13. PALEOMAGNETIC RESULTS FROM DSDP HOLE 391C AND THE MAGNETOSTRATIGRAPHY OF CRETACEOUS SEDIMENTS FROM THE ATLANTIC OCEAN FLOOR[1]

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ABSTRACT

Paleomagnetic study of Cretaceous sediments from DSDP Hole 391C shows numerous intervals of reversed polarity occurring within the Lower Cretaceous. When these results are combined with those from DSDP sites from Legs 40, 41, and 43, they allow us to construct a reversal sequence for the Cretaceous system. The results indicate that mixed polarity occurs in Maestrichtian sediments, normal polarity predominates in lower Campanian to upper Albian sediments, and mixed polarity characterizes the remainder of the Cretaceous system.

INTRODUCTION

The magnetostratigraphy of the Upper Cretaceous has been established through studies of DSDP cores, land sections, and the magnetic anomalies observed in the sea floor (see Keating et al., 1975a, b); but few paleomagnetic studies of the Lower Cretaceous have been made. For the pre-Maestrichtian portion of the Cretaceous, we must rely upon the sea floor anomaly interpretations (summarized by Larson and Hilde, 1975) or upon the older continental work as summarized by Helsley and Steiner (1969) or Irving and Couillard (1973). These studies of the Cretaceous can be combined to provide a basis for predicting polarity although large errors in age assignments and number of polarity zones may remain. Further refinement of this predicted polarity sequence requires that we study numerous rock units to establish a detailed magnetostratigraphy for the Cretaceous. Some of these units must be datable by biostratigraphic means so that the polarity sequence in turn can be correlated with various biostratigraphic zonations, radiometric dates, and marine anomaly patterns.

In an attempt to establish a polarity sequence for the Cretaceous, approximately 2000 oriented samples were collected from seven sites drilled in the Atlantic Ocean during Legs 40, 41, 43, and 44. The results from Legs 40, 41, and 43 have been discussed in previous volumes of the DSDP Initial Reports and when correlated with the results from Leg 44 presented below, provide a reversal sequence for the entire Cretaceous.

SEDIMENTS OF HOLE 391C

Hole 391C is located at 28°N, 75°W, in the northern Atlantic. The hole is in the Blake-Bahama Basin in an area of low amplitude sea floor magnetic anomalies. The sediment from Hole 391C was divided into five lithologic units which are described in the Site 391 report, this volume. The lowermost two units (Cores 14-52) were sampled for this study. Unit 4 (Cores 14-44) consists of Barremian to upper Tithonian limestone and shale. Unit 5 (Cores 45-52) consists of lower Tithonian limestones and claystones. The two lithologic units have been subdivided into six sub-units.

Sub-unit 4a (Cores 14-23) consists of gray to olive-gray limestones and shales. Very thin black shales are present and are cross-laminated. Sub-unit 4b (Cores 23-34) consists of limestones and shales as follows: light gray laminated calcilutite, light blue-gray bioturbated calcilutite, brown massive calcilutite, black shale, and dark gray laminated calcilutite. Unit 4c (Cores 34-37) consists of blue-white to bluish green bioturbated limestone with a few dark olive-gray clay stringers. Sub-unit 4d (Cores 38-44) consists of white limestone with occasional small greenish gray shale intervals.

Unit 5 was subdivided into two sub-units. Sub-unit 5a (Cores 45-49) consists of variegated argillaceous limestone. Sub-unit 5b (Cores 50-52) is a red marl ($CaCO_3$ content averages 41.6%).

BIOSTRATIGRAPHIC RESULTS

Planktonic foraminifers and nannofossils were studied from this site (see Site 391 report, this volume). For the most part age assignments for Hole 391C were made on the basis of nannofossil data. Within Core 15 *Epistomina* and *Lenticulina* (foraminifers), miliolids, echinoid-crinoid, and coral fragments were found. Within Core 22 a few *Dorothia* sp. and *Pseudonodosaria* were found. *Dentalina*, *Spirillina*, and *Haplophragmoids* occur as high as Sample 14, CC. Within Cores 46-52, tests of *Gublinella* sp., *Ophtalmidium*, *Ammodiscus*, *Lenticulina*, and *Spirillina* were found.

