Bull Volcanol (1994) 56:321–325

ORIGINAL PAPER

Alexandru Szakács

Redefining active volcanoes: a discussion

Received June 10, 1993 / Accepted May 17, 1994

Abstract The analysis of the current definitions of active volcanoes indicates that they are empirical, conventional, inaccurate, nongeological, and arbitrarily constraining. Redefinition is therefore needed. One possible approach is to refine the current empirical definitions. A statistically reasonable and practical redefinition using a geologically based time convention – Holocene or 10000 years – is suggested. A set of time conditions according to volcano typology – i.e. 1000; 10000 and 100000 years for high-frequency basaltic shields, andesitic-dacitic composite volcanoes and low-frequency large silicic calderas, respectively – as further refinement of the empirical definition is also envisaged. Devising a phenomenological definition as a theoretical approach is another possibility, but in practice extant "diagnostic" means are still unsatisfactory to discriminate accurately between dormant and extinct volcanoes. As a consequence of the redefinition, a classification of volcanoes according to their eruptive status is proposed. Redefinition of active volcanoes might increase accuracy in the usage of basic terms in volcanology and influence volcanic hazard assessment and risk mitigation projects.

Key words Active volcanoes · Definition
Conceptual volcanology

"Definitions are boring but necessary"
(G. A. Macdonald: Volcanoes)

Introduction

As scientific disciplines mature, they tend to undergo a transition from a descriptive to an interpretative stage, and from empirical to experimental focus. Advances in phenomenological knowledge and research methodology invariably are accompanied by concurrent adjustments in analytical and interpretative approaches. Volcanology is no different. Following several well-documented major volcanic events worldwide in recent decades, volcanology is experiencing a renaissance. It is rapidly becoming more quantitative, and volcanologic studies rely increasingly on high-tech methodology and computerized data acquisition and analysis. New terms and concepts have been introduced, and the original meanings of some older terms have evolved or have become obscured or perhaps inapplicable; these need to be reconsidered in light of contemporary knowledge and ideas. This brief paper, adapted from presentations at the Naples '91 International Conference on Active Volcanoes and Risk Mitigation (Szakács 1991) and at the Colima Volcano Fourth International Meeting (Szakács 1994), addresses the basic, but not simple, questions of: "What is an active volcano?", and "How do we distinguish between dormant and extinct volcanoes?".

A. Szakács
Institutul Geologic al Romaniei,
Str. Caransebes, 1, 78344 Bucuresti 32, Romania

Current definition

Several words are commonly used to describe the state of volcanoes: "active", "dormant", "extinct", "potentially active". The attribute "active" is currently used with at least two different senses: (1) "is erupting", and (2) "can be expected to erupt again". The world "dormant" also has dual usage: (1) "active but just not presently erupting", and (2) "it could be active again". In the first case it is synonymous with "active", and in the latter with "potentially active". At least the term "extinct" is unequivocal. Walker (1974) proposed the terms "live" and "dead" instead of "active" and "extinct", respectively, but they have not been generally adopted by other investigators.

Although not always explicitely stated, an "active volcano" is commonly defined as "a volcano with historical eruptions" or "... with historically documented eruptions" (e.g., Smithsonian Institution, 1989). In the first usage "active" refers to the volcanoes that experienced eruptions during "historical times", whereas in the second the definition is more constraining, being restricted to those volcanoes whose eruptions are mentioned reliably or described in "historical documents".

Both these definitions presume an implicit theoretical basis and some explicit conditions. The implicit theoretical assumption is:

"A volcano that erupted in a given time in the past will erupt again in the future".

This assumption stems from observation of periodically erupting volcanoes and is therefore empirical. A converse statement is suggested implicitly:

"Volcanoes lacking past eruptions in a given time span will not erupt in the future".

Needless to demonstrate the relativeness of these both statements.

The explicit part of the current definitions includes two conditions: a "time condition" and a "proof condition".

The time condition concerns the time at which the volcano last erupted for it to be assigned as "active", and it is expressed by the word "historical". This means that only eruptions occuring during human history are taken into account. But what does "history" as time specifically mean? "Recorded history" represents very different time entities in different places in the world (Walker 1974; Decker and Decker 1982): it spans more than 3000 years in Greece and Italy, over 1000 years in Iceland, less than 500 years in Philippines, less than 300 years in Kamchatka (since 1697) and Hawaii (since 1750), and so on. The usage of "recorded history" as a criterion in defining active volcanoes is unsatisfactory, not only for the above reason but also because there is no intrinsic connection between volcanic behaviour and history. Thus, the time condition is inaccurate and inappropriate.

