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The Applicability and Productiveness of a Systematic Literature Review Methodology in Volcanology Research: Case of the Magma Pathway at the Mount Cameroon Volcano

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Abstract

The presented research illustrates the applicability and productiveness of the systematic literature review methodology, a non-empirical methodology in the geological sciences, particularly volcanology. The systematic literature review methodology is a replicable, rigorous, and transparent methodology for synthesizing existing literature to answer questions on a specific topic. The synthesis allows for knowledge consolidation, such as identifying knowledge gaps. In our illustration of this methodology, we focused on the expanding knowledge about the magma pathway at Mount Cameroon, one of Africa's active volcanoes. Our synthesis of the relevant international geoscience research literature is based on the framework of knowledge about the magma pathway beneath a typical basaltic volcano. The framework has three primary components: magma supply, storage, and transport to erupting vents. Across these components is a total of twelve secondary components. The result is a previously non-existent and fragmented overall understanding of the magma pathway at Mount Cameroon. The gaps in the understanding (such as in the magma supply rates, timescales of chamber processes, and magma ascent rates) may be addressed in future research. Another key implication of the presented research lies in the proof of concept of the systematic literature review methodology as an applicable qualitative research methodology in the study of volcanoes.

Keywords

Systematic Literature Review, Volcanology, Magma Pathway,

Mount Cameroon Volcano

1. Introduction

In the natural sciences in general and particularly in the earth sciences, scientific realism is traditionally utilized. It is a commonly held view under this research tradition that science aims at providing increasingly accurate knowledge about observable or unobservable objects, and events of the natural world, that are independent of the human mind [1] [2]. In this context, accuracy means correspondence between the language and the existence and workings of the associated natural entity itself. Under this research tradition, the researcher relies heavily on experimentation, numerical data, and statistical techniques [3]. However, non-numerical data and qualitative investigative techniques are also utilized as seen in aspects of analytical chemistry, rock behavior, and field geology [4]-[7]. It has been argued that knowledge of the natural sciences is not centered around numbers, but around careful qualitative descriptions of phenomena [4]. In any case, quantitative and qualitative research have been instrumental in the production of scientific knowledge. Currently, the accumulated knowledge is huge and growing rapidly [8] [9].

In the face of the rapidly expanding knowledge, the task of staying abreast is becoming increasingly challenging. Decision-makers (such as civil protection authorities) are confronted with an increasingly overwhelming amount of evidence requiring processing [8] [10] [11]. Consequently, there is a recognized need for synthesizing the rapidly expanding volumes of scientific knowledge, to facilitate evidence-informed decision-making [12] [13]. For conducting the synthesis, the available methodologies include the quantitative methodology offered by meta-analyses and the qualitative methodology offered by systematic literature reviews [14] [15].

Unlike traditional literature reviews, systematic literature reviews (SLR) address specific research questions, using a replicable, systematic, and transparent methodology to identify and compile existing evidence, that meets pre-defined quality criteria [16] [17]. This statement embodies two related interpretations of the term SLR: a stand-alone research piece and a methodology. The presented research aligns with these two interpretations of the term. A methodology has been described as a specific overall way of conducting research [18] [19]. The use of SLR methodology holds significant importance across all disciplines, given that such literature reviews serve multiple purposes [20]-[22]. The purposes consist of consolidating and enhancing understanding of existing knowledge, positioning specific results within the spectrum of existing knowledge, identifying research gaps for future investigation, establishing a robust foundation for further research, and aiding decision-making processes.

The SLR methodology is part of the evidence-based movement that originated in the field of medicine before spreading to the social sciences [23] [24], and to various other fields. The fields include education, public and environmental health [25] [26]. In the natural sciences (where the presented study lies), SLRs are increasingly utilized to assess the current state of knowledge in specific fields and to identify research gaps [27] [28]. Examples of recent SLRs in the natural sciences can be found in the context of chemistry [29]-[31], and human biology [32] [33]. However, SLRs remain relatively rare within the earth sciences, with few readily available examples in the fields of geological sciences.

