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FRESH-WATER LIMESTONE FROM THE TOROLA VALLEY, NORTHEASTERN EL SALVADOR

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INTRODUCTION

The occurrence of probable late Tertiary (Pliocene?) lacustrine limestone and other sedimentaries in the Torola Valley, immediately west of the village of Carolina, northeastern El Salvador, was reported by Stirton and Gealey (1949, p. 1739). Our material was

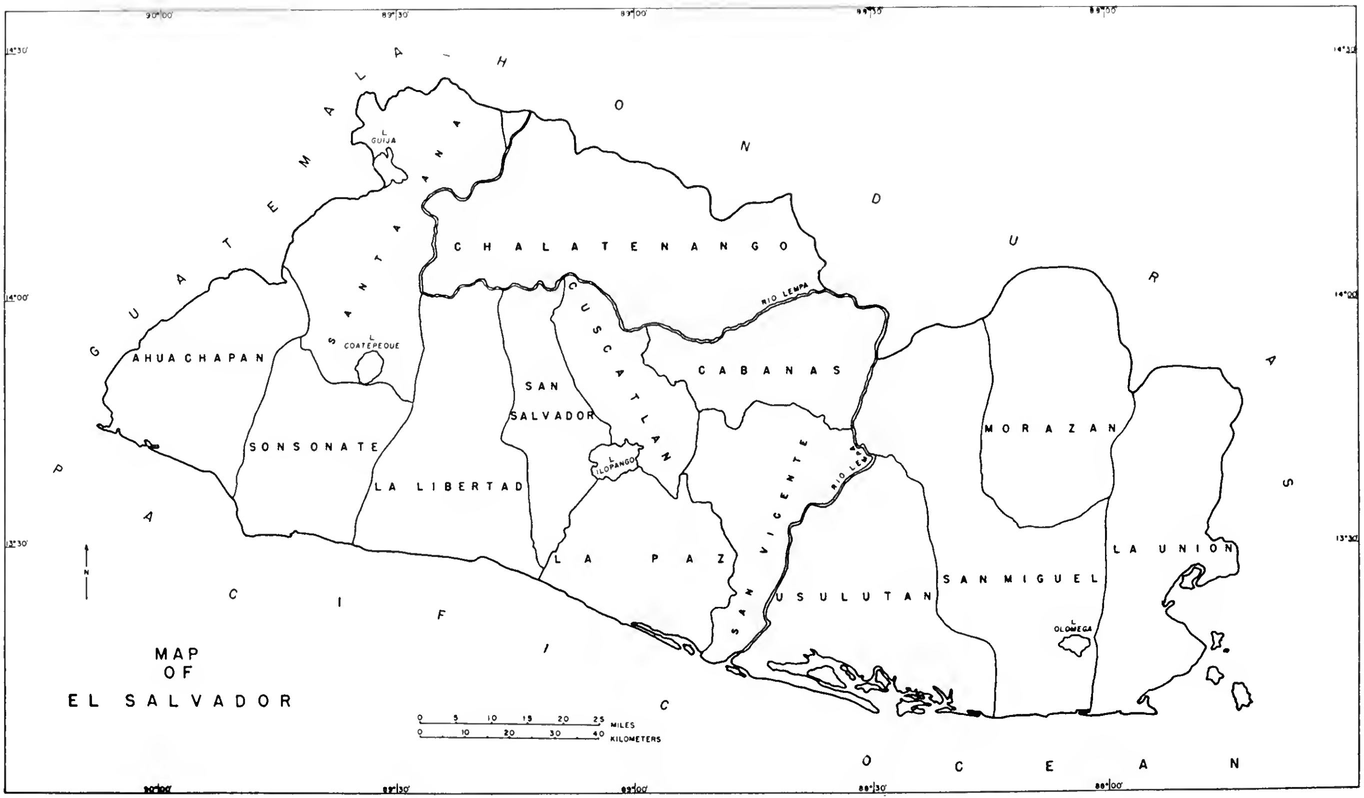

FIG. 66. Map of El Salvador, showing various departments.

