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LOG Id: LOG_0014
LOG Titel: Palaeomagnetism of quaternary volcanics of the East-Eifel, Germany
LOG Typ: article

Übergeordnetes Werk

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J Geophys (1982) 51:29–37

Journal of Geophysics

Palaeomagnetism of Quaternary Volcanics of the East-Eifel, Germany

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Abstract. Forty-seven Quaternary volcanoes in the East Eifel were studied palaeomagnetically. Demagnetization experiments, viscous remanent magnetization tests and ore-microscopic investigations show that the palaeodirections are reliable. The palaeomagnetic data allow several sites to be correlated with volcanoes of known age. It is discussed that identical palaeodirections can be used for dating purposes only under particular conditions which are not fulfilled for the East Eifel data.

Key words: Palaeomagnetism – East Eifel – Quaternary volcanism – Palaeomagnetic dating

Introduction

The Quaternary East-Eifel volcanic field (Laacher See area, Fig. 1) comprises about 70 volcanic centers of basanitic, leucititic, nephelinitic, tephritic and phonolitic composition erupted during the past 0.7 m.y. (Schmincke, 1977; Schmincke and Mertes, 1979). Forty-seven sites were studied palaeomagnetically to asses the palaeosecular variation during the Brunhes epoch (Kohnen and Westkämper, 1978) as well as to search for relations between different volcanic sites in the East Eifel. Geological investigations dating back to last century did not always lead to unambiguous results in relating lava flows to well defined centers of eruptions. Studies of heavy minerals in river terraces (Frechen, 1976), loess stratigraphy (Windheuser and Brunnacker, 1978) or radiometric age determination (Frechen and Lippolt, 1965; Schmincke and Mertes, 1979) have established a framework for the temporal evolution of volcanism. However, many volcanoes have not been dated and there are discrepancies between different studies. The aim of this study is to relate undated volcanoes to volcanoes of known ages as well as to asses independently relative ages between volcanic centers deduced by other methods. For this, all data available from previous studies are used together with the palaeomagnetic results.

Geological Setting

The tectonic setting, composition and volcanic evolution of the tectonic Neuwied Basin and the East-Eifel volcanic field was discussed by Brauns (1928), Ahrens (1932), Frechen (1976) and Schmincke and co-workers (Schmincke, 1977, 1979; and references therein). The temporal evolution of volcanism is given in Table 1, based upon geological age-estimates (Windheuser and Brunnacker, 1978) and K/Ar-dates (Frechen and Lippolt, 1965; Schmincke and Mertes, 1979). The volcanic activity, which spans the last 0.7 m.y., is confined to a small area of about 22 km × 30 km, with the caldera of the Laacher See at its center. The volcanism commenced at about the same time as the onset of the increased uplift of the Rhenish-Massif (Schmincke and Mertes, 1979).

Laboratory Procedures

Between three and seventeen samples were drilled for palaeomagnetic analysis from each of the 47 sites studied. Intensities and directions of the remanent magnetization were measured using a fluxgate spinner magnetometer (DIGICO). Routine AF-demagnetization techniques were applied to erase secondary components of magnetization. Figure 2 shows typical demagnetization curves. Most secondary components were small and could be removed in alternating fields of 8–16 kA/m. The directional stability of the remanent magnetization was tested by application of the stability index of Symons and Stupavsky (1974). Site mean directions of the characteristic remanent magnetization (CARM) were obtained by applying alternating fields for which this index was minimum, generally coinciding with the smallest confidence angle α_{95}.

Viscous remanent magnetization (VRM) tests were carried out to prove the reliability of the palaeodirections. Selected samples were thermally demagnetized to determine unblocking temperatures and thus the magnetic carriers. Grain size, modal composition and oxidation state of oxides were studied from polished sections of representative samples.

Experimental Results

Magnetic Properties and Palaeodirections

The intensities of the natural remanent magnetization (NRM) and the CARM as well as the directions and virtual geomagnetic poles (VGP) of the CARM are listed in Table 2 together with the standard statistical parameters N, k, α_{95}, dp, dm, susceptibility and Königsberger factor Q. The coordinates of the sites are also given. In Figure 3 the site mean NRM intensity is plotted against the site mean susceptibility χ. Both quantities vary widely, but a correlation with rock type is apparent. The phonolites are quite different from the other rocks presumably because of their low iron content, resulting in lower intensity of NRM and lower susceptibility. Basanites and tephrites tend to show lower susceptibilities and higher values of the NRM and larger Q-factors than nephelinites and leucitites. The reason for this may be a greater amount of microscopically undeterminable

