CORRELATION OF THE UPPER CRETACEOUS OR GULF SERIES OF THE GULF COASTAL PLAIN.*

LLOYD W. STEPHENSON.

GENERAL CHARACTER AND DISTRIBUTION.

The Upper Cretaceous or Gulf series consists chiefly of sand, clay, marl, chalk, limestone, and subordinately of gravel, and outcrops in a belt which, with certain interruptions due to the overlap of younger formations, extends approximately parallel to the inner edge of the Atlantic and Gulf Coastal Plain from Mexico to Marthas Vineyard, Mass. The belt attains its greatest width of over 100 miles in the region of Cape Fear River valley in North Carolina, and, information received since the accompanying correlation chart (Fig. 1) was drawn, indicates that the series reaches a maximum thickness of 3,500 feet or more in the Rio Grande valley in Texas.

The series is predominantly composed of marine sediments which were deposited in the ocean at depths ranging from a few feet in the shallow near-shore waters to probably not more than 600 feet (100 fathoms) in the off-shore waters. Some of the sediments were, however, laid down in coastal lagoons and estuaries, and some on the alluvial flood plains of streams. The beds composing the middle and upper parts of the series are in general finer and more uniformly of the deeper water type than those composing the lower part, which are coarser and more irregularly bedded. Sediments of shallow water origin are, however, not wanting in the middle and upper parts of the series, as in places in Georgia and Alabama. The fact that the deposition of many of the formations of the Gulf series began after periods of erosion without the introduction of conspicuous amounts of coarse materials into the sea to form basal conglomerates, indicates that low-lying lands were the source of the sediments.

The succession of formations which make up the series differs markedly from place to place along the linear extent of the Coastal Plain, so that many columnar sections are required

* This paper was presented as part of a symposium on the Mesozoic and Cenozoic stratigraphy of the Gulf States, at the Nashville meeting of Section E of the American Association for the Advancement of Science, December, 1927. Published by permission of the Director of the U. S. Geological Survey.

AM. JOUR. SCI.—FIFTH SERIES, VOL. XVI, No. 96—DECEMBER, 1928.

to completely represent the sequence of formations, and the age relations of the formations to each other.

The major divisions of the standard geological column of the Upper Cretaceous of Europe, with one exception, are represented in the Gulf series of the Atlantic and Gulf Coastal Plain. These are, in ascending order, Cenomanian, Turonian, and Senonian. If the Danian, which in Denmark overlies the Senonian, is represented in the Coastal Plain, it must be in the basal beds of the Eocene and not in the Cretaceous. In this connection it may be stated that the Cretaceous age of the Danian has not been established to the satisfaction of all even of the European stratigraphers. Although there are obviously certain close relationships between the fossil organisms of beds of corresponding age on opposite sides of the Atlantic, few species, especially among the molluscan invertebrates, are identical, and the correlations indicated on following pages should be regarded as tentative and subject to revision as new evidence is obtained.

Even in the Coastal Plain itself the age relations of the formations in the different parts of the area are not all established with finality and it is unwise to state with dogmatic assurance the age equivalence of beds more or less distant from each other, unless the evidence is very strong. Hasty conclusions based on insufficient evidence may introduce errors that will be quoted and requoted for years before they are corrected. The correlations of the lower formations of the series are based in part on fossil plants and in part on marine invertebrates; fossil plants, studied chiefly by Prof. E. W. Berry, have been the basis for the age determination of the Tuscaloosa formation of the eastern Gulf region, the Middendorf formation of South Carolina, and the Raritan formation of Maryland, Delaware, and New Jersey. The correlations in the middle and upper parts of the series are made chiefly on the evidence of marine invertebrates.

The part of the series corresponding in age to the Senonian includes two major fossil zones which have been differentiated practically throughout the length of the Atlantic and Gulf Coastal Plain. These are the *Exogyra ponderosa* zone, which probably roughly corresponds to the Santonian and Campanian subdivisions of the Senonian, and the *Exogyra costata* zone, which is referred to the Maestrichtian or upper Senonian. A more restricted zone, the *Exogyra cancellata* zone, in the lower part of the *E. costata* zone, is traceable from New Jersey to central Texas.

The standard Upper Cretaceous (Gulf) section of central Texas, as established by the pioneer geologists of the region, includes from the base upward, the Woodbine sand, the Eagle Ford clay, the Austin chalk, the Taylor marl, and the Navarro formation. These divisions are still the recognized formation units of central Texas, but both toward the southwest and the northeast they pass more or less completely into contemporaneous sediments of such different character as to necessitate their subdivision into different sets of formations.

