$^{87}Sr/^{86}Sr$ dating of Upper Cretaceous (Campanian and Santonian) depositional sequences: Bass River and Ancora, NJ ODP Leg 174 AX

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Abstract

The objective of this study is to date hiatuses associated with unconformities identified in the Campanian and Santonian section in the Ancora and Bass River boreholes using $^{87}Sr/^{86}Sr$ dating techniques. Sequence-bounding unconformities were previously identified fin the boreholes (Miller et al., 1998, 1999). This study constrains the younger age of the sequence boundaries at the base of the Navesink Formation at 66.5 Ma. The hiatus between the Navesink and Mt. Laurel Formations is approximately 5 Ma with the age of the older surface dated as 71.5 Ma. Another sequence separates the Marshalltown and the Englishtown Fomations; no detectable hiatus is associated with this boundary that is dated at ~75.0 Ma. The sequence boundary separating the upper and lower Englishtown Formations is dated at ~76.2 Ma. The base of the Merchantville Formation is dated to be 81.7 Ma. This study is significant because three depositional sequence boundaries (Marshalltown/Englishtown, upper/lower Englishtown, base of Merchantville) can be firmly tied to the geomagnetic polarity time scale for the first time.

Introduction

Strontium (Sr) isotope ratios in unaltered marine carbonates can be used as an effective relative dating tool (Burke et. al., 1980). In the ocean, Sr-isotope ratios are homogenous because the residence time of Sr (~4.0 Ma; Broecker and Peng, 1982) is longer than the mixing times if the oceans (~1 ka). Thus, variations in Sr can be used as a correlative tool.

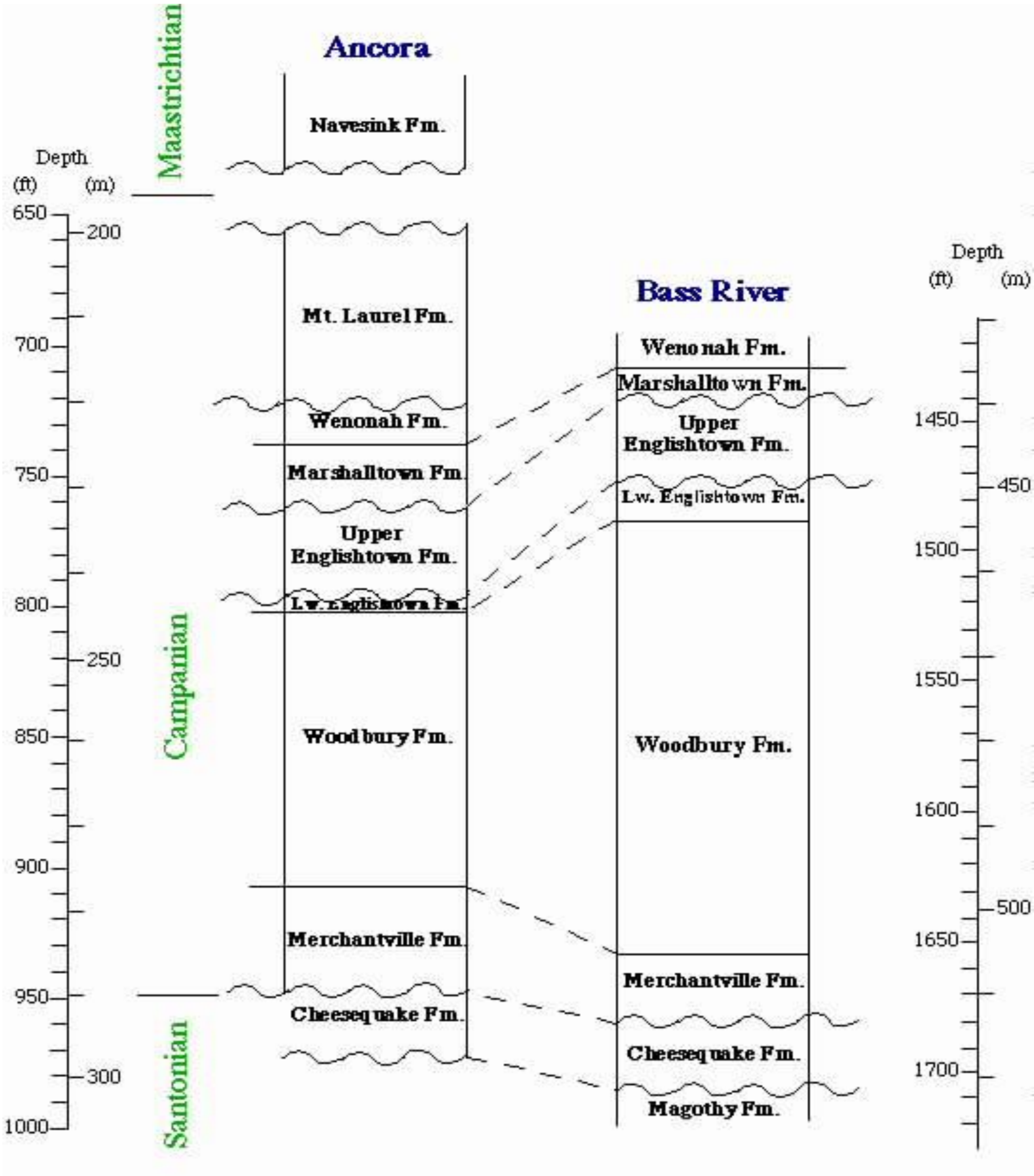
By tying Sr-isotopic measurements on discrete stratigraphic levels to a standard section tied to the geomagnetic polarity time scale, approximate sedimentation rates and hiatuses (time gaps) can be estimated. The objective of this study is to estimate the ages of sequences and sequence-bounding unconformities and suspected boundaries in Campanian and Santonian strata in the Ancora and Bass River boreholes. A record correlating Sr ratios and age has been established for the Cretaceous using paleomagnetics and biostratigraphy (McArthur and Howarth, 1988).

The Bass River and Ancora boreholes were drilled by Rutgers University and the New Jersey Geologic Survey (NJGS) as part of Ocean Drilling Program Leg 174AX (Miller et. al., 1998, 1999). Drilling at these sites focused on recovering lower Paleogene and Upper Cretaceous sequences. Descriptions of lithologies and preliminary sequence stratigraphic interpretation were published in Miller et al. (1998, 1999).

The Upper Cretaceous sections at Bass River and Ancora are fossiliferous allowing for Sr-isotopic analysis. Analyses of whole or fragmented shells have been used in previous Upper Cretaceous Coastal Plain studies, in part because of ease of sampling (Miller et al., 1999). Foraminifera are also carbonate taxa that can be used in Sr-isotope studies. Therefore, in Upper Cretaceous intervals where macroscopic shells are lacking in the Ancora and Bass River boreholes, we analyzed foraminiferal tests instead.

