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The Demagnetization Plane: A new method for presenting stepwise demagnetization

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Abstract A new method using a "Demagnetization Plane" is proposed to present the results of stepwise demagnetization of remanent magnetization. This method facilitates quantitative analysis of stepwise demagnetization results, allowing distinction between the multi-components of remanent magnetization. An AF demagnetization test on Pleistocene marine siltstone and sandy siltstone samples from the Boso Peninsula, central Japan, shows that most of the stepwise AF demagnetized vectors align on a plane containing their origin. This plane is called the "Demagnetization Plane". The spectrum of remanent magnetization for demagnetization steps can be read from the plots on the Demagnetization Plane. Quantitative analysis of the variation of remanent magnetization in Boso sediments shows that the remanent magnetization can be separated into soft, intermediate and hard components, using normalization with anhysteretic remanent magnetization.

Key words: demagnetization, remanent magnetization, multi-components, spectrum, projection method, Boso sediments.

INTRODUCTION

Demagnetization is the most important process in paleomagnetic studies to read the record of the geomagnetic field of the past. The paleomagnetic field has been recorded in rocks as remanent magnetization. The remanent magnetization contains influences of magnetic fields after the formation of the rock up to the present time. If we aim to obtain the record of the paleomagnetic field at the time of formation of the rock, we have to distinguish the initial paleomagnetic record from the remanent magnetization by demagnetization. Stepwise demagnetization procedures have been used to separate the initial component from the remanent magnetization, and quantitative methods have been developed to analyze the stepwise demagnetization results (e.g. Stupavsky & Symons 1978; Kirshvink 1980; Collinson 1983).

This paper reviews the conventional method and proposes a new projection method of stepwise demagnetization.

THE CONVENTIONAL PROJECTION-METHOD OF STEPWISE DEMAGNETIZATION DATA

The remanent magnetization vector can be described as a summation of multi-component magnetization vectors. Each component has a different response to demagnetization and one of the components might be the initial magnetization vector. The method of presentation of stepwise demagnetization should distinguish the components and quantify their changes.

Two methods have conventionally been used to present the results of stepwise demagnetization (e.g. Tarling 1983): 1) a combination of stereo-net projection of the directions and intensity changes (Fig. 1), and 2) a vector projection with orthogonal coordinate axes of north-south, east-west and up-down which is called a Zijderveld projection (Fig. 2) (Zijderveld 1967).

The stereo projection gives only information on the direction, and is not satisfactory for quantitative analysis of the multiple components. If the demagnetized vectors align on a plane through the origin, the projected points should align on a

