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THE ELTVILLE TEPHRA, A LATE PLEISTOCENE WIDESPREAD TEPHRA LAYER IN GERMANY, BELGIUM AND THE NETHERLANDS; SYMPTOMATIC COMPOSITIONS OF THE MINERALS

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(6 figures, 4 tables)

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ABSTRACT. A new study of the composition of the Eltville Tephra is performed for the three sites Lixhe/Belgium, Ringen/Germany and Eltville/Germany (previous stratotype). This tephra is a precise stratigraphical marker dated at about 20 ka and intercalated *in situ* in Upper Weichselien loess in Belgium, The Netherlands and Germany. Since most of the authors have identified the Eltville Tephra after its dark grey colour in yellowish loess body, the correlation has in some cases been doubted so that geochemistry of the material should be used to take position. We analyse the pyroclasts and the mafic minerals of the tephra (clinopyroxene, olivine and amphibole). The volcanic glass is totally altered to illite, but the minerals show a clear basaltic alkaline magmatic signature. The tephra resulted from a strong initial explosive activity of a basaltic volcano. The origin of the tephra would be the East Eifel volcanic field.

Keywords: Europe, Belgium, Germany, East Eifel, Quaternary, Upper Weichselien, Eltville Tephra, widespread tephra layer, tephrochronology.

1. Introduction

In Belgium, four tephra occurrences are registered in the Upper Pleistocene, from the youngest to the oldest: (1) the Laacher See Tephra (Juvigné, 1977a; Bogaard & Schmincke, 1985) dated at 12.9 ka (Bogaard, 1995), (2) the Eltville Tephra (Rohdenburg & Semmel, 1971; Juvigné & Semmel, 1981; Meijs *et al*., 1983; Juvigné, 1990) previously dated between 16 and 30 ka (Juvigné & Wintle, 1988), (3) the Rocourt Tephra (Gullentops, 1954; Juvigné, 1977b) dated between 74 and 90 ka (Pouclet *et al*., 2008), and (4) the Remouchamps Tephra found in two Belgian caves and dated between 61.5 ka and 112 ka (Gewelt & Juvigné, 1986) (Fig. 1).

The Laacher See Tephra originated from the Laacher See volcano (East Eifel). Conversely, the three other tephras found in Belgium are not linked with any specific volcano. It is accepted that the Eltville Tephra originated from the Eifel, but it is not clear whether the relevant volcano is located in the East Eifel (Meijs *et al*., 1983) or the West Eifel (Weidenfeller *et al.,* 1994). The Rocourt Tephra displays a distinct mineralogical association comprising enstatite, augite-diopside, and amphibole. The geographical grain size distribution and the chemical composition of the minerals indicate an origin from the Eifel (Pouclet & Juvigné, 1993). The Remouchamps Tephra is characterized by rhyolitic glass shards, hypersthene and ferri-tschermakite indicating an evolved calc-alkaline or tholeiitic magmatic signature, and a

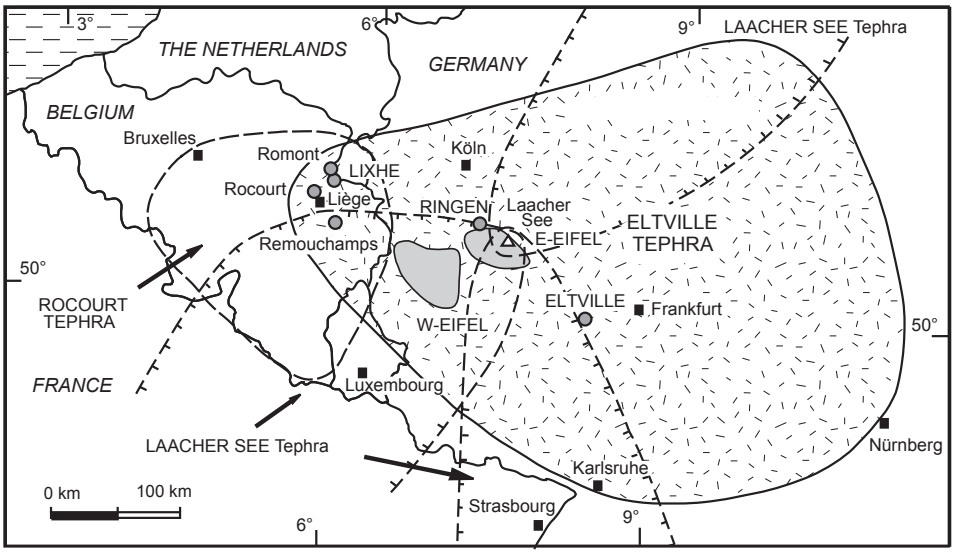


Figure 1. Lobes of the Eltville, Rocourt and Laacher See Tephra* and main localities cited in this paper. Grey zones are the West and the East Eifel Volcanic Fields.
(*) The lobe of the Upper Laacher See Tephra corresponds to the final products of the eruption which were transported westwards especially over southern Belgium. The other lobes correspond to the Lower and Middle LST which correspond respectively to the early and middle products. The whole products were erupted within 10 days (Bogaard & Schmincke, 1985).

possible origin from Iceland, owing to resemblance with Late Quaternary Iceland related ash deposits of northern Europe (Davies *et al*., 2005).

The aim of this study is to take part in the discussion on the reliability of the tephrostratigraphical correlations based on the Eltville Tephra throughout the lobe as drawn in Figure 1.

2. Chronostratigraphical data

The Eltville Tephra has been widely used as a tephrostratigraphical maker especially in loess sections in western Germany (e.g. Semmel, 1967; Bibus, 1973; Weidenfeller *et al*., 1994; Hatté *et al*., 1999; Frechen *et al*., 2003), in Belgium (e.g. Rohdenburg & Semmel, 1973; Juvigné & Semmel, 1981; Juvigné & Wintle, 1988) and in the Netherlands (e.g. Juvigné & Semmel, 1981; Meijs *et al*., 1983). Most of the authors have based the identification of the tephra layer on bare eye observations, referring to a mm-, to cm-thick dark grey layer in a yellowish loess body. Some of them provided various simplistic petrographical observations that cannot be used for correlations (see Juvigné, 1990: Tab.1).

