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Iron oxides as pedoenvironmental indicators: state of the art, answers and questions (Philippe Duchaufour Medal Lecture)

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The colour and magnetic properties of soils largely reflect the content and mineralogy of their iron oxides, which in turn relate to the physical, chemical and biological characteristics of the soil environment. For more than 50 years, soil mineralogists and chemists have collected data for iron oxides in soils formed in widely different environments and tried to understand the complex nature of the different suites and formation pathways for these minerals via laboratory experiments.

The discovery of ferrihydrite —the poorly crystalline precursor of most Fe oxides— in 1971, and the recognition of its common presence in soils, raised interest in deciphering the environmental factors that affect its transformation into goethite and hematite, the two most abundant crystalline iron oxides in soil. Field observations were consistent with laboratory experiments in which temperature, water activity, pH, foreign ions and organic matter were found to play a key role in the crystallization of ferrihydrite. Thus, the hematite/(hematite + goethite) ratio increased with increasing temperature and also with the likelihood of seasonal soil drying. Exploiting this ratio as a (pedo)environment indicator is, however, not devoid of problems derived from insufficient knowledge of the interactions between the influential chemical variables, difficulties in quantifying the two minerals and changes brought about by reductive dissolution.

Soil formation usually leads to magnetic enhancement as a result of the production of magnetite and/or maghemite, which are ferrimagnetic iron oxides, and, possibly, an ordered ferrimagnetic ferrihydrite, as suggested by recent laboratory experiments. The concentration of pedogenic ferrimagnets as estimated via proxies such as magnetic susceptibility or frequency-dependent magnetic susceptibility has been found to relate to climate variables [particularly (paleo)rainfall] in many studies reported over the last 30 years. However, extracting accurate environmental information from magnetic data is hampered by a still incomplete understanding of (i) the pathways through which pedogenic ferrimagnets are formed, and the chemical and biological factors that affect them; and (ii) the genetic relationships between ferrimagnets and other iron oxides. Competing hypotheses on these issues will be presented and their usefulness for pedoenvironmental interpretations discussed.