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Neotectonism and Sea-Level Changes in the Coastal Zone of Argentina

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ABSTRACT

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For the first time radiocarbon dates with corresponding altimetry over present mean sea level are correlated for the Holocene of Argentina. Relative rates of continental uplift for 15 localities distributed over 3,500 km of the Argentina coast are determined, and a model of coastal evolution is described. Maximum transgressive levels were reached between 4,000 and 6,500 yr BP. The relative uplift rates for the Holocene varied between 0.12 and 1.63 m/1,000 years.

The neotectonism along the Argentina coast is clearly evident as the minimum uplift rates are associated with sedimentary basins while maximum ones correspond to interbasin zones.

ADDITIONAL INDEX WORDS: *Argentine coast, sea-level change, neotectonic activity.*

INTRODUCTION

Argentina has over 3,500 km of coastline facing the southwestern Atlantic Ocean, and a wide and relatively flat continental shelf. Along the coast there are a large variety of geomorphological characteristics ranging from wide, smooth sandy beaches in the Buenos Aires province to 150 m cliffed shores in the Patagonian provinces. There are over 10 major estuaries and another 20 of minor importance that influence coastal sedimentation (PICCOLO *et al.*, 1987). In addition there are tidal flats, salt marshes and river deltas. All of these features are the result of a strong interaction between the sea and continent as the former rose dramatically in the late Holocene. Therefore, one necessary requirement to determine the origin of present coastal geomorphology is to establish the relative sea-level history of the Argentine coast within the late Holocene.

Most studies related to the Cenozoic stratigraphy of the Argentine coast are restricted to specific areas of the coast and show little or no relationship even with adjacent localities. The majority of this work is based on radiocarbon dating of biogenic materials found in the very common, raised beaches that are distributed all along the coast. As a basic characteristic, those raised beaches on the southern shores are associated with high-energy depositional environments; on the contrary, the northern raised beaches are low-energy features.

ALBERO *et al.* (1980) made the first compilation of radiocarbon ages of coastal environments of Argentina, although the first study that actually related radiometric ages with altimetry was presented by MARCOMINI *et al.* (1988).

The regional features of the Argentine coast, namely: (1) its trailing edge tectonic setting, (2) its north–south alignment, and (3) its relationship with the Antarctic geological environment, are all conditions one must understand to appreciate the regional change of late Quaternary sea level. The main objective of the present study is determination of late Quaternary sea level and its interaction with the neotectonic processes that occurred during the Holocene.

Geological Setting

To adequately define relative conditions between different localities spread over almost 3,500 km of coast, it is necessary to first describe the geologic conditions on which each sampling area is dependent. In Figure 1, we indicate with letters A through O the localities, from south to north, where both radiometric and altimetric data were

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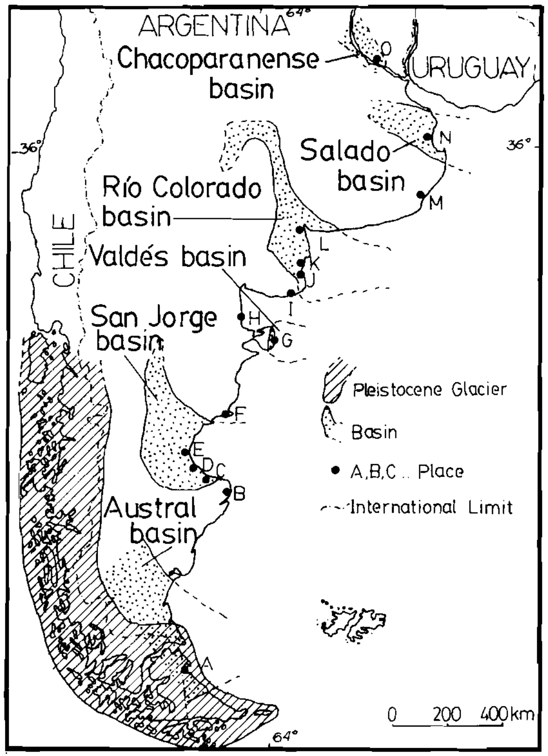

Figure 1. Locations of study sites.

available. The major sedimentary basins associated with the Argentine coast are also shown. They play, as will be demonstrated, an important role in the variations in regional relative sea-level change rates.

