

CALIZA DE AGUA DULCE DEL VALLE DE TOROLA AL NORESTE DE EL SALVADOR

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Sumario

El presente artículo trata de un depósito de caliza (más bien margá) de agua dulce que se encuentra en el margen sur del Río Torola, a unos 800 m al este de la desembocadura del Riachuelo de Carolina en el Torola.

El depósito consiste de un *banco basal oolítico* de unos 0.5 m de espesor; 90 % de los oolitos tienen diámetros entre 0.6 y 1.0 mm. El contenido de fósiles en el oolito es muy escaso, los pocos fósiles que se encontraron pertenecen casi todos al género *Planorbis*. El origen del banco es considerado amorgánico, precipitándose carbonato de calcio alrededor de partículas de cuarzo o feldespató.

El techo del oolito es formado por un *banco de caliza* de color gris claro hasta amarillento, de 1.8-3.6 m de espesor. El afloramiento se persigue por unos 100 m a lo largo del margen del Río Torola, corre

en dirección WNW-ESE y se inclina con unos 20° hacia el sur. La mayor parte de la caliza está fuertemente cargada de gastrópodos fósiles de origen lacustre, relacionados con algunas especies de los géneros *Viviparus*, *Ammicola*, *Helisoma*, *Platitaphius?* y *Physa*. Además, se han encontrado numerosos ostracodos y algunos dientes de peces. La edad de esta caliza es probablemente el terciario superior, posiblemente el pliocénico. El análisis químico detallado es comunicado, el contenido de SiO₂ es 44.58 % y el del CaO 24.41 %.

Toda esta serie es de origen lacustre. Durante la formación del banco oolítico, el lago probablemente era de poca profundidad. Se supone que las condiciones, tanto físicas como biológicas, cambiaron posteriormente a un lago de mayor profundidad con aguas tranquilas, por lo que se crearon condiciones más favorables para el desarrollo de la abundante fauna de gastrópodos en la parte superior del sedimento.

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Acknowledgments

The material which has been the subject of this paper was collected by SHARAT K. ROY in the summer of 1951 while he was engaged in geological work at the Instituto Tropical de Investigaciones Científicas de El Salvador, at San Salvador, Central America. The locality studied and other pertinent data relating to field observation will be found in their proper sequence. Here he wishes to take the opportunity to extend his sincere appreciation to Dr. Aristides Palacios, Director of the Instituto; to Dr. Adolf Meyer-Abich, Scientific Counsellor; to Dr.

Helmut Meyer-Abich, Chief of the Geological Laboratory; to Señorita Aida Cabezas O., Secretary; and to each and every member of the Instituto, for the assistance and splendid co-operation they all have accorded him. He is also greatly indebted to the Administrators of various fincas for their generous hospitality and their interest in field work much of which could not have been accomplished without their guidance. Dr. Helmut Meyer-Abich has rendered him invaluable aid by giving him access to laboratory and study collections, accompanying him to the field on numerous occasions, and discussing some of the controversial problems that have arisen from time to time.

Introduction

The occurrence of probable late Tertiary (Pliocene?) lacustrine limestone and other sedimentaries in the Torola Valley, immediately west of the village of Carolina, north-eastern El Salvador, was reported by STIRTON and GEALEY (1949, p. 1739). Our material was collected from a near-by outcrop of limestone situated 1.2 miles north and 34° east of Carolina, about 0.5 mile east of the junction of Rio Torola and Riachuelo de Carolina (fig. 2).

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 was examined and the lacustrine origin of the deposit was suspected.

Field observation supplemented by survey maps of the region fully confirms STIRTON'S and GEALEY'S view that the Torola Valley "is structurally a syncline, the axial portion being occupied by the subsequent Rio Torola. The river enters El Salvador about 20 miles northeast of Volcan Cacaguatique and, swinging sharply, flows westward along the syncline axis". (Op. Cit.).

The Torola Valley affords excellent opportunity for studies in late Tertiary geology. The road leading to the valley branches off the Pan American Highway at 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 to Carolina, 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 Rio Torola limestone is shown in the vertical section of the outcrop (fig. 3). The character and composition of the rocks composing the outcrop indicate that there had been 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

The oolitic beds, as referred to earlier, 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 specimen the oolitic rock is light brown or tan in color, and very friable (fig. 4). The individual oolites are buff colored and predominantly spherical and they can be extracted from the matrix with ease (fig. 5). 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	32
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. 6, 7, 7a and 8). 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 car-

bonate, 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 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. 7).