The proof condition is explicit from the words "historically documented" and concerns the means of documenting past eruptions; only historical records are accepted as proof. Therefore, the proof condition is arbitrarily constraining. It is now acknowledged that a number of eruptions occurred but were unrecorded in remote areas even during the 19th century. Moreover, submarine eruptions on the deep seafloor are probably occurring along the oceanic ridge system but not until recently have any been documented.

To summarize, the current definitions of active volcanoes are no longer viable because they are not only empirical and conventional but also inaccurate, nongeological and arbitrarily constraining. They reflect our poor knowledge of the active state of most volcanoes. A redefinition therefore appears necessary at this time.

Redefinition of active volcanoes

In my opinion, two approaches are theoretically possible for redefining active volcanoes: (1) refining the current definitions; or (2) devising a thoroughly new phenomenological definition.

Improvement of the current empirical definition

Improving the current empirical definition involves the preservation of its basic implicit assumption, and only the explicit conditions need to be replaced.

The principal requirements of an improved time condition are to be practical and relate to the eruptive behaviour of volcanoes. The repose-time statistics of active volcanoes, as recorded in the volcano data file of the Smithsonian Institution (Simkin and Siebert 1984), provide a suitable basis for discussion. The repose-time distribution of active volcanoes (Fig. 1) constructed following Simkin and Siebert's diagram using eruption interval statistics (1984, their Fig. 8.4) is roughly log-normal. Even though the median value (about 5 years) appears to be unrealistic (as Simkin and Siebert (1984) themselves concede), because the statistics are incomplete for long repose-times, the general pattern of the diagram remains applicable. In addition, a second curve was constructed assuming a median value one order of magnitude larger (50 years) as a reasonable adjustment. A third curve was also drawn, taking into account Walker's (1974) "median volcano" that erupts once per 220 years.

The median repose-time approach cannot be an entirely suitable time condition, because it would still exclude about half of the active volcanoes. Conversely, a maximum repose-time condition (actually unknown) would include a number of extinct volcanoes, because long repose-time volcanoes overlap in the diagram with extinct volcanoes that have had their last eruption thousands or tens of thousand years ago (Fig. 1). Consequently, the appropriate time condition should be chosen somewhere between median and maximum repose-times and the actual decision could be a matter of optimization. The task is to minimize both active volcanoes excluded and extinct volcanoes included in the definition using the given time condition. The optimized value is at the intersection of the distribution curves representing repose times of active volcanoes and last-eruption dates of extinct volcanoes (Fig. 1). Since the distribution pattern for active volcanoes is most deficient at its long repose-time end (Simkin and Siebert 1984), and as no statistics for last eruption of extinct volcanoes are as yet generally available, only a rough estimation could be undertaken. In my opinion, a distribution curve symmetrical to repose-time distribution that starts from values of about 1000 years, but not less than hundreds of years, as an order of magnitude, is a reasonable approximation for last-eruption-

