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Toward a morphotectonic model of the South-American coasts

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Abstract

An improved version of the continental distribution of the uplifted marine terraces and its corresponding modelled expresion is presented. For the analysis, only terraces with known altitude and absolute age (MIS) were selected. The marine terraces of the Pacific coasts are the highest of the continent, principally those of the Peruvian group. In exchange, the Atlantic terraces are manifestly lower. Parallely, if the northern coasts of the Pacific and the northern coasts of the Atlantic are compared, one can see that the former are frankly higher than the second. At once, uplift rates for different MIS are substantially bigger in the Chilean coast than in the Argentinean one. Of the same way, they are clearly higher for the northern coast of the Pacific than for the northern coasts of the Atlantic. Finally, the correlation between height and MIS indicates that, in the Pacific coasts , only 34 to 50% of the terrace heights are explained by the corresponding uplift time. In exchange, in the Atlantic coasts, between the 68 and 72% of the cases are explained by the corresponding uplift time. That is to say, the distribution of height of terrace is more irregular in the Pacific coast than in the Atlantic one. Therefore, the obtained model shows that the costal continental warping is represented by a trend surface, which is higher in the Pacific than in the Atlantic coast. This surface is a modulation of the arregularities derived from tectonic fragmentation, which is higher in the Pacific edge than in the Atlantic one.
Key words: South America, coastal terraces, heights, isotopic stages, morphotectonic model.

Resumen

Se presenta una versión mejorada de la distribución continental de las terrazas marinas elevadas y su correspondiente expresión modelada. Para el análisis, se seleccionó solamente terrazas con altitud y edad absoluta (MIS) conocida. Las terrazas marinas de las costas del Pacífico son las más altas del contienente, pricipalmente las del grupo peruano. En cambio, las terrazas del Atlántico son notablemente más bajas. Paralelamente, comparando las terrazas costeras norte del Pacífico y del Atlántico, se ve que las primeras son claramente más altas que las segundas. A mismo tiempo, las tasas de alzamiento para diferentes MIS son substancialmente mayores para la costa chilena que para la argentina. De igual modo, ellas son claramente más altas para la costa norte del Pacífico que para la costa norte del Atlático. Finalmente,la correlación entre altura de terraza y MIS indica que, en la costa del Pacífico, solamente entre 34 y 50 % de las alturas de terraza son explicados por el correspondiente tiempo de alzamiento. En cambio, en la costa atlántica entre 68 y 72 % de los casos son explicados por el correspondiente tiempo de alzamiento. Es decir, la distribución de alturas de terraza es más irregular en la costa del Pacífico que en la del Atlántico. Consecuentemente, el modelo obtenido muestra que el alabeo costero continental está representado por una superficie de tendencia más alta en la costa del Pacífico que en la atlántica. Ella es una modulación de las irregularidades derivadas de fragmentación tectónica, la cual es más acentuada en el borde pacífico que en el atlántico.
Palabras clave: Sudamerica, terrazas costeras, altitudes, estadios isotópicos, modelo morfotectónico.

Introduction

The ocean coasts of South America are related to four zones of tectonic influence: the Pacific collision edge, the Atlantic trailing edge, the southern straggler sharing edge and the northern straggler shearing edge. So, as indicators of past sea levels, the present elevation of marine terraces of Pleistocene and Holocene ages offers a measure of the relative importance of global eustatic forcing and regional tectonic deformation in their origin. A simplified model of elevation trend surface for South American marine terraces was carried out arranging them according to their marine isotopic signatures (Araya-Vergara, 2007). This preliminar model indicates than the coast of South America is tectonically warped (Fig. 1). The trend surface of elevation shows that the highest levels of deformation are in the Pacific coast and the lowest ones are in the Atlantic coastal edge. Nevertheless, the model is a simplification. Within the generalized pattern of distortion is observed tectonic segmentation, notably along the Pacific coasts, where terraces of the same age occur at different altitudes.

Since the construction of this first model to the present date, several works have been carried out on measures of absolute ages and altitudes of terraces belonging to differen isotopic stages. So, the aim of this work is to present an improved version of the continental distribution of the uplifted marine terraces and its corresponding modelled expresion.