The localities A, C, D, E, G, J, K, L and N (Figure 1) are included on basin zones with areas ranging between 204,000 km^2 (Austral Basin) and 19,000 km^2 (Valdés Basin). They are characterized by a thick sequence of Cretaceous-Cenozoic sediments resting over Precambrian–lower Paleozoic metamorphic rocks.

The localities B and F (Figure 1) are over positive areas. They are characterized by extrusive rocks formed during the middle–late Jurassic because of a large volcanic event that occurred on the meridional part of South America. On the other hand, Mar Chiquita (M, Figure 1) is also located on a positive area that is in contact with a low relief range which is mostly formed by Precambrian and Paleozoic rocks.

The neotectonism in the sedimentary basins located on the coasts of Argentina is controlled mainly by basement faulting; however, there is evidence of intermittent reactivation during the Cretaceous period.

Cenozoic sediments from the Salado, Colorado and Valdés basins are undisturbed and only present a regional tilt of 15–30° in the axial zone. On the other hand, in the Golfo San Jorge Basin these sediments are partially disturbed. Only in the offshore region, near the shelf break, there are regional tilts of the order of 5°. Meanwhile the Austral Basin has been affected by compressional tectonism presenting also some folding and inverse faults.

The Argentine Holocene coast is well known on the northern sector for extensive terraces constituted of almost exclusively terrigenous sands with important biogenic concentrations. On the southern sector, the marine terraces are less developed reflecting a higher wave energy environment. They are well known by rounded pebbles and gravels with sandy interstratifications containing biogenic material. Furthermore, the southern end has developed over glacial drift of Pleistocene age (Figure 1). Therefore, the Argentina coast is in general erosive with extensive and tall active cliffs. Among the less frequent marine accumulations the most common are gravel with occasional sandy beaches.

RESULTS AND DISCUSSION

This study is based on the analysis of the relationships between radiocarbon dates and the corresponding altimetric information for 172 samples from 15 localities on the Argentine coast (Figure 1, Table 1). From the original set of 241 samples, 69 samples were discarded because they lack either exact geographical position or altimetric control. Distributed by localities, the corresponding ages, altimetries and geographical locations of the samples are presented in Table 1. In the present study, 18 new radiocarbon ages for localities I and N are introduced, and also indicated in Table 1. Data for localities A thru H, J and K were obtained from CODIGNOTTO (1979, 1982, 1983, 1987), CODIGNOTTO *et al.* (1987, 1988a,b), CODIGNOTTO and KOKOT (1988), BAYARSKY and CODIGNOTTO (1982), CODIGNOTTO and BEROS (1987), TREBINO (1987), CODIGNOTTO and WEILER (1980), ARMELLA (1980), GUIDA (1980), WEILER (1983, 1988), GONZALEZ and WEILER (1983), while those for localities L thru O have been reported by GONZALEZ *et al.* (1982, 1983a,b), FARINATI (1984), GONZALEZ (1989), FASANO *et al.*

