Rb-Sr glauconite isochron of the Eocene Castle Hayne Limestone, North Carolina

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ABSTRACT

The 11-m-thick lectostratotype of the Castle Hayne Limestone in New Hanover County, North Carolina, consists of lower phosphate pebble biomicrudite; middle bryozoan biosparrudite; and upper bryozoan-sponge biomicrudite. The relative age of the Castle Hayne Limestone is equivocal. The planktic foraminiferal fauna and part of the molluscan fauna suggest that the entire formation should be correlated with the Gulf Coast Claibornian Stage (middle Eocene), whereas calcareous nannofossils, bryozoans, barnacles, and some molluscs indicate that the upper bryozoan-sponge biomicrudite is a Gulf Coast Jacksonian Stage (upper Eocene) equivalent. Because of problems correlating the Castle Hayne Limestone to equivalent Gulf Coast stages, the lectostratotype was dated by application of the Rb-Sr glauconite isochron.

Five hand-picked glauconite concentrates analyzed for Rb, Sr, and Sr-isotopic composition yielded an isochron age of 34.8 ± 1 m.y. ($\lambda Rb\,87 = 1.42 \times 10^{-11} yr^{-1}$) with an initial $(Sr^{87}/Sr^{86})_0$ ratio of 0.7083 ± 0.0004. The determined initial $(Sr^{87}/Sr^{86})_0$ ratio is in good agreement with previous estimates of the Sr-isotopic composition of sea water during the Eocene. Although the age is younger than the value of 37 m.y. earlier proposed for the Eocene/Oligocene boundary, it agrees with fission-track and K-Ar ages of tektites and microtektites, and K-Ar ages of bentonites and glauconites in upper Eocene marine and nonmarine units throughout the world.

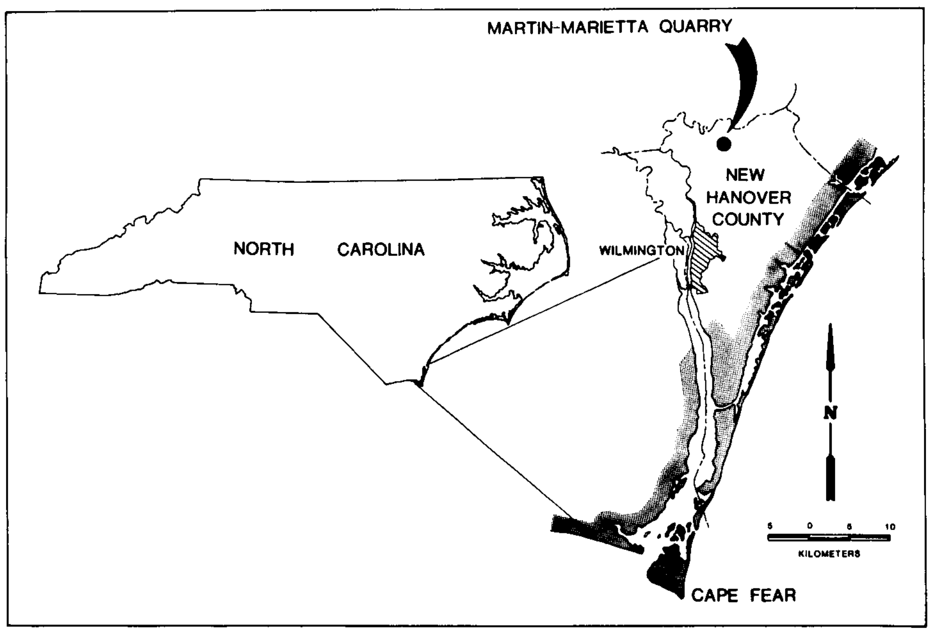

Figure 1. Location of Martin-Marietta quarry, New Hanover County, North Carolina. Sample of Castle Hayne Limestone was collected at this quarry.