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. 7a and 8).

Fossils in the oolitic beds are exceedingly rare; only five fresh-water gastropods belonging to the genus *Planorbis* were discovered, while freeing the individual oolites from the matrix. They are thin-shelled, white, and very small, ranging in size from 1.5 mm to 3.00 mm in diameter (fig. 9). Mr. EUGENE S. RICHARDSON Jr., Curator of Invertebrate fossils, believes that these gastropods may be referred to a new species.

Chemical Composition of Oolites and Matrix

ROBERT K. WYANT, Analyst

	Oolites per cent	Oolites in matrix per cent
SiO ₂	12.68	27.14
TiO ₂	.08	.20
Al ₂ O ₃	1.80	3.95
Fe ₂ O ₃	1.19	2.31
FeO	.11	.22
MnO	.02	.02
MgO	3.98	6.29
CaO	41.14	27.62
Na ₂ O	.30	.58
K ₂ O	.42	.90
H ₂ O-	2.52	2.16
H ₂ O+	.08	.31
P ₂ O ₅	.04	.06
CO ₂	35.41	28.16
SO ₃	.04	.06
C	.10	.12
	99.91	100.10

The presence of clay and carbonate mud is apparent in the table given here of the composition of the individual oolites. Their presence within 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. It is probable that these differences are due to the presence of additional clay and basaltic minerals in the matrix.

Notes on the Origin 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.

No attempt to ascribe any one particular theory cited above to the formation of the Rio Torola oolites has been made. They might be attributed to one or the other theories, but that they are of inorganic chemical origin is here favored. Examination of thin sections and of acid residues of the oolites show 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, seem 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 was 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 supersaturation, 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 of 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 mark 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 Rio Torola oolites were developed was shallow or deep, but it may be of interest to bring to attention the fact that, except for a suggestion of uniformity of size of the oolites, there does not seem to be any other supporting evidence (quoted in the preceding paragraph) that has been

observed in connection with the Rio Torola oolites. The oolitic rock as well as the overlying limestone contain fragile, thin-shelled fossils (figs. 9, 11-13), the presence of which apparently precludes strongly agitated waters; fragments of quartz and feldspar in the oolitic matrix, and in the closely associated limestone and clay are distinctly angular (figs. 7a, 8 and 15); no evidence of ripple marks or cross-bedding is present; and finally, and what is perhaps most significant, is that the carbonate cement is not clear but admixed with clay (figs. 6, 7, 7a, and 8).

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 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 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 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 Rio 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 overlie the oolitic beds. The thickness of the outcrop varies from six to twelve feet, the thickest portion being near the center of of the outcrop, where it has been separated by what appears to be a fault line widened into a gully 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 is well stratified, the beds having a general 20° S. and SSW. dip (fig. 10). No cross-bedding, suggesting any strong current action, was observed, although cross-bedded sandstones elsewhere in the Torola Valley have been reported by STIRTON and GEAL-EY (op. 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. 11-13). In thin sections the limestone appears to be even more fossiliferous (fig. 14). 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 the 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 index 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.

Dr. TENG-CHIEN YEN, a specialist in fresh-water molluscs, has examined the fossils (figs. 11, 12, 13) and given us his opinion, as follows: "It contains fresh-water gastropods related to species of *Viviparus*, *Ammicola*, *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 on a lake, which existed before the valley was occupied by the present Rio 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.

Chemical Composition of the Limestone

The chemical composition of the Rio Torola limestone and that of the composite of 345 limestones as determined by H. N.

STOKES is as follows: (U. S. Geological Survey, Bull. 770, p. 564).

ROBERT K. WYANT, Analyst

	Rio Torola Limestone	Composite of 345 Limestones
SiO ₂	44.58	5.19
TiO ₂	.12	.06
Al ₂ O ₃	4.01	.81
Fe ₂ O ₃	1.59	.54
FeO	.12	
MnO	.03	.05
MgO	1.72	7.90
CaO	23.41	42.61
Na ₂ O	.38	.05
K ₂ O	.72	.33
H ₂ O-	1.55	.56
H ₂ O+	.68	.21
P ₂ O ₅	.16	.04
CO ₂	20.19	41.58
SO ₃	.09	.05
C	.15	
	<hr/>	<hr/>
	99.50	100.09

It will be seen from the above comparative figures that the Rio 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 Rio Torola limestone (fig. 14), 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 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 higher phosphorus content than is usual in limestones.

