MAGNETIC SUSCEPTIBILITY MAPPING IN AUSTRIA: A CASE STUDY

Magnetic susceptibility mapping and further investigation of magnetic properties are used since several years to investigate the pollution influx on soils. The advantage of this method is the fast and easy spatial delimitation of heavy metal-polluted sites, due to the correlation of magnetic susceptibility and heavy metal content of soils, found in several studies in recent years. (Bityukova, et.al., 1999)

The area of investigation (Figure 1) is a valley in northern Styria, Austria, which is famous for its long history of iron mining and steel production. In the area of Vordernberg and Eisenerz, some ruins give evidence of the high time of steel industry, starting with small iron production sites built in the 13th century. Over a period of 6 centuries, iron production was the big business in this area. In the villages of Vordernberg and Eisenerz, which have now approximately 9000 inhabitants (www.eisenstrasse.co.at/…), 32 iron foundries (Figure 2) were in production in the middle of the 19th century. The last one of this iron foundries was closed just after the Second World War.

The valley was investigated along several profiles with a Bartington MS 2 D Kappameter. The exact measurement points were determined with a Trimble GPS Total Station. In order to get information only about the pollution influx from the industry, the distance to major and minor roads were kept at a minimum of 20 meters. This avoids the influence of the vehicle derived magnetic material (Hoffmann, et.al., 1999). The results of the field measurements are plotted in Figure 3.

In order to achieve more information on the origin of the magnetic materials, depth profiles were measured and soil core samples (30 cm length) were obtained. Most of the depth profiles showed enhanced susceptibility values in the topsoil. This is an important feature of anthropogenic influenced soils. (Hanesch, M. et.al., 2002) Only one depth profile showed a geogenic origin with magnetic susceptibility increasing from top to bottom. (Figure 4)

The susceptibility of the soil in the core samples was measured with a Bartington MS 2 B Sonde. These measurements built the basis for the sub-sampling for the measurements of further magnetic properties, such as Mass-specific susceptibility, the frequency dependence of the susceptibility, the high temperature behavior (Curie Points) and the isothermal remanent magnetization (IRM) behavior (Figure 5).

It is clearly visible that the magnetic susceptibility of the topsoils in the investigated area is dominated by two big anomalies.

The first anomaly in the village of Vordernberg shows the highest amplitude in magnetic susceptibility. During the field work, a layer of very dark material showing extremely high susceptibility values, with thickness ranging from 10 cm up to ~1m was found everywhere around this village. In accordance to historical reports, which says that all the houses in the village were covered with soot, this is a layer of ash and soot, a relict from the intensive iron production.

All the in-situ and core depth profiles showed anthropogenic pollution characteristics, with the highest susceptibilities in the top soil. This is also confirmed by the results of the detailed magnetic measurements on the subsamples (Table 1). Curie Temperatures (measured on exstracts) range from 580 to 605°C, the IRM Component analysis (Kruiver, et.al., 2001) showed very unstable (low coercive) components, both are indicative for technically derived magnetite-like material. Very indicative for this group of samples was a very high coercive component with $B_{½}$ at 1584 mT and enhanced values of PAH´s in geochemical analysis.

The second anomaly in the northern part, shows also high susceptibility values, but of less amplitude compared to Vordernberg. This is a result of the broader valley and therefore better wind and distribution conditions. This anomaly is also mainly caused by anthropogenic material, the depth profiles showed enhanced topsoil susceptibility (Figure 4, Profiles 4, 10) and the laboratory measurements indicate technically derived material (Table 2).

Another anomaly, spatially small and of low amplitude, was found in the "Goessgraben". For this anomaly the depth profiles showed small enhancement of susceptibility in the top soil, but also increasing values to deeper soil horizons. The influence of the high magnetic ignimbrites present in this area (Ströbl, 1980) is more indicative in the field measurements.

The IRM and Curie temperature characteristics of the geogenic minerals are disguised by the influence of the anthropogenic material, which is also present in the samples. IRM Component analysis gave evidence of two phases ($B_{½}$= 20 – 25 mT and $B_{½}$ = 79 – 125 mT) with increasing contribution of the higher coercivity component to the subsoil (Table 3).

