II

INDIVIDUALITY

We have reviewed briefly the manner in which the Texan area became a part of the continent by growth through workings of natural forces of sea and land. These, while operating in somewhat different ways to the north, the west, and the south, builded steadily to the completion and unifying of the whole.

This region, therefore, is, as we have seen, the meeting-place of three distinct provinces of geologic growth; and while there is a general uniformity in the deposits of the eastern and southern portions of the State with the coastal deposits of the other Gulf States, a similar uniformity of those of the northern portion with the great Central Basin region, and of the western portion with those of Mexico, New Mexico, and Arizona, there are also differences which, in their way, are as marked as the resemblances. These individualities are found not only in the character and extent of the deposits themselves, or the entire absence of deposits of certain periods, but also to a somewhat less extent in their present conditions as related to our use of them.

The pre-Cambrian rocks of the Diabolo region include a belt of limestones containing chert, and are more or less metamorphosed, some of them being marbles of pleasing color and texture. From their general character and stratigraphic position we have regarded them as the possible equivalents of the similar group of magnesian limestones in the Llano region called by Comstock the Texan marbles.

These limestones, which, in the Diabolos, seem to have a thickness of 500 feet, underlie a brown sandstone 150 feet in
Individuality

thickness, above which we find red eruptives—porphyry, basalt, and lava—200 feet thick. Pebbles and boulders of the eruptives, brown sandstone, and limestones are found in the basal conglomerate of the Cambrian of this region, showing that these rocks are all pre-Cambrian.

This brown sandstone and the overlying eruptives, therefore, bear a relation to the Cambrian deposits of the Diabolo mountains similar to that the Llanoria quartzite and overlying rhyolite porphyry of the Franklin mountains bear to the Cambrian of that area. There is the difference, however, that at some points in the Diabolos there seem to be evidences of other beds having existed between the eruptives and the conglomerate.

Underlying these limestones there appears in many places a massive body of even-grained red material called by Streeruwitz the Diabolo sandstone. It is also found in similar relation to the Texan marbles west of this locality in the valley between Eagle Flat Mountain and the scarp of the Diabolo mountains to the north, and in various exposures where the Texan marbles are absent, from erosion or non-deposition, the Cambrian, Silurian, or Pennsylvanian rocks are found in contact with it. This material forms the country rock of the Hazel mine, and exposures of it in the hills north of the mine show a thickness of 500 feet, and the base is not visible.

As we have seen, the earliest evidence of the Cambrian sea in Texas is found in the Franklin mountains near El Paso, and its waters did not reach the Llano region until a somewhat later period.

If we compare the early history of the Llano region with that of the Arbuckle and Wichita mountains, which, although some three hundred miles north, are the nearest points outside the State where the earlier formations occur
as surface rocks, we find a close similarity in the initial sediments of the two areas. The basal series of the Llano region, beginning with the Hickory sandstone and followed by greensands, shales, and shaly limestones, finds its duplicate and probable continuation in the Reagan sandstone of the Arbuckles, not only in the character of the materials, but in fossil contents.

The broad extent of the Cambrian sea, which embraced the trans-Pecos, Llano, and Arbuckle regions, is shown by Ulrich, who states: "Very similar, apparently contemporaneous, deposits and faunas are found also in New Mexico, Arizona, and the Bighorn mountains of Wyoming."

The beds of shaly and massive limestone or dolomite with chert of the Llano region which follow this Cambrian sandstone and show continuous sedimentation through the uppermost Cambrian and into the lower Ordovician, are also found in the Arbuckles, overlying the Reagan sandstones as the Arbuckle limestone. Here, however, the maximum thickness of 1000 feet, which the beds attain in the Llano region, is greatly increased, reaching 4000 and even 6000 feet.

At this point deposition in both areas seems to have ceased for a time, and with the emergence of this limestone as a land area the history of the two regions ceases to be the same.

In the Arbuckles, after a brief period of erosion, the land was again submerged, and deposition continued more or less regularly through the Ordovician, Silurian, and Devonian into the Mississippian, and during this time some 3500 feet of sediments were laid down, no representatives of which are now known in the Llano region. Just how far southward the seas in which these materials were deposited in the Arbuckle region may have extended, cannot now be even surmised, but apparently they did not reach the Llano region,
which stood through all these ages as the barrier between these waters and those of the southern ocean. Or if any portion of the overlying rocks of the Arbuckle section was deposited in this area also, they were so completely eroded prior to the deposition of the Bend as to have left no trace of their existence.

