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THE ENCHOVA PALEOCANYON (CAMPOS BASIN - BRAZIL): ITS OLIGOCENE-MIOCENE HISTORY BASED ON CALCAREOUS NANNOPLANKTON STRATIGRAPHY AND SEISMOSTRATIGRAPHY

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ABSTRACT The Enchova paleocanyon, located at the southeastern portion of Campos Basin, has had its sedimentary history investigated in detail through biostratigraphic analysis of calcareous nannofossil contents, electrical logs, and tracing the most significant seismic features. Integration of these data led us to conclude that the paleocanyon was carved during a meaningful erosive episode by the Late Oligocene, after deposition of the *Sphenolithus ciperoensis* Zone (N-540) approximately 24 Ma ago. The terrigenous sediments of the *Helicoponthosphaera recta* Zone (N-545) of Early Miocene age, filled up the paleocanyon during a relatively short-lived event of 1 Ma, geologically speaking. The tertiary section carved by the paleocanyon, of Middle-Eocene/Late Oligocene age, shows two other erosive episodes: one at the top of the *Micrantholithus procerus* Zone (N-460) of Late Eocene age, and another at the uppermost *Reticulofenestra umbilica* Zone (N-510) Early Oligocene in age. Probably, the Early Oligocene episode gave rise to a paleocanyon, this preceding that of Enchova. The obtained data allowed the construction of a qualitative curve of sea level fluctuations for the Oligocene and Early Miocene. Comparison with Vail's global curve of eustatic variations evidence some similarities as well as some contrasts.

RESUMO O PALEOCÂNION DE ENCHOVA (BACIA DE CAMPOS - BRASIL): SUA HISTÓRIA OLIGO-MIOCÊNICA BASEADA EM BIOESTRATIGRAFIA (NANOFÓSSEIS CALCÁRIOS) E SISMOESTRATIGRAFIA. O paleocânion de Enchova, localizado na porção sudeste da Bacia de Campos, teve sua história sedimentar detalhadamente investigada a partir de informações bioestratigráficas (nanofósseis calcários), de perfis elétricos de poços e de seções sísmicas. Com a integração dessas ferramentas geológicas, chegou-se à conclusão de que esta importante feição paleofisiográfica foi formada com a atuação de um evento erosivo ocorrido ao término do Oligoceno, após a deposição da Zona *Sphenolithus ciperoensis* (N-540) (24 Ma). Seu total preenchimento deu-se concomitantemente à sedimentação da Zona *Helicopontosphaera recta* (N-545) de idade eomiocênica e abrangeu aproximadamente 1 Ma. Na seção terciária (Mesoeoceno-Neoligoceno), abaixo da superfície do paleocânion, dois outros níveis de descontinuidades erosivas foram detectados: situam-se nos topos das biozonas *Micrantholithus procerus* (N-460, Neoeoceno) e *Reticulofenestra umbilica* (N-510, Eooligoceno). Provavelmente, o episódio eooligocênico deu origem a um paleocânion precedente ao de Enchova. Com base nas informações obtidas, esboçou-se, qualitativamente, uma curva de oscilações do nível marinho durante o Oligoceno e o início do Mioceno. Quando comparada com a curva global de variações eustáticas (curva de Vail), verificam-se algumas semelhanças e alguns contrastes.

INTRODUCTION The submarine canyons are important geologic features which occur along continental shelves all over the world. The hypotheses trying to explain their origin are innumerous, those related with the gravity flows bling the most acceptable ones by the scientific community (Shepard 1981, May *et al* 1983). When the sea level is relatively low, erosive processes become more effective and cause shelf sediments to move into deeper portions of the basin, giving rise to canyon excavation. Since then, canyons become the main route through which costal sediments reach distal marine environments.

The main goal of the present investigation is to ascertain the Oligo-Miocene sedimentary history of the Enchova paleocanyon, a feature approximately 200 km^2 in area, located in the SE portion of the Campos Basin (Figs. 1 and 2). This is

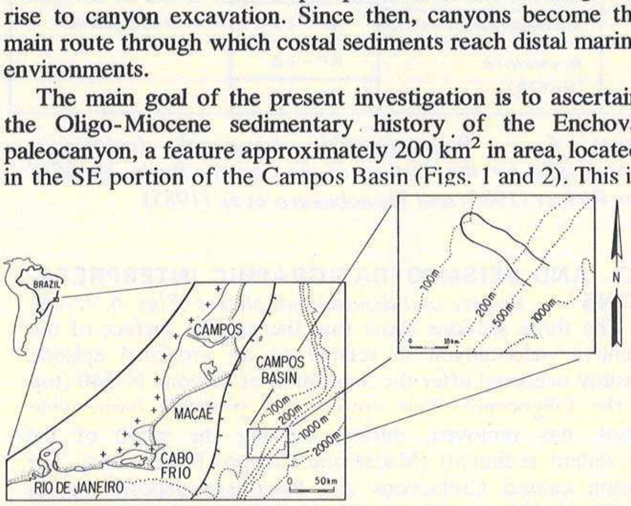

Figure 1 – Situation MAP

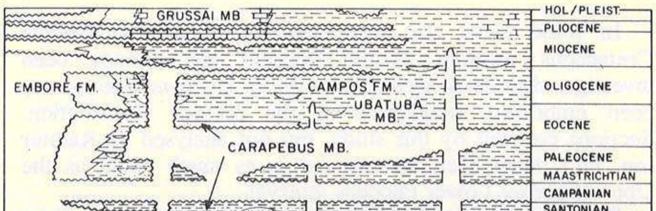

Figure 2 – Stratigraphic column, Campos Basin

a detailed study with the purpose of integrating and correlating the information from the Biostratigraphy (calcareous nannofossils), Seismology, and Geology (electrical profiles).

