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Structural analysis of active quarries in the Quaternary Western Eifel volcanic field and their relevance for the formation of diatremes

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Introduction

The Quaternary Western Eifel volcanic field, the classic maar region, is located in the western part of the Variscan Rhenish shield, Germany. It extends over 50 km from Bad Bertrich near the Mosel river to Ormont near Belgium. The volcanic activity began around 720 ka and the most recent eruption is 11 ka (Merz et al 2015). The sharp increase in volcanic activity in the last 60 ka, especially in the southeast of the volcanic field, indicates that it is an active volcanic field (Schmidt et al 2017). The erupted magma consist mainly of foidites, followed by basanites and very few tephrites and phonolites (Mertes and Schmincke 1985). Volcanic types include scoria cones and scoria rings, maars, and tuff-rings. The current geological survey of the 20 active quarries has significantly increased understanding about the formation of the deeper parts of these volcanoes.

Scoria Cones

Of the almost 300 volcanoes, scoria cones are the most common volcano type. Only a few scoria cones have the classic conical shape because most formed inside craters up to several 100 m wide, created by an initial phreatomagmatic eruption. The craters, which taper downward, are filled with scoria, agglutinate, dikes, lava plugs, and partially preserved lava lakes, from which lava commonly flowed out of the craters. Individual smaller eruptive centers nest within the primary craters; in some cases, these are in a linear pattern, although many are randomly distributed. As a result of these large initial craters, the scoria cones are usually only morphologically developed as mounds partially filling the craters, in places overlapping with other scoria scoria mounds. In some cases, even topographical depressions occur in the vent area so that a ring of scoria is deposited above the ring of initial maar tephra. We call this form of volcano a scoria ring, in a purely descriptive sense.

The initial phreatomagmatic tephra of the scoria cones is rich in vesicular juvenile components. Cauliflower-shaped lapilli and bombs are commonly peppered with thermally altered host rock fragments, even with many ash-sized clasts. This implies that both phreatomagmatic and magmatic eruption processes play a role in their formation.

Some scoria cones have no or only minor early phreatomagmatic phases and, therefore, erupted most of their scoria onto the pre-existing ground surface. Some of the craters of these scoria cones reach diameters of 100 m to 200 m, in exceptional cases up to 500 m (Lange et al 2022). Very few scoria cones formed a large crater and thick tephra aprons that extend radially around 1 km. They were formed by an alternation of strombolian and phreatomagmatic eruption processes. One example is the 500 m (N/S) x 800 m (E/W) crater of Graulei near Hillesheim, in which a thick lava lake formed. Crater sediments (redeposited tephra and mud), were squeezed upwards and outwards into the crater rim area due to the weight of the basaltic lava and pressed into the tephra wall parallel to the bedding.

Maars

The classic Eifel maars, the second most important type of volcano, are between 2 km and 80 m in diameter and represent a third of all volcanoes in the Western Eifel volcanic field. In contrast to the initial phreatomagmatic tephra of the scoria cones the ejected maar tephra is generally poor in juvenile particles and contains mainly ash, lapilli and blocks of Lower and Middle Devonian and Triassic host rocks. Some maar ejecta is almost entirely composed of host-rock fragments in the form of massive, lapilli-bearing ash layers and lapilli and block horizons (maars from Immerath and Ellscheid). Here, it appears possible that phreatic explosion processes are involved in the formation of these beds. One maar is filled by a lava lake from two neighboring scoria cones of the same age. Some maars display evidence that the phreatomagmatic eruptions took place close (within a few meters) to the surface, as at the newly discovered Little Daun Maar. For some larger maars, we assume that several eruption centers are randomly distributed within the large vent and that their explosive centers, where the water/magma contact took place, extended to greater depths.

Tuff-Rings

Around 6% of the volcanoes formed as tuff-rings. The size of their craters varies from 100 m to 1 km. They consist mainly of scoriaceous juvenile lapilli and flat tuff walls and were formed by water-rich, near-surface eruptions. Surface water probably played a significant role in their formation. In the case of Oberstadtfeld, after the formation of an initial maar and a cinder cone with many cannonball bomb layers,

Figure 1: Fault structure at the northern edge of the Wöllersberg tuff-ring. The tensional deformation zone extends to the north (right in the picture) up to a distance of 120 m. The Triassic Bunter Sandstone and the Wöllersberg tephra are displaced at several normal faults and are slightly rotated against the slope.

four conduits formed within the 1-km-diameter crater, cutting its tuff-ring deposits. The conduits contain blocks of near-vertically dipping tephra and intrusions that exploded into separate lapilli near the surface.

Rim Deformation

Pronounced tensile fault structures occur in exposed segments of the crater walls near the rims of the craters of five scoria cones with initial maar phases, three maars, and one tuff-ring, (Fig. 1). They extend up to a distance of 120 m beyond the crater rim and consist of numerous synthetic and antithetic faults as well as horst-and-graben structures and tilted blocks close to the crater rim. These structures were probably not only caused by instability of the inner crater slopes during the eruptions, but also by collapse into the very steep or undercut crater and diatreme inner slopes due to growth of the maar-diatremes. The most prominent example is the Eselsberg maar complex. After two eruptive centers initially formed a thick pile of scoriaceous lapilli, the Eselsberg maar formed south of the two centers. Eruptions deposited thick maar tephra on top of the scoriaceous deposits. This was followed by syn- and posteruptive collapse deformation in the area of the northern edge of the maar. This deformation produced four normal master faults with a cumulative movement of about 50 m and simultaneously active reverse faults. Closer to the crater rim of the Eselsberg maar, the tephra blocks dip steeply toward the crater. Toward the end of and after the tensional movements, the Eselsberg maar crater was completely filled by phreatomagmatic and strombolian tephra erupted by the "In der Boos" maar immediately to the south.

Volcanic Clusters

About thirty large multi-vent volcanic clusters are currently identified in the Western Eifel volcanic field, concentrated near its center or lined up like a string of pearls. In between are numerous individual volcanoes, mostly small scoria cones and individual maars. These centers and the linear groupings typically combine phreato-strombolian scoria-cone activity, phreatomagmatic maar-forming activity, and lava-flow eruption, typically from different vents.

Variety of Eruption Styles

The variety of eruption styles in the Western Eifel volcanic field may be tied to the poorly permeable aquifer in large areas. Water availability may affect the water-magma interaction as much as or more than other factors. Magmatic volatiles, heat pipes along fractures, dikes, and diatremes may move water to explosion sites (Valentine et al 2021). CO_2-driven water transport, perched aquifers, hydraulic short-cuts between different aquifers during dike intrusions, and frozen water in permafrost soils up to several tens of meters deep, may also be important.

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