Summer 6-6-1958

The Jurassic Todilto Formation of New Mexico

Henry O. Ash

JURASSIC TODILTO FORMATION - ASH

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UNNAMED
SANDSTONE

TODILTO
LIMESTONE

ENTRADA
SANDSTONE

Outcrop at Hornsby Ranch Section

THE JURASSIC TODILTO FORMATION
OF NEW MEXICO

By

Henry O. Ash

A Thesis
Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Geology

The University of New Mexico
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This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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DATE June 3, 1958

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ABSTRACT

The Todilto formation of New Mexico is a widespread and distinctive Jurassic unit confined to the northern one-half of the State and adjacent parts of Arizona and Colorado. It consists of a lower Limestone member and an upper Gypsum member. The Gypsum member also contains some limestone. The two members are not coextensive in area. Both are present in the central part of the area in which the formation is found, but the Limestone member extends far beyond the limits of the Gypsum member.

The lower contact with the Entrada sandstone is essentially transitional and locally intertonguing in nature. The upper contact is conformable to transitional and it is believed that part of the gypsum unit may grade laterally into Summerville or equivalent fluviatile sediments which overlie both the Limestone and the Gypsum members.

It is believed that the Todilto formation was deposited in a broad, shallow, non-marine lake rich in planktonic organic material. It appears that chemical precipitation and, locally, some clastic deposition produced the lower Limestone member. Thereafter an increase in aridity and evaporation, combined with restriction of the basin due to encroaching sediments, concentrated the residual waters and produced the upper Gypsum member.

Little new identifiable organic material was found. However, the character of material extracted through pollen

and spore analysis technique suggests a sapropelic environment similar to that which has produced oil shale deposits elsewhere. The laminated character of the limestone unit may represent varves.

It is recommended that the Todilto strata be accorded full formational status. The Todilto formation and at least some part of the overlying strata are best placed in the San Rafael group along with the underlying Entrada sandstone.

and spore analysis to [illegible] with [illegible], [illegible]

ment similar to that [illegible] [illegible] [illegible]

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may represent [illegible].

It is recommended [illegible] the [illegible] of [illegible]

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some [illegible] of the overlying [illegible] are [illegible]

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INTRODUCTION

Nature and Scope of the Work

The strata to which the name Todilto is assigned in New Mexico have been the object of rather persistent disagreement among geologists for several years. The Todilto is a somewhat anomalous unit consisting of limestone and gypsum occurring in an otherwise dominantly clastic section. Although a remarkably persistent unit traceable over a wide area, it is relatively thin except where the Gypsum member is well developed. The variance of opinion has concerned both the appropriate stratigraphic status of the unit and its mode of deposition or environment.

Although it was first designated as a formation, it has since been labeled a member of the Morrison formation, a member of the Wanakah formation of southern Colorado, and a member of the Entrada formation. Some workers, however, have continued to accord it full formational status. Regionally it has been correlated with the Carmel formation, the Curtis formation, and the lower San Rafael group.

The origin of the Todilto has been ascribed to lacustrine, marine, and abnormal marine environments.

The lower boundary of the unit has been stated to be disconformable, conformable, gradational, and intertonguing. The upper contact has been called both conformable and disconformable.

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The stratigraphy which the term Todilto is assigned in New Mexico have been the subject of rather persistent dis-agreement among geologists for several years. The Todilto is a somewhat anomalous unit, consisting of limestone and gypsum occurring in an otherwise dominantly clastic pattern. Although a remarkably consistent unit traceable over a wide area, it is relatively thin except where the gypsum member is well developed. The variance of opinion has concerned both the appropriate stratigraphic treatment of the unit and its mode of deposition or environment.

Although it was first designated as a formation, it has since been labeled a member of the Morrison formation, a member of the Wanakah formation or Summerville formation, and a member of the Entrada formation. Some workers, however, have continued to accord it full formational status. Regionally it has been correlated with the Curtis formation, the Carmel formation, and the [illegible].

The origin of the Todilto has been ascribed to lagoonal, marine, and also [illegible] environments.

The lower boundary of the Todilto has been regarded as disconformable, conformable, gradational, and interfingering. The upper contact has been [illegible] disconformable.

The present study was undertaken in an effort to resolve some of these dissimilar views. A detailed examination of the unit in question combined with laboratory investigations was undertaken in the hope of bringing to light new paleontologic and other pertinent evidence.

Fourteen outcrop localities, rather widely scattered across northern New Mexico were visited (Fig. 1). At each locality a detailed stratigraphic section of the Todilto was measured and described. Hand samples were collected from each distinguishable unit. In addition, descriptions were recorded and samples taken from the immediately underlying beds and, where possible, from the unit immediately overlying the Todilto. Measurements were made with a pocket tape, a Jacob's staff, and a Brunton compass. Field descriptions were made with the use of a hand lens.

Descriptive stratigraphic sections from six of these localities are presented in the Appendix. These particular sections were selected for several reasons. Each is complete and is representative of the Todilto in a particular area. These sections illustrate the different modes of development of the formation and include both the maximum and minimum measured thicknesses. Several of the sections presented are near the pinchout of the formation and one is also notable for its fossil content.

The writer had examined and collected samples from two Todilto outcrops prior to the present study. Hence, samples

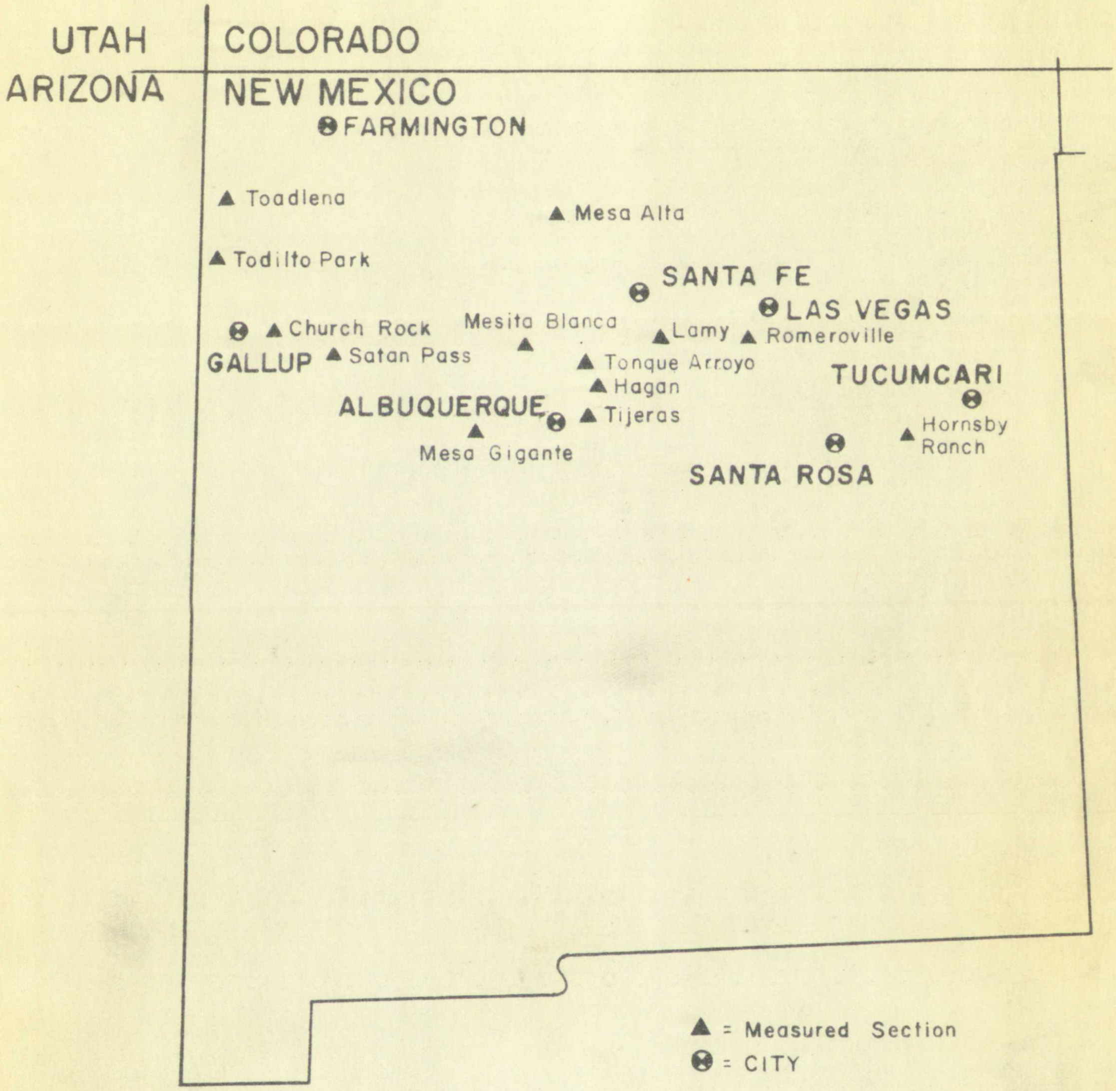

Figure 1. — Index Map of New Mexico showing location of measured sections

from a total of sixteen different Todilto localities were available for laboratory study.

Twenty-seven samples of material from fifteen localities were subjected to pollen and spore analysis in the laboratory. In addition five petrographic thin sections were prepared from rock samples of four different exposures. At least some material from each locality was examined under the binocular microscope.

The field and laboratory work was carried out intermittently during the Summer, Fall, and Winter of 1957.

Previous Work

In 1875 Gilbert (p. 552) noted a 2-foot bed of crystalline limestone in a stratigraphic section measured near Fort Wingate, New Mexico. The limestone bed is described as lying immediately above a 220-foot sandstone unit and below 200 feet of red and white banded sandstone. These three units were the lowest strata which he included in a larger unit. This inclusive unit totaled 712 feet and was designated "massive cross-bedded sandstone". The sandstone below the limestone bed was that which Dutton was later to name the Wingate sandstone, now known as the Entrada sandstone. The limestone, of course, is the Todilto limestone and the overlying unit has been variously designated and most recently interpreted as the Summerville formation or its equivalent (Wright and Becker, 1951), (Rapaport, Hadfield, and Olson, 1952), (Harshbarger, Repenning, and Irwin, 1957).

