Diagenetic rejuvenation of raised coral reefs and precision of dating. The contribution of the Red Sea reefs to the question of reliability of the Uranium-series datings of middle to late Pleistocene key reef-terraces of the world.

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Abstract: This paper is a general review of the dating of reefs on the coasts of the Red Sea, including those of Egypt, Jordan, Sudan, Eritrea, Saudi Arabia and Djibouti. New methods of sampling and dating (U/Th) already tested on the reefs and associate deposits of the African coast of Egypt have demonstrated that processes of rejuvenation shown to exist in the best-preserved corals are probably attributable to the diagenesis of the organic material in their bio-minerals, thus justifying a revision of a great many datings of corals supposedly younger or older than the age assigned to the high-level isotopic substage ($\delta^{18}O$) MIS 5.5 (= 5e). During this late Pleistocene substage, a rapid lowering of sea level, short and limited to about ten meters, was detected and associated with a glacio-eustatic episode of global influence. A comparison of these Middle East reef chronologies with those of New Guinea, Australia and the western Atlantic that are referred only with difficulty to the $\delta^{18}O$ global sea-level curves, casts doubt on the reliability of many regional reconstructions. Moreover the most "classic" reef chronologies, more or less out-of-phase with global isotopic records calls for a reexamination of the chronologic basis of the reference curves derived from marine isotopic data.

Key Words: Th/U α dating; coral reef; Pleistocene; Red Sea; diagenesis; glaciation; sea-level change; rejuvenation hypothesis; Australia; Bahamas; Barbados; Bermudes; Djibouti; Egypt; Eritrea; Ethiopia; Jordan; Papua New Guinea; Sudan.

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Résumé : *Rajeunissement diagénétique des récifs émergés et précision des datations absolues. La contribution des récifs quaternaires de la Mer Rouge à la question de la fiabilité des datations par la méthode des déséquilibres radioactifs de la famille de l'uranium des terrasses récifales de référence du Pléistocène moyen et supérieur.-* Une revue générale des datations de récifs de la Mer Rouge, affleurant sur les côtes d'Égypte, de Jordanie, du Soudan, d'Érythrée, d'Arabie Saoudite et de Djibouti, est commentée en fonction des méthodes d'échantillonnage et de datation, par comparaison avec les nouvelles conceptions testées sur les récifs égyptiens et divers dépôts associés. Des processus de rajeunissement révélés par les coraux les mieux préservés, attribuables à la diagenèse de la matière organique des bio-minéraux, justifient une révision de beaucoup de datations de coraux supposés plus récents ou plus anciens que l'âge admis pour le haut niveau marin du sous-stade isotopique ($\delta^{18}O$) MIS 5.5 (= 5e). Une baisse rapide du niveau de la mer, brève et limitée à une dizaine de mètres, a été mise en évidence pendant cette culmination majeure du Pléistocène supérieur et interprétée en termes de glacio-eustatisme dont l'enregistrement se doit d'être global malgré sa brièveté. Une comparaison avec les chronologies récifales les plus "classiques", de Nouvelle-Guinée, d'Australie occidentale et des Caraïbes, plus ou moins décalées vis-à-

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vis des courbes globales (isotopiques) du niveau de la mer remet en question plusieurs reconstitutions régionales et appelle un réexamen du fondement chronologique des courbes de référence qui en ont résulté.

Mots-Clefs : Datation radiométrique Th/U ; récif corallien ; Pléistocène ; Mer Rouge ; diagenèse ; glaciation ; variation du niveau marin ; hypothèse du rajeunissement ; Australie ; Bahamas ; Barbades ; Bermudes ; Djibouti ; Égypte ; Érythrée ; Éthiopie ; Jordanie ; Papouasie Nouvelle-Guinéa ; Soudan.

1. Introduction

The Pleistocene reefs of the Red Sea were among the first worldwide references concerning raised reefs (Darwin, 1842; Newton, 1899; Sandford & Arkell, 1939). A few Egyptian, Sudanese and Djibouti coral reefs were dated before 1980 (Butzer & Hansen, 1968; Veeh & Giegengack, 1970; Faure *et alii*, 1980) while other dates appeared in more recent decades, many of them assigning an extremely wide range of age to the lower of the reefs referred to Late Pleistocene times: from 150 to 50 ka. The most recent detailed studies of Egyptian reefs (Gvirtzman *et alii*, 1992; Gvirtzman, 1994; El Moursi, 1992; El Moursi *et alii*, 1994) interpreted the younger dates as indicative of the probability that 5c and 5a reefs are a part of above sea-level outcrops, despite the absence of evidence of an adequate upheaval of the associated 5e reef (see Reyss *et alii*, 1993; Plaziat *et alii*, 1998a, Fig. H2.35). On the other hand, an assumed tectonic activity during Holocene times (rift shoulder surrection or evaporite diapirism) in the preexisting hemi-graben series induced Ibrahim *et alii* (1986) to mistake a late Pleistocene (5e) reef for a raised Holocene reef and to refer gypsum residual tables of the same 5e substage (culminating more than 3 m above the Present littoral sabkhas) to Holocene salinas or sabkhas (see Orszag-Sperber *et alii*, 2001). In this paper we compile and discuss all the available Red Sea reef data, and compare them to the results of our 15 years of research on the reef stratigraphy of the Egyptian part of this shoreline (Fig. 1).

After the French and European research programs in association with Assiut University (Egypt) named GENEBASS and RED SEA, devoted to the initiation and development of the rift basin of the Red Sea and Gulf of Suez - mostly during Oligocene-Miocene times (first published in Montenat, 1986; Aissaoui *et alii*, 1987; synthesized in Purser & Bosence, 1998) - we began investigations on the post-rift Plio-Quaternary deposits to elucidate the possible influence of reactivated tectonics. The continental pediment (alluvial fans) merging into a narrow marine platform (fan deltas and reefs) were studied along the Egyptian Red sea coast from climatic and tectonic points of view (Freytet *et alii*, 1993; Plaziat *et alii*, 1989, 1990). The more recent association with the "Laboratoire des Sciences du Climat et de l'Environnement" (L.S.C.E) at Gif-sur-Yvette (France) favored a special study of the late Quaternary reefs and associated deposits (PNRCO research program), based on the introduction of an absolute chronology (Reyss *et alii*, 1993; Choukri, 1994; Plaziat *et alii*, 1995, 1998a, 1998b). That research introduced new methodological procedures and produced unexpected paleoclimatic outcomes (Plaziat *et alii*, 1998b).

Figure 1: Locations of the localities studied on the Red Sea coast of Egypt.

From at least earliest Pleistocene times, the Egyptian coast of the Red Sea has been characterized by the development of fringing reefs. Though the current arid to hyperarid climate of the eastern Sahara desert fluctuated owing to glacial-interglacial cycles, the tropical latitudes (24°-30° N) appear to have favored reef development during every interglacial highstand of sea-level. The Pleistocene sequences show at least five reefal units above the Present sea level. The earlier, undated Pleistocene fringing reefs have been raised moderately, up to 50 m (PLAZIAT *et alii*, 1990, 1998a), whereas the late Pleistocene reefal terrace has remained near its original altitude (averaging only 4 m of upheaval, REYSS *et alii*, 1993; PLAZIAT *et alii*, 1998a) everywhere, with the exception of a limited area at the entrance of the Gulf of Suez (Gebel Zeit), where the local rise of the hanging wall of a tilted block, caused by a reactivation of rift tectonics, does not exceed 14 m (PLAZIAT *et alii*, 1995, 1998a).

During the humid substages of the last glacial cycle, the Red Sea Egyptian coast and its hinterland remained in the driest Sahara desert core, apart from the heavy rain extensions of the Indian monsoon and Mediterranean rain referred to as "pluvial" stages, such as the Holocene Optimum (see ORSZAG-SPERBER *et alii*, 2001), responsible for the temporary contraction of the Sahara. The limited and episodic increase of rainfall and the relative tectonic stability of the shoreline suggest that the Egyptian reefs constitute an extremely favorable objective for a detailed study of the global climate and the instability of sea level during the late Quaternary highest stands (*i.e.* above Present sea level) for they were recorded by reef units referred to the Marine Isotopic Stages, MIS 7, MIS 5.5 and MIS 1 (= Mid Holocene Optimum) according to the $\delta^{18}O$ terminology (MARTINSON *et alii*, 1987).

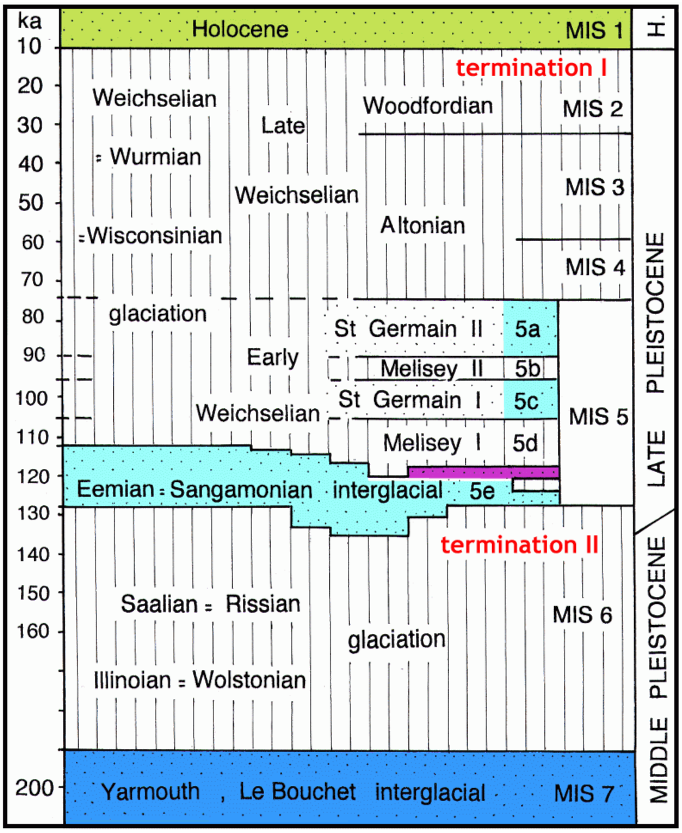


Figure 2: Relationships of the classical time scale allotted to the Upper Middle Pleistocene through Holocene. Ranges of the glacial stages and their proposed correlation with the Marine Isotopic Stages (MIS). Dots indicate warmer interglacial episodes. Note the several proposals derived from the literature for the time of initiation and the length of the Last Interglacial Stage, MIS 5.5.

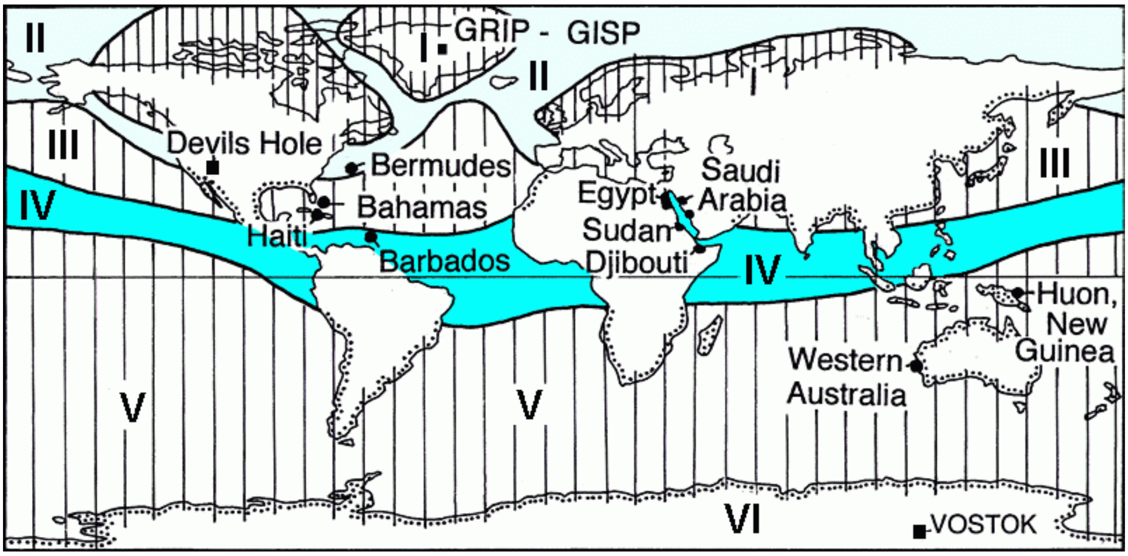


Figure 3: The locations of the principal late Quaternary reef and continental sites of the world mentioned in this contribution are indicated by the small black squares and circles (*e.g.* Huon, New Guinea). Post-glacial evolution: white areas with Roman numerals are tracts where glacio-isostatic rebound occurs. Blue areas (II and IV) indicate tracts without rebound according to CLARK *et alii*, 1978: Black dots paralleling coastlines indicate areas where "emerged beaches are expected in zones I, III, V and VI, whereas zones II and IV are continuously submerged".

The chronology of reefal and other marine and continental units is also referred, tentatively, to the accepted terminology of warmer and cooler episodes (glaciation substages) of the higher latitude Quaternary, keeping in mind uncertainties about the acceptance of and duration of most of the stratigraphic terms used in Europe and N. America (Fig. 2).

A critical comparison with other notable reefal areas in the world (location in Fig. 3) regarded as the major references for curves of variation in sea level was necessary, because the Egyptian findings do not coincide precisely with most of them. As the Egyptian coast did not suffer a major tectonic upheaval, we had only to take into account the possible influence on the height of relative sea-levels associated with the glacio-eustatic rebound anticipated during and after the melting episodes referred to as glaciation "terminations" (post-Saalian and post-Weichsellian terminations II and I). Modeling by CLARK *et alii* (1978) of shoreline behaviors on a global scale (Fig. 3) suggests that the Egyptian coast enjoyed a neutral situation, for it was at the boundary between emergent and submersed zones.

This is corroborated by the Holocene truncated (emergent) corals. They suggest a less than ± 1m rise of the Holocene Optimum mean sea-level (PLAZIAT *et alii*, 1998a).

2. The regional organization of the Egyptian late Quaternary reefs and associated marine deposits.

The Pleistocene fringing reef belt is nearly as continuous as the modern living reef, from the border with Sudan (S of Ras Banas, 24°N) to the entrance of the Gulf of Suez (28°N) (Fig. 1). Along the 500 km of coastline, the low carbonate cliff is interrupted only by flat-bottomed erosional valleys and low gradient, distal alluvial fans. Terrigenous detrital intercalations are very rare and local within the carbonate unit which therefore has been considered unique in the apparent absence of significant discontinuities in its growth, except where radiometric dates older than those anticipated suggested concealed superpositions. The littoral carbonate terrace generally includes fringing reefs and their shelly or terrigenous caps of pebbly beach referable to the same high stand. Consequently, we use the term "reef-and-beach unit" for the set of deposits associated with a single highstand (Figs. 4.1 - 4.2 - 4.3 - 4.4).

The tabular reefal unit extends inland from a few meters (rarely) to hundreds of meters (ranging up to two kilometers) and is commonly separated from the terrigenous inland relief by a line of depressions parallel to the coast. These depressions exist because erosion was more rapid where the reef rock cap meets the subjacent alluvial fan of non-lithified, soft detritus (Figs. 4.1 - 4.2). South of Safaga, 15 of these spaced basin fills are characterized by a low lying, white laminated gypsum deposit, now preserved in residual tables. Their location behind the relief formed by the fossil reef along the littoral suggests that they are either a sabkha or a marine salina deposit. The laminated and draped structure of this gypsum unit demonstrates subaqueous deposition in a salina environment. A layer of fossiliferous sand changing upward from an open-marine to a hyperhaline lagoonal environment precedes the deposition of laminar gypsum. The deep erosion to the Present sea level or a little below it that grooves into the reef-and-beach unit prior to the deposition of the gypsum, together with the lithologic sequence of the strata comprising the fill, led to the conclusion that most of the gypsum salinas were formed in marine-water basins that eventually became landlocked (PLAZIAT *et alii*, 1998a, 1998b; ORSZAG-SPERBER *et alii*, 2001). The detailed study of 10 of the 15 paleo-salina basins demonstrated that this morphology resulted from fluvial erosion during a lowstand, in back of the reef rim capped with beach deposits. The erosion removed the unconsolidated terrigenous substratum to a floor below that of the Present Sea-Level. The lithology of that floor includes Quaternary alluvial fans, Pliocene subtidal gravels, or sandwiched beach gravels and reef carbonates of earlier Pleistocene ages. The pattern of this wadi-like erosion is generally elongated parallel to the coast, perpendicular to the wadi drains that cut through the less than 10-meter-high littoral belt of carbonate terrace. Flooding by sea water through the narrow channel thus formed drowned the basin during the subsequent highstand (a second 5e marine transgression according to our interpretation; see below and PLAZIAT *et alii*, 1998b). The restricted width of this entrance channel accounts for an almost ubiquitous evolution towards its rapid and complete closure that resulted in the development of a salina environment in the lagoons. During the same highstand, basal subtidal sands, rich in marine mollusks and locally associated with reef corals were deposited on the seaward littoral while the closure did not exclude sea-water seepage through the sediment plugging the channel. The water level of the closed basin did not change significantly until the end of the highstand, including during the sedimentation of the laminated gypsum, several meters thick. Such an evolution of discrete landlocked marine basins formed by fluvial erosion appears to be a specific of arid tropical coasts. In Arabic they are usually referred to as "khor" (pronounce ror); thus we suggested that this term be used to specify and to describe the environment of the initial basin (PLAZIAT *et alii*, 1998a, 1998b; ORSZAG-SPERBER *et alii*, 2001). Accordingly, we propose to use the terminology "khor-to-salina evolution" and "khor-salina basin" or "-fill" (see Sharm el Luli section, Fig. 4.1). The complete sedimentary sequence so indicated comprises basal marine deposits followed by restricted lagoonal deposits (shelly sands with a lower

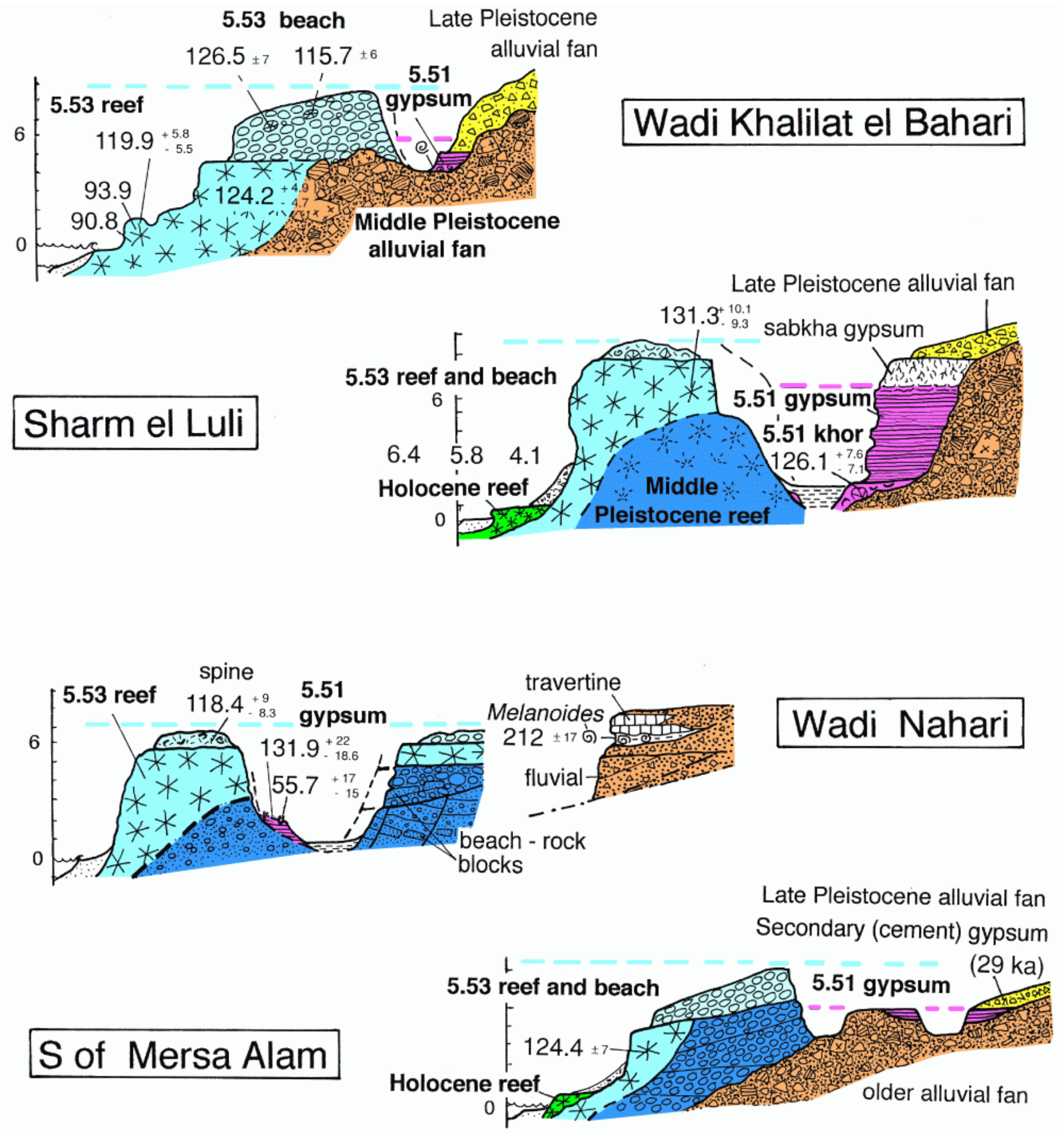


Figure 4.1: Schematic relationships of Late Pleistocene marine deposits in selected sites on the Egyptian Red Sea coast. Variations in the geometrical and chronological associations between the reef-and-beach entity referred to MIS 5.53 and its substratum. The entrenched khor-to-gypsum salina deposits are interpreted as the fills of erosional valleys of small wadis, excavated during the 5.52 lower stand of sea-level and drowned by the following MIS 5.51 sea rise. The respective Th/U dates (ka) are precisely located with respect to their altitude and distance from the sea, which demonstrates the rejuvenating influence of nearby sea-water in biogenic carbonates and the local recrystallization of gypsum at Wadi Nahari. Horizontal distances not to scale.