The relative thinness of the Gulf series in central Texas, as compared with its much greater thickness in both the East Texas embayment and the Rio Grande embayment (see Fig. 1), clearly records the effect of the Llano uplift, where repeated oscillations caused emergence and erosion from time to time during the upbuilding of the series.

In the western Gulf region the Upper Cretaceous (Gulf) series rests with a marked unconformity upon the Lower Cretaceous (Comanche) series. In the north Atlantic the Upper Cretaceous rests unconformably upon the Potomac group of the Lower Cretaceous series, a group which is of nonmarine origin and whose correlation is based upon fossil plant and vertebrate remains. In the Mississippi Embayment, the eastern Gulf region, and the south and middle Atlantic region, where the Lower Cretaceous is wanting, a great hiatus separates the Upper Cretaceous from underlying rocks of pre-Paleozoic and Paleozoic age, and to a very limited extent of Triassic age. Throughout the Coastal Plain the Upper Cretaceous series is unconformably overlain by strata of Eocene or later age.

The Woodbine Sand.

The Woodbine sand consists of a maximum of 500 feet or more of irregularly-bedded sand, clay, and some lignite, of shallow marine, brackish water, and subordinately of nonmarine origin. The formation rests unconformably on the Comanche series and is probably unconformably overlain by the Eagle Ford clay. The formation is in part fossiliferous, especially in the higher layers.

The Woodbine formation thins toward the south and pinches out in central Texas along the eastern side of the Llano uplift. Toward the north and northeast the formation has been traced through northeastern Texas and southeastern

Oklahoma into southwestern Arkansas. It has not been recognized east of Mississippi River, but it may be represented in the Tuscaloosa formation of Alabama. However, Prof. E. W. Berry, who has studied the fossil plants from the Tuscaloosa, has not recognized the Cenomanian age of any part of that formation, the correlation of which must depend chiefly on fossil plants.

The superposition of the Woodbine formation on the Comanche series, whose uppermost part is of either upper Albian or lower Cenomanian age, and the occurrence of several species of ammonites related to *Acanthoceras rotomagense* (Defrance), in the base of the overlying Eagle Ford formation, determines the Cenomanian age of the Woodbine. This correlation has been published by Dr. Gayle Scott and confirmed by Drs. T. W. Stanton and J. B. Reeside. The Woodbine formation is younger than any part of the Comanche series and is separated from that series by a pronounced unconformity.

Eagle Ford Clay and Equivalent Beds.

The Eagle Ford clay consists of 30 to 500 feet of dark more or less bituminous shaly clay with interbedded flaggy limestone, of marine origin. The formation is believed to rest with unconformable relations upon the Woodbine sand. In central and northeastern Texas it is separated from the overlying Austin chalk by an unconformity, but the continuation of this unconformity westward to the Rio Grande has not yet been demonstrated.

The formation is 500 feet thick in the east Texas embayment, thins to a minimum of 30 feet where it flanks the south side of the Llano uplift, and thickens again to at least 250 feet in the Rio Grande embayment.[1] Eastward in northeastern Texas where the Upper Cretaceous beds are partly concealed by alluvium of Red River, of Pleistocene age, the Eagle Ford seems to disappear as such, but paleontologic evidence indicates that it may be represented there in Woodbine-like sediments. The formation appears to be wanting in Arkansas. It may be represented in the shallow-water Tuscaloosa formation of Alabama, which is barren of marine invertebrate fossils; it may also be represented in the Middendorf

[1] Reports of thicknesses as great as 500 and 600 feet in wells in the Rio Grande valley have been received.

formation of South Carolina and in the "Cape Fear" formation of North Carolina.

As previously stated, the base of the typical Eagle Ford clay yields a fauna, characterized by several species of ammonites related to *Acanthoceras rotomagense,* which indicate its Cenomanian age. The Turonian age of the remainder of the formation above this basal zone is indicated by the ammonite genera, *Metoicoceras* (several species) in the lower part of the formation above the *Acanthoceras* zone, *Prionotropis* in the middle, and *Prionocyclus* in the upper part of the formation. *Prionocyclus* has not been found in the outcropping beds but has been identified in a stratum of upper Eagle Ford age in a deep well in DeSoto Parish, Louisiana. This correlation of the Eagle Ford clay is in harmony with the conclusions of several paleontologists who have critically studied the ammonites, including Doctors Stanton, Reeside, Scott, and others. The Turonian age of the Eagle Ford is also indicated by the bivalve species, *Inoceramus labiatus* Schlotheim, a world-wide Turonian index fossil, whose range in Texas appears to be through the zones of *Metoicoceras* and *Prionotropis.*

Austin Chalk and Equivalent Beds.