Furthermore it has been demonstrated that distinct dark grey tephra layers are present in single Weichselian terrain outcrops in Middle Germany, so that previous tephrostratigraphical correlations proposed in literature are doubted by Weidenfeller et *al*. (1994). Obviously, refined mineralogical and geochemical data from microprobes are needed to make the difference between the involved various 'dark grey tephra layers'.

2.1. Age of the tephra

Occurrences of mm- to cm-thick layers of the Eltville Tephra were discovered in western Germany (Hess, 1909; Brühns in Schönhals, 1951; Frechen, 1959; Semmel, 1967). The name Eltville Tephra was given by Semmel (1967). Later on the same tephra was found in other sites of Germany (Bibus, 1973; Brunnacker *et al*., 1978), in Dutch Limburg (Meijs *et al*., 1983), and in Belgium at Rocourt (Rohdenburg & Semmel, 1971), Lixhe (Juvigné & Semmel, 1981), and Romont (Juvigné, 1992). Meijs *et al*. (1983) showed that the Eltville Tephra may consist of five successive beds in the East Eifel. The first bed has the larger extent, from the centre of the lobe to the west, and corresponds to the layer present in Belgium. The second and the fourth beds are limited to the Eifel region. The third bed more widely overlaps the central area. The fifth bed constitutes the eastern part of the lobe.

As the Eltville tephra was discovered in loess sections in Belgium, it appears that the German and Belgian loess stratigraphies were incompatible over the boundary, since the tephra is present below the supposed Mid-Weichselian paleosol in Belgium (Gullentops, 1954) and above the equivalent paleosol (Lohner Boden) in Germany (Semmel, 1967). First, Haesaerts *et al*. (1981) pointed out that the original loess stratigraphy of Gullentops (1954) had been misinterpreted and they showed that the tephra was obviously below a paleosol (Nagelbeek Tongued Horizon : N.T.H.) that was younger than the Mid-Weichselian one, the latter being not present in the sections where the Elville Tephra was found in Germany.

Hence, the identity of both the tephra and the Mid-Weichselian paleosol were doubted, so that, a series of ^{14}C- and TL-datings from Belgian sites have shown that the Belgian loess stratigraphy had to be revised (Juvigné & Wintle, 1988) in spite of inconsistent TL- and ^{14}C ages: self consistent TL-ages were obtained for the tephra (16 ka) and the loess of the overlying N.T.H. (15 ka), but they were inconsistent with the ^{14}C age of about 22 ka BP for the humic material from the N.T.H.. Hence, it was prudent to bracket the age of the Eltville Tephra between 16 ka and 30 ka (Juvigné & Wintle, 1988).

A more precise age is obtained from additional data. Van den Haute *et al*. (1999) yielded TL-ages of 20-22 ka for the loess deposition of the N.T.H. at Kesselt, which imply that loess deposition was followed by soil formation and humic material within a short time span, around 22 ka. This data places the setting of the Eltville Tephra between 22 ka and the Mid-Weichselian soil formation (about 30 ka). Antoine *et al*. (2001) obtained an Optically Stimulated Luminescence (OSL)-age of 19 to 19.5 ka for the Eltville Tephra at Nussloch (Middle Rhine valley). Zöller *et al*. (2004) provided TL-ages of about 21 and 25 ka for the loess bodies below and above the Eltville Tephra, in southern Hesse. Bibus *et al*. (2007) provided Infra Red Stimulated Luminescence (IRSL)-ages of 18.7 ka and 23.2 ka for the loess bodies below and above the Eltville Tephra, in the loess stratotype of Nussloch (Frechen & Preusser, 1995; Preusser & Frechen, 1999).

It is concluded that, if the Eltville Tephra in Belgium and in the Middle Rhine valley correspond to a synchronous tephra fall, its current age should be very close to 20 ka, and the preliminary results of Juvigné and Wintle (1988) should be some 5 ka too young.

2.2. Environmental conditions at the time of the tephra deposition

After the age of the tephra, the relevant eruption has occurred in the time range of the last glacial maximum, i.e. in a very severe periglacial climate in middle Europe. Where the layer is well preserved in loess areas of Belgium, Netherlands and Germany (Fig. 2), it implies that no vegetation was present at the moment of the fall-out. This is also in agreement with the high rate of aeolian sedimentation in a cold and dry environment during the relevant time range (e.g.: Juvigné & Wintle, 1988; Hatté *et al*., 1999; Frechen & Preusser, 1995; Frechen, 1999; Preusser & Frechen, 1999; Van den Haute *et al*., 1999; Hilgers *et al*., 2001; Antoine *et al*., 2001; Lang *et al*., 2003; Frechen *et al*., 2003; Bibus *et al*., 2007).

2.3. Origin of the tephra

Based on increasing thickness of the tephra layer in the East Eifel volcanic field, Bibus & Semmel (1977) pointed

out the Korretsberg volcano as a possible origin for the Eltville Tephra. But, this volcano was dated around 200 ka (Bogaard & Schmincke, 1990) and thus highly predates the Eltville Tephra deposition. Nevertheless, increasing grain size of the mineral grains from Belgium towards the East Eifel volcanic field (Meijs *et al*., 1983) indicates that this volcanic field can be the original source. The report of a basaltic tephra having the same age range as the Eltville Tephra, in lake sediments of the Meerfelder Maar in the West Eifel, is used by Weidenfeller *et al*. (1994) to expect the centre of the eruption in West Eifel. But, this argument is weak, compared to that of the tephra thickness and grain size which point to the East Eifel. Unfortunately, no eruption is known in the East Eifel volcanic field at about 20 ka, so that no precise volcano can be pointed out as the source of the Eltville Tephra. Regarding a possible origin in the West Eifel, so far the undoubtedly Eltville Tephra has not been found in any site, nor in the cores of Hinkelsmaar (Juvigné *et al*., 1988) and Meerfelder Maar (Irion & Negendank, 1984) (western margin of the field) in spite of the fact that the host sediments of the appropriate time range are present in those sites.

