GEMAS: A European scale geochemical atlas for environmental management and mineral exploration

Clemens Reimann

40 Years Listening to the Beat of the Earth
2007: Eurometaux contacts EuroGeoSurveys:

Land-use related geochemical data needed at the European scale for REACH (Registration, Evaluation, Authorisation and restriction of Chemical substances)

2 sample materials at 1 site/2500 km²
<2 mm fraction
aqua regia extraction

agricultural soil (Aₚ-horizon), 0-20 cm

grazing land soil, 0-10 cm
GEMAS - 2008

Agricultural soil ($A_p$) 0-20 cm
N= 2108

Grazing land soil ($Gr$) 0-10 cm
N= 2024

33 countries - 5.6 million km$^2$ - 4132 samples in total

EuroGeoSurveys - The Geological Surveys of Europe
GEMAS: Analytical Programme

- pH_{CaCl_2}, CEC, TOC, LOI, grain size, Pb isotopes (7N HNO_3 extraction, Ap-samples), Sr isotopes (in progress), Magnetic susceptibility (Ap-samples), Kd-values (for 14 metals), MIR spectra
Accreditation or External Quality Control?

Randomised samples
Project standard(s)
Duplicates

Random plot should show random variation

X-Chart for the project standard

Ring test: results from 14 laboratories on the same sample. True value? Bias?
GEMAS: the maps are robust

**Lead:** Two independent sample materials show comparable patterns. Large difference between N- and S-Europe.
Soil parent material
(based on the European Soil Geographical Database 1:1 Million)

- alluvium/colluvium
- calcearous rocks
- clayey materials
- crystalline rocks
- detrital formations
- glaciofluvial materials
- loamy/silty
- marl
- other/organic
- sandstone/flysch/molasse
- sandy materials
- schists
- volcanic rocks

(C) Günther et al., 2013
GEMAS: supporting information

Precipitation (+ temperature + snow cover, etc.)

Population density (+ road network + mineral deposits + location of metal smelters, power plants, etc.)
GEMAS: total concentration, major elements

**Calcium (XRF):** limestone, note
Fennoscandia

**Silicon (XRF):** sandstone, coarse-grained sandy soil
GEMAS: distribution of rock types in Europe

**Cr (aqua regia):** ophiolite, greenstone belts, mafic volcanic rocks  
**Rb (XRF):** granitic intrusions
GEMAS: soil properties

+ eCEC + clay + Kd... – these parameters determine the availability of metals in soils
At the European scale climate is important, e.g. element enrichment in organic soil in coastal areas.

Sulphur (aqua regia): coast and organic material in soil

Selenium (aqua regia): strong coastal effect
GEMAS: source of anomalies

Ore deposits: 1, 3, 7, 8, 9, 12, 13, 14, 15, 16, 18, 19, 21, 24, 25, 26, 27, 20, 31, 33, 34, 35, 36, 37, 38, 39, 42, 44, 47, 53

Geology: 5, 20, 28, 29, 40, 41, 43, 46, 48

Cities: 2, 10, 11, 23, 49

Contamination: 6, 17, 32, 50, 51, 52

Unexplained: 4, 22, 45

EuroGeoSurveys - The Geological Surveys of Europe
GEMAS: isotopes show geological history

$^{206}\text{Pb}/^{207}\text{Pb}$ lead isotope ratio

- depicts geology
- some minor anthropogenic signals may be discernible (e.g., London, Paris, Amsterdam?)
- note the overall low values for the UK
GEMAS: source of anomalies

Ore deposits:
1, 3, 7, 8, 9, 12, 13, 14, 15, 16, 18, 19, 21, 24, 25, 26, 27, 20, 31, 33, 34, 35, 36, 37, 38, 39, 42, 44, 47, 53

Geology:
5, 20, 28, 29, 40, 41, 43, 46, 48

Cities:
2, 10, 11, 23, 49

Contamination:
6, 17, 32, 50, 51, 52

Unexplained:
4, 22, 45
GEMAS: mineral exploration

The mineral system model (Knox-Robinson & Wyborn 1997)
Mo: interesting anomalies in northern Europe – indications for ore deposits?