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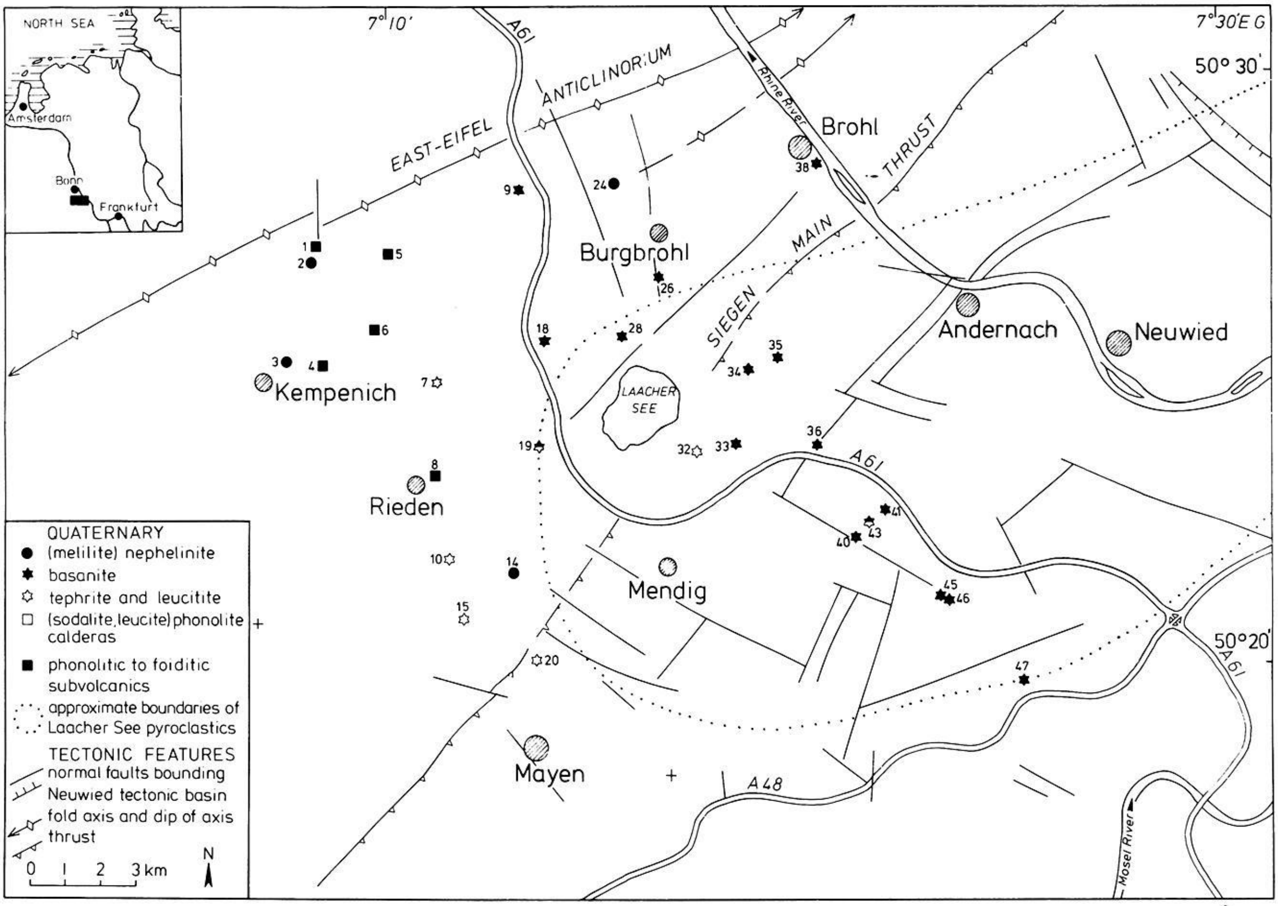


Fig. 1. Schematic map of the East Eifel with tectonic features and sampled Quaternary volcanoes (Nos. 1–47)

single domain grains in the basanites and tephrites than in the nephelinites and leucitites. Most of the basanites and tephrites came from more quickly cooled cinder cones (agglutinates) and lava flows, whereas many nephelinites and leucitites are from thicker flows or intrusions believed to have cooled more slowly. The determinable mean grain diameters differ only slightly and cannot explain the variations in Fig. 3: 2.33 μm and 2.45 μm respectively (mean values from Table 3).

Site 25 is Tertiary volcano and therefore neglected for further interpretation, as well as site 31 which probably is tectonically disturbed. The other site mean directions are plotted in Fig. 4 together with the confidence circles. All directions are normal and scatter around the direction corresponding to the field of a central axial dipole which has a mean value in the East Eifel of inclination = 67.5° and declination = 0°.

Preliminary palaeomagnetic investigations made some years ago in the East Eifel by Nairn (1962) resulted in site mean directions similar to the results of the more extensive investigations presented in this paper.

Reliability of Results

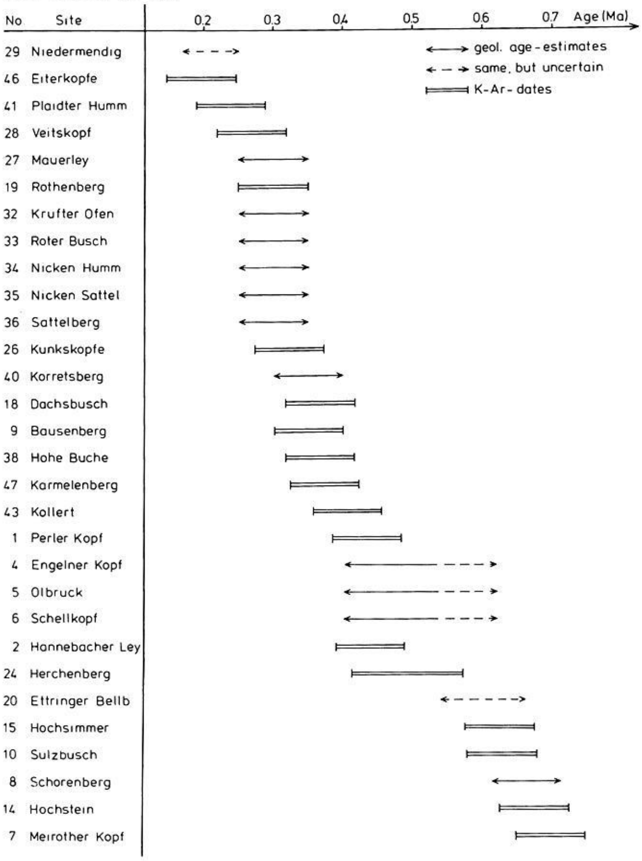
The time correlation between undated and dated lavas using statistical palaeomagnetic arguments, as outlined below, depends crucially on the accuracy and precision of the CARM-directions. We have, therefore, examined the influence of secondary components of magnetization by applying VRM tests. Samples from lavas in which strong secondary components were measured were subjected to a constant dc-field of 500 A/m, following Lowrie and Kent (1976). The VRM acquired in time t follows the relation $VRM = S \cdot \log t$ as shown in Fig. 5. The value of the magnetic viscosity coefficient S changed after a time of 2–5 h indicating that at least two relaxation mechanisms were operative. Extrapolating the steeper part of the curves to the ages of the volcanic eruptions and the intensity of the earth's field (Shimizu, 1960) gives VRM-intensities which are at least 10 times smaller than those of the NRM. Correspondingly, the time necessary to acquire a VRM as great as the NRM would be orders of magnitude greater than the ages of the volcanoes.

