Reappraisal of the volcanic source of the Rocourt Tephra, a widespread chronostratigraphic marker aged c. 78-80 ka in western Europe: additional supplementary material

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Abstract
Juvigné *et al.* (2024) demonstrated by geochemical arguments that the RT could have been emitted neither by the Pulvermaar, nor the Dreiser Weiher. The current report presents details relating to optical determinations of minerals which were not presented in the aforementioned article.

Keywords: Widespread tephra; Rocourt Tephra; Dreiser Weiher Tephra; Pulvermaar Tephra; Eifel Volcanic Field; Germany; Belgium; Quaternary.

1. Introduction

Under the aforementioned title, Juvigné *et al.* (2024) showed that the Rocourt Tephra (**RT**) was not emitted by either The Dreiser Weiher (Gullentops and Hocht, 1998) or the Pulvermaar (Förster *et al.*, 2020), two volcanoes of the West Eifel Volcanic Field. The major arguments come from the composition of pyroxenes. Less persuasive data based on optical determination of volcanogenic mafic minerals (**vmm**) could not be integrated into the article; they are presented here. Furthermore, for three quarters of a century they have made it possible to quickly identify the Rocourt Tephra; they may be useful to all those who, through research in the Eifel, could contribute to identifying the emitting volcano which remains unknown to this day.

2. Analytical procedure

Dense minerals ($\delta > 2.8$) have been separated as follows: boiling in $HCl_{10\%vol}$; sieving by 355/75 µm; extraction of dense minerals with bromoform ($\delta = 2.8$) in separating funnel by repeating agitation-decantation-harvest cycles, until no more harvest is obtained (generally 3 to 5 cycles). Aliquots were examined under the binocular magnifier, and smear slides were prepared in Canada balsam for identification with a petrological microscope.

3. Volcanogenic mafic minerals of the Rocourt Tephra

3.1. Localities with the Rocourt Tephra

RT is actually a crypto-tephra. The material is therefore always dispersed in host sediments, so that it has never been seen with the naked eye. All the sites in which it has been found are located in Figure 1.

