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DIFFERENCE BETWEEN AFTERSHOCKS AND FORESHOCKS IN THE RELATIONSHIP OF MAGNITUDE TO FREQUENCY OF OCCURRENCE FOR THE GREAT CHILEAN EARTHQUAKE OF 1960

By Shigeji Suyehiro

ABSTRACT

When a relatively small perceptible earthquake occurred near a tripartite net of high sensitivity in central Japan, a substantial difference was found between its 25 foreshocks and 173 aftershocks in the relation of frequency of occurrence and magnitude. For that study the coefficient "*b*" in the magnitude versus frequency equation is 0.35 for the former and 0.76 for the latter.

A similar investigation has been carried out on the great Chilean earthquake of 1960, also accompanied by many foreshocks and aftershocks. Using four sensitive and suitably located U.S.C.G.S. stations, Eureka, Tucson, South Pole, and Byrd, foreshocks and aftershocks were located in addition to those reported by U.S.C.G.S. or B.C.I.S. Forty-five foreshocks and 250 aftershocks were found in a period of 33 hours before and 33 hours after the main shock. The same characteristic found for the Japanese earthquake was also found for the Chilean earthquake; i.e. the foreshocks showed a different picture from the aftershocks for the frequency of occurrence, and an appreciably smaller value seems to be valid for "*b*" of the foreshocks.

Introduction

The coefficient, "*b*", in Gutenberg and Richter's equation,

$$\log N = a + bM$$

which represents the relation between frequency of earthquake occurrence and magnitude, is an important factor for the study of seismicity. Some difference in the value of "*b*" is seen among different seismic regions, and there have been many discussions of the significance of these differences. As far as the seismic activity in the same region is concerned, however, the coefficient seems unchanged in time including both ordinary and aftershock activities, according to sensitive observations made repeatedly in the same region.

When a small perceptible earthquake occurred only 18 km away from a tripartite seismic net of high sensitivity in central Japan, a fairly large number of foreshocks were recorded as well as many aftershocks, and much difference was found (Suyehiro, Asada and Ohtake, 1964) between 25 foreshocks and 173 aftershocks in the relation of frequency of occurrence and magnitude. For that study the ratio of small foreshocks to large foreshocks was smaller than the same ratio in the aftershocks, i.e. the coefficient, "*b*", is 0.35, which is abnormally small, for the foreshocks and 0.76, which agrees well with that of the ordinary activity in the region, for the aftershocks. Figure 1 gives its graphic presentation.

Many earthquakes in different parts of the world are reported to have been pre-

ceded by foreshocks, but for lack of nearby sensitive stations, very little data have been available for this type of study. The Chilean earthquake of 1960 was, however, exceptionally large, and many foreshocks as well as aftershocks were reported on the basis of teleseismic observations by United States Coast & Geodetic Survey and Bureau Central International Seismologique. From the published reports of these organizations, such difference in "*b*" was found also likely.

An investigation has been carried out in order to find the characteristics of the foreshocks for the Chilean earthquake of 1960, using the seismograms of four sensi-

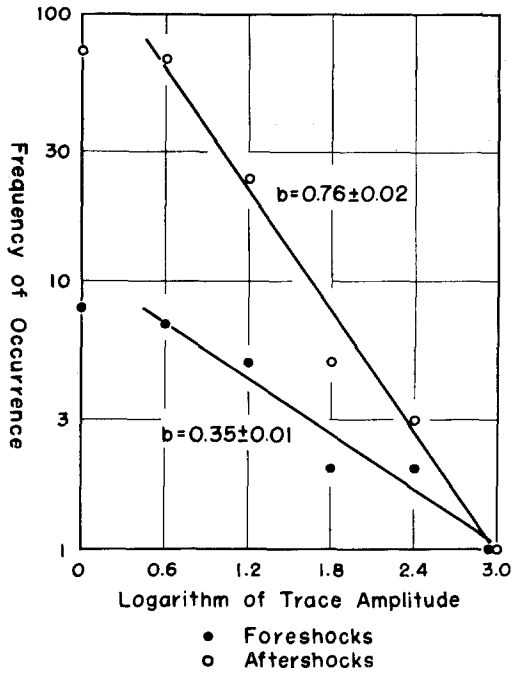

FIG. 1. Frequency of occurrence vs. logarithm of trace amplitude in the foreshocks and aftershocks accompanying a perceptible earthquake in Japan.

tive stations of U.S.C.G.S., namely, Eureka and Tucson to the north of foreshock and aftershock region, and Byrd and South Pole to the south of the region. Constants of the stations and seismographs are listed in Table 1.

LOCATION OF THE FORESHOCKS AND AFTERSHOCKS AND ESTIMATION OF MAGNITUDE

According to the epicenters reported by U.S.C.G.S., the present foreshock and aftershock activity took place in a region from 71° to 77°W. in longitude and 37° to 48°S. in latitude. In order to locate as many foreshocks and aftershocks as possible in the region in addition to those already reported, the difference of arrival times at the four stations in Table 1 was used. For the estimation of the magnitude of each shock the trace amplitude of *P* wave by the short period vertical seismograph described in Table 1 was employed. Figure 2 gives the expected difference

in arrival times at those stations in relation to the region, based on the Gutenberg-Richter's travel times. The time difference of EUR-TUT stays about 41 sec over the entire region.

TABLE 1

CONSTANTS OF THE STATIONS

Station	Location	Instrument	T_0	T_g	Maximum Magnification
South Pole (SPA).....	90°00'S. 0°00'	Benioff vertical	1.6	0.5	200,000
Byrd (BYR).....	80°01'S. 119°31'W.	Benioff vertical	1.2	0.5	100,000
Tucson (TUT).....	32°20'N. 110°43'W.	Benioff vertical	1.1	0.5	150,000
Eureka (EUR).....	39°30'N. 115°59'W.	Benioff vertical	1.2	0.5	500,000

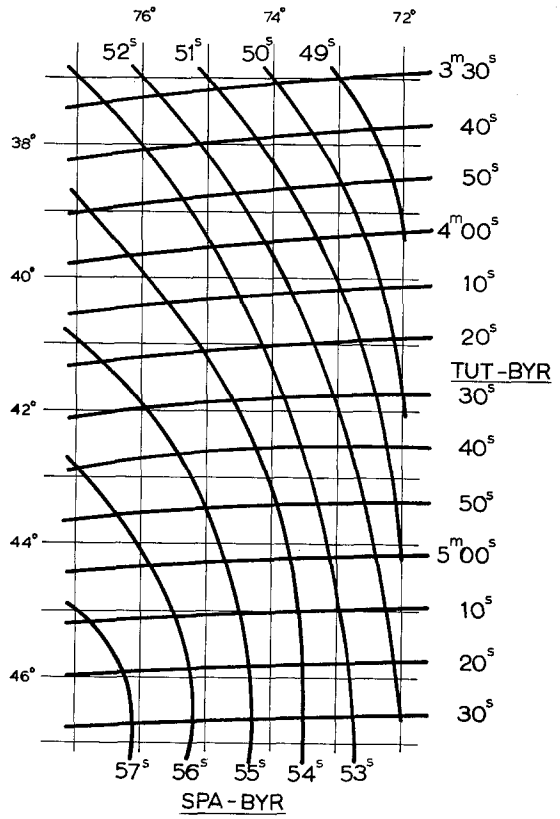

FIG. 2. Difference in arrival times at Tucson, Byrd Station and South Pole for shallow earthquakes in the region.

