# Oligo-Miocene transgression along the Pacific margin of South America : new paleontological and geological evidence from the Pisco basin (Peru)

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**Abstract :** *Diagnostic species of fossil diatoms (genus* Bogorovia, Triceratium, Thalassiosira*) and molluscans (genus* Pitar, Cucullaea, Peruchilus*) demonstrate the presence of a late Oligocene-early Miocene sedimentary unit in the Pisco basin, south-central Peru. The transgressive basal facies of this unit unconformably overlap older rocks, upward the unit shows subsident shelf conditions. This transgression took place after a compressional tectonic event which had affected the region by late Oligocene. These data, and data from other places in western South America, indicate that the late Oligocene-early Miocene was a transgressive period along this continental margin. These phenomena appear associated to (1) a global change in plate kinematics reflected by an increase of the convergence rate between the Nazca and South American plates and (2) a global rise of oceanic temperatures ; factors which could have favoured a sea-level rise. The amplitude of this transgression is variable along the margin which shows segments with different rates of subsidence : the northern and southern Andean segments display a mainly subsident character, whereas the central Andean margin exhibits a dominant tendency to uplift. Our data confirm that the central Peru segment is characterized by subsidence and constitutes an exception within the central Andean forearc. This characteristic is thought to be related to the presence of dense mantle material within the central-Peru forearc crust.*

**Key words :** Peru - Pisco - Andes - Sedimentary basin - Transgression - Caballas Formation - Tertiary - Late Oligocene - Early Miocene - Diatoms - Molluscans -Stratigraphy - Forearc - Marine facies - Tectonics - Subsidence - Eustatism.

**Résumé : Transgression oligo-miocène de la marge pacifique de l'Amérique du Sud : nouvelles données paléontologiques et géologiques provenant du Bassin Pisco (Pérou).** *Des espèces caractéristiques de diatomées (genres* Bogorovia, Triceratium, Thalassiosira*) et de mollusques (genres* Pitar, Cucullaea, Peruchilus*) fossiles démontrent la présence d'une unité sédimentaire d'âge Oligocène supérieur-Miocène inférieur dans le bassin de Pisco (Pérou sud-central). Les séquences de base de cette unité sont transgressives et reposent en discordance sur les terrains plus anciens ; dans la partie supérieure la série évolue vers des faciès de plate-forme subsidente. Cette transgression est postérieure aux déformations compressives qui ont affecté la région à la fin de l'Oligocène. Ces informations, ainsi que des données provenant d'autres localités de la côte occidentale de l'Amérique du Sud, indiquent que l'intervalle de temps Oligocène supérieur-Miocène inférieur correspond à une période transgressive le long de cette marge continentale. Ces phénomènes paraissent associés (1) à un changement global dans la cinématique des plaques qui se traduit par une*

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*augmentation de la vitesse de convergence entre les plaques Nazca et Amérique du Sud, et (2) à une élévation globale de la température des océans, ces deux facteurs ont pu favoriser une montée du niveau de la mer. L'amplitude de cette transgression est variable le long de la marge qui présente des segments dont les taux de subsidence diffèrent. Ainsi, les segments situés au nord et au sud des Andes sont principalement subsidents, tandis que la marge centrale des Andes présente une nette tendance au soulèvement. Nos données confirment que le segment du Pérou central est caractérisé par une tendance à la subsidence et constitue une exception par rapport au caractère général du fore-arc des Andes centrales. Cette caractéristique semble liée à la présence, dans la croûte de ce fore-arc, de matériel dense d'origine mantellique.*

**Mots-clés :** Pérou - Pisco - Andes - Bassin sédimentaire - Transgression - Formation Caballas - Tertiaire - Oligocène supérieur - Miocène inférieur - Diatomées - Mollusques - Stratigraphie - Fore-arc - Faciès marins - Tectonique - Subsidence - Eustatisme.

***Resumen :*** **Transgresión oligo-mioceno de la margen del Pacifico en America del Sur : nuevos conocimientos paleontológicos y geológicos provinientes de la cuenca Pisco (Perú).** *Especies caracteristicas de diatomeas (gén.* Bogorovia, Triceratium, Thalassiosira*) y moluscos (gén.* Pitar, Cucullaea, Peruchilus*) fósiles demuestran la presencia de una unidad sedimentaria de edad Oligoceno superior-Mioceno inferior en la cuenca de Pisco (Perú sud-central). Las facies basales de esta unidad son transgresivas y translapan discordantemente terrenos más antiguos, luego las facies evolucionan a las de una plataforma subsidente. Esta transgresión avanzo al interior del continente luego de una fase tectónica que afecto la región a fines del Oligoceno. Estos datos junto con aquellos de otros puntos de la costa occidental de Sudamerica indican una época transgresiva a lo largo de esta margen continental durante el periodo Oligoceno superior-Mioceno inferior. Estos fenómenos aparecen asociados a (1) un cambio global en la cinemática de placas que se traduce por el aumento de la velocidad de convergencia entre las placas de Nazca y Sudamericana y (2) un aumento global de la temperatura oceánica ; factores ambos que pueden haber favorecido una subida del nivel del mar. La amplitud de esta transgresion es variable a lo largo de la margen, la cual muestra segmentos con diferentes magnitudes de subsidencia. Así, el forearc en los Andes del Norte y del Sur tiene un caracter básicamente subsidente, mientras que aquel de los Andes centrales muestra una fuerte tendencia al levantamiento. Nuestros datos confirman que en este último segmento, la parte correspondiente al Perú central es anomala pues esta caracterizada por una tendencia al hundimiento. Esta característica se supone relacionada con la presencia de materiales densos de origen mantélico en la corteza de dicha margen del Perú central.*

**Palabras claves :** Perú - Pisco - Andes - Cuenca sedimentaria - Transgresíon - Formación Caballas - Terciario - Oligoceno superior - Mioceno inferior - Diatomeas - Moluscos - Estratigrafía - Ante-arco - Facies marinas - Tectónica - Subsidencia - Eustatismo.