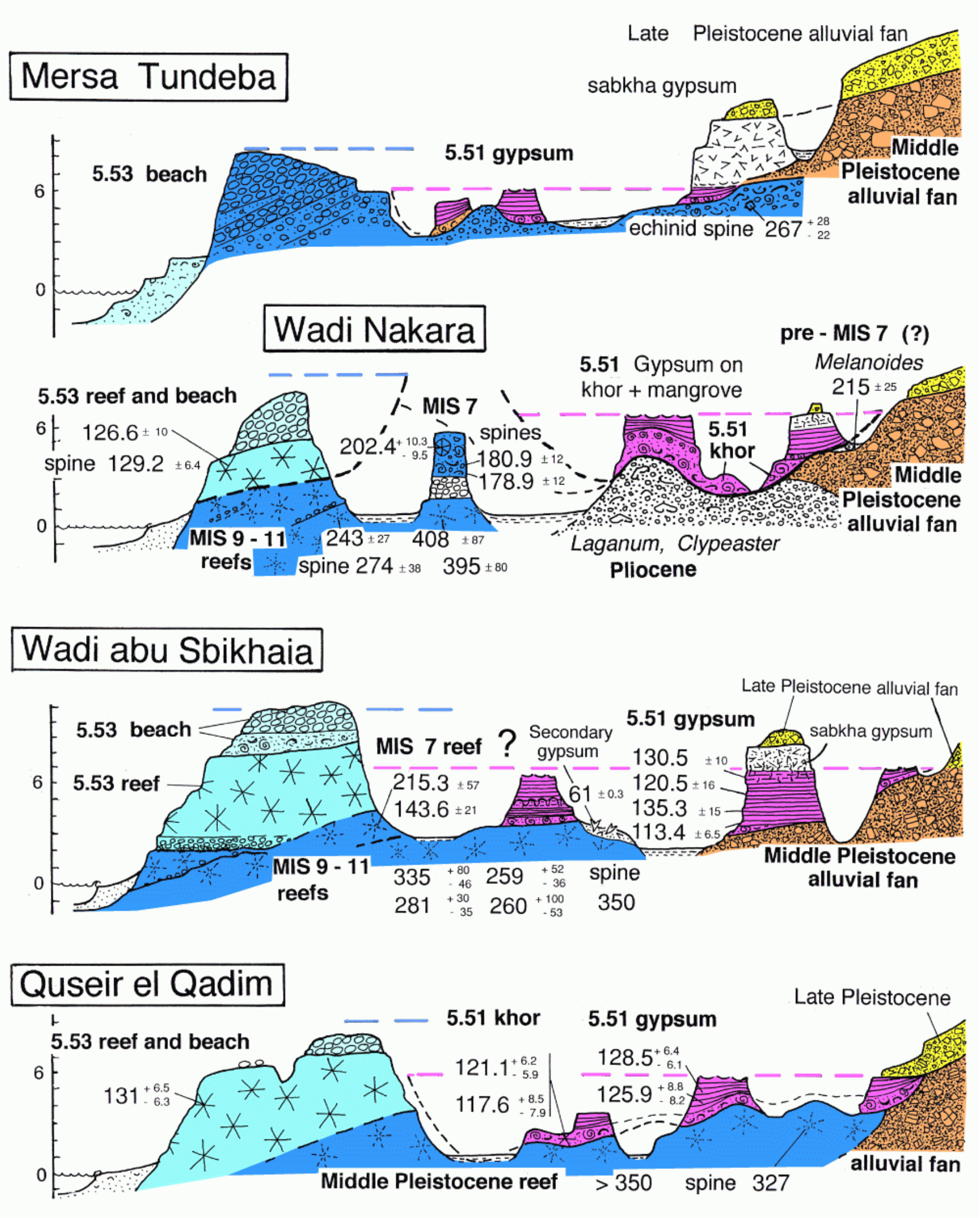


Figure 4.2: Schematic relationships of Late Pleistocene marine deposits in selected sites on the Egyptian Red Sea coast. Associations of the entrenchments in the MIS 5.51 khor-to-salina unit to various substrata ranging in age from Late Pliocene to the Late Pleistocene MIS 5.53 reef-and-beach unit deposited just before the entrenchment. Late Pleistocene continental deposits (sabkha, alluvial fans) cap the 5.51 marine gypsum locally.

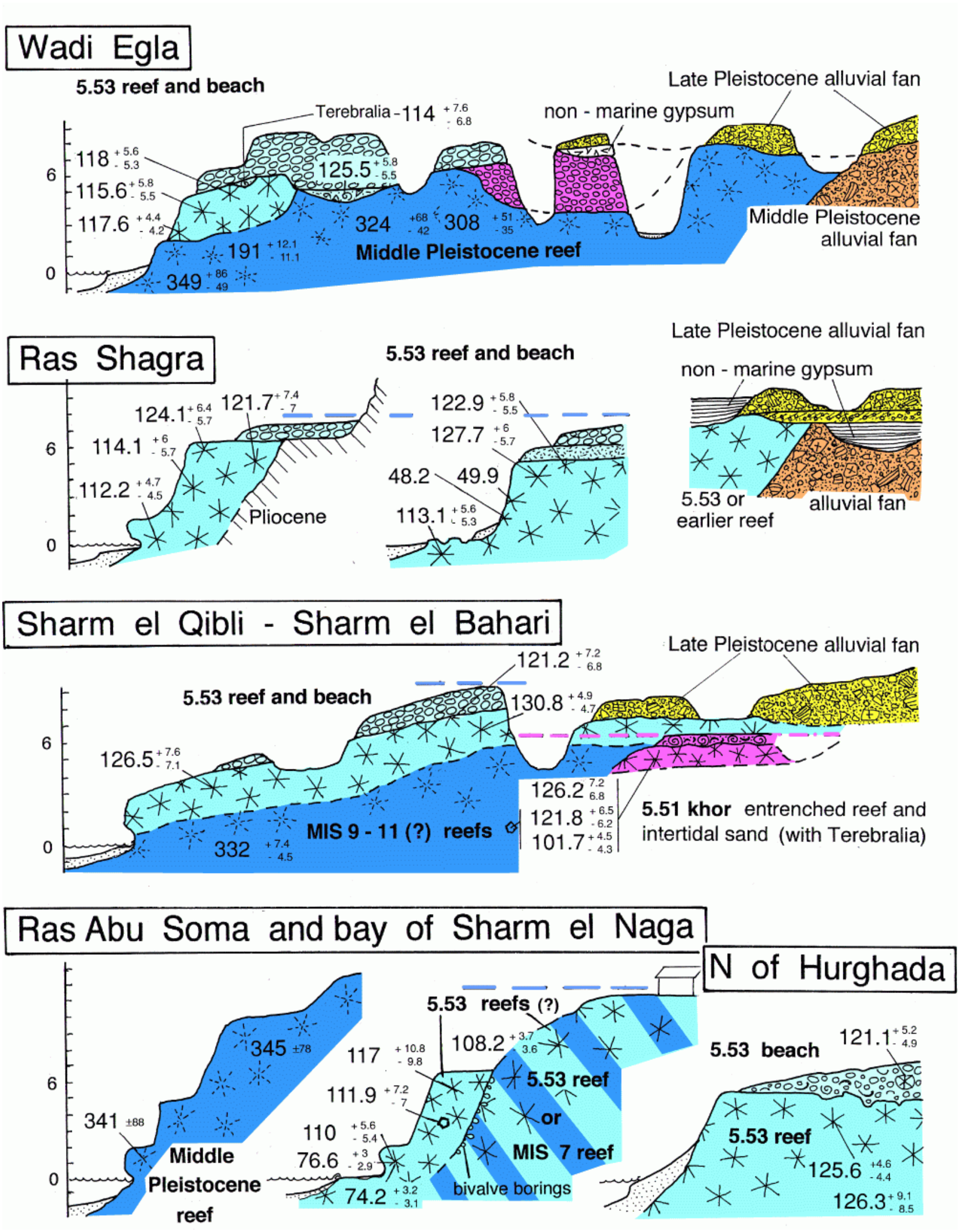


Figure 4.3: Schematic relationships of Late Pleistocene marine deposits in selected sites on the Egyptian Red Sea coast. Because of the complexity of the outcrops these conclusions are open to question, for fhe interpretation of radiometric dates played a major role in their decipherment. Perched gypsum deposits are referred to post-5e non-marine salinas; the entrenched khor reef and beach of Sharm el Bahari is considered to be a reliable interpretation but at Sharm el Naga the depiction of an onlapping 5.51 reefal unit separated from the 5.53 substrate by a bored surface is not securely incontestable because rejuvenation is especially important in this locality.

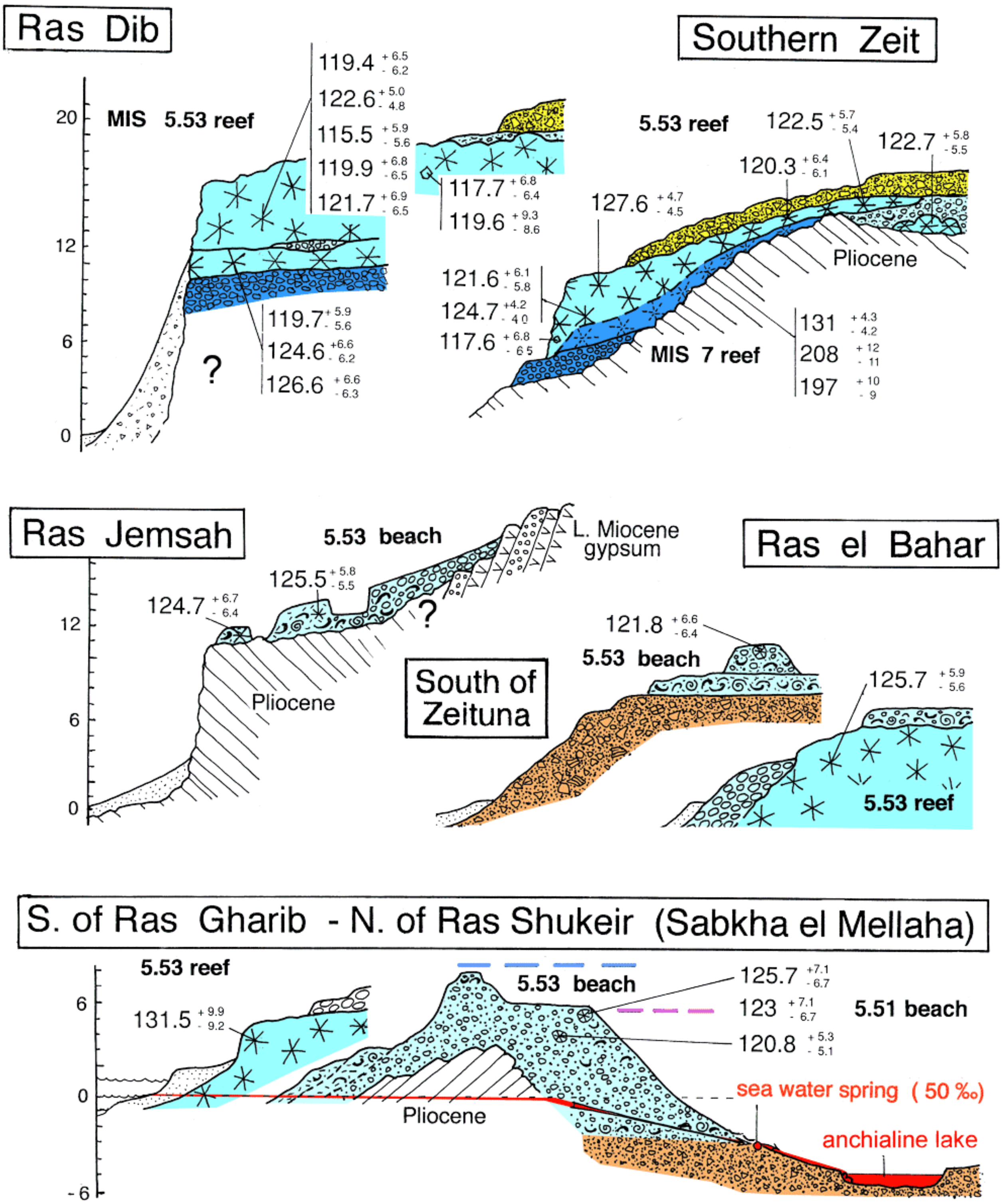


Figure 4.4: Schematic relationships of Late Pleistocene marine deposits in selected sites on the Egyptian Gulf of Suez. Local tectonism is influential in these settings, from a maximum uplift at Ras Dib to a normal altitude with back-littoral erosion below Present sea-level that resulted in the modern saline lakes of Sabkha el Mellaha (anchialine lake, see ORSZAG-SPERBER *et alii*, 2001).

biodiversity) and evaporites (marine salina gypsum, including laminae with potamid gastropods), which suggests that the depressions were continuously filled by seawater to a height in equilibrium with the global high sea-level. Thus we consider that the top of the subaqueous gypsum (with a local tepee morphology at the end) is a reliable indicator of the relative altitude of sea-level during the polyphased filling of such basins (ORSZAG-SPERBER *et alii*, 2001).

As the highest reef-and-beach outcrops have been subject to a more active erosion, it is not always easy to establish the "derived" mean sea-level (interpretative terminology according to PLASSCHE, 1986) at the time of the first sea-level culmination. But from the study of the best preserved khor-salina settings, it appears generally to have been some 3 meters higher than the second evaporite derived MSL.

Whatever the brevity of this second rise of sea-level we are prompted to search for the highstand shoreface deposits equivalent to the khor-salina units. As we shall see later this episode appears to be too short for the construction of a thick reef. The only locality where we observed a double reef possibly resulting from such a down-stepping accretion, the younger being separated from the older reef unit by a bored, steep discontinuity (Fig. 4.3), is Sharm el Naga, a shoreface locality but especially well-protected by the protrusion of cape Ras Abu Soma. The date obtained from the bored unit is obviously a rejuvenated one. We therefore cannot be certain that it is an earlier 5e reef unit (rather than a MIS 7 reef).

The other reefal deposit that might be referred to this second episode is a small construction developed on the inner flank of the Late Pleistocene drowned valley at Sharm el Bahari (Fig. 4.3 and PLAZIAT *et alii*, 1995, Figs. 5 & 8). It is exactly the setting along the modern Egyptian Coast which best illustrates what is called a "sharm". Reef corals built marginal constructions (subtidal trottoirs) fringing the eroded Pleistocene substratum in the drowned entrance of the wadi valley, up to a limited distance landward from the general reef front. Freshwater tankers use to enter Sharm el Bahari through the channel interrupting the fringing reef, a deep-water "thalweg" which is attributed to the wadi incision during the last glacial lowstand according to SESTINI (1965) and GVIRTZMAN *et alii* (1977).

Both of these probable remnant locations are in protected sites, which suggests that any limited growths of fringing reefs during the second MIS 5 highstand will be preserved only rarely, owing to the major erosion suffered by the steep outcrops of the reef fronts (not only Egyptian reefs) during the lowering of sea-level during the Weichselian glacial episode. The destruction of such a fragile veneer should be general in most of the reef-front settings of the world. We insist on the influence of the reef erosion resulting from the intercalary lowstand because most of the alleged 5e reef splits of the literature are based on the report of superimposed successive units which have been interpreted in terms of the increase in altitude of the two 5e highest sea levels. We contest this interpretation (in which the second 5e highstand would be higher than the first one) because such a low lying, bipartite sequence like that of some Caribbean outcrops is in contradiction with the respective altitudes of the derived Mean Sea-Levels obtained through our observations of the entrenched units of the Egyptian coast. In conformance with the preceding discussion, we suggest that the actual altitudes of superimposed 5e reef units would be compatible with that of a lower second MSL, provided that a local erosion of the earlier unit truncated its upper surface below the altitude of the second MSL. If so, the platform of an early 5e reef must have been lowered by erosion (from +6 to +1 m) before the second (late-5e) marine inundation which culminated at +3m.

