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TECTONIC EVOLUTION AND SEQUENCE STRATIGRAPHY OF THE CENTRAL PACIFIC MARGIN OF COSTA RICA

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ABSTRACT: On the Central Pacific of Costa Rica, more than 1600 km of seismic reflection dàta, and potential field data, located offshore and onshore, joined to the surface geology data have been analyzed in order to clarify the structural configuration, tectonic evolution and characteristics of the sedimentary infill. Two main depocenters are recognized in the area: the Nicoya basin comprising about 3.5 km of Cretaceous-Tertiary sediments in the offshore region of the Nicoya Gulf and extending toward the northeast on the onshore region; and the Parrita basin located offshore and onshore with a sedimentary fill of more than 4.5 km. Both basins are limited on the south by a shallow uplift of the basement which represents an extension of the outer arc over the platform.

It is interpreted that in the Cretaceous, the area now occupied by the Nicoya and Parrita basins, was part of an extense forearc system that spanned along the Pacific margin of Costa Rica encompassing the Tempisque and Terraba basins. The present structural configuration of the Parrita and Nicoya Basins initiates in the Middle Eocene, related to shear stresses caused by the rotation in clockwise direction of the southern portion of the Costa Rican territory along a main transcurrent fault zone. Such movement displaced the Tempisque and Terraba basins on the south and north respectively, developing the half-graben configuration and the extense system of strike-slip faults of the transtensive basins Parrita and Nicoya. The configuration of the sedimentary fill has been controlled by the transtension and the subsidence along this series of faults, transverse to the coast, which are in some cases, still active.

The seismic stratigraphy analysis defines five seismic sequences and an equal number of time structure maps, besides the top of basement. This analysis has been tied up to the surface geology information and discussed under the light of sequence stratigraphy concepts. In general, the sediment in depocenters of this central Pacific region of Costa Rica, can be characterized as a shallowing upward megasequence, including deposits ranging from slope to shallow marine.

RESUMEN: En la margen central Pacífico de Costa Rica, más de 1600 km de datos de reflexión sísmica, y campos potenciales, tanto marina como terrestre, unidos a los datos de geología de campo han sido analizados para ayudar a clarificar la configuración estructural, evolución tectónica y las características del relleno sedimentario. Dos depocentros principales son reconocidos en el área: la Cuenca Nicoya con cerca de 3,5 km de espesor de sedimentos Cretacico-Terciarios en la región marina del Golfo de Nicoya y que se extiende hacia el noreste en la región costera; y la Cuenca Parrita, localizada tanto sobre la plataforma como en tierra, con más de 4,5 km de espesor sedimentario. Ambas cuencas están limitadas en el sur por un levantamiento somero del basamento que representa una extensión del arco externo sobre la plataforma marina.

Se interpreta que en el Cretácico, el área ahora ocupada por las Cuencas Nicoya y Parrita, era parte de un extenso sistema antearco a lo largo de la margen Pacífica de Costa Rica, comprendiendo también las cuencas Tempisque y Térraba. El desarrollo de la presente configuración estructural de las cuencas Parrita y Nicoya se inicia en Eoceno Medio, relacionado con esfuerzos de cizallamiento causados por la rotación en el sentido de las manecillas del reloj, de la porción sur del territorio de Costa Rica a lo largo de una zona principal de falla transcurrente de Costa Rica. Tal movimiento desplazó las cuencas Tempisque y Térraba en el sur y norte respectivamente, desarrollando la arquitectura de grabenes y medios grabenes y el extenso sistema de fallas de rumbo en las cuencas transtensivas de Parrita y Nicoya. La configuración del relleno sedimentario ha sido controlado por la transtensión y la subsidencia a lo largo de esta serie de fallas, transversales a la costa, las cuales están activas actualmente, en algunos casos.

El análisis sísmico estratigráfico, define cinco secuencias sísmicas e igual número de mapas estructurales en tiempo, además del mapa del tope del basamento. Este análisis ha sido correlacionado con la información geológica de superficie y discutido a la luz de conceptos de estratigrafía de secuencias. En general, los sedimentos en los depocentros de la región centro Pacífico de Costa Rica, se caracterizan como una megasecuencia de somerización hacia arriba, incluyendo desde depósitos típicos de talud a marino somero.

INTRODUCTION

Scope of this article

The present article is the result of an extensive geological and geophysical petroleum evaluation carried out in the Pacific forearc region of Costa Rica, that complement in much a prior report done in Stavanger, Norway, in 1991 with the participation of the first author of the present paper. In that report a preliminary understanding of the structure, tectonics and sedimentary infill of the Central Pacific depocenters was treated.

The geophysical evaluation for this second stage was focused on the tie of the marine network of seismic lines and sparse land seismic data, to determine the tectonic model controlling the development of these basins.

The correlations of these two regions allowed a better understanding of basin evolution in the area. Quantitative basin analysis is been carried out and could be the subject of a future report. Also a systematic seismic sequence and structural analysis of the region, based on previous research made with the cooperation of the national oil company of Norway, Statoil, is intended.

THE STUDY AREA

This paper is focused on the central Pacific shelf of Costa Rica, from the Southern portion of the Nicoya Peninsula until Punta Quepos, where there is a basement uplift called Quepos Promontory (Fig. 1). The area is divided into two main depocenters: the Nicoya and Parrita Basins, separated by a shallow basement known as the Herradura Promontory. The Nicoya basin is located mainly offshore, with a narrow inland extension that runs parallel to the Tárcoles river, where Neogene sediments outcrop along the Interamerican road and near the Caldera harbor, as well as in the southern boundary of the Nicoya Gulf. The Parrita basin is well spreaded to the south, over the shelf. On the coast side, it is bounded by the Herradura High, where Cretaceous-Tertiary outcrops have been well-studied by the national oil company of Costa Rica (RECOPE) since 1987. Furtherly inland, it extends over the Parrita plains, limited by Quepos Promontory on the southern basin edge, and on the north, by Fila Bustamante highlands.

Main previous works

In 1983, Refinadora Costarricense de Petróleo S.A. (RECOPE) allowed Geophysical Services Inc. to survey a speculative regional marine seismic network of around 1300 km in the study area. Then, in 1985, RECOPE, through financing by the World Bank, made a regional geological and geophysical evaluation of the country. At that time, some sparse geochemical analysis was conducted (Van de Kamp, 1985). Concurrently, a regional seismic evaluation was carried out by Rockwell and Associates.

Based on these results, RECOPE decided in 1987 to use own resources to furtherly explore for hydrocarbons, focused on the clarification of sequence stratigraphy and structure of the study area. Later in 1989, also using own resources, RECOPE surveyed 87 km of regional seismic in the onshore Parrita area. In 1989, the Norwegian Agency for Development (NORAD) agreed to assist financially and technically a binational project between Costa Rica and Nicaragua, under the responsability of RECOPE and the Instituto Nicaragüense de Energía (INE) respectively, in order to improve the understanding of the petroleum potential of the region. It comprised the acquisition, processing and interpretation of 1,140 km of seismic and gravity marine data, and the processing of 87 km of onshore seismic lines, previously shot by RECOPE.

The first stage of the Project concluded in 1991, with a report that analyzed geological structure, unconformities, sequence definition, stratigraphy, some geochemistry analysis, a preliminary basin modeling and some ideas about possible petroleum plays.