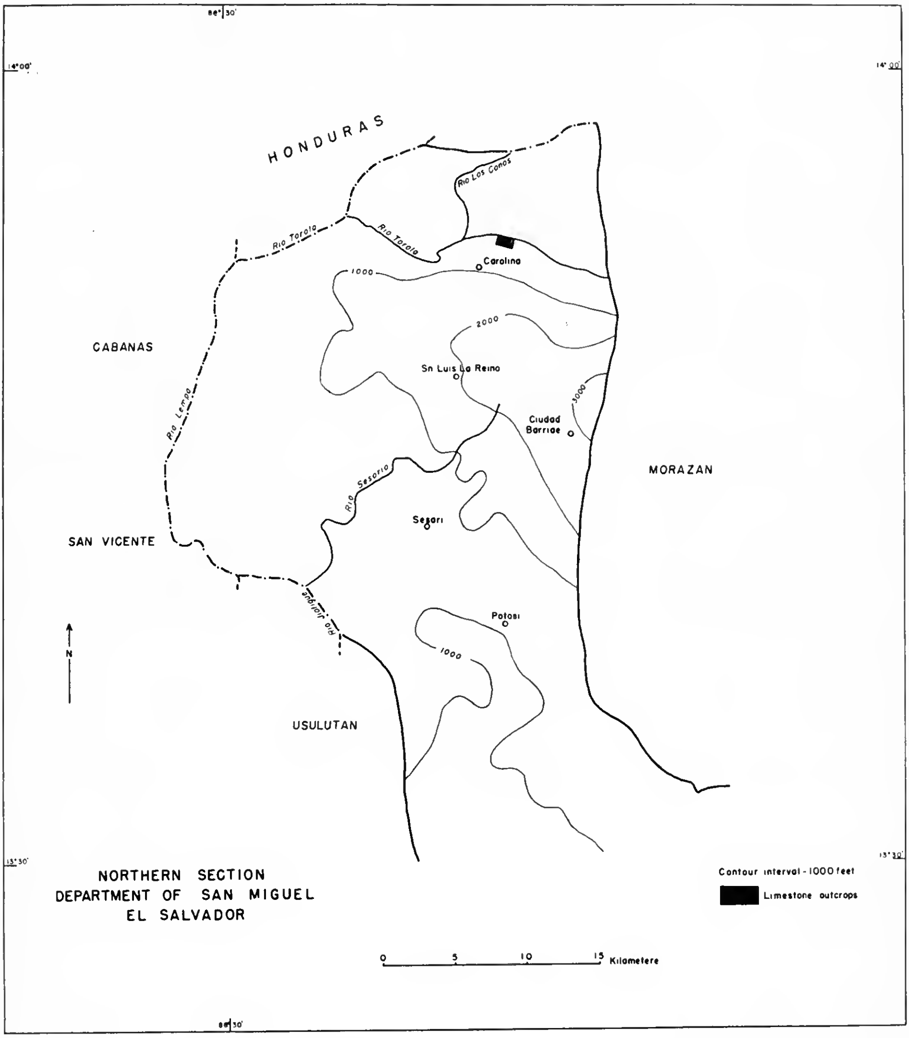

FIG. 67. Northern section of Department of San Miguel. Shaded area northeast of Carolina represents Río Torola limestone outcrop.

collected from a nearby outcrop of limestone situated 1.2 miles north and 34° east of Carolina, about 0.5 mile east of the junction of Río Torola and Riachuelo de Carolina (fig. 67). The latter name is not on any of the maps published by the Government of El Salvador.

The basal portion of the limestone is oolitic. Immediately above the oolitic deposit and intercalated in the limestone beds are thin lenses of grayish brown clay, which stands out conspicuously against the buff limestone.

The limestone locality was discovered accidentally, while the geological party was reconnoitering the Torola Valley. It was visited twice; the second visit was designed to obtain additional data after the fossil content of the limestone had been examined and the lacustrine origin of the deposit was suspected.

Field observation supplemented by survey maps of the region fully confirms Stirton and Gealey's (loc. cit.) view that the Torola Valley "is structurally a syncline, the axial portion being occupied by the subsequent Río Torola. The river enters El Salvador about 20 miles northeast of Volcan Cacaguatique and, swinging sharply, flows westward along the syncline axis." The valley might have resulted from faulting, though no fault scarp was observed.

The Torola Valley affords excellent opportunity for studies in late Tertiary geology. The road leading to the valley branches off the Pan American Highway about 128 kilometers (about 77 miles) east of San Salvador and passes through Chapeltique and Ciudad Barrios. It is a rough, dirt road, parts of which are impassable during the rainy season. North of Chapeltique the road becomes still rougher and more and more mountainous. Sharp curves and steep climbs add to the difficulty of motor travel. The trip should not be attempted in an automobile not equipped with four-wheel drive.

DESCRIPTION AND ANALYSIS OF RIO TOROLA LIMESTONE

The stratigraphic sequence of the Río Torola limestone is shown in the vertical section (fig. 68). The character and composition of the rocks composing the outcrop indicate that there was some change in physical or biological conditions during deposition, especially between the deposition of the basal oolitic beds and the overlying limestone.