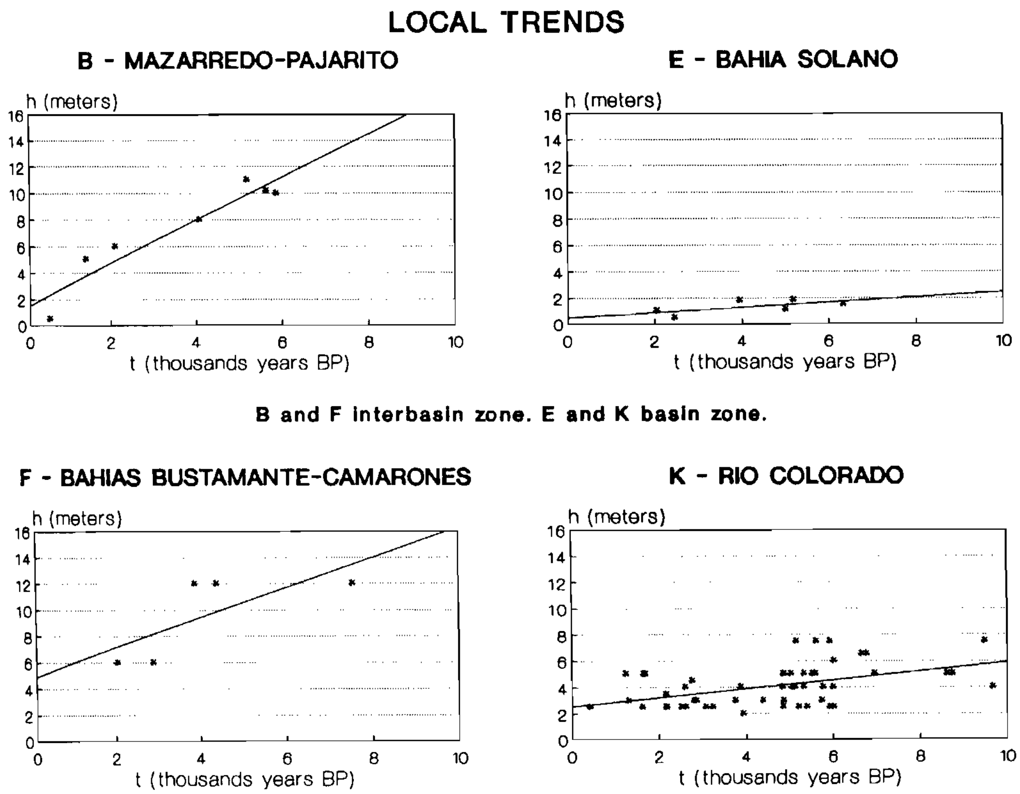

Figure 2. Altimetry-time diagrams with data fitted by least-square linear-regression procedures.

(1983, 1987), HUARTE *et al.* (1983), FIDALGO *et al.* (1981), FIGINI *et al.* (1984), GOMEZ *et al.* (1988), ALBERO and ANGIOLINI (1983, 1985), and GUIDA and GONZALEZ (1984). In all cases radiocarbon dates were corrected by $\delta^{13}C$ and samples correspond to radiometric determinations on complete marine shells found in their living position. The altimetry corresponds to the altitude of the sample above present mean sea level.

Over 60% of the samples occur in a range of ages between 3,500 and 7,000 yr BP, which correlates quite well with the estimated maximum transgression for most of the localities. However, at Río Colorado and San Blas, there are samples with ages between 8,000 and 9,500 yr BP that may be considered anomalous because there are no data from other localities related to them to confirm a possible, previous sea ingression.

Altimetry-time diagrams were produced for each locality and data fitted by least-square linear-regression procedures (4 examples are shown in Figure 2). Although considering a linear tendency gives an *a priori* indication of constant rate of uplift, as a first approach to compare different localities distributed along more than 3,500 km of the Argentina coast, it was selected as a reasonable assumption. The slopes of the linear trends give an estimate of the local rate of relative uplift of the coast. This information transformed to a common scale of m/1,000 yr is provided in Table 2.

The relationship between the velocity rates for each locality (Table 2) and their respective latitudes is shown in Figure 3. The data points were approximated by a cubic-spline curve. With this analysis it is possible to obtain the regional pattern of relative rates of uplift for comparison with the structural and geological associations of each area. Several maximum and minimum rates are observed along the curve. The lower rates of relative landrise are well correlated with the major sedimentary basins located along the Argentina