3. Investigated sites

Three sites were selected (Fig. 1): 1) Lixhe (Belgium) representing the loess sections of eastern middle Belgium; 2) Ringen (Lower Rhine Bay) that is on the way from the East Eifel volcanic field towards Belgium ; 3) Eltville (Middle Rhine valley) that is the type locality (Semmel, 1967) where the samples were collected in 1980 under leading of Arno Semmel himself (the site is not anymore open). In each site, a single layer is present.

At Lixhe, the Eltville Tephra outcrops a few decimetres below a palaeosol characterized by subvertical tongues of humic material which has penetrated the underlying loess body as a frost crack net followed by a frost creep movement (Fig. 2A). The tephra occurs as a single dark grey layer up to 5 mm thick (Fig. 2B). The coarsest clinopyroxenes do not exceed 150 μm.

At Ringen, the Eltville Tephra outcrops in a loess body, a few decimetres below the present soil (Fig. 2C). The tephra occurs as a single dark grey layer up to 1.5 cm thick (Fig.2D). The coarsest volcanic grains do not exceed 500 μm. Furthermore in the foreground of the wall (Fig.

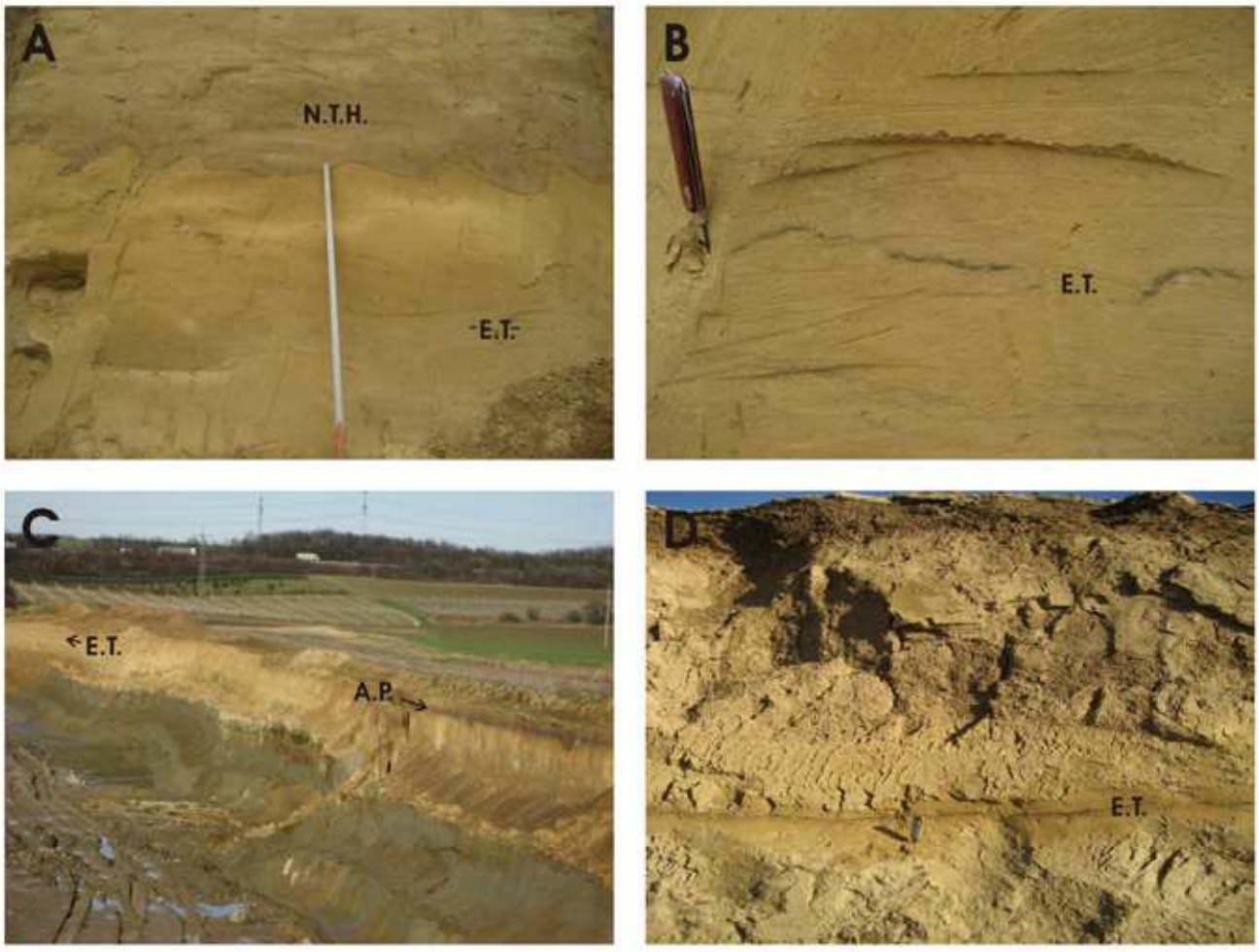


Figure 2. Eltville Tephra layer at Lixhe (Belgium) and Ringen (Lower Rhine Bay).
- In Lixhe: A, cryoturbated humic paleosol (Nagelbeek Tongued Horizon = N.T.H.) overlying a loess body containing the Eltville Tephra (E.T.) that is not visible because too thin; B, close-up view of the dark grey Eltville Tephra.
- In Ringen: C, wall of the quarry, the Eltville Tephra (E.T.) is present in the loess body at the background, and the humic horizon present in the foreground is the Allerød paleosol (A.P.); D, close-up view of the dark grey Eltville Tephra (E.T.).

