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Nota breve

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SEA-LEVEL VARIATIONS DURING THE QUATERNARY: THE ROCK AND AMINOSTRATIGRAPHIC RECORD IN THE MEDITERRANEAN BASIN BERMUDA AND THE BAHAMAS

Abstract: HEARTY P.J., *Sea-level variations during the Quaternary: the rock and aminostratigraphic record in the Mediterranean Basin, Bermuda and the Bahamas* (IT ISSN 0391-9838, 1991).

The Author supplies a scheme for the Quaternary seal-level fluctuations by comparing the amino acid geochronology (AAR) of Bahamas and Bermuda with respect to AAR of Lazio and Puglia. (KEY WORDS: Quaternary, Seal level, Aminoacid racemization).

Riassunto: HEARTY P.J., *Variazioni del livello del mare durante il Quaternario: sequenze litologiche e aminostratigrafiche nel bacino del Mediterraneo, alle isole Bermude e Bahamas* (IT ISSN 0391-9838, 1991).

L'Autore traccia uno schema delle variazioni del livello del mare durante il Quaternario confrontando i risultati geocronologici, ottenuti con il metodo della racemizzazione degli aminoacidi, delle isole Bahamas e Bermude e del Lazio e della Puglia (TERMINI CHIAVE: Quaternario, Livello del mare, Racemizzazione degli Aminoacidi).

A long and complex stratigrafic history of sea-level variations and tectonic movements is apparent in the Mediterranean basin. Unfortunately, these two variables, eustasy and tectonism, cannot be easily separated along most coasts in the Mediterranean. In order to understand the evolution of the coastlines, it became necessary to examine stable coastlines to confirm the seal-level variations of the Quaternary. Islands in Bermuda and the Bahamas have provided localities that have served this purpose, and through understanding this eustatic factor, the degree of tectonic deformation in the Mediterranean can now be more effectively quantified.

However, in order to study coastal deposits, it is necessary to examine the stratigraphy (bio-, litho-) and to determine the age of the deposits. Traditional dating methods (uranium-series and ^{14}C) are of limited use because of their short effective ranges (300,000 and 30,000 yr, respectively) and particular demands for sample materials (e.g. pristine corals or travertines for U-series, organics for ^{14}C). Amino acid racemization (AAR) geochronology is uniquely adapted to dating deposits older than 300,000 years, and when combined with rock stratigraphy, these tools have provided a means for correlating deposits across great distances. Chronologies have thus been established in the Mediterranean, Bermuda and the Bahamas (HEARTY & *alii*, 1986; HEARTY, 1986, 1987; HEARTY & DAI PRA, 1986, 1988; HEARTY & *alii*, 1992; HEARTY & KINDLER, in review).

In life, carbonate secreting organisms build complex, intertwined proteins and polypeptides that are preserved in the carbonate matrix of mollusks. Upon death, these proteins begin to slowly decompose and reorganize. It is this decomposition that is the basis of the AAR method (HARE, 1969; HARE & MITTERER, 1967). Marine and terrestrial mollusk shells are the typical sample materials, but bioclastic skeletal and oolitic sands are also useful (HEARTY & *alii*, 1992). D-alloisoleucine/L-isoleucine (A/I) is the most common amino acid ratio used in this study.

In Bermuda, AAR and rock stratigraphy (HEARTY & *alii*, 1992; VACHER & *alii*, 1989) have revealed at least seven pre-Holocene interglacials. We have extended the geochronological base in Bermuda by determining A/I ratios in (1) marine shells (*Glycymeris* and others) from deposits of sea-level high stands, (2) land snails (*Poecilozonites*) from protosols associated with the eolianites that comprise the bulk of Bermuda, and (3) whole-rock samples of bioclastic calcarenites. The three distinct types of samples provide independent aminostratigraphies (Aminozones C, E, F, G, H, J and K) that are mutually consistent and in agreement

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with the mapped lithostratigraphy (respectively Southampton, Rocky Bay, Belmont, upper Town Hill, lower Town Hill, unmapped unit, and Walsingham Formations). Correlation of the amino acid ratios with ages based on previously published U-series coral dates verifies the utility of the apparent parabolic kinetics model for estimation of amino acid racemization ages. From kinetic models based on calibration with previously published U-series coral dates, we have estimated ages of Middle Pleistocene and older aminozones:
F = 190,000-265,000 yr; G = 300,000-400,000 yr; H = 400,000-500,000 yr; J = >700,000 yr; and K = >900,000 yr.

