| Journal of Coastal Research | 8 | 4 | 882–905 | Fort Lauderdale, Florida | Fall 1992 |
|---|---|---|---|---|---|

# The Age and Stratigraphy of Middle Pleistocene and Younger Deposits along the Gulf of Taranto (Southeast Italy)

**Paul J. Hearty[1] and Giuseppe Dai Pra[2]**

[1] Department of Geology
University of South Florida
Tampa, FL 33620, U.S.A.

[2] ENEA
AMB-MON-EVEN
C.R.E. Casaccia
C.P. 2400
00100 Rome, Italy

## ABSTRACT

HEARTY, P.J. and DAI PRA, G., 1992. The age and stratigraphy of middle Pleistocene and younger deposits along the Gulf of Taranto (southeast Italy). *Journal of Coastal Research*, 8(4), 882–905. Fort Lauderdale (Florida), ISSN 0749-0208.

Tectonically elevated siliciclastic marine terrace deposits dominate coastal areas in the province of Basilicata, while further east along the Salentine Peninsula, authigenic and biogenic fossiliferous limestones are most common. These limestones are often stratigraphically superimposed along the margins of the low-profile carbonate platform. Amino acid racemization geochronology (AAR) and radiometric methods have been used to date and correlate 14 coastal sections along 200 km of the Gulf of Taranto. This is accomplished by calibration of D-alloisoleucine/L-isoleucine (A/I) ratios with U-series and $^{14}C$ dates which establishes an absolute age framework for marine transgressions, dune formation and pedogenesis. In addition, these data define the nature of the epimerization reaction as it proceeds toward equilibrium (A/I of *ca.* 1.30) for *Helix* and *Glycymeris* in timescales of $10^3$, $10^5$, and $10^6$ of years.

At least five shoreline complexes (littoral, eolian, and pedogenic depositional units) have been identified. Two middle Pleistocene transgressions are equated with Aminozones F and G. Aminozone H is associated with a third but is poorly defined. A late Pleistocene interglacial complex is bracketed by two aminozones. The earlier, Aminozone E, consists of widespread limestones, eolianites and thin soils, while the latter, Aminozone C, is less frequently preserved as marine calcarenite and dunes. Deposition during the Holocene (Aminozone A), however, was quite active as indicated by the numerous sequences of beaches, dunes and soils.

The AAR method is useful for correlating coastal deposits over great distances, reconstructing paleoenvironments, establishing a tectonic history, and estimating ages of these events the Gulf of Taranto.

ADDITIONAL INDEX WORDS: *Amino acid racemization, epimerization, geochronology, littoral deposits, shoreline stratigraphy, eustatic sea levels, interglacial periods, carbonate platform, tectonic uplift, Salentine Peninsula, Puglia and Basilicata Provinces.*

## INTRODUCTION

Few regions offer the diversity and abundance of stratigraphic exposures as those along the Gulf of Taranto, Italy. The earliest investigators (GIGNOUX, 1913; MIRIGLIANO, 1953, 1956; GIGOUT, 1960a–c) found numerous coastal sites from which they developed basic concepts of eustasy and biostratigraphy. Cold, temperate and tropical molluscan faunas are found in middle Pleistocene to Holocene marine deposits that lie at various elevations above sea level. Of particular importance is the *Strombus* (or "Senegalese", see NICKLÉS, 1950) fauna (including *Strombus bubonius, Conus testudinarius, Cantharus viverratus, Tritonium ficoides, Natica lactea, Mytilus senegalensis, etc.*) for which GIGNOUX (1913) assigned stratigraphic age "plus récent que tous les autres dépôts quaternaires (more recent than all other Quaternary (marine) deposits)." This climatic and faunal event, which on biogeographic grounds was indicative of sea temperatures 4° to 6 °C warmer than today, was termed the "Tyrrhenian" (ISSEL, 1914) after its "type locality" along the Tyrrhenian Sea coast near Calamosca, Sardinia. In later studies, due to the apparent occurrence of multiple *Strombus* levels, the Tyrrhenian was subdivided into the "Paleo-", "Eu-" and "Neotyrrhenian" by BONIFAY and MARS (1959). This concept of three (or more) *Strombus* levels (GIGOUT, 1960b,c; COTECCHIA *et al.*, 1969; AMBROSETTI *et al.*, 1972; BIGAZZI *et al.*, 1973) has persisted in the literature (HILLAIRE-MARCEL *et al.*, 1986). HEARTY *et al.* (1986a), HEARTY and DAI

---

*89024 received 17 April 1989; accepted in revision 30 March 1992.*
Current address: Programs in Geosciences, University of Texas at Dallas, Richardson, TX 75083-0688.

PRA (1986, 1987) and HEARTY (1987a) documented that *Strombus* flourished in the Mediterranean mainly during one interglacial period, that is the peak of the last interglacial (isotope Stage 5e), and that minor sea level fluctuations during this interglacial were responsible for the apparent multiple occurrence of the *Strombus* fauna.

Results from initial attempts to date these deposits were presented in COTECCHIA *et al.* (1969) using $^{14}$C. DAI PRA and STEARNS (1977) presented the first successful application of uranium-series techniques to solitary corals (*Cladocora cespitosa*) in the Mediterranean basin. Amino acid geochronology (AAR) was introduced to the Salentine Peninsula and the Mediterranean basin (HEARTY *et al.*, 1984, 1986a; HEARTY and DAI PRA, 1985) some years after the application of U-series dating. The introduction of the AAR method to the area was fortuitous considering the basin-wide lack of abundant corals, which created a problem for U-series dating. AAR has been used to establish lithologic correlations and to verify biostratigraphic ones. With calibration by radiometric dates, the absolute dating scheme is extended through the middle Pleistocene across several interglacial periods (HEARTY, 1986, 1987b; HEARTY *et al.*, 1986a,b, 1987; HEARTY and DAI PRA, 1985, 1986, 1987; HEARTY *et al.*, 1987; MILLER *et al.*, 1986).

AAR has provided a new opportunity to establish a chronology for middle and late Pleistocene deposits south Italy. Our efforts concentrate on the post-Sicilian events of the later half of the Quaternary after the Brunhes/Matuyama Boundary after 740 ka (BERGGREN *et al.*, 1985). Here, we review the stratigraphic data from previous studies and incorporate a large body of our own data from the Salentine Peninsula. Included among the main objectives of this work are the following: (1) to provide a comprehensive view of the middle Pleistocene to Holocene coastal stratigraphy and paleoenvironments along the Gulf of Taranto; (2) to assign relative, estimated and absolute ages to recognizable stratigraphic units through amino acid correlations, apparent parabolic kinetics (APK—MITTERER and KRIAUSAKUL, 1989) and independent radiometric dating; (3) to synthesize these data in order to derive an epimerization curve at ambient sedimentary temperatures over the past several hundred thousand years; and (4) to develop a chronology of sea level events and uplift intensity.

## GEOLOGIC SETTING

The study area is divided into three structural and geological provinces (Figure 1): (1) the Appennine orogenic belt and collision zone province to the west with associated folded and faulted flysch lithologies that generally range in age from Cretaceous to Tertiary; (2) the transform/subducting Bradano basin microplate boundary filled with Neogene sediments lying atop Cretaceous platform carbonates that are downfaulted in *en echelon* tear faults; and (3) the Puglia carbonate platform, rifted from the African plate in the Tortonian (late Miocene). This microplate is relatively stable from a tectonic perspective, compared to the more westerly provinces which are affected by intense tectonism.

This coastal study in Puglia and Basilicata expands on similar AAR and stratigraphic studies in neighboring Calabria (HEARTY *et al.*, 1986b; DUMAS *et al.*, 1988; CAROBENE and DAI PRA, 1990). These combined investigations provide an overall view of the Quaternary shoreline geology and tectonic history of south Italy.

## REGIONAL AMINOSTRATIGRAPHIC SETTING

HEARTY and DAI PRA (1985) laid the aminostratigraphic groundwork for the expansion of this research program at several localities in southeast Italy (mainly at sites 1, 3, 5, 6, 10, 12 and 13—Figures 1 and 2). At that time, *Glycymeris* and *Astraea* were analyzed and several aminozones were established. New marine sites (2, 4, and 11) were added to emphasize the last interglacial events, while terrestrial sites (7, 8, 9, and 10) focused mainly on the Holocene. Since HEARTY and DAI PRA (1985), the number of analyses in Puglia were increased many-fold, with a new focus on *Helix* land snails (over 60 analyses) from Pleistocene and Holocene soils and dunes. HEARTY *et al.* (1986a) and HEARTY (1986) expanded the aminostratigraphy program from Puglia to include coastal sites across the entire western Mediterranean. The first AAR kinetic curve for the Mediterranean encompassed over 1.2 my and included the Calabrian, Sicilian, middle Pleistocene (San Pantaleo Fm), and Tyrrhenian Stages (HEARTY *et al.*, 1986a). At that time, it was determined that the well-established middle Pleistocene "Milazzian" Stage at its type locality (Milazzo, north coast of Sicily), was equal to or younger than 125 ka, and therefore HEARTY *et al.* (1986a)

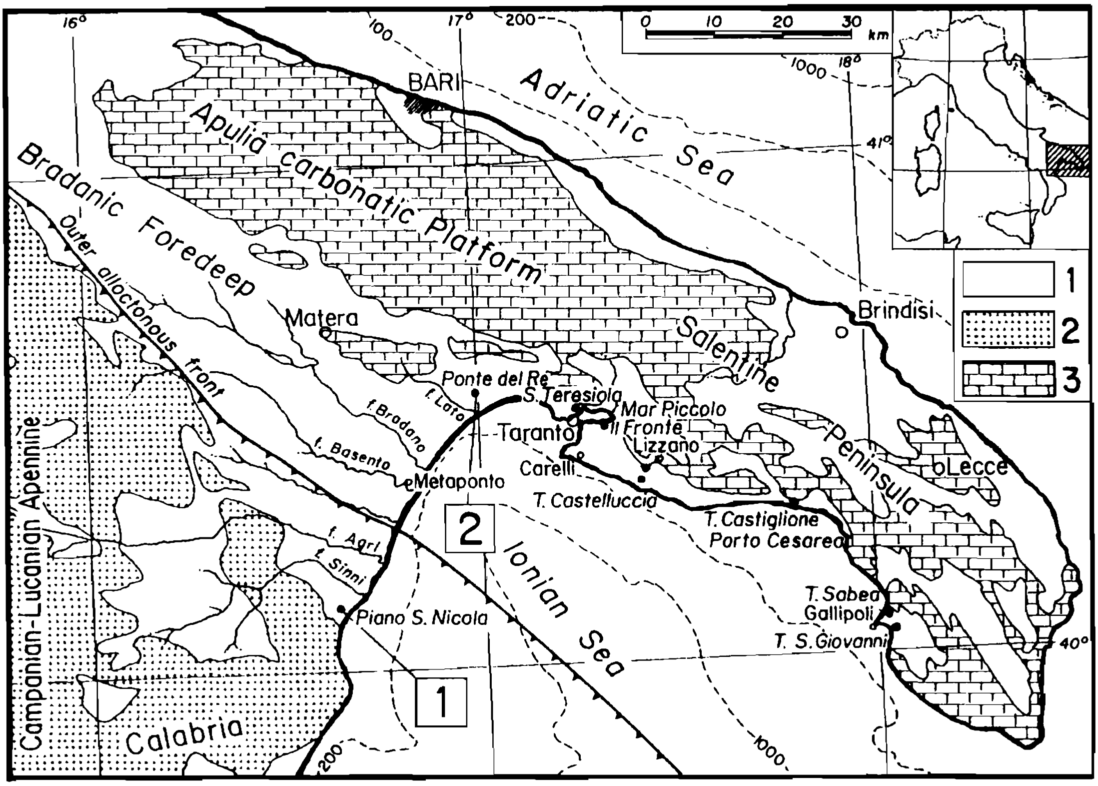

Figure 1. Structural scheme of the Gulf of Taranto. (1) Neogene sediments; (2) allochthonous Tertiary flysch deposits; (3) Cretaceous platform carbonates. Study sites 1 and 2 are identified in boxes. (Geology after Ogniben, 1973).

proposed that the term be abandoned. Hearty and Dai Pra (1986, 1987) adopted the "San Pantaleo Formation" for middle Pleistocene deposits in Lazio which belong to Aminozone G.

From studies from Bermuda (Hearty *et al.*, 1992), the southeast U.S. Coastal Plain (Hollin and Hearty, 1990), and Oceania (Hearty and Aharon, 1988), Hearty and Miller (1987) recognized a global pattern between A/I ratio and current mean annual temperature (CMAT) from last interglacial sites. Aminostratigraphic data from global localities are presented in Table 1, and demonstrate the depth of the database in which this study is framed.

A review of the preparation and analytical procedures is available in Hearty *et al.* (1986a), Miller and Mangerud (1985), and Miller and Brigham-Grette (1989). All ratios reported here were determined at the INSTAAR Geochronology Center (University of Colorado, Boulder) and are the peak-height A/I ratio.

