Structural Slope Fans Resulting from Paleogene Compression in the Veracruz Basin, Mexico*

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Abstract

During the Paleogene, the Veracruz Basin was filled by submarine fan complexes deposited on a structural slope and the adjacent basin floor. Sediments in the submarine fans were derived from Cretaceous calcareous units west of the basin. Additionally, siliciclastic sediments derived from the Juarez Terrane, the Mixtequita, and possibly the Chiapas Massif entered the basin from the south. Thick Mid- to Upper Cretaceous platform carbonates in the western part of the basin were thrusted towards the east along with Upper Jurassic (Kimmeridgian/Tithonian) and Paleocene detachments that represent the Cretaceous and Paleocene phases of Laramide deformation. The center of the basin underwent marked Eocene-early Oligocene subsidence. A basement high with similar length and orientation as the thrust belt underlies the Los Tuxtlas volcanic zone in the eastern part of the basin. This high has undergone two stages of uplift; one in the Eocene and another in the lower Miocene. During the Paleocene, submarine fans with well defined wedging to the west derived from the thrust belt flowed freely into the Gulf of Mexico until an easterly-tilted basin formed In the late Paleocene - early Eocene between the thrust belt and the Los Tuxtlas basement. Extensive submarine fans were deposited during the Eocene between the thrust belt and Los Tuxtlas until this depression was filled in the Oligocene and sedimentation once again prograded freely toward the Gulf of Mexico. More recent uplift has eroded most of the Paleogene section along the western edge of the basin, and equivalent shelf facies are unknown.

Background

It is postulated that between the Tectonic Front (TF) and the Height of the Basement of Los Tuxtlas (ABLT) a basin was formed in the Paleocene-Oligocene and that it completed its filling at the end of early Oligocene-Miocene. This basin was filled syntectonically by sediments that originated from the Tectonic Front in the north and the igneous-metamorphic complexes of Terreno Juárez, La Mixtequita, and the Macizo de Chiapas in the south. The sediments that fill this depocenter formed as complexes of turbidite flows on a structured slope.

Location

The area of this study covers the Tertiary Veracruz Basin, which is located in the central part of the state of the same name. To the north, it borders the Tampico-Misantla Basin and to the south, the Salina del Itsmo Basin; the Laramíridic Tectonic Front is to the west and the Los Tuxtlas Volcanic Field is to the east (Figure 1).

Objective

The purpose of this study was to identify the distribution and quality of the reservoir rocks in the Paleogene fan complexes. To achieve this objective, maps were prepared of the facies, thicknesses, porosities, and permeabilities of the above-mentioned complex.

Development of Theme

Availability of Data

3D seismic land and marine data was used to construct the regional geological model of the Tertiary Veracruz Basin. The 2D seismic data used basically covers the area between the 3D seismic land and marine data. Structural maps were constructed from the top of the Paleocene, Eocene, and Oligocene, as well as isopach maps, maps of net sand thicknesses and sand, porosity and permeability maps. At the same time, data from 40 wells was integrated with electrical logs that total or partially crossed the Early Paleogene sequences.

Stratigraphic Framework

The stratigraphic column of the Veracruz Basin (Figure 2) consists of a basement formed by igneous and metamorphic rocks, which are sometimes exposed, such as in the Sierra de Juárez, the Massif of Chiapas, and La Mixtequita. The Jurassic deposits, which lie on this basement, have a basal transitional facies and an uppermost marine facies, that represents a maximum flooding surface in the Tithonian. This time was of the most importance because it had the right conditions for the deposit of sediments rich in organic matter.

Overlying the Jurassic deposits are the Lower Cretaceous deposits, which represent the beginning of carbonate basinal deposition, which gradually evolved into conditions of a calcareous platform during the Albian-Cenomanian. During the Turonian, a global maximum flooding surface was experienced once again. This led to deposition of organic-rich sediments. The Laramide Orogeny commenced during the Maastrichtian. During this period, carbonate deposition ended, and terrigenous sediments were deposited duringt the Cenozoic until the Recent. The stratigraphic column of the Veracruz Basin is intruded by salt, presumably Callovian in age. It is also intruded by Oligocene igneous rocks belonging to the Los Tuxtlas Volcanic Field (González, 2005, González and Martínez, 2011). The potential Jurassic plays, the proven Cretaceous and middle Eocene oil plays, and the proven Neogene oil and gas plays are located in this basin.

Regional Tectonic Context

Unlike most of North America, which contains a stable craton that facilitated the formation of large platforms and a broad development of delta systems from this craton and to the Gulf of Mexico (Carfantan, 1983; Coney, 1972; 1978), the Veracruz basin, because of Laramide-related erosion of platforms developed in the Cretaceous, has a tectonic context dominated by a front coupled with continuous tectonic uplift and subsequent erosion. Due to this, in the Veracruz basin, the Paleogene was characterized by an erosive area (marked by a red line in Figure 3).

This area of erosion is defined from analysis of dozens of wells. In addition to the Tectonic Front, within the regional geological context, the Veracruz Basin is framed by the Terreno Juárez, formed by igneous and metamorphic rocks of the greenschist facies, La Mixtequita in the southern portion of the basin, formed by metamorphic rocks and granite, and the Massif of Chiapas, composed of rocks of the granite (Figure 3).

Distribution of Facies

Maps prepared of the major facies were based on the identification of stratigraphic features in all the Early Paleogene sequences, based on the 3D and 2D seismic data. The seismic transect (Figure 4) shows the fans that were identified. Maps of Paleogene facies (Figures 5, 6, and 7) show in the west a north-south-oriented strip of erosion caused by compressive cyclic tectonic events that began in the Late Cretaceous and continued until the late Pliocene. To the east of this stretch of erosion, slope fans were distributed over the Veracruz Basin; they represent potential hydrocarbon reservoir rocks.

In a regional context the proximal and medium facies are represented by the slope fans; their respective distal facies were deposited in the basin floor (Figure 5). Locally, each fan complex has its own distribution pattern of facies. In the northern part of the basin, the main area of origin of the fans is in the Cretaceous rocks of the Tectonic Front, with a distribution of sediments towards the northeast, with connection directly with the fan systems of the deep waters of the Gulf of Mexico.