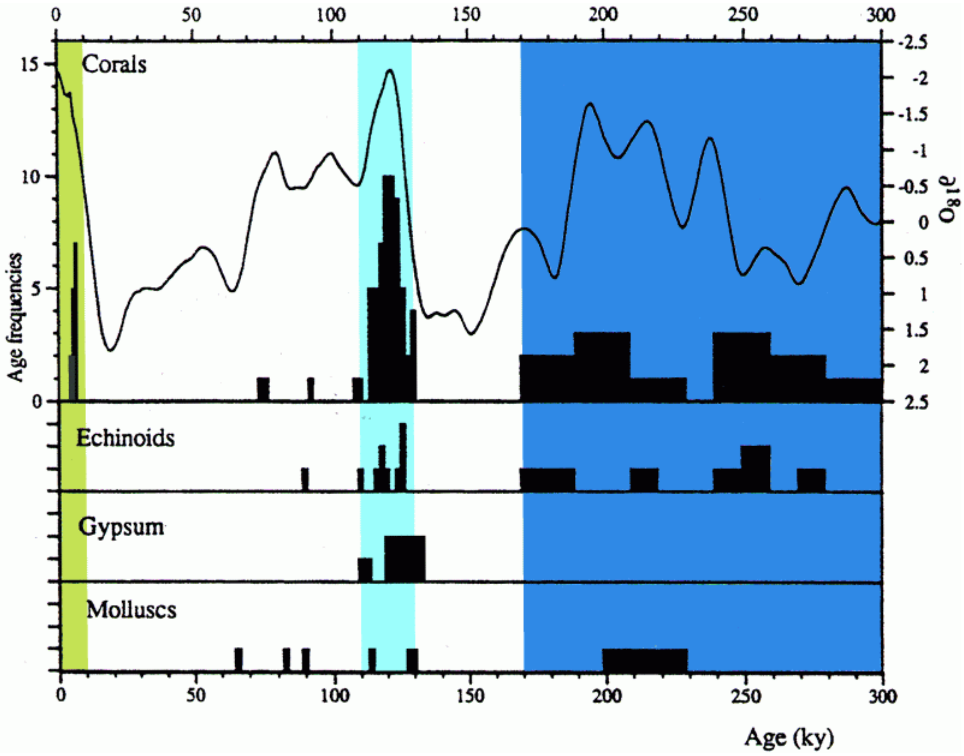


Figure 5: Frequency distribution of Th/U dates obtained by this research program (after PLAZIAT *et alii*, 1998a). The several sources are shown discretely in order to demonstrate their respective reliability.

3. U-Series chronology of the Egyptian reefs.

The validity of our interpretation that Egyptian Late Pleistocene marine units register rapid changes in sea-level rests on the integrity of regional absolute chronology elaborated through our Th/U α dating (Reyss *et alii*, 1993; Choukri, 1994) (Figs. 5-6, Table 1). So we begin with a description of the methods of field work and laboratory procedures that are the bases for our hypothesis regarding rejuvenation as the explanation for scattered dates.

We had the benefit of a simple, clear morphology that facilitated the identification of the respective depositional units, along the full length of 500 km of coast. The nearly continuous coastal reef-and-beach unit, its upper relief generally less than +10 m was taken as the leading feature. However, dating indicated this reefal core to be polygenic locally, *i.e.* more complex than expected in the light of field evidence.

Present-day weathering, especially in the saline-water impregnation zone (sabkha brines), is not easy to discriminate from older fresh-water and saline alterations. The established older carbonate substratum (Middle Pleistocene reefs), in which datable corals are poorly preserved, is often mimicked by low outcrops of Late Pleistocene reefs, brine-saturated by capillarity to several meters above the sabkha level. So a powdery appearance is not a reliable discriminating feature, for in many cases it is associated with scattered, well-preserved aragonitic coral skeletons.

Field selection of well-preserved structure, similar to that of sub-fossil specimens (crystallinity, density, colors) is a fairly rough but generally efficient method of discrimination. Limited internal solution appeared to be less harmful than diagenetic crystal growth to the reliability of their dating.

The X-ray was used to exclude from further study those of these selected corals with a calcite content of more than 3 %. The precise estimation is given in Table 1. In addition, we selected large echinid spines (*Heterocentrotus mamillatus* (Linnaeus), up to 10 cm long, 1.5 cm in diameter) that consist of massive calcite. This choice of another and unusual material for dating (Choukri *et alii*, 1995) is based on the assumption that the massive calcite was formed by a very early diagenetic process: the biogenic skeleton of echinoderms is a fenestrate "stereome" of high-magnesium calcite, and after death its anastomosing framework is thickened rapidly by syntaxial cement, a magnesium-rich calcite derived from seawater, so a massive, pseudo-monocrystalline spine develops in a few hundred (or thousands) of years (West, 1937; Evamy & Shearman, 1965; Raup, 1966). The unitary nature of this crystalline structure makes it less susceptible to subsequent internal leaching and implies a long-lasting mineral stability and resistance to peripheral solution along crystal contacts. In fact, most of our comparisons of pairs of coral and urchin spine from the same sample spot show a good agreement in dates (see Choukri *et alii*, 1995; Fig. 5), that is, a general but limited rejuvenation of the radiometric age of the spines, like that of the associated corals.

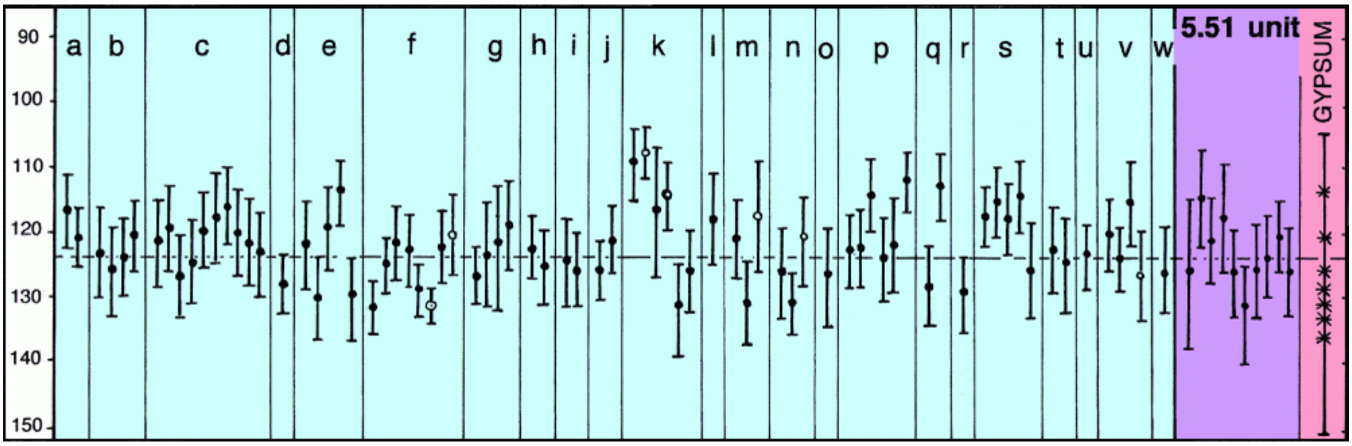


Figure 6: Th/U dates from 23 Late Pleistocene sites on the Egyptian coast. The reference line is 123 ka. The vertical bars show the ranges of dates for the 5.53 reef-and-beach unit. Black dots refer to the reliable ^{234}U/^{238}U. The 5.51 biogenic carbonate and gypsum dates were added (purple) to show their conformity in range. a = Gulf of Suez, 15 km N of Zafarana, Abu Darif; b = Sabkha el Mellaha (North of Ras Shukeir); c = Ras Dib (N Zeit); d = South of Ras Dib; e = Southern Zeit; f = Southern Zeit, reef platform section; g = S= south? of Zeituna; h = Ras el Bahar; i = Ras Jemsah; j = N Hurgada; k = Sharm el Naga; l = Wadi Siatin; m = Quseir el Qadim; n = Sharm el Bahari; o = Sharm el Qibli; p = Ras Shagra; q = N Ras Shagra; r = Wadi Nakada; s = Wadi Egla; t = Mersa Alam; u = Wadi Sifein; v = Wadi Khalilat el Bahari; w = Sharm el Luli.

Coral skeletons of pure aragonite are, beyond question, the basic references for reliable dating. However, discrepancies in dates obtained from multiple sampling in the same coral "colony" or between adjacent corals (still joined in life position), make complete confidence dubitable even in the best preserved corals.

The initial $^{234}U/^{238}U$ ratio ($\delta^{234}U_{t0}$) (*i.e.* the measured $^{234}U/^{238}U$ ratio corrected for the age of the sample) is still considered the best confidence test for diagenetic deterioration (EDWARDS *et alii*, 1986; HAMELIN *et alii*, 1991; CHEN *et alii*, 1986; BAR-MATTHEWS *et alii*, 1993; VILLEMANT & FEUILLET, 2003). The discussion of a possible evolution of this ratio in sea-water during the last 500 ka has established its relative stability, at least for the length of time required for the construction of the MIS 5 and MIS 7 reefs. Therefore, the higher values of this ratio (frequently associated with "astonishing older dates") have been interpreted to be the result of a post-mortem incorporation of uranium: BARD *et alii* (1991), HAMELIN *et alii* (1991), STEIN *et alii* (1991), BAR-MATTEWS *et alii* (1993), GALLUP *et alii* (1994). This implies that the initial content of radiogenic elements will be modified to some degree by a subsequent incorporation of uranium extracted from the diagenetic fluid (usually younger sea water) in contact with the carbonate skeleton of the coral. The ^{234}U content of this sea-water may increase through a limited leaching and replacement of the bio-mineral, aragonite. Recoil processes are more generally said to be implicated in the redistribution of isotopes of the U-series used for nuclear dating. The disintegration of ^{238}U induces instability in the daughter ^{234}U which results in a higher susceptibility to leaching than its parent. Such an outcome may enrich the water and the adjacent bio-minerals as well as the neo-precipited, diagenetic aragonite that fills the leached nanovoids. The intimate and random distribution of uranium atoms in the entire skeleton demonstrates that this process takes place at a multitude of loci. The high affinity of uranium to the reducing organic matter suggests that this labile phase plays a definite role in the diagenetic introduction of uranium into the aragonitic skeleton. As the basic unit in the construction of the coral (scleractinian) skeleton is a biogenic needle of aragonite coated with an organic sheath, it is tempting to infer that the subsequent diagenetic incorporation of younger uranium is linked to the decay of organic matter: changes in pH, oxido-reduction rates and inter- or intra-crystalline circulation of fluids must influence the timing and rate of such a post-mortem accumulation of uranium. Just after death, a major step would be the destruction of most of the organic matter, not only that coating the periphery of the skeleton of the Hexacorallians but also that present between and within the crystal needles. However, a significant portion of this organic matter survives the early stage of diagenesis and is worthy of analysis (CUIF *et alii*, 1997; GAUTRET & AUBERT, 1993; GAUTRET, 2000). This survival clearly suggests that the decay of organic matter may occur at any time during fossilization. A multi-stepped leaching is therefore likely to favor successive phases of uranium incorporation, or at least a variable rate in its uptake during the later phases of diagenesis. Our conclusion is that the theoretical "closed system", assumed from marine specificities in mineral geochemistry and used to validate the simple equations of a relationship between the decay rate of radiogenic isotopes and time, should first be questioned at the root level. The critical requirement should not concern only the precision of the methods used to measure isotope ratios (excessive overevaluation of the TIMS mass spectrometry).

During the last few decades, diagenesis of coral reefs has been a major topic of research by petrologists and geochemists (GVIRTZMAN *et alii*, 1973; JAMES, 1974; CONSTANTZ, 1986; BAR-MATTHEWS *et alii*, 1993; FRUIJTIER *et alii*, 2000; VILLEMANT & FEUILLET, 2003; SCHOLZ *et alii*, 2004). The great complexity of reef micro-cavities (more or less connected) and the possibility of change in the circulating fluid as uplift occurred (submarine, marine vadose, phreatic or vadose fresh water) are of concern along with the fact that a difference in the location of samples in the reef, although separated by only a few centimeters can modify the rate and degree of diagenesis relative to local micro-environments: below a sheltering shell, adjacent to a micro-channel, in a reef-growth cave, in a mud matrix or as a part of a coarse open-work rubble incrusted by red algae, heavily bored by cyanobacteria, *etc.*

A selection of assumed "reliable corals" involves the exclusion of obviously "weathered" specimens using common sense criteria: elimination of aragonite-calcite replacements (X-ray), and matrix- or cement-filled skeletons. To this end, a few authors go so far as to use thin-sections to detect the finest of cements coating the septa of corallia (HANTORO, 1992). Nevertheless, we question such respectable proceedings: the actual amount of uranium incorporated diagenetically by the biogenic skeleton is not visible, and paradoxically the earliest modifications (fill of microcavities, cement overgrowth) may carry the same chronological information as that of the biomineralized material. In other words, the radiogenic decay-rate of their respective uranium content gives the same age for the bio-minerals and for the diagenetic replacement-minerals within the usual range of error (even for TIMS measurements). On the other hand, a marine diagenetic environment involving leaching of organic matter and mineral replacement usually is not detectable using classic optical and geochemical criteria in an intimate mixture of bio-minerals and post-mortem minerals derived from sea water.

A confusion between the accuracy of dating and the reliability of the age calculated therefrom certainly explains the discredit put on the Th/U α counting method. But in the last 15 years geochemists and specialists of nuclear physics have greatly improved the precision of both measurements. The TIMS method reduced the "error" (better conceived as an uncertainty regarding the technical processes) of the measurement by an order of magnitude and advocated a selection of the less altered part of a coral head (through a reduction in sample size). However we must explain why a few scattered TIMS dates escape the clusters, and the reasons for the TIMS date inversions that are similar to the disordered sequences obtained by conventional α counting.

As a full elucidation of the complex timing of organo-mineral diagenetic processes still needs much work we can only point out its involvement in the rejuvenation hypothesis we have proposed to introduce into the interpretation of most so–called "reliable" but dispersed dates. We therefore prefer distinguish the result of a measurement (here the date) from the interpretation of that result (here the age). The "apparent dates" of Stirling *et alii* (1995) should be simply taken as "dates" because there is no reasonable doubt about the method of dating, and generally speaking, any dated sample of coral that satisfies the geochemical closure tests may be credited as a "true date" from which its age (the date of its life and death) can be determined from the stage of diagenesis of its skeleton. This distinction between (true) date and (true) age would appease the unjustified dispute concerning accuracy (precision) versus reliability of the dates obtained through the two methods, both based on the disequilibrium of radiogenic elements in the uranium family. Chemistry and physics can only determine the precise date of a sample whereas the proposal of an age for a sample or a stratigraphic unit should be the result of a case-study that includes a discussion of data consistency, as a complement of simple date and altitude parameters. The reliability of an age determination involves not only the date (a matter of measurement) but also the history of the deposit deduced from the diverse diagenetic records of adjacent fossil skeletons.

Because the discrepancies introduced by diagenesis are commonly much more important than the error produced by any method of measurement, imprecise dates (Th/U, α) should not be neglected to the benefit of more precise TIMS dates before a critical assessment of the reliability of individual TIMS-derived ages has been made.

As we could not rely on a priori criteria, we proposed an innovation in the procedures of field sampling. In order to provide a mean for testing the reliability of the dates, we sampled rather densely a limited number of sites. The precise location of the coral heads within the same reef unit (altitude, distance to the seafront, peripheral or internal location), the selection of adjacent colonies, a multiple sampling within a single head, parallel sampling of wadi valley outcrops and nearby isolated reliefs; all have been used as discriminatory tests of the respective influences of broad geomorphy and micro-topography (Plaziat *et alii*, 1998a). Discrepancies in the dates of the same unit from adjacent samples suggest that the calculated error (theorically introduced by chemical procedures and physical measurement by α-counting) is not overestimated and at the same time that instrumental error is not the main source of deviation. In conclusion, we suggest that the discussion of the reliability of each dated sample in terms of "geochemical-system closure" is much more influential than any bias in measurement, for it is independent of the dating method (α-counting versus TIMS).

Taken as a whole, the main sequence of α dates from the Late Pleistocene Egyptian reefs clusters around 122 ka (Figs. 5-6), which is not surprising in the light of published statistical studies like that in Smart and Richards (1992). Nevertheless, we point out a significant asymmetry in the distribution of date values (Fig. 5). Disregarding older, unreliable Th/U dates of more than 220 ka, three clusters stand out. The first, around 200 ka, may be referred to the MIS 7 (7.1 or 7.3 isotopic events ?) sea-level highstand. The second, with but very few exceptions, is apt to be post-128 ka, *i.e.* referable to the MIS 5.5 highest sea-level substage (taking into account an error bar of 1σ). On the other hand, a limited number of younger ages (from the same lithostratigraphic unit) range from 115 to 50 ka. We have interpreted these low values as the result of a rejuvenation due to the later addition of a "younger" uranium to the initial incorporation which is assumed to have entered the polypierite frames just after the polyp died. However the only indisputable demonstration of rejuvenation relies on two categories of data: first, the clearly anomalous, progressively younger dates obtained from the top to the base of Ras Shagra cliff (Fig. 4.3). A careful examination of the outcrop shows that it is a unique, massive coral reef, which excludes randomly preserved younger, Late Pleistocene corals living at positive altitudes, that would have been subsequently introduced in the reefal matrix that housed the 5e coral heads. Second are "apparent ages" younger than any high sea level episode of the Late Pleistocene, namely the ages around 50 ka, because this was a time when sea level was far below its current altitude. We must infer that some diagenetic process altered the isotopes ratio to the advantage of ^{234}U. A late addition of U is the explanation usually accepted, because thorium was generally considered as unleachable, no matter what its state of oxido-reduction is (see IVANOVICH & HARMON, 1992). However GALLUP *et alii* (1994) and FRUIJTIER *et alii* (2000) recently postulated that the mobility of ^{230}Th is similar to that of ^{234} U. Adjusted in accordance with the theoretical evolution of the open-system modeled by VILLEMANT and FEUILLET (2003), the aberrant dates have been recalculated in accordance with their method of correction. From our research we conclude that no process of geochemical recoil may be retained as an acceptable explanation for such important ageing or rejuvenation of Th/U dates. We therefore suggest that the intermediate dates (corresponding to low sea-level stages) are not reliable but should be interpreted as rejuvenated. In particular we propose to discuss the dates before 130 ka as possibly related to the preceding high sea-level stage (MIS 7). The main unanswered question is the geodynamic significance of the numerous dates between 130 ka and 123 ka from the 5.53 unit which is above Present sea-level. It was laid down at the end of the post-Saalian melting and ocean rise. This question has not only a local application but also is involved in a global elucidation of the timing of the termination of the penultimate glaciation (termination II). It cannot be approached until the reliability of the published sets of key-dates derived from the best studied reefal sequences in the world has been discussed (see below).

