increases remarkably. Actually 59 large shocks (instead of 22) would support the expectation of having some aftershock located. Fig. 3 shows a comparison of seismic events located in the periods 1950-63 and 1965-66. Yet recently more stations are forwarding data.

Briefly, studies of aftershocks sequences will become much profitable when they will be done on events of last years.

CONCLUSIONS

The data available for the period 1950-1963 is insufficient for any definitive study of aftershocks in the Central Andes.

In this area good samples for aftershocks study are not too frequent, since most foci are deep, producing small aftershocks.

Nevertheless future studies of aftershocks sequences will encounter greater facilities.

ACKNOWLEDGMENT

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- (1) USCGS.- Compilation of seismic locations appeared in: United States Earthquakes (Jan.1950-Dec.1960), ISS (Jan.1950-Dec. 1959), BCIS Bulletin (Jan.1950-Jun 1963).
- (2) Richter Ch.F.- Elementary Seismology.- Freeman and Co. 1958.
- (3) Bath, M.- International Upper Mantle Project. Report N°2, Dec. 1965.
- (4) Cabré R., S.J..- Location of Seismic Foci in the Central Andes during the Period 1950-63 and currently.- Geofísica Internacional. México. (in press).

Table 1.- Earthquakes of Magnitude 6 and their Aftershocks

N.B. Unless otherwise indicated, magnitudes were computed by Pasadena Laboratory, the other data by USCGS.

The date is given by Day, Month, Year; the actual aftershocks are indicated in the same column, instead of their date. The maximum magnitude expected according to Bath's rules is given in the last column.

<u>Date</u>	<u>Magn.</u>	<u>Lat.S</u>	<u>Long.W</u>	<u>Depth</u>	<u>Instit.</u>	<u>Max.Aft.Exp.</u>
14 3 50	6.75	8.0	74.0	150		4.75
21 5 50	6.0	14.0	72.0			4.8
7 6 50	7.13	4.0	76.5	100		5.5
9 7 50	7.0	8.0	71.0	650)	1.7
9 7 50	6.87	8.0	71.0	650		
aft.	6.37	8.0	71.0	650		0.8
14 8 50	7.25	27.0	62.5	650		1.7
18 9 50	6.0	8.0	71.0	650		0.4
2 12 50	6.75	7.5	71.0	650		1.2
aft.		7.5	71.0	650		
9 12 50	7.88	24	67	100		6.3
aft.		25	68.5	200		
10 12 50	7.0	14	76	60		5.6
aft.		15	77			
11 12 50	6.25	8	71	650		0.6
28 12 50	6.25	7.5	71	650		0.7
4 3 51	6.87	15.5	74	150		4.9
14 4 51	7.0	24	66.5	250		4.3
23 4 51	6.38	20.5	67	250		3.7
9 11 51	6.75	22	68	100		5.1
26 2 52	7.5	15	69	250		4.8
24 5 52	6.75	21.5	71			5.5
21 9 52	7.2	22.0	65.5	300		4.2
aft.		20.5	67	150		
14 4 53	6.6	7.5	71.5	630		1.5
17 4 53	6.0	5.2	77.2			4.8
9 8 53	6.25	22	68.5	150		4.2
27 10 53	6.75	19	66	300		3.7
7 12 53	7.37	22	68.5	110		5.7
12 12 53	7.4	3.5	81			6.2
15 6 54	6.63	5	77	100		4.9
21 6 54	6.6	23	68.5	150		4.6
19 12 54	6.63	23	66.5	250		4.9
19 4 55	7.0	30	72			5.8
aft.		30	71			
aft.	6.5	30	72.5			5.3
aft.		30.5	72.5			
aft.		29.9	71.6		ISS	
11 5 55	5.75	0	78			5.5
21 7 55	6.75	15	74	100		5.0
17 11 55	6.75	26.5	69	60		5.3

