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Neo-formation of a ferrimagnetic phase during thermal degradation of plant tissues: implications for the magnetic properties of top soils

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During thermal degradation of plant tissues under controlled atmosphere the neo-formation of a ferrimagnetic phase was observed. The results of this pilot study may at least partly explain the well known phenomena of magnetic enhancement in top soils.

Since the pioneering work of Le Borgne (1955) the possible influence of fire on the magnetic properties of top soils in particular and the natural environment in general has been the subject of research. Le Borgne argued that the very often unexpectedly high magnetic top soils got their properties via the neo-formation of ferrimagnets (maghemite) through the reduction of Fe-oxides by heating in natural fires. Similarly, magnetic enhancement in Pleistocene palaeosols of the Chinese Loess Plateau has been explained by the regular occurrence of fire during the interglacials when the biomass was several times bigger than during dry and cold glacial periods due to moist and temperate conditions (Kletetschka and Banerjee 1995). However, also thermal degradation of plant tissues itself has previously been proposed as possible source of ferrimagnetic phases in the environment (McClean and Kean 1993).

Here we report on thermal degradation experiments of grass, beech leafs, pine needles, branches and bark under controlled atmospheric conditions. The plant matter was collected in spring 2009 in a forest and grassland area south of Bayreuth, Germany, and air dried. The thermal degradation experiments were conducted using a quartz glass tube placed inside a well shielded demagnetization furnace. During the experiments different mixtures of air and nitrogen were applied in a constant flux to study the effect of the availability of oxygen on the thermal degradation process. The plant tissues were heated up to eight different maximum temperatures ranging from 200 to 700° C and subsequently cooled down to about 30° C. Each maximum temperature was kept constant for 15, 60 and 180 minutes, respectively. Onto heating the degradation products were carefully crushed using non magnetic tools and filled into standard palaeomagnetic sample boxes and fixed with diamagnetic wax. Initial magnetic susceptibility was measured at fields of 300 A/m and at frequencies of 300, 3000 and 800, 8000 Hz, respectively. Isothermal remanent magnetisation (IRM) at fields of 300 and 2000 mT as well as anhysteretic remanences (ARM) acquired in a 100 mT AC field and a 50 μT DC bias field were determined. All values were normalised to both, the mass of the raw material before heating and the mass of the degradation product after each heating step.

Up to 300° C values of susceptibility, IRM and ARM are very low and near to the detection limit. At higher temperatures the values increase constantly being at 600° C at least one order of magnitude higher depending on the raw material. The peak temperature has a significant influence on the concentration of the newly formed magnetic phases, whereas the influence of heating duration is negligible. A significant frequency dependence of susceptibility could not be observed. The newly formed phases are characterised by a constant ARM/IRM-ratio and an IRM-saturation already well before 300 mT. The concentration dependent magnetic parameters and their mineral and grain size specific ratios reveal the neo-formation of a ferrimagnetic phase mainly in single or pseudo-single domain state. Highest concentrations were observed in thermal degradation products of beech leafs and grass. Forthcoming experiments will hopefully help to evaluate the relevance of these results for the understanding of the complex processes that lead to magnetic enhancement in top soils.

Kletetschka and Banerjee 1995. Geophysical Research Letters 22, 1341–1343.
Le Borgne 1955. Annales de Géophysique 11, 399–419.
McClean and Kean 1993. Earth and Planetary Science Letters 119, 387-394.