REGIONAL GEOLOGY

Tectonic Setting

The area treated here comprises the offshore region of the Nicoya Peninsula and southeastward to Punta Quepos. Two main depocenters were delineated: the Nicoya and Parrita Basins, separated by a basement uplift called the Herradura Promontory (Fig. 1).

Costa Rica is located in the southwestern margin of the Caribbean Plate. The principal tectonic boundaries are indicated in figure 2. It is bounded to the north and east by the North American Plate, to the south by the South

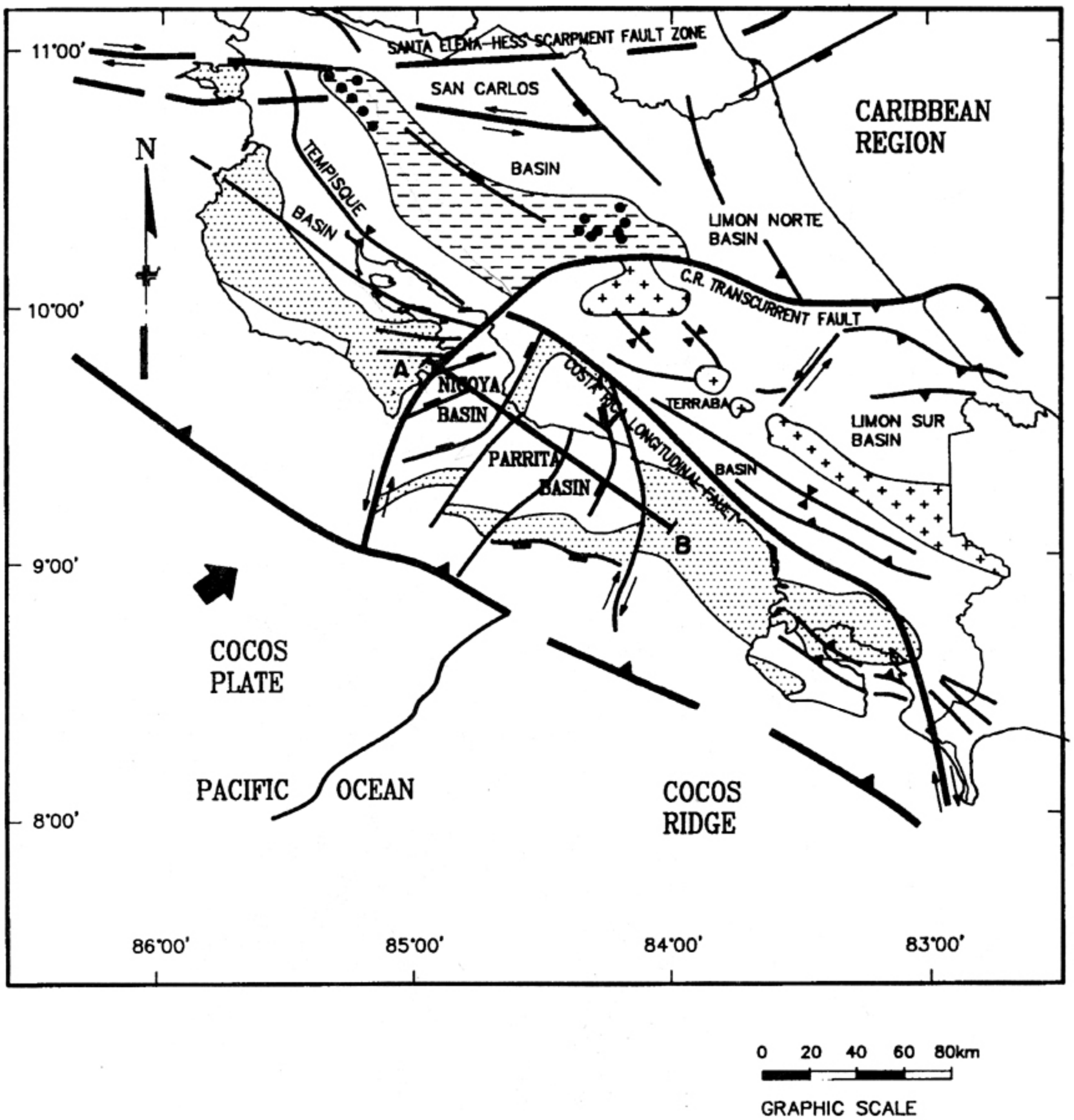

Fig. 1: Simplified structural map of Costa Rica. It shows in dotted pattern, the outer arc; in crossed and dashed pattern the present inner arc. Basin distribution and main structures are portrayed. Profile X-X' is shown in figure 3.

American Plate, and to the west and southwest by the Cocos and Nazca plates (Mann and Burke, 1984). The boundary between the North American and Caribbean Plates is defined by left-lateral strike-slip faults systems, such as the Motagua, Swan and Cayman Fracture Zones. On the east, this plate boundary becomes the Puerto Rico inactive subduction zone, whereas in the northeast, at the Lesser Antilles Trench, the North American Plate is being actively subducted beneath the Caribbean Plate.

Another series of right-lateral strike-slip faults forms the southern limit between the Caribbean and South American plates: Bocono, El

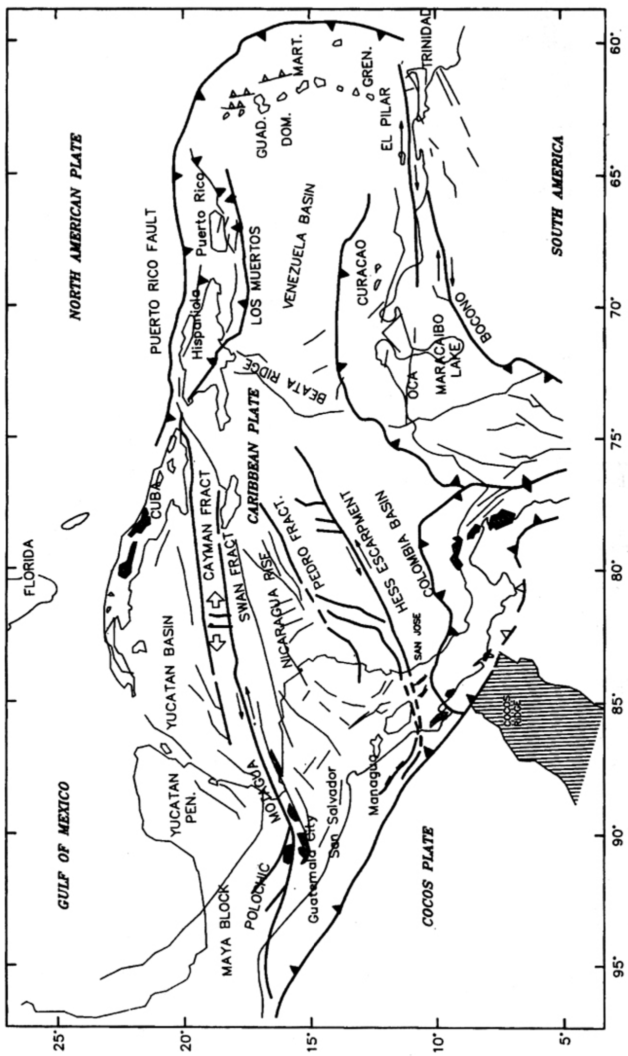

Fig. 2: Generalized Caribbean structural map. Main strike-slip features separate the Caribbean plate from North and South American Plates. This type of deformation along with the compression caused by the subduction zone, has its expression within the territory of Costa Rica, in the development of transtensive depocenters in the Pacific side.