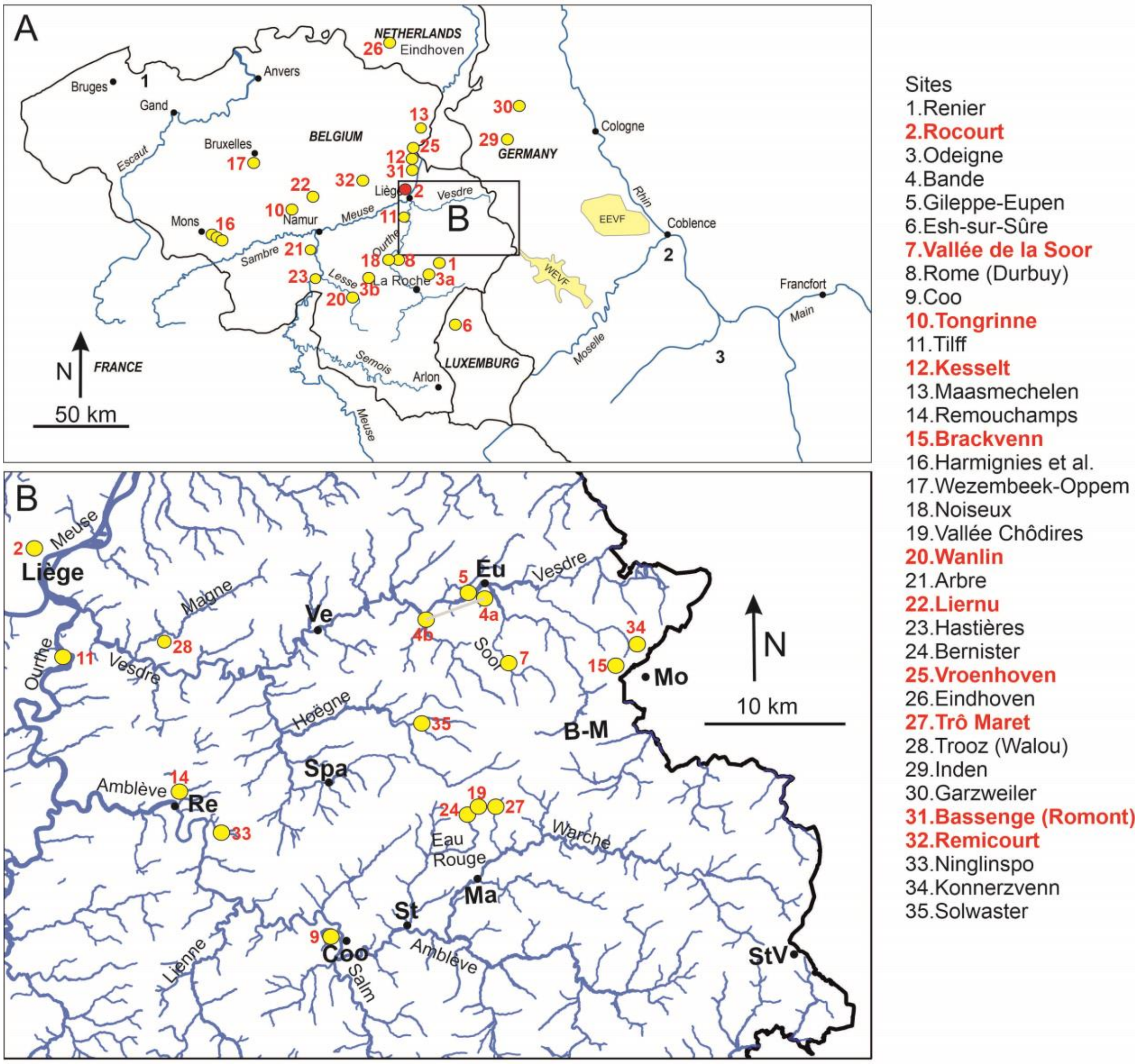

Figure 1. Location of sites where the vmm of the RT have been identified as well as some localities where enstatite has been recognized as traces in various associations. Explanation: the numbers referring to localities correspond to the relevant papers listed in the Table 1; sites in bold and red font are of major interest (mineralogical and/or chemical and/or stratigraphical data). Abbreviations: WEVF = West Eifel Volcanic Field; EEVF = East Eifel Volcanic Field; B-M = Baraque Michel; Eu = Eupen; Lg = Liège; Ma = Malmedy; Mo = Monjoie; Re = Remouchamps ; St = Stavelot ; StV = Saint-Vith; Ve = Verviers.

Authors	Année	Site #	Host sediment	Authors	Année	Site #	Host sediment
Tavernier & Laruelle	1952	s.o.	Alluvial plain	Pissart & Juvigné	1980	15	Rampart of lithalsa
Gullentops	1952	1	Soil	Ballmann et al.	1980	23	Cave deposits
Gullentops	1954	2	Loess section	Haesaerts et al.	1981	s.o.	Loess section
		3 & 4	Slope deposits	Pissart & Juvigné	1982	24	Valley bottom: periglacial deposits
		5	Slope deposits & terrace	Meijs & de Lang	1983	25	Loess section
Bourguignon	1955	1	Soil			26	Loess section
Hermans	1955	6	Slope deposits	Mees & Meijs	1984	25	Loess section
Bastin & Juvigné	1972	7	Valley bottom: periglacial deposits	Juvigné & Mörner	1984	s.o.	Palaeolake
Juvigné & Mullenders	1972	8	Loess section	Juvigné	1985	27	Terrace
Bustamante	1973 & 1974	9	Terrace	Juvigné	1990	s.o.	Varia
Juvigné	1973	10	Loess section	Pouclet & Juvigné	1993	27	Loess section
	1973	11	Terrace	Lacroix	1993	28	Cave deposits
Juvigné	1974	12	Loes section	Juvigné	1993	s.o.	Varia
Pissart	1974	13	Terrace	Juvigné et al.	1996	12	Loess section
Dewez et al.	1974	14	Cave deposits	Gullentops & Hocht	1998	29 & 30	Loess section
Bastin et al.	1975	15	Rampart of lithalsa	Meijs & Groenendik	1999	12	Loess section
Pissart et al.	1975	7	Valley bottom: periglacial deposits	Bringmans et al.	2000	s.o.	Loess section
Juvigné	1976	2	Loess section	Renson et al.	2002	28	Cave deposits
		12	Loess section	Meijs	2002	12 &25	Loess section
		10	Loess section	Pirson et al.	2004	28	Cave deposits
		16	Loess section	Juvigné et al.	2008	31	Loess section
		16	Loess section	Pouclet et al.	2008	2, 12, 32	Loess section
		16	Short term excavation			28	Cave deposits
		17	Short term excavation			27	Terrace
Juvigné	1977a	s.o.	Varia	Rixhon et al.	2010	33	Valley bottom: periglacial deposits
Juvigné	1977b	18	Loess & eolian sand	Meijs	2011	10	Loess section
Bastin & Juvigné	1978	19	Valley bottom: periglacial deposits	Pirson & Juvigné	2011	28	Cave deposits
Juvigné	1979a	20	Loess section	Juvigné et al.	2013	32	Loess section
Juvigné	1979b	s.o.	Terrace	Juvigné	2016	34	Rampart of lithalsa
Juvigne & Pissart	1979	15	Slope deposits	Jouannic et al.	2016	2	Loess section
Quinif et al.	1979	21	Cave deposits	Haesaerts et al.	2016	16	Loess section
Bolline et al.	1980a	22	Loess section	Juvigné et al.	2022	35	Valley bottom: periglacial deposits
				Juvigné et al.	2023	2 & 27	Terrace

