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OSL DATING OF UPPER PLEISTOCENE LITTORAL SEDIMENTS: A CONTRIBUTION TO THE CHRONOSTRATIGRAPHY OF RAISED MARINE TERRACES BORDERING THE GULF OF TARANTO, SOUTH ITALY

ABSTRACT: ZANDER A., FÜLLING A., BRÜCKNER H. & MASTRONUZZI G., *OSL dating of Upper Pleistocene littoral sediments: a contribution to the chronostratigraphy of raised marine terraces bordering the Gulf of Taranto, South Italy*. (IT ISSN 1724-4757, 2006).

The lower three of a flight of raised marine terraces bordering the northern side of the Gulf of Taranto, close to Metaponto (Basilicata and Puglia, South Italy) were studied using optically stimulated luminescence (OSL) dating techniques plus sedimentological and mineralogical criteria. Deduced from geomorphological correlation and independent age control, these littoral deposits, reaching up to 60 m a.s.l., represent late Middle Pleistocene and early Upper Pleistocene coastlines. OSL dating was carried out using single aliquot regeneration (SAR) protocols on coarse grain quartz and potassium feldspars as well as multiple aliquot additive (MAA) protocols on coarse grain feldspar and polymineral fine grain samples. Results obtained by multiple and single aliquot techniques for feldspar and fine grain samples are in good agreement; however, they underestimate the expected age ranges significantly, by more than 25%. Age determinations exceeding 90 ka are not feasible. Nevertheless, fading tests carried out over a time span of 11 months gave no indication for instabilities of the feldspar signals. Age estimates obtained by SAR dating on coarse grain quartz exceed the feldspar dating limit. They reveal saturation doses between 150 and 200 Gy and accordingly show low reproducibility and large uncertainties. Feldspar results obtained for the youngest terraces T2 and T1, which are correlated with marine isotope stages (MIS) 5.5 and 5.1, respectively (cf. Brückner, 1980a), indicate an accumulation of the littoral marine sediments during the transition time from MIS 4 to MIS 3. OSL-dating terrace T3, correlated with MIS 7, rendered feldspar age estimates of MIS 5.1. The study shows that OSL dating of marine deposits is far from being a routine technique.

KEY WORDS: Marine terrace deposits, Sea-level changes, OSL age determination, Upper Pleistocene, Gulf of Taranto, Italy.

RIASSUNTO: ZANDER A., FÜLLING A., BRÜCKNER H. & MASTRONUZZI G., *Datazione OSL di sedimenti llitorali del Pleistocene Superiore: un contributo alla cronostratigrafia dei terrazzi marini del Golfo di Taranto (Italia Meridionale)*. (IT ISSN 1724-4757, 2006).

La fascia costiera ionica della Basilicata e della Puglia occidentale (Italia meridionale) è nota per conservare estesi depositi attribuiti ad ambienti costieri, testimoni di fasi di relativo alto stazionamento del livello del mare nel corso del Pleistocene. Dall'interazione di questi stazionamenti e del sollevamento regionale è risultato un paesaggio caratterizzato da una successione digradante verso mare di superfici terrazzate a partire dalla quota di circa 400m. Alle superfici terrazzate corrispondono corpi sedimentari di ambiente costiero di transizione, tipici di ambienti di spiaggia, duna, stagni retrodunari e piane costiere; sono rappresentati da successioni di sabbie, limi e ciottoli essenzialmente di natura terrigena, spesso coperti da depositi continentali. Rari sono i depositi francamente marini; proprio in questi, nell'area più prossima all'avampaese pugliese, con superficie posta a circa 45 m s.l.m., è stata rinvenuta una fauna senegalese a *Strombus bubonius* che, seppur non in deposizione primaria, permette di inquadrare cronologicamente l'accumulo del deposito in un intervallo temporale non più antico del MIS 5.5.

