Geological Circular 80-2

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IMPORTANCE OF SECONDARY LEACHED POROSITY IN LOWER TERTIARY SANDSTONE RESERVOIRS ALONG THE TEXAS GULF COAST[1]

R.G. Loucks, M.M. Dodge, and W.E. Galloway[2]

ABSTRACT

Secondary leached porosity is common to dominant in near surface to deep subsurface lower Tertiary sandstone reservoirs along the Texas Gulf Coast. This secondary porosity is in the form of leached feldspar grains, volcanic rock fragments, carbonate cements, and carbonate-replaced grains. Leached porosity occurs in sandstones with compositions ranging from volcanic litharenite and lithic arkose to quartzose sublitharenite and quartzose subarkose.

A generalized diagenetic sequence indicates that leaching is a multi-staged phenomenon occurring at or near surface, at burial depths of 4000 to 6000 ft, and at burial depths of 7000 to 10,000 ft. Feldspar grains are dissolved during the first stage, whereas grains, cements, and replacement products are dissolved during the last two stages. Intensity of leaching in each stage varies in different formations and in different areas.

Plots of secondary porosity as a percent of total porosity versus burial depth show that secondary porosity is dominant beneath 10,000 ft, ranging from 50 to 100 percent of total porosity. Above 10,000 ft more than half the samples have secondary porosity as the dominant type. Similarly, individual plots for the Wilcox, Yegua, Vicksburg, and Frio sandstones all demonstrate the predominance of secondary leached porosity.

Primary porosity is destroyed by compaction and cementation with increasing depth of burial. If this were the only porosity type, no deep, high-quality reservoirs would exist. Leaching, however, restores reservoir quality after primary porosity has been reduced. Most productive lower Tertiary sandstone reservoirs, especially deep reservoirs, along the Texas Gulf Coast exist only because of secondary leached porosity.

INTRODUCTION

Loss of porosity with depth in Tertiary sandstones (fig. 1) along the Texas Gulf Coast is not a simple process of occlusion of primary pore spaces. As primary porosity is destroyed by compaction and cementation, secondary porosity is created by dissolution of grains and cements. This secondary porosity, however, may also be subsequently destroyed.

Secondary porosity is a common form of porosity at shallow depths, and it is the dominant form of porosity at depths greater than 10,000 ft. Other authors have noted the importance of secondary porosity along the Texas Gulf Coast (Lindquist, 1977; Loucks, Bebout, and Galloway, 1977; Stanton, 1977; McBride, 1977), but they made no attempt to quantify its abundance or relate its occurrence relative to primary porosity.

The objectives of this paper are:

1. to show general porosity and permeability trends of Tertiary sandstones in the onshore Texas Gulf Coast;
2. to quantify the abundance of secondary porosity relative to primary porosity; and
3. to indicate the diagenetic stages where secondary porosity develops.

GENERAL POROSITY AND PERMEABILITY TRENDS

Core analysis data from 253 wells were examined in this study (fig. 2). Such data provide the best measure of reservoir quality, short of production tests. The principal drawback of core analysis is that porosity and permeability measurements are made at atmospheric pressures and temperatures apart from the original pore fluid. The results give values that are commonly an order of magnitude too high. Of these 253 wells, only 156 wells from which whole core (core plug) analyses were made were used to determine regional porosity and permeability trends along the Texas Gulf Coast. Core plugs, taken by drilling a cylinder into a whole core, do not disturb the fabric of consolidated sediments. A sidewall core is taken by blasting a small hollow metal cylinder horizontally into the side of a wall. The explosive

CENOZOIC – TEXAS GULF COAST

SYSTEM	SERIES	GROUP/FORMATION
Quaternary	Recent	Undifferentiated
	Pleistocene	Houston
Tertiary	Pliocene	Goliad
	Miocene	Fleming
	—?——?—	Anahuac
	Oligocene	Frio
		Vicksburg
	Eocene	Jackson
		Claiborne
		Wilcox
		Midway

Figure 1. Cenozoic stratigraphic section, Texas Gulf Coast.

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[2]Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas 78712

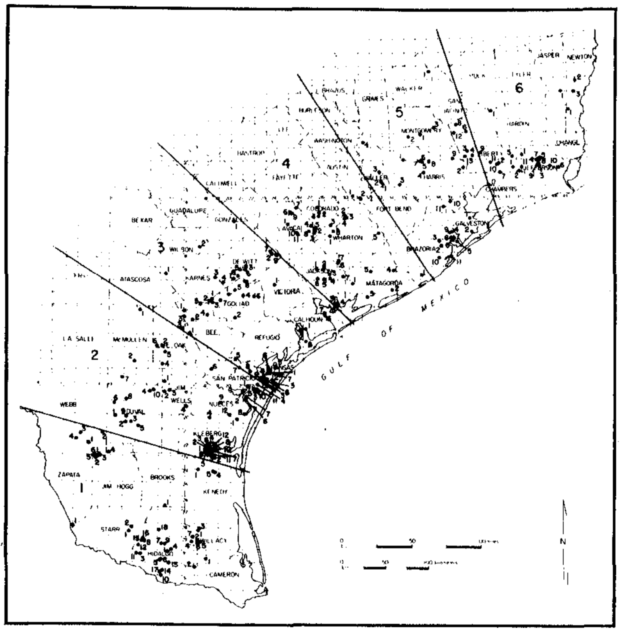

Figure 2. Location of wells with porosity and permeability data used to develop reservoir quality trends.

impact of the cylinder into the rock often fractures the sample, so that thin sections made from a sidewall core commonly show numerous fine, intragranular fractures. A sidewall core, therefore, tends to have a much higher porosity value than a whole core. Below a depth of 5,000 ft, porosity values from sidewall cores deviate significantly from those of whole cores, and the magnitude of the deviation increases with depth (fig. 3). Above 5,000 ft sidewall cores and whole cores produce similar readings of porosity because the sediments are not cemented. The process of sidewall coring at shallow depths will disturb the sediment by rearranging grains, but this will not increase porosity. Beneath 5,000 ft, the sediments start to become lithified (Loucks, Bebout, and Galloway, 1977; Loucks, Dodge, and Galloway, 1979), and the sidewall coring process will cause numerous hairline fractures to develop, creating new porosity and permeability paths. Therefore, only porosity and permeability values from whole core analyses are used in this investigation.