PREVIOUS WORKS The Campos Basin is very rich in respect to geological investigations. Previous work on the subject includes reports by Tessari *et al.* (1978), Figueiredo *et al.* (1983), Meister (1984), Guardado & Arso (1985), Richter

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(1985), Gambôa *et al.* (1986), Dias-Brito & Azevedo (1986), and Azevedo *et al.* (1987). However, none of the above mentioned investigations concern the geologic history of the Enchova paleocanyon.

On the other hand, Sonoki (1987), in his recent master's degree dissertation, has studied the evolution of this important geological feature based on Seismostratigraphy.

METHODOLOGY The inital step is the biostratigraphic analysis of the nannofossils contents of 28 exploratory wells, located in different strategic positions (Fig. 3). During this period, 750 slides made out of cutting samples, side-wall corings, and core samples have been investigated. Analyses were made for every 30 m interval. Emphasis was given in the biostratigraphic analysis of the Upper Eocene-Lower Pliocene interval.

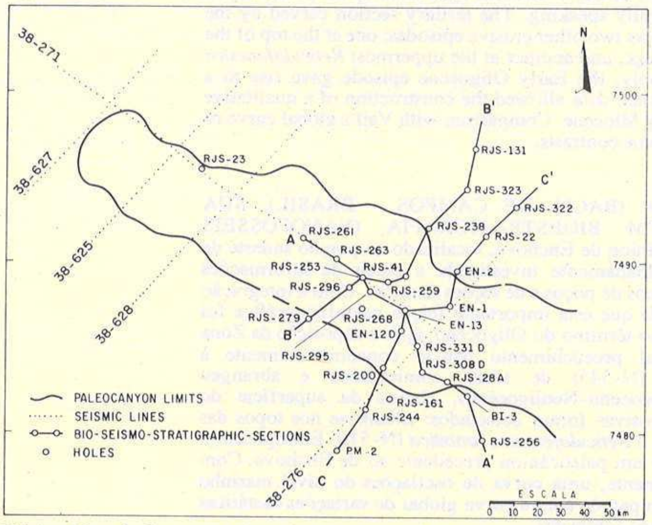


Figure 3 – Index map showing location of holes, sections, and seismic lines

In some wells, the lower part of the column (Middle Cretaceous through Middle Eocene) had already been investigated in detail by Richter (1985). His conclusions have been embodied unmodified in the present contribution. Sections covered by this study, but not analysed by Richter (*op. cit.*), have been investigated in as much detail as the Upper Eocene/ Lower Pliocene interval.

Following the establishment of the Cretaceous-Tertiary biostratigraphic framework of the area, this was compared with preliminary correlate sections obtained by combining both seismostratigraphic and electrical log data. Next, it was initiated the second and most important phase of the study: tracing of biozones in seismic charts and the identification of equivalences between bio- and seismostratigraphic horizons. During this phase, attention was paid to the hiatuses recognized through biostratigraphy and their relationships to possible unconformity levels.

Once the mapping of the paleocanyon boundaries was concluded, three bioseismiostratigraphic sections (two transverse and one approximately parallel to the axis of the paleocanyon) were constructed, in order to give a better picture of the observed geological features (Figs. 6, 7, and 8).

A chronostratigraphic chart and a geochronologic section, which coincides with the seismic line 38-276 (Fig. 10), have also been prepared (Figs. 11 and 12). Among other information they provide an estimate of the duration of the hiatuses observed in various parts of the section, as well as the approximate age of the erosive events. The methodology suggested by Van Hinte (1982) was employed in constructing the charts.

BIOSTRATIGRAPHY The studies of Troelsen & Quadros (1971), Shimabukuro *et al.* (1985), Richter (1985, 1987), and Azevedo et *al.* (1987) have provided data for the biostratigraphic zonation of the investigated wells. The integration of these works offers a relatively detailed biostratigraphic framework for the of the whole marine section of the Campos Basin, based upon nannofossils. Figures 4 and 5 show the correlation between Tertiary biozones adapted herein and the international zonation proposed by Martini (1971), as well as the geochronological scale presented by Vail *et al.* (1977).

Ma	BIOZONES	INTERNATIONAL ZONES (MARTINI, 1971)	AGE
	G. oceanica (N-720)	NN-21	HOLOCENE PLEISTOCENE
		NN-20	
		NN-19	
1.8	*D. brouweri* (N-670)	NN-18	PLIOCENE
		NN-17	
		NN-16	
3.2	*R. pseudoumbilica* (N-650)	NN-15	
		NN-14	
		NN-13	
		NN-12	MIOCENE
6.0	*D. quinqueramus* (N-640)	NN-11	
		NN-10	
11.0	*D. hamatus / Micrantholithus* spp. (N-630)	NN-9	
		NN-8	
		NN-7	
13.0	*C. floridanus* (N-590)	NN-6	
13.2	*S. heteromorphus* (N-580)	NN-5	
14.4	*H. ampliaperta* (N-570)	NN-4	
17.5	*S. belemnos* (N-560)	NN-3	
19.0	*T. carinatus* (N-550)	NN-2	
22.5	*H. recta* (N-545)	NN-1	
24.0	*S. ciperoensis* (N-540)	NP-25	OLIGOCENE
27.0	*S. predistentus* (N-530)	NP-24	
29.0	*S. pseudoradians* (N-510)	NP-23	
34.0	*R. umbilica* (N-510)	NP-22	
		NP-21	