Pilar, De Oca and Santa Marta Fracture Zones. This plate boundary is not well-defined because it is masked by structures related to northward directed compressive stresses.

To the West and Southwest the Caribbean and Cocos Plate boundary is traced by the "Middle American Trench". Active volcanism and seismicity prove that subduction is an ongoing process from the Motagua to the Panama Fracture Zones, to where subduction-related seismicity and volcanism are absent at the present time.

The theories about Caribbean Plate tectonic history are somewhat controversial as far as origin, evolution and relative motion is concerned. The main question is whether the plate was formed in-situ or if it was transported as a single or as several exotic terrains to its present position, between the North and South American plates (Donnelly, 1975; Burke et al., 1984; Winsemann, 1994).

Dengo, in 1985, described a series of tectonic crustal blocks that define the leading edge of the Caribbean Plate towards the Middle American Trench, based on basement composition and ages as well as their different geologic histories. He subdivided the region into the Maya, Chortis, Chorotega and Choco blocks, all of them bounded by strike-slip fault megafeatures. Two are the most pertinent to this study, the Chortis and Chorotega terrains. As stated, the Chortis terrain was formed north of its present position and has a crystalline Paleozoic basement. It is limited to the north by the Motagua fracture zone and to the south by the Río San Juan-Santa Elena Suture Zone. The Chorotega block, hosting the present territories of Costa Rica and southwestern Panama, was generated in a sea floor spreading ridge, far out in the Middle Pacific and has a basaltic oceanic basement of Mesozoic age. According to Pindell and Barret (1990), during the Middle Eocene, these tectonic terrains become coupled with the development of a suture zone between them.

About the same time, the Chortis-Chorotega tectonic terrains were subjected to an NW-SE dextral regime along the Sandino basin outer arc, changing direction to an E-W orientation along Santa Elena-Río San Juan region and extending along the Nicaraguan Rise in the Caribbean (Fig. 1 & 2). Plate convergence and the relative motion of these tectonic blocks have controlled the tectonic-sedimentary evolution of the eastern Caribbean region during Tertiary. This regional shear regime in the western margin of the Caribbean plate, resulted in Costa Rica in the development of strong left-lateral components with a east-west orientation.

Tectonostratigraphy

It is believed that, in the Cretaceous, the area now occupied by the Nicoya and Parrita Basins was part of an extensive forearc system along the Pacific margin and encompassing both the Tempisque and the Terraba basins. According to Pindell and Barret (1990), during the Middle Eocene, the Chortis and Chorotega terrains became coupled with the development of a suture zone between them. About the same time, the Chortis-Chorotega tectonic terrains were subjected to an NW-SE dextral regime along the Sandino basin outer arc, changing direction to an E-W orientation along Santa Elena-Río San Juan region and extending along the Nicaraguan Rise in the Caribbean.

Development of Nicoya and Parrita depocenters was initiated in the Middle Eocene as a result of shear stresses caused by the clockwise rotation of the southern portion of Costa Rica region along the major left-lateral Costa Rica transcurrent fault and offsetting the Tempisque and Terraba basins. The conclusion about this rotation is based on the analysis by the authors of the seismic maps of: basement, Base of Upper Eocene, Intra Lower Oligocene-Upper Miocene and Pliocene and the basement displacements showed in the tectonic element map (not included in the present work). The tectonostratigraphic evolution of the region is schematically portrayed in figure 3.

The Cretaceous to Plio-Pleistocene basin fill may be characterized as a shallowing upward megasequence, which is divided into three stages.

The oldest sequence A and subsequence B1 are a pelagic sedimentary succession that overlies an oceanic basaltic basement and includes siliceous-bituminous and carbonatic pelagic sediments from Sabana Grande and Loma Chumico Formations (Dengo, 1962, Astorga et al., 1989).

The lowermost B2 is strongly dominated by deep sea fan systems crowned by an interval of shallow marine to carbonate ramp deposits from Upper Eocene, assigned to Fila de Cal Formation. Due to the transtension during Middle Eocene, some areas were uplifted and neritic limestones were deposited over structural highs. At the same time, extensive parts of the forearc region subsided and carbonate turbidites were deposited over the slope-basin areas.

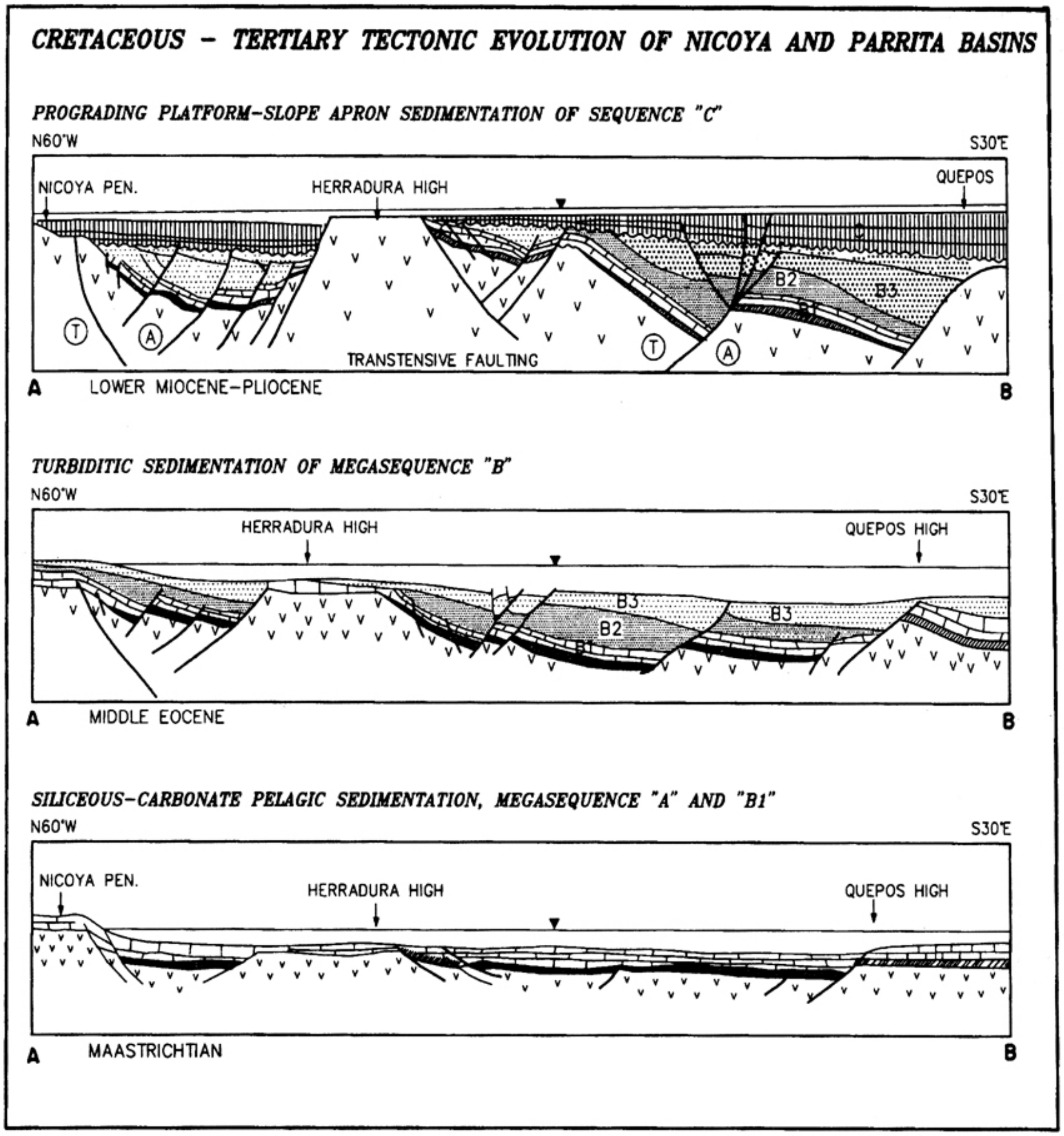

Fig. 3: Cretaceous-Tertiary tectonic evolution of Nicoya and Parrita Basins. Upper Cretaceous to present clastic deposition and structural evolution is schematicly shown on this cartoon. Middle Eocene is believed to be the onset of transtensive deformation which emphazised depocenters in the central Pacific region of Costa Rica. See figure 1 for location.

