Stratigraphy and Carbonate Petrology of the Pennsylvanian Upper Canyon Group in Stephens and Palo Pinto Counties, Texas[1]

PETER BRETSKY, JR.[2]

ABSTRACT

The strata of Pennsylvanian age in north-central Texas dip gently and uniformly to the northwest. They are subdivided, in ascending order, into the Strawn, Canyon and Cisco Groups. The study area was limited to the upper part of the Canyon Group in Stephens and Palo Pinto counties. Four formations were mapped and the petrology described; they are, in ascending order, the Placid Shale, Ranger Limestone, Colony Creek Shale and Home Creek Limestone; also mapped were outliers of the Trinity Group (Cretaceous). All the formations show lateral and vertical lithologic changes; therefore detailed field tracing was necessary to insure accurate stratigraphic correlations.

A detailed petrographic study of the carbonates showed that the limestones are composed almost entirely of comminuted organic material and have undergone little recrystallization. Much of the original sediment was mechanically deposited, and most lateral and vertical lithologic changes are believed to be related to variations in the physical environment. The limestone members are not characterized by a single rock type, but are divisible into distinct lithologies that generally can be traced throughout the area. The units vary from calcilutites to limestone conglomerates and appear to occur in rhythmic vertical succession.

INTRODUCTION

General Geologic Setting

The strata of Pennsylvanian age in north-central Texas dip uniformly one-half degree to the northwest. They are subdivided into three groups, in ascending order, the Strawn, Canyon and Cisco. The Canyon Group in the Brazos River valley is characterized by thick, fossiliferous limestones, whereas the Strawn and Cisco Groups are predominantly terrigenous. The Canyon sediments were deposited on a gently sloping shelf and provide an almost continuous record of rhythmic fluctuations of shallow marine depositional environments, which are believed to be related to regular fluctuations of energy base.

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[1] Based on a thesis submitted in partial fulfillment of the requirement for the M.S. degree at Southern Methodist University, 1963.

[2] Department of Geology, Yale University, New Haven, Connecticut.

The strata are conformable with those of the Strawn and Cisco Groups and have undergone so little tectonic modification that the gentle and uniform slope of the Pennsylvanian surface of deposition is reflected today in the uniform regional dip.

Present Study

Geology

The most recent investigation of the Canyon Group (Laury, 1962) has shown that lateral and vertical lithologic changes are common, and where it is not possible to trace a bed at the surface, detailed correlations are questionable. The area investigated adjoins the Canyon type area on the north. The formations mapped within the area are, in ascending order, the Placid Shale, Ranger Limestone, Colony Creek Shale and Home Creek Limestone.

Only the physical stratigraphy of these units was examined. A detailed petrographic study was made in addition to the field investigation and dealt especially with the carbonates. No attempt was made to organize the fossil record, although particularly outstanding areas of preservation are noted in the text.

Thus the study incorporates detailed mapping and measurement of stratigraphic sections with a careful laboratory study of the petrography of the carbonate units. By this means facies changes were accurately documented, correlations were clarified and subtle changes in depositional environment noted and interpreted.

Location

The study area is in southeastern Stephens County and the adjoining southwestern part of Palo Pinto County, and is bounded on the south by Farm Road 207 and on the north by U. S. Highway 180. The eastern and western boundaries are geologic contacts; the eastern being the top of the Winchell Limestone and the western the top of the Home Creek Limestone.

Methods

Reconnaissance of the upper Canyon strata in the Brazos River valley was carried out in the spring of 1962 and the field mapping continued throughout the summer of 1962 and intermittently into the spring of 1963. The petrological sampling was completed in the late spring and early summer of 1963.

Geological contacts were plotted on aerial photographs which are at a scale of 1:20,000. These were flown in 1951 and 1954 by the

U. S. Department of Agriculture. The contacts were transferred to a controlled photo-mosaic (1:24,000) and the map traced from this mosaic. Geologic contacts were mapped at the base and top of all members, but where a member was too thin or it formed a vertical exposure, a single contact has been shown on the map.

Grain size of terrigenous material has been described according to the Wentworth grade scale (1922) and the roundness and sphericity according to Rittenhouse (1943) and Powers (1953). The bedding thickness is classified according to McKee and Weir (1953), and Ingram (1954).

The four formations were sampled, but the carbonates received the most attention. Each member was mapped and then the measured sections were sampled. Samples were taken either at every significant change in lithology and bedding, or if both were reasonably consistent over a long vertical interval, random samples were collected at 5 foot intervals. Additional spot samples were taken at selected localities which are indicated on the map. In all, 408 samples were collected from more than 90 localities. Specimens were slabbed and polished sections prepared. Thin sections were made where it was deemed necessary for precise interpretation of texture or composition. Photomicrographs were made with a Pentax camera and Micro-Ibson attachment mounted on a Leitz polarizing microscope.

The petrographic study of the carbonates required the use of a slightly modified Wentworth scale, but the accepted division between silt and sand (i.e. 0.06 mm) has been retained. Further limits employed are as follows: coarse sand (2.00 mm-0.60 mm), medium sand (0.60 mm-0.20 mm), fine sand (0.20 mm-0.06 mm), coarse to medium silt (0.06 mm-0.02 mm), and fine silt and clay (0.02 mm-0.01 mm). Only in the coarse to medium-grained sand sizes could the original particle type be identified with consistency. It is reasonable to assume, however, that the closely related finer grains are composed of the same material which has simply been more highly comminuted. The classification used in this study is essentially that of Leighton and Pendexter (1962), but the various usages of the term micritic limestone have been supplanted by the terms calcilutite, calcisiltite and calcarenitic limestone.[1]

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[1] *Calcilutite*—A rock composed almost entirely of clay-size particles (90 per cent less than 10 microns), and may be referred to as microcrystalline.

Calcisiltite—A rock composed almost entirely of silt-size particles (90 per cent less

BASIS OF CORRELATION AND CLASSIFICATION

The difficulties encountered in correlating between the Brazos and Colorado River valleys are due primarily to a thick cover of Cretaceous that precludes any field tracing of Pennsylvanian beds, but matters are complicated further by abrupt lateral changes in lithology. These changes are sufficient to render unintelligible any attempted presentation of an all-inclusive stratigraphic profile of the Pennsylvanian strata in the Brazos River valley.

Laury (1962) summarized the historical development of the stratigraphic nomenclature of the Pennsylvanian in north-central Texas and emphasized the difficulties that have arisen in attempted correlations between the Brazos and Colorado River valleys. Earlier significant contributions in the Brazos River valley were made by Cummins (1891), Plummer (1919), and Plummer and Moore (1921). Later additions to the geologic literature of the Canyon Group in this portion of Texas are by Ross (1921), Plummer and Hornberger (1935), Bradish (1937) and Cheney (1940, 1948).

The term Canyon has been used as a series by Cheney (1940) and as a group (Laury, 1962). The criteria used to identify the Canyon beds in the present study were lithological; therefore the Canyon as used here is a group (American Commission on Stratigraphic Nomenclature, 1961).

Plummer and Moore (1921) used a lithologic classification and placed the boundaries of the Canyon Group at the base of the Palo Pinto Limestone and the top of the Home Creek Limestone. The upper contacts of the major limestones in the Canyon, however, can be detected only in a few places, and the Home Creek Limestone is no exception. Therefore the top of the Canyon Group is identified only discontinuously. On the other hand one cannot logically lower this stratigraphic boundary to the easily recognized base of the Home Creek since it is an integral part of the predominant carbonate deposition that prevailed during Canyon time. The overlying Cisco Group, on the other hand, is composed primarily of terrigenous material and only a few thin limestones.

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than 60 microns), and may be referred to as microclastic.

Calcarenitic (modifier) Limestone—Principally a microclastic but containing up to 50 per cent sand-size particles (2.00 mm-0.06 mm).

(modifier) Calcarenitic Limestone—A rock composed of greater than 50 per cent but less than 90 per cent sand-size grains.