Figure 4 – Biostratigraphic framework (calcareous nannofossils) for the Tertiary of the Campos Basin. Modified from Richter (1985) and Shimabukuro et al. *(1985)*

BIO- AND SEISMOSTRATIGRAPHIC INTERPRETATIONS *Erosive and depositional phases (Figs. 6, 7, and 8).* The three sections show that the present surface of the Enchova paleocanyon is related to an erosional episode possibly occurred after the deposition of biozone N-540 (top of the Oligocene). This episode, of probable basin wide extent, has removed, during, carving the much of the preexistent sediments (Macaé and Campos Formations). The erosion caused Cretaceous and Paleogene deposits (zones N-320, N-450, N-460, N-470, N-510, and N-530) to crop out again in the oceanic bottom.

The filling of the canyon occurred rapidly in the Early Miocene with the deposition of biozone N-545. Much of

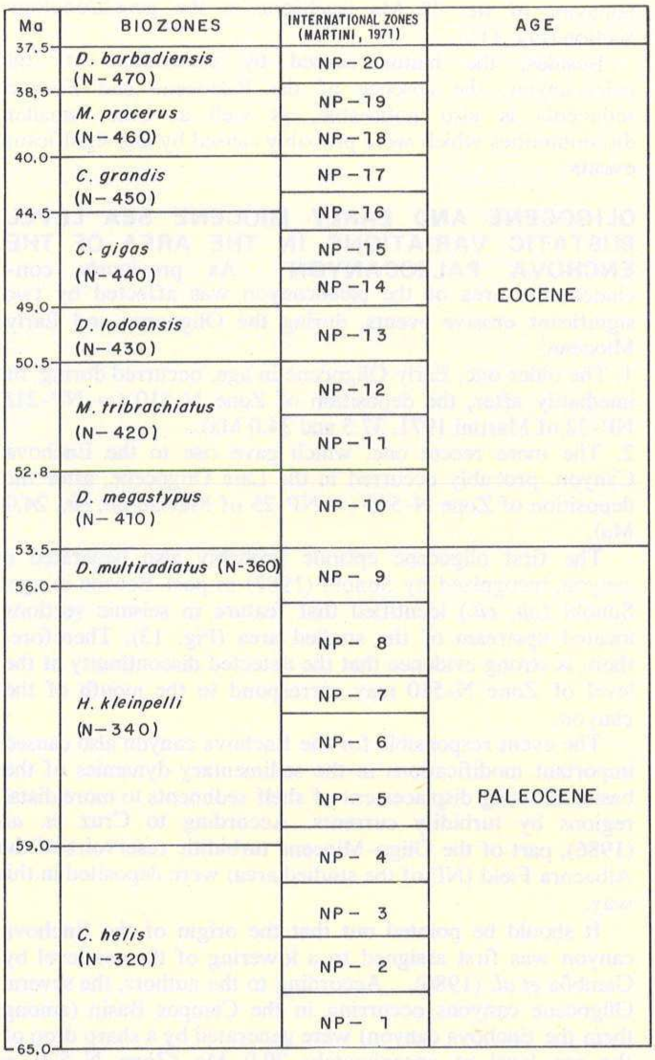


Figure 5 – Biostratigraphic framework (calcareous nannofossils) for the Tertiary of the Campos Basin. Modified from Richter 1985

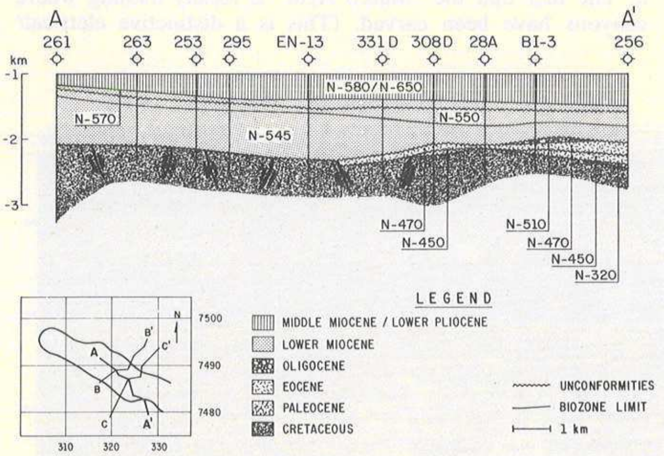


Figure 6 – Bio– seismostratigraphic section A - A'

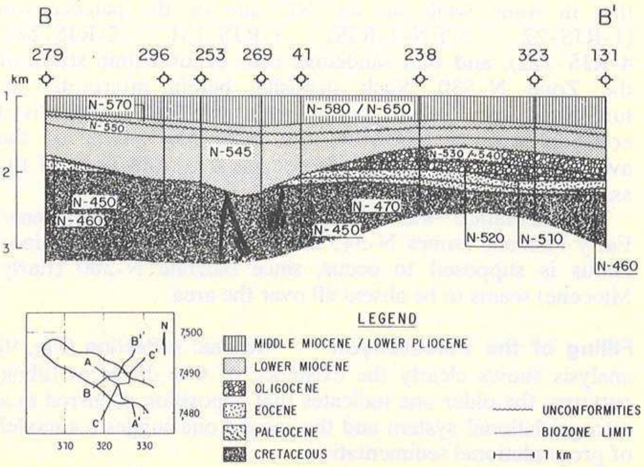


Figure 7 – Bio– seismostratigraphic Section B – B'