I tre corpi sedimentari più bassi in quota, corrispondenti alle più basse superfici della gradinata, sono state oggetto di uno studio sedimentologico e mineralogico e di datazioni con il metodo della luminescenza ottica stimolata (OSL). In base a correlazioni geomorfologiche questi depositi litorali corrispondono a linee di costa del tardo Pleistocene medio e del primo Pleistocene superiore. Le analisi OSL sono state effettuate appli-

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cando il *single aliquot regeneration protocols* su sabbie quarzose e feldspato-potassiche grossolane e quello di *multiple aliquot additive protocols* su sabbie feldspatiche grossolane e su campioni di sabbie fini polimineraliche. I risultati delle analisi effettuate su sabbie feldspatiche e su campioni di sabbie fini polimineraliche sembrano essere in buon accordo; comunque esse sottostimano l'età attesa almeno del 25% cosi che età più antiche di 90ka non sono attendibili. *Fading test* effettuati in un intervallo di tempo di circa 11 mesi non hanno fornito indicazioni di instabilità del segnale dei feldspati. Le età SAR stimate ottenute su sabbie quarzose superano il limite dii datazione dei feldspati. Le dosi di saturazione rilevate sono comprese fra 150 e 200 Gy e rivelano pertanto bassa riproducibilità e larga incertezza delle datazioni. I risultati ottenuti su feldspati dei depositi dei terrazzi più bassi in quota (T2 e T1), già correlati con i depositi del MIS 5.5 e del MIS 5.1, indicano l'accumulo dei depositi litorali fra il MIS 4 e il MIS 3. La datazione OSL dei depositi del terrazzo T3, già correlato con il MIS 7, suggerirebbe un'età stimata corrispondente al MIS 5.1. Queste attribuzioni cronologiche sono in contrasto con le evidenze stratigrafiche e paleontologiche e sottolineano una scarsa verosimiglianza del modello da esse derivato.

TERMINI CHIAVE: Depositi marini terrazzati, Variazioni del livello del mare, Datazioni OSL, Pleistocene superiore, Golfo di Taranto, Italia.

INTRODUCTION

The raised marine terraces along the northern coast of the Gulf of Taranto (Ionian Sea) in South Italy (fig. 1) are remarkably well preserved and bear witness to complex environmental change and landscape development. Glacio-eustatic sea-level fluctuations, tectonic uplift and continental morphodynamic processes were involved in their morphogenesis. The terrace edges are generally interpreted as paleocliffs, created by former sea-level highstands (e.g. Boenzi & *alii*, 1976; Brückner, 1980a; Boenzi & *alii*, 1985; Dai Pra & Hearty, 1988; Hearty & Dai Pra, 1992; Ferranti & *alii*, 2006). The terrace surfaces were shaped during regression phases (Brückner, 1980a, b; Sunamura, 1992) and are often covered by aeolian and colluvial sediments (Carobene, 1981, 2003; Palmentola & *alii*, 1990; Amato & *alii*, 1997).

The Metaponto flight of marine terraces is part of the Apennine Chain, located at the Gulf of Taranto between the Apulian foreland and the Northern Calabrian mountains. It rises from sea level up to 400 m a.s.l. (= above present mean sea level) in mega-steps comparable to a giant theatre in Antiquity. Both the basement of the Pleistocene marine terraces and the Lucanian mountains northwest of the Metaponto area are characterized by sand and silt sediments of the Apennine molasse basin which were deposited in the Plio-Calabrian Sea (Bradanian trench). The Metaponto area, between Taranto in the northeast and Rocca Imperiale in the southwest, stretches over a distance of approximately 80 km with a width of about 25 km. Its genesis was studied intensively by Fuchs (1874), Gignoux (1911a, b, 1913), Selli (1962), Mostardini & *alii* (1966), Cotecchia & Magri (1967), Vezzani (1967), Fuchs & Semmel (1974), Fuchs (1980), Boenzi & *alii* (1976, 1985), Brückner (1980a, b; 1982a, b; 1983), Dai Pra & Hearty (1988), Hearty & Dai Pra (1992), Amato & *alii* (1997) &

