

# The Volcano-Seismic Clock of the South American Pacific Margin

## A Possible First Link Between Natural Disasters Prevention and Expanding Earth

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**Abstract.** A volcano-seismic correlation was for a long time suspected to occur on the Pacific margin of South America. Scalera (2008) using the data available in 2006 in the Smithsonian Institution Catalogue of the volcanic eruptions, has revealed evidence that earthquakes happened into the South-American Wadati-Benioff zone – with magnitude greater than 8.4 – are associated to an enhanced rate of volcanic eruptions, but has been impossible to determine the causal chain between the two phenomena. After 2006, the effort of the Smithsonian Institution to improve our knowledge of this region has resulted in a greatly increased completeness of the catalogue, adding the new eruptions for the 2000-2010 interval, but also an additional 50% of new entries in the list of the Andean volcanoes. The occurrence of the Chilean earthquake of Maule – 27 February 2010 (M=8.8); occurred at five decades from the 1960 quake – has been the occasion to rework all the data searching for additional clues able to indicate a preferred causal direction eruptions-earthquakes or earthquakes-eruptions – or from a third more general cause (e.g. a mantle movements) to both eruptions and earthquakes. This short note discusses the three above-said hypotheses and tries to establish if these results could be useful to the aims of the Civil Protection in the programs of prevention and/or forecasting of natural disasters.

**Key words.** South American volcano-seismic correlation – Natural disasters prevention – Expanding Earth

### 1. Introduction

Few years ago, I was involved in checking the veracity of the plate tectonics' claim about the existence of near-planar distribution of hypocenters along the Wadati-Benioff zones. The result was that the new global catalogue of the relocated hypocentres (Engdahl et al., 1998) allows to better resolve the seismic foci in a series of clusters, that typically become narrow toward increasing depths. Having the hypocentres pattern such unexpected characteristics, it

is not possible to continue to believe to the hypothesis of large-scale subduction.

The possible relation of the South American hypocentral clusters with the surface geological features was searched for and the volcanism was judged the main one. Analyzing the Smithsonian Catalogue of Volcanic Eruptions, a strong evidence of correlation among Andean volcanic eruption rate and great earthquakes was recognized (Scalera, 2008).

My first analysis of 2006 was published on 2007 in the NCGT Newsletter and a report was provided to a Joint Commission

of Italian and South American scientists held in Rome in 2007 (by the hands of R. Dimaro, delegate INGV). Finally, the work about the South American volcano-seismic correlation was presented at the 2nd Humboldt Conference in Lima, Peru, 2008

On 2009, my tries to write a new report using a very large amount of new data was luckily stopped by an unlucky forced period of several months of illness (a surgery). The next volcano-seismic event occurred in 2010, Feb 27, and a full rework using all the additional data of the Catalogue of the Smithsonian Institution was performed with the aim to better define the causal-chain between eruptions and strong earthquakes.

The suspicion of a general possible relation between earthquakes and eruptions has its roots in ancient historical times, but about that concerns the Andes, a classical case was the report of Darwin about the eruptions occurred in a narrow time window around the date of the great earthquake of Concepcion (Southern Chile, 1835):

*[... ...], at the same hour when the whole country around Concepcion was permanently elevated, a train of volcanoes situated in the Andes, in front of Chiloe, instantaneously spouted out a dark column of smoke, and during the subsequent year continued in uncommon activity. It is, moreover, a very interesting circumstance, that, in the immediate neighbourhood, these eruptions entirely relieved the trembling ground, although at a little distance, and in sight of the volcanoes, the island of Chiloe was strongly affected. To the northward, a volcano burst out at the bottom of the sea adjoining the island of Juan Fernandez, and several of the great chimneys in the Cordillera of central Chile commenced a fresh period of activity. (Darwin, 1839; p. 380)*