BASAL OOLITIC BEDS

As stated above, the oolitic beds underlie the limestone. They have an average thickness of eighteen inches; their horizontal extension, about ten feet, is limited to the western extremity of the outcrop. It may be that the beds have a much greater extension, but they are not exposed.

In hand specimens the oolitic rock is light brown or tan in color, and very friable (fig. 69). The individual oolites are buff-

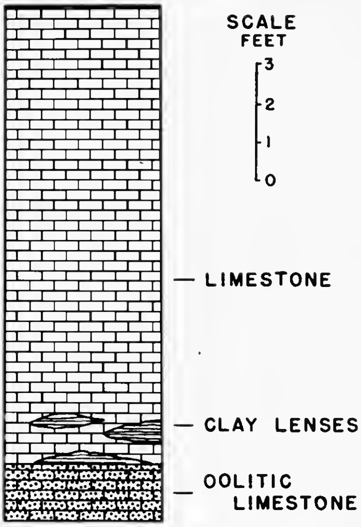

Fig. 68. Vertical section of the Río Torola limestone outcrop.

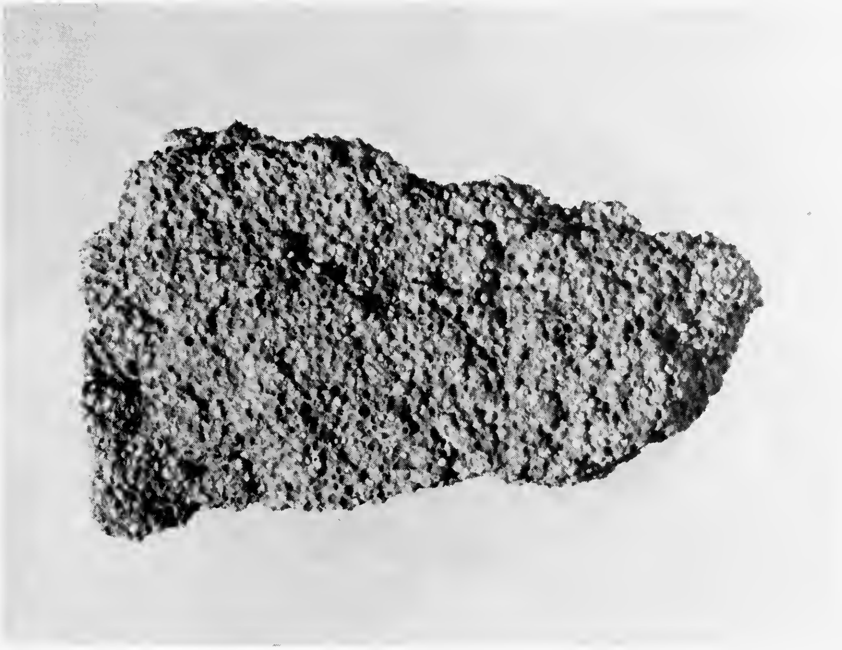

Fig. 69. Hand specimen of the oolitic rock. The oolites are loosely cemented and they can be freed easily. Natural size.

FIG. 70. Free oolites, showing shape and size. × 6.

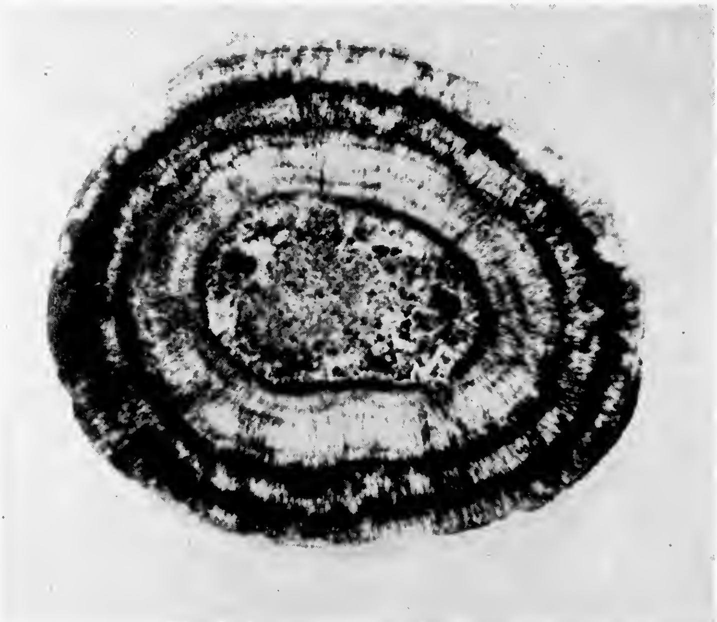

FIG. 71. Section of individual oolite, showing concentric and radial structure. Crossed nicols. × 60.

