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ANALYSIS OF THE ERUPTIVE HISTORY OF THE VOLCAN DE COLIMA, MEXICO (1560 - 1980)

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RESUMEN

Con base en diversas fuentes de información se elaboró el catálogo de la historia eruptiva del Volcán de Colima, México, para el período 1560 - 1980. Este volcán es actualmente el más activo del país, su historia eruptiva muestra una alta frecuencia de actividad de tipo explosivo, contándose por lo menos 29 erupciones de este tipo en los últimos 420 años.

El análisis de los datos del catálogo muestra 57 períodos de reposo. La aplicación de los modelos estadísticos de Wickmann (1966) y Thorlaksson (1967) permitió la evaluación de la función de razón de erupción $\phi(t)$, la función de distribución para la longitud de los períodos de reposo F(t), y la función de densidad de probabilidad para la misma variable f(t). El análisis del comportamiento de estas funciones permite estimar un máximo en la probabilidad de ocurrencia de un nuevo período eruptivo para períodos de reposo menores de 18 años.

ABSTRACT

A catalogue of the eruptive history of Volcán de Colima, México, (based on published papers and reports) for the period 1560 - 1980 is presented in this paper. This volcano is at the present time the most active in the country. The recorded data show that the dominant activity is of the explosive type with at least 29 eruptions of this kind in the last 420 years.

An analysis of the data shows 57 repose periods in this lapse the application of the statistical models of Wickman (1966) and Thorlaksson (1967) allows the computation of the eruption rate $\phi(t)$, the distribution function for the length of repose periods F(t) and the probability density function for the same variable f(t). These functions yield maximum probability for the occurrence of eruption at repose periods shorter than 18 years.

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INTRODUCTION

Volcán de Colima (V.C.), in the state of Colima, México, is at the present time the most active volcano in the country (Demant, 1979). Its proximity to densely inhabited centers increases the need for an evaluation of the probability of occurrence of a new eruptive period.

In the past years several statistical models have been developed and applied to volcanoes in an effort to forecast eruptions (Wickmann, 1966a, 1966b; Thorlaksson, 1967; Rose and Stoiber, 1969; Reyment, 1976; Wickmann, 1976; Scandone, 1980). In most of these models the eruptive history of the volcanoes is analysed to evaluate the probability of new eruptions, based upon information on the repose periods and eruption times.

The quality of the forecasts made on these bases relies strongly on the quality of the available data (Decker, 1973).

A reconstruction of the eruptive history of the V.C. from historical records is presented in this paper. The application of the statistical models of Wickman (1966a) and Thorlaksson (1967) to the data thus obtained allows estimation of the probability of eruption after various periods of repose.

GEOLOGY

Volcán de Colima, (19°30'45" N: 103°37'01" W; Fig. 1) is a typical stratovolcano displaying interbedded lava flows and pyroclastic layers. According to Mooser (1961) its formation began in late Pleistocene. This structure rises in a zone of tectonic grabens and recent volcanism of marked crustal weakness. To the north of the volcano, the intersection of the Sayula and Toliman grabens form a wider graben known as the Colima Graben. (Herrera, 1967, Fig. 2).

In the same area some other volcanic structures stand out as well: the older volcanoes of La Tigra and Nevado de Colima and the cinder cones, Comalito, San Antonio, Telcampana, Erita y Apaxtepetl.

The formation of the V.C. is related to the history of the older and largest volcano Nevado de Colima (19°33'44" N; 103°36'31" W), already extinct and strongly eroded (Mooser, 1961).

Two distinct periods of development for the V.C. are distinguished by Mooser (1961). In the first one, most of its formation took place followed by collapse; the eroded remains of the structure of this period can be seen in the caldera complex, forming a Somma Type Crater. In the second period, a new volcanic edifice was formed as a consequence of accumulation of pyroclastics and lava flows to reach the present form.

V.C., as well as the Mexican volcanic belt, presumably developed in response to the northeastward subduction of the Cocos Plate under the Mexican Plate. Molnar and Sykes (1969) have delineated a crude Benioff zone about 100 km below the V.C. complex dipping at an angle of 30° to the northeast. Nevertheless, the relation of V. C. to the Mexican Volcanic belt is not clear yet.

