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Reappraisal of the significance of volcanic fields

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ABSTRACT

"Volcanic field" is a term commonly used to loosely describe a group of volcanoes. Often, it is implicitly assumed that the volcanoes on a volcanic field are small, monogenetic and dominantly basaltic, but none of those attributes is indispensable on some definitions of the term. Actually, the term "volcanic field" can be used to describe a group of purely monogenetic edifices, a group of mixed monogenetic and polygenetic edifices, or even a group formed only by purely polygenetic edifices. Differences between each of those alternatives might be important, but the extent to which those differences are truly relevant remains still to be explored. Furthermore, there are several limitations on the current knowledge of this type of volcanic activity that explain the lack of a comprehensive effort to study volcanic fields in global contexts. In this work, issues concerning current definitions of a volcanic field are examined, and some criteria that can be used to distinguish volcanic fields from non-field volcanoes are suggested. Special attention is given to the role played by spatial scale on such a distinction. Also, the tectonic implications of their spatial distribution are explored. In particular, it is shown that volcanic fields are an important component of volcanic activity at a global scale that is closely associated to diffuse plate boundaries, and might well be considered the archetypical volcanic form of such tectonic scenarios.

1. Introduction

On the most general sense, volcanic field (VF) is a non-genetic term that can be used to describe any area within which a variety of structures of volcanic origin might be found. The structures in question include lava flows, lava domes, cinder, spatter, tuff or scoria cones, maars, tuff rings, shields, and even strato-volcanoes. Ubiquity of some structures, however, has commonly led to a more restrictive use of the term, so that emphasis is made (often implicitly) on the description of areas enclosing small, *probably monogenetic*, dominantly basaltic volcanic edifices (Connor and Conway, 2000; Németh, 2010; Germa et al., 2013a; Le Corvec et al., 2013). In some extreme cases, use of this term has been even more restricted to describe groups of volcanic structures all of which share a common characteristic, as it is the case, for example, of the "cone fields" examined by Settle (1979), or the definition of a monogenetic field given by Nakamura (1986) quoted by Takada (1994).

Perhaps one of the less restrictive definitions of the term was issued by Lockwood and Hazlett (2010), who stated that VFs are "especially large clusters of volcanoes, with or without a *central volcano*". Although those authors are not explicitly referring to the central volcano as strictly polygenetic, this possibility is suggested considering that, according to those authors, the central volcano is said to share the same magma reservoir with the surrounding edifices, or at least to have a common source of heat under the surface. On this form, a VF could be used to describe a group of purely monogenetic edifices, a group of mixed monogenetic and polygenetic edifices, or even a group formed only by purely polygenetic edifices. From a genetic point of view, differences between each of those alternatives might be important because the conditions for the formation of either type of volcano are sometimes considered to be mutually exclusive (Fedotov, 1981; Wadge, 1982; Walker, 1993; Takada, 1994; Walker, 2000). The extent to which those differences are truly relevant, however, remains still to be explored.

Besides the different forms in which monogenetic and polygenetic structures can enter the definition of a VF, there are other sources of ambiguity surrounding the usage of this term. For example, there is a lack of agreement concerning the number of volcanoes that are required to define a VF. Németh (2010) states that "fields commonly … include hundreds of structures", whereas Le Corvec et al. (2013) point-out that monogenetic VFs might include only a few tens of volcanoes. Similarly, Connor and Conway (2000) distinguish between small fields (<50 vents distributed over <1000 km^2) and large fields (>100 vents distributed over >1000 km^2), but in this case inclusion of the total area covered by the volcanic structures is also important. In any case, due to the absence of definitive limits, it is unclear under which circumstances a group of, say, four volcanoes should be considered to be a volcanic field or not. Likewise, it is uncertain if the area covered by the volcanoes forming "the group" must have a minimum average density (i.e., number of volcanoes/unit area), or if the distance between adjacent structures needs to have a specific length. Again, from a genetic point of view it is unclear to what extent those differences are important for the understanding of volcanic activity both locally and at a global scale.

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In this paper, I examine some issues concerning current definitions of a volcanic field, and explore some of the tectonic implications of the spatial distribution of this type of volcanism around the world. Most specifically, I address the issues of whether there is a threshold on the number of volcanoes that are required to form a VF, and of whether there is a typical distance that should be considered to envisage two volcanic edifices as independent structures. After having addressed those two issues, I suggest some criteria that can be used to distinguish VFs from non-field volcanoes based on current levels of information easily available in global databases. The tectonic implications of the spatial distribution of the identified VFs are finally explored.

Related issues, such as the relationship existing between polygenetic and monogenetic edifices, the types of structures that can be produced during monogenetic eruptions or their subsequent degradation, geochemical complexities that might arise within a field or within a single monogenetic edifice, the distinction between volcanic events and volcanic edifices, or between volcanic event, phase, or even the role played by temporal gaps on volcanic activity are addressed only to the extent that they might contribute to clarify general issues associated with lack of precision on the current definitions of a volcanic field. Readers interested in these other issues are referred to the works by Valentine and Gregg (2008), Szakács and Cañón-Tapia (2010), Kereszturi and Németh (2013), Németh and Kereszturi (2015), and references therein.