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Previous Work

In 1875 Gilbert (p. 552) mapped a 2-foot bed of crystalline limestone in a stratigraphic section measured near Fort Wingate, New Mexico. The limestone bed is described as lying immediately above a 20-foot sandstone unit and below 200 feet of red and white banded sandstone. These three units were the lowest strata which he included in a larger unit. This inclusive unit totaled 712 feet and was designated "massive cross-bedded sandstones". The sandstone below the limestone bed was that which Dutton was later to name the Wingate sandstone, now known as the Entrada sandstone. The limestone, or [illegible], and the [illegible] and the overlying unit are now variously designated and most recently interpreted as the Todilto formation or its equivalent (Wright and Dickey, 1958), ([illegible], and Olson, 1952), (Harshbarger, Repenning, and Irwin, 1957).

Although this limestone unit in a predominantly clastic sequence is rather striking, Dutton (1885), in speaking of the same general area, makes no reference to it. He does mention the presence of gypsum, probably the Todilto gypsum, in other areas. In his description of the Wingate sandstone he neglected to note that its preservation in such striking cliffs is largely due to its resistant limestone cap. It would seem that to Dutton this thin limestone, in contrast with the impressive sandstones of the area, was unworthy of comment.

Gregory (1917, p. 55), referring specifically to Gilbert's measured section, says of the limestone unit:

> "For this stratum I propose the name Todilto formation, from Todilto Park where I first studied it. At this locality it caps an eastward-sloping mesa of Wingate sandstone, and consists of 10 feet of resistant compact blue-gray limestone separated into two parts by a few inches of red sandy lumpy shale containing flattened calcareous mud pebbles. Near the top are well worn fragments of black, white, and gray quartz and chert in quantities sufficient to form irregular bands embedded in the limestone."

Thus the unit under discussion was established in the literature. Although rather well defined as a formation forty years ago, its status has been in doubt for approximately one-half of that time.

Baker, Dane, and Reeside (1936) decided that the Todilto did not merit formational status and designated it as a basal member of the Morrison formation. They also stated that it was not conformable with the underlying Wingate sandstone.

However, in 1947 the same authors reversed themselves. They decided not to include the Todilto limestone and gypsum in the Morrison but rather correlated it with the Wanakah formation of southern Colorado and designated it a member thereof. They further stated that the Todilto was in gradational contact with the underlying Entrada (formerly Wingate) sandstone.

In the 1936 paper, Baker, Dane, and Reeside did not think sea water essential to the formation of the limestone and gypsum sequence. However, in their 1947 paper it is at least inferred.

In 1949 and again in 1952 Imlay supported the marine or abnormal marine hypothesis and correlated the Todilto with the marine Curtis formation and the Wanakah formation.

In 1950, W. B. Hoover designated the Todilto as the middle member of an "Entrada formation", consisting of a lower Entrada sandstone member, the Todilto member, and an upper "Red Mesa" member.

Wright and Becker (1951) interpreted the limestone and gypsum of the Todilto as a lake deposit and in 1952 Rapaport, Hadfield, and Olson reached a similar conclusion.

Harshbarger, Repenning, and Irwin (1957) stated that the Todilto limestone was deposited during the final stages of continental Entrada deposition and during early Curtis-Summerville deposition. They believe that the Todilto basin was connected with the Curtis sea to the northwest by a

shallow "strait" across a submerged ridge in the Four Corners area of New Mexico, Colorado, Utah, and Arizona. They suggest that these conditions gave rise to restricted circulation of marine waters and produced an abnormal evaporitic marine environment.

It is well established that the Todilto unit everywhere rests on the Entrada (formerly Wingate) sandstone, although locally the latter has been assigned different names. It is also generally accepted that immediately overlying the Todilto are strata of pre-Morrison deposition. These beds have most often been interpreted as Summerville or equivalent.

Some of the published interpretations of the uppermost Triassic and Jurassic rocks in northern New Mexico are summarized in Figure 2.

Acknowledgments

The writer is indebted to Roger Y. Anderson, who originally suggested the project. Without his advice and encouragement the study would not have been completed.

A grant from the New Mexico Geological Society helped defray expenses.

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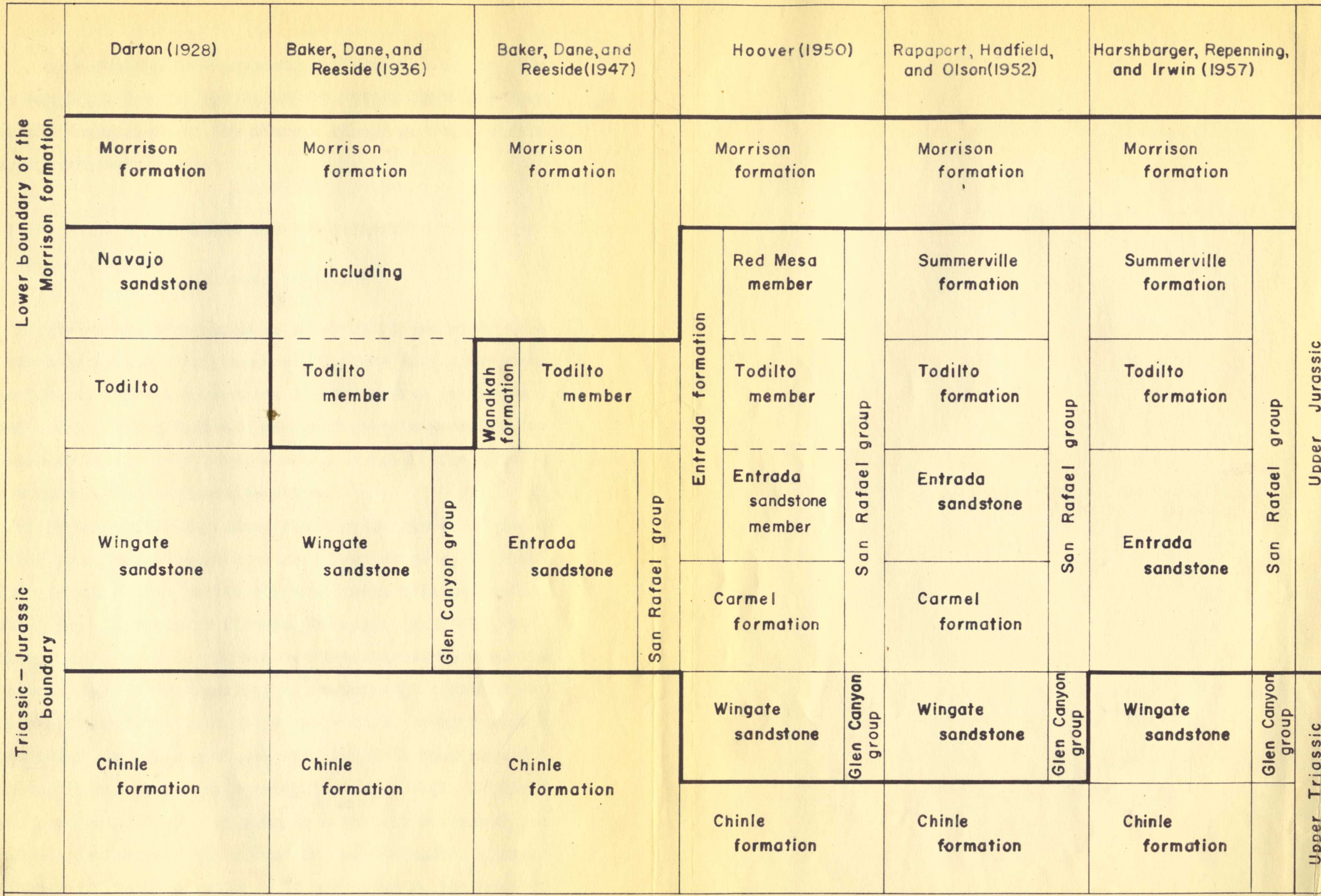

Figure 2.— Summary of stratigraphic interpretations which have been suggested for the Triassic—Jurassic rocks in northern New Mexico.

Appreciation is expressed to Oliver K. Ash and Sidney R. Ash for accompanying the writer during the field phase of the investigation. My sincere thanks go to my wife for typing the manuscript.

PRE-TODILTO STRATIGRAPHY

Entrada Sandstone

The strata which make up the Todilto are everywhere underlain by the same homogeneous, fine- to medium-grained sandstone. Always containing frosted quartz grains, massive and usually cross-bedded, this sandstone is generally conceded to be in large part of eolian origin. The unit is now known as the Entrada sandstone.

It was originally named the Wingate sandstone by Dutton (1885, p. 137) for exposures near Fort Wingate, New Mexico. This is the oldest published formational designation of strata on the Colorado Plateau (Rapaport, Hadfield, and Olson, 1952, p. 18). Subsequent investigations established the presence of two massive, cliff-forming sandstone units on the Colorado Plateau, both believed to be of Jurassic age. The lower one was correlated with Dutton's Wingate and included in the Glen Canyon group (Baker, Dobbin, McKnight, and Reeside, 1927). The younger sandstone was named the Entrada sandstone and included in the San Rafael group by Gilluly and Reeside (1928). It proved to be the more widespread and persistent of the two.

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By 1947 regional correlations had revealed that Dutton's Wingate in New Mexico was actually the Entrada of Utah. Priority of nomenclature dictated the abandonment of the term "Entrada" and extension of "Wingate" into Utah and elsewhere. However, the Utah terminology was favored by Baker, Dane, and Reeside (1947) and has since generally been adopted by others.

