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A Global Synthesis with implications
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Quaternary coastal morphology and sea level changes

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Detailed analysis of sea-cliff retreat and shore-platform formation in Punta Gorda (Ecuador): combined effect of El Niño effect and sea erosion in slow uplifting coast

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Introduction and background

Sea-cliff erosion results in the formation of a shore-platform (Short, 1999) and (Trenhaile, 2002). The coastal morphology inherited from previous interglacial periods makes difficult the appreciation of dynamic parameters of coastal evolution (Trenhaile, 2002). Active margins submitted to moderate uplift are appropriate to the study of sea-cliff/shore platform evolution, because no or limited effect is expected of previous interglacial shorelines overlaps.

Also the comparison between actual shore platforms and former marine terraces, allows us to appreciate the formation conditions of the later ones. The study area is located along the Ecuadorian active margin (7 km SW of Esmeraldas), on a coast submitted to a moderate mean uplift rate of 0.33 mm/yr during the Upper Pleistocene (Pedoja, 2003). The layered fine sandstone and silts of the Pliocene Onzole Formation crops out on the sea cliff, on the western part of the Borbon Basin (Aalto and Miller, 1999; DGGM, 1980). Some of those layers include up to 35% of swelling clay (smectite) (Perrin et al., 1998).

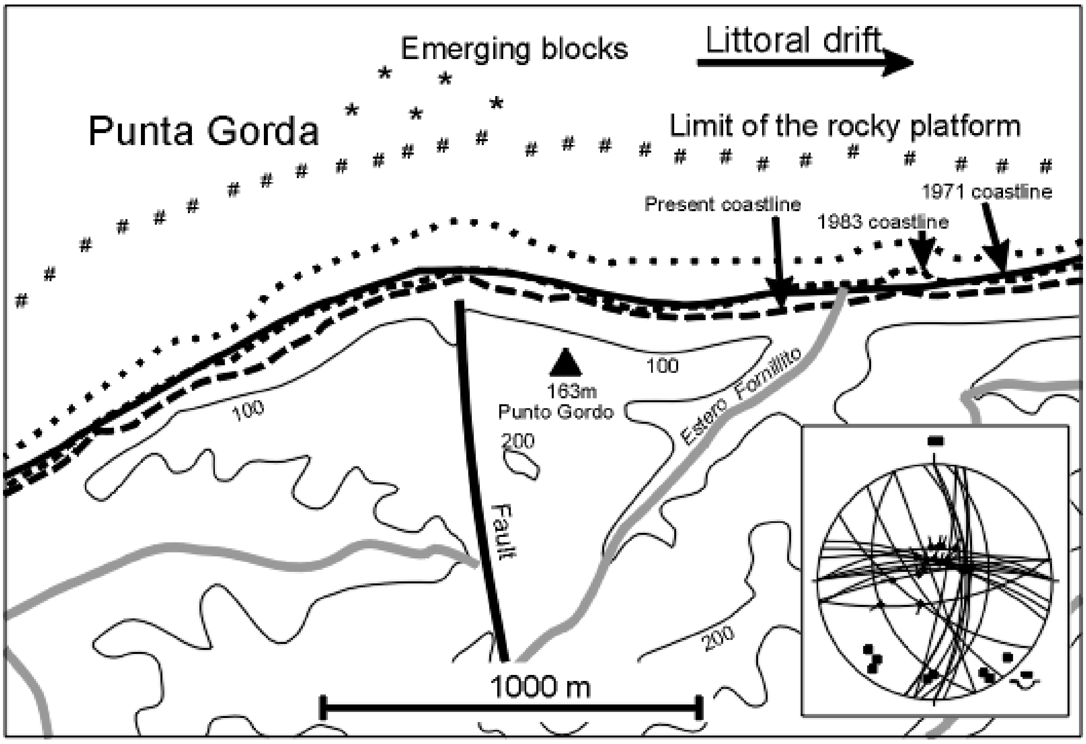

Figura 1. Synthetic map of the area of Punta Gorda Cap, showing the main part of the studied area. The enclosed diagram (Wulff, lower hemisphere) represents fault planes measured along the sea-cliff.

The structure is near horizontal, dipping slightly southward. A regional NNW trending fault crosses the area, reaching the coast in Punta Gorda (Fig. 1). Uplifted marine terraces are observed 25 km to the west of the studied area, as a flight of 3 terraces at about 20 m, 50 m and 100 m a.s.l. (Pedoja, 2003), correlated with the 3 last interglacial periods (MIS 5e, 7 and 9). The width of the terraces ranges between 1.5 and 2 km. The tide range measured in Esmeraldas is presently 3.5 m (INOCAR, 2001). El Niño events are accompanied by a rising of the sea level up to 45 cm above the normal level, during 1 to 2 months (Moreano et al., 1986; Zambrano, 1996). The main trend of wind is toward E-SE. The area is characterised by dry (July-November) and wet (December-June) seasons, with a mean annual precipitation rate of 800 mm (Terran, 1986). However, precipitation during El Niño periods is 2 to 3 times above normal, generating numerous landslides (Perrin et al., 1998).