All earthquakes recorded at Tucson telemetering station with readable P arrival were picked up from 33 hours prior to the main shock to about 37 hours after the main shock with an interruption for about four hours after the main shock when all the record traces were tangled and unreadable. Next, all the arrival times at

Tucson were compared with those at Eureka, Byrd and South Pole, and the relative size of the trace amplitude at each station was also compared to reduce the possibility of mistaking different shocks as the same one. There is, unfortunately, a period from 00h to 24h on May 22 when the Byrd record was not available. In this period it was difficult to locate the epicenter precisely because of a small change in TUT-EUR over the region. However, arrival times, relative amplitudes and seismogram appearance at the other three stations were sufficient to identify earthquakes in the present activity among the recorded earthquakes. Furthermore, there are five earthquakes readable only at Tucson and Byrd in the period of foreshocks because of highly tangled records at the other two stations. They must also be foreshocks and are added to the foreshock group, for no seismic activity is found in a region near 45°S. and 160°W., which is symmetrical to the present region with respect to Tucson and Byrd. Even if this were a mistake, these extra small foreshocks would not favor the resultant statistics since what was found is the comparatively smaller number of small foreshocks.

All earthquakes located in the region and in the period specified before are listed in the Appendix with the trace amplitude of P wave. Since the epicenters reported by U.S.C.G.S. or B.I.C.S. and those located by the present method agree fairly well as seen in the Appendix, it is unlikely that any foreshocks or aftershocks larger than a certain magnitude may have been missed or any extraneous earthquakes may have been added into the present activity.

As a measure of magnitude, the trace amplitude of P wave by the vertical Benioff seismograph at the Tucson telemetering station was used, where the record was available for all earthquakes except three foreshocks, the trace amplitude of which was estimated from the record of a seismograph of lower sensitivity. The trace amplitude at other stations, as mentioned previously, was used for a further confirmation of the correspondence of earthquakes among the four stations. Assignment of magnitude itself was not made for the reason that only the relative comparison between the groups of foreshocks and aftershocks of one large earthquake was studied.

Most foreshocks were located near the northern edge of the quadrant region, whereas, the aftershocks were more widely scattered, as shown in Figure 3. The epicentral distance to Tucson, at which the standard trace amplitude was measured, ranges from 76° to 85°. No correction, however, was made on the trace amplitude according to the change in the epicentral distance, for such a slight change at this distance would not appreciably affect the trace amplitude and, furthermore, the logarithmic class interval was used to count the frequency of occurrence.

Relation Bewteen Frequency of Occurrence and Magnitude for the Foreshocks and Aftershocks

A question arises whether it is adequate to consider the present earthquakes as a sequence of foreshocks, main shock and aftershocks. The following facts are considered important: (1) The shock of 19h 11m 17s on May 22 was outstandingly larger by one or more in magnitude than the rest. (2) Although most shocks preceding the largest one took place north of the largest shock, they shared the region with the shocks after the largest shock as shown in Figure 3. (3) The present shocks can be separated from the background activity as will be shown in the

following. It will, therefore, be reasonable to assume that the initial breakage indicated by the foreshocks started near the northern end of the region, the main fracture developed to the south by the main shock and the aftershocks took place all over the region.

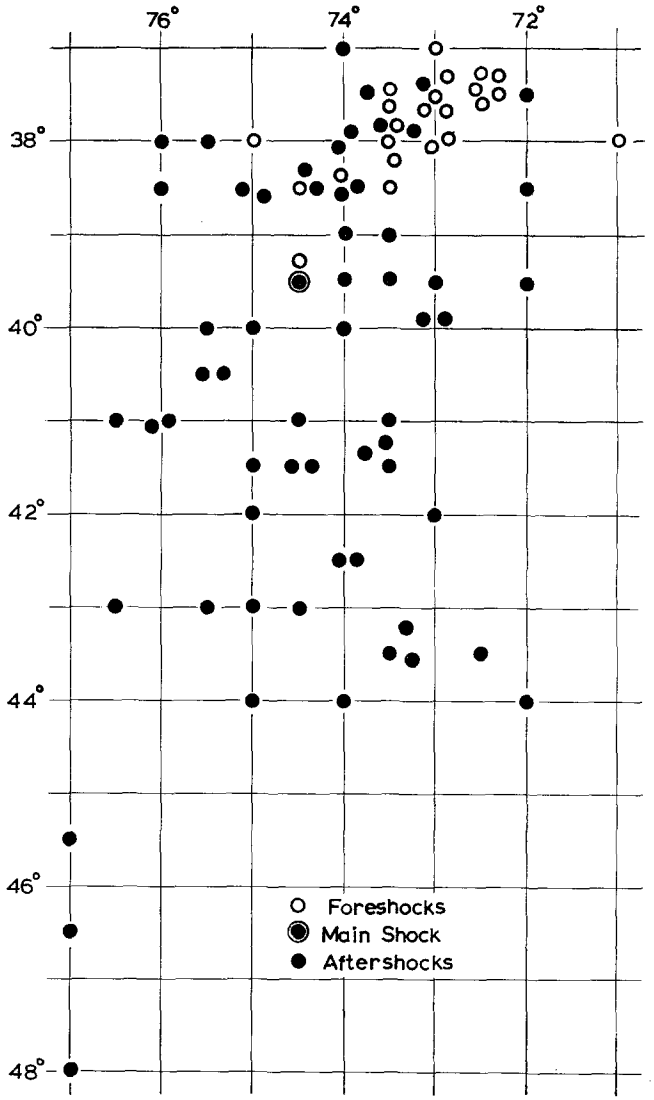

FIG. 3. Epicenters of foreshocks and aftershocks in a period 33 hours before and after the mainshock of the Great Chilean Earthquake of 1960 reported by U.S.C.G.S.

