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Chapter 28

Region 25, Yucatan Peninsula

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INTRODUCTION

The Yucatan Peninsula, in the eastern portion of Mexico, is bounded on the west and north by the Gulf of Mexico; on the east by the Caribbean Sea; on the southwest it merges with the Gulf Coastal Plain; and on the south it is bounded by the Sierra Madre del Sur (Fig. 3, Table 2, Heath, this volume). A humid tropical climate prevails over the peninsula with rainfall varying from 800 mm/yr in the northwest to 1,300 mm/yr on the east coast and 1,700 mm/yr on Cozumel Island off the east coast. Approximately 90 percent of the rainfall occurs in the May to October period. Mean annual temperature is 25°C, with highs in July and August and lows in December and January. High temperature and abundant vegetation cause about 85 percent of the rainfall to be lost through evapotranspiration; the remaining 15 percent infiltrates the subsurface; virtually no streams or surficial water bodies exist on the peninsula.

GEOMORPHOLOGY

The Yucatan Peninsula, part of the Mexican Gulf Coastal Plain, has dimensions of 250 km by 300 km. The greater portion of the peninsula is from 0 to 50 m above sea level; elevations as high as 300 m occur iu the southwest. Four distinct physiographic regions have been recognized: (1) Northern Pitted Karst Plain, (2) Sierrita de Ticul, (3) Southern Hilly Karst Plain, and (4) Eastern Block-Fault District (Weidie, 1985).

GEOLOGY

The peninsula is covered by Tertiary carbonates whose maximum thickness is about 1,000 m. They are horizontal to subhorizontal and overlie Cretaceous carbonates and evaporites that have been penetrated by various wells (Weidie, 1985).

Surface studies are hampered by few roads, thick vegetative cover, near horizontal bedding, few outcrops, and extensive calichification. Hence, a detailed geologic map of the entire peninsula has yet to be drawn.

Bonet and Butterlin (1962) described seven (7) Cenozoic units whose ages range from Paleocene to Quaternary. Their "formations" (actually biostratigraphic units) were modified by Lopez Ramos in 1981. The thickness of the Cenozoic section ranges from 200 to 1,000 m; they are subhorizontal in the north and east, but dips up to 30° have been reported in the southwest. In general, younger rocks crop out on the periphery of the peninsula, and older rocks occur in the southern and central area.

The most areally extensive rocks and the major aquifers are in carbonates of Eocene and Mio-Pliocene age. The Eocene is composed mainly of dense, recrystallized, fine- to medium-grained limestones. The lower part of the section contains marls and calcareous shales, which grade laterally into dolomitic limestone, marls, gypsum, and anhydrite. Most lithofacies have good permeability. Permeability is better developed in the Mio-Pliocene carbonates, which are coquinas, fossiliferous packstones, and grainstones; there are occasional thin interbeds of marl and calcareous shale.

In the southern and central portions of the peninsula the Paleocene and lower Eocene carbonates are dolomitic and, in part, slightly silicified. These rocks are pervasively fractured, permitting rapid infiltration and flow of ground water; water levels in this region are often many tens of meters to 100 m below the surface, making extraction of fresh water difficult.

Surficial carbonates on the greater part of the Yucatan Peninsula are covered by a thin (0.1 to 0.5 m) zone of massive caliche or by 0.5 to 10 m thick zone of "saskab," a chalky and friable weathering product of the limestones in this humid, tropical environment. These white to tan strata with occasional red horizons ("terra rosas") have been studied and described by various authors (see Isphording, 1974).

HYDROGEOLOGY

Northern pitted karst plain

This region (Fig. 1) occupies the northern portion of the peninsula. From the coastline, elevations gently increase inland to the south to about 35 to 40 m near the base of the Sierrita de