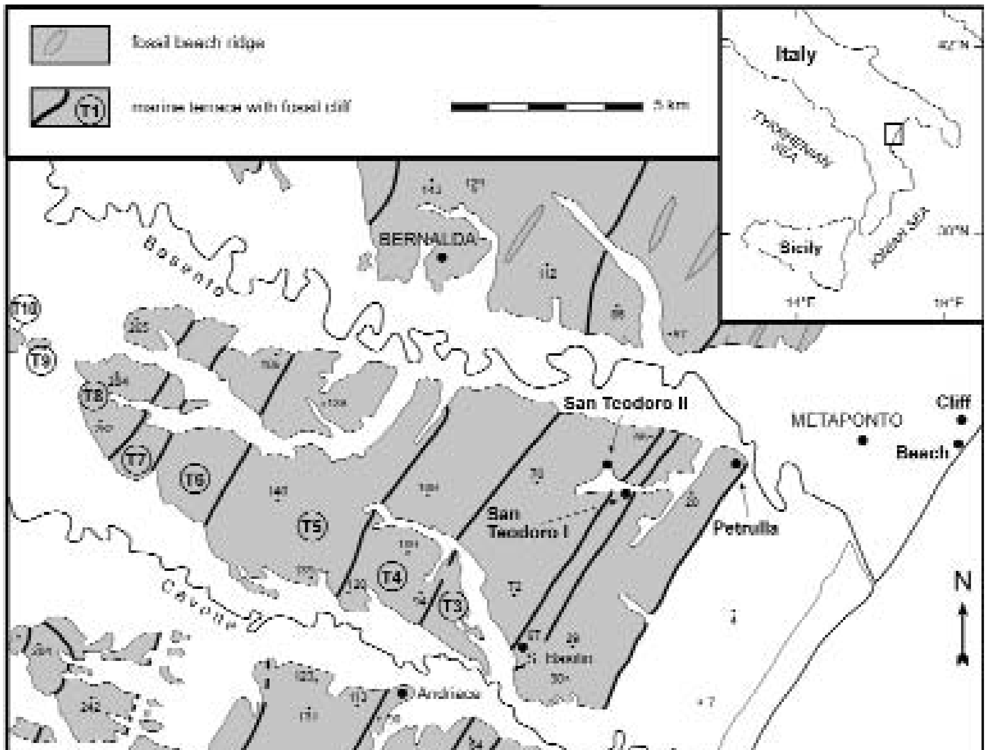


FIG. 1 - Map of the Metaponto coastal plain and the Pleistocene marine terrace flight T1-T10, as described and stratified by Brückner (1980a). Black circles mark the position of the discussed profiles Petrulla, San Teodoro I and San Teodoro II, as well as the locations of the «modern» samples from the beach and today's cliff close to Metaponto (modified after Brückner, 1980a: Supplement I).

Amato (2000). These authors described the effects of the combination of regional uplift and glacio-eustatic sea level changes during the Middle and Upper Pleistocene.

More recently, Bentivenga & *alii* (2004) suggested a different origin for the central part of the terrace sequences in Basilicata (formerly Lucania): (i) the conglomeratic-sandy body of the lowermost deposits refers to only one sedimentary event; and (ii) the flight of terrace surfaces is developed by faults related to large-scale gravitational processes. However, the authors lack an explanation for the development of the marine terraces both on the northeastern side of the studied area and on the Ionian side of the Apulian foreland where the terrace deposits are characterised by differences in faunal assemblage (e.g. Boenzi & *alii*, 1985; Caldara, 1987; Caldara & Laviano, 1980). Their interpretation also fails to explain significant differences in pedogenesis of the capping sediments (soil evolution and weathering intensity increase with altitude), and the correlation to the staircase of fluvial terraces being associated with the marine terraces (cf. Brückner, 1980b).

In the Mediterranean region, MIS 5.5 (= OIS 5e) deposits are marked by the occurrence of a Senegalese fauna. It immigrated from the west African coast into the Mediterranean Sea during the last interglacial period (formerly called «Tyrrhenian»; cf. Gignoux, 1911a, b; Issel, 1914; Dépéret, 1918; Bonifay & Mars, 1959); it is often associated with *Strombus bubonius*, a gastropod species. This key fossil was found in terrace sequences of Reggio Calabria (Bonfiglio, 1972) (highest occurrence at 157 m a.s.l.; Dumas & *alii*, 1987), near Crotone (84-25 m a.s.l.; Selli, 1962; Palmentola & *alii*, 1990) and around Mare Piccolo close to Taranto (12-0 m a.s.l.; Cotecchia & *alii*, 1969; Dai Pra & Stearns, 1977). In the proximity of the investigated area, Boenzi & *alii* (1985) and Caldara (1987) found *Strombus bubonius* and other species of Senegalese fauna at the eastern embankment of the Fiume Lato at 40 m a.s.l.