Descriptions of the Bass River and Ancora boreholes were published by Miller et al., (1998, 1999), and the following is derived primarily from their studies. The Upper Cretaceous sections of the two boreholes are ~128 m and ~91 m (Bass River and Ancora) thick (Fig. 1).

Figure 1: The Upper Cretaceous sections of the Bass River and Ancora boreholes are depicted. Formations and depth are from Miller et. al., 1998, 1999.



The Maastrichtian Navesink Formation consists primarily of clayey glauconite sands and glauconitic clays at both boreholes. Deposition occurred in an outer neritic environment (100-200m paleodepth). Underlying the Navesink is the Mount Laurel Formation, an upper Campanian glauconite quartz sand; the contact between the Navesink and Mount Laurel Formations is characterized by phosphate pellets at the upper contact, and is interpreted as a sequence boundary (Miller et al., 1999). The Mount Laurel Formation grades down into the Wenonah Formation, a micaceous, silty clay. The depositional environment of the Wenonah Formation is interpreted as inner neritic (0-30 m paleodepth). Glauconite increases downsection within the Wenonah Formation to a gradational contact with the Marshalltown Formation. Both the Wenonah and the overlying Mount Laurel Formations are part of a coarsening upward succession interpreted as a highstand systems tract (HST). The Marshalltown Formations consists of very dark gray to olive micaceous, glauconitic clays. These sediments are interpreted as the transgressive systems tract (TST). An erosional unconformity separates the Marshalltown Formation from the upper Englishtown Formation.

The Englishtown Formation is divided informally into upper and lower units. The upper Englishtown Formation is characterized by a coarsening/shallowing upward succession with basal glauconite sands grading upward to medial silts and clays and upper sands. An erosional unconformity separates the upper Englishtown from the lower Englishtown Formations. The lower Englishtown Formation is a micaceous, silty fine sand. It was deposited in inner neritic environments, and comprises the upper HST of the Merchantville-Woodbury-lower Englishtown depositional sequence. The Woodbury Formation is a laminated to slightly burrowed, very micaceous, very dark gray clay. The percentage of glauconite increases with depth in section. Its depositional environment is neritic or middle neritic (~20-100 m). The upper part of the formation is interpreted as the upper HST, and the thick clays are the lower HST. The underlying Merchantville Formation is lower Campanian to Santonian based on foraminiferal and nannofossil stratigraphy though this study correlates it as entirely Campanian. These glauconite clays were deposited in middle to outer neritic environments (30-200 m). An erosional unconformity separates the Merchantville from the Cheesequake Formation. In the Cheesequake Formation, glauconite-quartz sands grade down to glauconite clay. These sands are interpreted as the HST. An erosional unconformity separates the Cheesequake from the underlying Magothy Formation. The Magothy Formation is represented by medium to coarse quartz sand with interbedded silty layers. These sediments were deposited in nearshore to nonmarine environments including delta fronts and marine channels, and non-marine fluvial environments; the Magothy Formation does not contain shell or foraminifera at either Bass River or Ancora, and thus could not be dated by Sr-isotope stratigraphy.

Methods

Shells were sampled from the Bass River borehole. These samples were washed with sodium metaphosphate and dipped in 1.5 N HCl to remove surface contaminants. The samples were then examined under a microscope for any remaining contaminants (i.e., inclusions of various minerals in crevices of the shell). After being dried, the samples were crushed into a fine powder, using a mortar and pestle. Analyses from the Ancora borehole were performed on foraminifera rather than shell fragments. Core samples were washed with a sodium metaphosphate solution and oven dried. The samples were sieved and foraminifera were picked under a binocular light microscope. A mass of between five and ten milligrams (mg) of the powder or foraminifera was dissolved and the strontium separated by ion chromatography. Although this weight range is optimum, strontium ratios may be obtained with smaller amounts.

Prior to elution, the powder was dissolved into 1.0 mL of 1.5 N HCl, and then transferred to a microcentrifuge tube for centrifugation to reduce contamination. The cation exchange columns were backwashed with 1.5 N HCl, and the sample (1.0 mL) was added to each column. The column was rinsed twice with 1 mL of 1.5 N HCl. Volumes of 50 mL of 1.5 N HCl, 50 ml of 2.3 N HCl, and 9 mL of 7.3 N HCl were subsequently added.

Before the final addition of acid, the catch beakers were replaced with Teflon beakers. A final rinse of 14 mL of 7.3 N HCl was added to elute Sr. The eluate was collected beakers, which were set on a hot-plate to dry.

Results

Isotopic analyses were performed on a VG Sector Mass Spectrometer in the laboratory of M. D. Feigenson at Rutgers. These ratios were plotted versus depth (Figs. 2, 3). The error bars shown (Figs. 2,3, table 1) are machine precision for each analysis on the mass spectrometer results.

Figure 2: Sr-isotopic values vs. Depth at Bass River. The error bars are machine precision for each analysis.

