Petrophysical Characteristics, Depositional Systems, and Model of Geological Evolution in the Golden Lane Carbonate Sequences

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ABSTRACT

The Golden Lane area located in the southern Gulf of Mexico is a famous rimmed carbonate platform with significant oil production up to date. Different geological models have been developed to account for the formation of hydrocarbon fields in this area. With accumulation of significant data over the last decades, it came to a time to re-evaluate the mechanisms that controlled the accumulation of reservoir rocks and formation of hydrocarbon fields. In this study we conducted an integrated analysis on the depositional environments, sedimentary facies, sequences variations and geological evolution of the Golden Lane carbonate system in order to provide guidelines for future exploration and field development. We have reviewed a large amount of carbonate cores from various area in the Golden Lane, and compared the core data to petrophysical logs as well as seismic profiles.

Our study mainly concerns the Cretaceous interval that contains the major oil producers — the El Abra and Tamabra Formations. Two major mechanisms have been proposed to explain the geological evolution of the study area. First, the pre-Mesozoic basement experienced a period of stress relaxation, accompanied by post-mountain-building uplift. The Golden area may have started from a shallow marine carbonate bank, and this shallow sea carbonate bank is similar to the Bahama platforms today [Matthews, 1984; Enos, 1983] which rise abruptly out of several hundred meters of water and are constructed by the accumulation of carbonate and evaporite sediments at or near sea level during the continuing subsidence of this area since Cretaceous time. Second, overall sea level was continuously rising during the entire Cretaceous. The magnitude of this sea level rising was in the order of 300 to 400 meters based on a calibration from seismic stratigraphic records (Vail, 1977; Pitman, 1978). Our model differs from previous studies (Coogan, 1972; Minero, 1991) in the major mechanisms controlling the formation and distribution of the thick carbonate sequences, and their relationship to petroleum accumulation.

By the end of the Cretaceous, sea-level rise reached its peak. The upper Cretaceous basin facies carbonate covers the entire area. The Tertiary marked another episode of strong tectonic uplift, accompanied by a large-scale sea level falling. A layer of bentonite was deposited on top of the El Abra Formation, marking the end of Mesozoic marine deposit in the area. The area then underwent a period of depositional hiatus, which presumably caused a significant subaerial exposure on top of the Abra Formation. This suggests an important mechanism for the formation of hydrocarbon reservoirs in the study area. Another mechanism for the formation of oil reservoirs is through the development of natural fracture system. Such a general geological model allows us to make certain predictions and compare these predictions to the oil fields over the entire Golden Lane in consecutive studies.

INTRODUCTION

With more than 3000 km² in area, the Golden Lane (Faja de Oro) is a buried carbonate system of the Early-Middle Cretaceous, located in both offshore and onshore Poza Rica, Mexico (Fig. 1). The fields produce light oil from the El Abra Limestone. Discovered in 1930's, the middle Cretaceous carbonate reservoirs in the Golden Lane are comprised of dozens of scattered oil fields. These fields have been the source of more than 2 billion bbl of oil. Previous studies suggested that the El Abra Limestone was deposited in a shallow-water shelf or lagoon with scattered rudist patch reefs (Coogan *et al.*, 1972), or on a carbonate platform in general (Minero, 1991). Different interpretations of the morphology of the carbonate system implied different exploration strategies. With newly acquired seismic data available in the recent years, it became a time to re-evaluate the geological model of the area, the mechanisms that controlled the accumulation of reservoir rocks, and formation of hydrocarbon fields. In this study we conducted an integrated study based on analysis of core samples, seismic profiles and well log curves in order to provide guidelines for future exploration and field development. Our results support the conclusion of previous studies in some aspects but also differ from previous studies on some other issues.

LITHOFACIES

As one of the major hydrocarbon producers in the world, PEMEX has maintained great effort in acquisition of whole cores during exploration and development drilling. In the study area, cores from many wells are available, providing useful materials for investigation of the carbonate depositional system. The wells selected for this study include Miquetla-1, Canas-101, Muro-2, Atun-502, Triton-1, M-80, A-3, A-15, A-64, A-60, A-56, A-120, T-2, T-3, T-4, T-7, T-14, H-2, C-1, D-2, E-1, and M-3. We have conducted whole core description on available cores from all of these wells. The wells Miquetla-1,

Figure 1. *Location map showing the study area (modified from Morán-Zenteno, 1994).*

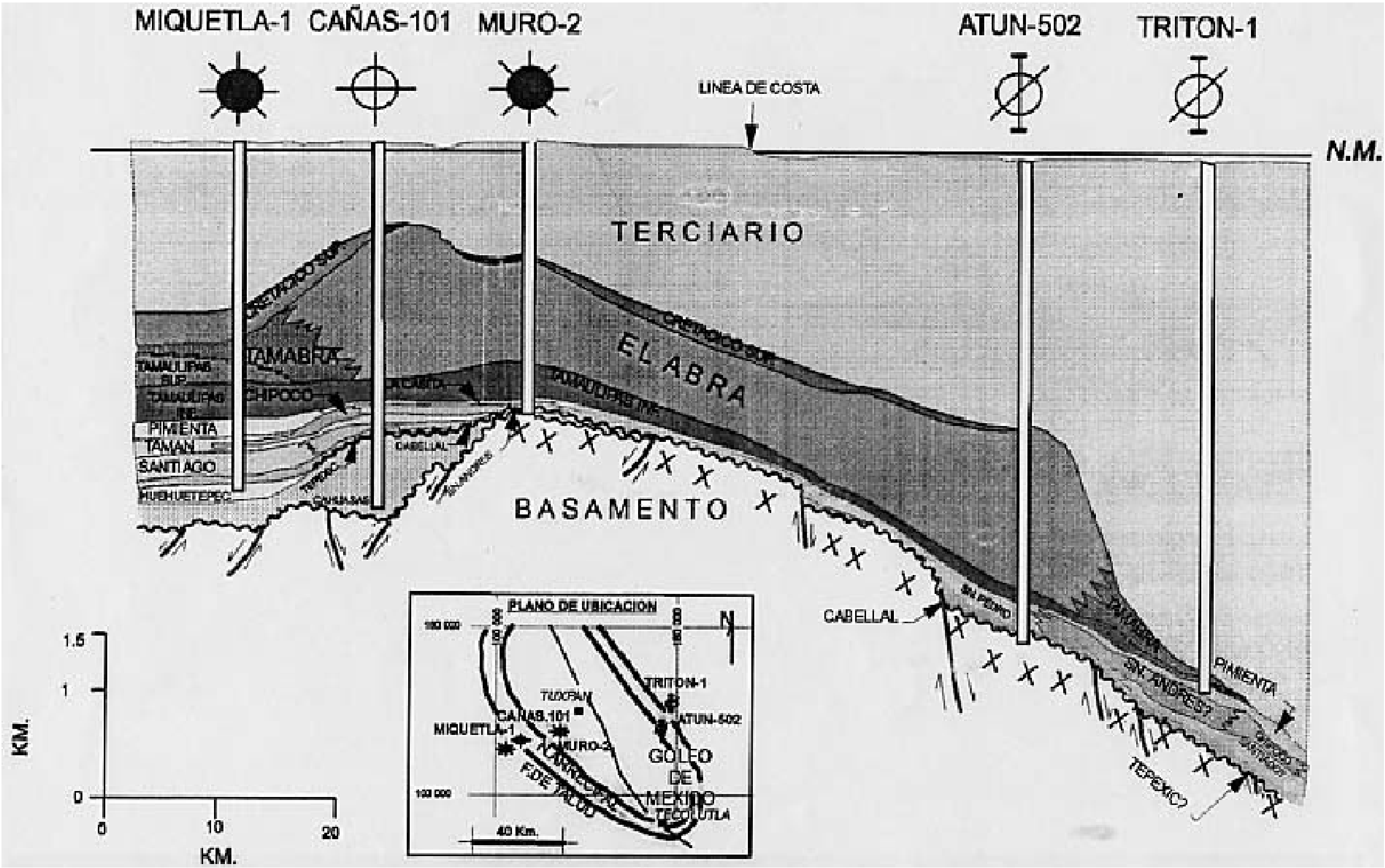

Figure 2. *Schematic map showing a west to east transit of the El Abra Formation in the Golden Lane area (data source: Pemex).*

Canas-101, Muro-2, Atun-502, and Triton-1 were located along a west-east transit cross the Golden Lane (Fig. 2). This allowed us to evaluate the variation of lithofacies and depositional systems over the entire lane and establish a regional model. Other wells were selected to conduct detail studies for some particular fields, in order to test the general model and predict the producing intervals. Detail whole core descriptions reveal variation of lithofacies and cyclic patterns, providing significant information as tied to logs. The whole core descriptions were included in our internal reports to PEMEX while conducting the projects. Due to the limitation of length for this paper, we present examples of the major lithofacies types and their associated environment here, rather than detailed well by well and zone by zone description.