The Austin chalk typically consists of 400 feet or more of thick to massive-bedded chalk and subordinate interbedded chalky marl, of marine origin. The formation is well developed from the Rio Grande, northeastward through Texas nearly to the valley of Red River in Grayson County. In central and northeastern Texas the chalk and its equivalents are separated from the underlying Eagle Ford clay by an unconformity. In central Texas as far north as the northern part of Ellis County the Austin and Taylor appear to be unconformable, but from Dallas County northward the upper part of the chalk seems to transgress upward in the geologic column so that in Collin and Grayson counties the upper part of the chalk is probably of the age of the lower part of the typical Taylor marl farther south. From Grayson County eastward part of the Austin chalk merges into nonchalky equivalents, so that in Lamar County the section corresponding to the expanded part of the chalk farther west would include in ascending order the Bonham clay, the Blossom sand, the Brownstown marl, and the Gober tongue of the Austin chalk, all of which are typical marine sediments. Of these the Bonham and Blossom corre-

spond in age to the typical Austin chalk of central Texas, and the Brownstown and Gober correspond to the basal part of the typical Taylor.

The Eagle Ford clay appears to have no representative in Arkansas, and the Tokio formation, composed of sand, clay and gravel immediately overlying the Woodbine, appears to be the shallow marine representative of the Bonham clay and Blossom sand, and therefore of the typical Austin chalk.

In the eastern Gulf region the Austin is probably represented in part at least by the marine shallow-water sands and clays composing the part of the Eutaw formation below the Tombigbee sand member, although there is no direct invertebrate fossil evidence for this correlation. There is paleontologic evidence, however, that the upper part of the Eutaw, the deeper-water Tombigbee sand member, is a little younger than the upper part of the typical Austin. The Austin may be represented in the lower part of Black Creek formation of the Carolinas and in the Magothy formation of Maryland, Delaware, and New Jersey.

The typical Austin chalk is considered to be the American representative of the lower part of the Senonian of Europe including the Coniacian and the lower part of the Santonian subdivisions. The direct paleontologic evidence consists of the common occurrence of *Inoceramus undulato-plicatus* Roemer in the Coniacian and in the middle and upper parts of the Austin, and of *Mortoniceras texanum* Roemer in the lower part of the Santonian and in the upper part of the Austin. The Austin also contains species of *Inoceramus* having the shell elongated parallel to the hinge line, unlike any of the species of that genus in the Turonian and older beds.

Taylor Marl and Equivalent Beds.

The Taylor marl of central Texas is typically composed of 500 feet or more of calcareous clay and marl of marine origin, with sandy and chalky facies, the more conspicuous of which, as determined by C. H. Dane and me,[1] have been named Durango sand member, Lott chalk member, and Marlin chalk member. The formation in central Texas rests unconformably upon the Austin chalk and is overlain probably uncon-

[1] Dane, C. H., and Stephenson, L. W., Notes on the Taylor and Navarro formations in east-central Texas: Bull. Am. Assoc. Petr. Geologists, 12, No. 1, 41-58, 1928.

formably by the Navarro formation. Westward in Texas the Taylor marl is replaced by the Anacacho limestone, a formation composed of impure shallow marine limestone and interbedded marl, and still farther west in the Rio Grande Valley the Anacacho is represented by the Upson clay and the overlying San Miguel formation. Toward the north in central Texas the unconformity which separates the Taylor from the underlying Austin chalk appears to die out and the chalk expands in such a manner that its upper part is equivalent in age to the lower part of the Taylor marl farther south. Farther toward the northeast the typical Taylor is represented by the Brownstown marl, the Gober tongue of the Austin chalk, and typical marl in which are interbedded the Wolfe City sand member and the westward-extending Pecan Gap tongue of the Annona chalk. Still farther toward the east the Taylor is represented by the Brownstown marl and the Annona chalk.

The equivalents of the typical Taylor in Arkansas are in ascending order the Brownstown marl, the Ozan formation, the Annona chalk, and the Marlbrook marl; these are all of marine origin.