Stepwise thermal demagnetization of some selected samples gave unblocking temperatures in the range of 250–600° C, indicating that titanomagnetites dominate the magnetic properties of these rocks. Anisotropy of directions can therefore be neglected.

Type and oxidation of magnetic carriers (dominantly titanomagnetite) were studied in polished sections. Table 3 summarizes modal composition, mean grain diameter, and high temperature and low temperature oxidation state indicated by maghemite and hematite. The mean grain diameter was determined according to Wilson et al. (1968). Subdivision of larger grains by exsolution, cracking or skeleted nature is neglected. The ores in the phonolites consist of an undeterminable ore pigment, minor phenocrysts being entirely granulated due to an intensive low temperature oxidation. The granulation has most likely taken place during the final phase of cooling because the rocks are very young.

Hydrothermal alteration has influenced most rocks studied. Maghemite was found in 4 samples, sphene in 4 samples but hematite in only one sample.

Table 1. Ages of East Eifel lava as determined from radiometric age determination and geological age estimates. Data from Schmincke and Mertes (1979)



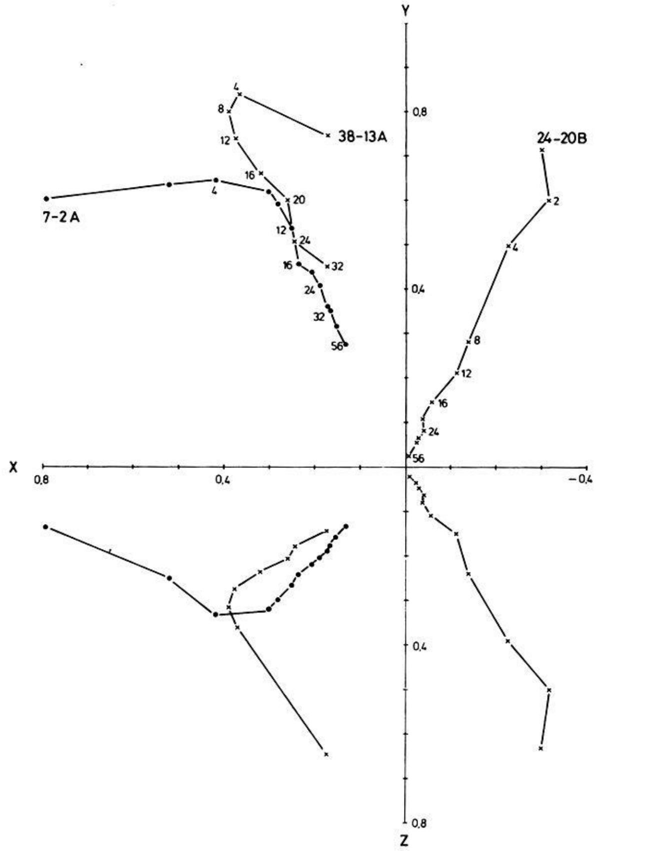


Fig. 2. Typical normalized curves of demagnetization (Zijderveld plots) of uncorrected directions. Symbols in the graph indicate site and sample numbers and peak laternating fields in kA/m

Titanomagnetite, and the corresponding mineral phases at the high temperature oxidation states, are present in all rocks, ranging from 2.2–14.4 vol.%. The mean grain diameter does not exceed 6.0 µm ranging between pigment and groundmass ores in most samples. Large phenocrysts up to 1.5 mm in diameter are present in seven rocks. The ore grains are mostly isometric with a form factor d_{max}/d_{min} of about 1 to 2. A more detailed discussion of the relation between ore microscopic parameters and rock magnetic data in several East Eifel lavas is in preparation.

The measured CARM values represent a primary and fairly stable magnetization because

a) viscous secondary components of magnetization are small,

b) magnetic carriers are mainly titanomagnetites at various high temperature oxidation states exhibiting small effective mean grain diameters, and

c) hematite is nearly absent.

Discussion of Experimental Data

As outlined above, the palaeodirections are attributed to the original TRM of the investigated lavas and are used here for geological interpretations along the following lines:

Comparison of different lavas, agglutinates (welded spatter) and dikes erupted from and within, respectively, the same volcano as based on field data. Cinder cones such as those in the East Eifel and their associated volcanic rocks are generally believed to have formed within a few days or a few months to a few years. All rocks formed during such small time intervals should show identical palaeomagnetic directions. If not, stratigraphic correlation may be faulty and more than one volcanic center may be involved or the volcano was built during several phases which should be detectable by geological or chemical criteria.

Consequently, palaeomagnetic directions can offer valuable stratigraphic information.

Correlation of Different Sites to Synchronous Volcanic Events Using Palaeomagnetic Data

Different sites belonging to the same volcanic event should have identical directions within the limits of error. A statistical measure to check the significance of directional identities is given with the *F*-test. The value of the application of the *F*-test to palaeomagnetic data has been demonstrated by McElhinny (1967). All sites in question were subjected to the *F*-test, and the following results were obtained:

Confirmed Correlations

1. A basanite lava flow outcropping at Thür (30, 31) is believed by Ahrens (1930) to have issued from Hochstein Volcano (14), about 5 km WNW. Identical palaeodirections confirm this correlation, which is further supported by similarity in chemical composition between Hochstein lava and the Thür lava outcropping at Mendig.