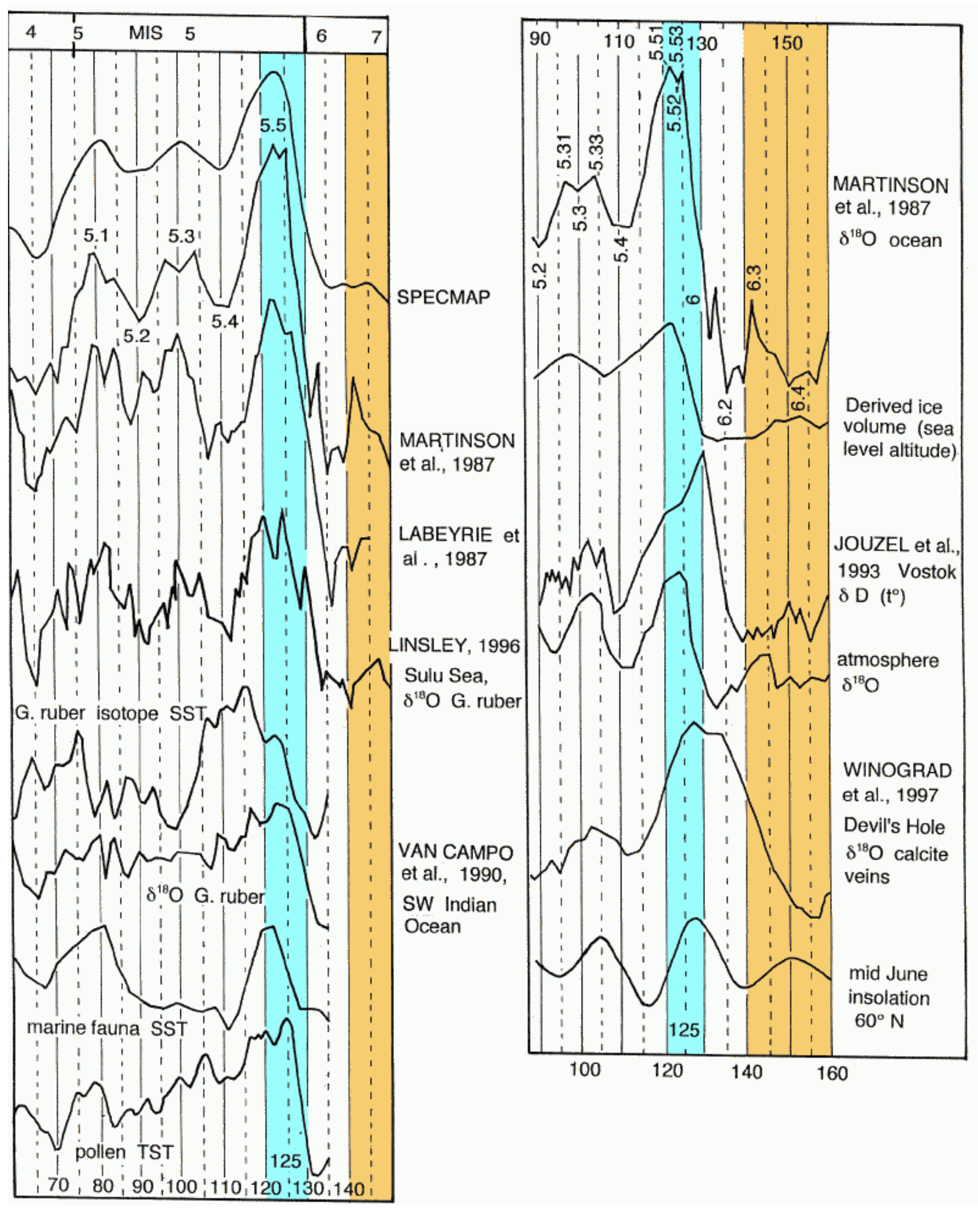


Figure 7: From nine sources a comparison of the divers timings of climate and sea-level variations suggested by δ^{18}O, δDeuterium and pollen analyses of marine and continental deposits. Shift in its location is illustrated and compared with the calculated variations between 160 and 90 ka of mid-June insolation at 60°N (in BERGER, 1978).

The khor-to-salina deposits that comprise the Egyptian entrenched unit yielded 17 Th/U dates (7 corals, 3 mollusks, 7 gypsum) (Fig. 5). Though post-dating the main reef unit as a whole, these diverse materials all suggest the same moderately dispersed ages, around 123 ka (131-115 ka for the biogenic samples; 135-113 ka for the gypsum) but with a larger uncertainty about the gypsum (Fig. 6). Consequently, using radiometric measures alone we could not separate this latter transgressive unit from the preceding episode of reef growth, but it is clear that these dates cannot be interpreted as having been caused by the 5c = 5.3 sea level high which is centered around 100 ka (using $\delta^{18}O$ stratigraphy the 5.3 isotopic event was estimated at 99.4 ka, *i.e.* between 5.33 = 103.3 ka and 5.31 at 96.2 ka, according to MARTINSON *et alii*, 1987) (Fig. 7). To the contrary, we suggested that the short-lived lowstand responsible for the erosion behind the 5e reef rim and the subsequent sea level rise reflect fluctuations within the last interglacial sea-level culmination (5e-Eemian) (PLAZIAT *et alii*, 1995), the details of timing being ascribed to the three 5e isotopic events known for 20 years from deep sea records (PISIAS *et alii*, 1984), and named and their ages "estimated" by the CLIMAP group (MARTINSON *et alii*, 1987) as a 5.53 highstand (129.84 ± 3.05 ka), a 5.52 lower stand (125.19 ± 2.92 ka) and a 5.51 highstand (122.56 ± 2.41 ka).

We do not accept naively these excessively precise ages of "isotopic events" for more or less lengthy highstand episodes but we insist on the good agreement of our radiometric data with the classic marine isotopic time scale (astronomically tuned) proposed long ago (1987 SPECMAP, CLIMAP curves) that has never been reevaluated for the period of time which includes the last interglacial and the beginning of the last glacial substages (*i.e.* MIS 5e-5a).

As a conclusion of this reconstruction, we propose a nine stage diagrammatic reconstruction (Fig. 8) that illustrates the sedimentary results of around 200 ka of evolution of the Egyptian reefal shoreline (details in PLAZIAT *et alii*, 1998a, 1998b, and ORSZAG-SPERBER *et alii*, 2001).

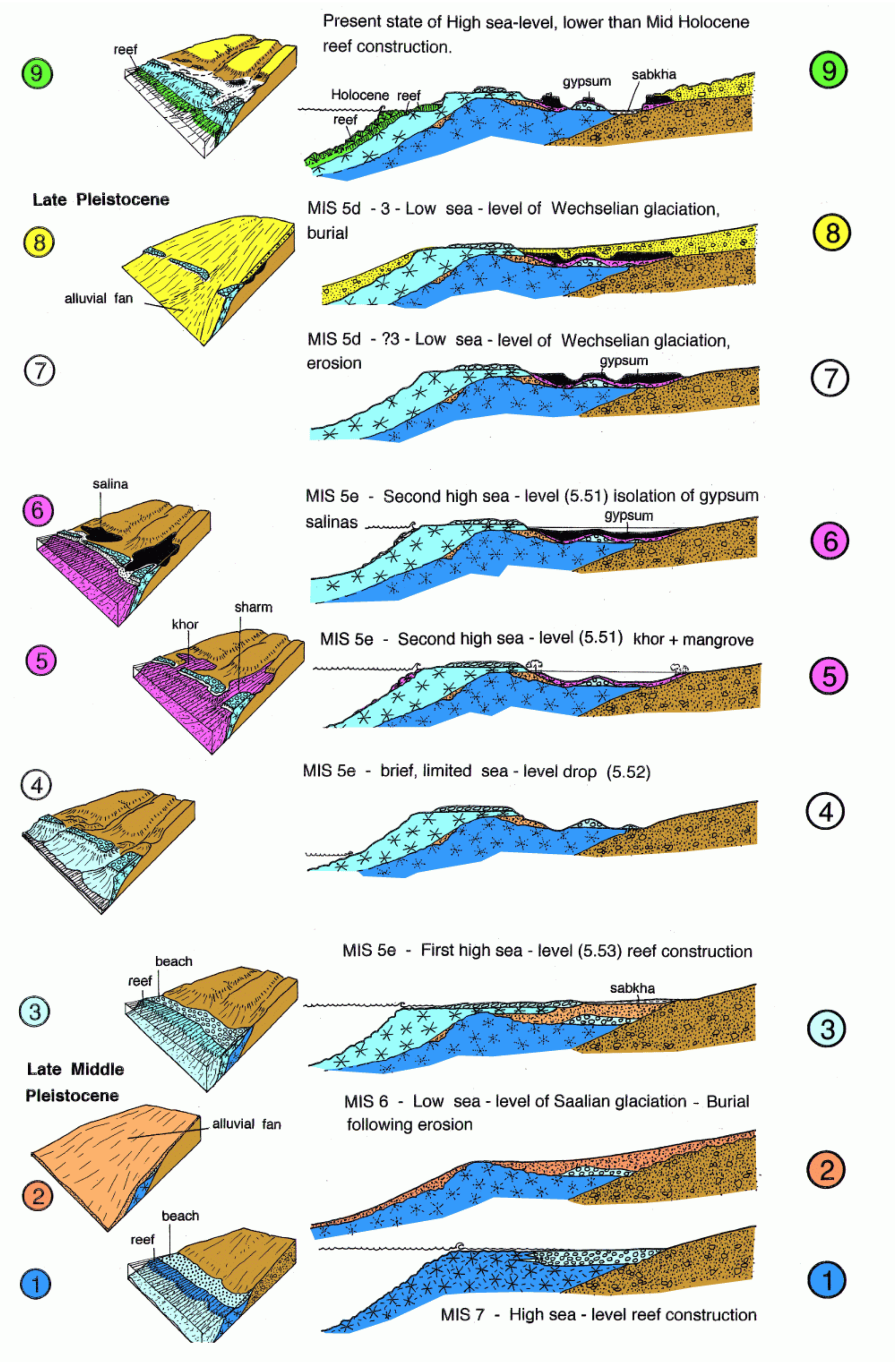
4. Other datings of Red Sea raised reefs, a review.

The Egyptian reefs "benefited" from the pioneer coral datings but later decades provided more varied contributions about that part of the African coast, along with some information on islands of the Red Sea and the Sinai peninsula (Fig. 9). As they were obtained by the same method of dating (Th/U, α), these older results may be directly compared with ours. We include in this review of Red Sea data published results from Sudan, Eritrea and Saudi Arabia along with early studies near Djibouti in the Gulf of Aden.

The southern Egyptian reefs described as from "south of Mersa Alam" were the first Late Pleistocene units dated (Fig. 9.a-b). BUTZER and HANSEN (1968) give two dates (118 and 80 ka) and VEEH and GIEGENGACK (1970) a cluster of three (89-92 ka); all of these are especially suspect as regards the probability of rejuvenation. In the more extensive work of EL MOURSI between Hurgada and Mersa Alam (EL MOURSI, 1992; EL MOURSI & MONTAGGIONI, 1994) we question both the field identification of reefal lithostratigraphic units and the chronostratigraphic interpretation of 13 radiometric dates (Fig. 9.i). We do not dispute the Late Pleistocene age (the measurements were obtained by the most reliable methods); it is the misinterpretation of platform morphologies as independent reefal constructions said to be responsible for the differentiation of three regional terraces, with the erroneous inference that during the Late Pleistocene there were three episodes of coral growth above the Present sea level where we observed only one continuous reefal construction. The alleged "terrace II" provides ages ranging from 72.1 to 123.6 ka (with median ages at 112.1 and 113.2 ka, averaged by the authors at 105 ka). This dating led to a risky correlation with the 5c highstand, despite its +3m altitude in sites where the 5e reef culminates at +8m (a positive altitude compatible with the less than 4 m of general tectonic rise). The lowermost Pleistocene "terrace", at +1.5 m, gave three ages (87.6, 86.6 and 57.6 ka) referred as a whole to the 5a substage. But the last one is compared to a supposed stage 3 coral of the New Guinean record (Huon Peninsula, in CHAPPELL & SHACKLETON, 1986).

A more recent study of the same coastal area (15 km N of Marsa Alam) by ARVIDSON *et alii*, 1994, provided 8 dates: the oldest, 248 ka, despite its high $(^{234}U/^{238}U)_{t0}$ value may be referred tentatively to MIS 9 while most of the others (122 to 102 ka) are within the usual range of the 5e reef (normal 120-122 ka plus rejuvenated 113-102 ka dates) (Fig. 9.h). The 133 ka date may be interpreted in the light of rejuvenation processes and, accordingly, is possibly referable to MIS 7. Its altitude (+3m) is compatible with this sea level rise and a MIS 5.5 drowning favoring rejuvenation during its subtidal diagenetic episode.

▶ **Figure 8:** Diagrammatic interpretations of the Quaternary marginal complex of continental (alluvial fans) and marine (reef-and-beach and khor-to-salina deposits) on the Egyptian shoreline of the Red Sea. These nine stages of littoral accretion and erosion are related to changes in sea level.


9
reef
Present state of High sea-level, lower than Mid Holocene reef construction.
Holocene reef
reef
gypsum
sabkha
9
Late Pleistocene
8
alluvial fan
MIS 5d - 3 - Low sea - level of Wechselian glaciation, burial
8
7
MIS 5d - ?3 - Low sea - level of Wechselian glaciation, erosion
gypsum
7
salina
6
MIS 5e - Second high sea - level (5.51) isolation of gypsum salinas
gypsum
6
khor
sharm
5
MIS 5e - Second high sea - level (5.51) khor + mangrove
5
4
MIS 5e - brief, limited sea - level drop (5.52)
4
beach
reef
3
MIS 5e - First high sea - level (5.53) reef construction
sabkha
3
Late Middle Pleistocene
alluvial fan
2
MIS 6 - Low sea - level of Saalian glaciation - Burial following erosion
2
beach
reef
1
MIS 7 - High sea - level reef construction
1

Another cluster of dates brings up the problem of rejuvenation again. ANDRES and RADTKE (1988) studied the Late Pleistocene raised reef of the southwestern coast of the gulf of Suez, at Gebel Zeit (Fig. 9.c). There, Late Pleistocene tectonics are responsible for a faulting and tilting (PLAZIAT *et alii*, 1998a) of the reefal unit dated by these authors (using Th/U, α) at 115, 114 and 102 ka. We studied with special attention the outcrops of the same reef (Ras Dib, N Zeit) and produced 24 dates (CHOUKRI, 1994). All but one are older than 115 ka, ranging from 130 to 116 ka.

The dates obtained by HOANG and TAVIANI (1991) from islands of the northern Red Sea and from Hurghada (= Ghardaqa, at the entrance of the Gulf of Suez) also suggest diagenetic disturbances of the radiochemical message (Fig. 9.d): six dates cluster from 150 to 125 ka. As their altitude (+2 and 8 m) and their $({}^{234}U/{}^{238}U)_{t0}$ are quite ordinary for MIS 7 and MIS 5.5 coral reefs, the authors concluded that these candidates for a 5e substage placement could not be separated except for the 150 ka date from Hurgada, then supposedly referred to MIS 7 in spite of its MIS 6 age. We add to the discussion of dating methodology that this case is representative of most dating campaigns as local cross-checking is impossible because each of the dated samples has been collected from a different site, at too great a distance from the others.

In our opinion, the date of 146 ka from Tiran Island, at the entrance of the Gulf of Aqaba (GOLDBERG & YARON, 1978, in GOLDBERG & BEYTH, 1991) is another clue supporting the widespread distribution of raised MIS 7 reefs in the Red Sea (Fig. 9.e). The Pleistocene reefs of the Sinai peninsula also evince an ambiguous message (Fig. 9.f-g). Taken as a whole, the 16 published dates (GVIRTZMAN *et alii*, 1992; GVIRTZMAN, 1994) establish the majority of MIS 5.5 reefs at a +17 m average Present altitude. Nevertheless we question the 141 ka age, and less-positively, three other pre-130 ka dates, along with the 98 and 81 ka dates for the same region. Though these reefs are in an uplifted area, GVIRTZMAN (1994), contrary to EL MOURSI *et alii* (1994), does not suggest that the younger dates could be 5c or 5a reefs. He included the 141 ± 9 ka date from the "Naama reef complex" (+17m) in the 5e substage, while the 216 ± 47 to 169 ± 8 ka dates of the "Murlika reef complex" (+15) have been interpreted as MIS 7 ages. We suggest that these reef complexes represent not only discrete MIS 5.5 and MIS 7 reefs but also puzzling amalgamations of underlying older reefs (MIS 7 below MIS 5e and a possible MIS 9 below MIS 7).

The most recent work, on admittedly "diagenetically altered fossil corals" of the Gulf of Aqaba (Jordan) reactivates the hypothesis of a MIS 5.1 sea level 4-5 m above Present MSL (SCHOLZ *et alii*, 2004). The Last Interglacial reef is split into two terraces: the higher one, 7-10 m a.s.l., is dated between 121.0 (+6.7, -5.3) and 121.9 (+7.0, -6.3) ka, so certainly is correlatable with MIS 5.5, whereas the lower terrace, dated between 117.1 (+19.7, -15.3) and 106.4 (+8.9, -8.1) ka, suggests another highstand during the later part of the MIS 5 interval. The isochron ages and decreasing elevations are said to be "consistent with existing sea level reconstructions from the Red Sea", a conclusion that represents the prevailing confidence in radiometric dates. However, we suggest an erratic rejuvenation of the lower part of the 5.53 reef, its better dates (121-122 ka) probably indicating only a slight rejuvenation. If so, the reported altitudes conform with a near stability during the Late Pleistocene of the Northern Red Sea coast like that of Egypt.

Farther south, the Sudanese coast has a major historic interest, for the coral reef was remarked by DARWIN (1842) as "upraised within a modern period", and was also the source of the first coral radiometric Th/U date from the Red Sea: D. THURBER gave a date at 91 ± 5 ka (in BERRY *et alii*, 1966) and clearly interpreted this measurement as the age of a Last Interglacial reef grown on a "stable coast" (9m above MSL) contrary to DARWIN's opinion.

A long time elapsed before the only recent research program (DALONGEVILLE & SANLAVILLE, 1992; HOANG *et alii*, 1996) was conducted. It yielded nine coral dates (Th/U, α) (Fig. 9.j). The older dated reefal unit is 253 ka and >300 ka, which surprisingly, has been interpreted as being of MIS 7 age instead of MIS 9. The "youngest formation", 2/6 m above sea-level, is referred as a whole to MIS 5.5 despite a range from 142 to 125 ka. We suggest a complete reassessment, extending the discontinuous coral reef growth from MIS 9 (or 11), to MIS 5.5, the later date being assigned only to the younger unit (125-131 ka; 2/4 m) of the lower fossil-reef complex which has encroached on an older, MIS 7, reefal core.

Some 800 km farther south, the Eritrean coast recently benefited from modern TIMS dating (WALTER *et alii*, 2000) (Fig. 9.k). The authors excluded two old dates (136.4 and 156 ka) from discussion, along with an ancient intermediate date (143 ka) from Dahlak Kebir Island (CONFORTO *et alii*, 1976), while the four others, ranging from 126 to 118 ka, are referred without question to MIS 5.5. Yet these most recent TIMS "ages" clearly illustrate a broad dispersion of dates, no matter what degree of precision the measurement technology provides.

On the other hand, among the excessively rare α dates from the Saudi Arabian coast of the Red Sea (Mangini in Jado *et alii*, 1989; Dullo, 1990) nearly all of the suggested rejuvenated samples of the lower reef unit (third reef in Jado *et alii*, 1989) are moderately raised (6 to 12 m) and dated at 95 to 112 ka (Fig. 9.l). Because this lower reef unit is interpreted as being made up of "three onlapping reef cycles", Dullo (1990) suggested (his Fig. 21) that all the 5e, 5c and 5a high sea-level stands were appreciably above Present sea level. From a global standpoint, this original hypothesis is as yet unconfirmed.

Two other dates of higher (middle) reefs, respectively culminating at more than +16 m and +20 m, are both dated at 205 ka. In the absence of information on the diagenesis of these corals (geochemical parameters) we can only suggest that these dates probably concern a rejuvenated MIS 9 reef, rather than the perfectly preserved corals of a MIS 7 reef.