A coast segment of 10 km (Fig. 1) is studied using 1971 and 1983 aerial photos and a new topographic levelling of the coastline (2001). The study period covers the El Niño events of 1982-1983 and 1992-1993. The fieldwork is focused on structural and morphological data.

Sea-cliff/shore platform characteristics

The shore-platform is flat, slopping 0.3% seaward, and continuous up to the “shore angle”, i.e. the angle between the sea-cliff and the shore platform. The shore angle is sharp and generally deposit-free, except where the shore angle is frequently reached by the higher tides. There the foot of the cliff is covered by a 50 cm thick accumulation of pebbles. The shore angle has an elevation ranged between the high levels of spring and neap tides, closer to spring tides. In most cases, there are no notches at the foot-cliff. The lower part of the cliff is frequently sub-vertical, and the upper part dips 45° to 60° seaward. This dip is far higher than the 25°-30° of the slopes of the hill-slopes in the hinterland, which are unstable during El Niño periods despite a relatively low slope.

Sea-cliff retreat

The 1971, 1983 and present coastlines are drawn on Fig. 1. This illustrates the coastline mean retreat of 45 m ±7 m since 1971 (mean rate of 1.5 m/y). The maximum retreat reaches 70 m ±7 m (mean rate 2.3 m/y) west of Punta Gorda, in the area of major exposition to wind and waves. However, the variation of shoreline position is rather irregular, as shown by the 1983 coastline just after the 1982-1983 El Niño event, which locally progress seaward relatively to the 1971 line position.

The apparent seaward progress of the coastline (between 1971 and 1983) is due to landslides occurring in the 1982/1983 El Niño event, at several places east and west of the Punta Gorda Cap (Fig. 1). On the eastern part of Figure 1, for example, the 1983 coastline shows a seaward deviation of 40 m compared to the 1971 coastline. This is due to a landslide which remnants are still observed as a thick layer of breccia stuck on the lower part of the present sea cliff. The effect of the 1997-1998 El Niño event is not as strong as the 1982-1983, but testimony of other major landslides is observed (Figure 2). A comparison between the 1983 and the present coastlines suggests that a period of about 20 years is enough to remove the material abandoned on the shore by landslides, and also to resume the wave erosion at the foot of the cliff. The relatively fast removal of the landslide material is due to the fast breaking up of blocks and boulders in centimetre size fragments when repeated wetting and drying is applied. Finally fine sand, silt and clay are transported out of the shore area. Few sedimentary material remains on the shore-platform. However, some sand accumulation occurs east of the studied area due to an artificial pier constructed in 1973. A rough calculation based on a mean sea cliff retreat of 1.5 m/yr and a mean elevation of the sea-cliff of 100 m gives a mean annual sediment erosion of 150000 m^3 by km of sea cliff. The segment of active erosion is about 4 to 5 km long, providing a mean supply of about 600000 to 750000 m^3/yr of sediments. The eroded material is not transported far along the shore, but most probably meets the Esmeraldas River or is directly sent to the Esmeraldas Cañon, through two valleys, the closer located just 2 km east of the shore platform (INOCAR, 1999). The coastal segment east of the Punta Gorda Cap is nearly parallel to a set of E-W trending normal faults related to the most recent tectonic event in the area (Fig. 1) (Witt, 2001). The combination of these normal faults with an N-S trending set of older faults results in a segmentation of the sea-cliff, which favours landslides. West of the Punta Gorda Cap the E-W trending fractures are slightly oblique with respect to the ENE-WSW trend of the coast, helping the mechanical erosion of the sea-cliff base (Fig.2, front part). The smallest retreat is observed at the Punta Gorda Cap. The regional fault that joins the coast in Punta Gorda has no effect on the erosion, but on the contrary is likely to exhume, on its western side, deeper

Figure 2. Photo of a landslide of blocks and crashed fragments occurred during the 1997-1998 El Niño event, and observed west of Punta Gorda Cap, near the left border of Fig. 1. Only the remote part of the landslide has been removed by 2001.

layers more resistant to weathering. This would provide hinterland relief and the rocky cap located west of the fault.

Conclusion

1. The mean rate of coastline retreat is relatively high, due to a combination of climate conditions, sensibility of rocks to weathering, and fast removal of the material at the foot of the cliff foot by waves.
2. The El Niño events obviously constitute a determining parameter for the collapse of the upper part of the cliff. However the shore platform is nearly cleaned up by wave erosion between two events.
3. Wave erosion at the sea-cliff foot cannot be neglected, as it maintains the slope steep enough to trigger further landslides.
4. The fast exportation of the eroded sediments is also important to maintain the sea-cliff erosion process active. Near the pier constructed in 1973 the accumulation of sand leads to the formation of a beach, which presently isolates the sea-cliff from further wave erosion.
5. The rate of sea cliff erosion observed over 30 years car hardly be extrapolated to the formation of the whole littoral platform, as well as to the older marine terraces: this would suggest that the formation of the first lasted only 3 or 4 hundreds years, and the second 1 or 2 thousands, what seems very short. This consideration suggests that the formation of littoral platform is probably not continuous, reflecting climatic pulses resulting in important variations in the rate of formation.

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