Intercalated Clay Lenses

The clay of the Rio Torola area is found above the oolite bed and occurs as thin discontinuous layers and lenses within the Rio 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.

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. 15). 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.

Chemical Composition of the Clay

ROBERT K. WYANT, Analyst

	Per cent
SiO ₂	54.12
TiO ₂	.73
Al ₂ O ₃	17.77
Fe ₂ O ₃	5.45
FeO	.41
MnO	.04
MgO	3.35
CaO	4.52
Na ₂ O	1.59
K ₂ O	2.40
H ₂ O -	6.89
H ₂ O +	.70
P ₂ O ₅	.09
CO ₂	1.81
SO ₃	.10
C	.19
	100.16

The calcium and magnesium present in this 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 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 Rio Torola limestone indicate that a body of fresh water of considerable size existed during 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 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 short duration. It also suggests that erosion and transportation of detrital material from the source area became less and less vigorous at the later stage of the

deposition of the Rio 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 Rio Torola is but a minor example.

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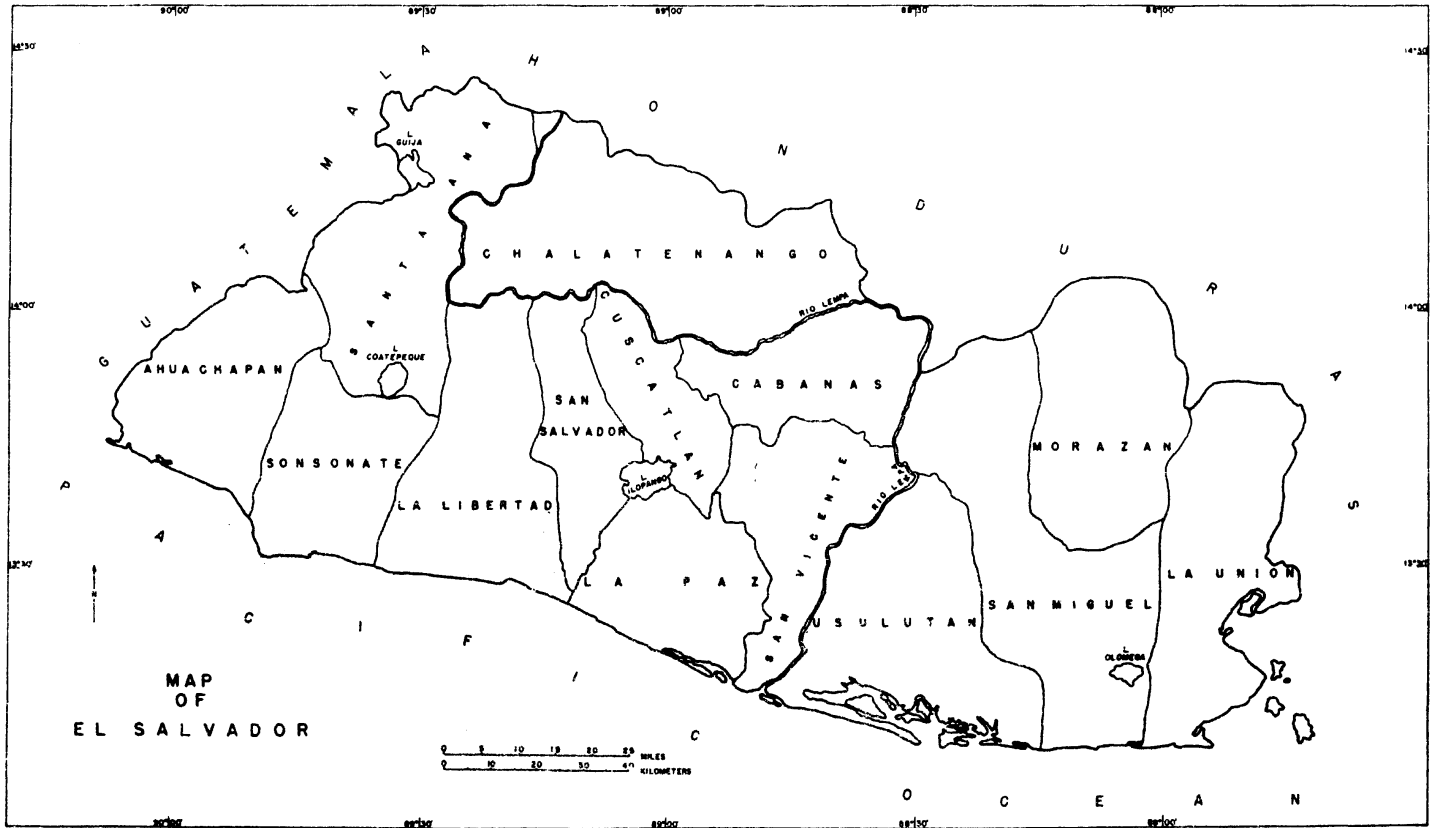