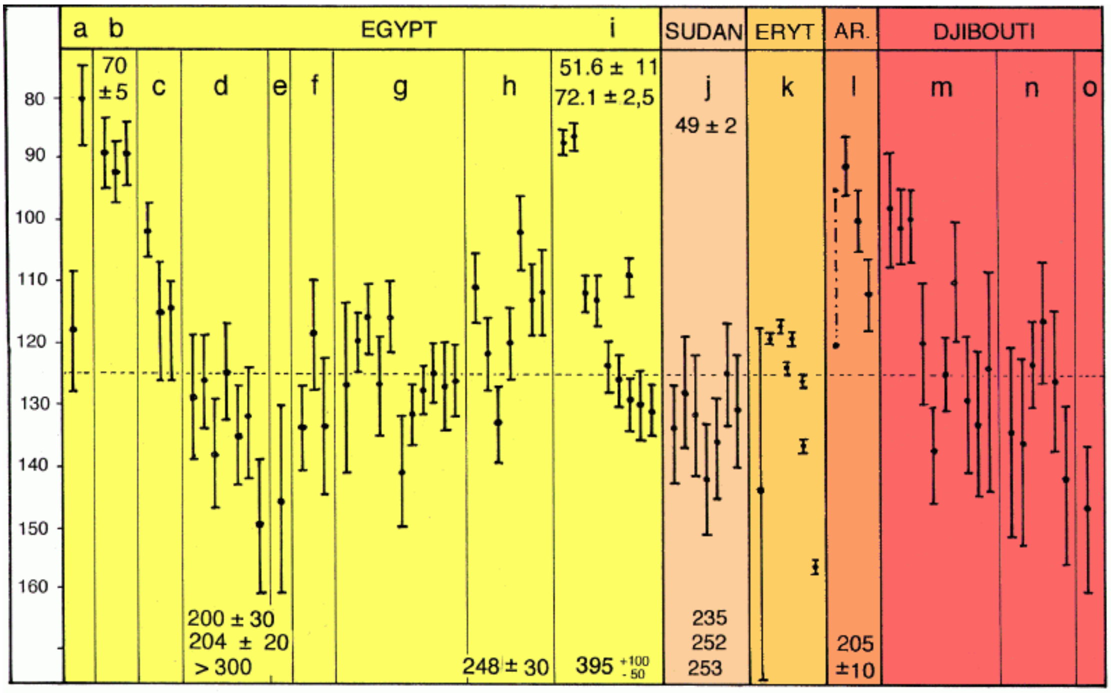


Figure 9: Published Th/U dates from Red Sea and Gulf of Aden Pleistocene reefs. The reference line is 125 ka. Egypt: a = Butzer and Hansen, 1968, S of Mersa Alam; b = Veeh and Giegengack, 1970, N Mersa Alam; c = Andres and Radtke, 1988, Zeit; d-e = Goldberg and Yaron, 1978, in Goldberg and Beyth, 1991, Tiran Island; f = Gvirtzman *et alii*, 1992, W Sinai; g = Gvirtzman *et alii*, 1992, in Gvirtzman, 1994, E Sinai; h = Arvidson *et alii*, 1994, N of Mersa Alam; i = El Moursi, 1992; El Moursi *et alii*, 1994; j = Dalongeville et Sanlaville, 1992; Hoang *et alii*, 1996; k = Conforto *et alii*, 1976; Walter *et alii*, 2000; l = Mangini in Jado *et alii*, 1989; Dullo, 1990; m-n = Faure *et alii*, 1980; o = Gasse and Fournier, 1993).

The raised reefs of the coast of the Gulf of Aden (Djibouti and adjacent Ethiopian outcrops) were studied very early and benefited from very intensive research in the then pioneer field of Th/U dating (Lalou *et alii*, 1970; Faure *et alii*, 1973; Hoang *et alii*, 1974; Gasse & Fournier, 1983) (Fig. 9.m-o). Not only corals but also bivalves, gastropods and echinids were tested, a range which explains an extreme dispersion of dates. For example an oyster and a coral from the same locus gave respectively 73 and 104 ka (Lalou *et alii*, 1970) both of which suggest a major rejuvenation of a MIS 5.5 age, the mollusk probably, as usual, having the more open geochemical system. Another cluster of dates (from Tadjoura, in Hoang *et alii*, 1974, Fig. 8) illustrates the same trend of spreading: 125 and 110 ka for the corals, 65 ka for the urchin, 59 ka for a *Strombus* and 57 ka for the *Tridacna* of the same reefal outcrop, 1 km NW of Fagal.

The distribution of these numerous dates put the 5e reef in the fore with its rejuvenated dates of around 100 ka. The oldest dates are from higher reefs, (258/256 ka) but several post-200 ka dates are likely to have been derived from MIS 7 reefs, although with the same altitude as those of the raised MIS 5.5 constructions, *i.e.* up to 20 m, which is entirely normal owing to the regional tectonic upheaval. A laminated gypsum unit is locally associated with the MIS 5.5 coral reef (usually several meters lower: Lalou *et alii*, 1970) which would suggest a striking similarity with the Egyptian sequence but the more complex tectonic setting includes recent deformation that for the time being discourages a detailed comparison.

Most of the dates assigned to the raised reefs of the Red Sea may be considered much too imprecise, owing to the use of the α counting method and a loose selection of acceptable samples. Nevertheless, from this review we conclude that the overall distribution of reef-growth ages is in good agreement with our results and may have been subject (to the extent that we could check the field data), to the same processes of rejuvenation that were invoked to interpret the broad deviations in the dates of Late Pleistocene 5e reefs on the Egyptian coast. A variable rejuvenation, related to local differences in the conditions that effected diagenesis, seems to be the key to the interpretation of the somewhat dispersed ages assigned to raised reefs. The validity of its application is more easily demonstrated where uplift is relatively insignificant. On such stable coasts, we insist on the importance of diagenesis under repeated sea-water influx, a consequence of the similarity in the relative altitudes of the reefal terraces (and the corresponding derived MSL) with regard to MIS 5.5, MIS 7, MIS 9 and probably MIS 11.

5. Relationships of Pleistocene reef outcrops to the altitude of the corresponding Mean Sea Level (MSL) in questionable reef sequences.

We introduce this problem before discussion of the most important reefal field-references of the world: those at the origin of or involved in the assessment of the classic glacio-eustatic curves of changes in sea level. To single out the entities involved in the amalgamation of successive constructions, two methods have been used commonly. The first is a lithostratigraphic identification of each raised reefal unit, defined by its altitude and its distinction from adjacent units by discontinuities in growth or by erosional phenomena. As the numerous reef discontinuities caused by brief local events are difficult to discriminate from the major (glacio-eustatic) interruptions in growth of a worldwide scale origin, their determination is dependent on "absolute" dating. This dependency explains the outstanding importance recently given to previously posted dates, when new field investigations of reef discontinuities turned the attention of specialists to the respective ages of newly defined units (see WHITE *et alii*, 1998; WILSON *et alii*, 1998).

The observed altitude of reefal deposits will be used in their placement in the time scale only where long-lasting tectonic stability can be assumed. This assumption must be confirmed by local history; if not, a precise curve describing the local gradient must be constructed. Where a major upheaval has been recorded by reef terraces staggered along a slope more than 100m high, such a local curve of uplift in a discrete region is an unquestionable prerequisite for the construction of a relative global sea-level curve. This is the case for the famous sequences of the Huon Peninsula (New Guinea), Barbados and northern Haiti, where the rate of uplift is assumed to have been uniform (at the very least a risky simplification). As an addition to this uncertainty about the basic premise, we direct attention to the difficulty in weathered tropical outcrops of identifying discontinuities and collecting reliable coral samples. This problem has led to several mutually exclusive interpretations.

We therefore insist on the relatively low degree of confidence to be attached to any discontinuity in lateral growth, whereas conversely it is of the highest importance to investigate the bathymetric significance of the uppermost limit (outcrop surface) of every reefal unit. In many cases, the initial shoreline deposits that included the MSL horizon were not a biogenic reef framework but loose intertidal, detrital materials ranging from bioclastic sands (including local beach-rock blocks) to ridges of terrigenous pebbles. In steep settings the preservation of such detrital material is sparse owing to its limited resistance to erosion, and is even rare on markedly uplifted coasts. On the other hand reef platform carbonates are particularly prone to solution and erosion through slope crumbling. The reef front with its facultative algal crest is the most resistant, but, although it is the portion lithified most strongly, it is also the part most exposed to erosion, which may explain why the fringing facies (VII_a) of the Last Interglacial reef of Huon is 10 m higher than the isolated (possibly eroded) crest (VII_b), although both have the same 118 ka age (in STEIN *et alii*, 1993).

The depth of a limited erosion, one that has removed less than 5 meters, is usually very difficult to determine. The planar, encrusted table of a mature reef flat is a diagnostic feature usable in perfectly preserved reefs (PLAZIAT *et alii*, 1989) but, when that surface is absent or removed, a detailed biogenic zonation of the residual crest rarely allows a reliable discrimination between an erosion of say 2 m rather than one of 5 m. As a general practice, experienced biologists in fact allow a 5 m uncertainty in their paleoecological estimations of bathymetry (see PLASSCHE, 1986).

A conclusion may be drawn from these warning remarks: it is necessary that the exact relationship between the uppermost facies of a reefal terrace and the MSL derived from it be checked with critical attention. The Red Sea coast taught us that most of the carbonate framework units were overlain by unconsolidated intertidal deposits, within which the MSL may be located with reasonably good precision (less than 1 m of uncertainty) because the tidal range is (and probably was) less than 2 m. Wherever such an intertidal (or any thick clastic) unit is absent, we must suspect a certain amount of erosion and accordingly propose a higher elevation for the "derived MSL". This procedure is far from some older practices such as the determination of the altitude of a reef from the elevation of its underlying platform (in ANDRES & RADTKE, 1988) or to take the altitude of any coral head for the MSL of the corresponding reef (many examples). Nevertheless, we admit that the practical use of our recommendations in the field is more difficult than the current non-demanding methodology. Finally, we emphasize above all else the uncertainty of or at least the high degree of approximation in many local "paleo-sea-level estimations". This concern is of more than anecdotal importance because the reliability of relative sea-level altitudes at key localities necessarily influenced the accuracy of global sea-level curve reconstructions.

6. The questionable reliability of paleo-sea–level identification despite an increased precision in coral dating, New Guinea, W Australia, W Atlantic reefs.

We question certain findings in the most famous and influential monographs on reefal terraces and offer an alternative interpretation for puzzling dates in the light of the recently evoked hypothesis of rejuvenation. Data concerning reefs VII_a-VII_b, on the Huon Peninsula (along with evidence from the Western Australian Rottnest Island and Leander Point reefs) serve as examples of the progress in the precision of dating (Figs. 10-11). Repeated international campaigns of field work finally resulted in a new and most original sea-level curve, differing in particular from the CLIMAP-SPECMAP proposal for the penultimate glacial termination II (start of the Last Interglacial, MIS 5.5) (Fig. 12).

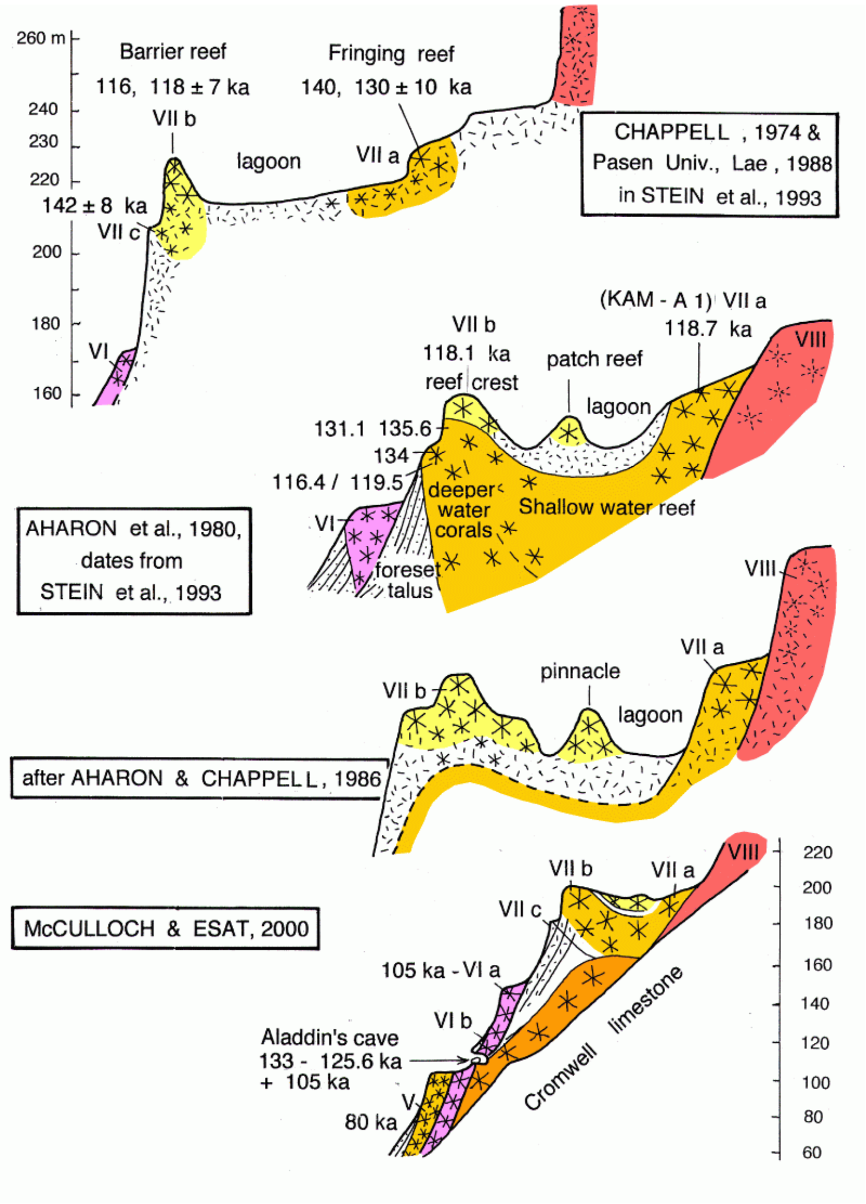


Figure 10: A selection of the main published interpretations of MIS 5 reefal outcrops of the Huon Peninsula (New Guinea-Papuasia). Introduction of new dates and dropping of a few older ones led to a drastic reconsideration of the reefal architecture but excluded identification of any MIS 7 reefs.

The first TIMS ages (Stein *et alii*, 1993) proposed for the VII$_a$-VII$_b$ reef terrace were based on an extremely critical selection of 8 dates. The partition into two "tight groups centered at 118 ka and 134 ka" reflects precisely (!) previous α counting ages that were respectively around 118 ka and 130-140 ka (Chappell, 1974, after Veeh & Chappell, 1970: reef complex V; and Bloom *et alii*, 1974: reef complex VII).

The older group of pre-TIMS dates (NG 616 samples, 140 ± 10 and 133 ± 10 ka) were taken from the higher fringing reef VII$_a$, while the younger (NG 618, 116 ±7 and 119 ± 7 ka) were from the VII$_b$ crest. This dual VII$_a$/A - VII$_b$/B locus terminology was a permanent reference until the publication of Esat *et alii* (1999) but it is worthy of note that the paleo-sea-level curve derived from these dates reversed the reef names (VII$_b$ for VII$_a$) used in Bloom *et alii* (1974) and Aharon and Chappell (1986). That assignment of designations for stepped outcrops was used in the most recent of publications but their order regarding successive reefs became confused. The so called "134 ka group" based on the upper fringing reef (VII$_b$) was discarded (replaced by a 118 ka TIMS date) but reappears on the reef-front (136-132 ka), below the VII crest (=VII$_b$) also dated by TIMS at 118 ka (Stein *et alii*, 1993; Esat *et alii*, 1999). The uppermost VII$_a$ outcrop is thus considered one of the youngest despite an assumed continuous uplift.

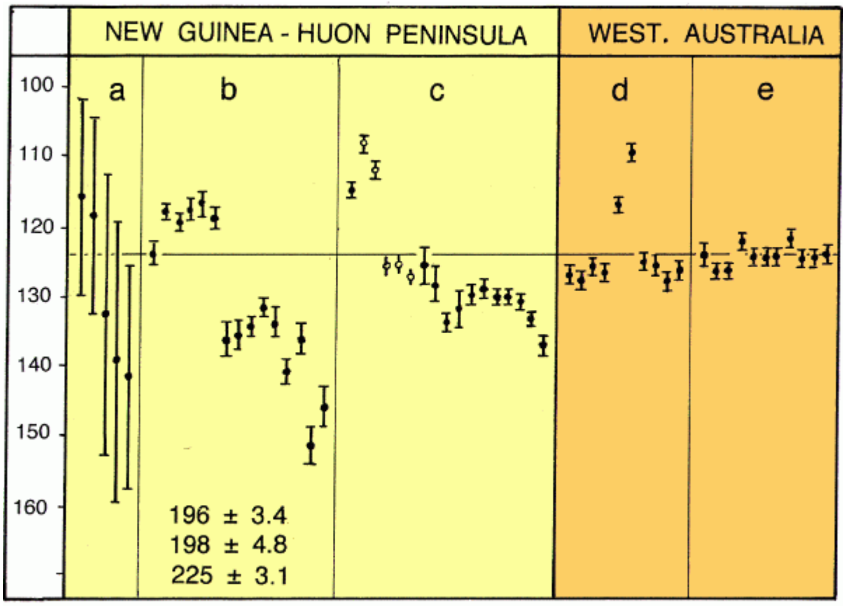


Figure 11: Selected Th/U dates based on α and TIMS dating from the literature concerning reefs in New-Guinea and Western Australia. The reference line is 123 ka. Huon peninsula: a = Veeh and Chappell, 1970; Chappell, 1974. b = Stein *et alii*, 1993. c = Esat *et alii*, 1999; McCulloch and Esat, 2000. d = Rottnest Island, Stirling *et alii*, 1995. e = Lander Point, Stirling *et alii*, 1995.

The older group of pre-TIMS ages (136-151 ka) is rejected by Stein *et alii* (1993) owing to their excessively high $\delta^{234}U_{(0)}$ and an inconsistency in their ages. This unreliability is unquestionably a consequence of diagenesis but we note that the authors prefer to explain (implicitly) this discrepancy as an error caused by a lowering in the age measurements rather than a rejuvenation of unknown amplitude of the coral material. The puzzling "absence of ages between 132 and 120 ka" has been filled by Esat *et alii* (1999) using well preserved corals from "Aladdin's cave", a site allowing horizontal penetration to the core of the reef VII complex at a location more than 100 m below its original crest (Fig. 10).

The 136-132 ka TIMS dates obtained from the reef front, 20 m below the VII$_b$ crest, have been interpreted as the exact ages of corals that lived near sea-level during a brief, moderately high sea-level stand preceding a major drop in sea-level (down to 80 m), followed by the classic rise to the 5e highstand (but no date older than 118 ka) (Fig. 10). The Aladdin's Cave corals (133.7-125.6 ka, plus one 105 ka date!), that also grew in shallow water, are assigned to a new (previously unrecorded) sea-level culmination preceding the beginning of the 5e rise. This culmination is interpreted as a first "melt water pulse" followed by a brief lowering of sea-level ("Huon Sialum event") that ended just after 130 ka (Esat *et alii*, 1999) as documented by the older Aladdin's Cave corals. Nevertheless, the recording of a few much younger corals suggests a complex mix of pre-5e and 5c corals. In fact, this scenario does not explain the "reliable" younger ages of 115 and 112 ka found in Aladdin's cave, nor the "unreliable" 107 to 129 ka ages. McCulloch *et alii* (2000) invoke once again a diagenetic increase in age as the only explanation, but the large number of anomalously young dates suggest a varied, stacked rejuvenation.