## INTRODUCTION

Several Cenozoic Pacific transgressions have been recognized along the western margin of South America (MARTINEZ, 1971 ; DUQUE CARO, 1976 ; BRISTOW & HOFFSTETTER, 1977 ; RAMOS, 1982 ; EVANS & WHITTAKER, 1982 ; MACHARÉ *et al.*, 1986). Those of late Eocene, middle-late Miocene and Pliocene age are known to be widespread. In addition, a late Oligocene-early Miocene transgressive event is well documented in Colombia, Ecuador and northernmost Peru and in the north-Patagonian basins of southern Chile and Argentina : however, it is yet very poorly documented in the Central Andes (5° to 41° S, fig. 1). The central Andean margin is characterized by a series of paired forearc basins separated from each other by a structural ridge roughly parallel to the plate boundary (THORNBURG & KULM, 1981 ; COULBOURN, 1981). In southern Peru and north-central Chile this ridge corresponds to the Coastal Cordillera ; and thus, the inner basins lie onshore. Conversely, in most of central Peru both inner and outer basins as well as the structural high lie entirely below sea level.

We have focused our research within the Pisco basin (fig. 2) near the hinge zone between the central Peru and the southern Peru-Chile segments. Owing to the arid climate and recent tectonic uplift, it offers good exposures of Tertiary marine deposits. The purpose of this paper is to present new stratigraphic data supporting the existence of a late Oligocene-early Miocene transgression in the Pisco basin. Their correlation with other recent data from the Central Andes demonstrates the widespread character of this late Oligocene-early Miocene transgression upon the Pacific margin of South America. Biostratigraphic correlations are based on the diatom zonation proposed by BARRON (1983) for the early Miocene of the eastern tropical Pacific, and molluscan records of Chile (PHILIPPI, 1887),

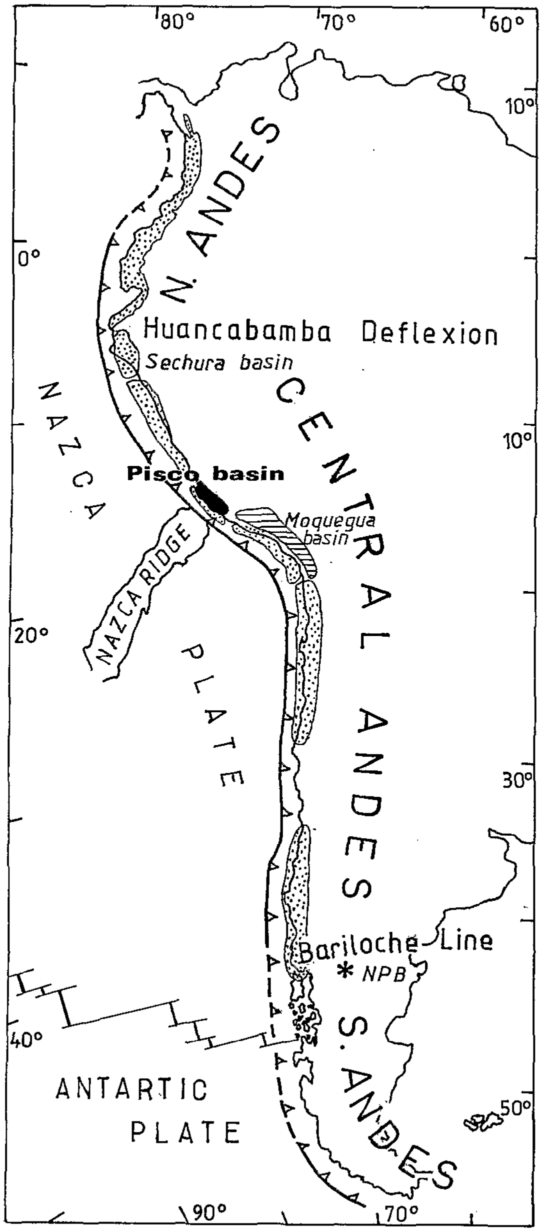


Fig. 1. — Map of western South America showing the three main segments of the Andean chain and the transversal features that separate each other. The solid jaugged line represents the oceanic trench, boundary between the continent and the subducting Nazca and Antartic plates. Stipple pattern indicate marine forearc basins. Pisco basin is in black. NPB : North Patagonian basins

northern Peru (OLSSON, 1931 and 1932), and southern Peru (PARDO, *in* PECHO & MORALES, 1969). Some of them have been controlled by foram-based ages (STAINFORTH, 1953 and 1955 ; WEISS, 1955 ; CRUZADO & SANZ, 1976 ; and ZUNIGA & CRUZADO, 1979).

## LATE OLIGOCENE-EARLY MIOCENE SECTIONS IN THE PISCO BASIN

The « East Pisco basin », named by THORNBURG & KULM (1981), is an inner basin situated between 13° and 15° 30′ S on the Peruvian coast (fig. 2). Unlike the inner basin (Moquegua basin) of southern Peru, which contains mostly continental volcanic and clastic deposits, the Pisco basin displays a well developed marine record, hence resembling more to basins of central Peru. The analysis of sedimentary facies of the basin indicates generally littoral to open shelf environments up to the late Tertiary. Emersion and uplift experienced by most of the basin during the Quaternary is thought to be related to the subduction of the aseismic Nazca Ridge (MACHARÉ *et al.*, 1986). The classical stratigraphy (PETERSEN, 1954) includes two distinct sedimentary cycles. The older one, represented by the Paracas and Arquillo formations, has yielded mollusks and benthic foraminifera from the late Eocene (NEWELL, 1956 ; RIVERA, 1957). The younger cycle, represented by the Pisco formation, was considered as middle to upper Miocene in age (PETERSEN, 1954 ; RÜEGG, 1956). Recent studies have extended the age of the Pisco formation into the Pliocene (de MUIZON & BELLON, 1980 ; de MUIZON & DEVRIES, 1985 ; FOURTANIER & MARCHARÉ, 1988). Thus, previous works suggested an early Oligocene to early Miocene hiatus.

Several partial sections have been integrated to obtain a composite stratigraphic column of the Oligo-Miocene unit. The position of uncomformities and the lateral facies variations are used to characterize the mode of transgression. The best exposures of Paleogene strata are found near the coast, whereas farther inland, Neogene and Quaternary deposits cover these older strata.