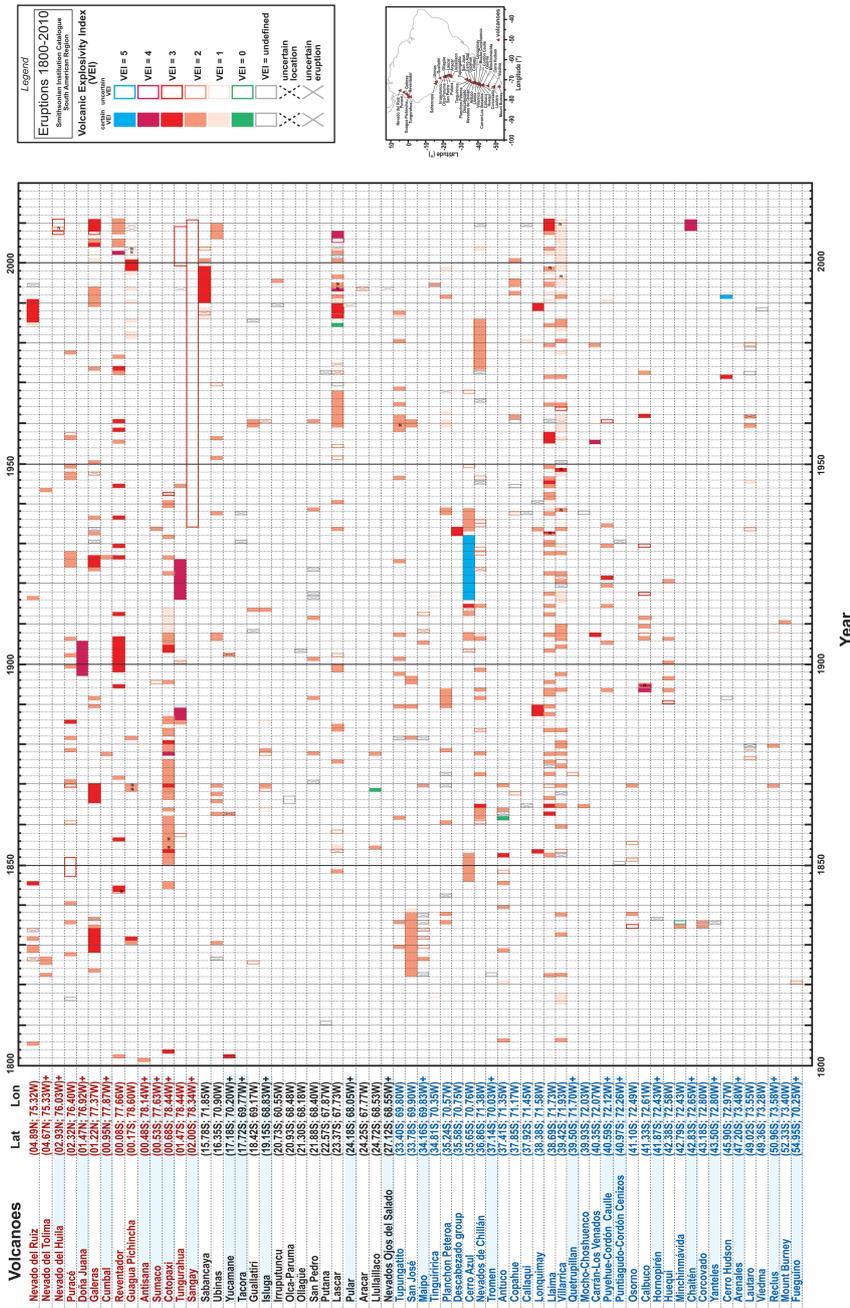
*From some additional information which I have met with since finishing*

*this chapter, I find the train of volcanic phenomena, which followed this earthquake, affected a larger area than that mentioned (seven hundred by four hundred miles), and affected it in a manner which gives great additional weight to the argument that South America is in that part a mere crust resting over a sheet of fluid rock; and likewise to the generalization that the action of volcanoes, and the permanent elevation of the land (and consequently, as I believe, the elevation of mountain chains) are parts of the same phenomenon, and due to the same cause. (Darwin, 1839; in "Addenda", p. 626)*

The Darwin's report was among the firsts scientifically grounded. On the same subject, more or less convincingly, and with large or restricted generality, many other followed (see for example the book of Edward Hull, 1904), and, in the occasion of the 1960 Chilean great earthquake, several observations of subsequent eruptions were reported (Tazieff, 1962; Casertano, 1963; Klohn, 1963; Lara et al., 2004; among others). Casertano wrote:

*Then it is probable considering the time lapse between the earthquake and the volcanic eruption that the action of the seismic events does not cause directly the fracturing of the zone in which the volcanic activity manifested. More likely this action was indirect, in the sense to have helped the magma maybe already in an advanced state of eruptive potentiality in opening its way in the zone of lesser strength. (Casertano, 1962; p. 214; translated by the author)*

A possible causal link between deep and intermediate earthquakes and eruptions was proposed by Blot (Blot, 1965; Blot & Prime, 1963), giving rise to discussions (Latter, 1971). In the first years of the subsequent decade, correlated sequences of earthquakes and eruptions were hypothesized as produced by a common cause, namely periods of tectonic instability and increased tensional conditions



**Fig. 1.** The complete catalogue of eruption data of the Andean belt from 1800 to 2010. The data has been collected by the Smithsonian Institution (Siebert et al., 2011). Light-blue highlight and '+' mark the new entries in the volcanoes list with respect to the data used in the analysis of few year ago (Scalera, 2008). On the time axis 1800-2010 the eruptions are represented by rectangular areas whose horizontal length is equal to the duration of the eruption and that are coloured with the Volcanic Explosivity Index (VEI) color scale on the right. The colored names of the volcanoes are subdivided in agreement to the three volcanic district (northern-reddish, central-black, southern-blue). In revising the data, the set of five criteria listed in the text have been adopted. Counting the eruptions by years or triennium a graph like the next Fig. 2 can be drawn.