Samples from Cores 14-22 indicate that the interval is representative of the *Calciclithina oblongata/Lithraphides bollii* nannofossil zone (Barremian). Nannofossils from Cores 24-32 are assigned to the *Cretarhabdus crenulatus* Zone (upper Berriasian-lower

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Valanginian). The interval from Cores 34 to 45 is assigned to the *Nannoconus colomii* Zone (upper Tithonian to lower Berriasian). Samples from Cores 46-52 indicate that the interval is representative of the *Parhabdolithus embergeri* Zone (lower Tithonian). Some Kimmeridgian species do occur in this interval. Thus, this interval may be lower Tithonian or upper Kimmeridgian.

PALEOMAGNETIC RESULTS

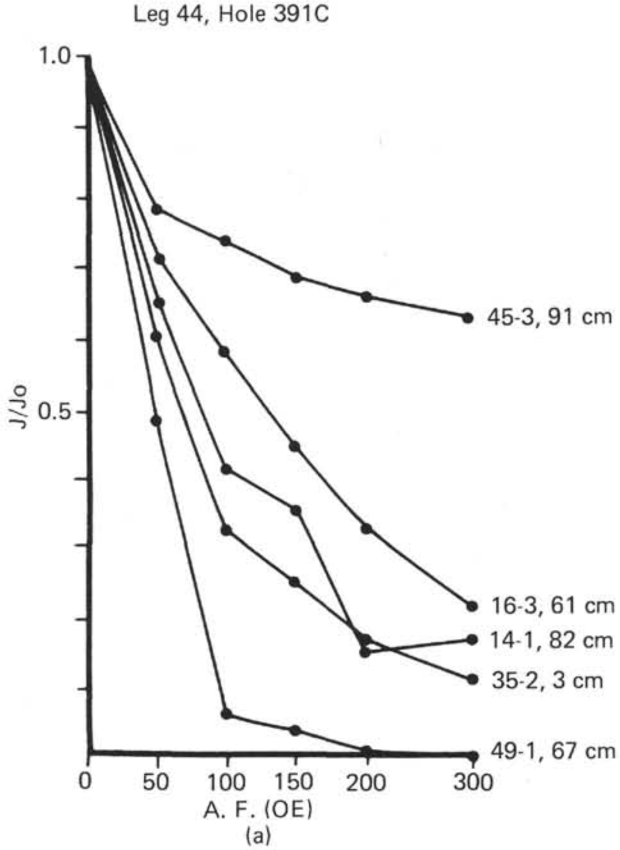
Samples from Hole 391C were collected using the procedure described by Keating and Helsley in Volume 40 of the DSDP Initial Leg Reports (in press). The one-inch-diameter cylindrical samples were cut to one inch lengths and measured on a ScT cryogenic magnetometer.

A pilot study was performed on a group of samples representative of the various lithologies present in the core (see Table 1). They were demagnetized in alternating fields up to 300 oe. The results of these experiments are shown in Figure 1. The demagnetization curves indicate that Sample 45-3, 91 cm (core-section-interval) is highly resistant to demagnetization and very stably magnetized. Samples 16-3, 61 cm, 14-1, 82 cm, and 35-2, 3 cm, have mean destructive fields of approximately 100 to 150 oe, whereas Sample 49-1, 67 cm has a mean destructive field of approximately 75 oe. Samples 16-3, 61 cm, 14-1, 82 cm, and 35-2, 3 cm, show gradual decreases in intensity upon demagnetization. Only one sample, 49-1, 67 cm, shows a sharp drop in intensity on demagnetization at low fields. A plot of inclination versus demagnetization field is shown in Figure 1b. Large changes in inclination occur on the first demagnetization step and at 200 oe (except for a large change in Sample 16-3, 16 cm, at 150 oe). The inclination usually appears to stabilize between the 50 to 100 oe demagnetization steps. Thus, all the samples from this site were treated with a 100 oe demagnetization step. Most of these samples appear to be stably magnetized.

The mean inclination calculated from the NRM results was 50.8° with a standard deviation of 18.9° ($N=337$). The mean inclination calculated from demagnetized results was 42.1° with a standard

TABLE 1
Samples Used in Pilot Study on Various Representative Lithologies

Sample (Interval in cm)	Lithology
14-1, 82	Bottom third: gray claystone. Top two-thirds: light gray mottled chalk.
16-3, 61	Gray claystone and light gray mottled chalk.
35-2, 3	White-gray mottled claystone.
45-3, 91	Red and white banded claystone.
49-1, 67	Bands of gray and red cherty claystone.