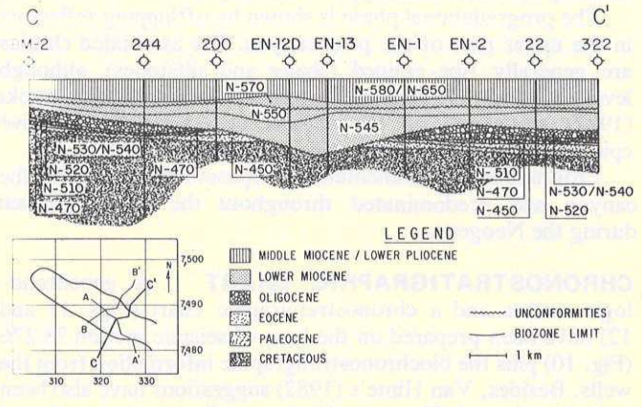


Figure 8 – Bio– seismostratigraphic section C – C'

clastics which filled up the trough are reworked basinal materials, as shown by frequent nannofossil reworking observed in biostratigraphic analysis. Cretaceous and Paleogene distinctive species are often recorded along with Early Miocene assemblages.

Other levels of erosional discontinuities were also detected below and above the surface of the paleocanyon, some of which already pointed out by Richter (1985). The oldest one is indicated by the extreme rarity of the Paleocene sediments. In three sections, Eocene sediments are observed to rest directly on Cretaceous ones. An exception is found in well 4-RJS-256 (section A-A') where a thin layer of Paleocene clastics is present. This unconformity, associated with a pre-Middle Eocene erosional event, occurs throughout the Campos Basin and was the subject of an accurate biostratigraphic study by Richter (*op. cit.*).

Another unconformity is detected in the Eocene strata, as indicated by the absence of zone N-460 (Late Eocene) in much of the area. The scarce sedimentary record of this biozone (1-RJS-131 and 3-RJS-279, section B-B') suggests that an erosional episode was in effect during, or immediately after, deposition.

Absence of Zone N-510 (Early Oligocene) in some of the investigated wells is also indicative of a still older erosional event (the first of the Oligocene). This episode was probably responsible for the carving of a canyon before that of the Enchova Canyon, upstream of the studied area. It was first recognized in an interpreted seismic section by Sonoki (1987), who, in face of the lack of conclusive information, could only assign a post-Eocene age for the excavation of the canyon.

Following this basal Early Oligocene erosional event, apparently continuons deposition gave rise to biozones N-520, N-530, N-540 all belonging to the Oligocene. These biozones occur throughout the area, except in localities of deeper trough exacavation. It should be emphasized, however, that in some wells on the NE side of the paleocanyon (1-RJS-22, 3-EN-1-RJS, 1-RJS-131, 2-RJS-244, 4-RJS-322), and thin sandstone beds occur within strata of the Zone N-530. Such deposits, herein interpreted as turbidites, may result from small amplitude, short-lived erosional events. However, the resolution power of the available biostratigraphy does not allow confirmation of the associated discontinuities.

Sedimentation was mostly continuous in the Miocene/ Early Pliocene (zones N-545 and N-650). However, a minor hiatus is supposed to occur, since biozone N-560 (Early Miocene) seems to be absent all over the area.

Filling of the Paleocanyon Seismic reflection (Fig. 9) analysis shows clearly the existence of two different filling patterns: the older one indicates that deposition occurred in a retrogradational system and the second one suggests a model of progradational sedimentation.

Retrogradational sedimentation, evidenced by configuration of onlapping reflectors at the base of the paleocanyon, includes predominantly coarse clastics which make up the basal diamictites of the canyon.

The progradational phase is shown by offlapping reflectors in the upper part of the paleocanyon. The associated clastics are generally fine-grained (shales and siltstones), although levels of sandstone may occur in most distal portions. Sonoki (1987) comments on the occurrence of rapid successive episodes of erosion and deposition during this phase.

Progradational sedimentation surpassed the limits of the canyon and predominated throughout the Campos Basin during the Neogene.

CHRONOSTRATIGRAPHIC CHART A geochronologic section and a chronostratigraphic chart (Figs. 11 and 12) have been prepared on the base of seismic section 38.276 (Fig. 10) plus the biochronostratigraphic information from the wells. Besides, Van Hinte's (1982) suggestions have also been partially adopted. These are fundamentally based on ratios of sedimentation calculated from the relation thickness *versus* time of deposition of the biozones.

Figures 11 and 12 illustrate well the observed discontinuities and the magnitude of associated hiatuses in each part of the section. Such data allow one to estimate the age of paleocanyon excavation as approximately 24.0 Ma, probbaly after deposition of Zone N-540. The canyon was filled up within approximately 1 Ma, as suggested by the behavior of the 23 Ma isochrone in the geochronologic section (Fig. 11).

Besides, the hiatus caused by excavations of the paleocanyon, the absence of the Paleocene and Eocene sediments is also noticeable, as well as other smaller discontinuities which were probably caused by less significant events.

OLIGOCENE AND EARLY MIOCENE SEA LEVEL EUSTATIC VARIATIONS IN THE AREA OF THE ENCHOVA PALEOCANYON As previously concluded, the area of the paleocanyon was affected by two significant erosive events, during the Oligocene and Early Miocene:

1. The older one, Early Oligocene in age, occurred during, or imediatily after, the deposition of Zone N-510 (= NP-21/ NP-22 of Martini 1971, 37.5 and 34.0 Ma).
2. The more recent one, which gave rise to the Enchova Canyon, probably occurred in the Late Oligocene, after the deposition of Zone N-540 (= NP-25 of Martini *op. cit.*, 24.0 Ma).