## COASTAL STRATIGRAPHY AND GEOMORPHOLOGY

A regional change in sedimentation history is observed that varies from the massive sediment wedges along the staircased coastline in the west part of the study area (Figure 1), to a moderate volume of clastic sediments in the central area near Mar Piccolo (Taranto), to a sediment-starved platform setting in the southeast along the Salentine Peninsula. Previous studies (Hearty *et al.*, 1986b) along the Calabrian Peninsula and Strait of Messina have identified last interglacial terraces at well over 100 m, with one example reaching as high as 157 m (Dumas *et al.*, 1988) requiring uplift rates exceeding 1 m/1,000 years. In addition to a changing sediment output, the tectonic factor is also associated with a lithologic gradient: from siliciclastic sands and gravels in the west, to bioalgal limestones and calcarenite along the Salentine Peninsula. As illustrated in the following

Table 1. *Mean a/I ratios comprising aminogroups from the Mediterranean, Bermuda and the southeast U.S. coastal plain. Mean a/I is for* Glycymeris *(Gly) or* Glycymeris *equivalents [GE in square brackets] from marine deposits unless otherwise indicated (see below). Definitions, analytical and methodological information are provided in* Hearty et al. *(1986a).*

| Region (T°C) Reference | Aminogroup | Mean A/I (Gly or GE) | (N=) | Radiometric*, Apparent+ or Estimated ~Age |
|---|---|---|---|---|
| *ITALY—Toscana—North Lazio* | C | 0.31 ± 0.02 | (7) | 90 ± 15 KA~ |
| (15.5–16.5) Hearty and Dai Pra, 1986a,b | E | 0.39 ± 0.02 | (39) | 118–135 KA+ |
| | F | 0.50 ± 0.01 | (18) | 180–250 KA+ |
| | G | 0.58 ± 0.03 | (35) | >300 KA+ |
| | K | 1.00–1.20 | (15) | >1 MY?+ |
| *ITALY—So. Lazio, Latina,* (~16) Hearty and | A | 0.12 ± 0.02 | (4) | 4,630 YR BP* |
| Dai Pra, 1986b; Antonioli *et al.*, 1988 | C | 0.29 ± 0.02 | (10) | 90 ± 15 KA~ |
| | E | 0.39 ± 0.03 | (25) | 118–135 KA+ |
| | G | 0.60 ± 0.02 | (19) | >300 KA~ |
| | H | 0.73 ± 0.05 | (3) | >400 KA?~ |
| *ITALY—Puglia* | C | 0.28 ± 0.02 | (5) | 90 ± 15 KA~ |
| (*ca.* 17), Hearty and Dai Pra, 1985; | E | 0.41 ± 0.03 | (42) | 123 ± 4 KA* |
| Hearty *et al.*, 1986; Hearty, 1986 | F | 0.48 ± 0.02 | (7) | 290 ± 50 KA* |
| | G | [0.64]a | (3) | >300 KA* |
| *ITALY—Puglia* | At | 0.12 ± 0.01 | (17)h | 5 ± 1 KA* |
| (16.9–17.2) (This study; includes 1985 data) | Cm | 0.29 ± 0.02 | (11) | *circa* 85 KA~ |
| | Ct | 0.28 ± 0.01 | (18)h | <85 KA+ |
| | Em | 0.39 ± 0.03 | (56) | *circa* 125 KA* |
| | Et | 0.34 ± 0.01 | (2)h | <125 KA+ |
| *ITALY—Calabria* | C | 0.29 ± 0.04 | (3) | 80–85 KA~ |
| (17–17.5) Hearty *et al.*, 1986b; Dumas *et al.*, 1988 | D? | 0.37 ± 0.03 | (3) | *circa* 105 KA+ |
| | Et | 0.39 ± 0.01 | (3)h | ≤125 ka+ |
| | E | 0.42 ± 0.03 | (33) | 118–135 KA* |
| | F | 0.51 ± 0.07 | (4)c | ≥180 KA+ |
| *MALLORCA* (17) | E | 0.41 ± 0.04 | (38) | 129 ± 7 KA* |
| Hearty, 1987 | F | 0.52 ± 0.04 | (18) | 180–250 KA~ |
| *SARDINIA* (17.5) | C | 0.32 ± 0.03 | (2) | 90 ± 15 KA~ |
| Ulzega and Hearty, 1986 | Et | 0.37 ± 0.04 | (4)h | ≤125 KA+ |
| | E | 0.43 ± 0.03 | (11) | 131 ± 7 KA* |
| | F | *circa* 0.52 | | >180 KA?+ |
| *SPAIN—Alicante,* (17.5) | E | 0.42 ± 0.02 | (18) | 143 ± 7 KA* |
| Hearty, *et al.*, 1988 | F | 0.59 ± 0.04 | (8) | 180–250 KA~ |
| | G | 0.73 ± 0.04 | (6) | >300 KA+ |
| *SOUTH CAROLINA* (18) | C | 0.37 ± 0.02 | (5)A | <125 KA+ |
| Hollin and Hearty, 1990. | E | 0.46 ± 0.05 | (29)A | *circa* 125 KA* |
| | F? | 0.59 ± 0.08 | (6)A | >125 KA+ |
| | J/K | 0.94 ± 0.07 | (23) | >460 KA* |
| *TUNISIA* (18.2) | C | 0.40 ± 0.04 | (11) | 90 ± 15 KA~ |
| Miller *et al.*, 1986 | E | 0.48 ± 0.04 | (42) | 126 ± 7 KA* |
| | E or F | 0.59 ± 0.04 | (5) | |
| | F? | 0.68 ± 0.06 | (14) | 180–250 KA+ |
| *SPAIN—Almeria* | E | 0.49 ± 0.05 | (8) | 118–135 KA~ |
| (18.5) Hearty *et al.*, 1987 | | | | |
| *BERMUDA* (21.2) | A | 0.014 | (1) | modern |
| Vacher and Hearty, 1989, Hearty, *et al.*, 1992 | C | 0.42 ± 0.04 | (14) | 85 KA* |
| | Ct | 0.40 ± 0.04 | (36)h | 85 KA |
| | Et | 0.49 ± 0.03 | (36)h | 120 KA* |
| | E | 0.57 ± 0.03 | (21) | 125 KA* |
| | Ft | 0.61 ± 0.05 | (10)h | 190 KA+ |
| | F | 0.69 ± 0.03 | (9) | 205 KA* |
| | Gt | 0.78 ± 0.04 | (11)h | 335 KA+ |
| | Ht | 0.91 ± 0.03 | (9)h | 450 KA+ |

N = number of shells analyzed. *h* = *Helicidae* (pulmonate gastropod); (*Glycymeris* a/I: Helicidae a/I = ~1.00, Hearty, 1987). *c* = *Cerastoderma* (*Glycymeris* a/I: *Cerastoderma* a/I = ~1.00, Hearty and Dai Pra, 1986b). *a* = *Astraea* (*Glycymeris* a/I: *Astraea* a/I

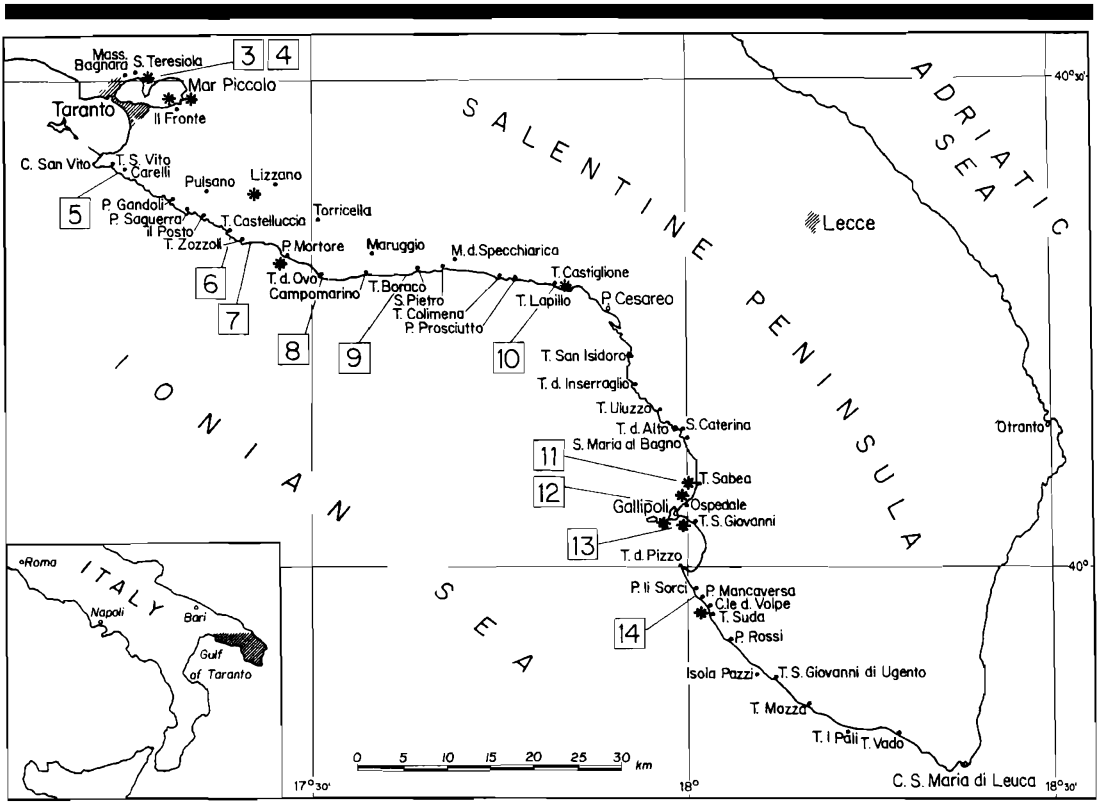

Figure 2. Location map of study sites 3 to 14 (boxes) along the Salentine Peninsula of southeast Italy.

figures and discussions, elevated and clearly defined marine terraces are present in the western part of the study area (COTECCHIA and MAGRI, 1967; BRÜCKNER, 1980; DAI PRA and HEARTY, 1988) as a result of interglacial sea levels imprinted on a tectonically-rising coastline. By contrast, in the southeast, positive marine cycles are not separated by tectonic uplift; marine deposits of several interglacials are stratigraphically superimposed at low elevations.

Nearly all of the sections are floored by Plio-Pleistocene silts and clays ascribed to the early Pleistocene Emilian Stage (RUGGIERI and SPROVIERI, 1984; RIO *et al.*, 1991). These shelf and shallow marine clays are exposed at 110 to 510 m in northern Calabria (CAROBENE and DAI PRA, 1990), nearly 1,000 m near Reggio Calabria (DUMAS *et al.*, 1980; RAFFY *et al.*, 1981), at around 400 m in Basilicata (western part of our study area), and near sea level along the Salentine Peninsula. Whereas the more westerly sites reflect the tectonic uplift history of the area, those sites lying to the southeast are more representative of glacio-eustatic changes. Of particular importance in this investigation are several sites that display sequential Pleistocene and Holocene sequences, providing a firm stratigraphic foundation for our geochronological studies.

In the subsequent discussions, shoreline complexes or sequences (VAN WAGONER *et al.*, 1988) resulting from marine transgressions are identified by Roman numerals (I, II, III, *etc.*, increasing with greater age), while sedimentary facies are identified by the letters M = marine; D = Dune or eolianite; S = soil, and sub-units as a, b, c, etc. Deposits dating from the mid Pleistocene to the

---

←

= 0.71, HEARTY and DAI PRA, 1985). *A* = *Anadara* (*Glycymeris* a/I: *Anadara* a/I = ~1.00, HOLLIN and HEARTY, 1990). Aminogroup subheadings: t = terrestrial deposits; m = marine deposits. "*" = information on radiometric dates is available in the respective publications.

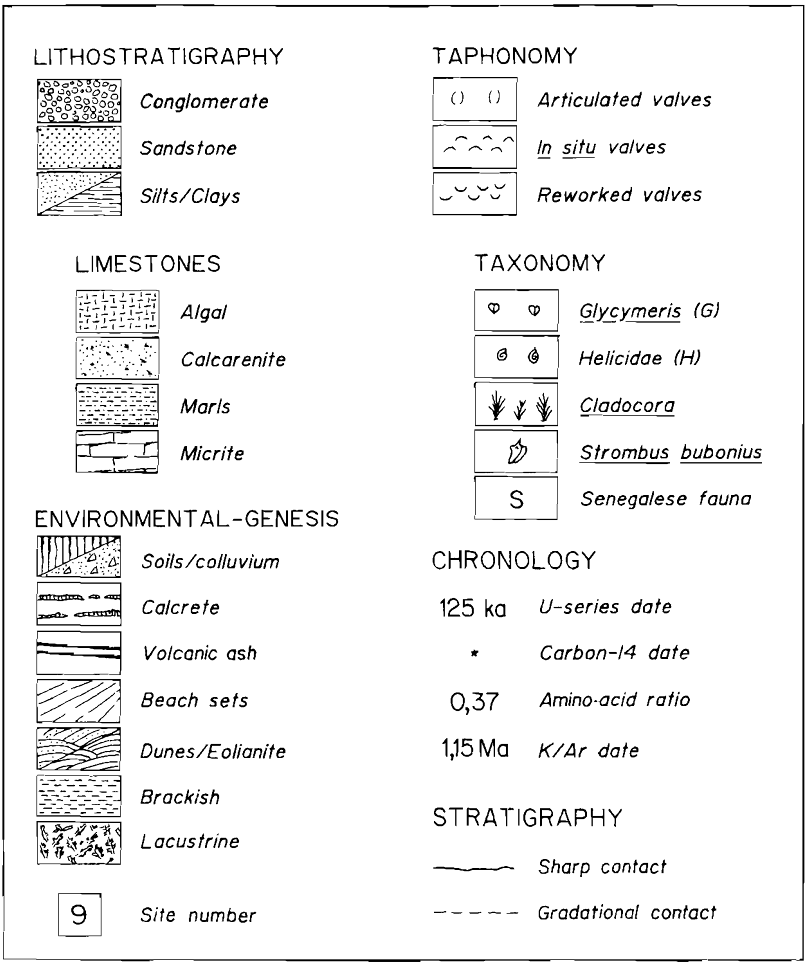

Figure 3. Legend for Figures 4 to 11. Stratigraphic complexes or sequences are identified by Roman numerals I (Holocene) to V (middle Pleistocene).

present are thus recognized in the text by names such as MIII or DIVa, *etc.*, in an effort to avoid confusion by introducing a new stratigraphic nomenclature. Figure 3 is the legend for Figures 4 to 11.

## THE STUDY SITES (FROM WEST TO EAST)

### Site 1: Piano San Nicola

The Piano San Nicola area (Figure 1) is characterized by tectonically uplifted marine and alluvial terraces (Figure 4). The geomorphology of this area was described by COTECCHIA and MAGRI (1967), VEZZANI (1967) and BRÜCKNER (1980). MONTCHARMONT-ZEI (1957) and NÉBOIT and RÉYNARD (1973) investigated the mollusks of the Piano San Nicola site where a rich, but temperate fauna ("banal", or ordinary in that it lacks the tropical Senegalese fauna) was reported. The first proposed age of these marine deposits (MII) at Piano San Nicola was published in HEARTY (1986) where a *late* last interglacial age was determined in support of the findings of the paleoecological studies.