Given the scarcity, the overarching purpose of the presented research was to illustrate the applicability of the SLR methodology, as a non-empirical qualitative research methodology in geology, in the specific context of volcanology. In this regard, we started by identifying the questions needed to drive the research conceptually. The focus was on sub-surface volcanic activities.

Volcanic eruptions exhibit a wide range of styles and durations, encompassing gentle lava flows to catastrophic explosions that can persist for hours or even years with various environmental hazards and landforms [34]-[36]. Poland, Miklius and K. Montgomery-Brow [37] assert that three fundamental sub-surface volcanic activities *i.e.* supply of magma to the volcano, magma storage, and magma transport to the erupting vents, govern all volcanic eruptions. The provision of a consolidated systemic understanding of these sub-surface activities has been and continues to be the focus of many studies, while gaps in the understanding of the activities do not permit reliable forecasts of either the magnitude or the style of some eruptions. The absence of such forecasts poses a challenge for decision-makers tasked with providing measures aimed at mitigating the detrimental consequences of eruptions on human lives and livelihoods within and beyond volcanic regions.

Our goal in the presented work was to illustrate the applicability and productiveness of the systematic literature review methodology in providing a consolidated understanding of the magma pathway at an active volcano. The consolidation enhances understanding of knowledge about the pathway, positions specific findings within the spectrum of this knowledge, and identifies knowledge gaps that researchers may address. Regarding the volcano, we utilized Mt. Cameroon, one of Africa's active volcanoes. Specifically, we tackled the following three research questions (RQs):

RQ1: What is the evidence about the magma pathway at Mount Cameroon volcano in a consolidated form?

RQ2: What does the consolidation of the evidence reveal about the relative research attention given so far to different pathway components?

RQ3: What gaps exist in the consolidated evidence, in the different components of the pathway?

2. Conceptual Framework

To address the research purpose and questions, we first compiled a description of the magma pathway beneath a typical volcano. The description provided a coherent framework that we could populate with evidence that we gathered about the magma pathway in the geoscience research literature, in terms of Mount Cameroon, thereby addressing our first research question (RQ1). With the population of the framework, we could then assess the varying degree of research attention dedicated to different components of the framework, revealing areas that have received the most attention, and the least attention (RQ2), in addition to the completely unexplored areas (RQ3).

We will now describe the magma pathway beneath a typical volcano. Existing research literature, including Scandone, Cashman, and Malone [38] and Wilson [39], recognizes that the magma pathway involves a sequence of processes (**Figure 1**).

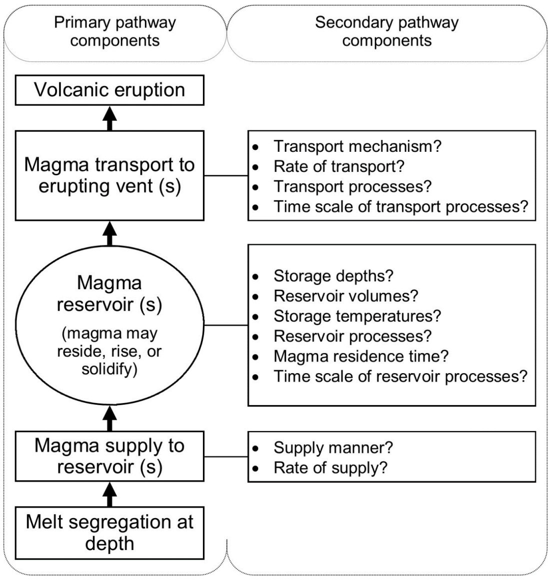

Figure 1. Components of a typical magma pathway (adapted from Wilson, 2007 and Scandone et al., 2008).