### **Salinas de Otuma — El monte section** (fig. 2, points, 1, 2)

Although the Tertiary formations were first described near the Pisco region, the stratigraphic and tectonic relations between them were never clearly established. At Salinas de Otuma (point 1, fig. 2), NEWELL (1956) described a 700 m section of tuffaceous sands and shales. He considered the basal 134 m to be Upper Eocene (i.e. Paracas formation) and the upper 566 m as undifferentiated Oligo-Miocene ; his poor stratigraphic precision is due to few diagnostic fossils. A finer correlation of this section (section 1, fig. 3) can be made on the basis of new paleontological data and structural considerations. The basal layers clearly belong to the Paracas formation ; however, an angular unconformity above the first 70 m of the section, though cited by NEWELL, appears to be a more important break than previously considered. Diatomaceous layers just above this unconformity were sampled to establish a minimun age to the tectonic and erosional event (sample 83111, section 2). The most stratigraphically significant diatom in this assemblage is *Bo-*

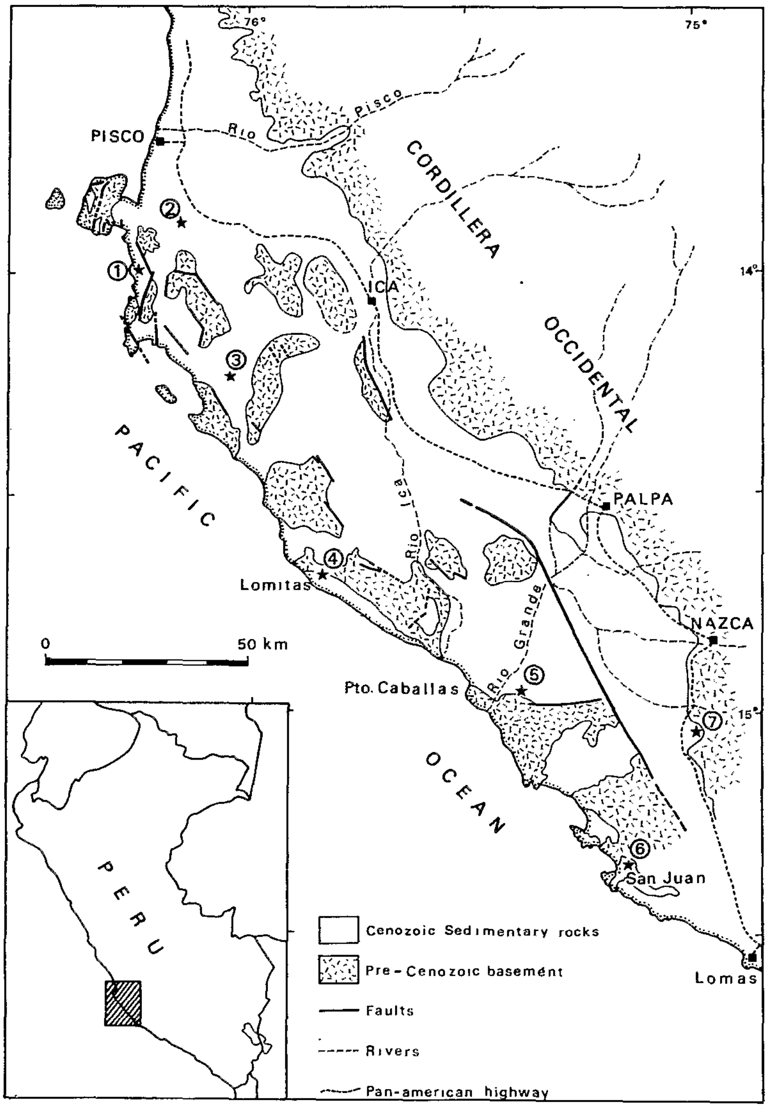


Fig. 2. — Geological sketch of the Pisco basin showing the studied sites as refered in the text (stars) : 1) Salinas de Otuma. 2) Punta Blanca-El Monte. 3) Pampa Chilcatay (4) Lomitas beach 5) Quebrada Huaricangana. 6) San Juan de Marcona. 7) Cerro Callejon de Piedra

*gorovia veniamini*, which ranges in the equatorial Pacific from the base of the *Bogorovia veniamini* Zone (ca. 26.5 Ma, latest Oligocene) to the top of the *Rossiella paleacea* Zone (ca. 19.6 Ma, early Miocene) (BARRON, 1985) (fig. 4). The presence of a form of *Cestodiscus* sp., observed in the lowermost Miocene of DSDP Site 71, as well as primitive forms of *Thalassionema nitzschioides* would favour an earliest Miocene age. This section, which is 150 m thick, is exposed in the area with very slight facies variations indicative of a continuous subsident shelf. A NNW-trending fault to the NE of Salinas de Otuma disrupts the continuity of this section (fig. 2), so that a small part of the sequence may be lost or repeated. The upper part of this section crops out between Punta Blanca and El Monte, 6 to 17 km NE of Salinas de Otuma (point 2, fig. 2). It is composed of some 220 m of siltstones and shales, with interbedded calcareous and tuffaceous layers, which represent gently subsident shelf conditions as in the lower part. Thin interca-

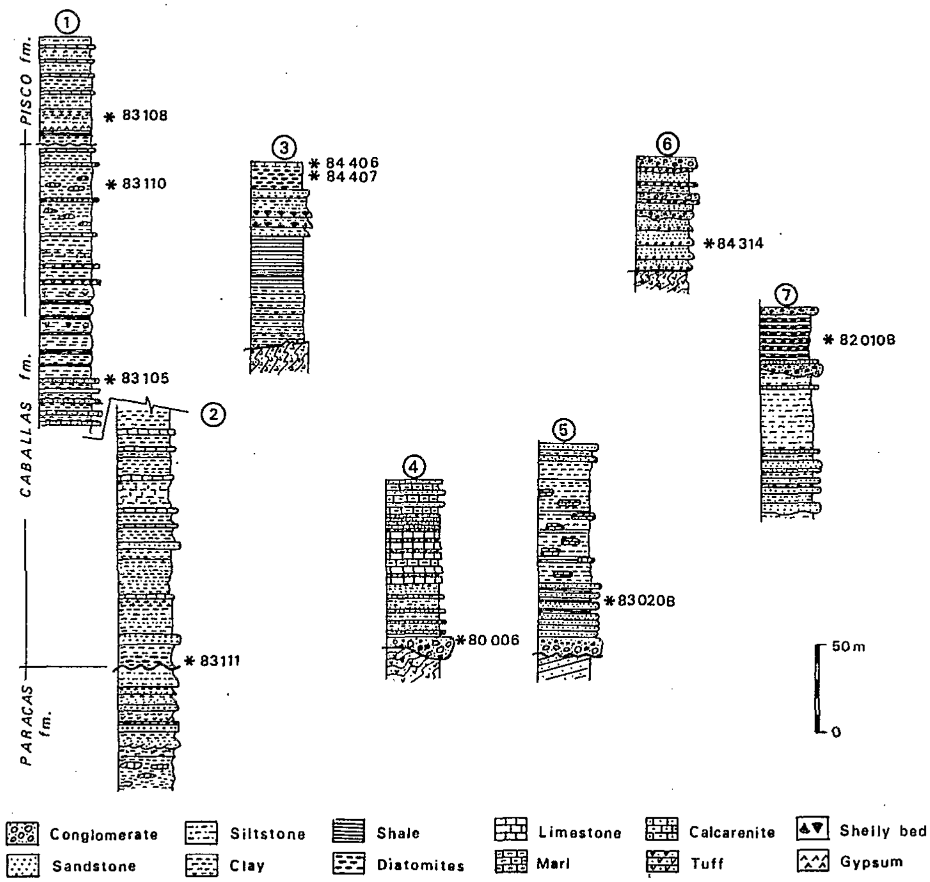


Fig. 3. — Stratigraphic logs of the late Oligocene-early Miocene sections in the Pisco basin (see figure 2 for locations). The numbered asterisks indicate paleontological samples