In recent years the presence of about 40 feet of "Utah Wingate" below the Entrada at Dutton's type locality has been established. This is a part of the sequence which he originally included under the term Wingate. This lowest portion of the original Wingate, now reassigned that name, is believed to be of Upper Triassic rather than Jurassic age.

When the Glen Canyon and San Rafael terms were first carried into northern New Mexico, the only recognized member of either group was the Wingate sandstone of the Glen Canyon group. Later the correlation of the Wingate of New Mexico with the Entrada of Utah reversed the situation. The Entrada of the San Rafael group became the only recognized representative of either group in New Mexico. Hoover (1950) re-introduced the Glen Canyon term in New Mexico by suggesting the presence of strata correlative with the Utah Wingate. Recently the trend has been to expand the sequence included in the San Rafael group, primarily at the expense of the overlying Morrison formation (see Figure 2).

The Entrada sandstone is now thought to consist of upper and lower clean sandy members and a medial silty member (Harshbarger, Repenning, and Irwin, 1957, p. 35). Only the middle and upper members are found in New Mexico and the Todilto rests upon the upper sandy member.

The upper sandy member forms prominent cliffs where exposed in northern New Mexico. The presence of thin, evenly-bedded sequences within the dominantly massive and cross-bedded sandstone indicates periods of subaqueous deposition. Intervals of subaqueous deposition during Entrada time, probably occurring in desert lake basins, presaged the Todilto basin of a later date.

At various times the Entrada has borne local names other than the original Wingate designation. In northeastern New Mexico and southeastern Colorado it has been called the Exeter sandstone (Parker, 1933). Also in northeastern New Mexico, where it is exposed around the Sangre de Cristo Mountains, the term Ocate sandstone has been coined and applied to the Entrada (Bachman, 1953).

The Entrada sandstone [illegible] upper and lower [illegible] (Harshbarger, Repenning, and Irwin, 1957, p. 36), [illegible] middle and upper members are [illegible] in New Mexico and [illegible] Todilto rests upon the upper sandy member.

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TODILTO STRATIGRAPHY

General Statement

Todilto strata are widespread in northern New Mexico. They extend to the western border of the State and locally into the eastern edge of Arizona, but are not found west of the Defiance Uplift (Wright and Becker, 1951). The northern limit of the Todilto formation extends well into Colorado (Wood, Kelley, and MacAlpin, 1948; and others). The southwestern limit of deposition is fairly well established. It lies along a line which trends generally northwestward and passes about 9 miles east of Gallup. Approximately 19 miles south of Grants it gradually swings to an east-west trend (Rapaport, Hadfield, and Olson, 1952). In central New Mexico the southern limit can only be inferred because of the removal of Mesozoic rocks and the interruption by the Rio Grande Depression. The southeastern limit of the Todilto is defined by the pinchouts along the northern scarps of the Llano Estacado. Northwest of these exposures Jurassic rocks have been removed by erosion but the Todilto is believed to have been continuous with outcrops near Las Vegas. The eastern and northeastern limits are poorly defined because of cover and the discontinuous nature of the Todilto.

The depositional basin of the Todilto is generally in accord with that of other Jurassic rocks of the San Rafael

TODILTO PALEOGEOGRAPHY

General Statement

Todilto strata are widespread in northwestern New Mexico. They extend to the western border of New Mexico and into the eastern edge of Arizona, but are not found west of the Defiance Uplift (Harshbarger, 1949). The northern limit of the Todilto Formation extends well into Colorado (Wood, Kelley, and MacAlpin, 1948; and others). The southwestern limit of deposition is fairly well established. It lies along a line which trends generally southeastward and passes about 9 miles east of Gallup. Approximately 15 miles south of Grants it gradually swings to an east-west trend (Rapaport, Hadfield, and Olson, 1952). In central New Mexico the southern limit can only be inferred because of the removal of Mesozoic rocks and the interruption by the Rio Grande Depression. The southeastern limit of the Todilto is defined by the pinchouts along the northern margin of the Llano Estacado. Northeast of these exposures Jurassic rocks have been removed by erosion but the Todilto is believed to have been continuous with outcrops near Las Vegas. The eastern and northeastern limits are poorly defined because of cover and the discontinuous nature of the Todilto.

The depositional basin of the Todilto is generally in accord with that of other Jurassic rocks of the [illegible].

group in western New Mexico. However, the Entrada and the overlying units extend beyond the limits of Todilto deposition.

The upper Gypsum member is more or less centrally located within the basin of deposition; the Limestone member, being the more persistent of the two, extends far beyond the limits of gypsum deposition.

The writer's interpretation of the extent and configuration of the Todilto basin is shown in Figure 4.

Pre-Todilto Boundary

As noted previously, the Todilto always rests on the Entrada sandstone. At all exposures examined in the course of this investigation the Limestone member was present. In some localities where the Gypsum member is present, the limestone has been reported as absent. It is possible that the limestone is simply covered by slumping of the gypsum in these cases.

Harshbarger, Repenning, and Irwin (1957) have included with the limestone some silt and mudstone beds in western New Mexico. These beds lie immediately below and above the limestone unit and may well belong with it. However, for the purposes of this investigation no such clastic strata were included unless they were found within the limestone.

On the west side of Todilto Park, a thin limy sandstone unit in the same stratigraphic position is probably equivalent

to the Todilto but is not here considered as part of it. Smith (1951, p. 72) illustrated the Todilto limestone as being present at that locality.

The Entrada-Todilto contact is one of a transitional to intertonguing nature. Although a conformable contact was accepted generally, with the exception of Baker, Dane, and Reeside (1936), it appears that Northrop and Wood (1946) were the first to suggest an intertonguing relationship. In 1947, Baker, Dane, and Reeside stated that the contact was gradational. Silver (1948) also reported intertonguing of the two units.

In the Satan Pass area north of Thoreau, New Mexico the intertonguing is well developed. Here sandy limestone layers and lenses 1 to 2 inches thick appear near the top of a 4-foot sequence of evenly though slightly wavy-bedded calcareous sandstone and silty sandstone. This unit is in gradational contact with typically massive Entrada sandstone below. Upward from the first appearance of carbonate deposition the limestone gradually becomes dominant with only thin partings of silty sandstone lying between layers of limestone. In this area the zone of intertonguing is about 5 to 8 feet thick.

Intertonguing is also found in the lower part of the limestone in the Toadlena section (Appendix, Section 5), and Hornsby Ranch section (Appendix, Section 3).

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Smith (1951, p. 12) illustrated the Todilto-like type as being present at that locality.

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Intertonguing is also found in the lower part of the limestone in the Todilto section (Appendix, Section 5), and Hornby Ranch section (Appendix, Section 3).

Elsewhere actual intertonguing is slight and can not be so clearly demonstrated. However, in all measured sections strong evidence of the transitional nature of the contact was found. This evidence ranges from the presence of sequences of evenly bedded, calcareous sandstone to siltstone below the limestone to transition zones no more than 2 or 3 inches thick. The transitional clastic sequences are from 6 inches to several feet thick and occasionally show wave ripple marks. The thinnest transition zone observed is in the Church Rock section (Appendix, Section 1). At this locality hand samples may consist of typical clean, soft Entrada sandstone on one side of the contact and grade through very calcareous sandstone to almost pure crystalline limestone in the space of approximately 2 inches. There is no intervening break or visible bedding plane. Coarse sand grains and occasional small pebbles are found near the contact, both in the sandstone and in the lower part of the limestone.

A slight undulation or waviness of bedding was the only irregularity observed in the basal contact zone of the Todilto. The actual relief of this irregularity is never more than one inch and the waviness usually appears in both the lower limestone layers and the uppermost clastic layers. Slight reworking of material by wave action in shallow water is believed responsible for this feature.

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Prior to the beginning of Todilto limestone deposition, shallow water gradually encroached upon the slightly irregular surface of the Entrada dune sands in a broad, nearly flat basin. Wind and wave action would have produced slight reworking of the uppermost sand with the first carbonate precipitation. With only a shallow body of water, parts of the dunes might have remained exposed and through wind and wave action occasionally contributed lenses and layers of sand within the lower part of the limestone. The influx of streams transporting some of the dune sand from around the edges of the basin would also have contributed to intertonguing. Coarser material occasionally brought into the basin by streams was sparse and concentrated near the margin of the Todilto basin. The probable broadly undulating character of the eolian sand surface would tend to be smoothed out. However, incomplete leveling would explain local variations in thickness of limestone. Gradually encroaching waters and carbonate precipitation would allow the preservation of near-shore features, such as intertonguing and reworking of underlying material, at a considerable distance inward from the final margin of the basin.

Post-Todilto Boundary

With the possible exception of some cross-bedded sandstone units, the overlying strata are believed to be of fluviatile origin (Rapaport, Hadfield, and Olson, 1952).

Prior to the deposition of the Todilto limestone, shallow water gradually encroached upon the slightly irregular surface of the Entrada dune sands in a broad, nearly flat basin. Wind and wave action would have produced slight reworking of the uppermost sand with the initial carbonate precipitation. With only a shallow body of water, parts of the dunes might have remained exposed and the edges with the wave action occasionally contributed lenses and layers of sand within the lower part of the limestone. The influx of streams transporting some of the debris from around the edges of the basin would also have contributed to intertonguing. Coarser material carried mainly through into the basin by streams was trapped and concentrated near the margin of the Todilto basin. The probable broadly undulating character of the eolian sand surface would tend to be smoothed out. However, incomplete leveling would explain local variations in thickness of limestone. Gradually encroaching waters and carbonate precipitation would explain the preservation of near-shore features, such as [illegible] reworking of underlying material, and [illegible] inward from the final margin of the basin.

Post-Todilto Boundary

With the possible exception of some cross-bedded [illegible] sandstone units, the overlying strata are believed to be of fluviatile origin (Harshbarger, Repenning, and Irwin, 1957).