The next question will be, "When did the foreshock activity begin, and when did the aftershock activity come to an end?" In the present case, the first part of the question is easily answered; the beginning of the foreshock activity was undoubtedly sudden. As for the aftershock activity, only the first 33 hours after the main shock, which is equal to the period of the foreshock activity, was taken into consideration.

Figure 4 shows the epicenters located in and near the southern part of South America by U.S.C.G.S. in a period of six years from January 1954 to April 1960, and the region indicated by bold line is of the present foreshocks and aftershocks. The ordinary seismicity in the region is much lower than in the other regions, and the last shock reported there occurred about two months before the Chilean earthquake. In a period of 48 hours prior to the first reported foreshock, no shocks could be located by the present method in the region. Therefore, the foreshock activity

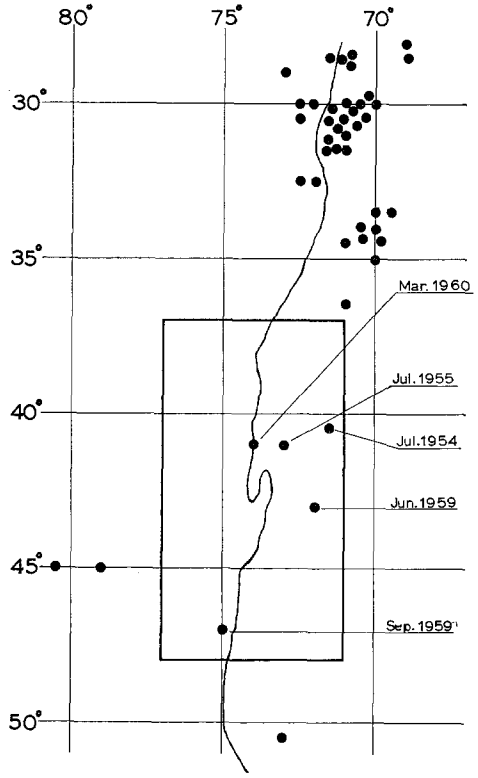

FIG. 4. Epicenters in the southern part of South America reported by U.S.C.G.S. in a period from Jan. 1954 to March 1960.

probably started with the largest foreshock, or had it been preceded by small shocks, they would have been too small to contribute to the present statistics. For counting the frequency of occurrence, a logarithmic class interval of trace amplitude, which is more or less similar to the class interval by magnitude was employed, and the lowest level was set to 2 mm, above which no earthquakes could possibly be missed. The frequency of occurrence thus counted is given in Table 2.

The result is graphically presented in Figure 5 and Figure 6. The rates of increase in frequency of occurrence with decreasing magnitude in the foreshock and aftershock activities were calculated by least squares with probable error as follows:

$$b = 0.55 \pm 0.05 \text{ for the foreshocks, and}$$

$$b = 1.13 \pm 0.04 \text{ for the aftershocks.}$$

As stated before, the class interval here is not according to magnitude itself, but to the logarithm of trace amplitude. Since the predominant period in P wave at the present epicentral distance is longer than the period of the seismograph, beyond which the magnification decreases sharply and the predominant period becomes

TABLE 2

FREQUENCY OF OCCURRENCE WITH THE LOGARITHMIC CLASS INTERVAL OF TRACE AMPLITUDE

Class Interval (mm in trace amplitude)	Foreshocks		Aftershocks	
	Frequency	Cumulative frequency	Frequency	Cumulative frequency
2–4	13	31	71	122
4–8	7	18	31	51
8–16	4	11	13	20
16–32	3	7	7	7
32–64	2	4	0	0
64–128	2	2	0	0

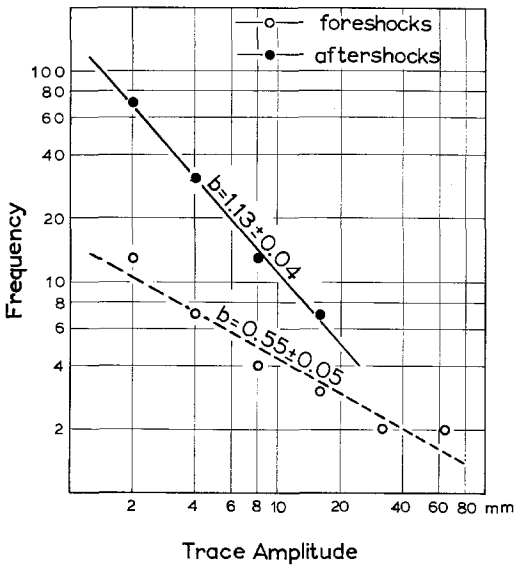

FIG. 5. Relation between frequency of occurrence and trace amplitude.

longer with increasing magnitude, the slopes given here are not quite equal to the value, "b", in Gutenberg-Richter's equation. Taking the above fact into account, the values obtained here are probably larger than the true values of "b", yet they are of the type of "b" rather than of the type of "m", which would be obtained by an equal class interval of the trace amplitude.

Obviously, a difference exists between the rates of frequency of occurrence with decreasing magnitude of the foreshocks and aftershocks. The cumulative frequency shows furthermore that the difference is not only in the rate of increase of occurrence, but also in the frequency of occurrence itself; namely, the frequency of occurrence is almost the same for larger shocks both in the foreshocks and after-

shocks, but for smaller shocks a much higher frequency of occurrence is seen in the aftershocks in the same period of time, 33 hours.

Discussion

In the present case, the magnitude of the main shock and the region of the foreshocks and aftershocks are both of the largest scale, yet it has interesting points

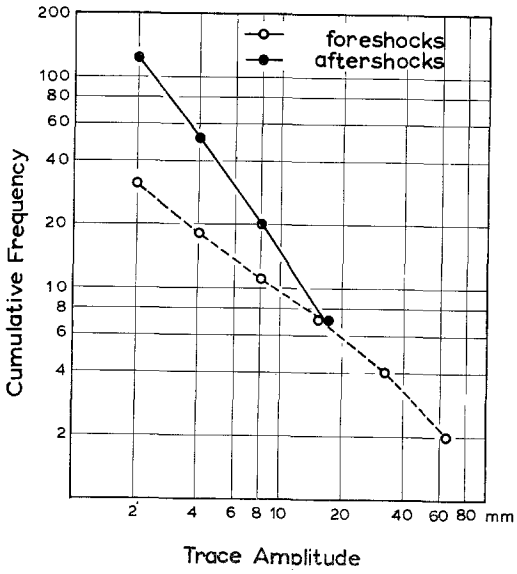

Fig. 6. Relation between cumulative frequency of occurrence and trace amplitude.