Table 1. For the Rocourt Tephra, articles reporting the presence of the RT in the sites of Figure 1, as well as the host sediments.

3.2. Mafic minerals of the Rocourt Tephra

The association consists of orthopyroxenes, clinopyroxenes, brown amphiboles, titaniferous magnetite and Cr-spinel. Due to several factors which act from the zonation of magma and the fall out (natural factors), as well as from sampling to optical determination (technical factors), the ranges of frequency of the individual minerals are somewhat large. In the sites with high frequencies of vmm, mineral suite were calculated (Table 2).

	Determinator	Cpx	Opx	Amphibole	Spinel	n=
Eupen, Soor valley, one section	Juvigné 1972	53	27	20		120
Eupen, Soor valley, other sections	Juvigné 1975	50	25	25		hundreds
Rocourt, loess section	Juvigné 1976	58,7	9,4	31,8		388
Kesselt, loess section	Juvigné 1976	65,5	13,4	21,1		739
Tongrinne, loess section	Juvigné 1976	49,7	25,6	24,6		107
Wanlin, loess section	Juvigné 1979	28,9	43,1	28		2888
Liernu, loess section	Juvigné 1980	22,9	34,2	42,9		73
Haytes Fagnes, Brackvenn, lithalsa	Juvigné 1980	46,8	22	31,2		not available
Vroenhoven, loess section	Meijs 1983	76,7	8,7	13,8	0,8	not available
Hautes Fagnes, Trô Maret, terrace	Juvigné 1985	45,34	25,55	29,11		1300
Trooz, Walou, cave	Juvigné & Pirson 2004	45,4	40,1	14,3		1279
Bassenge, Romont, loes section	Juvigné 2008	90,9	3,8	5,24		10550
Remicourt, loess section	Juvigné 2013	67,2	10	22,7		3735
Min		**22,9**	**3,8**	**5,24**		
Max		**90,9**	**43,1**	**42,9**		

Table 2. Percentage ranges of the vmm of the Rocourt Tephra.

Photos of the three most common volcanogenic mafic minerals of the Rocourt Tephra are presented in figure 2.

Figure 2. Photos of the three most common volcanogenic mafic minerals of the Rocourt Tephra.

4. The Dreiser Weiher Tephra

Two populations share some 90% of the entire population: very dark green to black euhedral minerals coated with dark magmatic glass and colourless to greenish grains which are not coated with magmatic glass. The magmatic coating impairs the transparency during microscope examination. Nevertheless, numerous dark green euhedral minerals could be identified as clinopyroxene as well as agglomerates of small euhedral clinopyroxenes. The colourless crystals consist of olivine. Traces of another two minerals were found: anhedral lawn-green crystals with serrated edges (clinopyroxene) and prismatic brown minerals (amphiboles). No significant stratigraphic variation was observed in the sequence (Table 3). Photos of the three most common volcanogenic mafic minerals of the Dreiser Weiher Tephra are presented in figure 3.

Label	Cpx	E&A	Oli	n=
DrW2	38,5	-	61,5	117
DrW3	40,0	2,9	57,1	105
DrW4	46,7	-	53,3	112

Table 3. Volcanogenic mafic mineral suite of the Dreiser Weiher Tephra after optical determinations (magnifier and microscope).