### Site 2: Ponte del Re

Recent paleoecological studies by BOENZI *et al.* (1985) and CALDARA (1986) pointed out the sig-

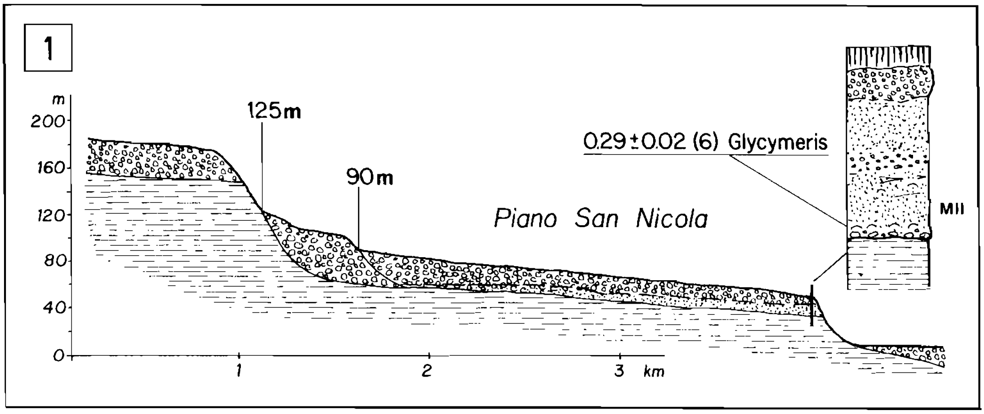

Figure 4. Site 1—The Piano San Nicola section.

nificance of environments associated with the invertebrate faunas in transgressive Tyrrhenian deposits (MIII) at Ponte del Re (Figure 5). Our stratigraphic studies of the site offer some minor revisions of previous views. These revisions center on evidence of two transgressions instead of one across the broad terrace at Ponte del Re.

### Sites 3 and 4: Mar Piccolo

The stratigraphy and paleontology of marine deposits in the Mar Piccolo basin (Figure 6) are well documented and have been the focus of numerous studies since the beginning of the century (Gignoux, 1913). More recent investigations include those in the area of micropaleontology (De Castro-Coppa, 1979), geomorphology and stratigraphy (Gigout, 1960b,c; Cotecchia *et al.*, 1969; Ciaranfi *et al.*, 1988) and chronostratigraphy (Dai Pra and Stearns, 1977; Hearty and Dai Pra, 1985).

The highly restricted Sea of Piccolo (Mar Piccolo) acts as a transition zone between marine and continental influences. Minor changes in sea level bring about major environmental changes in the basin. This concept is illustrated in stratigraphic sections from near the inlet where environmental settings change abruptly from continental sediments to fully marine conditions.

The marine exposures in the area are dominated by *Strombus*-bearing and coralliferous deposits dated around *ca.* 125 ka, particularly at Il Fronte. A date from *in situ* coral beds (or "Marne à Cladocora" of Gignoux, 1913) of 125 ± 6 ka (by B.J. Szabo, U.S.G.S. Denver, CO) favors our last interglacial stratigraphic correlation of these beds. Previous dates from older collections from the

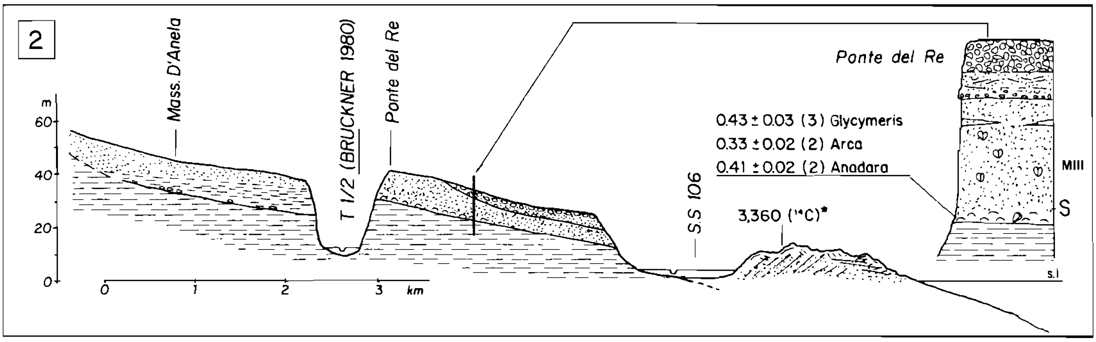

Figure 5. Site 2—The Ponte del Re section.

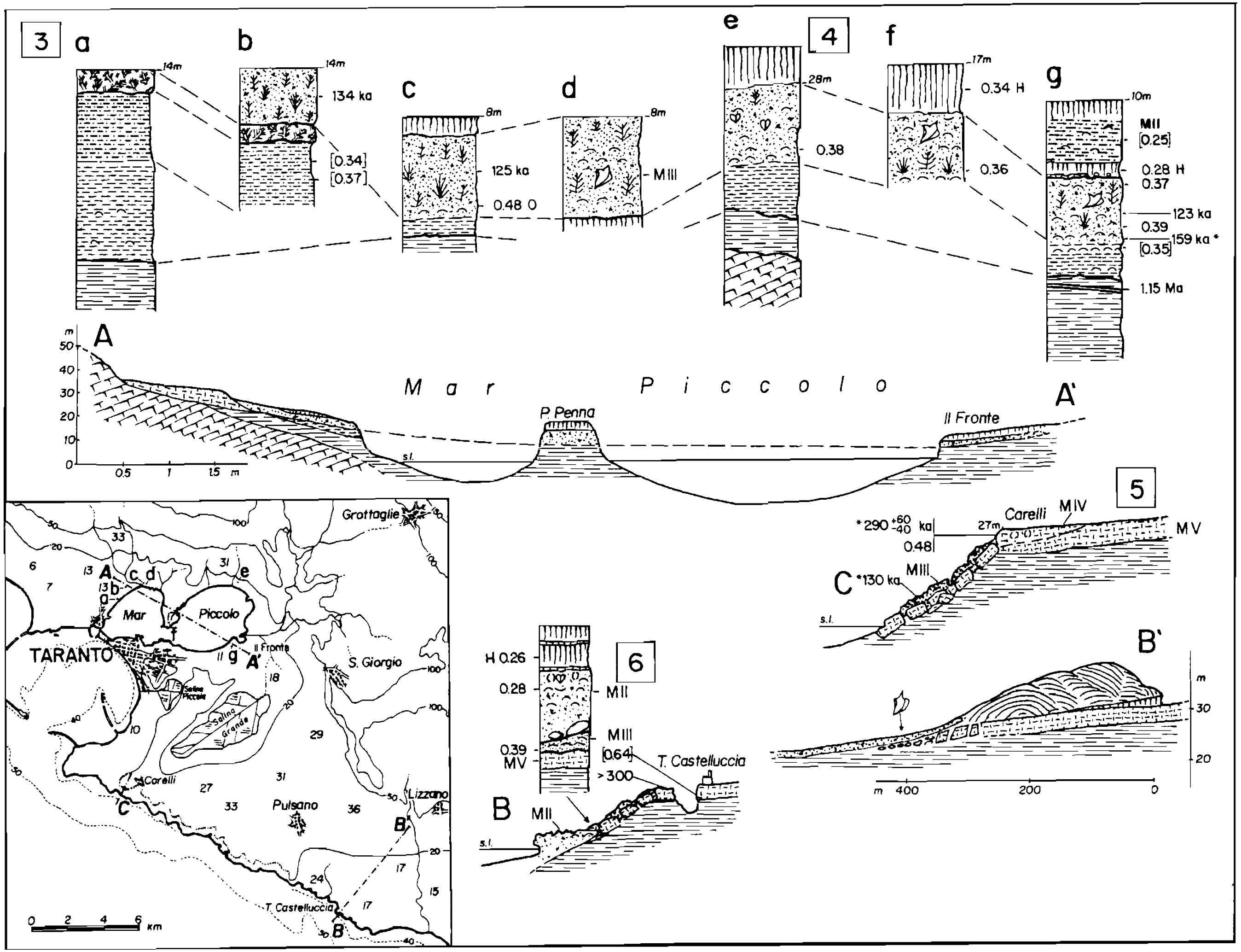

Figure 6. Study sites in the Mar Piccolo area: (Sites 3, 4, 5 and 6). Sections: a = Masseria Saracino; b = Masseria Bagnara; c = Santa Terisola; d = Santa Teresiola East; e = Masseria San Pietro; f = Punta Penna; g = Il Fronte. Correlations are indicated by the dashed line. Cross-sections A-A′, B-B′, and C-C′ are located in the inset.

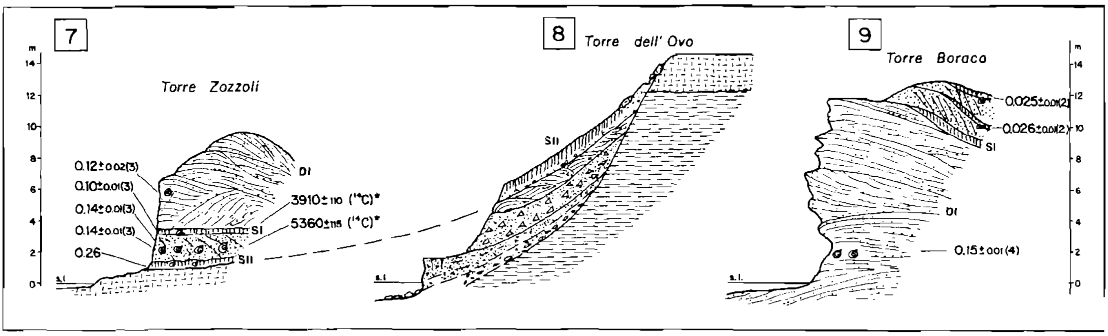

Figure 7. Torre Zozzoli (Site 7), Torre dell'Ovo (Site 8), and Torre Boraco (Site 9).

same locality yielded ages of 205 ka (DAI PRA and STEARNS, 1977) and 165 ka (GEWELT, *unpublished*). The differences in the dates could be a function of the methods for cleaning and/or analysis of the samples.

Early Pleistocene clays containing *Hyalinea balthica* (< 1.32 my, RIO *et al.*, 1991) interbedded with thin layers of volcanic ash K/Ar dated at 1.15 my (EVERNDEN and CURTIS, 1965; CAPALDI *et al.*, 1979) floor most of the basin. Preservation of successive deposits on these highly unstable clays is unlikely, whereas more rigid deposits, such as those of highly indurated mid Pleistocene algal calcarenites ("calcare bioclastico" of DAI PRA and STEARNS, 1977), readily protect overlying deposits from extensive erosion. In areas of such an unstable foundation as the clays, deposits of only the most recent transgressions are generally preserved.

### Sites 5 and 6: Carelli and Torre Castelluccia

In these two adjacent exposures (Figure 6), nearly all of the mid and upper Pleistocene marine units (MV, MIII and MII) are representative of an open coast high-energy environment (HEARTY and DAI PRA, 1985; DAI PRA and STEARNS, 1977). In a staircase of beach terraces, two mid Pleistocene shorelines (MV and MIV) have been identified at 35 m and 27 m (Carelli), while the last interglacial, MIII complex is present at nearly the same elevation as the mid-Pleistocene shoreline (section A). At Torre Castelluccia (section B), at least three marine events are represented in vertical sequence (MV, MIII and MII, lacking the Carelli calcarenites). The oldest of these is an algal calcarenite upon which lenses of the last interglacial calcarenite are preserved in circular depressions of a decimetric scale. *Strombus bubonius* was identified in these deposits at an elevation of 26 m (DAI PRA and STEARNS, 1977). A beach sand, consisting of a reddish calcarenite (MII) and containing a "banal" fauna in which no warmth-loving species are present, overlies the older marine units.

### Sites 7, 8 and 9: Torre Zozzoli, Torre del'Ovo and Torre Boraco

These sections (Figure 7) are generally characterized by a base of mid to upper Pleistocene marine deposits followed by a sequence of alternating soils and eolianites of late last interglacial to Holocene age. Sites 7, 8 and 9 comprise several Holocene eolianite/soil couplets (DIa-SIa; DIb-SIb; DIc-SIc). Abundant pulmonate gastropods (*Helix* sp.) are found in all units, and are one source of the geochronologic data presented later in the paper. Well-developed mid Holocene eolianites and soils are present and probably mark the maximum and close of an "altithermal period". Historical (Pre-Roman) soils are found near the Torre Boraco site and have produced abundant fossils and artifacts.

The area around Torre del'Ovo appears to have remained a headland through several transgressive cycles. Waves toppled blocks of mid-Pleistocene calcarenite which were subsequently buried by marine sands and subsequent dune deposits. *Terra rossa* (red earth) and breccia were shed from the cliff during the sea level regression.

### Site 10: Torre Castiglione-Torre Colimena

At Torre Castiglione, three marine deposits lie in superposition, separated by unconformities and discontinuous, thin soils (DAI PRA, 1982). The se-

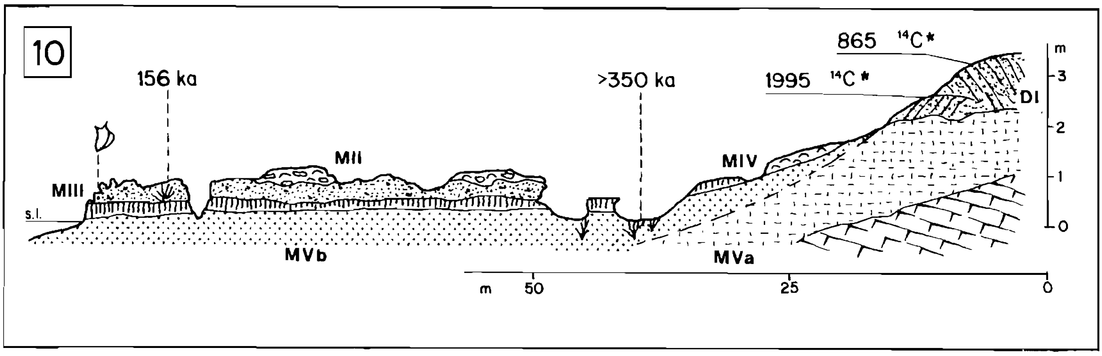

Figure 8. Torre Colimena/T. Castiglione section (after Dai Pra, 1982).

quence above tilted Cretaceous bedrock (Figure 8) is as follows: (1) Unit MVa is a light grey algal calcarenite with vacuolar structure (fenestrae). This unit is generally rich in *Astraea rugosa*. The age of this unit is greater than 300 ka (Dai Pra and Stearns, 1977) but post-dates underlying silty clays with *Hyalinea balthica* present between Taranto and Torre Colimena; (2) Unit MVb is a yellowish, medium-grained bioclastic calcarenite, rich in *Cladocora cespitosa* in growth position; (3) Unit MIV is composed of detrital organogenic limestones, and a clayey-marl matrix rich in embedded organic remnants of a pale brown soil with root and burrow-casts; (4) Unit MIII is unconformable on Unit IV and consists of bioclastic limestone with a micritic matrix. *Lithothamnium* and intraclasts are common. The fauna displays ecological diversity and includes *Cladocora*, *Spondylus*, *Conus*, *Glycymeris*, *Arca*, *Strombus bubonius*; and (5) Unit MII is a younger marine calcarenite contains reworked, rounded intraclasts of older units. This uppermost unit is stratigraphically correlated to MII at Torre Castelluccia (site 5).