The first oligocene episode probably also generated a canyon, recognized by Sonoki (1987) as post-Eocene in age. Sonoki (*op. cit.*) identified that feature in seismic sections located upstream of the studied area (Fig. 13). Therefore, there is strong evidence that the detected discontinuity at the level of Zone N-510 may correspond to the mouth of the canyon.

The event responsible for the Enchova canyon also caused important modifications in the sedimentary dynamics of the basin, allowing displacement of shelf sediments to more distal regions by turbidity currents. According to Cruz *et. al.* (1986), part of the Oligo-Miocene turbiditic reservoirs of the Albacora Field (NE of the studied area) were deposited in this way.

It should be pointed out that the origin of the Enchova canyon was first assigned to a lowering of the sea level by Gambôa *et al.* (1986). According to the authors, the several Oligocene canyons occurring in the Campos Basin (among them the Enchova canyon) were generated by a sharp drop of the sea level at aproximately 29.0 Ma (Zone N-520 = NP-23/NP-24, of Martini, 1971), as indicated in the well known Vail's curve (Haq *et al.* 1987, see Fig. 14). This interpretation was mainly based on two points:

a. The fact that the "Marco Azul" is locally missing where canyons have been carved. (This is a distinctive eletrical/

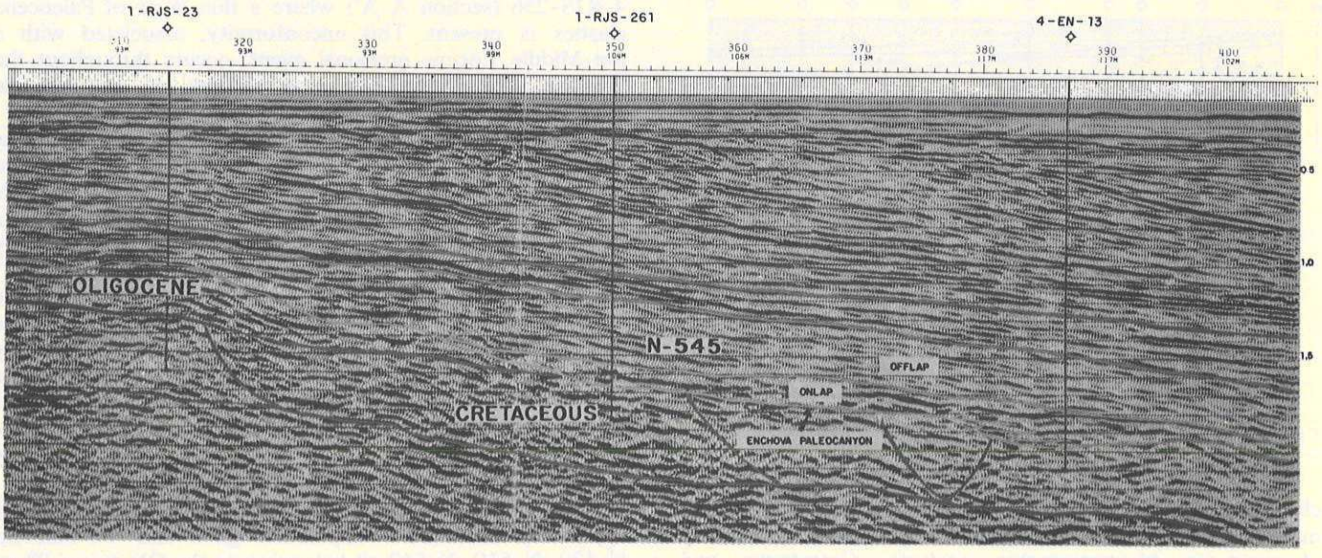


Figure 9 – Seismic Line 38-271. This section shows two different filling patterns of the Enchova Paleocanyon: onlap at the base and offlap in the upper portion