Table 1. *Radiocarbon dates and heights (m).*

Lat.S	Long.W	Height	Age
A—C. Espiritu Santo–P. Maria			
53.67	67.35	6	2,060 ± 90
53.17	68.62	6	2,990 ± 80
53.17	68.62	5	1,310 ± 100
53.17	68.62	7	3,220 ± 220
53.17	68.62	8	3,820 ± 80
B—Mazarredo–Pajarito			
47.05	66.64	11	5,160 ± 70
47.04	66.64	8	4,070 ± 130
47.04	66.64	6	2,100 ± 60
47.03	66.67	10	5,850 ± 100
47.03	66.67	0.5	500 ± 70
47.03	66.67	10.2	5,600 ± 70
47.03	66.67	5	1,450 ± 75
C—Bahia Lángara			
47.03	66.67	4	1,450 ± 75
47.03	66.67	2	500 ± 70
46.95	66.72	6.5	3,530 ± 100
46.95	67.72	6	4,450 ± 110
46.60	67.35	4.5	1,840 ± 70
46.60	67.35	2	660 ± 80
46.57	67.38	5	3,650 ± 90
46.05	67.62	2	950 ± 90
D—Caleta Olivia			
46.38	67.53	4.8	2,800 ± 140
46.35	67.55	4.7	2,300 ± 240
46.17	67.63	4.5	1,600 ± 700
46.12	67.63	5.5	4,230 ± 95
46.06	67.62	7	6,630 ± 120
46.06	67.62	6.5	6,420 ± 120
46.06	67.62	8	5,750 ± 115
46.05	67.62	7.5	5,230 ± 130
46.02	67.62	5	2,650 ± 50
46.02	67.58	8	5,750 ± 110
—	—	4	1,550 ± 85
E—Bahia Solano			
45.74	67.38	1	2,040 ± 80
45.71	67.36	1.8	3,940 ± 110
45.70	67.37	1.1	4,980 ± 90
45.70	67.37	0.5	2,430 ± 60*
45.70	67.37	1.5	6,310 ± 100
45.70	67.37	1.85	5,170 ± 110
F—Bahias Bustamante–Camarones			
45.07	66.47	6	2,880 ± 90
45.07	66.47	6	2,030 ± 85
44.80	65.68	12	3,860 ± 95
44.79	65.69	12	4,370 ± 95
44.75	65.67	12	7,520 ± 120
G—Caleta Valdés			
42.29	63.16	1	2,160 ± 85
42.22	63.73	6	5,720 ± 105
42.13	63.73	5	5,100 ± 100
42.12	63.73	1	1,330 ± 80
42.09	63.74	5	4,180 ± 100
H—Puerto Lobos			
42.00	65.08	6	750 ± 75
42.00	65.08	8	3,310 ± 90
I—Rio Negro mouth			
41.01	62.79	6	3,370 ± 80*
41.00	62.66	2	1,030 ± 80*
40.97	62.58	3	2,930 ± 90*
J—San Blas			
40.63	62.52	8	5,370 ± 110
40.63	62.52	6.5	4,100 ± 95
40.63	62.52	4.5	3,450 ± 110
40.63	62.52	3	2,320 ± 80
40.58	62.28	7	8,920 ± 120
40.58	62.28	6.5	7,450 ± 160*
K—Río Colorado			
39.96	62.34	4	9,640 ± 120
39.95	62.33	3	4,850 ± 80
39.94	62.33	7.5	5,900 ± 100
39.92	62.33	3.75	5,310 ± 90
39.92	62.33	5	5,570 ± 110
39.92	62.25	7.5	9,460 ± 120
39.92	62.25	2.5	5,900 ± 100
39.92	62.25	6.5	6,750 ± 100
39.92	62.33	2.5	5,200 ± 90
39.92	62.33	3.75	5,980 ± 110
39.92	62.25	5	4,850 ± 100
39.86	62.37	4	5,050 ± 110
39.86	62.37	4	5,100 ± 110
39.86	62.47	4	3,860 ± 90
39.85	62.37	4	3,860 ± 90
39.83	62.32	5	8,720 ± 140
39.82	62.32	5	8,590 ± 135
39.81	62.37	4	4,820 ± 100
39.81	62.35	5	5,510 ± 110
39.81	62.35	2.5	2,170 ± 80
39.80	62.36	5	4,830 ± 110
39.80	62.36	2.5	4,840 ± 100
39.80	62.39	7.5	5,590 ± 110
39.80	62.50	3	4,380 ± 80
39.78	62.18	2.5	2,620 ± 50
39.78	62.20	3	3,740 ± 90
39.78	62.18	3	2,790 ± 90
39.70	62.15	2.5	2,150 ± 110
39.67	62.25	4	2,590 ± 115
39.67	62.25	2	407 ± 100
39.67	62.12	2.5	3,220 ± 100
39.67	62.25	3	1,300 ± 90
39.67	62.25	6	6,000 ± 150
39.67	62.25	5	5,020 ± 100
39.67	62.25	3.5	2,156 ± 115
39.67	62.25	6.5	6,630 ± 120
39.67	62.25	4.5	2,750 ± 100
39.65	62.14	5	1,680 ± 85
39.65	62.13	2.5	2,500 ± 110
39.63	62.08	2.5	407 ± 105
39.63	62.08	2.5	6,000 ± 150

