LATE CENOZOIC GEOMORPHOLOGIC EVOLUTION OF THE ANTOFAGASTA AREA, NORTHERN CHILE

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INTRODUCTION

Recent observations in the southeastern part of Antofagasta bay (23°S) shed some new light on base level and paleoclimatic aspects of late Cenozoic deposits related to the genesis of the major regional features. In the Coastal Cordillera and coastal plain of the Antofagasta area a sequence of continental sediments overlie a series of old marine terraces in staircased disposition, with the oldest depositional units systematically higher than the younger units. The relative morphologic position of these units with respect to the late Pliocene-early Pleistocene "Antofagasta Terrace" (Martínez y Niemeyer, 1982; Ortlieb *et al.*, 1997) leads to distinguish pre-Pleistocene units from Quaternary units.

THE NEOGENE SEQUENCE

The oldest Neogene unit is composed of well-sorted sediments of regular textural maturity, which indicate an alluvial origin and suggest a relatively long transport from the source. These sediments may also include some lenses of coastal reworked material (therefore suggesting that the coastline was near-by). The surface of these deposits (unit 6, Fig. 1b and 1c) lies at elevations comprised between +210 m (above present sea level) at Coloso to +450 m inland.

The second older unit is composed of alluvial fan remnants (units 4 and 5, Fig.1b), whose upper surface lies at elevations varying between +300 m to +450 m. It corresponds to continental and coastal eolian deposits which cover marine terraces that are located at +330 m to +380 m elevations. From the texture of the alluvial sediments, the high proportion of eolian sands at the base of the sequences, and the wide areal extent and large thickness of these deposits (probably related to important erosion rates in the

Coastal Cordillera), we infer that they were deposited under less arid climatic conditions (more frequent rains) than nowadays and that they may have been coeval with a stage of continental uplift.

The youngest Neogene unit corresponds to alluvial fans (units 2 and 3, Fig. 1b) which lie at elevations increasing from +110 m to +300 m. The large proportion of eolian sand in the matrix of these deposits, and the important topographic upset between the upper surfaces of the fan remnants (30 m to 40 m observed), suggest that their deposition was directly linked to a relatively fast continental uplift motion, coeval with relatively wet conditions. In the Roca Roja locality, immediately north of Coloso, the unit includes coastal marine sediments which overlie a 10 m-thick alluvial sequence of the unit 2 (Fig. 1b). The presence of the pecten *Chlamys vidali* within these sediments suggest a late-Pliocene age (Herm, 1969).

