10 Conclusions

This study of the magnetic properties of one soil profile and sediments from three kettle lakes shows the value of Rock magnetic measurements for paleoclimate- or paleoenvironmental reconstruction. Sediment magnetic properties depend on a combination of geological, biological and climatic processes. They can complement and strengthen the results obtained by other techniques such as diatom-, ostracod- or pollen analyses, isotope geochemistry, or sedimentology.

Soil Profile, PBGP-95

Studies of the soil profile within the watershed of Pittsburg Basin show that the modern soil is enhanced in fine-grained (SD and SP) maghemite. This enhancement is reflected in increased concentration-dependent parameters such as magnetic susceptibility, SIRM or saturation magnetization, and increased values of frequency-dependent susceptibility χ_{FD} and ARM/SIRM. The enhanced phase is caused by the weathering of iron- bearing weakly ferrimagnetic or paramagnetic minerals and their transformation into ferrimagnetic maghemite.

The Farmdale paleosol is poorly expressed in this site and cannot be recognized on the basis of magnetic parameters. The Sangamon paleosol, on the other hand, shows well developed B-horizons and a strong signal of magnetic enhancement. This soil horizon extends into various kinds of parent material (loess, gravel, sand) and consists of at least two welded soil profiles. The interpretation of its magnetic signal is therefore more complicated. The magnetic signal is due to two processes: The translocation of fine-grained magnetic particles from the overlying Roxana silt into the Hagarstown gravel, and the pedogenic enhancement of the older gravel layers prior to the deposition of Roxana loess. Today the soil horizons are enriched in fine-grained hematite. The degree of pedogenesis that occurred in these horizons is probably underestimated when compared to soils and paleosols where the magnetic signal is due to the presence of strongly magnetic maghemite or magnetite.

Pittsburg Basin and Catfish Pond

Several cores have been recovered from these two lakes. Palynological analyses suggest that the Pittsburg Basin record spans the last interglacial-glacial cycle, while Catfish Pond sediments recorded climatic variations during the Wisconsinan and Holocene periods.

Rock magnetic parameters correlate well with the climatic information obtained through other techniques. Early postglacial sediments are characterized by high concentrations of coarse-grained (titano)magnetite similar to the magnetic particles found in the glacial sediments surrounding the lake. Interglacial sediments show variable concentrations of magnetic minerals but are generally finer-grained with an additional SD and SP component. Organic-rich sediments that were deposited during the early Sangamon when the area was covered by deciduous forest show a fine-grained (SD and SP) authigenic magnetite component, which was likely produced or mediated by bacterial activity. During the following prairie period the influx of terrigenous material and the concentration of magnetic minerals increased. The magnetic component of these sediments consists of fine-grained (SD and SP) maghemite. It is possible that this fine-grained component resulted from the erosion of pedogenically enhanced soil horizons that were formed during earlier periods of the Sangamon. The upper part of the Sangamon sediments shows a return to forested conditions, which is reflected in low concentrations of magnetic minerals. The grain-size information, however, is destroyed by the effects of subaerial weathering and a fluctuating water table, which occurred during the Wisconsinan glacial period. Low lake levels during this dry period caused the loss of the fine-grained magnetic component by reductive dissolution, but also the preservation of magnetically hard hematite in the sediment. Low lake levels during this period are also responsible for several hiatuses during the Wisconsinan glacial age. Drainage of the lake in the beginning of this century resulted in a fluctuating water table and loss of most of the magnetic information due to redoximorphic processes.

The magnetic record of Catfish Pond also shows the effects of fluctuating water tables and low lake levels, and hiatuses were likely to occur throughout the record. All of the sediments, except the uppermost meter are coarse-grained and show little variation. The magnetic properties of these sediments are very similar to their glacial counterparts in Pittsburg Basin. The youngest sediments are characterized by an increase in fine-grained material, which is caused by high erosion and lack of dissolution.

<u>Paleoclimate in Illinois</u>

Our multi parameter investigation of lake sediments from Illinois generally confirms the sequence of climatic change as outlined by previous studies [*Grüger*, 1972a; *Zhu and Baker*, 1995]. Our correlation of the Pittsburg Basin record to a speleothem record from Crevice Cave, Missouri, however, offers two alternative age models for the timing of climatic change in the midcontinental U.S.. Interglacial pollen assemblages can either be correlated with a time period approximately corresponding with marine isotope stage (MIS) 5e, or they can be extended throughout the entire MIS 5 and probably include parts of MIS 4.

<u>Kirchner Marsh</u>

The sedimentary record of Kirchner Marsh begins with the retreat of the Laurentide ice sheet from the region (13.3 ka) and extends throughout most of the Holocene. Today the former lake is a wetland and the record does not quite extend into modern time. Despite the difference in sediment age, the sedimentological and sediment-magnetic development is remarkably similar to the early record of Pittsburg Basin. The onset of sedimentation is characterized by organic poor sediment, rich in coarse-grained (MD) magnetite. Once the basin is covered with deciduous forest the input of terrigenous material decreases and the magnetic properties of the sediment are dominated by an authigenic component of fine-grained (SD and SP) magnetite. The hypsithermal prairie period led to an increase in terrigenous material, but fluctuating lake levels caused a magnetic signal similar to the one observed at Pittsburg Basin during the Wisconsinan dry period. Magnetic measurements reflect higher concentrations of coarse-grained magnetic minerals and a shift towards more hematite rich sediment, which indicate subaerial weathering conditions. Once the basin was again covered by deciduous forest, the principal magnetic component became authigenic fine-grained magnetite.

