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Preliminary Magnetic Study of the Quaternary Red-Soil Bed on Linkou Terrace, Northern Taiwan

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ABSTRACT

This study presents the preliminary magnetic results from analyses of the Quaternary red-soils and the fine grain sediments within the underlying conglomerate bed of the Linkou Terrace in northern Taiwan.

Magnetic susceptibility measurements indicate that the fine grain sediments taken from the conglomerate bed have extremely low susceptibilities relative to those of the red-soils. This phenomenon suggests that the source of the red-soil probably did not originate from the weathering of the conglomerate bed. From both paleomagnetic and rock magnetic results, it is thought that the red-soil bed was deposited during the period between the Jaramillo normal event and the Brunhes normal epoch, or later.

Stratigraphic variations of magnetic susceptibility of the red-soil samples before and after CBD (citrate-bicarbonate-dithionite) treatment show the same trend: the lower part of the red-soil bed has values about two times higher than those of the upper part. In addition, susceptibility of the upper part after CBD treatment has been reduced by more than 60%, but that of the lower part only has been reduced by less than 40%. It is known that CBD treatment can resolve hematite, goethite and ultra fine-grained magnetite. So, the results of this study might suggest that the upper part has much more soil development and lateritization than the lower part. Furthermore, the major (and possibly the original) magnetic mineral of the red-soil is magnetite.

In the area neighboring the Linkou Terrace to the north, there was a lot of volcanic activity during the early Quaternary. Magnetite has been identified as the major magnetic mineral of the volcanic rocks. Thus, it is proposed that the source of the red-soil bed in the Linkou area developed, at least partly, from the volcanic rocks. In addition, the boundary between the two groups, with distinct very different magnetic susceptibilities, might be used as an indicator for stratigraphic correlation in the study area.

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1. INTRODUCTION

For the last two decades, the magnetic method has been thought of as one of the most powerful methods for studying paleo-environment changes. The greatest advantages of the magnetic method for such studies are that it can support continuous time-dependent records and that the samples will not be destroyed during measuring. These magnetic results are not only very useful for stratigraphical correlation analysis, but could also provide many valuable indications for directly studying paleo-climate and environment changes. The method has been broadly applied to analyzing sediments from Chinese loess, lakes and marines (Creer et al., 1976; 1980; 1981; Creer, 1974; 1977; Doh et al., 1988; Heller & Liu, 1984; Hyodo et al., 1993; Kent, 1982; Kukla & An, 1989; Lin et al., 1995; Liu et al., 1993; Meynadier et al., 1995; Robinson, 1986; Robinson et al., 1995; Stoner et al., 1995; Stoner et al., 1996; Turner and Thompson, 1981). However, very few of them have reported dealing with red-soils.

In Taiwan, red-soil beds covered a large proportion of the island's surface, especially in the northern part. Since these might bear some important information about paleo-climate and environment changes, our aim is to apply the magnetic method to study it systematically. The Linkou Terrace has been chosen as the first testing area. Origin of red-soil beds in the Linkou area has been very ambiguous in the past. Several different propositions have been made, such as development from the underlying conglomerate due to weathering; lateritization from the previous soil bed deposited above the conglomerate; detrital sediments due to river deposits (Lin, 1991). In addition, due to a lack of available material for biostratigraphic and isotopic dating, the age of it is another interesting problem waiting to be solved. So, in this study, we plan to use paleomagnetic and rock magnetic methods to study the Linkou red-soils. Hopefully, some important results can be obtained which will help to solve the above problems.

2. GEOLOGIC SETTINGS

In western Taiwan, there are a series of Quaternary terraces. Linkou terrace is the most northern one. It is situated to the west of the Taipei basin (Fig. 1). The area is basically a flat terrace of up to 250 m in altitude (Ho, 1969).

Except for some minor deformed strata exposed along the Hsinchuang Fault, the Linkou terrace has a floor composed of flat-lying sedimentary strata that can be divided into two coeval stratigraphic units. To the east, the Linkou Formation consists mainly of conglomerates and intercalated sandstone. To the west, the Tananwan Formation comprises intercalating sandstone, mudstone, and conglomerates. Phase changes between the Linkou and Tananwan rocks are graded and believed to be indicative of a fan-delta system (Chen and Teng, 1990). A previous paleomagnetic study indicated that the age interval of the Tanawan Formation is between 1 and 2.4 Ma, i.e., is located in the magnetic time scale from the Gauss-Matuyama boundary to the lower boundary of the Jaramillo normal event (Lee et al., 1995). Pollen analy-