Research on dating littoral sediments in South Italy and on their correlation with marine oxygen isotope stages has noticeably expanded (Brückner, 1980a; Dumas & *alii*, 1988; Carobene & Dai Pra, 1990; Hearty & Dai Pra, 1992; Westaway, 1993; Amato & *alii*, 1997; Bordoni & Valensise, 1998; Cucci, 2004). Therefore, it is feasible to draw conclusions from the sedimentation history and chronology as well as from the altitude of cliff levels in order to establish models for tectonic uplift and displacement (Palmentola & *alii*, 1990; Dumas & *alii*, 1993; Bartolini & Carobene, 1996; Cucci & Cinti, 1998; Bordoni & Valensise, 1998; Amato, 2000). Apart from geomorphologic and biostratigraphic correlations (Brückner, 1980a; Dai Pra & Hearty, 1988), dating the terraces was mainly performed by uranium series (Dai Pra & Stearns, 1977; Brückner, 1980a; Hearty & Dai Pra, 1985, 1992; Hearty, 1986; Belluomini & *alii*, 2002) and amino-acid-racemisation analysis (Hearty & Dai Pra, 1985, 1992; Hearty & *alii*, 1986; Hearty, 1986; Dumas & Raffy, 1996; Amato & *alii*, 1997; Belluomini & *alii*, 2002; Cucci, 2004).

First dating attempts on littoral sediments from South Italy with thermoluminescence (TL) led in part to substantial age underestimations (Balescu & *alii*, 1991; Balescu & Lamothe, 1992). Considering biostratigraphic evidence, the dating results achieved by thermoluminescence (TL) and optically stimulated luminescence (OSL) on different beach terraces did not agree with expected age ranges (Balescu & *alii*, 1991; Mauz, 1999; Mauz & Hassler, 2000). Most show a general trend to age underestimations, which are assumed to derive on the one hand from signal instabilities of the 410 nm IR feldspar emission and on the other hand from saturation effects due to high sediment dose rates. Nevertheless, some dating results obtained by Mauz & Hassler (2000) in Crotone Peninsula, not far from the area studied in this paper, are encouraging. They allow chronological distinction of terrace levels which formed during the last interglacial/glacial cycle.

In this research, the three youngest fossil marine terraces, T1-T3 *sensu* Brückner (1980a), were investigated in the section between the rivers Basento and Cavone. Stratigraphic and chronologic aspects of the profiles Petrulla, San Teodoro I and San Teodoro II were studied in order to provide new geochronological data and to make new geomorphological and geochronological correlations with nearby areas.

Seventeen samples were taken for luminescence dating and accompanying analyses such as grain size and x-ray diffraction. The mineralogical composition of the sediments was of particular interest in that volcanic feldspars may have complex dating properties.

THE FLIGHT OF MARINE TERRACES

The staircase of marine terraces of the Metapontino is composed of sand and gravel layers. The terraces are attributed to different sea-level highstands which have occurred since the Middle Pleistocene. The diachronous filling of the Bradanic trench ranges from the Early Pleistocene in the northern part to the Middle Pleistocene in the Irsina area (Pieri & *alii*, 1996). The chronology of the filling is based on tephra from the Monte Vulture volcano, which was active from Middle to Upper Pleistocene times (De Marco, 1990). Reconstructing the original morphology of the raised terrace surfaces and the number of former sea-level stands is difficult due to the later terrestrial morphodynamic processes. Tectonic uplift, fluvial erosion, and deposition of alluvium/colluvium on top of the marine record have altered and masked the former geomorphology. Hence, the number of terraces given in literature ranges from 7 to 11.