East of Mississippi River in Tennessee and northern Mississippi the typical Taylor is represented by the shallow-water marine Coffee sand member of the Eutaw formation and the lower part of the deeper marine Selma chalk of that area. In east-central Mississippi and in west-central Alabama the section of Taylor age includes probably the Tombigbee sand member of the Eutaw formation and approximately the lower two-thirds of the overlying Selma chalk. Farther east in the Chattahoochee region (Alabama-Georgia) the corresponding section includes the Tombigbee sand and the lower part of the Ripley formation of that area. The Taylor is represented at least in part by the upper part of the Black Creek formation of the Carolinas, and by the Matawan formation of Maryland, Delaware, and New Jersey.

Probably the most outstanding fossil which ties the formations of Taylor age together throughout the Atlantic and Gulf Coastal Plain is *Exogyra ponderosa* Roemer. Although in Texas this species ranges downward into the upper part of the underlying Austin chalk, it does not range upward into the overlying Navarro formation. The Taylor and its equivalents therefore constitute the major part of the zone of *Exogyra ponderosa*. Numerous other fossil forms, some of

which have been found for only limited distances along the trend of the major zone, afford confirmatory evidence of the correctness of the correlation, but the details of this evidence can not be stated within the scope of this paper.

As nearly as can be determined with the present available evidence (the Taylor marl finds its European equivalent in the middle part of the Senonian, including the upper part of the Santonian and probably all of the Campanian sub-divisions. The evidence is somewhat indirect so far as the typical Taylor is concerned. *Scaphites hippocrepis* Morton, for example, as identified by Dr. J. B. Reeside, is common to the lower part of the Anacacho limestone of Texas, the lower part of the Brownstown marl of Arkansas, and the Merchantville clay of New Jersey, all of lower Taylor age, and to the Santonian of Europe. Especially significant is the occurrence in the Tombigbee sand of Mississippi, which is probably of lower Taylor age, of the stemless free-floating crinoid, *Marsupites americanus* Springer, which, according to Springer, is very closely, perhaps specifically, related to *Marsupites testudinarius* Schlotheim of the Santonian of Europe. Additional evidence of the approximate correctness of this trans-Atlantic correlation is afforded by the common occurrence of ammonites related to *Mortoniceras delawarense* (Morton) and of species of the bivalve *Inoceramus* of the *I. baribini* Morton type.

The Navarro Formation and Equivalent Beds.

The Navarro formation of central Texas is composed of 400 to 600 feet of marine clay, marl, and sand more or less glauconitic, and the formation is believed to rest unconformably upon the Taylor marl throughout most of its extent. In the Rio Grande region the lower part of the Navarro is represented only by the sediments of the nonmarine Olmos formation, or "coal series," and the middle and upper parts are represented by the Escondido formation, the uppermost beds of which may be somewhat younger than the youngest beds of the Navarro. In Arkansas the Navarro equivalents include the Saratoga chalk, the Nacatoch sand, and the Arkadelphia marl. In northern Mississippi the upper part of the Selma chalk and the Ripley formation are the approximate equivalents of the Navarro formation, but farther north these deposits are largely represented by the shallow water McNairy sand member of the Ripley, which extends through Tennessee

and Kentucky to the head of the Mississippi embayment; strictly marine deposits of lower Navarro age at the head of the embayment are indicated by the finding of *Exogyra cancellata* Stephenson in an excavation for a bridge pier near Cairo, Illinois. In east-central Mississippi and west-central Alabama the Navarro equivalent is found in the upper part of the Selma chalk and in the Chattahoochee region (Georgia-Alabama) in the upper part of the Ripley formation of that area.

Exogyra costata Say is a widespread and useful index fossil in the Navarro formation and its equivalents in the Coastal Plain, and for this reason the name *Exogyra costata* zone has been applied to the deposits. Non-typical specimens of the species are, however, occasionally found below the zone proper. Another species of the same genus, *Exogyra cancellata,* forms a more restricted zone in the lower part of the *Exogyra costata* zone. The *E. cancellata* zone is traceable in the Atlantic and Gulf Coastal Plain with certain interruptions from New Jersey to Milam County, Texas, a distance of fully 2,000 miles, beyond which toward the Rio Grande the *cancellata* zone appears to be wanting and is represented by the unconformity between the Taylor and Navarro formations and their equivalents. The range of *Exogyra cancellata* is also not closely restricted to the zone to which the name has been applied, for in Arkansas fairly typical specimens of the species occur in the uppermost part of the underlying *Exogyra ponderosa* zone, and in Tennessee the occurrence of the species in the Coon Creek fauna of the lower Ripley indicates a somewhat higher range than it is known to have elsewhere in the Coastal Plain.

