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Reconnaissance microfossil and magnetic stratigraphy of the Miocene Sayula-Isla sequence, Veracruz, Mexico

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RESUMEN

Se realizó un estudio piloto de biomagnetoestratigrafía en la bien definida (paleontológicamente) secuencia sedimentaria del Mioceno-Temprano a Medio en Sayula-Isla (sur de Veracruz, México). Se incluyen resultados de magnetismo de rocas como adquisición de magnetismo remanente isotermal (IRM) y experimentos de histéresis. Las curvas de adquisición de IRM resultaron muy parecidas en todas las muestras. Se alcanzó saturación en campos moderados del orden de 150-200 mT, sugiriendo espinelas como portadores de remanencia. De las razones de los parámetros de histéresis, parece que todas las muestras caen en la región del tamaño de grano pseudo-dominio-simple (PSD) o multidominio (MD). En la mayoría de las unidades estudiadas se pudieron observar de una a dos componentes paleomagnéticas. Se eliminaron fácilmente pequeñas componentes secundarias a temperaturas de 100-180°C. Algunas muestras mostraron comportamiento térmico inestable, sugiriendo la presencia de magnetización multicomponente. Se definieron las componentes de magnetización característica después de 250°C para esas muestras. La comparación de las zonas de polaridad de la sección Sayula-Isla muestra algunos problemas a causa de la escasez en el contenido de microfósiles. Se requieren más datos para definir con mayor detalle la Escala Geomagnética Temporal de Polaridad Local; sin embargo, se obtuvo una razonablemente buena correlación para las biozonas del Mioceno-Temprano a Medio de la Cuenca Salina del Istmo.

PALABRAS CLAVE: Magnetoestratigrafía, bioestratigrafía, secuencia sedimentaria, México.

ABSTRACT

A pilot biomagnetostratigraphic study has been performed on the paleontologically well constrained Early-Middle Miocene sequence at Sayula-Isla (southern Veracruz, Mexico). Rock magnetic investigations included isothermal remanence (IRM) acquisition and hysteresis experiments. IRM acquisition curves were found very similar for all samples. Saturation is reached in moderate fields of the order of 150-200 mT, which points to some spinels as remanence carriers. Judging from the ratios of hysteresis parameters, it seems that all samples fall in the pseudo-singledomain (PSD) or multidomain (MD) grain size region. In most of studied units one to two paleomagnetic components could be recognized. Small secondary components were easily removed applying 100-180°C. Some of the samples yielded unstable thermal behavior suggesting evidence for multicomponent magnetization. Characteristic remanent magnetization components have been defined after 250°C for these samples. The comparison of the Sayula-Isla polarity zonation poses some problems because of scarce microfossil content in studied sections. More data are required to better constrain the local Geomagnetic Polarity Time Scale, but reasonably good correlation was obtained for the Early-Middle Miocene biozones in the Salina del Istmo basin.

KEY WORDS: Magnetostratigraphy, biostratigraphy, sedimentary sequence, Mexico.

INTRODUCTION

Magnetostratigraphy studies of sedimentary rocks have proven to be a successful tool to determine the age and to make correlation between different series of terrestrial and oceanic sediments (Butler and Opdyke, 1979; Channell *et al.,* 1984; Ogg and Lowrie, 1986; Heller *et al.,* 1988; McNeill *et al.,* 1988; Aissaoui *et al.,* 1990; 1991; King and Channell, 1991). This method is based on the reversals of the geomagnetic field, which since the Miocene to the present has switched polarity more than 50 times. The reversal process, due to the dipolar nature of the geomagnetic field, takes from 10^3 to 10^4 years. Consequently, magnetostratigraphic studies can give very high resolution within this order of time.

Because the time involved between reversals is a random variable, the sequence of thicknesses of magnetozones in each part of a uniform deposited section is a characteristic mark that can be correlated between distant sections and compared to the geomagnetic polarity time scale (GPTS). The GPTS was established, and finely calibrated, based on radiometric isotopes, marine magnetic anomalies, and magnetostratigraphic studies. During the last three decades magnetostratigraphy has been essential for the calibration of the geologic time. It gives the link between the GPTS and biozones/bioevents, and therefore of geologic limits. The absolute radiometric ages and/or biozones are correlated directly to the GPTS in magnetostratigraphic sections creating a pattern of local GPTS. The aim of this work is to create a local GPTS supported by microfossil identification in our study area. Eventually, this will be useful to determine the absolute ages of microfossil sterile horizons and/or with poorly-preserved fossils, by interpolation using the local pattern of GPTS.

The microfossil data from the Sayula-Isla sedimentary sequence suggest that the sections belong to lower and middle Miocene. Therefore, paleomagnetic sampling was made to define the magnetic polarity reversals from each section. The time-span and the expected number of reversal magnetic polarities were defined by biostratigraphy. In an attempt to resolve the very short reversal polarities, the sampling was very dense in these sections.

GEOLOGIC SETTING AND BIOSTRATIGRAPHY

The sedimentary succession studied is located along La Tinaja-Coatzacoalcos highway (Figure 1). This area is geologically located in the Salina del Istmo basin that includes the northern part of the Tehuantepec Isthmus. The area comprises the coastal part of the Gulf of Mexico to the north, and small hills towards the south. The general structure results from complex folding due mainly to saline tectonism. The age succession ranges from Triassic to Recent. The oldest rocks are in the southern part of the basin, in the Sierra Madre Oriental, while the recent rocks are located towards the coastal plain.

The series are composed by dark gray sediments, sometimes slightly bluish, constituted by sandy lutite layers, with micaceous material, sometimes alternated with very thin layers of fine sand and in others with a great amount of volcanic ash.

A brief microfossil description of the sections is found below, and some representative examples of the best fossils are shown in Figure 2.