INTRODUCTION

Recent work in the United States by Ghosh (1972), Owens and Sohl (1973), Harris and Bottino (1974), Harris (1976), and Harris and Baum (1977), and in Europe by Priem and others (1975), Odin (1978), and Odin and others (1978) has demonstrated that glauconite ages can have direct application to conversion of the standard geologic column to a radiometric time scale. In addition, the accuracy of glauconite ages has also demonstrated that they can aid in the resolution of problems in correlation where faunal data differ.

As a result of these recent successful applications of Rb-Sr and K-Ar dating methods to glauconite, the Eocene Castle Hayne Limestone of the North Carolina Coastal Plain was selected for radiometric and faunal study. The Castle Hayne Limestone has been correlated with the Jacksonian Stage (Clark, 1909; 1912; Canu and Bassler, 1920; Kellum, 1925, 1926; Cheetham, 1961; Copeland, 1964). Brown (1958) and Baum and others (1978) correlated the unit with both the Jackson and Claiborne Stages; however, Brown and others (1972) and Ward and others (1978) correlated the unit with the Claiborne Stage. Therefore, because of problems in correlating the Castle Hayne Limestone with equivalent stages in the Gulf Coastal Plain or in Europe, the lectostratotype was examined for diagnostic fauna and was radiometrically dated by application of the Rb-Sr isochron method to glauconites.

GEOLOGIC SETTING

The Castle Hayne Limestone occurs throughout eastern North Carolina; how-

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ever, the unit crops out only between the Neuse and Cape Fear Rivers. Miller (1912) named the unit for exposures in the vicinity of Castle Hayne, New Hanover County, North Carolina. Because Miller did not designate a type section of the Castle Hayne Limestone, Baum and others (1978) designated the Martin-Marietta quarry, 4.5 km northeast of Castle Hayne, the lectostratotype (Fig. 1).

The Castle Hayne Limestone consists of three units: a lower phosphate pebble biomicrudite, a middle bryozoan biosparrudite, and an upper bryozoan-sponge biomicrudite (Baum and others, 1978). As defined by Baum and others (1978), the Castle Hayne Limestone does not include the overlying Spring Garden Member of Ward and others (1978).The phosphate pebble biomicrudite (New Hanover Member of Ward and others, 1978) forms a discontinuous conglomerate at the base of the Castle Hayne Limestone that does not exceed 1.5 m in thickness. It is present along the outcrop belt and is thickest where it overlies the Rocky Point Member of the Peedee Formation of Late Cretaceous age.

The bryozoan biosparrudite unit disconformably overlies the basal pebble biomicrudite of the Castle Hayne Limestone. It occurs as isolated patches in the vicinity of the Cape Fear fault and thickens to the northeast to a maximum of 12.2 m, where it interfingers with the overlying bryozoan-sponge biomicrudite. Bryozoan-sponge biomicrudite occurs throughout the area between the Cape Fear and Neuse Rivers and is the dominant unit exposed in outcrop. In the area of the Cape Fear fault, it contains numerous diastems and is locally dolomitized (Baum and others, 1978). The bryozoan biosparrudite and bryozoan-sponge biomicrudite lithofacies are the Comfort Member of the Castle Hayne Limestone of Ward and others (1978).

At the lectostratotype, the Castle Hayne Limestone is 11 m thick; it disconformably overlies the Cretaceous Rocky Point Member of the Peedee Formation, and disconformably underlies post-Eocene sand and gravel or Pliocene(?) sediments (Fig. 2). The lower contact of the Castle Hayne is the Cretaceous-Tertiary boundary and is a regional disconformity characterized by solution pits, phosphate, and glauconite. All three units of the Castle Hayne occur at the lectostratotype; however, the bryozoan-sponge biomicrudite forms the dominant part of the section. It consists of loose, unconsolidated carbonate sediment which contains a 1-m-thick dolomitized zone about 1.5 m above the disconformity that