colored and predominantly spherical, and they can be extracted from the matrix with ease (fig. 70). A sample consisting of about thirteen hundred free oolites was examined and measured, with the following results:

Diameter mm.	Percentage of total
0.60–0.80	58
0.80–1.00	31
1.00–1.70	8
1.70–2.00	3

The uniformity of size of the oolites is only remotely indicated by the dimensions shown in the table. In this particular sample, oolites having a diameter less than 0.60 mm. or greater than 2.00 mm. were not observed, although both smaller and larger oolites may exist in a given part of the formation.

In thin and polished sections the oolites show both concentric and radial structure (figs. 71–73). Growth seems to have taken place outward from a central core or nucleus, which is usually an oblate or rounded mass of clay and calcium carbonate, often admixed with grains of calcite and detrital feldspar or quartz. The fibers of the radial structure are composed of calcite and minor amounts of clay. They might have been originally composed of aragonite changed later to calcite. In some sections radial and polygonal cracks in

CHEMICAL COMPOSITION OF OOLITES AND MATRIX

ROBERT K. WYANT, *Analyst*

	Oolites per cent	Oolites and matrix per cent
SiO_2	12.68	27.14
TiO_2	0.08	0.20
Al_2O_3	1.80	3.95
Fe_2O_3	1.19	2.31
FeO	0.11	0.22
MnO	0.02	0.02
MgO	3.98	6.29
CaO	41.14	27.62
Na_2O	0.30	0.58
K_2O	0.42	0.90
H_2O-	2.52	2.16
H_2O+	0.08	0.31
P_2O_5	0.04	0.06
CO_2	35.41	28.16
SO_3	0.04	0.06
C	0.10	0.12
	99.91	100.10

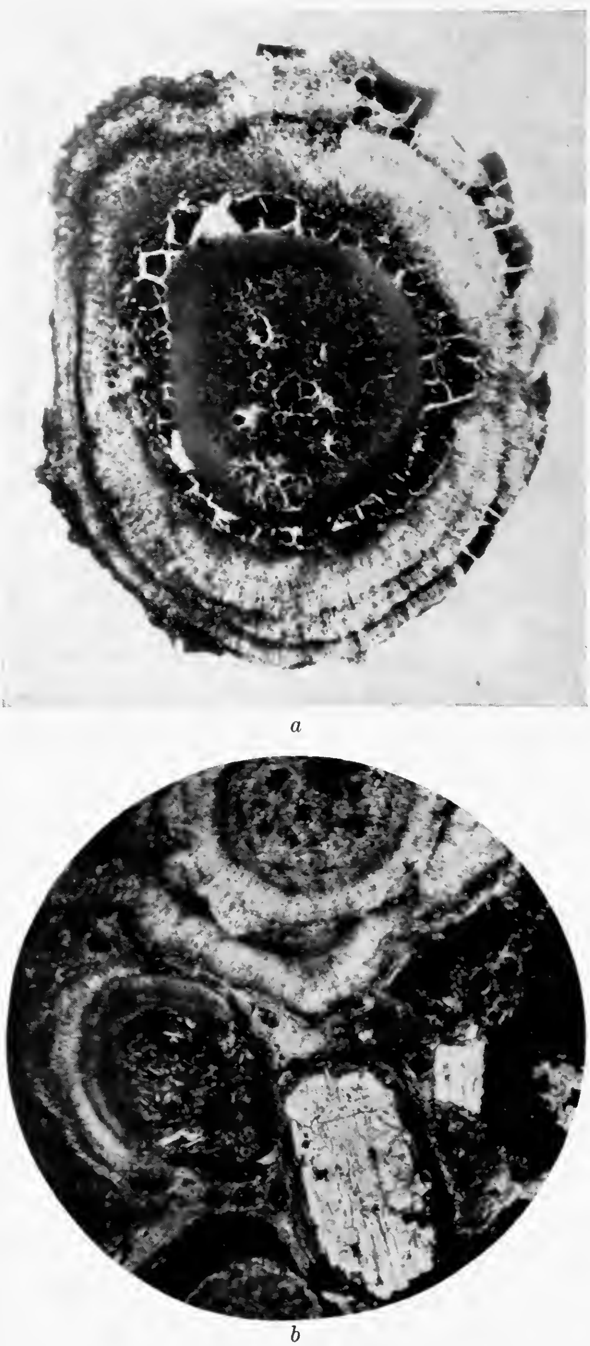

FIG. 72. *a*, Section of individual oolite. Note septarian structure surrounding the central core. Crossed nicols. × 60. *b*, Section of individual oolites, and matrix with clastic feldspar grains. Crossed nicols. × 60.

