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Recent State of Investigations on Quaternary Sea Levels along the Chilean Coast between Lat. 30° and 33° S.

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Recent State of Investigations on Quaternary Sea Levels along the Chilean Coast between Lat. 30° and 33° S.*

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(With 2 Figures)

Résumé—L'auteur montre l'existence, dans les secteurs relativement stables de la côte du Chili semi-aride, de cinq terrasses marines étagées entre 130 m et le littoral actuel, et taillées pendant le Quaternaire aux dépens de dépôts laissés par la transgression du Pliocène supérieur (formation de Coquimbo). Elles représentent l'effet morphologique de cycles marins (mouvements négatifs et positifs de l'océan) qui sont expliqués par le glacio-eustatisme. Une équivalence avec la chronologie méditerranéenne classique est proposée à titre d'hypothèse de travail.

Resumen—El autor subraya la existencia, en los sectores relativamente estables de la costa chilena en sus latitudes semi-áridas, de cinco terrazas marinas escalonadas entre 130 m y el litoral actual, y labradas durante el Cuaternario en los depósitos dejados por la transgresión del Plioceno superior (formación de Coquimbo). Representan el efecto morfológico de ciclos marinos (movimientos negativos y positivos del océano) que se explican por el glacio-eustátismo. Una equivalencia con la cronologia mediterránea clásica se presenta como hipótesis de trabajo.

One of the remarkable features of the Chilean coast is its series of step-like marine terraces, often covered by fossiliferous deposits. DARWIN (1846) was the first to mention them, and attributed their formation to a spasmodic uplifting of the continent, separated by pauses in the movement. Later on, BRÜGGEN (1929) assumed that sinking periods alternated with uplifting movements, but that the result, in general, was a lifting of the continent.

From a study now in progress of the ancient sea levels of the Chilean coast between Lat. 30° and 33° S, preliminary results can be announced. In the midst of sectors strongly affected by neo-tectonic movements (raised and toppled terraces, fractures displacing the more recent levels), some portions seem to have been more stable during the Pleistocene period. This is specially true as regards the vicinity of the Bay of Coquimbo (30° Lat S), the surroundings of the Bay of Tongoy (30° 15′ Lat. S) and the coast between the Bay of Pichidangui (32° 7′ Lat. S) and that of La Ligua (32° 23′ Lat. S) (Fig. 1).

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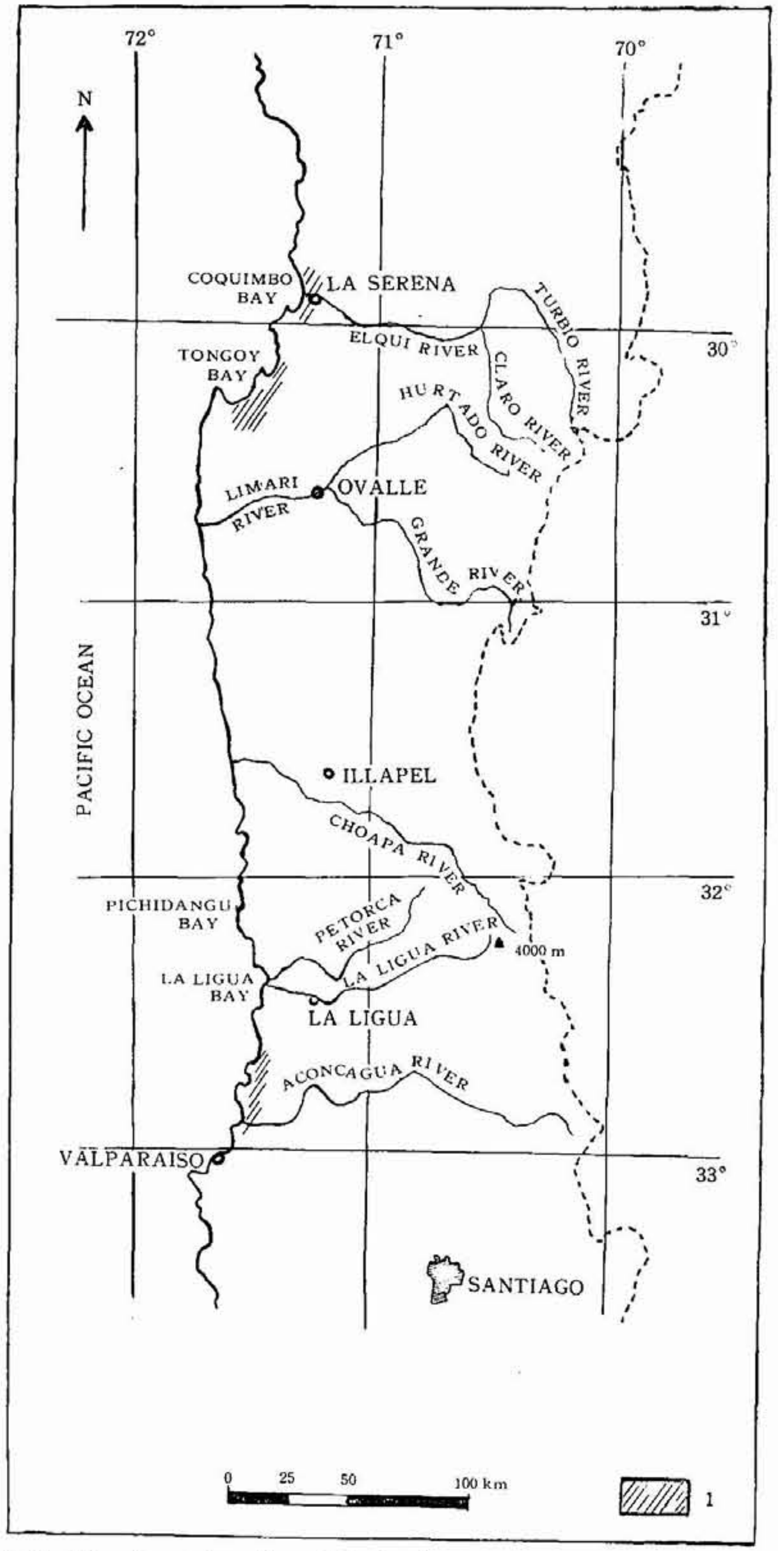