lations of calcarenites indicate temporary stades of shallower waters and yield an interesting molluscan suite (see section 1, fig. 3). *Pitar mancorensis*, which appears near the base of the section (sample 83105), is an inflated venerid (fig. 6, e) restricted to the late Oligocene Mancora formation of northern Peru (OLSSON, 1931). The transition to Miocene is marked by the appearence of *Dosinia delicatissima* (= *D. semilaevis ?*) in sample 83110. The age of the uppermost part of the section is more difficult to establish ; *Cucullaea* cf. *C. chilensis* which is present in sample 83110, has been reported from the Camana area of southern Peru (PARDO A. *in* PECHO & MORALES, 1969), where it was considered to be upper Miocene in age. However in its type area, *C. chilensis* PHILIPPI, 1887 occurs within late Oligocene-early Miocene strata (DEVRIES *et al., in press* ; in addition this sample contains an anadarid steinkern referable to *Anadara larkinii*, a late Miocene to early Pleistocene species (OLSSON, 1932 ; DEVRIES, 1985). Hence, these beds are situated near the boundary between the new Oligocene unit described here and the Pisco formation, which overlies with slight unconformity the older strata in this area.

## Pampa Chilcatay section (point 3, fig. 2)

Sometimes shelf facies rest directly upon the pre-Tertiary substratum, as observed in the Pampa Chilcatay area (point 3, fig. 2). There, Mesozoic volcanics are locally truncated by an erosional surface and directly overlain by a 100 m section, which begins with monotonous siltstones and shales, then grades upward into fine to medium-grained sandstones with cross bedding and bioclastic gravels. Diatomites, diatomaceous muds and calcareous siltstones cap the section. In sample 84407 (section 3) the occurrence of diatoms *Triceratium pileus*, *Thalassiosira fraga*, and *T. spinosa* allows correlation with the upper part of the *Craspedodiscus elegans* Zone through the *Triceratium pileus* Zone, so it can be assigned to the

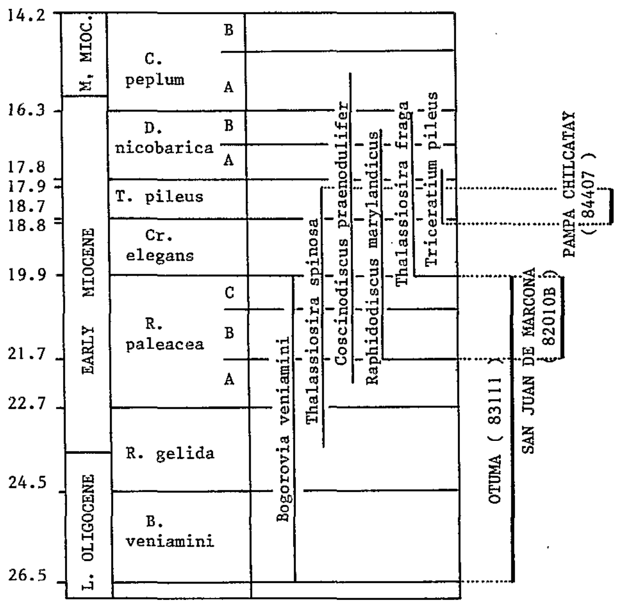


Fig. 4. — Age of Otuma, San Juan de Marcona and Pampa Chilcatay samples as determined by stratigraphic ranges of key diatom taxa. Ranges, zonation and ages in the eastern tropical — equatorial Pacific (*after* BARRON 1983, 1985, BARRON *et al.*, 1985)

middle part of the early Miocene (18.8 to 17.9 Ma) according to BARRON (1985). The presence of the silicoflagellate *Naviculopsis ponticula spinosa* in this sample supports this correlation based on the work of BUKRY (1982) and BARRON (1983) at DSDP Site 495 in the tropical Pacific. Some 10 m higher in the section the mollusks *Pitar mancorensis* and *Lucina (Lucinoma)* are present in sample 84406. This shows clearly that in this region the stratigraphic range of *Pilar mancorensis* extends into the early Miocene. *Lucina (Lucinoma)* has been reported in southern Peru, but it is probably not the North Pacific *L. acutilineata*, as is claimed by Pardo (*in* PECHO & MORALES, 1969) Other lucinomids in Ecuador (*L. playaensis* Olsson, 1964 ; Oligocene) and northern Peru (*L. trictracensis* Olsson, 1932 ; early Miocene) are probably more closely related.