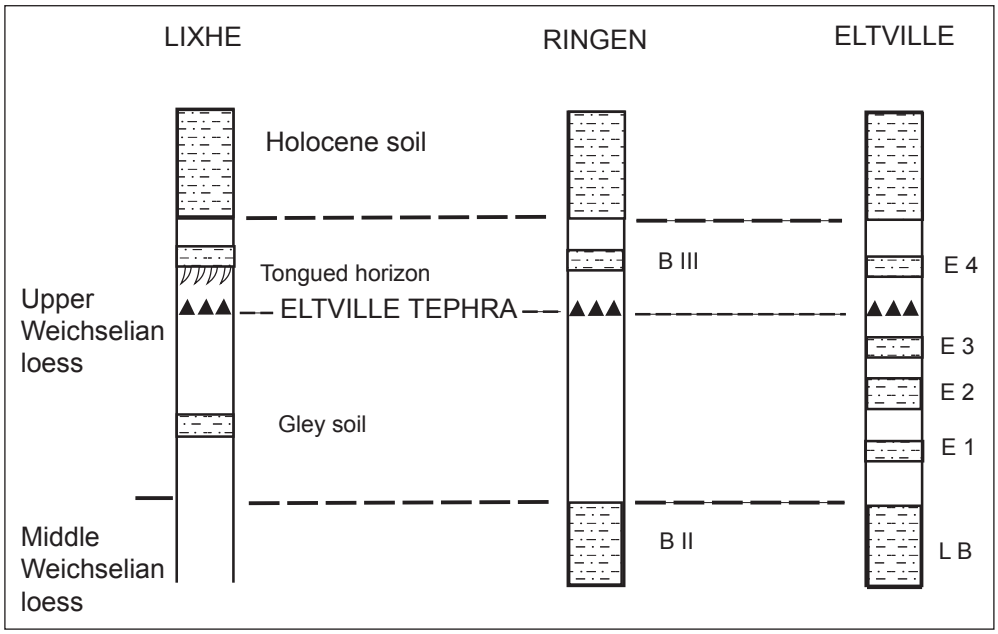


Figure 3. Stratigraphical correlation of the investigated loess sections. Decorated zones are palaeosols.
- Lixhe, after Juvigné and Renard (1991);
- Ringen, after Löhr & Brunnacker (1974): BII, Innerwürmboden II; BIII, Innerwürmboden III (Weichselian palaeosols).
- Eltville, after Semmel (1967). E1, E2, E3, E4: Erbenheimer Nassböden (Tundra gley paleosols); LB: Lohner Boden (brown subarctic palaeosol).

2C), a truncated humic paleosol outcrops in the upper part of the section. It contains material of the Upper Laacher See Tephra with high amount of titanite as found in the western lobe of that volcano (Juvigné, 1977a; Bogaard & Schmincke, 1985); hence that humic paleosol developed during the Bølling-Allerød interstadial. Its facies is quite similar to the soil that was blanketed by the Laacher See tephra in various quarries around the Laacher See crater (i.e. nearby the Wingertsberg quarry; Bogaard & Schmincke, 1985).
The position of the Eltville Tephra in the investigated loess sections is represented in Fig. 3.

3.1. Methods

Samples were boiled in water and sieved at 105 μm to eliminate the loess fraction (<100 μm) that contaminates the tephra material. For each sample, the fraction coarser than 105 μm was centrifuged in bromoform. Heavy minerals were gathered from each sample and smear slides were mounted for microprobe analysis. The volcanic glass fragments are so fragile that only the site of Ringen, that contains coarser material, has provided grains appropriate for microprobe analysis.
Electron probe microanalyses of the volcanic material from three sites were performed at the analytical laboratories of the University of Louvain-la-Neuve (Belgium) and of the University-CNRS-BRGM joint lab of Orléans (France), with SX50 and Microbeam Cameca analyzers. Technical conditions are: 15 kV, 6 to 10 nA, and 3 μm beam.

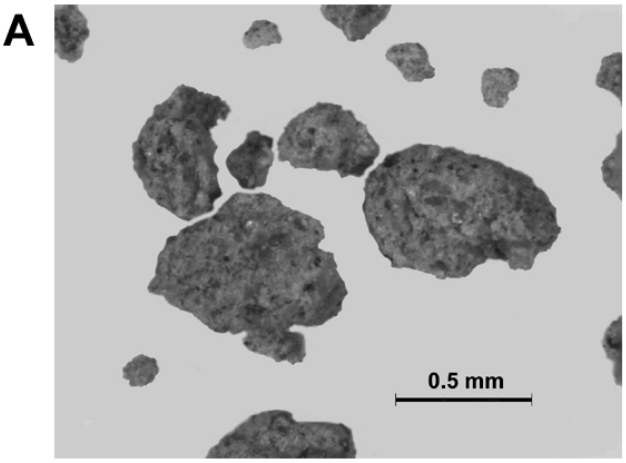
3.2. Tephra composition

The tephra layer is made up of pyroclasts and volcanic minerals. As feldspar grains are frequent in the loess, it was not possible to determine the abundance and the composition of the volcanic feldspars. We take into account only the volcanic heavy minerals. The heavy mineral composition is given by Meijs *et al*. (1983) and by Juvigné (1990): clinopyroxenes (40-60%), olivines (22-45%) and brown amphiboles (3-12%).