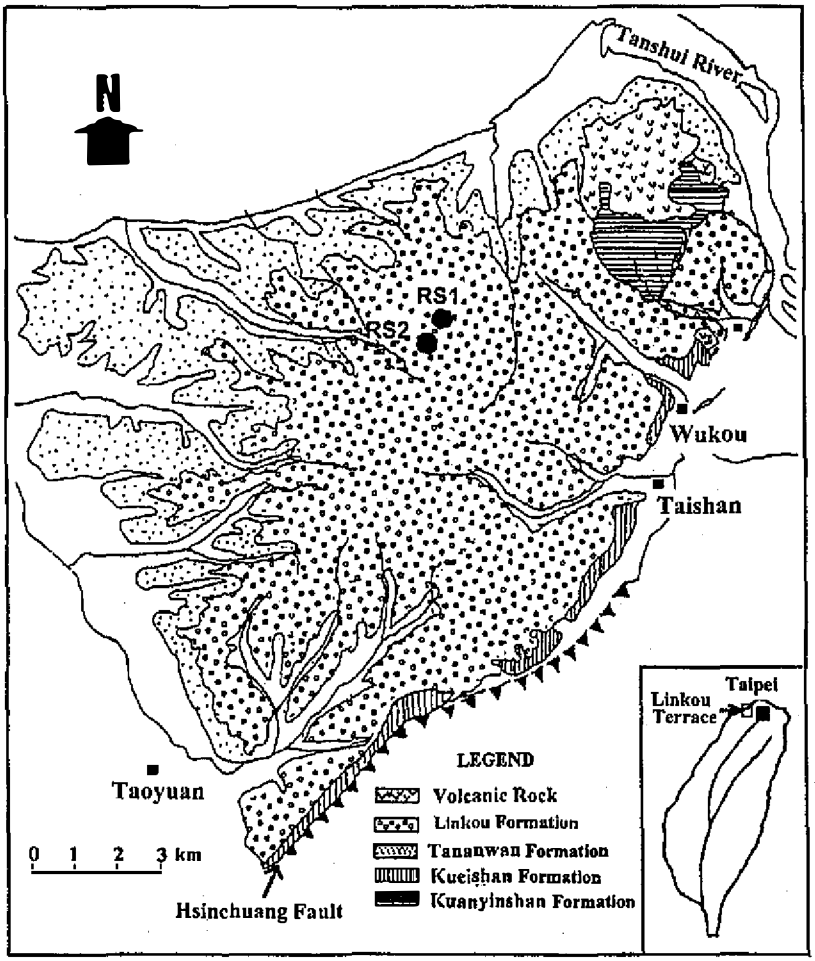


Fig. 1. Sketched geological map of Linkou Terrace and the site localities.

sis (Tseng et al., 1992), and ESR dating from molluscs (Shih, 1991) pointed out that the age of the upper part of the Tananwan Formation might be 0.7-0.9 Ma.

Overlying the Tananwan and Linkou Formations is a thick red-soil bed with a thickness of between 6 and 12 meters. Studying the mineralogy, Lin (1991) indicated that both magnetite and hematite are the major magnetic minerals contained in the red-soils. Due to a lack of fossils, the age of the red-soil beds was not directly reported. However, from the age data of the underlying Tananwan Formation, the red-soil bed of the Linkou Terrace should appear later than Jaramillo normal event of the paleomagnetic chronology.

At the northern tip of the terrace, a 700 m high Quaternary volcanic cone, the Kuanyinshan volcano, is found. The volcano has been dated as 0.6 to 0.2 Ma by K-Ar radiometry (Juang, 1988). It belongs to the Tatun Volcano Group which has reportedly had at least three stages of eruptions in the last 2 Ma.

3. METHODS

Continuous sampling was carried out for the studied red-soil section RS-1 (Fig. 1) by using plastic cubes of dimensions 2.0 cm×2.0 cm×1.6 cm. Generally, the vertical distance between two adjacent samples is around 5 cm. The detailed stratigraphical height of each sample was carefully measured, and a total of 135 samples were obtained. These samples cover a stratigraphical thickness of about 6 meters. The stratigraphic height of the lowest sample is set to be the origin, 0 cm, and positive upward in this study. However, it is actually still about 1.5 meters above the underlying conglomerate bed.

Measurements of the low field magnetic susceptibility (χ) were first carried out on a Bartington MS2 susceptibility instrument at its low frequency mode. Then, measurements of NRM acquired by the samples and their demagnetization treatments by stepwise increases of alternating field (AF) were performed on a horizontal type cryogenic magnetometer equipped with an AF demagnetizer (model SRM 755 from the 2G Enterprise Company) which is installed in a magnetic shielding room. The steps for the demagnetization treatments were from 0 mT to 100 mT in increments of 10 mT. Next, the ARM of each sample was built up by applying a stable magnetic field of 1 Gauss under a peak field of 100 mT AF demagnetization at the same time. Stratigraphical variations of χ, NRM and ARM before demagnetization treatment were set up and comparedy in order to find how important the influence of magnetic mineralogy is.

In order to discuss the origin and paleo-environment changes occurring in red-soil formation, some more samples were collected from a neighboring section, RS-2, at different levels including the underlying conglomerate bed. Their magnetic susceptibilities were measured and compared to those of the previous section. In addition, they were subjected to CBD (citrate-bicarbonate-dithionite) treatment. Their low field magnetic susceptibilities were re-measured and the results were then compared to those before CBD treatment.

In addition, magnetic separation was also carried out for some samples and magnetic mineralogy was studied by analyzing the hysteresis loops measured on a Princeton Micromag 2900 gradient magnetometer.