Mean average porosity of Texas Gulf Coast Tertiary sandstones, excluding those with clay matrix, decreases with depth (fig. 4). The average decrease in porosity is 1.23 percent per 1,000 ft starting with 27 percent porosity at 2,000 ft (fig. 4). A porosity-versus-depth plot for Louisiana Tertiary sandstones by Atwater and Miller (1965) shows a porosity loss similar to that of Texas Tertiary sandstones (1.29%/1,000 ft). Porosity at 2,000 ft in their plot, however, is 38 percent, 11 percent higher than in the porosity-versus-depth plot for Texas (fig. 5). A comparison of the two curves in figure 5 shows that Louisiana has a higher average porosity at all depths relative to Texas.

Even though mean average porosity decreases with depth in Texas Tertiary sandstones (fig. 4), there is a wide scatter of porosity values at all depths, and some porosity values are as high as 30 percent or more at 15,000 ft (fig. 6). High porosity values at depth are the result of creation of secondary porosity as will be shown later.

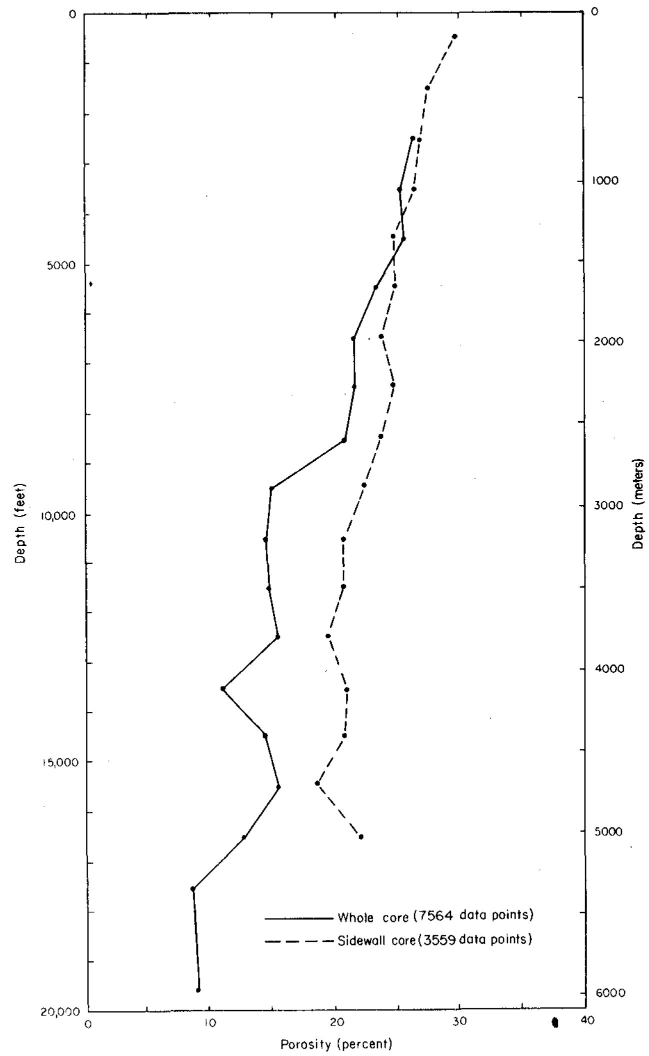

Figure 3. Mean porosity versus depth from both whole core and sidewall core for lower Tertiary sandstones along the Texas Gulf Coast. Porosity values are similar for both sampling methods down to a depth of 5,000 ft. Deeper than 5,000 ft, where the sediments begin to lithify, sidewall cores show consistently higher porosity readings because the percussion method of sampling creates fracture porosity.

High permeability values (fig. 7) are associated with high porosity values at depth. Both permeability and porosity show a wide scatter of values at all depths. The relationships between porosity and permeability for the Wilcox Group and the Vicksburg and Frio Formations are shown in figure 8.

SECONDARY POROSITY

Primary porosity is the original void space left between grains during sediment deposition. This type of porosity decreases through time and burial by compaction and cementation. Secondary porosity is created by leaching of detrital grains, by leaching of cements, and by leaching of authigenic replacement products of grains. Secondary porosity can increase with depth, and it is the dominant form of porosity in the lower Tertiary stratigraphic section in the moderate-and