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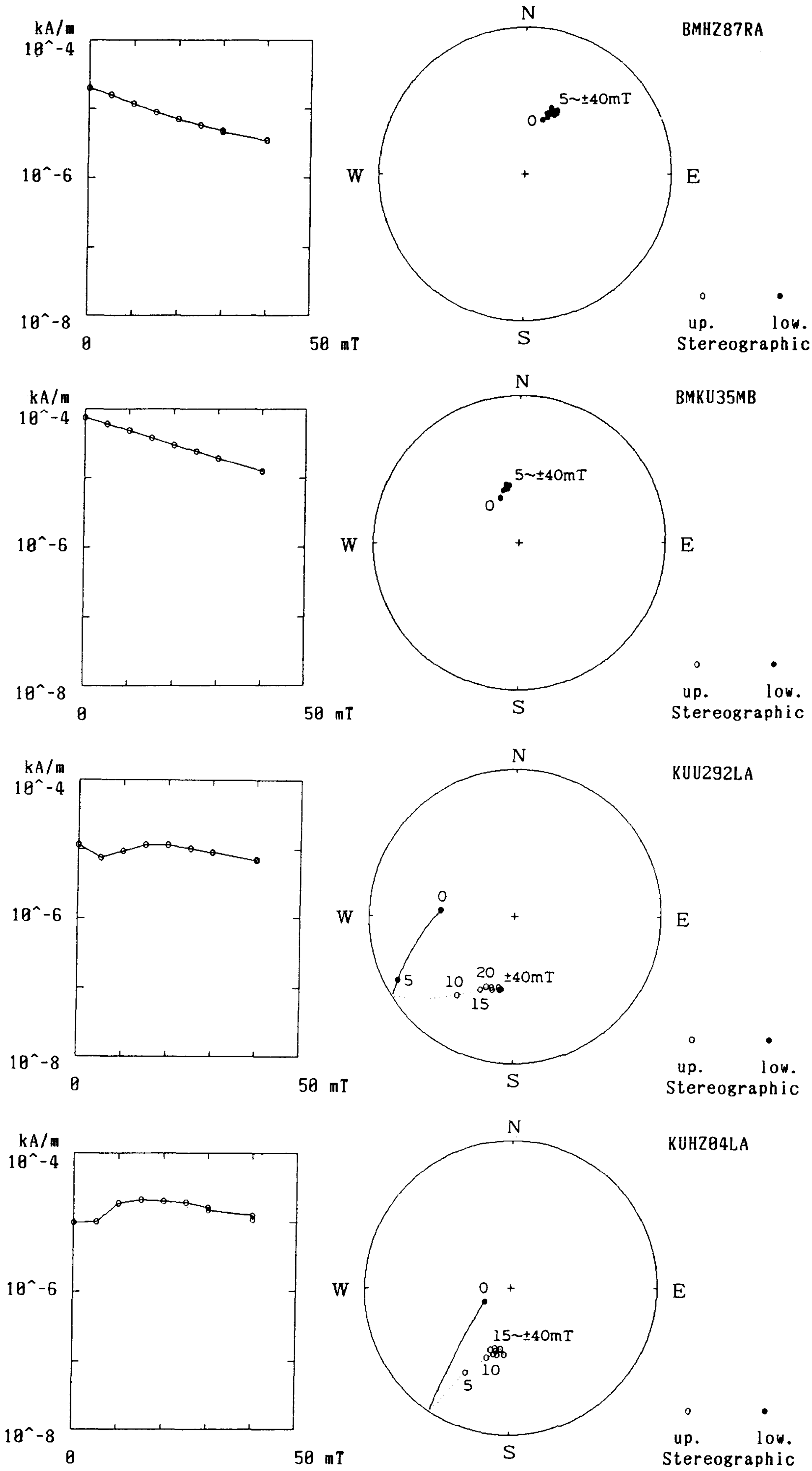

Fig. 1 Stereo-net projection and intensity change with stepwise AF-demagnetization.
normal: BMHZ87RA, BMKU35MB
reversed: KUU292LA, KUHZ04LA