The onset of sequence C is related to regional erosion over the present shelf area, linked to a worldwide sea-level drop during the late Oligocene. The base of sequence C marks the installation of the Neogene platform clastic systems, that comprise estuarine, deltaic and bay deposits over the shelf region during the Neogene.

STRATIGRAPHY

Since description of the stratigraphic units was reasonably treated in previous published and unpublished reports (Barboza & Zucchi, 1994), more effort is being focused in the age determination of main sequence boundaries, to allow a better chronostratigraphic correlation with the Haq et al. (1988) chart of sedimentary events.

Herein, the stratigraphy of the area is presented in terms of sequence stratigraphy, supported by recent biostratigraphic data from the study area. This new data would slightly change the previous works carried out by RECOPE since 1987.

SEQUENCE STRATIGRAPHY

Methodology

A general interpretation was done by applying sequence stratigraphy. The methodology was the following:

- Compilation of previous studies of the more recent academic works.
- Integration of biostratigraphy to each stratigraphic column surveyed by RECOPE since 1987.
- Delineation of cyclicity patterns, from major to minor order, on the basis of grain size (thickening-thinning or coarsening-fining upward trends), lithological composition and strata thicknesses.
- Sedimentological interpretation, characterization of sequential patterns and deduction of stratigraphic boundaries.

In addition to interpretation of a column of Nicoya and Parrita areas, a panel correlation by zone and a generalized stratigraphical column was generated in 1991. Based on this, a general stratigraphic column for the onshore sector of Nicoya-Parrita basins was constructed in which it is summarized all the sedimentological, stratigraphical and sequence stratigraphic units of the central Pacific of Costa Rica. A global correlation of all work zones for the region is intended by correlating the generalized columns, based on the studies done by Astorga since 1987, as part of the current activities at RECOPE.

A comparison of the regional onshore column with the table of sequence chronostratigraphy from Haq et al. (1987), allowed the establishment, in a global manner, of the main sequence chronostratigraphy subdivision units for the study area. This type of synthetic correlation is used here as a key argument for a reasonable correlation, in the onshore area, by using sequence stratigraphy and in the offshore depocenters, by applying seismic stratigraphy concepts.

Before going into any detail regarding sequence chronostratigraphy for the onshore units, it is convenient to indicate some criteria used in the definition of chronostratigraphic units itself:

Biostratigraphy

A total of 97 samples from the Pacific margin of Costa Rica were sent to a Simon Petroleum Technology Laboratory, in England. All samples were examined lithologically and by the most appropriate biostratigraphic analysis. Some samples were suitable for tests using more than one method, while others were of more doubtful use in biostratigraphy. The total number of samples carried out was 52 for micropaleontology, radiolaria, ostracods and any other age-diagnostic or environmentally significant microfossils (20 for processed/picked residues and 42 as thin sections) and 22 for palynology, giving a total of 116 analysis for this purpose.

Even though, most of the analysis were centralized in one lab, in cases of some acute chronostratigraphic problems, several extra samples were collected, and double checked at the same time, at the paleontological laboratories of the University of Costa Rica (UCR), Universidad Autónoma de México (UNAM) and RECOPE respectively. Although, the biostratigraphical results were a fundamental base, its chronostratigraphical accuracy has not been as desired to define chronostratigraphic stages. Therefore the majority of samples analyzed were dated on a series level.

This situation led to look for an alternate, more detailed correlative methodology, in this case, by using recorded sedimentary events and analyzed on the basis of the sequence chronostratigraphic cycles defined by Haq et al. (1988).

Finally, the cyclicity level that will be reached for the constructed stratigraphic columns will be an intermediate solution, with respect to the sequence chronostratigraphy, in the absence of reasonable well control. It means, somewhere in between supercycles (second order cycles) and cycles (third order cycles).

To avoid overinterpreting the available biostratigraphic data, a differentiation of supercycles hierarchies was done, and when permitted, also third order cycles have been informally grouped, assigning to them time-relationship letters (A,B,C, etc).

Sequence boundaries

With respect to grain size and thickness parameters, the Cretaceous-Tertiary succession of sediments of Nicoya and Parrita basins, reflects almost a continuous development of a series of prograding sequences beginning with deep pelagics and passing to a series of alternating coarsening and thickening upward cycles of slope sediments. This type of cycles occur in many different magnitude orders, from few meters to hundreds of meters of thickness. The delimitation of main major cycles is done, as main sedimentary events, for example as thick successions of conglomerates or as sandstones lobe complexes.

At the same time, compositionally, these deposits evidence the occurrence of important erosional processes in the coastal areas, that produced the resedimentation of tafocenoids from shallow marine environment, downward to the slope areas. The recording of these processes, that represent a chronology of exceptional sedimentary events, mostly related to deep marine deposits, has been used as a key criteria to define sequence boundaries in the present study, as previously applied in the study area by Astorga (1987; 1988) and Winsemann (1992).

The diagnostic criteria concerning shallow marine to transitional deposits was, in most of the cases, the occurrence of an abrupt change in lithology into a coarse-grained type of deposits, that implies abrupt changes in the depositional energy, as studied by Seyfried et al. (1987). These types of environmental changes were utilized to define a cycle of seaward transfer of coastal onlap and therefore a sequence boundary.

Low-stand system tracts

The general model for sequence stratigraphy is referred mostly for passive type of margins. It establishes that just after seaward transfering of coastal onlap, a low-stand system of sedimentation takes place. According to Posamentier et al. (1988), when this phenomenon happens, the sedimentation shifts seaward nearby the shelf break, in the case of an unconformity type I, and therefore the main deposition is then located on the slope area or on the shelf break zone.

Based on the general model, the sedimentation at this stage comprises two stages:

a) Basin floor fan: characterized by lobe and channeled facies

b) Slope fan: Represented mostly by sandy submarine fans of restricted influence that is overlaid by the progradational turbiditic wedge, which is characterized by the absence of sandy bodies.

This theoretical conception of facies wedges does not seem to be the most applicable for a fore-arc system. For our case, the lobe-type sand bodies tend to have a broader geographic distribution, in the similar manner as the basin floor fans, but also the generated turbidites reflect the same pattern, possibly related to the additional driven mechanism of structure during sediment deposition and in addition to eustatic processes, whose interpretation seems to be more complicated in the fore-arc setting.