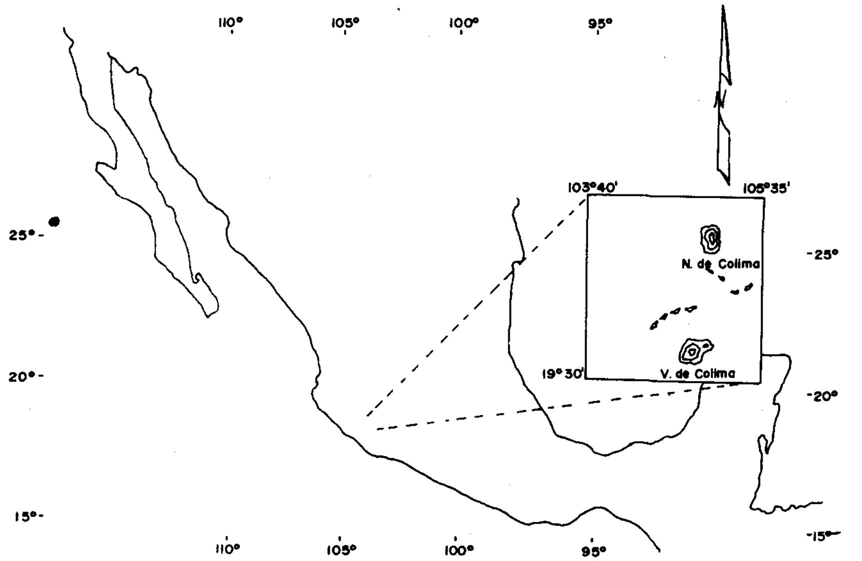

Fig. 1. Location of the Volcán de Colima.

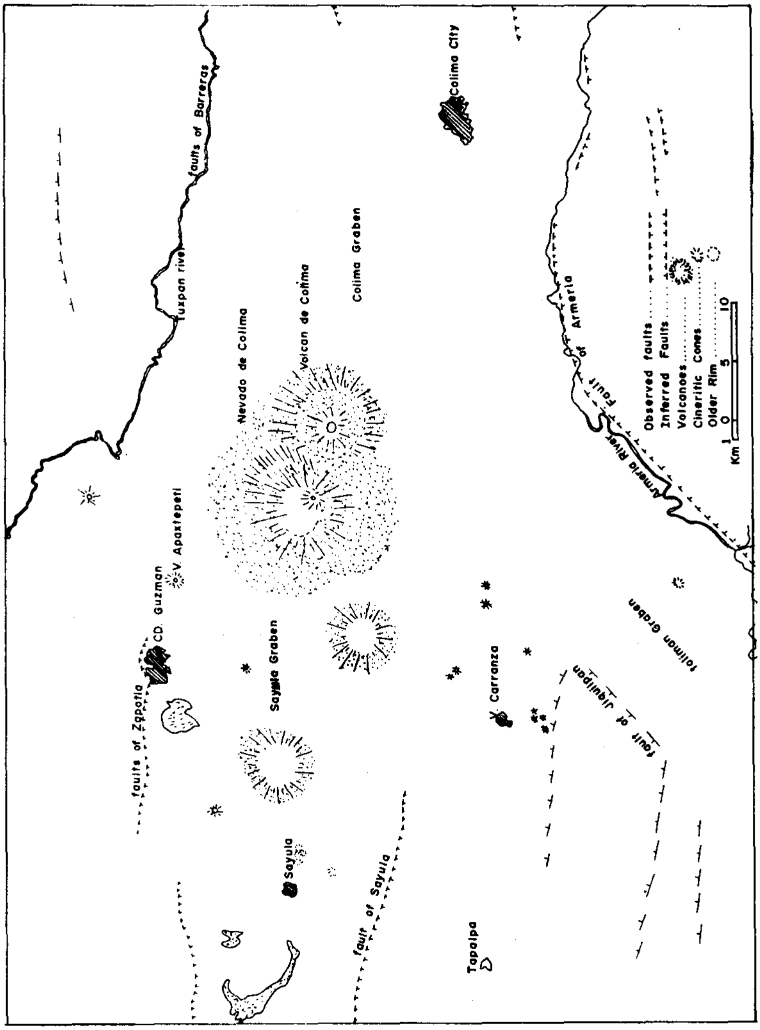

Fig. 2. Tectonic features of the area (after Herrera, C., 1967).

