

## Late Quaternary Paleomagnetic Intensity Record in Taipei Basin, Taiwan

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### ABSTRACT

This paper presents a paleomagnetic intensity record for late Quaternary time in Taiwan. Samples came from the lower part of an 86-meter sedimentary piston core drilled in the Wukou area of the Taipei Basin. The age interval of the studied portion, as determined by C-14 dating (Liu et al., 1994), was proposed to be between 9,000 yr.B.P. and 21,000 yr.B.P. Natural remanent magnetization (NRM), anhysteresis remanent magnetization (ARM) and low field magnetic susceptibility ( $\chi$ ) of the samples were analyzed.

Results show that the stratigraphical variation patterns of NRM/ $\chi$  and ARM/ $\chi$ , after 20 mT alternating field demagnetization treatments on both NRM and ARM of samples, are very similar. This implies that the acquisition of NRM and ARM are under the same magnetic mineralogical conditions. Thus, the ratio of the NRM to ARM at this demagnetization stage could represent the paleointensity secular variation of geomagnetic field in the area studied.

Four major high peak areas were found in the NRM/ARM record (after 20 mT demagnetization). These were at about 60 m, 70 m, 80 m and 90 m in depth. Three of them could be correlated to another intensity record analyzed from a lacustrine sediment core drilled in the Taihu area of China (Wang et al., 1997). Comparing these two records, and the C-14 dated ages of the two cores, the correspondent ages of the four intensity high peaks were proposed to be about 10,000, 13,500, 17,500 and 21,000 years before present, respectively. In addition, the age assigned to the peak at about 60 m in depth is also supported by the volcanic records in Japan (Tanaka, 1990). Thus, the record of this study presents a regional secular variation pattern of paleo-intensity of the earth's magnetic field during the last 9,000 to 21,000 years in East Asia.

(Key words: Paleomagnetism, Paleo-intensity, Secular variation,  
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## 1. INTRODUCTION

When studying the correlation between different stratigraphic sections and analyzing the events of paleo-environment changes, it is very important to have the age control as high resolution as possible. Paleomagnetic analysis, including polarity reversal records and/or secular variation patterns of earth magnetic field, has been broadly considered as a very powerful tool for contributing high resolution, continuous and more precise age data, in addition to paleontological and isotopic methods. For the last twenty years, paleomagnetic study has been very commonly used (Barton & McElhinny, 1981; Creer, 1974; 1977; Creer et al., 1976; 1980; 1981; Hyodo et al., 1993; Turner and Thompson, 1981). However, most of the works prior to the 1990s dealt only with the directional variations of the field and not its intensity, especially for the sedimentary rocks. This is due to paleomagnetic intensity being controlled not only by the earth magnetic field but also by the magnetic mineral assemblages contained in the samples. Also, the mechanism for the acquisition of the remanent magnetization plays another important role. To distinguish these factors to get more accurate paleo-intensity information is somewhat difficult.

For the volcanic rocks and archeological materials, Thellier and Thellier (1959) succeeded in developing a method to analyze the paleo-intensity of the earth's magnetic field based on the activity of thermal remanent magnetization. However, these data support only discrete age dating. To have a continuous time record, it is best to have analysis taken from the sedimentary sequences. However, for the sedimentary samples, the Thellier and Thellier method couldn't be applied because (1) magnetic minerals contained in the samples might be changed when oxidation occurred during heating processes and (2) the detrital remanent magnetization acquired mainly by the sedimentary rocks did not have the activity property.

