3 Geological Setting of the Illinois Sites

3.1 Introduction

We studied a total of three sites in south-central Illinois to establish a locally valid sediment-magnetic model for paleoclimate reconstruction. The study is part of a multi-proxy attempt to reconstruct midcontinental paleoclimate variations over the last 120 ka. Pittsburg Basin was cored in 1994 and 1996 to obtain a sedimentary record that spans the last 120,000 years. Multiple cores were retrieved from the basin in 1994 using a hollow-stem auger and a Livingstone piston corer mounted to a Giddings soil probe (PBAS 94). The site was drained in the early 20th century and its upper 2-3 m of sediment were severely oxidized and unusable for detailed paleoclimatic investigations. Samples from Pittsburg Basin were supplemented in 1996 by additional cores from Catfish pond, a nearby lake with a better preserved Holocene section (site CFP-96). To study the magnetic properties of the sediments and soils a gravel pit within the watershed of Pittsburg Basin was sampled in 1995 (site PBGP).

Pollen- and diatom-analyses were performed by R. Teed on cores from Pittsburg Basin and Catfish Pond. B. Curry studied variations in ostracodes for Pittsburg Basin, and E. Ito analyzed their stable isotopes.

This chapter begins with a description of the geological setting and lithology of the three sites. A geochemical analysis performed on sites PBAS 94 and PBGP attempts to correlate the lake sediments with their source material. This information is used to test the depth-age model that has been established for Pittsburg Basin.
Fig. 3.1: Location of the Pittsburg Basin and Catfish Pond sites. Dark shaded areas represent forested terrain, light gray areas are ponds.
3.2 Geological Setting and Site Descriptions

All sites discussed in this chapter are located in south-central Illinois near Vandalia in Fayette county. Figure 3.1 shows the location of the lakes and the position of the sites. The following geological description follows mostly the work of Jacobs and Lineback [1969]. Both Pittsburg Basin and Catfish Pond are situated between elongated ridges of the Hagarstown beds. These ridges contain a core of sand, poorly sorted gravels and gravelly till and are locally overlain by Vandalia till. The ridge gravels were deposited in ice-walled channels by meltwater streams and form elongate linear or gently curving ridges. The Hagarstown gravels are assumed to be deposited at the end of the Illinois episode. The Sangamon geosol developed in the Hagarstown beds. The ridges are capped by younger Roxana silt and Peoria loess. The Farmdale geosol is also visible at the top of the Roxana silt. All lithological units are exposed in a abandoned gravel pit (site PBGP) within the watershed. The high permeability of the ridges leads to little runoff and low erosion/deposition rates, allowing for more or less constant sedimentation in Pittsburg Basin and Catfish pond.

All sites are approximately 60 km south of the maximum Wisconsin ice margin. They have the potential of recording paleoclimatic variations from the end of the Illinoian glaciation through the Holocene.

3.2.1 Pittsburg Basin

Several cores were retrieved during the 1994 sampling campaign. Core PBAS 1994-5a, which was later sampled for the investigations described in this thesis, was taken from near the center of the basin (see Figures 3.1, 3.2) using a hollow stem auger. Pollen, ostracod and diatom analyses were conducted on cores 94-5b-d, approximately 1-2 m away from site 94-5a. These cores were obtained using a combination of a Livingstonepiston corer and a Giddings soil probe (Figure 3.3). Samples for thermoluminescence dating were obtained from core 94-5e, which was acquired by hollow stem auger within 1 m from site 94-5b-d.
**Fig. 3.2:** View of Pittsburg Basin from NW. The basin has been drained and converted to fields in the 1920's. The approximate location of the coring locations and the drainage ditch are marked on the image.

**Fig. 3.3:** The Giddings soil probe used in the 1994 and 1996 coring campaigns. A Livingstone piston corer was attached to the probe with chains and the power of the probe was used to push the piston corer into the sediment and retrieve the cores. Giddings probe courteously provided by Illinois State Geological Survey. The photo was taken during the 1996 coring campaign, persons in the image are from left to right: Herb Wright, Mark Shapley, Brandon Curry and Rebecca Teed.
Fig. 3.4: Lithology and magnetic susceptibility profiles for cores PBAS 94-5a and PBAS 96-2. Features that were used for depth correlation are marked by dashed lines.
All cores have been correlated to the master cores (94-5b-d) by lithological features and whole core magnetic susceptibility, measured on a Bartington susceptibility meter equipped with a MS2C loop sensor.