The southern part of the basin is characterized by the presence of a large depocenter formed between the Tectonic Front and the “Height of the Basement” of Los Tuxtlas (Figures 4 and 5). There large fan complexes developed, whose reservoirs were sourced largely from the igneous-metamorphic complexes from the Terreno Juárez, La Mixtequita, and the Massif of Chiapas and, to a lesser extent, from the Cretaceous rocks of the Tectonic Front.

During the Eocene and Oligocene, sediments were stacked in the depocenter, and they also were deposited to the north, forming fans on the basin floor in the Anegada-Labay and Holok-Temoa area (Figure 5). The Height of the Basement of Los Tuxtlas also functioned as a topographic high that controlled the flow of the sediments towards the Gulf of Mexico from the Paleocene to the Eocene. During the Oligocene, the depocenter was clogged, thereby allowing the flow of sediments to the Gulf of Mexico (Figure 5c).

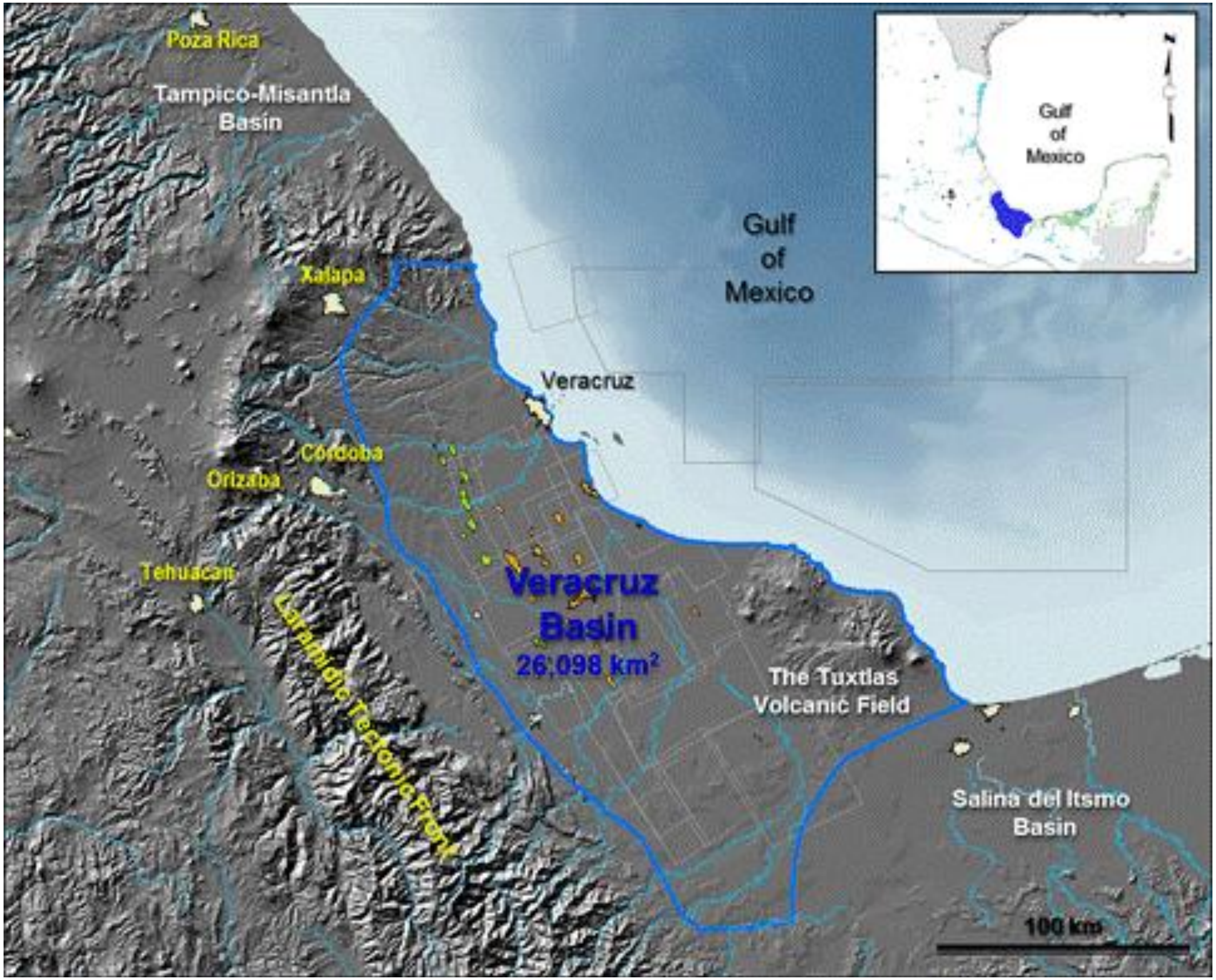

Figure 1. Location of the area of study.

