New Insights into the Stratigraphic Framework and Depositional History of the Paleocene and Eocene Chicontepec Formation, Onshore Eastern Mexico*

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Search and Discovery Article #30334 (2014)
Posted May 31, 2014

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG 2014 Annual Convention and Exhibition, Houston, Texas, April 6-9, 2014,
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Abstract

A detailed biostratigraphic analysis and stratigraphic framework of the Paleocene and Eocene Chicontepec Formation in the Tampico-Misantla Basin, onshore eastern Mexico, was conducted using 33 wells. The objective was to have an independent re-evaluation of the geological framework for future evaluation of the resources. The Eocene and Upper Paleocene stratigraphy in the basin is very complicated and it was found that a well spacing of 5-10 km was necessary in order to identify the depositional character of each sequence. A detailed Wheeler diagram, with time increments of 0.1 Ma, was constructed for the stratigraphic framework using the interpreted graphical biostratigraphic data on the wells. Rock accumulation rates (uncorrected for compaction, dewatering, etc.) in the sequences are between 10 and 20 cm/1000 yrs. The regional stratigraphic framework is defined by five sequence boundaries: SB 65.5, SB 60.4, SB 54, SB 46 and SB 38.1. Once these sequence boundaries were established it was possible to reconstruct the depositional history of the Eocene submarine fans which were sourced from the southwest margin of the basin. After SB 54, there are five sediment entry points into the basin from the southwest. The northern two entry points coincide exactly with two canyons identified from Chicontepec outcrop studies (Cossey and Van Nieuwenhuise, 2011). Additional entry points are identified to the south of the outcrop study area where fieldwork was inconclusive, but the subsurface evidence indicates the presence of three more canyons. After SB 46, there are six sediment entry points into the basin from the southwest. The additional entry point correlates exactly with the large San Lorenzo Canyon which was identified from fieldwork (Cossey and Van Nieuwenhuise, 2011).

Introduction

The objective of this project is to build a stratigraphic framework for the part of the Tampico-Misantla Basin, informally called the Chicontepec Basin. The basin is located in onshore eastern Mexico, between the cities of Tampico and Misantla (Figure 1). The study area is almost completely covered by several 3D seismic surveys and is approximately 170 km by 50 km (Figure 2). Approximately 100 of the deeper wells with biostratigraphic data were selected to create a network of transects and control points in the basin.

Paleogene Stratigraphic Framework

Previous workers in the basin had been aware that there were several unconformities in the basin (Figure 3). These had been informally named “A”, “C” and “E” by previous authors. However, the exact age of these unconformities was unknown and it was also not apparent if these were local unconformities or regional sequence boundaries. The Paleocene and Eocene stratigraphy was complicated by these unconformities because in many areas they were very erosive and removed a large part of the underlying sequence. It was therefore necessary to study the detailed biostratigraphy of the wells, and identify the sequences and hiatuses by graphic correlation before framework of the basin could be established.

Methodology

Data from over 100 wells was provided by Pemex. The geologic data provided was in the form of core photos, core descriptions, core gamma ray, petrographic studies, and well reports as well as biostratigraphic summaries and plots. About 85% of the core photographs were provided. The wells were drilled between 1936 and 2010, so the quality of data varied considerably. A total of 3,700 m of core was available in the project wells.

The main tool for constructing the stratigraphic framework is a Wheeler diagram. This was constructed from the interpreted graphical biostratigraphic data on 33 wells provided by Dr. Don Van Nieuwenhuise, University of Houston. The Wheeler diagram was created as a large spreadsheet with time increments in the vertical axis of 0.1 Ma where each well is plotted vertically. For each well, the depositional hiatuses and sequences are plotted vertically for their appropriate ages. For each sequence, the actual well depth is also recorded at the top and bottom of the sequence. The sequence boundaries are the time intervals common to all wells when there was no deposition. The identification and mapping of the sequence boundaries is key to the understanding of the basin. Once these are identified, the seismic lines can be flattened on the sequence boundaries to aid in the depositional interpretation.

A Wheeler Diagram cross-section through the basin of 20 of the most important wells is shown in Figure 4. Rock accumulation rates (uncorrected for compaction, dewatering, etc.) in cm/1000 yrs are also calculated for each sequence. Each depositional sequence was color coded according to the accumulation rate to allow slow (less than 10 cm/1000 yrs) and fast (>20 cm/1000 yrs) rates to be easily identified. It was found that most of the sequences in the Paleogene have rock accumulation rates of between 10 and 20 cm/1000 yrs. The missing sections below the sequence boundaries in this study are assumed to be erosional and those above the sequence boundaries are assumed to be non-depositional.

The Paleogene regional stratigraphic framework is defined by the sequence boundaries, of which five have been identified in this study (Figure 4). These are (from top to bottom): SB “E” at 38.1 Ma, SB “C” at 46 Ma, SB “A” at 54 Ma, SB “Z” at 60.4 Ma, SB “K/T” at 65.5 Ma. In the following section these will be referred to as SB 65.5, SB 60.4, SB 54, SB 46 and SB 38.1. Each sequence boundary was identified from the Wheeler diagram as a hiatus common to all wells. SB 38.1, SB 60.4 and SB 65.5 are very well defined and identified to an accuracy of 0.1 Ma. SB 46 and SB 54 are not so well defined and could range in age from 45.8 Ma to 46.1 Ma and 53.8 Ma to 54.1 Ma. A few other common hiatuses were identified in the wells from the Wheeler diagram, but these are only present in a few wells and are therefore considered local unconformities, such as the unconformity at 31 Ma (Figure 4).

Stratigraphic Framework and Paleogeographic Maps

Sequence 65.5 to 60.4 Ma

This sequence correlates to the Lower Paleocene (Danian) and started with the K/T impact event at 65.5 Ma. Outcrop studies in 2008 (Cossey, 2008) also concluded that the Lower Paleocene was only present in the northern and western outcrops of the Chicontepec Basin (Cossey and Van Nieuwenhuise, 2011). The impact of the asteroid (K/T impact event) at Chicxulub is now a well-documented geologic event which took place at the Cretaceous/Tertiary (K/T) boundary (Schulte et al., 2010). However, the effect of this event is relatively unknown in the Chicontepec Basin, only about 900 km to the west of the impact site.

While searching though well reports it was noted that a “brecha” (breccia) is often described at the top of the “Cretaceous” (which is often somewhat below the 65.5 SB) in many wells in the basin. This breccia is described as being gray or white, containing mudstone clasts, with a sandy matrix, recrystallized *Globotruncanas* with traces of chert, amber and bentonite (for example, in the Marques-1 well). Early geologists thought the breccia had been deposited in response to the Laramide uplift of the Sierra Madre Oriental. None of the 100 project wells cored the breccia.