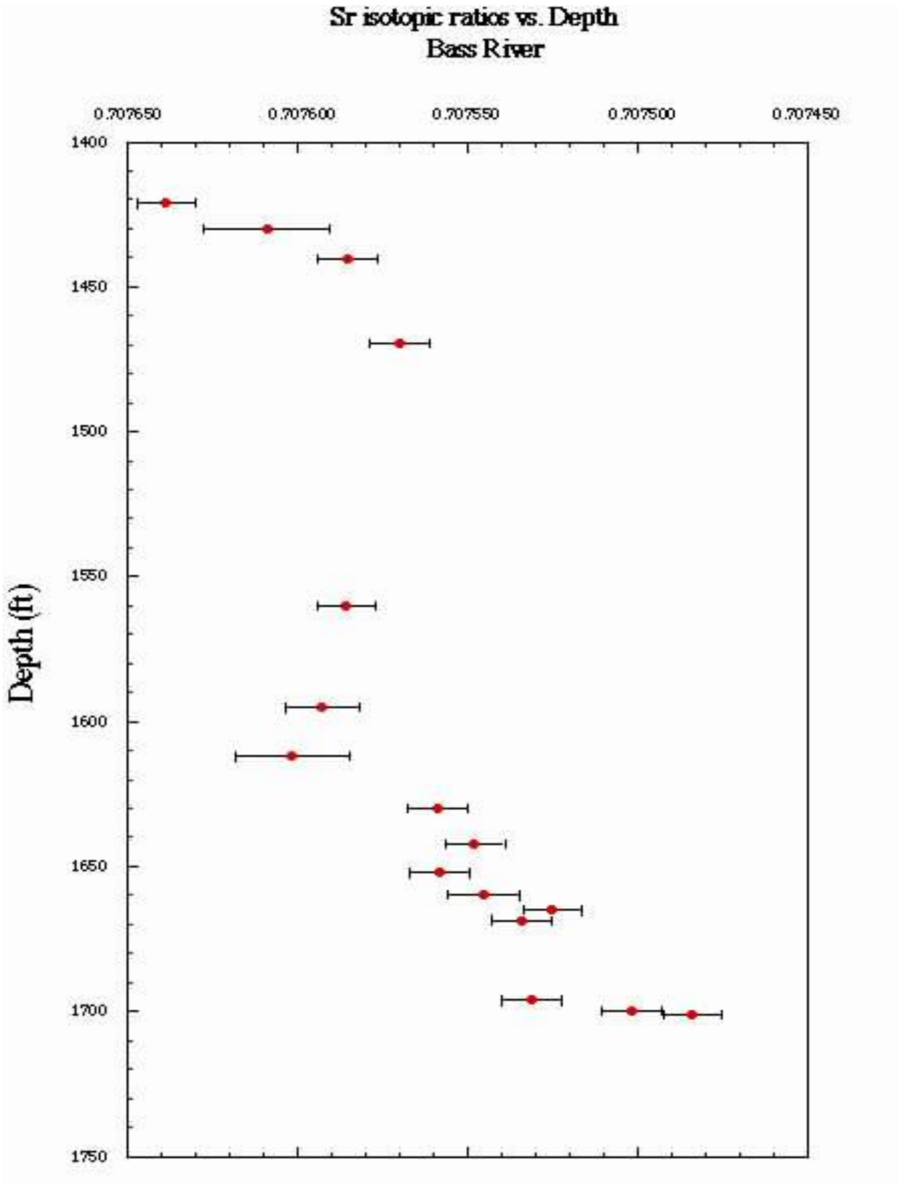
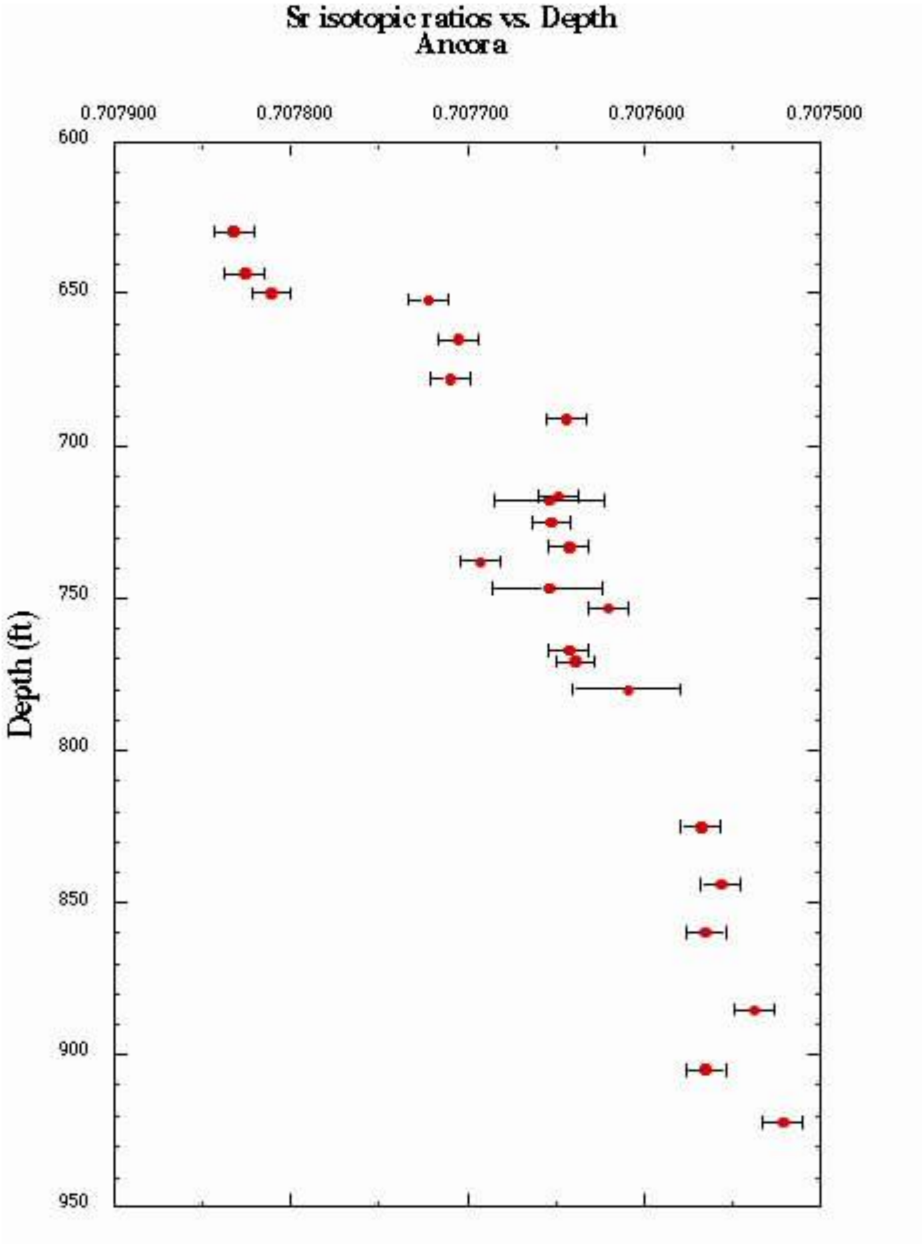


Figure 3: Sr-isotopic values vs. Depth at Ancora. The error bars refelect the accuracy of each analysis.



Isotopic ratios were converted to ages by correlation with the Sr curve of McArthur and Howard (1988) (Figs. 4 - 6).