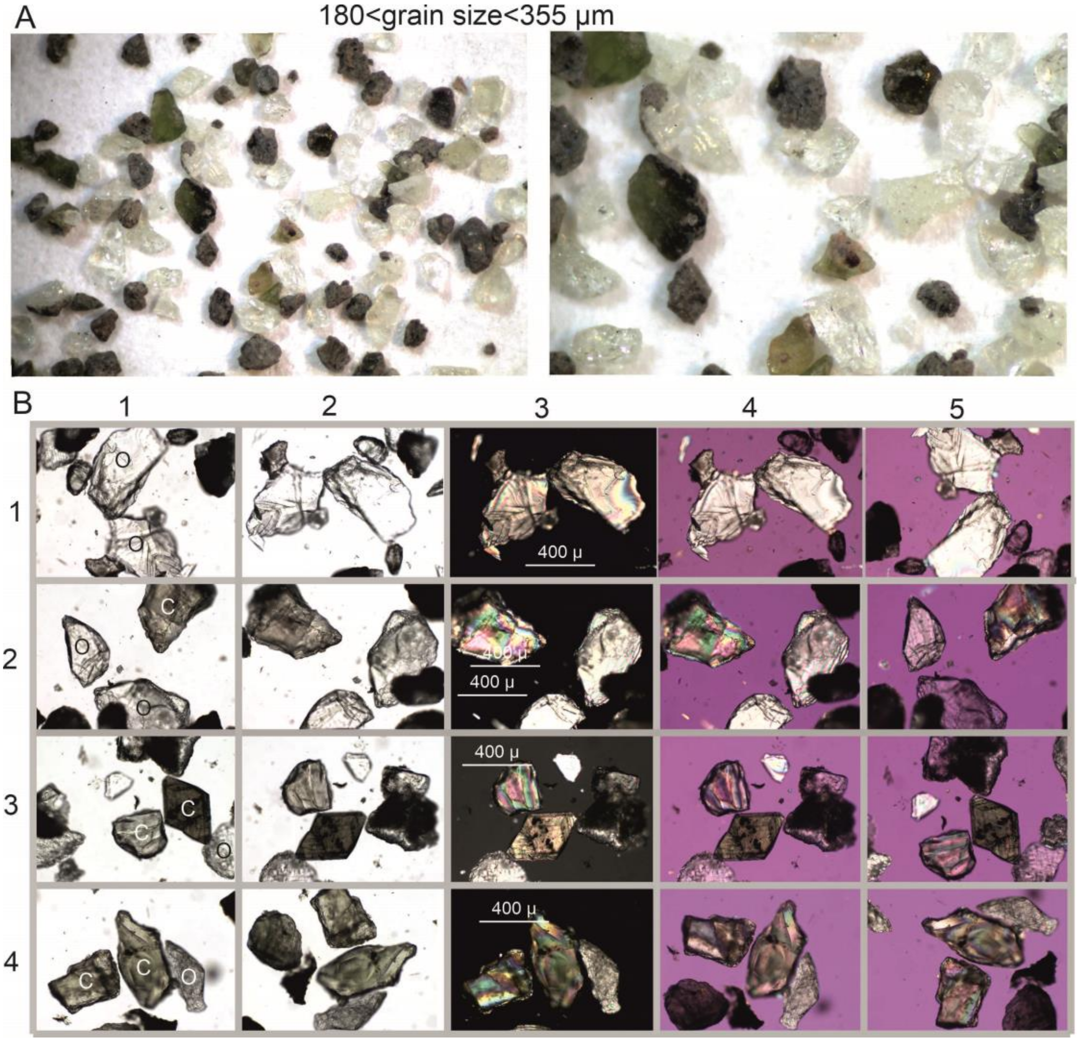

Figure 3. Photos of the two most common volcanogenic mafic minerals of the Dreiser Weiher Tephra. C = cpx; O = olivine

5. The Pulvermaar Tephra

Two populations make up most of the mass : very dark green to black grains mainly coated with magmatic glass are largely dominant over transparent colourless grains. Under the microscope, magmatic glass coating impairs the transparency of the former minerals. Nevertheless, several of them could be identified as subhedral to euhedral clinopyroxene as well as agglomerates of small euhedral clinopyroxenes. The transparent colourless minerals are likely to be olivine. Otherwise a few anhedral lawn-green minerals with serrated edges are present (clinopyroxene) as well as traces of prismatic brown grains (amphibole). The latter two minerals and the olivines are not coated with magmatic glass and so are grains of coarser crystals. Qualitative examination of the eighteen samples has been done and no significant stratigraphical variation was observed (Table 4). Photos of the two most common volcanogenic mafic minerals of the Pulvermaar Tephra are presented in figure 4.