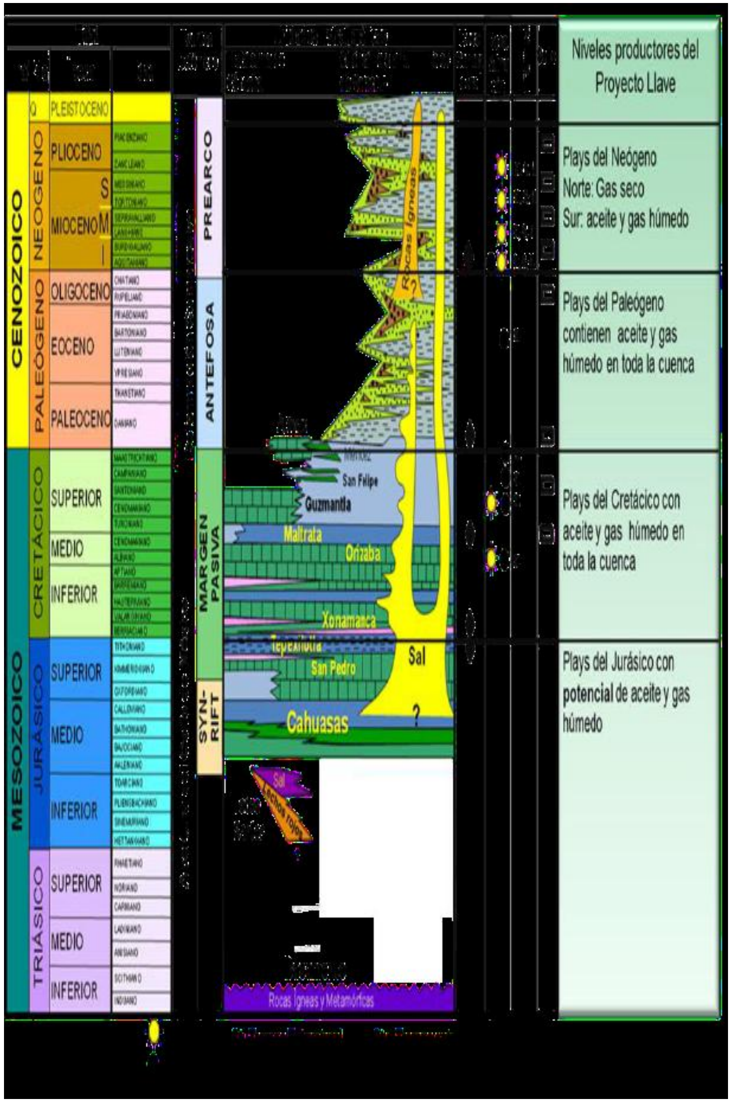

Figure 2. Stratigraphic column of the Veracruz Basin.

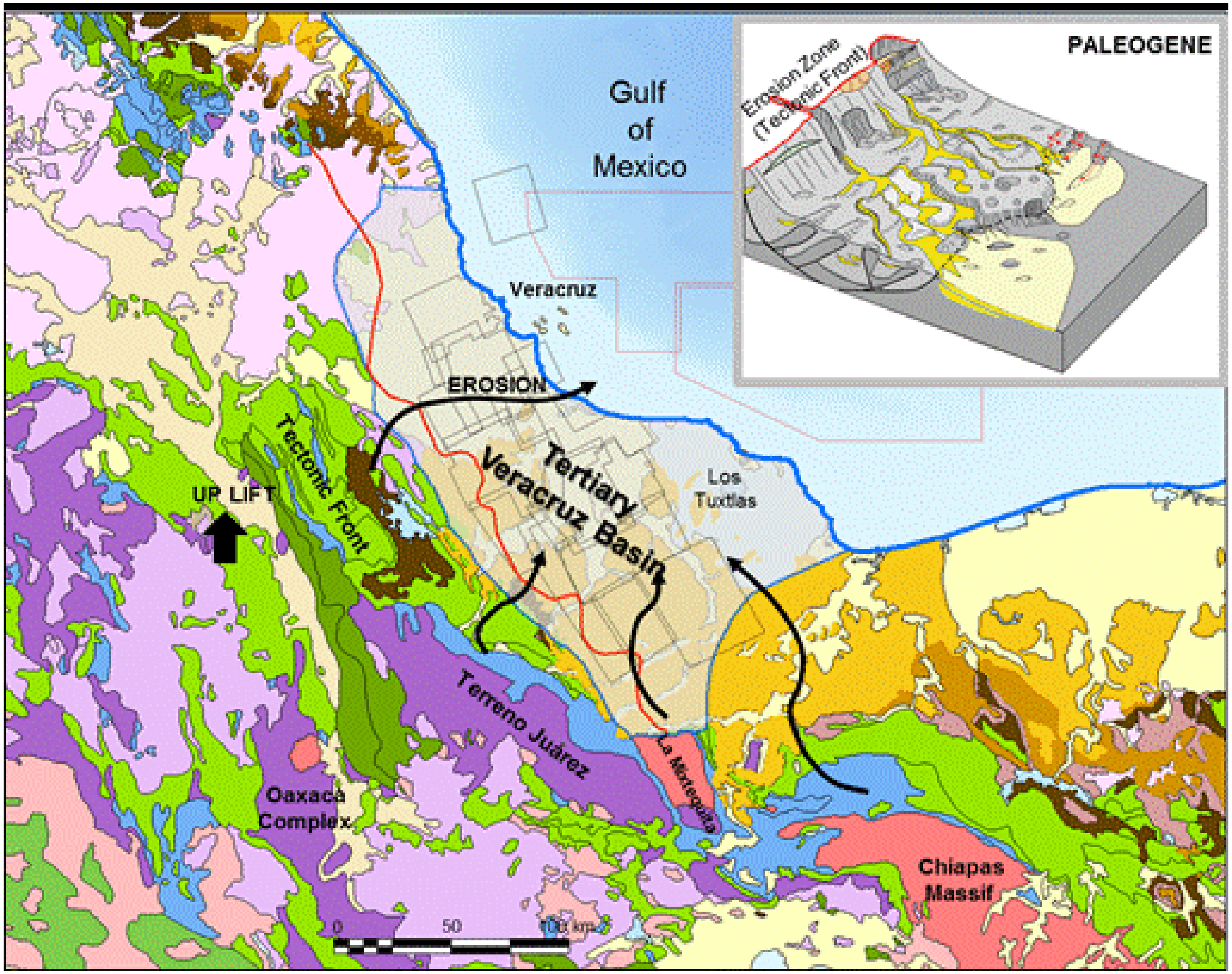

Figure 3. Regional geological context of the Veracruz Basin.