Section 1. The plankton foraminifers of section 1 are few and poorly preserved. Genus *Catapsydrax* is recognized as characteristic of the early Miocene. However, we cannot assign the samples to a specific zone within the early Miocene.

Section 2. Detailed study of the planktonic foraminifers of this section indicates that they belong to an Early Miocene age. The planktonic foraminifers are well preserved, allowing, in most cases, a suitable identification. The microfossil association is composed essentially of *Globigerinoides primordius*, G. *trilobus trilobus*, G. t. *immaturus*, *Catapsydrax dissimilis*, *C. stainforthi*, *Globorotalia mayeri*, *Globigerina venezuelana* and *Globorotaloides suteri*. The existence of *Catapsydrax stainforthi*, *C. dissimilis*, *Globigerinoides primordius* and *G. altiaperturus*, places the samples of this series in the lower part of the *Catapsydrax dissimilis* zone defined by Bolli *et al.,* 1985, equivalent to Zone N5 of Blow (1969) in the Early Miocene.

Section 3. Samples 1 to 12 are mainly marls of cream color where the microfossils go from few to abundant. Plankton foraminifers predominate, except in samples 4, 5, 9, 10 and 14, where benthic foraminifers are more abundant. The plankton foraminifers association is represented mainly by *Globigerina praebulloides praebulloides, G. venezuelana, G. yeguaensis, Globigerinoides diminutus, G. bisphericus, G. toruber, G. trilobus immaturus, G. trilobus trilobus, Globoquadrina globosa cf. altispira, G. dehiscens, Globorotalia mayeri, G. obesa, Praeorbulina glomerosa curva, P. g. glomerosa. P. sicana and P. transitory.*

Globigerinoides specimens are extremely abundant compared to those of *Globigerina* and of other genera. The species G. *diminutus* is the most abundant of the *Globigerinoides*, especially in samples 1 to 4, corresponding to the upper part of the section. The species of *Praeorbulina* are badly preserved, but could be determined specifically. Note the absence of *Globigerinatella insueta*, a zonal marker of the upper part of lower Miocene (Bolli & Saunders, 1985). In general, the benthic foraminifers are badly preserved except *Planulina* and *Nodosaria*, which are recognizable.

The middle Miocene age is assigned to samples 1 to 12, corresponding to *Praeorbulina glomerosa* zone of Bolli & Saunders (1985), equivalent to Zone N8 of Blow (1969). The age assigned is based on the association of *Praeorbulina glomerosa glomerosa*, *P. g. curved. P. sicana* and *Globigerinoides bisphericus*. According to Bolli & Saunders (1985), the zone of *Praeorbulina glomerosa* includes the first appearance of this species until the last appearance of *Globigerinatella insueta*. These authors also observe the absence of the genus *Catapsydrax*; this study