The magnetic data was then compared with some geochemical analysis, but due to a lack of geochemical data it was not possible to find a correlation.

The different anomalies which were found in the field cannot be delimited by an absence of magnetic material. In all samples, also in them, characterized by low susceptibility values, a low coercivity component was evident, but the contribution of more stable magnetic components increases in samples from "unpolluted" areas. The anomalies differ mainly in the secondary IRM components and the amplitude of susceptibility.

References:

Bundesamt für Eich- und Vermessungswesen (BEV),2001, Austrian Map 3D 2.0

Bityukova, L., Scholger, R., M. Birke,1999, Magnetic Susceptibility as Indicators of Environmental Pollution of Soils in Tallinn: Phys. Chem. Earth (A), 24, 829-835.

Hanesch, M., R. Scholger, 2002, Mapping of heavy metal loadings in soils by means of magnetic susceptibility measurements: Environmental Geology 42, 857-870.

Hoffmann, V., Knab, M., E. Appel, 1999, Magnetic susceptibility mapping of roadside pollution: Journal of Geochemical Exploration 66, 313-326.

Köstler, H.J., J. Slesak, 1986, Die Radwerke zu Vordernberg in der Steiermark: Verlag Podmenik (in German).

Kruiver, P., Dekkers, M.J., D. Heslop, 2001, IRM-CLG 1.0 manual.

Ströbl, E., 1980, Maschinelle Interpretationshilfen in der Geomagnetik mit Anwendungsbeispielen aus dem Gebiet zwischen nördlichen Kalkalpen und Saualpe: Ph.D. Thesis, Montanuniversität Leoben (in German).