### Site 11: Torre Sabea

The Torre Sabea section is floored by Unit MV into which the last interglacial sea level incised a small terrace at about 1 m (Figure 9). The low position of the MIII marine deposits near sea level suggests that slow downwarping has dominated the area since the last interglacial cycle. The beach facies consists of calcarenite with *Strombus* and grades upward and laterally into an eolianite (DIIIa) of the back beach zone. The same marine-eolianite unit is truncated, and overlain by a thin soil (SIII) and capped by another eolianite (DIIIb) for which an equivalent marine facies is not observed above sea level. Another thin soil (SII) separates the lower Pleistocene deposits from the DI eolianite capping the section.

Torre Sabea provides "evidence" of multiple *Strombus* events (Cotecchia *et al.*, 1969). The section clearly contains *Strombus* in a beach facies near present sea level, but also, higher along the coastline and about 500 m southwest of Torre Sabea, *Strombus* are found in great abundance in a *terra rossa* stained calcarenite.

### Sites 12 and 13: Gallipoli and Torre San Giovanni (Figure 9)

Like Torre Sabea, the marine deposits at Ospedale di Gallipoli have attracted Quaternary geologists and paleontologists throughout the Twentieth Century. Gignoux (1913), Blanc (1953), Mirigliano (1953, 1956), Gigout (1960c) and Cotecchia *et al.* (1969) have attempted to unravel this stratigraphic zone with apparently several marine deposits containing *Strombus*. The problem facing these and more recent investigators is that *Strombus* is present in a variety of disjunct exposures of differing sedimentary facies along the coastline. Despite our own original difficulties in interpreting the stratigraphy, Hearty and Dai Pra (1985) determined that "the mean aIle/Ile (or A/I in this study) ratios from all units (containing *Strombus*) lie within the standard error of the overall *Glycymeris* mean of 0.41 ± 0.04 (n = 15) for the site." That is, all of the deposits are essentially the same age. Considering this finding, we renewed our efforts to interpret the stratigraphy from the site. Our reconstruction in Figure 9 is the simplest and most direct solution

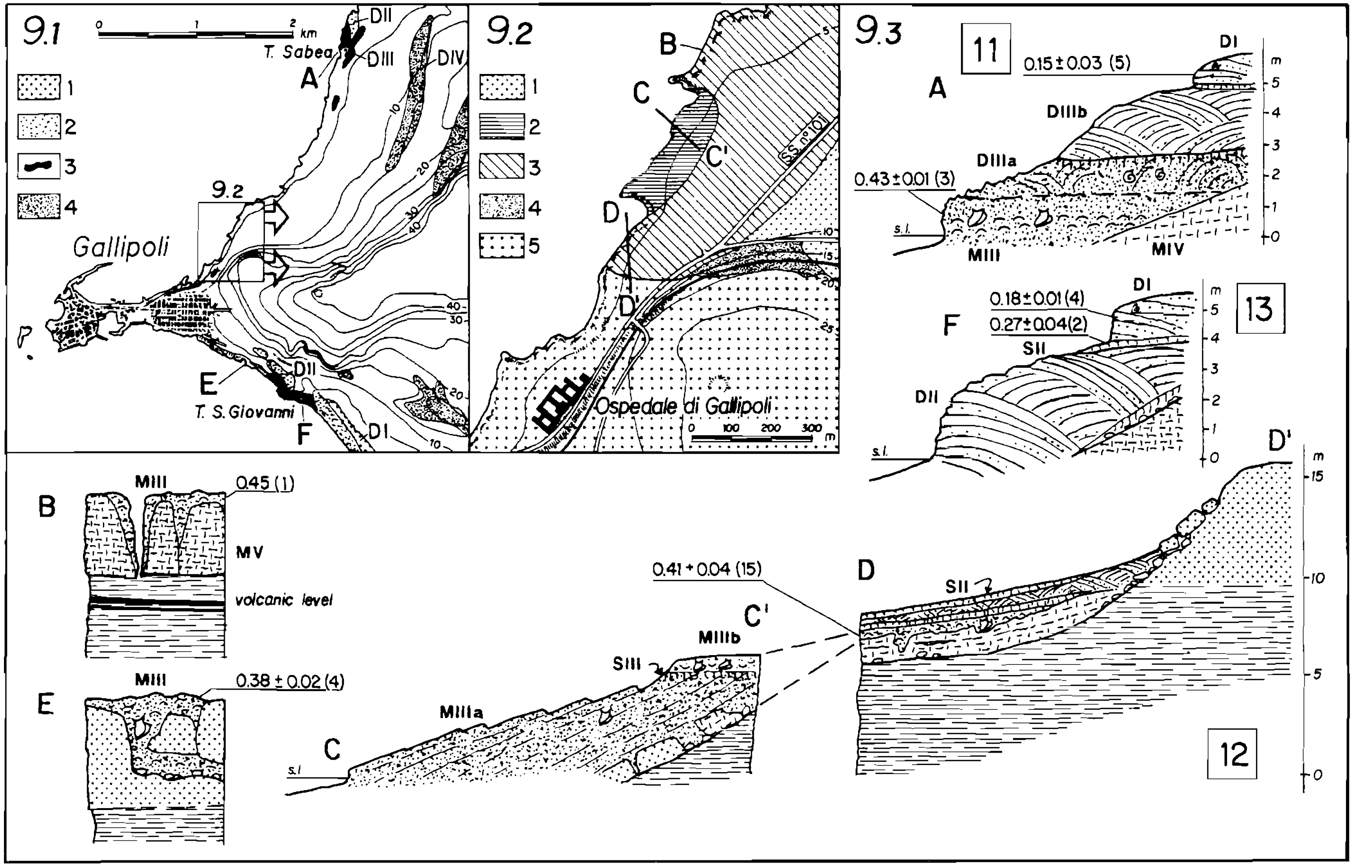

Figure 9. Stratigraphy of the Gallipoli area. Site 11 = Torre Sabea, Site 12B, 12C-C', and 12D-D' = Gallipoli (Ospedale), Site 13E and 13F = Torre San Giovanni. Legend for Figure 9.1 (Gallipoli Peninsula): (1) Historical dunes; (2) Holocene dunes; (3) post-*Strombus* dunes; (4) older dunes. Legend for Figure 9.2 (Ospedale di Gallipoli): (1) Holocene deposits; (2) beach deposits with *Strombus bubonius*; (3) bioclastic calcarenite; (4) eolianite; (5) "Sicilian" littoral sandstones with *Globorotalia truncatulinoides excelsa* (Coppa and Crovato, 1985; Rio *et al.*, 1991).

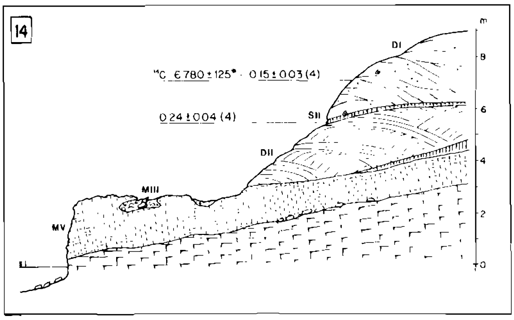

Figure 10. Site 14—Posto li Sorci/Mancaversa/Canale della Volpe section.

to the stratigraphic problems encountered at Gallipoli.

During the last interglacial period, a small cove contained a "catenary" or "pocket beach" between promontories of Sicilian sandstone (Figure 9.2). These MIIIa deposits well-preserved in their original form. However, to the southwest near the Ospedale di Gallipoli, Holocene coastal erosion has completely destroyed this pocket beach facies by cutting the present shoreline obliquely to, and inland from the paleoshoreline. This has exposed only the highest supratidal zone of the *Strombus* beach in the cliff. In order to restore the sequence normal to the paleocoast during the last interglacial period, we have aligned the segment C-C′ from the northeast zone, to segment D-D′ at the southwest zone (Figure 9.3 bottom). This profile very nearly completes the section as we interpret its original form. Similar more complete sequences are observed at Torre Sabea and Torre San Giovanni.

To add to the complexity of the *Strombus* sedimentary sequence at Ospedale, a thin soil (SIII) separates the lower planar beds of the shoreface (MIIIa) from an upper zone with highly concentrated shells (MIIIb). This thin, weakly-developed "soil" may either be penecontemporaneous with the beach deposits as a backbeach "protosol" (see HEARTY *et al.*, 1992) which was buried by marine deposits during storms, or, the soil may represent interglacial sea-level oscillations (HEARTY, 1986; HOLLIN and HEARTY, 1990; CHAPPELL and SHACKLETON, 1986). A stratigraphy reflecting such oscillations of sea level during the last interglacial period (Stage 5e) has been described in other localities in Italy (HEARTY and DAI PRA, 1987), Mallorca (HEARTY, 1987), Spain (HEARTY *et al.*, 1987), Tunisia (HERM *et al.*, 1980; PASKOFF and SANLAVILLE, 1983; MILLER *et al.*, 1986; HEARTY, 1986), and the U.S. Carolinas (HOLLIN and HEARTY, 1990).

At Torre San Giovanni, 1.5 km to the southeast, there is a similar last interglacial sequence (Figure 9) deposited under somewhat higher energy conditions. In the small eroded coves, the last interglacial shoreline is observed in cross section with broken blocks of Sicilian sandstone "mortared" (HEARTY and DAI PRA, 1985) by Tyrrhenian calcarenites with *Strombus*. These calcarenites are topped by calcretes and soils, and finally a younger eolianite (DI) stratigraphically equivalent to the uppermost unit at Torre Sabea.

### Site 14: Posto li Sorci/P. Mancaversa sections

Site 14 (Figure 10) displays a stratigraphy much like others in south Puglia. Algal limestones (> 300 ka) overlie Cretaceous limestones that floor the section. Small lenses of shell hash with rare *Strombus* (MIII) are plastered into the algal limestones and are capped by an eolianite (DIII) and a soil (SII). The uppermost unit, the DI eolianite, has been $^{14}$C dated at 6,780 years BP (COTECCHIA *et al.*, 1969).

## URANIUM-SERIES, $^{14}$C AND APK AGES

Extensive U-series data exist (some 50+ analyses) from studies in south Italy (DAI PRA and STEARNS, 1977; BRANCACCIO *et al.*, 1979; HEARTY *et al.*, 1986a; HEARTY, 1986; CAROBENE *et al.*, 1986; HOANG and HEARTY, 1989), however, a discussion of these data is beyond the scope of this paper. We do, nonetheless, integrate the chronological foundation provided by these dates into this paper (Table 2). Carbon-14 ages are those published in COTECCHIA *et al.* (1969) and CARRARA and DAI PRA (in press). In most cases, amino acid samples were collected from the same exposures as those furnishing the $^{14}$C and U-series dates. Apparent parabolic kinetic amino acid ages (Table 2) cited in this paper supplement those from MITTERER and KRIAUSAKUL (1989).

## CORRELATION OF COASTAL DEPOSITS

AAR has been particularly effective for correlation and dating in the Gulf of Taranto where corals do not commonly occur (Figures 4–10; Table 3). We assume that the climate history of the study area has affected all the sites equally, thus, the differences in A/I ratios reflect the relative

Table 2. *Summary of calibration ages used in kinetic models and correlations made in this study.*

| Aminozone | Species | A/I | APK Age | Other Ages |
|---|---|---|---|---|
| A | Helix | 0.10 | — | 3,910[1] |
| | Gly. | 0.12 | — | 4,630[1] |
| | Helix | 0.14 | — | 5,360[1] |
| | Helix | 0.15 | — | 6,780[1] |
| C | Helix | 0.25 | 52,000 | — |
| | Gly. | 0.30 | 74,000 | — |
| E | Helix | 0.34 | calibration | 120,000[2] |
| | Gly. | 0.39 | calibration | 125,000[2] |
| F | Gly. | 0.46 to 0.52 | 200,000 ± 25,000 | 250,000[3]<br>290,000[4] |
| G | GE | 0.57 to 0.65 | 310,000 ± 40,000 | >300,000[5] |
| H (Latina)[8] | GE | 0.70 to 0.76 | 440,000 ± 35,000 | — |
| major unconformity | | | major unconformity | |
| J (Lazio)[9] | Gly. | 0.90 to 1.00 | 825,000 ± 165,000 | >465,000[6] |
| K (Lazio)[9] | Gly. | ≥1.20 | ≥1,190,000 | 1,150,000[7] |

Calibration ages: (1) Carbon-14 ages from Cotecchia *et al.* (1969) and Carrara and Dai Pra (in press); (2) U-series ages from Dai Pra and Stearns (1977) and Hearty *et al.* (1986a); (3) U-series from Tommaso Natale (Hearty *et al.*, 1986a); (4) U-series from Carelli (Dai Pra and Stearns, 1977); (5) U-series from Torre Castelluccia (Dai Pra and Stearns, 1977); (6) Age of "pomici nere" (~430 ka, Evernden and Curtis, 1965) which is stratigraphically younger than the Aminozone J deposits (Sicilian); (7) Age of volcanic ash (Evernden and Curtis, 1965; Capaldi *et al.*, 1979) in Emilian-age deposits coeval with Aminozone K samples; (8) Ratios from Antonioli *et al.* (1988); (9) Ratios from Hearty *et al.* (1986a) and unpublished data

differences in age of the coastal deposits. Conversely, samples producing the same A/I ratios are most probably the same age.

To summarize, the AAR results are classified by aminozones:

### Aminozone A—The Holocene Period (Shoreline Complex I)

The Holocene is well represented on the Salentine Peninsula by coastal eolianites and soils indicating a complex and rapidly changing environment. A major eolian event is dated at around 6,000 years BP (mean A/I = 0.15). Thereafter, prolonged stability of the dunes is indicated by a strongly developed soil dated at around 4,000 years BP (mean A/I = 0.10). Eolian activity resumed in early historical times and continues up to the present. The stratigraphic sequence of the Holocene is indicative of the complexity of the depositional history during a single interglacial period.