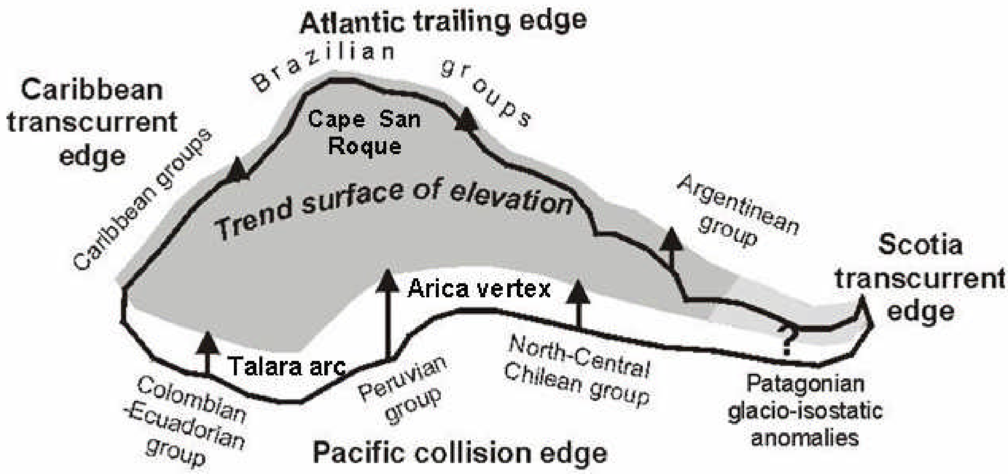

Fig. 1: Simplified model of elevation trend surface for South American marine terraces

Materials and methods

The coast of South America was divided into tectonic groups appointed by Araya-Vergara (2007). Within each one, only terraces with known altitude and absolute age were selected. For the Pacific coast, the compiled geochronological data were obteined of Dumont *et al.* (2003, 2005 and 2006), Pedoja *et al.* (2003 and 2206), Goy *et al.* (1992), Macharé & Ortlieb (1992), Casanova *et al.* (2006), Saillard *et al.* (2007), Encinas *et al.* (2006), Quezada *et al.* (2007), Ortlieb *et al.* (1996) and Marquardt *et al.* (2000). For the Atlantic coast, data were compiled of Rabassa *et al.* (2000), Bujaleski & Isla (2006), Bujaleski (2007), Rostami *et al.* (2000), Clapperton (1993), Schellmann & Radtke (2003), Aguirre *et al.* (2005), Esteves *et al.* (2000), Suguio (1999), Lessa *et al.* (2000), Bezerra *et al.* (2006), Martin (2003), Barreto *et al.* (2002), Estévez & Van Hinte (s/f), Macsotay & Moore (1974), Méndez-Baamonde (1985), Schubert & Szabo (1978) and Mennessier (1996).The dating methods used in these works were whether IRSL, U/Th, cronostratigraphy, amino-acids, ESR, ^{14}C, paleontology, ^{21}Ne, ^{26}Al or ^{10}Be. In its original and isolated presentation, the corresponding results seem a puzzle. Then, the task in the present work was its resolution, giving to the partial results a regional and continental significance. Terrace heights were distributed in agreement with their Marine Isotopic Stages (MIS) and refered to the different coastal tectonic groups. Finally, heights and MIS were correlated in order to see the expresion of the tectonic segmentation in front to an ideal model of no segmentation.