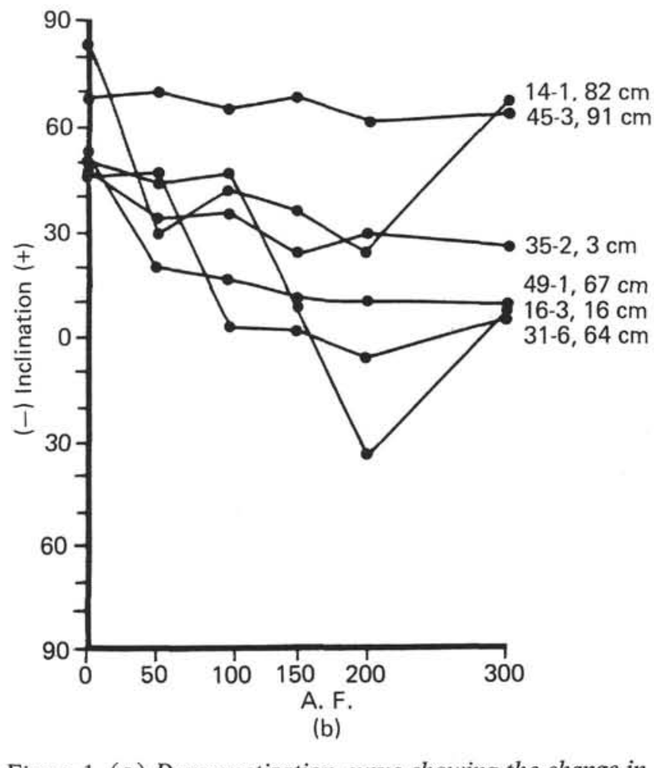


Figure 1. (a) *Demagnetization curve showing the change in intensity on demagnetization for "pilot study" samples;* and (b) *Plot of change in inclination on demagnetization for "pilot study" samples.*

deviation of 22.9° ($N=234$). The paleolatitude calculated from the demagnetized results is 24.3°.

The sample inclinations and intensities are plotted against depth in Figures 2 and 3. Where reversed polarity (negative inclination) is present, the vertical scale has been expanded and the inclinations are plotted on the left of the figure. Upon demagnetization the inclinations of many of the samples having positive NRM inclinations shallow and become negative indicating that a secondary component of magnetization of normal polarity is being removed. At approximately 1180 meters (sub-bottom depth) reversed polarity was indicated on the basis of NRM results. Unfortunately, these samples were overlooked during the demagnetization experiments and were not demagnetized.

DISCUSSION

On the basis of the NRM and demagnetized results, it appears that low alternating field demagnetization is successfully removing a secondary component of normal polarity (presumably the present earth's field direction); however, the magnetic directions from these samples remain very scattered. Many samples show low inclinations after the low field demagnetization. These samples probably have a primary component of reversed polarity on which a secondary component of normal polarity is superimposed. Further demagnetization is necessary to reduce the scatter in inclinations.

Paleomagnetic inclinations of samples from a nearby site (386) also showed a large scatter in NRM and demagnetized inclinations. In the case of Site 386, the scatter decreased significantly with further demagnetization (see Keating and Helsley, Volume 43, *Initial Reports of the Deep Sea Drilling Project*, 1978). Thus we believe that on further demagnetization the scatter in inclination from Hole 391C will also decrease.

Despite the large scatter remaining after demagnetization, we identified four rather long intervals of reversed polarity in cores from Hole 391C along with several short intervals of reversed polarity. Gaps between data points (such as those between 1060 and 1160 m) are a result of gaps in coring or because the sediments within that interval were unsuitable for paleomagnetic study. Nevertheless, these incomplete results indicate that the entire Lower Cretaceous is characterized by mixed polarity.