2. Spatial independence of a volcano

The independence of a volcanic structure is relevant for the distinction between monogenetic and polygenetic volcanism, and is central on the definition of a volcanic field. Small structures, usually resulting from a single eruptive event (hence termed monogenetic) are commonly found on top of larger volcanic edifices considered to be polygenetic because of the repeated cycle of eruption and quiescence events taking place from a single vent. The combined erupted products of the monogenetic and polygenetic vents contribute to the growth of the larger structure (the polygenetic edifice), and in many cases, the smaller edifices and associated products become completely engulfed and even buried by the eruptive products of the larger structure. In many cases, the small structures have been referred to as "flank" or "parasitic" volcanoes (Nakamura, 1977; Yokoyama, 2015), thus remarking their lack of independence relative to the larger one. Nevertheless, not all monogenetic structures have the same relationship with polygenetic volcanoes.

If looked as a whole, a group of neighboring monogenetic volcanoes may have eruptive histories and accumulated volumes comparable to those of large strato-volcanoes, with or without flank structures (Connor and Conway, 2000). If regarded in this form, the area enclosing the group can be considered to be the larger structure, and each of the smaller volcanoes could therefore be considered to be akin to the "parasitic" volcanoes described above. Nevertheless, the lack of a dominant polygenetic structure (i.e., a structure possessing a vent that has erupted cyclically) amidst the smaller edifices, favors in some cases the interpretation of the group of small volcanoes as an independent structure that could be called a VF. Insights concerning some characteristics of the magma source, mechanisms of magma production or transport, or related to the state of stress of the rock lying between the source of magma and the surface have been obtained through the identification of patterns on the spatial distribution of vents over the surface (Connor, 1987; Connor, 1990; Connor and Hill, 1995; Bernhard Spörli and Eastwood, 1997; Mazzarini and D'Orazio, 2003; Weller et al., 2006; Mazzarini, 2007; Mazzarini et al., 2008; Kiyosugi et al., 2009; Mazzarini et al., 2010; Capello et al., 2012; Richardson et al., 2012; Germa et al., 2013a; Le Corvec et al., 2013). Those insights reveal a structure that is in general different from the structure inferred to exist beneath larger polygenetic edifices (Sudo and Kong, 2001; Londoño and Sudo, 2002; De Natale et al., 2004; Soosalu and Einarsson, 2004; Nunziata et al., 2006; Park et al., 2007). Consequently, it would seem that some distinction between both non-field volcanoes and VFs is convenient, at least in some cases.

Another complication arises when the times between eruptions are considered. For example, if magma is extruded simultaneously from two vents separated by a short distance from each other, it will be easy to accept that they are part of the same volcano even if the two magmas are not identical in composition. In contrast, if the two eruptions take place separated by a large time, say a thousand years, but by chance they coincided more or less on the spatial location of their vents, it is not as easy to consider them as part of the same eruption (or the same volcano), but their independence is neither entirely clear. Actually, distinction between monogenetic and polygenetic activity, is not always straightforward, and many examples of apparently monogenetic volcanoes having complex internal architectures and polygenetic histories have been identified as the result of high-resolution studies (McGee et al., 2011; Needham et al., 2011; Sohn et al., 2011; Jordan et al., 2013; Shane et al., 2013; Jankovics et al., 2015). Similarly, the identification of groups of monogenetic volcanoes formed directly on top of larger polygenetic edifices, collectively referred to as "volcano cone fields" (Settle, 1979), suggests that not always there is a clear distinction between conditions under the surface and the generation of either monogenetic or polygenetic volcanoes. Departures from the simple two-end member classification have become so numerous, that some authors have suggested the need for the adoption of transitional types, or even the convenience of completely abandon the usage of the "monogenetic" and "polygenetic" terms (Bradshaw and Smith, 1994; Sheth, 2014; Németh and Kereszturi, 2015; Sheth and Cañón-Tapia, 2015). The question of which circumstances lead to two volcanic edifices to be considered as independent, however, remains open.

In a different line of reasoning, although cluster analysis differs from other statistical techniques aiming to determine if a specific dataset is well described by a specific distribution function, it is also convenient to assess the independence of the objects forming the database to avoid potential biases that could be introduced if duplication of observations, or no independence of objects, are allowed. For these reasons, it is important to examine with some attention the conditions upon which two volcanic edifices can be considered as independent structures.

2.1. Spatial independence of volcanic edifices

Although volcano independence can be established in various different forms (temporal, petrological, geochemical, morphological), in this work I only focus on their spatial independence. Spatial independence of two volcanoes is based on the determination of the distance between two reference points (one on each structure). Intuitively, the spatial independence of two volcanic edifices can be related to the distance separating them at their base, and on the degree of overlapping of the products erupted through independent conduits. Assuming, for the moment that all the products forming one edifice are erupted through the same vent (irrespective of whether they are erupted in a single or multiple events), it is easy to accept that two edifices showing no overlapping of their products reflect the presence of two independent conduits. Consequently, those two edifices can be safely considered to be independent volcanoes (Fig. 1a). If the conduits in question are relatively closer to each other, some degree of overlapping of their products could be allowed without implying interdependence of the two volcanoes (Fig. 1b). If the two conduits are positioned even closer to each other, a larger degree of overlapping of their products is likely to be produced (Fig. 1c). On the limiting case, when the two conduits coincide in space (effectively representing the same conduit), overlapping of their erupted material will be complete. Even if the intensity of the eruptions occurring from the two conduits is different, a complete overlapping of the products of the conduit that erupted with less intensity with the products of the other conduit is expected (Fig. 1d). Thus, based on this very general relationship, and using purely geometric arguments, it