This breccia outcrops in the southern part of the basin to the southwest of Martinez de la Torre (Figure 5). Here, the breccia is a clast-supported conglomerate with cobbles and boulders of limestone, sandstone (medium to coarse grained) and quartz. The matrix is a medium to coarse-grained sandstone. The K/T contact has been documented just to the west of this outcrop at Latitude 19^{o} 55.2018’ N Longitude 97^{o} 8.863’W (Mark Bitter, personal communication).

In many well reports it was also noted that the “Velasco Formation” overlies this breccia. The Velasco Formation is always described as a shale, red, gray or brown and compacted. The Velasco Formation was cored in the Entabladero-101 well from 1140-1149 m and is described as a compacted grey/brown shale. It is devoid of sand.

The presence and thickness of both the breccia and the Velasco Formation were noted and mapped. This is not a perfect way to map since the wells were drilled between 1936 and 2010 and the early wellsite geologists were probably not always aware of the detailed stratigraphic sequence. Additionally, the thickness of the breccia and the Velasco Formation are being estimated from cuttings. However, the reports seem to be fairly reliable.

The breccia is absent in the northern third of the Chicontepec Basin. The thickness of the breccia deposit varies between 4 m and 38 m, but is generally about 10-15 m thick. It pinches out to the southwest and is fan-shaped with “fingers” of the breccia pinching out to the southwest. This seems to imply a source area to the northeast. The only carbonate source area that is present to the northeast is the Faja de Oro atoll, an Albian age reef complex. Additionally, the distribution of the Velasco Formation seems to mimic the distribution of the breccia, but covers a slightly larger area. The Velasco Formation varies in thickness between 16 m and 145 m, but it is generally in the range of 30-40 m thick.

It is proposed that the breccia plus the Velasco Formation are actually a megabed created by the huge tsunami (estimated by some authors to be over 300 m high) from the K/T impact event (Figure 6). Many other megabeds around the world show these same characteristics (Cossey and Ehrlich, 1979). A megabed is simply a mega-turbidite, and the breccia would represent the basal Bouma “A”, or graded division. The Velasco Formation would represent the muddy top, or Bouma “E” division. A good analogue for this megabed is from the Jurassic of northern Tunisia (Cossey and Ehrlich, 1979) where a carbonate megabed up to 90 m thick is exposed.

After the K/T impact event, the Chicontepec Basin was the site of clastic deposition. Prior to 65.5 Ma, it was the site of mainly carbonate deposition. In the Paleocene, however, the clasts are sand sized grains, but composed of over 50% carbonate material (Bitter, 1993), so petrologically the Chicontepec Formation can still be classified as a carbonate. These carbonate sand-sized grains were deposited in a deep-marine basin by gravity flow deposits.

The source for the Paleocene turbidites was the Tanlajas canyon in the northern part of the basin (Figure 7). Outcrop studies of paleocurrent directions (Cossey, 2008) have shown that these lower Paleocene fans prograded from the northwest to the southeast and are represented by generally coarsening-upward sequences. However, some paleocurrents measured in the field show directions towards the northwest, and these must be explained by any depositional model. Seismic lines flattened on SB 65.5 show a subtle downlap of the lower Paleocene to the southeast between the Ojital-1 and Palo Blanco-101 wells.

The Lower Paleocene is mostly a shale-rich zone which was later eroded extensively at the top by SB 60.4. There is a sharp southeastward thinning of the 65.5 Ma to 60.4 Ma sequence on seismic sections that are flattened on the SB 60.4 between the Llano Lindo-1 and Esfena-1. This is interpreted as the southern boundary for the northern Chicontepec Basin and corresponds to the location of a strike-slip fault. This appears to have been a basin-sill or high (corresponding to a northeast-southwest strike-slip fault) in the area near Poza Rica which prevented early Danian sediments from spilling into the more distal southeast part of the basin. This would have been a physical high on the basin floor which caused the reflection of turbidity currents and paleocurrents to the northwest, as seen in the outcrops of the lower and middle Paleocene (Cossey, 2008). The low frequency seismic character of the K/T cocktail deposit can also be seen in flattened seismic sections. It is represented by a sharp lithologic change for the breccias overlain by a thick shaly section (Velasco Formation). In the Llano Lindo-1 well the breccia and Velasco Formation are 57 m thick.

SB 60.4 occurs at the top of this sequence (top of the Lower Paleocene) and a lot of the section immediately below this sequence boundary is missing, especially in wells Aragon-1001, Umbriel-1, Oberon-1, Carmen-1, Junior-1 and Cupelado-1. Many of the wells in the study do not have biostratigraphic data deep enough to document this sequence and it has also been eroded extensively to the southeast of Puya-1 well by the SB 60.4 erosional event.

Sequence 60.4 to 54 Ma

This sequence corresponds to the Upper Paleocene Selandian and Thanetian and lowermost part of the Eocene Ypresian (Figure 4). The paleogeography of the basin at this time consisted of the same single canyon entry point in the northwest (Tanlajas Canyon) and a basin axis trending northwest-southeast (Figure 8). The Upper Paleocene sedimentation breached the basin sill (near Poza Rica) and began to fill the basin as far to the southeast as the Carmen-1 well. This sequence is very sandy at the top and represents a fan system prograding from the northwest to the southeast.

Other seismic lines flattened on the SB 60.4 show a downlapping of the 60.4 to 54 Ma sequence to the southeast between wells Ojital-1 and Coyol-1 which is also evident on the Wheeler diagram as increasing missing section to the southeast of well Palo Blanco-101 (Figure 4).

Extensive erosion occurs at the 54 Ma sequence boundary which removed a lot of material from the upper parts of the fans. In some cases this sequence boundary erodes down to the 60.4 Ma (as in well Oberon-1) and 65.5 Ma (as in Cupelado-1) sequence boundaries and merges with them on seismic lines.

Sequence 54 to 46 Ma

Sedimentation patterns and styles changed dramatically after 54 Ma. There was a change from a single entry point in the northwest (Tanlajas Canyon) in the Paleocene to multiple entry points from the southwest in the lowermost Eocene (Figure 9). Also, a shelf developed along the southwest margin of the basin, allowing submarine canyons to form in this area. The basin was also narrower (about 30 km wide).