The lower contact of the Todilto represents a radical change from eolian clastic to subaqueous chemical deposition, but it was a change which came about gradually. On the other hand the upper boundary of the Todilto formation represents a more abrupt change, but one which is only a shift from one mode of subaqueous deposition to another.

The upper surface of the limestone, where exposed, usually shows some pitting and solution cavities which are present short distances downward in the unit. This pitting may be largely of recent origin and only in part immediately post-depositional. No long exposure and erosion of the limestone is believed to have preceded the deposition of overlying beds. Slight rejuvenation of source areas may have caused streams which had carried predominantly dissolved material into the Todilto basin to begin to transport clastic material, which transgressively overlapped the limestone unit.

The "primary folds" of the Zuni Uplift area described by Rapaport, Hadfield, and Olson (1952, p. 38-39) are pertinent to the discussion. These folds are minor anticlines from a few inches to 25 feet across, confined almost entirely to the Todilto limestone and basal silts and sands of the overlying Summerville beds. Usually asymmetrical, the folds die out rapidly below and gradually upwards. Some affect the entire Todilto limestone, the basal beds of the Summerville, and approximately the upper foot of the Entrada, whereas others are restricted to a single horizon within the

limestone. These folds display thickening on crests and troughs and thinning on the flanks and some are recumbent to more highly deformed, features which suggest plastic deformation of a penecontemporaneous origin. These folds show no apparent relation to the Zuni Uplift deformation which was accomplished primarily by rupture rather than plastic yielding (Rapaport, Hadfield, and Olson, 1952). These folds are believed to have been formed by creep of the calcareous, laminated Todilto muds down the primary slope of the basin under the weight of at least part of the overlying sediments. This would preclude significant exposure, drying out, and consequent lithification of the Todilto sediments prior to folding.

Under such transitional conditions the circulation of water through the overlying beds, combined with the plastic deformation, would favor solution and recrystallization of the uppermost part of the limestone. These factors would obscure laminae and produce the frequently noted coarser texture of the topmost Todilto limestone.

The establishment of a conformable contact above the gypsum member is more tenuous. The abrupt termination of the thick gypsum unit or its sudden extreme thinning in a comparatively short distance has led a number of geologists to postulate the presence of an erosional unconformity. However, where the actual contact is visible it appears conformable. Unfortunately the soft nature of the gypsum

limestone. These folds display intricate crests and troughs and thinning on the flanks and seem too intricate to have simply developed, rather they suggest plastic deformation of a concordant origin. These folds show no apparent relation to the main Todilto deformation which was accomplished primarily by gypsum's plastic yielding (Hopwood, Holfield, and Gibson, 1955). These folds are believed to have been formed by creep of the calcareous, laminated limestone down the slope of the basin or at the margin of an uneven surface of overlying sediments. This would produce significant ponding, drying out, and consequent lithification of the Todilto sediments prior to folding.

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The establishment of a conformable contact above the gypsum member is very tenuous. The abrupt termination of the thick gypsum unit or its marked decrease in thickness in comparatively short distances has led a number of geologists to postulate the presence of an erosional unconformity. However, where the actual contact is visible it appears conformable. Unfortunately, the soft nature of the gypsum

and the slope-forming character of the overlying sediments prevent frequent exposure of this contact. Nor can the nature of thinning of the gypsum be determined where sudden changes in thickness occur. An erosional interval would probably have left a very irregular surface on the soft gypsum which would be observable. Therefore a poorly defined but apparently flat contact is believed to be more indicative of conformity than nonconformity.

Terminology of the Todilto Formation

As previously noted the limestone unit is the more persistent and widespread of the two members. The type description of the formation was based upon the limestone unit alone and it has usually been called the Todilto limestone. Where the Gypsum member is also present this term is somewhat of a misnomer when applied to the entire unit. Where the members are differentiated, formal member names would perhaps distinguish between the lower limestone and limestones which do occur within the gypsum. To the writer's knowledge, no formal member name has been proposed for the gypsum unit but the terms Todilto Limestone member and Todilto Gypsum member have been applied informally where both are present. Although the impressive thickness of gypsum perhaps merits a locality or other formal member name, it is believed that nothing would be gained by proposing one after nearly forty years of the present usage.

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It is suggested, however, that at least the two-fold terminology be followed and the members differentiated.

Limestone Member

The Limestone member of the Todilto formation is perhaps the most consistent Jurassic unit exposed in New Mexico. It is lithologically almost the same throughout and ranges in thickness from a minimum of 0 feet to a reported 40 feet. The minimum thickness measured by the writer was 2 1/2 feet.

According to Gregory (1917, p. 154), the word Todilto is from the Navajo language and means "sounding water". The limestone causes a small waterfall in the perennial stream at the point where it was examined in Todilto Park. This is on the Navajo Indian Reservation and is near the type locality of the formation.

The limestone is a fine-grained, almost aphanitic, very thin bedded to very thinly laminated, medium to dark gray or black carbonaceous, and usually fetid unit. A small admixture of silt to very fine sand grains is often present, usually concentrated in the lower part of the limestone. A moderately coarse recrystallized and sometimes slightly brecciated zone often occurs near the top of the unit and obscures bedding and lamination. Slight waviness to extreme contortion of bedding is usually present, mostly in the upper recrystallized zone. Gypsum is often present, finely disseminated along bedding planes and fractures of the limestone,

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especially where the upper Gypsum member is also present and to a lesser degree elsewhere. This feature is usually limited to the upper one-third of the Limestone member.

Medium-grained clastic to oolitic limestone is found in the lower part of the unit in the Hornsby Ranch section where intertonguing occurs with the Entrada sandstone. The only other clastic sediments are a small amount of very fine grained material near the top of the Satan Pass section and the sand and silt which is present in the zones of intertonguing at the base of the unit.

Where overlain by the Gypsum member the limestone unit seems to contain more silt, gypsum, and carbonaceous organic impurities, causing the laminations to produce a "shaly" weathering. Here the weathered fragments may be readily split to the thickness of only one or two laminae.

Although the limestone has been called bituminous to asphaltic, at only two localities did this appear to be the case. Small amounts of black vitreous asphaltic material were found in thin seams along vertical fractures in the limestone at the Tonque Arroyo and Mesa Alta sections. This is similar to an occurrence in the Pony Express limestone reported by Read, Wood, Wanek, and Mackee (1949) from the Piedra River Canyon area of southern Colorado. The fetid odor produced on striking fragments of the limestone seems to be best developed where the Gypsum member is present. It has been suggested by Professor S. A. Northrop (personal

communication) that this may be caused by free sulfur liberated from the contained gypsum.

An exception to the well-bedded nature of the Todilto is found in the Church Rock section where a single crystalline bed of limestone comprises the entire formation. Qualitatively it may be stated that the limestone is of a more crystalline nature along the western margin of the unit and in the Grants uranium district, New Mexico than in its other areas of occurrence.

The presence of small bands and fragments of chert near the top of the limestone has been noted but the chert is generally not well developed. Some chert was found in the Satan Pass section, the Church Rock section, and the Todilto Park section. Chert occurrence in the Gypsum member of the Tonque Arroyo section is discussed later in the paper.

A feature which is well developed only in the Satan Pass and Todilto Park sections is the occurrence of ovoids of crystalline calcite scattered through the limestone. These structures weather into relief and range in diameter from about 0.5 millimeter to 4 millimeters.

The maximum thickness of the Limestone member which was measured during the course of this study was 19 feet, 9 inches in the Tijeras Coal Basin. The minimum thickness measured was 2 feet, 6 inches in the Church Rock section (See Figures 3 and 4 for extent and thickness trends of the Limestone member).

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Gypsum became significant in the latter stages of limestone formation and gradually gained dominance. The exact horizon in any outcrop at which gypsum first becomes the dominant constituent of the rock is impossible to pick. The change is gradual and usually from black, porous, contorted carbonate with intercalated layers and larger knots of white gypsum to white gypsum containing stringers and lenses of dark gray to black carbonate.

Gypsum Member

The Gypsum member of the Todilto formation exhibits less variation within its area of exposure than the basal limestone member. Where present, its relative thickness dwarfs the limestone but its homogeneity gives it a sameness throughout.

This member is composed of fine-grained white massive gypsum. Bedding is not apparent except where thin layers or beds of dark calcium carbonate interrupt the gypsum.

In exposure the member presents a rounded, drab gray, puffy appearance except where it holds vertical or near-vertical faces. In the latter case it has a grayish white smooth surface showing dark gray to black calcium carbonate defined bedding which is discontinuous and somewhat irregular. Other stringers and irregular patches of carbonate give the gypsum a mottled appearance. Where actual limestone beds occur within the gypsum they appear as more resistent and protruding gray ledges which persist across the outcrop.

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As previously noted, some limestone continued to be deposited after gypsum became the dominant product. The limestone is more abundant in the lower part of the gypsum but there appears to have been some calcium carbonate precipitation throughout the period of gypsum deposition. The uppermost portion of the Gypsum member commonly contains beds of limestone and in several areas they cap the entire gypsum sequence. Laminations are usually absent or only poorly developed in the limestone beds occurring within the gypsum.

In the Tonque Arroyo section (Appendix, Section 6) approximately the lower 20 feet of the upper Gypsum member consists of layers of gypsum from a fraction of an inch to 3 inches thick, separated by discrete laminae of black carbonate which are essentially noncontorted and persistent. Near the top of the member several limestone beds are found within the gypsum and one bed caps it. A similar bed of limestone forms the top of the Gypsum member in the Mesa Gigante section (Appendix, Section 2).

Some fragments of pink chalcedony or chert are often found associated with the gypsum. However, it is difficult to determine whether they are _in situ_ or not. In the limestone bed which caps the Gypsum member in Tonque Arroyo this material is found in irregular pieces and as a coating on bedding planes and fractures. Swift (1956, p. 55) included this limestone bed with his Cachana member of the Morrison formation.