http://www.eisenstrasse.co.at/vordernberg/index.html

http://www.eisenstrasse.co.at/eisenerz/index.html

Figure 1


WIEN
LINZ
ST.PÖLTEN
SALZBURG
EISENSTADT
BREGENZ
INNSBRUCK
GRAZ
KLAGENFURT
AUSTRIA

Figure 2

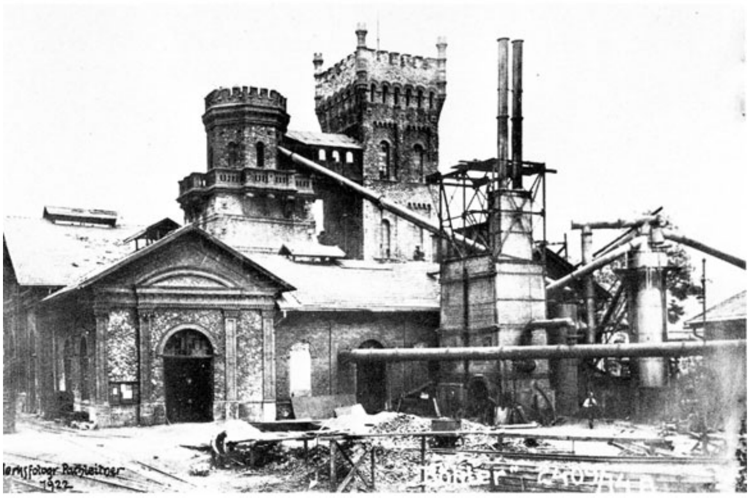

Figure 3

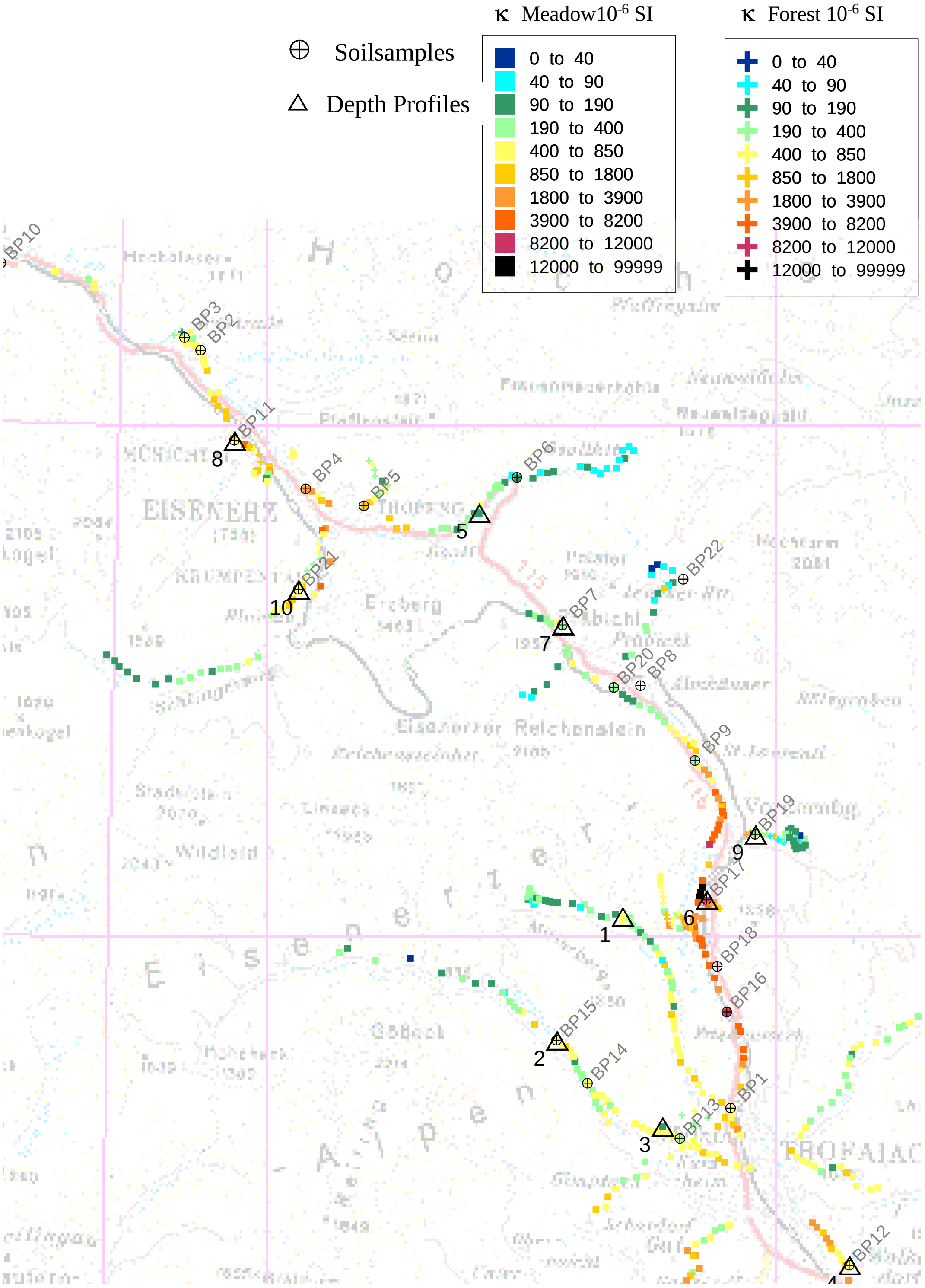
κ Meadow10^{-6} SI
0 to 40
40 to 90
90 to 190
190 to 400
400 to 850
850 to 1800
1800 to 3900
3900 to 8200
8200 to 12000
12000 to 99999
κ Forest 10^{-6} SI
0 to 40
40 to 90
90 to 190
190 to 400
400 to 850
850 to 1800
1800 to 3900
3900 to 8200
8200 to 12000
12000 to 99999
Soilsamples
Depth Profiles
BP10
BP3
BP2
BP11
BP4
BP5
BP6
BP21
BP22
BP7
BP20
BP8
BP9
BP19
BP17
BP18
BP16
BP15
BP14
BP13
BP1
BP12
EISENERZ
TROFAIAC
1
2
3
5
6
7
8
9
10