Table 1. *Continued.*

Lat.S	Long.W	Height	Age
39.63	62.18	5	5,310 ± 120
39.62	62.13	2.5	3,060 ± 100
39.61	62.23	5	6,930 ± 130
39.50	62.09	5	1,240 ± 80
39.49	62.06	3	5,750 ± 170
39.49	62.21	4	5,750 ± 170
39.47	62.06	2.5	1,600 ± 95
39.47	62.15	5	5,580 ± 90
39.47	62.07	5	1,640 ± 80
39.40	62.21	2	3,920 ± 60
39.03	62.14	3	2,850 ± 80
—	—	7.5	5,140 ± 110
—	—	2.5	5,390 ± 165
L—Bahia Blanca			
38.88	62.05	3	5,980 ± 130
38.72	62.33	8	6,650 ± 100
38.70	62.08	9.5	6,420 ± 100
38.70	62.08	9.5	6,000 ± 105
38.67	62.33	7	4,470 ± 90
38.67	62.33	7	4,520 ± 110
38.67	62.20	6	4,220 ± 100
38.67	62.33	7	3,570 ± 100
38.67	62.20	15	5,320 ± 100
38.67	62.33	6	3,920 ± 90
38.67	62.33	7.5	4,660 ± 100
38.67	62.33	7	3,950 ± 90
38.07	62.42	11	5,990 ± 115
38.07	62.42	8.5	5,400 ± 140
38.07	62.42	11	6,100 ± 120
38.07	62.42	8.5	5,100 ± 100
38.07	62.42	11	6,600 ± 120
38.07	62.42	11	6,350 ± 110
38.07	62.42	8.5	5,460 ± 105
38.07	62.42	8.5	5,280 ± 105
—	—	8.5	5,420 ± 110
—	—	9	5,470 ± 100
—	—	9	6,130 ± 110
—	—	9	6,000 ± 110
—	—	9	5,720 ± 100

Table 1. *Continued.*

Lat.S	Long.W	Height	Age
M—Mar Chiquita			
37.79	57.46	2.5	1,340 ± 50
37.77	57.25	2	3,430 ± 90
37.74	57.44	1.2	2,700 ± 50
37.74	57.44	1.2	2,920 ± 80
37.62	57.31	1.5	2,830 ± 80
37.62	57.31	1.5	2,880 ± 80
37.47	57.22	2.3	3,110 ± 80
37.45	57.25	2.4	3,840 ± 70
N—Bahia Samborombón			
36.60	56.77	2	1,660 ± 110*
36.45	57.15	2.5	3,000 ± 110*
36.42	56.77	3	5,810 ± 100*
36.40	56.77	2	3,370 ± 100*
36.40	56.75	2	1,970 ± 100*
36.40	56.82	2	2,770 ± 100*
36.33	57.38	5	7,220 ± 500*
36.32	56.75	2	1,720 ± 100*
36.23	57.42	5	4,960 ± 110*
36.11	57.43	4.5	4,860 ± 110*
36.11	57.43	5	5,580 ± 120*
35.97	57.45	4	4,100 ± 110*
35.97	57.45	5	3,320 ± 220*
35.77	57.38	2	2,540 ± 80*
O—Gualeguay			
33.42	58.58	4.5	5,490 ± 110
33.42	58.58	4.5	5,530 ± 110
33.42	58.58	4.5	5,410 ± 110
33.42	58.58	4.5	5,280 ± 100
33.27	59.45	5	5,680 ± 110
33.27	59.38	5	6,440 ± 110
33.25	59.50	5	5,610 ± 110
33.25	59.50	5	5,760 ± 110
33.23	59.47	4.5	5,720 ± 110
33.22	59.52	5	6,030 ± 140
33.22	59.52	5	5,620 ± 110
33.20	59.53	4	5,680 ± 110
33.15	59.28	5	5,960 ± 110

*Radiocarbon data given in the actual report

coast such as the Golfo de San Jorge and Colorado basins. The curve between the Salado and Chacoparanense basins is inferred from the general tendency because we lack adequate radiometric data in between.

