ARE ALL RAISED QUATERNARY MARINE TERRACES RECORDS OF HIGH SEA-LEVEL STANDS?

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ABSTRACT

From the international literature on raised flights of Quaternary marine terraces described worldwide, an implicit assumption seems to be currently in use: all of the outcropping (either constructional or erosional) marine terraces are related to sea level highstands. It commonly happens that this assumption is correct but every rule has its exceptions. In this paper we bring supporting evidence that ask for the careful use of this assumption. Therefore, detailed chronology of every single raised marine terrace is needed to corroborate its actual position in the step-like history of raised staircased marine terraces.

Keywords: Terrace flights, Marine terraces, Highstand, Quaternary, Absolute chronology.

¿SON TODAS LAS TERRAZAS MARINAS CUATERNARIAS EMERGIDAS REGISTROS DE ALTO NIVEL DEL MAR?

RESUMEN

El uso de los sistemas emergidos de terrazas marinas escalonadas cuaternarias, como marcadores de deformación tectónica vertical, descritas en la literatura mundial, parecen tener la siguiente suposición subyacente: todas las terrazas marinas (erosivas o constructivas) emergidas son automáticamente correlacionadas a un nivel alto del mar (“sea level highstand”) o a un máximo nivel interglaciar. Éste es generalmente el caso, pero toda regla aparenta tener sus excepciones. En este artículo presentamos evidencia que prueba que esta suposición debe ser manejada con sumo cuidado. Por ende, se recomienda que cada nivel de terraza marina emergida sea datada por métodos absolutos para probar su verdadera posición dentro de la serie de terrazas marinas escalonadas.

Palabras clave: Sistemas de terrazas, Terrazas marinas, Alto nivel del mar, Cuaternario, Cronología absoluta.

INTRODUCTION

In the last 30 years or so, the development of new, modern and more precise dating techniques (e.g., Uranium series, thermoluminiscence –TL-, optically stimulated luminiscence –OSL-, electron spin resonance –ESR-, among others; refer to Stratton *et al*. (2000) for more details on methods and applications), in combination with a more accurate reconstruction of the history of Quaternary sea levels based on variations in the oxigen isotopic composition of sea water (Shackleton & Opdyke 1973, Bloom *et al*. 1974, Chappell 1974, Chappell *et al*. 1996), has launched or accelerated the study of raised marine features in tectonically-active regions worldwide, as well as improved their time resolution. This has also been the case in Venezuela (Caraballo & Macsotay 1973; Schubert & Szabo 1978; Audemard 1993, 1996b, 1996c; Audemard *et al*. 1997; Méndez 1985a, 1985b, 1997). This has led to a better determination of vertical slip rates based on raised marine features. Very many appropriate areas have been studied in that respect and some regions of the world have become actual natural laboratories, such as Barbados in the west tropical Atlantic and Huon Peninsula in Papua-New Guinea.

SEA-LEVEL HIGHSTANDS

In these two sites (Barbados and Huon Peninsula) as in many others, a set of raised marine terraces (or coral tracts) has been thoroughly recognized and dated, and a tectonic vertical slip rate has then been derived in each case. However, from reading several publications regarding staircased uplifted Quaternary marine terraces, I have gained the feeling that a tacit assumption is being used worldwide when studying such series of constructional and/or erosional marine features: the higher the terrace or reef is, the older it must be. Examples to support this are very many but just to illustrate it, Burbank & Anderson (2001), although they clearly state that when sea level is stable for sufficiently long periods, corals will build platforms that are closely tied to sea level…, also indicate that these terraces (refering to the Huon Peninsula case) get older with increasing elevation, and they record the relative sea-level change through time". In the same sense, these authors say that a rising coastal landmass is like a strip chart that records and uplifts the geologic record of each successive high sea-level stand. To support this statement they use a case study from Lajoie (1986 in Burbank & Anderson 2001), where only the highstands of a real sea-curve are successively and successfully correlated with the raised strandlines. Ward & Valensise (1994) also use this same assumption when modelling or predicting patterns of strandlines cut in a steadily-growing anticline.