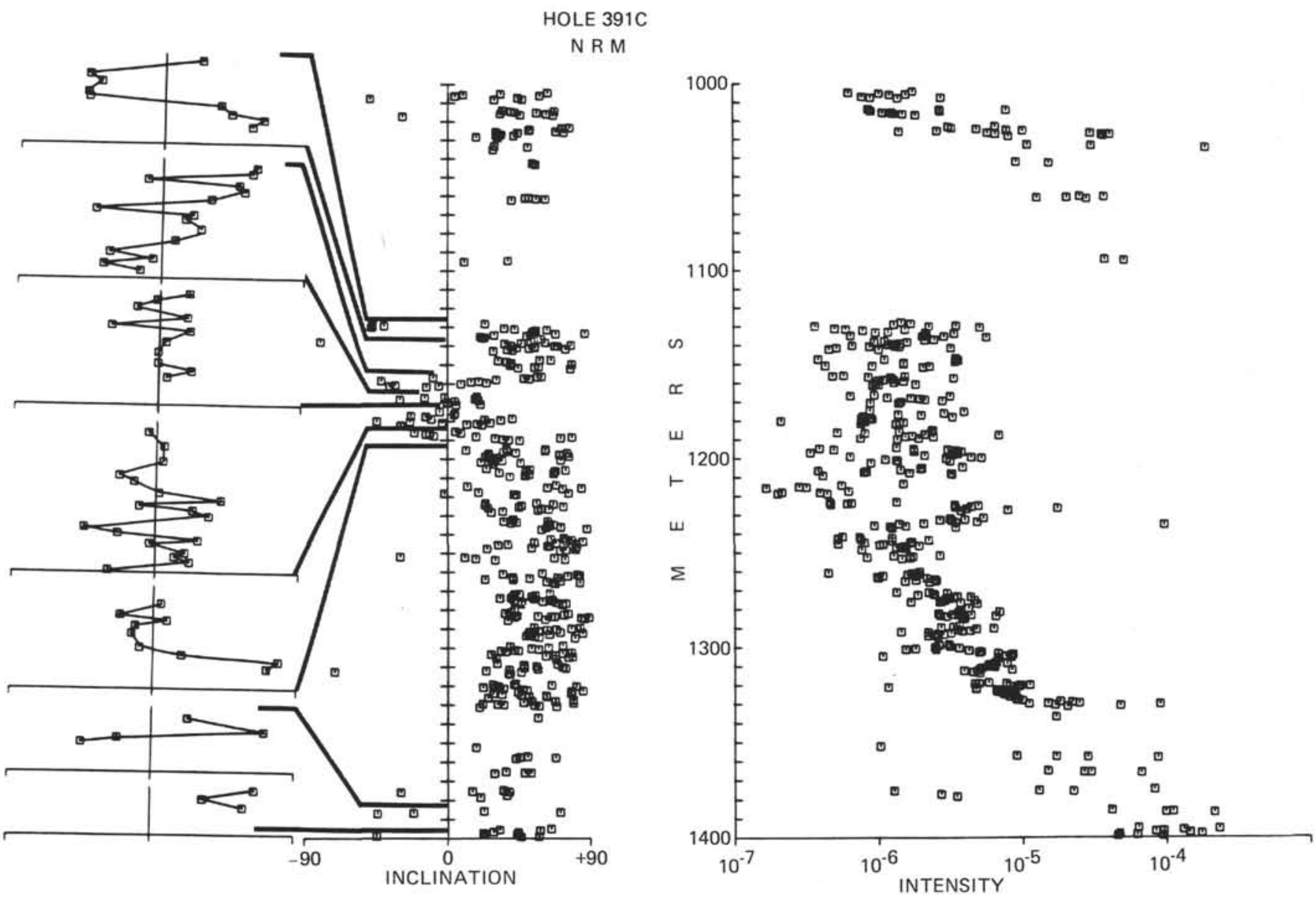


Figure 2. *Plot of sample NRM inclinations and intensities against depth for samples from DSDP Hole 391C. Sample intensity is measured in emu. Depths are from the drill rig floor. Gaps between data points are a result of poor recovery. The vertical scale for intervals of reversed polarity has been expanded by a factor of 10 and the expanded data points are shown to the left of the diagram.*