Fig. 1 Map of central-northern Chile showing locations mentioned in the text.
1. Pliocene deposits (Coquimbo formation).

A number of compared and concordant observations made in these places allows us to outline the fluctuations of the Pacific Ocean shoreline since the Pliocene. This paper completes and updates the sketch we had prepared for the VII International Congress of the INQUA (PASKOFF *in* FUENZALIDA *et al.*, 1965).

The Pliocene Transgression

An advance of the ocean, starting from the Middle Pliocene, is shown by a very fossiliferous, important sedimentary series, which was preserved behind coastal horsts. DARWIN (1846) described it around the Bay of Coquimbo, with the name of Coquimbo Formation. Later on, MÖRICKE and STEINMANN (1896) established that it belonged to the Pliocene period. It also appears near the Bay of Tongoy. The strata consist of neritic and sub-littoral deposits: yellowish, greenish or whitish fine and medium sands, sometimes cemented, with some gravel beds and conglomerates. On the whole, except in some special instances, the beds do not show important deformations; only minor flexures and slight undulations can be noted. The fauna was studied near the Bay of Tongoy by HERM (HERM, PASKOFF and STIEFEL, 1966); about 55% of its species and sub-species have since disappeared from the South Pacific coast, the majority of these now being extinct; 15% still live on the same littoral, but in warmer waters at lower latitudes; finally, of the 30% that can yet be found on the present beach, there are differences in size and relative frequency. According to HERM (op. cit.) the following fossils would be characteristic: *Oculina remondi* PHIL.; *Turritella cingulatiformis* MÖR.; *Fusus remondi* PHIL.; *Monoceros blainvillei* D'ORB.; *M. pyrulatus* PHIL.; *M. tenuis* PHIL.; *M. mirabilis* MÖR.; *Chlamys simpsoni* (PHIL.); *Chl. vidali* (PHIL.); *Pinna* sp.; *Magellania macrostoma* (PHIL.).

Transgression seems to have reached its highest level during the Upper Pliocene period, at a height of approximately +200 m measured from the present shoreline.

The Regression at the End of the Pliocene

A regression movement which lowered the littoral to an unknown height, started at the end of the Pliocene period or beginning of the Quaternary period. As a result of this recession, continental materials flowed, and caused disconformities on the Pliocene marine series (STIEFEL *in* HERM, PASKOFF and STIEFEL, 1966).

The following section, observed from bottom to top in the Quebrada Salina (30°25′ Lat. S), 2.5 km to the NW of its intersection with the Panamerican Highway, is specially instructive:

- a – Grey marine sands, from the Pliocene, containing whale bones and showing well-rounded pebble layers; these are visible through a thickness of 12 m.
- b – Unconformity: continental pink sands, with angular grains, badly stratified, mixed with raw-edged pebbles; thickness: 14 m.
- c – Finally, fluvial pebble deposits, most probably due to a change in the course of the Limari River; thickness 6 m.

  Height at the top of the section: 140 m approximately.

Quaternary Marine Cycles

During the Quaternary a series of advances and retreats of the ocean are recognized; but the final result is a regression to the present level (Fig. 2).