	1800 1809	1810 1819	1820 1829	1830 1839	1840 1849	1850 1859	1860 1869	1870 1879	1880 1889	1890 1899	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1969	1970 1979	1980 1989	1990 1999	2000 2009
old	4	6	15	22	11	15	33	25	23	25	40	23	29	28	26	20	39	32	40	48	
new	7	6	30	39	18	32	54	36	31	36	54	37	46	49	36	35	45	43	52	65	81
$\Delta$	3	0	15	17	7	17	21	11	8	11	14	14	17	21	10	15	6	11	12	17	81

**Table 1.** Comparison 10year  $\times$  10year between the old dataset 1800-2000 (42 volcanoes and a total of 504 eruptions) and the new dataset 1800-2010 (65 volcanoes and a total of 839 eruptions)

(Latter, 1971). Carr (1977) noted that the eruptions sometime preceded and sometime followed great seismic events and recommended more deep studies and implementations of seismic and eruption catalogues to improve our understanding of the causal link between the two phenomena. A more long series of papers is about the specific problem of the triggering of eruptions by earthquakes, at different distances from the hypocentral region (Uffen & Jessop, 1963; Latter, 1971; Barrientos, 1994; Linde & Sacks, 1998; Hill et al., 2002; Manga & Brodsky, 2006; Walter, 2007; Walter & Amelung, 2007). Nevertheless, also the possibility of a triggering of earthquakes by volcanic activity has been proposed by a scant group of people (Critikos, 1946; Kimura, 1976; Acharya, 1982; among others).

Finally, the mutual influence of volcanic activity on great earthquakes and viceversa by Coulomb stress time variations has been investigated by Nostro et al. (1998) on a broad Southern Italian region surrounding Vesuvius, but without a definitive conclusion.

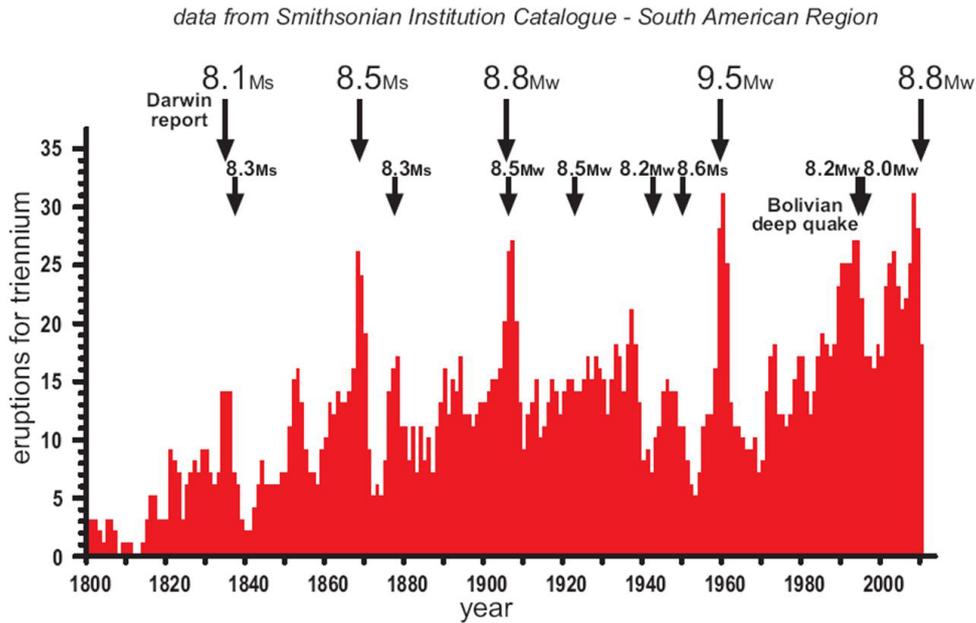
Today geosciences are dominated by the paradigm of plate tectonics and a possible common cause – underlying eruptions and quakes – has been individuated in the subduction process. This has led to accept the possibility to assume as sufficient the amount of the fuse and partial melting produced by a seismic event by friction in the very narrow slip region. But if the subduction is considered as only what it is, a mere hypothesis, other physical processes can be realistically taken in consideration.

An alternative conception deserving to be scrutinized is the non-compressional

mountain-building framework (Scalera, 2007, 2008). The main advantage of this noncompressional schema is the possibility to explain the great shallow earthquakes not as subhorizontal slip of a subducting lithosphere but as sudden vertical and dilatational movements along the complementary perpendicular fault plane of the focal mechanism (Scalera, 2007c; 2012, this volume) – under the forearc. This explanation has already found support in the detected coseismic variation of the gravity field (Han et al., 2006, 2010, 2011) and in the Earth's instantaneous rotation axis displacement (Scalera, 2012; this volume). This new interpretation can allow a common secular process involving the complete South American Pacific margin in a slowly expanding Earth schema.

The results of a preceding paper of Scalera (2008) were purely phenomenological, because they do not indicate a causal link, nevertheless they indicated the possibility (not the certainty) of a repetition of the correlation-event with an imperfect periodicity of about 45 years. In 2006, the volcanoes list contained 42 names and a total of 504 eruptions (with exclusion of discredited eruptions). Today, the Smithsonian Institution database has been implemented and on the same Andean region it lists 65 volcanoes (24 new entries, an increase of more than 50%; Cordón Caulle was split in Puyehue-Cordón Caulle and Puntagudo-Cordón Cenizos) and a total of 839 eruptions.