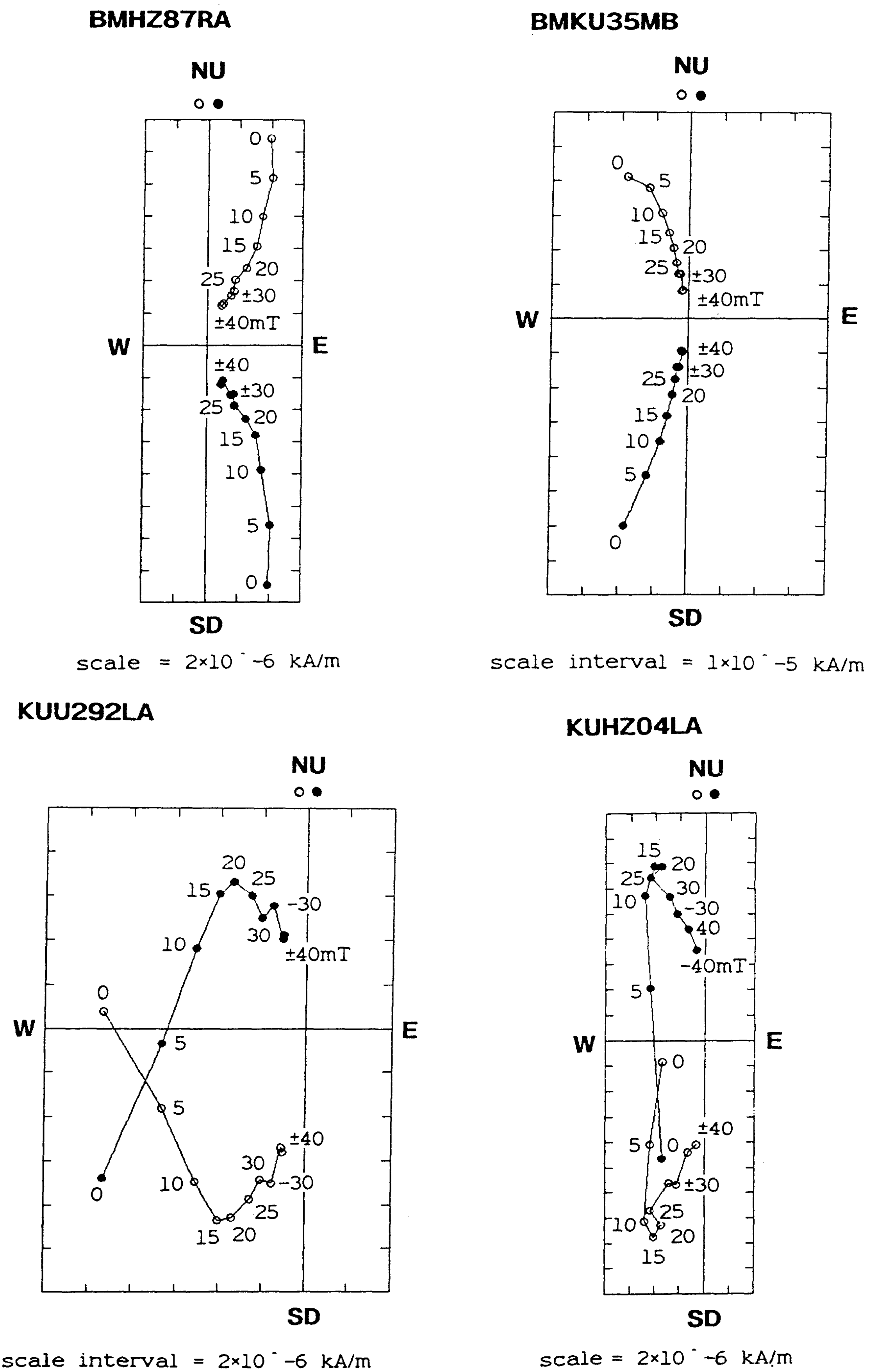

Fig. 2 Zijderveld projection.
Open circles: projected on N-S and E-W plane. Solid circles: projected on U-D and E-W plane.
normal: BMHZ87RA, BMKU35MB
reversed: KUU292LA, KUHZ04LA

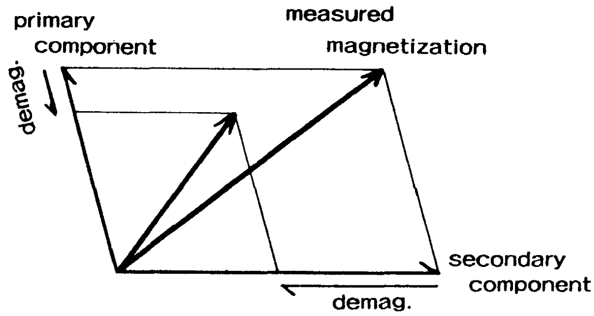

Fig. 3 Changes of two major components (primary and secondary) of remanent magnetization on the Demagnetization Plane with demagnetization.

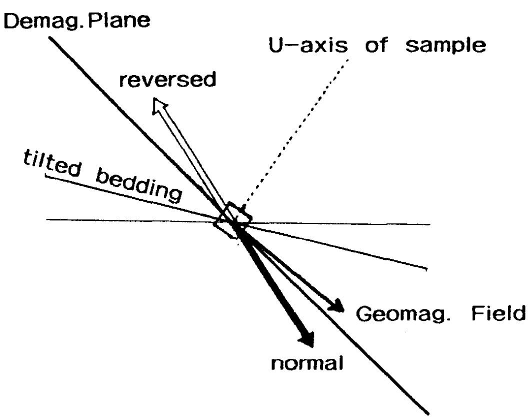

Fig. 4 Demagnetization Plane and its reference directions.

great circle on the stereo net.

The Zijderveld projection is better for quantitative analysis of each component of the magnetization. However, the projected points on the N-S & E-W plane and the U-D & E-W (or horizontal component) plane are plotted on one graph, which makes the coordination system of the graph difficult to understand, not only for a non-specialist, but also for a paleomagnetic specialist without careful reading of the figure caption. Because the projected plane is usually oblique to the trace of the magnetization vector with the stepwise demagnetization, the projection does not directly give the changes in the magnetization vector.

The samples used for demonstration in this paper are bathyal siltstone and sandy siltstone of late Matuyama to early Brunhes Chronozones, taken from the Boso Peninsula, central Japan. The stepwise demagnetized data are taken with an Automatic Paleomagnetic Processor which contains a highly sensitive ring-core flux-gate magnetometer, alternating field (AF) demagnetization system with polarity control, and magnetic field control systems for Anhysterisis Remanent Magnetization and measurement of susceptibility anisotropy with full computer control (Niitsuma & Koyama 1989, 1994, this volume).

