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Magnetic Parameters as Indicators of Late－Quaternary Environments on Fort Riley, Kansas

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巖石 磁氣 變數들을 이용한 第4紀 古環境 復元－Fort Riley, 캔사스

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ABSTRACT

Climatic change of the late－Quaternary period has been recorded in the loess deposits of the central Great Plains, and the record of such change is extractable using a number of approaches and parameters. The stratigraphy of loess deposits which have been investigated on Fort Riley exhibits the same sequence of loess units and intercalated buried soils as is found elsewhere in the region, but adds detail unique to the reservation. Upland late－Quaternary, composite stratigraphy preserved on the reservation consists of the basal Sangamon soil of the Last Interglacial(c. 120－110ka), Gilman Canyon Formation(c. >40－20ka), Peoria loess(c. 20－10ka), Brady soil(c. 11－10ka), Bignell loess(c. 9－?ka), and modern surface soil.

Application of magnetic analyses has provided proxy data sets that represent a time series of climatically regulated pedogenesis/weathering and botanical composition. Magnetic data have yielded an impression of the variation in climate from Sangamon time to the late Holocene, through a reconstruction of the history of

pedogenesis/weathering.

Sangamon soil formation dominated the reservation during the Last Interglacial as indicated by magnetic parameters. During Gilman Canyon time, loess influx was usually sufficiently slow as to permit pedogenesis, which appears to have been at a maximum twice during that time. Warm season grasses were important during soil formation, but diminished in importance during the periods of more rapid loess fall, which were cooler and perhaps wetter. Peoria loess fall, a function of the deterioration of climate during the Last Glacial Maximum, thinly blanketed the reservation, with thickest accumulations occurring to the northwest(Bala Cemetery site), proximal to the source region. Long–term surface stability did not apparently occur within Peoria time, but short–term stability may be indicated by the presence of thin weathering zones(incipient soils) in the Peoria loess. Regional landscape stability prevailed during the environmental shift at the Pleistocene/Holocene transition, resulting in formation of the well expressed Brady soil.

One or more weak soils, developed in the Bignell loess as it accumulated. A notable feature of the Bignell loess is the appearance of the Altithermal dry period : the loess experienced little weathering and was dominated by warm season grasses until the latter part of the Holocene.

要 約

미국 중부 평원의 뢰스 퇴적층에서 안정동위원소와 암석자기를 이용하여 제4기 후반의 기후변화의 기록을 복원하였다. 암석 자기의 기록들을 통하여, 풍화 또는 토양화 정도로 마지막 간빙기로 부터 홀로세까지 기후변화를 복원할 수 있었다. 간빙기와 아간빙기에는 뢰스의 유입량이 줄고 따라서 토양화의 속도가 상대적으로 증가, 자성물질의 양이 증가할 뿐 아니라 이들의 입자의 크기도 감소함을 확인 할 수 있었다. 반면에 빙하의 영향이 강했던 빙하최성기(약 18,000 yr B.P.)에 퇴적된 Peoria 뢰스에는 토양화/풍화의 속도보다는 뢰스 유입의 속도가 더욱 빠름으로 인해 자성물질의 양도 작고, 입자의 크기도 증대되는 것을 확인할 수 있었다. 하지만 빙하기에도 단기간의 지표 안정기가 있음을 확인 할 수 있었다.

후빙기로 접근하면서 기후변화의 양상은 고토양의 자성물질의 양이 두 배 이상 증가하고 세립화되어 간다. 자성 분석과 더불어 실시한 동위원소 계측에서도

온난/건조한 기후를 선호하는 C4 식물의 비율이 동시적으로 증가함으로써 암석자기의 기록들을 입증해주고 있다. 홀로세 기간중에도 Altithermal 기간 중에는 증가된 바람의 역할을 반영하듯 암석자기의 제변수들이 양의 감소와 조립화의 경향을 나타내었다. 충분한 정도의 ^{14}C 연대측정결과가 이용가능해지면 시대적으로 훨씬 정밀한 고기후 기록이 복원될 것으로 기대된다.

