On the origin of superparamagnetic minerals of tropical soils and their impact on landmine detection

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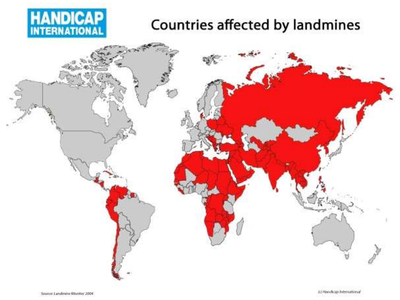
Motivation

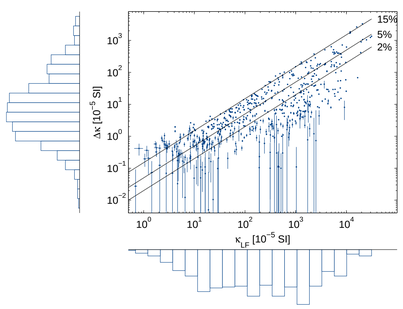


Metal detectors are the most frequently used devices for landmine detection. They are based on the principle of electromagnetic induction (EMI). Soils in which the landmines are buried may have a negative impact on detector performance dependig on their magnetic properties. Besides the absolute value of magnetic susceptibility [1] its frequency dependence is also of crucial importance [2]. From a worldwide perspective, the tropics are the regions which are mostly affected by landmines. Soils in this regions are highly weathered and they are the soils with the most distinct magnetic properties. Up to now, there is no classification system that can be used to predict the impact of tropical soils on landmine detection.

Magnetic soil properties

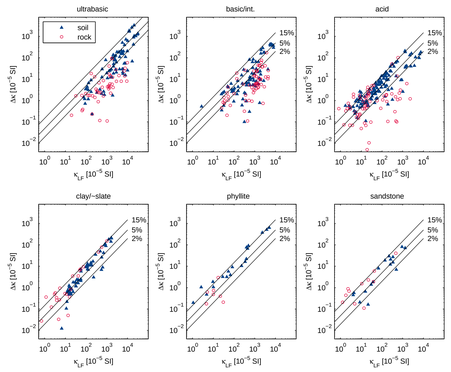
- governed by content of ferrimagnetic minerals: magnetite, titanomagnetite, maghemite
- lithogenic or pedogenic origin
- various mineral-grain size: multidomain (MD), stable single domain (SSD), superparamagnetic (SP)
- ultra-fine grained SP minerals cause frequency dependent susceptibility
- main source of SP minerals: neoformation during soil genesis
- resiual enrichment of lithogenic SP minerals is also possible
- frequency dependent susceptibility ⇒ negative effect on EMI sensors (low detection depth, low probability of detection, high false alarm rate)

Dataset

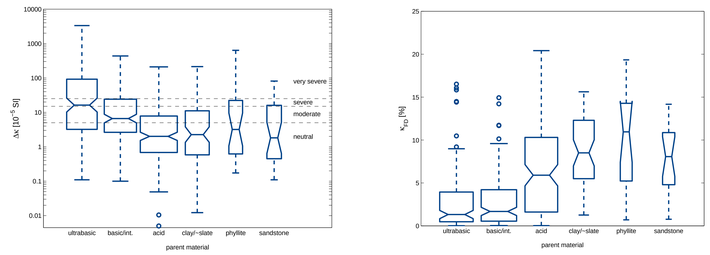


We measured frequency dependent susceptibility on 594 samples of soils and their parent material which were collected from the world's tropical belt. The samples include unweathered and weathered rocks, subsoils, and topsoils. They comprise a variety of silicatic parent rock groups. Absolute frequency dependent susceptibility $\Delta\kappa = \kappa_{LF} - \kappa_{HF}$ of all samples is plotted vs. κ_{LF} ($_{LF}/_{HF}$ = 465/4650 Hz).

Influence of parent material



The samples were grouped according to their parent material. Within each group soils show higher susceptibilities and frequency dependence than the associated parent rocks. This is a clear indication for the influence of pedogenesis on magnetic properties. The variability within the groups is caused by variable chemical and mineralogical composition of the parent material and variable degree of alteration (see influence of weathering).