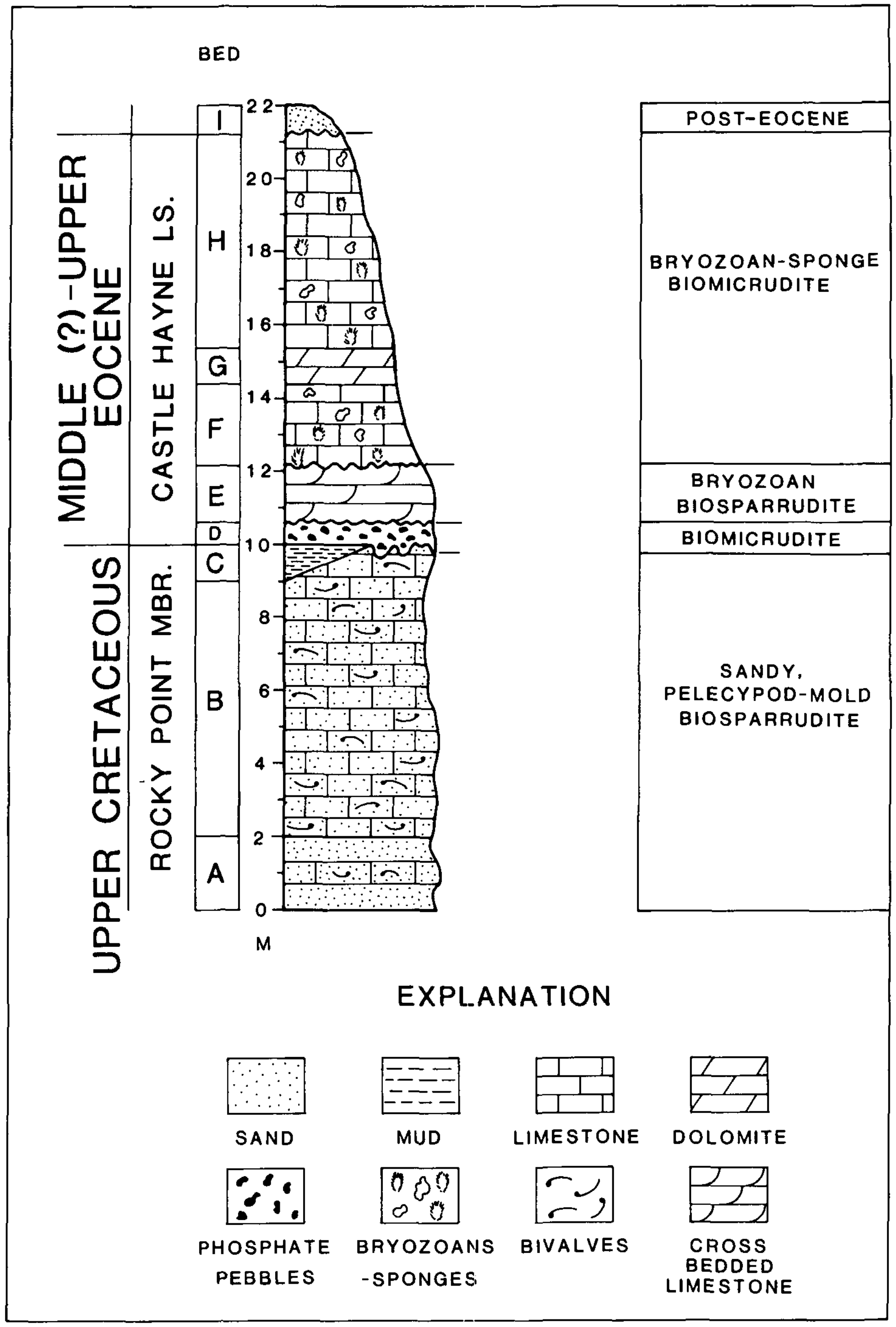

Figure 2. Columnar section of the lectostratotype of the Castle Hayne Limestone. Sample dated in this study was collected from the lower part of the bryozoan-sponge biomicrudite. Bed D is the New Hanover Member.

separates the bryzoan biosparrudite lithofacies from the overlying bryozoan-sponge biomicrudite lithofacies. The glauconite sample that was used for radiometric dating in this study was collected from a 25-cm-thick glauconite-rich zone immediately below the dolomitized zone in the bryzoan-sponge biomicrudite facies (Fig. 2).