Figure 1. Map of Salvador showing various Departments of the Republic.

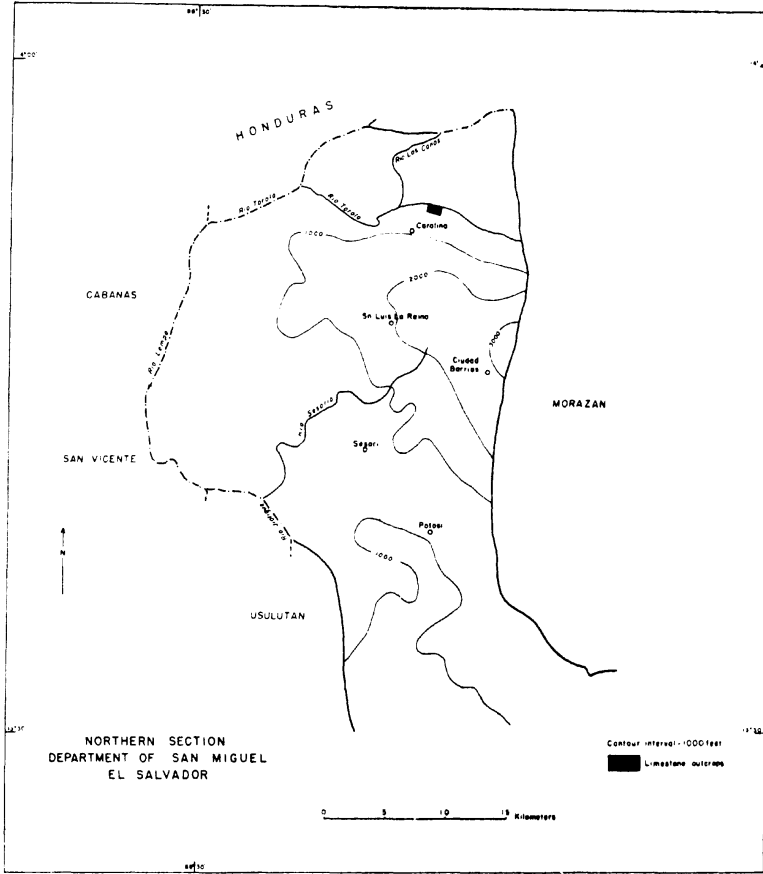


Fig. 2. Department of San Miguel. Shaded area northeast of Carolina represents Rio Torola limestone outcrop.

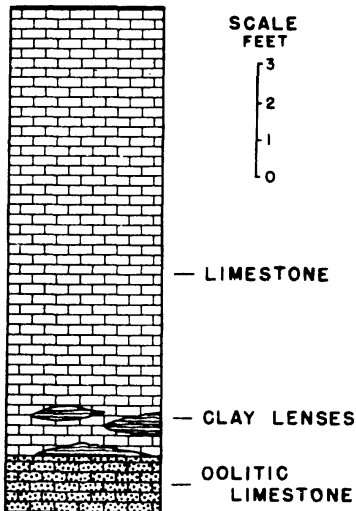


Fig. 3. Vertical section of the Rio Torola limestone outcrop.



Fig. 4. Hand specimen of the oolitic rock. The oolites are loosely cemented and they can be freed easily. Natural size.