With the close of the Mississippian came an elevation of the Arbuckle region, which then became a land area, and it does not appear to have been again entirely submerged at any time. In the early Pennsylvanian sea, which follows and which surrounded but did not cover these areas, we again find similar conditions prevailing in the vicinity of Llano and the Arbuckles and extending eastward into Arkansas.

In these waters were laid down the shales and limestones known as the Bend series in Texas, the Caney shales in Oklahoma, and the Fayetteville beds in Arkansas. Both in Llano and the Arbuckles these beds were laid down as a fringe around the land mass, and the fossils are the same throughout the extent of the beds. This condition was, however, comparatively short-lived, and with the close of deposition of the Caney shales in the north and the Bend in the south another uplift occurred which still further extended the land area and raised the Lampasas geanticlinal, running northeastward from the Llano region toward Red river, with a sea to the westward and land to the east.

In that portion of Texas east of this geanticlinal there has not yet been found the record of any deposits of earlier age than the Cretaceous, and the evidence from wells along the western border of the area proves that the Cretaceous rests upon a somewhat eroded surface of Bend materials.

To the northward in Arkansas, however, deposits were laid down both of earlier and of later age than the Caney-Fayetteville beds, and beds 15,000 to 20,000 feet in thick-
The Geology of Texas

ness are found, the materials of which are thought to have been derived from a land area lying to the south that must have covered a large part of east Texas.

The Coal Measure deposits of central Texas, which accumulated in the sea west of the Lampasas uplift, also argue a land mass in this area persisting, probably, through the Pennsylvanian, but of its character and extent nothing can now be told. While it must have been of considerable size to have supplied the materials which are supposed to have been derived from it, it had, apparently, practically disappeared prior to the incursion of the Cretaceous sea.

Toward the close of the Pennsylvanian the beds of the Coal Measures east of Henrietta were, in some part, added to the land area, causing a shallowing of the sea in the Red river region; and in these waters and on the land thus formed on the east and north there appeared a new and curious vertebrate fauna which marked a distinct advance in the life history of the globe. The earliest evidences we have of these animals are the bones found in the clays, limestones, and sands deposited at this time, which now form the surface materials of Wichita, Archer, Baylor, and adjoining counties, and which we call the Wichita and Clear Fork beds. They were brought into notice first by the studies of Professor Cope, and our knowledge of them has since been greatly enlarged by later extensive collections and study by other paleontologists. So abundant are they, and so well preserved, that the entire skeletons of several varieties of them are now fully known, and we are able to reproduce their forms with accuracy.

They include peculiar and highly characteristic forms of amphibians and some of the earliest known forms of reptilian life.

The study of these remains by the paleontologists has
done much to show "the ways in which the evolution of the reptiles from the amphibians has occurred; to discover archaic forms that, one by one, bridge over the class differences between the amphibians and the reptiles; . . . but we have, nevertheless, not yet found a creature about which there is doubt as to its position" in one or the other of these classes.

In addition to these animals we find, preserved in the clays, the remains of many plants which flourished upon the land surface to the east and north; and these, too, show the decided change which took place immediately following the close of the Coal Measures by the introduction of many new and distinctive forms to take the place of other forms abundant in the preceding period, but which disappeared at or soon after its close.

Furthermore, in some of the limestone layers of these beds in Wichita county we find among marine invertebrate forms, which have persisted from Coal-Measure times into this, certain forms of ammonites which are characteristic of the Permian elsewhere, but which, strange to say, have not yet been discovered further to the south in beds of the same age which are the direct continuation of these. One of these ammonites is one of the few forms found in this region which were also found in the Guadalupean deposits.

This shallowing of the sea in the northern part of our area does not seem to have materially affected the depth of the waters farther south, since, as we trace the individual strata of the clays and sands in that direction, they become more limy, passing at length into limestones and clays. In the southern extension of this sea, as now shown by rock exposures through Shackleford, Callahan, and Coleman counties, the deposits themselves indicate a somewhat deeper sea than that in which the Coal Measures were laid down,
but otherwise very similar conditions of sedimentation; and this is further emphasized by the invertebrate fossils found in them, which indicate that the forms of the Pennsylvanian persisted into these Permian beds (which constitute the Albany phase of the Wichita) without very marked change. So little difference is there between the fossils of this Albany limestone and those of the underlying beds of the Cisco that for a long time many considered it a part of the Coal Measures, and even in their northern extension Dr. White, who first discovered certain characteristic Permian ammonites in the Wichita beds, called attention to the essentially Coal-Measure character of the accompanying fossils. Only a few species were found which mark the advance, probably no more than have arisen during similar intervals between two stages of the underlying Coal Measures.