The lowermost part of each marine sedimentary sequence is characterized by a distinct disconformity indicating the marine transgression developed on the Argille Subappennine (Subapenninic clays) formation of the Bradanic trench (Brückner, 1980a, 1983). The basal part of the marine strata mainly consists of homogeneous fine sand with sparse intercalated gravel horizons (Cb = lithofacies of the transgressive basal conglomerate *sensu* Carobene, 2003). This terrace base continues upwards with generally coarser sediments of the main gravel layer formed in a littoral environment during high sea stand or regression. It is usually covered by or interbedded with shallow marine to lagoonal and fluvial deposits (Carobene, 2003).

Glacio-eustatic sea-level fluctuations during Quaternary are a major factor for the development of marine terraces. Their interference with continuous tectonic uplift has created the marine terrace flight in the Metaponto area (Brückner, 1980a, 1983) and led to the described structure of the marine terrace sequence. The sediment accumulation cycle starts with the slow submergence of the former beach and terminates with a second beach formed during the subsequent regression. In the interum, sands and pebbles are continuously deposited. Cliffs are formed rapidly by erosion during the active transgression and more slowly during transgression peaks. Hence, they specify the morphologic age of the subsequent lower terrace level (Brückner, 1983; Dumas & Raffy in this volume).

Many of the former studies of the Metaponto area dated marine fossils in order to correlate paleo-coastlines with sea-level highstands and to determine uplift rates (e.g. Brückner, 1980a; Dai Pra & Harty, 1988; Amato & *alii*, 1997). Triggered by the tectonic uplift of the Calabrian Apennines, uplift rates in the terraced coastal area decrease from about 1.6 m/ka in the southwest to 0.23 m/ka in the Taranto area (Brückner, 1980a; Bartolini & Carobene, 1996; Dai Pra & Hearty, 1988; Bordoni & Valensise, 1998; Amato & *alii*, 1997; Belluomini & *alii*, 2002). The rates reach 0.4-0.5 m/ka for terraces T1-T3 in the study area (Brückner, 1980a: tab. 17). The tectonic influence of the Apennine orogeny diminishes towards the Bradanian trench fault, the main folding front running between the Basento and Cavone rivers (Ambrosetti & *alii*, 1983).

Near the village of San Nicola, the coastline of the last interglacial transgression maximum (MIS 5.5) was identified between 125 and 90 m a.s.l. (Hearty & Dai Pra, 1992). In the same area, Hearty (1986) found *Glycymeris* sp. remains at an altitude of about 35-45 m a.s.l. which gave an Aile/Ile ratio of 0.29. These can be correlated with the Aminozone C and the shoreline complex II of Hearty & Dai Pra (1992), corresponding with MIS 5.1. Controversial data resulted from Amato & *alii* (1997). Using Aile/Ile analyses on *Glycymeris* sp. they correlated deposits ascribed to MIS 5.3 /MIS 5.5 to an abrasion platform at 100-114 and deposits ascribed to MIS 5.1/MIS 5.3 to an abrasion platform at 107-123 m a.s.l.

On the left bank of Cavone River, the tectonic influence decreases so that the MIS 5.5 terrace level reaches only 50 m a.s.l. (Dai Pra & Hearty, 1988; see also Brückner, 1980a: tab. 17). In the northeastern Metapontino, close to Ponte del Re, a terrace surface at about 40 m a.s.l. is correlated with the MIS 5.5 coastline due to the occurrence of *Strombus bubonius* in a *non in situ* mixed fossil assemblage with tropical character (Boenzi & *alii*, 1985; Caldara, 1987). Aile/Ile ratios on *Glycymeris* sp., *Anadara* sp. and *Arca* sp. indicate Aminozone E and MIS 5.5 (Hearty & Dai Pra, 1992). Another raised marine terrace linked with MIS 5.5 was identified in the northern Metapontino close to the city of Taranto. This area is adjacent to the relatively stable Apulian platform and thus is characterized by a comparably small tectonic uplift of about 0.23 m/ka (Bartolini & Carobene, 1996; Belluomini & *alii*, 2002). Here, sediments related to MIS 5.5 based on *S. bubonius* finds and a Th/U-dated coral specimen (*Cladocora caespitosa*) occur at about 37-10 m a.s.l. (Mastronuzzi & Sansò, 2003).