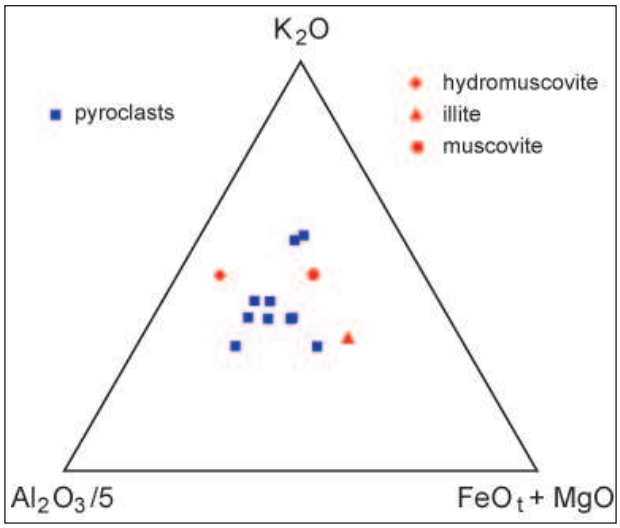
Pyroclasts

The pyroclasts consist of bubble-wall fragments and sub-rounded micropumices (Fig. 4A). They are moderately sorted and sized from middle to coarse ash, the largest grains reaching 0.5 mm at Ringen and 0.3 mm at Lixhe. As many grains were broken, precise sorting cannot be evaluated. However, the tephra features are consistent with a Strombolian scoria fall deposit. Micropumices are highly vesiculated (vesicularity up to 70%) with tiny vesicles (< 0.001 mm) which have coalesced to form an irregular and partly open framework (Fig. 4B). They resulted from a supply of lava at high temperature and low viscosity.

Microprobe analyses were performed with the micropumices of Ringen (Table 1). The very low total of oxides can be explained as follows: 1) in spite of the very small surface analysed the beam exceeded the size of the bubble walls; 2) the material is highly altered and hydrated. The volcanic glass is changed to a cryptocrystalline greyish mass of phyllite material. The recalculated analyses to the sum of oxides of 96 are close to an illite composition. Indeed, the Al_2O_3-K_20-FeO_t+MgO ratio is in the compositional range of hydromuscovite to illite (Fig. 5). Such a within-soil post-depositional replacement is a known process in volcanogenic sediments, as in the Rocourt Tephra (Pouclet *et al*., 2008). It cannot provide any information about the initial composition of the volcanic glass.



◄ Figure 4. Micropumices from the Eltville Tephra layer of Ringen on smear slides (A) and under the Electron Microprobe; the analyses of the Table 1 were done on white zones (B).



▲ Figure 5. $Al_2O_3/5$-K_2O-FeOt+MgO diagram of the pyroclasts. Hydromuscovite, illite, and muscovite after Deer *et al*. (1962).

▼ Table 1. Chemical composition of the micropumices of the Eltville Tephra from Ringen. Raw data and recalculated analyses to a sum of oxides of 96.

	1	2	3	4	5	6	7	8	9	10	average	standard deviation
SiO_2	38,83	39,04	42,19	43,08	45,30	46,27	49,51	46,87	40,18	44,82	43,61	3,57
TiO_2	0,31	0,22	0,22	1,25	0,26	1,57	0,21	0,63	0,69	0,56	0,59	0,47
Al_2O_3	20,46	23,08	24,83	19,96	21,44	14,64	19,24	19,64	23,99	24,95	21,22	3,16
Cr_2O_3	0,04	0,00	0,06	0,13	0,05	0,01	0,01	0,05	0,00	0,01	0,04	0,04
FeO_t	2,51	1,58	5,14	1,75	1,77	2,02	2,35	2,35	1,40	1,50	2,24	1,09
MnO	0,00	0,00	0,00	0,01	0,01	0,00	0,04	0,01	0,05	0,00	0,01	0,02
MgO	1,06	0,72	0,95	0,80	0,98	1,10	1,05	1,18	0,68	0,88	0,94	0,17
CaO	0,08	0,07	0,04	0,38	0,33	0,43	0,12	0,11	0,08	0,11	0,17	0,14
Na_2O	0,34	0,45	0,66	0,32	0,86	1,60	1,37	0,18	0,18	0,61	0,66	0,49
K_2O	4,54	4,93	4,83	3,89	4,98	8,21	9,39	4,46	3,03	4,43	5,27	1,97
Total	68,19	70,10	78,92	71,57	75,97	75,84	83,30	75,49	70,29	77,85	74,75	4,69
Recalculated to a total of 96.00												
SiO_2	54,67	53,47	51,33	57,78	57,24	58,57	57,07	59,61	54,88	55,27	55,99	2,52
TiO_2	0,44	0,31	0,27	1,68	0,32	1,98	0,24	0,80	0,94	0,68	0,77	0,61
Al_2O_3	28,81	31,60	30,20	26,77	27,09	18,53	22,17	24,98	32,77	30,77	27,37	4,47
Cr_2O_3	0,06	0,00	0,07	0,17	0,07	0,01	0,01	0,07	0,00	0,01	0,05	0,05
FeO_t	3,54	2,16	6,25	2,35	2,23	2,55	2,71	2,99	1,91	1,84	2,85	1,30
MnO	0,00	0,00	0,00	0,01	0,02	0,00	0,05	0,01	0,07	0,00	0,02	0,02
MgO	1,50	0,99	1,16	1,08	1,23	1,40	1,21	1,50	0,93	1,09	1,21	0,20
CaO	0,11	0,10	0,05	0,51	0,42	0,54	0,14	0,14	0,11	0,13	0,22	0,19
Na_2O	0,48	0,61	0,80	0,43	1,08	2,03	1,58	0,23	0,25	0,75	0,82	0,59
K_2O	6,39	6,75	5,88	5,22	6,29	10,40	10,82	5,67	4,14	5,46	6,70	2,18
Total	96,00	96,00	96,00	96,00	96,00	96,00	96,00	96,00	96,00	96,00	96,00	0,00

Mafic minerals

After microscopical determination of smear slides (see above), the mafic minerals are, in order of frequency, clinopyroxene, olivine and brown amphibole. Previous investigations of Juvigné (1990) have demonstrated that these minerals have similar compositions at the three sites of Lixhe, Ringen, and Eltville.