Following the production of magma from its source(s) within the Earth's mantle, it is transported through feeder complexes to the base of the volcano (**Figure 1**, bottom left). Within this specific segment of the magma pathway, two fundamental questions arise, as shown at the bottom right of **Figure 1**. These questions reflect two secondary categories of processes under the magma supply primary category. Existing literature on the topic of magma supply to the base of volcanoes suggests that this supply can occur in either an episodic or continuous manner [40] [41]. In either case, the rate of supply varies among different volcanoes and influences the style and frequency of eruptions. Thus, understanding the magma supply pattern of a volcano is a crucial factor in volcano investigation.

The magma supplied to the base of a volcano is in most cases stored in subsurface chambers (reservoirs) as depicted in the middle left of **Figure 1**. There are several significant questions associated with this component of the magma pathway, as illustrated in the middle right portion of the figure. In response to these questions, studies [42] [43] have revealed that a multitude of chemical and physical processes, operating at varying rates, take place within the reservoir(s). It is also important to note that a volcano may possess one or multiple chambers at different depths [44] [45]. Furthermore, the geometry of magma reservoirs can differ significantly. Examples include reservoirs with volumes reaching hundreds of cubic kilometers [44] [46], to very small spherical reservoirs with radii of around 100 meters [47].

For a volcanic eruption to take place, the magma stored in the reservoir(s) must be conveyed to the eruptive vents, as depicted in the top left section of **Figure 1**. In this regard, a set of questions emerges, as seen at the top right of **Figure 1**. How magma rises, the processes it undergoes during transport, the timescales involved, and the rate of magma movement, are pivotal in determining the eruption style, eruption intensity, and the resulting products. A comprehensive understanding of these aspects related to magma transport within a specific volcano is of utmost importance for accurate eruption forecasting and effective hazard mitigation measures.

3. Method of Study

The purpose of this study was to illustrate the applicability and productiveness of employing the systematic literature review (SLR) methodology in volcanology. In this regard, we used the typical magma pathway outlined in Section 2, to provide our SLR with conceptual guidance.

In general, an SLR has been described as a methodology for evaluating existing evidence, by following a well-defined set of procedures [48]. In an SLR, bias is minimized in the identification, assessment, and synthesis of the relevant literature-based evidence. Specifically, we employed an SLR methodology consistent with recent SLRs conducted in various scientific disciplines [27] [28] [49]. In this regard, we adopted a process with several distinct phases—a literature search, a screening process, data extraction, and data analysis.

3.1. Searching the Literature

To locate literature likely to contain evidence aligned with the purpose of our SLR, we first constructed search terms that are based on our research focus and conceptual framework (Sections 1 and 2). The search terms were all in English and consisted of "Mount Cameroon", "Mt. Cameroon", and "volcanic eruptions". We kept these search terms broad to identify more rather than less related literature. Using the search terms, we searched the full text of sources in the Web of Science database, Science Direct, Wiley Online, and Google Scholar.

We applied specific criteria to filter the search results. The literature had to be written in English, undergo peer review, and be in the form of a research article. We selected peer-reviewed research articles due to their higher quality resulting from the rigorous editorial process employed by most journals [50]. We placed no restrictions on the publication date of the articles, to ensure inclusivity and to gather a comprehensive dataset. For the Google Scholar search, we utilized the advanced search engine methodology, following Yang and Meho [51]. We conducted the searches in January-July 2023.

In total, the search across the aforementioned databases yielded 1,145 sources. These search results, forming part of the identification phase of the SLR (as depicted at the top of **Figure 2**), encompassed full articles, abstracts, short communications, and summaries, amongst other types of publications, despite the restriction on publication type. The breakdown of the search results by database is included in **Figure 2**.