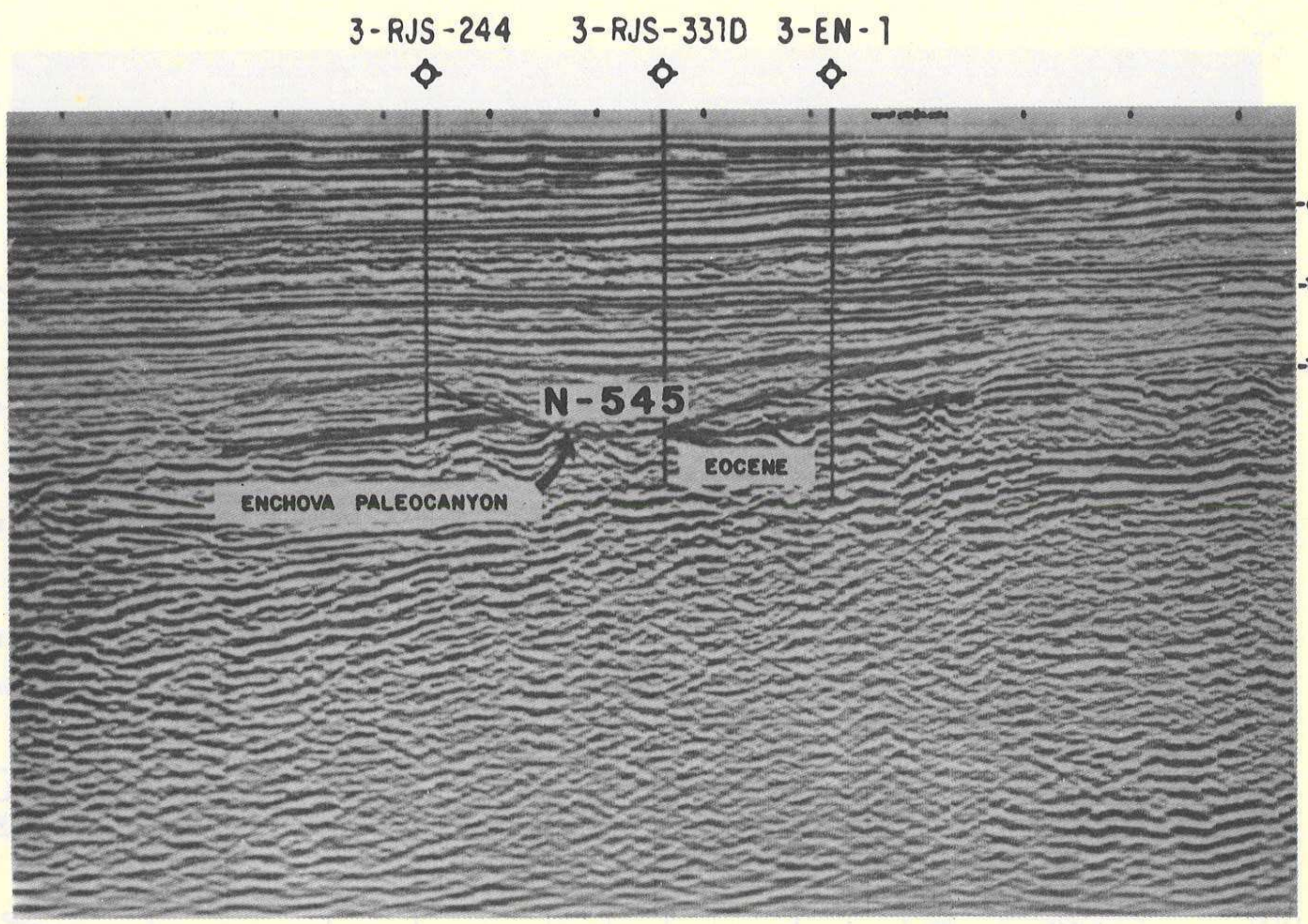


Figure 10 – Seismic Line 38-276 based on which the geochronologic section was constructed

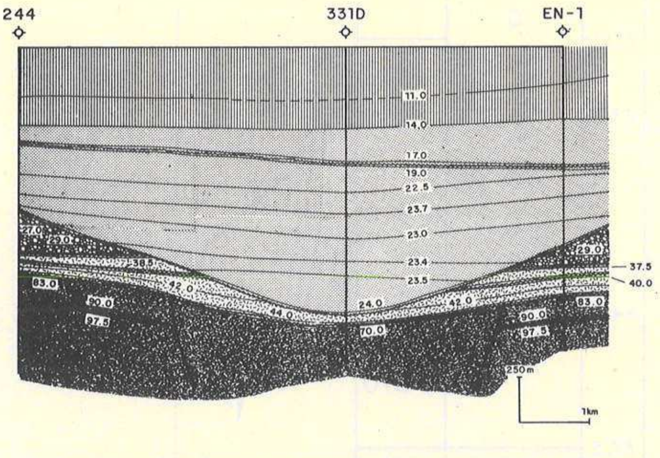


Figure 11 – Geochronologic section from section 38-276 base on biostratigraphic data (figures in million years)

seismic mark of the Campos Basin, interpreted as the graphic signature of calcilutites deposited under relatively high sea level, and regarded as approximately synchronous to the top of Zone N-520.);

b. The fact that the "Marco Azul" immediately underlies an extensive progradational wedge, the base of which is characterized by wide turbiditic fans.

However, according to the results of the present investigation, it can be clearly noticed that a significant time lag (around 5 Ma) exists between the event originating the Enchova paleocanyon and the drop of the sea level, which occurred 29 Ma ago. Therefore, the interpretation by

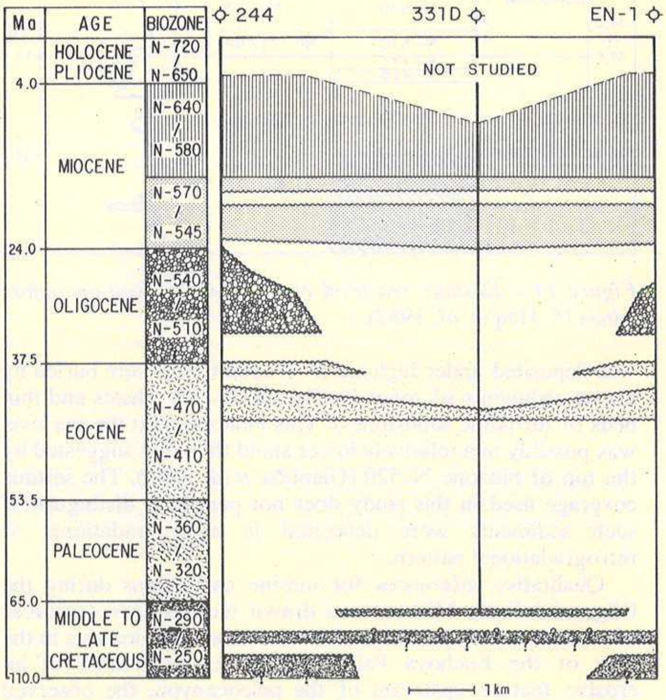


Figure 12 – Chronostratigraphic chart

Gambôa *et al.* (1986) is not completely supported by the new evidence.