TABLE 3

Comparison Between Two Shocks Preceded by Many Observed Foreshocks

Event	Date	M of Main Shock	Duration of Foreshock Activity (hours)	Beginning of Foreshocks	"b" of Foreshocks	"b" of Aftershocks
Chilean shock	May (1960)	8.5	33	Largest foreshock	0.55	1.33
Japanese shock	Jan. (1964)	3.3	4	Third largest foreshock	0.35	0.76

to be compared with the example which took place in Japan. Comparisons are tabulated in Table 3.

(1) Duration of foreshock activity and its beginning.

It is not certain whether the duration of foreshock activity depends on the magnitude of the main shock as is generally the case in the aftershock activity. Two examples are too scanty to be a basis of generalizations. An interesting point is that in both cases the foreshock activity started with one of the larger shocks.

(2) Difference of "b" between the foreshocks and aftershocks.

It must be considered whether the difference is significant or not. According to Gutenberg and Richter (1954) different values of "b" are assigned to comparatively

large earthquakes in different seismic regions, ranging from 0.6 to 1.3. On the other hand, Suzuki (1959) claimed virtually the same "*b*" value for both ordinary and aftershock activities in different seismic regions and showed how much the "*b*" value could fluctuate in the statistical process, having studied small earthquakes.

As for the Japanese case of foreshock activity, a number of sensitive observations had been repeatedly made in the region before the event and the value of "*b*" had always fallen between 0.7 and 0.9 even with the total number of earthquakes being less than 50 in some observations. The value of 0.35 obtained for the foreshocks deviates well from the established value of "*b*" in the region. Especially in the comparison between the foreshocks and aftershocks, the difference was found with the same mode of class interval and by the same recording system, and when the same period was considered before and after the main shock large shocks occurred with almost the same frequency, whereas the occurrence of small earthquakes was more than six times as frequent in the aftershocks than in the foreshocks.

The same discussion can also be applied to the Chilean case except to the regional seismicity of small earthquakes, which is not available. Therefore, the validity of the difference between the foreshock value of "*b*" and that of the aftershock sequence is better substantiated than in the case of mere comparison among "*b*" values obtained in different ways as to class interval, observation system, period, magnitude range, etc.

Conclusion

Some difference seems probable in the manner of occurrence between foreshocks and aftershocks. No conclusion should, however, be drawn at this moment, but in view of a possibility that different values of "*b*" could serve for earthquake prediction effort should be made to accumulate more information along this line. Two things are suggested: One is to pursue such laboratory experiments like the one made by Mogi (1963), which demonstrated a possible difference in the value of "*b*" between foreshocks and aftershocks. The other is to make observations of high sensitivity, preferably by array observations which are capable of locating epicenters in the regions where earthquakes are reported to have been preceded by foreshocks.

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APPENDIX

Origin Time Reported by U.S.C.G.S. or B.C.I.S.	Location Reported by U.S.C.G.S. or B.C.I.S.	Location Estimated by Present Method	Readings							
			TUT		EUR		BYR		SPA	
			Arrival time	Trace amplitude	Arrival time	Trace amplitude	Arrival time	Trace amplitude	Arrival time	Trace amplitude
h m s	S W	S W	h m s	mm	h m s	mm	h m s	mm	h m s	mm
					Foreshocks					
May 21										
10 02 50	37½ 73½	37½ 73½	10 14 52	126.	10 15 36		10 11 17	75.	10 12 07	
			10 31 08	06.0	Unreadable		10 27 32	03.5	Unreadable	
			10 34 08	04.5	"		10 31 09	04.6	"	
			10 42 05	04.0	"		10 38 34	01.6	"	
10 32 38	Chile		10 45 40	06.8	"		10 42 24	09.0	"	
10 53 51	37½ 72½		11 05 52	26.0	"		11 02 20	18.5	"	
			11 14 01	01.2	"		11 10 18	01.8	"	
			11 16 23	03.0	"		11 12 55	01.5	"	
11 47 58	38 71	37 72	11 59 55	03.0	"		11 56 24	03.3	11 57 12	04.8
		37½ 72½	12 09 25	03.0	"		12 04 46	00.3	12 05 35	01.5
12 21 16	37½ 73	37 72	12 33 16	05.5	12 34 02		12 29 48	04.0	12 30 36	16.6
		37½ 72½	12 58 52	01.8	12 59 35	05.4	12 55 15	01.3	12 56 04	02.4
12 59 58	37½ 72½	37 72	13 11 58	13.0	13 12 43	45.5	13 08 27	13.0	13 09 15	55.
			13 18 48	01.9	13 19 33	11.7	13 15 16	01.7	In the previous shock	
		36½ 75½	13 42 11	01.0	13 43 09	02.0	13 38 53	00.6	13 39 44	01.2
13 48.8*	Chile	37½ 72	14 00 49	01.0	14 01 27	06.5	13 57 12	01.2	13 58 00	02.6
13 59 17	37½ 72½	37½ 72½	14 11 19	08.1	14 12 02	27.2	14 07 44	03.5	14 08 33	08.5
14 26.6	Chile	36½ 71	14 38 47	00.5	14 39 30	03.0	14 35 18	00.5	14 36 05	02.4
14 31 59	37½ 72½	37 74	14 43 57	02.9	14 44 40	08.5	14 40 26	06.0	14 41 16	14.0
15 08 45	37½ 72½	36½ 72	15 20 43	07.5	15 21 28	25.5	15 17 18	01.9	15 18 06	08.6
15 34.6*	Chile	37½ 72½	15 46 33	01.0	15 47 21	04.4	15 43 00	00.8	15 43 49	01.8
16 37.9*	Chile		16 48 55	00.5	16 49 32	02.2	16 45 18	00.5	No trace	
		37 75	17 04 30	00.6	Power stoppage		17 01 06	00.6	17 01 57	02.0
19 06 23	37½ 73½	37 74	19 18 21	02.2	19 19 04	08.5	19 14 49	04.2	19 15 39	05.0
		36½ 73½	19 36 31	00.8	19 37 14	03.1	19 33 06	00.5	19 33 55	01.7
		38 74	20 31 52	00.7	20 32 30	03.1	20 28 11	01.1	20 29 02	01.8
22 05.6*	Chile	37½ 71½	22 15 41	02.1	Disturbed by local shock		22 12 08	00.9	22 12 55	03.5
22 26.8*	Chile	37 73	22 38 38	01.8	22 39 22	05.5	22 35 05	03.8	22 35 54	07.9
		37½ 73½	23 29 14	01.3	23 29 59	03.3	23 25 39	00.5	23 26 29	01.0
23 38.9*	Chile		23 50 56	01.1	23 51 40	10.2	Record unavailable		Changing record	