Figure 4: An age-depth plot was constructed using the McArthur and Howard Sr curve. Gaps in the data occur where the sediments contained too little SrCO3 to analyze. Error bars are ±1 Ma

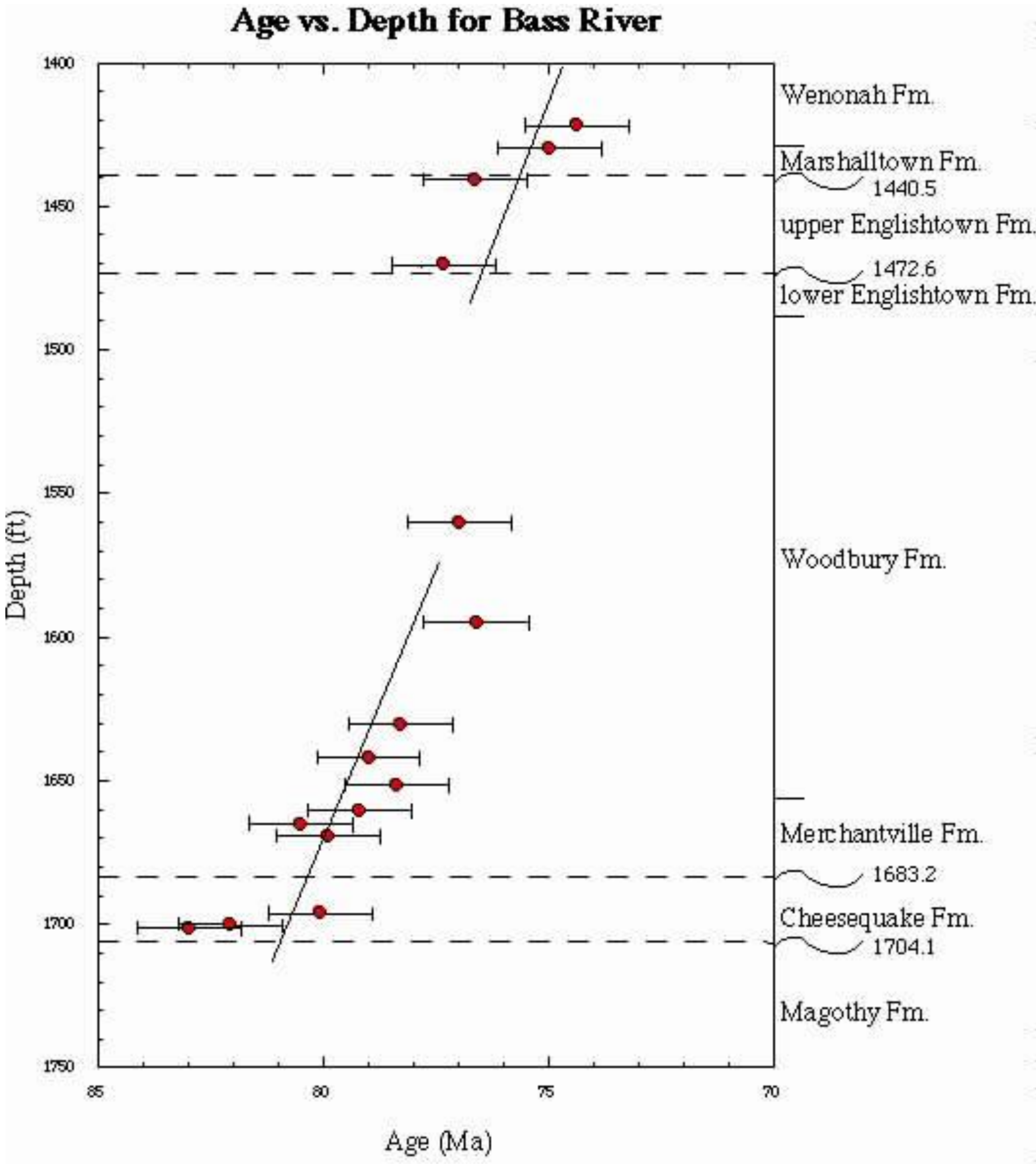


Figure 5: An age vs. depth plot for Ancora was constructed by using previously determined sequence boundaries (Miller et. al., 1999). Each sequence was considered separately. Error bars are ±1 Ma