As an alternative to the proposed solution, and in order to simplify the descriptive scheme for deep marine facies association; deep marine deposits for a fore-arc active margin can be divided into:

Turbiditic wedge deposits, represented by sedimentary prisms composed of turbidites and in minor degree, by lobe systems, sedimented on the slope or on the basin floor areas as well. The other type corresponds with lobe complex deposits and submarine channel-fill deposits, that represent submarine basin floor fans and sediments with punctual sediment source at the base of the slope, respectively. In this case, the sequence boundary among turbiditic successions is not located at the base of the first coarse grain occurrence, but within these packages, based on compositional and textural criterium.

CENTRAL PACIFIC MARGIN, NICOYA AND PARRITA BASINS

The sedimentary infill of Nicoya and Parrita basins represents a typical shallowing upward prograding succession of sediments that grades from pelagics to slope and continental deposits. The defined stratigraphic units reflect itself these gradual changes from deep marine crowned by shallow water deposition (Fig. 4 & 5). In this section, the formations that include all deep sea sediments are analyzed in the Nicoya and Parrita areas as follows:

Nicoya Basin (Fig. 4)

In terms of sequence stratigraphy and classical formation hierarchy methodologies the sedimentary infill of these depocenters can be divided as follows:

- Nicoya Complex and Loma Chumico Formation: Black shales and radiolarites interbedded with basalts flows and basaltic breccias.

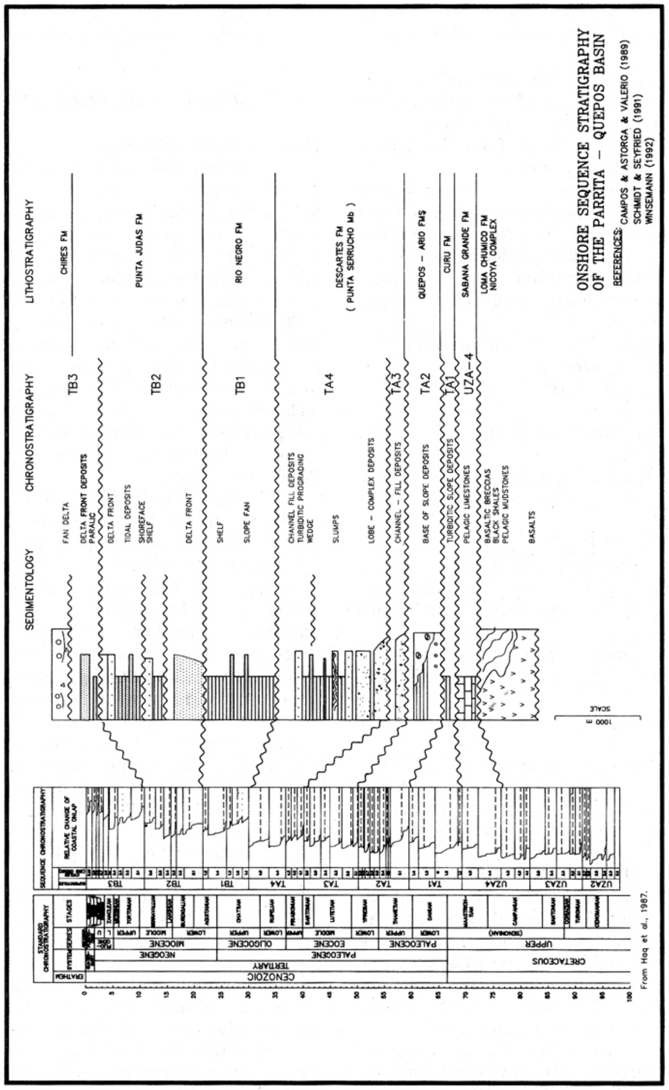

Fig. 4: Integrated geologic information and sequence chronostratigraphy for Parrita-Quepos Basins. A tentative correlation between *onshore sequence boundaries and Haq et al.'s chart of worldwide events is made. The same unconformities were recognized on off-*shore seismic data.

- Sabana Grande Formation (UZA-4): Pelagic and hemipelagic limestones and basin plain turbidites.
- Curu Formation (TA1): Prograding successions of clastic turbidites conformed by slope fans and turbiditic lobe deposits.
- Zapotal Member (TA2): Turbiditic deposits of prograding slope aprons.
- Descartes Formation (TA3): Thick prograding successions of clastic and carbonate turbidites conformed by sandy lobe complexes, prograding slope aprons and turbiditic fan deposits.
- Fila de Cal Formation (TA4): Carbonate deposits with microforaminifera of neritic environments.
- Caletas Unit (TB1): Clastic turbiditic, prograding slope deposits.
- Punta Carballo Formation (TB2): Tidal flat to shelf deposits.
- Mata de Limon Unit (TB2): Paralic to alluvial deposits.
- Tivives-Orotina Formations (TB3): Alluvial fan sediments and lahars.

Parrita basin (Fig. 5)

- Nicoya Complex and Loma Chumico Formation: Black shales and radiolarites interbedded with basalts flows and basaltic breccias.
- Sabana Grande Formation (UZA-4): Pelagic and hemipelagic limestones and fine turbidites.
- Curu Formation (TA1): Turbiditic slope deposits.
- Quepos-Ario Formations (TA2 and TA3): Megabreccias, slumps and olistrotomes deposited at the slope base, as well as hemipelagic limestones and carbonate turbidites of slope aprons.
- Descartes/Punta Serrucho Formations (TA4): Thick successions of clastic and carbonate turbidites formed by lobe fan complex at the base, slumped deposits at the middle section and crowned by a turbiditic prograding wedge and channel fill deposits.
- Rio Negro Formation (TB1): Clastic deposits of slope aprons, and neritic.
- Punta Judas Unit (TB2): Clastic neritic, and coastal deposits formed by delta front at the base, shoreface at the middle portion and tidal deposits to delta front at the top of the formation.
- Chires Unit (TB3): Deltaic paralic deposits as well as associated alluvial deposits.

SEISMIC INTERPRETATION

Data set and methodology

A seismic reflection data set of about 1,140 km, shot in 1989, under the CAM-009 agreement, as a infill semidetail survey, in addition to previous near 400 km of seismic lines, shot in 1983 in the study area by GSI, were available for the first stage of the project. A small regional survey of 80 km of seismic reflection lines was shot by RECOPE in 1990, on the onshore area of Parrita. These data were processed in 1992 and incorporated into the database for this stage. No well data was available to tie with the seismic. This data set was studied under the procedure of seismic stratigraphy for the sole purpose of this report and as an aid in the evaluation of the petroleum potential of the central Pacific of Costa Rica.

On the basis of reflection terminations and internal seismic attributes, five sequences bounded by unconformities were mapped and analyzed on the dataset. The correlation of the surface sedimentology with the seismic analysis allowed to define gross depositional environments and lithologies of the more evident packages in the Cretaceous-Tertiary sedimentary series of the offshore Central Pacific of Costa Rica, that in general shows a shallowing trend of the region.

In addition to the basement top, four unconformable horizons were mapped based on reflection terminations, seismic character and lateral continuity: the Base of Upper Eocene, the Intra-Oligocene surface, the Base of Upper Miocene and the base of Pliocene .

A series of time structures maps and one depth map for the basement horizon were generated in the first interpretation done in Norway in 1991. Since all those horizons represent sequence boundaries, the new task was focused on the following technical considerations:

a) Calibration of those horizons under the light of the new biostratigraphic information, obtained through activities at the final stage of the Project.

b) Correlation of those horizons with others recognized on the processed onshore seismic data on the Parrita plains.