The Wheeler Diagram (Figure 4) shows evidence for five sediment entry points into the basin from the southwest which created five submarine fans (A, B, C, D and E) (Figure 9). Fan A entry point is near Pachitepec-1, Fan B entry point is near Ahuatepec-1, Fan C entry point is near Miranda-1, Fan D entry point is near Carmen-1, and Fan E entry point is to the west of Cupelado-1. The northern two entry points (Fans A and B) coincide exactly with two canyons identified from the Chicontepec outcrop studies (Cossey, 2008) (Figure 9). The San Lorenzo canyon, which was identified from outcrop studies (Cossey, 2008) was not formed at this time, or was not active at this time. Additional entry points are identified to the south of the outcrop study area where fieldwork was inconclusive, but the subsurface evidence indicates the presence of three more canyons.

The fans appear to be symmetrical, with entry points from the southwest, except for Fan B, which is more elongate to the southeast. Each fan took up to 3-4 Ma to prograde from near the entry point to the distal part of the fan, a distance of up to about 26 km, as seen in the Wheeler diagram (Figure 4). The fans were very extensive and merged in areas where there is no downlap at times when sea-level was rising or the basin was subsiding.

Extensive erosion occurs at the 46 Ma sequence boundary which removed a lot of material from the upper parts of the fans. In some cases, the SB 54 to SB 46 fan deposits were completely removed, as in the Puya-1 well (Figure 4). This erosional event sets up the depositional patterns for the next sequence, which were slightly different.

Sequence 46 to 38.1 Ma

An extensive erosional event took place at 46 Ma and caused erosion of the underlying 54 to 46 Ma sequence. The Wheeler diagram (Figure 4) indicates that the maximum erosion took place in the more proximal parts of the fans. After this event, the same entry points (A, B, C, D and E) became active and deposited submarine fans in the basin (Figure 10). However, one additional entry point appeared, Fan F, at the location where the maximum erosion took place at 46 Ma (near the Puya-1 well). This entry point correlates exactly with the large San Lorenzo canyon which was identified from fieldwork (Cossey, 2008) (Figure 10). Seismic lines flattened on SB 46 show bidirectional downlapping of Fan B between wells Cacahuatengo-1014 and Ojital-1. The entry points for fans B and C seem to shift northward slightly from where they were in the previous sequence, a trend which continues into the uppermost Eocene (younger than 38.1 Ma).

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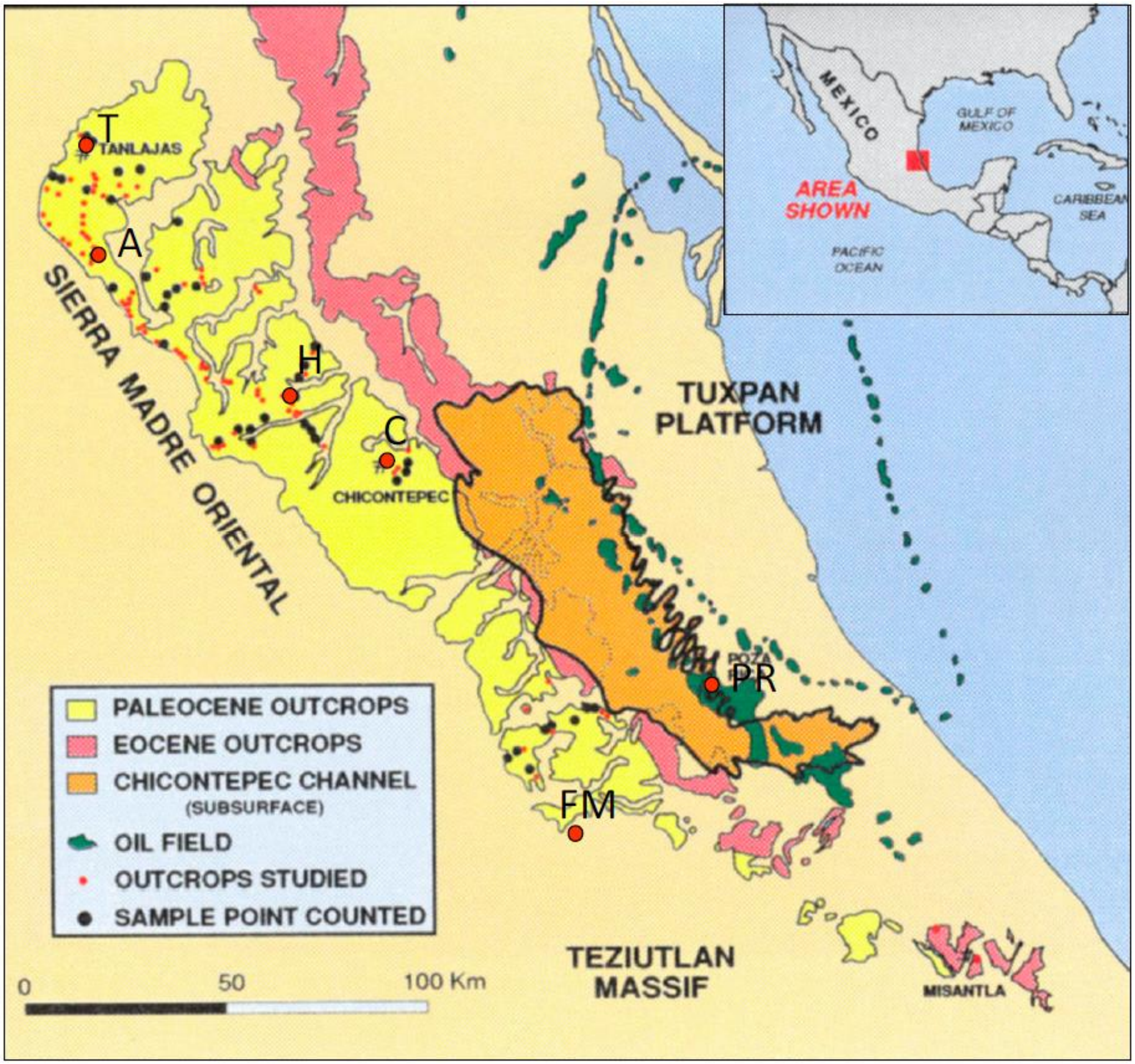

Figure 1. Location map showing the Chicontepec Basin of eastern Mexico. The orange area (misnamed the Chicontepec Channel) is the approximate study area outline.