INTRODUCTION

The sensitivity of grassland community composition and its boundaries to short−term climatic variation during the historical period is well documented for the central Great Plains(Tomanek and Hulett, 1970 ; Küchler, 1972). Despite the many published studies, however, little is known about the environmental conditions prevailing in the central Great Plains during the late Pleistocene and Holocene. Because the region has few bogs and natural lakes, there is a paucity of good sites for preservation of fossil pollen and botanical macrofossils. Therefore, climatic reconstruction in this region has traditionally relied heavily on the synthesis of other proxies such as vertebrate fauna, snails, and occasional botanical macrofossils. As a result, interpretations of late−Pleistocene vegetation of the region, for example, range from continuous taiga−like forest(e.g., Wells and Stewart, 1987) to grassland or steppe(e.g., Graham, 1987)

The quasi−continuously deposited loess of the central Great Plains represents some of the thickest and most complete loess deposits in North America and provides a largely untapped potential for reconstructing past climates. Ongoing research by this investigator and colleagues on magnetic records for these deposits indicates a tremendous potential for environmental reconstruction.

Recent research using nonmagnetic parameters has also been particularly rewarding. Two approaches that are now being employed include stable isotope ratio analysis (SIRA), especially that of carbon, and biogenic opal analysis, namely that of phytoliths ; these techniques have been very effective in contributing unique environmental information. The coincidental use of these three proxies of past environments provides a more comprehensive picture of past environments than use of only one parameter. Magnetic information, e.g., MS, indicates times of weathering and soil development in the stratigraphic sequence ; SIRA of carbon provides an overall impression of the type of climate to which the plants have adapted; and opal phytolith morphology permits identification of specific groups of plants.

STUDY LOCALITIES

Three sites were selected for magnetic study on. The upland sampling site is located adjacent to the Bala cemetery, a location nearly 40km northwest of the Kansas River valley and about 10km east of the Republican River valley. The site consists of approximately 2.75m of loess overlying the Permian Winfield Limestone, a much thinner loess mantle than at the former site located adjacent to the river valley.

The Pump House Canyon site consists of a loess deposit situated on a strath within the valley of that same name. Sampling was conducted in a 3.3m deep backhoe trench. The Manhattan Airport site, located approximately 1.5km northwest of the airport, consists of clay-rich late-Pleistocene and Holocene alluvium. The site was backhoe trenched to expose the upper 3.8m of fill, which included alluvial phases of the Sangamon soil(?), Gilman Canyon Formation, and Brady soil, which was overlain by Holocene alluvium.

METHODOLOGY

MAGNETIC ANALYSES

The primary carriers of magnetism usually comprise less than 5% of the sediment mass. Magnetic minerals are, however, common in terrestrial materials and extremely sensitive to environmental conditions. Since it is extremely difficult or near impossible to separate out these minute magnetic minerals in order to study them, the bulk magnetic characteristics of the sediments are usually characterized by one of the bulk properties, MS. MS is a measure of the extent to which a sample becomes more strongly magnetized when a small alternating magnetic field is applied, or simply the ratio of the induced magnetism to the strength of the applied field.

Whereas MS provides information on magnetic concentration, a related parameter, frequency dependence of MS(FD), provides information on the magnetic grain size. FD is the percent difference between MS measured at a low-frequency applied field compared to its measurement at an applied field with a higher frequency. Unfortunately, FD measured using only fixed low and high frequencies, as is the case with existing instrumentation, will discriminate only a portion of the total superparamagnetic (very small magnetic material) population. With the instrumentation currently available, only the presence of grains between approximately 18 and 20 nm in diameter (very fine clay size) can be detected. Even so, FD values are typically much higher in soils than in intervening loess intervals, reflecting abundant pedogenic material.