As previously noted, some limestone evidently was deposited after gypsum became predominant. The limestone is more abundant in the lower part of the gypsum but there appears to have been some calcium carbonate precipitation throughout the period of gypsum deposition. The uppermost portion of the Gypsum member commonly consists of beds of limestone and in several areas they cap the entire gypsum sequence. Laminations are usually absent or only poorly developed in the limestone beds occurring within the gypsum.

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The incompetent nature of the gypsum unit combined with the slope-forming character of the overlying sediments make it difficult to observe and examine the exact upper contact. However, where clearly seen, as in the Tonque Arroyo section and the Mesa Gigante section, this contact appears to be sharp but not irregular.

Darton (1928, p. 168) reports that an analysis of gypsum from the Todilto formation in the Nacimiento Mountains yielded 97 per cent pure gypsum, about 3 per cent of probable calcium carbonate, and only 0.18 per cent of insoluble residue.

The maximum observed thickness of the unit, 171 feet including the capping limestone beds, was in the Tonque Arroyo section (Appendix, Section 6). Figures 3 and 4 illustrate the writer's interpretation of the extent and thickness of the Gypsum member.

POST-TODILTO STRATIGRAPHY

Summerville Formation and Equivalent Strata

The sedimentary beds lying immediately above the Todilto formation have been variously assigned. When the Todilto was considered a basal member of the Morrison formation the overlying sediments were, of course, included in it. Since the 1947 revision of the Jurassic stratigraphy by Baker, Dane, and Reeside, excluding the Todilto from the Morrison, additional revisions have been suggested in northwestern New

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The maximum observed thickness of the unit, 1?? feet including the capping limestone beds, was in the [illegible] Arroyo section (appendix, section 4). Figures 3 and [illegible] illustrate the writer's interpretation of the extent and thickness of the gypsum member.

Post-Todilto [illegible]

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Mexico. In 1950 Hoover proposed the term Red Mesa member of the Entrada formation for strata lying above the Todilto formation in northwestern New Mexico. He stated that the Red Mesa member was probably correlative with the Summerville. Since then a number of workers have stated that a true Summerville unit is present in that position. Rapaport, Hadfield, and Olson (1952) and other writers have carried the term farther eastward to a position above the Gypsum member. In southern Colorado the Todilto-equivalent Pony Express limestone is considered the basal member of the Wanakah formation (Wood, Kelley, and MacAlpin, 1948). A Wanakah equivalent including the Todilto and some overlying beds has been postulated in northeastern New Mexico.

Swift (1956, p. 16) chose the top of the Todilto gypsum as the base of the Morrison formation in north-central New Mexico. Swift's (1956, p. 18) point that it is often difficult to differentiate the top of the San Rafael group from the Morrison is well taken. However, his suggestion that such units as the Summerville and Wanakah formations may be considered as local lentils of the Morrison formation would probably not meet with general agreement. It seems likely that at least part of Swift's Rio Gallina and Cachana members of the Morrison are actually pre-Morrison and as such would fall within the San Rafael group as Summerville equivalents.

The acceptance of the presence of strata of the San Rafael group below the Morrison implies a close relation to

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The acceptance of the presence of strata of the San Rafael group below the Morrison formation includes materials

the underlying Todilto formation. This seems to be a correct assumption. The strata in question are usually massive sandstones near the margins of the Todilto formation but otherwise composed of a well-bedded sequence of sandstone, siltstone, and mudstone throughout the main area of the basin. The Summerville, to which these beds are at least approximately equivalent, is considered marine in Utah. The strata are probably fluviatile and lacustrine in the Todilto region. No fossils are known from the Summerville in New Mexico.

The transitional nature of the upper Todilto contact noted particularly in the area outside of the Gypsum member raises the question of the relation of the Gypsum member to these post-limestone clastic sediments. Assuming no marked break in sedimentation at the end of limestone deposition, clastic sediments must have been accumulating above the limestone member while gypsum was being precipitated in the center of the basin. Gypsum deposition in only the central and deeper part of the Todilto Basin will account for at least part of the greater thickness of the total formation there. However, the observed ratio of gypsum thickness to limestone thickness of at least 8 to 1 seems difficult to explain in this manner. No visible wedging out of the gypsum has ever been reported. It is here suggested that at least part of the gypsum member probably grades into or interfingers laterally with the clastic sediments which were deposited contemporaneously around its margins. This interpretation

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is shown in the fence diagram (Fig. 3). The nature of the two deposits and the outcrops obscure any supporting field evidence.

ORIGIN OF THE TODILTO FORMATION

General Evidence

The Todilto formation occurs in a dominantly non-marine stratigraphic sequence in an area which is not far removed from the marine Jurassic rocks of the Curtis formation of southeastern Utah. The acceptance of a marine origin for the Todilto not only extends the limits of Jurassic marine inundation but may also raise questions regarding associated strata. Contradictory interpretations occur in the literature. Recent advocates of some type of marine environment have been Baker, Dane, and Reeside (1947), Imlay (1949, 1952), McKee et al. (1956), and Harshbarger, Repenning, and Irwin (1957). Authors supporting a non-marine, lacustrine origin have been Stokes (1944), Northrop (1950), Wright and Becker (1951), and Rapaport, Hadfield, and Olson (1952).

The impressive thickness of gypsum overlying a limestone unit and the normal precipitation order from sea water has seemed to support a marine origin. However, it does not follow that because the evaporation of sea water will always produce these two minerals in that order that all similar sequences were necessarily so formed. It is believed that

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ORIGIN OF [illegible]

General Statement

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such a sequence can be deposited from lake waters if the concentration of dissolved mineral matter is high enough.

There is no suggestion of the presence of any other normal marine evaporitic minerals such as chlorides anywhere in the Todilto to the writer's knowledge. Magnesium carbonate, commonly associated with gypsum of marine evaporitic origin, is absent.

The stratigraphic position of the Todilto and its relation to adjacent units also seems pertinent to any environmental interpretations. A thin marine limestone would indeed seem anomalous included between two thick, pure, coarse clastics with no related shales. The lower unit is believed to be eolian with local playa deposits and the upper one is apparently fluviatile. The transitional nature of the contacts has already been pointed out, and according to Rapaport, Hadfield, and Olson (1952, p. 26) beyond the pinchout of the Todilto the contact between these two units is completely arbitrary. These features do not seem suggestive of a period of marine deposition.

Some reasonable connection with known marine rocks of the same age must be shown to substantiate a marine origin for the Todilto. To the south the depositional pinchout is clearly demonstrated for all Jurassic strata in New Mexico. The southern delimiting and source area was an east-west trending Jurassic highland. In western New Mexico this positive element has been called the Mogollon Highland by

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Harshbarger, Repenning, and Irwin (1957, p. 43) and the name Zuni Highland was applied by Rapaport, Hadfield, and Olson (1952, p. 15). The work of Dobrovolny, Summerson, and Bates (1947) indicates an apparent extension of this positive area into eastern New Mexico. The Todilto basin was thus effectively cut off from the Jurassic marine waters of the Mexican geosyncline.

To the north the Uncompahgre positive area or range of southern Colorado blocked marine access to the basin. The only possible connections were to the northeast or the northwest. Both avenues of marine access have been postulated, with the idea that extensions of the positive mass restricted circulation of marine waters and produced an evaporitic basin.

In northeastern New Mexico all representatives of the San Rafael group either pinch out or thin considerably. The Todilto, in particular, becomes thin and spotty and difficult to trace to a pinchout. This has been ascribed to non-deposition rather than post-Todilto erosion (New Mexico Geological Society, 7th Field Conference Guidebook, 1956, p. 86). The Entrada alone is consistently present. This area then was not a locus of San Rafael deposition. The persistence of the Entrada in this marginal area of the San Rafael depositional basin may be ascribed to its manner of origin, for eolian sediments are capable of migration independent of gravity.

Harshbarger, Repenning, and Irwin (1957, p. 19) and the Zuni Highland was [illegible] by Baker, [illegible] and [illegible] (1952, p. 15). The work of Harshbarger and others (1957) indicates an apparent extension of this positive area into eastern New Mexico. The Chinle basin was effectively cut off from the Jurassic marine waters of the Sundance geosyncline.

To the north the Uncompahgre positive area or ranges of southern Colorado blocked marine access to the basin. The only possible connections were to the northeast or the northwest. Both avenues of marine access have been considered, with the idea that extensions of the positive area restricted circulation of marine water and produced an evaporite basin.

In northwestern New Mexico all three formations of the San Rafael group either pinch out or thin considerably. The Todilto, in particular, becomes thin and spotty and difficult to trace to a pinchout. This has been ascribed to nondeposition rather than post-Todilto erosion (Four Corners Geological Society, 7th Field Conference Guidebook, 1954, p. 54). The Entrada alone is consistently present. This area thus was not a locus of San Rafael deposition. The persistence of the Entrada in this marginal area of the San Rafael depositional basin may be ascribed to its manner of origin, for eolian sediments are capable of migration independent of gravity.

Marine connection to the northeast does not appear likely and in fact the northwest connection has been favored recently. Harshbarger, Repenning, and Irwin (1957, p. 46) postulate such a connection. They suggest a northwest-trending "strait" in the Four Corners area, connecting the Summerville sea with the Todilto "gulf" across a broad submerged ridge. Kelley (1955, p. 82) refers to this ridge as a northeast-trending cross-warp across a northwest-trending sag between the Mogollon and Uncompahgre uplands in the Four Corners area. The pinchout of the Todilto in this direction is fairly well known, with no equivalent unit extending beyond. The limiting ridge or cross-warp may have been emergent and prevented access of marine waters. The suggested subaqueous scouring of this ridge and consequent thinning of the Entrada in this area described by Harshbarger, Repenning, and Irwin (1957) could be equally well explained by subaerial erosion of the exposed ridge.