Au: the „gold line“ in Scandinavia is visible
GEMAS: mineral exploration

**Arsenic:** central Scandinavia - since 2003 eleven new massive sulfide deposits were found along the fringes of this 200,000 km² anomaly – the pattern is underlain by a heat flow anomaly.

Source: Baltic Soil Survey, Reimann et al. 2003
GEMAS: mineral exploration

**Pt**: Italian alkaline volcanic province causes the largest anomaly

**Na**: displays a major anomaly in N-Scandinavia, in the most prospective area
**GEMAS: mineral exploration**

**Aqua regia Fe:** no sign of the major iron ore provinces in N-Europe

**MMI-available Fe:** a major anomaly in N-Scandinavia
GEMAS: different analytical methods

**Zr (aqua regia):** note the Italian alkaline volcanics

**Zr (XRF):** the central European loess belt is visible
Pinatubo eruption in 1991 within 2 days:

- 10,000,000,000 t magma
- 20,000,000 t SO$_2$
- 2,000,000 t Zn
- 1,000,000 t Cu
- 550,000 t Cr
- 300,000 t Ni
- 100,000 t Pb
- 10,000 t As
- 5,500 t Cd
- 800 t Hg

60 volcanic eruptions per day

>3000 active vent fields at mid-ocean ridges

Photo: ©Daniela Szczepanski
GEMAS: volcanic impact

**TI (aqua regia):** note the Italian alkaline volcanic province
Selenium: health aspects

Selenosis in Limerick (cattle, horses)

Se deficiency is widespread in Finland, Sweden, Denmark

Se toxicity is more of a problem in animal husbandry

Se toxicity in drinking water (Reggio)

Practically no anthropogenic impact detected (note Finland!)
GEMAS: element deficiency

**Copper (aqua regia):** >10% of all values <10 mg/kg

**Zinc (aqua regia):** 5% of all values <12 mg/kg
Zinc (Zn) is an essential micronutrient. Zinc deficiency is widespread in soil. Nearly 50% of the soil on which cereals are grown have levels of available Zn low enough to cause Zn deficiency – <1% of the samples reach possibly toxic values. 

Source: Alloway (2008)
Boxplot comparison of nickel concentrations (aqua regia) in the participating countries (red: Ap, 0-20 cm; green: Gr, 0-10 cm)
GEMAS: anthropogenic impact

Cd (MMI extraction): anthropogenic pressure becomes visible

V (MMI extraction): input via sewage sludge? (+ Fe deposits in Scandinavia)
GEMAS: the most recent results

GEMAS Ap samples:
Magnetic measurements at Kazan Federal University, Tartastan, Russia - magnetic measurements provide an extremely detailed picture of the iron mineralogy which in soils is a sensitive fraction indicating lithology and environmental conditions.

Acquired data
- Magnetic susceptibility
- Magnetic hysteresis curves up to 1.5 T
- Magnetic remanence acquisition up to 1.5 T

The measured data provide many different magnetic parameter sets that can be mapped.

Fascinating maps are emerging, demonstrating that low density sampling & mapping functions not only for geochemistry.
Saturation magnetization $M_s$ reflects the ferrimagnetic mineral concentration; it is probably dominated by magnetite-titanomagnetite content.

High field slope indicates the dia/paramagnetic minerals; it is probably dominated by non-ferrimagnetic Fe-minerals.
Hc and Hcr are intensive quantities (independent of material concentration) - they reflect the average magnetic hardness of the ferrimagnetic phase (Hc) and the remanence carriers (Hcr).
GEMAS: risk assessment

**Cu (Ap):** 1.3% of samples at risk (RCR > 1) – mostly soil in vineyards

**Mo (Ap):** only 1 site at risk – location of Europe’s largest Mo deposit
GEMAS: some key results

- Evidence for diffuse industrial contamination?
- Evidence of other anthropogenic impacts?
- What levels of potentially harmful elements?
- Element deficiencies?
- Differences between the European countries?
- Geology and/or climate reflected?
- Consequences for mineral exploration?
Successful Large Scale Mapping Projects