Calcarenite—A rock composed of greater than 90 per cent sand-size grains.

Specific modifiers (e.g. skeletal, fusulinid, pellet, intraclastic) may be added in the latter three categories.

The Brad and Caddo Creek Formations of earlier workers (see esp. Plummer and Moore, 1921) have been supplanted in this study by the Placid Shale, Ranger Limestone, Colony Creek Shale and Home Creek Limestone (Laury, 1962).

STRATIGRAPHY

Pennsylvanian System, Canyon Group

Plummer and Moore (1921) described the Canyon Group as those beds laid down immediately after the source area to the east (i.e. "Ouachita System") had been worn down. Conditions during Canyon time favored the deposition of fine skeletal carbonates which may be attributed to two main factors: (1) the source of the coarse siliceous clastics so prevalent in the subjacent Strawn Group had been diminished considerably and (2), as a result, communities of lime secreting organisms were given the opportunity to become sufficiently extensive that they were able to contribute dominantly silt and sand size calcareous particles to the sediment. Potential dilution by coarse siliceous material from the eastern source was held to a minimum, and a sequence of thick fossiliferous limestones, calcareous to siliceous clays and a few non-calcareous lenses of quartz sandstone compose the Canyon. "These limestones and shales lie conformably upon the Strawn in most places. The Strawn dipping northwest at a slightly steeper angle . . . on the whole the change seems to have been gradational rather than abrupt." (Plummer and Moore, 1921, p. 90).

Cummins (1891) described the geology of a part of Palo Pinto County and was the first to delimit the strata now assigned to the Canyon Group. They were named for the now abandoned town of Canyon located four miles west of Strawn along the Texas and Pacific trunk line. The Canyon Group of Plummer and Moore (1921) included all the strata of Cummins' Canyon "division," and Laury (1962) states that the total thickness of the Canyon in the type area is about 725 feet. The thickness of the upper part of the Canyon is approximately 300 feet.

Placid Shale (Pp1)

The term Placid Shale was introduced by Plummer and Moore (1921) for a Pennsylvanian shale sequence in the Colorado River valley. It was a 30 to 50 foot interval between the subjacent Clear Creek Limestone and the superjacent Ranger Limestone. They believed it to be equivalent to a part of the Seaman Ranch beds in the

Brazos River valley, but Plummer and Hornberger (1935) redefined the Seaman Ranch beds as being correlative with the entire Placid Shale. Laury (1962) thought the term "Seaman Ranch beds" too ambiguous for further usage and employed the Colorado River valley term, Placid Shale, for the interval between the Winchell and Ranger Limestones (for further discussion see Laury, 1962, pp. 127-132). The Placid Shale is given formational rank in this paper, and is composed of two sandy shale members Ppl_1 and Ppl_3 and an intervening limestone member Ppl_2.

The Placid Shale is about 130 feet thick a few hundred yards north of Farm Road 207 (section 1, Pl. 1, and Laury, 1962, section 22). It thins northward to 116 feet at sections 15 and 16, and near U. S. Highway 180 is 110 feet thick (sections 29 and 30).

The Placid Shale, excluding limestones, is composed of gray and olive-green calcareous shales, lenses of ferruginous reddish brown to clear-white, quartz sandstone and siltstone. These sandstones are usually thin or irregular in outcrop, but beds ranging from 15 to 30 feet in thickness are present in sections 16, 26 and 29 where especially good ripple and bottom markings are preserved. The olive-green to gray calcareous shales and fine silts are only sparsely fossiliferous. All of the fossiliferous units are thin and most are of questionable lateral persistence. This shale and sandstone sequence is interrupted by a fine-grained limestone (i.e. calcisiltite and calcilutite), Member Ppl_2, which varies in thickness, lithology and stratigraphic position.

This limestone member is 7.5 feet thick and occurs 47 feet above the base of the Placid Shale at section 1. It is a thick-bedded clayey calcisiltite and is not unlike the irregular, thinner limestones in the lower shale member (Ppl_1). It thickens to 23 feet at section 3 and attains its maximum thickness of approximately 35 feet at sections 5, 7 and 16. Shale Member Ppl_3 varies little in thickness over this distance, but Shale Member Ppl_1 has decreased from 50 to less than 30 feet. The limestone member forms not only a pronounced topographic bench in the southern part of the area but also a small, rounded escarpment.

Limestone Member Ppl_2 begins to show signs of subdividing into two limestone units separated by a calcareous shale only ¼ mile north of section 7. At section 15 eleven feet of a very clayey calcilutite abruptly recede from a lower calcisiltite and is capped by another more indurated, thin, algal calcisiltite. Member Ppl_2 is composed of three separate units to the northeast and northwest of section 15, and the most striking phenomenon associated with this subdivision is the abrupt change in the stratigraphic positions of the upper and lower limestone units.

Almost 30 feet of calcareous shale separate the two limestone units approximately one mile down dip from these sections in the Ioni Creek canyon (sections 8, 10 and 26). The upper limestone unit "climbs" rapidly in the Placid Shale section and thus decreases the thickness of the upper Shale Member Ppl_3 approximately 15 feet in this distance down dip, and also along strike (sections 16 and 49). It can be traced easily to the north where it forms a small bench.

The lower limestone unit ranges in thickness from 9 to 17 feet and conversely falls in stratigraphic position both down dip and along strike. It may merge with the Winchell Limestone, but it cannot be traced beyond ½ mile north of section 49. A limestone conglomerate is exposed on the upper surface of the lower unit about 1 mile south of this section. One-half mile east of section 46 a similar-looking conglomerate is exposed in the basal limestone member of the Home Creek. Both may be either intraformational conglomerates or recently cemented alluvial deposits. The latter is believed to be the probable explanation but the evidence is not conclusive.

Ranger Limestone (Pr)

Plummer (1919) introduced the name "Ranger Limestone," and earlier workers distinguished the Ranger from other Canyon limestones by its abundant chert nodules and ferruginous-stained layers. This criterion applies only to the uppermost parts of the Ranger Limestone in this area. Ross (1921, p. 306) studied the Ranger near LaCasa and described it as being composed of three "members." They are, in ascending order: (1) a light gray, massive limestone 50 feet thick, (2) shale 12 feet thick and (3) a thin-bedded limestone 4 feet thick. Plummer and Moore (1921, p. 111) described the Ranger as follows: "An upper thin limestone fairly fossiliferous separated by 5-10 feet of yellow shale from a lower and more massive member that weathers into large square blocks, which give a wall-like appearance to its escarpment." This weathering phenomenon is common throughout the entire study area. Laury (1962) follows this three-fold classification, but the subdivisions are given member status as follows: a thick basal limestone (Pr_1), a thin calcareous shale (Pr_2) and a thin upper limestone (Pr_3). The Ranger is considered to be a formation rather than the upper member of Plummer and Moore's Brad Formation.

The three members that compose the Ranger Limestone can be mapped throughout much of the area. At some places they were not mappable, due to these main factors: (1) a patchy cover of Cretaceous conglomerate and outwash mainly in the southern and central portions of the area, and (2) local complete erosion of the uppermost part of the Ranger prior to the deposition of the Cretaceous. Even where present the contacts are difficult to place since the low Pr_3 escarpment recedes irregularly and usually far down dip from the main escarpment (Pr_1). The symbol "Pr" is used (Pl. 1) where the members of the Ranger Limestone cannot be distinguished, or appear to be absent. The total Ranger thickness is about 45 feet near Farm Road 207, and it gradually thickens to 58 feet at sections 9 and 17, and retains this approximate thickness to U. S. Highway 180 (sections 19, 20, 28 and 50).

The chert, believed to be characteristic of the Ranger Limestone in the type area, is never very abundant in the area of the present study, and is present only in the form of nodules usually less than 10 inches in diameter. It is confined geographically to the southern parts of the area and stratigraphically to a horizon that nearly coincides with the top of the lower Limestone Member Pr_1. The chert is typically dark brown with traces of light blue siliceous inclusions (chalcedony?), and within this siliceous "matrix" are fine-grained, white, calcareous, skeletal fragments. All of the chert is believed to be the result of replacement since gradational zones from a fine skeletal calcarenitic limestone into a remnant skeletal siliceous pod are common.