In 1996 we recored Pittsburg Basin to obtain two overlapping cores from near the center of the basin for paleomagnetic analyses (PBAS 96-2) and additional thermo-luminescence dating (PBAS 96-1). Sites 96-1 and 2 are within 2 m of each other and approximately 50 m north of site 94-5 (Figure 3.1). The depths of all cores used for magnetic investigations were correlated by using a combination of lithological and magnetic features.

Site Correlation PBAS 94-5a and PBAS 96-1,2

Figure 3.4 shows the lithology and susceptibility records for cores PBAS 94-5a and PBAS 96-2. Features that were used for correlation are indicated by dashed lines. All depths in the text are given with respect to a common depth scale based on core PBAS 94-5a, which is in turn based on the master cores 94-5b-d. This facilitates the comparison of magnetic and non-magnetic results because all non-magnetic results are recorded with respect to the depth of the master cores. Correlation between sites 94-5a and 96-1,2 is good throughout most of the core, and individual features can often be matched one by one over the distance of approx. 50 m that separates the two sites. Correlation is poor between 490 cm and 530 cm depth. In this depth interval the high susceptibility values of core 94-5a are not matched by samples from the corresponding depth in cores 96-1 and 96-2. The presence of distinct lithological features in this depth interval, however, allows for depth correlation based on core lithology alone.

Lithology of Pittsburg Basin Sediments

The sediments of all Pittsburg Basin cores consist of silty clay and organic layers of fissile peat and brown silty clay (Figure 3.4). A detailed description for all cores is given in appendix 4. The lowermost sediments in both cores consist of gray clayey silt, which is partially banded and laminated with darker, more organic material. The transition from the
**Fig. 3.5:** View of the abandoned gravel pit and location of soil profile PBGP. Approximate location of loess-gravel boundary is indicated.

**Fig. 3.6:** Lithology of soil profile at site PBGP. The modern soil extends from the top of the profile down to a depth of approximately 50 cm. The Farmdale paleosol extends from 100 cm depth (top of Roxana silt) to a depth of approximately 130 cm. The top of the Sangamon paleosol is at a depth of 152 cm, it extends far into the Hagarstown gravel and the transition from the b to the C horizon is very gradual. The upper 275 cm of the gravel is heavily oxidized and red in color (230 cm - 505 cm). Below 505 cm the gravels are gleyed and grey in color.
gray clay to the black fissile peat (≈760 cm) is gradual over a transition zone of approximately 20 cm. The black color of the peat is due to oxidation during storage. The initial samples right after coring were reddish brown, but they turned black within minutes of being exposed to atmospheric oxygen. The transition between the peat and the silty clay above (≈670 - 690 cm) is characterized by a series of cm- to mm-scale bands and laminae, which indicate oscillations between two depositional regimes. The overlying yellowish-brown silty clay (670 - 560 cm) is rather homogenous with two wide, somewhat coarser bands at 640 - 615 cm and 570 - 560 cm. These bands are characterized mainly by their susceptibility peaks. The transition to the dark brown crumbly silt (560 - 520 cm) is abrupt with some of the darker material worked into the lower unit. The transition to the brown silty clay above (500 - 450 cm) is marked by a distinct black layer in 94-5a, which is absent in the cores of site 96. The brown silty clay contains several shell-rich layers that can be used for correlation purposes. The brown clay layer that follows is mostly missing in PBAS-5a but is well known from the other cores of site 94-5. It is topped by a black, crumbly peat horizon that contains several shell layers (240 - 440 cm). The uppermost gray silty clay (< 240 cm) shows abundant redoximorphic features due to the drainage of the lake earlier in the century. This severely oxidized part of the core was not used in this study because it is affected by recent oxidation and agricultural use.