Consequently, the above-mentioned assumption implies that: 1) all preserved features correspond to sea level highstand deposition and 2) no marine units, detrital or biogenic in origin, can form or be preserved during sea level lowstands. This is in straightforward disagreement with the concept of reef tract formation during a certain stability of sea level if the time length needed to construct a reef is met (Bender *et al*. 1979); concept also applicable to detrital deposition. Therefore, Audemard (1996a) concludes that any relative sea level stillstand, highstand or lowstand -when a certain sea level stability occurs (e.g., when tectonic uplift and sea level rise rates are similar that generates a relative stability)- can allow deposition of beach facies and/or grow of coral reefs if conditions are given; although it is known that sea level lowstands do not offer the most favorable conditions for coral growth due to sea level fall, forcing corals to prograde instead of growing upward (James & Whittaker, 1990). About the previously-mentioned wide-spread assumption, Audemard (1996a) indicates that it should perfectly function in areas of as many as 80-to-100 m of recorded constant uplift if we take into account that maximum amplitude of sea level oscillation between glacial and interglacial periods is regularly assumed to be ranging between 100 to 130 m. However, in areas where outcropping marine terraces or reef tracts are as high as 200 m or even higher (Barbados, Peru, Chile, Indonesia, Papua-New Guinea, among others), Audemard (1996a) postulates that records of sea-level lowstands should also crop out and/or interfer with younger sea-level highstands

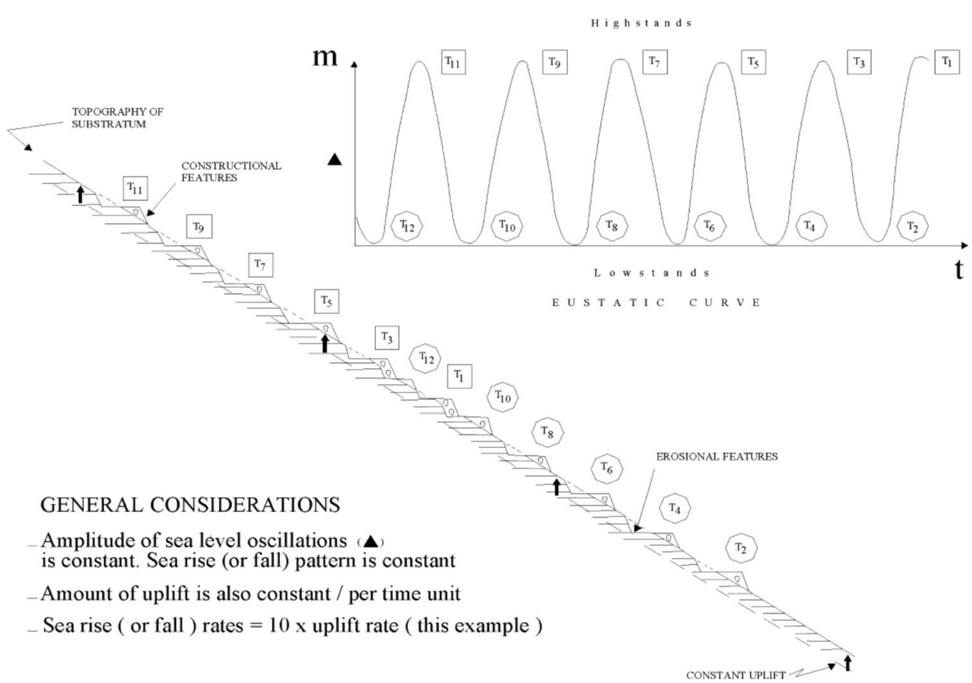

Figure 1. Evaluated case of uplift coast is the simplest, since uplift rate is constant and eustatic sea-level oscillations always keep the same amplitude and pattern. Schematic profile showing how highstand and lowstand records keep apart while total amount of uplift is less than amplitude of sea level oscillations between glacial and interglacial periods (after Audemard, 1996a). On the contrary, they mix when total uplift is higher than amplitude of sea level oscillation (see middle portion of profile).