The Ranger, especially the basal limestone member, has developed a prominent jointing pattern that is recognized easily on the aerial photographs. There are two notable vertical sets in this joint pattern; one strikes approximately N 35° E, whereas the other set strikes N 60° W. The set that strikes northeast results in the formation of the characteristic massive, blocky slump found at the base of the escarpment. This may be compared with the ill-defined escarpment exhibited by the basal Home Creek limestone member that shows no prominent jointing pattern.

One of the more conspicuous physiographic features of the Ranger Limestone is the formation of a few small, closely spaced escarpments and benches noticeable in the south-central part of the area. A stair-step topography has developed on the Ranger at sections 17, 32 and 39; four escarpments and three small benches compose the interval. One persistent bench occurs within the basal limestone member approximately 15 to 20 feet above the base of the Ranger (sections 8, 26, 9, 12, 17, 11 and 49). Some other benches are present farther to the north but it is questionable whether they can be traced at any regular stratigraphic position (sections 32, 37 and 29). This phenomenon is absent at the northern boundary of the area.

The units that recede on the benches are always less than 5 feet thick and are composed of a poorly indurated clayey calcilutite. Their apparent concentration in the central part of the area indicates that this area of deposition during Ranger time may have been subject to a slight increase in "siliceous" mud from an eastern source, thereby giving rise to an almost rhythmic dilution of the carbonates.

Colony Creek Shale (Pcc)

The shale and sandstone beds between the Ranger Limestone and the overlying Home Creek Limestone in the Brazos River valley were called the Hog Creek Shale by Plummer and Moore (1921, p. 117-118). They described it as a series composed of sandstone and shale and only rarely a limestone stringer. "The top of the series is a dark reddish brown, cross-bedded sandstone . . . and overlies shales containing lenses of sand and in a few places lentils of limestone."

Eargle (1960, p. 67) and Laury (1962, p. 139) summarize the complications that have arisen in the terminology concerning this particular interval in both the Colorado and Brazos River valleys. Briefly, because Plummer and Moore's use of the term "Hog Creek" has little validity in light of the original miscorrelation in the type area (Drake, 1893, in the Colorado River valley), the author follows the precedent set by Cheney (1948) who suggested that the name Colony Creek be used for those beds between the Ranger and Home Creek Limestones. The stratigraphic and geographic location of the type area is four miles west of Ranger, but was described inadequately by Cheney. The term Colony Creek, however, is applicable and shall be considered a formation in the Canyon Group.

The Colony Creek Shale overlies the Ranger Limestone and is beneath the Home Creek Limestone. The basal parts of the unit are eroded easily and the entire formation is cut far back by streams flowing normal to its northeasterly strike. The pattern of its outcrops is very irregular especially in the north.

The Colony Creek Shale is 48 feet thick ¾ of a mile north of Farm Road 207. It is almost impossible to measure a complete section in the south since its contact with the Ranger Limestone is located on a long, gentle slope and occasionally is obscured by unconsolidated Cretaceous sands and pebbles (section 35). The thickness of the Colony Creek increases rapidly northward to 76 feet at section 38 and 108 feet at section 42. The formation ranges in thickness from 100 to 110 feet at the northern border of the area (sections 21, 48, and 50).

The individual sandstone, shale and limestone units also vary in thickness. There is a marked increase in the sand to shale ratio to the north; this is due to a major influx of sand into the upper part of the formation. The amount of ferruginous sandstone increases so rapidly north of section 40 that any other lithologic units are either lost at the expense of this increase or are covered by the massive, sandstone slump blocks (sections 13, 14 and 42).

The massive-bedded ferruginous sandstones exhibit an extremely lenticular habit when traced to the northern boundary of the area, but the overall thickness of the formation varies little. Outcrops of this sandstone in excess of 70 feet are exposed at sections 48 and 50, but it diminishes rapidly up dip where it is less than 40 feet thick at section 21. The basal 70 feet of section 21 is composed of an alternating fossiliferous, gray, calcareous shale and a brown, non-calcareous shale. A few of the calcareous shale horizons contain a great variety of species. These fossiliferous horizons are present beneath a zone of non-calcareous brownish clays containing abundant ironstained concretions. Secondary calcite and selenite crystals are found concentrated in thin, vein-like sheets (less than 1 cm) that cut obliquely across the bedding planes.

Home Creek Limestone (Phc)

Drake (1893) introduced the name "Home Creek" for a limestone unit along Home Creek in southeastern Coleman County. He later correlated this with a limestone unit in northern Brown County and Plummer and Moore (1921) carried this latter unit into the Brazos River valley. Nickell (1938, p. 116) showed that the type locality of the Home Creek consisted of a limestone that Plummer and Moore had called Ranger. The type locality for the Home Creek is now in Brown County. Cheney (1948) in a more recent attempt at revision re-defined the Home Creek to conform to the time boundaries established in the Missouri Series of the Mid-Continent. The Home Creek is considered a purely lithological unit in this paper and is mapped as the uppermost formation of the Canyon Group.

Plummer and Moore (1921, p. 118) described the Home Creek Limestone near Caddo as being composed of two limestone layers which are separated by 5 to 10 feet of calcareous shale. "The upper layer is a dark blue, fossiliferous hard limestone and weathers to a yellow-brown color. The lowest layer is an impure, clayey, light gray, poorly bedded limestone 10 to 40 feet thick, which weathers into large, irregular slabs and chunks. It forms an escarpment of moderate size and where not covered by Cretaceous sands can be traced easily."

This generalized description of a three-fold subdivision of the Home Creek is most certainly a valid one, but Ross (1921, p. 306) presented a more accurate interpretation of the Home Creek. The locality he described was near LaCasa where he found three limestone units separated by shales. The upper two limestones and the intervening calcareous shale were found to be extremely variable in thickness and lithology by the present author, and are mapped as the upper member of the Home Creek Limestone (Phc_3). At section 33, located in a small abandoned quarry, a 2.5-foot calcareous shale interval was present between two limestones, but some other localities (sections 25-L, 43 and 27) show comparable overall thicknesses but no intervening shale. Complications in mapping have arisen because the upper member (Phc_3) thickens so rapidly down dip that at some places the beds seem to dip to the southeast, and where the upper shale unit is present the Home Creek interval consists of three definite limestone escarpments.

The three fold subdivision of the Home Creek Limestone introduced by Plummer and Moore (1921) is used in this report, and two Limestone Members Phc_1 and Phc_3 separated by a calcareous shale Phc_2 are mapped. Limestone Member Phc_1 forms a small escarpment but at many places it is badly slumped, weathering in massive slabs near the base and into small nodular chunks and pebbles near the upper parts of the unit. The middle member Phc_2 recedes rapidly from the underlying Phc_1 limestone and is poorly exposed on a gentle slope. It consists of a yellowish white, calcareous shale and contains a 4 to 9 inch horizon composed of a clay-sand fusulinid calcarenite that can be traced southward into the Canyon type area (Laury, 1962, section 5-A) and to the northern border of this study area (sections 46 and 47). Limestone Member Phc_3 forms a long, undulating dip slope and thickens considerably from 7 to 23 feet in the direction of dip. The basal parts of this unit are characterized by many solution pores. The overall thickness of the Home Creek Limestone ranges from 20.5 feet at section 31 to 50.5 feet down dip at section 40. It is 36 to 40 feet thick at the northern border of the area (sections 46 and 48).