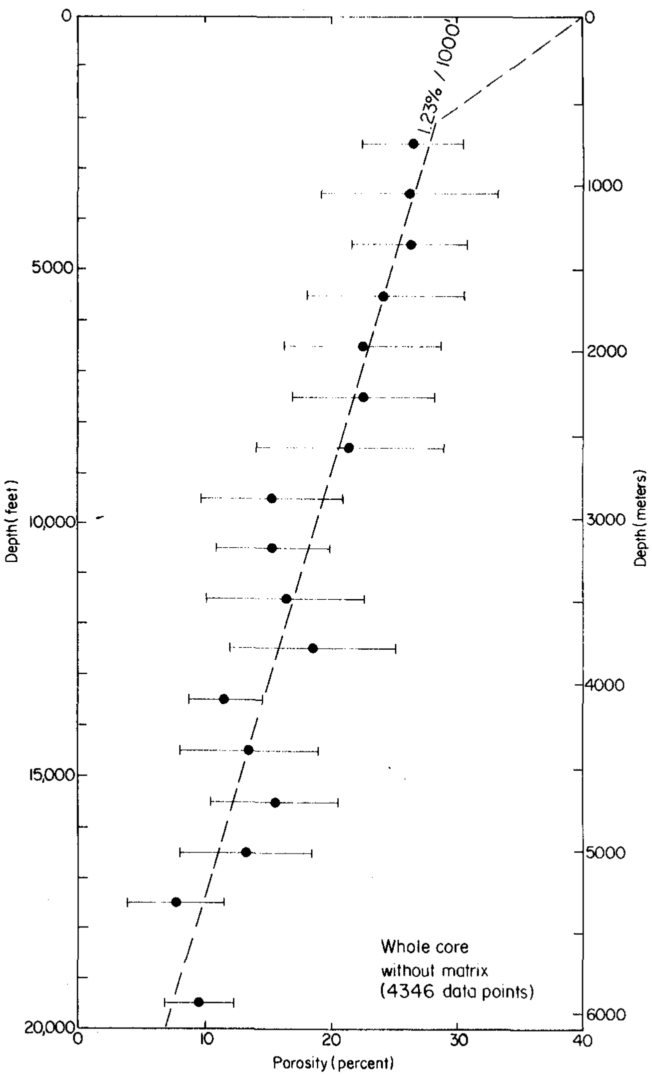

Figure 4. Mean sandstone porosity and standard deviation per thousand foot interval from whole core analyses for lower Tertiary sandstones along the Texas Gulf Coast. Only values from sandstones without matrix are used. Starting at the 2,000 ft interval, the average loss of porosity with depth is 1.23 percent per thousand feet.

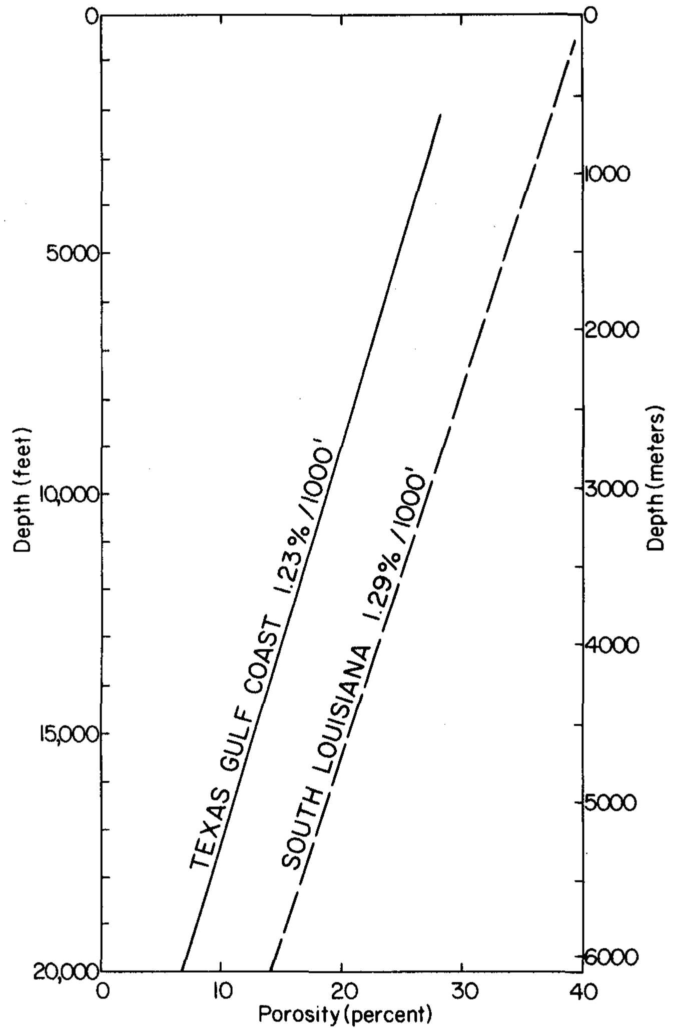

Figure 5. Comparison of mean sandstone porosity versus depth for Texas and Louisiana Gulf Coast areas. Even though Texas and Louisiana sandstones have similar porosity loss-versus-depth gradients, Louisiana sandstones are more porous at all depths. Data for Louisiana from Atwater and Miller (1965).

deep subsurface in the Gulf Coast. Criteria for recognition of secondary porosity were developed by McBride (1977); Schmidt, McDonald and Platt (1977); and Loucks, Bebout and Galloway (1977) and include:

1. *Partial to complete leaching of cements.* Calcite, dolomite, and ankerite cements are leached, resulting in patchy remnants with corroded boundaries.

2. *Partial to complete dissolution of grains.* Most leached grains are feldspars and volcanic rock fragments. Feldspars are commonly honeycombed, and the original grain outlines are preserved only by clay coats or rims.

3. *Oversized pore spaces.* Oversized pore spaces result when a grain is completely leached, leaving a pore space larger than adjacent grains. This process commonly creates the appearance of inhomogeneity in packing.

4. *Embayments in quartz overgrowths.* Embayments in quartz overgrowths result when grains that were embedded in the overgrowths are leached.