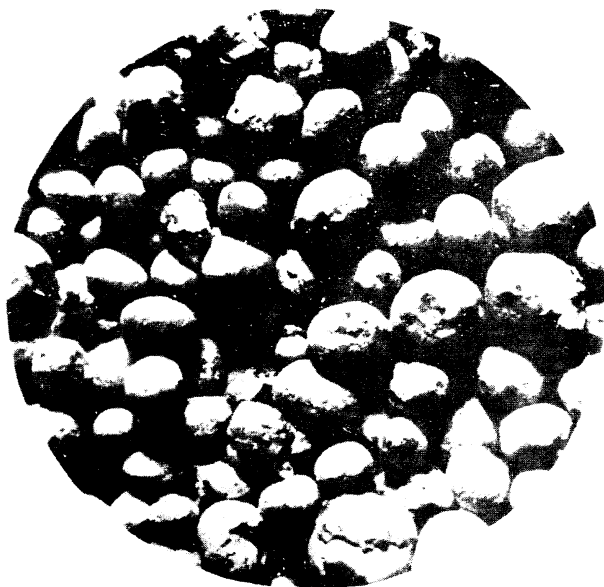


Fig. 5. Free oolites showing shape and size. x 6.



Fig. 6. Section of individual oolite, showing concentric and radial structure. Crossed nicols, x 60.



Fig. 7. Section of individual oolite. Note septarium structure surrounding the central core. Crossed nicols, x 60.



Fig. 7a. Section of individual oolite, showing elastic feldspar grains. Crossed nicols, x 60.

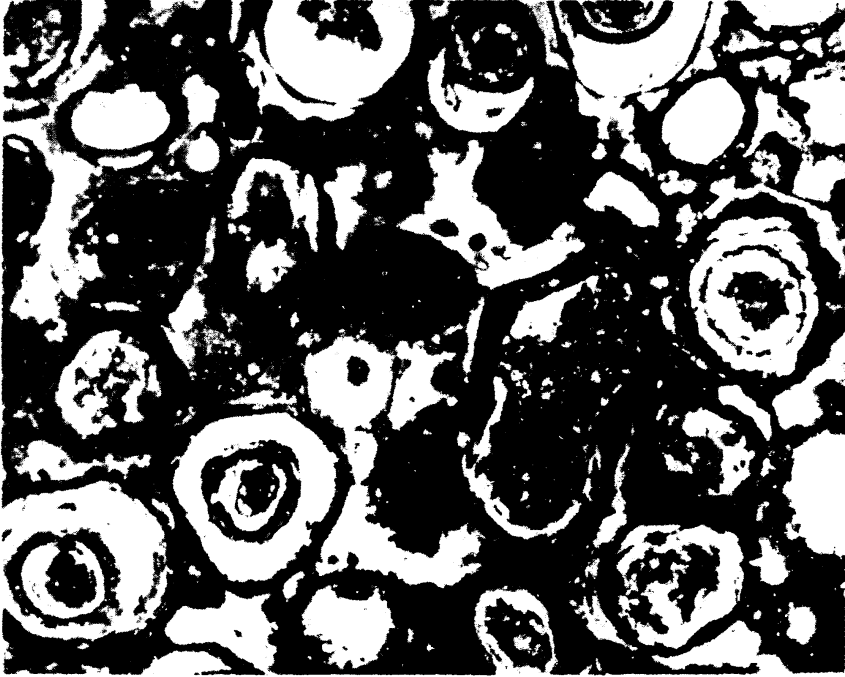


Fig. 8. Polished section of oolites in matrix. A large elastic basalt grain is on right. Reflected light, x 16.

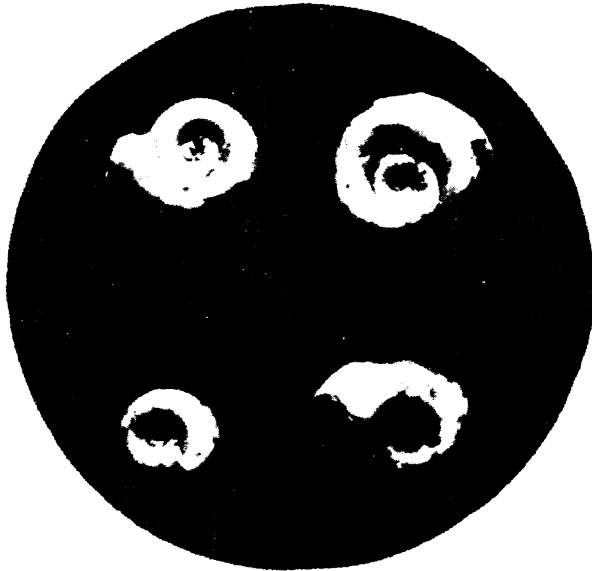


Fig. 9. Gastropods found in matrix beds. *Planorbis* sp. x 7.