Pennsylvanian System, Cisco Group

No attempt was made to study the Cisco Group in any detail. Plummer and Moore (1921) introduced the term Finis Shale for those beds immediately above the Home Creek Limestone in the Brazos River valley. Section 34 is fairly typical of the Finis Shale which is composed of a non-calcareous, olive-green shale and siltstone overlain by a massive-bedded, very porous, ferruginous sandstone and intercalated fine-grained siltstone. One hundred thirty feet of fine to medium-grained, ferruginous, cross-bedded sandstone overlies the Home Creek in the northwestern corner of the area, and it is believed to be part of the Cisco Group; but one cannot discount the possibility of its being Cretaceous (section 44).

Cretaceous System

Rocks of the Cretaceous age crop out as small outliers throughout. They are composed of ferruginous silts, sands and sub-rounded quartz and chert pebble conglomerates. Much of the Cretaceous is outwash (section 31) and is identified by either the red coloration of the soil or the abundance of unconsolidated quartz pebbles. The difficulty encountered in mapping the Cretaceous involves two main areas of subjective interpretation: (1) Cretaceous outwash usually covers the Cretaceous bedrock of very low relief thereby creating the problem of differentiating total outwash and outwash-covered bedrock and (2) the contact between the well-exposed Cretaceous bedrock and the Canyon Group is often covered by outwash deposits.

The Cretaceous outliers are concentrated on the extensive dip slope of the upper Home Creek Limstone and on portions of the upper

Ranger Limestone. Some of the outwash obscures the Ranger-Colony Creek contact in the southern part of the area. Also it is possible that some of these limestone conglomerates, mentioned above, are a Cretaceous phenomenon as parts of the Home Creek were torn up and recemented penecontemporaneously by the influx of the Cretaceous Sea. The symbol "Kt" (Pl. 1) is used for the Cretaceous rocks since they are part of the Trinity Group (Sellards, Adkins, and Plummer, 1932, Plate 11).

Quaternary System

The rocks of the Quaternary System consist of alluvial and terrace deposits along the drainage systems. Only the Ioni and Big Caddo drainage systems provided enough alluvium to be mapped at the sacle of $1'' = 2000'$. The deposits are undifferentiated and indicated as "Qal" on the map (Pl. 1). They consist of pebbles, cobbles and boulders of limestone and lack any of the red coloration so characteristic of the Cretaceous outwash. The valley floors in many places have been cut through to expose the Pennsylvanian bedrock. The Quaternary deposits range in thickness from 10 to 20 feet (sections 15, 43, 45 and 49).

CARBONATE PETROLOGY

Constituents

The limestones of the upper part of the Canyon Group are composed almost entirely of organic matter. This includes comminuted skeletal debris, sparite-filled worm tubes and fecal pellets. Also angular intraclastic and superficial oolitic textures are present but appear to be intimately related to organic activity. Authigenic constituents and effects of diagenesis are negligible. The particles show significant variations in size, and all gradations exist between gravel and lime mud.

Skeletal Particles

Calcareous algae, fusulinids, gastropods, pelecypods, bryozoans, brachiopods, crinoids and echinoids are the major skeletal elements. Sponges, solitary corals and colonial corals are found in very limited quantities.

Portions of the Placid Limestone Member Ppl_2 and Ranger Limestone contain the largest amounts of algae, but it seldom constitutes greater than 25 per cent of the rock. The algae are preserved as partially recrystallized filaments and angular fragments. The latter are at best questionably identified as algae. These threads rarely exceed 2 mm in width, but they range from 3 to 7 cm in length. A few are coated with an iron oxide stain. Tentative identifications were made by comparison with those genera recognized in the Missourian strata of Kansas (Johnson, 1946). The blue-green algae class is the only one found in the limestones of the upper Canyon Group. Algal filaments are associated with the coarser fraction, but the fragmental particles are more common in the finer silts and muds. A few well sorted patches of threads in the Ranger exhibit a definite preferred orientation of long axes sub-parallel to bedding, but most of the algae occurs as irregularly dispersed, poorly sorted threads and fragments. In exceptional cases algal growth forms appear to be in place; more commonly they are products of gentle, mechanical deposition. The importance of algal dust (Wood, 1941) and the extent of its recrystallization has not been evaluated. It is, however, very fine-grained, dark and drusy, and difficult to identify unless it coats the filamentous algae.

Fusulinids rarely constitute more than 5 per cent of a sample, but the upper two members of the Home Creek Limestone contain thin beds of a fusulinid calcarenitic limestone. The fusulines is the calcareous clays and fine-grained quartz silts of the Home Creek marl member show little wear, but those in the more indurated limestone units are well rounded. Most are associated with a quartz-lime silt and mud environment of deposition and the largest fusulines (4 to 6 mm axial length, 2 to 4 mm sagittal diameter) are common in the quartz silts.

Pelecypods and gastropods are present in considerable amounts in parts of the upper Canyon limestones. The identifiable and intact members rarely exceed an average overall diameter of 1 mm, and most are comminuted to fragments of a fine-grained sand size. Small conispiral gastropods are the most obvious constituents. Many of these molluscans and similar size non-molluscan fragments are concentrated into small pods and lenses within fine calcisiltites or calcilutites. Most of these pods are composed of more than 50 per cent sand-size particles, and the overall appearance is much like that of a disrupted quartz sandstone.

Identifiable brachiopods always constitute less than 5 per cent of any upper Canyon limestone sample. A few large brachiopods are randomly distributed throughout some fine calcareous silts and muds. Most of these valves are disarticulated, but some of those that are articulated show well preserved brachidia. A few fine brachiopod spines are present in some of the finer calcareous silts and muds, and exhibit a tendency toward a preferred orientation.

Bryozoans are local skeletal contributors in most of the upper Canyon limestones, but at no place is there any recognizable concentration greater than 5 per cent.

Echinoid fragments and spines are common in many units of the upper Canyon limestones but are concentrated especially in parts of the basal Ranger Limestone member. The spines are hollow and have an outside diameter of 300 to 500 microns. They compose about 10 per cent of some samples and at many places constitute the entire recognizable skeletal population. These spines usually occur with dense, white, skeletal fragments, some of which may be comminuted echinoid plates.

Crinoid columnals and plates are abundant in the fine silts and muds of the upper Canyon Group. The fragments are composed of dense, white calcite. The columnals have remained articulated in a few places, but this phenomenon is restricted to the finer silts and lime muds, where the fragments commonly show little wear. Comminuted crinoids and echinoids may be significant contributors to the small pods and lenses of concentrated skeletal matter, but identification is questionable.

Solitary corals are rare in the well indurated upper Canyon limestones, but some (e.g. *Lophophyllum* and *Campophyllum*) are present in some of the calcareous shales.

Rounded sparite-filled casts are present in some finer silts possibly indicating the presence of sponges, but the evidence is not substantial and many of the "molds" may have been pores.

Non-Skeletal Particles

The most important non-skeletal particles are fecal pellets, angular intraclasts, quartz sand and silt, and superficial oolites.

Fecal Pellets. Fecal pellets are present through most of the upper Canyon limestones, but are more abundant in the finer silts and muds. The pellets rarely exceed a diameter of 20 microns, but measurements up to 100 microns were recorded. They are oval or ellipsoidal, lack any internal structure and when viewed under a petrographic microscope in convergent light appear as yellowish brown objects in a lighter-colored matrix. Mixtures of well-sorted pellets and fine to medium skeletal silts are common. The pellets seldom exceed 25 per cent of any specimen, but in some are more highly concentrated in small pods and lenses much like those composed of fine skeletal material. Also apparently homogenous lime muds may be due to the accumulation of fecal pellets which have lost their distinctiveness after compaction, like those off the Florida coast (Ginsburg, 1957).

Swarms of fine rectilinear tubes are associated with some of these pods of skeletal and fecal material, but not exclusively confined to such. They are believed to have been formed by small burrowing worms that are approximately 20 to 100 microns in diameter and 5 to 7 mm long. These tubes are easily identified because of their sparry calcite filling and are well oriented in some places, giving the appearance of finely divided glass shards.