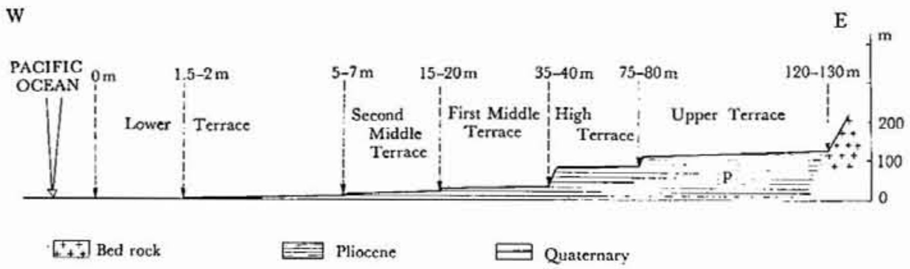

Fig. 2 Schematic cross section through the Pleistocene marine terraces of Coquimbo Bay (30° Lat. S).

The Upper Terrace—Its formation is explained by a transgression which raised the shoreline to +120~130 m. It is often veneered by characteristic deposits: beach pebbles, fossiliferous sands, indurated shell beds. It is a typical feature of the semi-arid Chilean coast.

In the surroundings of La Serena, a cut in the La Serena-Ovalle road, at the lower edge of this upper terrace, provides data on its genesis; the detailed section from bottom to top is:

a – Soft yellowish sandstones, with fossil prints, belonging to the marine episode of the Middle to Upper Pliocene, can be seen here through 3 m.
b – Heterometric pebbles with many fresh shells, Pliocene limestone cobbles; transgression deposit discordant to the precedent formation; thickness: 1 m.
c – Light-colored fine sands, thin gravel bed without organic debris; thickness: 2.20 m.
d – Pebbles and recent shells; thickness: 0.20 m.
e – Sands, with whole and broken shells; thickness: 2.20 m.
 d) and e) are regression deposits.
f – Calcareous evaporation crust; thickness: 0.20 m.
g – Hydroeolian pink sands; thickness: 0.50 m.
 Height of the top of the section: 90 m.

This upper terrace, then, appears to be linked to a marine cycle characterized by a transgression episode and a regression episode. The fauna of the deposits, examined by HERM (*op. cit.*) near Tongoy, consists of species belonging to relatively cold waters. They represent a different association than that of the Pliocene, being already very near that existing today. *Cardium grande* PHIL., *Cyclocardia* cf. *velutina* SMITH, *Acanthina crassilabrum* (LAM.), *A. calcar* (MARTYN), *Chorus giganteus* (LESS.) and *Buccinum grayi* KIEN are characteristic of this upper terrace, which we place in the Early Quaternary period.

The High Terrace—An ancient shoreline at +75~80 m is apparent around La Serena, where a well-defined level appears at this height. A cut, made for the new building of the University, shows, from bottom to top:

a – Pliocene marine sand, grey and yellowish, with well-rounded pebble beds, visible through 40 m.
b – Erosion unconformity with well-flattened and well-rounded marine blocks; thickness: 2 m.
c – Continental deposit pebbles; thickness : 3 m.
 Height at the top of the section: 78 m.

This high terrace corresponds to an abrasion level cut into the Pliocene series. The cut described above shows a regressive beach deposit, but data found elsewhere lead us to believe that a positive and negative movement of the ocean is responsible for the formation of the high terrace, which we can still place in the Lower Quaternary period. This high terrace has not been found anywhere except around the Bay of Coquimbo.

The First Middle Terrace—The first middle terrace is a distinctive feature of the landscape, as it is usually well-formed and well-preserved. In some places it is covered by beach shingles, or indurated shell beds. There are often ancient reefs on this terrace. The cliff which limits it towards the interior must have been formed when the ocean stood at 35~40 m above present sea-level. The following section, from bottom to top, is given as an example:

Place: Bay of Tongoy – 1 km to the SE of Puerto Aldea.
a – Pliocene yellow sands.
b – Indurated shell bed in disconformity with the yellow sands (transgression deposit); Thickness: 0.75 m.
c – Beach deposits in disconformity with the indurated shell beds (regression deposit); thickness: 0.75 m.
d – Outwash deposits, due to a wet, rainy climate (pluvial episode); thickness: 5 m.
e – Calcareous crust; thickness: 1 m.
f – Hydroeolian sands; thickness: 0.50 m.
 Height of the section: 40 m.

HERM (*op. cit.*) has found in these marine cycle deposits a fauna similar to that now existing along the littoral, with the exception of the *Ostrea ferrarisi* PHIL. But relative frequency of the species is not the same as now: the large number of *Chlamys purpurata* (LAM.), rare today, is a fair example. This marine cycle may belong to the Middle Quaternary.

The Second Middle Terrace—A new progression of the ocean explains the formation of a new terrace separated from the former by a cliff; the foot of this cliff is at +15~20 m.