Based on onshore geology, one type column for each basin was developed. Since most of the

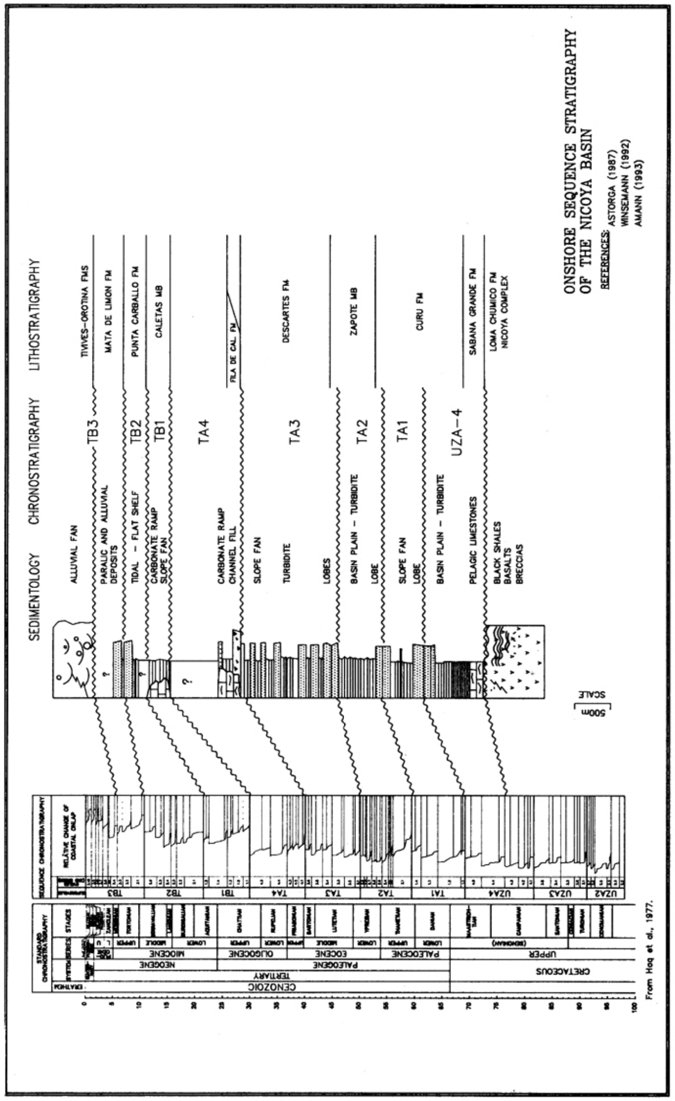

Fig. 5: Integrated geologic information and sequence chronostratigraphy for Nicoya Basin. Compared figure 4, for explanation. Late Oligocene and Lower Miocene hiatuses are determined for the onshore area that seem to extend to the offshore region.

seismic was shot offshore, a jump correlation between the seismic dataset and onshore geologic information was required for horizon dating. The presence of regional and local strongly eroded, basement highs, and major faults, made it difficult to correlate horizons and unconformities from one basin to another. The most reliable correlations were the angular unconformities which could be identified in both basins.

Several analogies were clear in the correlation work:

- On both basins, the Pretranstensional Cretaceous-Middle Eocene pelagic group of sequences is present.
- Several unconformities were recognized and dated through biostratigraphy and correlated throughout the whole onshore area.
- These sequences and unconformities were correlated with the seismic stratigraphy analysis.
- Seismic data, as well as geology, revealed the presence of a Oligocene hiatus on the Nicoya basin.

Main results

As a result of the seismic stratigraphy analysis, five sequences, bounded by unconformities were mapped and analyzed on the available seismic data set. The correlation of the surface sedimentology with the seismic analysis allow to define gross depositional environments and lithologies of the more evident packages in the Cretaceous-Tertiary sedimentary series of the offshore Central Pacific of Costa Rica, that in general show a shallowing trend of the region. Inland, outcrop analysis provide additional information about the nature of the sedimentary packages and main unconformities.

A few examples are used here to show the most characteristic features of the sediment infill as seen on seismic sections. As shown in figure 6, the basement, represented by the lowest vertical hachured section, has a very chaotic reflection pattern, bounded at the top by a relatively continuous, high amplitude event. On top of the basement, a series of relatively continuous reflections with variable amplitude, are interpreted as siliceous and bituminous pelagics.

On top of that, the events are discontinuous with variable amplitude, which are interpreted as calcareous pelagics. A continuous and very strong amplitude reflection marks the change in character between the pelagic limestones and the overlying turbiditic sequence. The packages shown with inclined hachures show poor continuity with low amplitude and are interpreted as distal turbidites, whereas the intervals having good continuity, high amplitude could be interpreted as proximal turbiditic facies. Two packages with more discontinuous reflections with low amplitude are interpreted as sandy shelf/delta deposits as reported onshore.

The overlain shallower package, is an onlapping unit of medium to highly continuous reflectors, whose basal part is more discontinuous, and is interpreted as shallow water deposit. The divergent character of the reflections indicate fault reactivation during deposition. A thinner package of similar character is interpreted between the deeper distal turbidites.

Some of the erosional events documented on the seismic example of figure 6 could be associated to structural inversions caused by transtension and block rotation. Some of the sequences show apparent toplaps which indicate sediment starvation. These sequence boundaries, as expected in an active margin, are the result of combined basin-wide events and eustatic changes.

Structural analysis

The Nicoya and Parrita forearc basins are made up of more than 3.6 and 4.6 km of a shallowing upward sedimentary megasequence, whose sediments range from deep marine pelagics, slope turbidites, shallow neritic and continental deposits. The structural configuration of the Nicoya depocenters is shown as a series of grabens and half grabens bounded by transtensive faults with an east to northeast orientation, transverse to the main NW-SE tectonic trend of the inner arc and Middle American Trench and slightly changing direction towards the Herradura High, as seen on figure 7 and 8. Faulting in the inner part of the basin was active until early Pliocene as shown in figure 8.

Parrita basin is located mainly offshore, with a smaller onshore extension. The southeast border of Parrita is formed by a major dextral fault that ends up against a basement high located in Punta Quepos. The depocenters and basement highs have been displaced by this transtensional tectonics.

At least three major sedimentary packages are identified on seismic sections (Fig. 9). The oldest sequence, which seems to belong to the Upper Cretaceous to Early Eocene, pre-transtensive stage,

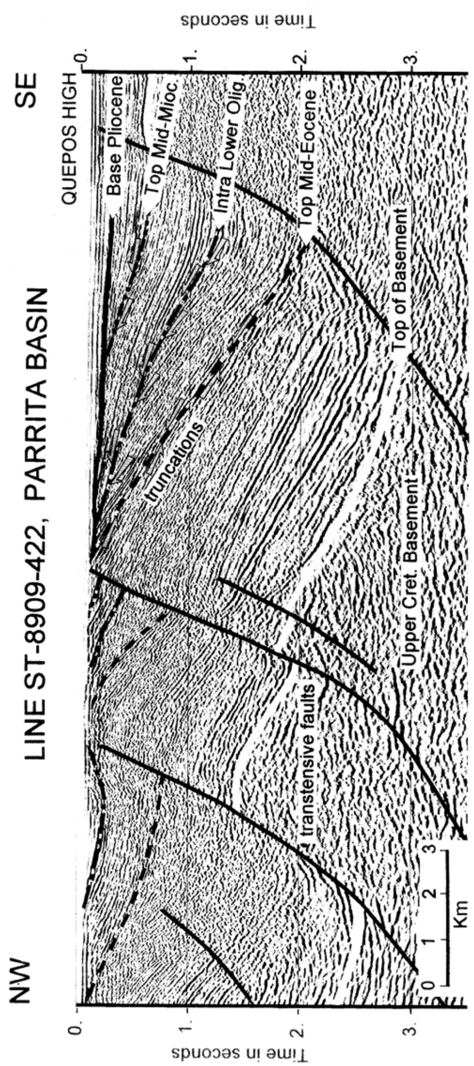

Fig. 6: Seismic stratigraphy **analysis of line ST-8909-422. A tentative correlation of seismic facies, environmental** prediction and associated lithologies are sketched on this seismic example. **A shallowing upward trend is identified for the Cretaceous-Tertiary** sedimentary megasequence.