Paleontologic Evidence

Fossil evidence has been invoked to support a marine origin for the Todilto formation. However, upon examination of the literature such evidence does not appear to be conclusive. The scarcity of fossil material is well known. No marine invertebrate megafossils or microfossils were found in the course of this investigation, nor have any ever been reported.

Marine connection to the northwest does not appear likely and in fact has not been proposed(?) recently. Harshbarger, Repenning, and Irwin (1957, p. 59) postulate such a connection. They suggest a continental-like "strait" in the Four Corners area, connecting the Summerville sea with the Todilto "gulf" across a broad uplifted ridge. Kelley (1955, p. 62) refers to this ridge as a northeast-trending cross-warp across a northwest-trending sag between the Mogollon and Uncompahgre uplands in the Four Corners area. The pinchout of the Todilto in this direction is fairly well known, with no equivalent unit extending beyond. The limiting ridge or cross-warp may have been emergent and prevented access of marine water. The suggested subaqueous scouring of this ridge and consequent thinning of the Entrada in this area described by Harshbarger, Repenning, and Irwin (1957) could be equally well explained by subaerial erosion of the exposed ridge.

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Two genera of fossil fish have been identified from the Todilto formation. They are Pholidophorus americanus Eastman, identified by Koerner (1930), and Leptolepis schoewei, described by Dunkle (1942).* The same two forms are found in the Pony Express limestone in Colorado (Read, Wood, Wanek, and Mackee, 1948). Occurrences are sparse in New Mexico. Fish were first found by Koerner (1930) in the area of the Hornsby Ranch section of this paper, where specimens of both forms were collected by the writer. A few other specimens have been found near Lamy, Acoma, and Suwanee, New Mexico. Scales are occasionally found in other areas. Both species are small; Pholidophorus ranges in length from 2 1/2 to 4 1/2 inches and Leptolepis probably does not exceed 2 1/2 inches in length.

These fish have been described as having marine affiliations (Baker, Dane, and Reeside, 1947). Investigations of the literature revealed several interesting facts. According to Romer (1945, p. 537), the genus Pholidophorus is an advanced holostean fish, an artificial grouping, containing precursors of the modern, spiny-rayed, teleostean fish. Leptolepis is variously assigned as an advanced holostean or a primitive teleost (Romer, 1945). Assuming the teleostean classification, Leptolepis belongs to the Isospondyli,

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a group which includes the present-day trout and other members of the salmon family. The Isospondyli contain both marine and non-marine types, some being adapted to both environments. Romer and Grove (1935), however, note a strong marine trend in actinopterygian fish during the Mesozoic. Both holostean and teleostean fish fall under this classification. Romer and Grove (1935, p. 808) state: "...we feel that the absence of invertebrate fossils in fish localities gives a fair presumption of fresh water conditions" and "limestone deposits weigh the evidence heavily in favor of marine conditions, but a lacustrine origin is not impossible." The North American literature reports no occurrence of the two genera of fish in question in association with invertebrate fossils. In the Upper Lykins formation, a red bed unit of Colorado, both types were found in association with a fossil gymnosperm seed cone (Dunkle, 1942, p. 1). Another example is that of specimens of <u>Leptolepis</u> found in association with plant fossils in a laminated siliceous shale of the Weber conglomerate of Nevada (David, 1941).

Swain (1946, p. 553) described a new species of ostracode, <u>Metacypris todiltensis</u>, from limestone of the Todilto formation north of Thoreau, New Mexico, the area of the Satan Pass section of this paper. Specimens were identified by the writer from samples collected at that locality. The ostracodes were found only in the lower portion of the formation and primarily in the zone of intertonguing where they occur both in the limestone beds and in the intervening

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clastic layers. The examination by binocular microscope of samples from other localities revealed no new occurrence of these ostracodes.

A number of papers refer to Swain's article and call the ostracodes non-marine or brackish water in type, the term "brackish" seeming to admit a possibility of abnormal or modified marine conditions. Examination of Swain's description shows that at least in the published remarks he made no mention of brackish water. Indeed, the only definite indication as to environment is found in the phrase "non marine ostracodes", from the title, and in the mention of similarity of the new species to Metacypris whitei of the Morrison formation. The Morrison is considered to be of fluviatile and lacustrine origin.

An alga, not yet described, was found some years ago by John R. Peters in the Todilto limestone at Todilto Park (S. A. Northrop, personal communication).

Results of Laboratory Investigations

It was considered likely that the application of pollen and spore recovery technique to the Todilto would yield new and perhaps decisive evidence as to the conditions under which it was formed.

The analysis of twenty-eight samples was completed. The analysis of one sample of gypsum was carried to completion along with two samples of uppermost Entrada sandstone.

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The analysis of twenty-eight samples was completed. The analysis of one sample of gypsum was carried to completion along with the analyses of specimens of limestone samples.

The remainder of the samples were taken from limestone units or included clastic layers. The residue from each sample was mounted on a laboratory slide, stained, and examined under high magnification. The source localities, descriptions of the samples, and results are tabulated in Table 1.

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Table 1. Summary of Samples Subjected to Pollen and Spore Extraction

Sample	Source	Rock Type	Organic Material
T-1	Outcrop on New Mexico Highway 156, 30 miles east of Santa Rosa	Limestone (fetid)	Abundant
T-2	Outcrop Sec. 5, T. 8 N., R. 27 E. west of Ima	Limestone (fetid)	Abundant
T-3	Unit #1 Mesita Blanca section	Sandstone (Entrada)	Little
T-4	Unit #2 Mesita Blanca section	Contact Entrada-Todilto silty ss.	Little
T-5	Unit #5 Mesita Blanca section	Argillaceous parting in limestone	Moderate
T-6	Unit #4 Mesita Blanca section	Silty limestone (fetid)	Abundant
T-7	Unit #3 Hagan section	Limestone (fetid)	Abundant
T-8	Unit #2 Church Rock section	Limestone (crystalline)	Little
T-9	Unit #2 West Todilto Park section	Calcareous ss.	Little
T-10	Unit #2 Satan Pass section	Calcareous ss.	Little
T-11	Unit #5 Satan Pass section	Limestone	Abundant
T-12	Unit #3 Tijeras Coal Basin section	Limestone (fetid)	Abundant
T-13	Unit #4 Tijeras Coal Basin section	Siltstone parting in limestone	Moderate
T-14	Unit #5 Tijeras Coal Basin section	Limestone (fetid)	Abundant
T-15	Unit #4 Satan Pass section	Limestone and sandstone containing ostracodes	Moderate

Table 1. (cont'd)

Sample	Source	Rock Type	Organic Material
T-20	Unit #12 Mesita Blanca section	Gypsum	Little
T-23	Unit #2 Hornsby Ranch section	Calcareous siltstone	Moderate
T-24	Unit #3 Hornsby Ranch section	Calcarenite	Abundant
T-25	Unit #4 Hornsby Ranch section	"Shaly" limestone (fetid)	Abundant
T-26	Unit #5 Hornsby Ranch section	Limestone (fetid) containing fish	Abundant
T-27	Unit #6 Hornsby Ranch section	"Shaly" limestone (fetid)	Abundant
T-28	Unit #7 Hornsby Ranch section	Limestone (porous, fetid)	Abundant
T-29	Unit #4 Lamy section	Limestone (fetid)	Abundant
T-30	Unit #7 Mesa Gigante section	Limestone (crystalline, fetid) capping gypsum	Moderate
T-31	Unit #2 Romeroville section	Silty limestone (fetid)	Abundant
T-32	Unit #3 East Todilto Park section	Limestone (slightly crystalline)	Moderate, probable algal spore
T-33	Unit #4 Toadlena section	Limestone and siltstone	Moderate, conifer pollen grain
T-34	Unit #2 Mesa Alta section	Limestone (fetid)	Abundant

The results, in identifiable microfossils, were essentially nil. One highly corroded conifer pollen grain was identified in a sample from the Toadlena section (Sample T-33). A possible algal spore was found in material from the Todilto Park section (Sample T-32). A few extremely small, circular, unidentifiable structures were also seen in this sample. In addition, occasional fragments of plant tracheids were found in several samples. These are believed to be from conifers.

The essential absence of recognizable microfossils is not due to a lack of organic material. On the contrary all samples analyzed from the Todilto were found to contain some organic material and most contained it in abundance. The material is, however, either in such a finely divided state or so badly corroded as to defy identification of origin. Many of the particles of pollen size appear to be simply aggregates of finer material and have no definite shape. Others show fairly regular outlines and suggest the possibility of being structures of some type which have been corroded beyond recognition.

The data and results of five thin sections are summarized in Table 2.

The results, in identifiable microfossils, were essentially nil. One highly corroded conifer pollen grain was identified in a sample from the Tonalea section (Sample T-31). A possible algal spore was found in material from the Todilto Park section (Sample P-13). A few extremely small, circular, unidentifiable structures were also seen in this sample. In addition, occasional fragments of plant tracheids were found in several samples. These are believed to be from conifers.

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The data and results of five palynological analyses are summarized in Table 2.

Table 2. Summary of Petrographic Thin Sections.

Thin Section	Source	Remarks
T-a	Outcrop on New Mexico Highway 156, 30 miles east of Santa Rosa	Limestone, cut across bedding; very fine grained, crystalline calcite mosaic with occasional quartz grains and carbonaceous streaks.
T-b	Same as above	Limestone, cut parallel to bedding; very fine grained, crystalline calcite mosaic with occasional quartz grains and irregular carbonaceous areas.
T-c	Sec. 5, T. 8 N., R. 27 E., west of Ima	Limestone, cut across bedding; very fine grained, crystalline calcite mosaic with occasional quartz grains and carbonaceous streaks.
T-d	Unit #8 Tijeras Coal Basin section	Gypsum; crystalline, fine grained unoriented fibrous or acicular texture with rare calcite grains.
T-e	Unit #3 Tijeras Coal Basin section	Silty limestone cut parallel to bedding; very fine grained, crystalline calcite mosaic with numerous quartz grains and disseminated carbonaceous material.