SOURCES OF INFORMATION

The violent activity shown by the Volcano throughout its many eruptions, has been recorded in several manuscripts dating from colonial times. The oldest known reference appears in the Archivo de Indias and is dated 1560 i.e. two decades after Spanish colonization of the region (M. Ahumada, personal communication). Most of the information for the 16th and 17th centuries was compiled from the reports of the "Archivo de Indias" (M. Ahumada, personal communication), and from a catalogue published by J. M. Arreola (1915).

Continuing activity drew attention from several naturalists since late 18th century. Some of their reports were published in the proceedings of the Sociedad Científica Antonio Alzate, in the late 19th century. Frequent and spectacular activity during the 19th century attracted growing interest. Two observatories were set up and carried out continuous observations over a period of 12 years. Daily records of activity were kept between 1893 and 1905 (Díaz, 1906). The last explosive eruptive period took place in 1913 and a complete report was given by Waitz (1936). In the following years several authors reported the rise of the lava level, which exceeded the crater rim in 1957. The rate of ascent in the plug was estimated to be of the order of 20 cm/day for the period may-1957, may-1958 (Mooser, 1961). The most recent activity, which consisted of a Merapian type overflow, was observed in 1975 (De la Cruz-Reyna, 1977).

CATALOGUE

The catalogue of the eruptive record of the V.C. may be divided in two parts according to the quality of the data. The first of these, from 1560 to 1750, has scarce information on the details of the activity and only the dates of the most relevant manifestations are known. Some eruptions were reported as consisting of "abundant ash and hot material fall out", reaching in many cases the city of Colima, 30 km away (Arreola, 1915) and "causing darkness and need for candlelight during daylight due to the ash fall". Data from this period should be used with caution.

The second part, from 1750 to this date, is of gradually improving quality due to the reports of qualified observers and to requests for information by the central government.

The information is summarized in Table 1, which includes a short description of the activity, and the source of the information (Columns 2 and 5). (The type of activity suggested is based on the description of Williams and McBirney, 1979). In many cases only the date of maximum intensity in the activity is known but not the duration of the eruptive period. In column 4 the type of activity is indicated with the nomenclature used in the Catalog of Active Volcanoes (Neuman Van Padang ed. 1957).

ANALYSIS OF THE DATA

The data of Table 1 show 29 explosive phases in the last 420 years (i.e. an average of 6.4 phases per century). This type of eruption seems to be the most dominant in the eruptive activity of the V.C. It is very probable that at least 40% of the explosive eruptions are of either the Vulcanian or Pelean Type (Fig. 3). Luhr and Carmichael (1980), have divided the activity of the volcano into 4 cycles. The first three ended with the large explosive emissions of 1611, 1818 and 1913. They believed that the last cycle, initiated in 1961, will end at the beginning of the next century with a violent explosive eruption similar to those mentioned above.