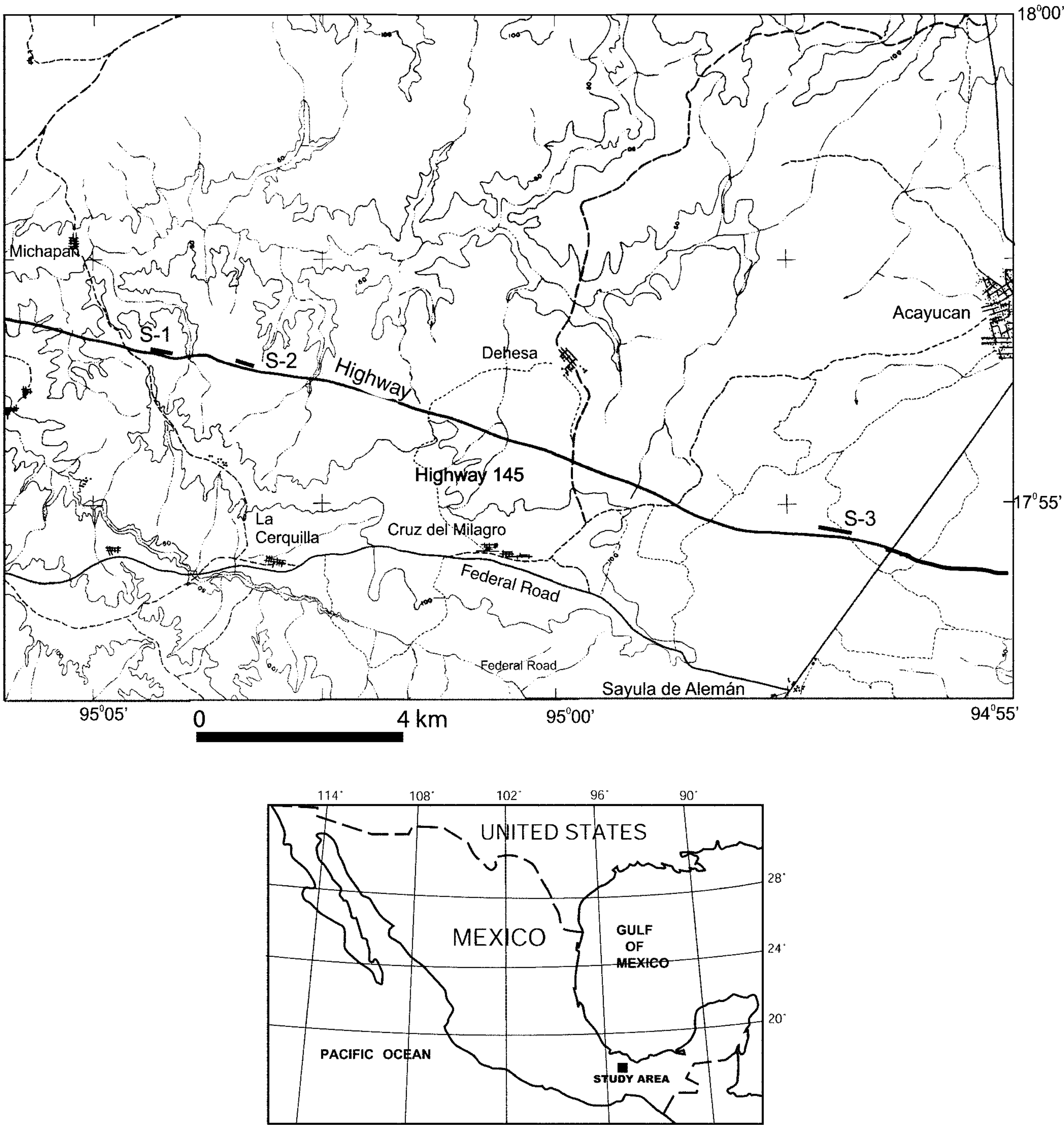

Fig. 1. Location of Lower Miocene sections along the La Tinaja-Coatzacoalcos highway. S-1, S-2 and S-3 refers to section number as described in the text.

confirms this observation. Abundant but non continuous presence of Globigerinoides *diminutus* was observed mainly in the youngest part of the section.

The *Praeorbulina glomerosa* zone is characterized by the evolutionary transition of this species with the subspecies *P. curva*, P. *glomerosa* and P. *circularis*, finalizing with the development of *Orbulina suturalis* (Bolli & Saunders, 1985). In this respect, the only transition observed in the studied samples is perhaps from *P. g. curva* to *P. g. glomerosa*, specifically from samples 9 to 10. There was no evidence of Orbulina *suturalis*.

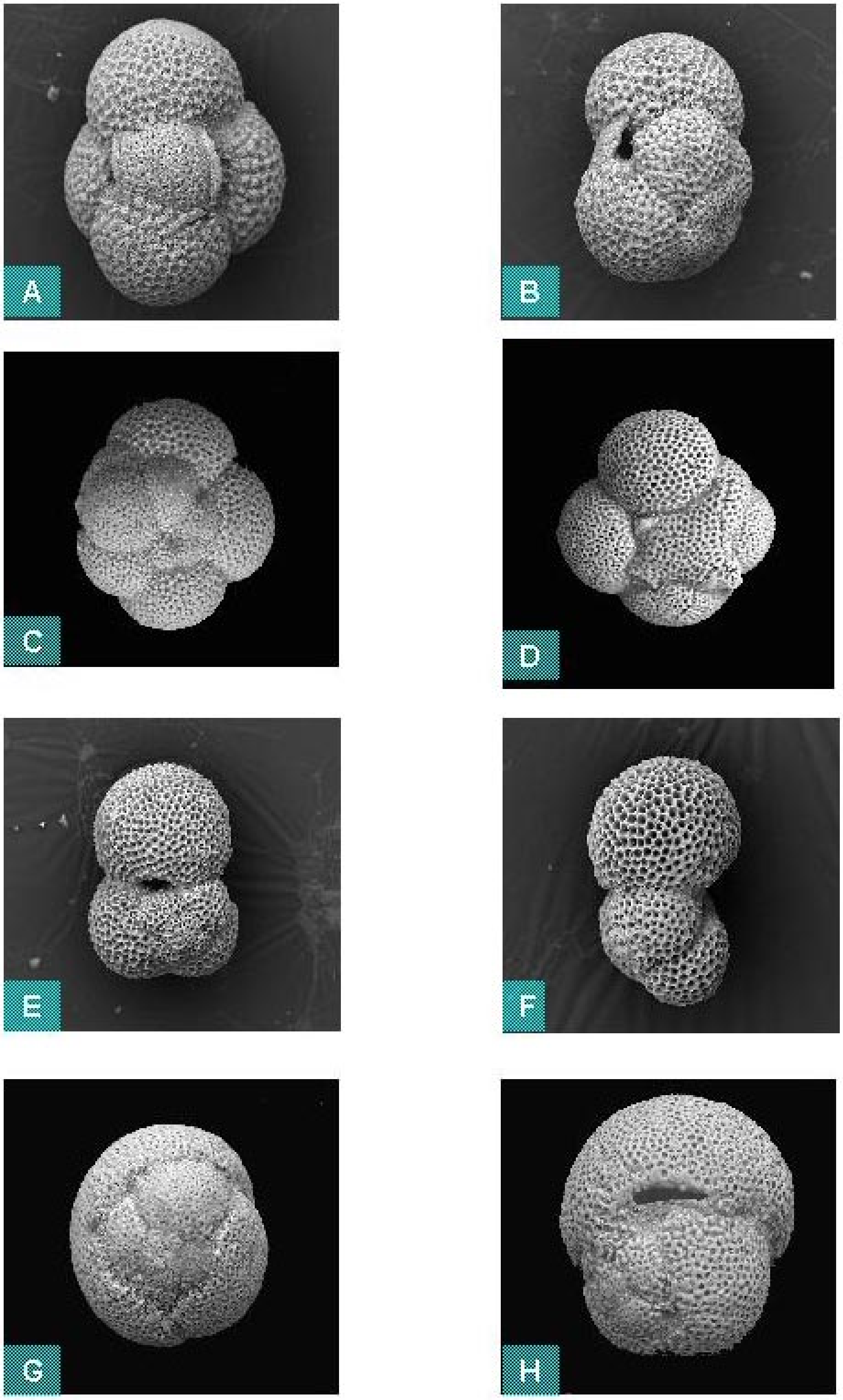

Fig. 2. Early Miocene plankton foraminifers from the Sayula region. (A) Catapsydrax dissimilis *Cushman & Bermudez. Umbilical view x 140. Size: 428 microns. Section-1. Zone N-5.* **(**B) Catapsydrax dissimilis *Cushman & Bermudez. Side view x 140. Size: 344 microns. Seq-1. Zone N5*. **(**C) Catapsydrax stainforthi *Bolli, Loeblich & Tappan. Dorsal view x 150. Size: 357 microns. Seq-1. Zone N5.* **(**D) Catapsydrax stainforthi *Bolli, Loeblich & Tappan. Umbilical view x 180. Size: 325 microns. Seq-1. Zone N5.* **(**E) *Globigerinoides primordius Blow & Banner. Dorsal view x 140. Size: 287 microns. Seq-1. Zone N5*. (F) Globigerinoides primordius *Blow & Banner. Side view x 200. Size: 208 microns. Seq-1. Zone N5*. **(**G) *Praeorbulina glomerosa Dorsal view x 150. Size: 357 microns. Seq-3. Zone N8*. (H) *Globigerinoides bisphericus Todd*. Umbilical view x 140. Size: 448 microns. Seq-3. Zone N8.