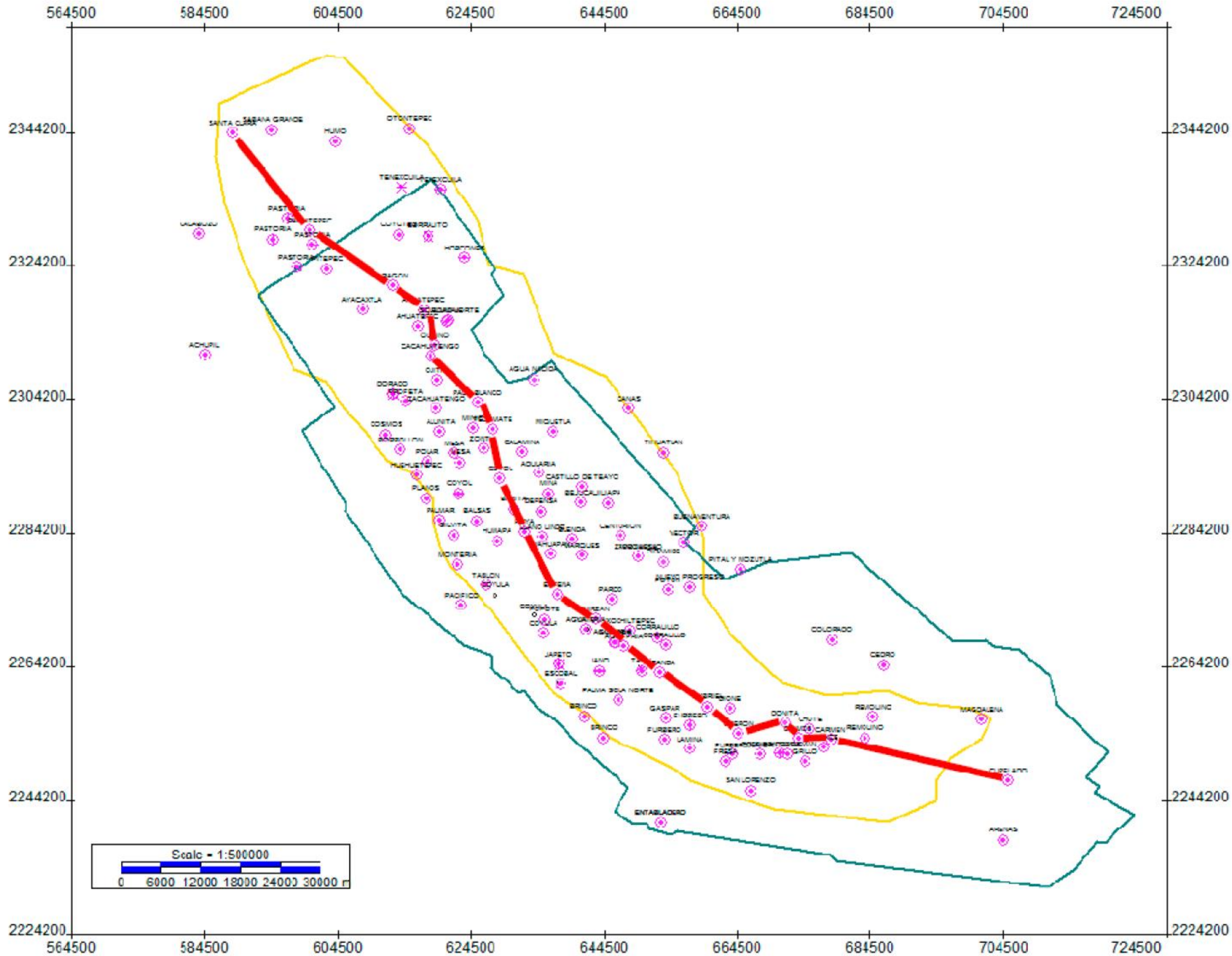

Figure 2. Study area showing location of about 100 wells used. Orange outline is approximately the same as the "Chicontepec Channel" in Figure 1. Blue/green line shows the outline of the 3D seismic coverage. Red line shows location of cross-section of Wheeler Diagram in Figure 3.