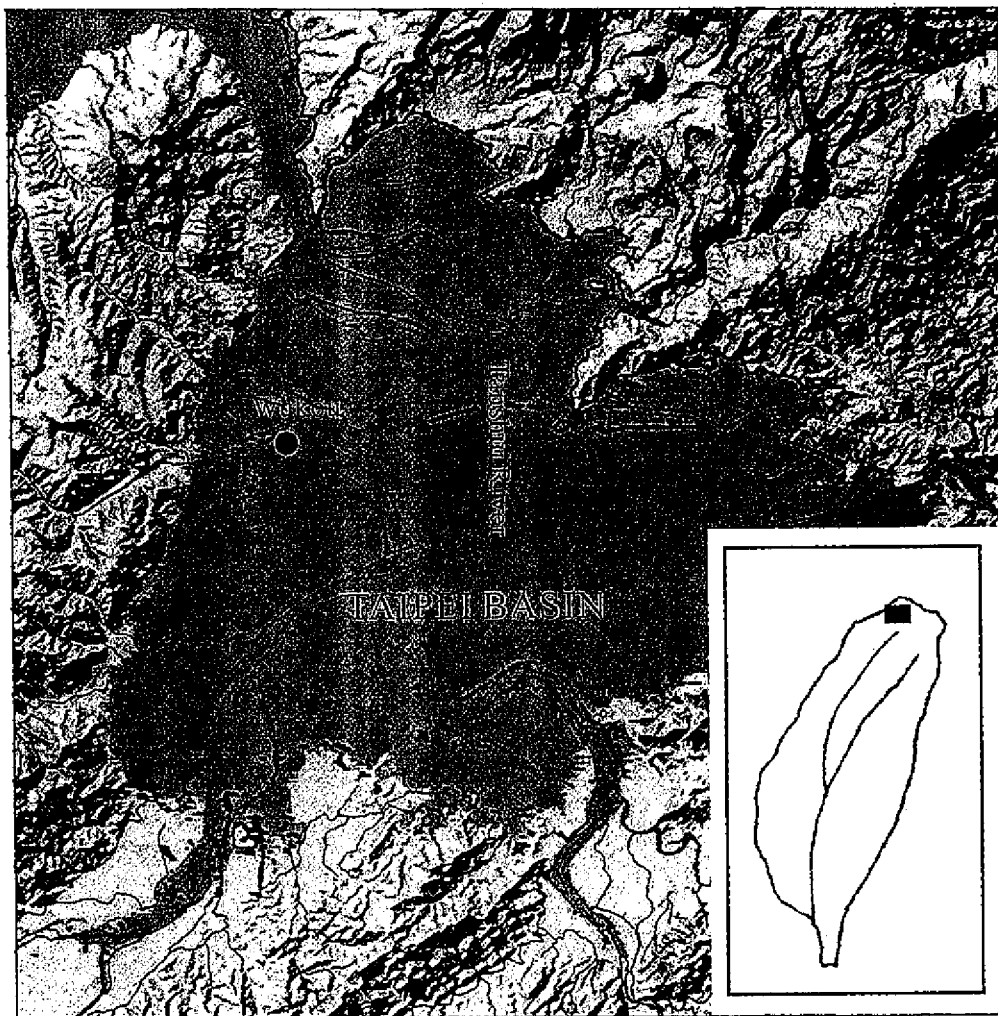
To try to investigate an effective way to study the paleomagnetic intensity from sediments, Tric et al. (1992) analyzed the intensities of NRM and ARM at different demagnetization steps, and compared the stratigraphic variation patterns of both NRM vs.  $\chi$  and ARM vs.  $\chi$  after 20mT cleaning treatment for five marine cores. They found that the two patterns are very similar. Furthermore, they pointed out that the pattern of the NRM vs. ARM at 20 mT cleaning could monitor the existing discrete paleo-intensity records taken from volcanic rocks very well. Since then, several similar studies have been made in marine and lake sediments (Meynadier et al., 1992; Valet & Meynadier, 1993; Yamazaki & Ioka, 1994) and the intensity secular variation pattern has been extended to about 4 million years before present (Valet & Meynadier, 1993).

The Taipei basin is located at the northwest margin of the Western Foothills. It is known to be formed due to tectonic movement, faulting. Since 1991, to assist development planning in the basin, the Central Geological Survey of the R.O.C. has drilled many long piston cores in order to study the detail geological and structural conditions under Taipei basin. One of them, herein referred to as #WK13, was chosen to do the paleomagnetic study for helping to set up the precise age intervals of the sedimentary formations in the basin. Because this core was not well oriented in the horizontal direction, the paleo-intensity study of the samples was performed employing the same method used by Tric et al. (1992). The established paleo-intensity secular variation pattern of this study is expected to be a standard record in Taiwan area for the

late Quaternary time, and it could be applied for future stratigraphic correlation and dating work.

## 2. GEOLOGICAL SETTINGS

The studied core #WK13 was drilled in the Wukou area at the western side of the Taipei basin (Figure 1). It has a length of about 86.4 meters distributed from a depth of 10 m to 96.4 m below surface. Stratigraphically, the whole core belongs to the youngest geological unit of the Taipei basin, the Songshan Formation. The detailed lithology of this core is shown in



*Fig. 1.* The morphology of Taipei basin and its surrounding area (modified from Tseng, 1998). The close circle shows the site locality of the studied core. Square in the index map shows the location of Taipei basin.

Figure 2. It was found that this core is mainly composed of mud, mud interbedded with silt and silt layers. Only a few sand layers appeared at the top part of this core. Sediments were generally the late Quaternary embouchure and/or fresh water lacustrine facies deposits.

Several levels of this core have been dated by the C-14 method (Liu et al., 1994). The results indicated that the top and the bottom of the core have C-14 ages of  $3,430 \pm 60$  yr.B.P. and  $21,070 \pm 130$  yr.B.P. The other important age data are  $9,010 \pm 110$  yr.B.P.,  $9,880 \pm 80$  yr.B.P.,  $10,180 \pm 150$  yr.B.P.,  $14,860 \pm 100$  yr.B.P. and  $17,380 \pm 70$  yr.B.P. dated at the depths of about 50 m, 61 m, 64 m, 68 m and 81 m, respectively. These C-14 ages could be used as the control for the paleo-intensity study of the earth's magnetic field in this paper.