PALEONTOLOGIC ANALYSES AND RESULTS

The fauna of the Castle Hayne Limestone was considered equivalent to Jacksonian Stage (late Eocene) faunas of the Gulf Coast until the publication of Cooke and MacNeil's (1952) revision of South Carolina

Tertiary stratigraphy. In that paper, Cooke and MacNeil concluded that the lower part of the Castle Hayne Limestone (the basal phosphate pebble biomicrudite and the overlying biosparrudite facies) in the type area was equivalent to the Santee Limestone of South Carolina and the middle Claibornian Stage (middle Eocene) of the Gulf Coast. The upper part of the formation (the bryozoan-sponge biomicrudite) was correlated with newly discovered strata overlying the Santee Limestone in South Carolina. Fossils from these beds were correlated with the fauna of the Gosport Sand that is considered uppermost Claibornian in Alabama. Cooke and MacNeil (1952) cited the following fossils in the Castle Hayne as indicative of Claibornian age: late Claibornian: *Crassatella alta;* middle Claibornian: *Eurhodia raveneli* (= *E. rugosa*)*, Hemipatagus subrostratus,* and *Ostrea sellaeformis.*

Species previously considered as Jacksonian indicators were discounted because they were thought to have been misidentified, or were found only at localities far removed from the type area of the Castle Hayne Limestone, or were known to occur as well in Gulf Coast Claibornian units.

LeGrand and Brown (1955) recognized both Claibornian and Jacksonian foraminiferal and ostracod assemblages from presumed Castle Hayne Limestone localities between the Cape Fear and Neuse Rivers. The single Claibornian fauna listed is from the vicinity of Fort Barnwell, Craven County. Microfaunal assemblages described from localities in the type area were considered of Jacksonian age. LeGrand and Brown concluded that the Castle Hayne Limestone was a time-transgressive unit in which deposition began in Claibornian time and lasted through Jacksonian time. Brown (1958), on the basis of ostracod assemblages from wells in the North Carolina Coastal Plain, recognized Claibornian and questionable Jacksonian strata in presumed subsurface equivalents of the Castle Hayne Limestone. In the southeastern counties of North Carolina, in the vicinity of the type area, only Jacksonian(?) strata were encountered. In the central counties, between the New and Neuse Rivers and in the region where the New Bern Formation of Baum and others (1978) overlies the Castle Hayne Limestone, both Jacksonian(?) and Claibornian microfossil assemblages were recognized. To the northeast, only Claibornian strata were encountered.

Brown and others (1972), again primarily on the basis of ostracod zonation, but also utilizing foraminiferal evidence, did not recognize any unit of Jacksonian age in the subsurface in North Carolina. All subsurface sediments associated with the Castle Hayne Limestone or the overlying New Bern Formation were considered Claibornian equivalents. These subsurface data were not related to previously described outcrops of the Castle Hayne Limestone, nor were previous determinations of subsurface Jacksonian microfossil assemblages (for example, Brown, 1958; Copeland, 1964) discussed.

Baum and others (1978) and Zullo and Baum (1979) also considered that most of the Castle Hayne Limestone was Claibornian but suggested that the uppermost unit, the bryozoan-sponge biomicrudite, might extend into the Jacksonian Stage. The overlying New Bern Formation was considered Jacksonian. Ward and others (1978) regarded the Castle Hayne Limestone and the overlying New Bern Formation as Claibornian equivalents. They cited the presence of *Cubitostrea sellaeformis* in the basal phosphate pebble biomicrudite (their New Hanover Member), of *Crassatella alta, Pecten clarkeanus,* and *P. membranosus* in the overlying biosparrudite and biomicrudite lithofacies (their Comfort Member), and of *Crassatella alta, Macrocallista neusensis* (Harris), and *Bathytormus protextus* (Conrad) in the New Bern Formation as evidence of Claibornian age.