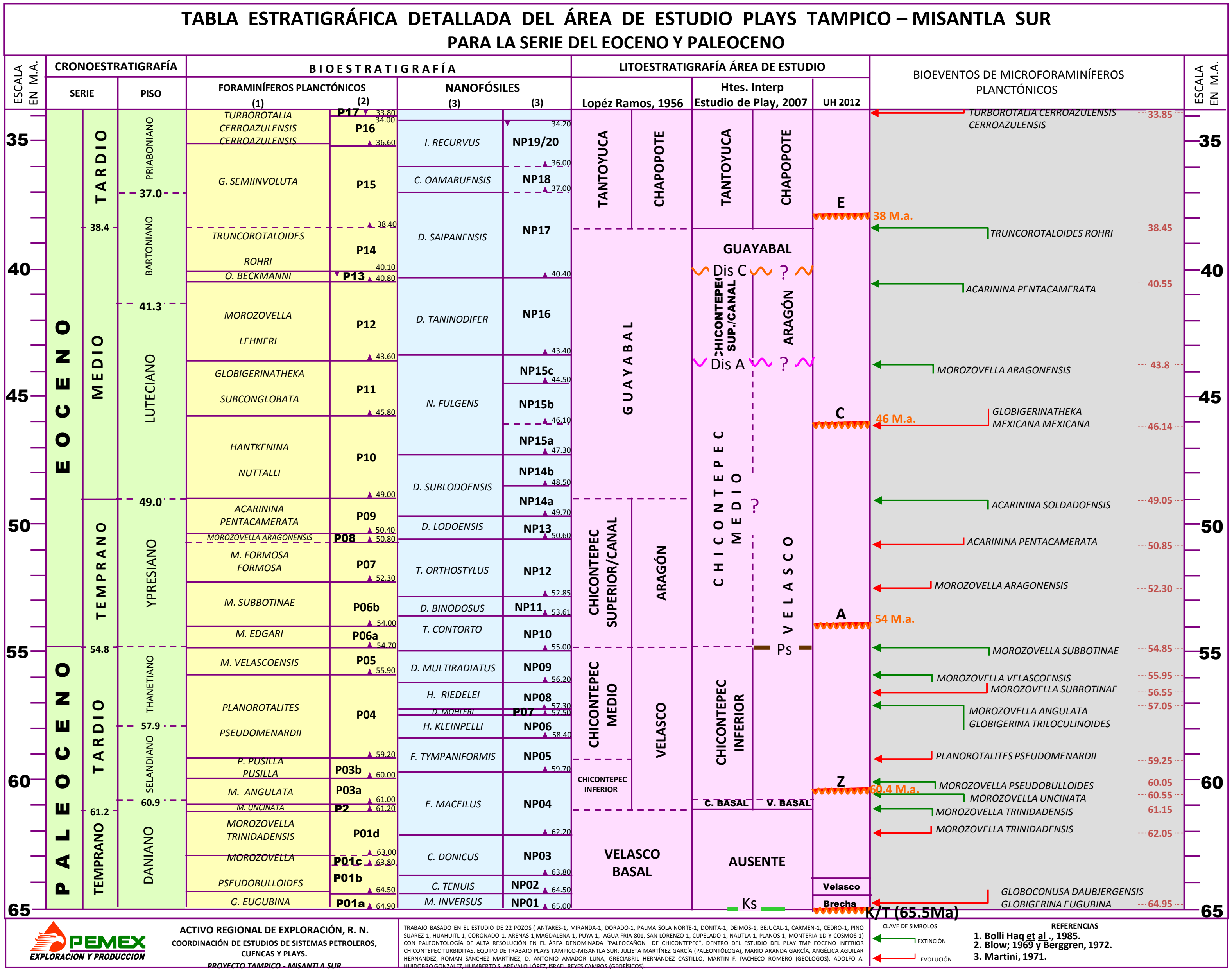

Figure 3. General Paleogene stratigraphy of the Chicontepec Basin. Previous workers knew of the existence of unconformities “A” and “C”, but did not know their ages. The new interpretation of sequence boundaries with ages (this study) are shown in column “UH 2012”.

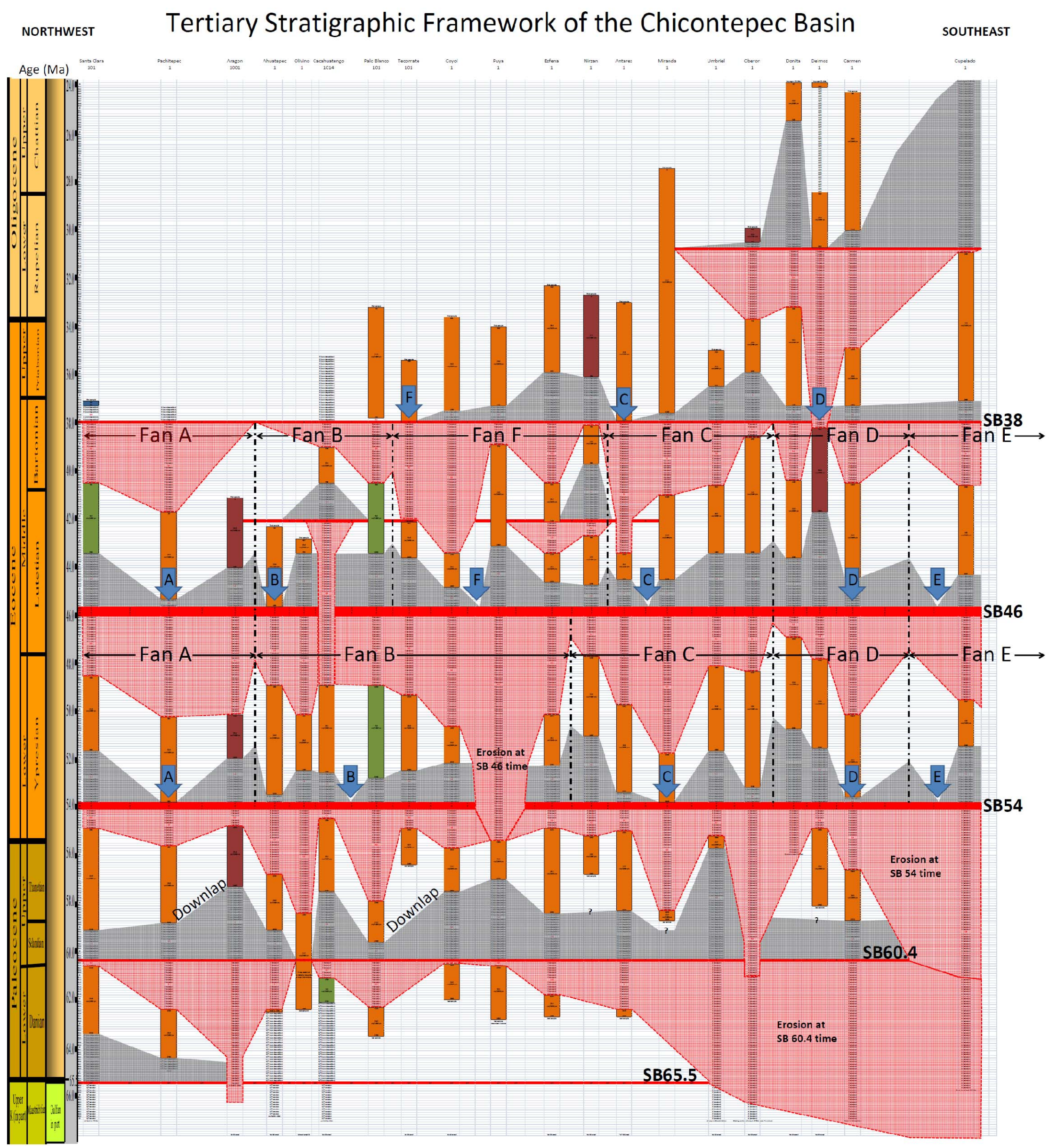

Figure 4. Northwest-southeast Wheeler Diagram cross-section of 20 wells in the Chicontepec Basin showing sequence boundaries (red horizontal lines), eroded section (red shaded areas) and non-deposition (gray shaded areas). Large blue arrows represent submarine fan entry points. Location map is shown in Figure 2.

Figure 5. Outcrop of the K/T breccia in the southern part of the basin, southwest of Martinez de la Torre at Latitude 19^{o} 58.747' N, Longitude 97^{o} 6.358'W. Note poorly-sorted clasts of limestone and sandstone.