### 3. SAMPLING AND LABORATORY ANALYSIS

Continuous sampling was carried out on the #WK13 core by using  $2.0 \text{ cm} \times 2.0 \text{ cm} \times 1.6$  cm plastic boxes. The detailed stratigraphical height of each sample was carefully recorded. More than 4,000 samples were obtained. One seventh of them have been analyzed and the results are represented herein. The stratigraphical heights of the samples studied are distributed from 44.3 m to 96.4 m in depth. The distance between two chosen adjacent samples is gener-

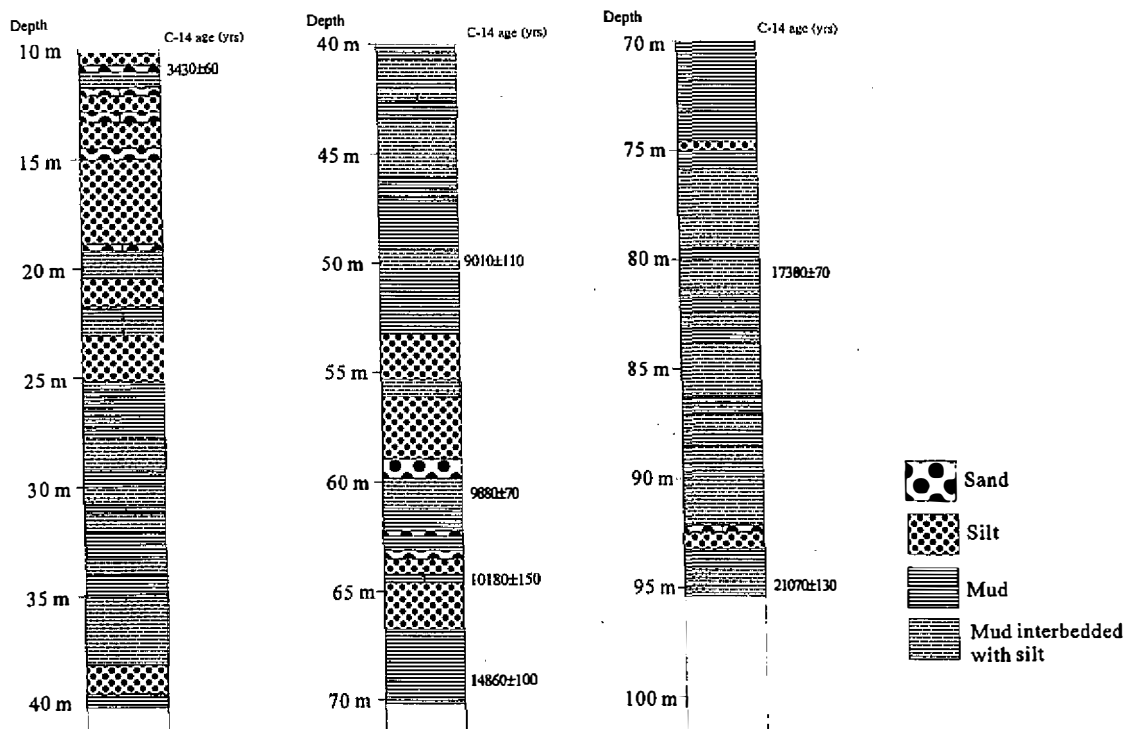


Fig. 2. The column profile of the core #WK13.

ally less than 10 cm.

For these samples studied, measurements of low field magnetic susceptibility were first carried out on a Bartington MS2 susceptibility instrument in its low frequency mode. Then, NRM measurements and the demagnetization treatments of samples were made on the horizontal-type cryogenic magnetometer (2G Enterprise Company, model SRM 755) which is equipped with an AF demagnetizer and has been installed in a magnetic shielding room at the Institute of Earth Sciences, Academia Sinica in Taiwan. The demagnetization treatments are stepwise from 0 mT to 100 mT in increments of 5 mT. After these processes, the acquisition of ARM for 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. This ARM acquisition was also carried out using the 755 SRM cryogenic magnetometer system. Finally, the samples' ARMs were measured and demagnetized again using exactly the same procedures as for the NRMs.

Stratigraphical variations of NRM and ARM before demagnetization treatment were first set up and compared mutually in order to find out whether ARM could simulate NRM. Then, variation patterns of  $NRM/\chi$  and  $ARM/\chi$  at different demagnetization levels were analyzed. These are used to find the influence of magnetic mineralogy especially the grain size of magnetic minerals and also to determine the optimum stage for paleo-intensity analysis in this study. In addition, to confirm whether the chosen step is suitable, the demagnetization plots on the Zijderveld diagram (Zijderveld, 1967) were analyzed. Although the core studied is not well oriented, the directional variation pattern during demagnetization should still help for such an analysis. Finally, the ratio of NRM vs. ARM at the chosen level was calculated for all the samples studied. The results obtained are compared to the other records and take the existing C-14 ages into consideration in order to build up a paleo-intensity secular variation pattern during the late Quaternary in Taiwan.

#### 4. RESULTS

Figure 3 shows the stratigraphic variation patterns of  $\chi$ , NRM and ARM intensities before AF demagnetization treatments of the samples studied. The patterns generally look very alike. This phenomenon seems to suggest that the ARM pattern could be used to simulate the acquisition of NRM. The acquisition of remanent magnetization (RM) of rock and sediment samples is not only controlled by earth's magnetic field but also by kinds, grain size and amount of magnetic minerals contained in the samples and also depend on the environments during and after the acquisition process. Therefore, using ARM and NRM to simulate the paleointensity pattern of paleomagnetic field at the area studied, discrimination of these factors should be done.