PROPOSED NEW METHED USING A "DEMAGNETIZATION PLANE"

The remanent magnetization of the rock usually has multiple components. If the remanent magnetization is mainly composed of two major components, the stepwise demagnetized remanent magnetization vectors should align on a plane which contains the vectors of the two components and the origin (Fig. 3). This plane is termed the "Demagnetization Plane" in this paper.

The new method involves a pair of projections on the Demagnetization Plane and the perpendicular plane. The associated perpendicular plane shows how the stepwise demagnetized vectors are aligned on the Demagnetization Plane. The Demagnetization Plane is calculated by least squares regression for the stepwise demagnetized vector endpoints (x_i, y_i, z_i) of the remanent magnetization.

Because the Demagnetization Plane passes through the origin, the equation of the plane can be express as

$$ax + by + cz = 0$$

and the constants, a, b and c are given as

$$a = \Sigma x_i y_i \Sigma y_i z_i - \Sigma y_i^2 \Sigma z_i x_i$$

$$b = \Sigma z_i x_i \Sigma x_i y_i - \Sigma x_i^2 \Sigma y_i z_i$$

$$c = \Sigma x_i^2 \Sigma y_i^2 - (\Sigma x_i y_i)^2$$

The values of the dip angle ($=90\text{-Atan}(c/(a^2+b^2)^{1/2})$) and the azimuth ($=\text{Atan}(b/a)$) of the Demagnetization Plane are given, and the dip azimuth is projected onto the plane.

The direction of the normal and reversed geocentric axial dipole fields at the time of formation of the rock (after tilt correction) is projected on the Demagnetization Plane, and the direction used as the vertical axis of the Demagnetization Plane. The inclination of the axial dipole vectors to the Demagnetization Plane are projected on the associated perpendicular plane.

The direction of the normal geocentric axial dipole at the sampling site (before tilt correction) is also projected on both planes as the reference to the present geomagnetic field. The upper direction of the up-down axis of the sample is projected on both planes as the reference of the artifact during sampling (Fig. 4).

Vector endpoints of the stepwise demagnetized remanent magnetizations, after bedding tilt correction, are presented as points on both planes and connected to each other in order of the demagnetization step. Software has been developed to make the calculation and graphics for the stepwise demagnetization data.

If the remanent magnetization is composed of three or more major components with different directions, the points should not align on the Demagnetization Plane, which can be checked by the positions of the points on the associated perpendicular plane. When the points align on the Demagnetization Plane, we can analyse