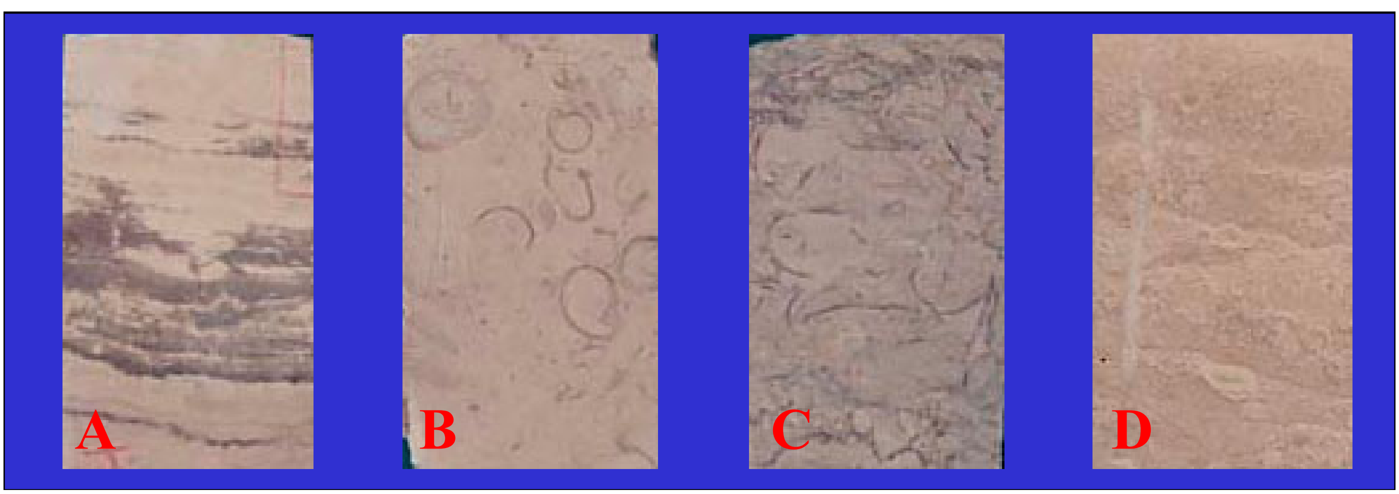

Figure 3. *Lithofacies identified near the top of the platform margin.* **A.** *Bindstone, well A-60, Core-4, Fragment (hereafter, "F")-31.* **B.** *Floatstone, well A-60, Core-4, F-7l.* **C.** *Rudstone, well A-60, Core-2, F-20.* **D,** *Grainstone, well A-120, Core-5, F-22. Even without typical reef facies such as bufflestone and framestone, these lithofacies indicate carbonate shoal deposit with high energy along the platform margin.*

We found it convenient to describe the major lithofacies types in the Golden Lane area using the classification and nomenclature of Dunham (1962). In general, rocks that were bound together during deposition (boundstone) and lacked of mud (grainstone) are often found on or near the top of the margin along the partially reefed platform. These rocks include bindstone, floatstone, rudstone, and grainstone (Fig. 3). Local heights in platform interior may also contain these rocks. On the other hand, packstone, wackestone, and mudstone (Fig. 4) are mostly found in platform interior or the margin when sea level was high. No direct evidence for framestone and baffle-

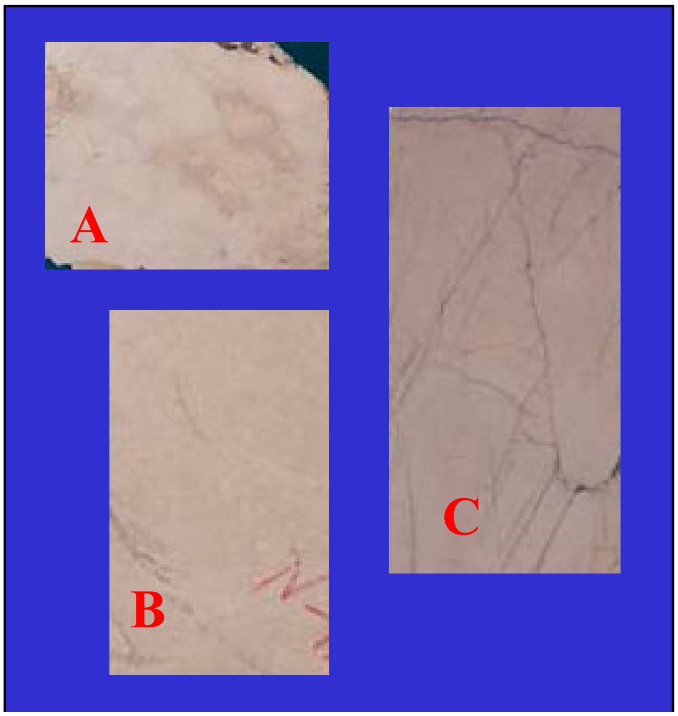

Figure 4. *Lithofacies indicating platform interior environment.* **A.** *Packstone, well A-60, Core-7, F-32.* **B.** *Wackestone, well A-60, Core-10, F-2.* **C.** *Mudstone (fractured), well A-60, Core-10, F-2. Although these wells are located near the margin, there were intervals where relative high sea-level flooded the margins, making the lithofacies here very similar to those identified typically from lagoon.*

stone has been found, possibly due to the lack of real reefs on the platform margin or the limit of drilling locations to penetrate to the reef. However, a fragment of coral has been found in one of the wells studied (Fig. 5), suggesting that at least patch reefs existed over certain time intervals. If this is true, the growth of patch reef must have played an important role in the development of the Golden Lane platform. In addition to what has been classified in Dunham (1962) based on depositional texture, carbonate breccia (Fig. 6) is another important rock type existing in many wells, especially in the intervals with significant subaerial exposure (Fig. 7). Some of these breccia intervals were found associated with bentonite deposits, indicating a possible link between regional sea-level drop and the volcanic activities. Other breccia intervals are

Figure 5. *A floatstone sample with coral fragment, well A-60, Core-13, F-41. Existence of coral fragment indicates that at least patch reefs were present at the platform margin, contributing to the vertical aggradation of the rimmed platform during the lower and middle Cretaceous in response to continuous rising of relative sea level.*

associated with development of fractures (Fig. 8). This set of fractures filled by bentonite may present little opportunity for hydrocarbon accumulation. On the other hand, some newer and open fractures present the opportunity for hydrocarbon migration and accumulation (Fig. 9). Understanding the pattern of lithology distribution is important because it allows us to conduct detail analysis on the relationship between lithofacies and depositional environment, and to identify areas with high potential based on integration of core, log, and seismic data.

STRATIGRAPHIC PATTERNS

Well log curves reflect petrophysical signatures resulting from carbonate deposition and diagenesis. Once a basic geological evolution model was established, carefully calibrating log curves with cores resulted in a better understanding of the depositional model and its relation to hydrocarbon accumulation. We have analyzed available log curves for the wells selected for this study. Attention was paid to identify the cycles of stratigraphic variations based on some key log types.

In our study area, we found that SP, GR, neutron density, and normal logs are quite useful and informative. In the carbonate system, the SP and GR together help to differentiate potentially porous and permeable reservoir rocks from nonpermeable shaly limestone and shales. They also help to define sequence boundaries and permit correlation of beds (Schlumberger, 1989). The neutron density logs were used to determine the porous intervals and their porosity. Further, both shallow and deep normal logs allow distinction between water- and oil-bearing intervals.