MS, along with FD, has a broad application to Quaternary paleoenvironmental studies. It may be used as a correlation tool, i.e., to construct and compare magnetostratigraphies. Also, provenance of a sediment sample or body may be determined by comparing its magnetic signature with that of the suspected source. Of primary importance to the research at Fort Riley is the application to detecting weathering zones and pedogenesis, i.e., buried weathering zones and soils within the loessal and alluvial record. Through the use of MS and FD, periods of soil development can be identified even when too subtle to be observed in cores or exposure profiles.

Methods. Samples were collected in the field from freshly exposed or cleaned profiles or from cores extracted and transported to the laboratory in clear plastic liners. The individual magnetic samples were collected in numbered, demagnetized, $8-cm^3$ plastic cubic containers with lids. The sample interval varied slightly, but averaged 40 per meter. These cubes were pressed by hand or driven with a rubber-coated, dead-blow hammer into the exposure or core to obtain the required amount of sediment.

MS and FD measurements were obtained using a Bartington magnetic measurement system consisting of a Model MS2 susceptibility meter and a dual-frequency sensor (MS2B). The facility is located in the laboratory within the Department of Geography at the University of Kansas.

RESULTS

Bala Cemetery. MS exhibits little variation in the upper 1 meter, but contains exaggerated variations in the lower 2m of the core(Fig. 1). Conversely, FD data exhibit high variance. When smoothed, the magnetic data, particularly FD, from this site are more easily interpreted.

The Gilman Canyon soil and a thin zone of relatively unaltered loess are apparent in both magnetic parameters, as is their contact with the underlying limestone bedrock. The ^{14}C age of 19,070 yr BP located at the top of the Gilman Canyon Formation is a terminal age for the formation regionally. Peoria loess has the characteristically low values for both magnetic parameters, indicating relatively low levels of weathering. The MS values indicate, in the absence of ^{14}C age control, that the Brady soil and Bignell loess do not exist at this site. Age data also indicates that the Brady soil is absent and that little or no Bignell loess is present.

From a minimum value at about 0.9m, FD increases to a plateau that is likely a buried soil(c. 0.75–0.5m) welded to the surface soil. The lack of surface soil definition in the MS data may be due to somewhat poor drainage at the site, but FD clearly signifies the surface soil.

Pump House Canyon. Although the site is believed to be a loess–mantled strath, backhoe trenching did not reach bedrock. The Pump House Canyon site contains an expanded Holocene portion of the section, thereby yielding a high–resolution record of Holocene deposition and environmental change