Based on this analysis, the regional land rates of uplift range between 0.12 and 1.63 m/1,000 yr. The larger rates are located on the southern localities (Figure 3), almost twice as much as in the northern end.

Although we consider that the rate of uplift may have varied in time, the composite correlation between altitude and age indicates an estimated rate of uplift for all the Argentina coast of 0.65 m/1,000 yr (Figure 4).

SUMMARY AND CONCLUSIONS

Based on radiometric dating of marine shells found at different heights above mean sea level at 15 localities distributed over more than 3,500 km, the general tendencies for the Argentina coast have been analyzed. During the Holocene, the maximum transgression may have occurred between 4,000 and 6,500 yr BP. However, some evidence exists that an earlier transgression, between 8,000 and 9,500 yr BP, occurred in the Colorado Basin, although these values cannot be assessed with similar data in other localities.

Estimates of the relative rates of uplift for the localities range between 0.21 and 1.63 m/1,000 yr,

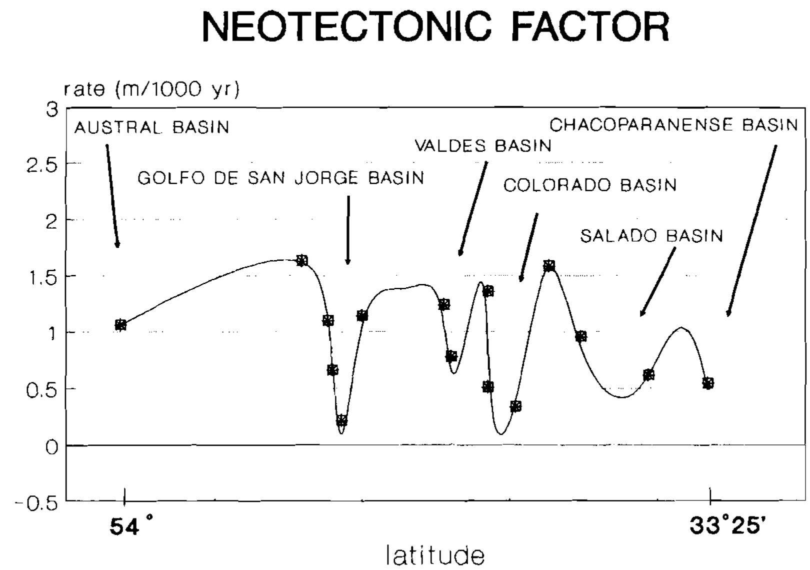

Figure 3. Rates of uplift for major structural features along the Argentine coast.

while the general tendency for all the coast is of the order of 0.7 m/1,000 yr. There is clear evidence that maximum rates are associated with inter-basin regions while minimum ones are found in the basins. This difference reflects the influence of neotectonic processes acting during the last 10,000 yr.

The southern end of the country shows uplift rates about twice as large as those observed near Buenos Aires, indicating a differential process.