### Aminozone C—Late Last Interglacial (Shoreline Complex II)

Younger marine deposits have produced a mean *Glycymeris* value of 0.285 ± 0.020 (n = 11) from sites 1 and 5 of Aminozone C. An *in situ* "banal" fauna from these sites has consistently produced lower A/I ratios than Aminozone E (Hearty, 1986 and Tables 1 and 3). At Torre Castelluccia, the marine deposits "feather out" at around 3 m adjacent to *Strombus* deposits that rise to 28 m in the area. A temperate molluscan fauna is described from marine deposits (43 m) at the lower edge of a large terrace rising to 85 m at Piano San Nicola (Montcharmont-Zei, 1957; Néboit and Réynard, 1973), supporting our late last interglacial age interpretation there (Dai Pra and Hearty, 1988). The initial age estimate interpreted for Aminozone C was 90 ± 15 ka (Hearty, 1986). Although independent U-series ages on corals have not confirmed this age in south Italy, recent studies on the tectonically stable island of Bermuda have directly tied Aminozone C *Glycymeris* ratios to U-series coral ages of ca. 85 ka (Vacher and Hearty, 1989; Hearty *et al.*, 1992). Similarly, Szabo (1985) has reported a considerable number of coral ages of 70 to 90 ka, and Hollin and Hearty (1990) calculated similar amino acid ages for sites along the southeast U.S. Coastal Plain. There is no similar concentration of ages centered on 105 ka, Substage 5c. Modelling the racemization reaction with apparent parabolic kinetics (Mitterer and Kriausakul, 1989) supports this age and has yielded an interpreted age of about 80 ka for Aminogroup C. In light of these arguments, we prefer to correlate our Aminozone C in Puglia with isotope Substage 5a which oc-

Table 3. *Amino acid ratios (A/I) and aminozone classification of samples from the Gulf of Taranto. Species definitions are listed at the base of the table. The data presented are in the format 0.40 ± 0.02 (4) indicating the mean value (0.40), the standard deviation (±0.02 (1σ)) and the number of shells analyzed in brackets (4). Brackets [ ] indicate ratios of other species normalized by* Glycymeris.

| Site No. | Locality/Unit | *Glycymeris* A/I | Other A/I (Spp.) | Aminozone |
|---|---|---|---|---|
| (1) | Piano san Nicola (43 m) | | | |
| | —MII | 0.29 ± 0.02 (6) | | C |
| (2) | Ponte del Re (24 m) | | | |
| | —MIII cmplx | 0.43 ± 0.03 (3) | 0.43 ± 0.01 (2) Ad | E |
| | Mar Piccolo Area— | | | |
| (3) | Il Fronte (0–10 m) | | | |
| | —MII | [0.25] | | C |
| | —SII | | 0.28 ± 0.01 (8) Hsp. | C |
| | —MIIIb–Sb | 0.37 ± 0.02 (10) | 0.27 ± 0.05 (22) An | E |
| | —MIIIa | | 0.30 ± 0.03 (5) An | E |
| | —MIII Ostrea | | 0.51 ± 0.06 (3) Osp. | E |
| | —MIII Transgr. | [0.39] | 0.30 ± 0.03 (5) An | E |
| | Punta Penna (17 m) | | | |
| | —SII | 0.41 (1) rw | 0.34 ± 0.01 (2) Hsp. | E/C |
| | —MIIIb Sb | 0.34 (1) | | E? |
| | —MIIIa Sb | 0.37 ± 0.01 (10) | | E |
| | —MIII | 0.39 ± 0.13 (3) | | E |
| (4) | Sta Teresiola (8 m) (aka Marne à *Cladocora*) | | | |
| | —MIII | | 0.48 ± 0.13 (3) Osp. | E |
| | Mass. San Pietro | | | |
| | —MII Sb | 0.38 ± 0.01 (3) | | E |
| (5) | Carelli (27 m) | | | |
| | —MIV | 0.48 ± 0.02 (7) | 0.71 ± 0.03 (3) Ar | F |
| (6) | Torre Castelluccia (0 to 5 m) | | | |
| | —SII | | 0.26 ± 0.01 (4) Hsp. | C |
| | —MII | 0.28 ± 0.02 (5) | 0.22 ± 0.03 (9) Ce | C |
| | | | 0.41 ± 0.03 (5) Ar | C |
| | | | 0.22 ± 0.03 (9) An | C |
| | —MIII | 0.39 (1) | | E |
| | —MV | [0.64] | 0.91 ± 0.04 (3) Ar | G |
| (7) | Torre Zozzoli (0 to 4 m) | | | |
| | —DIb | | 0.12 ± 0.02 (3) Hsp. | A |
| | —SIb | | 0.10 ± 0.01 (3) Hsp. | A |
| | —DIa | | 0.14 ± 0.01 (3) Hsp. | A |
| | —SIa | | 0.14 ± 0.01 (3) Hsp. | A |
| | —SII | | 0.17 (1) Hsp. | A? |
| | —SII | | 0.26 (1) Hsp. | C |
| (8) | Torre dell'Ovo (0 to 6 m) | | | |
| | —SIc | | 0.07 ± 0.03 (2) Hsp. | A |
| (9) | Torre Boraco (0 to 3 m) | | | |
| | —DIc | | 0.025 ± 0.006 (2) Hsp. | A |
| | —DIc | | 0.026 ± 0.007 (2) Hsp. | A |
| | —DI | | 0.15 ± 0.01 (4) Hsp. | A |
| (10) | Torre Castiglione (2 m) | | | |
| | —MIV | [0.47] | 0.36 ± 0.01 (2) An | F |
| (11) | Torre Sabea (0 to 5 m) | | | |
| | —DI | | 0.15 ± 0.03 (5) Hsp. | A |
| | —MIII Sb | 0.43 ± 0.01 (3) | | E |
| (12) | Gallipoli (0 to 7 m) | | | |
| | —SII | | 0.28 ± 0.03 (2) Hsp. | C |
| | —MIIIb Sb | 0.39 ± 0.04 (7) | | E |
| | —MIIIa | 0.43 ± 0.04 (7) | 0.31 ± 0.03 (2) An | E |
| | —MIII | 0.45 (1) | | E |
| (13) | Torre san Giovanni (0 to 5 m) | | | |
| | —DI | | 0.18 ± 0.01 (4) Hsp. | A |

Table 3. *Continued.*

| Site No. | Locality/Unit | *Glycymeris* A/I | Other A/I (Spp.) | Aminozone |
|---|---|---|---|---|
| | —SI | | 0.17 ± 0.01 (4) Hsp. | A |
| | —SII | | 0.27 ± 0.04 (2) Hsp. | C |
| | —MIII Sb | 0.38 ± 0.02 (4) | | |
| (14) | Posto li Sorci (0 to 8 m) | | | |
| | —DI | | 0.15 ± 0.03 (4) Hsp. | A |
| | —SII | | 0.24 ± 0.04 (4) Hsp. | C |

Species abbreviations and "*Glycymeris* equivalent" ratio: An = *Arca noae* (*Glycymeris* A/I = 1.31 Arca A/I); Ad = *Anadara diluvii* (*Glycymeris* A/I = 1.0 Ad A/I); Ar = *Astraea rugosa* (*Glycymeris* A/I = 0.71 Ar A/I); Osp = *Ostrea* species; Ce = *Cerastoderma* (*Glycymeris* A/I = 1.00 Ce A/I); Hsp = *Helix* sp. (*Glycymeris* A/I = 1.00 Hsp. A/I); Sb = *Strombus bubonius* (and/or *Strombus* fauna); rw = apparently reworded form older deposits. Facies definitions: M = Marine deposits; D = Eolian deposits (dunes; most often indurated); S = Soils: *terra rossa* or red colluvium with *Helix* sp

curred around 82 ka ago. A +1 m sea level at 85 ka contradicts much lower (−13 m) isotopic (Shackleton and Opdyke, 1973; Shackleton *et al.*, 1984) and constant uplift estimates (Bloom *et al.*, 1974; Matthews, 1973) for this event.

To summarize, geological and geochronological support for an 85 ka high sea level is provided by several independent arguments: (1) geomorphic evidence where younger beach and dune ridges lie juxtaposed and seaward of peak last interglacial ridges; (2) biological evidence that identifies unique faunas associated with the late last interglacial deposits; (3) multiple high sea level deposits associated with the last interglacial period; (4) radiometric dates of 70 to 90 ka from deposits adjacent to others producing 125 ka dates; and (5) amino acid data indicating a clearly-younger-than-the-last-interglacial aminozone, but not that of the Holocene. Further discussions on this topic can be found in Vacher and Hearty (1989), Hollin and Hearty (1990) and Hearty *et al.* (1992).

### Aminozone E—The Peak of the Last Interglacial (Shoreline Complex III)

A regional mean *Glycymeris* value of 0.388 ± 0.030 (n = 56) has been calculated from site data for Aminozone E, which is tied to an age of ca. 125 ka by several coral dates on *Cladocora cespitosa* (Table 3) from localities along the Salentine Peninsula as well as several other "calibration sites" around the Mediterranean basin where coral dates and *Glycymeris* ratios are directly compared (Table 1). Mean values for Aminozone E from other Mediterranean localities with similar CMATs produce similar or identical ratios (Hearty, 1986). Aminozone E correlation with the peak of the last interglacial period is supported across the Mediterranean basin by stratigraphic, biostratigraphic, geomorphic and radiometric data from nearly 100 sites (many available in Table 1). At none of these sites are exclusively older or younger *Glycymeris* ratios (Aminozone F or C) associated with an *in situ Strombus* fauna. However, mixed populations of A/I ratios (E and F) have been reported from Mallorca, Lazio and Tunisia, usually from shells in transgressive, last interglacial deposits which were reworking older deposits, perhaps now submerged and/or destroyed. We strongly support the reworking hypothesis rather than analytical error or natural variation, since the preponderance of the non-Aminozone E values center on the mean of the immediately preceding aminozone rather than randomly across the spectrum of possibilities.

### Aminozones F and G—Middle Pleistocene (Shoreline Complexes IV and V)

A considerable area of the Salentine Peninsula is capped by mid-Pleistocene algal limestones ("calcari di scogliera" of Cotecchia *et al.*, 1969). These deposits include deposits of at least two geomorphically distinct high stands that have been assigned individual aminozones (F and G) based on *Glycymeris* and *Astraea* ratios (Table 4, Hearty and Dai Pra, 1985). Near Mar Piccolo, Aminozone F deposits at Carelli (site 4) have also produced a coral age of 290 ± 50 ka (Dai Pra and Stearns, 1977). These deposits are more calcarenitic than the typical algal limestone that forms much of the terrace land of the region. These deposits are also found at a lower elevation in the Carelli area. Based on geomorphology, the low amino acid ratios from *Glycymeris* (0.48 ± 0.02, n = 7), and the possibility of a somewhat "old" coral age (Dai Pra and Stearns, 1977), we prefer to correlate this deposit to Stage 7 (195–251 ka, Shackleton and Opdyke, 1973) rather than Stage

9. Support for a Stage 7 age has also been provided by apparent parabolic kinetics (MITTERER and KRIAUSAKUL, 1989) from which an age of 200 ka has been calculated from the *Glycymeris* ratios (Table 2).

The higher and older terrace yields Aminozone G ratios (*ca.* 0.64) and coral ages >300 ka. We therefore suspect that this terrace deposit is equal to or exceeds the age interval of isotope Stage 9 (297 to 347 ka). AAR studies on sediments from boreholes in Lazio (in HEARTY and DAI PRA, 1986; ANTONIOLI *et al.*, 1988) have identified the same approximate mean *Glycymeris* values for Aminozones F and G, and an older one (Aminozone H) with an *Glycymeris* "equivalent" ratio of 0.73 calculated from *Cerastoderma* ratios. In the Torre Colimena area there is at least one more terrace that could also be Stage 9 or older. In the Mediterranean, these two or three mid Pleistocene deposits and terraces lie juxtaposed on early Pleistocene (Sicilian and Emilian) deposits (CAROBENE and DAI PRA, 1990), and are resolved by aminostratigraphy (Aminozone K, HEARTY *et al.*, 1986a). The AAR data indicate an hiatus of circa 0.5 my that agrees with a similar aminostratigraphic dataset from the southeast U.S. (HOLLIN and HEARTY, 1990), and a "world-wide lacuna" envisioned by BLACKWELDER (1981).

## SOILS, *TERRA ROSSA* AND EOLIANITES

We have collected and analyzed *Helix* sp. from a variety of terrigenous deposits and eolian (coastal dune) facies. *Helix* samples have produced consistent results when compared to those of the marine samples with which they are often intercalated or interbedded. The nearly equivalent *Glycymeris* and *Helix* epimerization rates have been established in previous studies in Mallorca (HEARTY, 1987a), in Lazio (HEARTY and DAI PRA, 1986), in regional Mediterranean studies (HEARTY *et al.*, 1986a) and in Bermuda (*Glycymeris* versus *Poecilozonites*, HEARTY *et al.*, 1992). Ratios from both taxa are thus effectively interchangeable.

In Puglia and Basilicata terrigenous sediments (protosol and *terra rossa*) are less frequently preserved than coastal marine deposits. One such terrestrial event (SII) occurred toward the end of the last interglacial period (s.l.). Land snails from these deposits have produced Aminozone C ratios of 0.281 ± 0.014 (n = 18) from several sections along the coastline (sites 3, 6, 7, 13 and 14; Figures 4 through 10). These deposits bracket Aminozone C marine deposits at Il Fronte and Torre Castelluccia.

Above this young terrigenous sediment package a widely distributed eolianite (DI) yields Aminozone A ratios and is associated with the mid-Holocene. Our amino acid samples are integrated with several $^{14}C$ dates from the area (COTECCHIA *et al.*, 1969). Holocene eolianites and soils at Torre Zozzoli, Torre Boraco and Posto li Sorci have been $^{14}C$ dated at around 6,000 years, and have provided an A/I of 0.147 ± 0.018 (n = 11), while a late Bronze age (2,500–2,000 years) soil, and a recent dune, respectively, yield A/I's of 0.068 ± 0.024 (n = 2) and 0.026 ± 0.007 (n = 5). Two levels at Torre Zozzoli dated at 3910 and 5360 years BP (COTECCHIA *et al.*, 1969) returned *Helix* ratios of 0.099 ± 0.003 (n = 3) and 0.143 ± 0.013 (n = 3) (Table 3).