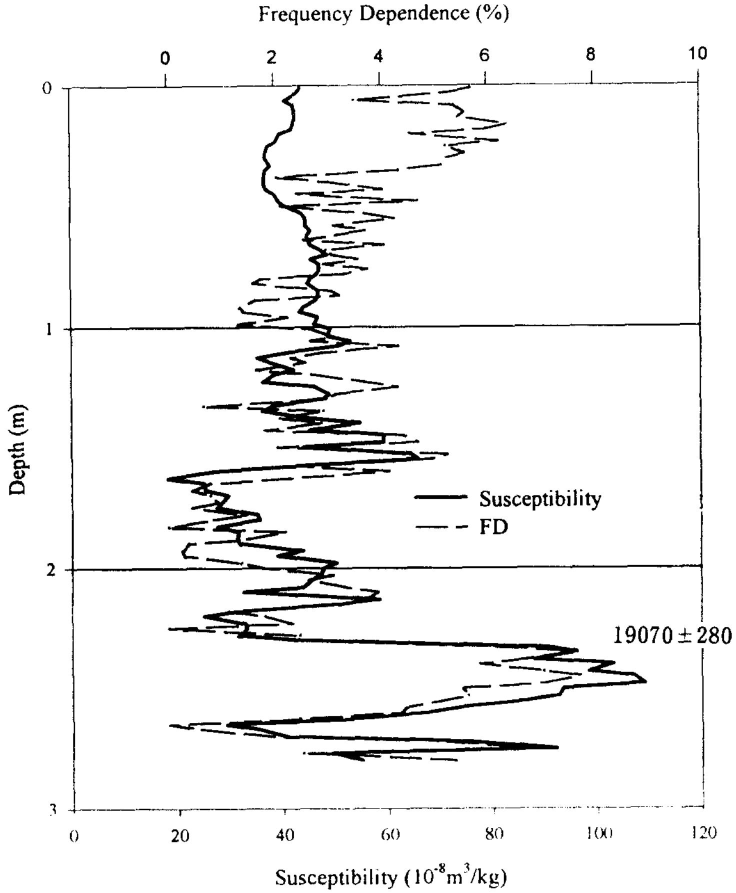

Figure 1. Magnetic susceptibility and frequency dependence data from the trench profile at the Bala Cemetery site.

(Fig. 2). The ^{14}C ages of 18,830 and 23,010 yr BP bracket the end of Gilman Canyon time, e.g., the soil appearing at the bottom of the backhoe trench.

The first soil above the presumed Gilman Canyon Formation is expressed well in both the MS and FD. The offset in data from the two parameters is common in other magnetic records obtained from the central Great Plains by this investigator: the MS response likely represents the A and AB horizons and the FD the B(Bt) and BC horizons. The soil' s position between the ^{14}C ages, magnetic signature, and physical appearence suggest that it is the Brady soil. At least one weakly developed soil occurs above the presumed Brady soil, based upon FD data. The surface soil is obvious from the values of both parameters; the characteristic reduction of

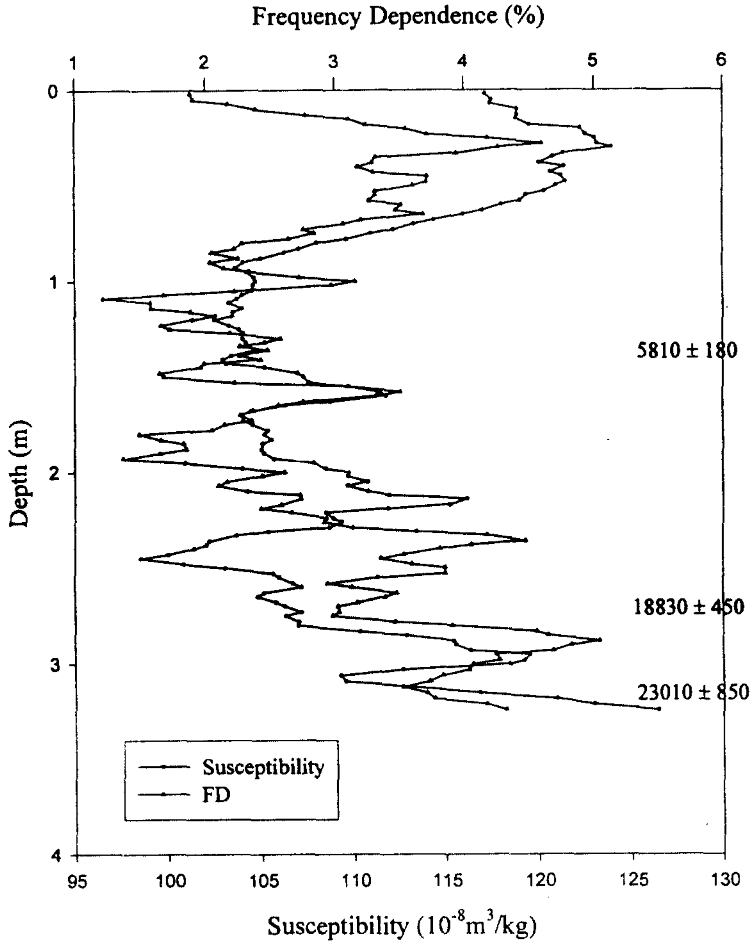

Figure 2. Magnetic susceptibility and frequency dependence data from the trench profile at the Pump House Canyon site. Numbers indicate the ^{14}C ages.

both parameters in the upper 25cm or so is due to the dilution effect of organic matter in uppermost A horizon.