Fig. 10. Limestone outcrop on the south bank of Rio Torola, 1.2 miles north and 34° east of Caroline.



Fig. 11. Fresh-water fossil gastropods related to species of *Viviparus*, *Ammicola*, *Helisoma*, *Platitaphius*, and *Physa*, in Rio Torola limestone. Natural size.

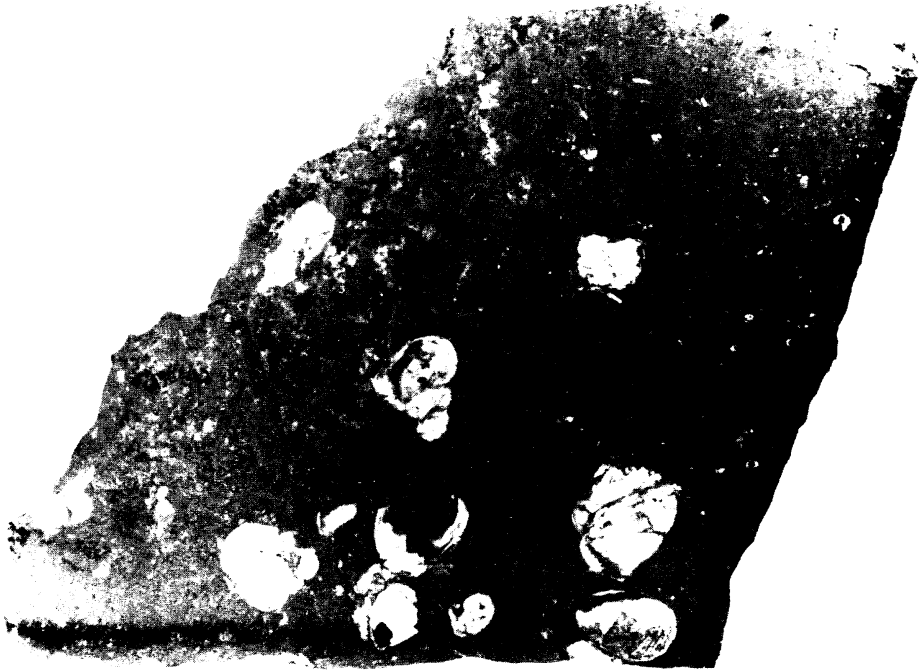


Fig. 12. Fresh-water fossil gastropods in Rio Torola limestone. Natural size.



Fig. 13. Fresh-water microfossils in Rio Torola limestone, containing gastropods, ostracods, fish teeth and plant remains (black fragments). Natural size.

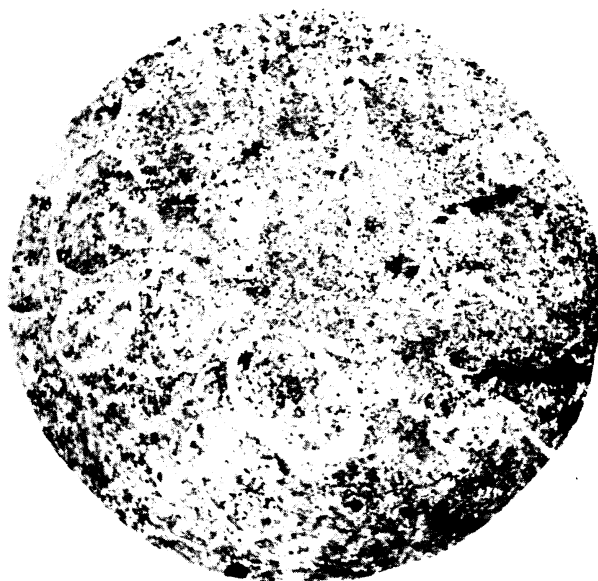


Fig. 14. Thin section of Rio Torola limestone containing carbonate mud and numerous cross-sections of fossil gastropods. x 60.



Fig. 15. Thin section of intercalated clay in Rio Torola limestone. Note detrital feldspar and quartz in the clay matrix. x 60.