Label	Cpx	E&A	Oli	n=	Label	Cpx	E&A	Oli	n=
Pvm 1	88,7	-	11,3	106	Pvm 10	88,4	-	11,6	109
Pvm 2	76,1	2,2	21,7	105	Pvm 11	81,8	-	18,2	110
Pvm 3	92,7	-	7,3	123	Pvm 12	94,8	-	5,2	144
Pvm 4	95,3	-	4,7	128	Pvm 13	88,6	2,9	8,6	105
Pvm 5	96,2	1,9	1,9	106	Pvm 14	87,5	-	12,5	112
Pvm 6	97,1	-	2,9	134	Pvm 15	96,8	-	3,2	126
Pvm 7	98,3	-	1,7	116	Pvm 16	94,9	-	5,1	118
Pvm 8	93,4	1,6	4,9	122	Pvm 17	89,6	-	10,4	134
Pvm 9	91,8	2,0	6,1	105					

Table 4. Volcanogenic mafic mineral suite of the Pulvermaar Tephra after optical determinations (magnifier and microscope).

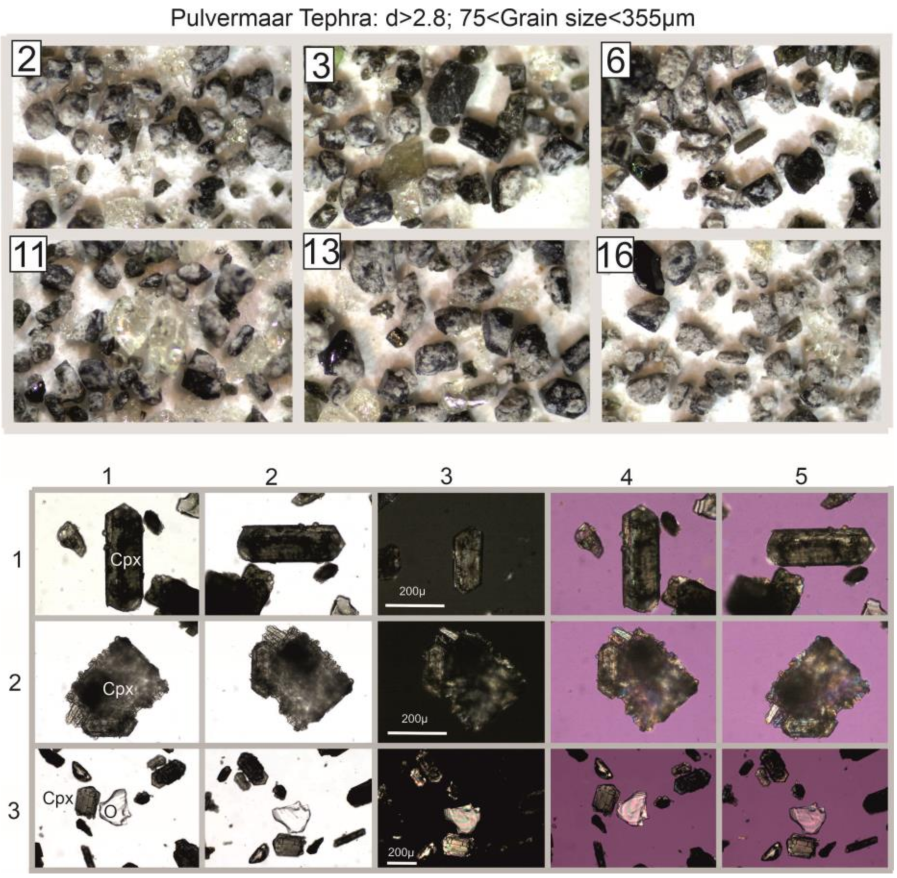

Figure 4. Photos of the two most common volcanogenic mafic minerals of the Pulvermaar Tephra. Row 2 = agglomerate of small euhedral clinopyroxenes.