<u>Date</u>	<u>Magn.</u>	<u>Lat.S</u>	<u>Long.W</u>	<u>Depth</u>	<u>Instit.</u>	<u>MaxAft.Exp.</u>
6 12 55	6.75	20	70			5.5
8 1 56	7.10	19	70			5.9
16 1 56	7.3	0.5	80.5			6.1
22 3 56	6.5	3.5	79	100		4.8
22 7 56	6.13	19	69	100		4.4
23 8 56	6.25	15	68	100		4.5
5 9 56	6.75	20	69	100		5.0
3 10 56	6.5	20	69.5	150		4.5
12 10 56	6.5	15.5	75	60		5.1
18 12 56	7	25.5	68.5	45	ISS	5.7
24 1 57	6.25	12.5	78			5.0
18 2 57	6.63	11.5	78	100		4.9
31 5 57	6.37	27.5	63	600		1.4
24 7 57	6.5	30	70.5	70	ISS	5.0
29 7 57	7.0	23.5	71.5	11	ISS	5.9
26 8 57	6.38	19	63			5.2
aft.		19	63			
26 8 57	6.0	2	81	34	ISS	4.8
29 11 57	7.8	21	66	200		5.5
15 1 58	7.3	16.5	72	60		5.9
28 4 58	6.5	11	74			5.3
30 4 58	6.0	21	67.5	150		4.0
8 5 58	6.38	24	67	200		4.1
25 5 58	6.5	3	77	100		4.8
aft.		3	77	100		
aft.		3.5	78.5			
29 6 58	6.5BRK	15.5	70.5	150		4.5
11 7 58	6.5	21	69	77	ISS	5.0
26 7 58	7.5	13.5	69	620		2.2
aft.		12.5	68	650	BCIS	
11 10 58	6.0	23.5	65	200		3.7
3 1 59	6.38MAT	14.5	75.5			5.2
7 2 59	7.38	4	81.5			6.2
12 5 59	6.75	23.5	64.5			5.5
aft.		20.5	63.5			
aft.		23.5	64.5		BCIS	
aft.		22.5	63.5			
21 5 59	6.0	28	69	60		4.6
14 6 59	7.38	20.5	68	100		5.7
6 7 59	6.75	26.5	61	600		1.9
6 7 59	6.88	26.5	61.5	600		
9 7 59	6.75	20.5	68.0	100		5.0
aft.		19	69			
19 7 59	7.0	15	70.5	200		4.7
aft.		15.5	71	20		
28 11 59	6.5	28.5	71			5.3
25 12 59	6.73	25.5	68.5	100		4.9
27 12 59	6.0	28	63	650		0.7
2 1 60	6.25	15.5	68	150		4.2
13 1 60	7.5	26	72	200		5.2
aft.	7.0	15	75	150		5.0
aft.	6.25	14.5	74.5	150		4.2
9 3 60	6.13	16.5	72.5	150		4.1

<u>Date</u>	<u>Magn.</u>	<u>Lat.S</u>	<u>Long.W</u>	<u>Depth</u>	<u>Instit.</u>	<u>Max.Aft.Exp.</u>
11 6 60	6.25	21	64.5	300		3.2
30 10 60	6.75	23.4	70.3	76)		
aft.		23.4	70.6	65)		
aft.		23.4	70.4	25)		5.4
10 60	6.75	22.9	58	60)		
20 11 60	6.75	18	81	55		5.4
aft.		6.5	80.7	73		
aft.		7.1	80.8	51		
2 12 60	6.75	24.6	69.7	19)		
12 60	6.75	24.4	69.5	46)		5.7
aft.		24.4	69.6	45		
aft.		24.3	69.6	51		
19 9 61	6.5	20.5	62.75	600	BCIS	1.5
18 4 62	6.25BRK	10.1	79.7			5.0
aft.		7	80		BCIS	
3 8 62	7.13	21.5	59	250	MOS	4.4
29 9 62	6.5	26	63	570	PEK	1.7
29 12 62	6.75	20	69.9	46	MOS	5.4
aft.		22.73	67.3	280	ANT	
13 4 63	6.38MAT	7.5	80		TAC	5.2
10 5 63	6.75	2.0	77.5		TAC	5.5

Table 2.- Number of Earthquakes per half a unit of Magnitude

Since M = 6

<u>Magnitude</u>	<u>Number of events</u>
6.0-6.4	26
6.5-6.9	41
7.0-7.4	20
7.5-7.9	3
8.0-8.4	1

Fig. 1.- Number of events per interval of $1/2$ unit of M .