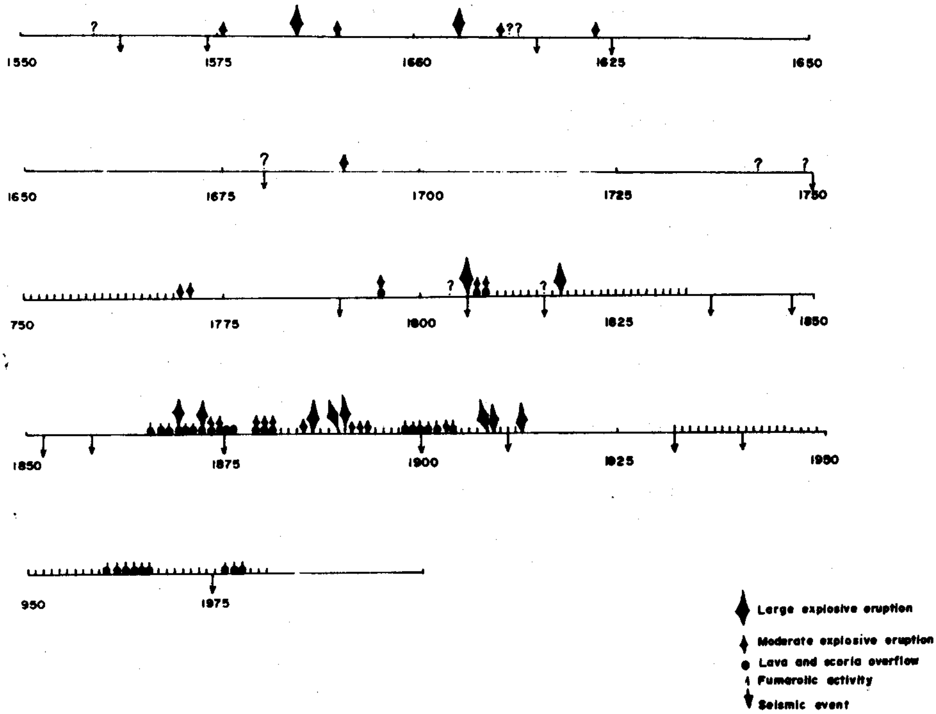

Fig. 3. Diagrammatic representation of the eruptive history of Volcán de Colima.

Luhr and Carmichael base their conclusions on the apparent periodicity of maximum activity throughout the history of the V.C. However, there are at least 2 events of great intensity that have not been taken into account in their analysis: those of 1590 and 1806. In addition to these there seems to have been important activity in 1690. These data would modify the pattern proposed by these authors.

In order to evaluate the probability of a new eruption of the volcano, the statistical model of Thorlaksson (1967) was applied to the data. This model is based on the distribution function of the length of the repose periods.

In this analysis 3 functions are employed: the eruption rate function $\phi(t)$, as defined by Wickman (1966a); the distribution function for the length of the repose periods F(t); and the probability density function, f(t), for the same variable. The relationship between these functions is as follows:

$$f(t) = F'(t) \qquad \phi(t) = \frac{f(t)}{\int_t^{\infty} f(u)\,du}$$

Two constants relative to the length of the repose periods are the mean (m) and the standard deviations (s). For the V.C. it is possible to recognize 57 repose periods with duration between 1 to 683 months, with: m = 59.4 month and s = 135.94 month.

According to Thorlaksson if the relation between the mean and standard deviations is $s/m > 1$, then $\phi(t)$ has the form:

$$\phi(t) = \frac{a}{1 + bt} \qquad (1)$$

where $a > 2b$. The constants a and b are defined by:

$$a = \frac{2s^2}{m(m^2 + s^2)} \qquad b = \frac{s^2 - m^2}{m(m^2 + s^2)}$$

Figure 4 shows the graph for $\phi(t)$; it also shows $\phi(t)$ as obtained from the graphical method of Wickmann (1966a). This consists in plotting the logarithm of the number of repose periods greater than t versus t ; $\varphi(t)$ is then evaluated by taking the derivate of the adjusted straight lines (Figure 4). As it is readily seen there is a good agreement between both values, taken into account that the $\phi(t)$ evaluated by the method proposed by Wickmann is approximated by 3 straight lines.

From equation (1), the probability density function is obtained as:

$$f(t) = a(1 + bt)^{-a/b-1}$$

The values for a and b obtained from the catalogue are:

$$a = 0.02827 \qquad b = 0.01144$$

With these values of a and b, $\phi(t)$, F(t) and f(t) are computed; the results are displayed in Table 2 and Figure 5. The last column of Table 2 shows the probability of duration of the repose periods:

$$P(x<t) = \int_0^t f(u)du$$

With the values of this column it is possible to conclude that most of the reposes are shorten than 36 months; the eruption rate function is at its maximum within the first 36 months.