Since the first geomorphologic study conducted by Boenzi & *alii* (1976), the marine terraces have been studied in detail and synthesised in geomorphological and geological maps by Brückner (1980a). According to his chronostratigraphy, deposition of the T2 gravel is correlated with the last interglacial transgression maximum (MIS 5.5). A few Th/U dating results point to an early last glacial accumulation for the subsequent lower T1 terrace, hence correlated with MIS 5.1.

The sedimentologic and petrographic composition of the T3 terrace differs considerably from the T1/T2-terrace cycle. The cap of the T3 terrace bears a reddish-brown palaeosol, suggesting a much longer soil forming process than on terraces T2 and T1. In consequence T3 gravel and fine grain terrestrial cover sediments were deposited during the penultimate interglacial period (MIS 7; Brückner, 1980a).

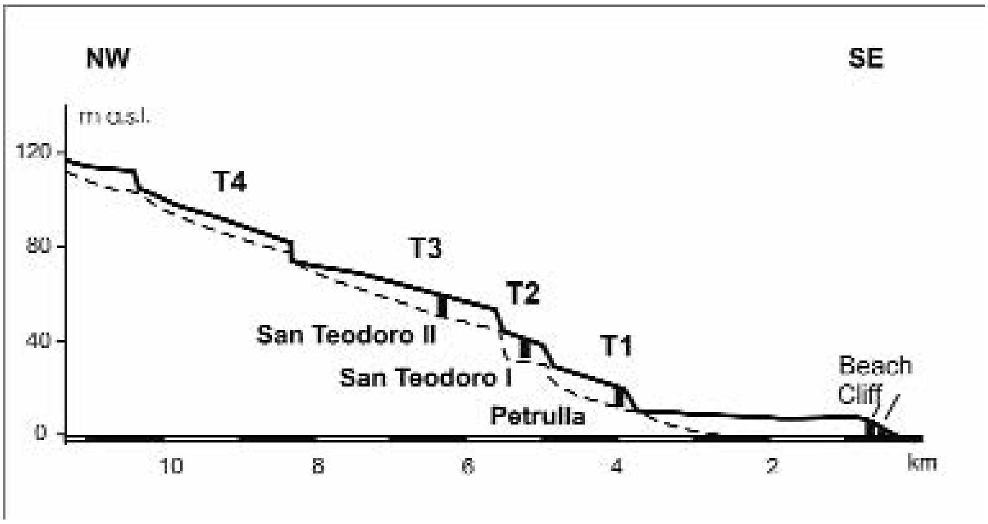
TERRACE STRATIGRAPHY AND SITE DESCRIPTION

In the study area, three geological profiles were investigated within terraces T1-T3: Petrulla, San Teodoro I and San Teodoro II (fig. 1). The first profile (E 16° 46' 40'' / N 40° 21' 58'', figs. 3 and 10) is located 3.5 km west of Metaponto village, above the right bank of the Basento River where the terrace surface T1 reaches 22 m a.s.l. (see also fig. 2). Seven samples were taken from the sandy terrace deposits for luminescence dating, four from the fine grained cover sediments (Terrace cover sediments = Tcs, corresponding to Ss and Cc *sensu* Carobene, 2003) and three from the main gravel layer (Marine terrace sedimentary body = MTsbd, corresponding to Si, Ags and Pds *sensu* Carobene, 2003) and the underlying sandy terrace base (Marine Terrace sediment base = MTsb, corresponding to Cb *sensu* Carobene, 2003).

Close to San Teodoro, a few kilometres west of Petrulla, two more massive gravel deposits are exposed in the bank of a Basento tributary. Two profiles were sampled in the gravel deposits at 42 m a.s.l. (T2) and 60 m a.s.l. (T3). Five samples each were taken from San Teodoro I (E 16° 44' 41'' / N 40° 21' 26'', fig. 12) and San Teodoro II (E 16° 44' 23'' / N 40° 21' 58'', fig. 13) for luminescence dating and further analyses.

The lower part (MTsb) in all three sections is dominated by fine to medium well sorted sand (fig. 5). Inorganic calcareous particles and small fragments of marine mollusc shells are abundant in the fine grained sand of the terrace base, indicating a shallow marine or sublittoral depositional environment at a water depth of at least a few meters. In the upper part of the terrace base, small intercalated gravel horizons indicate the influence of the shoreline and reduced water depth. In the Petrulla locality, the terrace

FIG. 2 - Schematic sketch of the Middle and Upper Pleistocene marine terrace flight of the Metapontino coastal plain showing altitude and location of the investigated terrace profiles and sample locations from the beach and the cliff.