6. Stratigraphical distribution of the Rocourt Tephra

In sites where the Upper Pleistocene lithostratigraphic units are sufficiently developed, the vertical distribution of the vmm was investigated, with the aim of finding the RT layer visible to the naked eye at a peak of concentration. However, the objective of identifying the RT in its primary position has never been achieved. In some cases, secondary concentration peaks have been highlighted (Fig. 5). The part above the main peak comes from sedimentary reworking and the lower part from bioturbation and/or cryoturbation (Juvigné, 1977a).

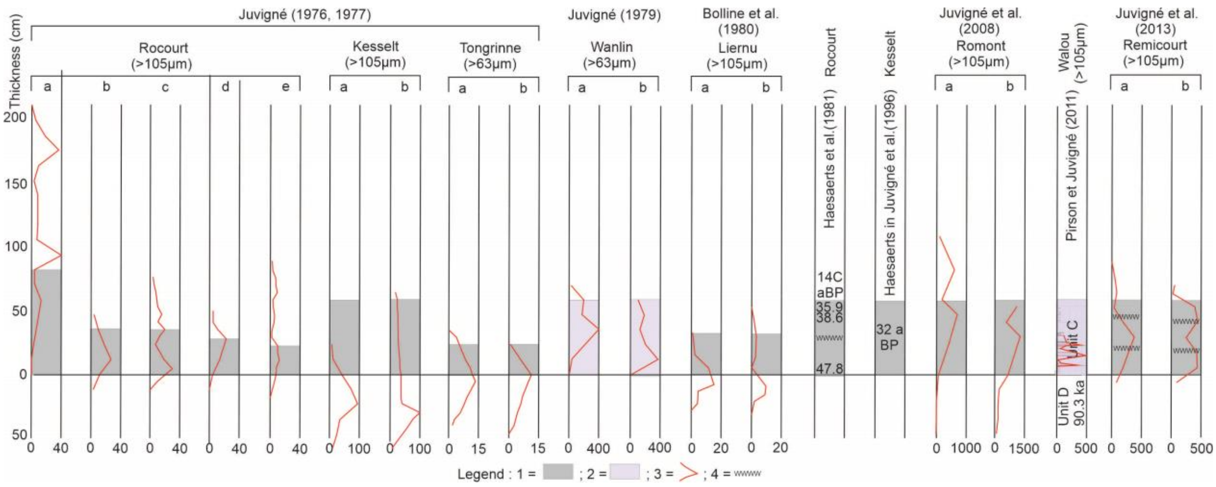

Figure 5. Vertical distribution of vmm of the RT in Upper Pleistocene sequences in Belgium. Legend: 1 = Humiferous Complex of Remicourt; 2 = palaeosol; 3 = frequency of vmm of the

RT; 4 = unconformity. Horizontal scale= quantity of vmm for varying weights of sediment from one site to another (see the original articles).

In the loess region of Middle Belgium (Rocourt, Kesselt, Romont, Veldwezelt, Remicourt, Tongrinne) (Fig. 5), the tephra is systematically associated with a humiferous pedocomplex known as the Humiferous Complex of Remicourt (Haesaerts *et al*., 1997, 2016). In High Belgium, two sites yielded detailed data for the RT stratigraphic distribution. In Walou Cave, the distribution peak is located on top of a humiferous horizon (unit CV-1), overlying a complex sequence including palaeosols (units DI-BT, CV-3 and CV-2; Pirson and Juvigné, 2011). In Wanlin brickyard, the peak of the RT was observed at the boundary between two palaeosols separated by a stony layer (Juvigné, 1979).

Hence, it seems that the fallout of the RT has occurred during a period of (relatively strong) soil formation, with sufficiently intense biological activity to disseminate the RT into the underlying units. In all the cases, the peak is situated above the Rocourt Pedocomplex or its equivalent. This pedocomplex is attributed to the Eemian interglacial and to the main part of the Weichselian Early Glacial (GS 25 to the lower half of GI 21, *sensu* Rasmussen *et al*., 2014; Haesaerts *et al*., 2016). In the most complete loessic sequences, the vmm concentration peak is generally in the HCR. There are a few exceptions, however. In one of the sequences studied at Rocourt, the RT peak was found above the HCR, but in other sequences, the RT was observed inside the HCR. In two sequences from Kesselt, the peak is below the HCR, but on other sequences from the same site, the highest concentration of RT-vmm was found inside the HCR at Tongrinne, the peak is located at the contact between the Rocourt Pedocomplex and the overlying HCR. The most significant site is that of Remicourt which allows the RT to be placed between 78 and 80ka (Juvigné et al., 2013)