Figure 4

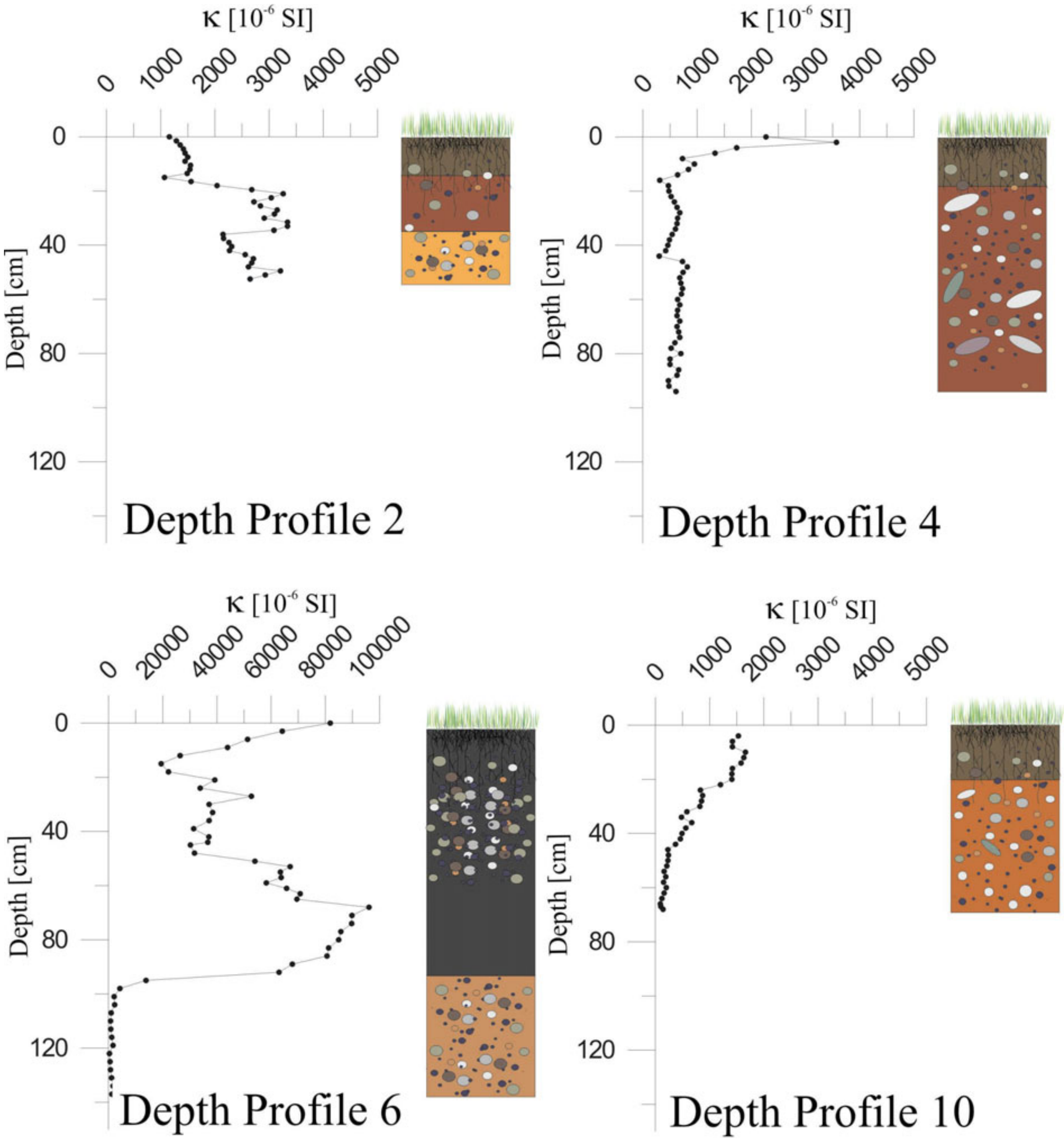
κ [10⁻⁶ SI]
0
1000
2000
3000
4000
5000
Depth [cm]
0
40
80
120
Depth Profile 2
κ [10⁻⁶ SI]
0
1000
2000
3000
4000
5000
Depth [cm]
0
40
80
120
Depth Profile 4
κ [10⁻⁶ SI]
0
20000
40000
60000
80000
100000
Depth [cm]
0
40
80
120
Depth Profile 6
κ [10⁻⁶ SI]
0
1000
2000
3000
4000
5000
Depth [cm]
0
40
80
120
Depth Profile 10