2. A basanite lava flow (39) on the west flank of Korretsberg and a scoria deposit near the top (40) believed to be part of the same volcano (Ahrens, 1932; Moses, 1978) have identical

Table 2. Summary of palaeomagnetic results from Quarternary lavas of the East Eifel. r, h, site coordinates; N, number of samples; M_0, intensity of natural remanent magnetization; x, initial susceptibility; Q, Königsberger factor; $H_\sim$, af-demagnetizing field amplitude; MDF, medium destructive field; Dec., Inc., mean site direction of the characteristic remanent magnetization; k, α_{95}: precision parameters; Lat., Long.: position of the virtual palaeomagnetic pole; dp/dm: parameters of the 95% oval of confidence

Site No.	Volcanic Occurence	Topogr. Map No	r	h	N	M_0 (A/m)	κ (10^{-3})	Q	$H_\sim$ (kA/m)	MDF (kA/m)	Dec. (°E)	Inc. (°)	k	α_{95} (°)	Long. (°E)	Lat. (°N)	dp/dm (°)
1	Perler Kopf	5508	80970	91250	6	0.650	0.97	17.3	12.0	≈33.2	28.8	70.3	559	2.8	73.0	72.1	4.2/ 4.9
2	Hannebacher Ley	5508	80875	90940	12	2.919	62.22	1.5	16.0	≈75.0	31.8	64.8	72	5.2	94.7	68.8	6.7/ 8.3
3	Kempeneich	5508	79890	87750	6	0.118	0.51	4.6	8.0	17.6	10.3	71.8	433	3.2	47.7	81.3	5.0/ 5.7
4	Engelner Kopf	5508	81190	88430	8	0.157	0.58	6.1	32.0	12.0	20.5	66.6	303	3.2	94.7	76.8	4.3/ 5.2
5	Olbrück	5509	83050	91380	6	0.090	0.54	4.2	16.0	18.4	72.3	81.5	162	5.3	33.9	52.6	9.9/10.2
6	Schellkopf	5508	82750	89150	10	0.242	1.18	4.7	4.0	18.0	37.0	75.6	95	5.0	51.1	66.6	8.4/ 9.2
7	Meirother Kopf	5509	84550	88280	7	5.048	12.57	9.1	28.0	28.8	0.4	63.7	331	3.3	183.7	84.9	4.2/ 5.3
8	Schorenberg	5609	84250	84825	10	0.126	2.93	1.1	6.0	15.2	5.3	60.6	149	4.0	162.7	80.4	4.6/ 6.0
9	Bausenberg	5509	87320[a]	93550[a]	14	7.999	27.58	10.5	16.0	12.8	13.6	73.7	150	3.3	42.2	78.0	5.3/ 5.8
10	Sulzbusch 1	5609	84900	82800	6	6.576	20.80	6.6	8.0	33.2	357.2	69.2	366	3.5	331.2	87.1	5.1/ 6.0
11	Sulzbusch 2	5609	85525	82475	10	2.848	12.01	12.3	8.0	26.0	340.9	68.7	160	3.8	292.4	78.0	5.5/ 6.5
12	Sulzbusch 3	5609	85950	82125	6	3.395	44.86	2.1	24.0	≈ 8.4	355.88	66.9	204	4.7	261.7	87.2	6.4/ 7.8
14	Hochstein	5609	87000	83300	10	6.700	40.28	5.5	8.0	15.2	4.5	63.3	263	3.0	156.7	83.7	3.7/ 4.7
15	Hochsimmer 1	5609	84725	80225	6	2.214	4.70	30.7	46.0	≈80.0	351.0	66.3	197	4.8	264.9	83.9	6.4/ 7.9
16	Hochsimmer 2	5609	86325	79450	6	4.460	45.20	2.7	24.0	20.0	351.3	64.8	183	5.0	248.4	83.3	6.4/ 8.0
17	Hochsimmer 3	5609	86450	79150	6	3.712	53.13	1.9	16.0	10.8	357.8	65.8	121	6.1	229.5	87.4	8.1/10.0
18	Dachsbusch	5509	87550	88825	10	2.299	1.23	44.9	24.0	>40.0	9.9	63.0	469	2.2	135.0	81.1	2.8/ 3.5
19	Rothen Berg	5509	87375[a]	85390[a]	17	8.576	30.58	7.2	16.0	≈36.8	8.6	75.8	188	2.6	23.9	76.4	4.4/ 4.8
20	Ettringen	5609	87925[a]	80750[a]	15	5.882	13.32	11.9	24.0	18.0	340.0	74.2	85	4.2	327.1	74.9	6.8/ 7.6
21	Mayen 1	5609	88325	78660	9	3.183	5.90	22.2	0	33.6	337.4	72.0	902	1.7	312.8	75.2	2.7/ 3.0
22	Mayen 3	5609	88425	78475	7	4.213	18.29	6.2	16.0	25.2	343.8	74.1	1294	1.7	331.2	76.5	2.7/ 3.0
23	Mayen 2	5609	88450	78160	12	3.408	9.30	9.2	24.0	26.0	337.0	74.3	1118	1.3	324.8	73.5	2.1/ 2.4
24	Herchenberg	5509	89600	93320	15	6.509	45.93	4.5	16.0	15.2	17.7	62.9	437	1.8	117.6	76.6	2.3/ 2.9
25	Steinbergskopf	5509	91500	94280	6	3.393	31.10	3.0	24.0	45.2	243.9	−64.8	448	3.2	256.8	−48.9	4.1/ 5.1
26	Kunkskopf	5509	90930	90960	12	5.959	12.97	12.6	0	28.4	3.1	68.6	667	1.7	58.5	87.6	2.4/ 2.8
27	Mauerley	5509	90150	90600	8	7.549	13.53	17.7	12.0	≈24.0	347.8	63.4	244	3.6	248.2	80.1	4.4/ 5.6
28	Veitskopf	5509	89600	88050	9	3.388	8.73	11.4	8.0	44.8	344.4	54.7	934	1.7	230.1	71.1	1.7/ 2.4
29	Niedermendig	5609	91830	83300	11	5.228	7.41	20.6	24.0	30.8	6.6	63.3	460	2.1	146.1	82.9	2.7/ 3.4
30	Thür	5609	91000[a]	81350[a]	10	3.654	22.38	4.3	8.0	29.6	357.8	66.0	260	3.0	222.6	87.5	4.0/ 4.9
31	Obermendig	5609	90625	82160	3	2.992	13.66	3.9	8.0		26.5	10.3	36	20.9	152.0	39.6	10.7/21.1
32	Krufter Ofen	5509	92000	85650	10	1.798	0.59	83.9	24.0	>64.0	350.3	49.9	339	2.6	211.1	69.0	2.3/ 3.5
33	Roter Busch	5509	92800	85915	9	8.004	5.73	50.9	28.0	>32.0	12.5	80.5	505	2.3	16.1	67.3	4.2/ 4.4
34	Nickenicher Hummerich	5509	93000	88150	6	10.887	15.85	29.4	12.0	>36.0	2.6	72.3	800	2.4	18.4	82.8	3.7/ 4.2
35	Nichenicher Sattel	5509	94650	88300	8	3.707	2.17	33.4	12.0	>32.0	21.2	69.8	891	1.9	75.2	76.6	2.7/ 3.2
36	Sattelberg	5510	95450	86030	11	5.877	6.52	28.2	20.0	>40.0	10.4	66.9	355	2.4	100.5	83.3	3.3/ 4.0
37	Kruft	5609	94500	85830	12	11.634	36.98	8.7	32.0	23.6	356.3	80.9	332	2.4	4.3	68.1	4.4/ 4.6
38	Hohe Buche	5510	94940	93300	12	4.931	11.08	15.4	16.0	32.0	344.1	64.8	245	2.8	263.4	78.9	3.6/ 4.5
39	Korretsberg 1	5610	95825	83575	6	2.861	11.20	6.8	8.0	32.4	349.2	70.6	516	3.0	315.5	82.1	4.4/ 5.1
40	Korretsberg 2	5610	96475	83700	10	4.016	9.57	12.8	12.0	15.2	344.8	72.0	388	2.5	319.2	78.9	3.8/ 4.5
41	Plaidter Hummerich 1	5610	97800[a]	84320[a]	16	4.379	38.80	3.0	12.0	10.8	345.5	48.0	105	3.6	219.9	66.0	3.1/ 4.7
42	Plaidter Hummerich 2	5610	98000	83725	5	3.485	30.11	3.4	12.0	30.0	354.2	48.6	369	4.0	201.5	68.7	3.5/ 5.3
43	Nachtheimvulkan (Kollert)	5610	97300	83700	11	9.615	18.49	20.2	12.0	30.4	27.7	59.4	458	2.1	114.5	68.2	2.4/ 3.2
44	Plaidt	5610	98950	83880	9	7.030	35.87	5.1	0	26.0	338.5	71.4	694	2.0	309.3	76.0	3.0/ 3.4
45	Eiterkopf 2	5610	99000	82050	6	4.647	3.15	36.0	12.0	>48.0	337.3	71.1	1129	2.0	306.9	75.5	3.0/ 3.5
46	Eiterkopf 1	5610	99170	82375	9	9.587	4.22	59.6	0	41.6	0.7	65.1	336	2.8	179.5	86.7	3.7/ 4.5
47	Karmelenberg	5610	02950	80540	9	8.478	30.61	6.9	12.0	≈25.7	350.9	74.1	313	2.9	343.6	78.7	4.7/ 5.2