MAGNETIC EXPERIMENTS

In total 63 oriented blocks belonging to three sedimentary sequences were sampled. Commonly the outcrops extend laterally over several tens of meters. In these cases we got typically one block per layer and then oriented with magnetic compass. The samples were distributed throughout each unit both horizontally and vertically in order to minimize the effects of block tilting and lightning. Small cubes were cut at the Instituto Mexicano del Petroleo (IMP) in 2 cubic-cm size. Some parts of the sequence could not be sampled because of lack of consistency of layers.

Acquisition of IRM

To determine the isothermal remanent magnetization (IRM) curves a previously AF demagnetized sample from all units was subjected to magnetic fields along vertical axes. The magnetic fields were steadily increased up to 3.2 T, their remanence being measured after each step. IRM acquisition curves were found very similar for all samples (Figure 3). Saturation is reached in moderate fields of the order of 150-200 mT, which points to some spinels as remanence carriers. The sample 133 shows a high IRM intensity that may be due to high concentration of magnetic minerals or to the fact that the applied field is parallel to the axis of easy magnetization of the magnetic minerals.

Hysteresis Experiments

Hysteresis measurements at room temperature were performed on all studied units using the AGFM 'Micromag' in fields up to 1.2 T. The saturation remanent magnetization (J_{rs}), the saturation magnetization (J_s) and coercitive force (H_c) were calculated after correction for the paramagnetic contribution. The coercivity of remanence (H_{cr}) was determined by applying progressively increasing backfield after saturation. Some representative hysteresis plots are shown in Figure 4. The hysteresis loops are symmetrical in all cases. Near the origin (right side of Figure 4), slight wasp-waisted behavior (Tauxe *et al.,* 1996) was detected, which probably reflects wide ranges of the opaque mineral coercivities. Judging from the ratios of hysteresis parameters, it seems that all samples fall in the pseudosingledomain (PSD) or multidomain (MD) grain size region.

REMANENCE MEASUREMENTS

The remanent magnetization of three to four samples from each unit were measured with a JR-5A spinner magnetometer (sensitivity ~ 10^{-9} Am^2). Measurements were recorded after stabilization of the remanence in this magnetometer. Both alternating field (AF) demagnetization using a laboratory made AF-demagnetizer and stepwise thermal demagnetization up to 670°C using a non-inductive

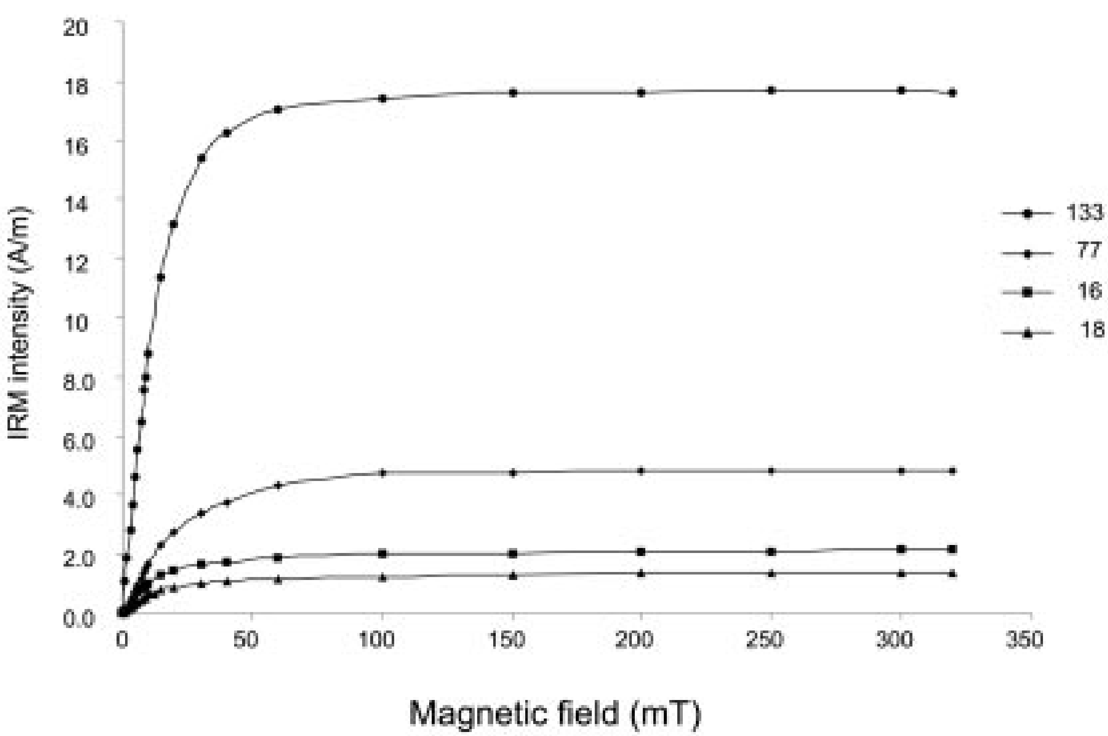

Fig. 3. Acquisition of isothermal remanent magnetization for representative samples.