This condition of only a slight change in the marine invertebrate fauna shows a marked difference from the life development of the land area immediately adjacent to it and of the same identical period, where, as we have seen, we have a well-developed Permian flora and vertebrate fauna; and it shows even greater differences from the marine fossils of the Guadalupe mountains, also of identical age, lying west of it, where open sea conditions at this same time permitted the coming in of an extensive invertebrate fauna of different species and of a decidedly later facies.

The discovery of the Guadalupean fauna was made by Dr. Shumard, over fifty years ago, while making examinations for artesian water in west Texas and New Mexico, under Captain Pope. His collections were made from the south end of the Guadalupe mountains, where the peak of white limestone known as El Capitan lifts its head 8500 feet above sea-level and reaches the greatest elevation known in our Texan area. Later examinations of these mountains
Individuality

and the Delawares, which are their continuation to the south, were made by other geologists, and the Guadalupean fauna has been studied and described by Girty, who states that it has a very individual character among known faunas, though it is probably related to several. After comparison with similar faunas of other regions, he decides that in all of these there is none with which the Guadalupean can really be considered closely allied, the nearest probably being those of the Salt Range and Himalayas in India and of the Fusulina limestone of Palermo in Sicily. He also states that while such differences might be expected from their widely separated geographic positions, greater freedom of migration, and their environment, he thinks it surprising to find the Guadalupean fauna so completely different from anything known in the Mississippi valley, whose geographic position is relatively so close. It is no longer so when surrounding conditions are known.

These three phases, which approximately occupy the same time interval and show in such different degree the development of life which is supposed to mark the change between the Carboniferous and the Permian, illustrate a feature of geologic history which may at times be of great importance.

The open land to the north and east and the open sea to the southwest gave free entrance to the new forms of vertebrates and plants, on the one side, and the new forms of invertebrates, on the other, while in the enclosed waters of the interior sea, largely cut off from outside influence, the old fauna continued to exist with little change.

From these conditions it can be clearly seen that however and wherever these changes in land and sea fauna that mark the advancing periods may have taken place, they were not always manifested in the same region simultaneously, but when conditions were unfavorable for such simultaneous in-
cursion there may have been overlapping, one way or another, of the land fauna or flora of one period and the marine fauna of another.

The history of our Triassic time is somewhat obscure, but it is apparent that during its continuance the greater portion of the State was above the sea and subjected to extensive erosion. Our only records are found in the old basin which existed in the Staked Plain region and which may have been inherited from the closing period of the Permian. The extent of this basin is not known, but we find that it underlay the entire area of the Staked Plain; that it extended southeastward to and beyond the Double mountains of Stonewall county, and to the north and west of the Plain into Oklahoma and New Mexico, so that the probability is that the portion within our area formed the southern extremity of a basin reaching far to the north and northwestward.

These deposits, which Cummins called the Dockum beds, are composed of sandstones, conglomerates, and clays, and the fossils show that it was a fresh-water inland basin. In them we find the fragmentary remains of batrachians and reptiles, including crocodiles and dinosaurs, which are similar to those of the same age found in the Great Basin region to the north; and along the eastern border of the lake we find banks of fossil shells of the Unio, of which four species have been described from one locality. These are of special interest, as has been previously stated, because of the fact that they are the earliest known forms of these fresh-water mollusks.

The Texas Cretaceous, taken as a whole, has an individuality which separates it in a measure from the Mexican deposits on the one hand, and those of the Gulf States on the other. From the latter it differs in the fact that the lower Cretaceous of Texas shows an extensive series of marine
Individuality 161

deposits, while the beds of similar age to the east are those of fresh water, and even in the upper Cretaceous approximate identity of faunal contents is only reached toward the top of the series. From the Mexican deposits, on the other hand, it differs in a section which is apparently less complete, of a greatly diminished thickness, and seemingly of deposits of more nearly marginal character. There are also marked variations in the fossils.

It shows, moreover, certain differences within our own borders which are of greatest interest to us, and it is of these that principal mention will be made at this time.

In any general consideration of the Cretaceous deposits of the State one must bear in mind the important fact that in the greatly extended area over which this formation occurs we naturally expect variation of conditions of sedimentation and consequent differences in the sediments themselves.