The correlative deposits of the marine cycle responsible for the formation of this fourth terrace appear in a section near the Panamerican Highway at the Estero Culebron site (Coquimbo Bay); they are, from bottom to top:

a – Pliocene yellowish sandstones, with lithophage holes at the top, visible here for 2 m approximately.
b – Indurated shell bed, containing pebbles and boulders (one bigger than 1 m), which represents a transgression deposit; thickness: 0.70 m.
c – Fine light-colored sands; thickness : 1 m.

d – Compact and hard indurated shell bed, regression deposit; thickness: 0.50 m.
e – Pink hydroeolian sands with kjoekenmoeding; thickness: 1 m.
Height at the top of the section: 12 m.

The fauna does not show any difference with that living today. The marine cycle is dated at the Upper Quaternary period; it left topographic evidences only around Coquimbo Bay, but there are also stratigraphic traces near Los Vilos (31° 55′ Lat. S).

The Lower Terrace—The lower terrace starts at the present shoreline and extends to a height of 5~7 m where it ends at the foot of an ancient cliff about 10 m high. The latter is always very remarkable as it is clearly defined and fresh, no matter what may be the material in which it was cut. This cliff is observed almost without exception along the littoral surveyed, being present even when late deformations are recognizable. The terrace belongs to an abrasion platform which is sometimes covered by a thin accumulation of sands, silts, or turbary deposits.

It is generally accepted that this lower terrace is evidence of a regression during the Holocene. However, we believe that it is necessary to separate on the one hand the abrasion platform and the cliff, on the other hand, the loose deposits which sometimes appear at the surface. If the latter seem evidently recent, in our opinion, the first must be attributed to a long transgression, and no doubt, to a stillstand of the ocean for a considerable length of time. The slowness of marine erosion makes it unlikely that such a high cliff could have been formed in a few thousand years, especially when hard rocks outcrop. It therefore seems reasonable to place this abrasion platform and its cliff in the Upper Pleistocene period.

Around 4,000 B.C. the shoreline must have been found at about 5 m above its present position, for otherwise the presence of thick kjoekenmoeding at close intervals cannot be explained. They appear at the top of this cliff, which is sometimes found a few hundred metres away from the present beach. These deposits are formed almost exclusively by remains of sea mollusks which were left by primitive human groups whose main activity was fishing. It is logical to think that seafood was eaten on the shoreline. Furthermore, no similar deposits are found on the lower terrace itself.

It appears probable that the ocean stabilized for a time at +2 m. The existence of beach ridges and non-functional marine notches seems to be linked to a stage in the recession down to the present level. Biochemical alteration spots on these forms suggest that they are beyond the reach of present storm waves.

Interpretation of this Shoreline Sequence

This outline of ocean shore levels found in the stable sectors of the Chilean coast between 30° and 33° Lat. S may lead us to consider a general recession beginning at the end of the Pliocene period. It also shows that this was a spasmodic movement which is really the result of marine cycles, that is of a number of pulsations, sometimes negative (regression), sometimes positive (transgression). We believe that these fluctuations

are due to glacio-eustatism of the Pleistocene period, and not, as is usually believed in the case of the Chilean coast, to rising and falling movements of the continent. It is interesting to note that the transgression which follows the end-of-the-Pliocene regression, shows a renewal of the fauna, which is characterized from then on by species belonging to colder waters (appearance of the Humboldt stream?)

This succession of marine cycles at "reasonable" heights very strongly calls for comparison with the now classic chronology established for Occidental Europe. It is not our purpose to establish correlations over such long distances from results which are only preliminary, but we believe that it is interesting to state the following tentative outline:

Upper terrace:	Calabrian
High terrace:	Sicilian
First middle terrace:	Paleotyrrhenian
Second middle terrace:	Eutyrrhenian
Lower terrace:	Neotyrrhenian
Loose deposits on the Lower terrace:	Flandrian, with perhaps a Calaisian level (4~5 m) corresponding to the Climatic Optimum, and a Dunkirkian (1.5~2 m) that may date back to the beginning of the Christian Era.

Conclusions

These evidences of glacio-eustatism effects—added to a slow uplift of the continent or to the opening of new oceanic trenches to explain the lowering of sea level—seem to us to be quite important because in Chile, up to now, only the tectonic movements—epeirogenetic uplift, rising and warping horsts, faults and flexures—were given as explanation of the "raised beaches". We believe it is indispensable to take glacio-eustatism into consideration, even where the effects of neo-tectonic movements are evident, because during the Upper Quaternary period, save some local exceptions, changes in the volume of the oceans were larger and above all faster than the deformations of the earth's crust. The existence of the lower terrace which is found in identical altimetric conditions over long stretches of coast is a good example. (R. PASKOFF, July 1966.)

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