The larger fecal pellets (50 to 100 microns in diameter) occur in many calcilutites that are highly disrupted. These are not present in the lime mud but in the sparry calcite that cements the lutitic fragments. Some of this "cementing material" also may be a replacement product and the pellets would then constitute the last unreplaced remnants; (the distinction between a chemically precipitated "drusy calcite" and a recrystallized "mosaic calcite" in these upper Canyon limestones has yet to be determined). Worms, however, are believed to have thrived locally in the bottom muds during the deposition of the Placid limestone member; tubes are distributed over wide areas in some of the calcilutitic beds of the Home Creek Limestone.

The larger tubes in the limestones of the upper Canyon Group also are filled with a sparry calcite and coated with dense, white calcite which probably was constructed from small bits of calcareous skeletal material present in the matrix. The tubes range from 500 microns to 3 mm in diameter and are of undetermined length (probably greater than 10 mm). Terebellid worm tubes have been described in the literature from the Canyon Group in this area, but they are much larger than any found during the present study (Howell, 1944, 1953).

Angular Intraclasts. Distinct angular sand and gravel size fragments are present throughout many of the limestones of the upper Canyon Group. These fragments are composed of fine calcareous silts and muds, and are major components in textures of varying disruption (e.g. a partially disrupted calcilutite, intraclastic calcarenite and limestone breccia). Those rocks that have been disrupted only slightly are composed of very angular intraclasts that are cemented by sparry calcite. Only a few of the intraclasts are rounded.

Those intraclasts that are well rounded are embedded in a calcilutitic matrix not unlike the material which comprises the intraclasts. The "groundmass," however, has a higher skeletal content and is darker colored than the "fragments," which show an outline atypical of most Canyon clastic limestone particles. Some of the intraclasts and a few "floating" detrital skeletal fragments show a preferred orientation and are believed to be the original product of mechanical deposition. Some of these intraclastic rocks appear, however, to be pseudobreccias (Dixon and Vaughan, 1911, and Bathurst, 1959). Rarely is recrystallization so complete in these pseudobreccias that whole rhombs of calcite are visible, but rather recrystallization takes the form of irregular masses of mosaic calcite. The reason for this patchy development of mosaic calcite in a pseudobreccia is not apparent but may be related to minor variations in constituents and porosity. Therefore in some manner the patchy recrystallization represents an original heterogeneity in the sediment.

True intraclastic textures probably were formed by the following processes: (1) the destruction of a partially consolidated bottom sediment by mechanical agents during periods of relatively intense current or wave activity; (2) the combined activities of burrowing organisms and minor fluctuations in the current energy. Worm tubes and pellets are present in all of the disrupted calcilutites and fine calcisiltites, and it is believed that the burrowers which formed these may be the major agents of reworking. The smaller size worm tubes and fecal pellets ranging from 4 to 20 microns ordinarily are associated with the more angular, less disrupted intraclasts that range from 1 to 2 mm in diameter. Some of the intraclastic calcarenites and limestone breccias are perforated by sparite-filled tubes approximately 2 mm in diameter, and the fecal pellets which range from 50 to 100 microns in diameter are concentrated in the cementing material and not in the intraclasts themselves as in the finer sizes. Small pieces appear to have been torn off the edges of intraclasts and are suspended in the sparry calcite cement with the pellets, but at many places it is difficult to differentiate between these and some of the floating detrital skeletal particles of the pseudobreccias.

The effects of currents cannot be dismissed although the burrowing activity appears to have been very extensive. Some of the intraclasts that are sub-rounded appear to have undergone some mechanical transportation. Also, poorly sorted skeletal fragments, which are intermixed with the intraclasts, are oriented in part. It is believed that increased agitation may have caused the influx of these coarser fractions into an environment in which the bottom sediments were already weakened by burrowing. The Placid Limestone Member Ppl_2 and parts of the Home Creek Limestone exhibit particularly well preserved intraclastic rocks.

Quartz Silt and Sand. Fine-grained quartz sands and silts are common in some of the limestones of the upper Canyon Group. Small stringers and pods of these siliceous particles generally are present in the limestones at and near the contact with a lower sandstone unit (e.g. basal beds of Ranger and Home Creek Limestones). A thin bed composed of a disrupted, calcareous quartz sandstone is occasionally present between the well indurated limestones above and the subjacent well sorted quartz arenites. Siliceous pods and stringers are composed of particles coarser than the calcareous matrix and are believed to be the result of slight increases in energy that represent the last phase of an earlier, predominant, more agitated environment of deposition. The pods and stringers are commonly well sorted but several poorly sorted lenses and particles of quartz sand and silt occur in the basal beds of the major limestone members. Quartz sand and silt are characteristic of the fusulinid calcareous clays of the Home Creek marl member. They range in roundness from sub-round to sub-angular and many of the quartz grains show undulatory extinction.

Chert is present only near the top of the basal Ranger Limestone member and is in the form of small pods. These apparently are due to replacement.

Superficial Oolites. Oolites are rare in the limestones of the upper Canyon Group, but superficial oolites that are composed of well rounded skeletal fragments coated with a thin layer of dense calcite are plentiful. They range in size from 200 microns to 1 mm and, although all sizes have undergone some reworking, the finer fractions (200 to 500 microns) are better sorted.

The oolites greater than 500 microns in average diameter are well rounded but lack the sphericity of the finer sizes and are usually ellipsoidal. There are two well defined superficial oolitic beds in the

Ranger Limestone, but the oolites are not confined exclusively to these horizons but are present throughout the limestones of the upper Canyon Group as small patches and irregular lenses within beds composed of finer skeletal silt.

Authigenic Constituents

The texture of the limestones of the upper Canyon Group has been altered in at least three ways: (1) recrystallization to a mosaic of fine calcite, (2) cementation by clear calcite and (3) silicification.

Mosaic Calcite. Recrystallization of the original rock particles to finely crystalline calcite takes place in a few of the finer calcisiltites and calcilutites. It is most common near the top of the upper Home Creek Limestone Member Phc_3 and in the lower parts of Limestone Member Ppl_2 of the Placid Shale. The interlocking grains are normally less than 60 microns in diameter.

Crystalline Calcite. Sparry or crystalline calcite is rare as a cementing material except in those rocks composed of angular intraclasts. It also is present in microfractures, pores and worm tubes. This cement consists of interlocking crystals 100 to 500 microns in diameter. The term "drusy mosaic" is used for grain mosaics that have been deposited on the walls of cavities, whereas "sparite cement" is applied where chemical deposition has apparently occurred in the pores of a detrital sediment. Spherulites, fine radiating fibers of calcite, are present around the walls of a few cavities, and in some of the pores and spheroidal fossil molds.

Silica. Silica is present as a partial replacement product near the top of the basal Ranger limestone member. It forms nodules and small pods that grade into a skeletal calcisiltitic matrix. Silicification also takes place in the fusulines in some of the fusulinid-skeletal calcarenitic limestones of the middle Home Creek member (Phc_2). The fusulines are commonly replaced completely but the process appears not to have affected any of the other constituents.

Classification of Carbonate Rocks

The carbonate grains, regardless of their genesis, behave much as detrital particles. Therefore a classification by particle size is appropriate. Such a scheme is relatively easy to apply since the original texture in most cases has been altered very little by diagenetic processes. The classification used is based entirely on size and volume of constituent particles (see footnote in *Introduction*).

Petrographic Correlations

Placid Shale

Limestones in Shale Members Ppl_1 and Ppl_3. The thin limestones in Placid Shale Members Ppl_1 and Ppl_3 are generally calcilutites, but there are variations in the minor amounts of coarser skeletal fractions and in the disruption of the calcilutites.

The limestones in the lower Shale Member Ppl_1 in the southern part of the area consist in part of a worm-bored calcilutite that is sporadically intraclastic. It is intermixed with pods and stringers of quartz silt and fine sand. The recognizable skeletal constituents are comminuted bryozoans, brachiopods, echinoid spines and a few solitary corals, but the percentage of fine, yellow-brown fecal pellets is much greater than the comminuted silt-size, skeletal particles. At some places the fragments and pellets are concentrated into small pods and lenses that are perforated with fine acicular bore holes.