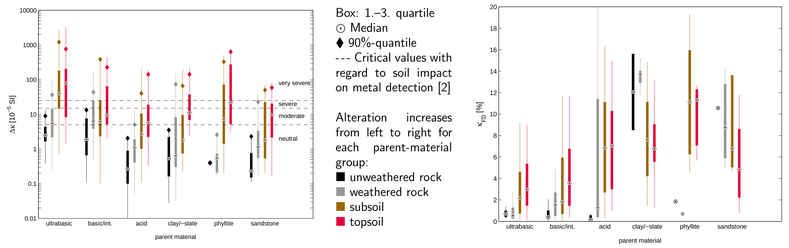
Absolute frequency dependence $\Delta\kappa$ (left) is a measure of the total amount of SP minerals in a sample and relative frequency dependece $\kappa_{FD} = \Delta\kappa/\kappa_{LF}$ (right) represents the concentration of SP minerals within the total of magnetic minerals.

- **ultrabasic + basic/intermediate origin:**
  high absolute and low relative frequency dependence
  ⇒ magnetic properties governed by lithologic minerals (MD, SSD, some SP) that were formed during crystallisation of Fe-rich magma and have been enriched during soil genesis
- **acid + sedimentary origin:**
  low absolute and high relative frequency dependence
  ⇒ magnetic properties governed by ultra-fine grained SP minerals that are formed during pedogenesis

References

[1] Preetz, H., Altfelder, S. & Igel, J., 2008. Tropical Soils and Landmine Detection – An Approach for a Classification System. Soil Sci. Soc. Am. J., 72,1: 151–159.
[2] Das, Y., 2006. Effects of Soil Electromagnetic Properties on Metal Detectors. IEEE Trans. Geosci. Remote Sens., 44,6: 1444–1453.
[3] CEN (European Committee for Standardization), 2008. Humanitarian Mine Action – Test and Evaluation – Part 2: Soil characterization for metal detector and ground penetrating radar per-formance, Workshop Agreement (CWA) 14747-2, available at: http://www.itep.ws/pdf/CWA_soil_characterization.pdf. European Committee for Standardi-zation.

Influence of weathering



Box: 1.–3. quartile
⊙ Median
♦ 90%-quantile
--- Critical values with regard to soil impact on metal detection [2]

Alteration increases from left to right for each parent-material group:
- unweathered rock
- weathered rock
- subsoil
- topsoil

Absolute (left) and relative frequency dependence of susceptibility (right). For each parent material the data are arranged as: unweathered rock, weathered rock, subsoil, topsoil.

- within **each parent-material group** absolute frequency dependence increases with alteration
  ⇒ increase of SP minerals by residual enrichment or neoformation
- **igneous rocks:** relative frequency dependence increases with alteration
  ⇒ neoformation of SP minerals
- **sediments:** frequency dependence is high regardless of alteration
  ⇒ weathering and neoformation of SP minerals balance each other

Prognosis of soil impact on demining

Parent material	Regardless of weathering	Degree of weathering: unweath. rock	weath. rock	subsoil	topsoil
Ultrabasic	■■	■■	■■	■■	■■
Basic/intermediate	■■	■■	■■	■■	■■
Acid	■■	■■	■■	■■	■■
Clay/clay-slate	■■	■□	■■	■■	■■
Phyllite	■■	□ –	■□	■■	□□
Sandstone	■■	□□	■□	■□	■□

Soil classification regarding influence on landmine detection:
■ neutral, ■ moderate, ■ severe, ■ very severe, – no data, □ only few data. The first and second symbol in each column are deduced from the median and 90%-quantile, respectively.

- frequency dependent susceptibility is rated according to its impact on metal detectors
- the first symbol represents an average influence; the second the influence in a more extreme scenario
- the system can be used by demining organisations to evaluate the soil influence on detection technique prior to a mine-clearance campaign
- the parent material can be determined by either geologic or pedologic maps or by consulting a geoscientist on site
- detector models can be selected that are suitable for a specific region
- other detection methods than EMI may be used in regions with extreme magnetic properties

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