Albeit it was not explicit in the preceding work (Scalera, 2008), it is clear that the subdivision of the time axis using the unity lasting 1 year is an artifact which has no sense for the nature. This time unity



**Fig. 2.** Using the complete catalogue of eruptions data of the Andean belt from 1800 to 2010, the triennial number of eruptions along the time axis has been plotted. All the non-discredited data have been used. Cusps of eruptions coinciding with the occurrence of great-magnitude earthquakes are confirmed, and an additional peak is correlated to the 2010 Maule quake ( $M = 8.8$ ). At the moment no explanation exists for all the large fluctuations and the minimums in the eruptions rate. But it must be stressed that a number of seismic events exist (up to  $M = 8.6$ ) that does not correlate with peaks of the triennial rate of eruptions, leading to the conclusion that different processes can cause strong earthquakes, and only a sub-set of them can cause the volcano-seismic events. In 1994, the occurrence of very deep and strong seismic event in Bolivia ( $M = 8.2$ ; depth=641 km, data USGS, 2007) is preceded by a decennium of increased rate of eruptions.

is necessary for the treatment of the data but it introduces a quantization of the time, with some unpleasant effects to be avoided. Indeed, if the onset of an eruption occurs in November 1980 and the conclusion of the eruption, say, in March 1982, have we to count also the last three months as an activity in 1982 – counting three years of erupting activity – or we have to disregard this tail counting only two years of activity? Many different choices are possible; however, in revising the data I have adopted the following set of five criteria:

i) I have assumed the lasting – in years – of an eruption as the lasting as if its onset was shifted to January of the year. As consequence a lasting, say, of one month or one day is counted as one year. Then, a lasting of eleven, thirteen, twenty-five months has been counted

one, two, three years respectively (at least).

- ii) If the onset month is unknown, it has been assumed July and the same preceding rule i) has been applied.
- iii) If the conclusion month is unknown, it has been assumed June and the preceding rule i) has been applied.
- iv) If the conclusion year is unknown, the same year of onset is assumed as conclusion.
- v) The value of the three-year rate of eruption has been assigned to the last year of the three-year period (while in Scalera, 2008, it was assigned to the central year).

Following these rules, a complete revision of the data and of their reckoning has been performed. The new results are summarized in Figs. 1, 2, 3 and 4.

In Fig. 1 the complete set of the eruptions data has been shown on the axis of time from 1800 to the year 2010. The geographical location of the volcanoes listed in Fig. 1a is plotted in Fig. 1b. The consequent histogram of the eruptions for triennium is represented in Fig. 2, confirming the existence of peaks of higher eruption rate in coincidence with the occurrence of most major earthquakes with  $M \leq 8.5$  (Scalera, 2008).

On the other hand, from Fig.2 it can be inferred that seismic events exist (up to  $M = 8.6$ ) that are not associated to a clear increase of the eruption rates. This leads to the conclusion that different processes can cause strong earthquakes, but only a subset of them can cause the volcano-seismic events. In 1994, the occurrence of very deep and strong seismic event in Bolivia ( $M = 8.2$ ; depth=641 km, data USGS, 2007) was preceded by a decade of increased rate of eruptions.

It is possible to discuss the details of 5 events of coincidence (instead of only 4 as in Scalera, 2008). May be that this set is still insufficient to draw definitive conclusion, but it can provide new clues about the involved geophysical processes. In Fig. 3abcd the detailed four representations of all the eruptions around few years centered on the great earthquakes of 1868, 1906, 1960, 2010 have been drawn.

Passing from the older coincidence events to the 2010 event, it is clear the trend – as soon as the data have become more precisely located on the time axis – of an enhanced rate of eruptions before the main seismic event. It has to be checked if this is a real trend or biased by some incompleteness of the data.

#### *The 1868 event*

In this case (Fig. 3d and Fig. 4d) we are out from the severe lacking of data (catalogue's incompleteness) characterizing the 1835 event, but the incomplete and imprecise knowledge of the onset date of several eruptions, and some considerations about the cause of this ignorance can lead to some progress and new reasoning. At