As an alternative we suggest that the "134 ka group of dates" should be considered rejuvenated MIS 7 corals rather than late MIS 6 corals. This interpretation does not exclude coral growth on the already fossil MIS 7 core during the MIS 6 to MIS 5 rise in sea-level (possibly documented by the post-130 ka corals of which the $\delta^{18}O$ readings indicated cooling:

see McCulloch *et alii*, 2000). As there is no good candidate above the reef VII outcrop for the required MIS 7 reef (sample SIAL-D1 of the following upper VIII terrace is much too old: 225.9 ± 3.1 ka) we suggest that the embarrassingly low altitude of the "134 ka group" covered by 118 ka corals would be better explained by a deep erosion (more than 20 m?) of the emerged VII (= MIS 7) reef before a progressive recolonization by MIS 5.5 corals as it was being drowned by the new sea-level culmination. Both groups of dates (before 130 ka and 118 ka) would be the rejuvenated ages of reefs developed respectively during the MIS 7 and MIS 5e highstands.

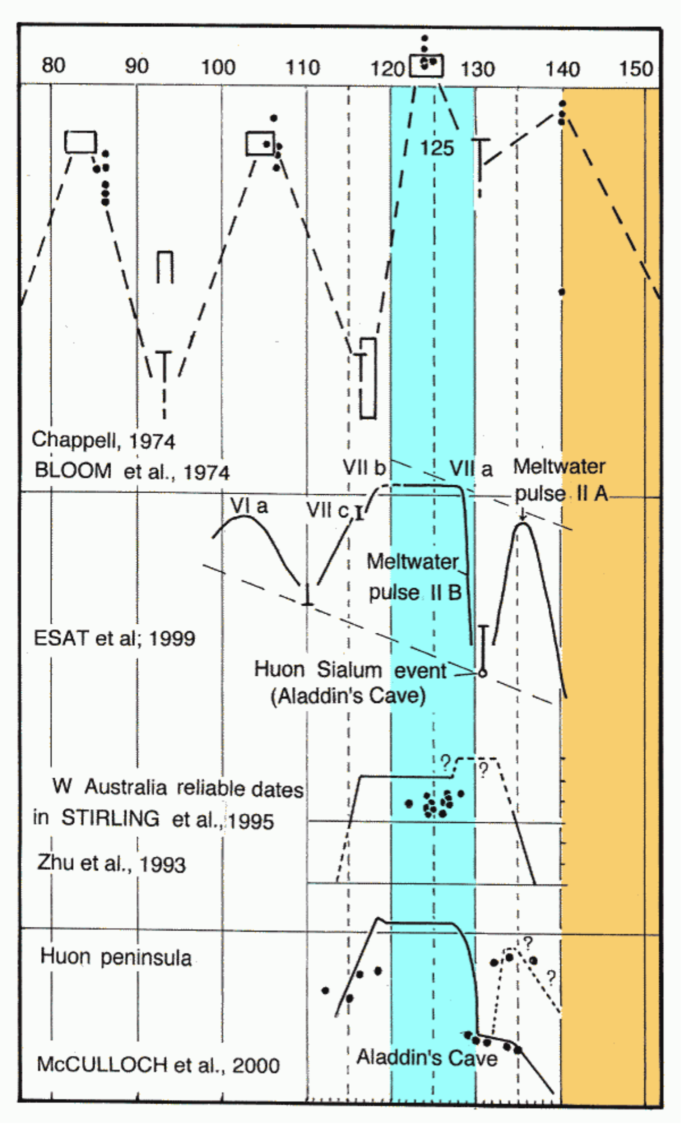


Figure 12: Selected sea-level curves from the reefs of the Huon peninsula referred to MIS 5 sea-level highstands. Heavy dots are coral Th/U dates. The Western Australian dates contribute an alternative to the regional reconstruction of post-130 ka sea-level changes. On the other hand, the significance of pre-130 ka dates of the shallow water coast of the Huon Peninsula is particularly doubtful.

The apparent conflict in the clustering (Fig. 11.d-e) around 125 ka in the Western Australian data reported by (Stirling *et alii*, 1995), was in later papers by Esat *et alii* (1999) and McCulloch *et alii* (2000) thought to have been explained by the compatibility between the "keeping-up" reefs of New Guinea developed during the rapid rise of termination II and the sea-level highstand reefs of the stable Western Australian coast. The scarce dates in Australia younger than 115 ka but generally considered as "reliable" for non-raised reefs could also have been the result of a rejuvenation of MIS 5.5 ages.

The Western Atlantic and Caribbean islands constitute the other major area of actively studied reefal terraces (Figs. 13-14). The studies of the several hundred meter high terraces on Barbados island and in northern Haiti have been complemented through the study of the last Interglacial reefs in the near sea-level stable Bermudas and Bahamas islands. The more precise dates published during the last few decades discredit the older α results, though we maintain a special interest in the pioneer works (*e.g.* Harmon *et alii*, 1981) because they show that dates ranging from 134 to 83 ka must be the result of a diagenetic rejuvenation of MIS 5e corals, whatever the dimensions of the error bar (Fig. 11.a-b). The more precise α dates (Fig. 13.d-f) are those obtained from Barbados (Ku *et alii*, 1990). They display the same scattering trend, but it is limited to between 134 and 100 ka. These results cannot be repudiated only because there are very few TIMS dates from Barbados (Bard *et alii*, 1990) (Fig. 13.c) for the 125 ka TIMS dates are in complete agreement with the most common α dates for MIS 5.5. The 110 ka date (referred to MIS 5c) is too old to be referred to this substage, and the 89 ka (referred to MIS 5.1) is too young and at odds with other dates (79-77 ka also referred to MIS 5a).

Seven, more recent TIMS dates from the Rendez-vous Hill, Barbados III terrace (Gallup *et alii*, 1996) with a 130-117 ka range are also in good agreement, if an unreliable 135 ka date is excluded.

The Bahamas, if not necessarily the "Rosetta stone of Quaternary stratigraphy" (Hearty, 1998), provide one of the best series of field studies for the purpose of precise dating (Chen *et alii*, 1991; Hearty & Kindler, 1995; Kindler & Hearty, 1996; Kindler *et alii*, 1998; White *et alii*, 1998; Wilson *et alii*, 1998: among the best latest references) (Fig. 11.g-j).

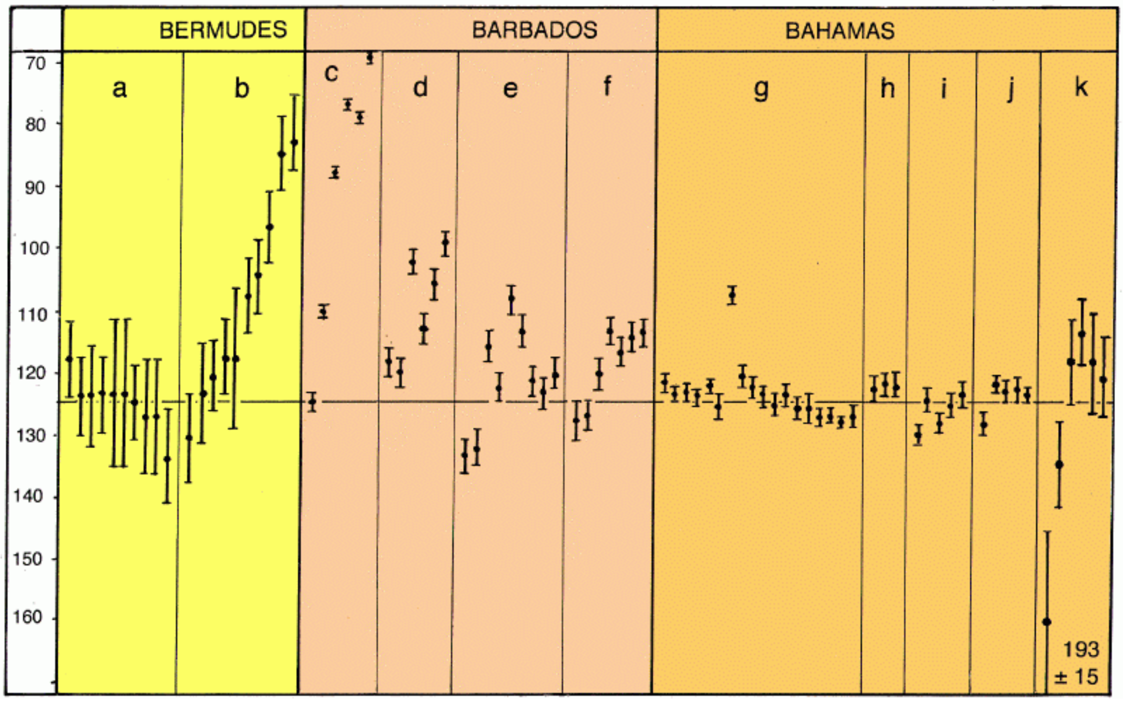


Figure 13: Selected Th/U dates including α and TIMS dating from the literature concerning the Atlantic ocean islands of the Bermudas, Barbados and the Bahamas. a-b: Bermudas (uplifted islands): HARMON *et alii*, 1981. Devonshire Fm (a), Spencer's Point Fm (b). c-f: Barbados. c: BARD *et alii*, 1990. d, e, f: KU, 1990. Rendez-vous Hill (Barbados III) terrace, AFM Site (d), Maxwell Terrace (f). g-j: The Bahamas: CHEN *et alii*, 1991; WHITE *et alii*, 1998. Cockburn Town reef (g), Sue Point reef (h), Devil's Point reef B-B' (i), C-C' (j). k: KINDLER *et alii*, 1998. Devil's Point. The reference line is 125 ka.

Data from several islands contributed to the construction of a sea-level curve common to this stable archipelago (Fig. 14). As Great Inagua and San Salvador islands were the locations of the major contributions from CHEN *et alii* (1991) to WILSON *et alii* (1998), we limit our discussion to this disputed area. At first sight, the TIMS dates published by CHEN *et alii* (1991) constitute a very impressive cluster of "reliable" dates, from 130 to 121 ka, with very few "escaping" values (108 and 132 ka). We do not discuss the "negative excursion" at 125 ka of NEUMANN and HEARTY (1996, Fig. 4), drawn on a Bahamian sea-level curve but dated from an analogy with previously studied series from the Mediterranean and South Carolina coasts. According to HEARTY and KINDLER (1995) a Bahamian reddish-protosol developed between an early 5e highstand (132-127 ka, estimated) and a more complex latter 5e highstand (123.5-120 ka). The eustatic significance of such a soil is not questionable but its chronological placement was influenced by the dates then available. It was referred to a brief mid-5e event similar in location to our 5.52 drop in sea level (between reef-and-beach and khor-to-salina Egyptian units). On the other hand, WHITE *et alii* (1998) emphasize the extreme brevity of such a mid-5e sea-level lowstand, deduced from the coral reef discontinuity seen at Cockburn Town (San Salvador) (WHITE *et alii*, 1998, Fig. 10). In this key locality, the bounding ages of the erosional episode (Fig. 14) are assumed to be 125.5 ka and 123.8 ka, the respective error bars of the limiting dates making them completely superposable. We have seen above that the superimposition of a more recent, late 5e unit (5.51), on the older one (5.53) is not necessarily in contradiction with an identification of this discontinuity with that which resulted in the entrenchment phase (5.52) of the Egyptian units, characterized by two down stepping highstands. The parallelism of this event in two widely separated areas seems reasonable because the top of the second marine unit of the Bahamas is less than +3m (like that of the second Egyptian-derived mean sea level referred to MIS 5.51 times) thus suggesting an important erosion of the underlying reefal unit. We can but wonder at the deep erosion that lowered the older reef terrace so much during an extremely short drop in sea-level. We focus our attention on the lack of MIS 7 reefal deposits reported by WHITE *et alii* (1998). In fact, a new program concerning Inagua reefs suggests that the reefal complex of Devil's Point should be re-interpreted as a three-marine-unit sequence (KINDLER *et alii*, 1998, 2007) (Fig. 13.k), for the subjacent, beach and paleosol are older than MIS 7, the lower reefal unit being referrable to MIS 7 (from 193 to 134 ka) and the upper coral rubble unit merging into a MIS 5.5 reef dated at 121 ± 7 and 118 ± 7 ka.

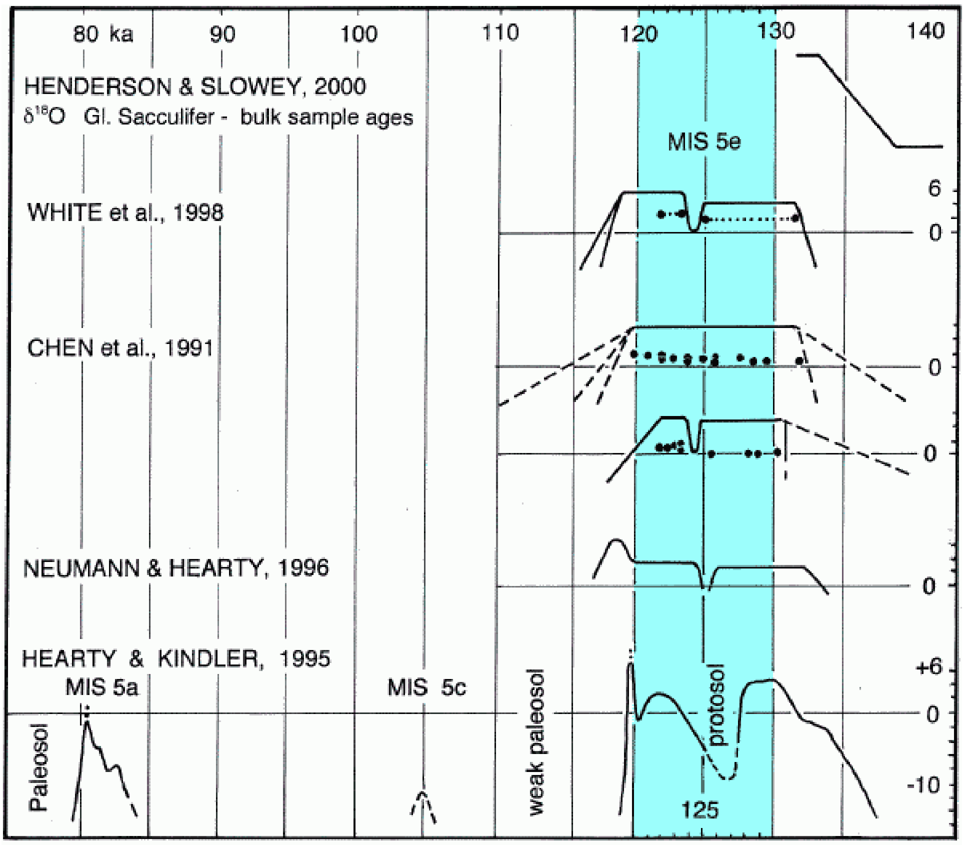


Figure 14: Selected sea-level curves from the dated sequences cropping out in the Bahamas archipelago. The $\delta^{18}O$ study of HENDERSON and SLOWEY suggests an earlier sea-level rise at termination II (Saalian glaciation melting). Heavy dots indicate the location of the Th/U dated corals with respect to time (ka) and altitude (m).

Another meaningful contribution from the Bermudas' raised reefs involves the surprisingly young dates of a Late Pleistocene terrace. Although 5e deposits are not tectonically uplifted, the Southampton Formation shows a basal marine subunit, 1 m a.s.l. (VACHER & HEARTY, 1998), dated close to accepted 5a times (85 ± 12 ka in HARMON *et alii*, 1981; 77.2-82.4 ka, in LUDWIG *et alii*, 1996). However this circa 80 ka period is classically associated with submerged reefs in the same area of the Caribbean (LUDWIG *et alii*, 1996). This viewpoint is more nearly in agreement with the SPECMAP bathymetric interpretation of the marine $\delta^{18}O$ data. Consequently, we object to the pre-eminence given to the radiometric data, accepted without discussion of their reliability. In our opinion the low altitude of the basal Southampton unit, in the spray zone of the Holocene to Present sea shore, should make it suspect of rejuvenation (MIS 5.5?).

Such a boring critical review is not a gratuitous exercise. It provides grounds for the following reflection offered as a research hypothesis: because the community of geochemists cannot suggest, at the present state of the art, a process to account for the purportedly important ageing chronology of many Th/U dates considered "reliable" from the "geochemical system closure" point of view (but very far removed from the timing of sea-level highstands), we suggest that widespread rejuvenation be considered as a potential explanation of the discrepancies in temporal measurements encountered, for the process has been adequately demonstrated for some Egyptian MIS 5.5 corals (PLAZIAT *et alii*, 1998a, 1998b, and this work) and has been accepted for a long time for dating mollusks. Therefore, we hope that this hypothesis will be discussed freely and without prejudice as regards the potential skewing of dates based on corals. We repeat that the methods of dating are not in dispute but that the actual ability to detect a post-burial addition of younger uranium in corals is still open to question and verification. This process is especially prone to occur where outcrops have been bathed or sprinkled by repeated marine transgressions during the initial 100 to 200 thousand years of the diagenesis of anthozoan biominerals.

7. Discrepancy between the chronology of the episodes of reef growth and the time scale of global climatic fluctuations.

The best way to confirm the accuracy of the dating of emergent coral reefs would be to check their "ages" against those of an accurate, unquestioned time scale, common to both marine and continental sequences (Figs. 7 & 15). As a matter of fact the time scales used in the construction of the classic curves of sea-level fluctuations as well as those of the temperature of the sea-surface and of the continental atmosphere (derived from polar ice caps and speleothems including vein calcite) are only approximations with admitted ranges of uncertainty.