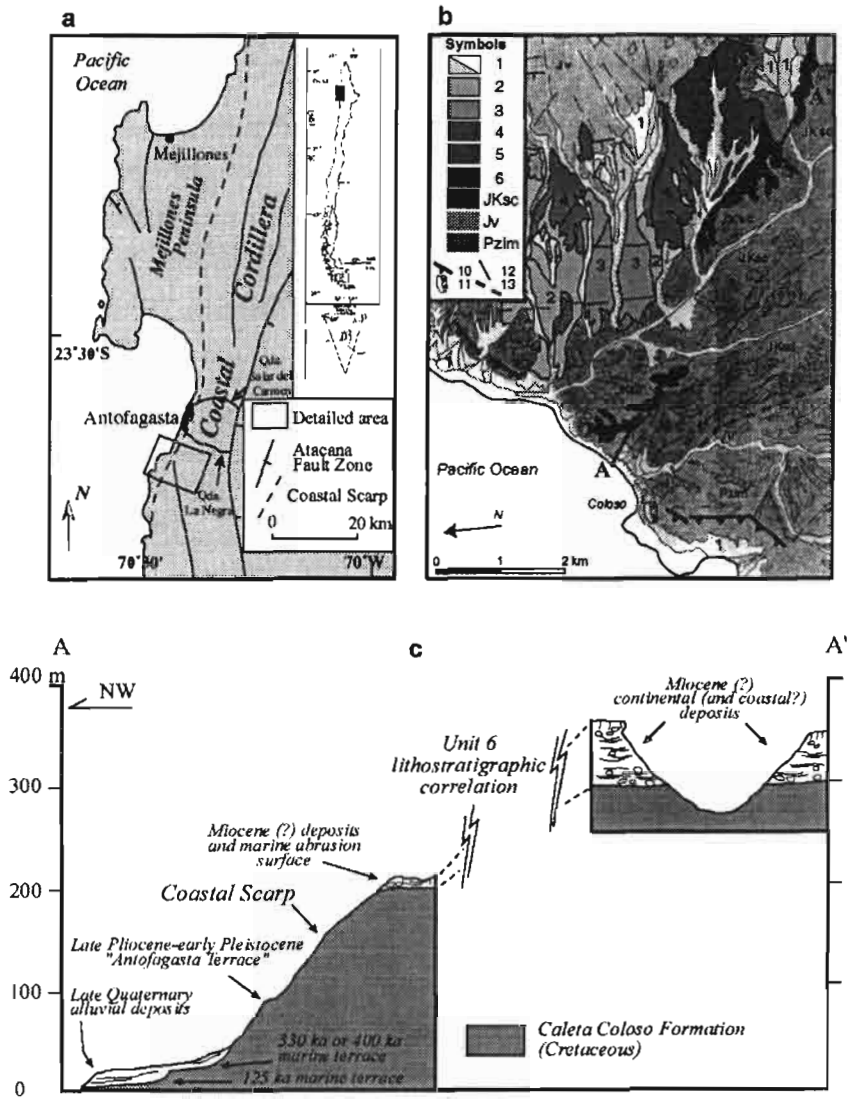

Figure 1. Major geomorphological features in the Antofagasta area

Fig1.: **a:** Localization map; **b:** Geomorphological sketchmap of the southeastern rim of Antofagasta bay; **c:** Schematic profile A-A' (see b) showing geometric relationships between the major sedimentary units and morphological features.

Symbols of sketchmap b : 1: Quaternary alluvial and eolian sediments. 2: Late Pliocene continental sediments. 3: Middle (?) Pliocene continental sediments. 4 and 5: Late Miocene to Early Pliocene (?) continental deposits. 6: Miocene (?) coastal and continental sediments. «JKsc»: Caleta Coloso Fm (Cretaceous). «Jv»: La Negra Fm (Jurassic). «Pzim»: Bolfin Fm (Paleozoic). 10: Coastal Scarp. 11: «Antofagasta Terrace». 12: Lineaments and/or fault scarps. 13 Caleta Coloso Fault.

THE QUATERNARY SEQUENCE

Three marine terraces, covered with Pleistocene-Holocene terrestrial deposits, are preserved in the narrow coastal plain that borders the small Coloso cove (Fig. 1). The highest-lying terrace, at +90 m, is the "Antofagasta Terrace" which has been assigned a Pliocene (Martínez y Niemeyer, 1982), or Plio-Pleistocene (Ortlieb *et al.*, 1995, 1997), age. The intermediate terrace, at +30 m, was interpreted as probably coeval with isotopic stages 9 (330 ka) or 11 (400 ka) high seastands (Radtke, 1989; Ortlieb *et al.*, 1995). The youngest marine terrace at Coloso which lies at a +6 m elevation (max. +11 m) was radiometrically dated as coeval with the isotopic stage 5e (125 ka) (Radtke, 1989; Ortlieb *et al.*, 1995).

Due to the uncertainty of the precise age of the Antofagasta Terrace, at Coloso, it is difficult to infer an uplift rate for Quaternary times. The total lack of diagnostic Pliocene fossils (*Chlamys vidali, Fusinus remondi, Herminespina mirabilis, Chorus* sp.) in the marine sediments that cover the narrow terrace at Coloso leads us to infer that it was formed during one (or several?) early Pleistocene high seastand(s), *i.e.* some time during the 1.8 to 0.8 Ma period. Accordingly, a range of mean uplift rate between 112 mm/ky and 50 mm/ky can be estimated for the last 1 or 2 Ma (Ortlieb *et al.*, 1996; Ortlieb *et al.*, 1997).

Regarding the 30-m terrace, a mean uplift rate of the order of 90 mm/ky, or 75 mm/ky can be calculated for the last 300 or 400 ky under the assumption that the sea level was in a similar position to its present datum at the maximum of the transgression during the isotopic stage 9, or 11 (Shackleton, 1987; Ortlieb *et al.*, 1996).

The position of the coastal sediments and erosive features of the youngest Pleistocene marine terrace strongly suggests that during the last 125 ky, the local uplift rate was much slower, and possibly nil (0 mm/ky) if one accepts the so-called eustatic model of a « global » sea level some 6 m above the present datum during the maximum of the last interglacial episode (isotopic substage 5e).