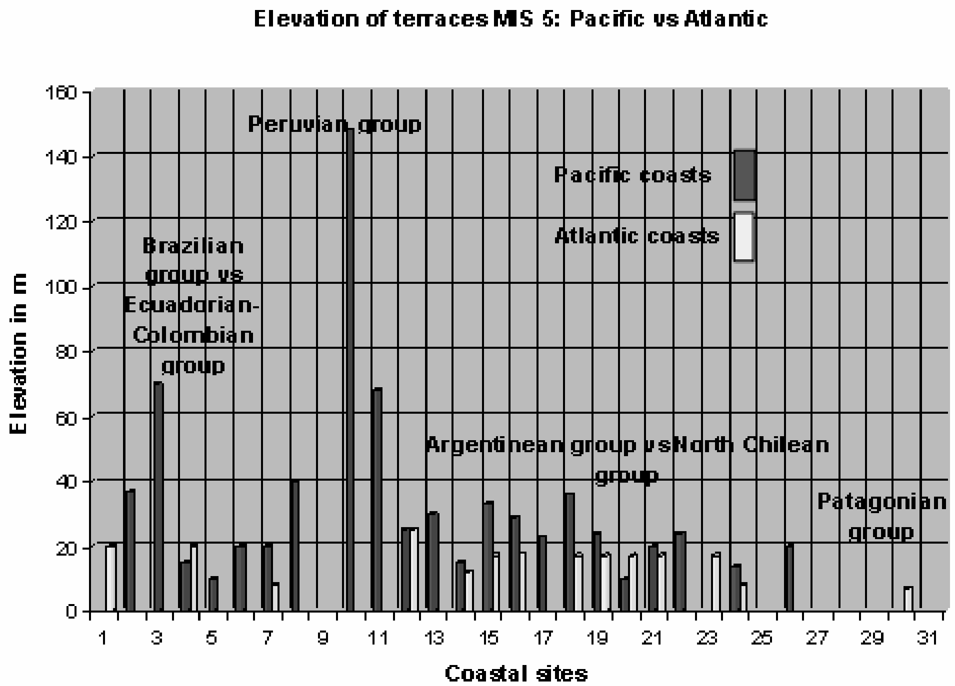

Fig. 2

Results

Comparison of heights between coasts of the Pacific and coasts of the Atlantic
The marine terraces of the Pacific coasts are the highest of the continent (Fig 2). The majority of the isotopically correlated terraces belong to the MIS 5, specially 5e, and they represent well the general distribution of the other MIS. The highest terraces are in the Peruvian group. Starting from this zone, the heights are smaller to the North an the South, showing an irregular pattern of altitude. In exchange, the terraces MIS 5 of the Atlantic coasts are manifestly lower, even though their distribution indicates less irregularity than in the Pacific case

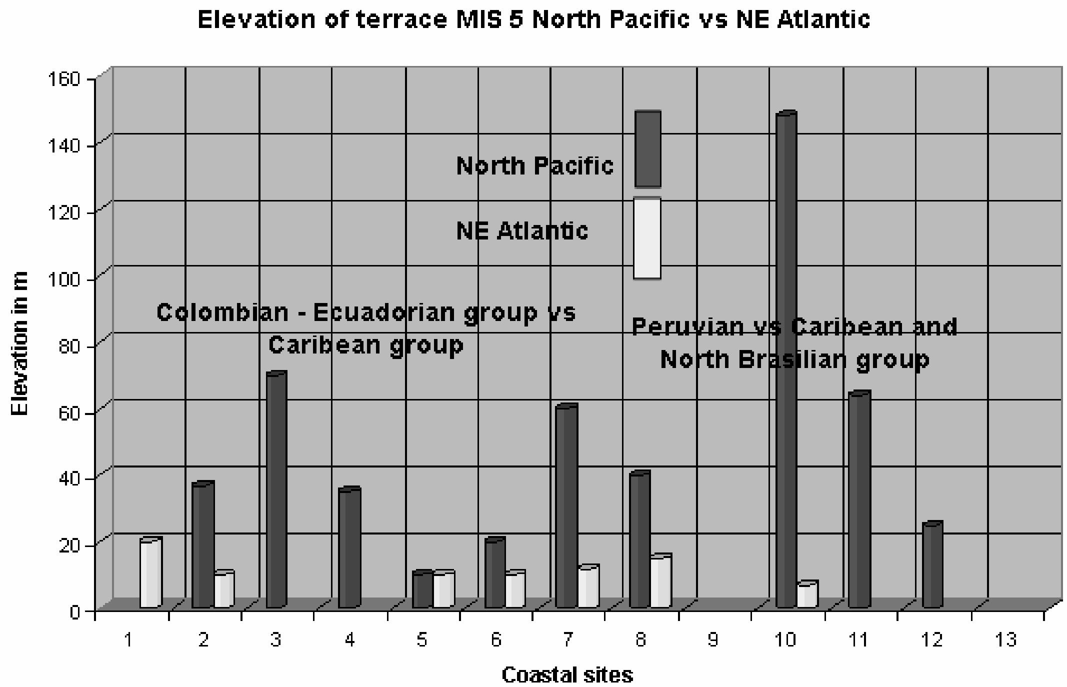

Fig. 3

Comparison of heights between the northern coasts of the Pacific and the northern coasts of the Atlantic (Fig. 3)