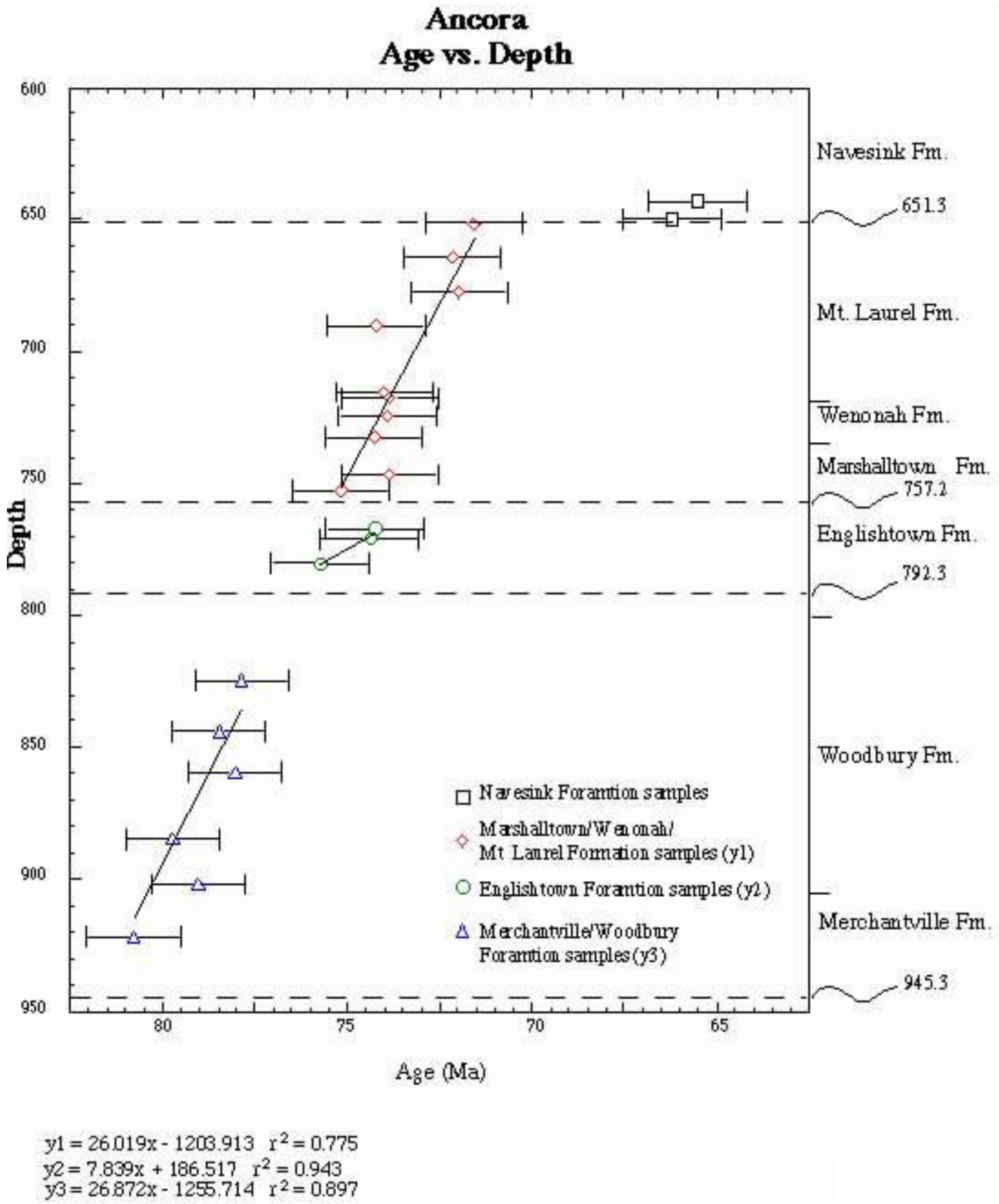
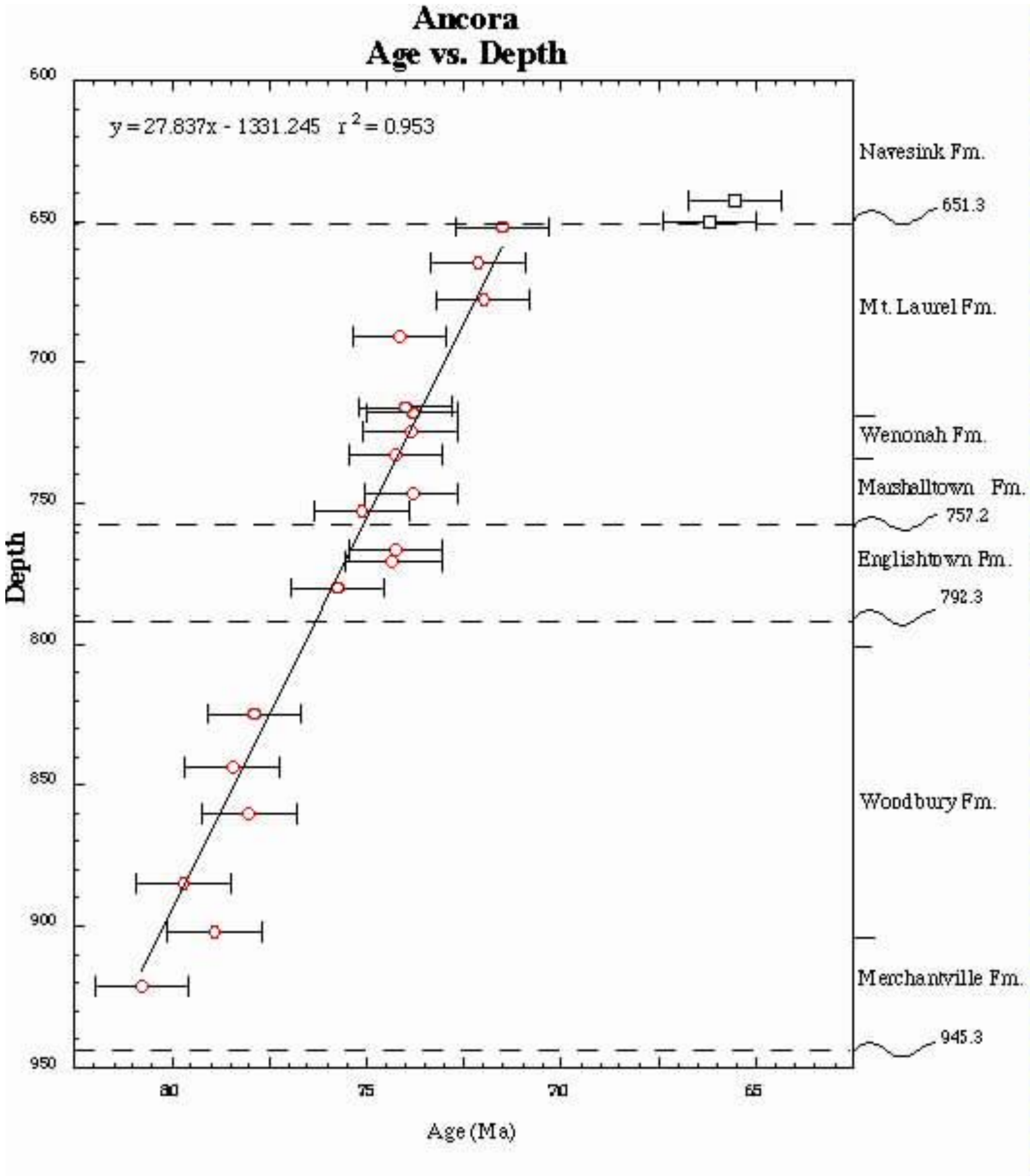
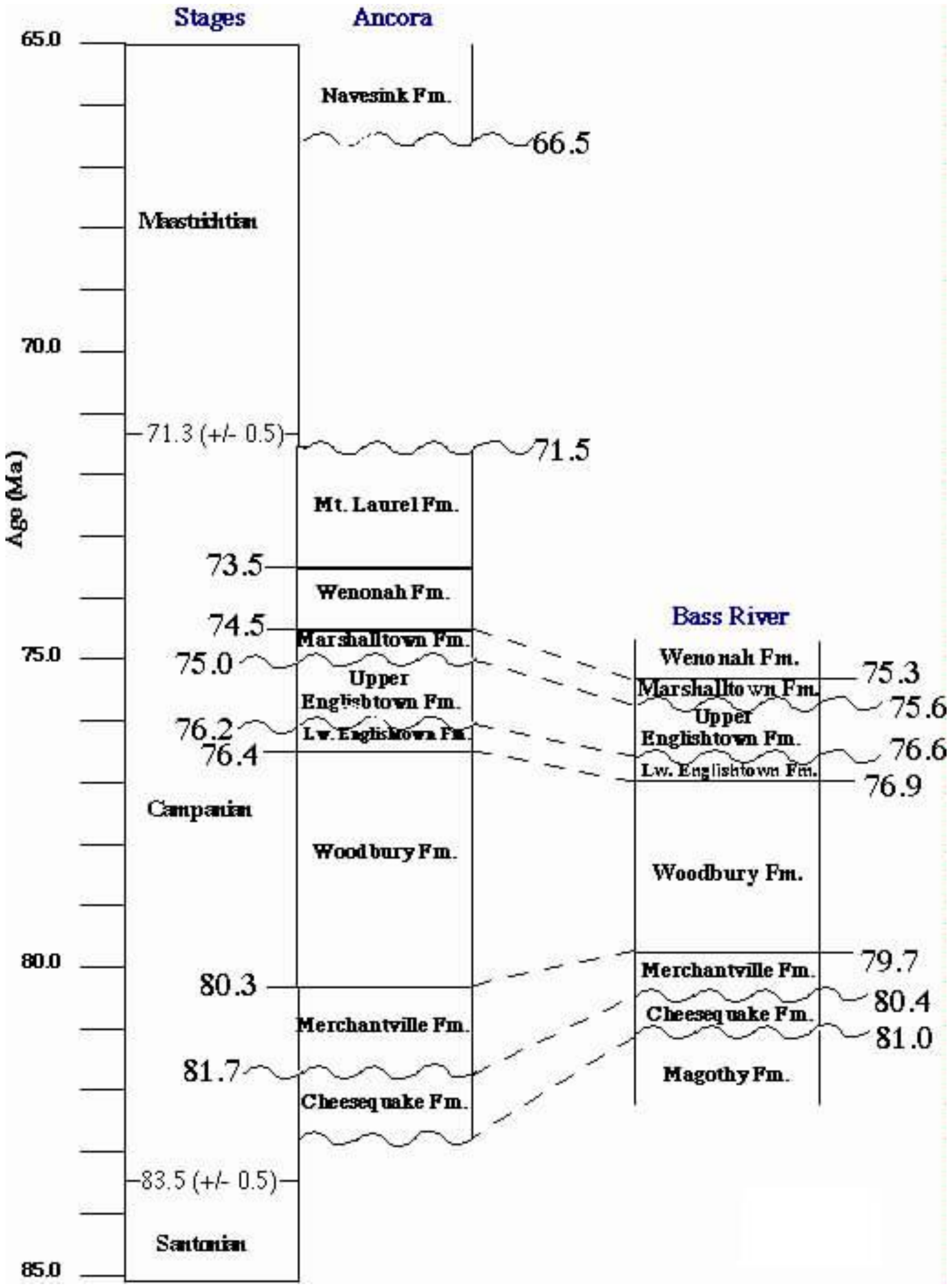