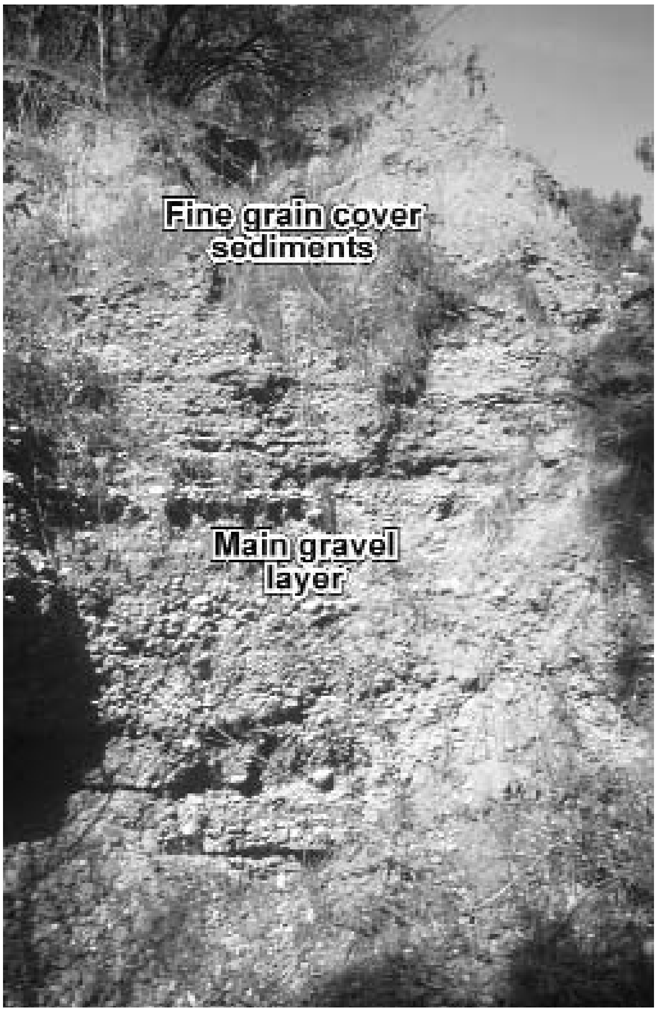


FIG. 3 - Main gravel layer (Marine terrace sedimentary body = MTsbd-1, corresponding to the Italian nomenclature Si, Ags, Pds of Carobene, 2003) and terrace cover sediments (Terrace cover sediments = Tcs-1 corresponding to Ss and Cc of Carobene, 2003) from Petrulla, marine terrace T1.

base is capped by the main gravel layer (MTsbd) at 6.50-2.00 m below surface (b.s.) (fig. 3). Flattened pebbles and boulders are imbricated – an evidence of deposition in an eulittoral environment. Disarticulated but well preserved mollusc valves (*Cerastoderma* sp. and *Glycymeris* sp.) confirming the proximity of a sublittoral environment occur at the localities Petrulla (ca. 2.30 m b.s., fig. 10) and San Teodoro II (ca. 3.50 m b.s., fig. 12). The matrix of the littoral sediment records (MTsb and MTSbd) mainly consists of well to fairly sorted fine to medium sand (fig. 5).

The main gravel layer is covered by up to 3.50 m thick loamy-sandy sediments of reddish to dark-brown colour (figs. 3 and 10). These cover sediments (Tcs) often contain thin gravel horizons or isolated pebbles in their lower part. Fuchs & Semmel (1974) described this loamy facies on terrace T1 as «loess-like». Brückner (1980a) interpreted the cover sediments as (i) lagoonal facies deposited during marine regression as indicated by the occurrence of foraminifera, and (ii) fluvial sediment derived from the Lucanian Mountains as indicated by granulometry. However, an aeolian component could also be present.