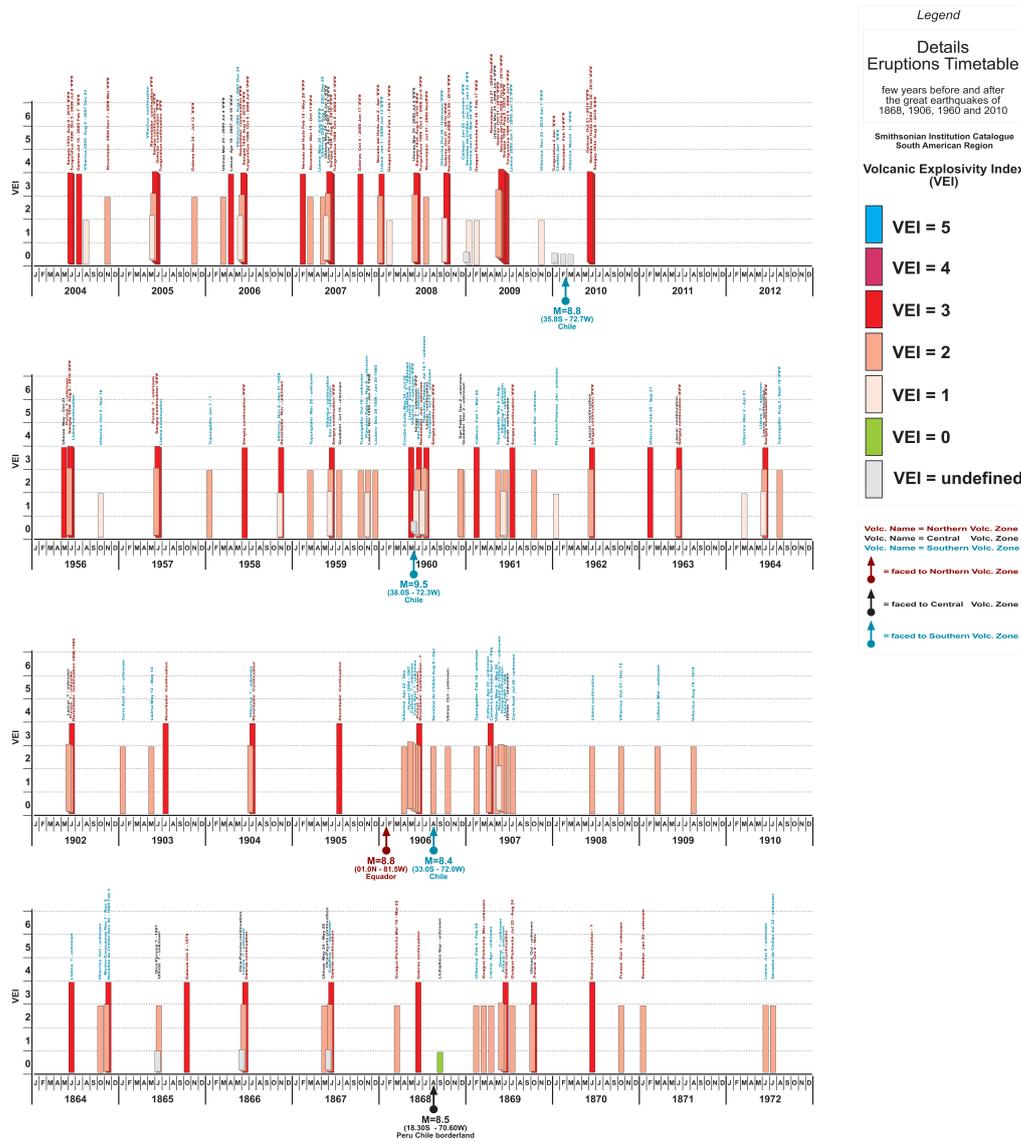
that time aeronautics was not available to help in performing rapid surveying of the long series of Andean volcanoes. The news about the occurred eruptions was collected only by visual witness, whether asking to inhabitant of the localities nearest the volcanic apparatuses or by people passing for a direct inspection on the slopes of the volcanoes and observing new active or consolidated magma flows. The date of the eruptions may be confused with the observation date, displacing the event many months after and possibly one or more years ahead. This source of errors could be occurred in the case of the small group of eruptions of uncertain date grouped in 1869 (Fig. 3d).

#### *The 1906 event*

This event (Fig. 3c and Fig. 4c) is complex because it is indeed a pair of great earthquakes (Ecuador, January 31;  $M = 8.8$ ; Lat = 01.0N, Lon = 81.5W; Chile, August 16;  $M = 8.4$ ; Lat = 33.0S, Lon = 72.0W) that occurred in the same year, seven months apart, separated by a very long distance ( $\approx 3500km$ ). In Fig. 3c two groupings of eruptions appear – in the middle of 1906 and in the middle of 1907. No enhanced volcanic activity is present in the interval 1902-1905. But the possibility that this lacking of eruptions may be only an artifact is open.

Indeed, in 1906 at least four eruptions have dates unknown of onset (Huequi, Calbuco, Cerro Azul, Puracé) and three (Nevados de Chillan, Llaima, Ubinas) in 1907. Then, the real distribution on the time axis might be different and considering the reasons explained above in the preceding 1868 case, it can be that some of the real onsets could have occurred many months before and also one or two years before.

Considering that the greatest seismic event of 1906 was in Ecuador ( $M = 8.8$ ) and that it occurred in the northern segment of the South American Pacific margin (Fig. 4c), the volcanic eruptions that started in the northern volcanic district were too few to be seriously taken in consideration (Reventador continued an erup-



**Fig. 3.** Details of the eruptions that occurred few years before and after the major South American earthquakes. The VEI is represented both in colour and in length on the vertical axis. The details of the eruptions are shown for the 1868, 1906 and 1960 seismic events. The eruptions are identified by the name of the volcano and – if available – the starting and ending dates. The color of the name is assigned as in Fig. 1. If, in the Smithsonian Institution Catalogue, the month of the starting date is not available, the bar representing the eruption is assigned arbitrarily to June or July of the same year. The occurrence of a greater rate of eruptions on the occasion of major earthquakes is observable in this plot, and a trend toward a precursory occurrence of an higher eruption rate is discernible passing from the oldest to the more recent correlation event. This can be seen with greater evidence in the next Fig. 4. The trend can be due to errors in assigning the years of the eruptions (see the discussion in the text) when modern scientific facilities were lacking. Albeit this trend has been consolidated by the 2010 volcano-seismic event, a longer time lapse for collecting data is needed to achieve more solid deductions.

tion from 1899 to an unknown month of 1906 and Puracé erupted as VEI=2 in a unknown date of 1906 or before) in an argument about the mutual influence of eruptions rate and earthquakes.