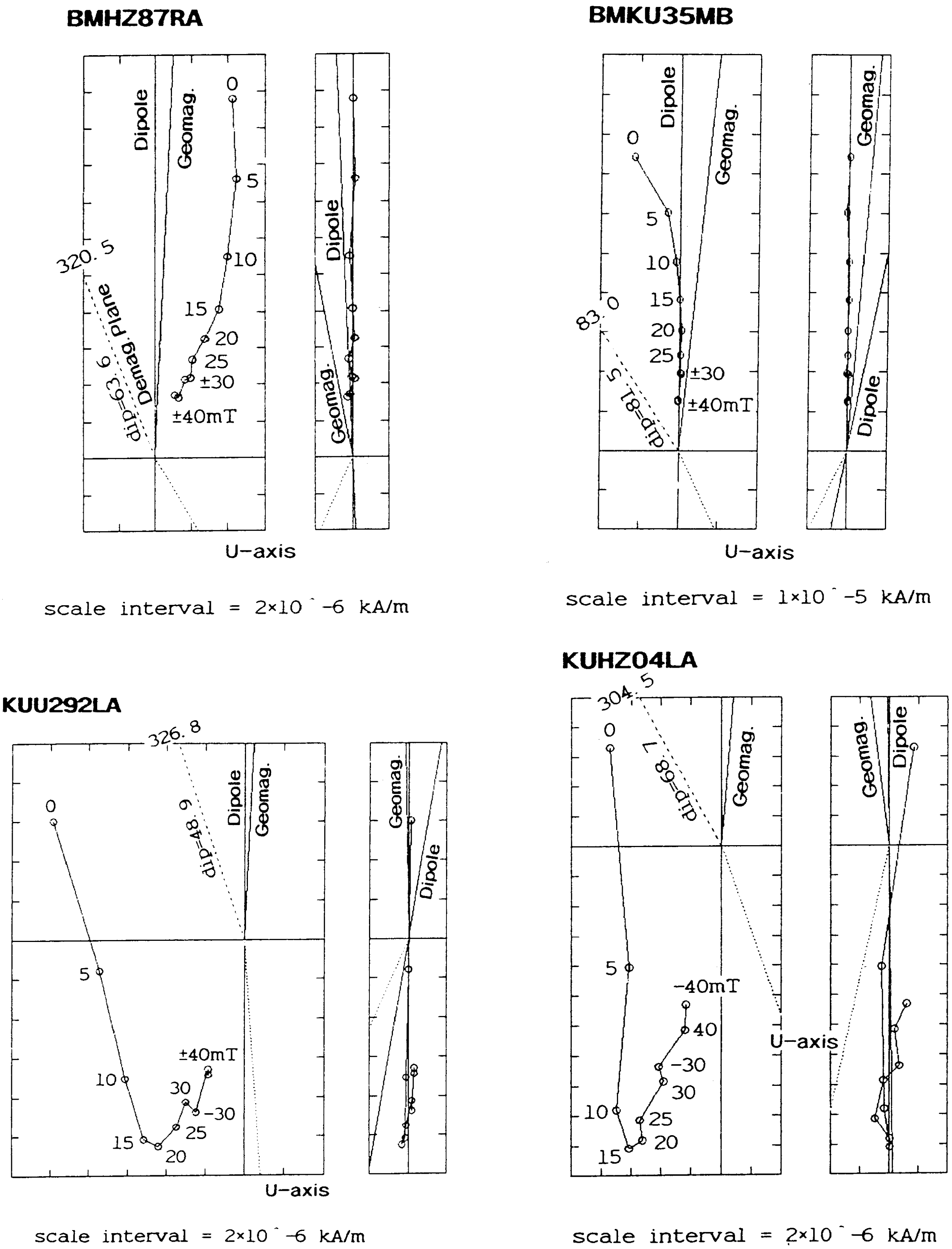

Fig. 5 Demagnetization Plane projection
BMHZ87RA: normal polarity, deeper inclination than dipole field and geomagnetic field at the site, eastward declination.
BMKU35MB: normal polarity, shallower inclination than dipole field and geomagnetic field at the site, sampling artifact in declination subtracted with 5~10 mT AF demagnetization.
KUU292LA: reversed polarity, inclination same as the antipodal field of geomagnetic field at the site which is shallower than dipole field, westward declination, and nomal polarity component reduces with AF demagnetization.
KUHZ04LA: reversed polarity, inclination same as the dipole field, westward declination, sampling artifact in declination and inclination subtracted with 5 mT AF demagnetization, and differences parallel to the U-D axis for AF demagnetization field polarity (±30 and ±40 mT), which means easily anhysteretic magnetized.

quantitatively the multi-components of the remanent magnetization vectors by using the points on the Demagnetization Plane.

EXAMPLE OF THE PROJECTION

Stepwise demagnetized data taken with an Automatic Paleomagnetic Processor were analysed to obtain the Demagnetization Plane (Fig. 5). The broken line on the Demagnetization Plane represents the dip azimuth of the Plane. The strike of the Demagnetization Plane is normal to the broken line through the origin and the end-point of the magnetization vector on the broken line side of the strike line shows that the magnetization vector has a positive inclination after bedding correction. The solid line on the Plane represents a normal geocentric axial dipole field at the sampling site. The vertical axis of the Plane is adjusted to the direction of the geocentric axial dipole field at the formation of the sample. The solid line through the origin of the associated plane represents the angle between the geocentric axial dipole field directions at the formation of the sample and the Demagnetization Plane. Dotted lines represent the upper direction of the up-down axis of the sample on the Demagnetization Plane and the associated plane.

The stepwise AF demagnetized vectors align on the Demagnetization Plane for most Pleistocene siltstone and sandy siltstone samples from the Boso Peninsula, central Japan, which contain the Brunhes/Matuyama Magnetic Polarity Reversal (Okada & Niitsuma 1989). Because the components normal to the Demagnetization Plane are significantly smaller than the components on the Plane, the multi-components of the remanent magnetization should align on the Plane.