10+11+12	Sulzbusch (10)	22	4.014	23.25	8.0	349.5	68.5	169	2.4	293.2	83.3	3.4/ 4.0
14+30	Hochstein (14)	20	4.908	31.67	4.8	1.3	64.7	235	2.1	173.5	86.2	2.8/ 4.3
15+16+17	Hochsimmer (15)	18	3.605	32.49	13.3	353.4	65.6	171	2.7	250.2	85.0	3.5/ 4.3
20+21+22+23	Ettringer Bellerberg (20)	43	4.355	11.71	12.7	339.4	73.6	210	1.5	323.2	75.1	2.4/ 2.7
33+37	Roter Busch (33)	21	9.499	24.19	33.5	2.7	81.0	377	1.6	9.4	67.9	3.1/ 3.2
39+40	Korretsberg (40)	16	3.631	10.31	10.0	346.5	71.5	427	1.8	318.1	80.1	2.7/ 3.1
41+42	Plaidter Hummerich (41)	21	4.146	36.53	3.1	347.6	48.2	116	3.0	215.9	66.8	2.5/ 3.9
44+45	Eiterkopf 1 (45)	15	6.189	25.65	16.7	338.0	71.3	871	1.3	308.3	75.8	2.0/ 2.3

[a] Sampling extended over several tens of meters

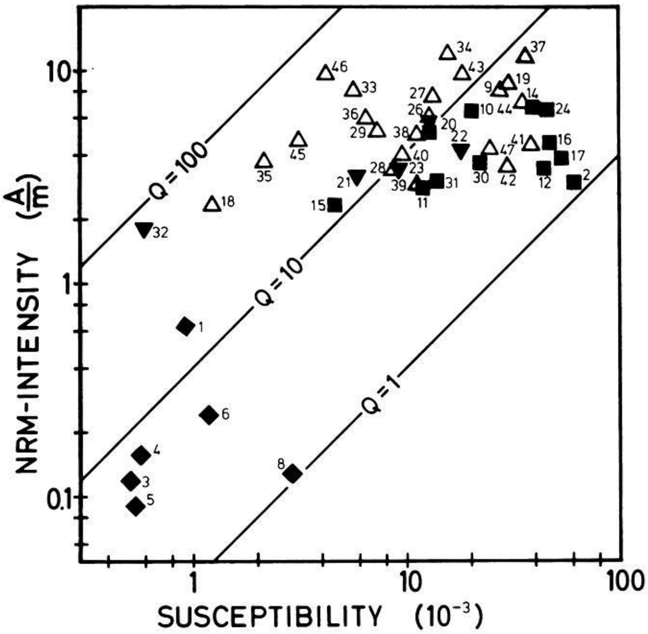


Fig. 3. NRM-intensity and initial susceptibility of investigated volcanics. Lines of constant Q-factor are plotted parametrically. Petrographic composition is indicated by symbols: ◆ Phonolites, ■ Nephelinites/ Leucitites, ▼ Tephrites, △ Basanites

palaeodirections confirming that they were erupted simultaneously.

3. A basanite lava flow (42) that outcrops ca. 500 m SE of Plaidter Hummerich and ca. 200 m N Haagsmühle was believed to have issued from Plaidter Hummerich (41) scoria cone by Ahrens (1932) and Moses (1978), a correlation confirmed by identical palaeodirections.

4. A long leucitite lava flow issued from the large Hochsimmer Volcano (Ahrens 1930) was studied at three sites (15–17), and identical CARM directions were obtained.