Instead, an increased number of eruptions occurred (starting in 1906 and 1907, but may be many months before) on the Chilean segment of the margin, near the hypocentral zone of the  $M = 8.4$  quake (Villarrica, Huequi, Calbuco, Cerro Azul, Nevado de Chillan, Tupungatito, Carran los Venados, Llaima, and a second time Villarrica and Cerro Azul).

The possible redistribution of these southern-district eruptions on the time axis can ideally lead to a balance between the eruptions preceding the August 1906  $M=8.4$  seismic event and the ones following it. But until that a more precise set of data may eventually be found in historical archives on the real start times of individual eruptions, we have no way to resolve this problem in favor or against the precursory occurrence of an enhanced rate of eruptions for this 1906 coincidence event.

#### *The 1960 event*

The strongest earthquake ever occurred (1960, Chile, Lat = 38.0S, Lon = 72.3W,  $M = 9.5$ ) was definitely in the times of more modern technologies and scientific instrumentations (the seismometry entered in a more advanced status) and surveying facilities (quick transportations, airplanes, helicopters, But difficulties in landing to directly observe the lava flows or debris was cited by Tazieff still in 1960). The hypocenter was located in front of the central part of the southern volcanic district, whose volcanoes as can be seen in Fig.4b – were the most involved in the event of volcano-seismic correlation.

Again, eruptions belonging to the central volcanic district can be considered inessential – belonging to a passive district – as concerns this analysis (Fig. 3b and Fig. 4b). The Sangay volcano continues its eruption from 1934 to our days, and the other eruptions of northern volcanoes, not overcome their normal back-

ground rate. Instead, an increase of the eruptions of the southern district can be seen in Fig.4b. Tupungatito erupted several time since January 1958 to 1964, followed by some eruptions of Villarrica and then by San José, Planchon Peteroa, Lautaro, Cordon Caulle, Copahue, Llaima, Calbuco. The southern district eruptions passed from one or two to six in 1959, to seven in 1960, and to five in 1961.

What still remains unresolved is the position on the time axis (Fig. 3b) of few eruptions onsets in 1959 (San José) and 1960 (Copahue, Llaima, Villarrica, Isluga, San José), which would have helped in define the precursory character of the eruption rate. But at least we can state that a real jump from two to six eruptions has occurred from 1958 to 1959 on the southern district.