Cheetham (1961) argued for a Jacksonian age for the Castle Hayne fauna. From a biostratigraphic analysis of 155 cheilostome bryozoan species described by Canu and Bassler (1920) from the type area of the Castle Hayne Limestone, Cheetham concluded that a late Jacksonian age was indicated. He also suggested that such previously determined Claibornian indicators, such as *Crassatella alta* and *Cubitostrea sellaeformis* were misidentified, as these identifications were based on molds, casts, or juvenile forms. Zullo (1979), in an analysis of the barnacle fauna from the bryozoan biomicrudite facies, concluded that the majority of species, including *Arcoscalpellum jacksonense, Euscalpellum* n. sp., and *Solidobalanus* n. sp. A, were indicative of Jacksonian age. The remaining species were undiagnostic. Studies on calcareous nannofossils from the bryozoan-sponge biomicrudite unit of the lectostratotype by Turco and others (1979) and by Worsley and Turco (1979) indicated that this unit is assignable to zones NP-19 and NP-20, or Jacksonian. Worsley and Turco also noted the presence of zone NP-18 nannofossils from an isolated outcrop near Newton Grove, Sampson County; the NP-18 zone is considered basal Jacksonian (Bybell, 1975).

As noted by both Cheetham (1961) and Brown (1963), and as evidenced by the paleontological discussion, the relative age of the Castle Hayne Limestone is as much disputed now as it has always been. The lack of conformity of opinion is a result of a complex of factors. The Castle Hayne fauna is highly endemic, although it has been suggestd that some so-called endemics may be conspecific with Gulf Coast species (for example, Ward and others, 1978). The value of some species that do appear to afford an opportunity for interregional correlation is lessened because of doubts concerning their identification and stratigraphic range both in the Atlantic and Gulf Coastal Plains, and because of the lack of updated systematic treatments of the genera or species groups to which they are assigned. Another major factor contributing to the dispute is the overwhelming tendency to include the Santee Limestone (in the broadest sense) of South Carolina in any discussion of the age of the Castle Hayne Limestone.

Although depositional environments represented by Paleogene sediments in South Carolina are similar to those in North Carolina, it is not correct to presume that similar sediment types in the two regions are contemporaneous. It has long been recognized that Cretaceous and Tertiary deposition in the Carolinas has been influenced by episodic movement along the Cape Fear fault (for example, Stephenson, 1912; Richards, 1950; Baum and others, 1978). More recently, it has been demonstrated that additional structural elements ("Santee fault," Neuse fault, Graingers wrench zone, Carolina fault) have affected Cretaceous and Cenozoic intrabasinal sedimentation in the Carolinas (Brown and others, 1972; Baum and others, 1978; Harris and others, 1979; Zullo and Harris, 1979). The net result of these discoveries is to emphasize the fact that the stratigraphic column cannot be interpreted merely in terms of eustatic transgressive-regressive cycles on a passive foreland. Rather, it is clear that the effects of eustatic sea-level change were specifically modified by tectonism.

Lithologic similarities between the Castle Hayne and Santee Limestones reflect regional paleogeography. The absence of clastics and the prevalence of calcareous bank deposits suggest a broad, low-lying foreland over which the sea transgressed rapidly, and an adjacent hinterland of low relief whose sluggish streams transported little sediment to the sea. Individual depositional environments within the Santee Limestone reflect the syndepositional-tectonic history within and about the Santee depositional basin; those of the Castle Hayne Limestone reflect the history of its basin. Thus, the initiation of deposition of these formations are, more likely, the products of intrabasinal environmental conditions and are not indicators of contemporeneity. The time-transgressive nature of Santee-Castle Hayne biofacies was alluded to by Cooke and MacNeil (1952, p. 24):

> It is not surprising that the faunas of the Santee, Castle Hayne, and Ocala limestones are somewhat similar, for these three formations represent similar facies. The Santee and Castle Hayne faunas were not recognized as of Claiborne age because no similar bryozoan-bearing limestone facies occurs in the Claiborne west of the Carolinas.