4. RESULTS

Figure 2 shows the hysteresis loop of the magnetic mineral separated from the lower part of section RS-1. It was found that magnetization could almost be saturated at the applied field up to about 3,000 Oe. This suggested that the major magnetic mineral contained in the lower part of the studied section is magnetite. This is in good agreement with the X-ray diffraction results analyzed from the other red-soil section, RS-2 by Lin (1991).

Figure 3 presents some normalized magnetic intensity curves of the samples studied during demagnetization and Fig. 4 shows some typical directional variation plots on the stereonet after AF demagnetization treatment. The NRM directions could not reach a stable and acceptable characteristic direction. This suggests that the AF demagnetization treatment used could not completely clean the secondary NRM component of the samples. However, the

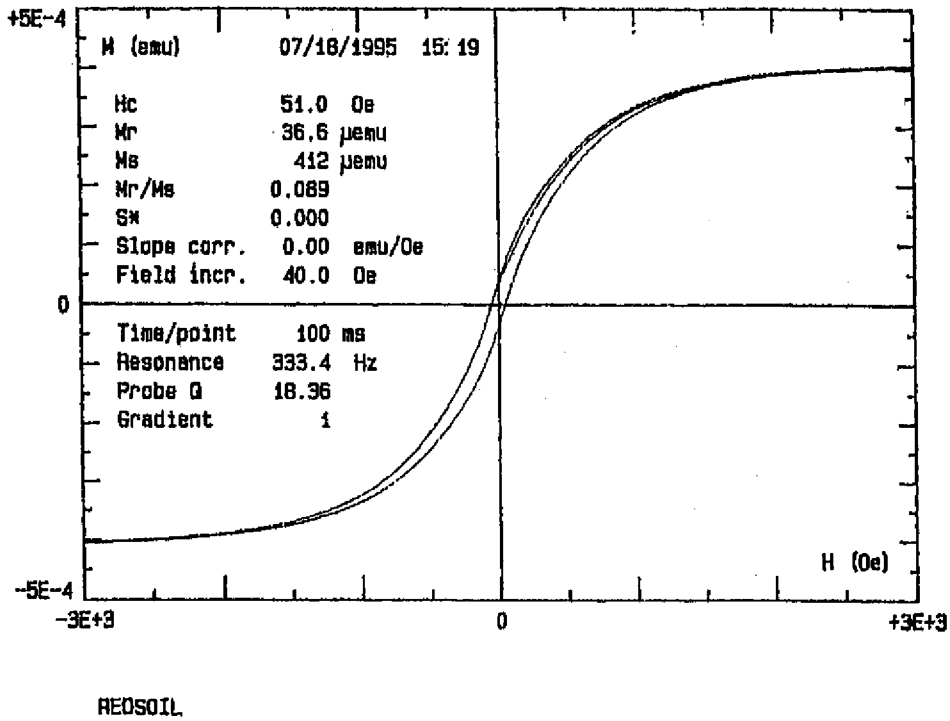


Fig. 2. Magnetic hysteresis loop for the sample from the lower part of the studied section.

NRM directions seem to change their polarity from positive to negative and to vary toward the west and southwest directions. Thus, it might be proposed that the red-soil bed was formed during a reversed magnetic event or an excursion period.

The variation patterns of low field magnetic susceptibility of the two sections studied, RS-1 and RS-2, are shown from bottom to top in Fig. 5. It was found that within the conglomerate bed, the magnetic susceptibilities of samples are extremely low. The lower part of the red-soil layers of the two sections has much higher values than the upper part. In addition, the magnetic susceptibilities of the top 100 samples of section RS-1 seem to show three cycles.

Figure 6 shows the variation patterns of χ, NRM and ARM of section RS-1. It was found that the three curves show almost the same variation pattern except those present in the lowest 70 cm of the section. This may indicate that the strength of remanent magnetization acquired by the samples is generally proportional to the amount of magnetic minerals in the top part, but this is unlike to be the only factor for the lower part. This will be discussed later.

To investigate whether the paleo-environment has changed during the formation of red-soil in the Linkou area, CBD treatment for the samples collected from section RS-2 was carried out. Magnetic susceptibilities both before and after CBD treatment are presented in Fig. 7. It was found that the two curves show the same trend: the lower part of the red-soil layer has values about twice those of the upper part. The significance of this will also be discussed later.