## COMPOSITE STRATIGRAPHY AND REGIONAL CORRELATIONS

Figure 11 summarizes the rock and aminostratigraphy for the middle Pleistocene to Holocene section of southeast Italy. This composite charts the major depositional events of the past half million years resulting from transgressive intervals. Regressions are indicated by major unconformities and occasionally *terra rossa* soils that serve as sequence boundaries (VAN WAGONER *et al.*, 1988). Interglacial sequences comprise marine, eolian and minor pedogenic processes. This study has identified five stratigraphic complexes that coincide with statistically unique aminozones (Aminozone A = Complex I; C = II, E = III, F = IV, and G = V). As expected, the highest resolution of ages and events is during the Holocene, where numerous soil and eolianite couplets compose the majority of the interglacial complex. In Puglia, substages of the last interglacial period (s.l.) are easily resolved by bounding Aminozones C and E. In adjacent Calabria, the same last interglacial period comprises four uplifted terraces: samples from the lowest (youngest) terrace are Aminozone C, and those from the oldest two terraces fall into Aminozone E (HEARTY *et al.*, 1986b; DUMAS *et al.*, 1988). An intermediate terrace is associated with A/I ratios between Aminozone C and E.

Mean ratios from *Glycymeris* and *Glycymeris* equivalents from surface sites and borehole in Lazio have yielded nearly identical values for Aminozones E, F and G (HEARTY and DAI PRA, 1986, 1987; ANTONIOLI *et al.*, 1988). Aminozone E is a

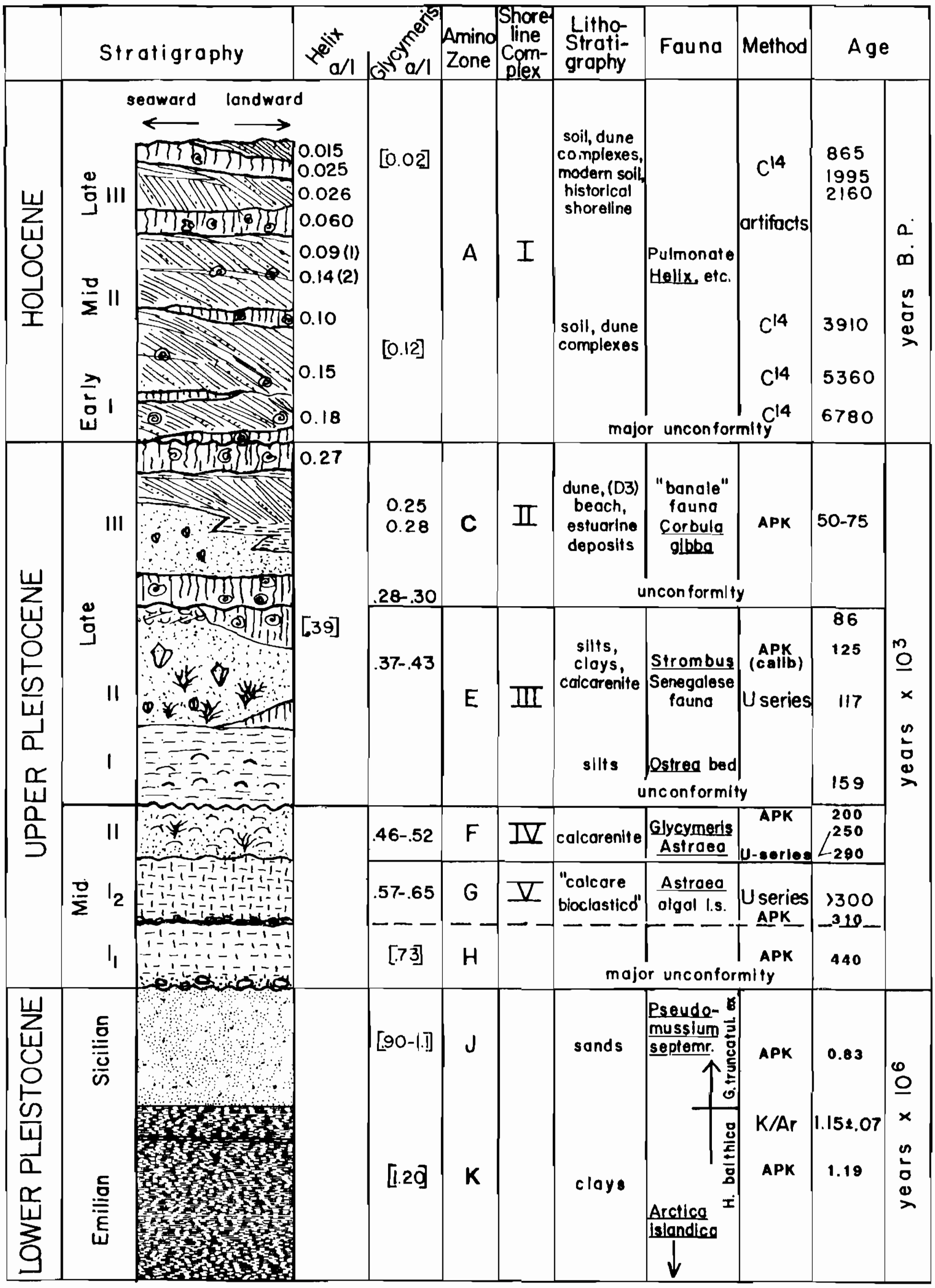

Figure 11. The composite stratigraphic section of southeast Italy includes rock sequences (I to V) bounded by unconformities, aminostratigraphy and aminozones, invertebrate biostratigraphy, and chronostratigraphy. The composite section reflects a multiple-systems approach to the geological evolution of the area. Legend as in Figure 3.

major depositional event of the late Pleistocene correlated with the Eutyrrhenian (*i.e.* associated exclusively with the *Strombus* fauna) and Il Fronte Formation (HEARTY, 1986). Aminozone F is relatively minor and, if not uplifted, is generally eroded and removed by the Il Fronte transgression. Aminozone G is correlated to the San Pantaleo Formation near Rome (HEARTY and DAI PRA, 1986, 1987) and is the most significant depositional event of the middle Pleistocene.

"Aminogroups" C, E, F and G are correlated across the Mediterranean (HEARTY *et al.*, 1986a; HEARTY, 1986, 1987a,b; MILLER *et al.*, 1986), Bermuda (VACHER and HEARTY, 1989; HEARTY *et al.*, 1992) and the Carolinas (HEARTY and HOLLIN, 1986; HOLLIN and HEARTY, 1990). With confidence in our multi-systems approach (employing geomorphology, stratigraphy and geochronology), we propose a correlation of aminozones with the isotope stages of SHACKLETON and OPDYKE (1973): A, C, E, F and G, with isotope Stages 1, 5a, 5e, 7 and (probably) 9, respectively. It is uncertain at this time whether Aminozone G is equivalent to Stage 11 or 13.

## CALCULATED TECTONIC UPLIFT

Based on the present elevation of correlated peak last interglacial deposits with the assumed original sea level at *ca.* +6 m at 125 ka (LAND *et al.*, 1967), the tectonic uplift is calculated at 0.70 m/ka near to the Appennine Zone at Piano San Nicola, and diminishes to 0.40 and 0.20 m/ka at Ponte del Re and Mar Piccolo, respectively (DAI PRA and HEARTY, 1988). Further to the south and east along the Salentine Peninsula, decreasing uplift rates continue until neutrality and subsidence appear to dominate near Porto Cesareo. The trend of subsidence persists southward until near Gallipoli where the last interglacial again rises above modern sea level.

## EPIMERIZATION KINETICS

When mean A/I ratios from *Glycymeris* and *Helix* are plotted against radiometric and estimated ages (Table 2) on three different time scales ($10^3$, $10^5$ and $10^6$ of years), a detailed epimerization history is constructed (Figure 12). These empirical curves track the reaction through geologic time at ambient temperatures. In order to fully describe the kinetic pathways in Figure 12, it was necessary to incorporate data points from adjacent study areas having similar geology, CMAT's, and the appropriate taxa (*Glycymeris*) (see footnotes in Table 2). Three kinetic phases are apparent from the curves in Figure 12:

### Phase I. Early Rapid Phase—A/I 0.0 to 0.20

Aminozone A ratios from land snails in Holocene marine, soil, and eolianite sequences are the basis of Phase I. This collection of A/I ratios versus $^{14}$C dates (COTECCHIA *et al.*, 1969; CARRARA and DAI PRA, in press) demonstrate the rapidly evolving A/I ratio during that period. The configuration of the relationship between A/I and age is from Puglia is basically linear (Figure 12). GOODFRIEND'S (1987) Holocene land snail A/I vs. $^{14}$C data from the Negev Desert also reflect linearity. In AAR studies on the Great Barrier Reef, Australia, HEARTY and AHARON (1988) determined that epimerization in *Tridacna* was sublinear up to approximately 0.25 to 0.30, after which parabolic kinetics prevail. Thus, in order to safely estimate ages from A/I ratios during Phase I, the use of a linear model is effective up to an A/I of ~0.20.

### Phase II. Transitional Phase—A/I 0.20 to 0.40

Phase II can be subdivided into two rate intervals. First, there is a greatly reduced epimerization rate between Aminozones A and C that contrasts greatly with the speed of Phase I. This slower rate is a fundamental reflection of the cooler climate during the last glacial period in the Mediterranean. And secondly, there is a substantially faster rate which includes the period encompassing Aminozones C and E, but is much slower than Phase I. Phase II data (Figure 12) suggest that the reaction is still sensitive to climatic warmth *within* the interglacial period. Although not in absolute terms, this configuration of the kinetic pathway would probably apply to most late Pleistocene sequences in the middle latitudes (25° to 60° N. Lat.).

### Phase III. Final Sublinear Phase—A/I 0.40 to 1.30

During Phase III (Figure 12), the ever slowing reaction appears to become insensitive to changes within an interglacial cycle (although a paucity of data exists). The pathway continues on a sublinear to parabolic route from Aminozone F until equilibrium is reached at 1.0 to 1.5 my (Figure 12) (HEARTY *et al.*, 1986a). It is during Phase III, up to an A/I of 1.0, that MITTERER and KRIAU-

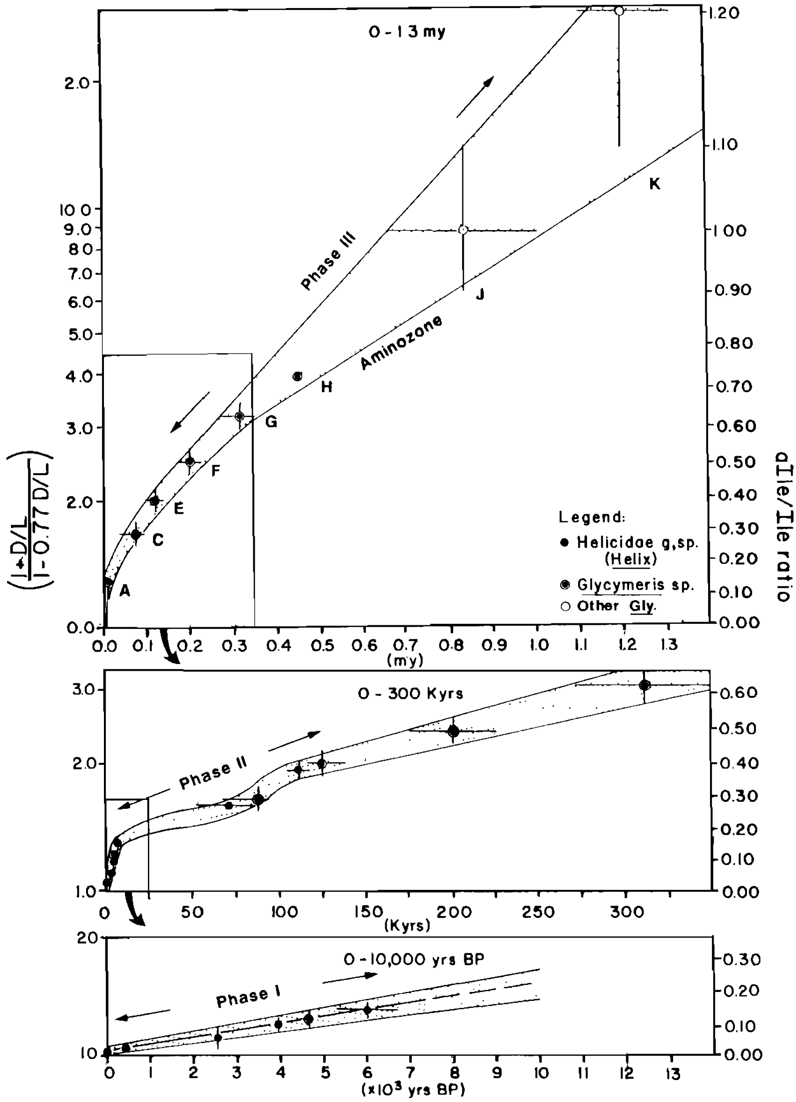

Figure 12. Kinetic history of *Glycymeris* and *Helix* compiled from D-alloisoleucine/L-isoleucine (A/I) ratios from sites along the Gulf of Taranto. Mean A/I ratios are plotted against $^{14}$C, U-series, APK, and K/Ar dates from the area (Table 2). Stippled area indicates error envelope. The ages of soils and eolianites capping marine deposits of Aminozones C and E are inferred from stratigraphic relationships. Open circles represent points incorporated from adjacent study areas in Italy (*i.e.* HEARTY *et al.*, 1986a,b; DUMAS *et al.*, 1988; HEARTY and DAI PRA, 1985, 1986a,b), and are bound by identical parameters. Three rate phases are identified: Phase I—Early Rapid Phase during the Holocene; Phase II—Transitional Phase between 12 ka and 135 ka; Phase III—Final Parabolic Phase between 135 ka and the early Pleistocene (> 1.0 my).

SAKUL (1989) found estimating ages from "parabolic kinetics" most effective. However, an APK age of 1.19 my from a ratio of 1.20 (Table 2) for the Emilian (early Pleistocene) marine deposits corresponds well with K/Ar ages for the same unit of 1.15 my (EVERNDEN and CURTIS, 1965).