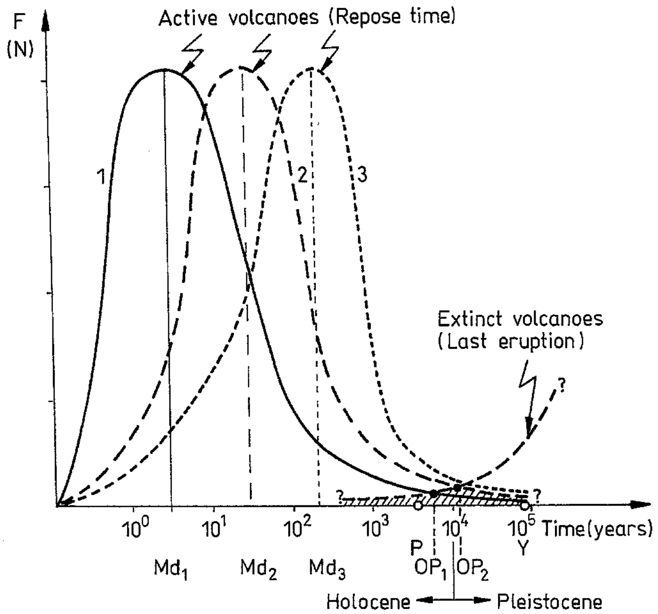

Fig. 1 Repose-time frequency of active volcanoes and last-eruption-time frequency of extinct volcanoes. *Curve 1*, after Simkin and Siebert (1984); *curve 2*, adjusted after curve 1 assuming a more reasonable median repose time (one order of magnitude larger); *curve 3*, inspired by Walker (1974) (see text for further explanation). The *hatched area* represents the overlapping fields of long repose-time active volcanoes and most recently erupted extinct volcanoes. *Md-1* (5 years), *Md-2* (50 years) and *Md-3* (220 years) are median repose-time values for curves 1, 2, and 3, respectively. Op_1 and Op_2 are optimization values for curves 1 and 2, respectively (for further explanation see text). *P*, Pavin volcano (French Massif Central); *Y*, Yellowstone caldera (western USA) (for discussion see text)

date distribution of most extinct volcanoes. In this case, the value of optimization should be somewhere within the timespan of thousands to tens of thousands years (Fig. 1). Within this statistically reasonable range we could find a practical and, possibly, geologically based time condition.

A practical time condition is already used by the Japanese Meteorological Agency, which defines volcanoes that erupted during the last 2000 years as "active" (Aramaki 1991). Even lacking geological basis, this definition is precise enough to be useful. However, other time conditions could be considered in order to minimize excluded active volcanoes. A possible one is Holocene or 10000 years. It will include the great majority of active volcanoes and, in addition, the Pleistocene/Holocene boundary is often marked by an easily recognizable geological boundary. In many volcanic areas of the world, post-glacial volcanic features are readily distinguishable from older ones. An intermediate time condition, i.e. 5000 years, could, of course, also be taken into account if appropriate and needed.

Once a specific time condition is accepted – either 2000 or 5000 or 10000 years – a special proof condition is needless and no constraints on dating methods are required. Any scientific evidence, geological or non-geological, including historical record, should be accepted (Aramaki 1991).

In summary, I suggest that an improved empirical definition could be the following:

"A volcano is termed active if it has erupted at least once during the last 10000 or, alternatively, 5000 or 2000 years as demonstrated by any scientific method".

A final decision on the unique time condition could be the task of an official IAVCEI meeting in the future.

It is worthwhile to stress that, given the poor statistics of long repose times at active volcanoes and the lack of any statistics concerning last eruption dates of extinct volcanoes, the 10000 year time condition is proposed on a qualitative rather than a strictly quantitative basis. The emphasis is on the need for a unique *practical* time condition that lies within a statistically reasonable range.

Even improved, our definition is far from perfect because it allows exceptions.

The volcano that hosts Lake Pavin in the French Massif Central is now classified inactive. Its last eruption occurred about 5860 years ago (Brousse and Lefevre 1990). According to our proposed definition, if the 10000 years time condition is accepted, it ought to be considered as active. On geologic grounds it most likely is extinct. The volcanic field that includes this volcano is now inactive: no volcano has erupted during the last 5000 years, so that deep geological processes controlling volcanic activity probably have ceased in this region. This shortcoming could be overcome by applying geological constraints – "to be in an active volcanic field", for instance. In turn, this involves a further definition concerning "active volcanic field" accompanied by another time condition – 5000 years, for instance (see discussion below).

An opposite example could include those volcanoes whose last eruption occurred long before Holocene time and which experienced signs of unrest during recent decades or centuries that suggest their magma plumbing systems are still working. Yellowstone caldera in the western U.S.A. is such a volcano. Although its last eruptive activity – the extrusion of about 1000 km^2 of intracaldera rhyolite flows – has been dated between 150000 and 75000 years B.P., it displays historical unrest (hydrothermal activity, seismicity and uplift) comparable to that at the most active calderas in the world, leading to the idea of the likeliness of future eruptions (Newhall and Dzurisin 1988). Thus, the Yellowstone caldera should be considered as an active volcano.