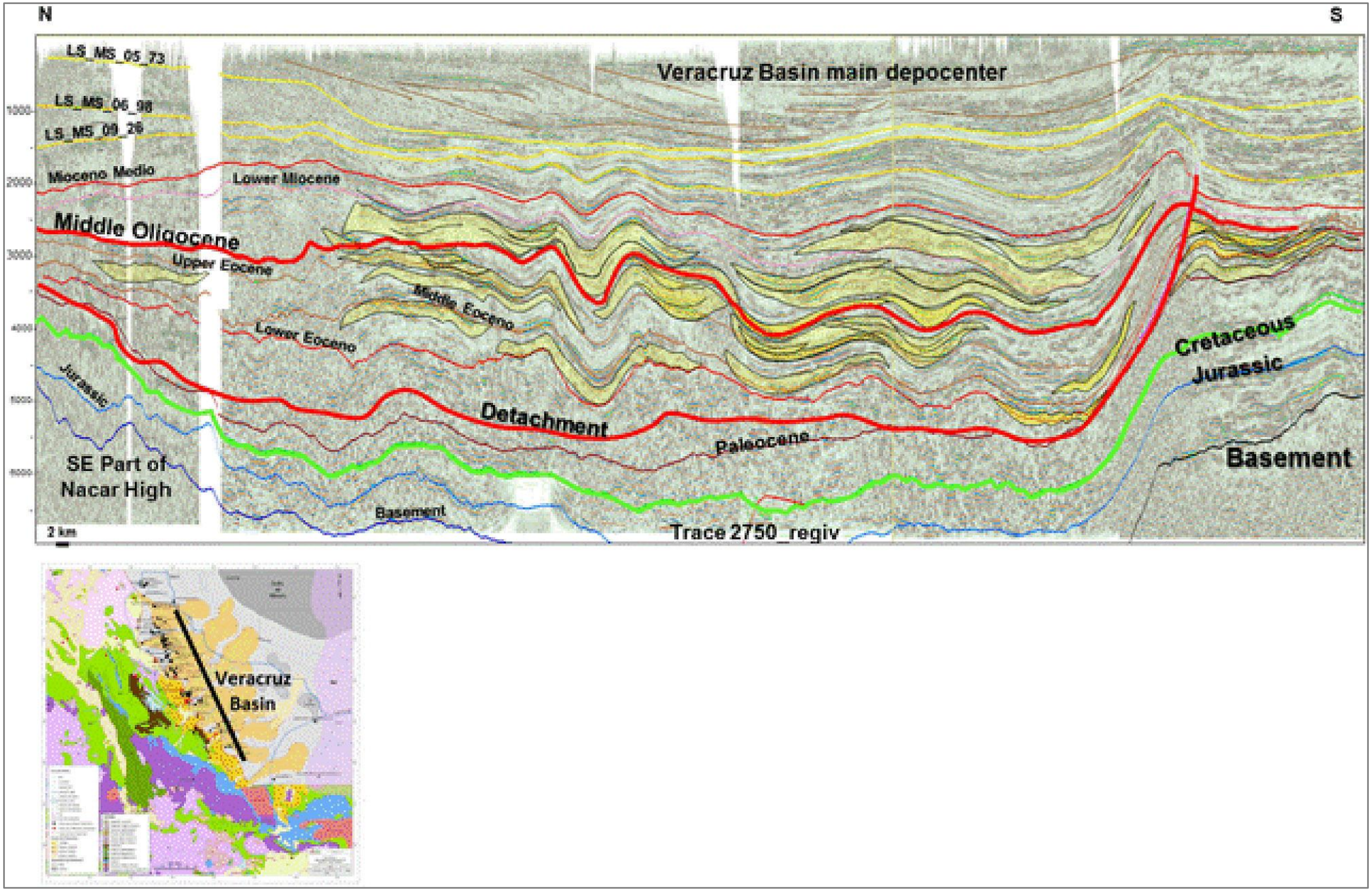

Figure 4. Regional seismic section showing the stack of fans throughout the Paleogene.