The Colombian-Ecuadorian group shows MIS 5 terraces which are frankly higher than those of the Caribbean group, but the difference of height of the former group shows a pattern more irregular than that of the second group, which shows good similarity of heights. Confronting the Peruvian vs. Caribbean groups, is clear that the inmense difference of heights, even though in the case of Brazil there is only one exemplar**.**

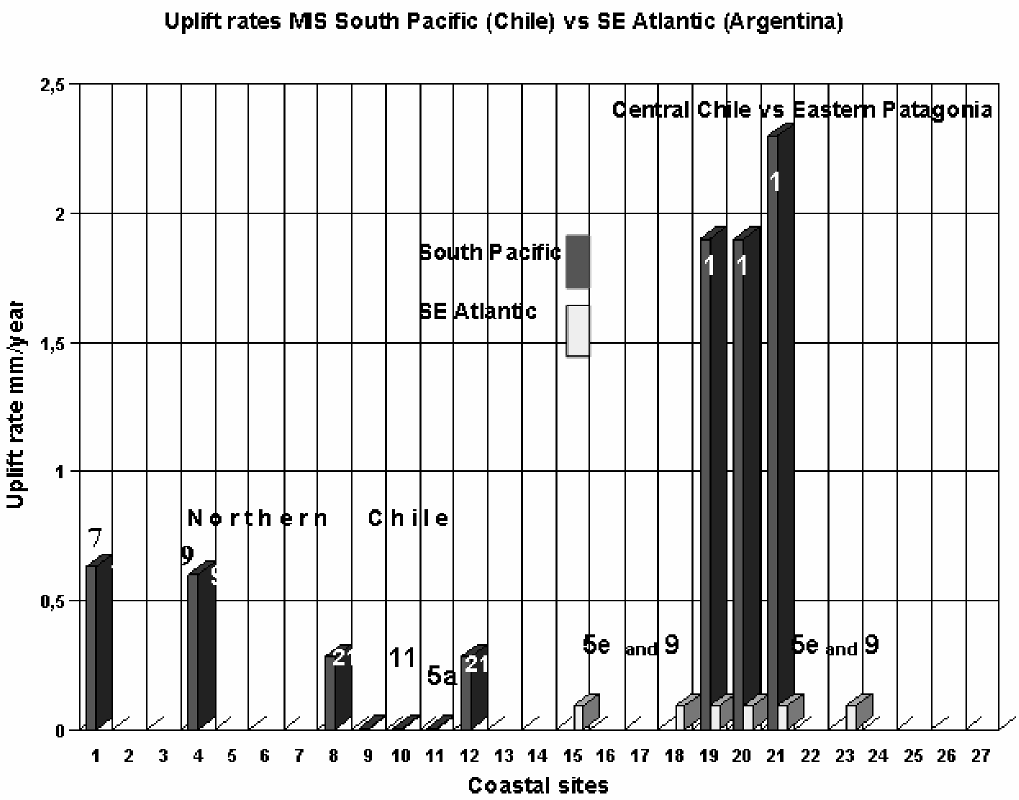

Fig. 4

A first confrontation can be shown between the southern coasts of the Pacific and the south eastern coast of the Atlantic. No available information for Brazil has been found. So, the comparation of uplift rates is done only between Chilean and Argentinean coastal terraces. Uplift rates are substantially bigger in Chile than in Argentina for terraces of different MIS (Fig. 4). The differences are smaller for MIS 5, but very high for MIS 9. Contrarily to the general situation, the lower uplift rates are in northern Chile in the cases of MIS 5a and 11. Manifestly, the highest cases of uplift rate are shown by MIS 1 terraces

A second confrontation (Fig. 5) can be done between the northern coasts of the Pacific (northernmost of the Arica vertex; Colombian-Ecuadorian and Peruvian groups) and the coasts of the Caribbean group (North Atlantic coasts). Uplift rates are manifestly higher for the marine terraces of the Colombian, Ecuadorian and Peruvian groups than for the Caribbean group. Clearly, the highest rates are in the Peruvian group for five MIS. An isolated case of very high elevation rate is evidenced by a MIS 1 terrace. It is present in the Colombian – Ecuadorian group. For the Caribbean group, other isolated case of MIS 3 appears with the highest rate, although it is difficult see in nature terraces of this stage, because in it the sea level was not sufficiently high. Its presence is interpreted as an strong tectonic uplift in Araya Peninsula (eastern Venezuela).