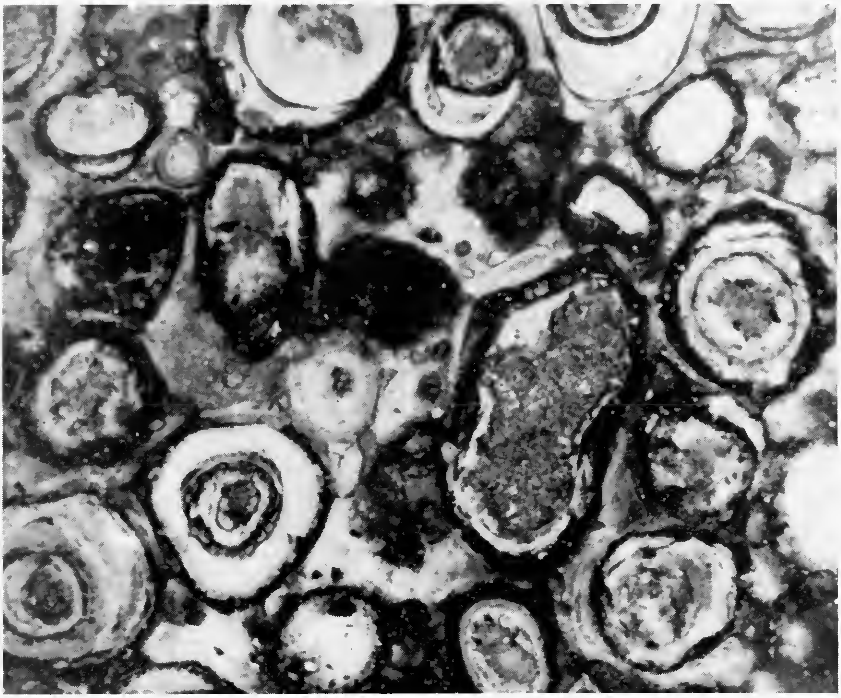

FIG. 73. Polished section of oolites in matrix. A large clastic basalt grain is on right. Reflected light. × 16.

the laminae surrounding the central core have been observed. They resemble septarian structure and apparently have resulted from shrinkage cracks that were subsequently filled with mineral matter (fig. 72, *a*).

The matrix enclosing the oolites is composed largely of fragments of oolites held together by small amounts of clay and carbonate mud. Clastic basalt grains, angular quartz, feldspar, and hornblende, some of clay size, are minor components of the matrix (figs. 72, *b*, and 73).

Fossils in the oolitic beds are exceedingly rare; only five fresh-water gastropods, all belonging to the genus *Planorbis*, were discovered, while we were freeing the individual oolites from the matrix. The gastropods are all thin-shelled, white, and very small, ranging in size from 1.5 mm. to 3.00 mm. in diameter (fig. 74). Mr. Eugene S. Richardson, Jr., Curator of Invertebrate Fossils, believes that they may be referred to a new species.

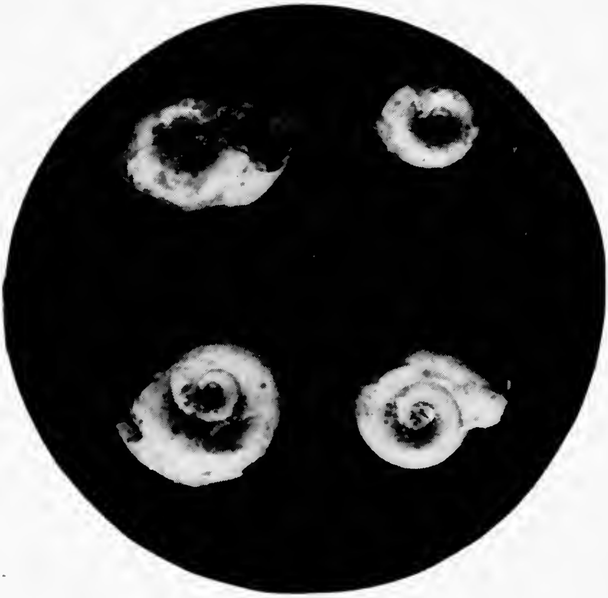

FIG. 74. Gastropods found in oolitic beds. *Planorbis* sp. × 7.

The presence of clay and carbonate mud is apparent in the composition of the individual oolites (see Table). Their presence in the concentric and radial structure and in the central core of the oolites has also been observed microscopically.