It is well known that strength of magnetic susceptibility generally reflects most of the effects due to kinds and amounts of magnetic minerals. To eliminate such effects, NRM and ARM should be normalized by magnetic susceptibility  $\chi$ . The stratigraphical variation patterns of  $NRM/\chi$  and  $ARM/\chi$  are shown in Figure4 for different demagnetization levels. The similarity between  $NRM/\chi$  and  $ARM/\chi$  before AF demagnetization (0 mT treatment) indicates that the acquisition of ARM is probably under the same grain size distribution condition

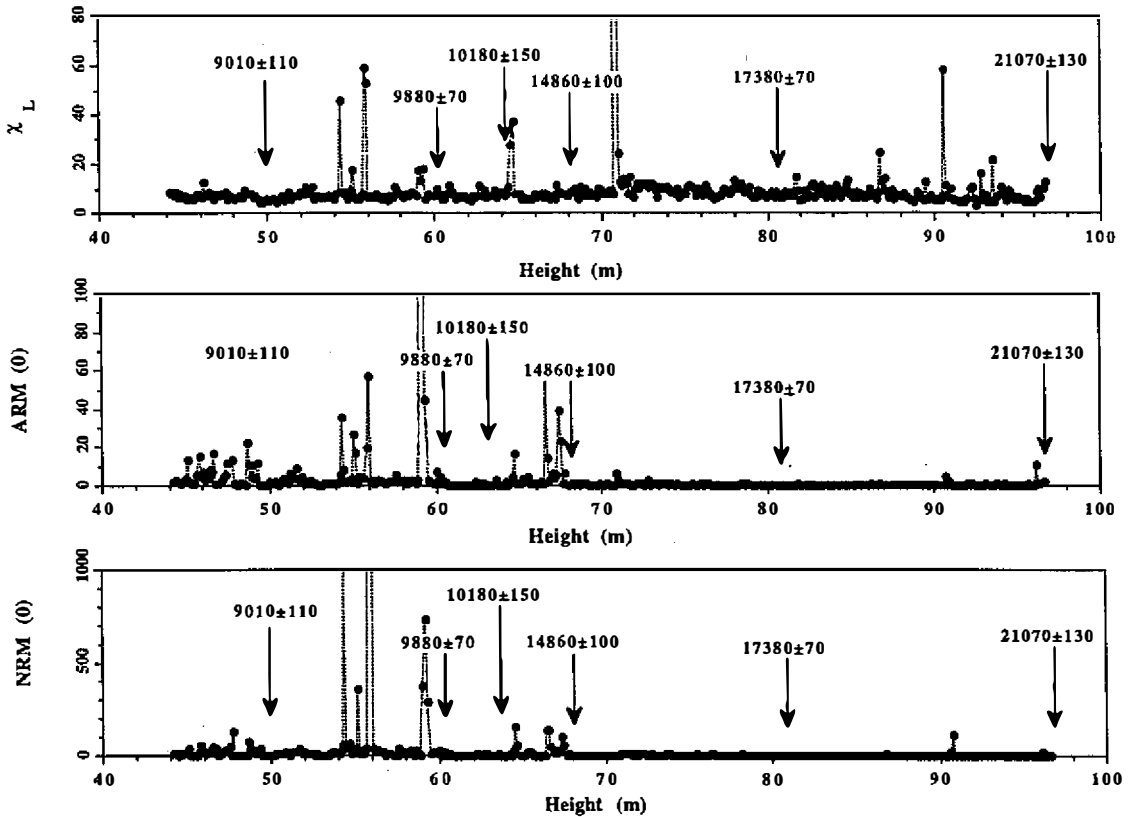


Fig. 3. The stratigraphical variation patterns of magnetic susceptibility ( $\chi$ ), NRM and ARM before AF demagnetization treatment.

as that of NRM. Furthermore, it could also be found from Figure 4 that the  $NRM/\chi$  and  $ARM/\chi$  patterns almost exceed 95% identity after 20 mT AF demagnetization. Thus, the comparison of NRM and ARM at 20 mT demagnetization step is considered to be the most suitable step for studying the paleo-intensities recorded in the #WK13 core. It supports the proposition made by Tric et al. (1992) for the paleo-intensity study of the earth's magnetic field on sediments.

To confirm the suggestion, demagnetization plots of the NRM shown on the Zijderveld diagrams were studied (Figure 5). They clearly indicate that the secondary component seems to have been almost completely cleaned out before or at 20 mT. So, the variation pattern of NRM vs. ARM at the 20 mT AF demagnetization level (Figure 6) is thought to be capable of representing the proposed secular variation pattern of paleo-intensity of the earth's magnetic field during 9,000 to 21,000 yr.B.P. at the area studied. In this figure, four high value peak areas appearing close to 60 m, 70 m, 80 m and 90 m could be clearly identified. These peaks could certainly be used as indicators in stratigraphical correlation.