Paradoxically most of the key dates concerning sea-level fluctuations during the Middle to Late Pleistocene transition have been derived from the first reef coral dates. This practice certainly accounts for the reasonably good consistency between reef and other marine chronologies. The dates of the uppermost episodes of reef growth in emergent reefs in stable areas appear to be in close agreement with the $\delta^{18}O$ SPECMAP time scale (around 120-125 ka, see Fig. 15), the 5e spike being around 125 ka. As the average (absolute) error of the $\delta^{18}O$ curve was assumed to be ± 5 ka (MARTINSON *et alii*, 1987), subsequently reduced to ± 2 ka (see for example CORTIJO *et alii*, 1994; BAUMANN *et alii*, 1995), the shift of the 5e spike toward 123 ka suggested in another reference curve taken from LABEYRIE *et alii* (1987) appears to be insignificant (Fig. 7). In both time scales, the ages were derived from "calculated ages of isotopic events" linked by linear interpolation of assumed rates of sedimentation, the chronology of $\delta^{18}O$ variations having been adjusted to reflect the calculation of orbital variations of planet revolutions. So the accepted time scale derived from $\delta^{18}O$ studies reflects subordination to the MILANKOVITCH theory and, in the short interval of time under discussion (the two most recent interglacials), involves no precise independent contribution of absolute (radiometric) dating. Nevertheless, there are now exceptions: SLOWEY *et alii* (1996) used TIMS to determine the Th/U ages of seven MIS 5 and two MIS 7 samples: the MIS 7 spike is established at 190 ± 5 ka and the MIS 5 spike (MIS 5.5) at 124/127 ka. The duration of 5e highstand, derived from four other dates, is 10 ka (129-119 ka) or even longer (132-115 ka) but the average spike age at 123.5 ± 4.5 ka is in good agreement with the SPECMAP chronology. A brief fluctuation in $\delta^{18}O$ in the 5e record is also worthy of note. Another contribution (HENDERSON & SLOWEY, 2000) based on the same core from the southern slope of the Little Bahama Bank gives direct datings for termination II (Fig. 15). The authors strongly suggest that a first $\delta^{18}O$ culmination referred to the 5e highstand is earlier than 130 ka (132.2 ka according to a Th/U isochron, see our Figs. 14-15). The limited reliability of this chronology (age inversions, 3 ka in range) excludes it from a discussion of precision of these dates. The 5 ka shift separating the respective sea-level curves of this study from those of the classic SPECMAP certainly deserves corroboration because a confirmation of the validity of the shift would reduce or compensate for the major difference (5 ka) usually admitted between the reversal of the trend of thermic changes in the atmosphere (Vostok ice, Devils Hole phreatic water) and in the ocean (marine water), as illustrated in WINOGRAD *et alii* (1977), JOUZEL *et alii* (1993) and PETIT *et alii* (1999) (Fig. 7). The new time scale suggested by this one core may not contradict the astronomical tuning of deep sea records because we know that the $\delta^{18}O$ chart is a "floating construction" in terms of absolute chronology. Its dates suggest only that the lead for the polar temperature increase (Vostok δD in ice) would be reduced in comparison with the fluctuations of $\delta^{18}O$ in tropical sea water taken as a proxy for the sea-level curve (Fig. 15). In other words, the rise in sea-level of termination II would have attained the Present sea-level before 130 ka. When compared with the earliest dates from reefs now above sea level (on stable coasts) this new chronology strongly reinforces the validation of early, though post-132 ka, 5e reefs. On the other hand the current chronology is in better agreement with the astronomically-tuned variations of insolation (at 55-60°N in June or July) giving a 128 ka maximum generally assumed to be "fairly anterior" to the "complete" melting of the polar ice. These quotation marks are in reference to classical but questionable ideas: the ice caps of both poles did not melt completely during the last interglacials (see GRIP, GISP, Vostok ice cores) and the delay between a major thermic variation and its effect on global sea-level (via sea water uptake as sea-ice and stacked snow) is necessarily brief, for during the Last Interglacial 5.5 substage the drop and rise in sea level were extremely short (PLAZIAT *et alii*, 1998b).

Because modeling the South Polar ice cap and southern hemisphere insolation is beyond our competence we do not discuss the attempts at an explanation for this brevity, the timing of variations in insolation between the hemispheres (HENDERSON & SLOWEY, 2000), or the difference between earlier global atmospheric warming and the increase in the insolation of the high latitudes of the Northern hemisphere We insist only on their possible contribution to the discussion of the reliability of the dates derived from the SPECMAP time scale, in turn clearly relevant to the chronology of raised reefs in itself closely coordinated with the causes of changes in sea-level.

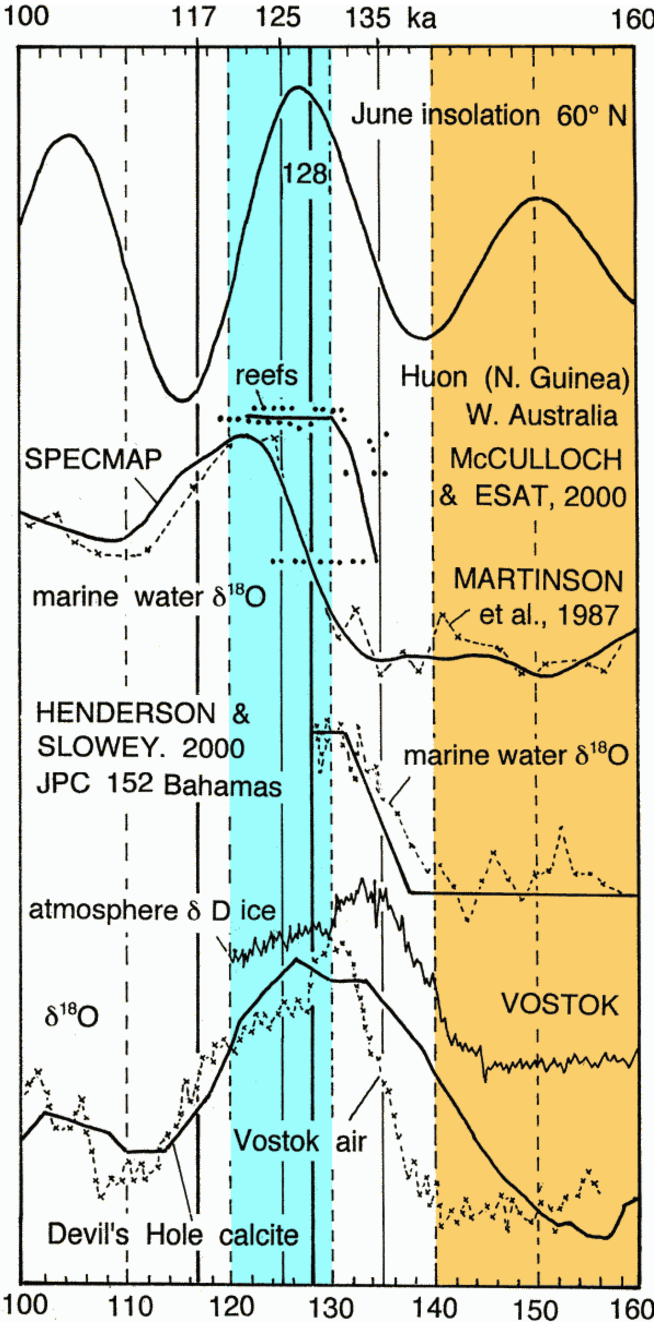


Figure 15: Comparison of: (1) The last interglacial, most recently dated marine series (Australian reefs and JPC 152, Bahamas coring) (2) the calculated insolation curve of the northern-hemisphere (3) orbitally tunned $\delta^{18}O$ curves, and (4) continental climate-linked curves. The proposed 132-130 ka date of the beginning of the MIS 5e culmination of sea level surprisingly predates the maximum of June insolation as well as the synthetic isotopic (Martinson *et alii*, 1987) and SPECMAP curves derived from $\delta^{18}O$ marine data. Such a discrepancy suggests a need to reevaluate the bench-marks of the timing of the general curves.

8. Conclusion: the contribution of Egyptian reefs to Quaternary climatic reconstruction.

The very limited uplift of the Egyptian coastal plain suggests that the respective altitudes of the late Quaternary marine terraces (at least MIS 5.5 and 7 and possibly 9 and 11 highstand reefs) indicate their respective derived sea-level altitudes very close to that of Present Mean Sea Level. The small differences in absolute altitudes indicated by the complex superpositional relationships of the 5.5, 7 and 9? reef units could be explained by variation in the local erosions of the upper part of each preceding reef but a more likely interpretation seems to be a slightly higher culmination of the MIS 5e sea-level (MIS 5.53, MIS 5.51).

Th/U dates unquestionably demonstrate a rejuvenation of MIS 5.5 corals (Plaziat *et alii*, 1998a, Fig. H2.6; our Fig. 4.3 : Ras Shagra and Sharm el Luli sections), so we question the ages of well preserved corals with dates intermediate between those of MIS 7 and MIS 5.5. The apparently "normal" MIS 6 dates must be interpreted as rejuvenated MIS 7 ages but the main problem concerns the samples with a Th/U date very near the disputed starting-point of the MIS 5.5 (5e) highstand, *i.e.* dates between 133 and 128 ka. Do they indicate an earlier than anticipated rise above Present sea-level or do they come from an underlying MIS 7 reef that was highly rejuvenated during the MIS 5.5 drowning and thereafter? Taken as a whole, the dates of MIS 5.5 reef corals obtained during our research in Egypt agree completely with a post-128 ka culmination (shown by its existence 5 to 10 m above Present sea-level). This dating of the culmination is also suggested by the "best" TIMS dates from stable Western Australia (Stirling *et alii*, 1998), from Barbados (Bard *et alii*, 1990) and by most of the "reliable dates" from the Bahamas (Chen *et alii*, 1991). We insist on the fact that the conjoined association of ranges in age from most of the key localities, especially those from precise TIMS datings, together demonstrate that the uncertainty (unreliability) of the so called "reliable ages" may exceed the precision (accuracy) of the measurements. Given the relative unreliability of the more precise "ages", we suggest that the MIS 5.5 Egyptian reef-growth episodes - taking into account the imprecision of the dates - conforms adequately with the insolation reference curve (June, 60°N) that purports to give the timing and amplitude of heat changes in the northern hemisphere. The necessity of synchronizing global reef-growth above Present sea-level and glacio-eustatic highstands emphasizes their inconsistency with both the South Polar ice δD curve and the SPECMAP seawater $\delta^{18}O$ curve. The Vostok data reflect local variations of climatic conditions (possibly before those of the northern hemisphere, if the insolation curve of the southern hemisphere is different; see HENDERSON & SLOWEY, 2000), but the resulting lowest $\delta^{18}O$ of the Vostok atmosphere is not far distant from the date of the 5.5 optimum in the insolation curve of the northern hemisphere (128-126 ka) calculated from astronomical parameters (Fig. 15). On the contrary the SPECMAP sea water $\delta^{18}O$ curve appears to be retarded which is especially disconcerting as its time scale too is orbitally tuned. The 4/5 ka shift is particularly obvious on synoptic diagrams (Fig. 7) but we must keep in mind that the precision of the time scale of this marine $\delta^{18}O$ curve was published with the same estimate of uncertainty (5 ka in MARTINSON *et alii*, 1987). Therefore, we are prompted to question the accuracy of the SPECMAP time scale rather than to exclude "anomalous" dates.

The $\delta^{18}O$ events chart proposed by PISIAS *et alii* (1984) and completed by MARTINSON *et alii* (1987) suggests a complex 5.5 interglacial optimum better defined than in the averaged SPECMAP curve. Whatever its precise (but questionable) absolute chronology may be, we must call attention to its major contribution: the evidence of a brief and limited increase of $\delta^{18}O$ that might have been interpreted (but was not) as related to a brief lowering of sea-level during its highest stand. We do not undervalue the possible significance of the then published mid-5e drop in sea-level in the descriptions of reef VII from Huon Peninsula (CHAPPELL, 1974; BLOOM *et alii*, 1974; CHAPPELL & SHACKLETON, 1986) but this feature has been found so often in ocean cores that it is no longer questionable (see PLAZIAT *et alii*, 1998b). That is the reason for our use since 1998 of MARTINSON's terminology, the substage designations 5.51-5.52-5.53, that were erected from isotopic events. Such a common terminology extended to lithostratigraphic units however does not mean that we believe in the precision accorded to estimated dates that were neither measured nor calculated.

The entrenchment of the second 5.5 transgressive deposits in Egypt (Fig. 8) coincides precisely with the 5.52 $\delta^{18}O$ event. It is within the range of uncertainty of our radiometric dates of both the 5.53 and 5.51 events and we have pointed out (PLAZIAT *et alii*, 1995, 1998a, 1998b) that it is the first published record of an almost irrefutable evidence for the short duration of the lowering of sea-level responsible for a mid 5.5 erosion. Owing to this brevity, we do not exclude the possibility that the precise bracket of 124 ± 0.5 ka given by WHITE *et alii* (1998) is the exact age of the 5.52 drop in sea level, for this age is not far from the 125.19 ± 2.92 ka date proposed by MARTINSON *et alii* (1987) for the 5.52 isotopic event.

On the other hand, this short lowering of sea-level should not be considered as equivalent to the long lowstand (SHERMAN *et alii*, 1993) that supposedly interrupted the 5e culmination, especially when the earlier reefal unit is assumed to be more than 130 ka old. If such be the case, we suggest that the discontinuity be referred to MIS 6 (Saalian glaciation), in the same way that this discontinuity was reappraised in the Inagua sequence (KINDLER *et alii*, 1998).

An estimation of the duration of such a marked but brief cooling during the 5.5 optimum is difficult, for it is rarely registered in reefal sedimentation but in Egypt it is linked to a lowering of approximately 10 m in sea-level. This is a general problem because like all the boundaries of cooler (glacial?) episodes (7.4, 7.2, 5.4, 5.2) there is no general agreement on their definitions (see PETIT *et alii*, 1999). As the Weichsellian glaciation is now taken to include most of the MIS 5 climatic variations (5.3 to 5.1 stadials and interstadials of the early Weichsellian glaciation, see Fig. 2) we must establish the climatic significance of the major cooling episodes in relation to isotopic events 7.4 to 6.2. The first of the problems concerns the age of the penultimate, above-Present-sea-level highstand (MIS 7) because the contradictory polar (Vostok) and tropical (Caribbean) data suggest that three isotopic events – namely 7.5 (240 ka), 7.3 (215 ka) and 7.1 (193 ka) - are probably coincident with above-Present-sea-level stands. The validity of a relationship between them is of special importance for the codification of the reefs older than the ubiquitous 5.53 early Late Pleistocene reefal episode. As we have suggested that most of the dates relating to the penultimate climatic cycle are biased by a diagenetic rejuvenation, we cannot discuss the amplitude of a rejuvenation without establishing the "true age" of each MIS 7 episode prone to reef growth. Currently, this problem is certainly one of the most difficult to resolve.

Field evidence together with new interpretations of the radiochemical dates of the Egyptian marine deposits laid down above Present sea-level during the Late Pleistocene highstand, brings to light disturbing conclusions concerning the reconstruction of Quaternary changes in sea-level and the associated rapid, short-lived variations in climate suggesting high frequency variations in polar ice growth and melting.

The controversial question of the reliability of Th/U α counting method that is certainly less precise than TIMS technology appears to be secondary to the question of the validity of the age inferred from every dated sample. Rejuvenation of its biominerals after the date of death of a coral appears to be inseparable from the diagenetic processes involved in its fossilization as is the case for biominerals of other organisms (mollusks for instance). The fossilization of their skeletons involves a diagenetic evolution of the organic matter intimately associated with the acicular crystals of aragonite. The incorporation into this organic matter and diagenetic crystals of uranium from sea-water, or later from continental and marine waters, is certainly facilitated by the decay of the organic matter (changes in pH, the opening and filling of micro-voids due to disintegration of crystal sheaths, crystal leaching and syntaxial growth, *etc.*). It is not easy to determine whether or not the marine isotopic signature in fossil coral skeletons was primarily produced during life through aragonite mineralization or is the result of a replacement, especially by a secondary aragonite during marine diagenesis caused by exposure to splash and spray, by a drowning in a later highstand, or by capillarity permeation from the sea-water table (this possibly much later). For all these indisputable reasons, disregarded because the minute scale of diagenetic changes makes them difficult to see, a selection of supposedly unmodified corals prior to radiometric analysis is certain to fail, except when the substitution of vadose or phreatic low-magnesium calcite is obvious. On the other hand, a massive cementation occurring during the earliest marine diagenesis may, paradoxically, be favorable for the desired closure of the geochemical system, for it gives a date close to the time of death.

Consequently, we suggest that the distribution of dates scattered around a value should be reinterpreted statistically, not as a Gaussian distribution but as a pattern of clusters of which a portion is rejuvenated, the older modal maximum of the dates being close to the true value (age) while distant dates for the most part would have been caused by a rejuvenation (Fig. 16).

The application of this rejuvenation hypothesis to reefal units that have dates older than 130 ka should cause a reconsideration of many "early 5e" reefs, that are likely to be of MIS 7 age (see Fig. 10). The suggested long-lasting 5e highstand (17 ka in duration) may thus be lessened to about 10 ka. The presumed gap between the so called "early" and "late" 5e reefal units will be accordingly lengthened, for it will be assigned to the penultimate glaciation (MIS 6). In terms of absolute chronology, a discussion of the local factors influencing the reliability of each dated sample in a regional sequence should be evaluated in respect to diagenesis and its consistency with changes in sea level. However the reliability of a date cannot be determined only from its degree of consistency with the chronology of sea-level curves: a reassessment of the accuracy of the accepted time scales of the reference curves must be made before a high precision in the graph determination of ages can be assured.

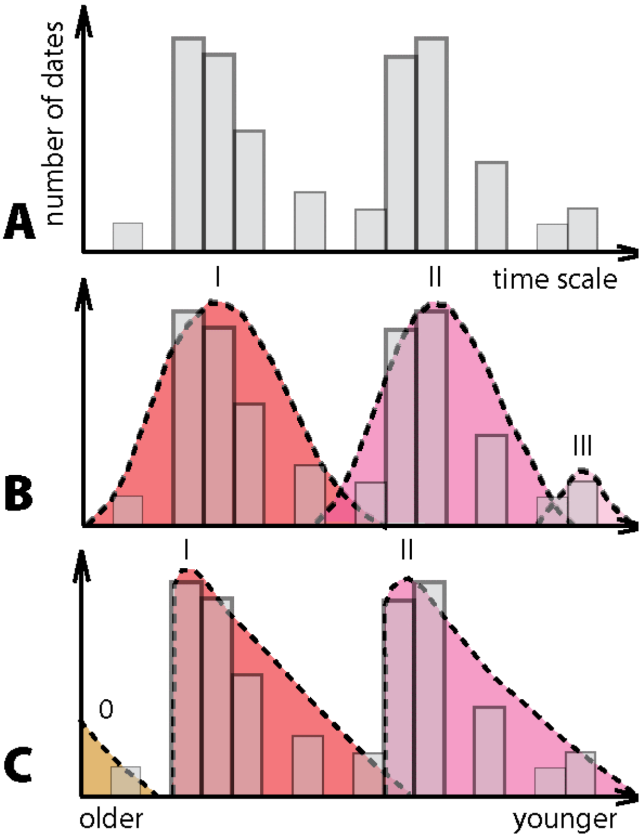


Figure 16: Interpretative diagrams of a theoretical bimodal distribution of ages. The usual statistical (Gaussian) interpretation (B) suggests that sparse dates distant on either side from the more numerous dates (Gaussian mode) clustered around the "true" age are the results of gross error, thus favoring the average values. The rejuvenation hypothesis (C) induces a selection of older dates as the true ages. Note that they are earlier than the average values. The sparse staggered values are regarded as the result of rejuvenation and are referred to the preceding reef growth.