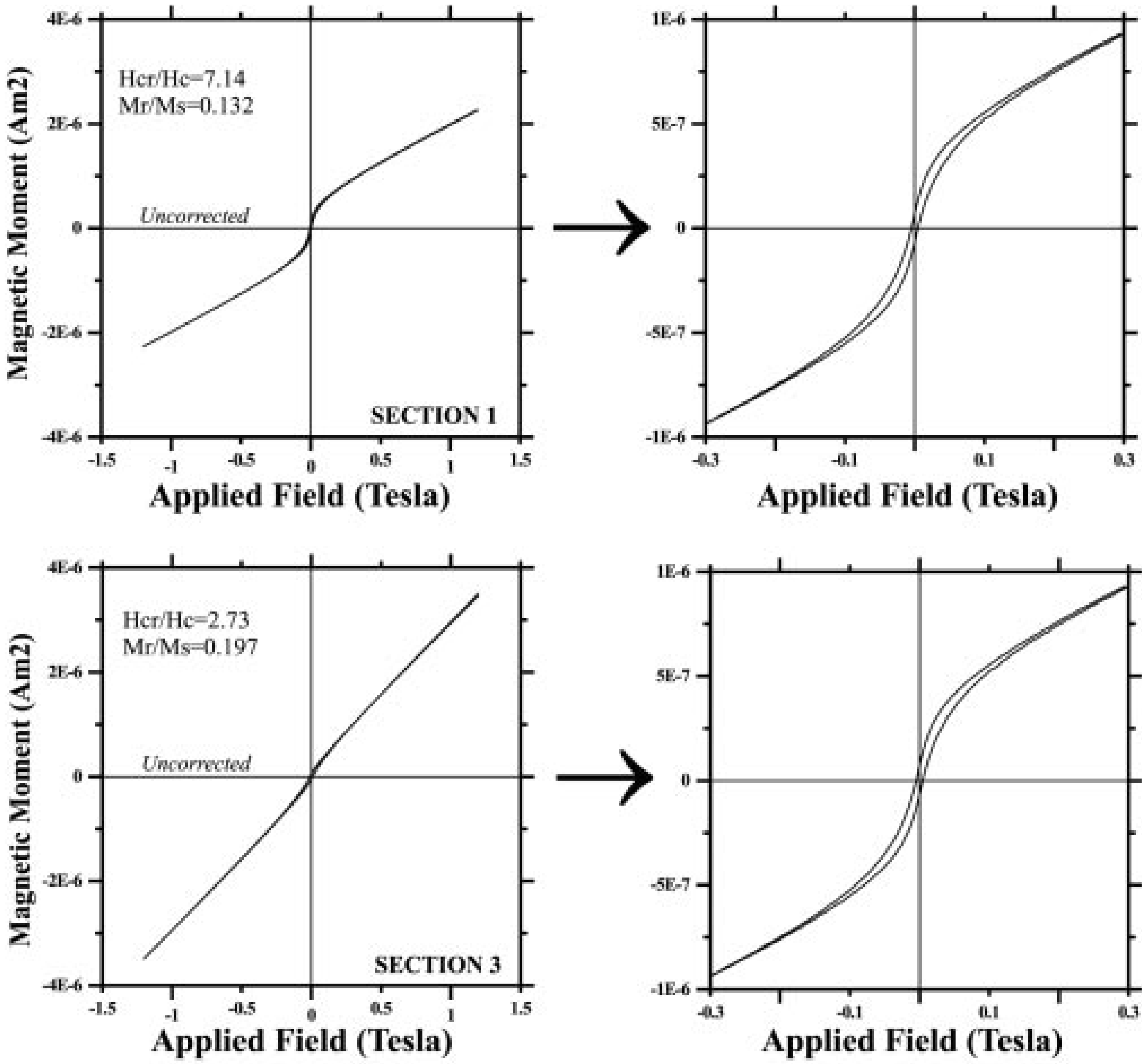

Fig. 4. Typical examples of hysteresis loops (uncorrected) of small chip samples.

Schonstedt furnace were carried out on the pilot samples. However, alternating fields were found less efficient to separate characteristic remanent magnetization. Thus, thermal treatment was selected as an adequate treatment. All the cube-specimens were subjected to thermal demagnetization (Figure 5). In general, 12-14 temperature steps were distributed between 20 °C and 600 °C. During thermal demagnetization, the low-field susceptibility at room temperature were measured after each step with a Bartington susceptibility meter, to check if chemical/or mineralogical changes had take place in magnetic minerals during heating.

In most of the studied units one to two paleomagnetic components could be recognized (Figure 5). Small secondary components were easily removed applying 100-180 °C. Some of the samples yielded unstable thermal behavior suggesting evidence for multicomponent magnetization. Primary magnetization components have been defined after 250°C for these samples. The greater part of remanent magnetization was removed at temperatures between 300 and 500°C (Figure 5) which may indicate relatively medium-to-high-Ti titanomagnetites as responsible for magnetization with similar coercivity. Alternatively, we can speculate that the rapid de-