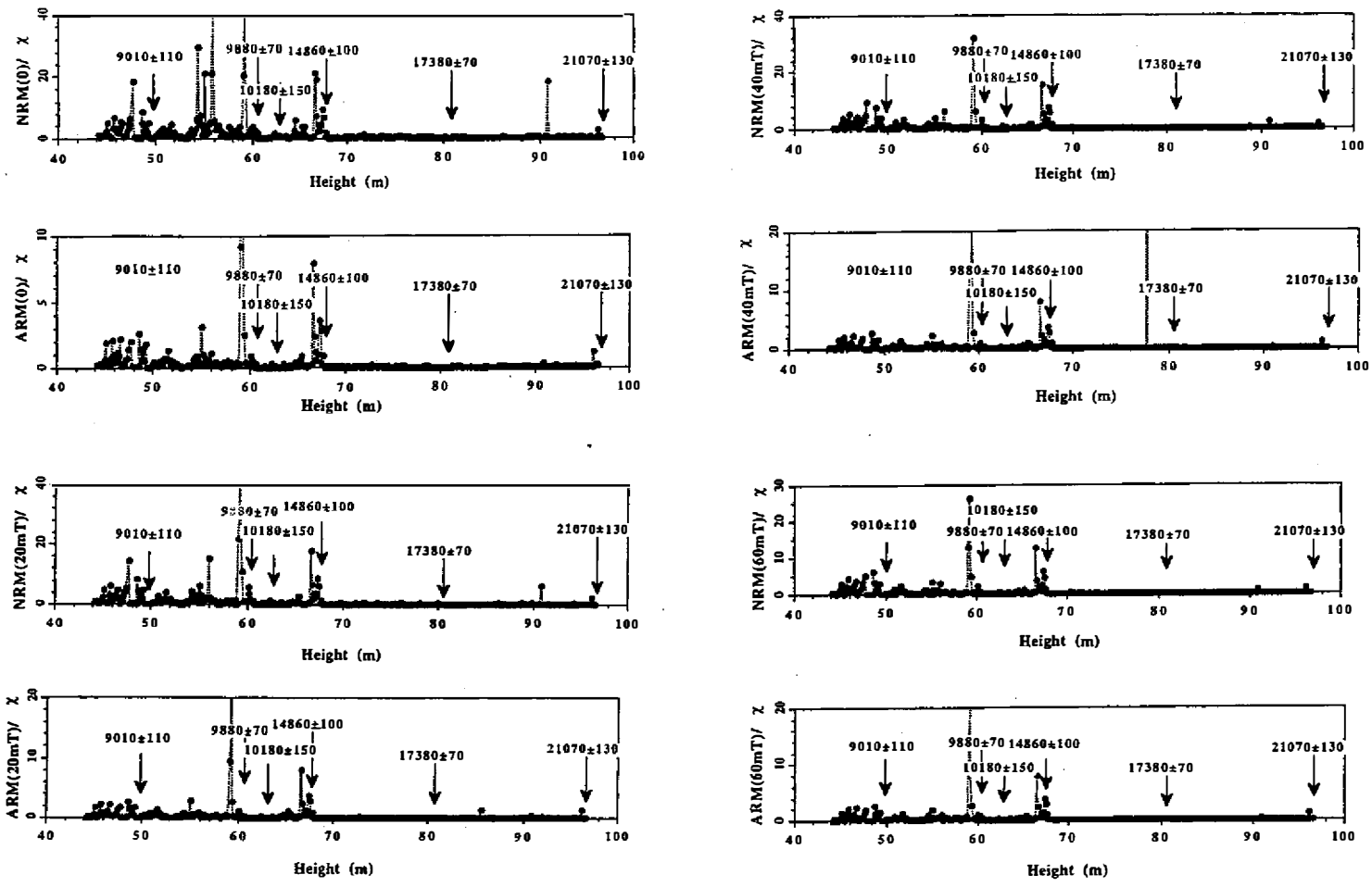


Fig. 4. The stratigraphical variation patterns of NRM/χ and ARM/χ at different alternating field demagnetization levels.