in the lower section (in some cases even in the middle part depending on how high the uplift rate is) of the staircased sequence of marine terraces or reef tracts, if not eroded or capped by younger deposits (Figure 1). Particular coastal environments, commonly of low energy, would favor preservation of the low sea-level stand deposits/features and avoid erosion by the younger superimposed highstands, such as leeward side of islands, protected coastal embayments and eventually estuaries. In the same sense, Yeats *et al*. (1997) clearly state that marine erosional terraces are cut at a time when the tectonic uplift rate and the rate of eustatic sea-level rise are about the same and this is reached just before a eustatic sea-level maximum and just after a minimum. In other words, this condition is always met in rising sea-level, either when rise rate decreases to reach a highstand or when rise rate starts to increase just after a lowstand (refer to Figures 7-19 of Yeats *et al*. 1997). Next, we shall present supporting evidence to the eventual intercalation of lowstand relics among highstand equivalents.

BARBADOS REVISITED

Two sites in Barbados (indicated A and B in Figure 2), located on top of the accretionary wedge east of the Lesser Antilles subduction in the west tropical Atlantic ocean, image the actual intercalation of lowstand deposits into a rather well understood and thoroughly studied sequence of raised highstand marine terraces or reef tracts. The first example comes from Animal Flower Cave (Figure 3), which is in the northern coast of the island (Figure 2). This cave was

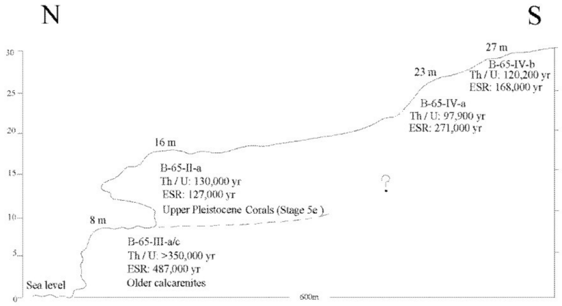

Figure 3. Schematic profile of Animal Flower Cave, indicating Th/U and ESR ages (after Radtke *et al*. 1988).

carved by wave action and lies at about 8 m above present sea level. Here, older Calcarenites (dates: Th/U: >350 ka and ESR: 487 ka, after Radtke *et al.* 1988) are overlain (and partly truncated?) by a stage 5e reef tract (dates: Th/U: 130 ka and ESR: 127 ka, after Radtke *et al.* 1988, Figure 3). The overlain unit age does not correlate with any known eustatic sea-level highstand. However, if it is assumed that: (1) the maximum sea level oscillation is about 100 m from glacial to interglacial periods (Burbank & Anderson, 2001) and (2) the older calcarenites from Animal Flower Cave are hypothetically ascribed to a sea level lowstand, the derived uplift rate for northern Barbardos is about 0.278 m/ka (100 m/360 ka). This value is very similar to the rates calculated by Radtke & Grün (1990), along three different traverses (Christ Church, Clermont Nose and Thorpe) in southern and western Barbados, ranging between 0.24 and 0.384 m/ka. This would suggests that ages may be right as well as our assumptions.

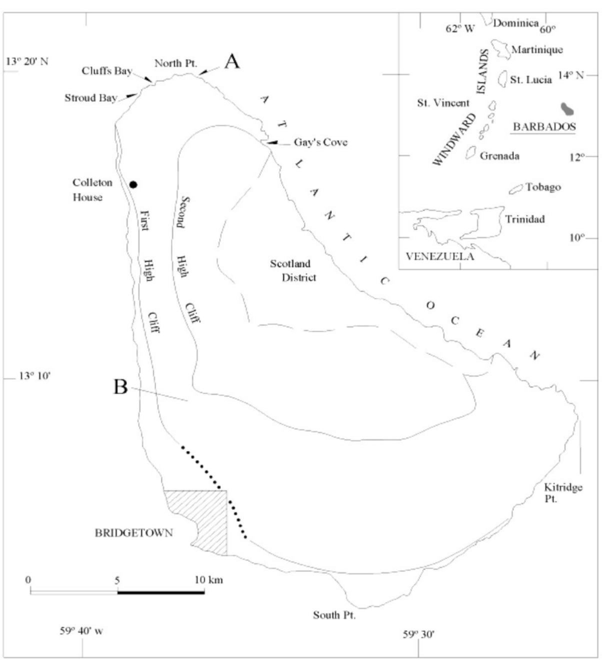

Figure 2. General map of Barbados, indicating relative location of the two visited sites (simplified from Radtke *et al*. 1988): A: Animal Flower Cave, B: Thorpe traverse.