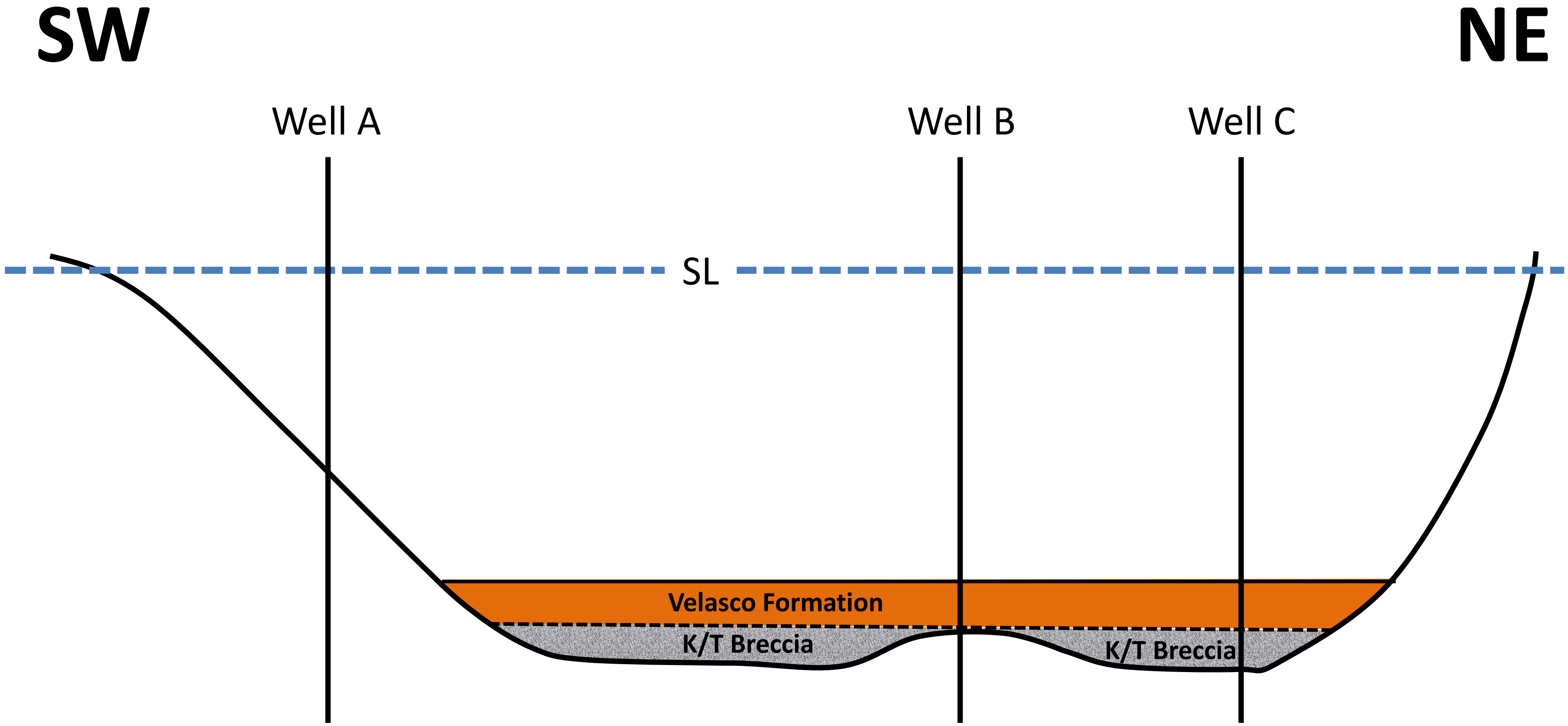

Figure 6. Proposed model for the K/T breccia and the Velasco Formation “Megabed”. Note that the Velasco Formation would extend to an area slightly larger than the breccia and that some wells might only penetrate Velasco Formation, depending on basin-floor topography.

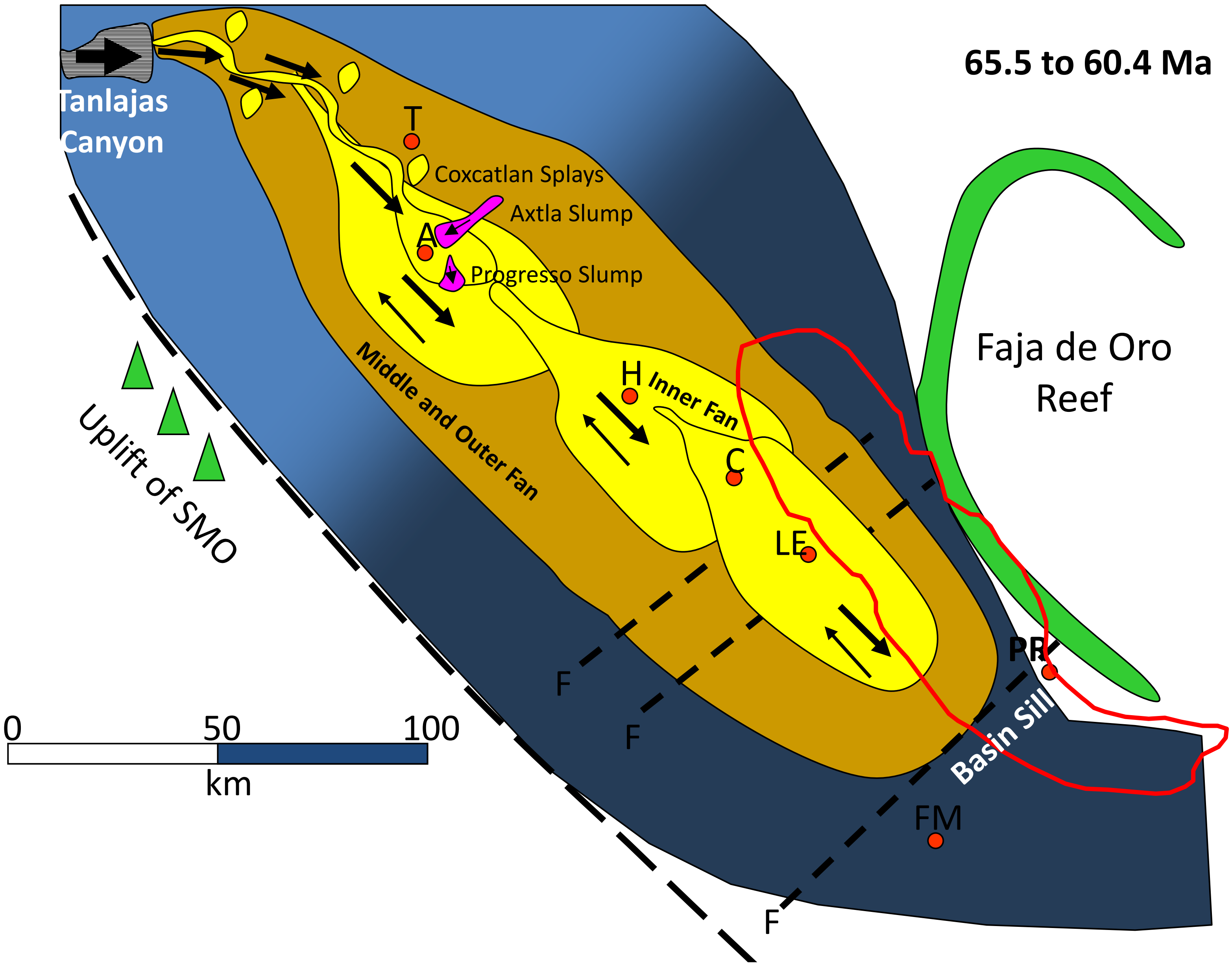

Figure 7. Paleogeographic map of the Chicontepec Basin for the Lower Paleocene (65.5 to 60.4 Ma) showing northwest source (Tanlajas Canyon) for the turbidites. The Paleocene basin was much wider than it is today. Study area is the red outline. A basin sill existed near Poza Rica (PR). H=Huejutla, C=Chicontepec, FM=Filomena Mata, LE=Llano Enmedio, F=Faults.