Amounts of primary and secondary porosity were determined by point counting 540 thin sections from 197 wells (fig. 9). Either primary or secondary porosity can be dominant to a depth of 10,000 ft in the Tertiary sandstones, but deeper than 10,000 ft secondary porosity is most commonly the dominant form (fig. 10). This trend in abundance of porosity types is also shown by plots for the Wilcox Group and the Yegua, Vicksburg, and Frio Formations (figs. 11, 12, 13, and 14).

STAGES OF DISSOLUTION

Three stages of dissolution create secondary porosity, and these are shown in the general diagenetic sequence for lower Tertiary sandstones (fig. 15) developed by Loucks, Dodge and Galloway (1979). A brief description of the general diagenetic sequence is given below:

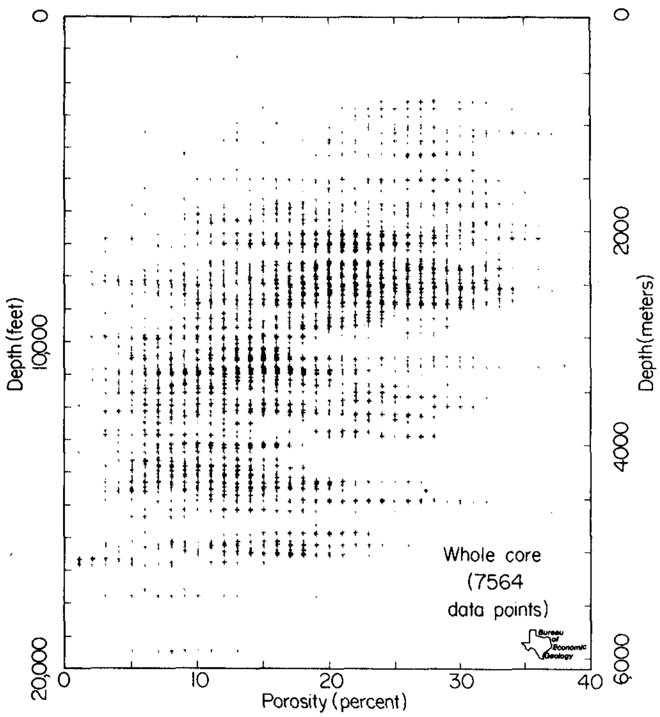

Figure 6. Sandstone porosity versus depth from whole core analyses for lower Tertiary sandstones along the Texas Gulf Coast. Sandstones with and without matrix are included. Note that there is a wide range of porosity values at all depths.

Surface to shallow subsurface diagenesis (0 to 4,000 ft ±) begins with formation of pedogenic clay coats, leaching of feldspar, and replacement of feldspar by calcite. Minor amounts of kaolinite, feldspar overgrowths, and Fe-rich carbonate are locally precipitated. Porosity is commonly reduced by compaction from the original 40 percent to less than 30 percent.

Moderate subsurface diagenesis (4,000 to 11,000 ft ±) involves leaching of early carbonate cements and subsequent cementation by quartz overgrowths and later by carbonate cement. Cementation commonly reduces porosity to 10 percent or less, but this trend may be reversed by later leaching of feldspar grains, rock fragments, and carbonate cements. Restoration of porosity to more than 30 percent can occur, but this may be reduced once more by later cementation by kaolinite, Fe-rich dolomite and ankerite.

Deep subsurface diagenesis (>11,000 ft ±) is a continuation of late Fe-rich carbonate cement precipitation.

During diagenesis of the sediment, compaction and cementation reduces porosity, whereas dissolution increases porosity. The three stages of dissolution will offset some of the loss of primary porosity with depth, and the resulting porosity-versus-depth plot will be a smooth parabolic curve (fig. 16). This smooth curve shows a general decrease of porosity with depth. In another case the porosity created by dissolution at some given depth may be greater than the loss of primary porosity; this will result in a reversal in the porosity-versus-depth curve (fig. 16). If the secondary porosity is not reoccluded by cementation in the deep subsurface, high quality reservoirs may exist to considerable depths. The Chocolate Bayou field in Brazoria County,

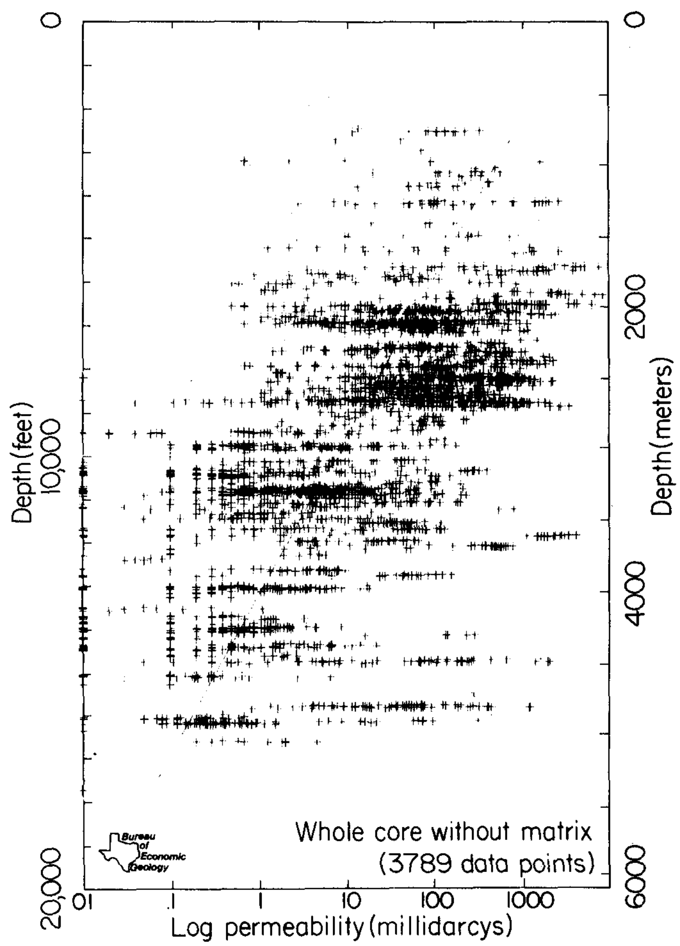

Figure 7. Sandstone permeability versus depth from whole core analyses for lower Tertiary sandstones along the Texas Gulf Coast. Only values from sandstones without matrix are used. Note that there is a wide range of permeability values at all depths.