May 22											
			00 44 38	01.0	00 45 22	02.0	Record unavailable		00 41 50	01.5
00 47.6*	39½ 74½		00 59 49	01.1	01 00 33	04.9	"	"	00 57 12	04.3
			01 03 05	00.9	01 03 48	02.9	"	"	01 00 29	01.9
00 52.4*	Chile		01 04 17	01.5	01 05 02	06.0	"	"	01 01 41	04.8
01 31.0*	Chile		01 43 00	00.5	01 43 43	10.0	"	"	01 40 15	01.5
03 06.5*	Chile		03 18 37	01.6	03 19 21	03.0	"	"	03 15 50	02.0
03 32.6*	Chile		03 44 46	02.5	03 45 24	05.3	"	"	03 42 02	02.8
03 46 22	37½ 73		03 58 20	08.5	03 59 05	23.0	"	"	03 55 38	14.0
04 15 45	37 73		04 27 40	02.6	04 28 26	06.5	"	"	04 25 06	03.7
06 01 36	38 73½		06 13 37	05.0	06 14 22	10.5	"	"	06 10 49	07.0
07 07 18	38 75		07 19 23	01.3	07 20 01	03.7	"	"	07 16 30	02.0
07 36 04	38 73½		07 48 03	03.0	07 48 46	07.0	"	"	07 45 14	14.5
08 10 53	37½ 73		08 22 55	17.5	08 23 39	41.0	"	"	08 20 07	09.5
10 30 39	38 73½		10 42 40	24.0	10 43 23	46.3	"	"	10 39 51	31.0
10 32 43	37½ 73		10 44 45	64.0	10 45 28	104.	"	"	10 41 47	110.
11 36.2	Chile		11 48 13	03.0	11 48 55	07.0	"	"	11 45 28	02.0
12 16 43	38 73		12 28 47	14.3	12 29 31	33.5	"	"	12 25 55	33.0
13 02 56	38 73		13 14 58	02.5	13 15 38	05.3	"	"	13 12 13	03.6
			13 15 37	03.2	13 16 20	09.3	"	"	13 12 55	10.0
			13 28 34	01.8	13 29 24	04.0	"	"	13 25 48	02.4
17 12 34	38½ 73½		17 24 38	02.0	17 25 22	07.0	"	"	17 21 46	08.0
18 55 57	38 73½		19 08 00	56.0	19 08 43		"	"	19 05 07	
19 10 37	38½ 74½		19 22 40	63.0	Unreadable		"	"	Unreadable	

Aftershocks

May 22											
22 07 48	44 72		Unreadable		Unreadable		Not available		Unreadable		
22 14 02	39 74		"		"		"	"	"		
22 15 23*	39 74		"		"		"	"	"		
22 48 14*	38 73½		23 00 10	05.5	23 00 52	09.0	"	"	"		
			23 01 25	03.5	23 02 08	07.1	"	"	22 58 35	07.2	
22 52.8*	Chile		23 04 49	06.2	23 05 32	18.0	"	"	23 00 55	10.0	
			23 08 11	02.5	23 08 52	04.7	"	"	23 04 18	07.2	
			23 14 06	03.5	23 14 46	02.5	"	"	23 09 35	02.0	
			23 16 22	03.5	23 17 02	03.5	"	"	23 12 00	06.5	
23 04 38	41 76		23 16 45	11.5	23 17 27	15.5	"	"	23 13 26	19.0	
23 07.0*	Chile		23 19 09	05.8	23 19 51	07.8	"	"	23 15 52	09.5	

APPENDIX—*Continued*

Origin Time Reported by U.S.C.G.S. or B.C.I.S.	Location Reported by U.S.C.G.S. or B.C.I.S.	Location Estimated by Present Method	Readings							
			TUT		EUR		BYR		SPA	
			Arrival time	Trace amplitude	Arrival time	Trace amplitude	Arrival time	Trace amplitude	Arrival time	Trace amplitude
h m s	S W	S W	h m s	mm	h m s	mm	h m s	mm	h m s	mm
					Aftershocks—*Continued*					
							Not available			
23 12 39	40 75		23 24 46	06.7	23 25 28	05.7	"	"	23 21 35	04.0
			23 29 06	02.0	23 29 48	02.9	"	"	23 25 36	04.0
23 29 18	39½ 72		23 41 29	10.5	23 42 13	28.0	"	"	23 38 37	15.5
23 32 40	41½ 73½		23 44 51	04.4	23 45 33	07.5	"	"	Changing record	
23 34 59	42 73		23 47 16	07.1	23 47 57	09.4	"	"	"	"
23 39.0*	40 74		23 51 12	06.3	23 51 53	22.0	"	"	23 47 11	16.2
		40½ 77½	23 55 52	02.3	23 56 35	03.8	23 51 45	00.5	23 52 40	02.6
			23 56 43	02.3	23 57 27	12.0	23 53 02	01.5	Not clear P	
		38 75	23 58 58	01.4	23 59 42	03.5	23 55 17	00.8	23 56 08	03.0
		38½ 73.0	00 07 33	02.7	00 08 13	07.2	00 03 43	01.5	00 04 33	02.0
23 56 10	42½ 74	40½ 73½	00 08 20	09.0	00 09 03	22.5	00 04 08	14.3	00 05 00	22.0
May 23										
00 07 58	44 75	43½ 73½	00 20 20	03.4	00 21 01	05.7	00 15 28	02.5	00 16 21	07.3
		44.0 71½	00 23 06	02.5	00 23 47	04.4	00 18 01	03.1	00 18 51	05.0
		40.0 75.0	00 28 39	01.3	00 29 22	04.4	00 24 35	01.5	00 25 28	04.5
		41 74½	00 34 14	02.4	00 34 54	04.7	00 29 58	02.1	00 30 51	04.5
00 25 44	38½ 75	38 74	00 37 45	27.5	00 38 30	70.	00 34 02	21.5	00 34 53	31.0
00 41 46	39 73½	39 73½	00 53 48	20.5	00 54 31	31.	00 49 55	10.1	00 50 46	29.
			00 56 06	02.7	00 56 51	09.0	In previous shock		In previous shock	
		38.0 73	01 01 12	02.0	01 01 55	06.5	00 57 27	02.5	00 58 17	02.3
		38½ 73	01 03 04	02.0	01 03 47	03.5	00 59 17	00.8	01 00 07	02.5
00 51 15	37½ 71½	37 72	01 03 15	13.8	01 03 59	50.	00 59 41	05.7	01 00 29	26.
00 53 57	39½ 73	39½ 74	01 06 04	31.5	01 06 50	47.0	01 02 07	07.2	01 02 59	21.5
01 01 45	38½ 72	38 73	01 13 45	10.5	01 14 30	22.5	01 10 00	08.5	01 10 50	14.2
		38 74	01 20 14	02.7	01 20 58	08.2	01 16 32	01.0	01 17 23	05.2
		41½ 72½	01 24 43	03.3	01 25 25	06.7	01 20 13	03.3	01 21 04	06.5
		40½ 71	01 28 31	02.4	01 29 14	05.8	01 24 16	02.0	01 25 04	05.0
		40 74½	01 33 20	02.2	01 34 04	04.2	01 29 13	02.2	01 30 06	03.0
		41 74	01 35 49	03.5	01 36 30	08.5	01 31 28	02.5	01 32 21	07.0
		45 75	01 37 39	02.7	01 38 20	04.5	01 32 33	02.8	01 33 28	08.5
01 34 53	39½ 74	39 72½	01 47 01	20.0	01 47 43	30.0	01 43 05	06.5	01 43 55	26.5