Interpretation of the Evidence

The abundance of organic material but lack of recognizable microfossils which was demonstrated quite early in the study was at first very puzzling. Mr. Roger Y. Anderson was the first to note the similarity of the material with that found in oil shale deposits. Bradley (1930), in his work on the Green River formation and oil shales, describes similar material. In some parts of the Green River strata there is also excellent preservation of microfossils. This formation accumulated in an Eocene lake basin, the deposits of which show yearly lamination or varves. The Green River varves are composed of pairs of organic and fine-grained carbonate layers.

The abundant very fine organic material found in the Todilto formation is probably of the same type as the sapropel which forms in modern lakes. Two types of sapropel exist: one called "gyttja", in which the organic matter is more or less determinable, and the other, "dy", if the material before deposition is in colloidal form (Twenhofel, 1950, p. 694). The latter type material is characteristic of dystrophic lakes which have scanty oxygen in their bottom waters and little nutrient matter.

The very thinly laminated character of the Todilto limestone is perhaps one of the best documented of the facts about it. Swift (1956, p. 14) described this feature as "varvelike laminar structure". The similarity of the fine

organic material with that of other varved deposits, combined with the similarity and regularity of laminations suggests that the Todilto limestone may also be varved. Douglas Kirkland (personal communication), pursuing a separate investigation on this aspect of the formation, has reached such a conclusion.

If the assumption of a varved nature of the Limestone member is correct, it would appear to favor a lacustrine environment. In speaking of varved deposits of glacial origin, Twenhofel (1950, p. 67) states: "...if melt waters flow into salt lakes or the sea, the fine sediments are flocculated and varves do not form...". This may be applicable to other types of varved sediments also.

The possibility that the Todilto limestone might also be of an oil shale nature is apparent. It is believed that if this were the case in the geologic past it is no longer an oil shale. The appearance of the organic material and the fossil fish suggest fairly complete carbonization. A true oil shale does not contain oil or bituminous material as such, but will yield oil only upon destructive distillation of the organic material. The presence of asphaltic material in some areas and an oily scum which is formed upon the solution of the limestone in acid suggests that distillation of any available material may have already taken place through geologic processes.

The bottom of a body of water, poorly aerated and high in dissolved mineral matter, would have been inhospitable to organisms of any sort. Consisting of alternating layers of partly decayed organic material and carbonate mud, the bottom probably supported few if any organisms. Bottom-dwelling scavengers would, of course, have tended to destroy the laminations. It is believed that any life which existed was planktonic. There was probably some contribution of wind-borne material such as pollen but this would have suffered the same fate as organic material produced within the lake. Most alteration of material must have occurred prior to its deposition on the bottom. Almost all the preserved fossils are found near the edges of the original basin where some clastic deposition occurred. These localities are far from the suggested connection with marine waters. The writer suggests that both the fish and the ostracodes were fresh-water types which were carried into the basin by streams or lived near their mouths. It seems probable that the inhospitable environment killed them and they were then entombed.

Fossil evidence is not conclusive as to a marine or lacustrine origin for the Todilto but seems to favor a lacustrine origin. The results of laboratory investigations carried out in this study suggest a lacustrine origin. Field evidence seems to indicate the same. Paleogeographic considerations probably do not weigh heavily for either

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interpretation, but a non-marine one is certainly not incompatible with them. Therefore it is concluded that the Todilto formation was probably deposited under non-marine lacustrine conditions.

Lake Todilto

The postulated Lake Todilto would have been a transitory feature as are all lakes. Based upon his study of the possible varved nature of the formation in the Warm Springs area, Douglas Kirkland (personal communication) has calculated that the entire Todilto sequence including both members could have been formed in slightly less than 20,000 years.

The lake is visualized as a broad, relatively shallow body of water without outlet and lying in an arid region. Aridity is suggested by the intertonguing of the Limestone member with the underlying Entrada dune sands as well as by the presence of gypsum. The paucity of clastic material and the high amount of dissolved mineral material which must have been present in the water suggest several things. First, the surrounding area must have been of slight relief and probably in old age, physiographically. The origin of the stream waters must have been at considerable distance from the basin. The rate of evaporation must have equaled the rate of inflow and with no outlet the level of the lake was probably fairly constant. Planktonic growth must have been abundant in the surface water.

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The postulated Lake Toldito would have been a transitory feature as are all lakes. Based upon his study of the possible varved nature of the formation in the Sierra Blanca area, Douglas Kirkland (personal communication) has calculated that the entire Toldito sequence including both members could have been formed in slightly less than 20,000 years.

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Lake Todilto was probably a relatively static body of water for the greater part of its existence. It must have begun to dry up gradually because of increased evaporation, decrease of water supply, or both. Calcium sulfate precipitation gradually replaced that of calcium carbonate in the central part of the basin. It is believed that a slight rejuvenation of surrounding areas accompanied the drying up of the lake and caused fluviatile clastic sediments to be deposited above the Limestone member, progressively overlapping it and further restricting the central body of water in which gypsum was being deposited. Occasional freshening of the water, perhaps yearly, caused the return of calcium carbonate precipitation. In some areas the last deposition was dominantly limestone. During the final stages of the lake in some areas it may have been reduced to disconnected bodies of water in which either limestone or gypsum was deposited in greater than average thicknesses. During this period other parts of the limestone and gypsum may have been left exposed and susceptible to solution and some reworking. Deposition of the limestone unit where it stands alone must have been essentially complete at the time when gypsum precipitation became dominant in the central area.

The writer's interpretations of the distribution, thicknesses, and relations of the Todilto Limestone member and Gypsum member to each other and related strata are shown in Figures 3 and 4.

CONCLUSIONS

The following conclusions regarding the Todilto strata in New Mexico are deemed justifiable upon consideration of the evidence available:

1. The Todilto strata should be accorded full formational status as an extensive and mappable unit, consisting of two distinct members--the lower Limestone member and the upper Gypsum member, the two not being everywhere coextensive.
2. The Entrada sandstone-Todilto contact is transitional to locally intertonguing in nature and represents the incursion of Todilto waters upon the slightly irregular surface of predominantly eolian sands.
3. The Todilto formation was deposited in a broad shallow non-marine lake, rich in organic material and high in dissolved calcium, carbonate, and sulfate ions.
4. The laminae of the Limestone member are probably varves. The organic material contained therein was originally of a sapropelic nature and is similar to that found in oil shale deposits.
5. The Gypsum member represents the final stages of the desiccation of Lake Todilto and was deposited in the central part of the basin during the incursion of Summerville or equivalent sediments.

It is equivalent in time to some portion of these sediments and probably grades into or interfingers laterally with them.

6. The upper contact of the Todilto formation is conformable to transitional.

7. The Todilto formation and some part of the overlying sediments are best placed in the San Rafael group as it is known in New Mexico.

APPENDIX

Selected Stratigraphic Sections

Section #1. Church Rock Section.

Location: East of Gallup, New Mexico, north of U. S. Highway 66, approximately NW 1/4 Sec. 8, T. 15 N., R. 16 W. (measured by H. O. Ash and O. K. Ash, June 6, 1957).

Top of section

	Feet
Summerville formation:	
3. Sandstone, brownish maroon and light gray, fine grained, silty; composed of subrounded to subangular clear quartz grains with some amber-colored grains and with dark accessory mineral grains. Very calcareous, resembles Entrada sandstone but is even-bedded and color-banded above, weathers massive, forming steep slope; base is sharp and slightly wavy	Not measured
Todilto formation:	
2. Limestone, light pinkish gray, very fine grained, crystalline and tough, with small amount of crystalline calcite as stringers and ovoid segregations; sandy at base; obscure, slightly wavy bedding planes; rare small rounded chalcedony pebbles occur in the lower portion of the unit. Weathers flaggy to blocky; forms ledge capping Entrada benches; base is undulatory and transitional	2.5
Total Todilto formation .	2.5
Entrada sandstone:	
1. Sandstone, light gray, fine grained, calcareous cemented transition zone at top of massive, cross-bedded sandstone. This transitional zone, approximately 1 1/2 feet thick, is composed of subrounded quartz grains with some silt and rare small, rounded chalcedony pebbles scattered throughout; weathers massive; forms rounded to sheer "typical" Entrada cliff	Not measured

Bottom of section

Section #2. Mesa Gigante Section.

Location: South face of Mesa Gigante; approximately SE 1/4 Sec. 16, T. 9 N., R. 3 W. (measured by H. O. Ash, July 15, 1957).

Top of section	Feet
Summerville formation:	
8. Mudstone, medium grayish green, very calcareous, thin; overlain by even-bedded brownish maroon, alternating sandstone and mudstone beds weatherint rubbly; forms steep slope; base poorly exposed, but appears transitional with unit 7	Not measured
Todilto formation:	
Gypsum member:	
7. Limestone, dark gray to black, fetid, finely crystalline; not laminated; contains small amount of pink chert in thin streaks; base slightly irregular and transitional with unit 6	0.5
6. Gypsum, white to light gray, fine grained crystalline, slightly calcareous throughout with occasional lenses or patches of black carbonate; bedding absent or obscure except in the lower one-third where thin carbonate layers define it; weathers massive, giving rounded "badlands" topography with a porous, puffy surface; dirty light brown to pinkish in color; base is transitional; thickness approximate	80.0^{+}_{-}
Total Gypsum member	80.5^{+}_{-}
Limestone member:	
5. Limestone, brownish gray to black, fetid, fine grained; in part appears fragmental to recrystallized near upper contact; bedding contorted with irregular laminations; thin layers of gypsum irregularly intercalated with limestone layers in upper portion; weathers massive; forms ledge at top of cliff; base is transitional	4.0
4. Limestone, very dark gray to black, fetid, fine grained with suggestion of some brecciation and recrystallization; bedding and laminae contorted; base is transitional	2.5

Section #2 (cont'd) Feet

3.	Limestone, dark gray, fetid, very fine grained, slightly silty to sandy, rather coarsely laminated; bedding undulatory; base is sharp and flat	1.5
2.	Limestone, dark gray, fine grained, sandy, very thinly laminated; bedding and upper and lower contacts slightly wavy; top marked by 1- to 2-inch yellowish brown gypsiferous zone; base is sharp and relatively flat	0.5
	Total Limestone member ..	8.5
	Total Todilto formation .	89 ±

Entrada sandstone:

1.	Sandstone, medium gray, fine to medium grained, clean, very calcareous near upper contact; well-defined cross-bedding below but no visible bedding near contact; weathers massive; forms rounded cliff	Not measured

Bottom of section

Section #3. Hornsby Ranch Section.