## **Lomitas section** (point 4, fig. 2)

Coarse basal facies are also present, especially near the basement exposures of the Coastal Cordillera. They are littoral or continental conglomerates which overlap both the upper Eocene layers and the pre-Tertiary substratum. At Lomitas beach (point 4, fig. 2), the base of the sequence near the contact with the substratum (section 4, fig. 3), is composed of basement gravel and coarse-grained sandstone with shell debris. Laterally it grades into fine-grained sandstones interbedded with yellow siltstones and coarse-grained calcareous sandstones. Upsection, yellowish and greenish marls, grey marly limestones and grey calcarenite containing terrigenous impurities follow. The succession of nearshore facies show small variability in the depositional water depth. In sample 80006, which comes from the basal layers, the mollusks *Pitar mancorensis, Cyclocardita* n. sp. and the same lucinomids seen in sample 84407 were recognized. As at Pampa Chilcatay, they indicate a late Oligocene-early Miocene age. Further South, near the mouth of the Rio Grande and Puerto Caballas (point 5, fig. 2), the Oligo-Miocene unit uncomformably overlies the folded and faulted beds which are assigned to the late Eocene « Paracas formation ». The Oligo-Miocene unit begins with thin transgressive conglomerates and medium-grained sandstones, followed by finner grained sediments which indicate subsident shelf conditions. The most complete section is seen in Quebrada Huaricangana (point 5, fig. 2) where it reaches a thickness of more than 200 m. It consists of calcarenites interbedded with grey shales which pass into brown marls and green claystones with limestone nodules. Capping the section are shallow, near-shore sediments, grey sandstones and shell beds which constitute a final regressive sequence. These strata are gently folded, eroded and uncomformably overlain by the middle Miocene to late Pliocene Pisco formation. The lower part of the section (sample 83020B, section 5) contains *Pitar mancorensis* which is characteristic of the upper Oligocene-lower Miocene (cf. *supra*), accompanied by *Peruchilus* n.sp. aff. *P. culberti*. *P. cuberti*. has been found in the Chira and Mancora formations of northern Peru (OLSSON, 1931) which date from late Eocene and late Oligocene times, respectively (ZUNIGA & CRUZADO, 1979 ; Occidental Petroleum, unpublished data). *Hemichenopus*, a Chilean counterpart (see OLSSON, 1931, for discussion) is Miocene or older. The Peruvian specimen from Rio Gande (fig. 6c) has lost its anterior canal and wing-like outer lip making a specific or positive generic assignment difficult.

## **San Juan de Marcona section** (point 6, fig. 2)

The southernmost exposure of the Oligo-Miocene sequence in the Pisco basin is observed around San Juan de Marcona Bay (point 6, fig. 2). These beds were considered upper Miocene and mapped as Pisco formation (CALDAS, 1978). However, diatoms sampled near the local top of the section (82010B, section 7, fig. 3) are discrepant with this correlation. The presence of both *Coscinodiscus praenodulifer* and *Bogorovia veniamini* in this sample argues for an early Miocene age between 27.7 and 19.6 Ma. In the equatorial Pacific, *C. praenodulifer* has its first occurrence within the Subzone A of the *Rossiella paleacea* Zone (22.7 to 21.7 Ma), whereas the last occurrence of *Bogorovia veniamini* coincides with the top of the *Rossiella plaleacea* Zone (19.6 Ma) (BARRON, 1985). Moreover, the presence of *Thalassiosira spinosa* without *T. fraga* supports this correlation.

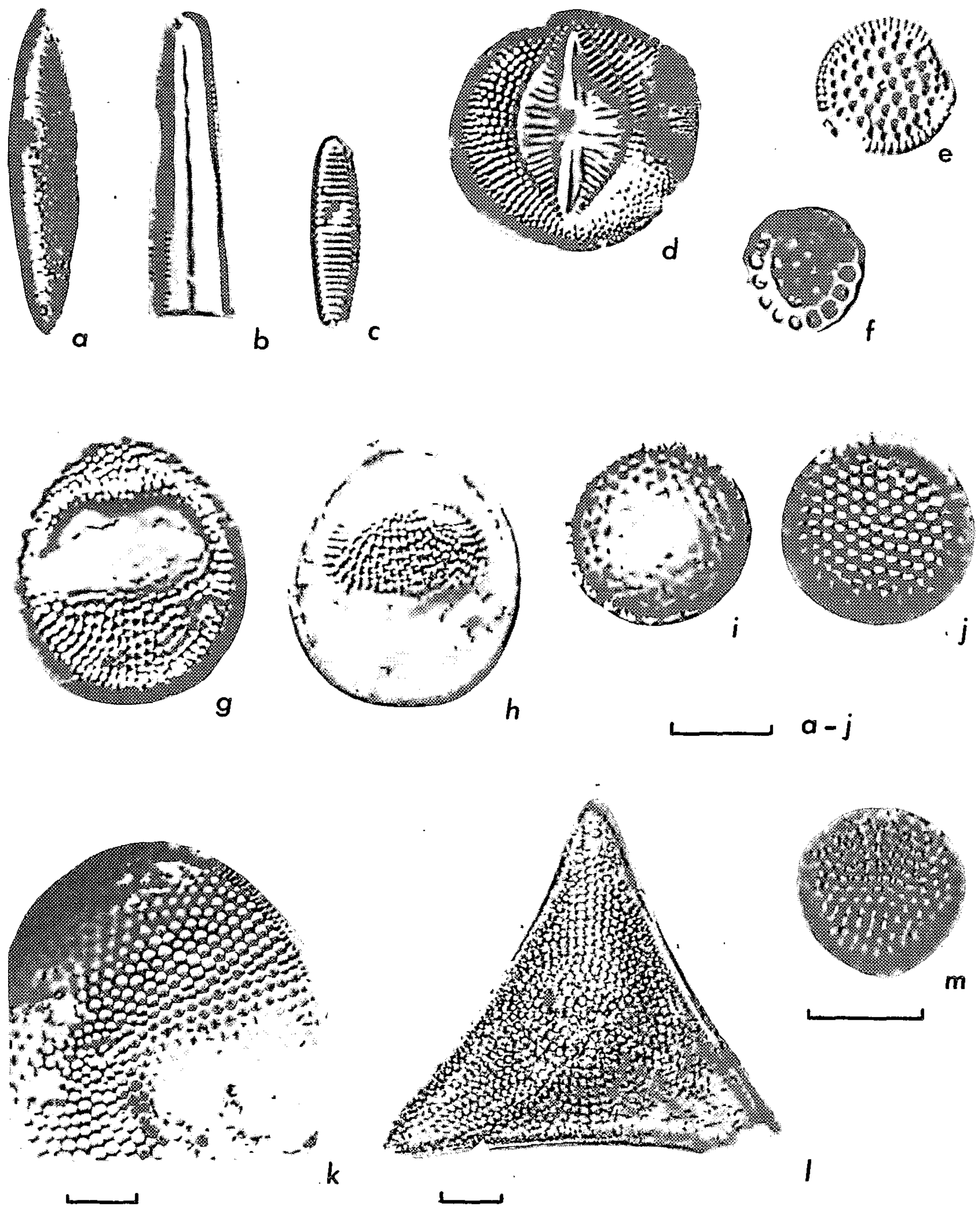


Fig. 5. — Characteristic Oligo-Miocene diatoms of the Pisco basin (scale bar=10 μ). a) *Bogorovia veniamini* Jousé — 82010B — x1500. b) *Synedra jouseana* Sheshukova-Poretzkaya — 82010B — x1500. c) *Nitzchia pusilla* Schrader — 82010B — x1500. d) *Raphidodiscus marylandicus* Christian — 84407 — x1500. e) *Coscinodiscus praenitidus* Fenner — 82010B — x1500. f) *Macrora stella (Azpeitia)* Hanna — 84407 — 1500. g-h) *Coscinodiscus sawamurae* Akiba, low and high focus — 82010B — x1500. i-j) *Thalassiosira fraga* Schrader, low and high focus — 84407 — x1500. k) *Coscinodiscus praenodulifer* Barron-82010B — x1000. l) *Triceratium pileus* Ehrenberg — 84407 — x897. m) *Thalassiosira spinosa* Schrader — 84407 — x1714