Texas, has high quality reservoirs at depths greater than 16,000 ft (Bebout, Loucks, and Gregory, 1978). Porosity, predominantly secondary, is as high or higher than 30 percent, and associated air permeabilities are greater than 1,000 millidarcys.

IMPORTANCE OF SECONDARY POROSITY

Loucks, Bebout, and Galloway (1977) pointed out that the zone of well-developed secondary porosity occurs at depths and ambient temperatures that place it well within the liquid window of hydrocarbon generation and preservation (fig. 17) as defined by Pusey (1973). The liquid window encompasses the temperature/depth range within which major oil fields occur, unless there is significant vertical or lateral migration or post-accumulation changes in the thermal regime. The liquid window characteristically brackets oil production in Tertiary basins such as the Gulf Coast. The window, which extends from 150°F to 300°F, includes the minimal temperature (150°F) for generation of petroleum from source kerogen and the maximum temperature (300°F) of liquid preservation (LaPlante, 1972; Pusey, 1973). At temperatures

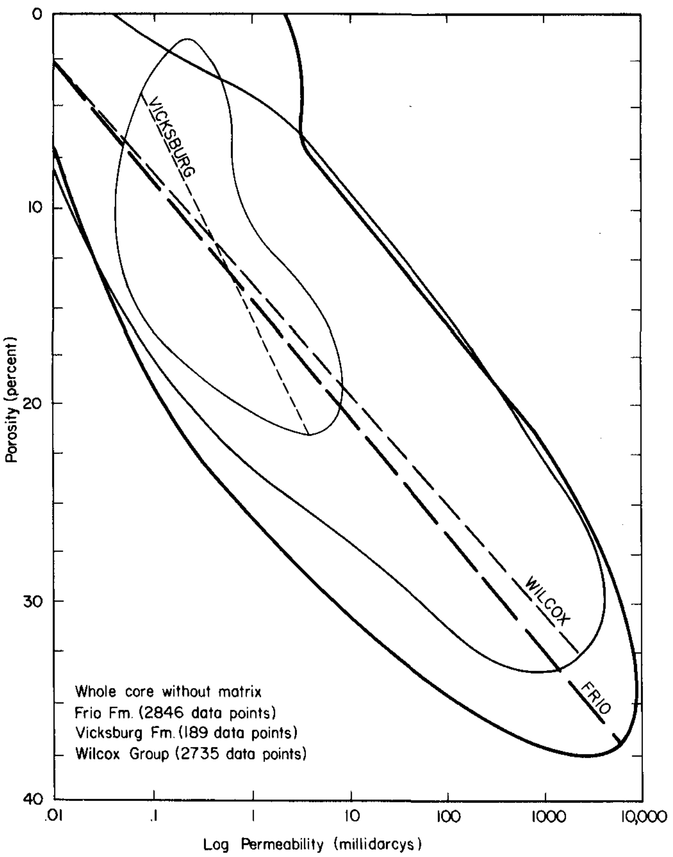

Figure 8. Relationship of porosity to permeability for Wilcox Group and Vicksburg and Frio Formations. Straight dashed lines represent the least-square fit for the range of data shown by the envelopes for each formation.

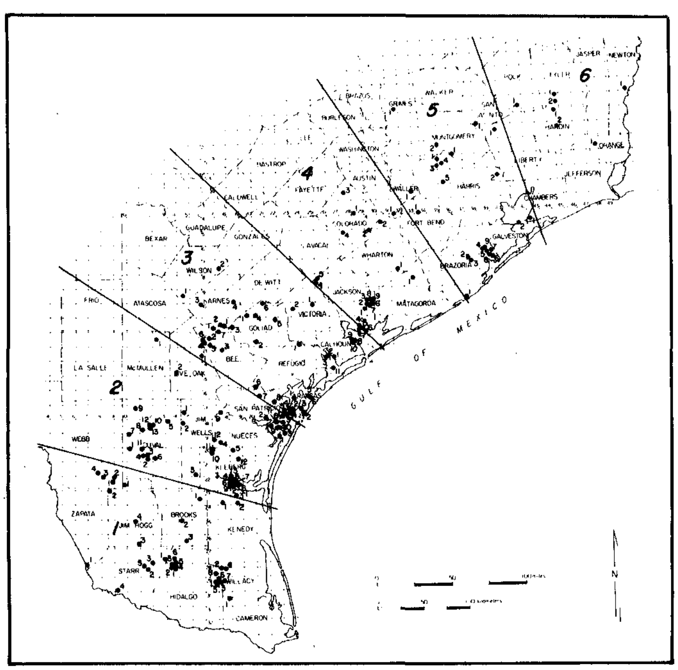

Figure 9. Location of wells with whole core samples used in this investigation.

above 300°F, only dry gas or gas with minor amounts of liquids are typically found (Klemme, 1972). The high porosity produced by secondary leaching within a similar depth range of the liquid window suggests that most oil and essentially all deep gas and gas-plus-condensate production from the lower Tertiary is mainly from secondary porosity (fig. 17).

