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POSISIBLE INFLUENCE OF THE NAZCA RIDGE ON THE DEVELOPMENT OF THE RIMAC-CHILLON ALLUVIAL FAN, PERU

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INTRODUCTION

The Plio-Pleistocene development of the Rímac-Chillón alluvial fan at Lima, Perú, reflects geomorphologic and sedimentological features that cannot be accounted for by eustatic sea-level changes alone. For example, deep valleys carved into the basement indicate erosion of up to 525 m below present sea-level, which is probably due to local tectonic movements acting in combination with global sea-level oscillations. However, in spite of the fact that various authors have examined sea-level changes along the Peruvian coast (1,2,3,4), it remains difficult to identify them precisely due to the lack of geochronological data (5). In this paper, we attempt to unravel the processes responsible for the observed features of the Rímac fan, and although we can only speculate on the relative influence of these effects, we do so within the constraints of available information. The latter seems to indicate that the Nazca Ridge caused substantial uplift along the Lima coast prior to 5.3 Ma.

STRATIGRAPHY AND AGE OF THE RIMAC GROUP

The Rímac Group is composed of three main stratigraphic units. The basal deposits consist of fine-grained sandstones, siltstones and mudstones, shown by electric resistivity measurement to reach a thickness of about 400 m in the deeper parts of the Rímac valley (6, 7). Overlying these deposits is a succession of conglomerates with interbedded sandstones and mudrocks known as the Lima Conglomerate (8). A thickness of at least 86 m has been recorded in wells, which conforms to the average thickness revealed by geophysical methods (7). In some areas, the Lima Conglomerate is succeeded by more than 16 m of fine siltstones and mudstones (8) occurring in semi-isolated depressions along the southern boundary of the Rímac valley.

(8) suggested a Pleistocene age for the Lima Conglomerate. A middle Pleistocene age is also supported by J.S. Noller, (pers. comm., 1999), on the grounds of geomorphologic, stratigraphic and soil stratigraphic evidence. The only fossil evidence that we are aware of is from the top of this formation where a molar of ***Equus curvidens*** Owen, of Pleistocene age, was recovered (6).

GEOPHYSICAL DATA

Electric resistivity measurements taken at more than 2000 stations in the lower part of the Rímac and Chillón valleys (7) indicate that the valley floor of the Rímac lies at a maximum depth of 525 meters below present sea-level. This indicates tectonic downwarp of the valley floor, which was probably preceded by uplift and erosion as suggested by the shape of the incised channels. During the Pliocene/Pleistocene, maximum sea-level lowstands were of the order of -125 m according to isotopic sea-level curves (9,10,11), so that these alone cannot account for the total depth of fluvial incision. This could imply an uplift of at least 400 m. We would tentatively terminate this erosional period at the end of the Miocene, for reasons outlined below.

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POSSIBLE UPLIFT RELATED TO THE APPROACH OF THE NAZCA RIDGE

There is good reason to believe that the Lima coastal area underwent substantial elevation during the Miocene. (5) discuss evidence for uplift of the south-central Peruvian coast during the latest Pliocene/earliest Pleistocene due to the approach of the Nazca Ridge. Adapting an earlier model of (12), they proposed an asymmetrical dome-shaped uplift with a maximum elevation of 900 m developing some 70 km south of the landward projection of the ridge axis. The uplift had a total range of influence of about 500 km along the coast, with the ridge beginning to affect the coastal segment some 4-5 Ma ago (5). Due to its southeastward migration, the ridge would have been located several hundred km further north during the Pliocene (13).

To reconstruct the position of the Nazca Ridge at different periods in the past, we used a sinistral strike-slip component of 145º with a velocity of 42.4 mm/yr, based on vector relationships in Fig. 4c of (13) and the relative plate velocities of (14). Taking the strike of the ridge axis as 040º, it would therefore have been located about 110 km southwest of Pisco at 1.7 Ma, with the area of maximum uplift 115 km from the trench/ridge intersection and 75 km southeast of Pisco (Fig. 1). At 3 Ma, the ridge would have been located 225 km south of Lima and the area of maximum uplift just southeast of Pisco, 210 km to the southeast. Using a slope of 0.0036 (900/25000), uplift of less than 150 m would have been produced in the Rímac-Chillón area. Combined with the sea-level lowstand of about -70 m at the time (11), this would account for erosion of less than 220 m preceding deposition of the basal fine-grained member. Before the end of the Miocene at 5.3 Ma, however, the uplift could have been at least 485 m, which together with a lowstand of ca. -50 m at the time (11) could account for the observed erosion at Lima. During the Pliocene, subsidence in the wake of the southeastward-migrating Nazca Ridge would have precluded the extent of erosion required to produce the deep Rímac-Chillón valleys.

DOWNWARP IN THE WAKE OF THE NAZCA RIDGE

The fine-grained basal unit filling these valleys up to a depth of 400 m (7), indicates sedimentation in a relatively low-energy environment. A suggestion was made that these mudrocks are of marine origin in the vicinity of Callao (8), although no evidence was presented. Assuming that this is indeed the case (which seems likely in view of their fine-grained nature), it would indicate at least partial drowning of the former river valleys. This implies tectonic downwarp, as eustatic changes alone cannot account for such a pronounced relative rise in sea-level. The maximum highstand as derived from oxygen isotope curves of deep-sea foraminifer tests (15) occurred at 1.7 Ma (early Pleistocene), with an elevation of only about 50 m above present sea-level. Together with the maximum lowstand of about -125 m during the Pliocene, eustatic processes could therefore have produced a relative sea-level rise of only 175 m, leaving at least 225 m to be accounted for by subsidence. However, we would tentatively correlate deposition of the basal fine-grained unit with the transgression at 1.7 Ma. At this time the Nazca Ridge would have been located more than 250 km south of Lima, so that this area would have fallen largely outside its sphere of influence. (5) note that the area to the north of the present-day Nazca Ridge probably underwent subsidence during the Quaternary, which may also have been the case following the migration of the ridge past Lima.