Figure 6: Considering the ages at Ancora as a single data set rather than multiple sets (figure 5) provides a better illustration of the sequences. The r^2 value obtained was (0.953). Error bars are ±1 Ma



Sr-isotopic age estimates at Ancora increase within the expected sample error from 65.53 Ma at 643.1 ft (196.0 m) to 80.75 Ma at 921.9 ft (281.0 m). Ages of the individual formations at Bass River are offset from those at Ancora (Fig. 7), although the offset is relatively minor (<2 Ma) for the interval examined.

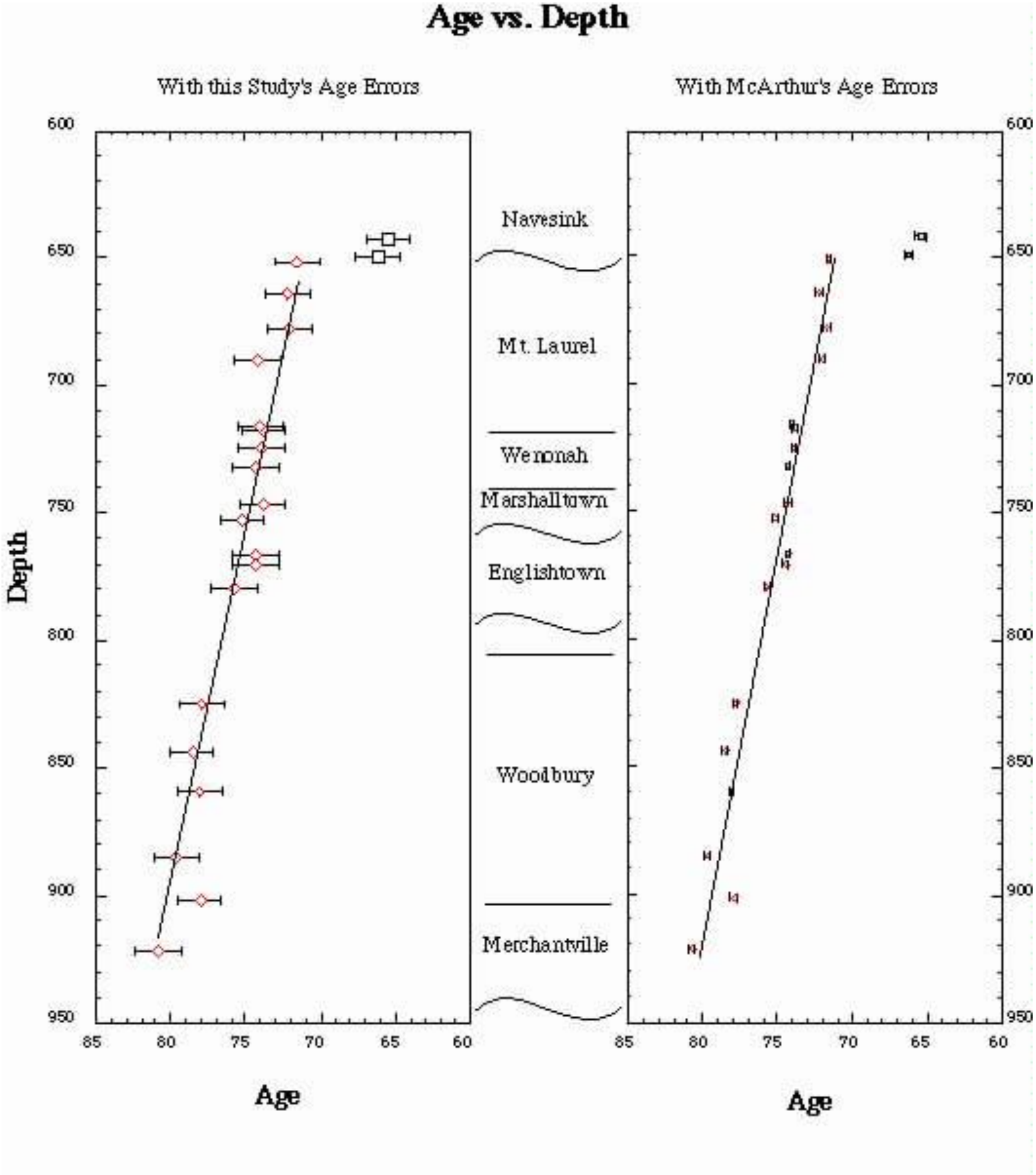
Figure 7: The Upper Cretaceous sections of the Bass River and the Ancora boreholes are depicted with ages for both sequence boundaries and formations. Note the slight offset in ages between the two boreholes.



Although Sr developed ages at Bass River are thought to be altered by diagenesis (Miller et al. 1999), the offset of ages between the two boreholes in this study are not conclusive.