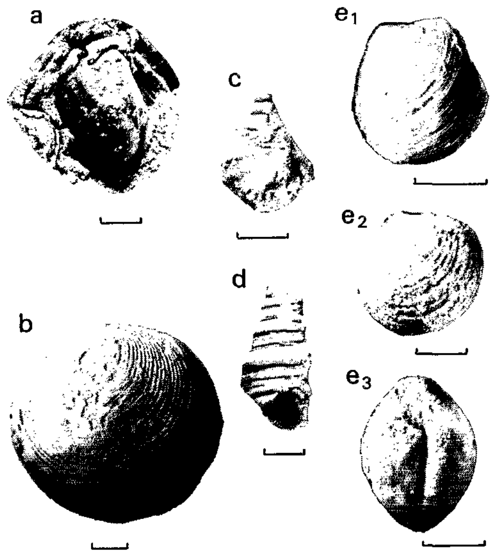


Fig. 6 — Molluks of the Oligo-Miocene section of the Pisco basin (scale bar=1 cm). a) *Cucullaea* cf. *C. chilensis* Philippi, 1987. Interior mold of left valve — 83110 — x0 54. b) *Dosinia delicatissima* Brown and Pilsbry, 1912. Exterior of left valve — 83108 — x0 445 c) *Peruchilus* n. sp ?. Apertural view, anterior canal and anterior portion of outer lip are broken — 83020B — x0.68. d) *Turritella woodsi* Lisson, 1925 : Apertural view, anterior and posterior are broken — 84314 — x0 53 e) *Pitar mancorensis* Olsson, 1931 — 83020B — 1. Exterior of right valve (x0.68) 2. — Exterior of right valve (x0 97) 3. — Dorsal view (x0 84)

## Cerro Callejon de Piedra section (point 7, fig. 2)

The Oligo-Miocene transgression reached the foot of the Andes, as seen in Cerro Callejon de Piedra, at the eastern border of the basin (point 7, fig. 2). In this area, Jurassic volcanic rocks are cut by an erosional surface and covered by a 50 m section of medium-grained grey sandstones interbedded with shell beds and thin conglomerate layers. The section grades upward into lacustrine clays, mud flows, and alluvial gravels, the top displays a pyroclastic flow. The littoral facies in the lower half of the section corresponds to the maximum extent of the transgression, and the upper part signifies a return to continental conditions. Farther East, the erosional basal surface is covered by the 22 to 18 Ma-old ash-flow sheets of the Nazca Group (NOBLE *et al.*, 1979). Tuffaceous strata, likely belonging to this group, are laterally intercallated in our section. From the shell beds (sample 84314, section 6, fig. 3) we identified *Turritella woodsi*, *Ostrea* sp. and *Isognomon* sp. indet... The former is a gastropod, which merits a short discussion. It is commonly considered as a late Eocene species, because it occurs in the Paracas region (implicitly considered as coming from the Paracas formation) (RIVERA, 1957). However, the holotype comes from the Caraveli region (LISSON, 1925), certainly from the only marine intercalation of that region which has given K/Ar ages by 25 Ma (NOBLE *et al.*, 1985). Therefore, either the Paracas occurence is late Oligocene-early Miocene or *Turritella woodsi* has a longer life-range than previously thought.

In summary, paleontologic determinations have been used for dating a till now-unidentified late Oligocene-early Miocene sedimentary unit in the Pisco basin. We propose to refer to it as the « Caballas formation » (cf. appendix and fig. 7). Regarding this unit, several important points are noteworthy : (1) This sequence is transgressive in character, since it overlaps older rocks of different ages and shows transgressive facies at its base, like basal conglomerates and fining-upward sequences (Q. Huaricangana,

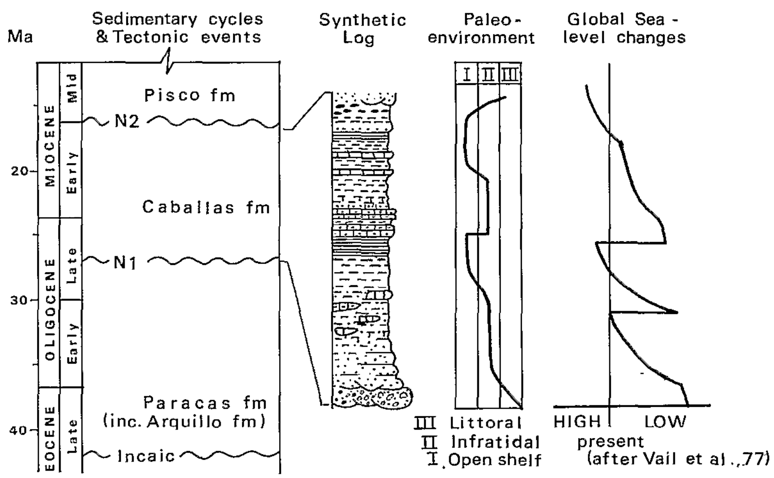


Fig. 7 — Position of the Caballas formation in the stratigraphic — tectonic context of the Pisco basin

site 5). (2) The rapid vertical evolution of the sequences indicates that the transgression occurred rapidly. (3) This marine invasion advanced inland to the foot of the Andes (Callejon de Piedra, site 6). (4) The Caballas formation is clearly uncomformable on the late Eocene Paracas formation at three points (Caballas and Rio Grande, site 5 ; Otuma, site 1). (5) The Caballas formation locally appears to be unconformably overlain by the middle Miocene to Pliocene Pisco formation.

## EXTENTION AND CHARACTERISTICS OF THE LATE OLIGOCENE-EARLY MIOCENE TRANSGRESSION IN WESTERN SOUTH AMERICA

The late Oligocene-early Miocene transgression appears to be more widespread along the Pacific margin of South America than previously proposed (CAMACHO, 1967). The expressions of this transgression are not uniform all over the margin ; crustal structures proper to each Andean tectonic segment (fig. 1) seem to control both magnitude and mode of transgression.