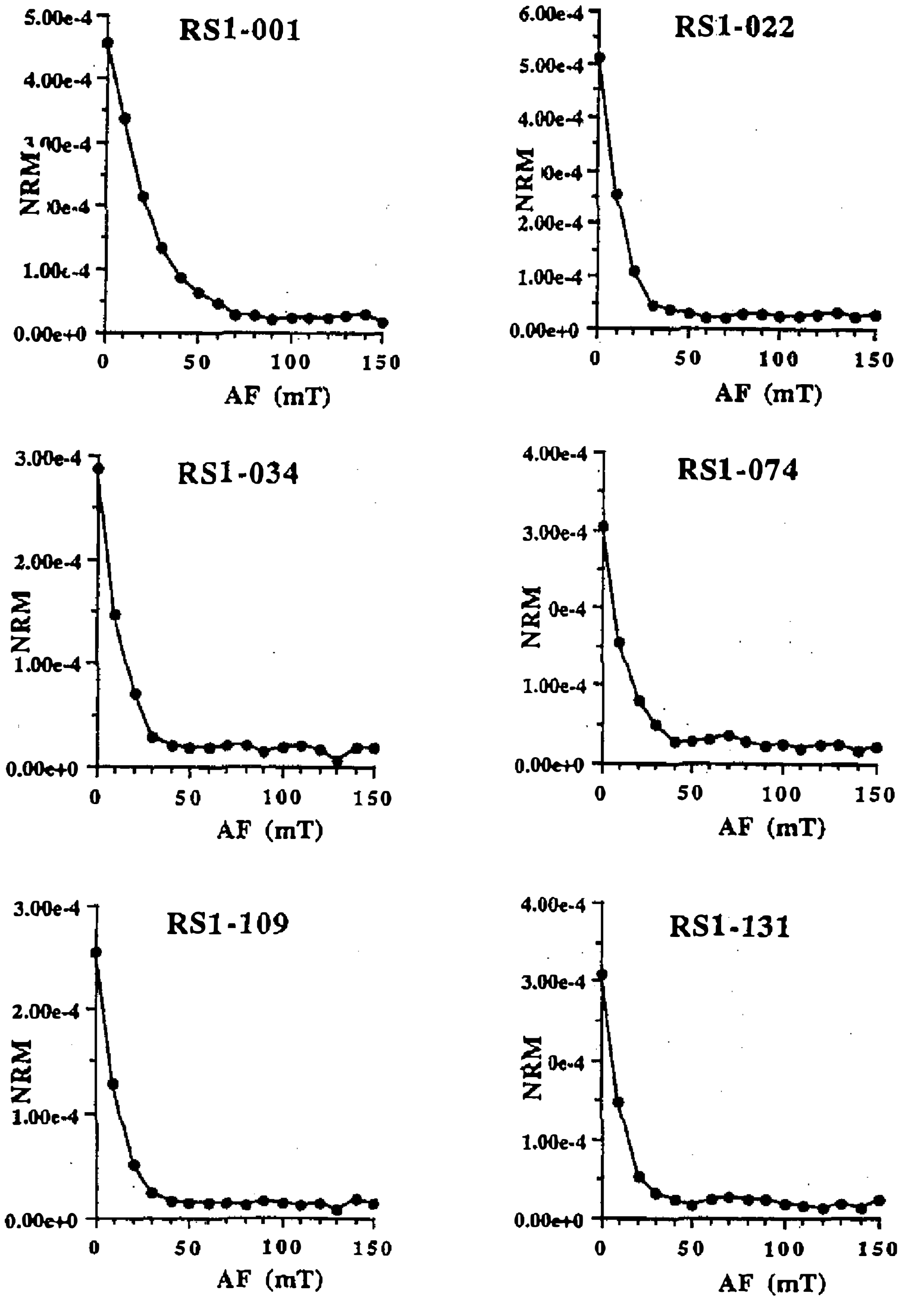


Fig. 3. Some normalized magnetic intensity curves of the samples studied from section RS-1.

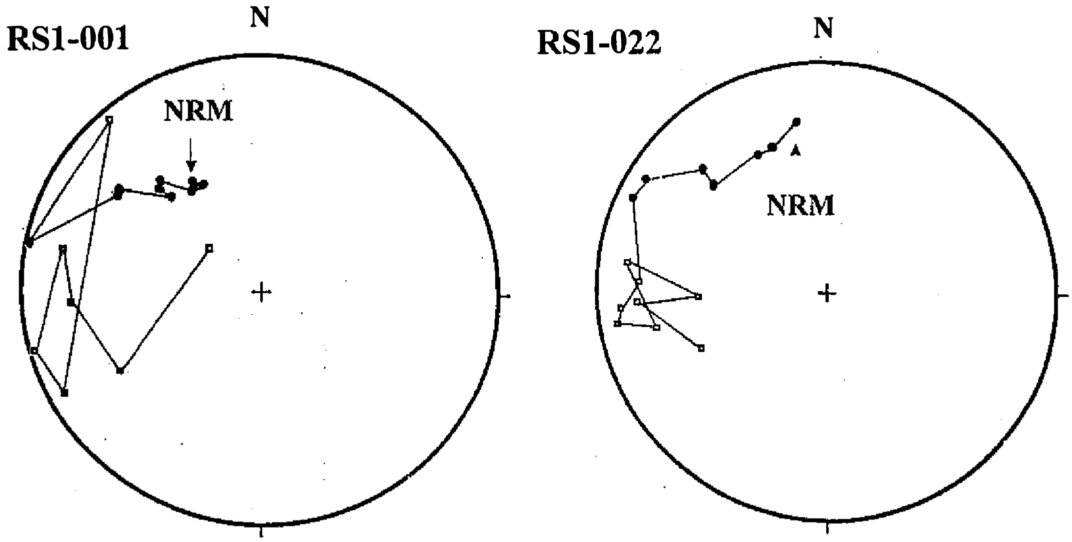


Fig. 4. Directional variation plots shown on the stereo-net of samples after AF demagnetization treatments (open symbol: negative inclination; closed symbol: positive inclination).