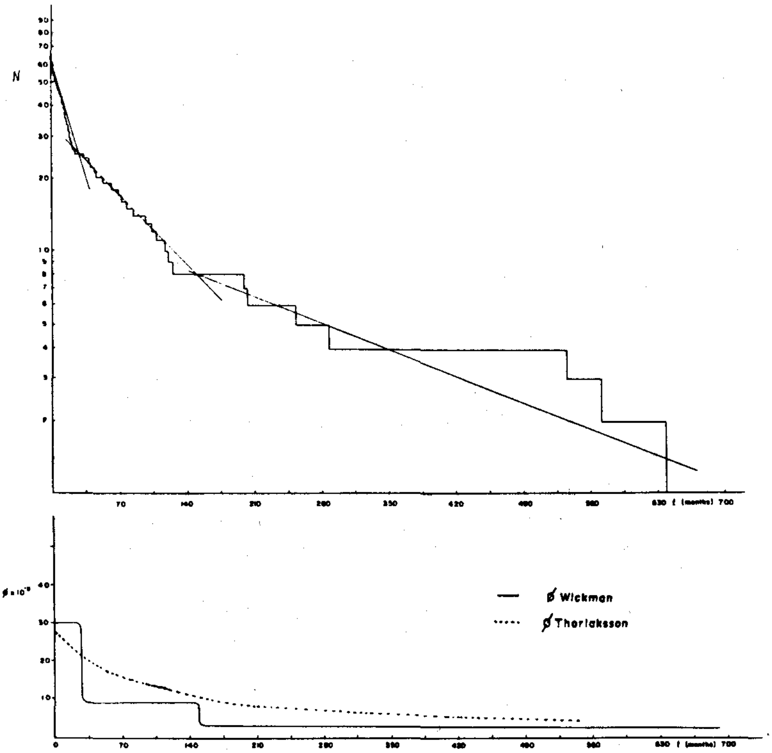

Fig. 4. Eruption rate function evaluated by the Wickmann and Thorlaksson methods.

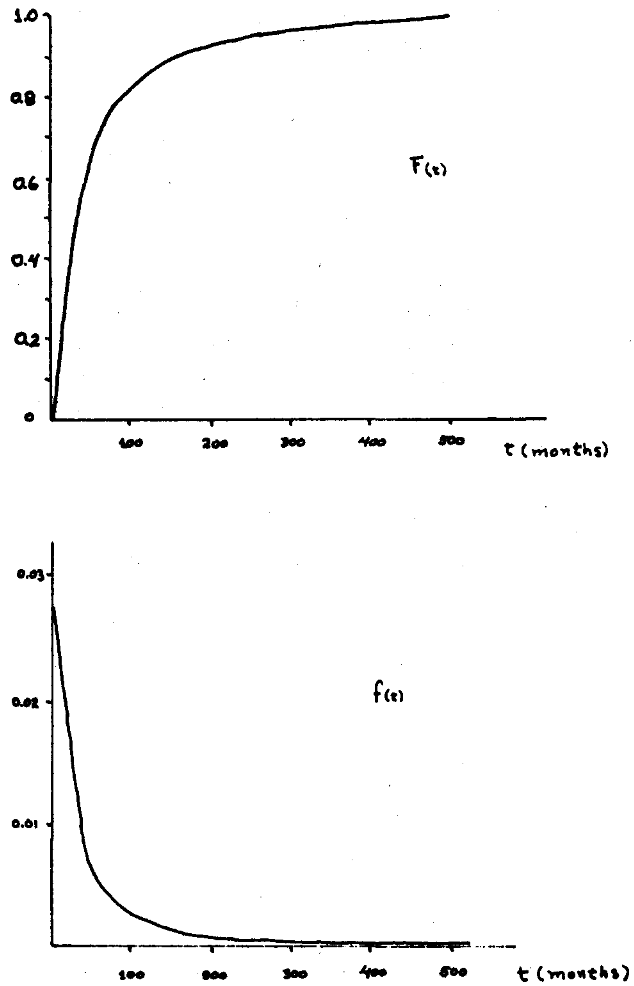

Fig. 5. Distribution function for the repose periods, F(t) and density probability function, f(t) for the same variable.

CONCLUSIONS

From this analysis it is concluded that the probability of a new eruption taking place in the volcano is of the order of 95% for repose periods shorter than 220 months. Given that the last eruption was in 1975, the maximum probability for the occurrence of an eruption would be for periods ending after 1992, in agreement with the supposition of Luhr and Carmichael. This is true only if the eruptive pattern in the last 420 years is continued in the future.[1]

In the above analysis repose periods of as short as 1 month were considered as separate repose periods. Taken the activity separated by periods of this length as a single event does not significantly alter the results since still s/m > 1 and the other relevant parameters remain almost the same.