The fact that no coarse material reached the valleys at this time is unlikely to be related to the continued presence of an ice cap over the Andean Cordillera. (16) showed that the late Pleistocene snowlines in the Central Andes were only 500-1200 m lower than their present 5100 m elevation. If a similar situation existed earlier in the Pleistocene, this would not have restricted river erosion on the lower slopes, even if the glaciers extended down the valleys for another 1000-2000 m. During transgression, on the other hand, accommodation space would have been created towards the interior, preventing coarse material from reaching the present coastal area.

RENEWED UPLIFT RELATED TO ANDEAN TECTONICS

Subsequent relative marine regression must have taken place before deposition of the Lima Conglomerate, as suggested by the complete absence of any marine influence (e.g. beach imbrication) in the exposed part of the Rímac fan along the coast. A eustatic fall in sea-level occurred between 1.3 and 0.62 Ma, as shown by oxygen-isotopic data (10,17). At the end of this lowstand cycle, warming and melting of the cordilleran ice cap would have caused the glaciers to retreat, exposing ground and valley moraine and increasing the capacity and competence of rivers transporting this material to the coast. During this time, the Lima Conglomerate was presumably deposited.

After 1.7 Ma, a total uplift of at least 430 m must have occurred in parts of the Rímac-Chillón fan to account for the fact that the upper contact of the basal fine-grained deposits occurs at an elevation of 480 m above present sea-level (taking into account the early Pleistocene highstand of 50 m). This implies an elevation rate of about 0.25 mm/yr, which is more than twice the general rate of uplift in the Andes (18). This upper contact, which presumably was horizontal at the time of deposition, declines to below sea-level at the coast, indicating that the rate of elevation increased markedly toward the east.

Although the timing of this upwarp in the interior is not known, it does seem to have affected the drainage pattern on the Rímac-Chillón fan. The Chillón migrated towards the western limit of its alluvial plain, whereas the Rímac apparently abandoned its course towards the southeast and made use of the increased westward slope to take a shortcut to the Pacific Ocean.

CONCLUSIONS

As sea-level changes alone cannot account for the deeply eroded valleys underlying the Rimác-Chillón fan at Lima, tectonic uplift must have played an important role in their development. The southeast-migrating Nazca Ridge, which produced uplift at Pisco 200 km southeast of Lima at around 1.7 Ma, would have been located much farther north during the Late Miocene/Early Pliocene. A reconstruction based on relative plate velocities and vector relationships indicates that it could have produced uplift of at least 485 m prior to 5.3 Ma, which together with a sea-level lowstand of ca. -50 m at the time could account for the observed erosion.

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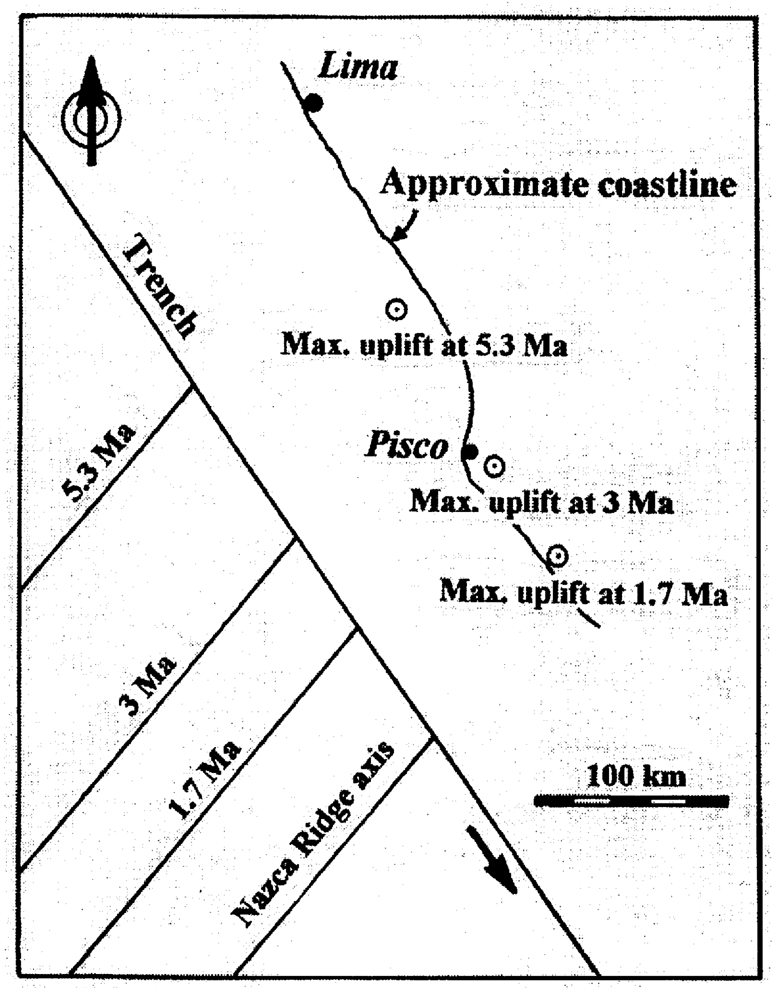

Fig. 1. Reconstruction of the location of the Nazca Ridge at different times during the Pliocene/Pleistocene.