The above examples suggest that considering a unique time condition for all volcanoes is a rough and inexact solution to the problem that ignores the diversity of volcano typology. Thus, choosing a set of time conditions according to volcano typology in place of a single time condition promises a better solution. Smith and Luedke (1984, p. 48 and Fig. 4.1 therein) suggest that different types of volcanoes and volcanic systems can be arranged on an order-of-magnitude scale according to their ranges of eruptive periodicities. Following this idea, four types of volcanoes (or volcanic systems) would be taken into account: (1) high-frequency basaltic volcanoes with periodicities of 1–100 years (e.g. Mauna Loa), (2) medium-frequency andesitic-dacitic stratovolcanoes (100–10000 years; e.g. Colima), (3) low-frequency large silicic systems or caldera volcanoes (10000–1000000 years; Yellowstone Caldera), and (4) continental extensional basaltic systems (1000–100000 years; e.g. Rio Grande Rift Zone). If we accept such a typology, distinct time conditions should be chosen for each group. A possible set of time conditions would include, for instance, 1000 years for high-frequency basaltic shields, 10000 years for andesitic-dacitic composite volcanoes and 100000 years for large silicic calderas. Fields of monogenetic volcanoes of continental basaltic and/or alkaline extensional volcanism constitute a distinct figure, and the monogenetic volcanic systems (i.e. the volcanic fields), instead of individual monogenetic volcanoes, should be considered. A possible time condition for them would be 5000 years (see also discussion above). To better define the multiple time conditions, further study of volcano typology and repose-time distributions for each type is required. One may assume, however, that even applying multiple time conditions, the empirical definition still must allow exceptions.

A third solution has been suggested by De la Cruz-Reyna (1993, private communication). He envisaged a system using a quantitative ad-hoc rule, based an a statistical study of eruptive patterns, applied to each volcano individually. Such an approach requires a thorough statistical study of the long-term eruptive patterns of volcanoes in order to establish the rule (or rules, if volcanic typology is considered), and a good knowledge of the eruptive history of individual volcanoes.

Of the three possible solutions, the first one (unique time condition) seems to be the most practical (i.e. immediately applicable) although imprecise, while the third one, based an individual time conditions, is the most promising from the viewpoint of quantitative precision.

A phenomenological definition

Devising a phenomenological definition is another possible way to redefine active volcanoes. It can be achieved only by having good knowledge of the inherent nature of volcanic phenomena.

Redefinition of active volcanoes on phenomenological grounds requires, first of all, the change in our basic assumption from empirical to phenomenological, as for instance:

"A volcano should be considered active if its magmatic plumbing system is still working."

But how can we know if it is so? Conventions or conditions are no longer useful. We need a diagnosis! A reliable diagnosis requires the establishment of volcano-monitoring networks to record signs or symptoms that indicate ongoing subsurface magma generation and transport processes and the existence of possible "active" magma chamber(s) beneath the volcano. Despite the considerable advance of volcano geophysics during recent decades, the present state of volcanology does not yet allow the development of reliable diagnostical systems for discriminating between extinct and dormant volcanoes. Maybe it is unrealistic to expect the development of low-cost techniques able to lead to such critical distinction in the foreseeable future.

From the above discussion it becomes clear that a workable phenomenological redefinition of active volcanoes cannot be made without future developments in theoretical and applied volcanology.

Consequences

The consequences of a redefinition of active volcanoes are both theoretical and practical. Such redefinition would increase the accuracy in usage of basic terms in volcanology.

A possible classification of volcanoes according to their current eruptive status is given in Fig. 2.

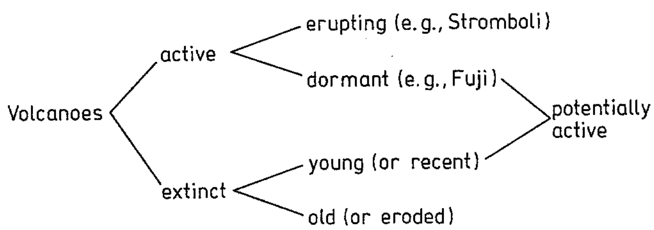

Fig. 2 A proposed classification of relative terms describing the current state of volcanoes

In this classification, "active volcano" and "extinct volcano" are mutually exclusive terms and their usage is a function whether they do, or do not, satisfy the specific time condition. Active volcanoes could be conveniently subdivided into "erupting" and "dormant" types based on their current state. In turn, extinct volcanoes could be classified as "young" (or "recent") or "old" using convenient criteria such as the extent of erosion and/or age (e.g. Quaternary for young extinct volcanoes), for instance. The state of many fresh-looking volcanoes lacking both documented eruptions and reliable dating could remain undetermined. Thus, the term "potentially active" should be preserved as designating ambiguous or insufficient knowledge. As investigations proceed, "potentially active volcanoes" could become dormant active volcanoes or young extinct volcanoes. Moreover, improved knowledge could change the assumed state of a volcano from "extinct" (as classified previously by extant dating) to "active" if justified by further dating.

