Evolution of the Quaternary melilite-nepheline Herchenberg volcano (East Eifel)

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Abstract. The Quaternary Herchenberg composite tephra cone (East Eifel, FR Germany) with an original bulk volume of $1.17 \times 10^7 \text{ m}^3$ (DRE of $8.2 \times 10^6 \text{ m}^3$) and dimensions of ca. 900-600-90 m (length-width-height) erupted in three main stages: (a) Initial eruptions along a NW-trending, 500-m-long fissure were dominantly Vulcanian in the northwest and Strombolian in the southeast. Removal of the unstable, underlying 20-m-thick Tertiary clays resulted in major collapse and repeated lateral caving of the crater. The northwestern Lower Cone 1 (LC1) was constructed by alternating Vulcanian and Strombolian eruptions. (b) Cone-building, mainly Strombolian eruptions resulted in two major scoria cones beginning initially in the northwest (Cone 1) and terminating in the southeast (Cones 2 and 3) following a period of simultaneous activity of cones 1 and 2. Lapilli deposits are subdivided by thin phreatomagmatic marker beds rich in Tertiary clays in the early stages and Devonian clasts in the later stages. Three dikes intruded radially into the flanks of cone 1. (c) The eruption and deposition of fine-grained uppermost layers (phreatomagmatic tuffs, accretionary lapilli, and Strombolian fallout lapilli) presumably from the northwestern center (cone 1) terminated the activity of Herchenberg volcano. The Herchenberg volcano is distinguished from most Strombolian scoria cones in the Eifel by (1) small volume of agglutinates in central craters, (2) scarcity of scoria bomb breccias, (3) well-bedded tephra deposits even in the proximal facies, (4) moderate fragmentation of tephra (small proportions of both ash and coarse lapilli/bomb-size fraction), (5) abundance of dense ellipsoidal juvenile lapilli, and (6) characteristic depositional cycles in the early eruptive stages beginning with laterally emplaced, fine-grained, xenolith-rich tephra and ending with fallout scoria lapilli. Herchenberg tephra is distinguished from maar deposits by (1) paucity of xenoliths, (2) higher depositional temperatures, (3) coarser grain size and thicker bedding, (4) absence of glassy quenched clasts except in the initial stages and late phreatomagmatic marker beds, and (5) predominance of Strombolian, cone-building activity. The characteristics of Herchenberg deposits are interpreted as due to a high proportion of magmatic volatiles (dominantly CO$_2$) relative to low-viscosity magma during most of the eruptive activity.

Introduction

In many fields of monogenetic basaltic volcanoes, eruptive mechanisms range from dominantly magmatic (Strombolian/Hawaiian scoria cones plus lava flows) to dominantly phreatomagmatic (Vulcanian) maars and tuff rings as inferred principally from the nature of the deposits and edifices. Mafic volcanoes of the Quaternary East Eifel volcanic field (EEVF) show all gradations between these two end members (Schmincke 1977a, b): (a) maars and tuff rings formed entirely by Vulcanian activity (e.g., Lummerfeld Maar); (b) scoria (agglutinate) cones entirely of Strombolian/Hawaiian origin (e.g., Ettringer Bellerberg, Tönchesberg), and (c) those in which phreatomagmatic (Vulcanian) and Strombolian/Hawaiian styles alternate such as at Rothenberg volcano (Schmincke 1977a, b, 1990; Houghton and Schmincke 1986, 1989). Herchenberg volcano consisting almost entirely of lapilli deposits allows us to evaluate another factor: the characteristics of deposits from eruptions of low-viscosity/high-volatile mafic magma.

Herchenberg volcano, situated about 5 km north of the Laacher See at the northern rim of the late Quaternary East Eifel volcanic field (EEVF, Figs. 1, 2), is largely composed of hauyne-bearing melilite-nepheline tephra. In the EEVF, some 100 volcanic centers have erupted in several major phases, which can be distinguished compositionally and spatially (e.g., Schmincke 1977b, 1991; Duda and Schmincke 1978). An older suite (> 400 000 years B.P.) of leucitites, melilite-nephelines, and evolved rocks is concentrated in the western area of the EEVF (Rieden-Kempenich area). The younger subfield of the EEVF is dominated by scoria
cones of basanitic to tephritic composition. The volcanic activity in the EEVF culminated in the eruption of ca. 5 km$^3$ DRE of Laacher See pumice about 11000 years B.P. (e.g., Bogaard and Schmincke 1985).

Most previous work at Herchenberg volcano was concerned with tephrochronological aspects and is reviewed by Bednarz (1982). Here we will discuss the evolution of the volcanic complex. The origin of peculiar, ellipsoidal, dense lapilli is discussed elsewhere (Bednarz and Schmincke, in prep). Mineralogy, petrology, and magma properties are treated in Bednarz and Schmincke (in prep). Recent $^{40}$Ar/$^{39}$Ar laser dating of Herchenberg phlogopites (Bogaard, unpublished data) indicates an eruptive age of approximately 480,000 years B.P.

The basement beneath Herchenberg volcano is made up of Lower Devonian (Siegenian) sandstones and slates with a total thickness of about 4 km (Meyer and Stets 1975); fold axes trend ENE-WSW. The weathered Devonian rocks are overlain in the Herchenberg area by about 20 m of Tertiary clays and sands topped by >2 m of Pliocene gravels ("Kieseloolitherrasse"), which form an important regional marker bed (Ahrens 1929; Fig. 3). Ahrens (1930) postulated a small local Quaternary tectonic collapse basin with up to 50 m subsidence around Herchenberg based on the low elevation of these gravel beds (ca. 220–235 m asl) compared with their regional elevation of approximately 270 m asl. Quaternary deposits around Herchenberg comprise loess, soils, and several tephra layers derived from other volcanic centers of the EEVF. Clastic dikes, dominantly phonolites, originated at the Dümplemaar center 0.5 km southwest of Herchenberg (Bednarz and Schmincke, in prep) at 116,000 ± 16,000 years B.P. (Bogaard et al. 1987). Phonolitic Dümplemaar tephra (DMT) overlies the Herchenberg scoria cone with a maximum thickness of approximately 6 m.

**Petrology and geochemistry**

Herchenberg lavas are phric to glomerophyric, hauyne-bearing melilite nephelinites with 10–14 vol% clinopyroxene, 1–3 vol% olivine, 1–2 vol% hauyne, 1–4 vol% titanomagnetite, and <1 vol% plagioclase phenocrysts. Clinopyroxene, nepheline, melilite, and Fe-Ti oxides are the dominant groundmass phases. Accessory phases are microphenocrysts of carbonate and chrome spinel. Carbonate globules (ocelli) with maximum diameters around 0.2 mm occur mainly in the vitric groundmass of early lapilli. Patchy cenem-

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**Fig. 1.** Location map of the East Eifel volcanic field (EEVF) showing mafic volcanoes evolved eruptive centers and volcanic complexes.