Manhattan Airport. The majority of the fill is Pleistocene, but, on the basis of a single Holocene ^{14}C age, the upper 1 to 1.5m is Holocene(Fig. 3). The Holocene fill may have originated from an unnamed tributary entering from the west, rather than from the Kansas River; contributions of Bignell loess may also be present. Soils present presumably represent the alluvial, or valley phases of those expressed regionally(e.g., Sangamon, Gilman Canyon, Brady).

Physical attributes from about 2.75m to the bottom of the trench indicated the Sangamon soil; the relatively weak magnetic signal, partic-

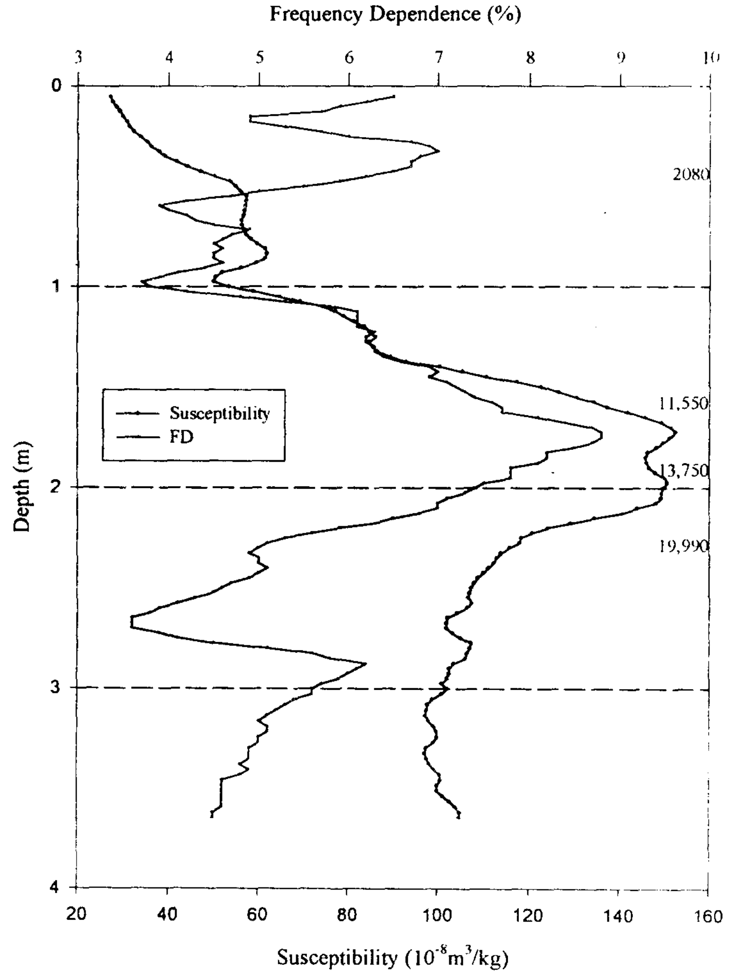

Figure 3. Magnetic susceptibility and frequency dependence data from the trench profile at the Manhattan Airport site.
Numbers indicate the ^{14}C ages.

ularly for MS, is probably due to poor drainage conditions of the alluvial plain during Sangamon time. The Gilman Canyon soil does not appear magnetically; the 19,990 yr BP age, a terminal Gilman Canyon age, should identify the top of the soil. The pronounced central bulge in both parameters is likely the Brady soil, based on the ^{14}C ages. The steady upward decline in MS above 1m depth may be indicative of poor drainage, but is also related to relatively rapid alluviation. The three modes within FD for the same interval are not clearly interpretable, but may relate to episodic alluviation during the Holocene.