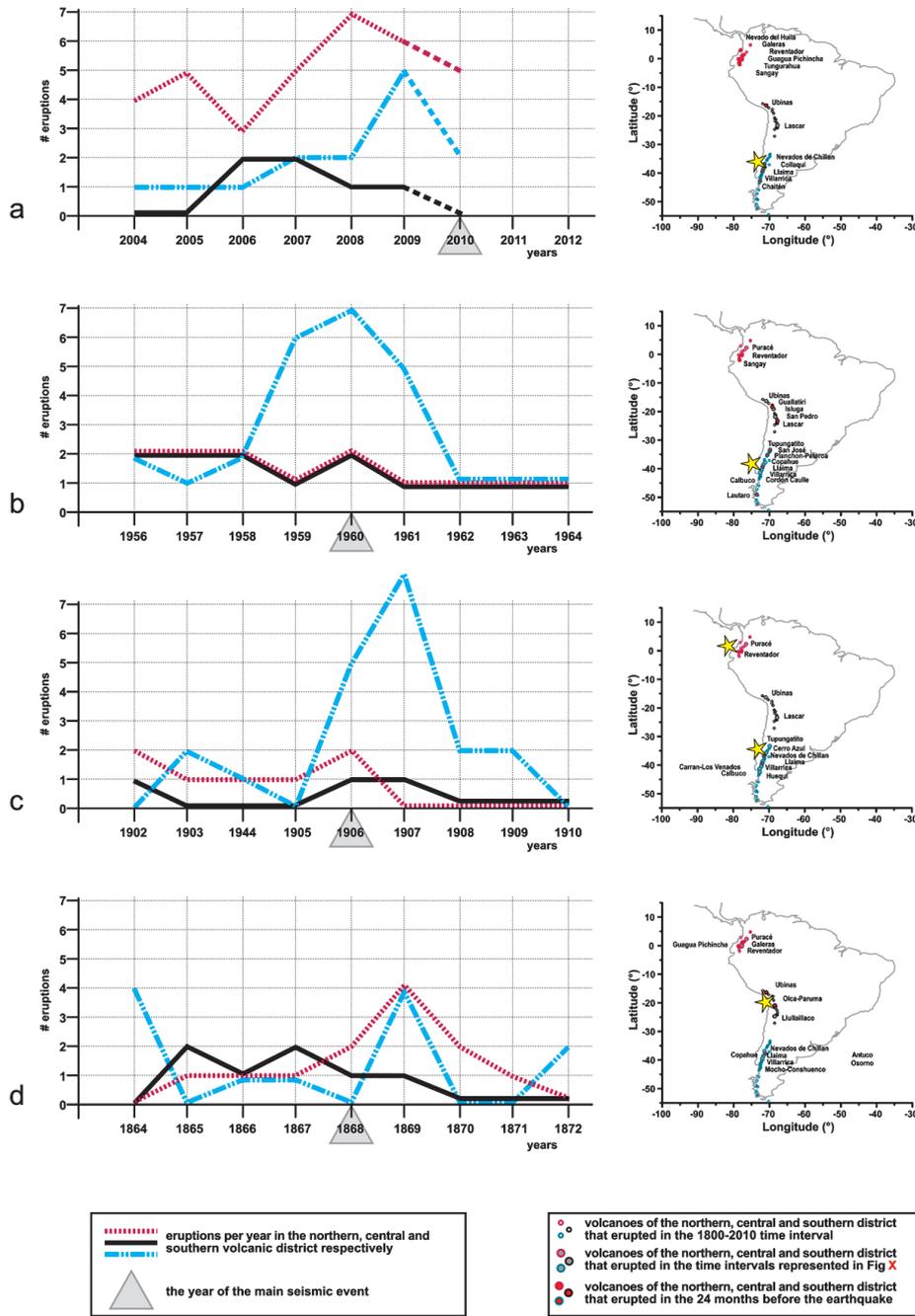
#### *The 2010 event*

This time (Fig. 3a and Fig. 4a) all the onset date of the eruptive events are known thanks to improvements of satellites, aeronautical and terrestrial remote digital surveillance methods. The rate of eruptions occurred in the northern and southern volcanic district increased from one-two erup/year to five in 2009.

The northern volcanic district was particularly active in the interval 2007-2009, while the central district with its one or two eruptions/year does not contribute to the constitution of the volcano-seismic correlation event. It is then to be considered as well grounded the statement of a precursory behavior of the northern and southern volcanic activity in this case. The higher eruption rates of both northern and southern districts should be considered a clue of a global nature of the phenomenon.

## **2. Problems of emergencies management**

The possibility to forecast the imminent occurrence of a potentially disastrous geophysical event has been for a long time seriously considered by the geosciences community (Nigg, 2000). Well-nourished lists of candidate precursors of seismic



**Fig. 4.** Details of the eruptions rates, separated following the three volcanic districts. The colors are assigned as in Fig.1. The stars in the maps indicate the hypocenters of the main seismic events. The trend toward a precursory occurrence of a higher eruption rate is clear passing from the 1868 to the 2010 correlation event. The central volcanic district seems passive in producing high eruption rates – also in the occasion of the 1868 earthquake that occurs near the central district. Southern district is involved in all the four events. The higher eruption rates of both northern and southern districts in 1868 and 2010 are a clue of a possible link of the phenomenon to the global Earth geodynamics

or volcanic events exist, and the richer is the list of the alleged seismic precursory phenomena (Caputo, 1987). But no one of these seismic forecasting methods has been validated because the still insufficient statistical relevance of the association of the precursory event to the earthquake. Complex methodologies based on the old idea of *pattern recognition* (Keilis-Borok et al., 1988) are under experimentation (Panza et al., 2009) but a second phase with their real-world use is still very far.

Is the correlation eruptions-quakes in some way linked to prediction? We have to check if it is possible to answer to the question: in which space window, with which time window, and with what consequences the event can repeat in future. It is clear that we would be satisfied only if it is possible a useful and sufficient contraction of the space-time window of occurrence of the event. In this practical case of the South-American correlation events, we can only state the following points:

- i) The events have not stopped to occur from 1835 (a probable underestimated magnitude earthquake). Five events and four time intervals are available to the analysis.
- ii) The time window of 68% of probability of re-occurrence of the events is of  $\pm 8.5$  years centered on the 43th year after the last happened event.
- iii) In the more recent pair of cases when the catalogue is becoming more complete an increased rate of eruptions has preceded the seismic event in some volcanic districts.
- iv) The space window can be narrow in longitude but – due to peculiar geographic characteristics of this correlation-phenomenon – its latitudinal length can be more than 1500-2000 km in latitude (the maximum length of a volcanic district).

It is self-evident that on the basis of the available data on the mean recurrence time we cannot contract the time window toward a useful amount of few days or weeks nor months. The *clock* of the cor-

relation events is too vague, and we cannot at moment know if their occurrences are subordinate to a unique mantle process – albeit, indeed, this process can be hypothesized (see Scalera, 2012; this book). Consequently we cannot affirm with certainty that the until now large time intervals (four intervals observed) between two consecutive events will be repeated in future, or that in virtue of a possible independency of the regions and of the events, the time intervals can drop to few years or even months.

43 years are too much to be used in a seismic alarm that desirably should lead the population to temporary leave their houses. Consequently, a forecasting would be very weak. Nevertheless, the recognition of the long average interval between two consecutive events, and of its standard deviation ( $\sigma_{68\%} = 8.5 \text{ years}$ ) can allow the long- intermediate-time planning of a series of prevention activities – mainly the reinforcement of the existing buildings and the progressive creation and maintenance of a security coastal band in the tsunami prone areas. In these areas new houses must not be built and virtually the already existing ones should be removed.