01 42 40	39½ 73½	39 74½	01 54 42	08.0	01 55 26	18.4	01 50 48	05.2	01 51 40	06.9
01 43 59	38½ 75	38 74½	01 55 58	11.8	01 56 42	29.5	01 52 19	07.6	01 53 10	18.4
01 55 57	38 74	38 74	02 07 51	06.0	02 08 35	13.2	02 04 10	03.1	02 05 01	06.0
		39 73½	02 13 57	01.1	02 14 40	02.9	02 10 04	00.7	02 10 55	01.6
02 04 52	38 74	38 74	02 16 53	04.7	02 17 37	13.3	02 13 10	03.4	02 14 01	03.2
02 06 43	41½ 75	41½ 74	02 18 54	02.7	02 19 36	06.0	02 14 31	02.5	02 15 24	05.6
02 12 17	42 75	41½ 73½	02 24 31	06.3	02 25 13	10.5	02 20 07	02.0	02 20 59	04.0
		38 76	02 25 51	03.4	02 26 35	06.0	02 22 10	01.2	02 23 03	02.2
		38 74	02 27 29	01.9	02 28 12	05.0	02 23 46	01.9	02 24 37	02.5
		41 75	02 33 59	04.2	02 34 42	03.6	02 29 40	03.5	02 30 34	09.4
02 25.8*	37½ 73½	38 73	02 37 50	02.8	02 38 35	17.5	02 34 08	02.8	02 34 58	06.0
02 37.2*	Chile	38 72½	02 49 11	04.0	02 49 54	11.0	02 45 30	03.2	02 46 19	04.5
02 39 51*	38½ 75	38 74½	02 51 49	06.4	02 52 36	16.0	02 48 09	09.5	02 49 00	09.0
02 43 38	37½ 73½	38 74	02 55 40	05.2	02 56 24	12.0	02 51 58	04.0	02 52 49	05.2
02 46 30	41½ 73½	41 73½	02 58 48	12.3	02 59 30	26.0	02 54 26	14.6	02 55 18	26.0
02 56 17	43 75½	42½ 74½	03 08 38	14.5	03 09 21	35.	03 03 59	12.	03 04 53	36.0
03 00.0*	37½ 73½	41 73½	03 12 00	07.8	03 12 45	12.5	03 07 40	03.7	03 08 32	06.5
03 03 16	44 74	43½ 73½	03 15 36	05.0	03 16 17	10.0	03 10 44	02.3	03 11 37	06.3
		40½ 73½	03 24 26	00.9	03 25 08	02.7	03 20 14	01.1	03 21 06	02.0
		38 73½	03 24 51	01.9	03 25 35	05.8	03 21 12	02.0	03 22 02	03.9
03 17.8*	43 73	42 73	03 30 10	01.4	03 30 51	03.6	03 25 35	01.4	03 26 27	02.8
		42½ 73	03 34 36	01.2	03 35 15	02.4	03 29 57	03.2	03 30 49	02.0
		43 73½	03 37 21	01.5	03 38 02	03.0	03 32 36	01.5	03 33 29	02.8
		39 74½	03 46 06	01.5	03 46 50	08.7	03 42 22	03.1	03 43 14	03.2
03 56 18	38½ 74½	38 73½	04 08 19	02.5	04 09 02	06.6	04 04 36	01.7	04 05 26	02.6
		36½ 73½	04 11 55	01.0	04 12 40	04.1	04 08 31	01.4	04 09 20	05.2
		44½ 73½	04 17 41	01.6	04 18 22	03.8	04 12 38	01.0	04 13 31	02.5
		43½ 74	04 20 15	02.0	04 20 58	04.2	04 15 25	01.5	04 16 19	03.6
		38 73½	04 27 01	01.0	04 27 45	02.0	04 23 21	00.4	04 24 11	01.2
04 20 20	43½ 72½	43 71	04 32 43	03.1	04 33 23	04.4	04 27 54	01.7	04 28 43	07.5
		45½ 74	04 37 40	02.8	04 38 22	04.6	04 32 33	02.0	04 33 17	07.2
04 26 58	38 75½	38½ 75	04 38 58	08.2	04 39 42	38.0	04 35 14	03.8	04 36 06	09.0
		38½ 73	04 49 34	01.4	04 50 19	03.5	04 45 43	01.2	04 46 33	01.5
04 47 46	43 75	42½ 74	05 00 05	02.7	05 00 47	08.7	04 55 28	03.1	04 56 21	10.6
		41½ 74	05 05 09	01.4	05 05 50	04.0	05 00 46	01.1	05 01 39	02.1
		45 75½	05 14 13	01.6	05 14 53	01.5	05 09 06	01.4	05 10 02	03.1
		39 73	05 15 07	01.8	05 15 52	03.3	05 11 14	00.7	05 12 04	01.4
		43 73½	05 23 46	03.2	05 24 26	05.5	05 19 00	02.2	05 19 53	05.0
05 13 41	38 73	38 72½	05 25 39	24.4	05 26 22	114.	05 21 58	17.0	05 22 47	50.0
05 48 02	46½ 77	46½ 75½	06 00 34	03.7	06 01 14	07.0	05 55 09	04.2	05 56 05	13.6
06 08 46*	43 76½	43 75½	06 21 07	06.8	06 21 49	22.0	06 16 25	04.0	06 17 20	08.6