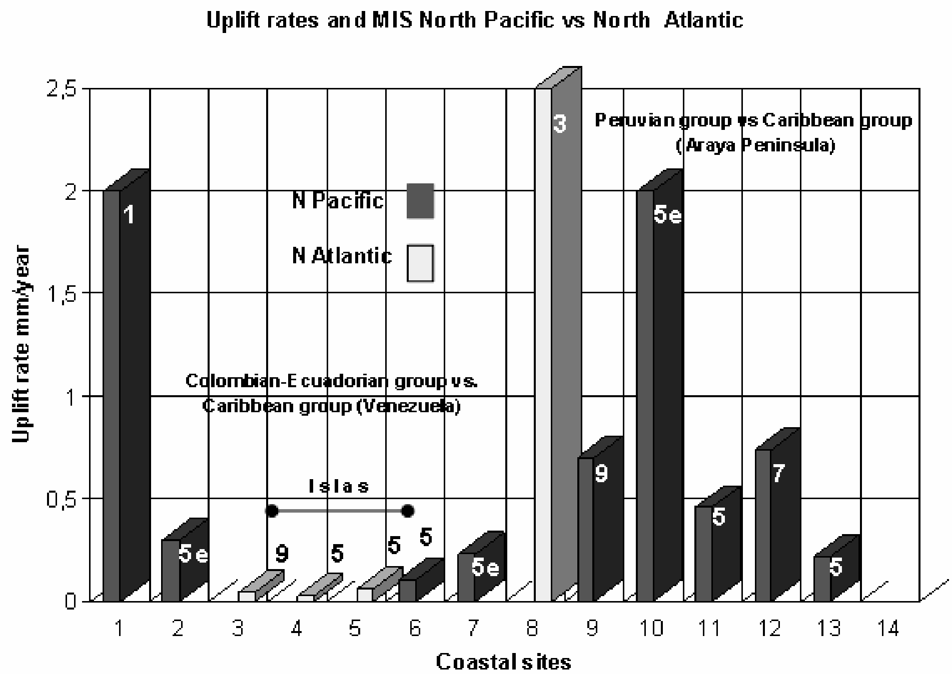

Fig. 5

The degree of irregularity in the uplift for terraces of the different identified MIS

The southern coasts of the Pacific vs the southeastern coast of the Atlantic

The correlation between terrace altitude and MIS for southern coasts of the Pacific (from Arica vertex to Cape Horn, Fig. 1), presents a considerable degree of dispersion (Fig. 6). Only the 49 – 50 % of the terrace height is explained by the uplift time of the corresponding MIS terrace. Moreover, it is common the overlapping of heights between distinct isotopic stages if they are compared.for different sites. On the other hand, in the correlation for the southeastern coast of the Atlantic (from Patagonia to Cape San Roque, northeastern Brazil, Fig. 1), the degree of dispersion is smaller (Fig. 7). The 68 % of the terrace height is explained by the uplift time of the corresponding MIS terrace, but there is a high level of heights overlappings between distinct isotopic stages if each stage is compared for different sites.
Consequently, in the southern coasts of the Pacific, the irregularity of heights in the distribution of terraces is bigger than in the southeastern coast of the Atlantic.