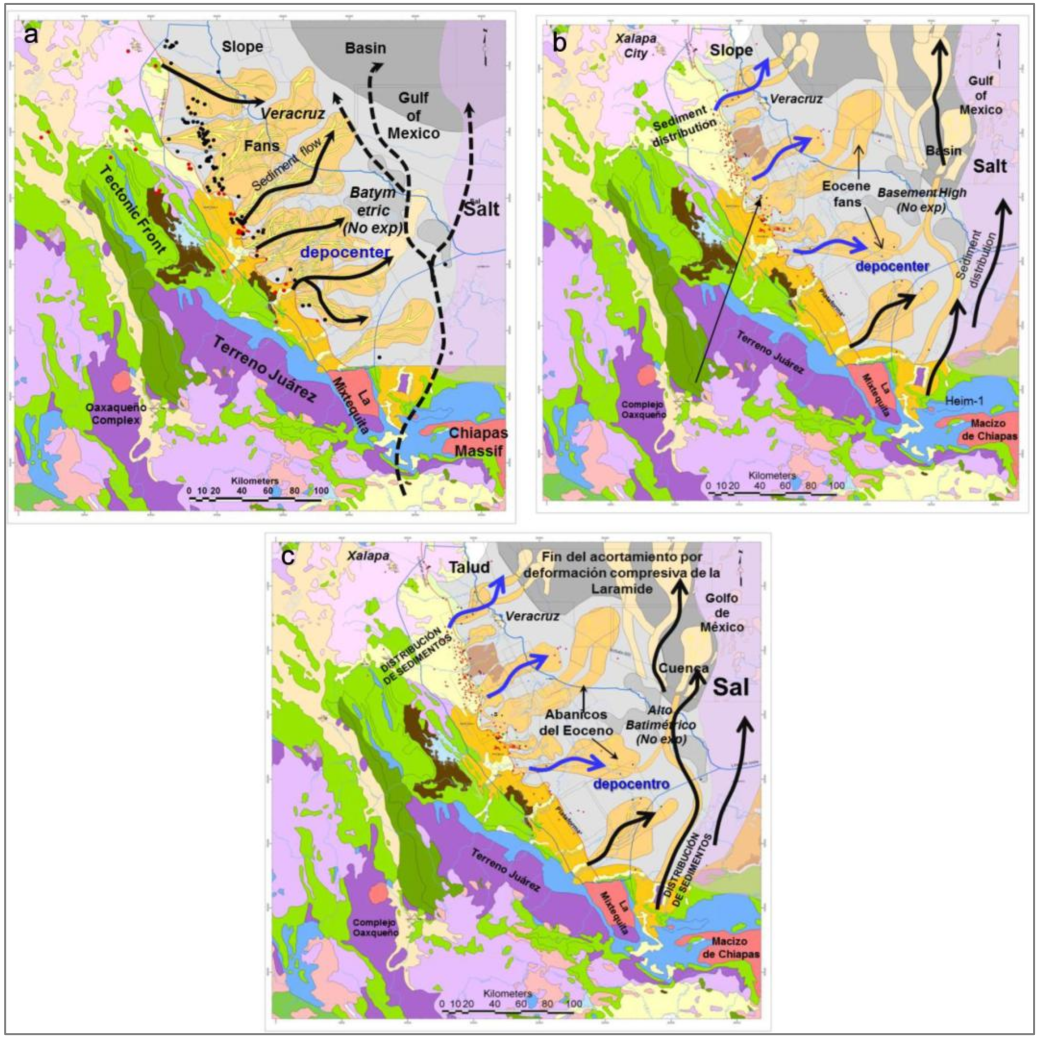

Figure 5: (a) Current distribution map of Paleocene facies. b) Current distribution of Eocene facies. c) Current distribution of Oligocene facies.

Quality of Reservoir Rock

The maps of the quality of the reservoir rock were prepared based on the data of about 40 wells. Many of the wells included for the preparation of the maps are located along a NW-SE strip adjacent to the Tectonic Front, in which the Paleocene, Eocene, and Oligocene sequences are at shallower depths in comparison with the rest of the basin.

In the lithological context, the northwest of the basin was observed as having proximal facies formed by conglomerates and sandstones (fragments of carbonate rocks), thus causing the reservoir rock to be of poor quality. The southwest of the basin has fans consisting of conglomerates and sandstones formed by a mixture of fragments of igneous, metamorphic and carbonate rocks, in addition to a high percentage of detrital quartz, which improves the quality of the reservoir rock. These conditions change gradually towards the east where sandstones predominate; this translates into an increase in the quality of the reservoir rock at the base of the Height of the Basement of Los Tuxtlas, in both its land and marine portions.

In particular, the Paleocene rocks show maximum thicknesses of sands of 445 m associated with the canyons that supply sediments towards the basin. The intermediate porosity values are between 10 and 15%, whereas the permeability is within a range of 0.035 to 2.5mD. The maps in Figure 6 emphasize trends of a northeasterly direction, similar to those of the facies of the Paleocene (Figure 5).

In the case of the Eocene sandstones, the maximum thickness of 693 m are associated with the entry points of sediments along the Tectonic Front and in the southern part of the basin. The porosities vary between 10 and 25%, and average permeabilities fluctuate between 0.001 and 40mD in the lower levels of the Eocene section and up to 50mD in the upper Eocene reservoirs. Some permeability values reach 198mD. Figure 7 shows the distribution trends of net thickness of sand, porosities, and permeabilities following the same trends as the facies (Figure 5).

The general trend for the Oligocene sandstones shows that the maximum thickness is 400 m, associated with the entry points of sediments in the central part of the basin, as well as to the sediment discharge areas in the marine zone, with a thickness of 330 m. Moreover, the porosity values are between 15 and 20% and permeability is between 0.02 and 110mD (Figure 8).

Figure 9 shows graphs of porosity compared to permeability. The upper graph, of core data of the Miocene, shows porosity in the range of 20 to 30%, whereas the lower graph, of core data of the Paleogene, shows that the permeability decreases by 10 units with relation to the Miocene. This graph shows that the decrease in the porosities in Paleogene rocks is most probably due to the effect of compaction due to depth of burial. Moreover, a global analysis by Ehrenberg et al. (2009) of the porosity based on depth and age of the rock shows that porosity trends also depend on the geological age (Figure 10). Paleogene rocks at a global level are observed to have porosities between 14 and 16% at depths between 3 and 4 km and minimum porosity of 10% at depths of 5.5 km. Based on the interpretation of their study, possible Paleogene reservoir rocks at depths between 4000 and 5000 m may have porosities of between 10 and 15% (Figure 10).

In the deposits in the Veracruz Basin, the porosity cut-off in the Neogene deposits is 8%. In accordance with the quality analysis of reservoir rock provided in this study, minimum cut-off values of porosity of 10% were established, determining that the Paleogene rocks in the Veracruz Basin are potential reservoir rocks.

Conclusions

Stacks of fans were deposited on a structured slope during the Paleocene and Eocene in the Veracruz Basin, forming large generally east- to northeast-oriented lobes with complex channels. In the northwest, the complex of fans was deposited on a structured slope and then on the basin floor in the Holok area. Towards the southwest land portion, the distribution of the fan complex is controlled by the Height of the Basement of Los Tuxtlas and only certain channels crossed it to be deposited in the Gulf of Mexico. It is towards this part of the basin where a better quality of reservoir rock is expected. In the Oligocene, the depocenter between the Tectonic Front and the Height of the Basement of Los Tuxtlas was clogged, and the sediments were transported farther towards the Holok area in the Gulf of Mexico.