5. DISCUSSIONS

The results of CBD treatment shown in Fig. 7 suggest that the patterns could be a very important indication of stratigraphic correlation. Furthermore, it was found that magnetic susceptibilities of the samples in the upper part were reduced by more than 60% after CBD treatment, but those in the lower part were reduced by less than 40% only. Generally, CBD treatment resolves magnetic minerals such as hematite, goethite and ultra-fine grained magnetite that were formed by weathering (Fine & Singer, 1989; Hunt et al., 1995). Thus, the results shown in Fig. 7 may indicate that the upper part has much more soil development and lateritization than the lower part.

Based on this mechanism, it is thought that much more magnetite has been oxidized to become hematite, goethite etc. in the upper part and that more magnetite remained in the lower part. The magnetic susceptibility patterns shown in Fig. 5 point out the possible existence of three different cycles in the top part of the section studied and the high value peak in its lower part certainly reflects this fact. In addition, such a variation pattern provides a good opportunity for future stratigraphic correlation studies in the Linkou red-soil area.

In the lowest 1.5m of section RS-1, the NRM and ARM did not show the increasing trend as that of χ (Fig. 6). This implies that kinds and grain size of magnetic minerals probably play a more important role than amount in this portion of the section. However, magnetite has been identified as the major magnetic mineral from Fig. 2, Fig. 7 and X-ray diffraction analysis