The upper part of the Navarro formation and its age equivalents from central Texas in the western Gulf region to Georgia in the eastern Gulf region carries a large number of identical and closely related species of mollusks which are absent or rare in the underlying zone of *Exogyra cancellata.* Some of the more conspicuous and useful of these are:

Trigonia eufaulensis Gabb
Pulvinites argentea Conrad
Crenella serica Conrad
Pholadomya littlei Gabb
Dreissensia tippana Conrad
Liopistha protexta Conrad
Crassatellites subplana (Conrad)
Cardium stantoni Wade
" tippanum Conrad
" dumosum Conrad
" kummeli Weller
Aphrodina tippana Conrad
Turritella vertebroides Morton
Sargana stantoni (Weller)
Morea cancellaria Conrad
Liopeplum liodermum (Conrad)
Ringicula pulchella Shumard
Scaphites conradi Morton (including several varieties)
Sphenodiscus (several species)
Belemnitella americana (Morton)

In the Carolinas the Peedee formation is clearly the equivalent of the Navarro, and in the north Atlantic region the Navarro is represented by the Monmouth group. These correlations are confirmed by the common occurrence of numerous fossils of restricted range.

The upper third or so of the *Exogyra costata* zone is characterized by a varietal form of *Exogyra costata* with narrower and weaker costae than those of the more typical shells in the middle and lower parts of the zone. This variety occurs in the uppermost part of the Navarro formation in Texas, in the Arkadelphia clay of Arkansas, in the upper parts of the Ripley and Selma formations in the eastern Gulf region, and in the upper part of the Peedee formation of the Carolinas.

The Escondido formation, which has its fullest development from Medina County, Texas, to the Rio Grande, is the time equivalent of the middle and upper parts of the typical Navarro formation, and carries a molluscan fauna which differs in many important respects from that of the Navarro. This is due in part at least to the different environmental conditions which existed in the Escondido sea, for the formation was laid down in shallower marine waters of the Rio Grande embayment which were receiving a greater bulk of sediments than was the Navarro sea. However, the lower part of the Escondido is tied to the middle part of the Navarro and equivalent beds by *Exogyra costata, Pecten venustus* Morton, and a few other forms. Closely related species of the genus *Sphenodiscus* are common to the two formations, and this genus ranges to the top of the Escondido.

The Navarro formation and its equivalents are believed to be approximately of the age of the Maestrichtian, the uppermost division of the Senonian of Europe. The most direct evidence of the correctness of this correlation is afforded by the ammonite genus *Sphenodiscus* which is common to the upper part of the Navarro and to the Maestrichtian, and by a species of the ammonite genus *Pachydiscus*, related to *P. gollvillensis* D'Orbigny (identified by J. B. Reeside), found in the lower part of the Escondido formation; the latter species occurs in the Maestrichtian of Europe. The same correlation is suggested by the occurrence in the Maestrichtian of *Belemnitella mucronata* D'Orbigny, an analogue of *B. americana* (Morton). The reference of the lower part of the Navarro, the *Exogyra cancellata* zone, in which *Sphenodiscus* has not been found, to the Maestrichtian, rather than to the upper Campanian, may be open to question, but it is tentatively

regarded as lower Maestrichtian until further evidence is obtained.

The approximate age equivalents in the Western Interior of the standard Upper Cretaceous section of Texas have long been approximately known, but the continued studies of Doctors Stanton and Reeside have resulted in the recognition in the latter province of several restricted fossil zones which correspond quite closely with similar zones in the former province.

The Woodbine sand is correlated with the Dakota sandstone, using that name as applied to the basal sandstones of the Upper Cretaceous below the typical Benton shale. In south-central Colorado a zone of *Acanthoceras* aff. *A. rotomagense* is now recognized in the Graneros shale, a formation of lower Benton age. The same zone is found in a similar position near the base of the Mancos shale in west-central Colorado. It would appear, therefore, that the lower Benton is of Cenomanian age. In the beds of Benton age above the *Acanthoceras* zone have been recognized a *Metoicoceras* zone, followed at a higher level by a *Prionotropis* zone, and at a still higher level by a *Prionocyclus* zone. It would appear therefore that the Benton formation and its equivalent beds in the Western Interior, like the Eagle Ford clay, include a basal zone of Cenomanian age, though they consist chiefly of rocks of Turonian age as has been generally accepted. *Inoceramus labiatus* Schlotheim and *I. fragilis* Hall and Meek are common to the Eagle Ford and to the Benton. In the Eagle Ford *I. fragilis* occurs more abundantly in the *Metoicoceras* zone and *I. labiatus* more abundantly in the *Prionotropis* zone; in the Benton and its equivalents the reverse seems to be true. Probably the two species range through both of these zones. *Ostrea lugubris* Conrad occurs in a zone at the top of the Eagle Ford, and also in a zone of upper Benton age in New Mexico and southern Colorado.