If we draw a line from El Paso to a point on Red river north of Montague and follow the river to the eastern border of the State, we mark the northern boundary of all our Cretaceous deposits except those underlying the Llano Estacado. The latitudinal extent of the formation thus marked out is over 700 miles.

The exposures south of this line occupy an area roughly crescentic, the greatest width of which is 350 miles.

The eastern extension of this line on Red river and the western on the Rio Grande at El Paso are the regions of littoral sediments, while the deposits of the demilune to the south—the direction from which the sea encroached upon the land—are those of deeper waters.

Therefore the deposits of the two extremities are sands, clays, marls, and somewhat meager limestones which, as we go southward, gradually pass into clays, shales, and heavy limestones. This fact is apparent with the greater number
of the subdivisions of the Cretaceous, beginning with the Trinity.

It is quite certain that the basal Trinity sands do not reach Red river, but that the sands found there are Paluxy. Similarly, the Trinity is not known on the Rio Grande closer than fifty miles from El Paso. This indicates that land conditions persisted in these localities through a part or all of the Trinity, and the deposits which follow show that they were not submerged as deeply as the more southern territory.

The long period elapsing between the emergence of our region at the end of the Permian, extending as it did through the entire Triassic and Jurassic, gave time for great erosive action over the land surface, and this resulted, so far as can now be seen, in a fairly complete base-leveling of the greater part of the old Carboniferous land prior to the incursion of the Cretaceous sea.

This base-leveling facilitated the encroachment of the water so that the Trinity sea probably covered the land, relatively, with considerable rapidity. The gradual extension of the waters to the north and the deepening of the sea to the south is beautifully told in the sediments exposed along the Colorado river on the eastern border of the Llano region.

The erosion of the Colorado and its affluents has channeled through the entire thickness of the early Cretaceous beds, clearly showing the basal sands of the Trinity with the overlying arenaceous limestones of the Glen Rose. These attain their maximum thickness north of Austin, thinning toward the northwest, and by following the outcrops of the various beds of limestone in that direction we find that they finger out into the underlying sands, showing that they are but deposits in the deeper waters of the sea of which some portion of the Trinity sands are the contemporaneous lit-
Individuality

toral sediments. Just as the Trinity grades upward, imperceptibly, into the Glen Rose, so do these limestones, in turn, grade upward into the sands of the Paluxy, where it is present, so that at many localities there is no apparent sedimentary break between them.

The thinning of the beds continues to the north and west of the Llano region until the Glen Rose beds entirely disappear and the Paluxy sands are directly superposed upon the Trinity, while further north it is probable that the Trinity itself is entirely lacking and that the basal sands, if present, represent only the Paluxy or even some later stage.

Page calls attention to the fact that the entire Trinity is missing at several places in Burnet county, apparently through non-deposition, and that the Walnut clays and Comanche Peak limestone directly overlie the Ordovician limestone. Thus the 500 feet of Trinity and Glen Rose sediments which are exposed in the Colorado near the Burnet-Travis county line thins out entirely in the distance of 25 miles, due to the fact that parts of the land at the more northern locality, even at that date, stood too high for the sea to engulf them.

On the southern border of the Llano region this condition is even more noticeable than on the eastern, for there the granite peaks more clearly show the conditions of deposition that surrounded but did not cover them during the Trinity and Fredericksburg periods.

Other detached areas lying some distance to the southeast of Burnet were similarly too high and formed islands in the Trinity sea, but these were covered by the succeeding Comanche Peak sediments. Several such have been found in drilling for artesian water.

The absence of the Trinity has also been noted in some of the buttes lying east of the Staked Plain.
Such uncovered areas, however interesting they may be geologically, form so small a percentage of the great surface covered by this mantle of sand east of the Pecos as to be practically negligible when we study its economic value as the source of so large a portion of our artesian water.

The Rio Grande discloses conditions somewhat similar to those between the Colorado and Red river. Exposures in or near the river valley in the vicinity of the Chinati, Quitman, and Malone mountains show the basal sands and overlying Glen Rose limestones in strong development. In the vicinity of Presidio the basal sands seem to have a thickness of 400 feet and the Glen Rose 700, while on the south slope of the Quitmans there is a series of sandstones and silicious limestones apparently of great thickness underlying the beds referable to the Glen Rose and which are here 900 feet thick or even more.

To the northward, across the railroad, these beds show a greatly diminished thickness, soon thin out entirely and are overlapped by later deposits. The most northerly and westerly occurrences known are those of the ridges just north of Sierra Blanca, Flat Mesa, and the Finlay mountains.