Comparison of the composition of the individual oolites with that of the oolites in matrix shows that there is a definite increase in silica, aluminum, iron, and magnesium in the latter, and a smaller increase in sodium and potassium. These differences are probably due to the presence of additional clay and basaltic minerals in the matrix.

NOTES ON THE ORIGIN OF OOLITES

The origin and structure of oolites have attracted the attention of numerous investigators and many theories have been advanced, but there does not seem to be a general agreement on the various interpretations proposed. The consensus is that oolites, whether of fresh- or salt-water origin, develop as a result of several different combinations of conditions. Thus, they may be formed organically through the agency of lime-secreting algae, or inorganically in a gel medium or by direct chemical precipitation. They may also result as a replacement structure.

We have not attempted to explain the formation of the Río Torola oolites although we favor the theory that they are of inorganic chemical origin. Examination of thin sections and of acid residues of the oolites shows no inclusions of organic matter, such as cells of algae. This absence of organic matter, coupled with the nature of the occurrence of the deposit as observed in the field, seems to support the assumption that they were chemically formed by precipitation of calcium carbonate about a core of mud or about particles of quartz and feldspar or both. The source of calcium may be referred to the adjacent decomposing volcanic land mass, and that of the interstitial clay to the silt and clay that were thrown into suspension when the bottom of the lake was stirred up by storms.

Artificial production of oolites in the laboratory under conditions closely approaching those prevalent in nature has clearly demonstrated that sodium carbonate and ammonium carbonate are the most effective precipitating agents (Linck, 1903). These reagents are generated by the decomposition of animal and plant matter, both of which were abundant in the locality under consideration here; the climate was also most favorable for rapid decay. Some of the sodium carbonate might have been obtained from the adjacent volcanic areas.

Precipitation of calcium carbonate other than that resulting from the precipitating agents referred to above might be due to evaporation of water and consequent super-saturation, or to loss of excess of carbonic acid (required to hold the carbonate in solution) because of heating of the water. The Torola Valley is in a recently extinct volcanic area containing a number of fumaroles and hot springs. It is thus possible that they were a factor in heating the water and that the oolites might have originated from precipitation of calcium carbonate due to loss of carbonic acid.

It is also believed that the oolites were developed at or near their present site of deposition. Absence of ripple marks and cross-lamination, the angularity of the clastic grains of the oolite matrix, and the relatively close association of the oolites with unbroken, thin-shelled fossils suggest a minimum of transportation.

The oolitic texture is thought to be a primary feature "that is characteristic of shallow, strongly agitated waters. The uniformity of the size of the oolites, the association with well-worn quartz and sand grains, the cross-bedded character of some oolitic rocks, and clear crystalline chemical carbonate cement (and absence of fine interstitial carbonate mud) are supporting evidence for this interpretation." (Pettijohn, 1949, p. 301.)

It cannot be readily inferred if the lake in which the Río Torola oolites were developed was shallow or deep, and except for a suggestion of uniformity of size of the oolites there does not seem to be any supporting evidence quoted in the preceding paragraph. The oolitic rock as well as the overlying limestone contains fragile, thin-shelled fossils (figs. 74, 76–78), the presence of which apparently precludes strongly agitated waters; fragments of quartz and feldspar in the oolite matrix and in the closely associated limestone and clay are distinctly angular (figs. 72, *b*, 73, and 80); no evidence of ripple marks or cross-bedding is present; and finally, and what is perhaps most significant, the carbonate cement is admixed with clay (figs. 71–73).

Fig. 75. Limestone outcrop on the south bank of Río Torola, 1.2 miles north and 34° east of Carolina.

It would thus seem that oolites of inorganic origin may develop in conditions at some variance from those in which they are generally believed to occur. Although it is based upon post-depositional evidence, this interpretation may find support, unless the change in the lithological character, from oolitic texture to limestone, implies a concurrent change in physical conditions, which were substantially different from those in which the overlying limestone was deposited. That there had been a change, physical and biological, between the deposition of the oolitic rock and the limestone is apparent, but

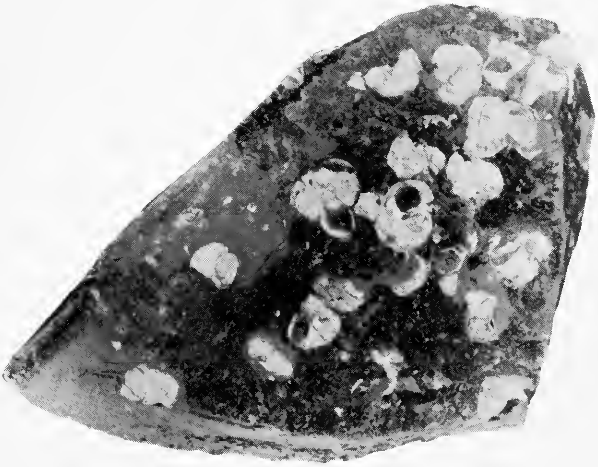

FIG. 76. Fresh-water fossil gastropods related to species of *Viviparus, Amnicola, Helisoma, Platitaphius?,* and *Physa,* in Río Torola limestone. × ⅔.