Clinopyroxenes

Pyroxenes have the same range of composition at the three sites. They exhibit typical patterns of phenocrysts of alkaline magmas characterized by high Ti- and Al^{VI}-contents (Ti-Tschermak and Tschermak end-members), which induce a fassaitic feature (Table 2). With the range composition of 31.6<XMg%<48.9, 0.4<XFe^{2+}+Mn% <15.9, 46.5<XCa%<58.8, they widely overlap the 50% Ca limit in the Mg-Fe^{2+}+Mn-Ca diagram (Fig. 6A). The Al^{IV} vs Al^{VI} and Ti vs Al^{VI} diagrams are used to discriminate the high pressure xenocrystic and megacrystic pyroxenes from the low pressure volcanic pyroxenes. The areas of the mantle xenoliths, high-pressure cumulates, and middle- to low-pressure magmatic phases are drawn according to the Pouclet *et al.* (2008) study of the Rocourt

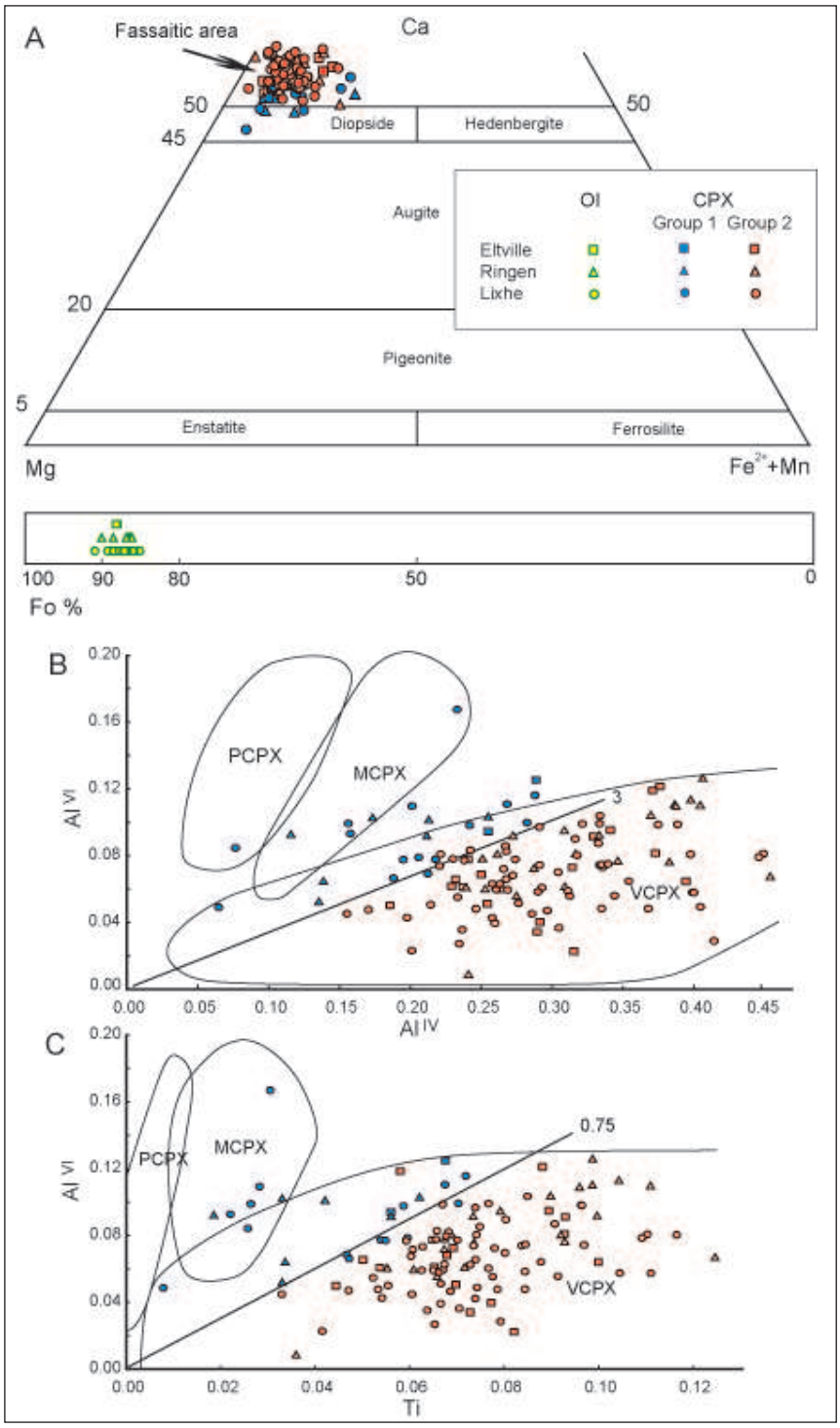


Figure 6. Classification of pyroxenes and olivines of the Eltville Tephra.

A. Mg-Ca-Fe^{2+} + Mn diagram of pyroxenes and Fo% ratio diagram of olivines.

B. Al^{IV} vs. Al^{VI} diagram of pyroxenes.

C. Ti vs Al^{VI} diagram of pyroxenes.

VCPX, area of pyroxenes of the Eifel lavas; MCPX, clinopyroxene megacrysts of alkaline lavas; PCPX, clinopyroxenes of upper mantle xenocrysts of alkaline lavas; areas drawn after the data of Aoki & Kushiro (1968), Becker (1977), Stosch & Seck (1980), Sachtleben & Seck (1981), Duda & Schmincke (1985); Mertes & Schmincke (1985), Stosch & Lugmair (1986), Witt & Seck (1987), Witt-Eickchen & Kramm (1998), Witt-Eickchen *et al.* (1998), Shaw & Eyzaguirre (2000), and Shaw (2004). The lines having a ratio of 3 (diagram B) and of 0.75 (diagram C) discriminate the groups 1 and 2.