7. About correlations with the Rocourt Tephra

The identification of RT in some 36 sites in Belgium and in the neighboring regions of the Netherlands and the Lower Bay Rhine was based solely on determinations of vmm made under the microscope and more particularly on the presence of enstatite. The correlation of RT with the Dreiser Weiher (Gullentops and Hocht, 1998) or with the Pulvermaar (Förster *et al*., 2020) was rejected mainly by the composition of pyroxenes (Juvigné *et al*., 2024). We add here detailed data of optical origin which, although less reliable, allows us to argue in the same way. The photos show fragments of megacrysts (without magma coating) in the RT and euhedral cpx with magma coating at Pulvermaar.

Moreover, the fields of the associations of vmm of both Pulvermaar T. and the Dreiser Weiher T. are very far from each other in the ternplot of figure 6. To defend the relationship of the RT with one or the other of the relevant volcanoes, one would have to imagine for example that: (1) olivine was present in the RT and disappeared entirely by iddingitization which would place the original RT in the red field of the triangle without leading to an overlap with the other tephras; (2) brown amphibole and enstatite were present in the proximal tephras of Pulvermaar and Dreiser Weiher and then disappeared by alteration; (3) the three minerals involved in the present discussion have disappeared by alteration and in this case an overlap of the respective fields can be obtained. This type of debate leads to declaring as inappropriate, tephra comparisons based on optical determinations of minerals.

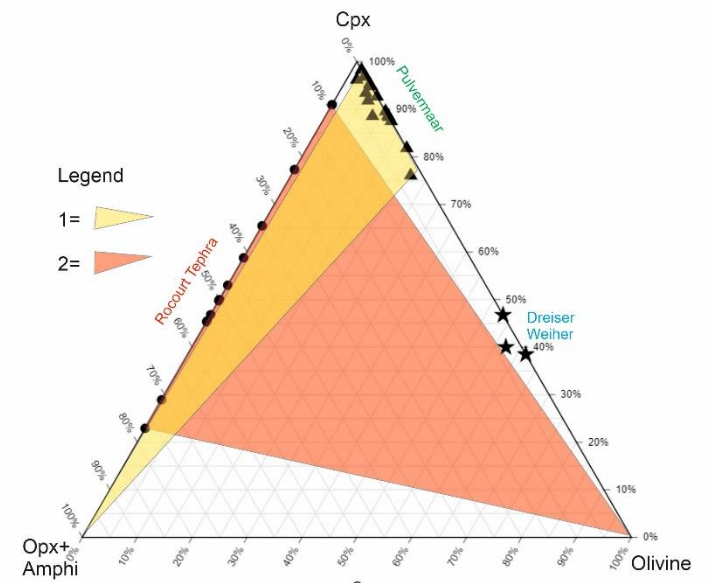

Figure 6. Comparisons of vmm associations of RT (black circles), Pulvermaar (black triangles) and Dreiser Weiher (black stars). Legend: 1 = possible distribution of the vmm association assuming the disappearance by alteration of brown amphiboles and enstatites in the proximal tephra of the Pulvermaar T.; 2 = possible distribution of the vmm association of the RT assuming the disappearance by alteration of olivines in all types of host sediments.

8. About the possible presence of the RT at Schwalbenberg

Fisher *et al.* (2021) report the possible presence of the RT in the Schwalbenberg loess section (Middle Rhine valley). It is a thick (centimeters) coarse grain tephra resting on a paleosol which could be the equivalent of the HCR in Belgium (see above). Unfortunately, the authors do not report any mineralogical or geochemical data concerning that tephra. Their hypothesis calls for further investigations, because: (1) the site is on the road to the Inden and Garzweiler mines (Lower Bay Rhine) where Gullentops and Hocht (*op. cit.*) found the RT; (2) but very unexpectedly the emitting volcano would rather be in the nearby EEVF.

9. Conclusion

Those who would like to help identify the Rocourt Tephra or its emitting volcano now have all the useful observations at their disposal.

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