5. The nearby Ettringer Bellerberg Volcano is thought to be the source for the widespread lava flow at Mayen (Ahrens, 1930); palaeomagnetic measurements at four different sites (20–23) gave identical directions.

6. A basanite lava flow that outcrops along the eastern cliff of the Nette River was thought by Ahrens (1932) to have issued from the Eiterköpfe group of volcanoes. Judging from palaeomagnetic directions, the Eiterköpfe comprise a group of volcanoes active at different times but one (Eiterköpfe 2, No. 45) has CARM directions identical to those obtained from the lava flow which was sampled ca. 2 km NNE in Piladt (44).

7. A basanite lava flow exposed along the freeway between Kruft and Nickenich (37) has directions identical only to those of the lavas from the Roter Busch Volcano (33) about 1 km WNW; accordingly we may assume that the lava flow comes from this volcano.

8. Measurements on different volcanic rocks (lavas, dikes, agglutinates) within the same volcano gave, in all cases, identical directions. These results show that differences in K/Ar ages between dikes and lavas, as found for instance in Rothenberg and Karmelenberg volcanoes, are due to factors such as excess argon and are not real.

Discrepancy Between Geological and Palaeomagnetic Data

1. Phonolite lava outcrops at Engelner Kopf and near the town of Kempenich. Ahrens (1930) believed that both lavas

Table 3. Results of the ore microscopic investigations. $\bar{x}$: mean grain size diameter

EEL No.	Number	Rock type	Ore contents (vol.%)	$\bar{x}$ (μm)	Oxidation M(1–6)	Number J(1–3)	Maghe-mite	Granu-lation	Sphene	Hema-tite	Pheno-crysts
24	HB2B	Nephelinite	8.7	3.6	3.9	–	×	–	–	–	×
2	HL12B	Nephelinite	4.8	2.8	5.6	–	–	–	×	–	×
2	HL9	Nephelinite	4.9	2.6	1.06	–	×	–	–	–	–
10	SB39A	Leucitite	2.2	1.5	1.2	–	×	×	–	–	–
12	SB2A	Leucitite	3.0	1.7	1.0	–	×	–	–	–	–
32	KO2B	Tephrite	14.0	2.0	6.0	–	–	–	×	–	×
22	MYII4B	Leucitite	14.4	2.2	2.5	–	–	–	–	–	×
20	ETXII7	Leucitite	4.6	2.6	2.9	–	–	–	–	–	–
29	NMI2	Tephrite	2.9	2.4	2.8	–	–	×	–	–	×
17	SiII2A	Leucitite	4.1	2.7	1.3	–	×	–	–	–	–
28	VT4A	Basanite	3.6	2.0	3.0	–	–	×	–	–	–
30	TH2C	Nephelinite	4.8	2.1	3.0	–	×	–	–	–	–
42	PH205B	Basanite	4.5	1.7	2.6	–	×	×	–	–	–
41	PH31B	Basanite	5.8	2.1	1.1[a]	–	×	–	–	–	–
26	KK16	Basanite	4.1	1.8	2.5	–	–	×	–	–	–
26	KK4A	Basanite	2.9	2.1	6.0	–	×	–	–	–	–
9	BB1	Basanite	2.5	1.9	1.0	–	×	–	–	–	–
7	MK2A	Leucitite	2.9	2.1	4.1	–	–	–	–	–	–
36	SA7B	Basanite	4.8	1.7	1.2	–	×	–	–	–	–
35	NS4B	Basanite	3.8	1.7	6.0	–	–	–	×	–	–
33	RB7A	Basanite	9.0	3.7	4.5	–	–	–	–	–	×
27	ML3	Basanite	3.2	3.1	4.5	–	×	–	–	–	–
19	RO139	Basanite	2.1	3.0	1.4	–	–	–	–	–	–
19	RO3A	Basanite	3.5	2.3	1.1	–	–	–	–	–	–
14	HSI/5	Nephelinite	8.3	3.1	1.8	1.0	×	–	–	×	–
1	PK1A	Phonolite	n.d.	n.d.	titanohematite and granulation (ore pigment)						×
45	Ei20A	Basanite	5.9	2.5	5.5	–	–	×	×	–	–
44	PL10B	Basanite	5.6	2.4	4.8	–	–	–	–	–	–
37	KR12	Basanite	12.3	3.6	2.8	–	–	–	–	–	
39	KB8B	Basanite	4.7	3.6	5.0	–	–	–	–	–	–
39	KB2A	Basanite	7.2	2.2	3.7	–	–	–	–	–	–
5	OL5A	Phonolite	n.d.	ore pigment, seldom phenocrysts, but then completely granulated							
3	KP3B	Phonolite	n.d.	ore pigment, phenocrysts granulated (∅ 7.5 μm)							
8	SC5B	Phonolite	n.d.	ore pigment, phenocrysts granulated (∅ 0.38 μm)							
4	EK1A	Phonolite	n.d.	ore pigment not determinable, in some cases hematite							
6	SL5A	Phonolite	n.d.	ore pigment granulated, pyrite							
34	HU3A	Basanite	3.5	2.3	3.4	–	–	–	–	–	–
34	HU7B	Basanite	2.8	1.7	2.2	–	–	×	–	–	–
38	FK9	Basanite	4.4	2.1	5.0	–	–	–	–	–	–
25	SK6	Alkalibasalt	5.0	1.9	1.0	–	×	–	–	–	–

[a] Ilmenite surrounding titanomagnetite grains; n.d.: not determinable

belong to the same volcano, the former being a plug, the latter lava erupted from a fissure. Palaeomagnetic directions from Engelner Kopf (4) and a road cut at Kempenich (3) are significantly different suggesting that both occurences were emplaced with at least a several thousand years hiatus.

2. The basanitic Veitskopf volcano in the NW corner of the Laacher See basin is believed to be the source for two lava flows: one to the southeast, exposed near the lake shore (28), and the more extensive flow (Mauerley, 27) to the north. Palaeomagnetic directions of these occurences are quite different, indicating longer lasting activity of the Veitskopf volcano because no other source is known for these flows.