At Ancora, Sr-isotopic age estimates generally increase with depth from 650 ft (198.1 m) to 950 ft (289.6 m) (Figs. 5, 6). Error bars were added taking into consideration machine error as well as the limitations of the dating technique (i.e., external precision and errors in the age regression). Two plots are provided: 1) using a fixed error of ± 1 m.y as a conservative error estimate (Fig. 8a, left); and 2) using statistical age errors provided by McArthur and Howard (1988) (Fig. 8b, right). Although McArthur and Howard (1998) purport to estimate errors statistically, their errors are extremely small for the interval considered. In contrast to their errors, Sugarman et. al. (1995) estimated the Maastrichtian Sr-isotope/ age regression had an error of approximately ± 1 Ma External precision (sample reproducibility) at Rutgers has been estimated statistically as ± 0.00020/ Ma (Oslick et. al., 1994). Given that the rate of change of Sr-isotopic ratios was 0.00022/ Ma for the interval 70 to 82 Ma (McArthur and Howard, 1998), a minimum error estimate would be ± 0.9 Ma Given that the McArthur and Howard (1998) age errors are unrealistically small, we show errors of ± 1 Ma as a conservative estimate.

Figure 8: a) and b) Error bars from this study are compared to those of McArthur et al. (1998) The error bars of ± 1 Ma better illustrate the interval considered.



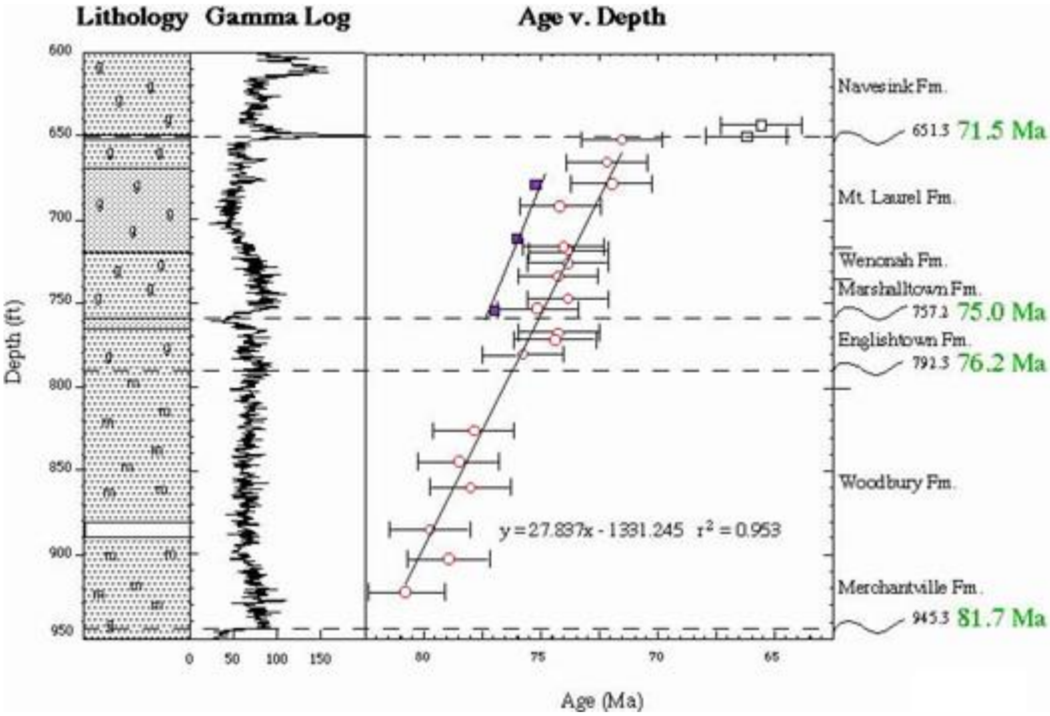
The age-depth model shows a distinct hiatus associated with the Navesink/Mount Laurel contact. At 650 ft (198.1 m), the Sr age is 66.5 Ma. A significant offset (hiatus) in the ages occurs between the samples at 650 and at 652 ft (66.5 and 71.5 Ma). This offset correlates with a large spike in the gamma log obtained from Miller et al. (1999) (Fig. 9). This confirms work done previously on this sequence boundary (Miller et. al., in press, Miller et. al., 1999). The use of gamma log and lithologic data furnished by Miller's earlier studies supports the location of the sequence boundary detected by this study. The base of the Navesink, dated at approximately 66.5 Ma, and the top of the Mt. Laurel, dated at about 71.5 Ma, constrain the hiatus to a duration of 5.0 Ma Below the Navesink/ Mt. Laurel contact, no other significant offsets (hiatuses) are noted.

The data were broken into three distinct groups corresponding to the Mt. Laurel/Wenonah /Marshalltown, the upper and lower Englishtown, and the Woodbury/Merchantville sequences. Linear regression was performed on each group with r^2 values of 0.775, 0.943, and 0.897. However, lumping the ages of all three sequences together (Fig. 6) provided an r^2 value of 0.953 and better illustrates the sequences.

Physical stratigraphy requires that some time is not represented at sequence boundaries (i.e. hiatuses should be associated with these boundaries). Due to the brief duration of the other hiatuses, no marked separation was noted in Sr ages. Based on the error estimate described above, a hiatus less than ~1-2 Ma in duration would be too short to be detected. From this estimate it is concluded that the remaining hiatuses in the study are less than ~1-2 Ma Although more samples might better constrain these hiatuses, Sr-isotopic stratigraphy is limited by the errors associated with the dating technique. Some errors may be as large or larger than the actual duration of these hiatuses.