We may not agree with their age assessments, but we agree fully with their philosophical approach (Fig. 3).

ANALYTICAL PROCEDURES AND RADIOMETRIC RESULTS

A composite sample of the glauconitic zone was collected from the lectostratotype of the Castle Hayne Limestone, New Hanover County, North Carolina. Five glauconite concentrates were separated on the basis of grain size and external morphology into samples designated: MM1-100HT; MM1-100HM; MM1-100HF; MM1-70HF; and MM1-70HT. The samples were further prepared for analysis according to the procedure described by Harris and Bottino (1974). The concentrated samples contained less than 1% impurities of pyrite and dolomite. X-ray diffraction analysis of the glauconite samples confirmed that the samples consisted of the well-ordered to disordered glauconite defined by Bentor and Kastner (1965).

The five glauconite samples were analyzed for Rb, Sr, and Sr-isotopic composition using standard chemical and isotopic dilution procedures. A technique using concentrated acids and small ion-exchange columns also was employed for separation of Rb and Sr (Russell, 1978). In addition, Fe was separated from all Sr samples using these small columns. The results are shown in Table 1. Rb and Sr blanks were collected in order to monitor contamination encountered in handling and preparing the samples for analysis. Analysis of the blanks has shown that procedural contamination for the Rb and Sr was negligible. Therefore, no correction for the blanks has been made on the values given in Table 1. On the basis of analyses of the National Bureau of Standards Standard Sam-