Sample	altitude m	calcite %	^{238}U ppm	$(^{234}\mathrm{U}/^{238}\mathrm{U})_{t0}$	$^{230}\mathrm{Th}/^{232}\mathrm{Th}$	$^{230}\mathrm{Th}/^{234}\mathrm{U}$	Date	limits (1σ)		MIS
Quseir al Qadim										
95-33(b)	8	<0.1	3.220 ± 0.044	1.237 ± 0.029	>502	0.979 ± 0.018	329	+43	-31	9?
91-1	2.5	<1	2.924 ± 0.052	1.160 ± 0.013	>131	0.683 ± 0.019	121.1	+6.2	-5.9	5e
95-27a	4	0.3	2.969 ± 0.060	1.178 ± 0.026	>470	0.714 ± 0.019	131	+6.6	-6.3	5e
95-31	2.5	1	3.911 ± 0.101	1.207 ± 0.030	>163	0.675 ± 0.027	117.6	+8.5	-7.9	5e
Sharm el Bahari										
91-1	4	<1	3.939 ± 0.082	1.281 ± 0.013	>133	0.706 ± 0.022	126.2	+7.2	-6.8	5e
93-10	7	<0.5	2.508 ± 0.035	1.224 ± 0.019	>447	0.716 ± 0.014	130.8	+4.9	-4.7	5e
94-23	7.5	2	3.306 ± 0.082	1.201 ± 0.032	88	0.686 ± 0.022	121.2	+7.2	-6.8	5e
Ras Shagra										
95-16 (5)	0	<0.1	3.408 ± 0.050	1.176 ± 0.018	>225	0.451 ± 0.011	364.2	+2.2	-2.1	5e
91-3 (R3)	4.5	<1	2.999 ± 0.043	1.150 ± 0.011	>177	0.688 ± 0.018	122.9	+5.8	-5.5	5e
94-49	5	<0.1	2.656 ± 0.053	1.152 ± 0.027	>245	0.686 ± 0.019	122.3	+6.3	-6.0	5e
95-16 (1)	2	<0.1	3.039 ± 0.063	1.166 ± 0.028	>110	0.661 ± 0.020	114.1	+6.0	-5.7	5e
95-16 (2)	4	<0.1	2.485 ± 0.041	1.149 ± 0.025	566	0.692 ± 0.019	124.1	+6.4	-6.0	5e
95-16 (3)	5	0.2	2.805 ± 0.080	1.172 ± 0.041	307	0.686 ± 0.022	121.7	+7.4	-7.0	5e
95-16 (4)	1.5	0.2	3.031 ± 0.048	1.137 ± 0.021	200	0.653 ± 0.015	112.2	+4.7	-4.5	5e
95-19 b1	1	<0.1	4.154 ± 0.070	1.137 ± 0.018	137	0.361 ± 0.012	48.2	+2.0	-1.9	5e
95-19 b2	1	<0.1	3.984 ± 0.081	1.122 ± 0.022	>133	0.366 ± 0.012	49.1	+2.1	-2.0	5e
95-18	3	2	2.823 ± 0.048	1.163 ± 0.025	>340	0.703 ± 0.017	127.7	+6.0	-5.7	5e
95-19a	0.1	<0.1	2.436 ± 0.054	1.1168 ± 0.017	>879	0.657 ± 0.018	113.1	+5.6	-5.3	5e
Wadi Egla										
Mai 91-1	5	<1	3.269 ± 0.049	1.176 ± 0.013	>732	0.673 ± 0.014	3117.6	+4.4	-4.2	5e
Déc 91-1	4	<1	2.409 ± 0.049	1.151 ± 0.016	>173	0.664 ± 0.018	115.6	+5.5	-5.3	5e
Déc 91-2	6	<2	3.151 ± 0.065	1.162 ± 0.027	>163	0.675 ± 0.018	118	+5.8	-5.2	5e
94-45	1	<0.1	2.447 ± 0.044	1.189 ± 0.024	>540	0.663 ± 0.018	114.5	+5.4	-5.2	5e
95-23	4	<0.1	2.751 ± 0.054	1.160 ± 0.029	267	0.698 ± 0.022	126	+7.6	-7.2	5e
95-20Por.	2	<0.1	3.433 ± 0.062	1.131 ± 0.030	>276	0.842 ± 0.019	191.3	+12.3	-11.0	7 or 9
94-44	5	0.8	3.341 ± 0.071	1.163 ± 0.033	>320	0.926 ± 0.024	258	+30	-624	9?
94-46	5.25	<1	2.315 ± 0.040	1.210 ± 0.034	>350	0.934 ± 0.023	261	+28	-23	9?
94-46b	5.25	<1	2.100 ± 0.052	1.253 ± 0.069	316	0.991 ± 0.031	358	+136	-61	9?
94-20Styl.	2	1.5	2.968 ± 0.053	1.304 ± 0.050	>262	0.993 ± 0.026	349	+86	-49	9?
95-21	5	1.8	3.248 ± 0.046	1.264 ± 0.046	>262	0.971 ± 0.026	308	+51	-35	9?
95-22	5	0.3	2.536 ± 0.043	1.261 ± 0.047	>122	0.979 ± 0.027	324	+68	-42	9?
Wadi Nakara										
94-36	4	<0.1	2.678 ± 0.053	1.172 ± 0.024	>433	0.708 ± 0.018	129.2	+6.4	-6.1	5e
93-3a	5	1.5	3.816 ± 0.050	1.136 ± 0.018	>897	0.859 ± 0.015	210	+11	-10	7 or 9
93-3b	3	1.5	3.711 ± 0.040	1.146 ± 0.016	>1035	0.883 ± 0.013	219	+11	-10	7 or 9
94-35a	1	<1	3.205 ± 0.076	1.161 ± 0.040	>238	0.918 ± 0.030	250	+35	-26	9?
94-35b	1	<1	3.599 ± 0.088	1.202 ± 0.044	>271	0.959 ± 0.039	297	+83	-48	9?
95-12b	1	1	3.195 ± 0.054	1.218 ± 0.027	>264	0.917 ± 0.026	243	+27	-22	9?
95-12a	1	1	2.619 ± 0.057	1.232 ± 0.059	>332	1.001 ± 0.032	408	+ inf.	-87	9?
95-14	1	0.8	3.415 ± 0.090	1.270 ± 0.074	815	1.002 ± 0.034	395	+ inf.	-83	9?
Wadi Khalilat el Bahari										
94-30	1.2	<0.1	3.316 ± 0.069	1.165 ± 0.020	>342	0.587 ± 0.017	93.9	+4.4	-4.3	5e
91-1(R6)	1.2	<1	3.740 ± 0.060	1.157 ± 0.014	>134	0.679 ± 0.018	119.9	+5.8	-5.5	5e
91-3(R5)	5	<1	3.312 ± 0.034	1.158 ± 0.014	>247	0.697 ± 0.015	124.2	+4.9	-4.7	5e
91-4	6	<1	2.608 ± 0.053	1.164 ± 0.014	>356	0.677 ± 0.021	115.7	+6.5	-6.2	5e
94-30.	6	1	2.494 ± 0.056	1.191 ± 0.034	>208	0.701 ± 0.021	126.5	+7.1	-6.7	5e
Wadi Abu Sbikhaia										
94-26inf a	4	<0.5	2.522 ± 0.023	1.089 ± 0.020	>373	0.965 ± 0.025	335	+80	-46	9?
94-26inf b	4	<0.5	2.465 ± 0.025	1.111 ± 0.023	>220	0.938 ± 0.029	281	+49	-34	9?
94-26inf c	4	<0.5	2.493 ± 0.026	1.128 ± 0.028	>634	0.980 ± 0.017	366	+65	-41	9?
95-9 (a)	2	<0.1	2.340 ± 0.036	1.244 ± 0.048	>447	1.007 ± 0.025	435	+*inf.*	-87	9?
Mersa Sifein										
94-40	1.8	<0.1	3.876 ± 0.056	1.149 ± 0.016	>467	0.689 ± 0.015	123.2	+5.1	-4.9	5e
Sharm el Luli										
95-8	2	<0.1	2.786 ± 0.075	1.180 ± 0.039	96	0.700 ± 0.022	126.1	+7.6	-7.1	5e
95-7 inf	8	<1	3.407 ± 0.069	1.142 ± 0.089	166	1.006 ± 0.030	>350			9?
Mersa Alam										
95-24	2	1	2.481 ± 0.056	1.155 ± 0.030	>264	0.693 ± 0.021	124.4	+7.0	-6.6	5e
95-2 Haut	6	2	2.991 ± 0.055	1.188 ± 0.024	>610	0.689 ± 0.020	122.6	+6.4	-6.1	5e

Table 1: Identification and geochemical parameters of dated Pleistocene samples (Th/U, α counting) from the Egyptian, western Red Sea-Gulf of Suez coast. Chemical procedure is derived from that of Ku (1965) and α counting is performed with both grid chambers and semi-conductor. Errors given are one σ derived from counting statistics.

Sample	altitude m	calcite %	^{238}U ppm	$(^{234}U/^{238}U)_{t0}$	$^{230}Th/^{232}Th$	$^{230}Th/^{234}U$	Date	limits (1σ)		MIS
North of Suez										
95-38	3	1	3.206 ± 0.073	1.200 ± 0.050	606	0.921 ± 0.031	248	+35	-25	7 or 9
Abu Darif										
95-46	7	2	2.376 ± 0.035	1.193 ± 0.021	32	0.685 ± 0.014	121	+4.6	-4.4	5e
15km N of Zafarana										
95-48	6	<0.5	2.762 ± 0.054	1.168 ± 0.024	85	0.670 ± 0.018	116.7	+5.7	-5.4	5e
Ras Shukeir										
92-1	2	<2	3.487 ± 0.071	1.169 ± 0.030	>120	0.689 ± 0.021	123.0	+7.1	-6.7	5e
92-2	3	<2	3.028 ± 0.060	1.176 ± 0.031	72	0.698 ± 0.021	125.7	+7.1	-6.7	5e
92-19	5	<1	2.638 ± 0.032	1.171 ± 0.020	>132	0.692 ± 0.019	123.8	+6.4	-6.1	5e
93-14	5	<1.5	2.992 ± 0.043	1.166 ± 0.021	>259	0.682 ± 0.016	120.8	+5.3	-5.1	5e
94-1 Por	5	3	2.591 ± 0.080	1.214 ± 0.049	120	0.717 ± 0.028	131.5	+9.9	-9.2	5e
94-1 Fav	5	1.2	2.508 ± 0.108	1.081 ± 0.055	260	0.650 ± 0.040	112.4	+12.6	-11.3	5e
Gebel Zeit tectonic area (Ras Dib to S of Zeituna)										
91-1a	17.5	<1	4.631 ± 0.101	1.155 ± 0.027	>237	0.685 ± 0.021	121.7	+6.9	-6.5	5e
91-1b	17.5	<1	3.149 ± 0.056	1.167 ± 0.017	>157	0.678 ± 0.020	119.4	+6.5	-6.2	5e
91-3(1)	12	<1	3.326 ± 0.077	1.162 ± 0.031	>243	0.702 ± 0.022	126.6	+6.6	-6.3	5e
92-4(1)	12.5	<1	4.065 ± 0.053	1.167 ± 0.016	>200	0.694 ± 0.020	124.6	+6.6	-6.2	5e
92-5(2)	14	<1	3.837 ± 0.083	1.166 ± 0.027	>234	0.679 ± 0.018	119.7	+5.9	-5.6	5e
92-6(3)	15	<1	3.332 ± 0.061	1.173 ± 0.024	>150	0.673 ± 0.022	117.7	+6.8	-6.4	5e
92-8(3-4inf)	15	<1	3.426 ± 0.062	1.162 ± 0.026	>160	0.665 ± 0.019	115.5	+5.9	-5.6	5e
92-9(3-4moy)	16.5	<1	3.185 ± 0.059	1.179 ± 0.028	157	0.680 ± 0.023	119.9	+6.8	-6.5	5e
92-10(3-4sup)	17	<1	4.631 ± 0.101	1.155 ± 0.027	>237	0.685 ± 0.021	121.7	+6.9	-6.5	5e
92-12	13	<1	4.640 ± 0.067	1.167 ± 0.020	>490	0.703 ± 0.014	127.6	+4.7	-4.5	5e
92-14	12	<1	3.924 ± 0.061	1.162 ± 0.028	>160	0.685 ± 0.021	121.8	+6.8	-6.4	5e
92-16	7	<2	3.726 ± 0.047	1.149 ± 0.040	>406	0.693 ± 0.013	124.7	+4.2	-4.0	5e
92-17	10	<1	3.502 ± 0.068	1.168 ± 0.023	>280	0.685 ± 0.019	121.6	+6.1	-5.8	5e
92-18a	14	<0.5	3.653 ± 0.070	1.150 ± 0.022	>129	0.687 ± 0.017	1227	+5.8	-5.5	5e
92-18b	14	<0.5	3.393 ± 0.037	1.152 ± 0.014	415	0.707 ± 0.012	129.1	+4.1	-4.0	5e
92-18c(spm)	14	<0.5	3.109 ± 0.070	1.175 ± 0.010	715	0.714 ± 0.008	131.4	+2.6	-2.5	5e
92-19	15.8	<0.5	3.803 ± 0.058	1.162 ± 0.017	>236	0.687 ± 0.020	122.5	+5.7	-5.4	5e
92-20	16	<0.5	3.135 ± 0.058	1.194 ± 0.023	>237	0.683 ± 0.020	120.3	+6.4	-6.1	5e
94-7	2.2	<0.1	2.889 ± 0.034	1.121 ± 0.016	>556	0.697 ± 0.013	126.6	+4.5	-4.4	5e
94-8	0.6	<0.1	3.365 ± 0.076	1.177 ± 0.029	222	0.684 ± 0.024	121.2	+8.0	-7.5	5e
94-9	3	<0.1	2.431 ± 0.089	1.174 ± 0.052	>220	0.708 ± 0.045	129.1	+16.6	-14.5	5e
94-10	12	<0.1	4.898 ± 0.116	1.174 ± 0.023	>200	0.678 ± 0.020	119.3	+6.5	-6.2	5e
94-11(17)	18.5	<0.1	3.046 ± 0.063	1.126 ± 0.025	133	0.689 ± 0.019	123.6	+6.5	-6.2	5e
94-12 Por inf	5.4	0.3	3.594 ± 0.069	1.133 ± 0.024	>1000	0.710 ± 0.019	130.8	+6.7	-6.3	5e
94-12 moy	8	<0.1	4.269 ± 0.058	1.162 ± 0.017	624	0.678 ± 0.020	119.4	+6.4	-6.1	5e
94-12 sup	11.5	<0.2	3.372 ± 0.049	1.167 ± 0.019	>75	0.660 ± 0.017	114	+5.1	-4.9	5e
95-36a por	10	<0.2	3.410 ± 0.035	1.188 ± 0.013	>1000	0.715 ± 0.012	131.1	+4.3	-4.2	5e
94-12 inf s1	5.5	<0.2	3.612 ± 0.071	1.128 ± 0.028	>812	0.834 ± 0.023	186	+14	-13	7
94-12 inf s2	5.5	<0.2	3.443 ± 0.070	1.171 ± 0.024	1230	0.823 ± 0.027	179	+15	-13	7
95-35 a acr	10	<0.1	3.491 ± 0.063	1.158 ± 0.025	>430	0.834 ± 0.021	185	+13	-11	7
95-35 b styl	10	<0.1	3.759 ± 0.053	1.175 ± 0.019	218	0.837 ± 0.018	186	+11	-10	7
95-36 b	7	<0.2	3.947 ± 0.050	1.227 ± 0.018	151	0.877 ± 0.017	208	+12	-11	7
95-36 c	7	<0.5	3.716 ± 0.057	1.311 ± 0.022	>856	0.866 ± 0.017	197	+10	-9.0	7
Ras el Bahar										
Mai 91-1	5.5	<1	2.757 ± 0.046	1.153 ± 0.015	>172	0.687 ± 0.015	122.6	+5.0	-4.8	5e
92-15	4	<1	3.308 ± 0.065	1.159 ± 0.027	>269	0.697 ± 0.017	125.7	+5.9	-5.6	5e
Ras Jemsah										
92-16 inf	12	<1	4.315 ± 0.088	1.169 ± 0.029	>177	0.695 ± 0.020	124.7	+6.7	-6.4	5e
92-16 sup	13	<1	2.390 ± 0.046	1.164 ± 0.027	>222	0.697 ± 0.021	125.5	+5.8	-5.5	5e
Hurgada										
93-4	4.8	<1	3.207 ± 0.052	1.145 ± 0.020	>408	0.696 ± 0.014	125.6	+4.6	-4.4	5e
95-3	6.5	<0.5	3.161 ± 0.064	1.154 ± 0.026	74	0.683 ± 0.016	121.1	+5.2	-4.9	5e
94-4	3.8	0.7	3.511 ± 0.090	1.202 ± 0.057	>133	0.976 ± 0.039	333	+142	-62	9?
Sharm el Naga										
93-3a	6.5	2.3	3.864 ± 0.056	1.152 ± 0.017	>186	0.512 ± 0.014	76.6	+3.0	-2.9	5e
93-3b	6.5	2.3	3.800 ± 0.072	1.158 ± 0.019	>286	0.501 ± 0.015	74.2	+3.2	-3.1	5e
93-1a	6.5	0.2	2.528 ± 0.043	1.156 ± 0.019	>268	0.646 ± 0.019	110	+5.6	-5.4	5e
93-1b	6.5	0.2	2.735 ± 0.035	1.166 ± 0.016	>264	0.641 ± 0.013	108.2	+3.7	-3.6	5e
94-16	2	0.4	3.714 ± 0.105	1.123 ± 0.033	>200	0.668 ± 0.032	117	+10.2	-9.4	5e
94-17	1.2	<1	2.430 ± 0.051	1.162 ± 0.031	>467	0.663 ± 0.017	114.8	+5.1	-4.9	5e
95-1	5	3	2.190 ± 0.054	1.120 ± 0.038	53	0.712 ± 0.022	131.6	+8.2	-7.6	5e
95-2	1.5	0.5	2.305 ± 0.045	1.144 ± 0.028	314	0.697 ± 0.019	126.1	+6.5	-6.2	5e
94-14b	1	<0.1	2.591 ± 0.031	1.199 ± 0.026	>1128	0.970 ± 0.016	318	+34	-29	9
94-15a	7	0.5	2.933 ± 0.056	1.316 ± 0.045	>693	0.994 ± 0.022	349	+67	-42	9
94-15b	7	<0.1	2.038 ± 0.031	1.187 ± 0.040	>500	0.976 ± 0.019	335	+52	-35	9
94-18	4	2.8	2.366 ± 0.040		>1700	1.054 ± 0.021	>350			9
Sharm el Qibli										
93-3 sup	4	<0.1	3.136 ± 0.086	1.125 ± 0.035	>492	0.697 ± 0.022	126.5	+7.6	-7.1	5e
93-3 inf	3	<0.5	2.830 ± 0.065	1.271 ± 0.054	>586	0.983 ± 0.027	332	+74	-45	9?
Wadi Siatin										
95-34	9	<0.5	2.858 ± 0.082	1.188 ± 0.037	472	0.675 ± 0.022	118.2	+6.9	-6.6	5e

With respect to global concerns, our regional results concerning sea-level changes imply a connection with the Quaternary processes of climate involved in glacial-interglacial evolution. If we accept a 10 m lowering of sea level during the 5.52 isotopic event, it implies that extremely brief climatic changes can modify the water budget of the ocean-atmosphere system. Only a storage in polar ice of a part of the evaporation of the then-current volume of sea water can explain such an ocean-wide lowering. In addition to a large increase in the amount of sea-ice (BERGER *et alii*, 1996), some inlandsis enlargement is necessary to account for such a considerable reduction in the volume of sea water. We also must take into account the shortness of the time postulated to make and store the polar ice, for stabilizing the ice cap, and for the nearly complete melting of the stored ice representing a volume of the world's sea water more than 10 m thick with each step taking less than a millennium for its completion. So we must consider that extremely rapid and immediate changes in sea-level can result from moderate changes in the heat budget (climate), including those that occurred during interglacial stages that are known to be greatly restricted in time and in the range of thermic variation.

Consequently, we must insist on the interest of reef studies in the most stable arid regions like Egypt. The need for a more precise dating of these privileged outcrops is essential, but we also emphasize the necessity of a reappraisal of the chronological charts, based on an interactive discussion of every bench-mark proposal, that in turn must be inferred from a coherent set of radiometric dates.

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Note added in proof

The general findings of our research on the Pleistocene reefs of Egypt have been recognized and confirmed recently by an independent, more precise chronology of sea-level fluctuation during the MIS 5.5 substage (ROHLING *et alii*, 2008). Stable isotope dates are not exempt from methodological difficulties made evident by comparisons of cores, but the brevity and great amplitude of sea-level changes during an interglacial highstand appear to be unquestionable. Their significance with respect to forecasts of events should be evident to all.

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