Normal polarity samples have a normal polarity direction in all steps of AF demagnetization and the intensity decreases as the AF demagnetization step increases (Fig. 5).

Reversed polarity samples have a normal polarity in remanent magnetization in the steps of 0 to 15 mT of AF demagnetization, and the remanences flip to reversed polarity in the higher steps of AF demagnetization (Fig. 5).

There are two levels of AF demagnetization, 10 and 20 mT, in which the direction of remanence change. The samples release the sampling artifact of remanence in the first level. Reversed polarity samples release the remanence of normal polarity direction in the second level. Normal polarity samples do not show clear changes in the direction of remanence.

QUANTITATIVE ANALYSIS OF THE REMANENCE

NRM (Natural Remanent Magnetization) should be controlled by the amount, grain size and species of magnetic minerals in the sample and also by the ambient magnetic field during the magnetization. The direction and amount of NRM spectrum vector can be read out directly from plots on the Demagnetization Plane, if the vector endpoints for stepwise Demagnetized NRM are put on the Demagnetization Plane. The spectrum of ARM (Anhysteretic Remanent Magnetization) can be used for normalization to the amount and grain size of magnetic minerals, and to distinguish the character of the magnetization.

ARM was acquired under 11.9 μT of direct field and 40 mT of alternating field with an Automatic Paleomagnetic Processor, and then stepwise AF demagnetization was made as for NRM. The maximum of the ARM spectrum appeared between 15 mT and 25 mT of the AF demagnetization step.

The spectrum of the NRM to ARM ratio (NRM/ARM) gives useful information on magnetization and rock magnetic characters (Fig. 6). Because the maximum of the NRM spectrum appears between 0 mT and 10 mT, the maximum of the ratio NRM/ARM appears in the spectrum at the step from 0 to 5 mT. The ratio gradually decreases as the AF demagnetization step increases and reaches an almost constant value at steps higher than 15 mT of AF demagnetization for normal polarity samples. In the case of reversed polarity samples, the ratio gradually decreases as in the normal polarity samples and has a minimum value between 15 mT and 25 mT, then reaches a constant value in the steps higher than 25 mT. The convergent value of NRM/ARM has been used for estimation of the paleointensity of the geomagnetic field (Okada and Niitsuma 1989).

The behavior of NRM/ARM indicates that the NRM/ARM spectrum can be separated into three parts, soft (0 - 10 mT), intermediate (10 - 25 mT) and hard (25 to higher than 40 mT of the AF demagnetization step). The parts of the spectrum are well correlated with the direction of the NRM spectrum, mentioned above.

The ratio NRM/ARM is a maximum in the soft part, and the value of the ratio between 0 and 5 mT is less scattered within the range of 0.5 to 1.5 (mostly ~1.0), in spite of the large range of the NRM and ARM spectra (1.6 to 18×10^{-6} kA/m). The constancy indicates that the intensity of the NRM spectrum in the soft parts is controlled mainly by rock magnetic characteristics rather than the ambient magnetic field during the magnetization.

The direction of the NRM spectrum changes drastically from normal polarity to reversed

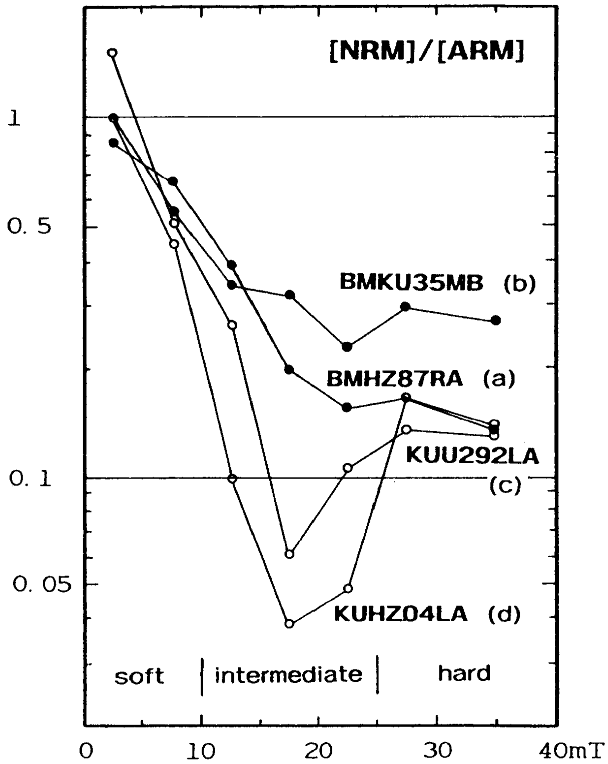

Fig. 6 NRM/ARM spectrum in logarithmic scale.
normal: a. BMHZ87RA, b. BMKU35MB
reversed: c. KUU292LA, d. KUHZ04LA

polarity for reversed polarity samples in the intermediate part (Fig. 7).