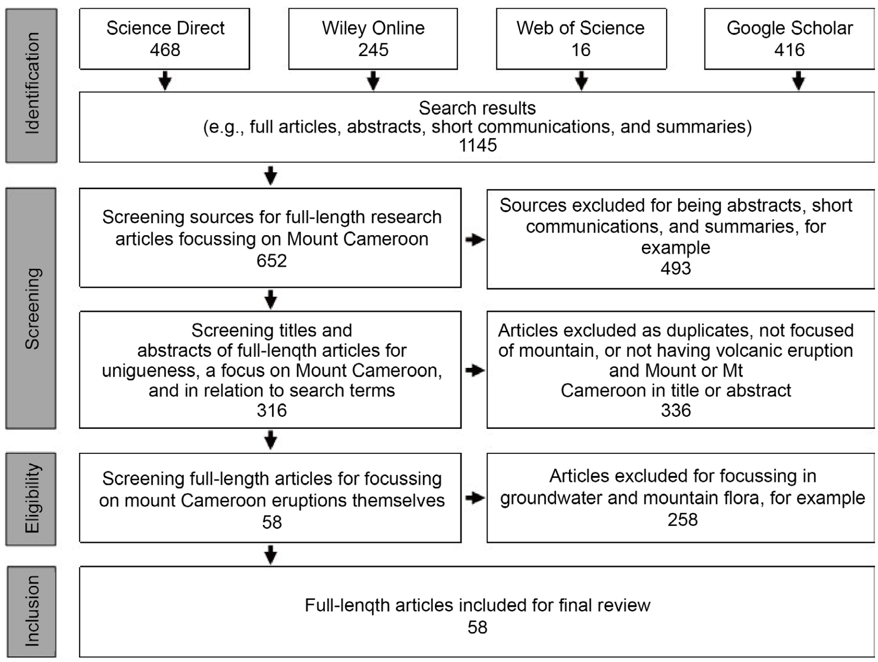

Figure 2. Summary of the paper identification, screening, and selection process adapted from [49].

3.2. Screening the Literature

The screening step of the SLR encompasses the screening and eligibility stages depicted in **Figure 2**. Initially, the 1,145 articles obtained from the online searches were sorted into full research articles and other sources. In the latter category were 493 sources, consisting of e.g. abstracts, short communications, and summaries. As these sources did not align with our inclusion criteria, they were excluded from further consideration, leaving 652 full-length peer-reviewed research articles for further evaluation.

Next, the titles of the 652 articles were checked for duplicates and relevance to the study's focus. It was observed that some articles did not specifically address Mount Cameroon. The titles and abstracts of the remaining articles were skimmed using the search terms "volcanic eruptions" and "Mount Cameroon" or "volcanic eruptions" and "Mt. Cameroon." Through this screening process, a further 336 articles were excluded.

The next step involved carefully reading the abstracts of the remaining 316 articles to ensure that they focused on volcanic activities, rather than unrelated topics on Mount Cameroon. Examples of excluded articles include [52], on iron adsorption in volcanic ashes from Mount Cameroon and [53], on flow dynamics and age of groundwater in Mount Cameroon. Following the thorough examination, a total of 58 unique full-length articles that specifically focused on volcanic eruptions on Mount Cameroon were identified to be fully read and analyzed as part of this SLR, as indicated at the bottom of **Figure 2**.

3.3. Data Extraction and Analysis

In this SLR, the data comprised existing pieces of evidence related to the components of the magma pathway outlined in Section 2, but specifically in the context of Mount Cameroon volcano. To extract the evidence, all 58 retained articles were thoroughly read in their entirety. The extracted evidence was subjected to qualitative, and then descriptive statistical analyses, similar to other SLRs in scientific research literature [27] [49].

The qualitative analysis was conducted beginning with the deductive technique in content analysis, described by Crabtree and Miller [54]. This technique involves a systematic process of identifying categories beforehand, based on existing knowledge. Starting from our conceptual framework (Section 2), we established predefined primary and secondary categories for organizing the evidence about the magma pathway. The primary categories were magma supply, magma storage, and magma transport. Taking magma supply as an example, the secondary categories included supply manner and rate of supply. Each piece of extracted evidence concerning the magma pathway was then assigned to the corresponding primary and secondary category.