Since for the period before 1750 it is likely that only the largest eruptions were recorded the estimates for m and s should be considered as an upper limit. Thus, the 220 month period should be considered as an upper limit as well. This and the fact that since 1975 the volcano's plug is in continuous ascent, indicate that there is a high probability of the occurrence of a new eruptive period much sooner than the end of the century.

[1] After completion of the present paper a new eruptive period took place (January, 1982). This activity follows the same pattern as that of the past 400 y.

Table 1

Catalogue of the eruptive activity of Colima volcano
Period of activity 1560 - 1750

Year	Date	Description of the activity	Type of activity	Source
1560 - ?	———	Eruptive activity is mentioned without reference to details of the eruption type.	0 ?	8b
1576 - ?	———	Large explosive eruption probably of Pelean or vulcanian type with abundant ash rain and strong seismic activity. (Deaths due to the activity are mentioned).	0↑ → † (g)	2, 3, 8a, 13, 31
1585 - ?	Jan 10	Large explosive eruption probably of Pelean type with abundant ash rain and strong seismic activity. (The ashfall covered an area of radius greater than 30 km). (Probably "nuée ardente" at the SW)	0↑ → ■(g)	2, 8a, 9, 20
1590 - ?	Jan 14	Explosive eruption with abundant ash rain.	0↑ → (m)	2, 13, 19, 31
1606 - ?	Nov 25 and Dec 13	Large explosive eruption probably of Pelean type with abundant ash rain and strong seismic activity. The ash fall covered an area of radius greater than 50 km. (Probably "Nuée ardente" at the WSW).	0↑ → ■(g)	2, 9, 19, 20

Table 1 (continued)

Year	Date	Description of the activity	Type of activity	Source
1611	Apr 15 and Oct 20	Large explosive eruption probably of vulcanian type with abundant ash emission.	0↑ → (g)	2, 3, 13, 21, 31
1612 - 1613	----	Eruption activity with seismic movements. No reference to the details of activity type.	0↑	3
1623 - ?	Jun 8 and 9	Explosive eruption probably of vulcanian type with abundant ash rain which covered an area of radius greater than 50 km.	0↑ → (g)	2, 8a, 9
1680	----	Strong seismic activity very local around the volcano area. Only one of the sources referred to activity in the volcano.	-----	8a, 9
1690 - ?	----	Large explosive eruption probably of Pelean type with abundant emission of ash and strong seismic activity.	0↑ → (g)	8a, 20
1743 - ?	Oct 22	The source refers to strong seismic activity during 12 days, very local. This activity produced the fall of trees in the zone. By this fact it is possible to consider some activity in the volcano.	0↑ (?)	3, 29
1749	----	Eruptive activity with strong seismic movements. No reference to the eruption details.	0↑ (?)	13, 31

Table 1 (continued)

Year	Date	Description of the activity	Type of activity	Source
		Period of activity 1750 - 1980		
1750 - 1769	----	Fumarolic state.	$\overset{\uparrow}{\circ}$	3
1770	----	Explosive eruption with emission of ash.	0→ (m)	13, 14, 31
1771 - ?	----	Explosive eruption with emission of ash and seismic activity.	0↑ → (m)	2, 3
1795 - ?	----	Eruptive activity probably of Merapi type with emission of lava and scoria.	0 ≈>(m)	13, 14, 31
1804	----	Eruption, no reference to the details of activity type.	0(?)	29
1806	Mar 25	Large explosive eruption probably of Pelean type with abundant emission of ash and strong seismic activity. The source refers to deaths due to the activity.	0↑ → † (g)	2, 3, 13, 16, 31
1807 - 1808	----	Eruptive activity probably of Merapi type with abundant emission of lava and scoria.	0 ≈>(m)	2, 3, 13, 29
1809	----	Reduced fumarolic activity with several explosions in the plug.	$\overset{\uparrow}{\circ}$ ↑	13
1810 - 1817	----	Fumarolic state.	$\overset{\uparrow}{\circ}$	3

Table 1 (continued)