Samples from near the Ioni Creek Canyon are more commonly disrupted. This breakup of the lime muds is believed to be due primarily to the activity of burrowing worms since the increased numbers of intraclasts coincides with an increase both in the number and average size of the burrows.

The percentage of sand-size, skeletal fragments increases farther to the north; echinoid spines and crinoid fragments are most abundant. These fragments are composed of a dense, white calcite and are poorly sorted in a pelletal-microclastic matrix. The number of pods and stringers of skeletal material, also, increases northward, but they continue to be intercalated with a fine pelletal calcisiltite and small lenses of quartz silt.

The thin limestones of the upper Shale Member Ppl_3 are composed of essentially the same constituent particles as the limestones in the lower member, but are characterized by small amounts of fine algal threads and fragments. The calcilutites have not been disrupted to form intraclastic calcarenites although sparite-filled worm tubes are common. The lenses and pods of fine skeletal material increase in number northward and expand into a few small lentils intermixed with the microclastics.

Limestone Member Ppl_2. The Placid Limestone Member Ppl_2 is composed of the same sorts of constituents as the thinner limestones in the shale members, but their concentration varies noticeably.

Limestone Member Ppl_2 consists of an intercalated pelletal calcisiltite and intraclastic calcarenite south of the Ioni Creek Canyon. No definite pattern of deposition is developed through time, and all gradations exist between the lime mud and intraclastic texture. The intraclasts are angular and composed of calcilutite material similar to the non-intraclastic calcilutites. Again some highly comminuted skeletal material is concentrated in small pods and lenses, and in a few places skeletal fragments and pellets are present in the crystalline calcite cement surrounding the intraclasts. Occasionally the particles and some of the finer intraclasts show a preferred orientation.

Where the limestone member divides into two limestone units and an intervening calcareous shale, the lower unit is composed of a sparsely algal-pelletal calcisiltite and intercalated intraclastic calcarenitic limestone. The calcisiltite thickens northward at the expense of the intraclastic calcarenite to the point where this limestone unit either pinches out or merges with the subjacent Winchell Limestone. The one thin limestone in the intervening calcareous shale is a disrupted calcilutite which contains a few fine skeletal and algal fragments.

A fine skeletal-pelletal calcarenitic limestone comprises the upper unit of the middle limestone member. It thickens to the north and becomes intercalated with a worm-bored calcilutite near the point where the lower unit "pinches out." The sequence is gradational through time and varies from place to place, but generally the basal strata are composed of a pelletal calcisiltite, the middle unit a fine skeletal-pelletal calcisiltite and the upper beds a skeletal-pelletal calcarentic limestone. There is a definite trend toward a decrease in the percentage of worm tubes and pellets northward, and at the northern border of the study area both are rare. Coincident with this is an increase in the amount of skeletal calcarenitic limestone and the addition of algal filaments that constitute up to 15 per cent of the total rock in a few places.

Ranger Limestone

Limestone Member Pr_1. The basal Ranger limestone member is divisible into five distinct but vertically gradational lithologic units. The thickness of these units varies throughout the area but the sequence through Ranger time remains the same.

The basal unit generally is composed of a fine-grained, skeletal calcisiltite which is slightly more lutitic near the contact with the subjacent Placid Shale. Most of the skeletal fragments are comminuted beyond recognition and occasionally are concentrated in small pods or lenses; this phenomenon appears to be typical of all the upper Canyon limestones. Identifiable fragments consist of brachiopods, crinoids, echinoids and bryozoans. Algae are present but are very fragmental and never constitute greater than 5 per cent of any sample. Fecal pellets vary in abundance from 5 to 25 per cent and show a marked increase coincident with an increase in the number of sparite-filled worm tubes. A few higher concentrations of pellets have been recorded in the lenses and pods of skeletal material. The fine calcisiltites and calcilutites are partially disrupted in a few places but intraclastic textures are not common in the basal Ranger.

This fine skeletal calcisiltite grades upward into a medium-grained, skeletal calcarenitic limestone that generally is less than 5 feet thick. It is intercalated with an algal calcarenitic limestone and an algal-skeletal calcarenitic limestone. The algae always occurs as long filaments, some of which are well lineated sub-parallel to bedding.

The third major lithologic division consists of a thin (less than 10 feet) but persistent horizon of calcilutite and fine-grained calcisiltite. It represents a rapid vertical gradation to and from a much coarser calcarenitic limestone. Fine sand-size, skeletal fragments are present in the calcilutitic groundmass but always constitute less than 10 per cent of any sample. Fine pellets are common but only occasionally compose more than 15 per cent of the rock. The character of the skeletal fragments is believed to have changed little but the only identifiable members are algae and a few echinoid spines. Small pods of silica replace some of the calcilutite in the southern part of the study area. The lime mud is more disrupted near the top of this lithologic unit but never becomes an intraclast, and again the increased disruption is accompanied by an increase in the percentage of worm tubes.

A skeletal-superficial oolite calcarenitic limestone bed occurs directly above this partially disrupted calcilutite. It can be traced throughout the area and its absence at some places is believed to be due to the construct of the outcrop. The superficial oolites appear to be composed entirely of skeletal material, but no simple recognizable relationship seems to exist between the rounded and angular skeletal fragments as concerns a possible mechanism for the rounding. The percentage of angular skeletal fragments increases upward at the expense of the superficial oolites and grades into an algal-skeletal calcarentic limestone that shows no new skeletal elements but is characterized by the numerous echinoid spines. This unit is subjacent to another thin lime mud.

The uppermost unit is very thin and absent at most localities, but again this may be due to the construct of the outcrop. It is a partially disrupted calcilutite much like the widespread lime mud below. Skeletal fragments are finely comminuted and the coarsest fraction (fine silt) constitutes less than 10 per cent of any rock. Only a few echinoid spines can be identified. The calcilutite never becomes an intraclast but shows a definite trend through time toward such. The upper parts are highly perforated with sparite-filled worm tubes.

Limestones in the Shale Member Pr_2. The thin limestones in the Ranger Shale Member Pr_2 are composed of calcisiltites and calcilutites that are disrupted in a few places. No coarse clastic layers exist and only a few small pods and lenses of fine-grained skeletal material are present in the calcilutitic matrix. These fragments are composed of a dense, white calcite not unlike the color of crinoid fragments but their fine to medium silt-size makes any positive identification impossible.

Limestone Member Pr_3. The upper Ranger Limestone member is divisible into two rather ill-defined lithologic units. It is generally less than 7 feet thick and there are few good exposures. These two lithologic units may be discontinuous but they are present at some widely separated localities.

The basal unit consists of a fine skeletal-superficial oolitic calcarenite not unlike that of the basal Ranger Limestone member. It is irregularly intercalated with an algal-skeletal calcarenite that contains none of the superficial oolites. This basal unit is very thin and of questionable lateral persistence. Most of Limestone Member Pr_3 is composed of a fine pelletal calcisiltite and calcilutite, but there are occasional small patches of fragmental algae and pods of dense, white skeletal material. The only identifiable members of the comminuted skeletal population are a few, fine spines. The unweathered calcilutite is a dark bluish gray, but where only slightly weathered it exhibits numerous small reddish brown clay particles. The reddish tinge of this calcilutite was believed by early workers to be characteristic of the Ranger. No insoluble residue tests were run but it appears as if the lutitic percentage may be at its maximum in the reddish colored Ranger samples. The reddish tinge is present only in the lime muds.

Colony Creek Shale

Limestones in Colony Creek Shale. Only a few thin limestones are present in the shales and sandstones of the Colony Creek Shale and they crop out in the south and south-central parts of the area. They are composed of a fine pelletal calcisiltite and calcilutite that grades laterally into an intraclastic calcarenite. These intraclasts are composed of calcilutitic material and are cemented by crystalline calcite. Worm tubes are abundant but patches of fine silt-size, skeletal fragments are rare. Identifiable skeletal constituents are fine spines, a few disarticulated valves and algal fragments.