The early Pleistocene age of Aminozone K is confirmed by the reversal magnetic polarity of the rocks (HEARTY & McNEILL, unpublished).

Aminozone G, which is correlated to the upper Town Hill Formation and isotope Stage 9, is volumetrically the most important depositional event of the middle Pleistocene. The shear mass of sediment deposited during this period suggests and interglacial of great duration and prolonged shelf submergence, during which the island grew to over half of its present size. Only the last interglacial (*sensu lato*; Stage 5; 135,000 to 85,000 yr ago; Aminozones E and C) rivals Stage 9 in volume of eolianite deposited on the island.

In San Salvador Island, Bahamas, our studies reveal that there is an important and complex pre-Sangamonian sedimentation history on the island that may be correlated to isotope Stages 9 and 7 (Owls Hole and Fortune Hill Formations). The last interglacial, isotope Substage 5e is associated with a complex of at least four catenary ridges of the Grotto Beach Formation U-series dated at 123,000 yr. Evidence of near-present sea level deposits dated at around 80,000 yr exist on the energetic western edge of San Salvador. The Holocene Rice Bay Formation (CAREW & MYLROIE, 1987) is associated with several eolianites, soils and the present marine deposits.

To summarize, our sea level studies from stable coastlines in Bermuda and the Bahamas indicate that there were at least two important high sea levels of the early Pleistocene, at least three interglacials with sea levels higher than present during the middle Pleistocene, and a complex sea-level history during both the last interglacial and Holocene. The last intergalacial substage 5e is associated with oscillations above (+5 m to +10 m) and below (< −10 m) present between 135,000 and 120,000 yr ago. Late in the same interglacial, substage 5a is associated with a brief rise of sea level to near the present datum (VACHER & HEARTY, 1989). The most significant events appear to correlate with Stages 9 and 5.

We recognize some of the same events in the Mediterranean, which are summarized in the proposed correlations of table 1.

The most important correlation that allows the construction of this global scheme is the peak last interglacial period, isotope Stage 5e, which has been U-series coral dated at ca. 125,000 yr from all of the study areas mentioned

Amino-group HEARTY & *alii*, 1986	Bermuda HEARTY & *alii*, 1992 VACHER & HEARTY, 1989	San Salvador HEARTY & KINDLER *(in press)*	Italy HEARTY & *alii*, 1986; HEARTY & DAI PRA, 1986, 1987, 1992	Tunisia MILLER & *alii*, 1986, HEARTY, 1986	Isotope Stage SCHACKLETON & OPDYKE, 1973
A	Recent	Rice Bay	Flandrian	Sidi Salem#	1
C	Southampton Fm	Almgreen Cay Fm	T. Castelluccia (Neotyr.)	Chebba Fm	5a
E	Rochy Bay Fm	Grotto Beach Fm	Il Fronte Fm *Strombus bubonius*	Rejiche I (Kniss) and II Fm *Strombus bubonius*	5e
F	Belmont Fm	Fortune Hill Fm	Carelli (Puglia); Il Giglio (Lazio)	unnamed unit?	7
G	upper Town Hill Fm	Owl's Hole Fm	T. Castel. (Puglia); San Pantaleo Fm* (Lazio)	Douira Fm	9
H	lower Town Hill Fm	—	125 m terrace - Tarquinia	High terraces?	11-13?
major	unconformity		major	unconformity	
J	unnamed +22 m marine	—	Sicilian		25?
K	Walsingham Fm	—	Emilian		31?

PASKOFF & SANLAVILLE, 1986.
* «Milazzian Stage» deposits at the type locality have been shown to be of Tyrrhenian age (HEARTY & *alii*, 1986) and thus the term «Milazzian» should be abandoned from the nomenclature.

in this review. In the Mediterranean, this level alone is tied to the occurrence of *Strombus bubonius*. The AAR ratios from each last interglacial site are tied independent age calibration. And, with an adequate understanding of the kinetics of racemization from fully calibrated models, we can establish an absolute age framework for each of the respective areas beyond the range of U-series dating.