On the other hand, this work reveals that the sediments of Zone N-520 (the upper portion of which, the "Marco Azul",

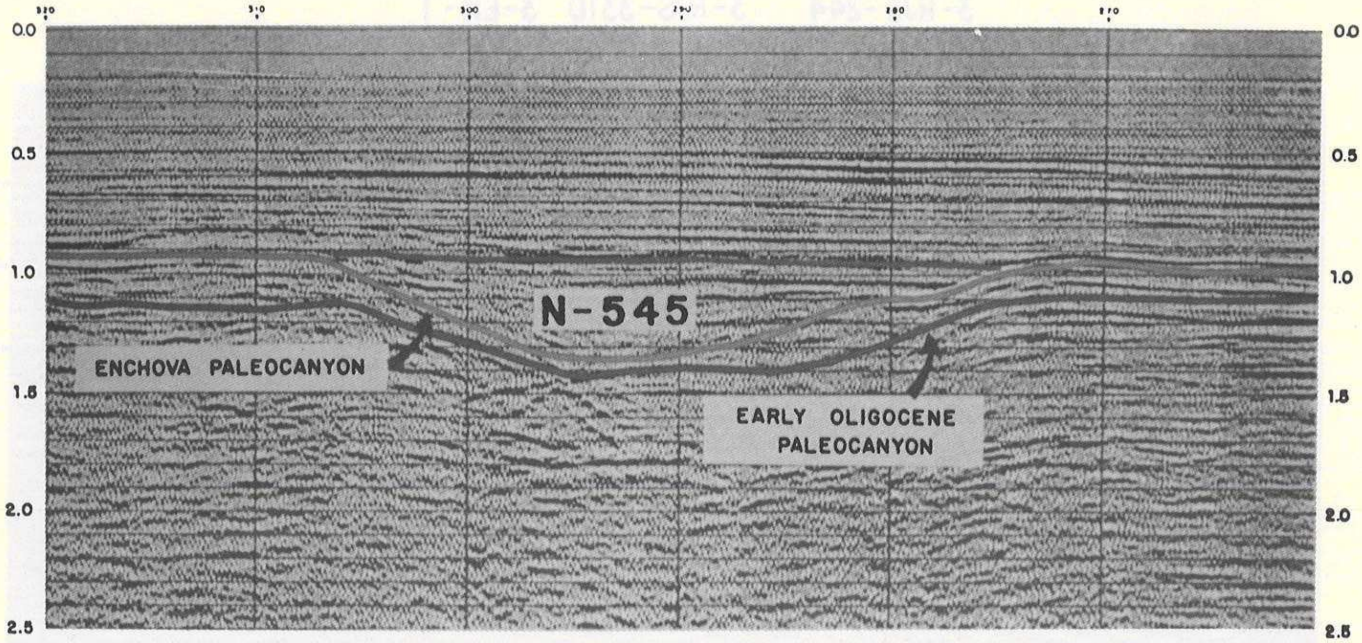


Figure 13 – Seismic Line 38-628. This section shows the Early Oligocene paleocanyon generated by the erosive event occurred after or during deposition of N-510 biozone

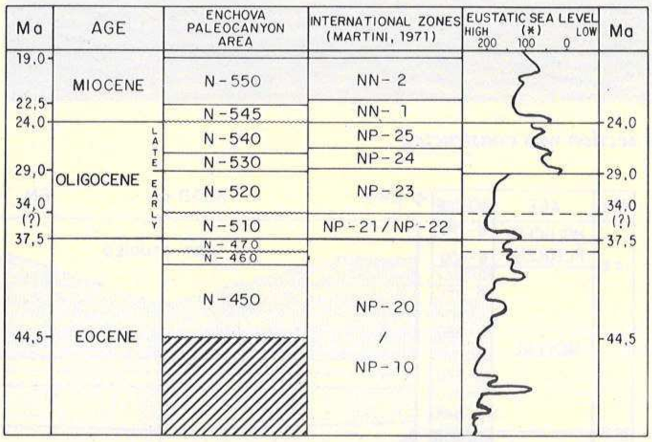
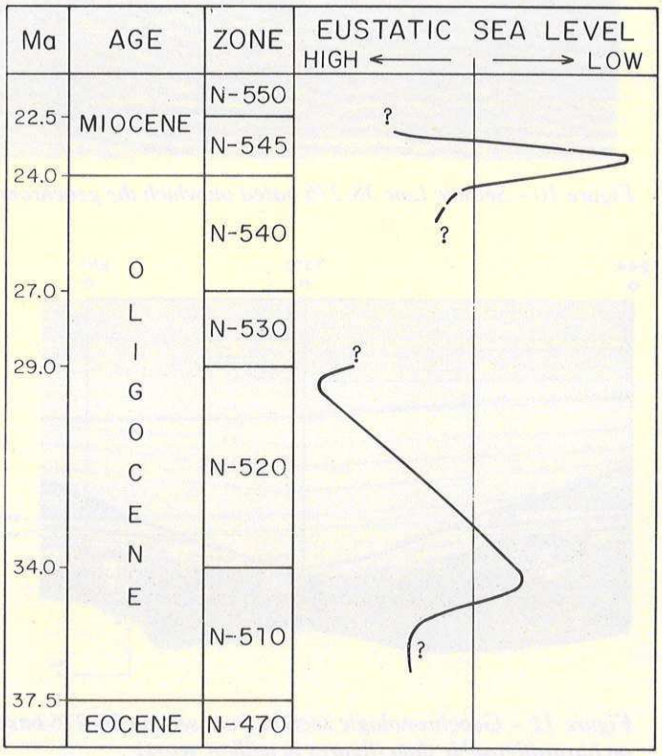


Figure 14 – Eustatic sea level curve and observed unconformities (* Haq *et. al.* 1987)

was deposited under high sea level conditions) were buried by clastic sediments of zones N-530 and N-540 (shales and thin beds of turbiditic sandstones). This indicates that the sea level was possibly in a relatively lower stand than that suggested by the top of biozone N-520 (Gambôa *et al.* 1986). The seismic coverage used in this study does not permit to distinguish if such sediments were deposited in a progradational or retrogradational pattern.