Acknowledgments

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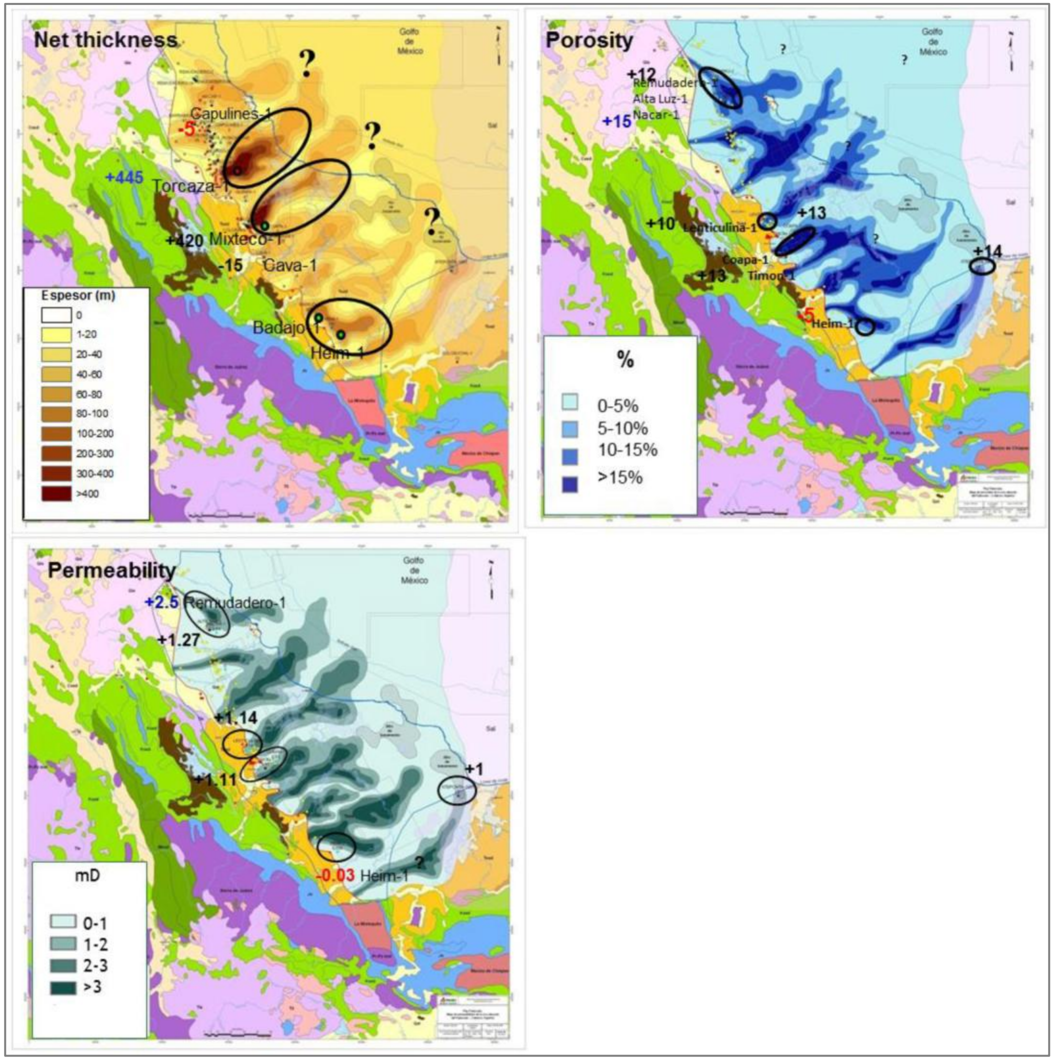

Figure 6. Maps of the quality of the reservoir rock of the Paleocene period. Upper left: map of net sand thickness; Upper right: map of porosity. Lower left: map of permeability.

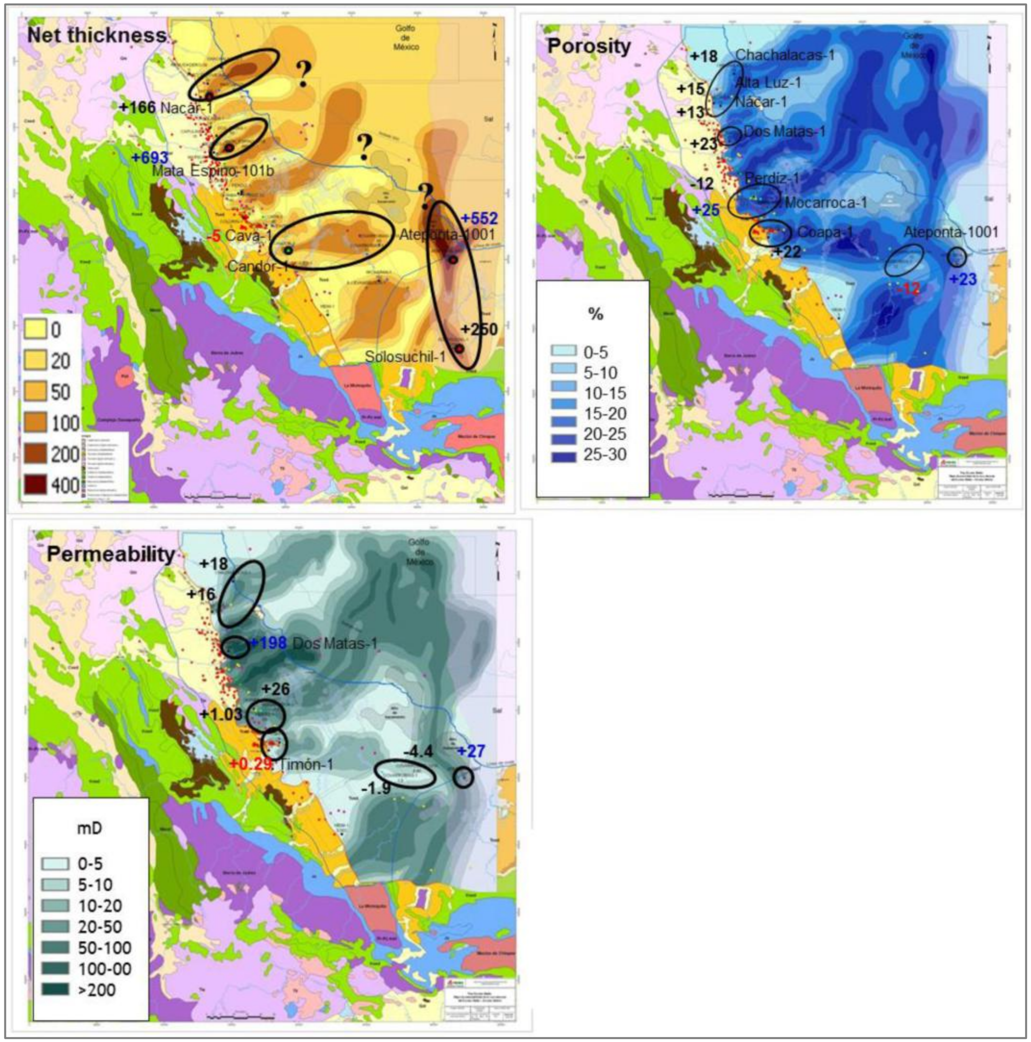

Figure 7. Maps of the quality of the reservoir rocks of the Eocene. Upper left: map of net sand thickness; Upper right: map of porosity. Lower left: map of permeability.

