6 Magnetic Record of Catfish Pond

6.1 Introduction

The Holocene and Late-Wisconsinan record of Pittsburg Basin are severely damaged by oxidation due to the drainage of the lake in the early 20th century. Catfish Pond is a small lake, approximately 5 km NE of Pittsburg Basin (Figure 3.1), and it was cored to fill in the gaps of the paleoenvironmental record of Pittsburg Basin. The lithology of the cores CFP-1 and CFP-2 has already been discussed in chapter 3 (Figure 3.8). Detailed study of the cores revealed that many of the sediments are disturbed either by wave action or (bovine) bioturbation. At present Catfish Pond has a water depth between 0.5 - 1 m and a smaller watershed than Pittsburg Basin. Its sedimentary record is likely to contain many hiatuses and some dry periods are probably not recorded.

Section 6.2 gives a detailed overview of the magnetic properties of Catfish Pond sediments and their interpretation in terms of magnetic mineralogy, concentration and grain-size. A paleoenvironmental interpretation of the magnetic and palynological findings is presented in section 6.3. This section is quite brief, since most of the interpretation is presented in chapter 7.

6.2 Magnetic Properties

6.2.1 Magnetic Mineralogy

The magnetic mineralogy has been characterized by a combination of magnetic analyses, including Curie temperature and low-temperature magnetic measurements, hysteresis loops and the determination of S-ratios. Figure 6.1 shows several Curie temperature measurements. All samples have final Curie temperatures between 570 and 580°C, indicating the presence of (titano)magnetite or maghemite, but several samples show additional drops in magnetic moment near 320°C (indicated by arrows in Figure 6.1), which may be due to small amounts of pyrrhotite. All samples have higher magnetic moments after being heated to 650/700°C, which is due to the conversion of a weakly magnetic phase into magnetite.
Fig. 6.1: Curie temperature measurements for samples from Catfish Pond. Arrows indicate slight drops in magnetic moment that might be due to the presence of pyrrhotite.
Fig. 6.2: Thermal demagnetization curves of low-temperature SIRM. Only a) shows a distinct Verwey transition, but a slight transition is present in all samples as can be seen from the gradient of the demagnetization curve. The change in gradient above 270 K may be related to the thawing of the wet sample.
Thermal demagnetization curves of low-temperature SIRM (Figure 6.2) show a distinct Verwey transition between 100K and 120K only for the uppermost samples (above 100 cm depth). All other samples show only a slight change in magnetic remanence, which is revealed in the first derivative of the demagnetization curve (open symbols in Figure 6.2). Gradient curves for samples above 100cm show transitions that are smeared out towards lower temperatures, while the samples below 100cm have Verwey transitions close to 120K.