Wells A-64, A-60, A-56 and A-120 provide an example for such sequence analysis based on selected log curves (Figs. 10 and 11). Well A-64 is located in a position toward the platform interior. Well A-60 is located at what was the top of the platform margin during most of the early and middle Cretaceous, while well A-56 and A-120 are located in what was the windward front of the platform margin. Each

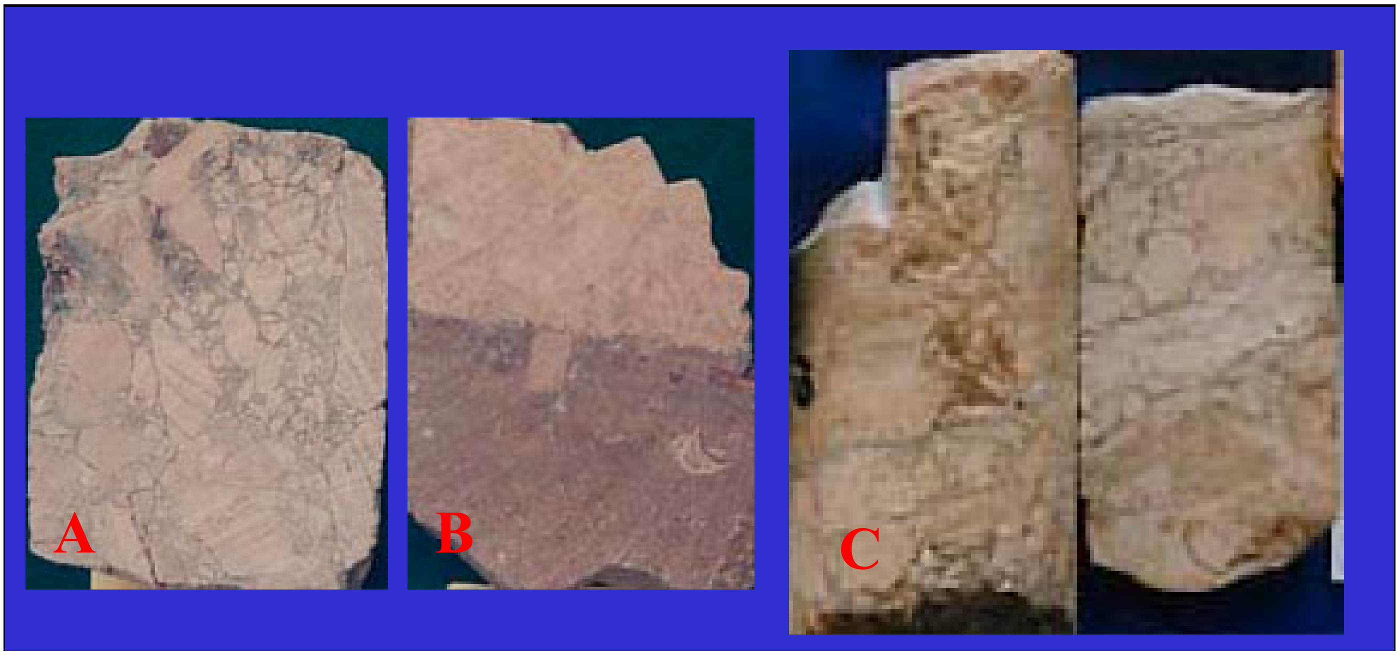

Figure 6. *Examples of carbonate breccia, deposited due to local erosion.* **A.** *Well A-120, Core-1, F-7.* **B.** *Well A-120, Core-2, F-3.* **C**. *Well M-3, Core-17, F-19.*

deposition cycle started with a transgressive phase. At the very beginning the carbonate factory tried to catch up with rising sea level, but rate of sea-level rise ultimately outpaced sedimentation rate, resulting in deposition of a widely distributed shaly interval, corresponding to the maximum flooding surface (Fig. 10, blue broken lines). The early stage of the highstand system tract favored rapid carbonate deposition, which eventually outpaced sea-level rise. Each sequence boundary coincides with intervals where SP and GR indicate higher shale and mud content. The causes for these variations may be due to the increase of erosion toward the top of a depositional sequence where subaerial exposure surfaces likely existed, indicating depositional hiatus and development of fabric selective porosity such as vugs and caverns.

In A-60, the producing intervals are all located near the top of a sequence (below a sequence boundary). This strongly indicates that subaerial exposure was a major mechanism for the development of reservoir rocks. The early transgression in a next sequence commonly generated a nonpermeable zone that can serve as the seal layer. Besides subaerial exposure, development of natural fractures (Fig. 9) serves as another mechanism for development of hydrocarbon reservoir in the study area.

DEPOSITION MODE AND DIAGENESIS PROCESS

Recently acquired seismic data significantly enhanced the ability to delineate the depositional system of the Golden Lane area. Fig. 12 shows the locations of the 2-D seismic lines available to this study. A number of lines, both perpendicular and parallel to the strike of the lane, were selected for detail seismic analysis of the morphology (Figs. 13-18). The seismic data were then integrated with petrographic and petrophysical analysis in order to verify models developed from log and core calibration. The results reveal features regarding the geomorphology of the carbonate platform, the variation of depositional sequences over the lagoon, reef margin, slope and talus, the stacking relationship of the various sequences, and its implication for the regional geological model.

How did the platform start to develop? Empirically, seismic sections can provide insight into this question. The Golden area might have started from a shallow marine carbonate bank, similar to the Bahama platforms today (Matthews, 1984; Enos, 1983) which rise abruptly out of several hundred meters of water and are constructed by the accumulation of carbonate and evaporite sediments at or near sea level. The magnitude of early Cretaceous sea level rise might be in the order of 300 to 400 meters based on a calibration from seismic stratigraphic records (Vail, 1977 *et al.*; Pitman, 1978), but perhaps less considering isostatic compensation of the basin due to sediment loading (Matthews, 1984; Matthews and Frohlich, 1998).

It has been found that the western side of the lane was buried at shallower depth compared to the eastern side, by a magnitude of 1000 to 1500 meters. The seismic lines presented here clearly demonstrate this feature. Previous study (Coogan *et al.*, 1972) suggested that during the Eocene the platform was tilted downward to the west allowing for the accumulation of a thick section of Eocene clastic deposits over the Golden Lane. After the Eocene, titling occurred again to the east and resulted in the thick sediment accumulation of the Oligocene section. This implies that tectonic tilting occurred prior to deposition. After investigating the seismic sections, we propose that a structural titling mechanism is not necessary to explain the pattern of the strata on the Golden Lane. After the El Abra