A coding scheme was developed to facilitate the assignment of evidence. Each piece of extracted evidence was allocated a code in the form of "Xyz," where "X" represented the primary category and "y" denoted the secondary category. The coding scheme, including the assignment of values for X and y, is provided in **Table 1**. The values that "z" could take are explained in the subsequent sections.

As illustrated in **Table 1**, the "X" component of the code is represented by uppercase letters A, B, or C, corresponding to the three primary components of the magma pathway. The "y" component is represented by Arabic numerals, indicating the secondary components within each primary component. The number of secondary components varies from one to six, depending on the primary component. For instance, if the extracted evidence pertained to the magma supply rate, it would be coded as A2.

In cases where similar evidence was obtained from multiple studies, the third dimension of the code, "z," was introduced. Lower-case letters such as a, b, c, and so on were assigned to each similar piece of evidence. The categorization was completed for all the extracted pieces of evidence, to address RQ1, and to facilitate the descriptive statistical analysis that helped address RQ2 and RQ3.

Table 1. Part of the coding scheme for the gathered evidence on the magma pathway.

Primary category		Secondary category	
Name	Code (X)	Name	Code (y)
Magma supply	A	Supply manner	1
		Magma supply rate	2
Magma storage	B	Storage depths	1
		…	
		Times scales of reservoir processes	6
Magma transport	C	Transport mechanism	1
		…	
		Times scales of transport processes	4

Regarding the statistical analysis, we counted the number of pieces of evidence per category, enabling us to determine the relative research emphasis on different primary and secondary components of the magma pathway (RQ2). This process also allowed us to identify categories without evidence, indicating knowledge gaps in the magma pathway (RQ3).

4. Findings

4.1. RQ1: What Is the Evidence about the Magma Pathway at Mount Cameroon Volcano, in a Consolidated Form?

We gathered 39 pieces of evidence about the magma pathway beneath the Mount Cameroon volcano, seen in the first three columns of **Table 2**. In consolidated form, the evidence is described next.

Magma supply: *Magma supply manner and rate.* Through isotope and trace element ratios, slight variations have been observed in the composition of Mount Cameroon lava suggesting that magma supply to the volcano occurs in discrete batches [47]. Additionally, [55] [56] conducted studies using bulk rock geochemistry and Mount Cameroon melt inclusions. They observed differences in certain trace element ratios (e.g., V/Rb) and volatile contents, interpreted as indicators of an episodic mode of magma supply to the volcano's chambers.

Magma storage: *Reservoir location, temperatures, in addition to reservoir geometry, reservoir processes, and magma residence times*. The evidence we gathered on storage location shows that there are multiple storage zones beneath Mount Cameroon at a depth range of 3km and greater than 30 km [45] [57] [58]. Also, there is evidence that a spherical magma reservoir of volume about 2.3×10^6 - 1.3×10^7 m^3 hosted the magma that fed the 1982 eruption of Mount Cameroon [47]. The pre-eruptive reservoir temperatures are in the range of 1150 - 1200˚C [45] [56] [58]. Additionally, we gathered evidence of many processes taking place within the magma storage zones. The processes include fractional crystallization [59]-[61], crystal settling [62], and magma mixing. Moreover, we found evidence that the magma that fed the 1999 and 2000 eruptions resided for more than several decades and less than a few thousand years before the eruption [63].

Magma transport: *Manner of magma transport and magma transport processes.* Dyke intrusions are the main means through which magma is transported from the reservoirs to erupting vents, while low buoyancy dykes are unlikely to reach the surface of the earth [62] [64]. Degassing is the main process that occurs as the magma rises from lithospheric depths [63].

4.2. RQ2: What Does the Consolidation of the Evidence Reveal about the Relative Research Attention Given So Far to Different Pathway Components?