Figure 5

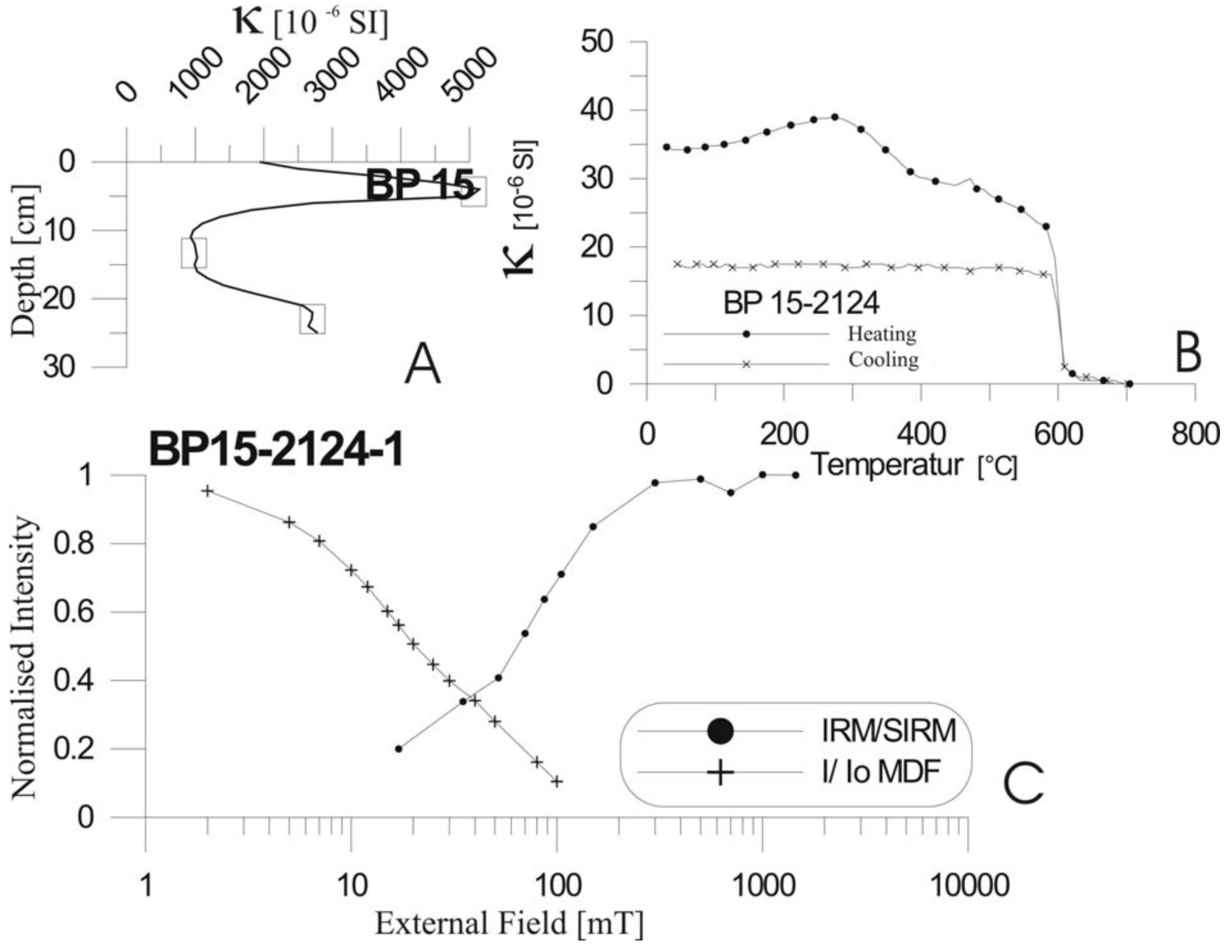
κ [10 -6 SI]
0
1000
2000
3000
4000
5000
Depth [cm]
0
10
20
30
BP 15
A
50
40
30
20
10
0
κ [10-6 SI]
BP 15-2124
Heating
Cooling
B
0
200
400
600
800
Temperatur [°C]
BP15-2124-1
Normalised Intensity
1
0.8
0.6
0.4
0.2
0
IRM/SIRM
I/ Io MDF
C
1
10
100
1000
10000
External Field [mT]