APPENDIX—*Continued*

Origin Time Reported by U.S.C.G.S. or B.C.I.S.	Location Reported by U.S.C.G.S. or B.C.I.S.	Location Estimated by Present Method	Readings							
			TUT		EUR		BYR		SPA	
h m s	S W	S W	Arrival time h m s	Trace amplitude mm	Arrival time h m s	Trace amplitude mm	Arrival time h m s	Trace amplitude mm	Arrival time h m s	Trace amplitude mm
					Foreshocks—*Continued*					
		38½ 73	06 25 48	02.0	06 26 32	12.0	06 22 12	01.4	06 23 02	02.0
		38½ 74	06 28 26	01.9	06 29 09	04.8	06 24 36	00.6	06 25 27	02.3
06 17 50	38½ 74	38 74	06 29 48	02.7	06 30 32	08.2	06 26 05	03.2	06 26 56	09.8
06 25 29	38½ 76	38 74	06 37 28	03.5	06 38 12	07.3	06 33 45	04.1	06 34 36	05.6
		38 78	06 41 07	01.9	06 41 44	06.0	06 37 35	01.0	06 38 29	02.7
		41 75½	06 45 24	04.7	06 46 07	06.0	06 41 09	02.9	06 42 03	04.1
		42 73	06 50 44	02.1	06 51 25	05.2	06 46 12	01.7	06 47 04	04.0
		40 74	06 58 12	02.5	06 58 55	06.1	06 54 04	01.6	06 54 56	05.6
		38 73½	07 04 01	01.6	07 04 44	07.8	07 00 19	01.1	07 01 09	06.5
		38½ 74	07 11 03	01.4	07 11 47	03.5	07 07 17	00.9	07 08 08	01.5
		42½ 73	07 15 36	03.0	07 16 18	03.3	07 10 55	01.5	07 11 47	03.2
07 09 17	48 77	48 76	07 22 00	17.0	07 22 39	15.1	07 16 17	13.0	07 17 14	35.
			07 27 24	04.5	07 28 05	05.7	07 22 43	02.4	In foregoing shock	
		41 74½	07 31 38	02.5	07 32 16	05.5	07 27 21	02.1	07 28 14	04.5
		42½ 74	07 36 26	02.5	07 37 10	04.5	07 31 47	01.7	07 32 40	02.6
		43½ 73½	07 37 35	02.5	07 38 15	06.0	07 32 43	03.5	07 33 36	06.8
		46½ 72	07 44 51	02.7	07 45 34	05.1	07 39 20	01.7	07 40 12	03.3
08 13 15	40½ 75½	40 74½	08 25 26	09.1	08 26 07	07.3	08 21 17	04.7	08 22 10	21.0
		43½ 73½	09 15 03	02.1	09 15 44	03.4	09 10 21	01.0	09 11 14	01.4
		38½ 75	09 28 35	00.8	09 29 18	03.5	09 24 49	01.2	09 25 41	02.0
		38 74½	09 36 47	01.0	09 37 29	03.3	09 33 09	01.3	09 34 00	02.7
09 26.2*	40 73	41 73½	09 38 25	03.0	09 39 07	07.3	09 34 08	04.0	09 35 00	06.1
09 45.6*	40 73	38 73½	09 57 49	03.2	09 58 32	06.2	09 54 08	01.7	09 54 58	05.0
		39½ 74	10 02 09	02.0	10 02 50	03.4	09 58 12	00.8	09 59 04	03.7
09 52 20	37½ 73	37½ 73½	10 04 21	23.0	10 05 03	69.	10 00 45	05.5	10 01 35	24.0
		37 74	10 22 03	02.2	10 22 44	03.9	10 18 32	01.5	10 19 22	04.0
		38 73	10 24 40	02.2	10 25 24	06.0	10 20 57	01.1	10 21 47	04.2
		43½ 73½	10 43 02	01.0	10 43 44	03.0	10 38 09	01.5	10 39 02	04.5
10 37 59	43½ 73½	43½ 73	10 50 27	14.3	10 51 06	19.6	10 45 38	10.8	10 46 30	27.0
		41½ 73	11 10 19	00.7			11 05 54	01.3	11 06 46	01.6
11 22 33	41 74½	40½ 73½	11 34 44	03.3	11 35 25	06.7	11 30 28	03.6	11 31 20	05.6
		39½ 74	11 39 41	01.0	11 40 24	03.0	11 35 40	01.1	11 36 32	02.5
		42½ 74½	11 54 15	02.1	11 54 57	03.9	11 49 34	01.1	11 50 28	04.2

		43 73	11 57 37	01.1	11 58 17	03.0	11 52 52	02.0	11 53 44	04.0
11 50 22*	43½ 73½	42½ 73½	12 02 46	04.0	12 03 27	05.7	11 58 05	04.2	11 58 58	04.6
12 02 36	38 76	38 75½	12 14 30	04.5	12 15 14	19.7	12 10 53	02.7	12 11 45	05.5
		40½ 72½	12 15 50	01.5	12 16 30	05.0	12 11 37	04.0	12 12 27	06.5
		42½ 73½	12 52 09	02.9	12 52 52	04.6	12 47 32	01.3	12 48 24	02.8
		39½ 73½	12 55 00	03.9	12 55 42	03.3	12 51 07	00.9	12 51 58	03.0
		41 73½	13 29 30	00.5	13 30 12	02.5	13 25 10	00.9	12 26 02	01.5
		39 74½	13 36 32	03.4	13 37 14	07.0	13 32 41	01.5	13 33 33	03.2
		38½ 74	13 39 27	01.6	13 40 10	04.2	13 35 38	01.0	13 36 29	01.9
		39 74½	13 42 03	01.7	13 42 47	04.2	13 38 12	01.5	13 39 04	03.5
14 00 29	45½ 77	45 75½	14 12 53	05.1	14 13 33	11.7	14 07 44	02.7	14 08 40	11.0
14 01 37	42½ 74	42½ 74	14 13 59	11.7	14 14 40	28.8	14 09 20	13.3	14 10 13	24.0
		38 73½	14 18 18	03.2	14 19 00	08.3	14 14 37	01.2	14 15 27	04.0
			Disturbed by local shock		15 54 22	04.0	15 49 58	01.6	15 50 48	02.0
15 44 50	43½ 73½	42½ 73½	15 57 11	03.1	15 57 56	06.6	15 52 34	08.0	15 53 27	06.4
		42½ 74½	16 35 58	02.6	16 36 40	07.0	16 31 22	04.0	16 32 16	04.0
		38½ 74½	16 51 34	01.8	16 52 13	03.9	16 47 44	01.4	16 48 36	02.4
		40½ 76	17 14 55	00.6	17 15 37	03.4	17 10 48	00.7	17 11 42	02.2
		44½ 75	17 57 27	01.9	17 58 08	02.8	17 52 27	00.8	17 53 22	03.3
18 22 24	41 76½	40½ 75½	18 34 34	06.9	18 35 14	06.5	18 30 22	02.1	18 31 16	06.0
18 55 20	38½ 74	38½ 73	19 07 23	03.0	19 08 05	14.0	19 03 37	01.3	19 04 27	05.5
		42 74	19 17 24	02.3	19 18 05	04.5	19 12 54	01.2	19 13 47	03.2
		39 75½	19 18 10	02.0	19 18 57	02.5	19 14 17	01.6	19 15 10	02.2
19 09 08	40 75½	39½ 75	19 21 12	06.5	19 21 55	08.8	19 17 14	08.0	19 18 07	06.5
19 26.4*	38½ 74½	38 74	19 38 19	02.0	19 39 03	09.3	19 34 36	02.3	19 35 27	03.6
19 44 24	38½ 74½	38½ 74	19 56 20	01.5	19 57 03	05.5	19 52 35	02.0	19 53 26	02.4
		44 73½	20 06 14	02.0	20 06 55	08.5	20 01 19	01.6	20 02 12	03.4
19 59.8*	41 75	40½ 73½	20 12 00	02.6	20 12 43	02.7	20 07 44	02.7	20 08 36	04.0
		37½ 73½	20 34 23	02.4	20 35 07	07.0	20 30 45	01.4	20 31 35	04.5
		43½ 73½	20 45 59	01.2	20 46 39	02.1	20 41 09	00.7	20 42 02	03.0
		41½ 73	20 53 00	01.3	20 53 41	02.4	20 48 33	00.7	20 49 25	03.2
		39 73½	20 56 59	00.9	20 57 43	03.2	20 53 06	00.6	20 53 57	01.2
		38½ 74½	21 00 29	01.1	21 01 13	04.2	20 56 42	00.9	20 57 34	01.5
		40 74½	21 19 40	04.0	21 20 23	09.5	21 15 33	05.7	21 16 26	08.6
		40½ 73½	21 26 23	01.3	21 27 05	02.5	21 22 22	01.5	21 23 14	04.0
		39½ 72½	21 40 56	02.4	21 41 37	02.4	21 36 56	00.8	21 37 46	02.1
		38½ 73	21 53 04	01.3	21 53 42	06.0	21 49 14	02.0	21 50 04	02.2
		38½ 73½	21 54 57	01.5	21 55 38	05.0	21 51 08	01.7	21 51 59	03.2
		38 73½	21 56 23	02.3	21 57 07	07.2	21 52 43	01.4	21 53 33	02.2
		39 73	22 02 56	02.0	22 03 39	02.5	21 59 03	00.8	21 59 53	02.3