The second evidence (B in Figure 2), also from Barbados Island, correponds to an unexplained natural fact, that was mentioned by Dr. Radtke during a field trip to western Barbados attended by the author in November 1993. The issue that called my attention upon was the occurrence of a deeply recrystallized reef tract (undated on published cross-sections by Radtke & Grün 1990, Figure 4) at about a 105 m in elevation that is topographically intercalated between two perfectly preserved reefs. These two neighboring reef tracts had been normally ESR dated and ascribed respectively to isotope stage 9 and 11 (possibly 13?) by Radtke & Grün (1990). Therefore, not to accept this as an older low sea-level stand, which would easily account for its high degree of recrystallization in comparison with its unaffected neighbour reef tracts, many speculations on very rapidly changing climatic and very site-specific conditions are to be called on. This would seem very unlikely, when all of the dated highstand tracts are well-preserved; more likely indicating that climate has not significantly changed in the last 500 ka. If this strandline corresponds to a lowstand, its age could be estimated at 700 ± 150 ka (stage 20?), assuming a total uplift in the order of 200 m (present height + eustatic low sea-level of at least -100 m) and a constant uplift rate (0.24-0.384 m/ka) (Radtke & Grün, 1990).

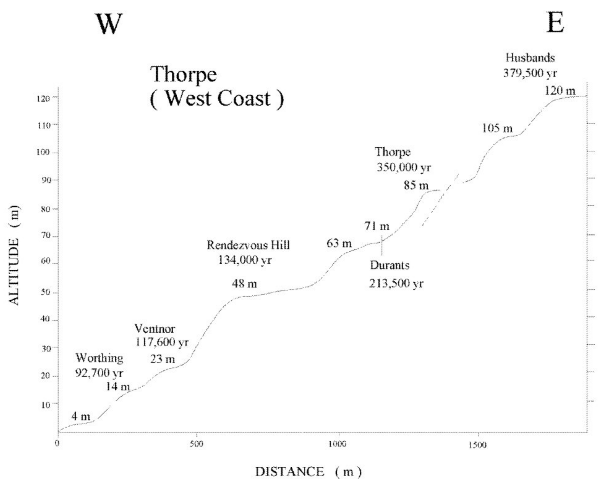

Figure 4. Thorpe traverse, across the west coast (after Radtke *et al*. 1988). Notice that the 105-m-high terrace is undated, while terraces below and above are.

DISCUSSION

These two observations have drawn my attention to the possible occurrence of older marine features "drowned" among younger biogenic or detrital raised marine units. The most likely explanation to this would be that older lowstand records are mixed among younger highstands records, as imaged in Figure 1. Some other study cases from all over the world have confirmed my strong belief that some of the terraces, for instance those described by Ota *et al.* (1995) on Huon Peninsula of Papua-New Guinea, correspond and could be ascribed to eustatic sea-level lowstands. In that particular case, a 400 m tectonic uplift has happened since the last interglacial (maximum uplift rate of about 3 m/ka), raising several constructional terraces, U-series dated between 70 and 40 ka BP, that should match to some glacial maxima.

CONCLUSION

No age of any single marine strandline can be taken for granted, even within an apparent continuous steadily-rising marine terrace flight. Two cases in the repeatedly studied sections of the Barbados island attest to this, where low sea-level stands appear intercalated among highstands records. Therefore, if these intercalations of older lowstands and younger highstands are to occur in areas under rather quick tectonic uplift, fine dating techniques (^{14}C, ESR, U-series, Th/U, TL) are required to date precisely each level of a set of staircased (erosional or constructional) marine terraces since any relative age ascription or isotope stage interpolation or extrapolation can be performed without any reasonable doubt, implying that the single application of geomorphological and/or paleontological correlations may be very risky and misleading.

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