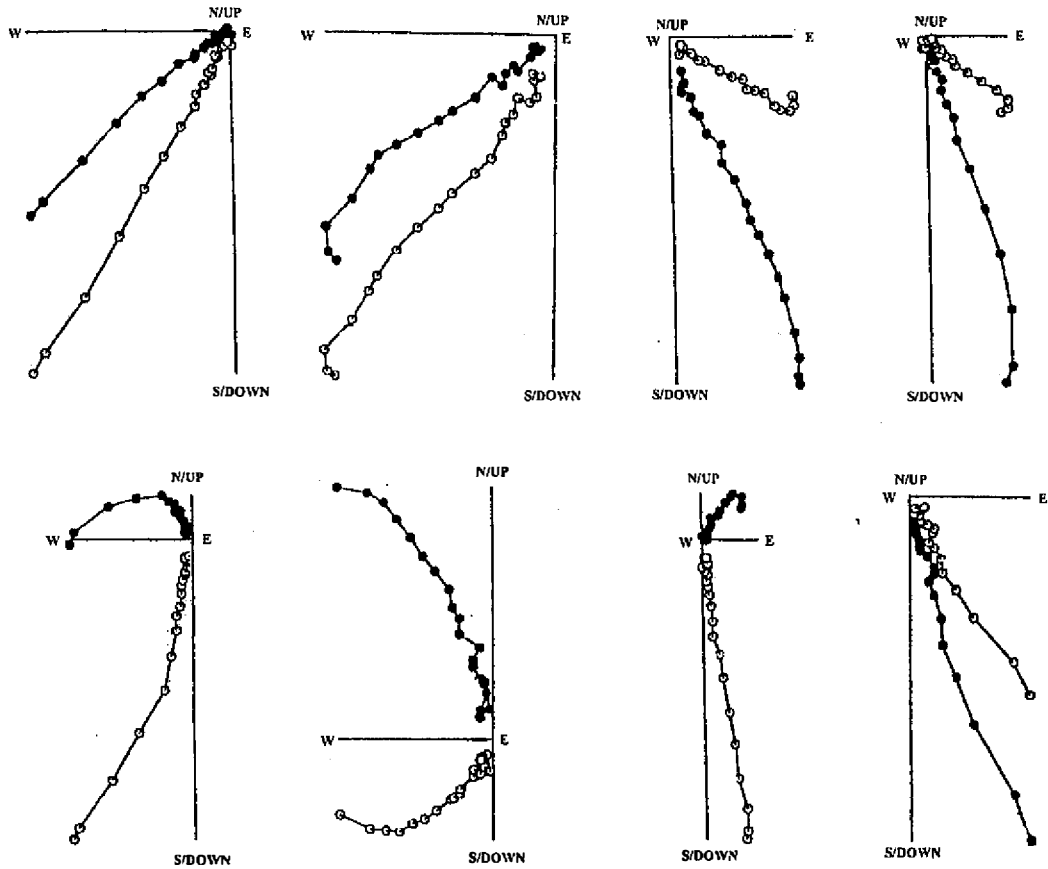


Fig. 5. Some typical orthogonal plots of the paleomagnetic directions of the samples studied show that the secondary components of NRM have been cleaned after 20 mT AF demagnetization treatment.

## 5. DISCUSSIONS

Whether a paleomagnetic secular variation record represents only a local pattern or a regional or even a global event, it should be compared with the other data under the same time base. In Taiwan and East Asia, no continuous paleomagnetic secular variation pattern of very high resolution has been reported before, except for one from a lacustrine sediment core drilled from Taihu area, China by Wang et al. (1997). The variation patterns of the two records, from core #WK13 and Taihu, are shown in Figure 7.

From this figure, if the C-14 dated ages of both cores are considered, three of the four major high peak areas of the #WK13 record appear to correlate with the peaks in the Taihu record. These appeared at depths of around 60 m, 70 m and 80 m for core #WK 13 and at



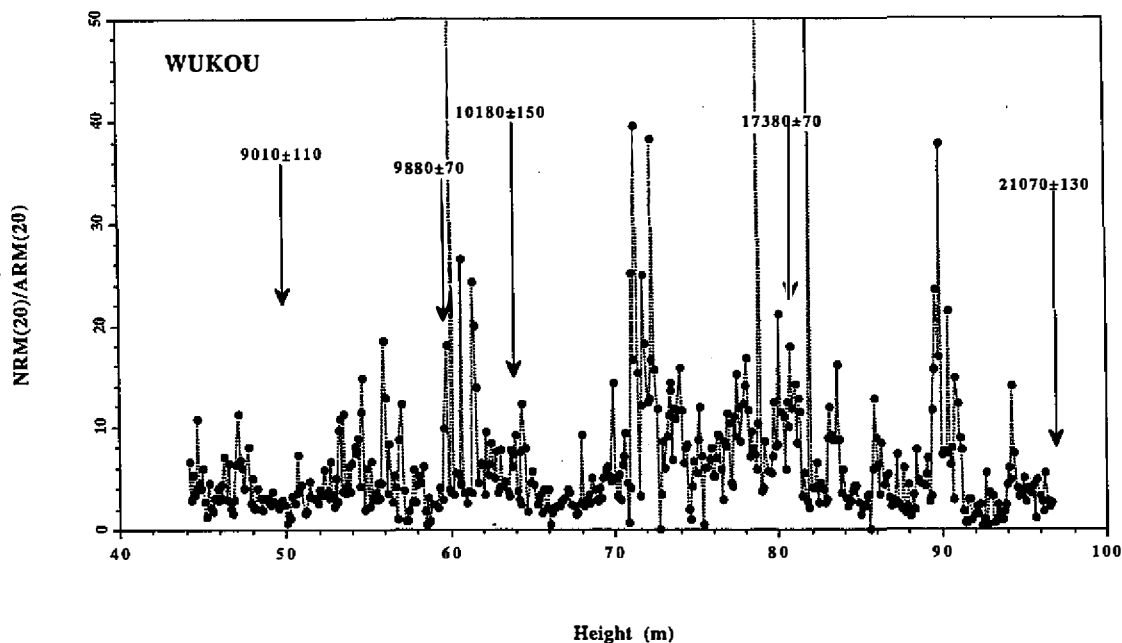


Fig. 6. The stratigraphical variation patterns of NRM vs. ARM of the core studied at 20 mT AF demagnetization level shows the secular variation pattern of paleo-intensity of earth magnetic field during 9,000 to 21,000 yr.B.P. in Taipei basin.

depths of 8.3 m, 11.5 m and 13.5 m for the Taihu core. Under such a comparison, the C-14 age dated at 68 m for core #WK13 seems inconsistent with that at 11.5 m for the Taihu core. From the previous magnetic susceptibility ( $\chi$ ) analysis of the Taihu core (Wang et al., 1996), it was pointed out that an extremely high  $\chi$  was found below a depth of about 12 m. It has been proposed that this anomaly is due to the last glacial event. Generally, it was proposed that last glacial period ended at about 14,000 yr.B.P. Thus, it is doubtful whether the age of core #WK13 at 68 m is as old as obtained from C-14,  $14,860 \pm 100$  yr.B.P. This indicates that the material used for C-14 dating at the depth of about 68 meters might have been reworked. However, this should be further investigated.