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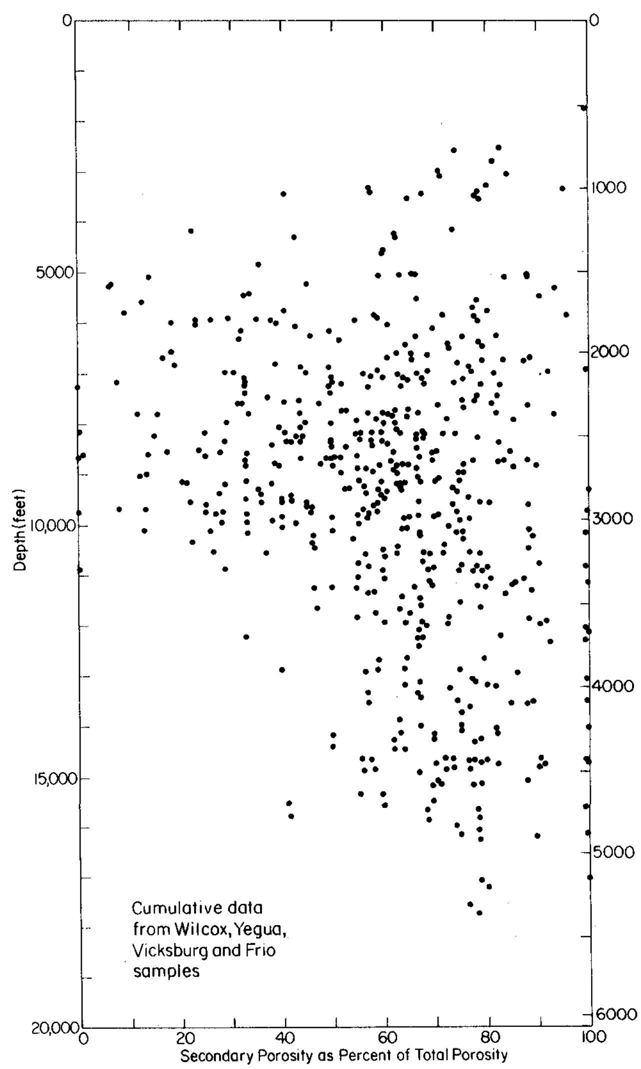

Figure 10. Secondary porosity as a percent of total porosity versus depth for lower Tertiary sandstones. Below 10,000 ft secondary porosity is the dominant form of porosity in nearly all samples. Above 10,000 ft primary or secondary porosity may be the dominant form.

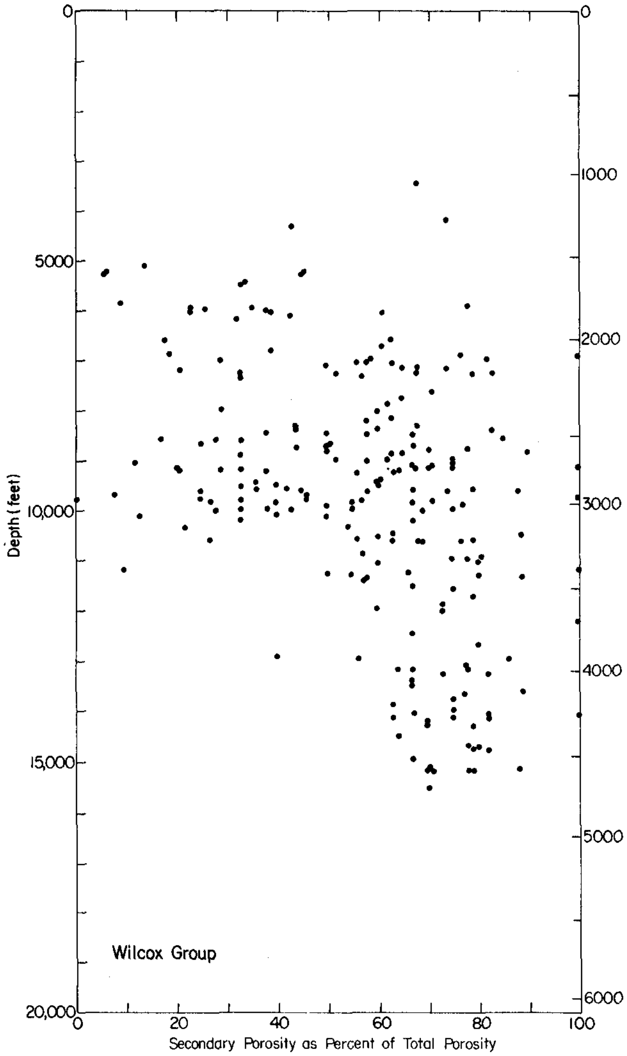

Figure 11. Secondary porosity as a percent of total porosity versus depth for Wilcox sandstones.