FIG. 77. Fresh-water fossil gastropods in Río Torola limestone. × ⅔.

FIG. 78. Fresh-water micro fossils in Río Torola limestone containing gastropods, ostracods, fish teeth, and plant remains (black fragments). × ⅔.

any attempt to estimate the degree of change—moderate or otherwise—is likely to be subject to errors.

THE LIMESTONE

The limestone outcrop occurs on the south bank of Río Torola and extends eastward, skirting the river bank for about three hundred feet or more. It consists of thick continuous strata, the western end of which overlies the oolitic beds. The thickness of the outcrop varies from six to twelve feet, the thickest portion being near the center of the outcrop, where it has been separated by what appears to be a fault line widened into a gulf by water running down the high volcanic mountains that rise abruptly back of the outcrop.

The limestone is dense, gray to buff in color, and well stratified, the beds having a general 20° S. and SSW. dip (fig. 75). Cross-bedding, which would suggest strong current action, was not observed, although cross-bedded sandstones elsewhere in the Torola Valley have been reported by Stirton and Gealey (loc. cit.). The individual beds of the limestone are finely laminated, indicating deposition in calm waters.

Much of the limestone is highly fossiliferous, and by far the most numerous fossils are fresh-water gastropods (figs. 76–78). In thin sections the limestone appears to be even more fossiliferous (fig. 79). The fossils are dead-white in color and are composed largely of clear calcium carbonate. They vary greatly in size: some cannot be seen with the unaided eye; others measure up to about three-fourths of an inch in length. The shells are typical of those of fresh-water lake fauna—paper thin and extremely fragile. Shells of the river fauna, as opposed to those of the lake or calm water fauna, are heavier and stronger, adapted to withstand strongly agitated waters such as are caused by waves, currents and floods of a river. This contrast in the shell development illustrates environmental adaptation and furnishes the clue to the origin of the deposit in which the shells are found. Other fossils occurring in the limestone are ostracods, fish teeth, and plant remains.

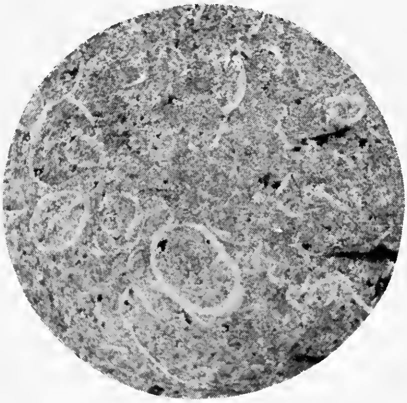

FIG. 79. Thin section of Río Torola limestone containing carbonate mud and numerous cross sections of fossil gastropods. Ordinary light. × 40.

Dr. Teng-Chien Yen, a specialist in fresh-water molluscs, has examined the limestone (figs. 76–78) and given us his opinion, as follows: "It contains fresh-water gastropods related to species of *Viviparus*, *Amnicola*, *Helisoma*, *Platitaphius?* and *Physa* together with some fish teeth and numerous ostracods. The state of preservation does not permit specific identification of the molluscan species. The enclosing deposit is perhaps of late Tertiary age, and possibly laid at Pliocene time."

From the foregoing evidence—absence of cross-bedding and occurrence of finely laminated beds enclosing characteristic fresh-water lake fauna—it is manifest that the limestone was deposited in a lake, which existed before the valley was occupied by the present Río Torola, and that the deposition took place, as may be inferred from the age of the fossil content, during the late Tertiary, probably during the Pliocene.