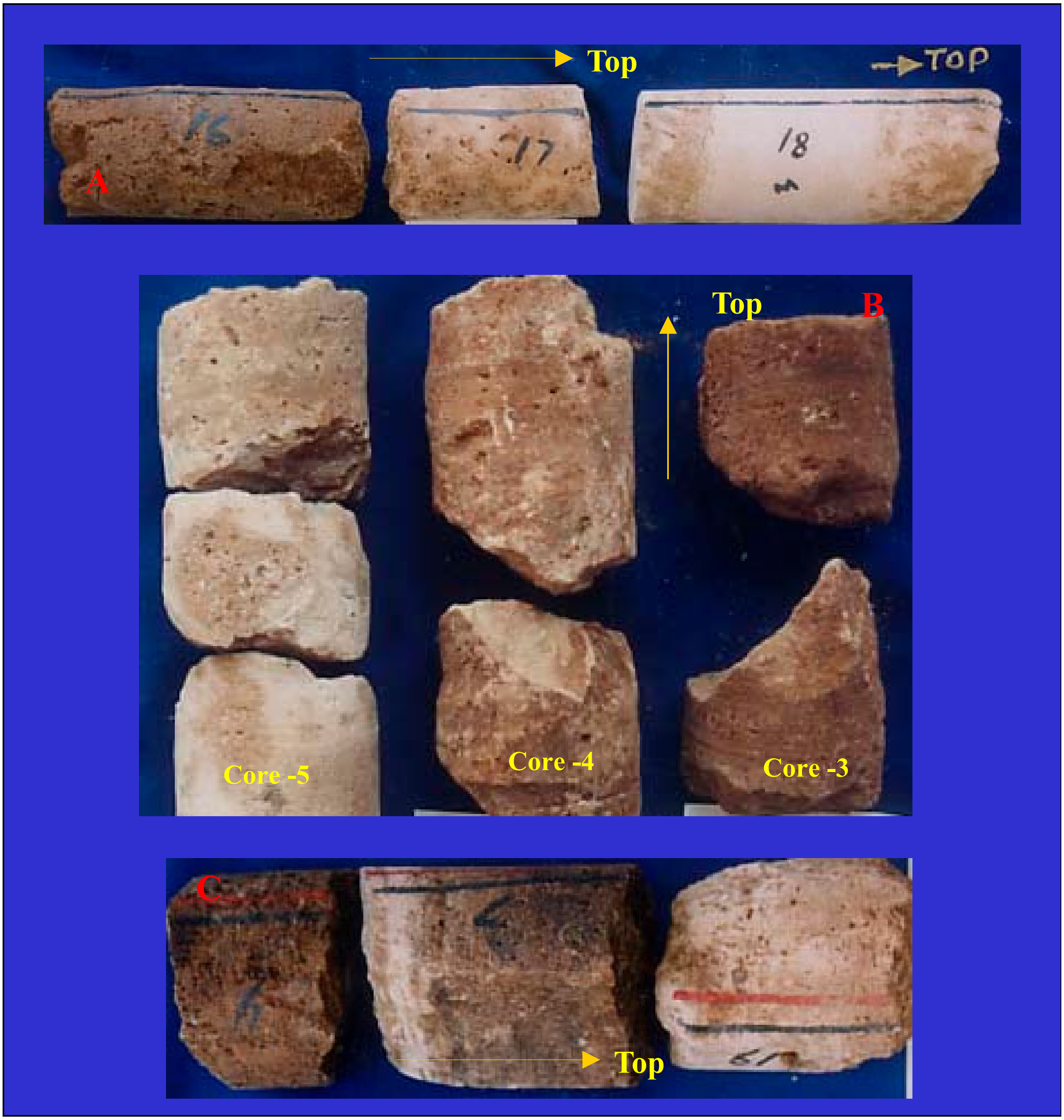

Figure 7. *Cores from the tops of the El Abra Formation.* **A.** *Well C-1, Core-5, F-16, -17, -18.* **B.** *Well T-1, Core-3, Core-4, and Core-5.* **C.** *Well H-2, Core-2, F-4, -7, and -19. All segments were deposited within highstand system tracts and later subjected to subaerial exposures, resulting in development of secondary porosity which are highly oil stained. In cases* **A** *and* **C***, the upper part (near the sequence boundary) was less permeable then the lower part, perhaps due to the effect of marine diagenesis from the next cycle of sea-level rising. In contrast, in Case* **B** *the upper part (near the sequence boundary) is more permeable, indicating less effect of marine diagenesis after the subaerial exposure.*

Formation was deposited, the surface elevation of the platform must have been nearly even from the west to the east, except for the reef margin where high relief is expected. Deposition of the Tertiary clastic sequence centered to the east of the platform resulted in basin subsidence and hence isostatic compensation, which may have further triggered the differential subsidence of the Golden Lane, causing the east side to be buried about 1000 to 1500 meters deeper than the western side. Uplift of the near-by Sierra Madre Oriental (about 40 miles to the west of the Golden Lane) during the Tertiary might also have contributed to the apparent tilting of the Golden Lane.

Previous studies regarded the Golden Lane as a shallow water shelf or lagoon with scattered rudist patch reefs over the shelf (Coogan, 1972), or carbonate platform with both open margin and island-protected margin (Minero, 1991). Along the latitudinal direction, seismic sections (Figs. 13, 14, 15, 16) clearly reveal high depositional profile along the seaward margin of the platform. In some areas the contrast in topographic relief may reach 250 ms or over 300 meters (Fig. 16). It is difficult to call on physical process such as shoaling upward alone to result in such a remarkable relief. Combined with the fact that coral samples were found in some wells (Fig. 5), it is very likely that the vertical aggradation of the Cretaceous Golden Lane lagoon sequence was largely controlled by scattered but highly effective distribution of barrier patch reefs over the margin. The patch reefs served as posts, and the sand shoals derived from the complex biological and chemical precipitation filled in the space between the reefs.

Along the longitudinal direction, seismic profiles (Figs. 17 and 18) clearly show the presence of tidal channels cutting through the reef top. These channels typically were developed during the lowstand period and filled with carbonate mud or limey shale during the transgressive period. Fragments of previously deposited carbonate rocks were carried to the slope break where fluid energy reduced significantly, much the same way as clastic deposition. Possible talus sediments can be identified from the latitudinal seismic sections (Figs. 13, 14, 15, and 16). This observation has two implications.

First, the middle and lower Cretaceous El Abra Formation, the Tamara Formation, and the upper Tamaulipas Formation in the Golden Lane area are generally equivalent in their deposition time, but represent different facies that recorded different depositional environments. While the El Abra Formation contains both platform interior (lagoon) and marginal facies, the Tamara Formation records limited slope and talus deposits mixed with carbonate mud, and the Tamaulipas Formation represents basin facies mudstone deposits. The boundary between the El Abra Formation and the Tamara Formation is generally easier to identify than that between the Tamara Formation and upper Tamaulipas Formation. The former is often coincident with a depositional bypass while the later is marked with gradual facies variation.

Second, the carbonate depositional cycles over the top of the platform and to the basin were strongly influenced by sea level variation at Cretaceous time (Brown and Fisher, 1980; Haq *et al.*, 1987; 1988; Handford *et al.*, 1993). In a typical sea level cycle (3rd order, for instance), if sea level drops to a level lower than the old sediment-water interface, the lowstand system tract at the platform top will be impacted by a depositional hiatus. This further will result in subaerial exposure of the previous deposited highstand tract, causing extensive erosion, transportation of talus flow to the slope and basin, and development of secondary porosity in the relic of the weathered sequences. Consequent sea level rise over the

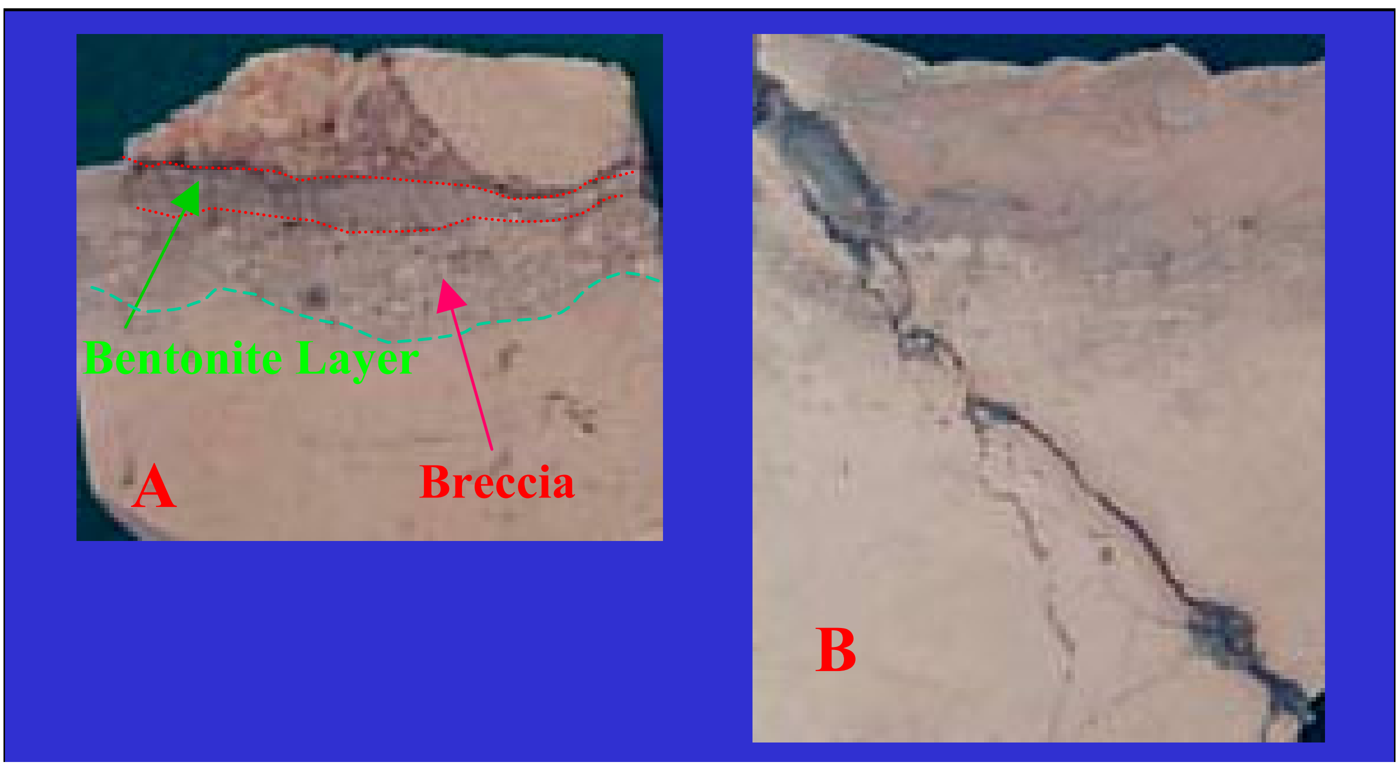

Figure 8. A. *Deposition of bentonite layer in the carbonate system, well A-60, Core-8, F-11.* **B.** *Fractures filled by bentonite deposit, well A-60, Core-2, F-24. Deposit of the bentonite layer in between the carbonate breccia probably indicates that the volcanic activity was associated with regional tectonic movement toward the end of the middle Cretaceous.*