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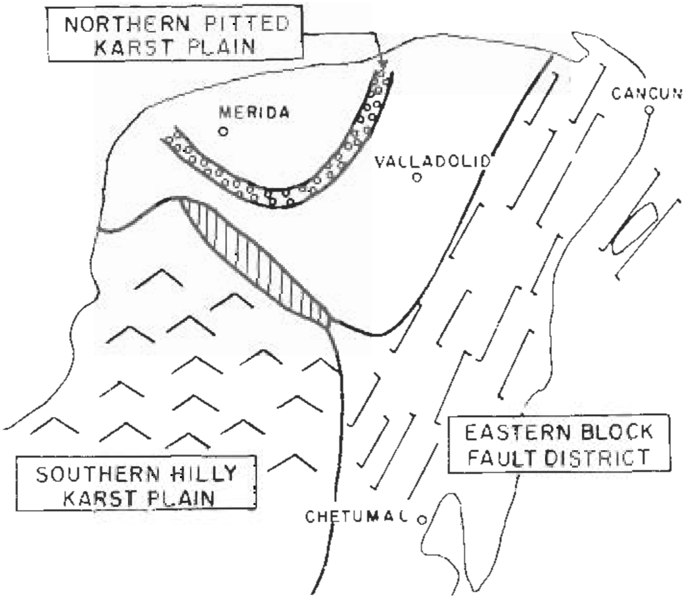

Figure 1. Map showing physiographic regions (Weidie, 1985).

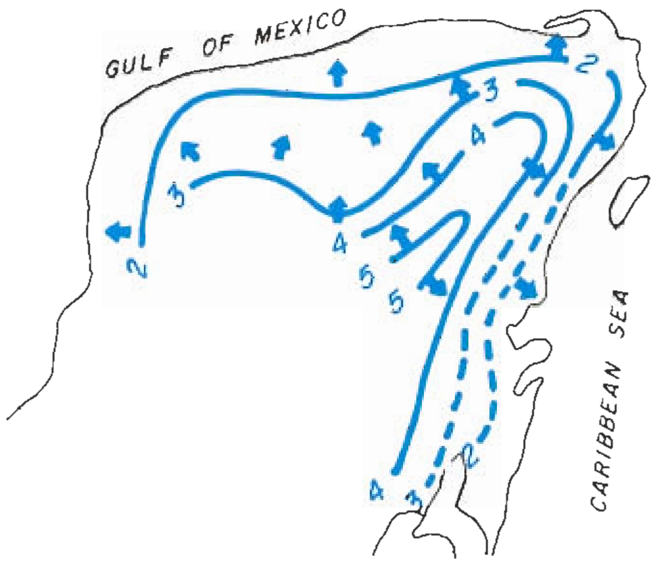

Figure 2. Map showing altitude of water table.

Ticul. Local relief rarely exceeds 10 m, and relief diminishes as one moves to lower elevations near the coast. This area is formed by marine Tertiary carbonates that have been subjected to extensive dissolution. Large solution holes and cavities have been formed by infiltration of rainfall and have formed a highly permeable aquifer. The high degree of karstification permits rapid infiltration, and there are no surface streams. In the absence of stream erosion, there is strong subsurface erosion resulting in the development of typical karst topography. Both mechanical and chemical erosion occur in the subsurface.

Mechanical erosion occurs near the surface where clays are washed into dissolution openings and deposited beneath the calichified surface. This absence of soil cover is one of the characteristics of the plain. Clays are found at depths of 0.5 to 1.5 m beneath the surface where plant roots tend to trap them.

Rapid infiltration of rainfall into the aquifer results in unsaturated waters retaining a high potential for dissolution. Dissolution enlarges the fissures and cavities, producing large openings and caverns. Collapse of rocks above the openings produces the dolines and sinkholes known locally as "cenotes," a word of Mayan origin. These karst features are of various types and have formed in response to fluctuations of the water table. The water table occurs at depths of 3 to 15 m in this region of 4 to 20-m surface elevations (Fig. 2). Most "cenotes" are circular with vertical walls and diameters of about 100 m where the depth to water is about 15 m (Fig. 3). Work by divers shows the "cenotes" narrow with depth and have a conical form.

Frequently the "cenote" roof has collapsed completely; in other cases it is hemispherical with small openings 1 to 3 m in diameter. These openings typically enlarge with depth, and their diameters may reach several tens of meters (Fig. 4). The formation of these "cenotes," as well as the other karst features, is a function of the depth of the water table. At this depth the water is charged with carbon dioxide, promoting the formation of carbonic acid which dissolves the subsurface carbonates. Various levels of dissolution show that the water table has fluctuated, apparently in response to the gradual emergence of the peninsula.

In the northern part of the peninsula the Tertiary carbonates are horizontal and show significant lateral facies changes, which control the occurrence of zones of different degrees of karstification. The "cenotes" or sinkholes occur along the entire length of the peninsula, but they are more notable and numerous in certain zones (Fig. 4) where an elongated strip is characterized by abundant karst features, especially those of great size.