The chemical composition of the Río Torola limestone and that of a composite of 345 limestones (U. S. Geol. Surv., Bull. 770, p. 564) is as follows:

CHEMICAL COMPOSITION OF THE LIMESTONE

	Robert K. Wyant, *Analyst* Río Torola limestone	H. N. Stokes, *Analyst* Composite of 345 limestones
SiO_2	44.58	5.19
TiO_2	0.12	0.06
Al_2O_3	4.01	0.81
Fe_2O_3	1.59	0.54
FeO	0.12	
MnO	0.03	0.05
MgO	1.72	7.90
CaO	23.41	42.61
Na_2O	0.38	0.05
K_2O	0.72	0.33
H_2O-	1.55	0.56
H_2O+	0.68	0.21
P_2O_5	0.16	0.04
CO_2	20.19	41.58
SO_3	0.09	0.05
C	0.15	....
S	....	0.09
Cl	....	0.02
	99.50	100.09

It will be seen from the above comparative figures that the Río Torola limestone is considerably higher in silica and somewhat higher in iron, aluminum, sodium and potassium. The presence of irregular clay masses, quartz of clay size, and carbonate mud, as well as minor amounts of angular fragments of quartz, feldspar, and hornblende, as observed in thin sections of the Río Torola limestone (fig. 79) would account for the noted variance in composition from the composite limestones.

Indications are that the detrital minerals were derived from volcanic areas adjacent to the body of water in which the limestone was deposited, and that much of the calcium carbonate present was derived from the accumulation and deposition of shells of fresh-water gastropods and other invertebrates; some might have been precipitated inorganically or by lime-secreting plants. The presence of fish teeth may account for a higher phosphorus content than is usual in limestones.

INTERCALATED CLAY LENSES

The clay of the Río Torola area is found above the oolite bed and occurs as thin discontinuous layers and lenses within the Río Torola limestone. The distribution of these lenses is limited to the lower portion of the outcrop; none was seen on the upper part of the limestone.

FIG. 80. Thin section of intercalated clay in Río Torola limestone. Note detrital feldspar and quartz in the clay matrix. Crossed nicols. × 40.

Fresh surfaces of the clay appear gray in color with visible clastic grains included. Exposed parts are usually mottled with brownish stain of iron oxide.

In thin section the rock is composed of poorly sorted fragments of basalt and basalt minerals cemented by a fine brown clay (fig. 80). A few of the larger basalt fragments enclose phenocrysts of feldspar. There is no indication that the clay matrix is the result of devitrification of glassy igneous material.

The calcium and magnesium present in the analysis are largely an indication of the unweathered igneous silicates present in the clay. It is thought that the clay matrix containing basaltic detrital minerals was deposited locally and discontinuously within the limestone by normal non-marine depositional processes.

The angularity and freshness of the feldspars within the clay combined with the volcanic nature of the surrounding areas might suggest that the feldspars and other clastic minerals were pyroclastic in nature. The limestone surrounding the discontinuous clay layers, however, contains very little feldspar and other basaltic

CHEMICAL COMPOSITION OF THE CLAY

Robert K. Wyant, *Analyst*

	Per cent
SiO_2	54.12
TiO_2	0.73
Al_2O_3	17.77
Fe_2O_3	5.45
FeO	0.41
MnO	0.04
MgO	3.35
CaO	4.52
Na_2O	1.59
K_2O	2.40
H_2O-	6.89
H_2O+	0.70
P_2O_5	0.09
CO_2	1.81
SO_3	0.10
C	0.19
	100.16

minerals. Therefore, it is probable that the basaltic minerals were derived from rapidly eroding areas and transported by water a short distance before final deposition.

SEQUENCE OF GEOLOGIC EVENTS

The mode of occurrence, the lithological character, and the fossil content of the Río Torola limestone indicate that a body of fresh water of considerable size existed during the late Tertiary time. Inclusions of angular detrital minerals in the limestone, particularly in the clay lenses, further indicate that this body of water was adjacent to a volcanic area, which was undergoing disintegration and decomposition under humid conditions. Since the detrital minerals in the clay and the limestone proper are typical common constituents of basalt or andesite-basalt, it would seem that the elevated portions of the volcanic area were active in ejecting pyroclasts and lava flows of basic or intermediate composition.

The first in the sequence of deposition within the body of fresh water consisted of the calcareous oolites admixed with carbonate clay. This was followed by a change in physical and biological conditions—deepening of the water and increase in the invertebrate faunal population. The limestone containing molluscan shells of the fresh-water lake fauna type was deposited next. The intercalated clay lenses with fragments of basalt and basaltic minerals were deposited discontinuously within the limestone. The absence of clay layers in the upper portion of the limestone suggests that the deposition of the clay was of short duration. It also suggests that erosion and transportation of detrital material from the source area became less and less vigorous in the later stage of the deposition of the Río Torola limestone.

Widespread uplift of land has been in progress in El Salvador since the Pleistocene. It is manifest throughout the entire length and breadth of the country. The emergence of the late Tertiary sediments in the gorge of the Río Torola is but a minor example.

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