The Austin chalk appears to be approximately contemporaneous with the Niobrara limestone and its equivalents, a correlation heretofore generally accepted, and this age assignment is directly indicated by the presence in the Niobrara of *Inoceramus deformis* Meek and *I. undulato-plicatus* Roemer, and the occurrence of the upper Eagle Ford species *Ostrea lugubris* just below the Niobrara in southern Colorado, and in the bed of upper Benton age in New Mexico to which reference has just been made.

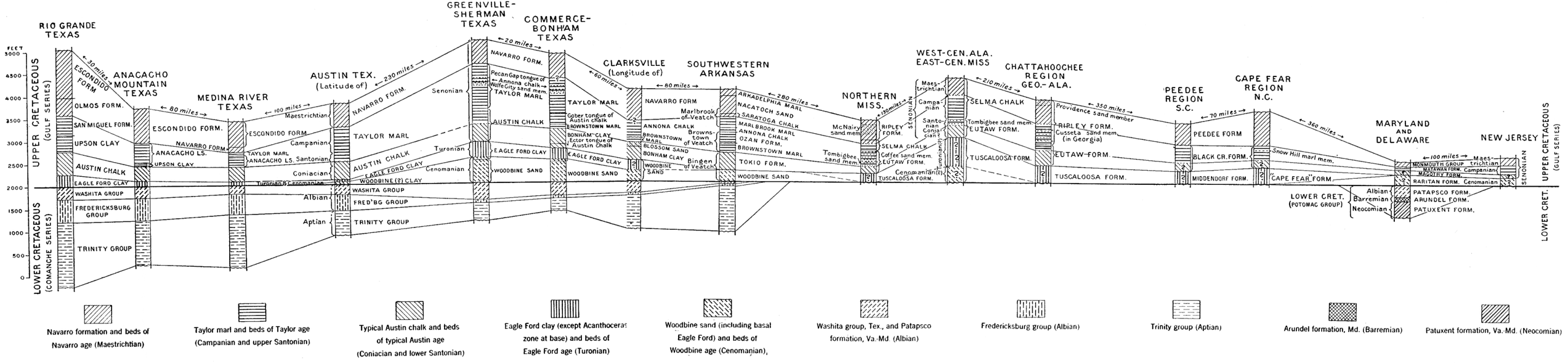

Fig. 1. Tentative correlation chart of the Cretaceos deposits of the Atlantic and Gulf Coastal Plain. The chart emphasizes age relations rather than lithologic units.

The Taylor marl of the Gulf region lies between the Austin chalk below and the Navarro formation above, and the Pierre shale of the Western Interior (Colorado, Wyoming, and adjacent States) lies between the Niobrara below and the Fox Hills sandstone above. The Pierre and Taylor must therefore be of approximately the same age, but the uppermost Pierre may be a little younger than the uppermost Taylor, and therefore of lower Navarro age. Certain faunal elements in the Eagle sandstone (of lower Pierre age) such as *Scaphites hippocrepis* Morton, *Mortoniceras delawarense* (Morton) and *Inoceramus* aff. *I. sagensis* Owen, tend more directly to tie the lower Pierre to beds of lower Taylor age. In the middle Pierre faunas of Utah, Colorado, and southern Wyoming, a considerable number of species closely related to those of upper Taylor age afford another tie.

As nearly as can be determined with the available evidence, the part of the Navarro formation above the *Exogyra cancellata* zone corresponds in age to the Fox Hills sandstone of the Western Interior. This correlation is indicated by the occurrence in the Fox Hills of a group of ammonites of the genus *Scaphites*, which are closely related to *Scaphites conradi* Morton and to one or two of its varieties in the upper Navarro and equivalent beds, and in the common occurrence of the ammonite genus, *Sphenodiscus;* the latter genus did not make its appearance in either the Atlantic and Gulf Coastal Plain, the Western Interior, or Europe, until late in Upper Cretaceous time.

U. S. Geological Survey,
Washington, D. C.