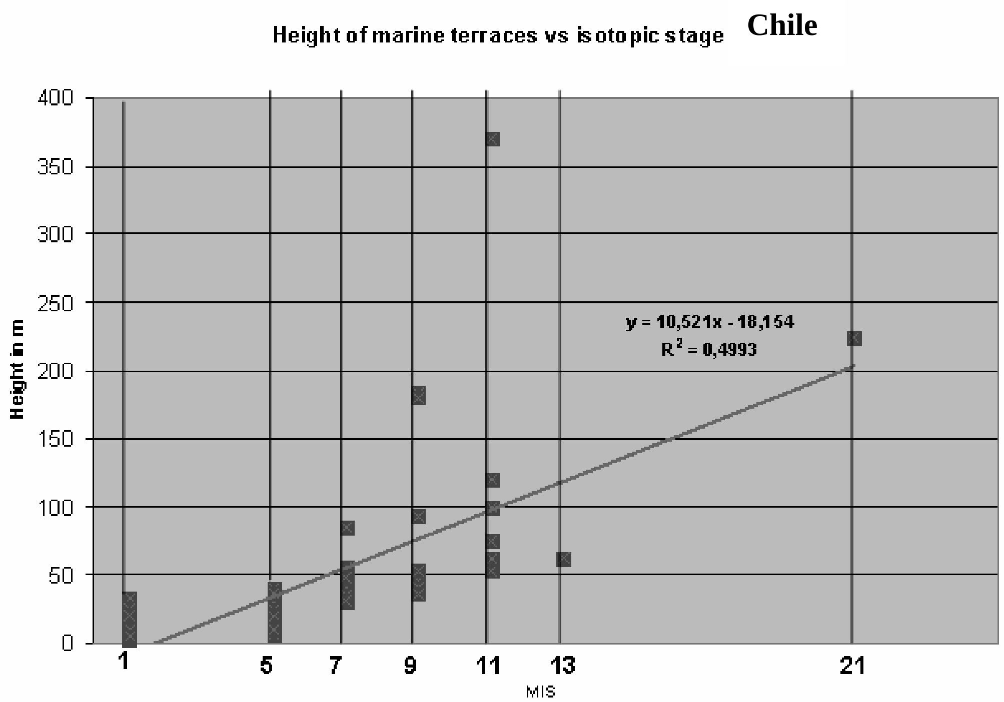
Height of marine terraces vs isotopic stage
Chile
400
350
300
250
200
150
100
50
0
Height in m
y = 10,521x - 18,154
R2 = 0,4993
1
5
7
9
11
13
21
MIS

Fig. 6

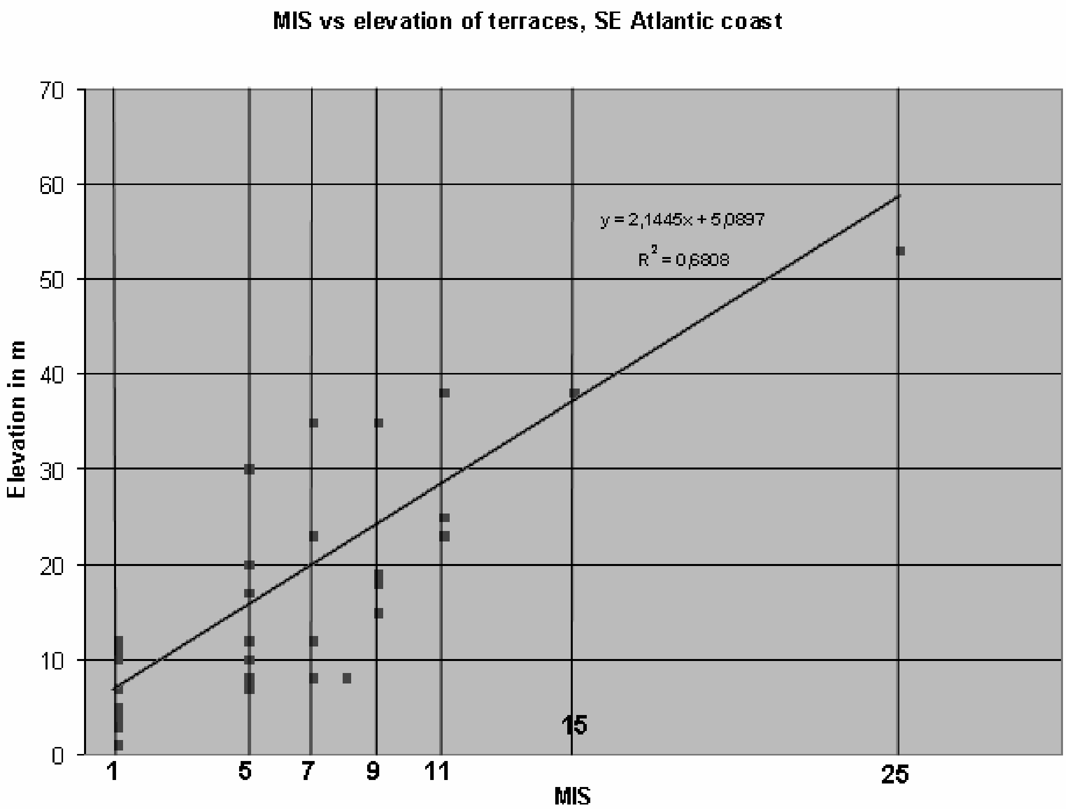
MIS vs elevation of terraces, SE Atlantic coast
70
60
50
40
30
20
10
0
Elevation in m
y = 2,1445x + 5,0897
R2 = 0,6808
15
1
5
7
9
11
25
MIS

