[Supplementary material]

Alpine ice-core evidence for the transformation of the European monetary system, AD 640–670

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S1 data on Colle Gnifetti tephra from AD 536 volcanic event

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The geochemical composition of eight particles from the 57.67–57.88m depth interval in the CG ice core was established using the University of Maine's Tescan Vega-II XMU scanning electron microscope (SEM) equipped with an Apollo SSD40 energy dispersive spectroscopy (EDS) detector. The methodology for tephra fingerprinting was adapted from one developed by the NIST DTSA-II analytical software team (Newbury & Ritchie 2015). Two volcanic glass particles were confirmed as rhyolitic. The preliminary annual layer-based timescale placed this depth interval at approximately AD 500, with an estimated maximum error of ±72 years at AD 600, prior to the establishment of absolute chronological markers (Bohleber *et al*. 2018).

Several volcanic eruptions were evaluated as possible sources based on timing of the tephra deposits and the rhyolitic geochemical composition of CG tephra particles. Because rhyolitic tephra has not often been deposited in Europe in the last 2000 years (Global Volcanism Program 2013), there were not many source candidates to consider. In addition, the grain size (8μm) of analyzed glass shards helped to establish that volcanic ash was likely transported via the troposphere. Based on the preceding, the possible volcanic eruptions we considered were: AD 536 unknown (Van der Bogaard & Schminke 2002; Pilcher *et al*. 2005; Lawson *et al*. 2012; Sigl *et al*., 2015), Hekla 3 (~1000 BC) (Óladóttir *et al*. 2011), White River Ash (AD 843) (Richter *et al*. 1995), Ilopango (AD 200) (Garrison *et al*. 2012), and El Chichon (AD 540) (Nooren *et al*. 2017) (Figure S1). We determined that the AD 536 volcanic event is the most likely candidate based on the similarity of the geochemical signatures of volcanic glass in the Greenland NEEM-2011 ice core (dated AD 536±2) (Sigl *et al*. 2015), European lakes (dated AD 776–887 using interpolated 14C based control points) (Newbury & Ritchie 2015) and German peat bogs (dated AD 400–650) (Van der Bogaard & Schminke 2002; Pilcher *et al*. 2005) (Table S1 and Figure S1). Notably, the geochemical signatures of tephra deposits are well constrained within the field of Icelandic volcanic rocks2 (Figure S1). Therefore, we suggest that the source of the "AD 536 Unknown" volcanic event is Icelandic and correlates geochemically with tephra deposits from 57.67–57.88m interval in CG.

Figure S1. Geochemical correlations for Colle Gnifetti tephra deposits. Outlined field defines general chemical characteristics of eruptive products from Iceland (Bourne *et al*. 2016).

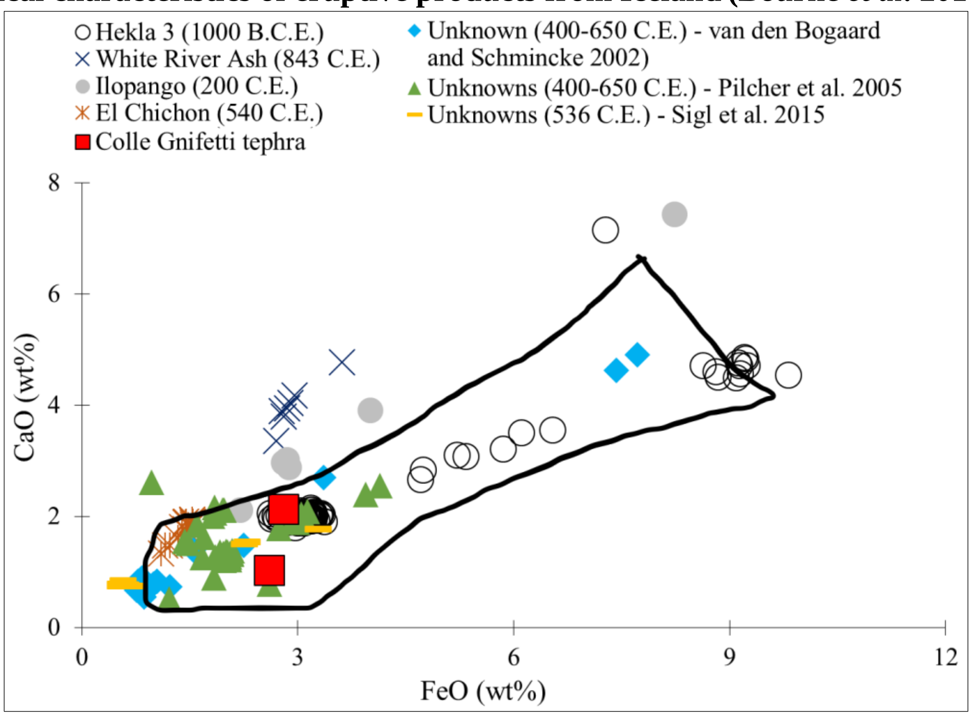

Table S1. Normalised major element oxides in weight percent.