Most samples from Catfish Pond have S-ratios below 1.0 (Figure 6.3), suggesting the presence of an additional magnetically harder mineral besides magnetite or maghemite. A plot of remanence ratios ($M_{r}/M_{s}$) vs. coercivity ratios ($H_{c}/H_{c}$) (Figure 6.4) shows that many samples are shifted toward the right side of the diagram, which can also be due to the presence of a magnetically hard (higher $H_{c}$) component. A scatter plot of remanence ratio vs. S-ratio (Figure 6.5) shows a negative correlation between the two parameters. Samples that have low S-ratios tend to have high remanence ratios. In this case $H_{c}/H_{c}$ is therefore not necessarily an indicator for grain-size changes or a proxy for the presence of coarse multi-domain grains. No X-ray or SEM-analyses have been performed on samples from Catfish Pond. It is therefore difficult to confirm the mineralogy of this magnetically hard component. The smeared out Verwey transitions in the upper part of the core can be caused by the combined presence of magnetite and maghemite [Özdemir et al., 1993], and the relatively sharp transitions in the lower samples (as indicated by the well localized peaks in the gradient curve) could be explained by the preferential reductive dissolution of pre-existing maghemite in the core. If this is the case it is unlikely that the low S-ratios observed in Figure 6.3 are due to the presence of hematite or goethite, which should also be readily dissolved. It is possible, however, that the high concentrations of maghemite and magnetite in the top 100 cm of the core are mainly caused by an increased input of iron oxide minerals due to anthropogenic influences. The absence of maghemite in the lower layers can then be explained by changes in erosional behavior, and the magnetically hard iron oxides might be more or less stable throughout the entire record.
Fig. 6.3: S-ratios for samples from Catfish Pond. S-ratios close to 1 are due to magnetically soft minerals such as magnetite or maghemite, while magnetically hard minerals such as hematite or goethite shift the S-ratio towards lower values.
Fig. 6.4: Plot of remanence ratio $M_{rs}/M_s$ vs. coercivity ratio $H_{cr}/H_c$. Grain-size labels on plot after Day et al. [1977]. Shaded area represents $M_{rs}/M_s$ vs. $H_{cr}/H_c$ combinations obtained from synthetic sample sets of known grain-size [modified after Dunlop and Özdemir, 1997]. Many samples are shifted to the right of the plot due to the presence of magnetically hard minerals.
Fig. 6.5: Scatter plot of coercivity ratio $H_c'/H_c$ vs. S-ratio. Samples with low S-ratios tend to have higher remanence ratios, indicating that $H_c'/H_c$ is not just a function of particle size but also reflects changes in magnetic mineralogy.
Iron-sulfides are another possibility to explain the low S-ratios in Figure 4.3. IRM-acquisition curves for pyrrhotite [Dekkers, 1988b] and greigite [Krs et al., 1992] show that both minerals are not fully saturated at 300 mT and can cause low S-ratios. Greigite-bearing lake sediments from Sweden, on the other hand, show relatively high S-ratios, close to 1.0, in the greigite-containing horizon [Snowball, 1991]. Curie measurements for the Catfish Pond samples show no thermally unstable behavior characteristic for the presence of iron sulfides, except for the slight decrease in magnetic moment near 320°C. Pyrrhotite may be present in some samples, but it is unclear whether it is present in sufficient amounts to explain the observed behavior in S-ratios and remanence ratios.

6.2.2 Concentration of Magnetic Minerals

Figure 6.6 shows the variation of concentration-dependent parameters with depth. Sediments above 100 cm depth are strongly magnetic, and many of the records are truncated in order to show the more subtle variations in the lower part of the core. The magnetic concentration of magnetic minerals roughly correlates with core lithology, which is sketched in Figure 6.6a. Organic sediments tend to have lower concentrations of magnetic minerals than silty clays that have a low organic matter content. Figure 6.6b shows the influence of para- and diamagnetic minerals on magnetic susceptibility. Crosses (×,+ ) show bulk susceptibility values for cores C.P.-1 and C.P.-2. High field susceptibility has been calculated from hysteresis measurements, and the ferrimagnetic susceptibility \( \chi_{\text{ferr}} = \chi_{\text{total}} - \chi_{\text{hf}} \) is shown as solid circles (●) in Figure 6.6.b. Both bulk susceptibility and ferrimagnetic susceptibility are higher in the silty clays. The contrast between clays and organic horizons is lower for ferrimagnetic susceptibility because it has been corrected for the presence of paramagnetic minerals in the silty clays and diamagnetic contributions, which tend to occur in the more organic rich layers. Scatter plots of SIRM (Figure 6.7a) and ARM (Figure 6.7b) vs. magnetic susceptibility also show the influence of para- and diamagnetic minerals on magnetic susceptibility.
Fig. 6.6: Variation of concentration-dependent parameters with depth for Catfish Pond.