3.2.2 Pittsburg Basin Gravel Pit

To study the properties of the parent material around Pittsburg Basin we sampled a soil profile in an abandoned gravel pit (site PBGP-95). The site is located approximately 1 km east of sites PBAS 94-5a and PBAS 96-1,2, on the southern rim of the basin (Figure 3.1). Figure 3.5 shows the site as seen from the west and Figure 3.6 gives the lithology of the site. The top of profile PBGP consists of modern soil, which is probably stripped of its A horizon due to human activity. A very thin A horizon is followed immediately by an E-horizon (0 - 16 cm).
Fig.3.7: View of Catfish Pond from WNW. At present the lake is less than one meter deep and the coring platform, which is visible in the image, is anchored in the pond with 4 long coring rods.
The modern soil developed in Peoria loess, which extends down to a depth of approximately 100 cm. A thin layer of Roxana silt is found between 100 and 150 cm depth. The Farmdale paleosol is barely distinguishable in the top part of the Roxana silt by a slight increase in soil structure. The Sangamon paleosol is developed in coarse silt (152 - 205 cm), which contains an increasing amount of gravel with depth (205 - 230 cm) and extends into the gravel beds of the Hagarstown formation (> 230 cm). The Hagarstown gravels that make up the rest of the sequence consist of poorly sorted gravels and interbedded sand layers. The gravels are red, except for the very base of the profile, which is grayish brown. The oxidation of the profile is probably a fairly recent feature due to human activity in the pit.

The positioning of the Sangamon geosol in Figure 3.6 is somewhat problematic. All authors terminate the Sangamon geosol with the onset of Roxana silt deposition [e.g. Jacobs and Lineback, 1969; Follmer, 1978; Mc Kay, 1986]. At Pittsburg Basin the paleosol horizon, as defined by an increase in clayskins and by soil structure, clearly starts near 152 cm depth and the onset of the Hagarstown gravels occurs about 50 cm lower, between 200 and 230 cm depth. Two explanations are possible: the Sangamon soil extends upward into the Roxana silt, or the Hagarstown gravels are capped by an older silt that we failed to distinguish from the Roxana. If the rate of deposition for the Roxana silt was low enough, it is possible for the existing soil to incorporate this material. The same paleosol can therefore extend into the Roxana silt, and it is probably reasonable to call it by one name instead of artificially truncating it at the base of the Roxana. Jacobs and Lineback [1969] studied 5 sections near Vandalia and did not find an additional silt unit between the Hagarstown beds and the Roxana silt. The results of pedogenesis such as clayskins and root channels, are more or less present throughout the entire loess section (Roxana and Peoria), and the Farmdale paleosol is only weakly expressed with respect to this pedogenic background. In his description of the Pleasant Grove School section Mc Kay clearly extends the Sangamon soil into the Roxana silt, as it can be seen in his Figure on p. 16 [Graham et al., 1986]. In this figure a thin line separates the Sangamon from the Roxana, but the pedological features clearly cross the boundary between...
Illinoian and Wisconsinan sediments. Since the same soil should not go by two names I therefore extended the Sangamon paleosol into the Roxana silt (Figure 3.6), even though this might be formally incorrect. The site was sampled in 1995. Unoriented samples were taken at 10 cm resolution and stored in plastic bags until they were measured in the lab over the course of several months.

3.2.3 Catfish Pond

Catfish Pond is a small lake, approximately 3.5 km ENE of Pittsburg Basin (Figure 3.1). At present the lake is approximately 50 - 70 cm deep and has never been drained. It was hoped that Catfish Pond would provide a good Holocene record and a modern analog for the pollen studies of Pittsburg Basin. Several cores were taken from near the center of the lake. The sediments are highly compacted, often crumbly and difficult to penetrate with a man-powered coring rig. Several drives yielded only very short cores of crumbly, disturbed organic sediment, which were not sampled for magnetic studies. Figure 3.8 shows a simplified lithology of Catfish Pond. The sediments are often disturbed by wave action or bioturbation. Patches of darker sediment are worked into lighter colored clays as indicated in Figure 3.8. The disturbances are only visible in the clay-rich sections but it cannot be assumed that the gyttjas remained undisturbed.
Fig. 3.8: Lithology of Catfish Pond. Several cores were taken within 1-2 m from each other. Core recovery was poor in very hard gyttjas, but an almost complete set could be collected. Light gray cores were not sampled for magnetic measurements.
3.3 Geochemical Analyses of Sites PBAS 94-5a and PBGP-95

3.3.1 Introduction

The source material for the sediments of Pittsburg Basin changes from Illinoian age gravels to loess that was deposited during the Wisconsinan glaciation (Figure 3.6). This shift should be accompanied by a shift in chemical composition, which can be used to determine the onset of loess deposition in the lake sediments. Since the sediments of Pittsburg Basin are only poorly dated the onset of Roxana silt deposition (≈ 55 ka) will be used to test the existing age model. Bulk chemical analyses were performed on 20 samples from site PBGP-95 and 30 samples from core PBAS 94-5a, using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS). Organic carbon was removed by igniting the samples prior to the analyses. Element abundances are either given as weight percentages of their oxides or in ppm (µg/g). The Hagarstown gravel consists of a large percentage of sand and gravel. This particle-size fraction is nearly absent in the lake sediments. In order to make the two sites more comparable only the silt and clay fractions (< 62 µm) were used for the chemical analyses.