Home Creek Limestone

Limestone Member Phc1. The basal Home Creek Limestone member can be divided into three lithologic units. The middle unit "pinches out" northward along strike and also down dip.

The basal unit is composed of a disrupted calcilutite. Sparite-filled worm tubes and pellets are the most numerous components, but there are a few small pods of fine quartz sand and silt especially near the contact with the subjacent Colony Creek Shale. There are only a few bore holes in the lime mud down dip, but it contains some algal fragments.

The middle lithologic unit ranges in composition from a fine skeletal calcisiltite in the southern part of the area to an algal-skeletal calcarenitic limestone in the central portions where it pinches out. The number of medium sand-size, skeletal particles decreases noticeably down dip and the skeletal calcisiltites grade into very fine calcisiltites and calcilutites. The calcilutites show only a few sparite-filled worm tubes and pellets, and are never disrupted. The identifiable skeletal components differ little from those encountered in the other upper Canyon limestones, but for the first time there is a minor influx of fusulines. The other skeletal constituents are algae and echinoid spines; although some of the skeletal material is of fine sand-size it has been comminuted sufficiently to prevent positive identification.

The upper unit is composed of intraclastic calcarenites and limestone breccias. The breccias and a few conglomerates most commonly occur near the upper parts of the unit. The intraclasts and gravels are composed of a calcilutite and grade down dip into a highly bored calcilutite that in turn grades into an almost pure calcilutite.

The intraclasts are cemented together by crystalline calcite that contains some lineated ellipsoidal fragments. The identification of these fragments is uncertain, but they may be either fecal pellets or well rounded skeletal fragments. The cementing material also contains small pods of dense, white fragments and in a few places is actually a mixture of sparite, pellets and rounded skeletal fragments. The fragments in the pods are fine to medium sand-size and generally are coarser and more poorly sorted than those present in some of the upper Canyon calcilutites described above. The preferred orientation seen in these skeletal fragments is typical of many intraclastic calcarenites in the upper Canyon Group but the pods of concentrated skeletal material in the sparry cement appears to be characteristic of this basal Home Creek unit. Recrystallization of parts of the lime-mud matrix may account for some of the skeletal pods now located in what appears to be a sparry cement.

Limestones in Marl Member Phc_2. The limestones in the marl member of the Home Creek Limestone range in composition from sparsely fusulinid, fine calcisiltites and calcilutites, to sandy-skeletal-fusulinid calcarenites. The calcarenites are most common and the fusulines show little wear. The other comminuted skeletal material is composed primarily of brachiopods and crinoids.

A few of the sandy-fusulinid-skeletal calcarenites grade into superficial oolitic calcarenites that are intercalated with some lenses of a fine skeletal calcisiltite. There are no worm tubes in the calcilutites and fine calcisiltites and the lack of fecal pellets is unique in an upper Canyon limestone. Some of the skeletal calcisiltites are disrupted, however, and a few fine intraclasts show a lineation similar to that seen in parts of the subjacent Limestone Member Phc_1. It is believed that the disruption of these bottom sediments and intercalations with a superficial oolite calcarenite are due primarily to current agitation, but one cannot discount the possible activity of organisms although there is no preserved record of their presence. A few of the skeletal particles have been replaced by a black siliceous material. These are fairly well rounded and may have been washed into this area of eventual preservation. No rock has been found that contains greater than 2 per cent of these siliceous particles.

Fine calcisiltites and calcilutites are present in the upper parts of the marl member and contain fusulines (5 to 10 per cent) which are fairly well rounded. As in the coarser fractions there are no sparite-filled worm tubes or pellets.

Limestone Member Phc_3. The upper Limestone Member Phc_3 of the Home Creek Limestone is divisible into two lithologic units. Both can be traced throughout the area, but lateral gradations are common. The rapid thickening of this member down dip and the poor condition of many of the outcrops necessitates a more generalized description of a probable vertical lithologic division than in some of the subjacent limestone units.

The lower unit is composed of a fine skeletal calcarenitic limestone and calcarenite and grades laterally into a medium to coarse skeletal calcisiltite. These layers are intercalated with thin calcilutites that contain many small pods and lenses of fine to medium silt-size skeletal particles. The skeletal elements common in this lower unit are spines, fusulines and a few algal fragments.

The upper unit is a calcilutite and fine calcisiltite that contains only a few small pods of coarser skeletal material. Some sparite-filled worm tubes and fine pellets are present in these pods and the only identifiable skeletal particles are a few fusulines and algal fragments. Stylolites are common in this unit which grades upward into worm-bored and disrupted calcilutite. Intraclastic calcarenites and calcilutitic breccias are present near the top of this unit. Some of the breccias are more highly recrystallized than any other limestones in the upper Canyon Group and are believed to be pseudobreccias resulting from partial recrystallization of the lime muds to a mosaic calcite.

Environmental Significance of the Upper Canyon Limestones

Some general interpretations concerning the probable genesis of these sediments can be made even though the agents of transportation and deposition are not directly observable. Particle shape and size generally reflect the type and intensity of the transporting agent and the nature of material in the source area. Regardless of how the fragmentation of the organic material took place, the physical factors of environment (i.e. the action of waves and currents) appear ultimately to have controlled deposition. Thus the factors governing the deposition of these carbonate sediments are believed to be similar to those which control the deposition of the mechanically deposited siliceous sediments. Diagnostic criteria observed in the area are: (1)

preferred orientation of the skeletal particles, pellets and algal threads with their longest axes sub-parallel to bedding or to each other; (2) thin lenses and layers differing in particle content; (3) small pods and individual particles surrounded by a lime mud; and (4) general uniformity of texture (an uneven grain growth would be expected in a growth mosaic or chemically deposited mosaic).

Lateral size gradations of carbonate particles are common in the limestones of the upper Canyon Group. Generally the upper Canyon limestones exhibit a decrease in particle size down dip that coincides with an increase in lutitic material. Studies of recent carbonate deposits in the Persian Gulf have shown that there a classical depositional sequence of sand-, silt-and mud-sized particles occurs. Since the situation there is apparently somewhat analogous to that in the Canyon depositional area we may conclude that the factors which produced the sediments of the latter are similar.

The coarser skeletal fractions and the intercalated stringers of quartz sand probably accumulated in an environment of relatively greater agitation. Some protection against this agitation was necessary for deposition of the finer material to be achieved. This could have been provided by an increase in the depth of the water or by physical barriers against the currents in shallow waters. The high concentrations of the fine calcisiltites and calcilutites indicate that current or wave action was inadequate to winnow out this finer material, or only strong enough to transport this fraction to deeper, quieter waters. Thus the thin, discontinuous, coarse calcarenites and calcarenitic limestones that are present in the microclastic series represent sudden short-lived increases in the physical energy. The activity of burrowing organisms as an agent for the sorting of some of the finer fraction cannot be disregarded, but their efforts appear to be limited to some of the finer lenses and pods.

The relationship between water depth and particle composition and size are not known. It is believed, however, that the sudden vertical and lateral lithologic fluctuations that are common throughout the upper Canyon Group may more reasonably be associated with shallow water. Moreover, since the sediments were laid down on a gently sloping shelf the presence of small bars and shoals would be expected.

Disrupted sub-angular quartz sands and skeletal particles are common at the base of the Ranger Limestone and Home Creek Limestone and in the marl member of Home Creek Limestone. The sorting is generally poor and the sands appear to have been deposited in a discontinuous manner. The relatively abundant thin intercalated layers and pods of quartz sand in the Home Creek Limestone directly above the Colony Creek Shale probably represent surges of higher energy and, perhaps, greater accessibility of sand in the source area.