In addition to the sedimentary record, the first high peak area having an assigned age of about 10,000 yr.B.P. also seems to be supported by the volcanic records analyzed by Tanaka (1990) in Japan. Thus, the correspondent ages of the four high intensity peaks of core #WK13 could be proposed as about 10,000, 13,500, 17,500 and 21,000 years before present of the uncalibrated C-14 age, respectively. Because the record in this study is similar to those from both the Taihu area and the volcanic record from Japan, it might be at least a regional pattern representing the paleo-intensity secular variation pattern of the earth's magnetic field during the last 9,000 to 21,000 years in East Asia.

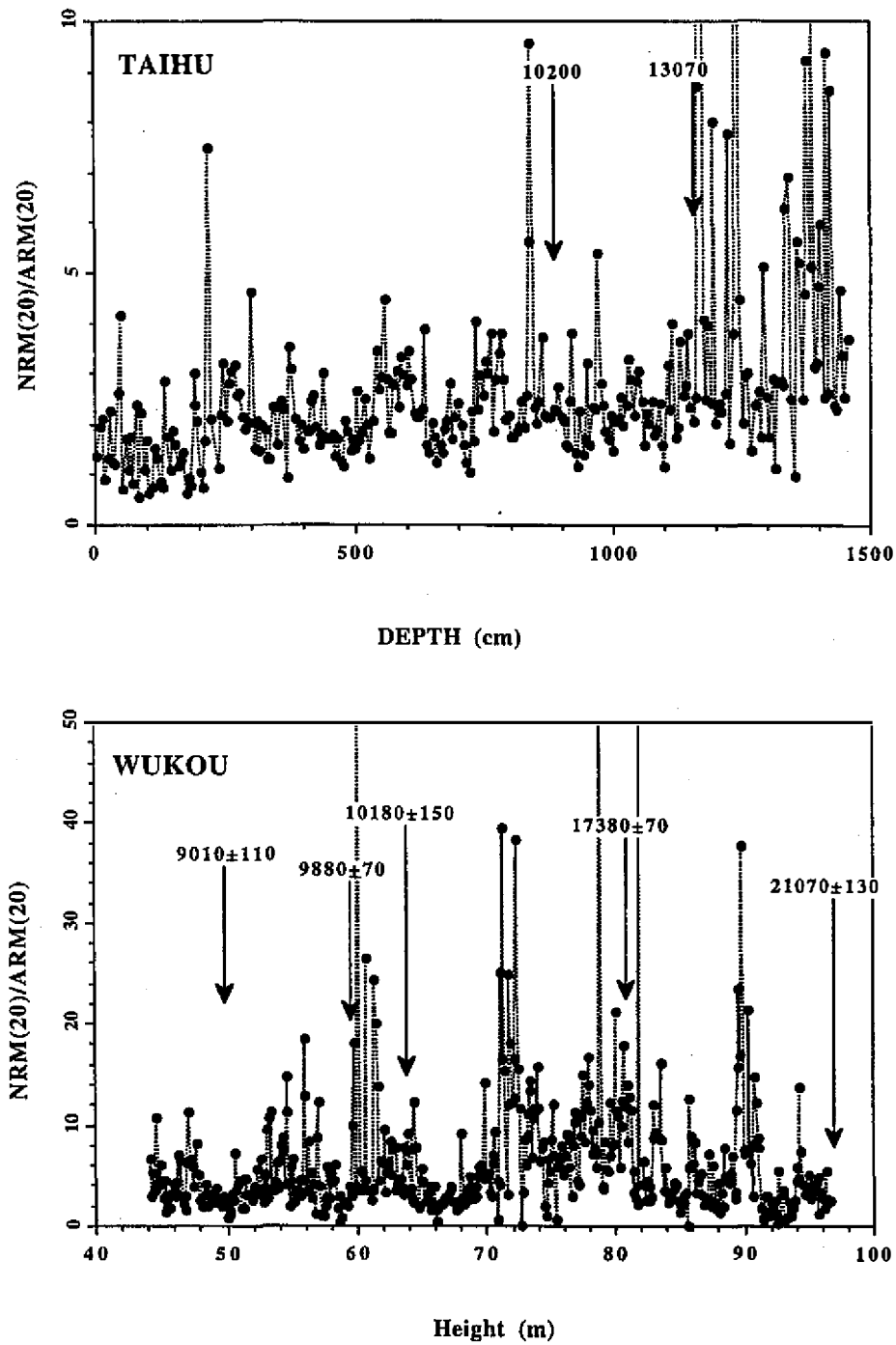


Fig. 7. The paleo-intensity secular variation patterns of core #WK13 from Taipei basin and core from Taihu show that they are well correlated.

## 6. SUMMARIES

This paper shows a paleomagnetic intensity record in Taiwan. The results show that after 20 mT alternating field demagnetization treatments on both NRM and ARM of samples, the stratigraphical variation patterns of NRM/ $\chi$  and ARM/ $\chi$  are very similar. This implies that the NRM vs ARM ratio at this demagnetization stage could represent the paleo-intensity secular variation of the geomagnetic field in the area studied for the time period between 9,000 yr.B.P. and 21,000 yr.B.P.