The hard part gives almost the same NRM/ARM ratio, but the value of the ratio is spread across a wide range, from 0.07 to 0.36, which might be related to the ambient magnetic field during the magnetization.

ROUTINE APPLICATION OF THE DEMAGNETIZATION PLANE

The Demagnetization Plane projection has been applied to more than 150 samples of Pleistocene marine sediments of the Boso Peninsula, and most of the AF demagnetized remanence vectors align on the Demagnetization Plane. The result of the preliminary application suggests that the Demagnetization Plane projection can be used for routine analysis of stepwise demagnetization.

If the remanence vectors do not align on the Demagnetization Plane, which can be detected from the projection on the associated perpendicular plane, the remanence should be composed of three or more dominant components. In such a case, we can apply the Demagnetization Plane projection to divided data sets at a certain demagnetization level, in which most of the softest component can be removed.

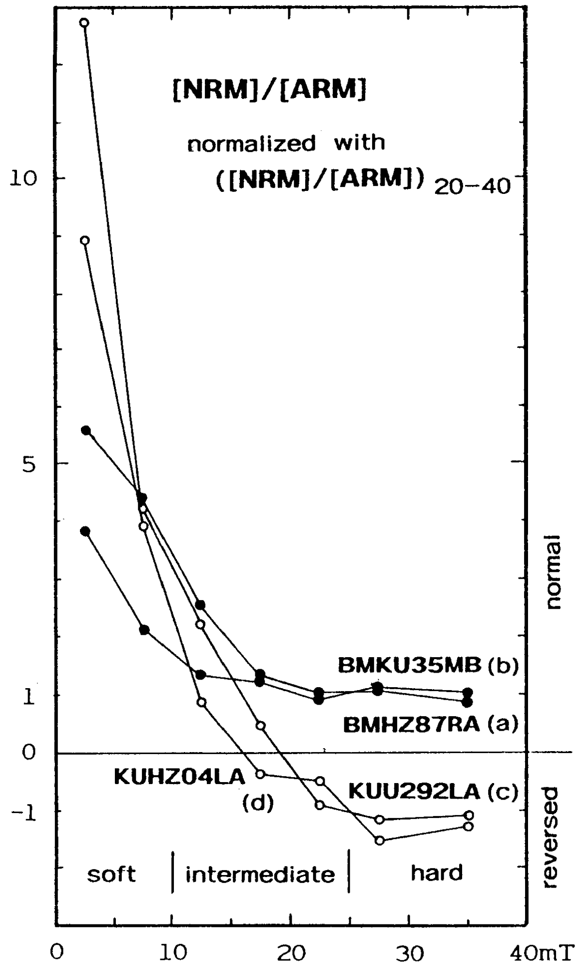

Fig. 7 NRM/ARM spectrum normalized by spectrum between 20 and 40mT $(NRM/ARM)_{20-40}$ in linear scale. Positive: normal component of NRM. Negative: reversed component of NRM.
normal: a. BMHZ87RA, b. BMKU35LB
reversed: c. KUU292LA, d. KUHZ04LA

SUMMARY

A new method using a "Demagnetization Plane" is proposed for the quantitative analysis of stepwise demagnetization results, allowing distribution between the multi-components of remanent magnetization.

An AF demagnetization test on Pleistocene marine siltstone and sandy siltstone samples from the Boso Peninsula, central Japan, shows that most of the stepwise AF demagnetized vectors align on a plane containing their origin. This plane is called the "Demagnetization Plane".

The spectrum of remanent magnetization for demagnetization steps can be read out from the plots on the Demagnetization Plane. Quantitative analysis of the spectrum from the Boso sediments shows that the remanent magnetization can be separated into soft, intermediate and hard components, using normalization with anhysteretic remanent magnetization.

The new method shows quantitatively the alignment of the remanence vectors on a Demagnetization Plane, and in the case of poor alignment, the new method can be applied to divided data sets at a certain demagnetization level.

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