The principal practical consequence of the redefinition, regardless of the time condition adopted, would be the significant increase in the number of cataloguable active volcanoes from about 520 in the present to over 1300 if Holocene volcanoes are taken into account (Tilling 1989). This would influence volcanic hazard assessment and risk mitigation projects in many countries in the world, including those with no historic record of volcanic eruptions but with volcanoes erupting during the last several thousand years as proven by geological means. It also will stimulate geological and volcanological investigation on "potentially active" volcanoes.

In addition, increased awareness of local authorities and populace concerning volcanic hazards and risks is expected as more volcanoes, including those without recent eruptions, are catalogued as active and thus potentially dangerous. Unfortunately, public perception of volcanic hazards will be more attuned to those volcanoes with short recurrence intervals and most will ignore threats from dormant volcanoes with longer repose times. Scientists are well aware that the latter can be much more hazardous.

Acknowledgements I am especially grateful to Robert I. Tilling of the USGS, whose encouragement and assistance contributed importantly to turning my Naples '91 talk into the present paper, and whose critical review an pertinent suggestions were extremely helpful in improving the original version of the text. I would like to thank Donald Peterson of the USGS for his kindness in providing me with important reference articles not available in Romania. I am indebted to Ioan Seghedi (Institutul Geologic al Romaniei), Jose-Luis Brändle and Jose-Maria Fuster Casas (Universidad Complutense de Madrid) for their thoughtful comments on the draft. The manuscript benefited from reviews by Norman J. Snelling, Eumenio Ancoechea Soto and Alfredo Hernandez-Pacheco (Complutense University of Madrid), whom I would also like to thank. Special thanks are due to Norman J. Snelling for his final revision of the English text. The final form of the article resulted after taking into account the valuable suggestions of the two official referees, Donald A. Swanson (USGS, U.S.A.) and Servando De la Cruz-Reyna (Instituto de Geofizica, UNAM, Mexico, D.F.).

References

Aramaki S (1991) Hazardous volcanic eruptions in Japan. Episodes 14, pp 264–268

Brousse R, Lefevre C (1990) Volcanisme en France et en Europe limitrophe. Masson, Paris, pp 1–263

Decker R, Decker B (1982) Introduction to volcanoes and the Earth's interior. Readings from Scientific American, WH Freeman, San Francisco, pp 3–5

Newhall CG, Dzurisin D (1988) Historical unrest at large calderas of the world. USGS Bulletin 1855, pp 1–1108

Simkin T, Siebert L (1984) Explosive eruptions in space and time: Durations, intervals, and a comparison of the world's active volcanic belts. In: Explosive volcanism: Inception, evolution and hazards. Studies in Geophysics, National Academy Press, Washington DC, pp 110–121

Smith RL, Luedke RC (1984) Potentially active volcanic lineaments and loci in western conterminous United States. In: Explosive volcanism: Inception, evolution and hazards. Studies in Geophysics, National Academy Press, Washington D.C., pp 47–66

Smithsonian Institution (1989) Global volcanism 1975–1985. Prentice Hall, New Jersey, pp 1–655

Szakács A (1991) Redefining active volcanoes. Some proposals. International Conference on active volcanoes and risk mitigation Abstracts, Naples

Szakács A (1994) Can we distinguish between dormant and extinct volcanoes? Colima Volcano Fourth International Meeting, Abstracts, pp 43–44, Colima

Tilling RI (1989) Volcanic hazards and their mitigation: Progress and problems. American Geophysical Union, Reviews of Geophysics 27, pp 237–269

Walker GPL (1974) Volcanic hazards and the prediction of volcanic eruptions. In: Funnell BM (ed) Prediction of geological hazards, Geological Society of London, Miscellaneous Paper 3, pp 23–41