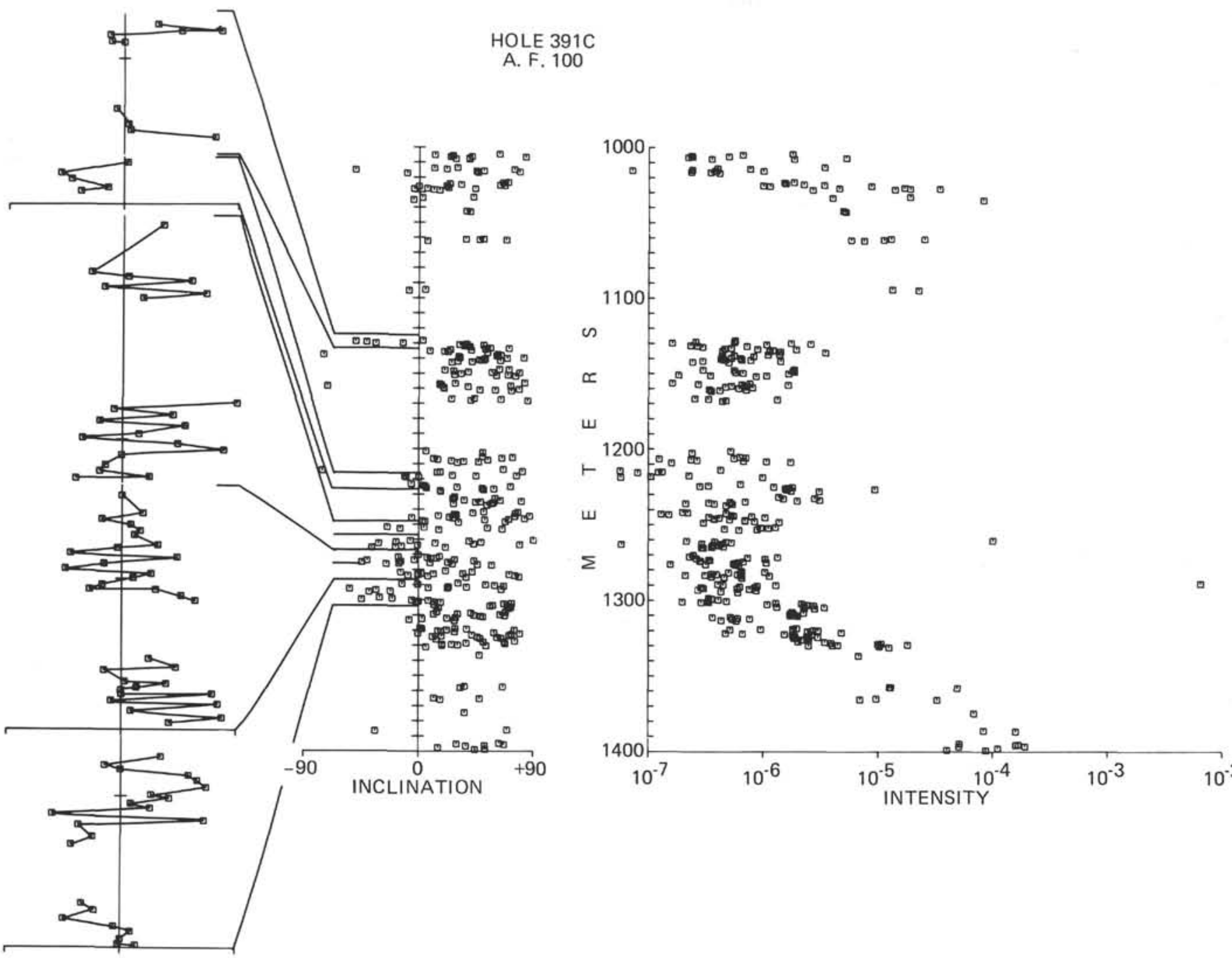


Figure 3. *Plot of demagnetized sample inclinations and intensities against depth. Depths on vertical scale are from the drill rig floor. Reversed polarity intervals have been plotted at an enlarged vertical scale and are shown at left.*

POLARITY SEQUENCE DERIVED FROM DSDP LEGS 40, 41, 43, AND 44

Hole 391C is one of numerous sites studied in an attempt to construct a paleomagnetic reversal sequence for the Cretaceous. The results of the paleomagnetic study of Cretaceous sediments from Legs 40, 41, 43, and 44 are shown in Figure 4, along with a composite polarity sequence.

The reversal sequence derived in these studies is dependent upon age assignments made on the basis of microfossils. The biostratigraphic designations are often made very hastily by scientists onboard ship and some of them will probably be revised after detailed studies are made. Consequently, the reversal sequence developed in this study may need revision at a future date.