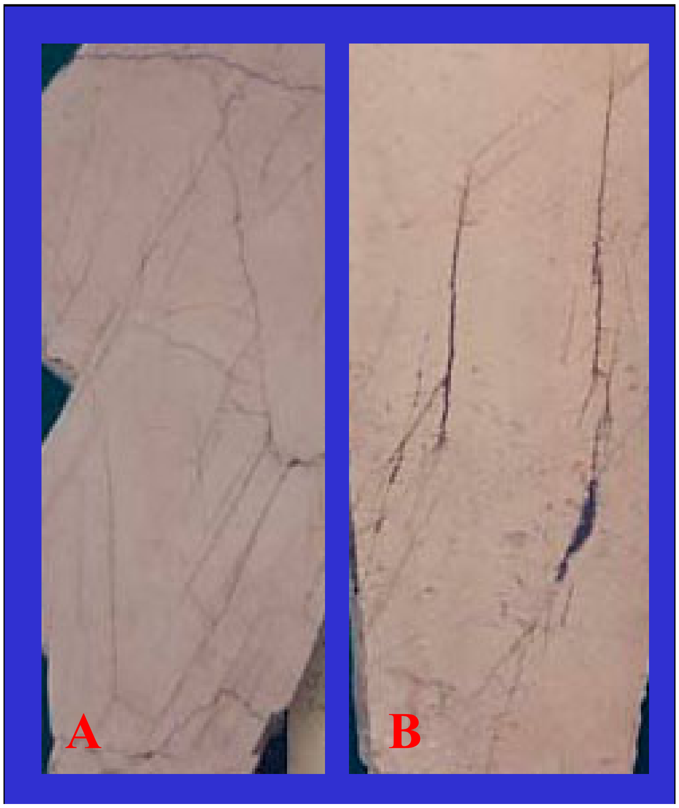

Figure 9. *Development of open fractures.* **A.** *Well A-60, Core-10, F-9.* **B.** *Well A-60, Core-12, F-19. Note that the fractures were partially filled by oil.*

platform will result in renewed carbonate deposition likely characterized by patch reefs and skeletal deposit between the reefs. With sea level rising outpacing the vertical aggradation of the carbonate sequence, shale content will increase until the maximum flooding surface is reached. A possible shale layer could then be expected. As a matter of fact, such shale intervals are observed in both core and logs (Figs. 10 and 11). During the highstand system tract, production of the carbonate factory at the platform top may outpace the sea level rising, resulting in accelerated growth of the carbonate sequences. Therefore, at platform top, lowstand system tract is marked with non-deposition, erosion, and subaerial exposure, and the carbonate sequences basically accumulated during the transgressive and highstand system tracts. In contrast, in the talus deposition regime, during the lowstand system tract deposition, the sequence is dominated by intraclasts, litho-fragments, and breccia, interbedded with some carbonate mud. Such a lowstand system tract is the major depositional package at the slope and talus position. During the transgressive and highstand system tracts, the slope sediment is dominated by mudstone, shaly mudstone and shale. The thicknesses for these system tracts are presumably much thinner than that in the platform top. Such a relationship between platform deposition and talus-basin deposition is illustrated in a conceptual model presented in Figure 19.

The depositional model described above further provides insight into the diagenesis history. In a typical sea level cycle, the carbonate sediment will undergo different types of diagenesis. During the transgressive system tract immediately following depositional hiatus, rising sea level promotes submarine cementation in open marine sandy sediments and local vadose meteoric diagenesis in peritidal environment. This is equivalent to what is described as eogenesis (Minero, 1991). Further rising sea level and vertical aggradation triggers burial diagenesis, altering the composition and texture of the carbonate sequence. According to Minero (1991), although burial in general results in extensive compaction, Mg-rich connate brines derived from Guaxcama gypsum resulted in dolomitization and lithification, thereby precluding further compaction. This type of burial diagenesis is equivalent to mesogenesis. It may continue until the end of the sea level cycle, where dropping of relative sea level results in extensive subaerial exposure and development of secondary porosity (Fig. 7). Therefore, eogenesis and mesogenesis were the major factors controlling the carbonate diagenesis in the Golden Lane area, although we recognize that telogenesis process may also superimpose its effect on the carbonate sequences. If the lowest level of an individual sea level cycle was low enough for the carbonate sequence to have a significant exposure, and the following transgressive period was rapid enough to provide efficient burial, the carbonate rock could evolve to a high quality reservoir interval. During the early Tertiary, uplift of the Sierra Madre Oriental caused prolonged exposure at the top of the El Abra Formation, resulting in significant enhancement of porosity. This explains why the top of the El Abra formation has been such a good producer. To the Cretaceous carbonate sequence, the early Tertiary tectonic events can be ascribed as telogenesis process, which may also result in development of fractures and further enhancement of permeability for the producing intervals.

CONCLUSIONS

The El Abra Formation may have started to develop from a shallow marine carbonate bank in the early Cretaceous and may have grown due to the overall sea level rise from the early to the middle Cretaceous. Although during this geological time period, there were intervals of relatively low sea levels and associated subaerial exposures, the overall trend was continuous basin subsidence associated with the overall rising sea level and increasing sediment load. The magnitude of sea level rise is perhaps in the order of 300 to 400 meters, but may be less considering isostatic compensation.

Once relative sea level rising reached its peak at the end of the middle Cretaceous, extensive exposure occurred at the top of the El Abra Formation, resulting in enhanced dissolution and development of secondary porosity. Combined with favorable local topographic conditions and development of sealing zones at the top, the subaerialy exposed zones locally evolved into high quality reservoirs. Below the top of the El Abra Formation, there are various intervals with evidence of subaerial exposures reflecting the influence of sea level cycles at various orders, but not as prominent as the exposure at the