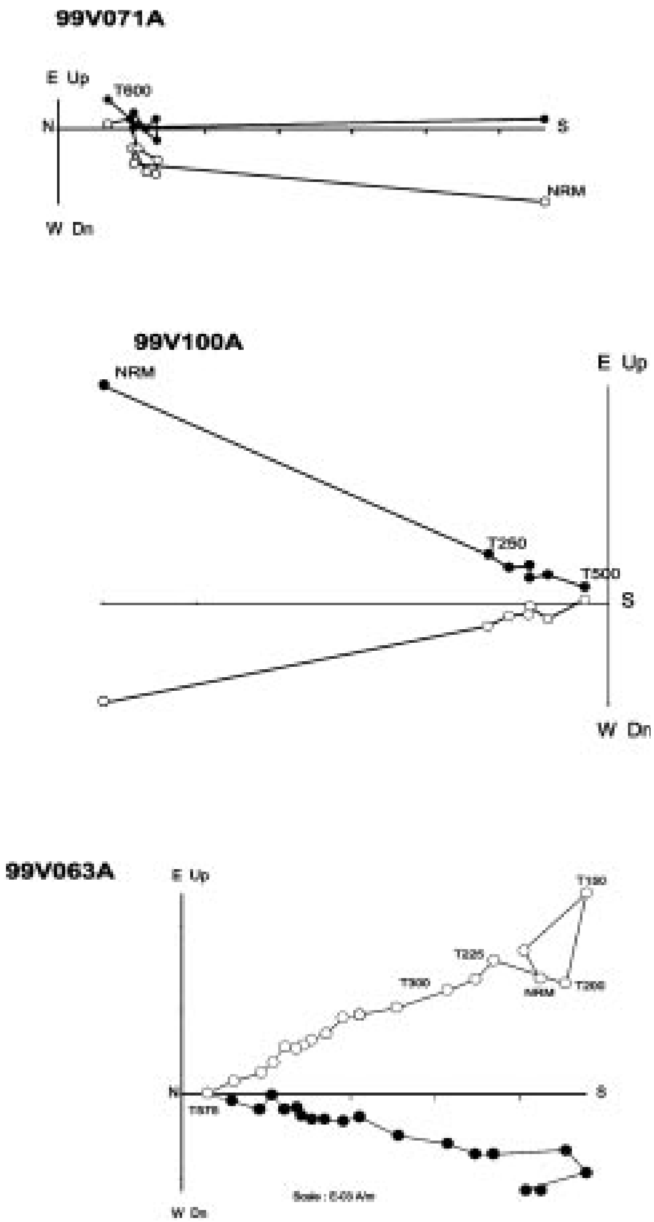

Fig. 5. Representative orthogonal vector plots of stepwise thermal demagnetization (stratigraphic coordinates). The numbers refer to the temperatures in °C. o - projections into the horizontal plane, x – projections into the vertical plane.

cay of NRM around 300°C may correspond to greigite, which is also a ferrimagnetic mineral (Dunlop and Özdemir, 1997) and can provide a stable remanence.

Directions of characteristic magnetization components were calculated by principal component analyses (Kirschvink, 1980), a minimum of 4 points being taken for this determination. A correction was made for tectonic tilt of the sedimentary units. The average unit directions were precisely determined, and the declination/inclination obtained from the characteristic component of each sample served to calculate the virtual geomagnetic pole latitude (VGP) reported on Figures 6 and 7, according to their stratigraphic levels. Section 1 shows clearly one unit normally magnetized and one unit with reverse polarity magnetization (Figure 6). We note however that level 4 from unit section 2, which is presented only with one block sample (three specimens), cannot be accepted as reversely magnetized (Figure 6). The results for section 3, are two reversed, one normal, and two intermediate polarity zones (Figure 7). Section 3 shows a richer spectrum in fossil content than the others.

DISCUSSION AND CONCLUSIONS

The virtual geomagnetic pole (VGP) latitudes of the characteristic paleomagnetic directions yield a magnetic polarity sequence in all sections (see Figures 6 and 7). For each section, the paleomagnetic study highlights a few magnetic polarities succession, that is due to the small thickness of the sections sampled as a result of the few outcrops.

One sample from the lower part of section 1 is difficult to interpret, because of its very weak NRM. It did not provide clear primary magnetization due to highly unstable behavior. One reverse polarity is recorded at the base of this section, and is represented by three levels. The following levels are normal polarity. Plankton foraminiferal biostratigraphy played an essential role in correlating section 1 to the geomagnetic polarity time scale (GPTS) of Cande and Kent (1995). The association of foraminifers restricts the age of the section at the lower part of N5 zone (Blow, 1969) corresponding to zone M2 of Berggren *et al.* (1995). This zone is correlated to chron C6n-C6An (Figure 8). If so the normal polarity of section 1 could be correlated to chron C6An and the reverse polarity can be correlated with the reverse chron C6An.1r. We suggest an approximate age of 20.7-20.9 Ma for section 1 (Figure 8).

Section 2 is about 22 m thick and shows predominantly normal polarity. The only reverse polarity is represented by one level (sample 4) that is doubtful. In case that the reversed polarity is an artifact, and taking into account the biochronological age, the long normal polarity might be correlated to chron C6n (Figure 8).

The results obtained of the section 3 showed only two reverse polarity zones. This section belongs to zone N8 of Blow (1969). The age assigned was based on the assembly of *Praeorbulina glomerosa glomerosa*, *P. curva*, *P. sicana* and *Globigerinoides bisphericus*. The faunal association indicates an early to middle Miocene age, and we can cor-