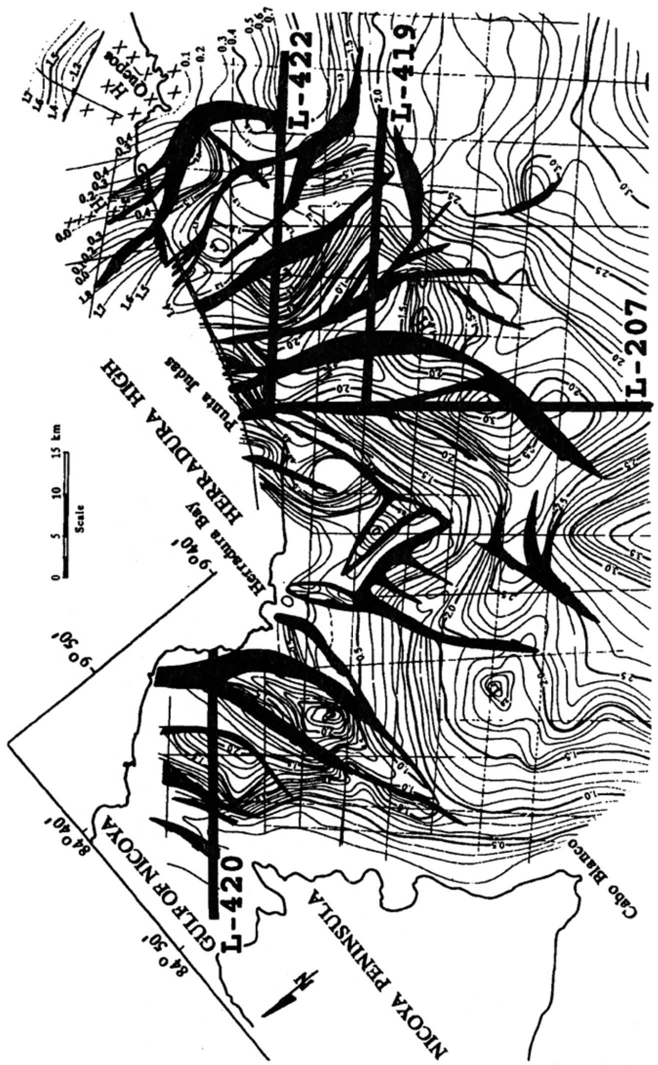

Fig. 7: Top of basement time map. This map integrates all seismic data in the area for the determination of the basement top. Tilted basement blocks in a half-graben configuration is typical of the transtensive depocenters of this region. Large vertical fault displacements exceed one second in most of the cases. Location of seismic examples are shown here.

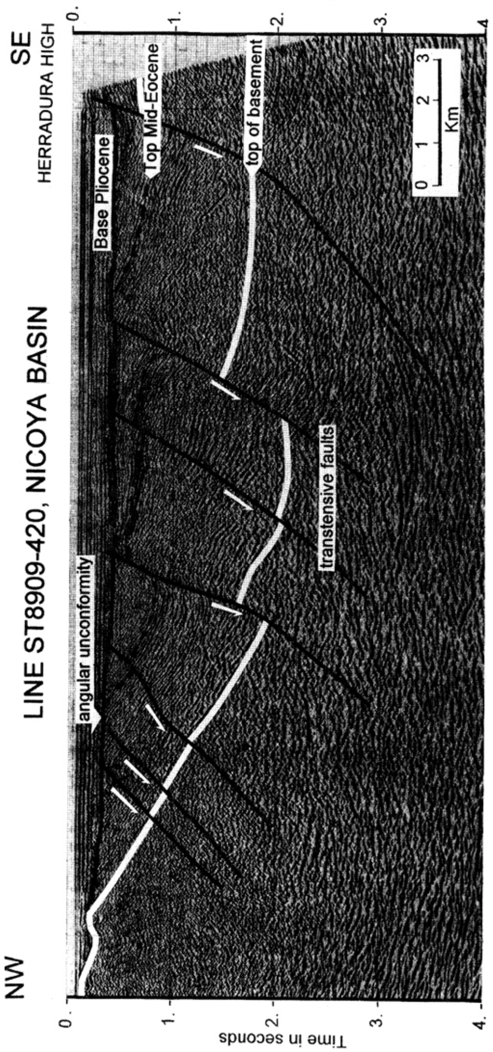

Fig. 8: Seismic section **ST8909-420. A series of half grabens is the main characteristic of this section at Nicoya Basin.** At least three unconformities are recognized here. Again, as defined onshore, some of the Neogene section was eroded, Pliocene to Recent shelf deposits rest on Cretaceous-Tertiary section.

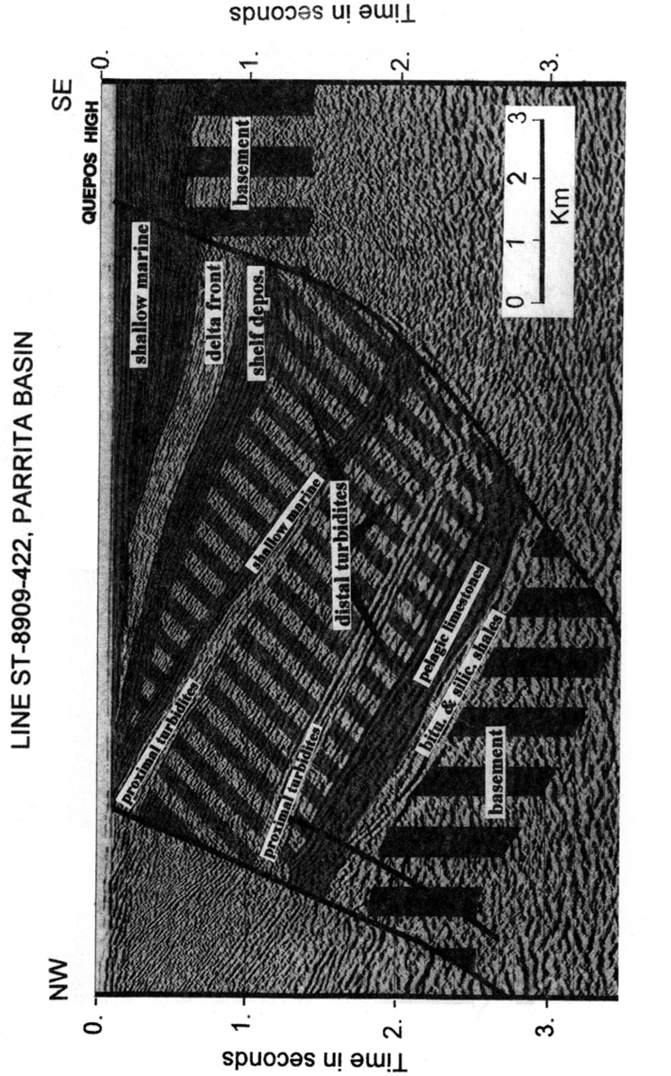

Fig. 9: **Seismic section ST8909-422. Seismic example of Parrita depocenter in which development of structural inversions below the top of Mid-Eocene unconformity could have positioned coarse-grained turbiditic facies against major faults, with possible trapping mechanisms in the upward position.**