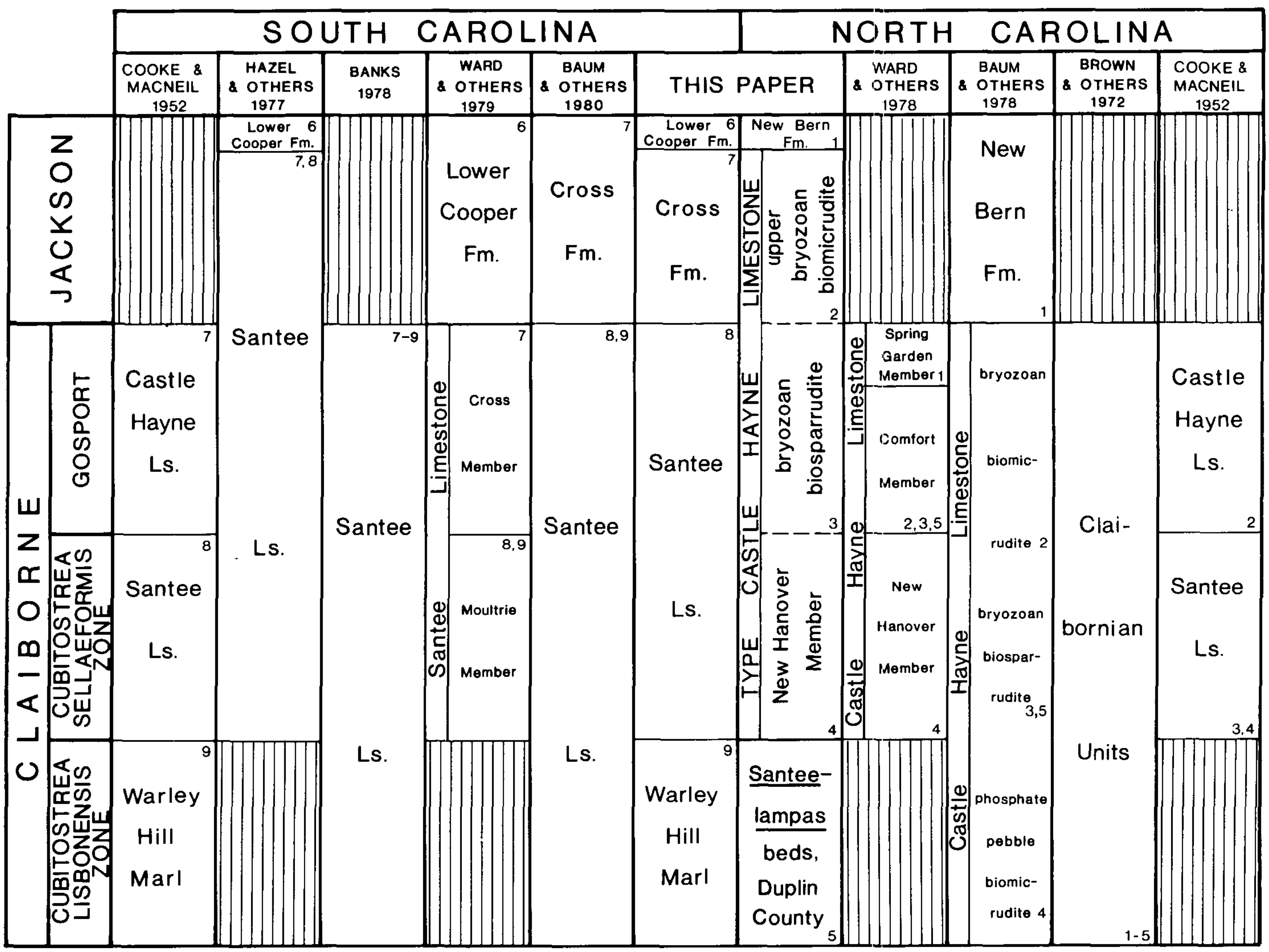

Figure 3. Suggestion correlation of Eocene strata of North and South Carolina. Numbers indicate equivalent rock units.

TABLE 1. Rb-Sr ANALYTICAL DATA FOR THE EOCENE CASTLE HAYNE LIMESTONE, LECTOSTRATOTYPE, NEW HANOVER COUNTY, NORTH CAROLINA

Sample	Rb (ppm)	Sr (ppm)	Rb^{87}/Sr^{86}	$(Sr^{87}/Sr^{86})_N$
MM1-100HT	202.08	13.39	43.77	0.7301
MM1-100HM	195.91	26.85	21.14	0.7182
MM1-100HF	199.80	29.66	19.52	0.7188
MM1-70HT	189.78	50.25	10.94	0.7135
MM1-70HF	196.96	19.48	29.31	0.7223

ple 70a, K-feldspar, the one-standard-deviation experimental errors are ± 0.0005 for the Sr^{87}/Sr^{86} and 1.0% for the Rb^{87}/Sr^{86} ratios.

The Sr^{87}/Sr^{86} values in Table 1 have been normalized to Sr^{86}/Sr^{88} = 0.1194. The value obtained from the Massachusetts Institute of Technology standard Eimer and Amend carbonate sample during the period of analyses was $(Sr^{87}/Sr^{86})_N$ = 0.7090. The isochron age was calculated using the recently proposed decay constant of $\lambda Rb^{87} = 1.42 \times 10^{-11} yr^{-1}$ (Steiger and Jager, 1978).

The Rb-Sr mass spectrometry was performed with a single-focusing, 12-in., triple-filament mass spectrometer. Data were collected and analyzed with a Nuclide DA/CS-III automation and data-reduction computer system.

The results on the five glauconite samples have been calculated as an isochron age using the least-squares regression method of York (1966). The isochron plot for the five glauconite samples indicates an age of 34.8 ± 1 m.y. for the Eocene Castle Hayne Limestone with an initial $(Sr^{87}/Sr^{86})_0$ = 0.7083 ± 0.0004 (Fig. 4).