CONCLUSIONS

Elevated marine deposits in the Mediterranean are often the result of both eustatic changes and tectonic uplift. An understanding of eustatic sea-level history can be obtained from stable islands in Bermuda and the Bahamas. With such a record in hand, neotectonism can more seriously be evaluated in the Mediterranean.

Amimo acid geochronology (AAR) is useful for several reasons: a) it is effective on marine shells, land snails that occur in marine deposits, dunes, soils, colluvium and lacustrine deposits; b) the method can be used to correlate deposits over a broad area; c) AAR has an effective range of over 1,000,000 years; and d) age estimates can be made when AAR ratios are calibrated to independent ages from U-series and C^{14}.

Both the timing and the amplitude of sea-level changes can be established from Bermuda and the Bahamas. Corresponding temporal events are recognized from Lazio and Puglia in Italy, and indicate the measure of tectonic uplift. In a global context, early Pleistocene transgressions are separated from middle Pleistocene ones by a lacuna of approximately 400,000 years (between Stage 25? and 11?), and Stages 9 and 5 are most important during the middle and late Pleistocene. The Holocene is well represented in some areas, San Salvador and Puglia, and less-so in others, such as Bermuda and some Mediterranean coasts.

REFERENCES

CAREW J.L. & MYLROIE J.E. (1987) - *A refined geochronology for San Salvador Island, Bahamas.* In: CURRAN H.A. (ed.) - Proceeding of the 3rd Symposium of the geology of the Bahamas. CCFL Bahamian Field Station, 35-44.

HARE P.E. (1969) - *Organic geochemistry of proteins, peptides and amino acids.* In: ENGLINTON AND MURPHY (eds.) - Organic Geochemistry. Springer-Verlag, New York, 438-463.

HARE P.E. & MITTERER R.M. (1967) - *Non-protein amino acids in fossil shells.* Carnegie Institutions of Washington Yearbook, *65,* 236-364.

HEARTY P.J. (1986) - *An inventory of last interglacial (s.l.) age deposits from the Mediterranean basin: a study of isoleucine epimerization and U-series dating.* Zeit. Geom., Suppl. Bd., *62,* 61-69.

HEARTY P.J. (1987) - *New data on the Pleistocene of Mallorca.* Quat. Sc. Rev., *6,* 245-257.

HEARTY P.J. & DAI PRA G. (1986) - *Aminostratigraphy of Quaternary marine deposits in the Lazio region of central Italy.* Zeit. Geom., Suppl. Bd. *62,* 131-140.

HEARTY P.J. & DAI PRA G. (1987) - *Paleogeographic reconstruction of Quarternary environments in Toscana and North Lazio, Central Italy.* Boll. Serv. Geol. It., *106,* 189-224.

HEARTY P.J. & DAI PRA G. (1992) - *The age and stratigraphy of Quaternary coastal deposits along the Gulf of Taranto (South Italy).* Journ. Coastal Res., 8, *4,* 882-906.

HEARTY P.J. & KINDLER P. (*in review*) - *Geological Evolution of San Salvador Island, Bahamas.* Geol. Soc. Am. Bull.

HEARTY P.J., MILLER G.H., STEARNS C.E. & SZABO (1986) - *Aminostratigraphy of Quaternary shorelines around the Mediterranean basin.* Geol. Soc. Am. Bull., *97,* 850-858.

HEARTY P.J., VACHER H.L. & MITTERER R.M. (1992) - *Aminostratigraphy and Ages of Plesistocene Limestones of Bermuda.* Geol. Soc. Am. Bull., *104,* 471-480.

MILLER G.H., STEARNS C.E. & PASKOFF R. (1986) - *Amino acid geochronology of Pleistocene littoral deposits in Tunisia.* Zeit. F. Geom., Suppl. Bd., *62,* 197-207.

SHACKLETON N.J. & OPDYKE J.N. (1973) - *Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: Oxygen isotope temperatures and ice volumes on a 10^5 and 10^6 year time scale.* Quaternary Research, v. 3, p. 39-45.

VACHER H.L. & HEARTY P.J. (1989) - *History of stage-5 sea level in Bermuda: with new evidence of a rise to present sea level during substage 5a.* Quat. Sc. Rev., *8,* 159-168.

VACHER H.L., ROWE M. & GARRETT P. (1989) - *Geologic Map of Bermuda: 1:25,000 scale.* Oxford Cartographers, U.K.