The Fredericksburg also presents different facies in different localities. In its typical development it comprises three members—the Walnut clays, the Comanche Peak beds, and the Edwards limestone. These three divisions are clearly recognizable over a very large area east of the Pecos, including the line of buttes which form the Callahan divide and the outcrops south of the Llano region.

Throughout a large portion of this area the Edwards limestone consists of deposits laid down in clear water of some depth, far enough from shore to escape the admixture of terrigenous sediments. In the region of shallower water
along Red river it shows an increase of coastal debris, and many of the fossil forms characteristic of its purer phase do not occur in it. It is in fact no longer separable from the underlying Comanche Peak beds, and the two are, therefore, considered as the Goodland limestone, which at its best attains a thickness of only a few feet.

Going southwestward from Austin toward the Pecos and trans-Pecos region—a region which was covered with deeper waters for a long period of time—we find that the Comanche Peak marls gradually change to limestone and the Walnut clays to marls and limestones, both finally coalescing with the overlying Edwards so that there is no longer any lithological difference between them. In such case their presence can be known only through distinguishing fossils. In this manner, due entirely to different conditions of deposition, we have in places the limestones of the Fredericksburg resting directly upon the Trinity.

Still further west in the Rio Grande region we find, on the contrary, thin beds of sandstone coming in and separating these beds of limestone, and to the northward across the railroad lines the sandstones thus occurring become thicker and the limestones are also silicious, indicating that the deposits were laid down nearer a shore-line.

It is, therefore, apparent that in this immediate area the shore-line of the Cretaceous sea maintained an approximately constant position from early Trinity time to well through the Fredericksburg. This line was probably not more than 50 to 60 miles southeast of El Paso. That the sea did not include El Paso during this period is shown by the absence of deposits there which can be referred to it.

Between the Finlay-Sierra Blanca region and El Paso later deposits cover and conceal any extensions of the Cretaceous beds that may exist, and the next exposures to be seen
are the basal beds of limestone of the Muleros mountains. These seem to represent practically the top of the Fredericksburg, and show only a small development (70 feet) beneath the overlying marls in which Washita forms appear.

Here again, as noted in the Red river section, in the beds referred to the Fredericksburg we miss the characteristic fossils of the Edwards limestone, and find instead an assemblage of forms which more nearly resemble those of the Goodland limestone.

Similarly, too, the deposits referable to this division in these two regions of shallow water exhibit only a small portion of the thickness attained by the beds in the off-shore areas.

The Fredericksburg, with its extensive development of deep sea limestones and comparative poverty of shallow water sediments, was followed by the Washita, in which these conditions are largely reversed. It is in the littoral regions of Red river and El Paso that the deposits of the Washita show their widest differentiation and greatest thickness, while in the deep sea area they are less variable and in most cases of less thickness. In its simplest expression the Washita is composed of a basal limestone, the Washita or Georgetown, overlain by the *Exogyra arietina* or Del Rio clays and the Buda limestone. This is the section at Austin and south and westward to the trans-Pecos region.

Going northeastward from Austin toward Red river, the Buda limestone, which is 80 feet thick on the Colorado, gradually thins out, and beyond the Brazos it is no longer distinguishable even through its fossils, although it seemingly is found again north of Red river in Oklahoma.

The Del Rio clay, however, with a thickness of 80 feet at Austin, maintains a similar thickness to the Brazos, beyond which stream it is gradually expanded into a series
of shales, marls, sands, clays, and limestones known as the Denison beds, with a thickness of 200 feet at Denison.

Similarly, the Washita limestone, with a thickness of 80 feet at Austin, shows a separation into several members when followed northward.

In the Red river section the Kiamitia clays form the base followed by the marls and chalky limestones of the Duck creek beds, capped by the Fort Worth limestone, and these together show a thickness twice as great as the Georgetown limestone at Austin.

The fossils of these various subdivisions of the Washita are very numerous and characteristic. Many of them are seemingly confined to the nearer shore deposits of the northern border, but others are as wide-spread as the formation. By far the greater number and the greater variety of species found within the several beds of this division are those of the shallower water. In the deeper sea conditions were more stable and there were fewer changes of form—so little, in fact, that in the vicinity of Devil's river and further west certain aberrant forms which are characteristic of the Edwards limestone throughout its extent have persisted and are found in the Washita (Georgetown) limestone as well.

As has been stated, the section south of Austin is more regular than that to the north of the Colorado. The basal limestone shows a decrease in thickness in some places, and is so similar to the underlying Edwards that it can be distinguished from it only by the fossils that it carries. This is true as far west as the Chisos mountains and also near Sierra Blanca.