The North Andean forearc basins (North of 5º lat. S), whose basement are constituted by oceanic crust accreted to the continent (FEININGER, 1977 ; DUQUE CARO, 1976), are highly subsident during the Tertiary, as evidenced by thick sedimentary sequences. As the other Cenozoic transgressions, the late Oligocene-early Miocene event is well recorded. It corresponds to turbiditic sediments of the Truando and Lower Rio Salado groups in Colombia (DUQUE CARO, 1971, 1976). In Ecuador, it is represented by bathyal-depth mudstones intercalated with bioturbated sandstones known as Pambil and Viche formations in the North and Tosagua formation (Villingota member) in the central and southern basins (EVANS & WHITTAKER, 1982, BRISTOW & HOFSTTETER, 1977 ; J. BARRON, unpub. rep.). In the Talara-Tumbes basins of northwestern Peru, this cycle corresponds to the transgressive sequence composed by the Mancora and Heath formations (STAINFORTH, 1955 ; LEON, 1983).

Ophiolitic material has also been reported within the basement of the Southern Andean continental margin (South of 41º lat. S) ; it is thought to be emplaced during a backarc spreading in early Cretaceous (DALZIEL *et al.* 1974). Possibly related to its dense crust, this margin has easily subsided during the Tertiary, allowing several Pacific transgressions to reach the North Patagonian basins (NPB in fig. 1) (RAMOS, 1982). This author has documented the late Oligocene transgression, which is represented by shallow water marine intercalations within the continental Nirihuau and Norquinco formations of the Bariloche-Cholilla region (41º to 42º 30′ lat. S).

Conversely, along most of the Central Andean segment (5º to 41º S) which is free of ophiolites, the Coastal Cordillera constitutes a major barrier which obstructs the Cenozoic marine transgressions and therefore the inner forearc basins are generally infilled by piedmont continental deposits (SÉBRIER *et al.* 1979).

In northern and central Chile, for example, the Tertiary planated topographies, which are formed by erosion-agraddation processes, on to the Coastal Cordillera (i.e. Tarapaca Pediplain of MORTIMER & SARIC, 1975) are thought to have a purely continental origin. Imprecisely dated abrasion surfaces that could be related to the late Oligocene-early Miocene transgression are only preserved on the Pacific flank of the Coastal Cordillera. In southern Peru the Camana formation of late Oligocene age (RÜEGG, 1952 ; STAINFORTH and RÜEGG, 1953) was previously thought to be restricted to the Pacific slope of the Coastal Cordillera. However, it has been recently shown that the late Oligocene sea transgressed beyond the Coastal Cordillera and temporarily invaded the inner « Moquegua » basin (fig. 1) which is infilled chiefly with continental deposits (SÉBRIER *et al.*, 1982 ; HUAMAN, 1985). There, volcanic material intercalated within this marine sequence has yielded a K/Ar age of ca. 25 Ma. (NOBLE *et al.*, 1985). In this region, the coastal Pacific slopes, display good outcrops of the Camana formation, whose strata younger and younger climb up to the basement over more than 1 000 m (after faulting-correction). It indicates that, in this region, the Oligo-Miocene transgression was accompanied by an exceptional tectonic subsidence (SÉBRIER, *pers. comm.*).

The northern part of the Central Andean forearc (5º to 16º S), including the Pisco basin, exhibits a more constant subsident behavior. In the Sechura basin of northwestern Peru (5º to 7º S, fig. 1), oil-exploration wells have recovered an upper Oligocene-lower Miocene sedimentary cycle (i.e. Mancora and Heath formations) bounded above and below by uncomformities (OCHOA, 1980). Both Pisco and Sechura basins show almost continuous marine sedimentary records which indicate a dominant subsident tendency from late Eocene to late Pliocene times. The other forearc basins between those of Sechura and Pisco lie below sea level, and the only available information comes from two exploration wells (one in the upper slope basin, and the other over the submerged Coastal Range) and geophysical profiles (THORNBURG & KULM, 1981 ; JONES, 1981). According to these data, the structure and evolution seem to be rather homogeneous all along this central Peru segment (5º to 16º S), namely characterized by a continuous tendency for low subsidence. We think that this character could be explained by the presence of dense materials within the crust as evidenced by modelling of gravity anomalies (COUCH & WHITSETT, 1981). This characteristic is thought to be acquiered by the injection of mantle rocks into the crust during a backarc stage which affected the Central Peru margin in middle Cretaceous time (ATHERTON *et al.*, 1983).

A common characteristic of the late Oligocene-early Miocene transgression all along the South American margin is that its base overlies an uncomformity. Elsewhere this uncomformity is marked by an erosional surface which can be either a mature surface or a very differentiated paleotopography. In places this uncomformity displays an angular discordance between the late Oligocene-early Miocene unit and older rocks whose youngest ages are generally late Eocene. since lower Oligocene marine sediments have not been clearly documented. In southern Peru, this discordance is related to a compressional tectonic pulse, imprecisely dated around 26-28 Ma (SÉBRIER *et al.*, 1979 . MERCIER, 1981 ; SÉBRIER *et al.*, 1983, 1988).

## GLOBAL CLIMATIC AND TECTONIC EVENTS, RELATED EUSTATISM AND THEIR INFLUENCE OVER THE CONTINENTAL MARGIN

Owing to their high mobility, active margins are not suitable to study absolute sea level changes ; however, some large scale events in these regions can be tentatively compared with global « eustatic » curves such as that of VAIL *et al.* (1977). We have shown that the late Oligocene-early Miocene transgression is present not only along Northern and Southern Andes but also along the Central Andean margin demonstrating the generality of the relative sea-level rise along the Pacific coast of South America at that time. This widespread late Oligocene-early Miocene transgression in South America agrees with the eustatic sea-level rise between 26 and 17 Ma. on the Vail's curve - disregarding the third order fluctuations - (cf. fig. 7). The lack of lower Oligocene sediments along the Andean margin, however, does not agree with the rise and highstand between ca. 37 and 30 Ma proposed by that curve. It seems unlikely that a strong erosional event has removed the traces of an eventual early Oligocene transgression along the whole margin, specially if climate was yet arid as suggested by SÉBRIER *et al.* (1982). South American Pacific data seem to be more in agreement with an early Oligenece lowstand as it has been alrealy proposed. For exemple, stratigraphy of North Atlantic margins displays an uncomformity with absence of early Oligocene sediments, which is interpreted as due to a sea level fall at this time (OLSSON, 1980 ; MILLER *et al.*, 1985) ; in the East Antartic basins, WEBB *et al.* (1984) report an early Oligocene regression accompanied by glaciar development that seem associated to a general cooling. These stratigraphic data, in addition to a global drop in the Carbonate Compensation Depth (van ANDEL *et al.*, 1975), the increase of $\delta^{18}O$ in nearby Antartic DSDP sites (SHACKLETON & KENNETT, 1975) and paleobotanical studies in the northern Hemisphere (WOLFE 1978) suggest a climatic deterioration at that time