Both the Ranger and Home Creek Limestones are vertically repetitious sequences of calcilutites and calcarenites. The calcilutitic layers appear to be of greater lateral extent than the calcarenitic units, which are believed to indicate the presence of high energy conditions localized laterally and in time. The formation of the disrupted angular intraclasts is due to slight, localized agitation. Once formed these particles undergo little or no transportation. The limestone conglomerates and breccias usually are poorly sorted, contain a great deal of sparry calcite, and probably are the result of more active currents and waves. Many of the intraclastic textures, however, may be due primarily to the activity of burrowing organisms and have been affected only slightly by the physical environment.

SUMMARY AND CONCLUSIONS

Stratigraphy

1. The upper Canyon Group of middle Pennsylvanian age in southeastern Stephens and southwestern Palo Pinto Counties is composed of thick limestone formations separated by shales, thin limestones and lenticular sandstones. The total thickness of the section included in this report is approximately 315 feet and consists of 4 formations and 10 members. The formations are, in ascending order: Placid Shale (Shale Ppl_1, Limestone Ppl_2 and Shale Ppl_3 Members); Ranger Limestone (Limestone Pr_1, Shale Pr_2, and Limestone Pr_3 Members); Colony Creek Shale (no members) and Home Creek Limestone (Limestone Phc_1, Marl Phc_2 and Limestone Phc_3 Members). Members are specified by rock type and no new formal names are introduced.

2. The most easily mapped units in the upper Canyon are the limestones and this includes not only the limestone members of the Ranger and Home Creek but also the middle limestone member of the Placid Shale. The intervening shales and sandstones are generally less well exposed and must thus be mapped with less precision.

3. The nomenclature used in this report follows that established in the Canyon type area by Plummer and Moore (1921) and revised

by Laury (1962). The stratigraphic limits of the Canyon Group are not equivalent to those of the Missouri Series in the mid-continent, and all its contained units discussed in this paper are recognized purely on a lithological basis.

4. The predominant carbonates of the Canyon Group contrast with the terrigenous clastics of the Strawn and Cisco Groups. The Canyon was a time during which the source area to the east had apparently been worn down far enough to prevent extensive terrigenous dilution of rapidly enlarging biological communities on a gently sloping shelf. Their colonization and the consequent preservation of their comminuted remains throughout Canyon time appears to have been influenced by rhythmic fluctuations (eustatic or tectonic) that affected environmental conditions.

5. The general stratigraphy is as follows:

a) The Placid Shale is divided into a basal Shale Member Ppl_1, a middle Limestone Member Ppl_2 and an upper Shale Member Ppl_3. The overall thickness of the formation varies little throughout the area but Limestone Member Ppl_2 thickens considerably near the Ioni Creek Canyon where the single limestone unit divides and incorporates a middle calcareous shale. The basal limestone unit resulting from this division "pinches out" a few miles north of the Creek and the middle member again consists of a single thin limestone (the upper unit of the division) that can be traced to the northern border of the study area. The limestone is a clayey-intraclastic calcisiltite at most places. The shale members above and below are composed of calcareous shales and lenticular beds of sandstone.

b) The Ranger Limestone is divided into a basal massive Limestone Member Pr_1, a middle thin Shale Member Pr_2 and an upper thin Limestone Member Pr_3. All three members can be traced throughout the area. The limestones are composed of intercalated algal-skeletal and clayey calcisiltites but a few distinctive horizons (e.g. superficial oolitic and skeletal calcarenites) do occur in the upper and lower limestone members. Chert is present in the upper part of the lower member (Pr_1) but only in the southern part of the area and never in abundance. The reddish brown outcrop coloration believed by earlier workers to be typical of the Ranger was found consistently only in the upper limestone member (Pr_3). The shale member (Pr_2) is composed of multi-colored calcareous clays and contains the most abundant megafaunal assemblage in the Ranger.

c) The Colony Creek Shale has not been sub-divided. It thickens notably to the north and massive, lenticular, ferruginous sandstones appear in the upper part of the section. Olive-green to gray calcareous shales compose most of the section along the southern and northern borders, but ferruginous sandstones predominate throughout the remainder of the area. The gray calcareous shales at some places are extremely fossiliferous and contain a greater variety of fossils than any other formation in the upper Canyon.

d) The Home Creek Limestone is composed of three members: a lower limestone member (Phc_1), a middle marl member (Phc_2) and an upper limestone member (Phc_3). The formation thickens to the northeast along strike and rapidly down dip. All of the members vary somewhat in thickness and lithology, but most important, the marl member thickens in the south-central part of the area with the inclusion of a well indurated fusulinid calcarenitic limestone in the calcareous shale sequence. A poorly consolidated sandy-fusulinid calcarenite horizon that occurs in this member can be traced throughout the area. The upper limestone member thickens rapidly down dip and in some places is intercalated with a thin calcareous shale which is easily eroded and gives the Home Creek the appearance of a five member formation in a few down dip localities. The most common rock type in the Home Creek Limestone is a fine skeletal-clayey calcisiltite.

Carbonate Petrology

1. The limestones of the upper Canyon Group were deposited in shallow water, and the slight fluctuations in current agitation either due to changes in sea level or the formation of barrier shoals or bars created vertical sequences of intercalated lime muds and calcarenites. The coarse fragmental "stringers" themselves may represent the presence of calcarenitic shoals that were flanked by deeper and less agitated water; the calcarenites grade laterally into fine-grained material. The finer silts and muds appear to have been winnowed from the shoals by moderate current activity which at the same time allowed the concentration of the coarse fractions on the more elevated areas.

2. An evaluation of the exact roles played by chemical precipitation, by comminuted shell material, and by fine pellets and algal dust in the formation of these limestones is not possible at present. However,

some of the homogenous lime muds may have been the result of an accumulation of fine fecal pellets or algal dust.

3. Finer-grained sediments are present in all down dip exposures and are believed to be related to the increasing depth and lessening agitation of the water. The calcarenites and calcisiltites grade into calcilutites and silicilutites. Apparently the latter predominate where a biological community could no longer survive. The middle limestone member of the Placid Shale and the upper parts of the Ranger and Home Creek Limestones are composed of fine calcisiltites and calcilutites that grade upward into calcareous shales and fine sands. These lime muds occasionally contain crinoid columnals and plates that show little evidence of wear; they appear to be similar in their degree of abrasion to those fossils found by earlier workers in the Canyon marine shales (Sloan, 1955).

4. Vertical repetition of certain textural features is typical of the upper Canyon limestones. The coarsely fragmental beds are interspersed regularly throughout the finer calcarenites, calcisiltites and calcilutites and may be related in some way to the overall rhythm of the Pennsylvanian sedimentation in Texas (Plummer, 1931).

5. The limestones in the upper Canyon Group can be subdivided into distinct lithologic units. The variations in particle size of the comminuted organic remains in these units reflect variations in the physical energy that affected the depositional environment.

6. Rapid lateral and vertical fluctuation in sediment properties suggest that deposition took place in shallow water on a gently sloping shelf.

7. Intraclasts and most limestone breccias are the result of organic activity and local currents. They are poorly sorted and most often very angular. Stronger currents and waves produced better sorting, superficial oolites and lenses of fine sub-round skeletal fragments (the best sorted skeletal fragments are in the medium to coarse silt-sizes and are present as pods and lenses in the partially disrupted calcilutites. These may reflect slight, localized conditions of increased physical activity).

8. Particle fragmentation may be due to the activity of organisms Feray and others, 1962). However, the presence of angular fragments that appear to be attributable to the biological crushers is noted only in the finer sand-sizes (Houbolt, 1957). It is to be noted that the upper Canyon limestones contain the spines of many echinoids,

one of the principal crushing organisms. Thus comminution of the shells of some members of the biological community by other organisms may have taken place. However, the distribution of these crushed fragments is primarily due to physical activity. Criteria which indicate mechanical rather than biological control of deposition are: a preferred orientation of longer axes sub-parallel to the bedding, layers of differing fragment size, homogeneity of texture within a given layer and the presence of isolated detrital particles.

9. Recrystallization patterns in the Canyon limestones are not obvious and uncertainty exists regarding their significance.

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