## CONCLUSIONS

Quaternary coastal geology along 200 km around the Gulf of Taranto is quite variable due to diverse histories of tectonism, sediment provenance and paleoenvironment. Along the Basilicata coastline

(Piano San Nicola to Fiume Bradano), the deposits are characterized by a high percentage of terrigenous silicates deposited on broad, constructional terraces. Coastal areas of the Salentine Peninsula are typified by low terraces, veneered with carbonate deposits. These terraces show evidence of repeated occupation by higher-than-present sea levels. Along high-energy, exposed coastlines, erosion dominates and deposits are thin and patchy. Terrigenous deposits (soils and *terra rossa*) interfinger with marine deposits while eolianites grade laterally landward from their source beach. A composite stratigraphy assembled from the study sites (Figure 11) suggests episodic deposition of marine and continental deposits mainly during the major transgressive periods. Minor sea level fluctuations of ±10 m occurred during the last interglacial period (s.s.). Erosion clearly dominates during the regressive (glacial) cycle when sea level falls to −50 to −100 m, and few Würmian (Weichselian) deposits are recognized above present sea level in this study area.

Peak last interglacial marine sands often contain tropical molluscan fauna and microfauna, some now extinct in the Mediterranean basin. One of the fauna includes the *Strombus* fauna, now common along the coast of West Africa. Younger marine deposits contain molluscan faunas much like today's in sediments yielding less carbonate and more detrital materials.

Marine deposits of the mid Pleistocene are characterized by algal limestones nearly stromatolitic in character, with rocky-coastline taxa (*Turbo, Astraea, Arca, Lima, etc.*) than in the calcarenites. The algal limestones suggest low sedimentation in shallow seas at temperatures higher than today's. An algal reef facies is typical in the present day sublittoral of Bermuda.

Uranium-series coral dates from the *Strombus* beds in Mar Piccolo have produced a mean age of 118 ± 5 ka (n = 11). Each of the U-series data sets among the four laboratories varies slightly but nonetheless falls within Stage 5, tending toward 125 ka.

Despite the geologic diversity of the study sites, amino acid ratios are consistent across the study area. Substages of isotope Stage 5 are resolvable and produce mean *Glycymeris* values of 0.388 ± 0.030 (n = 56) for Aminozone E, and 0.285 ± 0.020 (n = 11) for Aminozone C. Two mid Pleistocene marine events have been identified by amino acid ratios of 0.48 ± 0.02 (n = 7) for Aminozone F (*ca.* 200 ka), and 0.64 for Aminozone G (> 300 ka). A third middle Pleistocene unit remains poorly defined by aminostratigraphy.

Nearly identical mean *Glycymeris* A/I ratios have been determined in Lazio, central Italy (HEARTY and DAI PRA, 1986, 1987) and Mallorca (HEARTY, 1987a), both of which have similar CMATs. Warmer sites in Tunisia (MILLER *et al.*, 1986), southern Spain (HEARTY *et al.*, 1987), and Bermuda (HEARTY *et al.*, 1992) produce appropriately higher mean ratios for the same genera.

*Helix* ratios are consistent with the morphostratigraphy and epimerize at a rate similar to *Glycymeris*. Regionally consistent Aminozone C ratios for *Helix* have placed an important soil/*terra rossa* event (SII) at the close of last interglacial period (*ca.* 70 ka). Holocene deposits indicate a complex depositional history, alternately dominated by dune building, and soil formation.

The parallel epimerization history of southeast Italy (Figure 12) is characterized by three rate phases: Phase I is very rapid during the 10 ka of the Holocene, evolving the A/I ratio 15% of the equilibrium value (1.30). During a rate-transitional Phase II, the reaction is slowed during the cooler isotope Stages 2 to 4, and accelerated during the warmth of the last interglacial period. Thirty percent of the reaction is accomplished during Phase II. The slowing reaction during Phase III (mid to early Pleistocene) does not yet permit resolution of substages, but rather the broad imprint of interglacials back to the beginning of the Pleistocene.

## ACKNOWLEDGEMENTS

We are greatly indebted to G.H. Miller and J.T. Hollin for their personal and financial support of our research. Amino acid analyses were performed at the INSTAAR Geochronology Center; some under contract with ENEA-Rome through GDP. Thoughtful reviews by John Wehmiller and two anonymous reviewers are greatly appreciated. Butch Matthews provided faithful field assistance and constant amusement. Production funds were provided by Duke University Marine Laboratory, University of South Florida, and ENEA-Rome.

## LITERATURE CITED

AMBROSETTI, P.; AZZAROLI, A.; BONADONNA, F., and FOLLIERI, M., 1972. A scheme of Pleistocene chronology for the Tyrrhenian side of central Italy. *Bollettino della Società Geologica Italiana*, 91, 169–189.

ANTONIOLI, F.; DAI PRA, G., and HEARTY, P.J., 1988. I.

sedimenti Quaternari nella fascia costiera della piana di Fondi, Italia (Lazio meridionale, Italia). *Bollettino Società Geologica Italiana,* 107, 491–501.

BERGGREN, W.A.; KENT, D.V., and VAN COUVERING, J.A., 1985. Neogene geochronology and chronostratigraphy, *In:* SNELLING, N.J. (ed.), *Geochronology of the Geological Record. Geological Society of London Memoir,* 10, 211-260.

BIGAZZI, G.; BONADONNA, F.P., and IACCARINO, S., 1973. Geochronological hypothesis on Plio-Pleistocene boundary in the Latium region (Italy). *Bollettino della Società Geologica Italiana,* 92, 391–422.

BLACKWELDER, B.W., 1981. Late Cenozoic marine deposition in the United States Atlantic coastal plain related to tectonism and global climate. *Paleogeography, Paleoclimatology, Paleoecology,* 34, 87–114.

BLANC, A.C., 1953. Notes sur le Quaternaire marin des Puilles. *Livret-guide du IVième Congrès de l'INQUA,* pp. 19–30.

BLOOM, A.L.; BROECKER, W.S.; CHAPPELL, J.M.A., MATTHEWS, R.K., and MESOLELLA, K.J., 1974. Quaternary sea level fluctuations on a tectonic coast: New 230-TH/234-U dating from the Huon Peninsula, New Guinea. *Quaternary Research,* 4, 185–205.

BOENZI, F.; CALDARA, M., and PENNETTA, L., 1985. La trasgressione tirreniana nei dintorni di Castellaneta (Taranto). *Geologica Applicata ed Idrogeologia,* 20, 163–175.

BONIFAY, F. and MARS, P., 1959. Le Tyrrhénien dans le cadre de la chronologie quaternaire méditerranéenne. *Bulletin Société Géologique Française,* 7(1), 62–78.

BRANCACCIO, L.; CAPALDI, G.; CINQUE, A.; PECE, R., and SGROSSO, I., 1979. $^{230}$Th/$^{234}$U dating of corals from a Tyrrhenian beach in the Sorrentine Peninsula (Southern Italy). *Quaternaria,* 20, 175–183.

BRÜCKNER, H., 1980. Marine Terrassen in Süditalien. Eine Quartärmorphologische Studie über das Küstentiefland von Metapont. *Düsseldorfer Geographische Schriften,* 14, p. 235.

CALDARA, M., 1986. La sezione tirreniana di Ponte del Re (Castellaneta Marina, Taranto): Analisi paleoecologica. *Atti Società Toscanese de Scienze Naturale Memoire,* Série A, 93, 129–163.

CAPALDI, G.; CIVETTA, L.; LIRER, L., and MUNNO, R., 1979. Caratteri petrografici ed eta K/Ar delle cineriti intercalate nelle formazioni pleistoceniche della fossa bradanica. *Geologia Applicata e Idrogeologia,* 14, 493–501.

CAROBENE, L. and DAI PRA, G., 1990. Genesis, chronology and tectonics of the Quaternary marine terraces of the Tyrrhenian coast of northern Calabria (Italy). Their correlation with climatic variations: *Il Quaternario,* 3(2), 75–94.

CAROBENE, L.; DAI PRA, G., and GEWELT, M., 1986. Niveaux marins du Pléistocène moyen-supérieur de la côte tyrrhénienne de la Calabre (Italie méridionale) Datations 230Th/234U et tectonique récent. *Zeitschrift für Geomorphologie,* N.F., Suppl.-Bd. 62, 141–158.

CARRARA, C. and DAI PRA, G., in press. Depositi marini olocenici sollevati all'Isola di Palmarola (Italia Centrale): Il Quaternario.

CHAPPELL, J. and SHACKLETON, N.J., 1986. Oxygen isotopes and sea level. *Nature,* 324, 137–140.

CIARANFI, N.; PIERI, P., and RICCHETTI, G., 1988. Carta geologica nella Puglia, dal F. Otranto a Santa Maria di Leuca. *Atti 74° Congresso nella Società Geologica Italiana,* B, 112–116.

COPPA, M.G. and CROVATO, P., 1985. Osservazioni biostratigrafiche e paleoecologiche sui depositi argillosi emiliani e siciliani di Gallipoli (Puglia). *Bollettino Società Naturalisti in Napoli,* 92, 159–225.

COTECCHIA, V. and MAGRI, G., 1967. Gli spostamenti delle linee di costa Quaternarie del Mare Ionio fra Capo Spulico e Taranto. *Geologia Applicata e Idrogeologia,* 2, 3–28.

COTECCHIA, V.; DAI PRA, G., and MAGRI, G., 1969. Oscillazioni tirreniane ed oloceniche del livello mare nel Golfo di Taranto, corredate da datazioni col metodo del radiocarbonio. *Geologia Applicata e Idrogeologia,* 4, 93–148.

DAI PRA, G., 1982. The late Pleistocene marine deposits of Torre Castiglione (southern Italy). *Geografia Fisica e Dinamica Quaternaria,* 5, 115–119.

DAI PRA, G. and HEARTY, P.J., 1988. I levelli marini pleistocenici del Golfo di Taranto. Sintesi geocronostratigrafica e tettonica. *Atti del 74° Congresso della Società Geologica Italiana* (In stampa) *Memoirie Società Geologica Italiane,* Napoli, 41, B183–189.

DAI PRA, G. and STEARNS, C.E., 1977. Sul Tirreniano di Taranto: Datazioni su coralli con il metodo del 230-Th/234-U. *Geologica Romana,* 16, 231–242.

DE CASTRO-COPPA, M.G., 1979. I foraminiferi delle argille Pleistoceniche delle localita "Il Fronte" (Mare Piccolo, Taranto). *Bullettino Società Naturalisti in Napoli,* 88, 1–131.

DUMAS, B.; GUÉRÉMY, P.; LHÉNAFF, R., and RAFFY, J., 1980. Terrasses quaternaires soulevées sur la façade calabraise du Détroit de Messine (Italie). *Comptes Rendus Hebdomadaires de l'Academie des Séances,* Paris, Série 290, 739–742.

DUMAS, B.; GUÉRÉMY, P.; HEARTY, P.J.; LHÉNAFF, R., and RAFFY, J., 1988. Morphometric analysis and amino acid geochronology of uplifted shorelines in a tectonic region near Reggio Calabria, south Italy. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 68, 273–289.

EVERNDEN, J.F. and CURTIS, G.H., 1965. The potassium-argon dating of late Cenozoic rocks of east Africa and Italy. *Current Anthropology,* 6(4), 343–364.

GIGNOUX, M., 1913. Les formations marines pliocènes et quaternaires de l'Italie du sud et de la Sicile. *Annals de l'Université de Lyon,* 36, 1–693.

GIGOUT, M., 1960a. Sur le quaternaire marin de Pulsano (Tarente, Italie). *Comptes Rendus Hebdomadaires de l'Académie des Séances,* 250, 881–883.

GIGOUT, M., 1960b. Sur le quaternaire marin de Tarante (Italie). *Comptes Rendus Hebdomadaires de l'Académie des Séances,* 250, 1094–1096.

GIGOUT, M., 1960c. Sur le quaternaire marin de Gallipoli (Italie). *Comptes Rendus Hebdomadaires de l'Académie des Séances,* 250, 1295–1297.

GOODFRIEND, G.A., 1987. Radiocarbon age anomalies in shell carbonate of land snails from semi-arid areas. *Radiocarbon,* 29(2), 159–167.

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. *Zeitschrift für Geomorphologie,* Suppl.-Bd., 62, 51–69.

HEARTY, P.J., 1987a. New data on the Pleistocene of Mallorca. *Quaternary Science Reviews,* 6, 245–257.

HEARTY, P.J., 1987b. Age and aminostratigraphy of Quaternary shoreline deposits around the Mediterranean basin. Ph.D Thesis, University of Colorado, Boulder, Colorado, 207 pp.

HEARTY, P.J. and AHARON, P., 1988. Amino acid chronostratigraphy of late Pleistocene coral reef sites: Huon Peninsula, New Guinea and the Great Barrier Reef, Australia. *Geology,* 16, 579–583.

HEARTY, P.J. and DAI PRA, G., 1985. Aminostratigraphy and 230-Th/234-U dating of Quaternary shoreline in the Puglia region of southern Italy. *Proceedings of the Fifth International Coral Reef Congress, Papeete, Tahiti,* May 1985, 163–169.

HEARTY, P.J. and DAI PRA, G., 1986. Aminostratigraphy of Quaternary marine deposits in the Lazio region of central Italy. *Zeitschrift für Geomorphologie,* Suppl.-Bd. 62, 131–140.

HEARTY, P.J. and DAI PRA, G., 1987. Paleogeographic reconstruction of Quaternary environments in Toscana and north Lazio, central Italy. *Bollettino Servizio Geologico d'Italia,* 106, 189–224.

HEARTY, P.J. and HOLLIN, J.T., 1986b. Isotope Stage 5 marine transgressions in the Carolinas. *Geological Society of America Annual Meeting, Abstracts with Programs,* 18(6), 633.

HEARTY, P.J. and MILLER, G.H., 1987. Global trends in isoleucine epimerization: Data from the circum-Atlantic, the Mediterranean and the south Pacific. *Geological Society of America Annual Meeting, Abstracts with Programs,* 19(7), 698.

HEARTY, P.J.; HOLLIN, J.T., and DUMAS, B., 1987. Geochronology of Pleistocene littoral deposits on the Alicante and Almeria coasts of Spain. *In:* C. ZAZO (ed.), *Late Quaternary Sea Level Changes in Spain.* Trab. Neogeno-Cuaternario, 10, 95–105.