The Del Rio clays have often been mentioned as a formation of rather remarkable regularity for one of its composition. This distinctive clay bed is nearly always present in approximately the same thickness and is characterized by
its peculiar fossil, the *Exogyra arietina*. It carries numerous other forms, especially toward the top, but nothing like the number that are found in its northern development on Red river.

The Buda limestone also maintains a rather constant thickness and character throughout all this section.

In some parts of the trans-Pecos the Washita occupies a very prominent place among Cretaceous deposits, as it was during this period that the Cretaceous sea, which had been held back so successfully during the Trinity and most of Fredericksburg time, spread northward over the former land area lying east of the Guadalupe to and beyond the northwestern border of the State, overlapping the Fredericksburg and the Trinity, or, more probably, the Paluxy.

This is particularly well shown in the vicinity of Kent on the Texas and Pacific railroad. Here there is no Fredericksburg visible at the surface, and what is found in excavations is rather of the nature of the Goodland limestone phase. No Edwards limestone is known. South of the railroad track the Washita limestone is well developed, with great numbers of fossils. As we go northward we find the Paluxy sands underlying the Washita and successively higher and higher beds of the limestone coming down into direct contact with it. The Washita materials are not found overlying the other Cretaceous of the Llano Estacado, but the section of Tucumcari mountain shows, directly overlying the Triassic, beds of the Washita with fossils similar to those at Kent. Consequently, it is very probable that it did cover the plains at some time. At Kent the clays of the *arietina* have not been observed, although they are found in their regular position at points south.

The Buda limestone, however, does occur with its usual fossils.
In the Big Bend of the Rio Grande, including Presidio, Brewster and adjoining counties, the exact line of separation between the Washita limestone and that of the Fredericksburg is difficult to find, owing to the great similarity of the two. The Washita becomes softer and more shaly toward the top and can be recognized through its fossils. Its thickness in the region adjacent to the Rio Grande is variable, just as is that of the Fredericksburg, and, like it also, it at times far exceeds anything that is known further north and east.

The Del Rio clays are usually present, although the *Exogyra arietina* is not always to be found in them. The Buda forms the capping stratum, as usual.

Going northward from the river, the Washita becomes more marly in character, as has been noted in the Kent section. West of Sierra Blanca the Washita only occurs in remnantal patches which show sandy shales and sandy limestones with fossils of this period, with a total thickness for the entire division of not much over 100 feet. Here, in its more northern exposures, it overlaps the Fredericksburg and is imposed directly upon the Carboniferous.

The difference in the conditions which existed in the eastern and western portions of our area is shown by the variations in the horizons of certain fossils occurring in them. In the Red river region the little *Exogyra plexa* is found in the Kiamitia clay, corresponding to the lower part of the Washita limestone. At Kent and further west it occurs either at the top of the Washita limestone or in the Del Rio clay. On the other hand, the *Nodosaria texana*, which throughout the east is confined to the Del Rio clays, is found in the Sierra Blanca-Malone region in the Washita limestone and Fredericksburg as well.

In the Muleros mountains we find a development of the
Washita which differs in many particulars from that of other portions of the trans-Pecos, and, while possessing features distinctly its own, is more nearly similar to the Red river section.

Beginning at the base, there is a band of clays and clayey limestones followed by ledges of harder limestones and overlain by a considerable thickness of clay shales with indurated limy bands, the fossils of which seem to show a close relationship with the Preston beds of the Red river section. These beds and their fossils, taken in connection with the underlying limestone, give a section which, in its assemblage and distribution of fossils, shows a close resemblance to that on Red river including the Goodland limestone, Kiamitia clays and Duck creek beds.

Succeeding these are flaggy argillaceous limestones with marls and shale partings a hundred feet in thickness, which are, stratigraphically and in a general way, the faunal correlatives of the Fort Worth limestone.

Following this, the Del Rio clay is here represented by brown sandy calcareous layers passing upward into clay shales and lime bands alternating with sandy flags containing both *Exogyra arietina* and *Exogyra plexa* as well as other Del Rio fossils. These beds are in turn capped by red, gray or white sands varying in thickness from 60 to 300 feet.

This massive sandstone is followed by clay shales with bands of limestone nodules, passing gradually into a hard limestone. This carries the fossils of the Buda limestone, including *Hemiaster calvini*.