	Eltville				Ringen				Lixhe			
Pyroxenes	Gr. 1		Gr. 2		Gr. 1		Gr. 2		Gr. 1		Gr. 2	
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.
analyses number	2		17		7		21		15		61	
SiO_2	46,33	1,70	45,44	1,99	48,35	1,39	44,24	1,69	47,91	2,15	45,33	1,84
TiO_2	2,20	0,24	2,58	0,57	1,40	0,52	2,90	0,75	1,58	0,69	2,63	0,58
Al_2O_3	8,69	0,84	8,27	1,75	5,96	1,49	9,24	1,91	6,60	1,89	8,20	1,65
FeO	5,95	1,12	6,79	1,60	6,21	2,41	7,13	1,77	6,37	2,26	7,07	1,49
Cr_2O_3	0,30	0,28	0,08	0,09	0,33	0,35	0,09	0,15	0,22	0,31	0,10	0,16
MnO	0,06	0,01	0,12	0,10	0,16	0,10	0,13	0,09	0,21	0,22	0,12	0,07
MgO	12,51	1,73	12,15	1,51	12,66	1,58	11,50	0,96	12,34	1,69	11,87	0,95
CaO	22,40	0,20	22,94	0,65	22,23	0,61	22,64	0,61	22,35	0,85	23,01	0,69
Na_2O	0,59	0,07	0,54	0,29	0,74	0,32	0,54	0,16	0,80	0,39	0,58	0,26
K_2O	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,01	0,01	0,01	0,03
Total	99,03	1,63	98,92	1,03	98,05	0,60	98,43	0,67	98,37	1,25	98,92	0,79
Structural formulae (6 oxygens)												
Si	1,727	0,024	1,703	0,063	1,822	0,051	1,671	0,065	1,800	0,066	1,702	0,065
Al^{IV}	0,273	0,024	0,297	0,063	0,178	0,051	0,329	0,065	0,200	0,066	0,298	0,065
Al^{VI}	0,109	0,022	0,069	0,027	0,087	0,020	0,082	0,026	0,093	0,028	0,065	0,019
Ti	0,062	0,008	0,073	0,016	0,040	0,015	0,082	0,021	0,045	0,020	0,074	0,017
Fe^{3+}	0,074	0,001	0,118	0,035	0,056	0,025	0,119	0,038	0,070	0,041	0,124	0,048
Cr	0,009	0,008	0,002	0,003	0,010	0,010	0,003	0,004	0,006	0,009	0,003	0,005
Fe^{2+}	0,112	0,038	0,095	0,033	0,140	0,065	0,106	0,047	0,131	0,051	0,098	0,039
Mg	0,694	0,080	0,679	0,087	0,711	0,090	0,647	0,065	0,690	0,102	0,664	0,064
Mn	0,002	0,000	0,004	0,003	0,005	0,003	0,004	0,003	0,007	0,007	0,004	0,002
Ca	0,895	0,013	0,921	0,018	0,898	0,028	0,916	0,022	0,900	0,039	0,926	0,026
Na	0,043	0,006	0,039	0,022	0,054	0,024	0,040	0,012	0,058	0,029	0,042	0,019
K	0,001	0,001	0,000	0,001	0,001	0,001	0,001	0,001	0,000	0,001	0,001	0,001
Mg %	40,75	4,00	39,84	3,21	40,50	4,36	38,65	2,36	39,87	4,20	39,23	1,96
Fe^{2+} + Mn %	6,68	2,35	5,86	2,18	8,29	3,79	6,57	2,84	8,01	2,96	6,00	2,24
Ca %	52,58	1,65	54,30	1,75	51,21	1,54	54,78	1,99	52,12	2,26	54,77	1,81
End-members												
Di%	59,74	5,05	61,22	7,44	64,09	6,49	57,62	5,73	62,72	6,89	61,25	5,69
Hd%	9,82	3,58	8,88	2,95	13,19	6,25	9,70	3,81	12,67	4,69	9,35	3,44
En%	5,02	1,62	3,36	1,14	3,68	1,87	3,61	1,29	3,28	2,59	2,64	1,43
Fs%	0,78	0,10	0,50	0,32	0,66	0,30	0,67	0,58	0,57	0,29	0,41	0,37
Ac %	4,29	0,60	3,91	2,16	4,94	2,39	3,97	1,20	5,29	3,05	4,21	1,93
Jd %	0,00	0,00	0,00	0,00	0,50	0,85	0,00	0,00	0,54	1,66	0,01	0,08
Ca-Tsch %	10,96	2,14	6,89	2,70	8,21	1,88	8,23	2,64	8,75	3,39	6,45	1,95
Ti-Tsch %	6,21	0,80	7,29	1,62	4,00	1,50	8,23	2,11	4,49	2,00	7,43	1,66
Es %	3,18	0,54	7,95	3,39	0,72	1,07	7,97	3,49	1,69	1,61	8,23	4,12
Ko%	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Table 2. Chemical composition and structural formula of the clinopyroxenes of the Eltville Tephra.

Tephra pyroxenes, by using the pyroxene analyses of the Eifel volcanic rocks for which the origin has been determined. Most of the Eltville Tephra pyroxenes plot in the common volcanic phenocryst area (Fig. 6B, C). However, many pyroxenes, in a significant amount, have a Al^{IV}/Al^{VI} ratio down to 3 and a Ti/Al^{VI} ratio down to 0.75, which are indicative of a medium to high pressure crystallization. Using these ratios, pyroxenes are distributed into two groups: *Group 1* for high to medium pressure minerals and *Group 2* for low pressure minerals. We note that there is no solution of continuity between the two groups. Consequently, the chemical variation of the pyroxenes is better explained by polybaric crystallization from an alkaline basaltic magma. The contribution of xenocrystic pyroxenes is probably small. According to the Nimis & Ulmer (1998) geobarometer, pressure conditions ranges from 6 to 0 ± 2 kbars.

Olivines

The forsterite content of olivines ranges from 86.1 to 91.3 (Tab. 3; Fig. 6A). Such a composition is compatible with a basaltic magma.

Amphiboles

Amphiboles are magnesian, titaniferous, aluminous and moderately alkaline potassic ($0.56<Mg/Mg+Fe^{2+}<0.82$; $2.9<TiO_2\%<4.7$; $2.03<Al^{IV}<2.34$; $0.16<Al^{VI}<0.44$; $4.0<Na_2O+K_2O\%<4.6$; $0.4<K/Na<0.8$) (Tab. 4). In the amphibole nomenclature of Leake *et al*. (1997), they are determined as Ti-rich pargasites close to kaersutites. Most of these amphiboles have the composition of alkaline basaltic phenocrysts (Fig. 7). A few of them may originated from upper mantle to lower crust cumulates and veins.