Beside the uncertainties regarding the respective age of the preserved terraces and the fact that the marine terrace record is limited to only three remnants in the area of Coloso, these data strongly suggest a

diminution of the uplift rate of the coastal region, throughout the Quaternary. It is not clear from the available data whether the variation in the uplift rate was progressive or sudden.

OTHER MORPHOSTRUCTURAL OBSERVATIONS IN THE AREA

A series of morphostructural observations in the Coastal Cordillera and in the coastal plain (Vargas, 1996) show that the Late Cenozoic deformation of the area is closely controlled by regional and local structural features which induce faulted block tectonics.

1. The altimetric position of altogether the youngest and oldest Pleistocene terraces in the northern reaches of the town of Antofagasta, indicate that the Antofagasta coastal plain was uplifted at a higher rate than the Coloso area, south of the town.
2. Quebrada Salar del Carmen separates two areas in terms of relationship between the dimensions of alluvial fans and the areal extent of their respective watershed.
3. There is a change in the general orientation of the coastline and the coastal scarp between Coloso and the southern sector of Antofagasta bay (grossly NE-SW) on one hand, and the centre and north of the Antofagasta coastal plain (N-S), on the other.
4. N-S, NW, NE and ENE lineations and fracture systems in the Coastal Cordillera are predominant in the watersheds, and show various changes across the quebradas Salar del Carmen and La Negra.
5. The geographical orientation of the Coastal Scarp and of some major lineations at a local scale are parallel.
6. There is also a parallelism between local scarps with associated grabens or semi-grabens in Pleistocene and pre-pleistocene alluvial sequences with some of the main lineation systems. One of these small scarps is oriented in the same direction that the Coastal Scarp.
7. Last but not least, there is a regional pattern of inflections in the vertical profiles of the quebradas that cut the Coastal Cordillera. The inflections, which are aligned in the different quebradas and follow some of the major structural lineations, determine a steeper gradient in the upper part of the coastal plain than within the Coastal Cordillera.

DISCUSSION

The geomorphologic evolution of the area was dominated by a net relative sea level fall, which may have begun in the Miocene, and was strongly controlled by structural features. This relative motion depicts an important regional uplift of the coastal region. Because of large uncertainties regarding the « eustatic » (worldwide), or regional, evolution of the sea level during the Miocene and the Pliocene, it is not possible to quantify the uplift motions during the Neogene within the considered area. Nevertheless,

several morphostratigraphic features and the general staircase disposition of the landforms point to a strong vertical deformation that seems to have been particularly active during the Neogene.

The oldest deposits (unit 6) that were laid before the formation of the Coastal Scarp suggest climatic conditions very different from the present ones. Units 5 and 4, which are tentatively assigned a late Miocene age, were possibly coeval with the large alluvial fan, described by Dörr *et al* (1995), which was also deposited under a wet climate and during a phase of strong uplift. From their mosphostratigraphic relations with the sediments containing *Chlamys vidali* fossils at Roca Roja and with the Antofagasta Terrace, units 3 and 2 are assigned a middle (?) Pliocene and late Pliocene age, respectively. At least during the deposition of unit 3 the uplift motions remained strong. During the episode of unit 2, it seems that the rate of uplift diminished, as suggested by the similar elevations of the Antofagasta Terrace and of the coastal sequence at Roca Roja. As previously observed on the north rim of Quebrada La Negra (Ortlieb *et al.*, 1995, 1997), the Coloso data indicate that during the early Pleistocene, the sea reoccupied a marine terrace previously formed during the late Pliocene. These observations suggest that the vertical motions of the coastal area were of limited amount between the late Pliocene and the early Pleistocene, and inclusively that they were slower than afterwards , during the middle Pleistocene. At the end of the Quaternary (late Pleistocene), these motions were drastically reduced.

At Antofagasta, as along the coastal plain north of Mejillones and Hornitos, the Coastal Scarp thus seems to have been formed essentially before the late Pliocene (*i.e.* middle Miocene to middle Pliocene), when strong uplift motions were registered. These regional vertical motions (of several hundred metres) co-occurred with the activation of a grossly N-S oriented major fracture system and produced the Coastal Scarp. During Quaternary times, the Antofagasta area, which was uplifted by about a hundred metres, was affected by tectonic deformations that are consistent with an E-W extensional stress regime (Delouis *et al.*, 1996).

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