Fig. 2.- Comparison of actual aftershocks and Bath's rules.

Fig. 3.- Monthly average of seisms located in the Central Andes.

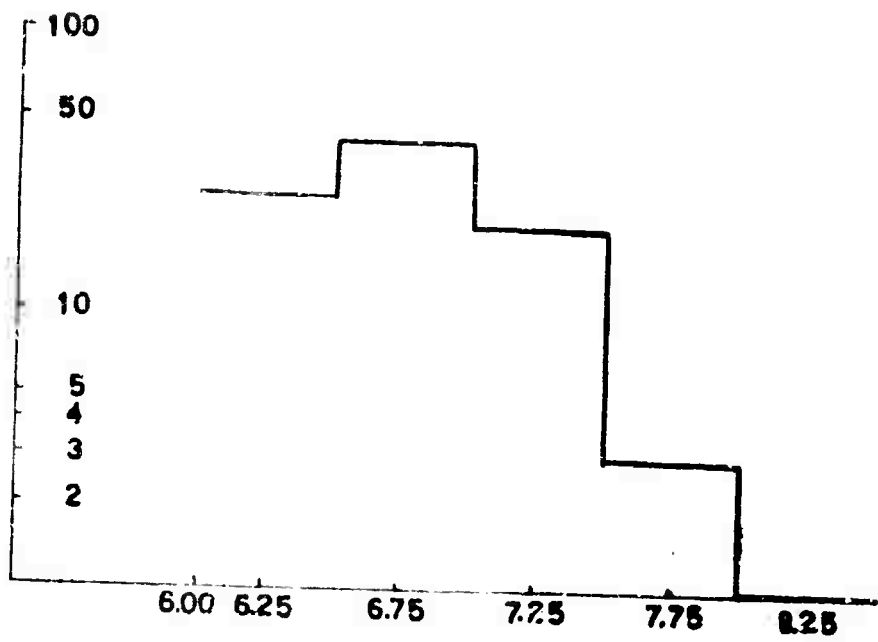
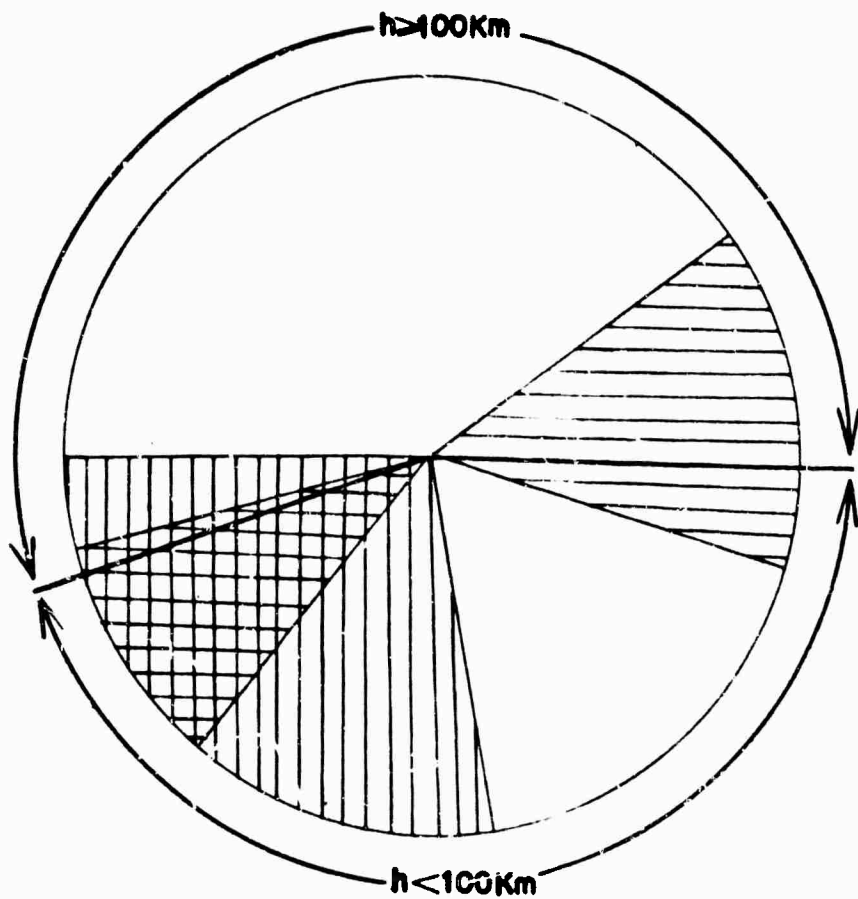