Campanian and Maestrichtian rocks suitable for paleomagnetic studies were recovered during Legs 40 through 44 at five sites (361, 363, 364, 369, and 386). The results obtained from these cores are completely compatible with those of Keating et al. (1975a) and show that the Maestrichtian is characterized by mixed polarity whereas the Campanian is dominantly normal with reversed polarities being present only near its upper and lower boundaries. The upper Campanian reversed polarity is an extension of the Maestrichtian mixed polarity sequence and the two reversals found near the Campanian-Santonian boundary are probably the same as those reported by Keating et al. (1975b). The two reversals in the lower Campanian occur as a pair surrounded by long intervals of normal polarity. Very little can be said about the polarity of the Santonian through Cenomanian materials recovered on Legs 40 through 44 for little sediment of these ages was recovered on these legs. Previous studies by Keating (1976) and by Helsley and Steiner (1969) indicate that this interval is characterized by normal polarity which is completely consistent with the observations made on samples from DSDP Legs 40 through 44. The only exception is a few reversed samples occurring near the Turonian-Cenomanian boundary at Site 361. A reversed polarity event has been observed elsewhere in DSDP material (Keating, 1976) at this boundary and a similar event may have been observed on land by Shive (personal communication).

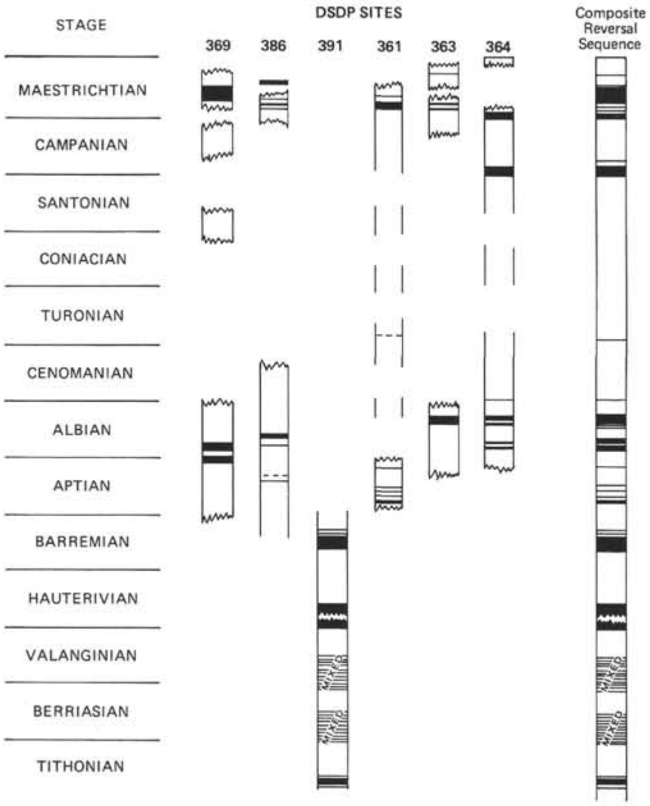


Figure 4. *Summary of paleomagnetic studies of Cretaceous sediments from DSDP Legs 40, 41, 43, and 44. Within the polarity summary columns, black represents reversed polarity and white represents normal polarity. The composite polarity summary column is drawn on the basis of the results from Legs 40, 41, 43, and 44 and those reported by Keating (1976).*

The Lower Cretaceous has been much more extensively sampled during Legs 40 through 44, which greatly facilitates the construction of magnetostratigraphy for this portion of the column. Albian and Aptian sediments were present at five sites. At all of these sites, evidence of mixed polarity was found. Unfortunately, because biostratigraphic dating in this interval is uncertain it is difficult to say how the composite sequence should look. Figure 4 shows a composite sequence that is compatible with the data if one assumes that the biostratigraphic ages are exactly correct. This assumption results in 11 intervals of reversed polarity within the Albian and Aptian. A more conservative viewpoint, however, is that each of the age assignments is subject to some error and thus fewer reversed polarity intervals may be present. Even so, the minimum number required is eight or nine (a combination of the Site 361 and 364 data). Hole 391C is the only site of Legs 40 through 44 in which samples of the lower part of the Cretaceous were recovered and, although these samples have been incompletely demagnetized, considerable evidence is present for a large number of reversed intervals.