Columns 3 and 4 in **Table 2**, show the distribution of the evidence we gathered across the components of the magma pathway. The statistics in the table show that the largest proportion of the gathered evidence lies under magma storage, as this component alone contains more than four-fifths of the gathered evidence. Magma transport and magma supply contain less than one-fifth of the evidence of the magma pathway that we gathered. Specifically, the least studied primary component of the magma pathway at Mount Cameroon is magma supply, whereas the most investigated primary component is magma storage.

Table 2. Distribution of the compiled evidence across components of the magma pathway at Mount Cameroon volcano.

Component of pathway		Pieces of evidence compiled		
Primary	Secondary	Number	Proportion (%) [a]	
Magma supply	Supply manner	3	7.7	7.7
	Magma supply rate	0	0	
Magma storage	Reservoir processes	17	43.6	79.6
	Storage depths	8	20.5	
	Storage temperatures	4	10.3	
	Reservoir volumes	1	2.6	
	Magma residence time	1	2.6	
	Times scales of reservoir processes	0	0	
Magma transport	Transport mechanism	3	7.6	12.7
	Transport processes	2	5.1	
	Rates of transport	0	0	
	Times scales of transport processes	0	0	
Total		39	100	100

[a]N = 39.

The statistics also reveal that although magma storage is much more studied, the secondary components in this aspect of the pathway (e.g., storage depth and magma residence time) have received different levels of attention from researchers. Specifically, reservoir processes have received the most attention (~44%), whereas magma residence time and reservoir volumes have benefited from the least attention (~2%, respectively).

4.3. RQ3: What Gaps Exist in the Consolidated Evidence, in the Different Components of the Pathway?

The statistics in Table 2 show that the knowledge about the magma pathway at Mount Cameroon is fragmented. The gaps in knowledge about the pathway are wide in the case of magma supply and magma transport, when compared to magma storage. One may think this is due to the larger number of secondary components under magma storage (six) as opposed to magma supply (two) and magma transport (four). However, the mean proportion of the evidence per secondary component is much larger in the case of magma storage (~13%) as opposed to magma supply (~4%) and magma transport (~3%).

Knowledge gaps in the secondary components of the magma pathway occur in all three primary components of the magma pathway. In the magma supply component, we didn't find any evidence of the magma supply rates. Under magma storage, we also didn't gather any evidence of the time scales of reservoir processes. In the context of magma transport, we didn't find evidence about the rate and the time scales of magma transport.

Looking more closely at each primary component in which we gathered evidence, we noted additional gaps in the present knowledge regarding the magma pathway beneath Mount Cameroon. For example, under magma storage, and in the specific context of magma storage, and as concerns reservoir volume, we didn't find evidence of the volume of the reservoirs that powered other recent eruptions of the volcano other than the 1982 eruption. Concerning the magma residence time within the reservoir, we didn't find evidence of the magma residence time for eruptions of Mount Cameroon magmas, except that which fed the 1999 and 2000 eruptions.

5. Discussion

It is pertinent to recall that the purpose of the presented study was to illustrate the applicability and productiveness of the SLR methodology as a non-empirical qualitative methodology in volcanology. The illustration focused on systematically compiling and synthesizing the scientific evidence dispersed throughout the geoscience research literature, concerning the magma pathway beneath the Mount Cameroon volcano. The synthesis was meant to yield a consolidated understanding of the evidence and to inform further research. In this regard, although we gathered 39 pieces of evidence about the magma pathway, the evidence relates mostly to magma storage at the expense of magma supply and transport while covering only eight of the twelve secondary components we considered in our analyses (Section 3). Overall, the findings of the SLR present a new and fragmented understanding of the up-to-date research knowledge concerning the complete magma pathway beneath this volcano.