On the other hand, even hoping to activate a continuous counting of the eruptions, the space-window cannot be well defined. We can try to put under constant observation the eruption rate of the whole Andean volcanic chain and additionally to distinguish among the rates of the three volcanic districts. We can hope to individuate the district on which the eruptions are becoming more numerous but it will be impossible a definition of the latitudinal width of the emergency zone narrower than the same district.

Nevertheless, from the analysis of districts in Fig. 4 we can infer a greater than expected complexity of the phenomenon. Indeed, at least in the 1868 case (Fig. 3d), the activated districts were the two ones adjacent to that in which the seismic event occurred. In 1906, the main event ( $M = 8.8$ ) was located in the northern district, but (Fig. 3c) the main enhance-

ment of the volcanic activity was recorded in the southern district – probably linked to the August Chilean  $M = 8.5$  event. In the years preceding the seismic event of 2010 (Fig. 3a), it was the northern district to become activated (more clearly starting from 2008), followed only in 2009 by an increased eruption rate in the southern district. Only the 1960 quake seems to be linked to a precursory activation of only the southern volcanism with absolutely no evidence of enhancement of the eruption rates in the northern and central districts (Fig. 3b).

Notwithstanding the consequent impossibility to associate an enhancement of the eruption rate of a specific district to a great earthquake occurred in the same district, the volcano-seismic correlation-events occur with their typical peaks of volcanic activity, very evident in Fig. 2.

This apparently complex and paradoxical behavior of the region hides some fundamental process still not understood. I can only stress that this behavior cannot be well explained in the plate tectonics framework. This because the impossibility to correlate a great production of magmatic materials without the occurrence of great production of friction-heat associated to the seismic events produced by the subduction. The cooperation of all the districts – but less evidently for the central district – to the constitution of the phenomenon is a clue of its origin in a general tectonic process. This *cooperation* is not settable in the currently accepted framework of plate tectonics because of the incompatible geometry of the Nazca plate boundaries in comparison to its transform faults intersections with the Andean Pacific margin, in relation to the northern and southern volcanic district. The already cited words of Latter (1971) seem more realistic, and preceding papers of Scalera (2003, 2006, 2011, 2012) could be linked to the described phenomena in a general way.

A further difficulty in a possible methodology of prediction comes from the deep earthquakes like the Bolivian event of 1994. On the time series in Fig. 2 it is

discernable a ramp of increasing rate of eruption per year and per triennium starting to be neatly over the background in 1983. The triennial eruption rate in Fig. 2 reached the peak value of 22 eruptions in 1994, which is greater than the rate associated to the 1868 earthquake and equal to the rate of the 1906 event (1960 and 2010 events reached 31 eruptions). A false alarm would be launched if - as a criterion for the alarm - it was required to achieve or exceed, say, the 21 eruptions triennial rate (that is the minimum peak rate of the 1868 event). Can we avoid at least this kind of false alarms? Deeper studies are needed, and we can only hope that in future a forecasting (with more narrow time and space windows) would be possible only in joint venture with additional methods (e.g. gaps, pattern recognition, ecc.; see Gelfand et al., 1976; Caputo et al., 1980; Keilis-Borok et al., 1988; Panza et al., 2009; among others).

### 3. Conclusions

A reanalysis of the Smithsonian Institution data for the eruptions in the South American region on the basis of many new entry in the listed volcanoes and on the last great Chilean earthquake of February 2010, has confirmed the occurrence of peculiar volcano-seismic events with a mean return time of 43 years. The convictions of old thinkers about this argument and this region was of a trigger influence of the earthquakes on the eruptions, but a more detailed analysis – with an additional discrimination in three volcanic districts – has produced evidence of a precursory increase of the eruption rate, passing from the old incomplete catalogue (that store second-hand popular chronicles or otherwise imperfect date of eruptions onsets) – to the modern one (which items come from Observatories of Volcanology, satellites data and aeronautical observations). Obviously this time-relation cannot be generalized to other region of the Earth, but can at least be of some help for the South American Civil Protection in the programs for disasters preventions.

The use of this precursory phenomenon as an individual tool for a deterministic forecasting is not possible. Eventually, only the awareness to have entered in a period of an increased rate of eruption can be reached. This should be considered not a pessimistic position, but only the admission that the occurred real cases are still too few, and with the conviction that the new future occurrences of correlation events will be occasions to refine our knowledge, increasing our operative skill in eventual scientific projects dedicated to predictions.

The information about the increasing eruptions rate should be provided to a more wide forecasting program, like – among other possible programs – the pattern recognition program (Gelfand et al., 1976; Caputo et al., 1980; Keilis-Borok et al., 1988; Panza et al., 2009), in which other clues are mutually considered, like seismic gaps, general seismicity pattern, deep seismicity occurrence, etc. Only this or others more general research programs can hope to eventually restrict the eligible emergency zones. On the South American Pacific margin, the information coming from the rising of the eruption rate would be of invaluable importance to these methods and to Civil Defense Authorities. In this perspective, some next centuries of new data collecting will be needed to provide a firm solution and hopefully to open new problems in natural disaster prevention and forecasting.

But the progresses that we hope for, can be achieved only adopting a new, more realistic geodynamic theory, which can only be the *expanding Earth*.

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