The entire thickness of the Washita section in the Mule-ros mountains is 600 feet or over—fully 200 feet more than the Red river section. This difference is fully accounted for in the body of massive sandstone which is found here between the Del Rio clay and the Buda limestone, the only
occurrence of the kind known within our entire area. The only similar occurrence which is now known is the sandstone which occurs at the top of Washita deposits in Tucumcari mountain. A peculiarity of the sand at Muleros is the number of large shells of the *Exogyra clarkii* which are found in it and which continue upward through the overlying marls and limestones of the Buda.

The earliest deposition of the upper Cretaceous consists of the sands of the Dakota or Woodbine series, which are found in Texas in both littoral zones. On the east they form a sandy belt known as the Lower Cross Timbers, extending from Red river to the Brazos at Waco. In the west they are found in the Muleros section and in one or two outlying exposures, such as that at Eagle Flat, 20 miles east of Sierra Blanca. The time relation of these marine deposits to the brackish or fresh water beds of the interior is proved by the identity of the fossil flora found in both, in addition to which our beds both east and west carry a marine fauna which is distinct from that of the lower Cretaceous. As has been previously stated, the Dakota is absent throughout the greater portion of our area, and the succeeding beds of clays and shales which we call the Eagle Ford, and which are stratigraphically and faunally the continuation of the Benton shales of the interior region, are the lowest member of the upper Cretaceous which we find.

From Red river southward the clayey members decrease and the limestones persist and increase in thickness until along the Rio Grande between Del Rio and Eagle Pass they are lime shales almost exclusively. In the Big Bend of the Rio Grande they are lime shales at the base, grading upward into marly clays, and in the Muleros section they consist of fine-grained sandstones, and shales with some silicious limestone.
Of all the upper Cretaceous deposits, the Eagle Ford seems to be the most uniform and constant. While it has its near shore phase of sands and clays, the bulk of the deposits are limy shales, and these not only encircle the Edwards plateau, but stretch southward into Mexico for two hundred miles or more, where they attain a very much greater thickness than anything we know in Texas. Furthermore, these deposits, wherever we find them, whether sands or clays or lime, are consistently shales and carry a characteristic fauna throughout their entire extent.

During the deposition of the Chalk a condition of clearer waters existed, and in the main the Chalk is fairly free from materials derived from the land area and is an almost pure chalk, but there are localities where the clays were carried out and deposited with it, occasionally to such an extent as to make it merely a chalky marl.

In its relation to the underlying Eagle Ford it shows the same variations noted in other similar contacts. In the eastern part of the State the division is quite clearly defined and the line of separation can be fairly well made out even on the Rio Grande east of Del Rio. To the south it is sharply defined, but to the west the distinction is not so readily apparent, and in the region of the Big Bend of the Rio Grande, where the Eagle Ford takes on a more marly character and the Austin chalk is marly also, it is difficult to find the dividing line without careful examination of the fossils.

The upper margin of the Chalk is not so well defined, since at most places it grades almost imperceptibly into the base of the overlying Taylor marls.

On the eastern border the Taylor marls and Navarro beds, as a whole, mark a period of gradually shallowing water, interrupted, however, in the northern part for a time
by conditions of deeper, clearer waters in which the Anona chalk was laid down.

On the Rio Grande border also we find in the region lying between Eagle Pass and Uvalde a very considerable variation of the deposits belonging to these formations. Along the river below old Fort Upson the representatives of the Taylor and Navarro are found for a distance of 40 miles and include various members not present further east.

The basal beds or Upson clays are marls similar to the more eastern deposits and carrying calcareous nodules which are septarian in form. These are followed by the San Miguel, a series of sandstones and clays with glauconite which passes upward into more calcareous strata, also glauconitic. Fossils are abundant throughout the entire series. Overlying this there are other sands and clays with beds of coal, one or more of which are workable. While the area of workable coal in Texas is not very great, the extension of these beds south of the Rio Grande in Mexico furnishes the principal Coal Measures of that republic.

The upper beds of the formation are sands and clays with bands of limestone, reefs of oyster shells, and many other fossils which are known as the Escondido beds. The entire series has a thickness of more than 2000 feet.

Going northeastward toward Uvalde from this extensive exposure along the river, these various beds gradually coalesce, and in the southeastern part of Kinney county we find them represented in the Anacacho mountain by a small thickness of the basal clay passing into the Anacacho limestone, which is covered by a comparatively small amount of the upper portion of the Escondido beds. These have here a total thickness of not more than 400 feet, and this is less than 30 miles from the river.
The Anacacho limestone is largely made up of broken shells and remains of sea organisms, and apparently represents in time and general character the Anona chalk of the eastern portion of the State.