HEARTY, P.J.; VACHER, H.L., and MITTERER, R.M., 1992. Aminostratigraphy and Ages of Pleistocene Limestones of Bermuda. *Geological Society of America Bulletin.* 104(4), 471–480.

HEARTY, P.J.; MILLER, G.H.; STEARNS, C.E., and SZABO, B.J., 1984. Aminostratigraphy of raised shoreline deposits in the Mediterranean basin. *AMQUA 8th Biennial Meeting Program and Abstracts,* p. 57.

HEARTY, P.J.; MILLER, G.H.; STEARNS, C.E., and SZABO, B.J., 1986a. Aminostratigraphy of Quaternary shorelines around the Mediterranean basin. *Geological Society of America Bulletin,* 97, 850–858.

HEARTY, P.J.; BONFIGLIO, L.; VIOLANTI, D., and SZABO, B.J., 1986b. Age of late Quaternary marine deposits of southern Italy determined by aminostratigraphy, faunal correlation, and uranium-series dating. *Revista Italiana di Paleontologia e Stratigraphia,* 92 (1), 149–164.

HERM, D.; PASKOFF, R., and SANLAVILLE, P., 1980. La stratigraphie des falaises d'Hergla (Sahel del Sousse, Tunisie) et son importance pour la compréhension du quaternaire marin récent de la Tunisie. *Comptes Rendus Sommaire de Societé Géologique Française,* 1, 25–28.

HILLAIRE-MARCEL, C.; CARRO, O.; CAUSSE, C.; GOY, J-L., and ZAZO, C., 1986. Th/U dating of *Strombus bubonius* bearing marine terraces in southern Spain. *Geology,* 14, 613–616.

HOANG, C-T. and HEARTY, P.J., 1989. A comparison of U-series disequilibrium dates and amino acid epimerization ratios between corals and marine mollusca of Pleistocene age. *Chemical Geology, Isotope Geoscience Section,* 79(4), 317–323.

HOLLIN, J.T. and HEARTY, P.J., 1990. South Carolina Interglacial Sites and Stage 5 Sea Levels. *Quaternary Research,* 33, 1–17.

ISSEL, A., 1914. Lembi fossiliferi quaternari e recenti nella Sardegna meridionale. *Accademia Nazionale dei Lincei,* Série 5(23), 759–770.

LAND, L.S.; MACKENZIE, F.T., and GOULD, S.J., 1967. The Pleistocene history of Bermuda. *Geological Society of America Bulletin,* 78, 993–1006.

MATTHEWS, R.K., 1973. Relative elevation of late Pleistocene sea level stands: Barbados uplift rates and their implications. *Quaternary Research,* 3, 147–153.

MILLER, G.H. and BRIGHAM-GRETTE, J., 1989. Amino acid geochronology: Resolution and precision in carbonate fossils. *Quaternary International,* 1, 111–128.

MILLER, G.H. and MANGERUD, J., 1985. Aminostratigraphy of European marine interglacial deposits. *Quaternary Science Reviews,* 4(4), 215–278.

MILLER, G.H.; STEARNS, C.E., and PASKOFF, R., 1986. Amino acid geochronology of Pleistocene littoral deposits in Tunisia. *Zeitschrift für Geomorphologie,* Suppl.-Bd., 62, 197–207.

MIRIGLIANO, G., 1953. La macrofauna del tirreniano di Gallipoli (Lecce). *Bollettino Zoologico,* 20.

MIRIGLIANO, G., 1956. Il tirreniano di Gallipoli (Lecce). *Atti IV$^{e}$ INQUA Congresso,* (Roma-Pisa 1953), 2.

MITTERER, R.M. and KRIAUSAKUL, N., 1989. Calculation of amino acid racemization ages based on apparent parabolic kinetics. *Quaternary Science Reviews,* 8, 353–357.

MONTCHARMONT-ZEI, M., 1957. Foraminiferi e molluschi di un livello tirreniano presso Nova Siri Scalo (Matera). *Bollettino Società Naturalisti in Napoli,* 66, 53–68.

NÉBOIT, R. and RÉYNARD, P., 1973. Étude géomorphologique et écologique du gisement quaternaire de la terrasse de "Piano San Nicola" près de Nova Siri Scalo (Italie du Sud). *Géobois,* 6, 291–305.

NICKLÉS, M., 1950. *Mollusques testaces marins de la côte occidentale d'Afrique.* Paul Lechevalier, Paris.

OGNIBEN, L., 1973. Conclusioni sullo stato attuale delle conoscenze nella geologia dell'Appennino. Atti "Moderne vedute sulla geologia dell'Appennino", Quaderno numero 183, *Accademia Nazionale dei Lincei,* Roma, 367–445.

PASKOFF, R. and SANLAVILLE, P., 1983. Les Côtes de la Tunisie: Collection de la maison de l'Orient Mediterranéen no. 14. *Série Géographique et Préhistorique,* 2, 192 pp. Lyon, France.

RAFFY, J.; DUMAS, B.; GUÉRÉMY, P., and LHENAFF, R., 1981. Uplift of Quaternary marine terraces to the east of Villa San Giovanni (Calabria, Italy). *Zeitschrift für Geomorphologie,* N.F. Suppl. Bd. 40, 119–125.

RIO, D.; SPROVIERI, R., and THUNELL, R., 1991. Pliocene-lower Pleistocene chronostratigraphy: A re-evaluation of Mediterranean type sections: *Geological Society of America Bulletin,* 103(8), 1049–1058.

RUGGIERI, G. and SPROVIERI, R., 1984. Remarks on the chronostratigraphic classification of the lower Pleistocene. *Bollettino Società Geologica Italiana,* 103, 251–259.

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

SHACKLETON, N.J.; BACKMAN, J.; ZIMMERMAN, H.; KENT, D.V.; ITALL, M.A.; ROBERTS, D.G.; SCHNITKER, D.; BALDANF, J.G.; DESPRAIRIES, A.; HOMRIGHAUSEN, R.; HUDDLESTUN, P.; KEENE, J.B.; KALTENBACK, A.J.; KRUMSIEK, K.A.O.; MORTON, A.C.; MURRAY, J.W., and WESTBERG-SMITH, J., 1984. Oxygen isotope calibration of the onset of ice-rafting and history of glaciation in the North Atlantic region. *Nature,* 307, 620–623.

SZABO, B.J., 1985. Uranium-series dating of fossil corals from marine sediments of southeastern United States Coastal Plain: *Geological Society of America Bulletin,* 96, 398–406.

ULZEGA, A. and HEARTY, P.J., 1986. Geochronology of Sardinian shoreline deposits. *Zeitschrift für Geomorphologie,* Suppl.-Bd. 62, 119–130.

VACHER, H.L. and 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. *Quaternary Science Reviews,* 8, 159–168.

VAN WAGONER, J.C.; POSAMENTIER, H.W.; MITCHUM, R.M.; VAIL, P.R.; SARG, J.F.; LOUTIT, T.S., and HARDENBOL, J., 1988. An overview of the fundamentals of sequence stratigraphy and key definitions, *In:* Wilgus, C.K. *et al.,* (eds.), *Sea-Level Changes: An Integrated Approach:* SEPM Special Publication 42, 39–45.

VEZZANI, L., 1967. I depositi Plio-Pleistocenici del litorale ionico dela Lucania. *Atti Acc. Gioenia Scienze Naturale de Catania,* 6(18), 159–179.

## ☐ RÉSUMÉ ☐

Des dépôts de terrasses marines clastiques siliceux, surélevés tectoniquement dominent le littoral de la province de Basilicate, tandis que plus à l'est le long de la péninsule tarentine, on rencontre davantage de calcaires fossilifères. Ces calcaires sont souvent superposés aux marges du bas profil de la plateforme carbonatée. On a utilisé une chronologie par les amino-acides (AAR) et des méthodes radiométriques pour dater et correler 14 secteurs littoraux sur 200 km du Golfe de Tarente. Ceci a été réalisé par calibration du rapport D-alloisoleucine/L-isoleucine (A/I) avec les datations U et $^{14}$C qui ont permis d'établir un âge absolu pour les transgressions marines, la formation des dunes et la pédogenèse. De plus, ces données définissent la nature de la réaction d'épimérisation vers un équilibre (A/I environ 1.30) pour *Helix* et *Glycymeris* aux échelles de temps de $10^3$, $10^5$, et $10^6$ ans.

On a finalement identifié cinq complexes littoraux (littoral, éolien, et unités de dépôt de pedogenèse). Deux des transgressions du milieu du Pleistocène sont correlées avec les aminozones F et G. L'aminozone H est associé à une troisième mais peu définie. Un complexe interglaciaire de la fin du Pléistocène est rattaché à deux aminozones. Le plus ancien, le E est constitué par des calcaires éparpillés, des éolianites et des sols minces; le plus récent, l'aminozone C, constitué par des calcarénites marines et des dunes, est moins fréquemment préservé. La phase holocène de dépôt (aminozone A) a été relativement active, comme l'indiquent de nombreuses séquences de plage, dunes et sols. La méthode des AAR permet de corréler des dépôts sur de grandes distances, de reconstituer des paléo-environnements, d'établir une histoire de la tectonique et d'estimer, dans le golfe de Tarente, l'âge de ces évènements.—*Catherine Bousquet-Bressolier, Géomorphologie E.P.H.E., Montrouge, France.*

## ☐ ZUSAMMENFASSUNG ☐

In der süditalienschen Provinz Basilicata setzen sich die tektonisch herausgehobenen marinen Terrassen der Küstenregion i.w. aus silikatisch-klastischem Material zusammen. In Richtung Osten, entlang der Halbinsel von Salentino, dominieren dagegen fossilhaltige authigene und biogene Kalksteine. Diese Kalksteinformationen liegen häufig den Rändern der unterlagernden Karbonatplattform auf. Mit Hilfe der Aminosäure-Razemisierungs-Altersbestimmungsmethode (engl. AAR abgekürzt) und anderen radiometrischen Methoden wurde die Datierung und Korrelation von vierzehn Küstenabschnitten an 200 Kilometern des Golfes von Tarent vorgenommen. Dies wurde erreicht durch die Kalibrierung des D-Alloisoleucin/L-Isoleucin-Verhältnisses (A/I) mit Ergebnissen der Thorium/Uran- und der Radiokohlenstoff-Datierung (Th-230/U-234 bzw. C-14). Anhand dieser absoluten Altersbestimmungsmethoden war es möglich, einen zeitlichen Rahmen für die Entstehungszeit der marinen Terrasen, der Dünen- und der Bodenbildung zu schaffen. Weiterhin liefern diese Daten eine genauere Kenntnis der Razemisierungsreaktion, die einem Gleichgewichtszustand der Aminosäuren (A/I von ca. 1.30) bei *Helix* und *Glycimeris* zustrebt (in Zeiträumen von $10^3$, $10^5$ und $10^6$ Jahren).

Es werden mindestens fünf Küstenlinien-Komplexe ausgegliedert, die sich aus Ablagerungseinheiten zusammensetzen und welche eine litorale, äolische und pedologische Genese haben können. Den sog. Aminozonen F und G werden zwei mittelpleistozäne Meerestransgressionen gleichgesetzt. Eine dritte Transgression, die nicht eindeutig abgegrenzt werden kann, muß wahrscheinlich der Aminozone H und ebenfalls dem Mittelpleistozän zugeordnet werden. Ein jungpleistozäner interglazialer Terrassenkomplex wird von zwei verschiedenen Aminozonen eingeklammert. Die ältere Formation, Aminozone E, besteht in großem Umfang aus Kalkstein, aus Äolianiten und einem dünnen Boden, während die jüngere Transgression, Aminozone C, weniger gut erhalten geblieben ist und zwar in Form von marinen Kalkareniten und Dünen. Die weitverbreiteten holozänen Ablagerungen (Aminozone A) sind durch zahlreiche Sequenzen von Stränden, Dünen und Böden repräsentiert.

Der Einsatz der Aminosäure-Razemisierungs-Alterbestimmgsmethode bewährt sich bei der Korrelation von litoralen Ablagerungen über große Entfernungen, der Rekonstruktion von paläoökologischen Verhältnissen, der Bestimmung der tektonischen Entwicklung und der Altersabschätzung dieser Ereignisse im Golf von Tarent.—*Ulrich Radtke, Geographisches Institut, Universität Düsseldorf, Germany.*

## ☐ RESUMEN ☐

Las áreas costeras de la provincia de Basilicata, se hallan dominadas por terrazas con depósitos marinos silicoclásticos tectónicamente elevadas, mientras que hacia el este a lo largo de la Península Salentine, lo más común son las calizas fosilíferas autígenas y biogénicas. Estas calizas normalmente se encuentras estratigráficamente superpuestas a lo largo de los márgenes de las plataformas de carbonatos de perfiles bajos. La geocronología de racemización de amino ácidos (AAR) y los métodos radiométricos fueron utilizados para fechar y correlacionar 14 secciones costeras a lo largo de 200 km en el Golfo de Taranto.

Esto fue realizado por medio de la calibración de la relación D/L, (A/I) con las series U y fechados de C-14 los cuales establecen una edad absoluta como marco de referencia para las trangresiones marinas, la formación de dunas y la pedogénesis. Además, estos datos definen la naturaleza de la reacción de epimerización cuando va hacia el equilibrio (A/I de ca. 1.30) para *Helix* y *Glycymeris* en escalas temporales de $10^3$, $10^5$, y $10^6$ años.

Se identificaron cinco costas complejas (litoral, eólica, unidades pedogénicas y deposicionales). Dos transgresiones del Pleistoceno medio son igualadas con Aminozonas F y G. La Aminozona H esta asociada con una tercera que es pobremente definida. Un complejo interglacial del Pleistoceno tardío se encuentra encerrado por dos aminozonas. La primera, Aminozona E, consiste de calizas dispersas, eolianitas y suelos delgados, mientras que la última, Aminozona C, se halla frecuentemente menos preservada como calcarenita marina y dunas. Sin embargo, la depositación durante el Holoceno (Aminozona A), fue activa como lo indican numerosas secuencias de playas, dunas y suelos.

El método AAR es útil para correlacionar depósitos costeros sobre grandes distancias, recostruyendo paleoambientes, estableciendo una historia tectónica, y estimando las edades de estos eventos en el Golfo de Taranto.—*Néstor W. Lanfredi, CIC-UNLP, La Plata, Argentina.*