Figure 6

Table 1

Sample-name			κ [10^{-6} SI]	k [10^{-8} m³/kg]	fd [%]	SIRM [A/m]	T_c [°C]	H_{cr} [mT]
BP9	1112	1	2948	1,28	187			
BP9	2225	1	1106	1,44	43			
BP16	0912	1	21452	1,40	1141	566,62	600	15
BP16	2628	1	25548	1,36	1196			
BP17	O	1	90051	0,16		1714,74	580	15
BP17	U	1	1161	1,45	99	13,14	605	17
BP18		1	12595	1,30	620	138,93	592	15
BP19	1417	1	3018	1,25	145			
BP19	2527	1	333	0,00	12			
			IRM Comp.1	**IRM Comp.2**	**IRM Comp.3**	**IRM Comp.4**		
BP16	0912	1		20,9 (98,4 %)		1584,9 (1,6 %)		
BP17	O	1	15,8 (94,4 %)			1584,9 (5,6 %)		
BP17	U	1		22,4 (89,6 %)	316,2 (6,7 %)	1584,9 (3,7 %)		
BP18		1	17,8 (99,3 %)			1584,9 (0,7 %)		
			$IRM_{-0,3T}/IRM_{1T}$	**$(1-IRM_{-0,3T}/IRM_{1T})/2$**				
BP16	0912	1	0,982	0,991				
BP17	O	1	0,969	0,985				
BP17	U	1	0,919	0,959				
BP18		1	0,983	0,991				
			AF Comp.1	**AF Comp.2**	**AF Comp.3**			
BP16	0912	1	11,2 (93,2 %)		18,2 (6,8 %)			
BP17	O	1	8,9 (25,0 %)	10,7 (74,0 %)				
BP17	U	1	11,2 (91,4 %)					
BP18		1	10,0 (70,9 %)		14,1 (29,1 %)			

Table 2

Sample-name			κ [10^{-6} SI]	k [10^{-8} m³/kg]	fd [%]	SIRM [A/m]	T_c [°C]	H_{cr} [mT]
BP2	**0508**	**1**	1572	70	3,21	19,5	590	24
BP2	**1415**	**1**	1518	77	2,70	5,44	605	32
BP2	**2628**	**1**	473	19	3,51			
BP3	**1112**	**1**	2475	139	2,05			
BP3	**1819**	**1**	1683	80	2,02			
Sample-name			**κ [10^{-6} SI]**	**k [10^{-8} m³/kg]**	**fd [%]**	**SIRM [A/m]**	**T_c [°C]**	**H_{cr} [mT]**
BP4	**0506**	**1**	8561	367	1,68			
BP4	**1214**	**1**	7126	318	1,53			
BP4	**1921**	**1**	8699	414	1,31			
BP4	**2324**	**1**	8406	646	1,63			
BP5	**0406**	**1**	2519	137	2,37			
BP5	**1617**	**1**	3076	147	1,65			
			IRM Comp.1	**IRM Comp.2**	**IRM Comp.3**	**IRM Comp.4**	**IRM Comp.5**	
BP2	**0508**	**1**	25,1 (55 %)		60,3 (32 %)	398,1 (12,5 %)		
BP2	**1415**	**1**		35,5 (76,3%)		316,2 (15,3 %)	1258,9 (8,5 %)	
			$IRM_{-0,3T}/IRM_{1T}$	**$(1-IRM_{-0,3T}/IRM_{1T})/2$**				
BP2	**0508**	**1**	0,875	0,938				
BP2	**1415**	**1**	0,767	0,883				
			AF Comp.1	**AF Comp.2**	**AF Comp.3**			
BP2	**0508**	**1**	11,2 (86,0 %)		15,8 (14,0 %)			
BP2	**1415**	**1**		13,2 (91,5 %)	15,8 (8,5 %)			