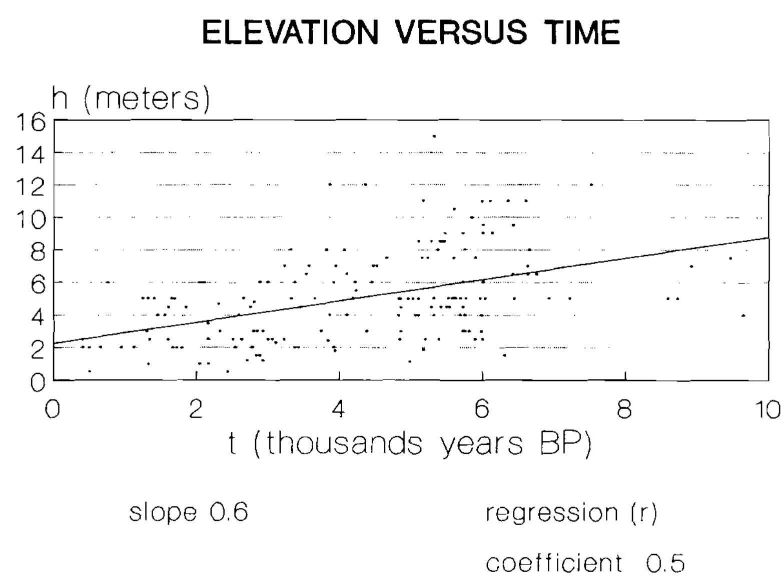

Figure 4. Composite rate of uplift along the Argentine coast.

Table 2. *Slope values for each studied locality.*

Location	Slope	Regression Coefficient (r)
A—C. Espiritu Santo–P. Maria	1.06	0.92
B—Mazarredo–Pajarito	1.63	0.95
C—Bahia Langara	1.10	0.92
D—Caleta Olivia	0.66	0.90
E—Bahia Solano	0.21	0.70
F—Bahia Bustamante-Camarones	1.14	0.73
G—Caleta Valdés	1.24	0.97
H—Puerto Lobos	0.78	1.00
I—Negro River mouth	1.36	0.81
J—San Blas	0.51	0.69
K—Colorado River	0.34	0.50
L—Bahia Blanca	1.58	0.68
M—Mar Chiquita	0.95	0.76
N—Bahia Samborombon	0.61	0.76
O—Gualeguay	0.54	0.50

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□ ZUSAMMENFASSUNG □

In dieser Arbeit werden zum ersten Mal Radiokarbon-Daten und ihre Höhenlage in bezug auf den gegenwärtigen Meeresspiegel für das Holozän von Argentinien in Beziehung gesetzt. Relative Raten kontinentaler Hebung wurden für 15 Lokalitäten entlang der 3,500 km langen argentinischen Küsten bestimmt und daraus ein Modell der Küstenentwicklung entworfen. Die max. Werte der Transgression wurden zwischen 4,000 und 6,500 B.P. erreicht. Die relativen Hebungsraten für das Holozän schwanken zwischen 0.12–1.63 m/1,000 Jahre. Das neotektonische Verhalten an der argentinischen Küste zeigt ganz klar die geringsten Werte im Bereich von Sedimentbecken, während die höchsten mit zwischengeschalteten Lagen außerhalb der Becken korrespondieren.—*Dieter Kelletat, Universität Essen, Germany.*

□ RÉSUMÉ □

On a pour la première fois correllé les datations au radiocarbone avec les altitudes correspondantes pour le Holocène de l'Argentine. Pour 15 localités réparties sur 3500 Km de côtes, on a déterminé les valeurs relatives de transgression continentale, et un modèle de l'évolution côtière est décrit. Les niveaux maxima de la transgression ont été atteints entre 4000 et 6500 BP. La valeur moyenne de la transgression varie entre 0,12 et 1,63 m/1000 ans. La néotectonique est évidente sur les côtes d'Argentine: les minima de surélévation sont associés aux bassins sédimentaires, et les maxima correspondent aux zones interbassins.—*Catherine Bousquet-Bressolier, Géomorphologie EPHE, Montrouge, France.*

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In dieser Arbeit werden zum ersten Mal Radiokarbon-Daten und ihre Höhenlage in bezug auf den gegenwärtigen Meeresspiegel für das Holozän von Argentinien in Beziehung gesetzt. Relative Raten kontinentaler Hebung wurden für 15 Lokalitäten entlang der 3500 km langen argentinischen Küsten bestimmt und daraus ein Modell der Küstenentwicklung entworfen. Die max. Werte der Transgression wurden zwischen 4000 und 6500 B.P. erreicht. Die relativen Hebungsraten für das Holozän schwanken zwischen 0,12–

1,63 m/1000 Jahre. Das neotektonische Verhalten an der argentinischen Küste zeigt ganz die geringsten Werte im Bereich von Sedimentbecken, während die höchsten mit zwischengeschalteten Lagen außerhalb der Becken korrespondieren.—*Dieter Kelletat, Universität Essen, Germany.*