In addition, global plate-kinematic changes, which produce modifications in the Nazca-South America convergence, seem to have induced tectonic deformations into the continental margin, these having partly controled the magnitude of the late Oligocene-early Miocene transgression. According to finite plate reconstructions (PILGER, 1983 ; CANDE, 1983), associated with the break up of the Farallon plate, by the time of magnetic anomaly 7 (ca. 26 Ma.), the direction of convergence has changed from NE-SW to E-W, being preceded by an increase of the convergence rate of about 2 cm/yr. Such a reorganization is coincident in time and likely related to forearc events, as illustrated within the Pisco and other basins :(1) the tectonic compressional pulse which deformed the upper Eocene deposits before the latest Oligocene, (2) the subsequent tensional regime associated to the deposition of the late Oligocene-early Miocene sediments (i.e. Caballas formation) and (3) the increase of diatom-bearing facies which may be related to an important increase of $SiO_2$ due to a high rate of the arc volcanic activity along the whole central Andes (Mc BRIDE *et al.*, 1983).

## CONCLUSIONS

Along the Central Andean convergent margin, the Pisco basin provides a good example of evolution of the forearc basins lying on this margin. It displays an almost continuous record of Tertiary marine deposits.

A new upper Oligocene-lower Miocene sedimentary unit (Caballas formation) has been identified within the Pisco basin. It has been dated by its characteristic diatom and molluscan fossil contents. The Caballas formation extends the regional significance of a late Oligocene-early Miocene Pacific transgression onto the continental margin of South America. The widespread character of this transgression is stated from comparison between new data from Pisco basin and those from the others Andean forearc and interarc basins.

In general terms, the late Paleocene-early Neogene transgressive and regressive history of the Pacific margin of South America can be correlated to global climatic and tectonic events which are able to control the relative changes of the sea level. Oceanic isotopic records show high values of $\delta^{18}O$ (low sea level) between 31 and 28 Ma. This low sea level has probably produced a stratigraphic hiatus of sedimentation in the basins of the continental margin, by the midst of the Oligocene. Approximately between 28 and 26 Ma, there is an increase of the Nazca-South America convergence rate, which is thought to have produced compressional deformation and uplifting of the continental margin as well as an arc broadening with the increase of volcanic production. The following decrease in the oceanic $\delta^{18}O$ likely indicates a sea level rise. This sea level rise seems to be important enough to produce a marine transgression along the Pacific margin of South America between late Oligocene and early Miocene times.

In addition to global events mentioned just above, the behavior of forearc basins is controled by their own particular crustal structure. Thus, the more permanent subsident basins contain dense, mantle-related materials within the crust (Northern Andes, Southern Andes and central Peru segments), whereas light continental crust characterizes segments with tendency for uplift (southern Peru, northern and central Chile).

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## APPENDIX

*Proposal for a new formal stratigraphic unit*
Name : Caballas formation.

Bottom : Over the late Eocene Paracas formation. Top : Under the middle or late Miocene to Pliocene Pisco formation

Type locality : Puerto Caballas and lower Rio Grande valley, in coastal Peru, at 75°30' long W and 15° lat S.

Approximate thickness : 300 m.

Lithology (see synthetic log in fig. 4) : Conglomerates, sandstones, siltstones with calcareous concretions and shales in the first half ; calcarenites, tuffaceous and diatomitic siltstones and fine sandstones in the second half.

Age : Late Oligocene to early Miocene.

Correlation : With Mancora and Heath formations of NW Peru and Camana formation of Southern Peru.

Table I

Occurence of stratigraphically significant Diatom and Silicoflagellate Taxa.
Caballas formation, Pisco basin, Peru

| TAXA / SAMPLE | 83111 | 82010B | 84407 |
|---|---|---|---|
| *Borogovia veniamini* Jousé | + | + | + |
| *Cestodiscus pulchellus* Gréville | | + | |
| *C. pulchellus* (coarse) | + | | |
| *C.* sp. (similar to those seen in lowermost Miocene of DSDP site 71) | + | | |
| *Coscinodiscus praenitidus* Fenner | | + | |
| *C. praenodulifer* Barron | | + | |
| *C. sawamurae* Akiba | | + | + |
| *Cymatogonia amblyoceras* (Ehrenberg) Hanna | | + | |
| *Cymatosira compacta* Schrader & Fenner | + | | + |
| *Delphineis* sp. | | + | + |
| *Macrora stella* (Azpeitia) Hanna | | | + |
| *Nitzschia pusilla* Schrader | | + | + |
| *Pseudodimerograma* sp. | + | + | + |
| *Raphidodiscus marylandicus* Christian | | + | + |
| *Synedra jouseana* Sheshukova-Poretzkaya | | + | + |
| *S. miocenica* Schrader | + | + | + |
| *Thalassionema nitzschioides* (Grunow) Van Heurck | | + | + |
| *T. nitzschioides* (very primitive form) | + | | |
| *Thalassiosira fraga* Schrader | | | + |
| *T. spinosa* Schrader | | + | + |
| *Triceratium pileus* Ehrenberg | | | + |
| *Naviculopsis ponticula spinosa* Bukry (silicoflag.) | | | + |

Table II
Mollusk taxa from the Caballas formation,
Pisco basin, Peru

| TAXA / SAMPLE | 80006 | 83020B | 83105 | 83108 | 83110 | 84406 | 84314 |
|---|---|---|---|---|---|---|---|
| *Anadara cf. A. larkini* | | | | + | | | |
| *Cucullaea cf. C. chilensis* | | | | + | | | |
| *Cyclocardita sp.* | + | | | | | | |
| *Dosinia delicatissima* | | | | | + | | |
| *Isognomon sp. indet.* | | | | | | | + |
| *Lucina (Lucinoma)* | + | | | | | + | |
| *Ostrea sp.* | | | | | | | + |
| *Peruchilus aff. P. culberti* | | + | | | | | |
| *Pitar mancorensis* | + | + | + | | | + | |
| *Turritella conquistadorana* | | | | | | | + |

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