Correlation of Independent Volcanoes Using Palaeomagnetic Data

For all sites being correlated the resulting mean virtual geomagnetic pole (VGP) was calculated for more detailed analysis. The combined data are listed in the lower part of Table 2. Figure 6 shows the remaining independent VGPs with their confidence ovals. Obviously many volcanoes may be of same age, as the confidence ovals of their VGPs overlap. However, the agreement of the VGPs may not be due to a similar age of the volcanics, but may be attributed to an accidental coincidence as a consequence of the secular variation. The probability for the latter is appreciable because the volcanic activity spans a time of roughly 0.7 m.y. This time difference corresponds to 70 cycles of the secular variation if a period of the dipole wobble of 10^4 years (McElhinny and Merrill, 1975) is assumed as the main part of the secular variation. The distribution of the VGPs obtained is Fisherian (Kohnen and Westkämper, 1978). Therefore, the probability of accidental coincidence is particularly high at the North Pole and diminishes with decreasing latitude. Below we discuss whether this statistical behaviour may be used to calculate a probability for accidental coincidence (or coevalness, respectively) from the palaeomagnetic data. This would give further criteria for stratigraphic correlations.

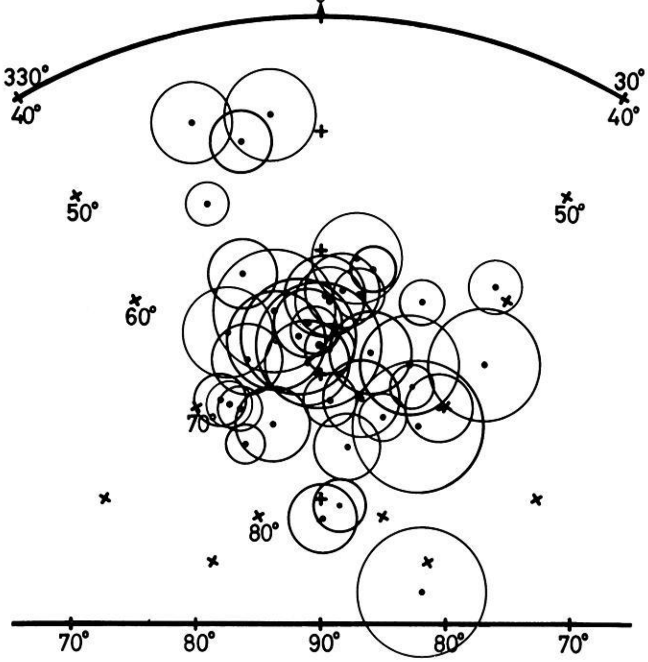


Fig. 4. Site mean directions and α_{95} confidence circles of all investigated lavas of the East Eifel

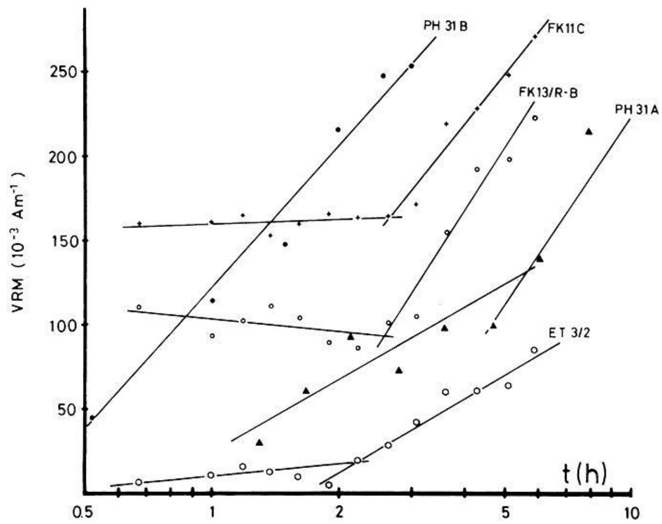


Fig. 5. Viscous remanent magnetization (VRM) acquired in magnetic fields of 415 A/m (PH 31A and PH 31B) and 500 A/m (others)