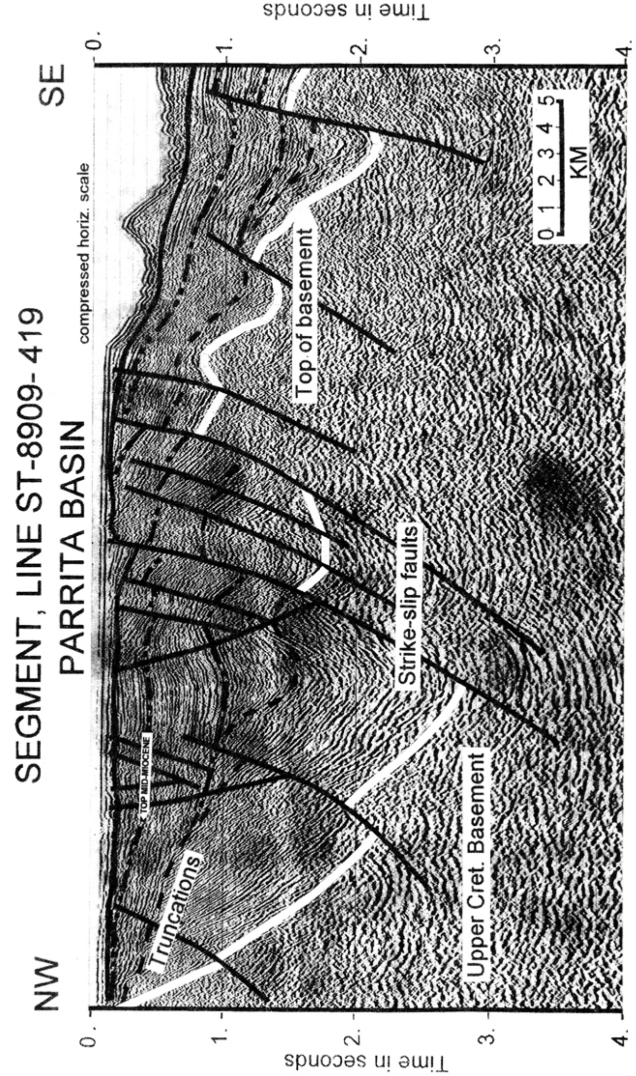

Fig. 10: **Seismic section ST8909-419, detail. Seismic example on Parrita Basin showing deformation along major transtensive** faults resulting on the generation of rollover anticlines. Hydrocarbon traps could be associated to the combination of angular unconformities and structural features as observed in the middle of the section below one second.

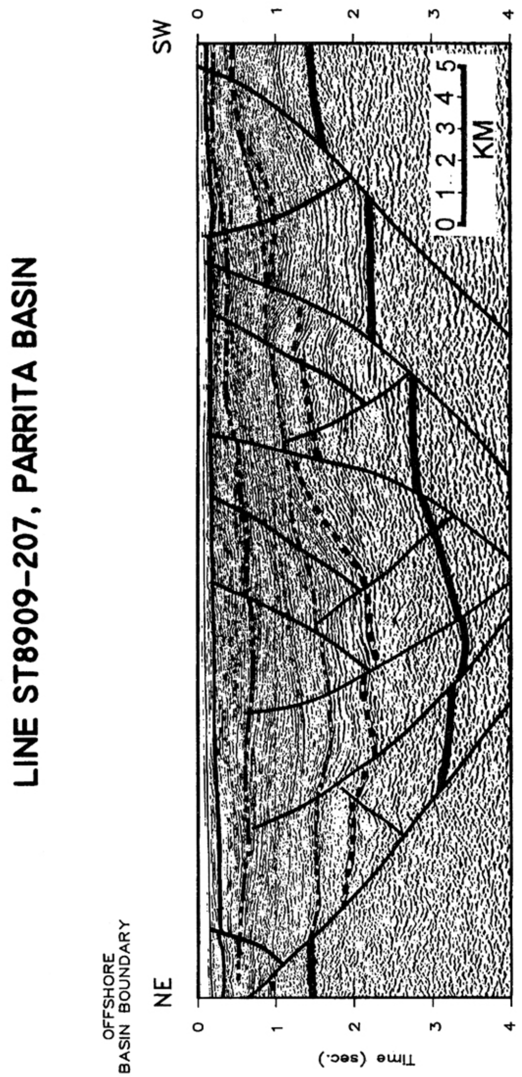

Fig. 11: Dip Seismic section ST8909-207. This line runs perpendicular to the coast, and shows the magnitude of deformation along major faults. Sedimentary packages imbrication, caused by active subsidence in the Neogene is clear on the upper-left sector of this line.

is a fairly homogeneous thickness of deep marine sediments. The second package is the Middle Eocene to Oligocene succession of slope sediments. These two are crowned by a shallow marine sequence of Miocene to Pliocene rocks (Fig. 9 and 10).

The semigrabens are bounded by series of strike-slip normal faults (negative flower structures) which have enhanced the accommodation space for sediments since Middle Eocene. Most of these semigrabens are tilted towards the SE, and trending obliquely to the Middle American Trench. The vertical basement displacement across major faults is, in most of the cases greater than 1 second, which gives an idea of the magnitude of the tectonic subsidence of these depocenters (Fig. 7, 8 and 11).

The coastal basin edge on the dip direction is a basement high associated to an accretionary wedge. The seaward edge of the basin is the extension of the outer arc uplift. More than 4.5 km of sediment thickness have been estimated for this depocenter in line 207 (Fig. 11).

The offshore portion of the Nicoya and Parrita basins is composed of several major features whose genesis and relationship could be synthesized as follows: Compressional stresses caused by the subduction at the Middle American Trench, in addition to a conjugate left lateral strike-slip, basement related fault system acting, since the Middle Eocene, resulted in transtensional deformation on the forearc region and extending to the East over the shelf with extensive normal listric faulting that, in some areas, reach even through the youngest sediments . Listric normal faults soling-out on the basement provided additional subsidence and accommodation space for sediments on these basins since Mid-Eocene time.

CONCLUSIONS

Offshore seismic stratigraphic data show a clear correlation with the onshore stratigraphic data. Both areas show a sedimentary fill with a shallowing trend. Inmediately over the basement reflector, correlated to the Nicoya Complex, the seismic sequences are interpreted as pelagic deposits. Overlying these deposits, thick seismic facies are interpreted as turbitic wedges and deep water fan deposits. The basin is fulfilled by a succession interpreted as shallow marine sediments, deposited on shelf and coastal environments.

Typical shear faults in a transtensional regime are the main characteristic of the structure in the shelf basins of the central Pacific of Costa Rica. The half graben configuration of the main depocenters seems to have developed since Middle Eocene, according to the tentative age of main unconformities mapped in the offshore region. These depocenters include sedimentary sequences characteristic of slope and shelf deposits in a shallowing upward megasequence.

The structure and configuration of these depocenters is believed to have been controlled by strike-slip motion along major tectonic features, one of which is known as Costa Rica Transcurrent Fault Zone.

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