The coal-bearing character of the Taylor marls is also exhibited in the Rio Grande valley around San Carlos in the northwestern portion of Presidio county. In this region the base of the section is composed of shales with lime concretions overlain by interbedded sands and sandstones which are more or less calcareous. Then follows a considerable thickness of coal shales with two beds of coal overlain by red and brown sands capped by a lava flow. Overlying the lava bed we find a conglomerate passing upward in sandstones of various colors interbedded with coal, calcareous clays, and volcanic ash. These beds have a thickness of over 2000 feet and are capped by the heavy lava flow which forms the rim rock of the Sierra Vieja.

It would appear from the data so far obtained that the coal of this region is somewhat lower in the section than is that at Eagle Pass.

We have in this region, therefore, conditions of coal formation which, in a measure, correspond with those of the Montana beds of the Interior Basin region, and which are the correlatives of these in age; but the fossils which are found in great abundance in both of the Texas regions, while in part similar to those of the Interior Basin region, are more nearly akin to those of the Ripley of the upper Cretaceous of the Gulf.

The occurrence of basalt and volcanic ash in connection with the Taylor marls in the Austin region, as well as in the far west at San Carlos, gives an idea of the wide-spread activity of the igneous forces which came into operation dur-
Individuality

The close of the Cretaceous and must have continued well into the Tertiary.

What has already been stated regarding the Eocene deposits of our State gives in a general way their relations to and differences from beds of similar age in adjoining regions.

The Lignitic, which in the northeastern portion of the State carries such vast bodies of lignites, gradually loses these toward the southwest, and beyond the Guadalupe these features are practically absent.

The Queen City beds of the east, with a thickness of less than 100 feet, increase on the Rio Grande to several times that thickness, and the overlying Yegua and Fayette, the fossils from which are almost unknown in the east, carry a very plentiful fauna on the Rio Grande. Taken as a whole, however, the different substages are very constant in their composition and characteristics entirely across the State.

Of the later beds of the Tertiary there is little more that can be said. So recent has been their emergence from the sea, and so little have they been disturbed by erosion or earth movements, that it is difficult to get any real information of them, except what they themselves show upon their surface.

In the later Tertiary deposits, both of the Llano Estacado and of the Coastal Plain, we find remains of the abundant animal life of the period, most of which is now extinct or unknown on this continent.

Herds of mastodon and elephants of different species roamed over this area. Camels of various kinds, gigantic species of ox (Bison latifrons), of the sloth (Megalonyx), the armadillo (Mylodon), and land tortoise existed, together with peccaries, wolves, foxes, and many smaller ani-
The Geology of Texas

mals. The saber-toothed tiger, a species of lion, and the rhinoceros are also found.

Horses, which appear to have become extinct before the discovery of the continent, are represented by numerous species ranging from the three-toed variety to an animal of immense size which is found in southwest Texas.

One of the most interesting chapters of our history would be that of the igneous rocks, but so little have they been studied up to this time that there is little that can be safely stated of them.

The basalts that accompanied the vulcanism of late Cretaceous time from Pilot Knob near Austin to Fort Inge have been mentioned, as also the beds of volcanic ash which are found intercalated in certain horizons of Tertiary rocks. It is in the trans-Pecos region, however, that these forces have their greatest manifestation, and here they have yet to be studied.

The peaks of Sierra Blanca are composed principally of igneous rocks, but we as yet know nothing of their history, nor are we sure of the age of the granites of the Quitman range.

In the Eagle mountains, however, we find great shafts of porphyry thrust skyward through rocks of upper Cretaceous age, and similar protrusions occur in many of the mountains to the southeast. In the Sierra Viejas a capping of basalt 300 feet in thickness was spread over the top of the upper Cretaceous beds before the great rift occurred which, in the vicinity of San Carlos, caused a dislocation of fully 2000 feet in the separated portions of these beds. In some places the basalts or porphyries, instead of reaching the surface, were thrust along the planes between beds of limestone or other material and are now found as sills in them, and at
others vast bodies of tuffs or volcanic ash are interbedded or commingled with the deposits.

In the Terlingua region three distinct periods of vulcanism were made out, each accompanied by characteristic eruptives, and their relative ages determined; but as to the actual time of their activity nothing could be determined save the fact that it was after the deposition of the lower Cretaceous, since these rocks were cut by them.

This branch of our history, therefore, like that of our more recent coastal land, must await more study before we can appreciate its full significance.