3.3.2 Gravel Pit Site

Figure 3.9 shows the distribution of major chemical elements with depth for site PBGP-95. The boundaries between Peoria loess, Roxana silt and Hagarstown gravel are indicated by dashed horizontal lines. The contact between gravel and silt is gradual and occurs between 200 cm and 230 cm depth. The Sangamon geosol developed in the Hagarstown gravel and extends into the lower parts of the Roxana silt.

Several processes can affect the chemical composition. Changes in source material are visible between the loess and gravel units. The break between the calcareous loess and the non-calcareous gravels is clearly visible. Hagarstown gravels have lower concentrations of Ca, K, SiO₂, Ti and Zr, while they are enriched in Al and Fe. Transport processes are another way to affect the distribution of elements. The differences in carbonate and sodium content between the Peoria and Roxana silts are probably due to weathering and pedogenic leaching of the Peoria loess. Furthermore, the effects of
Fig. 3.9: Variations of some chemical elements with depth for site PBGP-95. Major elements are given in weight percent of their oxides. The trace element Zr is given in ppm (µg/g). All elements were measured with an inductively coupled plasma mass spectrometer (ICPMS) using only the silt and clay fraction of each sample. Organic carbon was removed by ignition prior to the measurement.
Fig. 3.10: Several weathering indices calculated for site PBGP-95. The ratio of SiO$_2$/Al$_2$O$_3$ represents the class of weathering indices that normalizes various combinations of leachable elements by a stable component that is assumed to be unaffected by weathering. In the case of PBGP-95 this index mainly tracks the change in parent material but fails to detect weathered horizons. In the second column the ratio of SiO$_2$/Al$_2$O$_3$ is normalized by the SiO$_2$/Al$_2$O$_3$ ratio for the presumably unweathered parent material. For the normalization process each parent material is represented by a different sample. They are indicated by horizontal arrows in b). The normalized SiO$_2$/Al$_2$O$_3$ ratio tracks the movement of SiO$_2$-rich material from the loess horizons into the Sangamon Bt horizon. Jenny's leaching factor [Jenny, 1941] (p. 26-27) shows the depletion of easily soluble elements in the paleosol horizons.
pedogenesis can be traced into the gravel beds. Zr and Ti concentrations are high in loess (Zr ≈ 450 ppm, Ti ≈ 0.9 %) but low in the gravel (Zr ≈ 200 ppm, Ti ≈ 0.6 %), except for the zone between 230 and 300 cm where a gradual decrease in Zr and Ti concentrations is observed. This zone corresponds well with the lower limit of magnetic enhancement as discussed in chapter 4 (e.g. Figure 4.12b).

The degree of pedogenesis and weathering can be estimated by calculating weathering indices for a soil profile. Birkeland [1984] (p. 81) and Jenny [1941] (p. 26-27) list several indices, and some of them are applied to the geochemical data of site PBGP-95. Figure 3.10a shows the ratio of SiO$_2$/Al$_2$O$_3$ vs. depth. For PBGP-95 this parameter, and many others that measure a ratio between soluble and insoluble minerals mainly track the shift in parent material between the Hagarstown gravels and the loess units and the mixing that occurs between the two. Figure 3.10b shows the same ratio, but normalized for the SiO$_2$/Al$_2$O$_3$-ratio of the "unaltered" parent material. These unaltered samples are marked with horizontal arrows in Figure 3.10b. The choice of these samples is somewhat arbitrary. For the Peoria silt the bottom sample just above the Roxana silt and the Farndale paleosol (90 cm) was chosen. For the Roxana silt a sample between the Farndale and Sangamon paleosols is assumed to be representative of the unweathered parent material (140 cm). Unweathered Hagarstown gravel is represented, more or less arbitrarily, by the deepest sample from 455 cm depth. It should be kept in mind that all three units were to a varying degree subjected to leaching and weathering [Jacobs and Lineback, 1969]. The normalized SiO$_2$/Al$_2$O$_3$-ratio shows the movement of quartz-rich material into the Sangamon Bt soil horizon between 150 and 300 cm depth (shaded area in Figure 3.10b). The "depletion" of the following gravel layers (300 - 425 cm) is probably due to a poor choice of the "representative", unaltered parent material. However, since the gravel unit is very inhomogeneous it is unlikely that a different choice would have increased the quality of the method.
Fig. 3.11: Variations of some chemical elements for site PBAS 94-5a. Major elements are given as weight percent of their oxides. Zr is given in ppm (µg/g). All elements were measured with an ICP-MS using only the silt and clay fraction of each sample. Organic carbon was removed by ignition prior to the measurement.
Figure 3.10c shows Jenny's weathering factor $\beta$, which is defined as:

$$\beta = \frac{\left(\frac{K_2O + Na_2O}{SiO_2}\right)_{\text{of weathered material}}}{\left(\frac{K_2O + Na_2O}{SiO_2}\right)_{\text{of unweathered parent material}}}$$

$\beta$ seems to track the loss of easily soluble minerals from the system, and we see that the Sangamon soil (shaded area) is most affected by pedogenesis and suffered the heaviest losses.

3.3.3 Pittsburg Basin Sediments (Site PBAS 94-5a)

Figure 3.11 shows the concentrations of several major and trace elements for site PBAS 94-5a. A comparison between Figures 3.9a and 3.11a shows that the Ca concentrations in the lake sediments are by an order of magnitude higher than in the source material at site PBGP-95. This indicates leaching of the gravel and loess units of site PBGP-95. The concentration of Ca in the lake sediments is most likely a function of biogenic carbonate production and preservation (salinity) and is unlikely to reflect a change in source material. Since the detection of such changes is an aim of this study I attempted to correct for the amount of carbonates present in the sediments. The weight fraction of CaO was first converted to an equivalent weight fraction of CaCO$_3$ by multiplying it by a factor of 1.77 ($= \frac{m(\text{CaCO}_3)}{m(\text{CaO})}$). CaCO$_3$ was then removed from the element sum, and the remaining elements were renormalized to 100 %. After the influence of CaCO$_3$ was removed, most elements show little systematic variation, only Na drops between 300 cm and 750 cm, and the amounts of Ti and Zr slightly increase above a depth of approximately 300 cm (Figure 3.12). Of all the elements shown in Figures (3.11 and 3.12) TiO$_2$, Fe$_2$O$_3$ and ZrSiO$_4$ are considered the most stable under subaerial weathering conditions [Pye, 1987] (p.229). A comparison of Figures 3.9 f,h and 3.12 e,g shows that this holds true for Ti and Zr, which have very similar abundances in
both sites. Iron-oxides, however, are only stable under subaerial conditions and are lost under reducing anoxic conditions, as $\text{Fe}^{3+}$ is reduced to $\text{Fe}^{2+}$, which is highly soluble. Consequently Fe concentrations in the lake sediments reach, on average, only 30% of the Fe concentrations of the source material (Figures 3.9g, 3.12f). Fe-concentrations are therefore not suited for tracing source material.
3.3.4 Correlation between sites PBGP-95 and PBAS 94-5a

A correlation between the two sites is attempted in order to constrain the onset of loess deposition in the Pittsburg Basin sediments, which can be used to test the age model established in section 3.4.

Several authors [Birkeland, 1984; Pye, 1987] list a number of elements that resist weathering and are considered stable in loess or soil environments. Among them are Al, Fe, Ti, Ba, Rb, Th, U, Co, Cr, and Zr, which are all considered stable in subaerial weathering environments. Many of these minerals, however, can occur in multiple oxidation states (Fe, Th, U) and are soluble in their reduced state (i.e. under anoxic conditions). Others occur primarily in feldspars or olivine (Ba, Rb, Co, Cr), which are also quite susceptible to weathering. All these elements were measured but showed no systematic variations with depth that allowed them to be used in the correlation of the two sedimentary records. A very stable primary source of U and Th, however, is zircon, which can contain large amounts of these elements. For Pittsburg Basin the source of these elements has to be elsewhere, since Th and U (not shown) concentrations do not correlate with Zr concentrations. Hf, on the other hand, which is also a major impurity of zircon [Matthes, 1987 (p. 106)] shows an almost perfect correlation with Zr (Figure 3.13). Therefore only Ti and Zr remained as potential candidates that could be used in the correlation.