- **Lithology**
  - gray silty clay
  - gyttja

**Depth (cm)**

- max $\chi$ at $5 \times 10^{-7}$ m$^3$/kg
- max ARM at 0.00025 Am$^2$/kg
- max SIRM at 0.006 Am$^2$/kg

**Magnetic Susceptibility**

- total magnetic susceptibility
- ferrimagnetic susceptibility

**Concentration-dependent Parameters**

- max ARM at 0.00025 Am$^2$/kg
- max SIRM at 0.006 Am$^2$/kg

**Fig. 6.6:** Variation of concentration-dependent parameters with depth for Catfish Pond.
Fig. 6.7: Scatter plots of ARM and SIRM vs. susceptibility $\chi$. The correlation between remanence parameters and susceptibility increases when $\chi$ is corrected for para- and diamagnetic contributions.
Neither SIRM nor ARM depend on para- or diamagnetic contributions, and the scatter in Figure 6.7 can be reduced by plotting both remanence parameters vs. ferrimagnetic susceptibility (solid symbols) rather than bulk susceptibility (open symbols). Remanence parameters such as ARM (Figure 6.6c) and SIRM (Figure 6.6.d) show variations with depth similar to those in ferrimagnetic susceptibility. Since all magnetic parameters correlate with lithology it is possible that the variations in concentration-dependent parameters are due to the dilution of a uniform detrital source by non-magnetic organic material. Figure 6.8 shows a plot of ferrimagnetic susceptibility and ARM vs. total organic carbon (TOC) content. A good correlation between magnetic susceptibility and TOC suggests that variations in bulk concentration of magnetic minerals, which is dominated by large particles, is due to the dilution of a detrital source by organic matter. The correlation between ARM and TOC, however, is much worse. ARM does not only depend on the abundance of magnetic minerals, but is also strongly influenced by the presence of small single-domain grains, which are easily affected by dissolution processes. The good correlation between magnetic susceptibility and TOC, combined with the poor correlation between ARM and TOC, indicates that dissolution began to remove fine-grained particles from the sediments, but failed to affect the coarse-grained susceptibility-contributing fraction to a large degree.

### 6.2.3 Magnetic Granulometry

The variation of several grain-size dependent parameters is shown in Figure 6.9. ARM/χ (Figure 6.9.b) and ARM/SIRM (Figure 6.9.c) are both indicators of the relative abundance of single-domain particles, while frequency-dependent susceptibility (χ\textsubscript{fD}) can be used as a proxy for the presence of super-paramagnetic grains. Both ARM/χ and ARM/SIRM suggest the presence of fine-grained magnetic particles in the uppermost part of the core (< 100 cm), while the rest of the record is relatively coarse-grained, as indicated by low ratios of ARM/χ and ARM/SIRM.
Fig. 6.8: Scatter plot of ferrimagnetic susceptibility and ARM vs. total organic carbon (TOC). The good correlation between susceptibility and TOC suggests that the bulk concentration of magnetic minerals is dominated by the dilution effects of organic matter. The absence of any correlation between ARM and TOC is probably due to dissolution of fine grains in some horizons, which is not connected to the presence of organic matter.
The interval between 100 cm and 140 cm depth is characterized by large variations in ARM/\(\chi_{\text{total}}\) (which disappear when corrected for dia- and paramagnetic components) and ARM/SIRM, which is only affected by ferrimagnetic minerals. The lithology of this part of the core consists of organic rich gyttja without any internal structure. It is therefore hard to tell whether the large variations in this part of the core are due to disturbance of the core or some other unidentified process. Figure 6.9b and 6.9c show slight differences below 140 cm depth which may be due to the effects of paramagnetic minerals that were not entirely compensated for. Figure 6.9d shows variations of frequency-dependent susceptibility (solid symbols, ●) and variations of ARM/SIRM (same as Figure 6.9c, but at expanded scale). \(\chi_{\text{FD}}\) values are generally quite low (the error associated with \(\chi_{\text{FD}}\) measurements is between 2 and 3%) and do not show a good correlation with ARM/SIRM, except for the interval between 220 and 260 cm, where both parameters show low values. The low values of \(\chi_{\text{FD}}\) throughout the lower part of the core (> 100 cm) agree with the low ARM/\(\chi\) and ARM/SIRM ratios and indicate a mostly coarse-grained magnetic component that is little influenced by superparamagnetic grains.