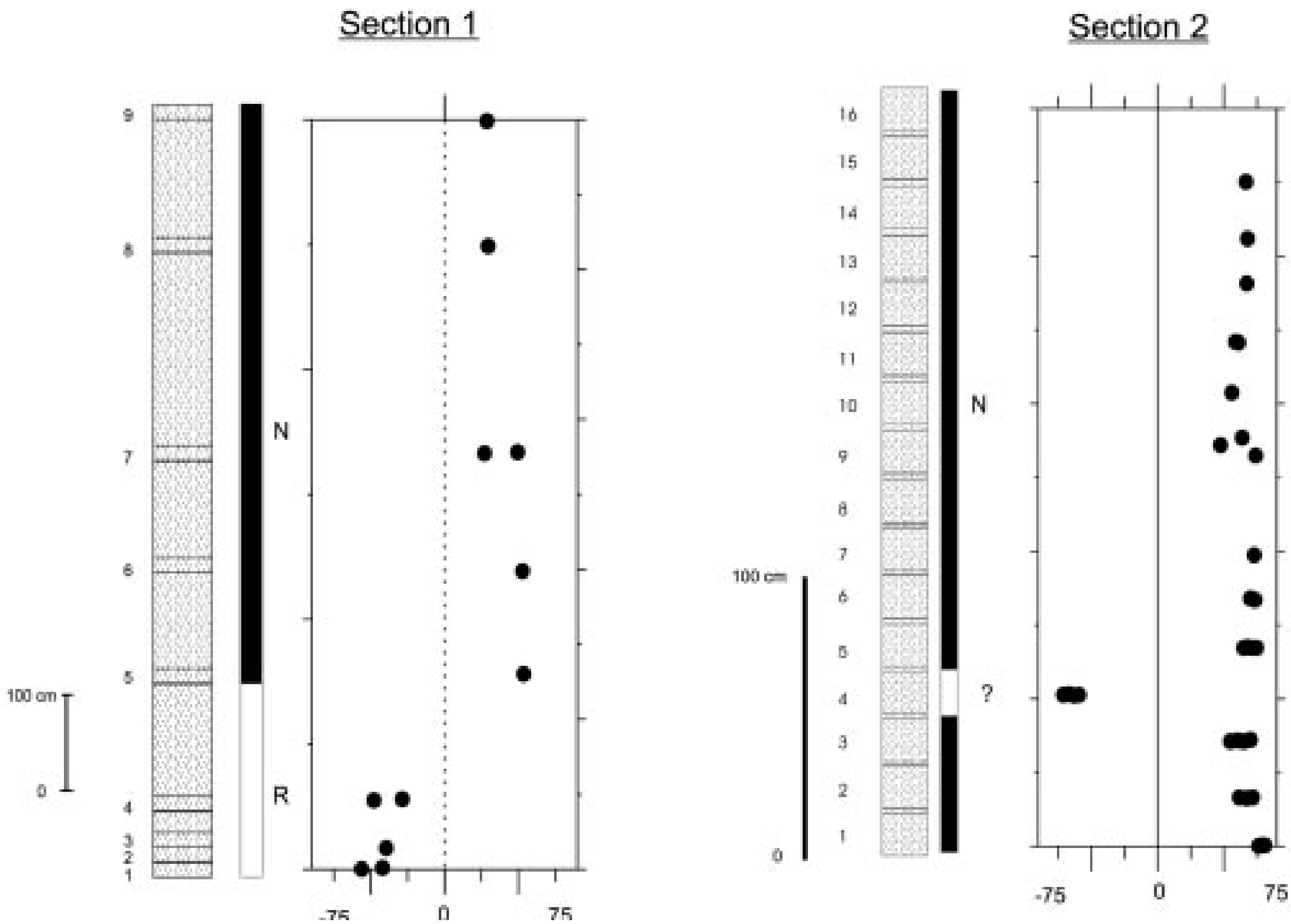

Fig. 6. Magnetic polarity zonation for the stratigraphic sections 1 and 2. It is showed (from left to right): scale, number of sample, stratigraphic section, polarity, and VGP latitude. The suffix '+' ('-') is used to denote normal (reverse) magnetic polarity.

relate the reverse polarity R1 to chron C5Cn.1r, N1 to chron C5Cn.1n and R2 to chron C5Br.

In conclusion, the biochronologic and magnetostratigraphic results (Figure 8) allow us to place these sections in their most probable stratigraphic position. The distance and the outcrop condition do not allow us to make correlation in the field. According to our results, we can conclude that section 1 is the older one and section 3 is the youngest.

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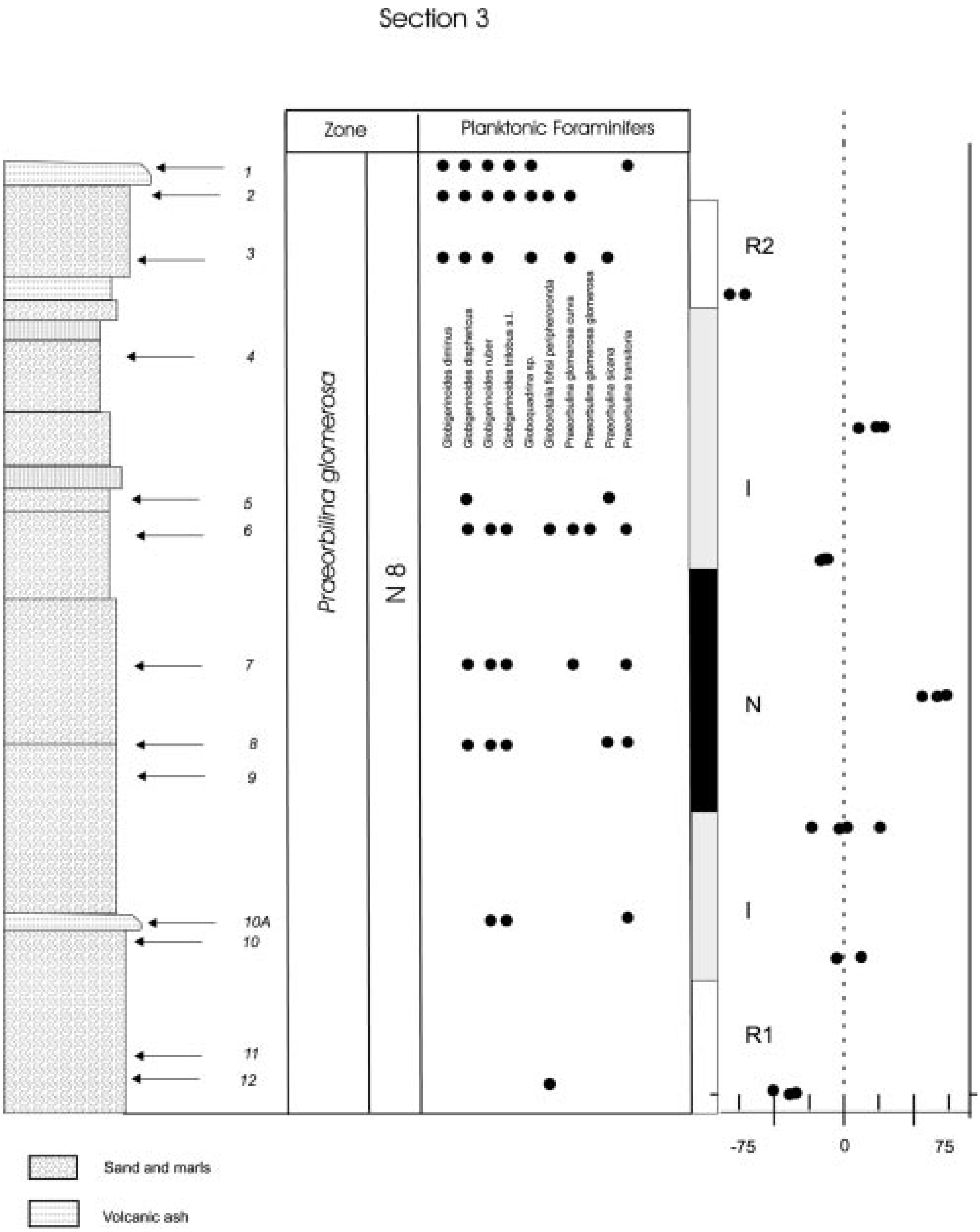