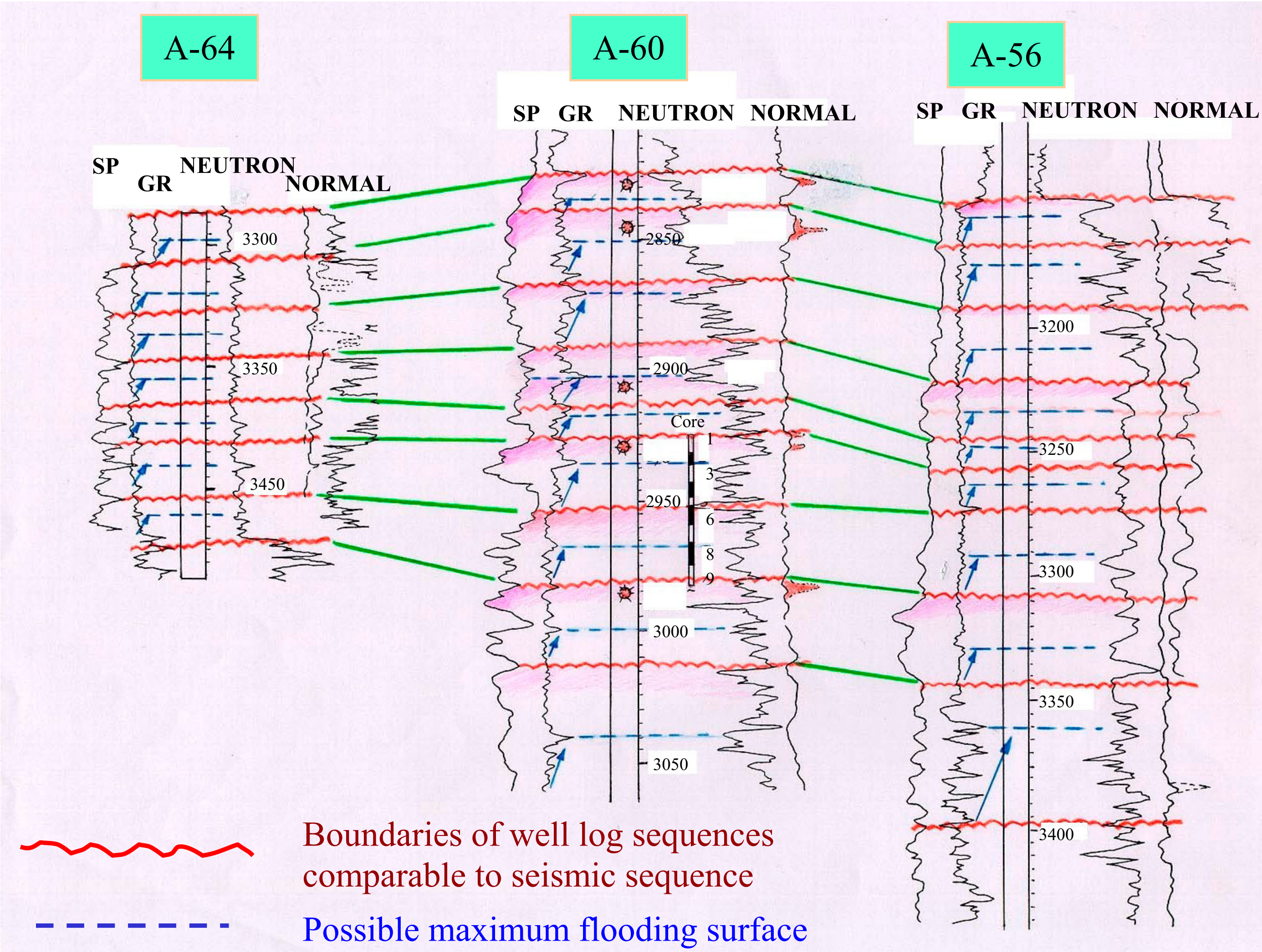

Figure 10. *Sequence pattern identified from well log interpretation, an example from wells A-64, -60, -56 that are located from the west to the east crossing the platform margin. Note that four out of the five producing/oil show intervals in well A-60 are located immediately below a sequence boundary where subaerial exposure is inferred. The interval with oil show at 2905–2908 m is likely due to development of natural fractures.*

top of the formation. Beside subaerial exposure, development of natural fractures is another mechanism attributing to the formation of hydrocarbon reservoirs, but it is of secondary importance in the study area compared to subaerial exposure.

Typical platform margin, lagoon interior, and basin deposition lithofacies have been identified in various positions over the Golden Lane, significantly enhancing the ability to delineate the regional geological model. Well log interpretation provides information on the stratigraphic pattern of the carbonate system over the Golden Lane, and the stratigraphic model successfully explains distribution of the producing intervals.

The tilting of the Golden Lane may have been simply the result of differential subsidence due to isostatic compensation, because the Tertiary depocenter was located to the east of the Golden Lane. Similarly, although the thickness of the entire Golden Lane seismic sequence may imply that the magnitude of Cretaceous sea level rise was in the order of 300 to 400 meters, this magnitude may be actually lower considering the effect of isostatic compensation.

The results of this study suggest that the vertical aggradation of the Cretaceous Golden Lane carbonate sequence can be largely attributed to the scattered but highly effective distribution of barrier patch reefs over the margin. The patch reefs served as posts, and the sand shoals derived from the complex biological and chemical precipitation filled in the space between the reefs.

A deposition model developed based on integrated core, log and seismic analysis also suggests that the El Abra Formation, the Tamabra Formation and the upper Tamaulipas Formation were deposited at a same time interval but with facie transition. Lithofacies and texture distribution can be tied to sea level variation, and the facies contrast between platform margin and talus deposit strongly supports this model.

The depositional model also implies process of diagenesis. In a typical 3rd sea level cycle, eogenesis and

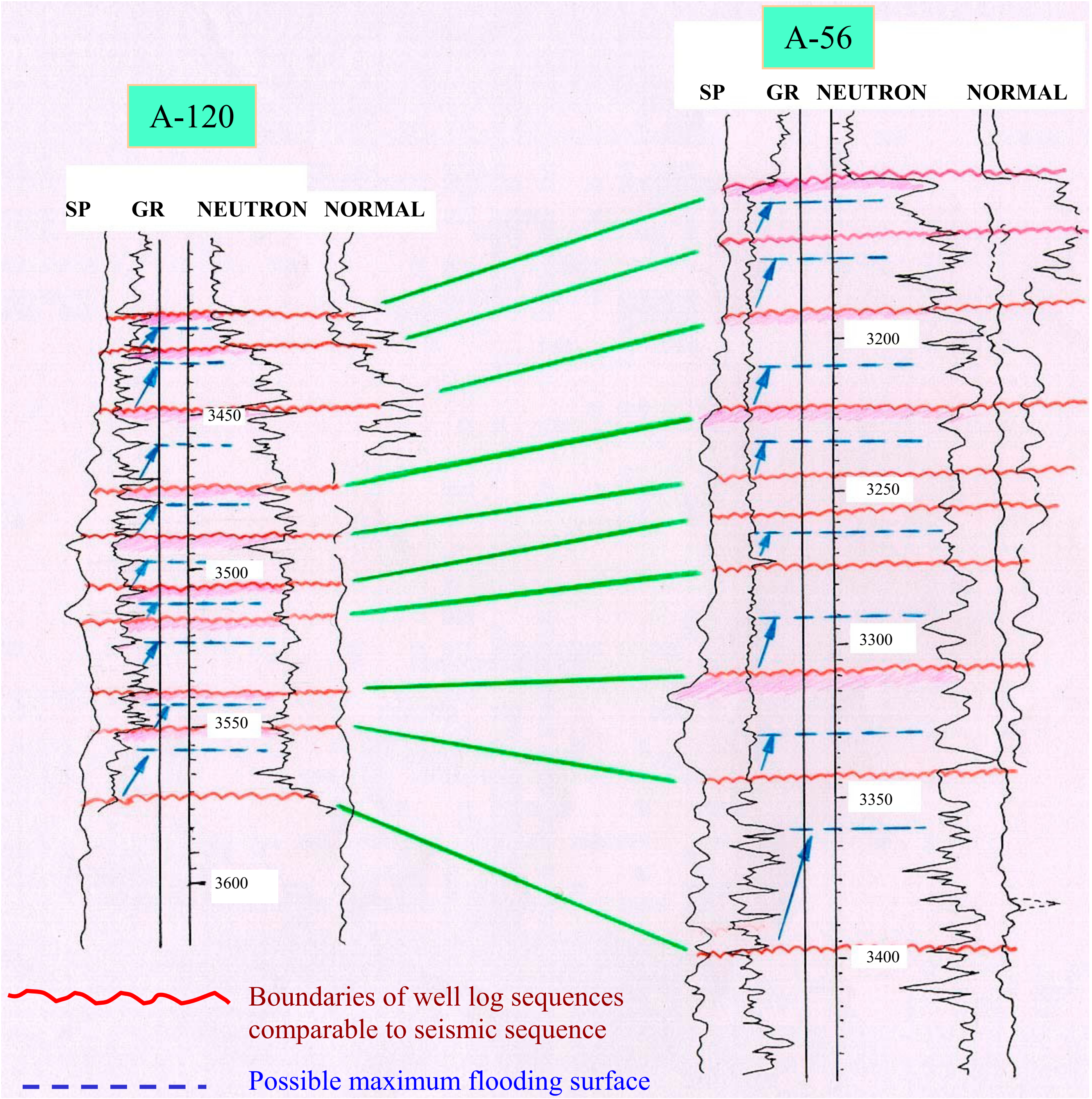

Figure 11. *Sequence pattern identified from well log interpretation, an example from wells A-56 and A-120 that are located along the platform margin.*

mesogenesis affect each individual stratigraphic sequence at the top of the platform, while telogenesis has longer influence.

The major conclusions of this paper resulted from an integrated study based on 2-D seismic data. In the recent years, 3-D seismic data have become available. We believe that interpretation of the newly acquired 3-D seismic data will improve the model developed in this study. To this end, we present this study as a continuous effort to understanding the geological model of the Golden Lane area, rather than the final "conclusions" for the study area.