Colle Gnifetti (this study)													
ID	Analytical Method	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	FeO	Total	Original Total	Established Source
7	SEM-EDS	5.36	0.43	13.30	74.53	2.36	1.04	0.36	0.03	2.60	100	86.35	Icelandic

10	SEM-EDS	3.85	0.65	11.84	73.98	4.68	2.13	0.00	0.05	2.81	100	88.36	Icelandic
NEEM-2011 unknowns (Sigl et al. *2015)*													
ID	Analytical Method	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	FeO	Total	Original Total	Suggested Source
1	EMPA-WDS	3.65	0.06	13.09	77.25	4.64	0.75	0.01	0.00	0.54	100	97.34	Inyo/Mono Craters
1	EMPA-WDS	3.54	0.02	13.13	77.06	4.69	0.75	0.08	0.05	0.67	100	98.29	Inyo/Mono Craters
10	EMPA-WDS	3.66	0.07	13.04	77.06	4.72	0.78	0.10	0.04	0.53	100	97.47	Inyo/Mono Craters
11	EMPA-WDS	4.16	0.11	12.98	76.51	4.58	0.85	0.05	0.18	0.58	100	92.37	Inyo/Mono Craters
12	EMPA-WDS	4.26	0.05	12.55	77.05	4.49	0.77	0.18	0.03	0.62	100	94.49	Inyo/Mono Craters
13	EMPA-WDS	3.91	0.09	12.33	75.48	2.83	1.78	0.32	-0.03	3.29	100	99.25	Inyo/Mono Craters
German peat bog unknowns (van den Bogaard & Schmincke 2002)													
ID	Analytical Method	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	FeO	Total	Original Total	Suggested Source
Dom-3	EMPA-WDS	3.57	0.02	13.18	77.11	4.25	0.84	0.00	0.26	0.78	100	93.43	Icelandic
Dom-3	EMPA-WDS	3.81	0.13	13.13	76.84	4.05	0.74	0.00	0.08	1.22	100	94.48	Icelandic
Dom-3	EMPA-WDS	3.73	0.06	13.54	76.62	4.32	0.89	0.00	0.00	0.84	100	93.88	Icelandic
Dom-4-C	EMPA-WDS	3.60	0.00	12.79	77.34	4.57	0.56	0.11	0.17	0.86	100	96.13	Icelandic
Dom-4-M	EMPA-WDS	4.03	0.08	13.10	76.13	4.53	0.79	0.33	0.02	1.00	100	95.69	Icelandic
Dom-4-C	EMPA-WDS	3.99	0.00	13.15	76.75	4.52	0.67	0.07	0.09	0.76	100	95.32	Icelandic
Dom-4-C	EMPA-WDS	3.71	0.00	13.99	75.94	4.29	0.83	0.11	0.09	1.04	100	95.23	Icelandic
Dom-4-M	EMPA-WDS	4.17	0.02	13.38	76.64	2.73	1.40	0.00	0.11	1.55	100	95.49	Icelandic
Dom-4-M	EMPA-WDS	4.07	0.06	12.90	76.18	2.61	1.48	0.28	0.17	2.25	100	97.86	Icelandic
Dom-4-M	EMPA-WDS	3.09	0.78	12.60	73.91	2.33	2.70	0.96	0.28	3.36	100	97.51	Icelandic
Dom-4-M	EMPA-WDS	4.16	1.15	15.49	63.95	1.71	4.63	1.06	0.34	7.43	100	96.70	Icelandic
Dom-4-M	EMPA-WDS	4.66	1.27	15.19	62.53	1.86	4.91	1.49	0.38	7.72	100	96.51	Icelandic
European lake unknowns (Pilcher et al. *2005)*													
ID	Analytical Method	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	FeO	100	Original Total	Suggested Source
51–52 cm	EMPA-WDS	4.45	0.39	14.24	74.59	2.07	2.03	0.37		1.84	100	98.86	Icelandic
51–52 cm	EMPA-WDS	4.29	0.44	14.35	74.62	1.96	2.18	0.31		1.85	100	99.56	Icelandic
51–52 cm	EMPA-WDS	4.03	0.39	14.25	74.95	2.13	2.08	0.33		1.85	100	99.67	Icelandic
51–52 cm	EMPA-WDS	4.61	0.13	14.82	72.52	2.60	1.94	0.38		2.99	100	97.94	Icelandic
53-54 cm	EMPA-WDS	4.56	0.14	14.30	73.27	2.42	2.06	0.18		3.06	100	97.04	Icelandic
53-54 cm	EMPA-WDS	4.68	0.13	14.31	73.26	2.48	1.91	0.21		3.01	100	99.28	Icelandic
53-54 cm	EMPA-WDS	4.79	0.14	14.30	72.90	2.53	2.04	0.23		3.06	100	99.84	Icelandic
53-54 cm	EMPA-WDS	4.52	0.03	12.93	76.68	2.66	1.30	0.16		1.72	100	97.23	Icelandic
53-54 cm	EMPA-WDS	4.48	0.45	14.32	74.26	2.75	1.86	0.28		1.60	100	99.72	Icelandic
53-54 cm	EMPA-WDS	4.57	0.41	14.27	74.20	2.83	1.67	0.32		1.73	100	97.77	Icelandic
53-54 cm	EMPA-WDS	4.64	0.04	13.42	75.59	2.86	1.26	0.18		2.01	100	99.51	Icelandic
53-54 cm	EMPA-WDS	4.69	0.03	13.23	75.59	2.89	1.34	0.17		2.06	100	100.23	Icelandic
53-54 cm	EMPA-WDS	4.85	0.37	13.98	74.58	2.90	1.51	0.35		1.47	100	100.74	Icelandic
53-54 cm	EMPA-WDS	4.74	0.34	13.99	74.70	2.95	1.53	0.33		1.42	100	101.01	Icelandic