Location: On the Duke Hornsby ranch northwest of Ima, New Mexico, east side of Bull Canyon (measured by H. O. Ash and S. R. Ash, July 28, 1957).

Top of section	Feet
Unnamed unit:	
8. Sandstone, light gray, speckled with yellow and black, weathering to light tan to buff, speckled with white, fine to medium grained, well sorted; composed of subrounded clear quartz with some pink and pale green chalcedony grains; firmly cemented, calcareous; cross-bedded; weathers massive; forms rounded ledges. Base is sharp and slightly undulatory	Not measured
Todilto formation:	
7. Limestone, fetid, very dark gray to black, carbonaceous, weathering medium gray; very fine grained with coarsely recrystallized zones showing solution cavities, undulatory thin-bedded to laminated; weathers flaggy; forms top of ledge; base is gradational	2.0
6. Limestone, fetid, very dark gray to black, carbonaceous, very fine grained and silty; flat, finely laminated bedding; weathers hackly; forms notch in ledge; base is gradational	0.5
5. Limestone, fetid, very dark gray to black, carbonaceous, fine grained, silty, probably clastic in part and resistant; thin to very thin flat-bedded; contains moderately abundant carbonized fish scales and fragments and rarely complete fish; weathers flaggy to platy; base is gradational	1.5
4. Calcarenite and shaly limestone, very dark greenish gray to black, carbonaceous; consists of finely laminated, silty to shaly limestone, and beds and lenses of fine- to medium-grained, oolitic calcarenite interspersed throughout the interval; contains moderately abundant carbonized fish scales in the uppermost shaly parts; weathers hackly to flaggy; base is gradational	1.0

Section #3 (cont'd) Feet

3. Calcarenite and silty to shaly limestone, very dark greenish gray to black, carbonaceous; consists of a lower 4-inch and an upper 2-inch bed of fine-grained, sandy calcarenite with lenses and stringers of coarse-grained calcite particles, weathering into relief on the bedding planes. Intervening and overlying shaly limestone partings are the same as in unit 6; weathers flaggy; base is sharp and flat 0.6

2. Siltstone, medium gray; soft calcareous; very thin bedded; weathers platy; base is sharp and flat 0.3

Total Todilto formation 5.9

Entrada sandstone:

1. Sandstone, light gray, weathering to very light gray, tan and light reddish tan; occasional small limonite stains; fine to medium grained, well sorted; composed of rounded to subrounded clear and frosted quartz grains with some amber-colored and bluish green grains; poorly cemented, friable, generally massive, except that the upper foot is a fluvial bed with cross bedding marked by coarse sand grains which also occur at the top of the bed; weathers massive; forms rounded cliff .... Not measured

Bottom of section

Section #4. Romeroville Section.

Location: Approximately 300 yards north of U. S. Highway 85 on the west side of Romeroville Gap, New Mexico (measured by H. O. Ash, Sept. 21, 1957).

Top of section	Feet
Immediately overlying strata concealed by talus debris	
Todilto formation:	
5. Limestone, dark gray to black, fetid; irregular portions appear partly clastic or recrystallized and are porous and crumbly while the balance is very fine grained, crystalline and compact. In part massive; coarse laminations exhibit contortions. Top is broadly undulating and solution pitted. Exact upper contact not observed; base is gradational	3.0
4. Limestone, black, fetid, very fine grained crystalline, tough; slightly undulating laminae; weathers platy to flaggy; base is transitional	4.0
3. Limestone, black, fetid, very fine grained crystalline; shows flat thin laminae, in part shaly; other portions weather flaggy	2.5
2. Limestone, dark greenish gray, fetid, fine grained, sandy to silty, thinly laminated with shaly fracture; base is indistinct, to some degree gradational	1.5
Total Todilto formation .	11.0
Entrada sandstone:	
1. Sandstone, buff to yellowish tan, calcareous, compact, fine to medium grained, rounded to subangular; weathers massive into rounded cliff ...	Not measured
Bottom of section	

Section #5. Toadlena Section.

Location: Along road to U. S. Highway 666, approximately 1/4 mile east of the town of Toadlena in a road cut through an east-dipping hogback (measured by H. O. Ash and O. K. Ash, Oct. 25, 1957).

Top of section	Feet
Summerville formation:	
7. Sandstone, brownish maroon, very calcareous, fine grained, silty, soft; appears to be derived from the Entrada Sandstone; base is transitional ..	Not measured
6. Claystone, light olive-gray, calcareous, silty, slightly bentonitic; base sharp and broadly undulating but with only slight relief	2.0
Todilto formation:	
5. Limestone, medium olive-gray, very fine grained crystalline and dense; bedding thin, slightly wavy; some fine laminations but not fissile. Abundant thin bands of white crystalline calcite and near the top the unit is generally somewhat more coarse in texture. Top is solution pitted; weathers flaggy to slabby; base is transitional	8.5
4. Limestone and sandstone, interbedded, highly calcareous, very fine grained silty sandstone which is very thin bedded to laminated and fissile, and includes 1/2 - 1 1/2 inch layers of medium gray very fine grained crystalline limestone; base is transitional	3.5
Total Todilto formation .	12.0
Entrada sandstone:	
3. Siltstone, light greenish gray, calcareous and sandy; base is sharp and flat	2.5
2. Mudstone, medium dark brownish red, slightly calcareous and sandy; base is irregular and gradational	5.5
1. Sandstone, pale orange to tan, slightly calcareous, fine to medium grained; rounded to subrounded quartz grains with minor black and pale green grains	Not measured

Bottom of section

Section #6. Tonque Arroyo Section.

Location: On the Hagan road approximately 2.5 miles east of U. S. Highway 85 up Tonque Arroyo (measured by H. O. Ash, Jan. 16, 1958).

Top of section	Feet
Summerville formation or equivalent:	
12. Claystone and mudstone at base; mottled maroon and light grayish-green, calcareous, intermingled claystone and mudstone zone approximately 2 feet thick. Above is a fine-grained, calcareous brown sandstone bed bearing pink chert fragments. Similar alternations form the balance of the unit. Weathers rounded to blocky; forms irregular slope; base is sharp and flat	Not measured
Todilto formation:	
11. Limestone, medium to dark gray, not laminated, very fine grained crystalline with stringers and zones of coarsely recrystallized calcite and some thin stringers of gypsum; contains abundant pink chert as granular-appearing layers on top surface, along fractures and as zones in the limestone. Contains occasional small rounded limestone pebbles within the matrix; forms dip slope	2.0
10. Gypsum, white with a slightly pinkish tinge; very fine grained, earthy; pink chert fragments abundant on the surface but not found in place; forms rounded slope; base is sharp	13.0
9. Limestone, medium gray, very fine grained, crystalline, base sharp and flat	0.3
8. Gypsum, white to grayish white, fine grained slightly calcareous; base is sharp and flat	0.5
7. Limestone, medium gray, very fine grained, crystalline; base is sharp and flat	0.2

Section #6 (cont'd) Feet

6.	Gypsum, white to grayish white, fine grained, crystalline, slightly calcareous throughout; in lower part black calcium carbonate layers are abundant as flat partings or bedding from 1 to 3 inches apart, becoming less apparent upwards until not visible in approximately the upper one-half of the unit; weathers to rounded hummocky hills and slopes with a "puffy" appearance; base is transitional	153.0
5.	Gypsum and limestone, white, fine-grained crystalline gypsum layers from 1/4 to 1 inch thick, alternating with layers of black limestone 1/16 to 1/4 inch thick, the two in approximately equal amounts; limestone is dominant below and gypsum above; bedding delineated by carbonate layers is slightly undulatory; weathers to a near vertical face; base is transitional	2.0
	Total Gypsum member	171.0
	Limestone member:	
4.	Limestone, fetid, very dark gray to black, carbonaceous; very fine grained with coarsely recrystallized zones showing solution cavities in the upper one-third of the unit; fine laminations in the lower part grade upward from a slightly undulatory nature through moderately contorted and broken laminations to highly contorted laminations with intercalated gypsum layers at the top of the unit. The lower portion weathers papery; forms top of ledge; base is transitional	5.0
3.	Limestone, fetid, medium to dark gray, carbonaceous, very fine grained, thinly laminated with a few intercalated gypsum laminae; contains black, vitreous asphaltic material along fractures; base is transitional	1.0

Section #6 (cont'd) Feet

2. Limestone, fetid, dark gray to black, carbonaceous, very fine grained, silty, thinly laminated with some layers of crystalline limestone 1 to 2 inches thick and a few intercalated gypsum laminae; contains black, vitreous asphaltic material along fractures; weathers papery; base is slightly undulatory 2.0

Total Limestone member ... 8.0

Total Todilto formation .. 179.0

Entrada sandstone:

1. Sandstone, yellowish tan, fine grained, well sorted; composed of subrounded quartz grains, poorly cemented and friable except for the upper 2 to 4 inches which is a very calcareous medium gray, apparently transitional zone; thin stringers of gypsum occur along fractures; a suggestion of even bedding in the upper portion; weathers massive; forms rounded cliff .... Not measured

Bottom of section

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