SEM analyses show that Ti is mainly due to the presence of ilmenite (FeTiO$_3$), which is more stable than magnetite (Fe$_3$O$_4$) under anoxic conditions [White et al., 1994]. Zr occurs in the form of zircon (ZrSiO$_4$), a very stable heavy mineral. Since the Roxana silt is enriched in Ti and Zr, both elements should be suited to detect the addition of loessic material to the sediment.

Figure 3.14 shows the abundances of Ti and Zr for core PBAS 94-5a. The average abundances of both elements in Hagarstown gravel and the Roxana/Peoria silt are also indicated. At depths below approximately 300 cm Ti and Zr show relatively low abundances, close to values characteristic of Hagarstown gravel. An average "baseline" value is indicated by horizontal dashed lines in both Figures 3.14a, b.
Fig. 3.12: Same geochemical data as shown in Figure 3.11 after correcting for CaCO₃. Most of the variations seen in Figure 3.11 decreased, showing that these variations are mainly caused by changes in CaCO₃ concentration.
Fig. 3.13: Scatter plots of Hf and Th vs. Zr concentrations for samples from Pittsburg Basin, site PBAS 94-5a. Hafnium and thorium are both found as impurities in zircon (ZrSiO₄), but while Hf shows a nearly perfect correlation with Zr, Th concentrations are nearly independent of Zr content. This suggests a source for Th other than zircon grains.
Above a depth of 300 cm the abundances of Ti and Zr increase sharply towards values more typical for Roxana or Peoria silt. The exact onset of this increase is hard to determine, due to an erosional layer, which is enriched in zircon grains. This layer is characterized by a high gravel and sand content (≈ 50%). Zircon is a heavy mineral (ρ = 4.7 g/cm³) and is concentrated in such a layer, where depositional energies are high, and small and lightweight grains are preferentially removed. This initial increase in Zr is therefore not necessarily due to the deposition of loessic material. Ti-concentrations are also slightly elevated in this layer, but the effect is less noticeable than in the case of Zr. A best fit through the Ti and Zr concentrations in samples above 300 cm intersects the baseline value between 290 cm (Ti) and 270 cm (Zr) depth. Since the onset of loess deposition is likely to be gradual the first deposition of Roxana silt may have occurred before these depths. For correlation purposes I assume a depth of 290 ± 25 cm for the first sediments that are affected by Roxana silt deposition. With the assumption of a basal age of 55 ka ±5 ka this result is indicated on the depth-age correlation of Figure 3.15.

The Zr-curve (Figure 3.14b) shows significant drops near 540 cm and 720 cm depth. These drops correlate with organic rich sediment horizons and periods of forest growth in the area. Organic material was removed by ignition from the samples prior to their chemical analysis. The correlation between TOC of the sediment and Zr-content indicates that Zr acts as an indicator for loessic material even before the main onset of loess deposition in the region. When the region was densely forested both eolian deposition and erosion rates were low, leading to sediments rich in organic matter but poor in (eolian) Zr.
Fig. 3.14: Variations in Ti and Zr content for site PBAS 94-5a. The average Ti and Zr concentrations for the Hagarstown gravel and Roxana and Peoria loess are indicated by gray horizontal lines. The onset of loess deposition is assumed to occur at approximately 3 m depth, when both Ti and Zr concentrations increase from a relatively constant background value. Zr/Al and Ti/Al ratios are also shown (open symbols, dashed gray lines). Normalized values of Zr and Ti show larger variations in the lower part of the core but show a similar increase above 300 cm depth.
3.4 Age Control for Pittsburg Basin Cores