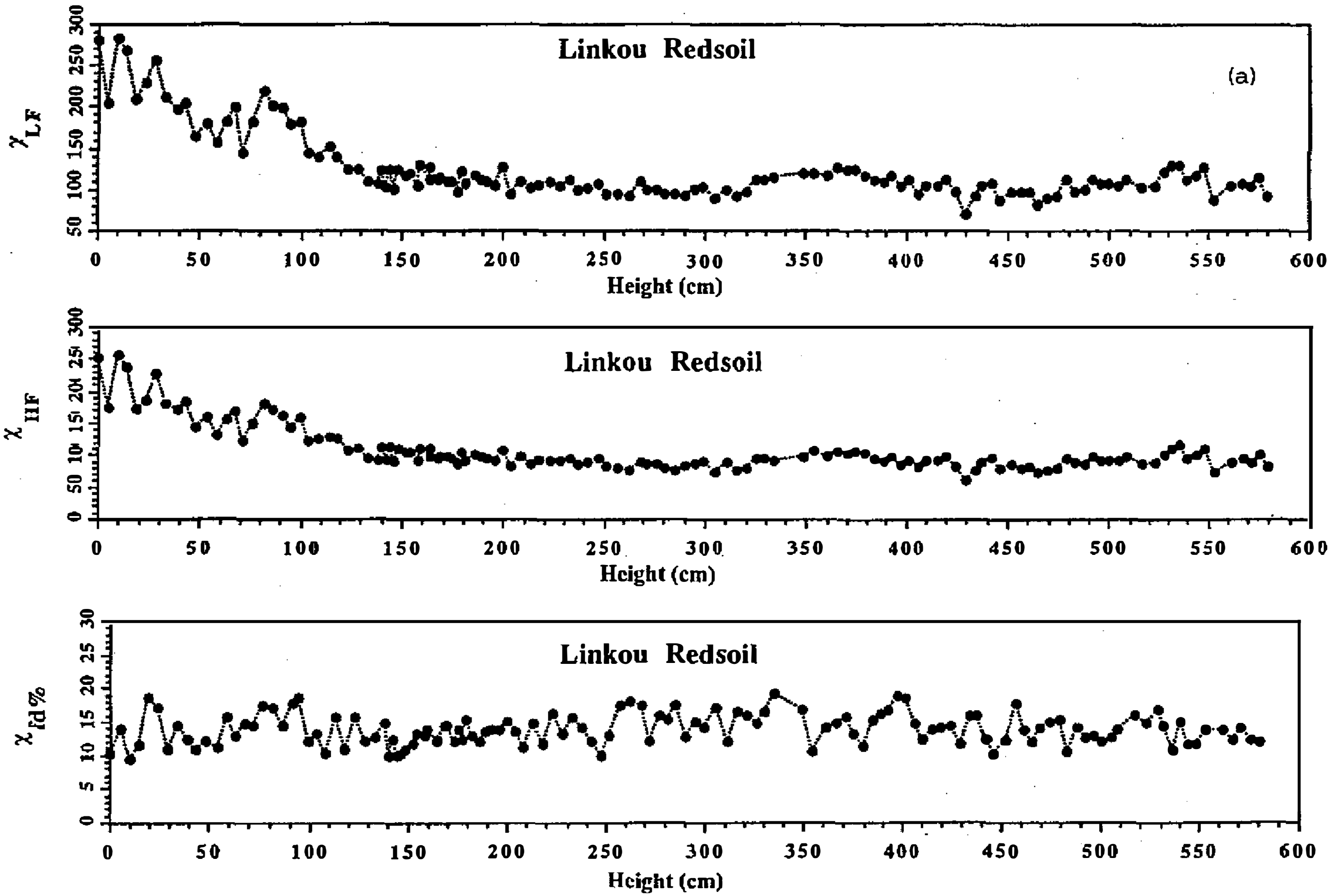
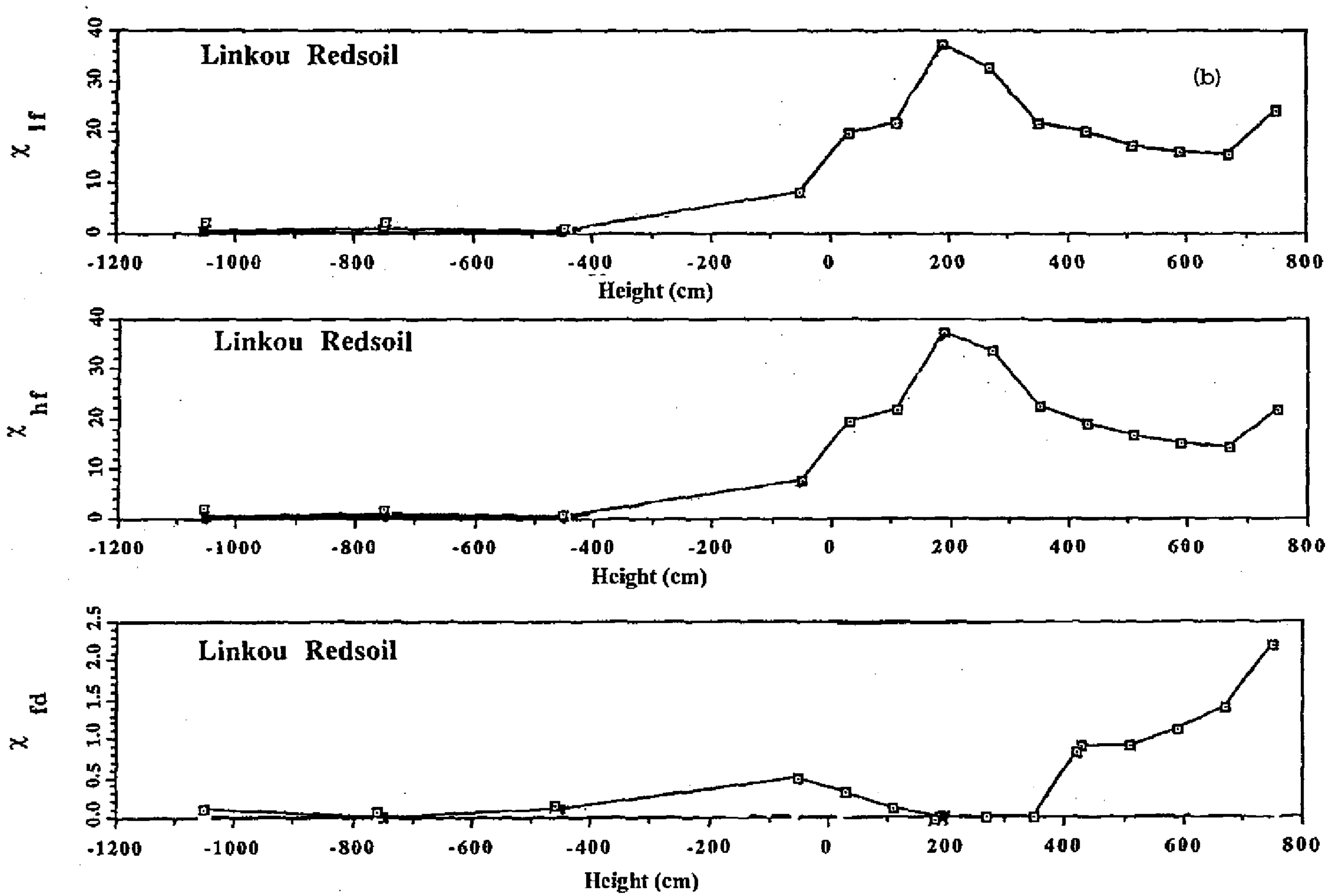


Fig. 5. The stratigraphical variations of low field magnetic susceptibility including low frequency, high frequency and percentage of frequency dependent modes of the samples studied from (a) section RS-1 and (b) section RS-2.



(*Fig. 5.* continued)