Fig. 7

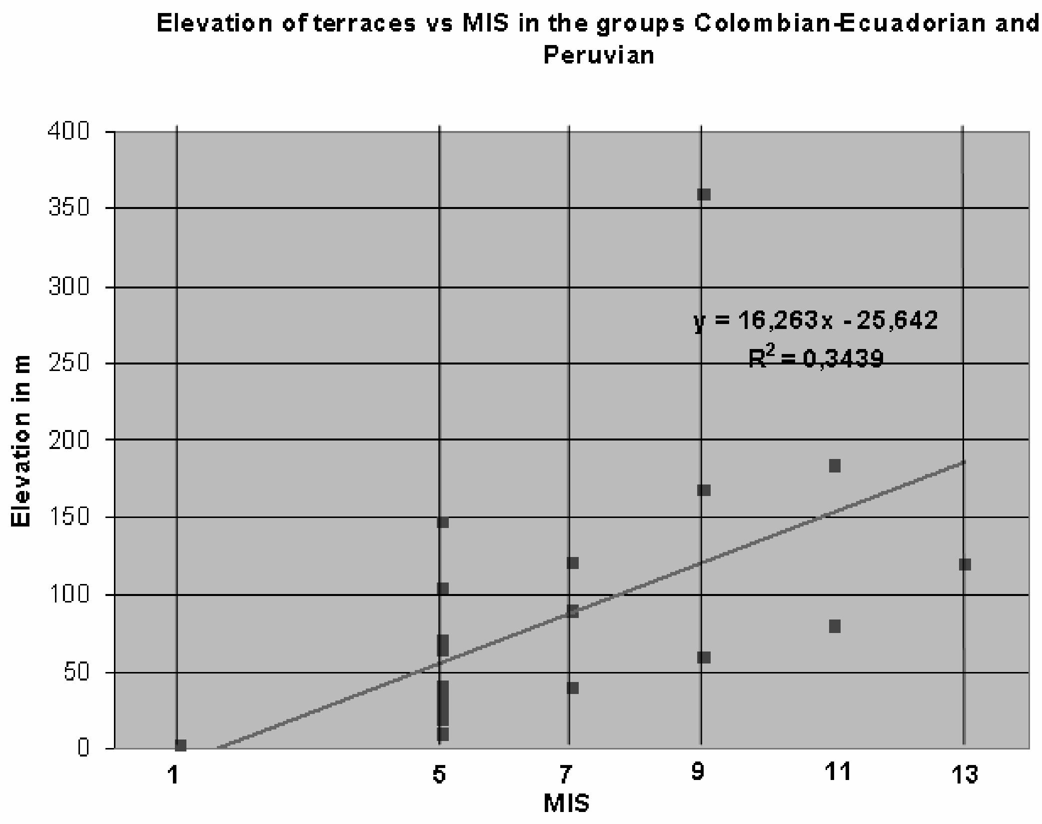
Elevation of terraces vs MIS in the groups Colombian-Ecuadorian and Peruvian
y = 16,263x - 25,642
R^2 = 0,3439
Elevation in m
MIS
400
350
300
250
200
150
100
50
0
1
5
7
9
11
13