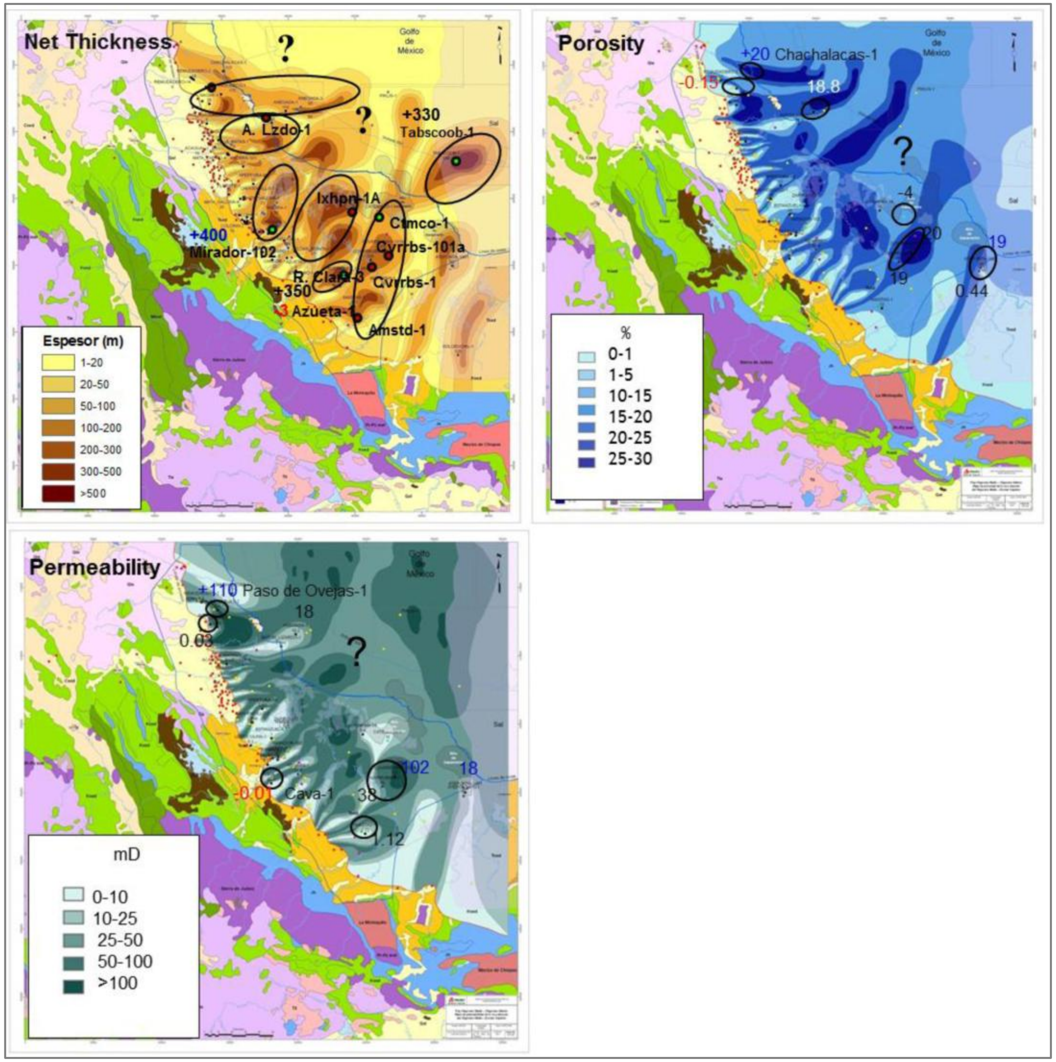

Figure 8. Maps of the quality of the reservoir rocks of the Oligocene. Upper left: map of net sand thickness; Upper right: map of porosity. Lower left: map of permeability.