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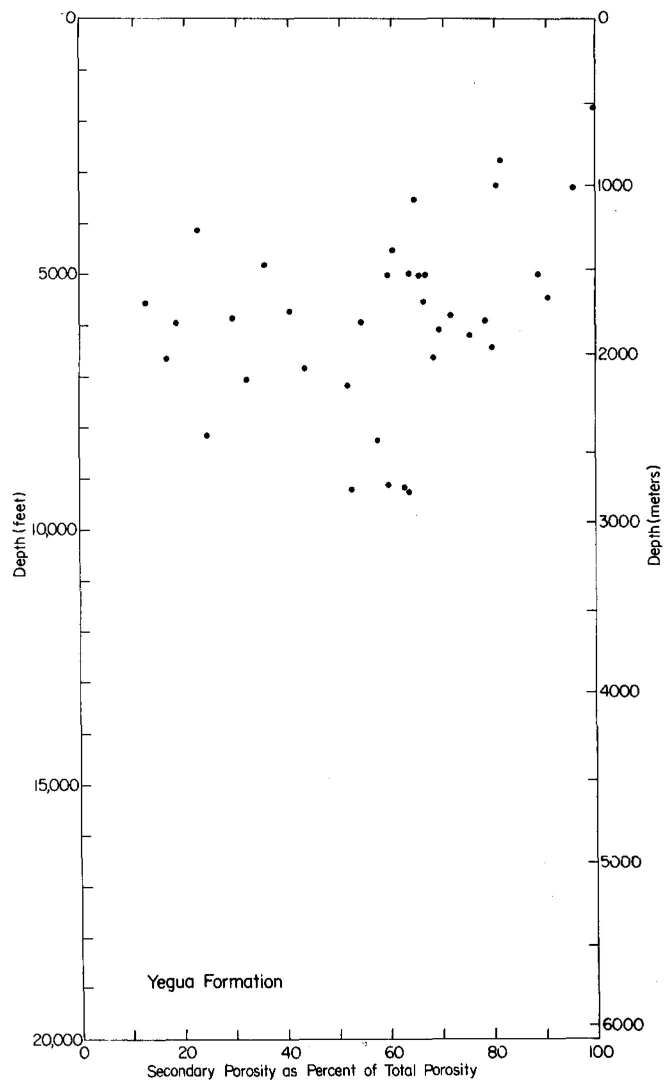

Figure 12. Secondary porosity as a percent of total porosity versus depth for Yegua sandstones.

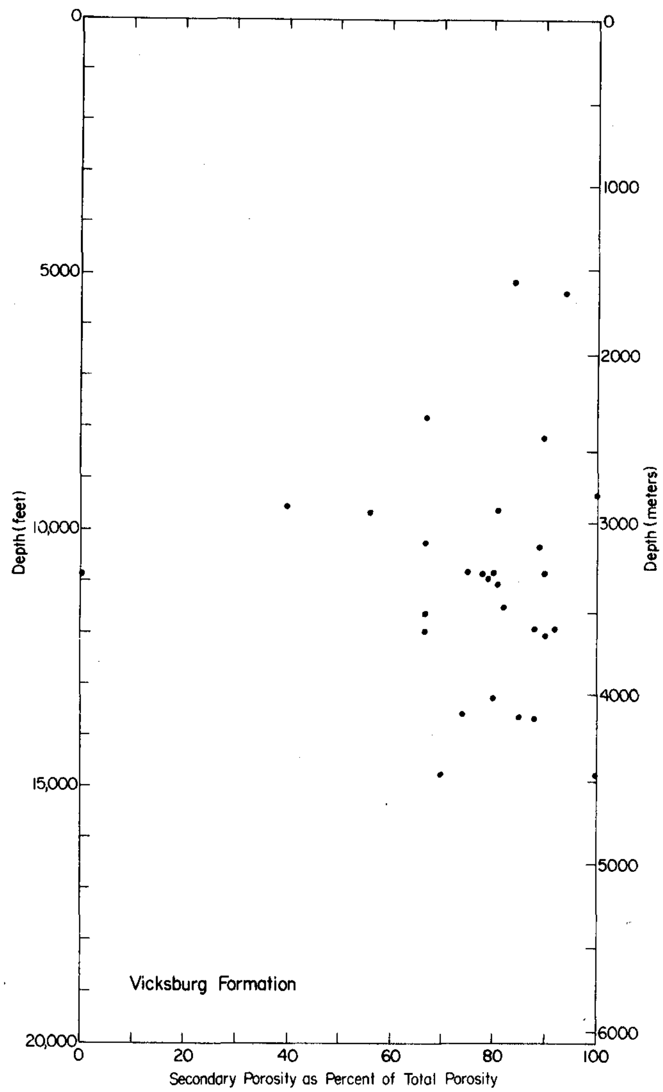

Figure 13. Secondary porosity as a percent of total porosity versus depth for Vicksburg sandstones.