One can summarize the pre-Cenomanian work by saying that mixed polarity is present throughout the Lower Cretaceous and is first encountered near the Lower/Upper Cretaceous boundary. Mixed polarity continues across the Cretaceous/Jurassic boundary and is present in rocks as old as lower Tithonian in Hole 391C. Again these observations are compatible with those of Helsley and Steiner (1969) and Irving and Couillard (1973).

We find by comparing the reversal sequence derived from sediments with that from sea floor magnetic anomalies (for example, Larson and Hilde, 1975), that sea floor anomalies *M-3* and *M-17* are very large and are the most easily identifiable anomalies within the sea floor magnetic anomaly *M* sequence. The only intervals of equivalent duration found in sediments occur in the Barremian and Hauterivian. The observation is substantiated by additional studies of Lower Cretaceous sediments of Keating (1976). Thus, our tentative correlation between the sediment-derived reversal sequence and the sea floor anomaly sequence indicates that anomaly *M*-3 is of late Barremian age. The Aptian and Albian intervals of reversed polarity would then be equivalent to anomalies younger than the *M* sequence. Such intervals of reversed polarity have been suggested by Hilde (1975), Vogt et al. (1970), and Osburn (1975). This correlation would require age assignments for the *M* sequence similar to those originally suggested by Larson and Pitman in 1972, but are not entirely compatible with later assignments such as Larson and Hilde (1975).

ACKNOWLEDGMENTS

We thank John Fiske for his help during the three weeks required to collect these samples at Lamont, and especially for his willingness to put snow tires on the core carts. In addition, we thank Barry Lienert for his aid with programs and equipment, Jane Neugent for keypunching all the data from this and other legs, and Emilio Huerrero for measuring many of these samples. This work was supported by the National Science Foundation through Grants GA43299 and EAR76-13369.

REFERENCES

Helsley, C.E. and Steiner, M.B., 1969. Evidence for long intervals of normal polarity during the Cretaceous period: *Earth Planet. Sci. Lett.*, v. 5, p. 325.

Hilde, T.W.C., 1975. Mesozoic Sea Floor Spreading in the North Pacific; *D. Sc. Thesis,* University of Tokyo, Japan.

Irving, E. and Couillard, G.W., 1973. Cretaceous normal polarity interval: *Nature, Phys. Sci.*, v. 244, p. 10.

Keating, B., 1976. Contributions to paleomagnetism: *Ph.D. Dissertation,* University of Texas at Dallas, Dallas, Texas.

Keating, B.H. and Helsley, C.E., in press. Magnetostratigraphy of Cretaceous age sediments from Sites 361, 363, 364, and 365. *In* Bolli, H.M., Ryan, W.B.F., et al., Initial Reports of the Deep Sea Drilling Project, Volume 40: Washington (U.S. Government Printing Office).

________, 1978 Magnetostratigraphy of Cretaceous sediments from DSDP Site 386. In Tuchoke, B., Vogt, P., et al., *Initial Reports of the Deep Sea Drilling Project.* Volume 43: Washington (U.S. Government Printing Office).

Keating, B.H., Helsley, C.E., and Pessagno, E.A., Jr., 197a. Late Cretaceous reversal sequence: *Geology,* 2, p. 75.

________, 1975b. Reversed events within the Late Cretaceous normal polarity interval: *E.O.S., Trans. Am. Geophys. Union,* v. 56, p. 354.

Larson, R.L. and Hilde, T.W.C., 1975. A revised time scale of magnetic reversals for the Early Cretaceous and Late Jurassic: *J. Geophys. Res.*, v. 80, p. 2586.

Larson, R.L. and Pitman, W.C., III, 1972. World-wide correlation of Mesozoic magnetic anomalies and its implications: *Geol. Soc. Am. Bull.*, v. 83, p. 3645.

Osburn, W.L., 1975. Geophysical Study of the Great Abaco Fracture Zone: Ph.D. Dissertation, University of Delaware.

Sclater, J.G. and Fisher, R.L., 1974. Evolution of the East Central Indian Ocean, with emphasis on the tectonic setting of the Ninety-east Ridge: *Geol. Soc. Am. Bull.*, v. 85, p. 683.

Vogt, P.R., Anderson, C.N., Bracey, D.R., and Schneider, E.D., 1970. North Atlantic Magnetic Smooth Zones: *J. Geophys. Res.*, v. 75, p. 3955.