3.4.1 Chronostratigraphy for the midwestern U.S.A.

Chronostratigraphic units are generally considered as isochronous units. They are represented by rocks or sediments that were deposited during a certain span of time. Using an isochronous classification system for Quaternary deposits is problematic because many lithological units such as tills and paleosols, do not have isochronous boundaries. They are time-transgressive. For example, a paleosol unit that develops after the retreat on an ice sheet will start to form earlier in a southern location than in a site farther to the north. *Watson and Wright* [1980] realized the problems associated with an isochronous classification system and proposed a diachronous classification that allows for time-transgressive boundaries and is based on a system of event units (*phases*) which are identified by stratigraphic or morphologic criteria. Phases were originally considered time units related to an event such as a glacial advance, but today the actual event is often more emphasized than the time unit. Event classifications, however, depend largely on the interpretation of certain rock or sediment strata. Geologic-climate units were defined from subdivisions of Quaternary sediments and included a paleoclimatic interpretation of the conditions under which these sediments were formed. Geologic-climate units divide the Quaternary into a series of glaciations and interglaciations (e.g. Wisconsinan glaciation, Sangamonian interglaciation). They can be subdivided by stades and interstades, which represent smaller glacial advances or retreats. Some informal time units are also based on the climatic interpretation of sediments. The often used term *Sangamon*, for example, characterizes "a division of time where the climate was similar or warmer than present" [*Richmond and Fullerton*, 1986]. Since interpretations often disagree, the event- and geologic-climate classification systems were replaced by a system of diachronous units [*Hansel and Johnson*, 1996], which are comprised of unequal spans of time that are represented by a certain body of rock. Diachronous units differ from event units in that their emphasis is temporal and each unit has a designated type section that provides a material reference to each unit. Diachronous units do not include morphological or non-stratigraphic criteria and are not linked to a specific event.
Table 3.1 gives an overview of some of the classification schemes used for Quaternary deposits. Since continental climate changes are often correlated to the marine isotope record, marine isotope stages (MIS) are also marked. The lithological units that are found in the watershed of Pittsburg Basin are shown in the column to the far right of table 3.1.

3.4.2 Chronology of Pittsburg Basin

Figure 3.15 shows all the available age information for Pittsburg Basin. The open symbols denote radiocarbon measurements performed on bulk sediments from Grüger [1972b] original core. These dates were correlated with our cores by comparison of pollen analyses. Open diamonds represent $^{14}$C dates obtained from Pittsburg Basin, open circles are $^{14}$C dates obtained from nearby lakes that were correlated with Pittsburg Basin on the basis of pollen analyses. Closed symbols show data obtained in the course of this study. Infrared Stimulated Luminescence dates (IRSL) were obtained by Sanda Balescu of the University of Quebec at Montreal for cores PBAS 94-5e (▲) and PBAS 96-1 (▼) (S. Balescu, unpublished data). An AMS radiocarbon date (◼) was obtained by R. Teed from a seed grain found in PBAS 94-5a at 288 cm depth. The age for the top of the core is constrained by the onset Holocene vegetation (●), which occurred at a depth of 170 cm [Teed et al., 1996].

A comparison of the two IRSL data-sets yields contradicting results. Measurements obtained from PBAS 94-5a (▲) suggest variations in sedimentation rates, with the highest sedimentation rates occurring between 300 cm and 550 cm depth (12.5 cm/ka) and relatively low sedimentation rates between 170 - 300 cm depth (3.25 cm/ka) and 550 - 800 cm depth (3.1 cm/ka). Results from core PBAS 96-1, on the other hand, suggest rapid sedimentation during this last interval, with sedimentation rates of 16.5 cm/ka between 570 and 800 cm depth. Possible sources of error in these measurements are a weak thermoluminescence signal or a poor estimate of the paleodose that caused the observed signal. The paleodose was estimated by measuring the amount of radioactive elements (Th, U, K) present in the sample and correcting it for the amount of water present in the sample.
**Table 3.1**: Overview over Quaternary temporal classification schemes. Formal geochronological units and informal time divisions as outlined by Richmond and Fullerton [1986]. The marine isotope stage are data taken from Martinson et al. [1987]. Chronostratigraphic units ae from Willman and Frye [1970] and the event classification scheme roughly follows Follmer [1983]. The diachronic classification is simplified from Hansel and Johnson [1996]. In the original classification scheme the Michigan subepisode contains numerous phases that are not recorded in southern Illinois. The lithostratigraphy of the Pittsburg Basin area follows own field notes.
Fig. 3.15: All available age data for Pittsburg Basin. Open symbols are $^{14}$C ages by Grüger [1972b]. Open diamonds: $^{14}$C ages from Pittsburg Basin, open circles: $^{14}$C ages from nearby sites correlated to Pittsburg Basin by pollen analyses. Closed symbols: Age data from this study. ● beginning of Holocene, base on pollen analyses [Teed et al., 1996], ■ AMS $^{14}$C age from plant macrofossil (Teed, unpublished data), triangles : IRSL ages from cores PBAS 94-5e (▲) and PBAS 96-1 (▼) (Balescu unpublished data). The onset of the Roxana silt deposition is indicated by an open square at a depth of approximately 300 cm. Stars show correlation of pollen record with speleothem data from Crevice Cave (Dorale, unpublished data).
Both the abundance of radioactive elements and water content in the sample may have changed over time. Chemical analyses of sediments from sites PBAS 94-5a and PBGP-95 suggest that U and Th were mobile (see section 3.3.3) and subject to leaching. The water content of the sample was affected by compaction during sedimentation and potential water loss during storage of the cores in the laboratory. Underestimation of the palaeo-water-content of the samples leads to underestimated paleodoses and therefore sample ages that are too young. There are several techniques that attempt to correct for these errors, but it is speculative how successful these corrections are. The fact that both sample sets are internally consistent but disagree with each other casts serious doubt on the validity of the IRSL dates.