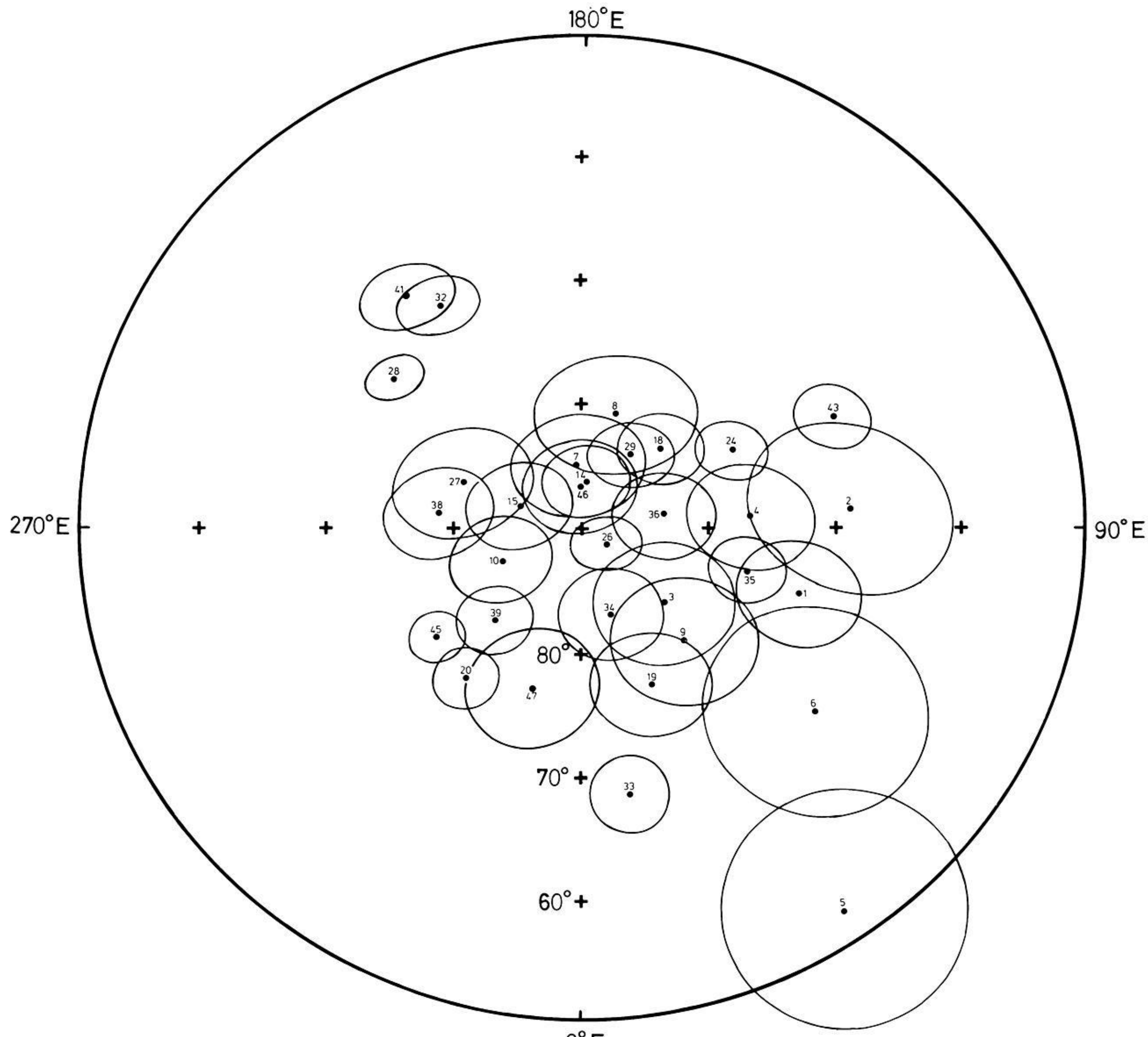


Fig. 6. Virtual geomagnetic poles (VGP) and confidence ovals of the independent volcanoes. The numbers refer to the sites listed in Table 2

Table 4. Coinciding VGPs of similar age. *N*: number of VGPs belonging to the group considered, *z*: number of secular variation cycles possibly encompassed

Group	No.	Site	N	Age (m.y.)	z
Ia	7	Meirother Kopf	3	0.57...0.75	18
	14	Hochstein			
	15	Hochsimmer			
Ib	7	Meirother Kopf	3	0.62...0.75	13
	8	Schorenberg			
	14	Hochstein			
IIa	1	Perler Kopf	3	0.38...0.6	22
	2	Hannebacher Ley			
	4	Engelner Kopf			
IIb	1	Perler Kopf	4	0.25...0.6	35
	2	Hannebacher Ley			
	4	Engelner Kopf			
	35	Nickenicher Sattel			
IIc	2	Hannebacher Ley	3	0.39...0.6	21
	4	Engelner Kopf			
	24	Herchenberg			
III	26	Kunkskopf	3	0.15...0.37	22
	36	Sattelberg			
	46	Eiterkopf 1			
IV	9	Bausenberg	3	0.25...0.4	15
	19	Rothenberg			
	34	Nickenicher Humm.			
V	32	Krufter Ofen	2	0.19...0.35	16
	41	Plaidter Humm.			

Statistical Considerations

Two or more volcanoes may be of the same age if the confidence ovals of their VGPs mutually overlap. The probability P that two poles fall into an area, defined by their coordinates and confidence ovals, can be calculated using the formula of Fisher (1953). Consider a group of n VGPs in such an area, the probability is P^{n-1}. A small value of P^{n-1} means that the probability is low for the VGPs to fall into the given area. Conversly, $1-P^{n-1}$ being large means that the probability for a nonaccidental conformity of the VGPs is high. The considered volcanoes, therefore, may be coeval on a statistical basis.

If the timespan of the volcanic activity covers several cycles of secular variation, this has to be taken into account for the calculation of the probability: a VGPs may fall into the area during one secular variation cycle, b VGPs during another one, etc. If $a+b+\ +\ +x=n$ is the total number of poles considered, $P_a=P^{a-1}$, ..., $P_x=P^{x-1}$ are the probabilities of subgroups of poles falling into the area during different secular variation cycles. The probability for all subgroups doing this is:
$P_t=P_a \cdots P_x=P^{a-1} \cdots P^{x-1}=P^{n-z}$, where
z is the number of subgroups possible, which clearly equals the number of secular variation cycles within the timespan given by radiometric and geological datings. Further, z is limited by the number n of VGPs.

P_t only has values <1 if the number of poles considered is greater than the number of secular variation cycles. Groups of VGPs with mutually overlapping confidence ovals are taken from Figure 6 and listed in Table 4. The last column gives the number z of secular variation cycles, which are possibly encompassed, as deduced from the age determinations (Table 1). According to McElhinny and Merrill (1975) a 10^4 years period is assumed for one secular variation cycle, long enough to yield a Fisherian distribution of VGPs. In all cases the number z of secular variation cycles is larger than the number n of poles within a group. Consequently, there are no statistical arguments to conclude on the basis of palaeomagnetic data that the VGP groups can be attributed to coeval volcanic events. The overlaps are caused with high probability by the secular variations of the magnetic field.

These examples show that even perfectly coinciding, reliable poles from different volcanoes belonging to the same polarity epoch cannot be used for reliable dating purposes.

Conclusion

Stratigraphic and radiometric methods applied to the Quaternary East Eifel volcanics do not lead to unambiguous assesment of their ages in all cases. The application of palaeomagnetic methods resulted in the successful correlation of several volcanic sites to volcanoes of known age but in most cases palaeomagnetic data alone were not sufficient for secure dating. It has been shown that these volcanic rocks can be satisfactorily dated only by combining all three methods.

Acknowledgements. The work was supported by the Deutsche Forschungsgemeinschaft (Un 29/14) and the Bundesministerium für Forschung und Technologie (ET 4236). We thank Dr. Krumsiek for the possibility to use the thermal demagnetization apparatus. Our thanks are also due to Dr. Bleil for valuable criticism on the manuscript.

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Received September 8, 1980; Revised November 5, 1981 and February 25, 1982

Accepted February 25, 1982