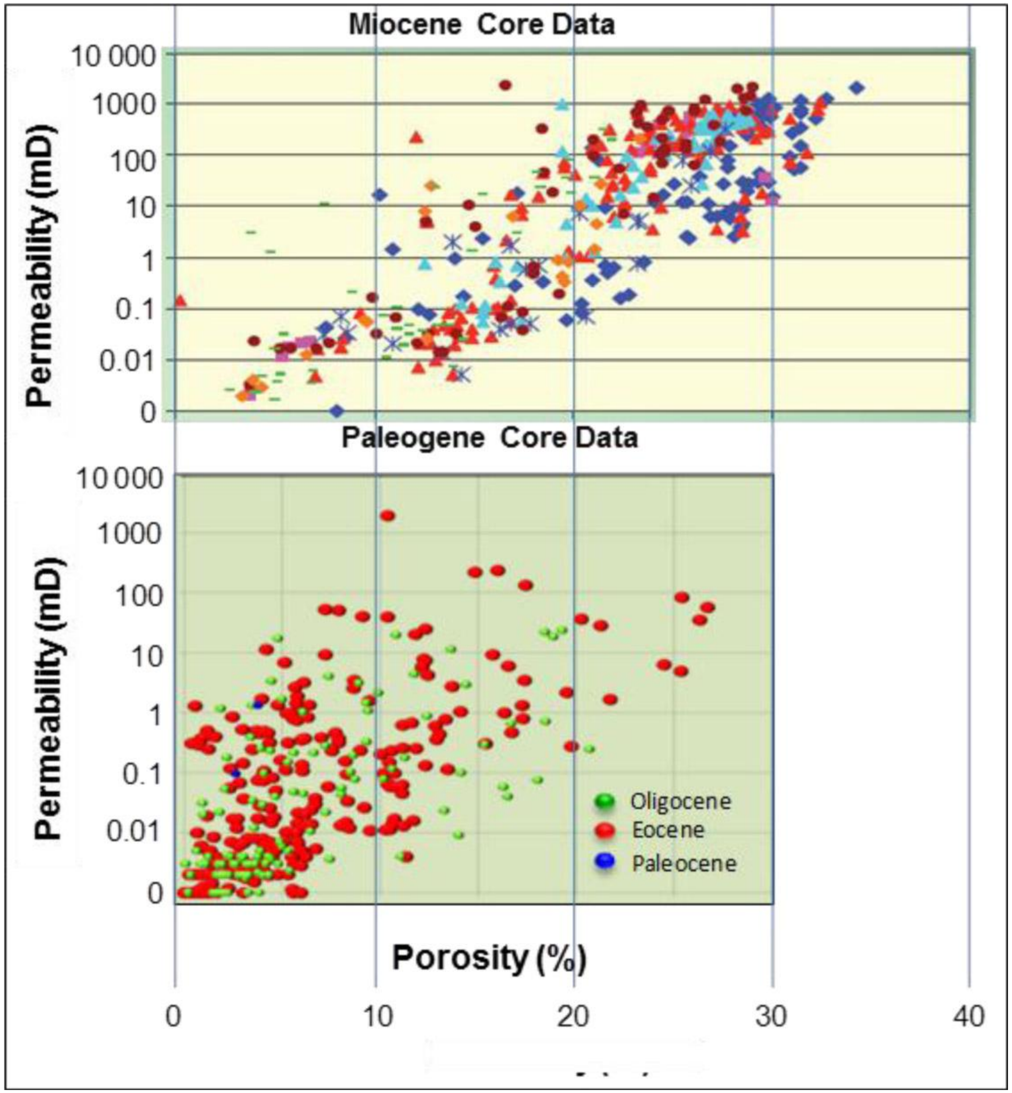

Figure 9. Graph of porosity vs. permeability from core analysis of Miocene and Paleogene rocks in the Veracruz Basin.

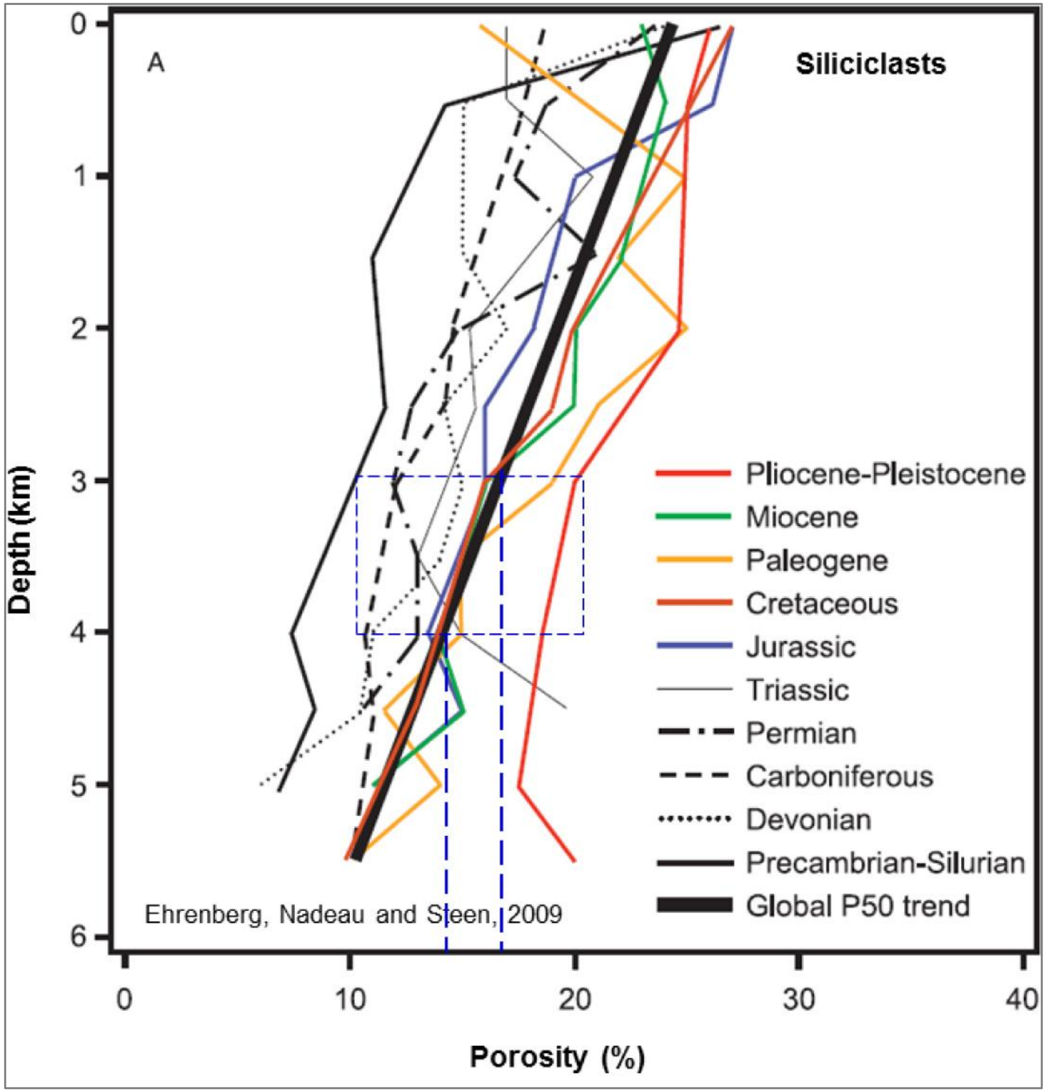

Figure 10. Porosity vs. depth in siliciclastic rocks based on geologic age (from Ehrenberg et al., 2009).