APPENDIX—*Continued*

Origin Time Reported by U.S.C.G.S. or B.C.I.S.	Location Reported by U.S.C.G.S. or B.C.I.S.	Location Estimated by Present Method	Readings							
			TUT		EUR		BYR		SPA	
h m s	S W	S W	Arrival time h m s	Trace amplitude mm	Arrival time h m s	Trace amplitude mm	Arrival time h m s	Trace amplitude mm	Arrival time h m s	Trace amplitude mm
			Aftershocks—*Continued*							
22 05 44	37 74	37 73	21 17 36	03.5	22 18 20	09.2	22 14 10	02.0	22 14 59	06.2
		40 72	22 21 17	01.5	22 22 00	03.3	22 17 04	01.0	22 17 53	04.7
		41 73	22 51 43	01.2	22 52 25	02.5	22 47 22	01.1	22 48 13	01.9
22 42 19*	41½ 73½	41½ 73½	22 54 37	02.7	22 55 18	04.9	22 50 09	01.4	22 51 01	06.2
		42½ 73	22 58 14	01.7	22 58 55	05.5	22 53 36	01.8	22 54 28	06.0
23 13 14	41½ 74½	41 73½	23 25 29	02.2	23 26 10	05.4	23 21 11	05.1	23 22 03	09.5
		44½ 73½	23 43 37	01.3	23 44 13	03.4	23 38 35	01.1	23 39 28	02.5
24th										
		39 73½	00 31 50	01.7	00 32 33	02.0	00 27 53	00.9	00 28 44	02.5
		44½ 73½	00 38 52	00.8	00 39 30	03.3	00 33 51	00.7	00 34 44	03.2
00 43.9*	Chile	42½ 73	00 56 03	02.8	00 56 44	10.2	00 51 25	02.7	00 52 17	02.4
		42 72	01 13 06	01.1	01 13 45	03.6	01 08 34	01.4	01 09 24	03.0
01 37 39	43 74½	43 73	01 49 59	04.0	01 50 40	07.0	01 45 15	03.0	01 46 07	08.4
01 40 56	41½ 74½	41 74	01 53 11	06.2	01 53 52	11.5	01 48 49	04.2	01 49 42	12.0
		39½ 74	01 58 46	01.2	01 59 29	03.1	01 54 45	01.0	01 55 37	02.6
		39½ 74	02 09 45	00.6	02 10 28	02.8	02 05 44	01.0	02 06 36	02.4
		43 73	02 22 01	00.9	02 22 39	02.5	02 17 18	01.0	02 18 10	01.8
		40½ 72½	02 45 16	01.3	02 45 55	02.0	02 41 11	00.8	02 42 01	03.5
		41 73½	02 53 45	00.9	02 54 27	03.2	02 49 26	01.3	02 50 18	03.5
02 47 14	41 76	40½ 74½	02 59 24	04.2	03 00 07	06.2	02 55 12	03.4	02 56 05	13.0
		38 74	03 08 17	01.1	03 09 01	02.2	03 04 33	00.9	03 05 24	01.3
		44 72	03 18 30	01.5	03 19 09	02.2	03 13 35	01.4	03 14 26	02.1
03 24 00	38½ 74	38 72½	03 35 59	06.3	03 36 42	10.7	03 32 19	03.0	03 33 08	05.1
03 46.6*	39 73	39 71½	03 58 45	06.3	03 59 27	10.0	03 54 49	01.9	03 55 38	08.0
		41 73	04 01 20	02.5	04 01 02	06.0	03 56 59	01.9	03 57 50	05.0
		38½ 76	04 05 15	00.7	04 05 58	03.1	04 01 30	02.3	04 02 23	03.0
		40 72½	04 27 00	01.2	04 27 47	01.8	04 22 51	00.9	04 23 41	03.0
		42½ 72½	04 55 39	01.1	04 56 21	02.4	04 51 02	00.7	04 51 53	01.1
		37 74	04 58 43	01.1	05 59 22	03.5	04 55 16	01.1	04 56 06	01.9
		40½ 72½	05 01 27	01.1	05 02 09	02.7	04 57 15	01.4	04 58 05	05.9
04 57 32	43½ 73½	43 72½	05 09 51	03.5	05 10 28	05.0	05 05 05	03.7	05 05 56	12.0
		41 72½	07 14 55	01.0	07 15 36	02.5	07 10 36	00.8	07 11 27	01.5
07 52.4*	Chile	46 73½	08 04 27	04.5	08 05 08	03.0	07 59 03	03.5	07 59 57	13.0