6.3 Paleoenvironmental Interpretation

6.3.1 Correlation of Pittsburg Basin and Catfish Pond Records

Two \(^{14}\text{C}\)-ages were obtained for Catfish Pond sediments. A macrofossil found at 100 cm depth yielded a date of 170±40 years. The abrupt increase in magnetic mineral concentrations can therefore be correlated with the onset of agriculture in the watershed. A radiocarbon date from 200 cm, which corresponds to the onset of Holocene vegetation, however, yielded only an age of 5970±40 years.

\[3\] Since dia- and paramagnetic minerals cannot be neglected for the susceptibility measurements \(\chi_{\text{FD}}\) has been corrected for dia- and paramagnetic contributions as outlined in chapter 2.
Fig. 6.9: Variation of grain-size dependent parameters for Catfish Pond. ARM/κ and ARM/SIRM are proxies for the relative abundance of single domain grains, $\chi_{FD}$ can be used as a proxy for the presence of superparamagnetic grains.
For Illinois, Holocene vegetation patterns were established between 14 ka and 10.9 ka BP [King, 1981]. This late date for the end of glacial vegetation and the absence of the hypsithermal prairie period confirm the existence of hiatuses in the Catfish Pond record. Since no dates are available for Pittsburg Basin in this time range the correlation between the two cores has to rely on variations in the palynological and magnetic record. Considering the likely presence of hiatuses in both sites only a very crude correlation is attempted.

Magnetic records for both sites are consistent but are quite homogenous and lack distinctive features that enable us to use them for detailed correlation purposes. Pollen assemblages allow us to correlate them on the basis of the onset of Holocene vegetation patterns and the zone of high spruce concentrations. Table 6.1 lists the possible correlation markers.

<table>
<thead>
<tr>
<th>Palynolog. Feature</th>
<th>Depth Pittsburg Basin</th>
<th>Depth Catfish Pond</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onset of Holocene Vegetation</td>
<td>170 cm</td>
<td>260 cm (200 - 260 cm)</td>
<td>best defined by the decline in pine at 260 cm, because spruce peak between 200 and 260 cm is mainly due to the absence of any pollen</td>
</tr>
<tr>
<td>Onset of Spruce and Pine</td>
<td>250 cm</td>
<td>400 cm</td>
<td></td>
</tr>
</tbody>
</table>

**Table 6.1:** Correlation Between the two sites Based on Palynological Features
Based on all the available information it is possible to say that the glacial record represented in Catfish Pond represents the late part of the Wisconsinan and does not extend into the Sangamon interglacial.

6.3.2 Paleoenvironmental Interpretation

Based on their magnetic properties Catfish Pond sediments are very similar to the corresponding horizons found in Pittsburg Basin. With the exception of the uppermost 100 cm the magnetic fraction is characterized by coarse-grained ferrimagnetic particles and an additional magnetically hard component (hematite or goethite), which might be indicative of dry climate with at least some periods when the lake dried out completely.

The absence of the early Holocene and the hypsithermal period from the Catfish Pond record has already been discussed in section 7.6.2. The onset of agriculture is well documented in Catfish Pond by an abrupt increase in concentration of magnetic minerals, leading to very high values of magnetic susceptibility, ARM and SIRM. An increase in Ambrosia pollen is also observed.

6.4 Summary

The two cores that were retrieved from Catfish Pond consist of silty gray clay and crumbly gyttja, and are probably disturbed throughout large parts of the record. The record is likely to contain many hiatuses.

Sediments above 100 cm depth show very high concentrations of magnetite and maghemite. These high concentrations are due to increased erosion caused by farming within the watershed of Catfish Pond. Below 100 cm the concentration of magnetic minerals decreases abruptly. The magnetic minerals have been characterized by Curie temperature measurements and thermal demagnetization of low-temperature SIRM. They consist of (titano)magnetite, pyrrhotite and probably hematite. Bulk susceptibility in this interval is controlled by the dilution of detrital material by organic carbon. Small grain sizes, however, were also affected by dissolution, leading to a coarse-grained magnetic assemblage, low in ARM/χ and ARM/SIRM.
The sediments of Catfish Pond record part of the Holocene and the Wisconsinan. Neither the Holocene hypsithermal nor the Sangamon interglacial are recorded in the cores retrieved from this site.