Year	Date	Description of the activity	Type of activity	Source
1816	----	Strong seismic activity during 8 days, without reference to the volcano.	----	20
1818	Feb 15 and May 31	Large explosive eruption probably of Pelean type with abundant emission of ash which covered an area of radius greater than 100 km. Small emission of lava and strong seismic activity. Deaths and surface manifestations due to the activity are mentioned. (Probable glowing avalanche to the SW).	0 ↑ → ≈> ▨ + (g)	2, 3, 8a, 13, 21, 31
1819	----	Reduced fumarolic state with several explosions in the plug.	↟ ↑	3
1820 - 1834	----	Fumarolic state.	↟	2
1866 - 1868	Mar 4 (1866) Jun 12 (1869)	Rise of lava level from 200 m depth until outflowing the crater rim. Increased fumarolic activity. Formation of parasitic vent (El Volcancito).	↟ ⊓	2, 3
1869	Jun 12	Large eruption in the parasitic vent (El Volcancito) with abundant emission of lava.	0 ↟ ∞ ≈> (g)	
1870 - 1871	----	Eruptive activity in the adventice vent with small emission of lava. Increased fumarolic activity in the principal crater.	0 ↟ ∞ ≈> (ℒ)	1, 2, 18, 31, 25

Table 1 (continued)

Year	Date	Description of the activity	Type of activity	Source
1872	Feb 26 Mar 8, 19 Mar 26, 27, 28 Apr 10, 14, 16 Aug 13, Dec 24	Large explosive eruptions some probably of Strombolic type, with abundant emission of ash and overflow of lava and scoria in the parasitic vent. Strong seismic activity The ash covered an area of radius greater than 30 km. The principal crater increased the fumarolic activity. (ash cloud or probably glowing avalanche to the S.).	0 ↕ ∞ ↑ → ≈> ■ (g)	
1873	Jan 5, 8, 25 Feb 8 10, 27 Mar 14	Moderate explosive eruptions with small emission of lava in the adventice vent. Small overflow of scoria in the principal crater with increase in the fumarolic activity.	0 ↕ ↑ ∞ ≈> (m)	2, 3, 15a, 18, 21, 25
1874	Jun 12 Nov 19	Moderate explosive eruptions with small emission of lava in the adventice vent. Intense fumarolic activity in the principal crater.	0 ↕ ↑ ∞ ≈> (m)	2, 3, 19
1875 - 1878	———	Eruptive activity in the adventice vent with small emissions of lava and scoria. Fumarolic activity in the principal crater.	0 ↕ ∞ ↑ ≈ (ℒ)	2, 3

Table 1 (continued)

Year	Date	Description of the activity	Type of activity	Source
1879 - '80 '81	Dec 23 Mar 31, Apr 30 Mar 23, Apr 12	Strong explosive eruptions with emission of lava and pyroclastic materials through the principal crater	0 ↑ → ≈>(g)	2, 3, 19, 31
1882 - 1884	-----	Persistent fumarolic activity with small explosions in the plug.	0 ↑ ↕∘	2, 14
1885	Dec 26	Strong explosive eruption with emission of lava and pyroclastic materials through the principal crater. Strong seismic activity.	0 ↑ ≈>(m)	2, 3, 14, 31
1886	Jan 6 Feb 19, Mar, May, Aug 19, 26, 28, Sep 16, 24, Oct	Large explosive eruptions, some probably of Vulcanian type with abundant emission of ash and strong seismic activity.	0 ↑ → ■ (g)	2, 3, 8a
1887 - 1888	-----	Reduced fumarolic activity	↕∘	2
1889	Aug 9 Oct 26 Nov 5, 8 Dec 10 Dec 18, 22, 26	Large explosive eruptions, some probably with abundant emission of ash and strong seismic activity (Probably glowing avalanches to the SE and SW).	0 ↑ → ≈>(g)	2, 19

Table 1 (continued)

Year	Date	Description of the activity	Type of activity	Source
1890	Jan 4 Feb 16 Nov 18	Large explosive eruption with abundant emission of ash which covered an area of radius greater than 100 km.	0 ↑ → (g)	1, 2, 19
1891	Jul Aug, Sep Nov, Dec	Explosive eruptions with continuous emissions of ash and pyroclastic materials.	0 ↑ → (m)	1, 2, 19
1892	Jan, Feb, Mar, Apr, May, Jun	Explosive eruptions with continuous emissions of ash and pyroclastic materials.	0 ↑ → (m)	1, 2, 19
1893	Dec 4	Explosive eruption with emission of ash and strong explosions in the plug.	0 ↑ → (m)	6
1894	-----	Persistent fumarolic activity with strong explosions in the plug.	0 ↑ ⇞	1, 6, 14
1895 - 1900	-----	Persistent fumarolic activity with strong explosions in the plug and overflow of lava and scoria. Strong seismic activity.	0 ↑ ⇞ ⪢ (m)	1, 6, 14, 15a, 15b
1901 - 1902	-----	Persistent fumarolic activity with strong explosions in the plug and overflow of lava and scoria. Small emission of ash.	0 ↑ ⇞ ⪢→ (ℒ)	1, 6, 13, 15a, 15b