Southern hilly karst plain

In this zone the topography is varied; there are isolated, low-relief, conical karst hills about 40 m above the surrounding land surface. Maximum altitude in this region is 300 m above sea level.

The plain is formed of Eocene carbonates including limestone, dolomitic limestone, and dolomite. Some of the carbonates show a slight degree of silicification. Attitude of the beds ranges from horizontal to small folds with 15° to 20° dips; and they are highly fractured.

The high fracture permeability of these carbonates is reflected in low gradients of the water table. In places the water table is 100 m beneath the surface, making ground-water exploitation difficult and costly. For this reason there are few large villages or agricultural development in this region of higher topography and deeper aquifers.

Sierrita de Ticul

Between the extensive plains of the northern peninsula and

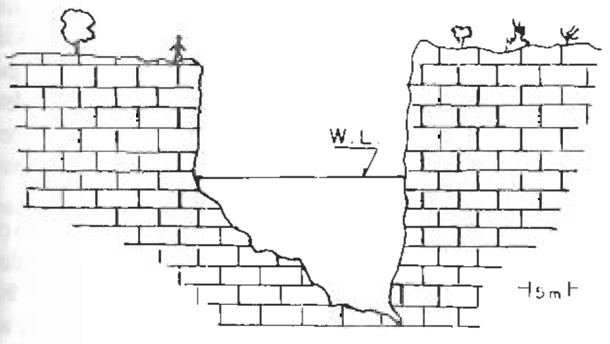

Figure 3. Sketch showing typical vertical walls of the cenotes.

the hills of the south there occurs an elongated topographic high known as the Sierrita de Ticul. It is composed of Eocene limestones, trends northwest to southeast, and is 160 km long and 15 km wide. The sierrita is a fault scarp formed by a normal fault whose down-dropped block is on the north. Altitudes in the region are 150 m above sea level and 100 to 110 m above the plain to the north. The elevations along the scarp are practically the only geomorphic feature interrupting the otherwise nniform countryside.

Eastern block-fault district

This area, about 80 km wide, extends from Cabo Catoche, the northeastern tip of the peninsula, south to Belize. In this region the carbonate rocks have been faulted by a series of north-northeast-trending normal faults (the Rio Hondo fault zone), forming horsts and grabens. The faults are of varying lengths and displacements, and many of them are expressed at the surface.

Notable surficial expressions of these faults are along the Caribbean coast, including Cozumel Island, a horst block bounded on the east aud west by large faults. On and near the coast there is a marked orientation and alignment of bays, such as Chetumal and Ascencion. Slightly inland, elongated depressions 10 to 15 m deep form lakes or marsh and swamp regions. Good examples of these long depressions are the lakes of Bacalar, which are oriented northwest to southeast and northeast to southwest and are formed by down-dropped blocks 8 to 10 m lower than the surrounding land surface. The lakes vary in width from as little as 2 to 10 m and may attain lengths up to 50 km. Further to the northwest near the coast, similar but smaller features occur only a few meters above sea level, giving rise to marshes and small lakes. In the coastal zone, ground-water discharge into the Caribbean dissolves the carbonates and forms coastal inlets ("caletas") and lagoons (Back and others, 1979).

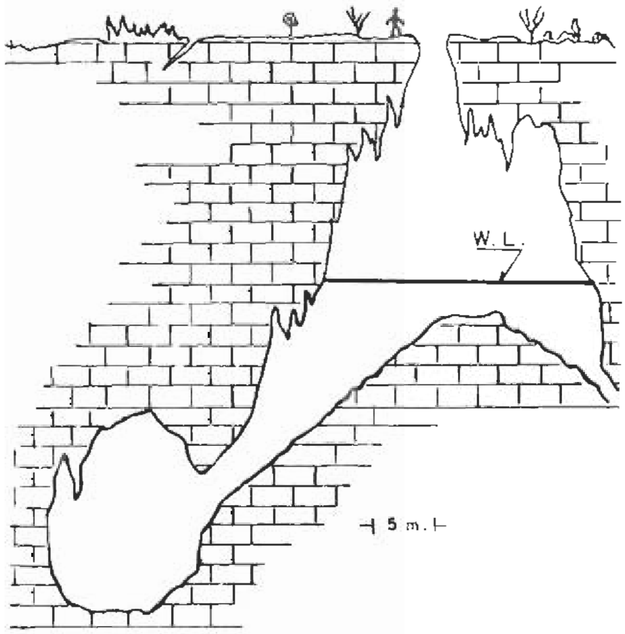

Figure 4. Sketch showing cenote formed by collapse of a cave roof.