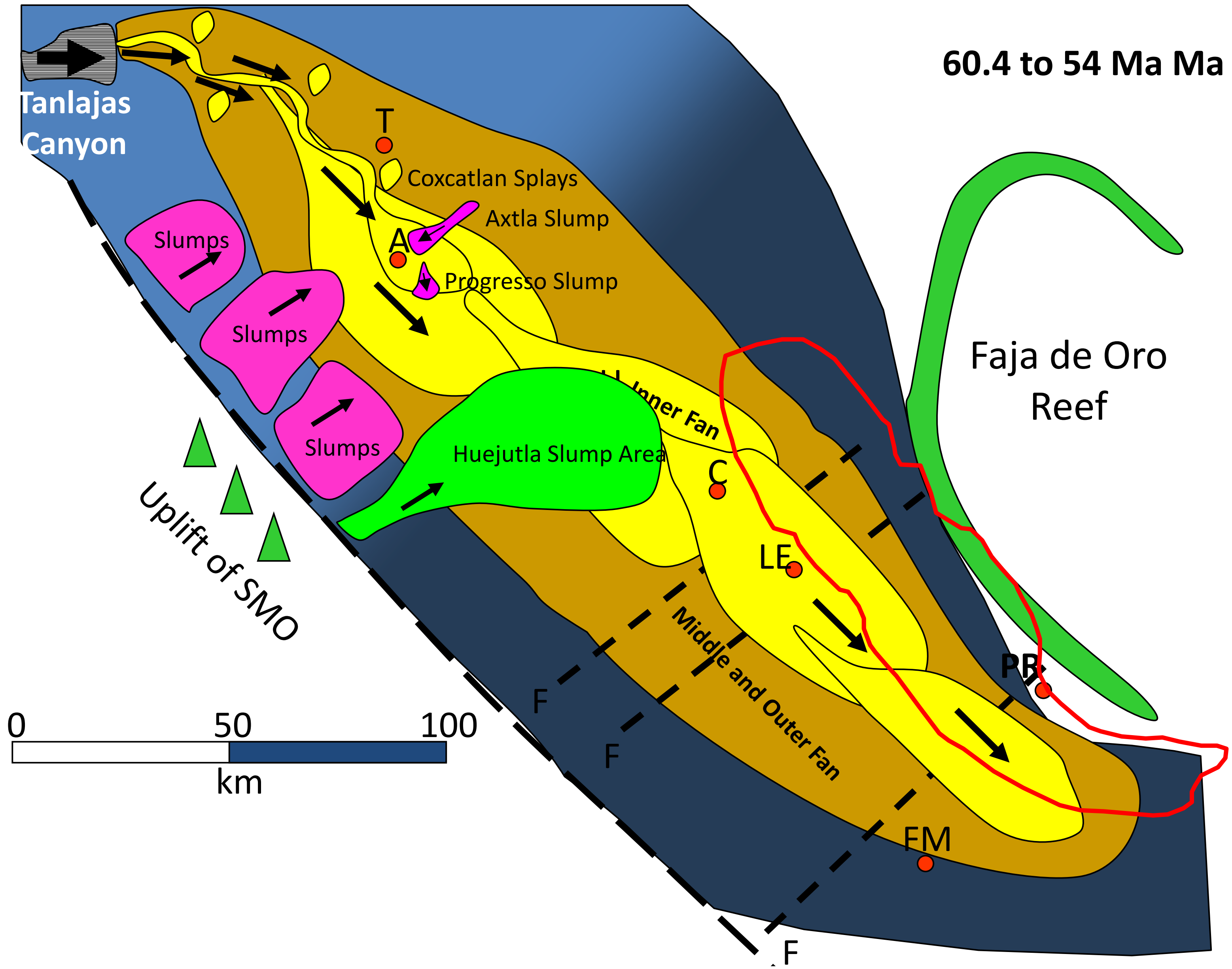

Figure 8. Paleogeographic map for the Upper Paleocene and lowermost Lower Eocene (60.4 to 54 Ma) showing northwest sediment source (Tanlajas Canyon) for turbidites. Slumping was from the southwest to the northeast in the northern part of the basin. The basin is slightly narrower than in the Lower Paleocene. Basin sill near Poza Rica (PR) was breached.