Fig. 1.- Number of events per interval of $\frac{1}{4}$ unit of M.



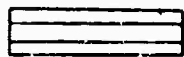
SEISMS WITH $M \geq 6$



should have, and in fact have aftershocks located.



should have, but they have not.



have, but they should not.



neither should nor have.

Fig. 2.- Comparison of actual aftershocks and Bath's rules.

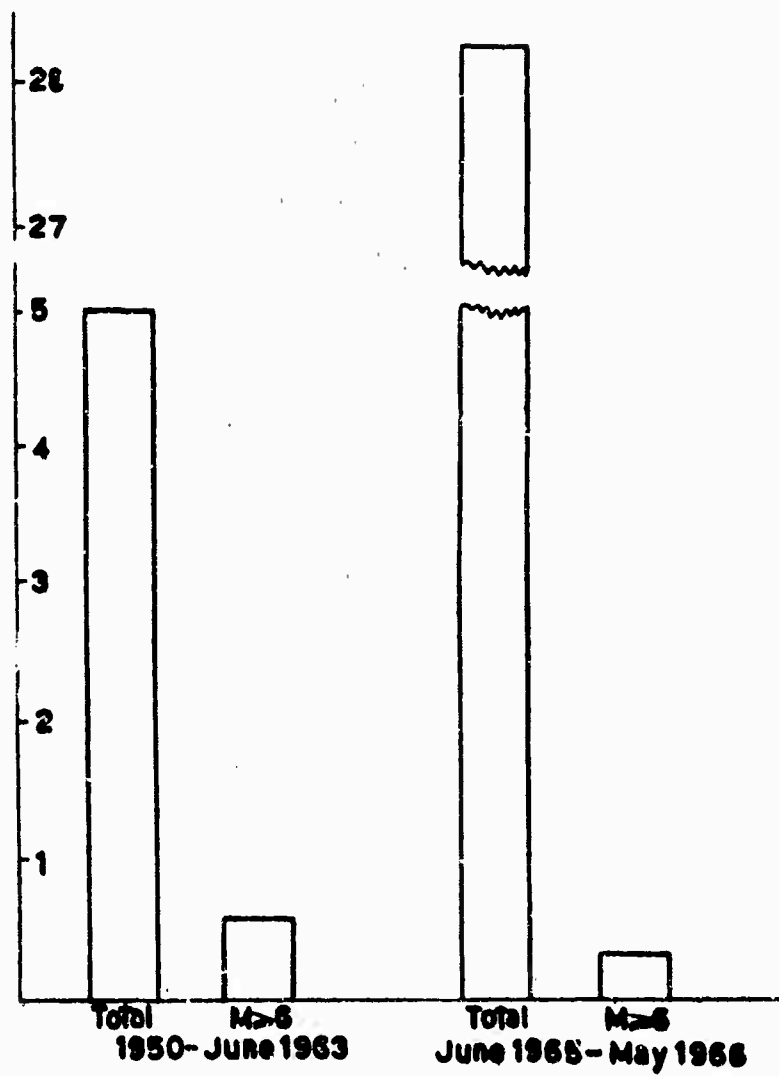


Fig. 3.- Monthly average of seisms located in the Central Andes.

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13. ABSTRACT

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