A good age model, however, is essential to the paleoclimatic interpretation of the site. For that reason we attempt to correlate the paleoclimatic data of Pittsburg Basin with a well dated speleothem record from Coldwater Cave, Missouri. Measurements of oxygen and carbon isotope variations in speleothems can reveal changes in paleoclimate [Dorale et al., 1998] and we attempt to correlate the paleoclimatic changes found in the pollen record of Pittsburg Basin with the paleoclimatic record of Coldwater cave. The results and paleoclimatic implications of this correlation are discussed in chapter 7.

An attempt to test the existing depth-age model of Pittsburg Basin is to locate the onset of Roxana silt deposition in site PBAS 94-5a. The Roxana silt is a widespread loess unit which was deposited during the Wisconsin glaciation. Its basal age is debated. Willman and Frye [1970] assume an age of 75 ka from the extrapolation of $^{14}$C-dates. This estimate was corrected by McKay [1979] who found a basal age of 55 ka to be more likely. Extrapolation of $^{14}$C ages from the upper Mississippi valley [Leigh and Knox, 1993] arrive at a basal age of 55 ka, which is in good agreement with Mc Kay's earlier estimate. On the basis of $^{10}$Be inventories Curry and Pavich [1996] estimated a basal age of 55 ka. TL-measurements of loess units in the lower Mississippi valley [Pye and Johnson, 1988], however, find an age of approximately 75 ka for the stratigraphic equivalent of the Roxana silt.
Fig. 3.16: Normalized oxygen isotope record after Martinson et al. [1987], indicating changes in global ice-volume (ice volume increases to the left). The maximum extent of the Wisconsinan ice sheets occurred between 25 ka and 15 ka. This glacial advance is accompanied by a large drop in $\delta^{18}O$, which is comparable in size to the drop observed during the Illinoian glaciation. In contrast to those major ice advances the increase in ice volume during MIS 5d was relatively minor.
Since this southern unit is extremely thin and weathered I put more credibility in the more recent work by Leigh and Knox [1993] and Curry and Pavich [1996] and assume an age of 55 ka ± 10 ka for the onset of Roxana silt deposition. Ti and Zr concentrations in core PBAS 94-5a indicate that first traces of Roxana silt can be found at approximately 3 m depth (see section 3.3.4). The onset of Roxana silt deposition is marked on Figure 3.15 and fits well into the depth-age curve for the upper part of the core. Nevertheless, the age control for the lower part of the core remains poor. At present it is not possible to decide whether the sedimentary record of Pittsburg Basin yields information about the Sangamon interglacial stage. Adam [1988] doubts that the Pittsburg Basin record is older than Marine Isotope Stage (MIS) 5d and that the two deciduous forest periods discussed in chapter 7 reflect the somewhat warmer stages 5a and 5c. Based on a curve of global ice volume this scenario is not very likely. Pittsburg Basin is situated in the Vandalia till and Hagarstown gravels and developed after the retreat of the ice sheet that deposited these units. The base of Pittsburg Basin consists of gravel and sand equivalent of the Hagarstown gravel found outside the lake. Figure 3.16. is a curve of relative global ice volume change after Martinson et al. [1987]. Between 25 ka and 15 ka the Laurentide ice sheet reached its peak size during the Wisconsin glaciation. This expansion is reflected in the very low δ¹⁸O values as seen in Figure 3.16. However, the ice sheets terminated approximately 50 km N of Pittsburg Basin. Glacial advances during MIS 5d are connected with a much smaller increase in global ice volume, yet glacial advances that reach down into southern Illinois during this stage are needed to explain the deposition of the Vandalia till. It is therefore reasonable to assume that the Vandalia till is really of Illinoian age and that the interglacial pollen assemblages of Pittsburg Basin do reflect the Sangamon interglacial.