Links between Paleoclimate and Sediment Magnetic Properties

Based on the similar sediment magnetic responses of all three lakes to climatic variations I outline below several processes that are likely to link paleoenvironmental to sediment-magnetic variations in small kettle lakes. The processes discussed here cause relative changes in magnetic mineralogy, concentration and particle- size distribution. They are highly idealized and will need further verification by additional field data.

During the earliest stage of a kettle lake high erosion rates combined with low productivity lead to sediments that are high in terrigenous material and detrital magnetic minerals. This magnetic component is dominated by the magnetic properties of the source material, which, in these cases was coarse-grained (titano)magnetite.

Warm periods, when densely vegetated slopes reduce erosion and productivity of the lake is high, are characterized by organic-rich sediments that have low concentrations of magnetic minerals. This magnetic component tends to be fine-grained (SP and SD) magnetite, which is likely of authigenic biomediated origin. This authigenic component may be present throughout the history of the lake but is likely to be overshadowed by a much stronger terrigenous component of coarse-grained material during times of high erosion.

Dry periods can have various effects on the sediment magnetic properties. Changes in vegetation in the basin can change erosion rates and increase terrigenous input. The magnetic properties of the lake sediments can then depend on the composition of the source material. Erosion of paleosols that are enhanced in fine-grained maghemite might lead to a relatively fine-grained magnetic assemblage. This process can explain the magnetic signal observed during the Sangamonian prairie period in Pittsburg Basin. Low and fluctuating lake levels can cause the redeposition of older lake sediments, which might have been affected by earlier diagenetic loss of iron oxides. These sediments tend to have lower concentrations of magnetic minerals than the unaltered source material. Furthermore, because they often lost part of their magnetic minerals due to dissolution, they tend to be coarser-grained. This scenario explains the magnetic properties of sediments deposited during the Holocene hypsithermal period in Kirchner marsh. A shift in mineralogy towards more stable iron-titanium oxides (e.g. ilmenite) might also be possible. Subaerial weathering and a fluctuating water table can also cause loss of iron oxides, combined with an increase in hematite in the sediment. Unfortunately, periods of low lake levels do not only cause hiatuses in the sedimentary record, they also affect older sediments and can erase part or all of the magnetic signal.

Recent sediments are often characterized by extremely high erosion rates due to human disturbance of local vegetation. These sediments tend to be very rich in magnetic minerals and are generally finer-grained than older sediments deposited under similar conditions because they have had less time to be affected by dissolution of fine-grained material.

Useful Techniques for the Characterization of the Magnetic Component

Rock magnetic techniques used for initial core studies should be fast and nondestructive since it is desirable to process a large number of samples which often have to be returned to colleagues for further studies. The following list is a suggestion of useful techniques. The list is not complete and will have to be supplemented by other experiments to answer specific questions. Magnetic measuremnts should be conducted as soon as possible to prevent laboratory diagenesis of iron-oxide minerals. An initial set of Rock magnetic experiments could include measurements of

- initial weight (water content)
- magnetic susceptibility (concentration of magnetic minerals, normalization parameter)
- ARM (fine-grained SD, PSD particles)
- SIRM (concentration of magnetic minerals)

- S-ratios (mineralogy)
- hysteresis loops (grain size, mineralogy, high-field and ferrimagnetic susceptibility)

This set of measurements gives a rough idea about the abundance of magnetic minerals in the sediment, grain-size distribution and the presence of magnetically soft or hard minerals. Hysteresis loops are listed as an initial measurement, assuming that an instrument that allows for large sample throughput is available. Otherwise one might perform fewer hystersis loops on selected, representative samples.

A second set of more time-consuming measurements would further attempt to characterize the magnetic mineralogy and give further grain-size information:

- frequency-dependent susceptibility (presence of SP grains)
- low-temperature experiments (detection of phase transitions, Néel points, mineralogy and presence of SP grains)

It is also possible to (freeze) dry the samples prior to the low-temperature experiments. This allows for the calculation of, and often more meaningful, mass-normalized parameters and prevents time-consuming freeze-ups of instruments during low-temperature experiments. Frequency-dependent susceptibility is listed as a slow measurement because it is assumed that χ is to be measured at more than two frequencies in order to gain increased accuracy and an estimate of the quality of the measurement.

Finally, a set of chemically or texturally destructive measurements such as the preparation of SEM or XRD samples from magnetic extracts can be performed to further clarify the mineralogy of the samples. High temperature experiments such as thermal demagnetization curves or Curie temperature measurements can also be conducted, but they may be of little use when dealing with lake sediment due to the thermal alteration of the sample.

Rock magnetic Measurements as a Tool for Paleoclimate Reconstruction

Magnetic properties of lake sediments can reflect climatic change and are a useful tool for the reconstruction of paleoenvironmental change. Future work should include an extension of sediment-magnetic studies to other lakes and lake types (e.g. saline, larger size, tropical etc.) and the development of a more or less standardized set of measurements. Standardization would guarantee a certain baseline of magnetic information and allow for easier comparison of different sites. Expansion to other lakes will increase our knowledge about the processes that link sediment magnetic properties and paleoenvironmental change, which in turn will allow us to use magnetic techniques as a rapid method for paleoclimate reconstruction.