HYDROGEOCHEMISTRY

In the Yucatan Peninsula there are two sources of saltwater: (1) dissolution of evaporite deposits interbedded in the carbonate sediments, and (2) the sea water surrounding the peninsula.

In the northern and southeastern plains the freshwater aquifer is 30 to 70 m thick and overlies saline water, which is found at depths of 40 to 80 m. The principal source of saltwater is from the dissolution of subsurface beds of gypsum, anhydrite, and halite. Rainfall over the peninsula infiltrates, and the fresh ground water moves seaward toward the coastline. There is constant replenishment of fresh water in the upper part of the aquifer, and salinities increase at greater depths. Some "cenotes" and a few wells are deep enough to permit the detection and measurement of saltwater; Figure 5 shows the approximate position of the fresh and saltwater bodies.

Along the coastline there is saltwater intrusion into the fresh-water aquifers. Owing to the high permeability of the carbonates, the water table is only a few centimeters above sea level, and its altitude gently increases inland. Because of this, the saltwater interface is close to the surface, and the fresh water forms a thin wedge. Villages along the coast are forced to develop their water supplies from 15 km or more inland.

Sea-water intrusion occurs in annual cycles. No recharge during dry seasons, combined with exploitation of the aquifers, permits the advance of the saltwater front to as much as 12 km inland. During the rainy season, with its major recharge and lower pumping rates, there is a seaward retreat of the interface; the high permeability permits rapid movement of the interface.

A typical example of sea-water intrusion is on Cozumel Island off the eastern coast of the peninsula. Holocene and Pleistocene carbonates crop out and are underlain by Mio-Pliocene carbonates, similar to much of the northern peninsula. Sea water has intruded along the island margins, and only in the central part of the island is recharge sufficient to maintain a thin lens of fresh water about 20 m thick. Shallow wells about 10 m deep in the central region yield flows of 1.0 L/sec; greater rates of pumping lower water levels and permit greater sea-water intrusion (Fig. 6). High pumping rates can result in withdrawal of saltwater, and reduction in pumping results in near-instantaneous recovery of water levels and quality.

STRUCTURE

The near-horizontal Cenozoic carbonates of the peninsula are fractured extensively. Two sets of vertical, perpendicular fractures facilitate the rapid infiltration of water into the subsurface.

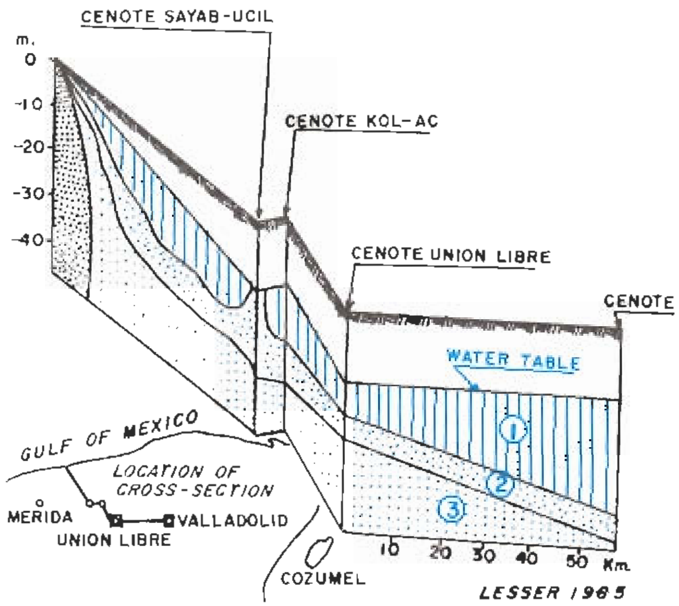

Figure 5. Cross section showing distribution of fresh saltwater.

Virtually all the carbonate rock types are affected by these fractures. Direct observation of fractures inland is difficult because of the lush tropical vegetation, but numerous aligned sinkholes, cenotes, and other karst features attest to their presence. Removal of vegetative cover through "slash and burn" agricultural techniques shows the fracturing to be pervasive. Fractures are easily observed in the less vegetated coastal areas and contribute significantly to coastal erosion by the formation of bays and caletas. These features vary in size from a few meters to tens of kilometers. The fractures are major conduits of seawater ground-water discharge and solution.