5.1. Contribution

The presented SLR is a proof of concept in non-empirical qualitative volcanological research methodology. In this regard, the study illustrates the applicability of the SLR methodology. SLRs have been conducted about health and tourism in volcano settings [65] [66], for example. However, this methodology was still to be employed to investigate the volcanoes themselves. Thus, the presented study illustrates a new and non-empirical qualitative methodology for the study of volcanological phenomena. This methodology comes to add to the existing empirical qualitative methodology that has been utilized in aspects of rock behavior and field geology, for example. Also, the presented research contributes to fostering the SLR methodology in the wider field of geology. In this area of science, SLRs are still to be commonplace.

The presented SLR also reveals the productiveness of the SLR methodology in volcanology research. In this regard, the presented study differs from previous studies which have predominantly focused on investigating specific aspects of the volcano's magma pathway, as seen in Section 3. Instead, this study aimed to synthesize specific insights from existing research. The result is a consolidated although fragmented understanding of the entire magma pathway of the Mount Cameroon volcano. Such an understanding is lacking in previous investigations of this and other volcanoes.

5.2. Implication for Further Research

The productive application of the SLR methodology to study the magma pathway beneath the Mount Cameroon volcano in this study, suggests that the same methodology could be utilized to similarly reach a consolidated understanding of other areas of the studied volcano, while informing further research in the area. An example is its eruptive style. This aspect of the volcano has been investigated in many studies [59] [67]. Also, the methodology can be considered in the investigation of the magma pathway, eruptive style, and other aspects of volcanoes in other places around the world.

In the presented study, the application of the SLR methodology revealed several knowledge gaps. An example is the lack of evidence on the rates of magma supply to the Mount Cameroon volcano (Section 3.2.1). There have been extensive investigations on this aspect at other active volcanoes around the world, including Kilauea, where the magma supply rate has been found to range from 0.02 - 0.18 km^3/yr [37] [68]. At Yellowstone, Caldera, [69] measured a magma influx rate of 0.1 km^3/yr. At volcanoes that erupt periodically such as Mount Cameroon, knowledge of the magma supply rate is vital in understanding the behavior of the volcanic system in terms of the production of melt over time. For instance, major changes in the style of activity as well as compositional variations in erupted lavas at Kīlauea and Mauna Loa, have been attributed to variations in magma supply rates [70] [71]. Thus, feature research on the magma supply rate at Mount Cameroon is very important for eruption forecasting.

The consolidated evidence includes evidence of the pre-eruptive processes within the magma reservoirs of the Mount Cameroon volcano (Section 4.1). However, a quantitative understanding of these processes is still to be developed. Future research on time scales of the volcanic activities in Mount Cameroon magma reservoirs is very important towards enhancing understanding of the rates of magmatic differentiation. Such an understanding is at a more advanced level regarding some of the world's most active and well-monitored volcanoes [43] [72].

This SRL also revealed a deficit in knowledge about magma chamber geometry in Mount Cameroon volcano (Section 4.1). This knowledge deficit is inexistent in the context of volcanoes such as Kilauea, Piton de la Fournaise, and Mt. Etna [71] [73]. Establishing the sizes and shapes of the multiple reservoirs in the Mount Cameroon volcanic system is important for better understanding its magma pathway, and is invaluable in the ongoing monitoring activities.

6. Conclusion

The presented research is an illustration of the applicability and productiveness of the SLR methodology, a previously unused qualitative dimension in volcanology research. The productiveness of this methodology has been illustrated through the resulting consolidated understanding of the magma pathway associated with Mount Cameroon volcano, which was previously lacking. However, the understanding is fragmented, and there are differences in the research attention already given to the different components of the pathway, with the emergence of numerous knowledge gaps. Thus, our SLR contributes to informing a research agenda for Mount Cameroon volcano. Thus, the SLR serves as an illustration of the productiveness of the methodology in volcanology. The findings produced are useful for informing local monitoring and hazard mitigation efforts. Another key implication of the presented study is its illustration of the applicability of an SLR as a non-empirical qualitative research methodology that volcanologists can consider when addressing similar research questions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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