Fig. 8

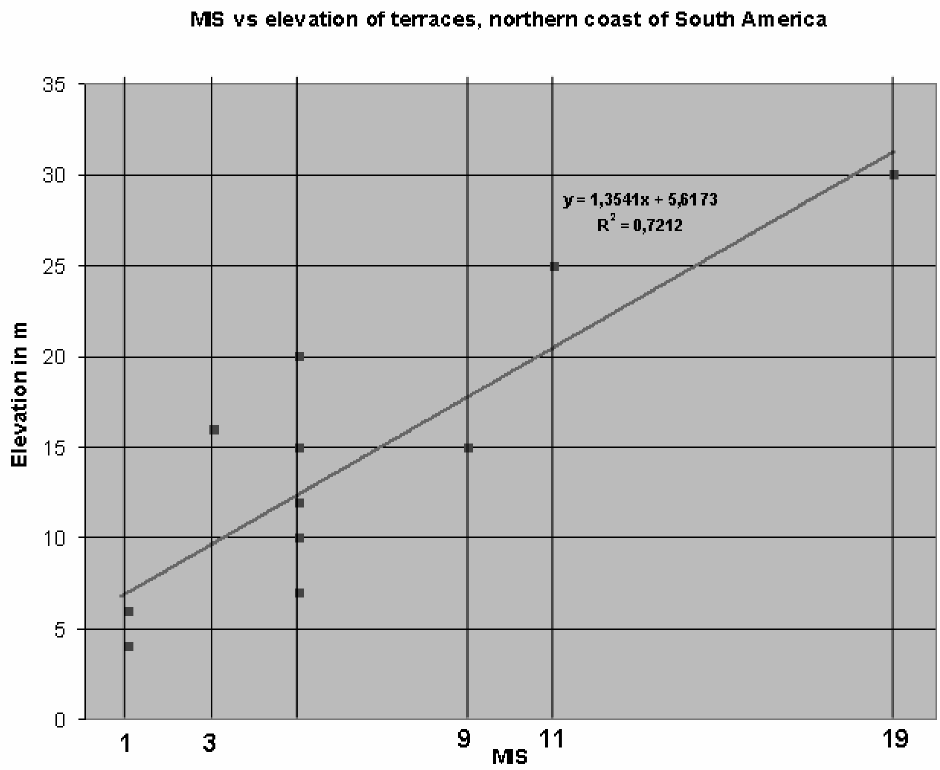
MIS vs elevation of terraces, northern coast of South America
y = 1,3541x + 5,6173
R^2 = 0,7212
Elevation in m
MIS
35
30
25
20
15
10
5
0
1
3
9
11
19

Fig. 9

The northern coast of the Pacific vs. the northern coast of South America

The correlation between terrace altitude and MIS for the groups Colombian-Ecuadorian and Peruvian indicates the biggest dispersion for the South American terraces (Fig. 8). Only the 34 % of their heights is explained by the uplift time of the corresponding MIS. The overlapping among the height ranges for terraces of the different MIS is very generalized, if different sites are compared. In opposition, this correlation for the northern coast of South America (between Cape San Roque and the western end of the Caribbean group, Fig. 9) indicates that the degree of dispersion is the smallest of the South American terraces. The 72 % of their heights is explained by the uplift time of the corresponding MIS. The overlapping among the height ranges for terraces of different MIS is low.

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Therefore, between these coasts, the biggest difference of irregularity in the distribution of height of marine terraces of South America is observed.

Discussion and conclusion

Different time lapses can be indicated for the uplift of terraces associated to diverse MIS.The system of terraces MIS 5 has been uplifted since ~ 100 ky ago (pricipally interglacial Eem or 5e). The system of 7a-e has been uplifted since ~ 180-240 ky ago (interglacial sub-stages of the Saalian complex). Uplift of the terraces MIS 9 takes action since ~ 280-320 ky ago (also interglacial sub-stages of the Saalian complex). The system MIS 11 has been uplifted since ~ 400 ka (interglacial Holstein). Finally, the oldest terrace found (MIS 21 to 25) has been uplifted since 850-950 ky ago (Cromerian complex or before). Quezada *et al.* (2007) observed in Chile that its cliff is the highest compared with those of the other terraces. So, features of uplift are observed at least since the beginnings of the Cromerian complex. Then, the warping of the coastal system of South America is thought to have began during this lapse of time.

But the warping, expresed in a continental asymmetry is not the unic result of differential uplift. The irregularity measured by means of correlations of height vs MIS of terraces, indicates that they are the rusult of tectonic segmetation of the coast, which is higher in the Pacific coast than in the Atlantic one. So, the actual dispersions observed shows true models of segmented coasts in front to the ideal model of Lajoie (1986), which assumes a constant space-time uplift rate for terraces of the different MIS (model of no segmentation).

As conclusion, the model shown by Araya-Vergara (2007) is corroborated by new observations, but with the following new statement: the continental warping of the coast is represented by a trend surface higher in the Pacific than in the Atlantic coast. This surface is a modulation of the irregularities derived from tectonic fragmentation, which is higher in the Pacific edge than in the Atlantic one.

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