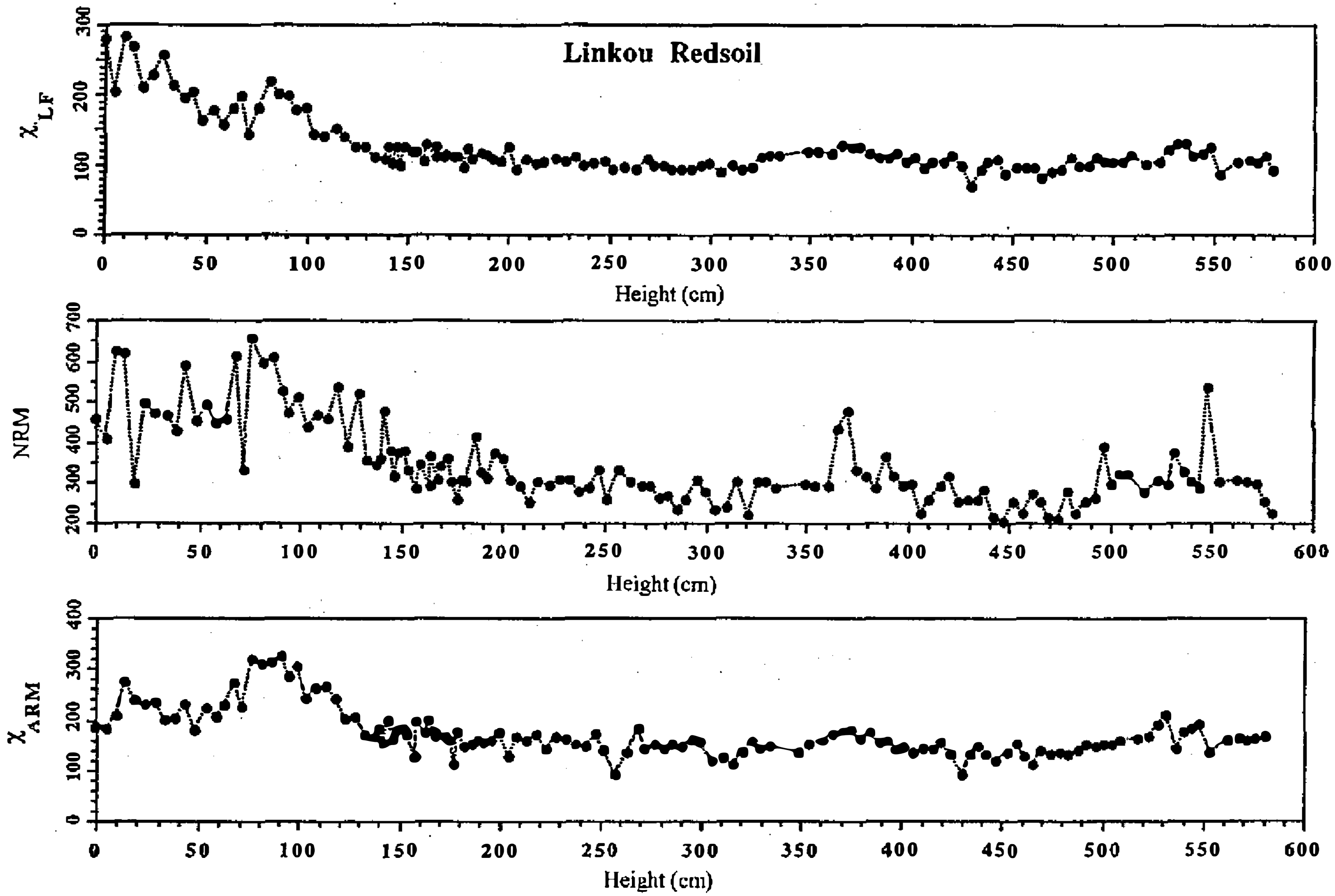


Fig. 6. Comparison of the variation patterns of magnetic susceptibility, NRM and ARM.