53-54 cm	EMPA-WDS	4.51	0.30	14.24	73.74	3.43	1.42	0.35		2.01	100	95.44	Icelandic
53-54 cm	EMPA-WDS	4.45	0.33	14.06	73.73	3.50	1.43	0.32		2.17	100	96.28	Icelandic
53-54 cm	EMPA-WDS	5.26	0.26	14.79	71.47	4.55	0.79	0.26		2.62	100	99.78	Icelandic
53-54 cm	EMPA-WDS	4.35	0.06	13.11	75.74	3.77	0.91	0.20		1.85	100	98.83	Icelandic
54–55 cm	EMPA-WDS	4.70	0.09	15.20	73.43	2.60	2.69	0.29		1.00	100	97.25	Icelandic
54–55 cm	EMPA-WDS	3.78	0.07	11.67	79.11	3.16	0.53	0.43		1.24	100	97.53	Icelandic
54–55 cm	EMPA-WDS	4.27	0.04	13.45	76.02	2.79	1.34	0.14		1.95	100	94.74	Icelandic
54–55 cm	EMPA-WDS	4.13	0.00	13.26	76.22	2.93	1.35	0.12		1.99	100	96.16	Icelandic
54–55 cm	EMPA-WDS	4.17	0.43	14.29	74.51	2.16	2.13	0.32		1.98	100	98.97	Icelandic
54–55 cm	EMPA-WDS	4.50	0.42	13.97	74.47	2.19	2.10	0.37		1.98	100	100.23	Icelandic
54–55 cm	EMPA-WDS	4.21	0.34	14.44	73.97	3.34	1.27	0.37		2.07	100	95.50	Icelandic
54–55 cm	EMPA-WDS	4.18	0.13	14.88	73.43	2.37	1.89	0.23		2.90	100	94.55	Icelandic
54–55 cm	EMPA-WDS	4.70	0.14	14.42	72.79	2.57	2.09	0.27		3.02	100	98.71	Icelandic
54–55 cm	EMPA-WDS	4.82	0.15	14.39	72.80	2.56	1.94	0.25		3.09	100	100.38	Icelandic
54–55 cm	EMPA-WDS	4.70	0.16	14.41	72.78	2.47	2.09	0.25		3.13	100	99.96	Icelandic
54–55 cm	EMPA-WDS	3.84	0.47	12.73	74.00	2.12	2.41	0.46		3.96	100	99.44	Icelandic
54–55 cm	EMPA-WDS	4.68	0.30	14.80	70.84	2.36	2.55	0.35		4.12	100	100.36	Icelandic
61-62 cm	EMPA-WDS	4.30	0.34	14.54	73.64	3.42	1.37	0.36		2.03	100	96.90	Icelandic
61-62 cm	EMPA-WDS	4.28	0.29	14.69	73.71	3.25	1.37	0.37		2.04	100	96.61	Icelandic
61-62 cm	EMPA-WDS	4.39	0.29	14.63	73.54	3.41	1.31	0.37		2.06	100	96.45	Icelandic
61-62 cm	EMPA-WDS	3.95	0.30	14.82	73.76	3.42	1.30	0.37		2.09	100	95.41	Icelandic
61-62 cm	EMPA-WDS	4.49	0.32	14.80	73.23	3.36	1.41	0.34		2.06	100	97.29	Icelandic
61-62 cm	EMPA-WDS	4.28	0.31	14.43	73.85	3.34	1.35	0.36		2.08	100	96.53	Icelandic
61-62 cm	EMPA-WDS	4.19	0.30	14.88	73.56	3.31	1.29	0.36		2.10	100	95.94	Icelandic
61-62 cm	EMPA-WDS	4.15	0.35	14.74	73.53	3.41	1.41	0.31		2.09	100	96.46	Icelandic
61-62 cm	EMPA-WDS	4.46	0.33	14.52	73.52	3.40	1.36	0.33		2.08	100	97.62	Icelandic
61-62 cm	EMPA-WDS	4.43	0.31	14.66	73.50	3.38	1.31	0.34		2.09	100	98.05	Icelandic
61-62 cm	EMPA-WDS	4.22	0.28	14.73	73.43	3.51	1.28	0.38		2.16	100	95.02	Icelandic
61-62 cm	EMPA-WDS	4.48	0.29	14.56	73.49	3.34	1.36	0.37		2.11	100	98.45	Icelandic
61-62 cm	EMPA-WDS	4.20	0.35	14.33	73.79	3.43	1.37	0.37		2.16	100	96.31	Icelandic

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