Fig. 7. Magnetic polarity zonation for the stratigraphic section 3. It shows (from left to right): scale, stratigraphic section, number of sample, microfossil description, polarity, and VGP latitude. The suffix '+' ('-') is used to denote normal (reverse) magnetic polarity.

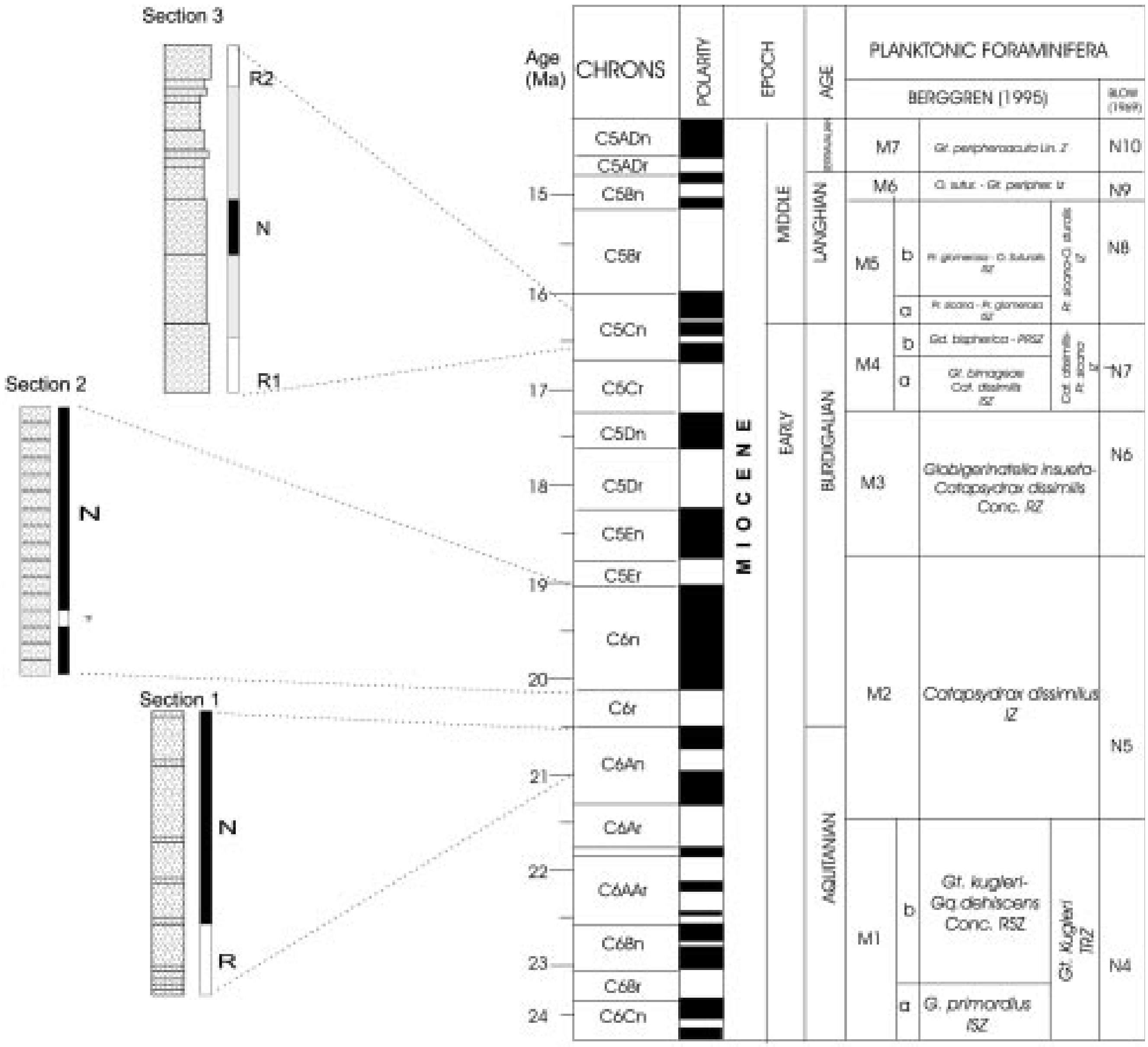

Fig. 8. A tentative magnetostratigraphic correlation between Sayula-Isla section and geomagnetic polarity time scale (retrieved from Berggren, 1995).

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