The ground water is normally saturated with respect to calcite, but near the coastline it mixes with saline water; the resultant mixture is undersaturated, causing carbonate dissolution and fracture enlargement leading to the formation of coastal bays and caletas (Back and others, 1979; Back, this volume).

The more dolomitic Eocene rocks are intensively fractured, sometimes presenting a "slaty" appearance. In these rocks, fracturing is the most important factor controlling the development of aquifers. In the more soluble limestones of Mio-Pliocene age that dominate the peninsula, aquifer formation is primarily a result of dissolution processes.

The horizontal limestones of the eastern portion of the peninsula are faulted extensively; the normal faults form a series of horsts and grabens recognizable on the surface and verified by drilling and geophysical methods. Topographic and structural lows in this region frequently are filled with more clayey material. These depressions are enlongated parallel to fault trends and frequently form lagoons or lakes. The depressions are from 2 to 10 km wide and as much as 50 km in length despite vertical displacements as small to 5 to 10 m along the faults.

The most notable lineaments associated with the faulting may be observed in: (1) the course of the Rio Hondo in the southeastern part of the peninsula and extending into Belize, where the river follows the northwest to southwest faulting for a considerable distance; (2) the Laguna de Bacalar, which is 5 km

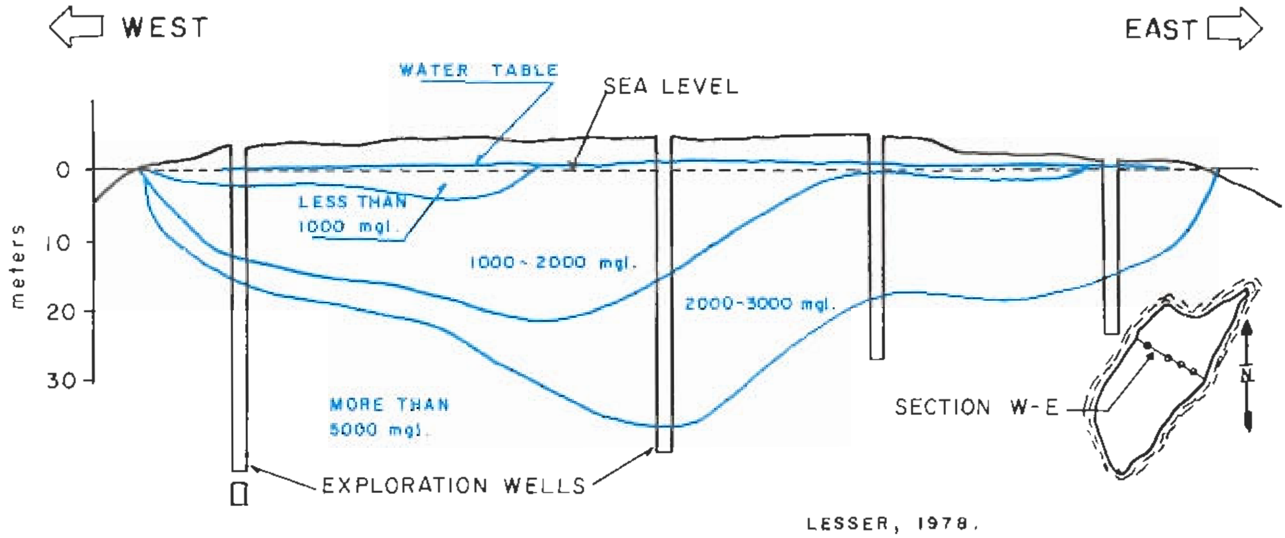

Figure 6. Cross section showing distribution of salinity of water on the island of Cozumel.

wide and 50 km long and occupies a graben depression; the lagoon and adjacent lows are maintained by rainy season precipitation. Some depressions are sites of ephemeral lakes, and most low-lying areas are oriented either northeast to southwest or northwest to southeast; and (3) northeast to southwest submarine fault scarps in the Caribbean adjacent to the eastern margin where water depths may reach 1,000 m a few kilometers offshore. The offshore island of Cozumel is a horst block of this fault system.

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