Qualitative inferences for marine oscillations during the Oligocene-Early Miocene are drawn from different sources of evidence, such as: the sequence of observed biozones in the area of the Enchova Paleocanyon; the recognition of an erosive feature upstream of the paleocanyon; the observed fact that the top of Zone N-520 has been deposited in deep marine environment (Gambôa *et al.* 1986); the hypothesis of a relatively lower sea level stand during deposition of biozones N-530 and N-540; and, finally, the later dating of carving and filling up events of the Enchova Paleocanyon. All this lead to the recognition of the following pattern of sea level oscilation (Fig. 15):



QUALITATIVE CURVE OF SEA LEVEL CHANGES

Figure 15 – Enchova Paleocanyon area, Campos Basin

• after the lowering that generated the canyon in the earliest Oligocene (Zone N-510), the sea level rose continuously during the remainder of the Early Oligocene. Probably by the end of the sedimentation of Zone N-520, the sea reached its highest stand as indicated by the "Marco Azul". This was followed by a regressive period, suggested by clastic sedimentation of biozones N-530 and N-540. However, the inception of this phase is difficult to estimate in the studied area, because no bio- and/or seismostratigraphic discontinuities have been detected; it is only hardly indicated by ceasing of a deep-sea "starving" condition due to arrival of clastics;

• by the close of the Oligocene (Zone N-540), the rate of sea-level lowering was probably greatly increased: at this time the Enchova Canyon was formed and the sea reached a very receded position;

• at the earliest Miocene, the sea level rises again at a very high rate, causing sudden drawning of the system and the rapid filling of the Enchova Canyon by the clastics of zone N-545 (duration of 1 Ma).

EUSTATIC VARIATION CURVE FOR THE ENCHOVA PALEOCANYON AREA *VERSUS* VAIL'S CURVE

In spite of the qualitative nature and lack of continuity of the eustatic variation curve inferred for the Enchova Paleocanyon (Fig. 15), it is possible to compare it with the most recent version of the Vail's curve (Haq *et al.* 1987, Fig. 14).

Similarities The basal Early Oligocene lowering suggested here apparently corresponds with the lowering indicated in the Vail's curve at the Eocene/Oligocene boundary. However, a chronologic disparity may occur between both, which can not be measured; it is only inferred that the earliest Oligocene sea-level lowering occurred during or immediately after the deposition of Zone N-510 (37.5 to 34.0 Ma).

Following the basal Early Oligocene event, the two curves show that sea level remained in a relatively high stand. Vail's curve, however, indicates a slight lowering; if this occurred indeed in the area of Enchova Paleocanyon, no remarkable discontinuities were generated that point out to such event. According to Haq *et al.* (*op. cit.*) lowerings of this sort tend to promate erosion of emergent areas (unconformities type 2).

The lowering that gave rise to the Enchova canyon is also represented in global curve of the eustatic variations as an event of medium to small magnitude. However, available evidence indicates that the lowering affected considerably the sedimentary evolution of the Campos Basin.

The sea-level behavior in the Early Neogene is very similar in both curves; Vail's curve shows an abrupt rise of the sea level in the beginning of the Early Miocene, that is also corroborated in the present study.

Contrasts The greatest contrast observed in the comparison of the two discussed curves is related to the Late Oligocene interval.

Vail's curve indicates three sea level drops for this period, among which the oldest one can be distinguished by its greatest lowering magnitude. On the other hand, the curve sketched for the Enchova paleocanyon area does not present inferences related to the sea level behavior for the Late Oligocene.

In wells drilled through Oligocene sediments (zones N-520, N-530, and N-540), it is clearly noticed that the deposition was continuous, as far as the resolution power of the zonation used is concerned (average about 2 to 3 Ma). Within biozone N-530, however, thin sandstone strata are observed (probably turbidites), which may reflect short-term sea-level drops.

The seismic coverage used in the area is not appropriate for the recognition of eventual unconformities in the Late Oligocene strata: dip lines are absent on either sides of the paleocanyon, whereas other lines in strike position were interpreted only in the neighborhood of the feature.

Due to lack of conclusive information, qualitative inferences concerning sea-level behavior during the Late Oligocene should preferably avoided.

If the Late Oligocene eustatic oscilations postulated by Vail's curve were effective in the Campos Basin, the behavior of the sea level must have varied accordingly: the subsequent rise and the return to depositional processes after each fall were likewise very rapid. In other areas of the basin, however, situations may occur in which the ages of the recognized discontinuites are compatible with those of the lowerings indicated in the global eustatic variation curve.

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Só se pode verdadeiramente *conhecer* e *explicar* quando se reduzem as intuições a uma apreciação exata dos fatos e das suas conexões lógicas. Um investigador honesto terá de admitir que nem sempre é possível uma tal redução, mas será desonesto da sua parte não ter isto sempre presente no espírito.

C.G. Jung, 1964, O homem e seus símbolos, p. 92