Table 1 (continued)

Year	Date	Description of the activity	Type of activity	Source
1903	Feb 15, 24	Large explosive eruptions with abundant emission of ash and pyroclastic materials.	0 ↑ → ⥲ (g)	1, 6. 13. 15a. 15b
	Mar 2, 7, 14	Strong seismic activity.		
1904	-----	Large explosive eruptions with abundant emission of ash and pyroclastic materials.	0 ↑ → ⥲ (g)	6, 20
1905 - 1907	-----	Persistent fumarolic activity	0 ↑̥	6, 31
1908	Dec 18	Large explosive eruption with abundant emission of ash and pyroclastic materials. Strong seismic activity.	0 ↑ → ⥲ (g)	14, 31
1909	Feb 4, 21 25	Explosive eruptions with emission of ash and scoria and strong seismic activity.	0 ↑ → ⥲ ⁞̂ (g)	14, 31
	Mar 5	Phreatic explosion.		
1910 - 1911	-----	Reduced fumarolic activity	↑̥	14
1911 - 1912	-----	Reduced fumarolic activity	↑̥	14
1913	Jan 20	Large explosive eruption of Pelean type with abundant emission of ash and glowing avalanches.	0 ↑ → (g)	13, 4, 22, 31
1914 - 1922	---	Rise of lava level from 300 m depth.	⊓	14, 19, 28

Table 1 (continued)

Year	Date	Description of the activity	Type of activity	Source
1923 - 1931	---	Rise of lava level from 60 m depth	□	14, 19, 28
1932	----	Persistent fumarolic activity.	↑∘	14, 19, 28
1933 - 1941	---	Moderate fumarolic activity	↑∘	14, 28
1942 - 1956	---	Moderate fumarolic activity.	↑∘	14, 28
1957 - 1959	----	Rise of lava level until exceeding the crater rim. Strong explosions in the plug and small outflow of scoria. The rate of ascent is estimated in 20 cm/day. Persistent fumarolic activity.	0 ↑ ≈> ↑∘ □ (£)	14, 19, 22
1960 - 1965	----	Small flows of lava and scoria and moderate seismic activity. Persistent fumarolic activity.	0 ↑ ↑∘ ≈> □ (£)	28
1966 - 1973	---	Persistent fumarolic activity.	↑∘	28
1974 - 1975	---	Persistent fumarolic activity.	↑∘	—
1975 - 1977	Dec 25	Eruptive activity of Merapi type with lava flows and fumarolic activity. Small explosions in the plug.	0 ↑ ≈> □ (m)	4
1977 - 1980	---	Persistent fumarolic activity with small emission of ash and microseismic activity.	0 ↑∘ → ↑ (£)	—

Table 2

t (months)	$\varphi(t)$	f(t)	F(t)	P(x<t)
0	0.028270	0.028270	0	0
10	0.025368	0.019411	0.234823	0.234840
20	0.023006	0.013827	0.398983	0.398995
30	0.021047	0.010151	0.517698	0.517670
40	0.019395	0.007644	0.605878	0.605884
50	0.017983	0.005880	0.673025	0.673009
100	0.013186	0.002003	0.848096	0.848120
120	0.011914	0.001410	0.881651	0.881989
200	0.008598	0.000454	0.947197	0.947210
220	0.008038	0.000359	0.955337	0.955427
300	0.006379	0.000161	0.974761	0.974760
400	0.005070	0.000073	0.985602	0.985690
500	0.004207	0.000038	0.990967	0.990980
600	0.003595	0.000022	0.993880	0.993880
700	0.003138	0.000014	0.995539	0.995630

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