Table 3

Sample-name			**κ [10^{-6} SI]**	**k [10^{-8} m^3/kg]**	**fd [%]**	**SIRM [A/m]**	**T_c [°C]**	**H_{cr} [mT]**
BP15	**0406**	**1**	4250	262	1,26	94,68	595	
BP15	**1115**	**1**	2829	215	1,56	17,74		40
BP15	**2124**	**1**	2864	108	1,24	10,45	600	38
			IRM Comp.1	**IRM Comp.2**	**IRM Comp.3**			
BP15	**0406**	**1**	20,0 (81,3 %)	79,4 (18,8 %)				
BP15	**1115**	**1**	25,1 (44,4 %)		125,9 (55,6 %)			
BP15	**2124**	**1**	20,0 (47,6 %)		100,0 (52,4 %)			
			$IRM_{-0,3T}/IRM_{1T}$	**$(1-IRM_{-0,3T}/IRM_{1T})/2$**				
BP15	**0406**	**1**	0,993	0,997				
BP15	**1115**	**1**	0,924	0,962				
BP15	**2124**	**1**	0,983	0,991				
			AF Comp.1	**AF Comp.2**	**AF Comp.3**	**AF Comp.4**		
BP15	**0406**	**1**						
BP15	**1115**	**1**		12,6 (54,0 %)	17,8 (21,6%)	79,4 (24,3 %)		
BP15	**2124**	**1**	10,0 (45,2 %)	11,2 (9,0 %)	18,2 (7,2 %)	79,4 (38,6 %)		

Figure 1: Map of Austria with area of investigation (red rectangle); (from AMap 3 D, BEV, 2001)

Figure 2: Iron Foundry in Vordernberg (Radwerk 14), built in 1554, production stop in 1922 (Köstler, et.al.,1986)

Figure 3: Distribution of surface susceptibility on meadow (boxes) and forest (crosses) soils. Indicators for soil sample and soil profile position

Figure 4: Susceptibility in depth profiles with sketches of soil horizons observed in the field . All profiles except profile 2 are showing anthropogenic characteristics. Depth profile 2 is influenced by highly magnetic ignimbrite (Ströbl, 1980). Profile 6 is in the center of Vordernberg. Please note the different scale of x-axis. At the position of this profile, the highly magnetic layer, which was found all over the valley, reaches maximum thickness. Profile 4 and 10 are from the area around Eisenerz.

Figure 5: Determination of magnetic parameters. A: Measurement of susceptibility on soil cores, boxes mark the position of subsamples; B: High temperature susceptibility on extracts from subsamples; C: IRM acquisition and AF demagnetization of SIRM on subsamples; see Table 1,2 and 3 for data on all samples

Figure 6: Depht profile 6 with layer of ash and soot (black)

Table 1: All magnetic parameters for the samples from Vordernberg; κ is Volume susceptibility; k is mass-specific susceptibility, fd is frequency dependence of susceptibility (fd = 100* ((k_{lf} – k_{hf})/k_{lf}), SIRM is saturation remanent magnetization at 1450 mT; Tc is Curietemperature (determined by physical definition), Hcr is Coercivity of remanence, IRM / AF Comp are Components determined with IRM-CLG; BP 17 O is a Topsoil sample; BP 17 U is a Subsoil sample

Table 2: All magnetic parameters for the samples from Eisenerz; for description of parameters see Table 1

Table 3: All magnetic parameters for the samples from Goessgraben; for description of parameters see Table 1