The four major high peak areas found in core #WK13 of this study occurring at around 60 m, 70 m, 80 m and 90 m in depth were assigned to have the ages of about 10,000, 13,500, 17,500 and 21,000 years before present, respectively. These age assignments are under a correlation between the record obtained in this study and the record collected from Taihu area, China (Wang et al., 1997). Also, all the C-14 dated ages for the two cores are taken into account. In addition, the youngest peak, with an assigned age of about 10,000 yr.B.P. seems to also be supported by the volcanic records from Japan (Tanaka, 1990). So, primarily, this study establishes a continuous paleo-intensity secular variation record of the earth's magnetic field in East Asia for the last 9,000 to 21,000 years.

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## REFERENCES

- Barton, C. E., and M. W. McElhinny, 1981: A 10,000-year geomagnetic secular variation record from three Australian maars. *Geophys. J. R. Astro. Soc.* **67**, 465-485.
- Creer, K. M., 1974: Geomagnetic variations for the interval 7000-25000 BP as recorded in a core of sediment from Station 1474 of the Black Sea cruise of "Atlantis II". *Earth Planet. Sci. Lett.* **23**, 34-42.
- Creer, K. M., 1977: Geomagnetic secular variations during the last 25,000 years: an interpretation of data obtained from rapidly deposited sediments. *Geophys. J. R. Astr.Soc.* **48**, 91-109.
- Creer, K. M., T. W. Anderson, and C. F. M. Lewis, 1976: Late Quaternary geomagnetic stratigraphy recorded in Lake Erie sediments. *Earth Planet. Sci. Lett.* **31**, 37-47.
- Creer, K. M., P. W. Readman, and A. M. Jacobs, 1980: Paleomagnetic and palaeontological dating of a section at Gioia Tauro, Italy: identification of the Blake Event. *Earth Planet. Sci. Lett.* **50**, 289-300.
- Creer, K. M., P. W. Readman, and S. Papamarinopoulos, 1981: Geomagnetic secular variations in Greece through the last 6000 years obtained from lake sediment studies. *Geophys. J. R. Astr.Soc.* **66**, 193-219.
- Hyodo, M., C. Itota, and K. Yaskawa, 1993: Geomagnetic secular variation reconstructed

- from magnetizations of wide-diameter cores of Holocene sediments in Japan *J. Geomag. Geoelectr.* **45**, 669-696.
- Liu, T. K., Y. G. Chen, W. S. Wu, C. C. Lo, and K. Wei, 1994: Implications of the ages of sediments and groundwater from Taipei Basin, Taiwan. Proc. of the joint symposium on Taiwan Quaternary (V) and on investigation of subsurface Geol./Engin. Envir. of Taipei Basin, 143-146 (in Chinese with English abstract).
- Meynadier, L., J.-P. Valet, R. Weeks, N. J. Shackleton and V. L. Hagee, 1992: Relative geomagnetic intensity of the field during the last 140 ka. *Earth Planet. Sci. Lett.* **114**, 39-57.
- Tanaka, H., 1990: Paleointensity high at 9000 years ago from volcanic rocks in Japan. *J. Geophys. Res.* **95**, B11, 17517-17531.
- Theillier, E., and O. Theillier, 1959: Sur l'intensité du champ magnétique terrestre dans le passé historique et géologique. *Ann. Geophys.* **15**, 285-378.
- Tric, E., J. P. Valet, P. Tucholka, M. Paterne, L. Labeyrie, F. Guichard, L. Tauxe, and M. Fontugne, 1992: Paleointensity of the geomagnetic field during the last 80,000 years. *J. Geophys. Res.* **97**, 9337-9351.
- Tseng, M. H., 1998: The past and present of Taipei Basin. *Taiwan Museum*, 105 pp. (in Chinese)
- Turner, G. M., and R. Tompson, 1981: Lake sediment records of the geomagnetic secular variation in Britain during Holocene times. *Geophys. J. R. Astr. Soc.* **65**, 703-725.
- Valet, J. P., and L. Meynadier, 1993: Geomagnetic field intensity and reversals during the past four million years. *Nature* **366**, 234-238.
- Wang, L. W., M. T. Chen, and T. Q. Lee, 1996: Magnetic susceptibility analysis on a high sedimentation-rate core near Taihu Lake, and its paleoenvironment Implication. Proc. of the joint symposium on Taiwan Quaternary (VI) and on investigation of subsurface Geol./Engin. Envir. of Taipei Basin, 266-270 (in Chinese with English abstract).
- Wang, L. W., M. T. Chen, and T. Q. Lee, 1997: Paleomagnetic study of a high sedimentation-rate core near Taihu Lake. in the Program and expanded abstract of the 1997 annual meeting of Geol. Soc. of China, 134-136 (in Chinese with English abstract).
- Yamazaki, T., and N. Ioka, 1994: Long-term secular variation of the geomagnetic field during the last 200 kyr recorded in sediment cores from the western equatorial Pacific. *Earth Planet. Sci. Lett.* **128**, 527-544.
- Zijderveld, J. D. A., 1967: Methods in Paleomagnetism: AF demagnetization of rocks Analysis of results. In: D. W. Collinson, R. M. Creer, and S. K. Runcorn (Eds.), Elsevier, New York, 254-286.