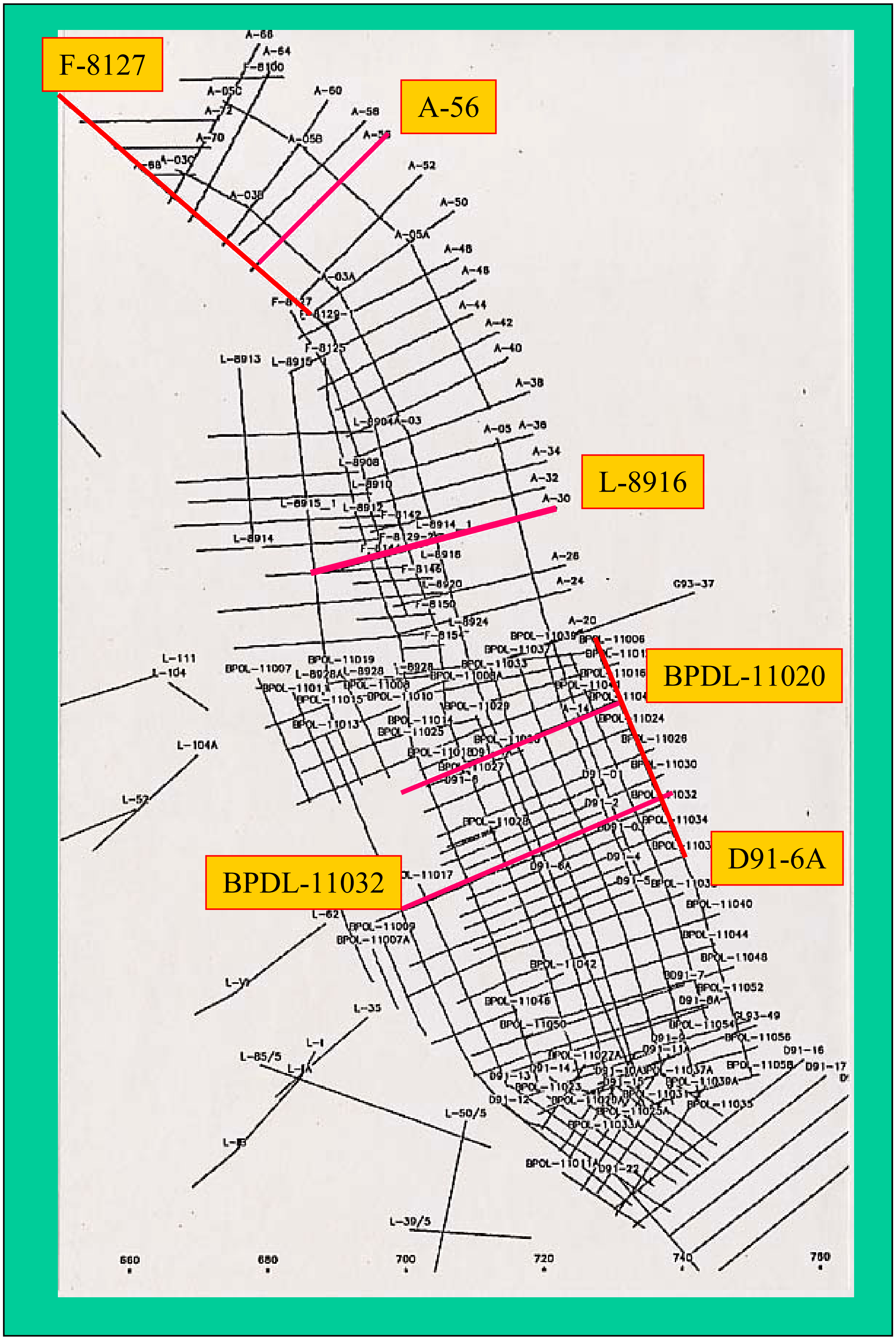

Figure 12. *Location of 2-D seismic lines utilized in this study. The red lines are those selected to present in this paper, with names of the lines indicated in the figure.*

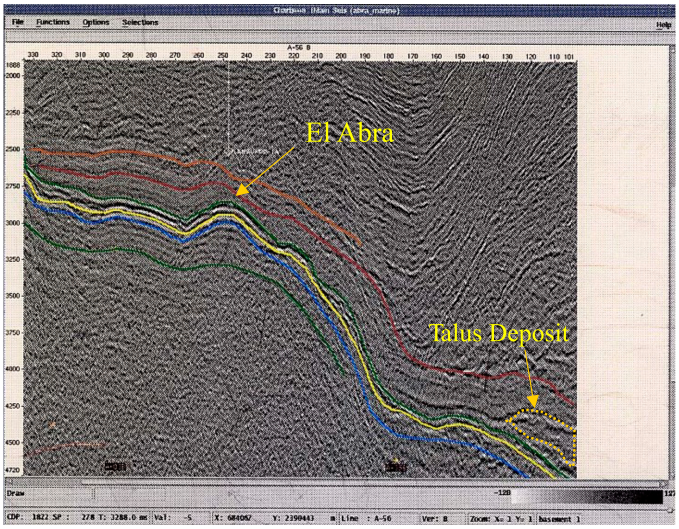

Figure 13. *Seismic line A-56B, located in the northern part of the study area, perpendicular to the strike of the eastern platform margin (see Figure 12 for location). High relief along the margin of the platform is clearly observed. In addition, synchronous carbonate talus deposited toward the east of the margin is indicated by the seismic profile.*

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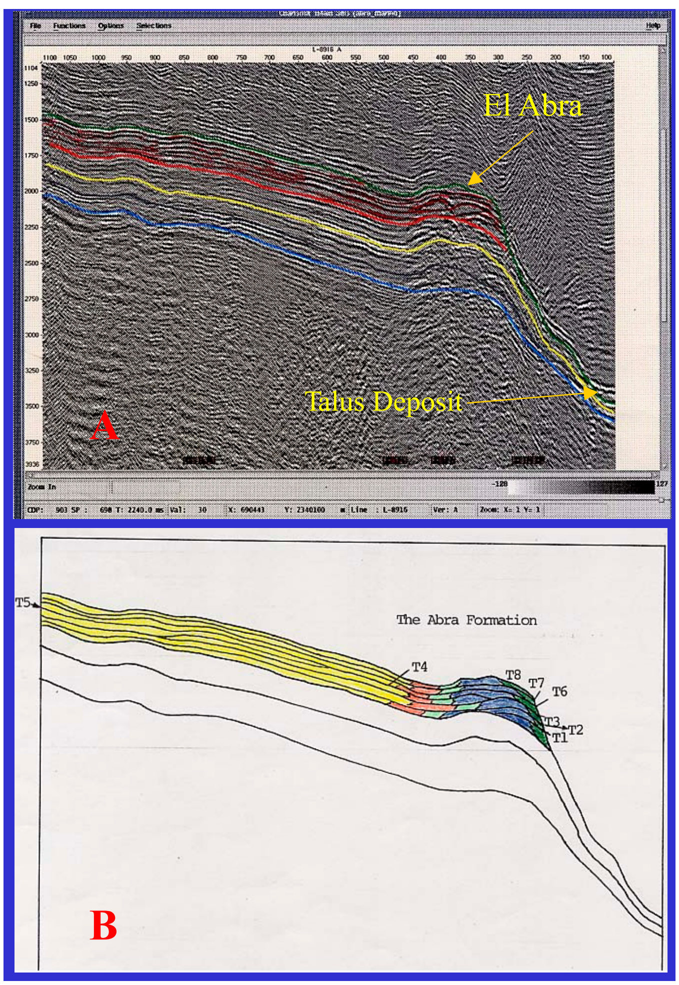

Figure 14. *Seismic line L-8916A* **(A)** *and interpretation of the seismic sequences* **(B)**.*Sedimentary sequences aggraded with rising sea level during the middle Cretaceous. At least eight subsequences are present in the El Abra Formation. The earliest horizon, T1, is only preserved in the eastern margin. T2, T3, T6, T7 and T8 distribute along the entire region. T4 and T5 are discontinued in the center of the lagoon, probably indicating existence of erosion surfaces. Several features are noted here: 1) These time planes are chronologically significant; 2) Each seismic horizon defined by the time planes has contained different facies, reflecting changes in depositional environment. From the center of the lagoon (the west of the mapping area) to the margin, the types of lithofacies include: lagoon (yellow), back reef (orange), reef top plain (light green), platform or reef crest (blue), and reef front (dark green). 3) Seismic profiles also indicate existence of some truncation surfaces and erosion processes.*