4. Conclusion

The numerous TL and OSL-ages that have been obtained by various laboratories on the loess body containing or bracketing the Eltville Tephra, as well as the ^{14}C-dates of the humic material of the immediately overlying paleosol called N.T.H. allow us to allocate an age of roughly 20 ka to the Eltville Tephra. Furthermore the high rate of sedimentation of the loess body containing the tephra fits quite well with a very active aeolian deflation on the nearby floodplains (Meuse, Rhine and tributaries) in the coldest part of the Weichselian glaciation.

	Eltville		Ringen		Lixhe	
Olivines	average	standard deviation	average	standard deviation	average	standard deviation
SiO_2	40,49	0,06	40,86	0,46	40,39	0,35
TiO_2	0,04	0,02	0,01	0,01	0,02	0,02
Al_2O_3	0,07	0,04	0,04	0,02	0,02	0,02
FeO	10,87	0,01	11,01	2,13	12,52	1,80
MnO	0,15	0,03	0,20	0,03	0,23	0,07
MgO	46,90	0,30	49,65	1,40	48,37	1,47
CaO	0,34	0,04	0,25	0,12	0,32	0,07
Total	98,84	0,51	102,01	0,46	101,87	0,27
Structural formulae (4 oxygens)						
Si	1,008	0,003	0,988	0,005	0,985	0,004
Ti	0,001	0,000	0,000	0,000	0,000	0,000
Al	0,002	0,001	0,001	0,000	0,001	0,001
Fe^{2+}	0,226	0,001	0,223	0,044	0,256	0,039
Mn	0,003	0,001	0,004	0,001	0,005	0,001
Mg	1,741	0,003	1,789	0,040	1,759	0,041
Ca	0,009	0,001	0,007	0,003	0,008	0,002
Total	2,990	0,002	3,012	0,005	3,014	0,004
Fo%	88,35	0,03	88,75	2,18	87,11	1,99

Table 3. Chemical composition of some olivines of the Eltville Tephra.

Amphiboles	average	standard deviation
analyses nb.	11	
SiO_2	39,06	0,86
TiO_2	4,03	0,49
Al_2O_3	14,11	0,81
Cr_2O_3	0,03	0,06
FeO	10,11	2,35
MnO	0,15	0,17
MgO	13,27	1,64
CaO	11,77	0,37
Na_2O	2,30	0,25
K_2O	2,01	0,30
Total	96,84	0,66
Structural formula (23 oxygens)		
Si	5,830	0,100
Al^{IV}	2,170	0,100
Al^{VI}	0,312	0,081
Ti	0,453	0,056
Cr	0,003	0,007
Fe^{3+}	0,152	0,091
Fe^{2+}	1,112	0,328
Mn	0,019	0,022
Mg	2,948	0,335
Ca	1,883	0,052
Na	0,665	0,071
K	0,383	0,059

Table 4. Chemical composition of some amphiboles of the Eltville Tephra.

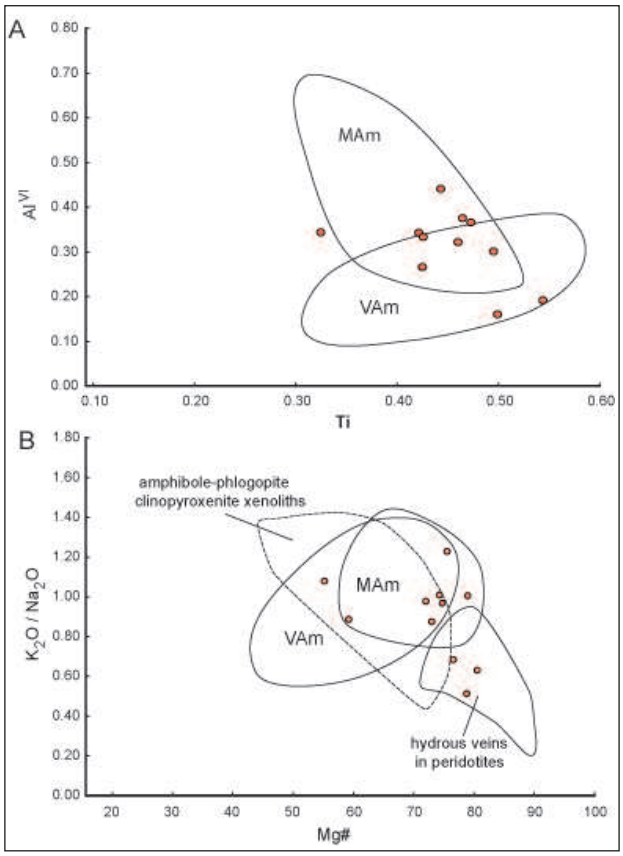


Figure 7. Ti vs. Al^{VI} (A) and Mg# vs. K_2O/Na_2O (B) diagrams of amphiboles. Mg# = Mg / (Mg + Fe^{2+}); VAm, amphiboles of the Eifel lavas; MAm, amphibole megacrysts of the Eifel lavas; areas drawn after the data of Becker (1977), Duda & Schmincke (1978), Wörner & Schmincke (1984), Witt-Eickschen *et al.* (1998), Shaw & Eyzaguirre (2000), and Harms *et al.* (2004).

According to the characteristics of the pyroclasts, the Eltville Tephra resulted from a strong Strombolian eruption of a high temperature and low viscosity lava. The volcanic glass being totally altered to phyllite, the composition of the lava is unknown. But, the magmatic signature of the minerals is clearly consistent with an alkaline basaltic magma.

The more recent and accurate age data yield to an age of 20 ka. Considering the increase of the tephra thickness and grain size, the East Eifel volcanic field could be the original location of the eruption. In that case, the challenge is to discover a large basaltic volcano that could be dated at 20 ka.

5. Aknowledgments

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