PALEOENVIRONMENTAL AND CLIMATIC INTERPRETATIONS

The composite magnetic record for the reservation is consistent with the regional records Soil formation during Gilman Canyon time is well expressed in the magnetic record at all sites except Manhattan Airport, an alluvial, not eolian sequence. On the basis of magnetic signals from the Bala Cemetery and Pump House Canyon sites, the Gilman Canyon soil is better developed than the surface soil. The Gilman Canyon soil is, as noted above, best described as a composite geosol in that pedogenesis was diminished somewhat during formation of the soil by an acceleration in the rate of loess fall, albeit still very low. As a result, the magnetic signal(MS and FD) typically have a bimodal character; this bimodality is present at the Bala Cemetery site, but not at the Pump House Canyon site because the sampling apparently stopped(trench bottom) in the minimum between the two pedogenic modes.

Peoria loess deposition occurred at a relatively rapid rate as to preclude any significant pedogenesis. Low MS and FD values(c. 40 and 2, resp.) at the Bala Cemetery site reflect the rapid rate of deposition and lack of significant pedogenesis. The increase in MS and FD that occurs in the Peoria loess at about 1–1.5m depth does, however, suggest one or more brief periods of soil development. The absolute timing of the pedogenesis/surface stability is unknown but is probably centered around the Last Glacial Maximum (c. 18ka); a moderately developed glacial maximum soil has been identified elsewhere in the region(e.g., Park, 1997). Unfortunately the Peoria loess is not preserved in an unweathered state in any other of the sites examined, thereby precluding a local corroboration of the glacial maximum soil.

The Brady soil, while not expressed at the Bala Cemetery site, is well exhibited at the Pump House Canyon, and Manhattan Airport sites. Of the two sites, soil development in the alluvial environment of the Manhattan Airport progressed relatively rapidly in this presumably well-watered and high-biomass location, i.e., both magnetic parameters are elevated. From the magnetic signal, Brady soil development at Pump House Canyon appears intermediate in development, i.e., approximately equivalent to the modern surface soil, with a moderate to strong response in both magnetic parameters(Fig. 2).

Deposition of Bignell loess occurred at a faster rate than that of the Peoria loess and reflects more the microclimatology of a particular region, principles well illustrated at Fort Riley. As the southerly winds of the Holocene evolved, loess was lofted from the Kansas and Republican River flood plains onto the adjacent uplands. Consequently, the Pump House Canyon site contains a Bignell loess component ; Bala Cemetery site is too far removed from riverine environments to the south, and Manhattan Airport site has experience the accumulation of Holocene alluvium, not loess. The Pump House Canyon site has 2-3m of Bignell loess, with the loess being slightly coarser at the Pump House Canyon site due to its lower elelvation, i.e., closer vertical proximity to the alluvial bottoms.

Evidence of the Altithermal, or middle Holocene dry episode appears at the Pump House Canyon. The depressed MS and FD values during the middle Holocene are indicative of an increased rate of deposition and decreased intensity and/or time of weathering. Evidence of pedogenesis still appears, particularly at Pump House Canyon. One of these middle Holocene soils has been dated to 5,810 yr B.P. a time of major Holocene soil development in both the alluvial and upland environments elsewhere in the region(Johnson and Martin, 1987 ; Johnson and Logan, 1990 ; Johnson et al., 1996a, b ;). Although probable, this interpretation is not absolute in that neither site has the resolution of ^{14}C dating needed for a reasonable level of confidence, e.g., the Brady soil identified at the Pump House Canyon site is an interpretation based on physical soil attributes and the intensity of the magnetic signal, but not on absolute age data.

Although few in number and at scattered stratigraphic levels, ^{13}C values determined for the purpose of correcting ^{14}C ages for isotopic fractionation provide a limited insight into the variation in climatic conditions as reflected in the vegetation. Late-Pleistocene ^{14}C ages tend to have smaller isotopic values (i.e., more C3 influence) than do those derived from Holocene age sediments, e.g., -15.6 for the middle Holocene but -16.5 or less for the late Pleistocene at Manhattan Airport.

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