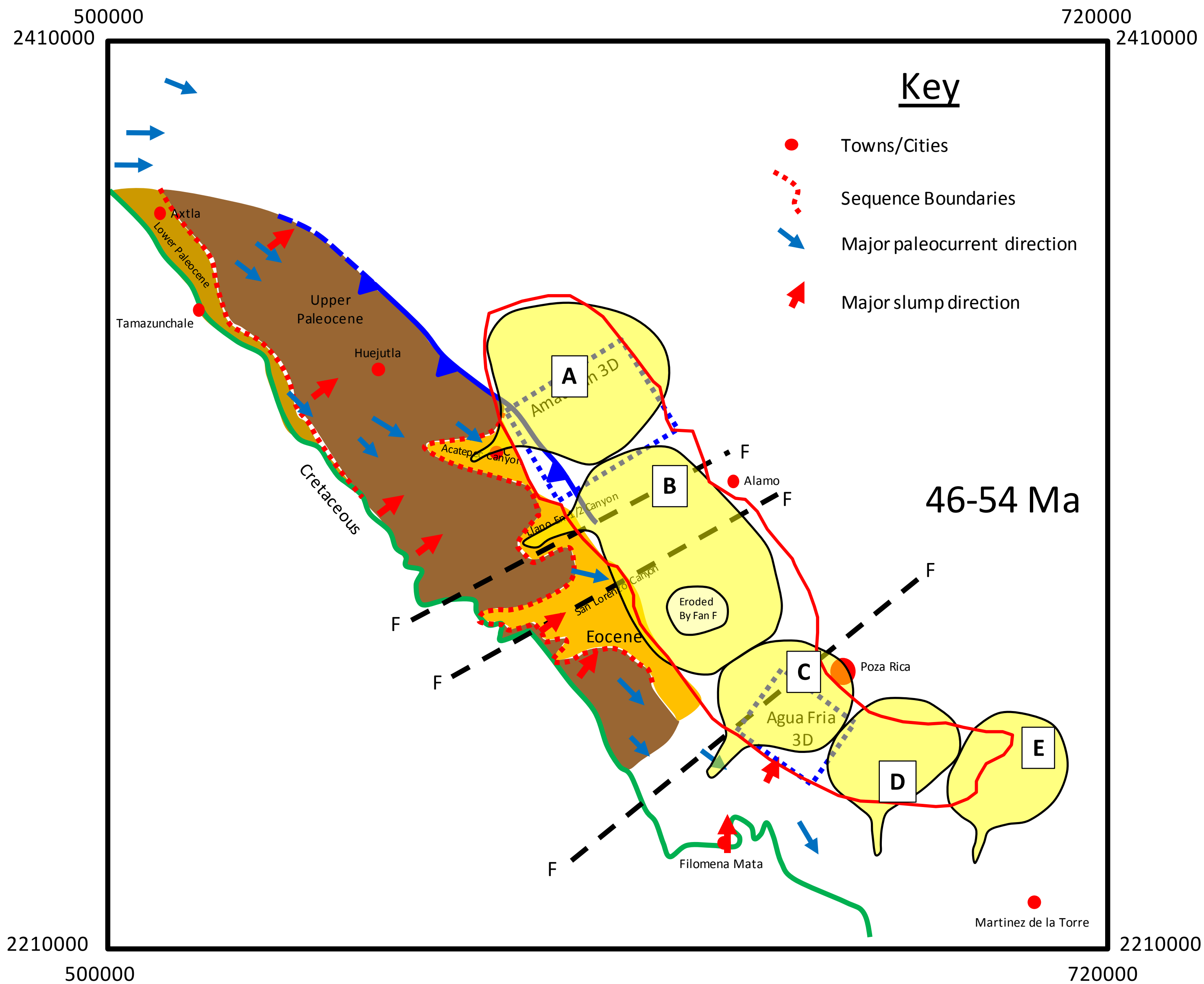

Figure 9. Regional map showing the 5 submarine fans (A, B, C, D and E) deposited in the 46 to 54 Ma sequence overlain on an outcrop interpretation from Cossey (2008). Note coincidence of the source of Fan A with the Acatepec Canyon and Fan B with the Llano Enmedio Canyon (and strike-slip fault). The San Lorenzo Canyon was not active at this time.

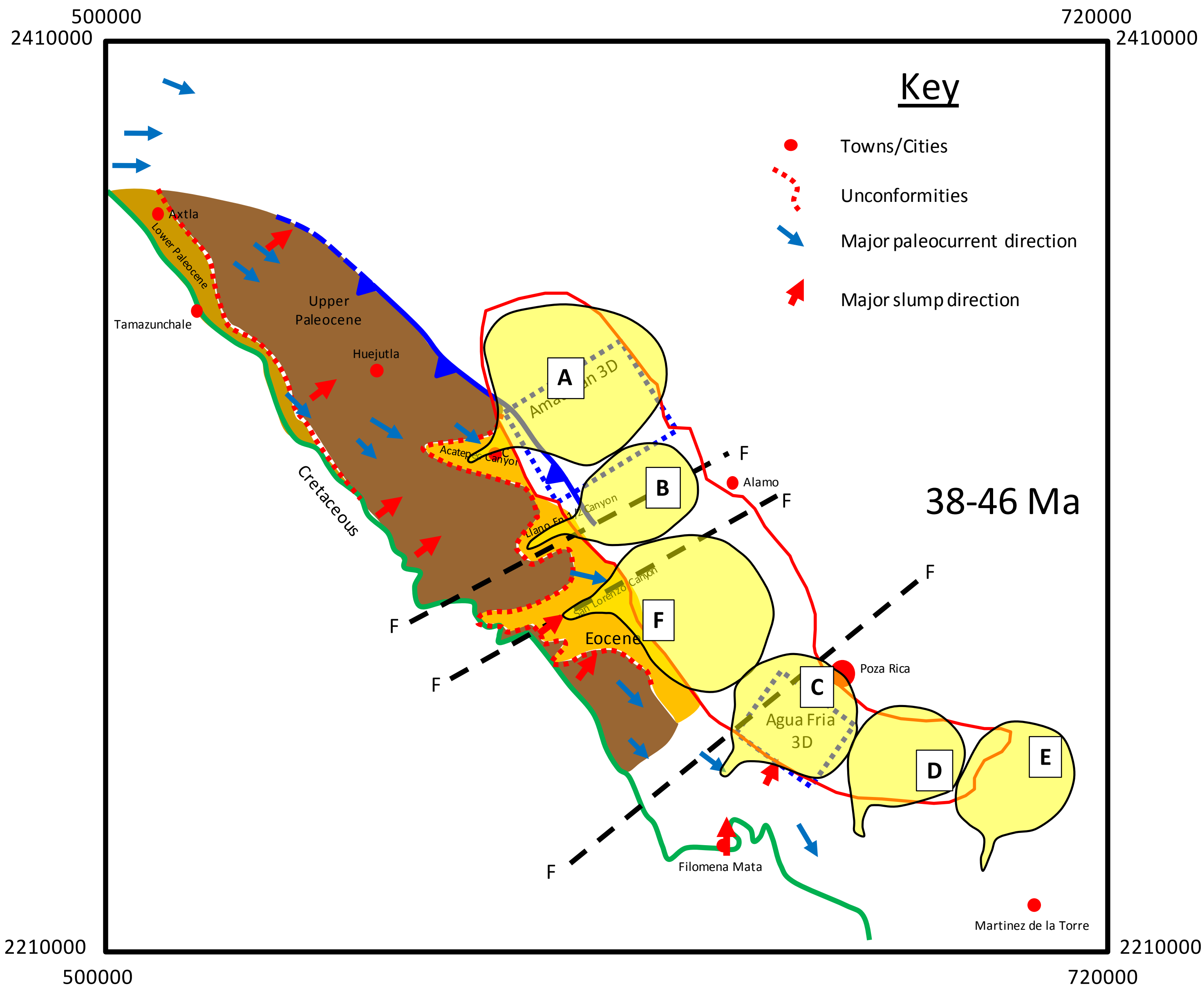

Figure 10. Regional map showing the 6 submarine fans (A, B, F, C, D and E) deposited in the 38 to 46 Ma sequence overlain on an outcrop map from Cossey (2008). Note coincidence of the source of Fan A with the Acatepec Canyon, Fan B with the Llano Enmedio Canyon and Fan F with the San Lorenzo Canyon (and strike-slip faults).