DISCUSSION AND CONCLUSIONS

Funnell (1964), Berggren (1972), and Hardenbol and Berggren (1978) placed the Eocene-Oligocene boundary between 37.5 and 37 m.y. on the basis of a compilation of various age types. However, the volcanic ages of Evernden and others (1964), the glauconite ages of Ghosh (1972) and of Odin and others (1978), and the microtektite ages of Glass and others (1973) and Glass and Zwart (1977) indicate a much younger age for the boundary, between 33 and 35 m.y. Odin and others (1978) determined glauconite ages of marine sequences in England (type Barton beds) and in Germany and suggested that the age of the Eocene-Oligocene boundary was about 33 m.y. In marine sequences in North America, Glass and others (1973) and Glass and Zwart (1977) considered the Eocene-Oligocene boundary less than 34.2 to 34.6 m.y. on the basis of microtektite ages; this conclusion is supported by the glauconite and bentonite ages of Ghosh (1972) from marine exposures in Mississippi and Alabama. Data from nonmarine sediments in North America and East Africa place the Eocene-Oligocene boundary between 33.9 and 37.5 m.y. (Evernden and others, 1964). In addition, Tarling and Mitchell (1976) used isotopic age determinations of sediments overlying oceanic magnetic anomalies to suggest that the "probable stratigraphic age . . ." for the Eocene-Oligocene boundary is close to 35 m.y.

Several conclusions may be drawn from this study. An abundance of published radiometric ages of glauconite, tektites and microtektites, and volcanics indicates that the Eocene-Oligocene boundary is closer to 33 than to 37 m.y.; this age is supported by the 34.8 m.y. isochron age of the Castle Hayne Limestone. Secondly, the glauconite isochron method can provide accurate ages for conversion of the standard geologic column to a radiometric column. Although many Rb-Sr glauconite ages may be young because of the preferential loss of radiogenic Sr relative to Rb^{87} (Thompson and Hower, 1973), the agreement of the Rb-Sr isochron age of the Castle Hayne Limestone with published ages from Europe, Africa, and North America indicates that this is not a problem in this study.

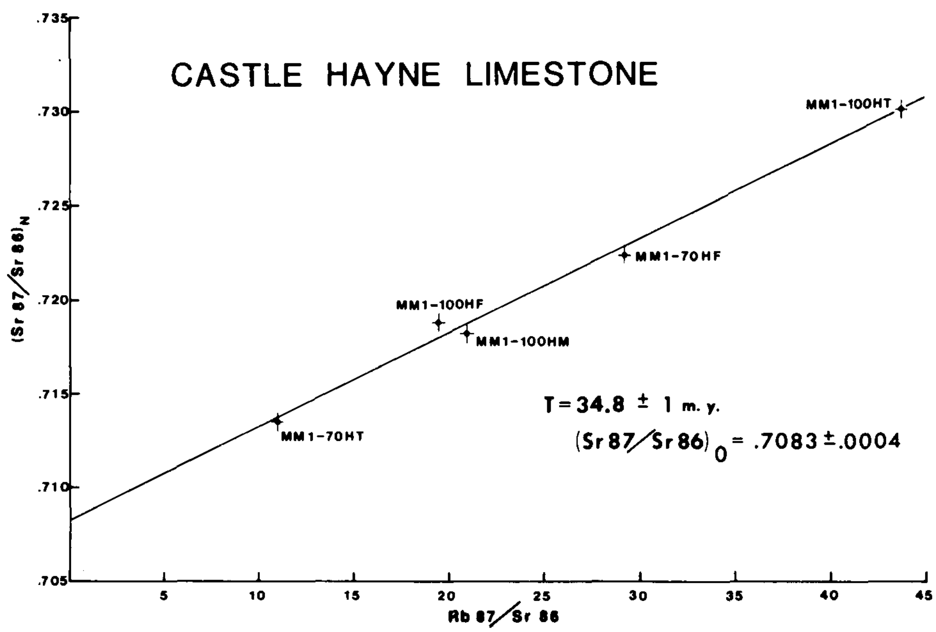

Figure 4. Plot of $(Sr^{87}/Sr^{86})_N$ versus Rb^{87}/Sr^{86} for glauconites from the Castle Hayne Limestone, New Hanover County, North Carolina.

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