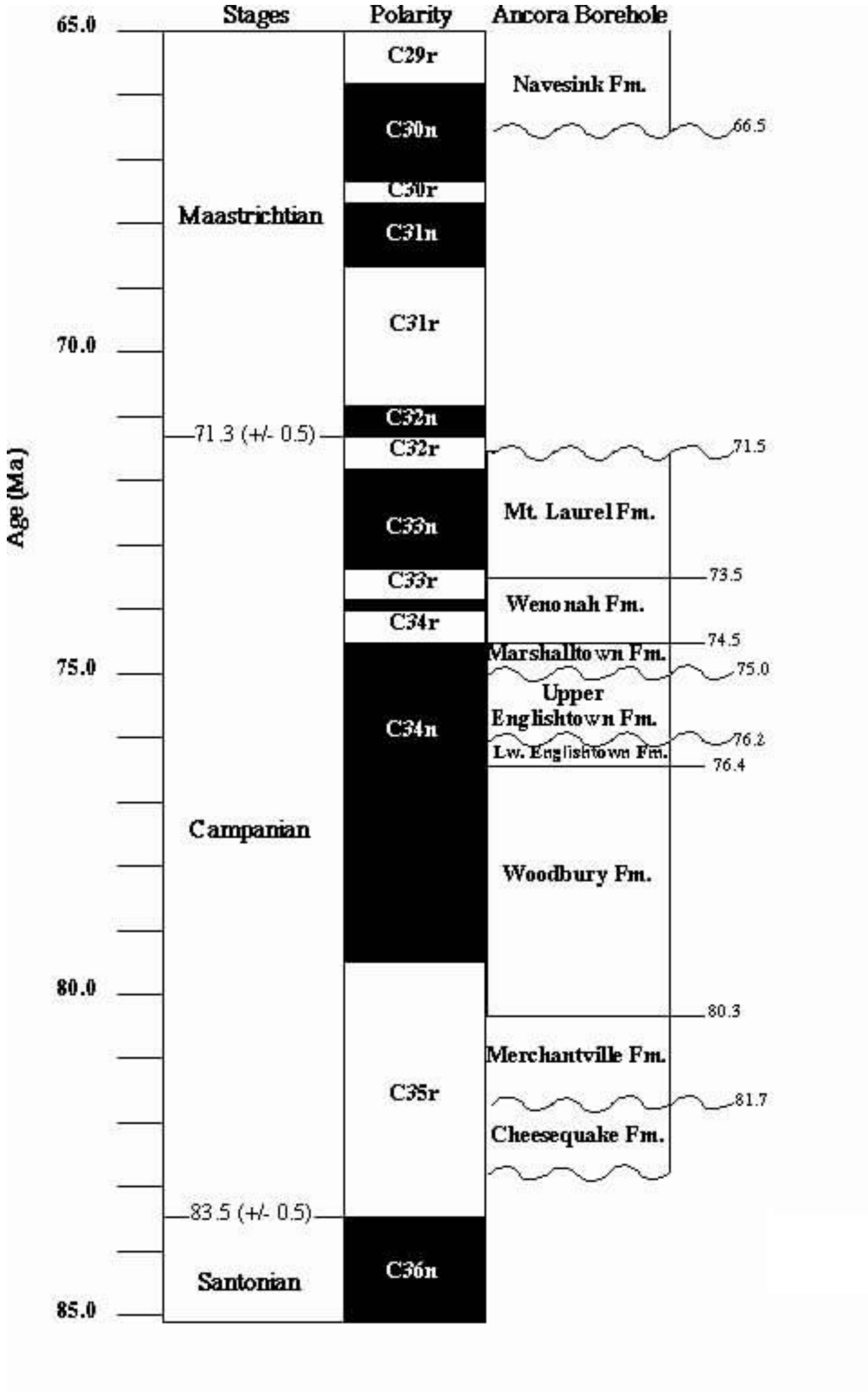
Although no other hiatuses could be readily seen, sequence boundaries could be identified through physical stratigraphy (Miller et. al. 1998, 1999) and dated. The sequence boundary separating the Marshalltown and the Englishtown (757.2 ft. at Ancora) is dated as ~75.0 Ma. The sequence boundary separating the upper and lower Englishtown (792.3 ft. at Ancora) is dated at ~76.2 Ma. The sequence boundary separating the Merchantville from the Cheesequake (945.3 ft. at Ancora) is dated as ~81.7 Ma. The sequence boundaries at 757.2 and 793.2 ft. are interpreted to be real due to kicks in the gamma log and changes of lithology (Fig. 9).

Figure 9: The gamma log and lithology (Miller et. al., 1999) is combined with the age-depth plot from this study. Note the large gamma spike at the Navesink/Mt. Laurel Formation boundary. No other significant offsets (hiatuses) are noted.



The dates of sequences and formations can be tied to the geomagnetic polarity time scale (GPTS) (Fig. 10).

Figure 10: The dates of the sequences were tied into the geomagnetic polarity time scale. The ages of this study link well with the established time scale.



The Sr-isotope stratigraphy predicts that the reversals associated with C33 and C34 should be represented in the fine-grained Wenonah Formation and the C34n/C35r should be represented in the fine-grained Woodbury Formation. Because coarse-grained, shallow-water units (e.g., Mount Laurel Formation) generally are unsuitable for magnetostratigraphy, future studies of magnetostratigraphy should focus primarily on the Wenonah and Woodbury Formations.

A comparison was also made to nannofossil data provided by Miller et. al.(1999). These three nannofossile-derived ages (L. de Romero, written communication, 2000) were plotted along with the Sr age-depth plot for Ancora (Fig. 9). Although the regression line for the age values parallels the plotted nannofossil data, there is an offset of approximately 2.5 Ma from the Sr-isotopic age estimates. We suggest the offset is due to calibration problems between nannofossils and the GPTS or Sr-isotopes and the GPTS. Future work is needed to evaluate both nannofossil-age and Sr-isotopic-age calibration.

Sr-isotope data suggest that sedimentation rates remained fairly constant throughout the Merchantville to Mount Laurel Formations. The sedimentation rate for the interval studied is 8.74 m/Ma (0.0874 cm/ka) This relative constancy is somewhat surprising considering the diverse marine and deepmarine environments represented, but it is consistent with previous studies (Sugarman et. al., 1995)

Conclusion

Sequences and boundaries were dated in the Campanian-Santonian sections of Ancora and Bass River. Hiatuses associated with sequence boundaries, other than the one between the Navesink and the Mount Laurel Formations, cannot be resolved by strontium isotopes. For greater temporal resolution, other stratigraphic tools would need to be used. The base of the Navesink is ~66.5 and the top of the Mt. Laurel is ~71.5 Ma and the hiatus between these two formations is ~5 Ma. The sequence boundary between the Marshalltown and Englishtown Formations is dated at ~75.0 Ma with an inferred hiatus lasting less than ~1.5 Ma. The Englishtown Formation is divided by a sequence boundary dated at 76.2 Ma. The base of the Woodbury Formations is dated to be ~76.0 Ma. The base of the Merchantville Formations is a sequence boundary dated at ~81.7 Ma. Hiatuses of less than 1-2 Ma can not be detected by relying solely on Sr dating. The mean sedimentation rate for this study for all formations is 8.74 m/Ma. The dates developed by nannofossil ages and Sr ages are offset by ~2.5 Ma This offset may be due to a time scale problem.

Future work

Sr-isotopic analysis is a good relative dating tool. The hiatuses and their approximate duration were established in this study. However, a more complete picture of the Upper Cretaceous section at Ancora needs to be developed. A $\delta^{18}O$ record would provide a proxy for glacioeustasy. Magnetostratigraphy at Ancora would be used as a comparison for the chronology developed in this study.

Magnetostratigraphy data from Ancora and Bass River would be compared to determine the extent of diagenesis, if any, at Bass River and to test the regional age consistency at sequences. A deep-water Campanian reference integrating Sr-isotopes, $\delta^{18}O$, magnetostratigraphy, nannofossils and planktonic foraminifera is necessary to calibrate the nearshore sequences to the global time scale.

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