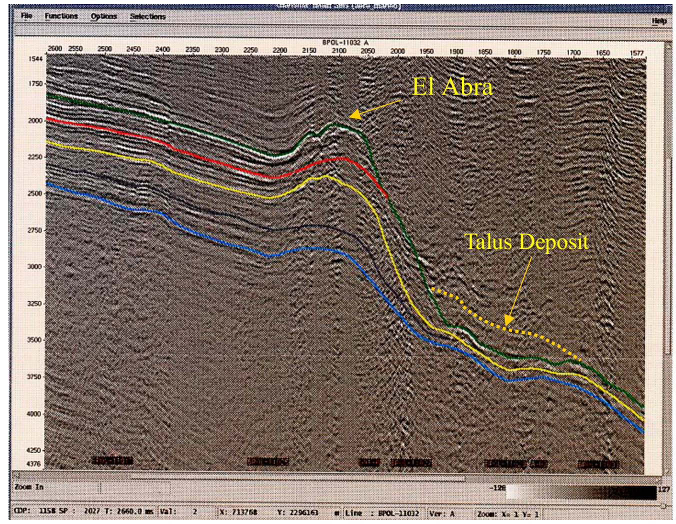

Figure 16. *Seismic line BPDL-11032A, located in the southern part of the study area, perpendicular to the strike of the eastern platform margin (see Figure 12 for location). High relief along the margin of the platform is clearly observed, likely indicating existence of some patch reefs. In addition, synchronous carbonate talus deposited to the east of the margin is indicated by the seismic profile.*

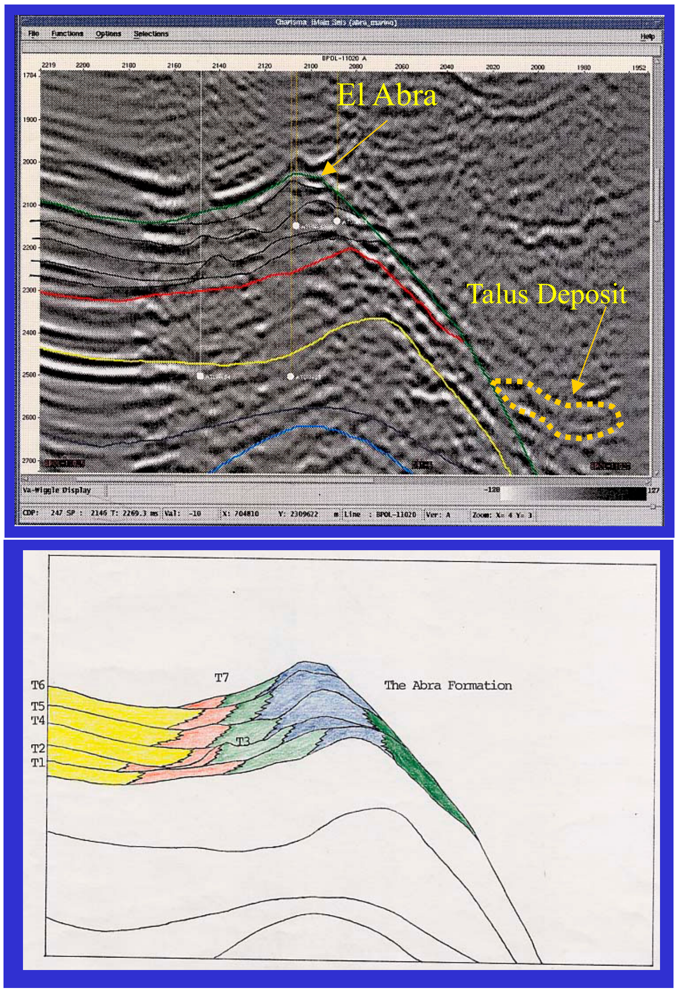

Figure 15. *Seismic line BPDL-11020A* **(A)** *and interpretation of the seismic sequences* **(B)**. *At least seven subsequences can be identified from the seismic profiles. T1, T2, T3, T4, T5, T6 and T7 represent the seismic time planes, or top boundaries of the subsequences. See Figure 14 for a detail explanation of the signals. Note specially that while the horizons below T1, T5 and T6 are more or less complete, those below T2, T3, T4 and T7 are partially eroded.*

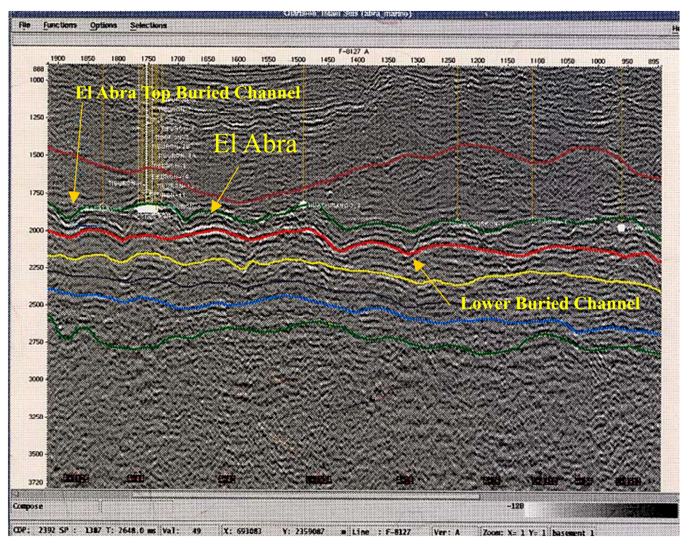

Figure 17. *Seismic line F-8127, parallel to the northwest-southeast striking Golden Lane. In comparison to the lines perpendicular to the strike, no high topographic contrast can be observed along this orientation. However, note several channel cuts at the top of the El Abra. This formed the individual mound shape topographic features that might have served as stratigraphic traps in the upper El Abra Formation.*

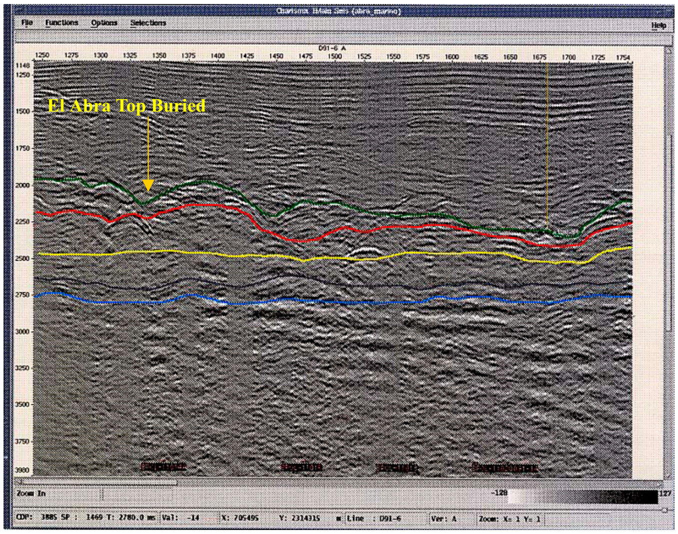

Figure 18. *Seismic line D-91-6A in the southern part of the lane, parallel to the northwest-southeast striking Golden Lane. Similar to line F-8127 in the north, no high topographic contrast can be observed along this orientation, while channel cuts at the top of the El Abra can be observed.*

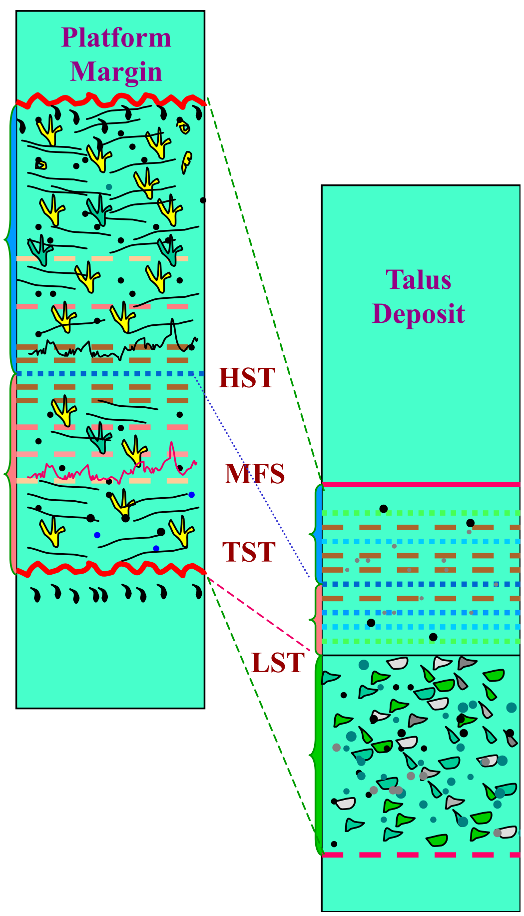

Figure 19. *Cartoon showing the facies contrast between platform top and the talus deposit. HST: Highstand system tract; TST: Transgressive system tract; LST: lowstand system tract; MFS: Maximum flooding surface. See text for detail explanation.*

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