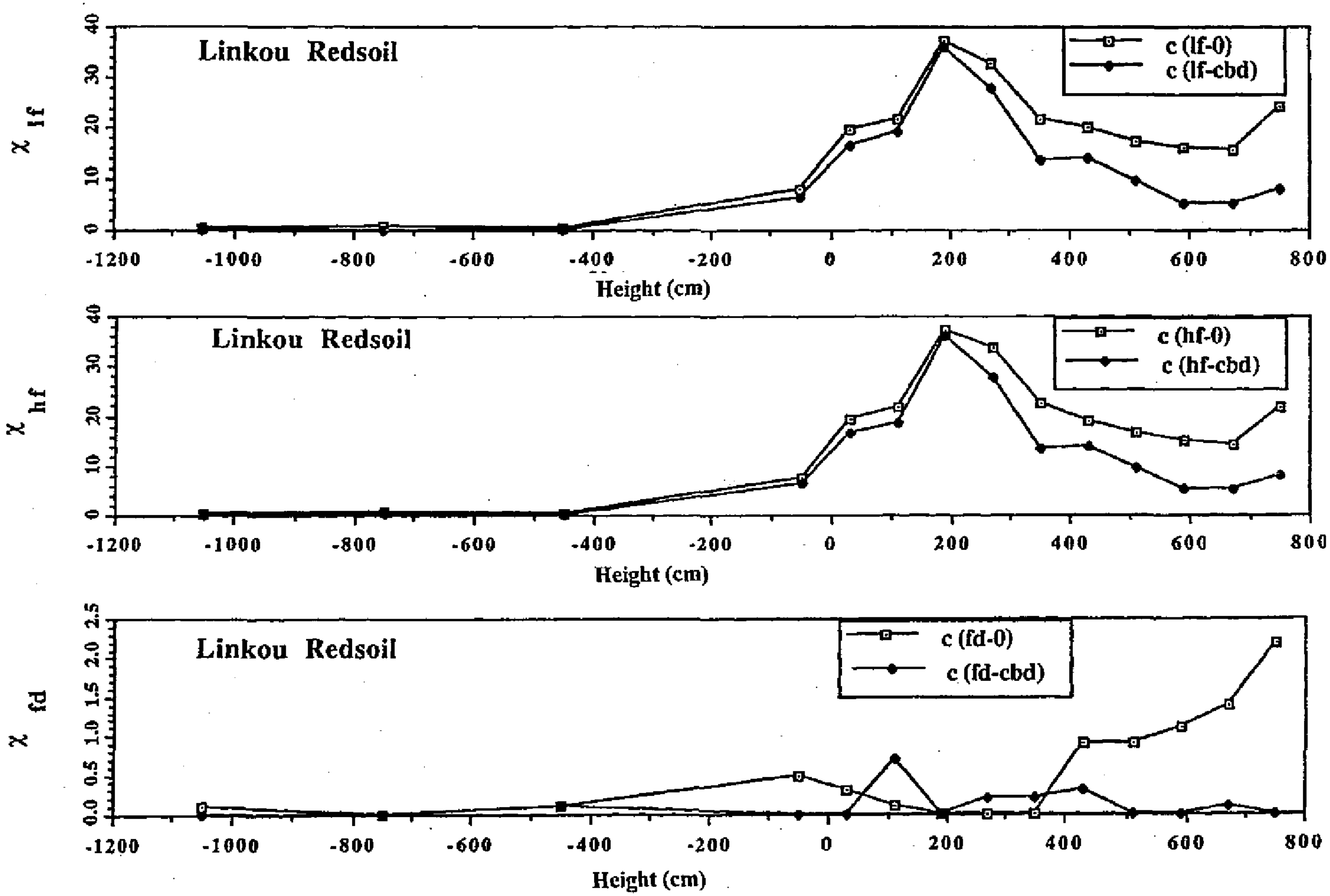


Fig. 7. The results of samples before and after CBD treatment for section RS-2 (open square: before CBD treatment; solid diamond: after CBD treatment).

(Lin, 1991). Magnetite can usually acquire much stronger remanent magnetization than the other magnetic minerals. So, grain size is considered to be the most important factor for the variation in NRM and ARM trends in the lowest part of section RS-1. The decreased magnetic susceptibility in the correspondent portion of section RS-2 (layer from conglomerate up to about 2 m high) after CBD treatment may reflect the fact that the resolved magnetic mineral is ultra fine grain magnetite (Fig. 7). Such a kind of grain has the characteristics of superparamagnetism and it does not make an important contribution to NRM and ARM.

The magnetic susceptibility results of samples before and after CBD treatment shown in Fig. 7 may also provide valuable information on the formation of the red-soil. In this figure, it can be seen that the fine grain sediments taken from the conglomerate bed have extremely low susceptibilities relative to those of the red-soil. This phenomenon suggests that magnetic mineral contained in the red-soil did not mainly derive from the weathering of the conglomerate, although residual concentration might have occurred in the past. Instead, in consideration of the origin of magnetite, it is thought that the major source of the magnetic minerals may be strongly related to the Quaternary volcanic activities at the neighboring area to the north. The most probable mechanism is that the sediments derived from the surrounding rock formations where the volcanic material was delivered by rivers in the area. However, further study is necessary.

Paleomagnetic directions of the samples studied did not show proper normal or reversed polarity due to insufficient AF demagnetization. However, they seem to have a tendency toward reverse magnetized. If the samples have been reverse magnetized, the deposition age of the red-soil bed in the Linkou area could be proposed to be between 0.98 and 0.78 Ma (Cande & Kent, 1992), i.e., earlier than the Brunhes normal epoch but later than the Jaramillo event. This assignment is basically based on a previous paleomagnetic study of the Tananwan Formation in the Zueshukenchi section (Lee et al., 1995). If this is not the case, i.e., the characteristic remanent magnetization of the samples could be represented by the direction after demagnetization treatment, the paleomagnetic directions might imply that they were acquired during a period of magnetic excursion. In this case, the red-soil beds could be considered to be younger in age, probably appearing in the Brunhes normal epoch. Since several excursion events have already been found in the Brunhes epoch, there is no doubt that further study is required for the purpose of investigating the real age interval of the red-soil beds.

6. SUMMARIES

This study is the first trial to study the rock magnetic properties of red-soils in Taiwan. Several points have been noted:

1. The red-soils on Linkou Terrace do not mainly originate from the weathering of the conglomerate. Instead, it is proposed to relate them to the early Quaternary volcanic activities in the neighboring area to the north.
2. From paleomagnetic analysis, the red-soil is proposed to appear at either the latest reversed time interval in the Matuyama epoch (later than Jaramillo normal event) or in a magnetic excursion within Brunhes epoch. Certainly, it should be studied further.

3. The variation patterns of magnetic susceptibility, NRM and ARM could be used for future stratigraphic correlation of the red-soil beds in the area studied.
4. Magnetite is identified as the major magnetic mineral in the red-soil. However, after CBD treatment, the results of this study indicate that magnetite contained in the upper part of the bed has been oxidized to become hematite and goethite much more than that of the lower part. This might imply much greater soil development and lateritization at the upper part.
5. The lower part of the red-soil bed might contain relatively abundant ultra fine grain magnetite. This could be revealed by the variation patterns of NRM, ARM and χ.

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