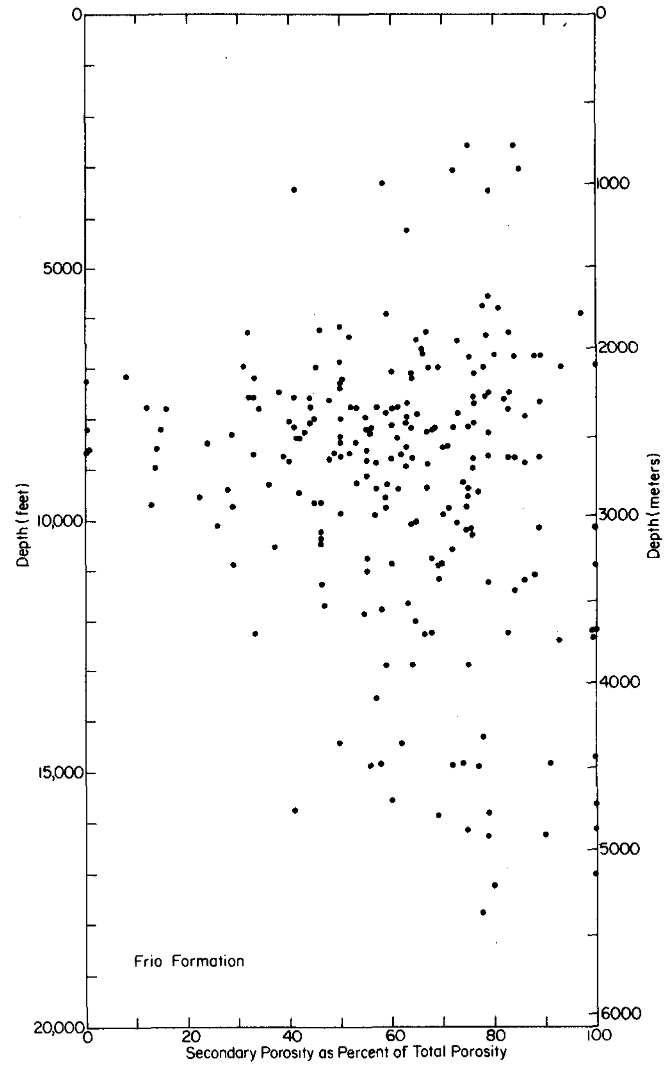

Figure 14. Secondary porosity as a percent of total porosity versus depth of Frio sandstones.

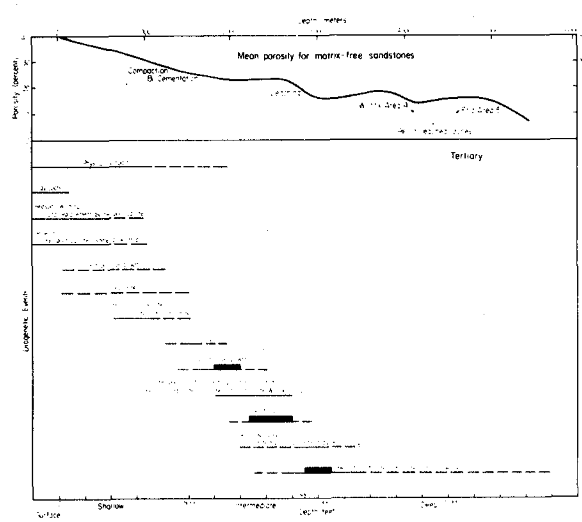

Figure 15. General rock consolidation stages with increasing depth of burial for lower Tertiary sandstones. Porosity curve at top of figure is for matrix-free sandstone (same curve as in figure 4).

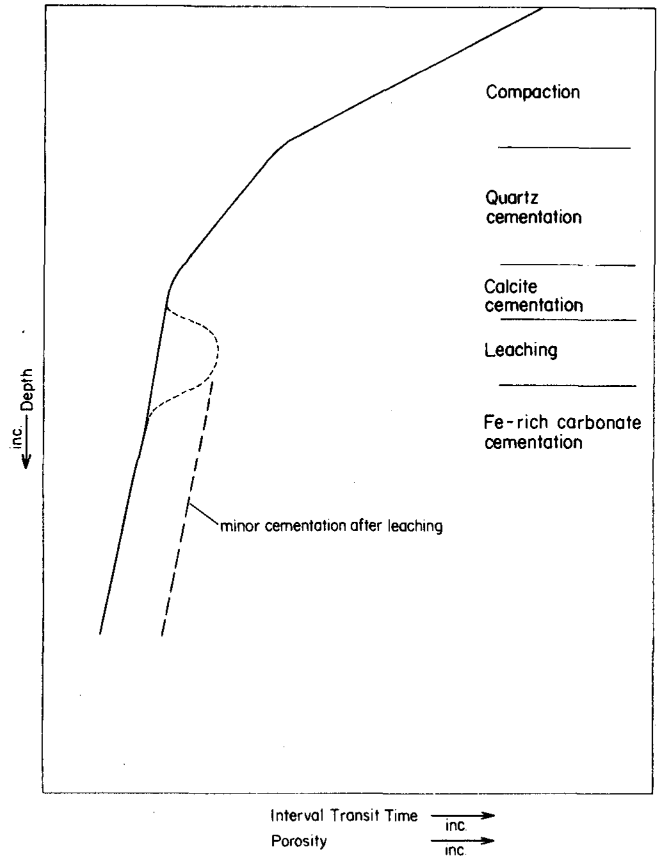

Figure 16. Idealized sandstone porosity paths versus depth showing possible relationship to major diagenetic stages. Interval transit times from acoustic logs should show similar curves.

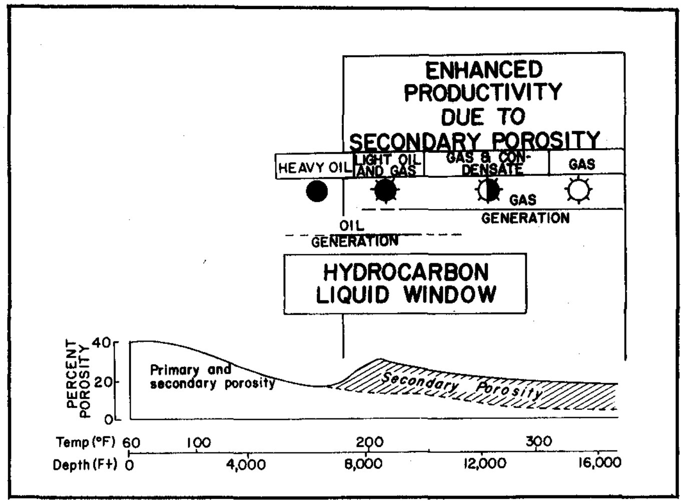

Figure 17. Schematic porosity versus depth/temperature curve for lower Tertiary sandstones showing relative significance of primary versus secondary porosity. The lower three-quarters of the hydrocarbon liquid window, which is characterized by the production of light liquids and distillate, as well as all of the deep gas productive section, lie within the zone of secondary porosity and permeability.