These cap sediments exhibit a poor sorting. They show comparatively high silt content and hence an infralittoral sedimentation environment is unlikely. Silt and clay contents from 10 to over 20% suggest a post-sedimentary enrichment of clay and silt due to soil formation processes on top of the terraces. Pedogenic properties, as observed in the Petrulla profile, support this assumption. However, an additional aeolian contribution is also likely. Concerning granulometry, figure 8 shows a clustering of the terrace cap sediments and positive inclination in comparison to the samples from the underlying littoral sand (after Folk & Ward, 1957).

The fine grained cap sediments at Petrulla reveal a very special feature: their lower part between 1.70-2.15 m b.s. is interspersed with well rounded terrace gravel in a mainly horizontal adjustment; but, some pebbles show a vertical adjustment of their longitudinal axis in the fine grained

FIG. 4 - Detail from the lower part of the fine grained cover sediments between 1.70-2.15 m b.s. on top of the T1 main gravel layer. The vertical orientation of some pebbles in this horizon was probably induced by temporary frost action during the last glacial maximum in MIS 2.

matrix (cf. fig. 4). The vertical texture of the pebbles obviously occurred after deposition and probably was induced by frost action during the last glacial maximum (LGM). The palaeoclimate record derived from lacustrine sediments of the Lago Grande di Monticchio, a maar lake in the Monte Vulture volcano about 100 km northeast of Taranto, shows a significant climate depression during MIS 2 for southern Italy. This demonstrates that the northern Hemisphere climate system extended its influence as far as the central Mediterranean (Allen & *alii*, 2000). Pollen assemblages indicate predominant steppe vegetation with only small patches of woodlands or scrubs (Allen & Huntley, 2000). The proxy data for MIS 2 predicts oscillations between approximately 0 °C and -12 °C for mean temperature of the coldest month. Even if distinct periglacial conditions with permafrost are not very likely in southern Italy, the data from this climate archive suggest strong frost periods during LGM. The overlying fine-grain cover sediments show no frost features, although a deposition during MIS 2 is very likely.

X-RAY DIFFRACTION ANALYSIS

A detailed characterisation of the sedimentary feldspars used for luminescence dating is necessary in regard to volcanic activity in southern Italy and the catchment areas of the sections. Some feldspars are inclined to fading (i.e. a signal loss that occurs without supplying stimulation energy), which leads to significant age underestimations. This phenomenon was first described by Wintle (1973) in relationship with TL measurements of different minerals of volcanic origin. Spooner (1992, 1994) accomplished intensive investigation of the IRSL signal loss from feldspars, thereby proving that particularly sanidine is affected by the fading phenomenon. However, IRSL signal intensity of sanidine minerals is comparatively small (Spooner, 1992; Wintle, 1994). In combination with other potassium feldspar minerals, sanidine's share and influence on the total feld-spars signal is normally negligible. If, however, sanidine minerals are predominant among the feldspars, they may dominate the feldspar luminescence signal. It is therefore crucial to check the sediment samples for their sanidine content.

Sanidine, a high temperature modification of potassium feldspar $K[AlSi_3O_8]$, occurs in volcanic rocks such as trachyte and basalt; whereas, orthoclase and the low temperature modification microcline are rock-forming in granites and pegmatites. A manual separation of sanidine and other potassium feldspar varieties by sodiumpolytungstate or any other density separation technique is not possible because of the very similar densities of feldspar varieties (around 2.55 g cm^{-3}).

Qualitative x-ray diffraction analysis was carried out in the range 4-70° (2-Theta). Bulk samples show a homogeneous mineral composition of the marine terrace sand. Quartz, albite, members of the potassium feldspar family and calcium carbonate are the most frequent minerals. Some samples contain additional dolomite, muscovite and kaolinite. Two samples from Petrulla and San Teodoro were chosen for checking the specific feldspar varieties. They were separated by heavy liquid and analysed in the range of 20-40° (2-Theta) (fig. 9).

The x-ray diffraction spectra enabled a clear identification of microcline and albite and a less clear identification of orthoclase. The alignment of three independent sanidine lines, obtained from sanidine minerals from the Drachenfels (Germany), reveals a fairly good agreement with the sanidine peak (d = 3.225); but other mineral-typical peaks are missing. Due to the mixed crystal character

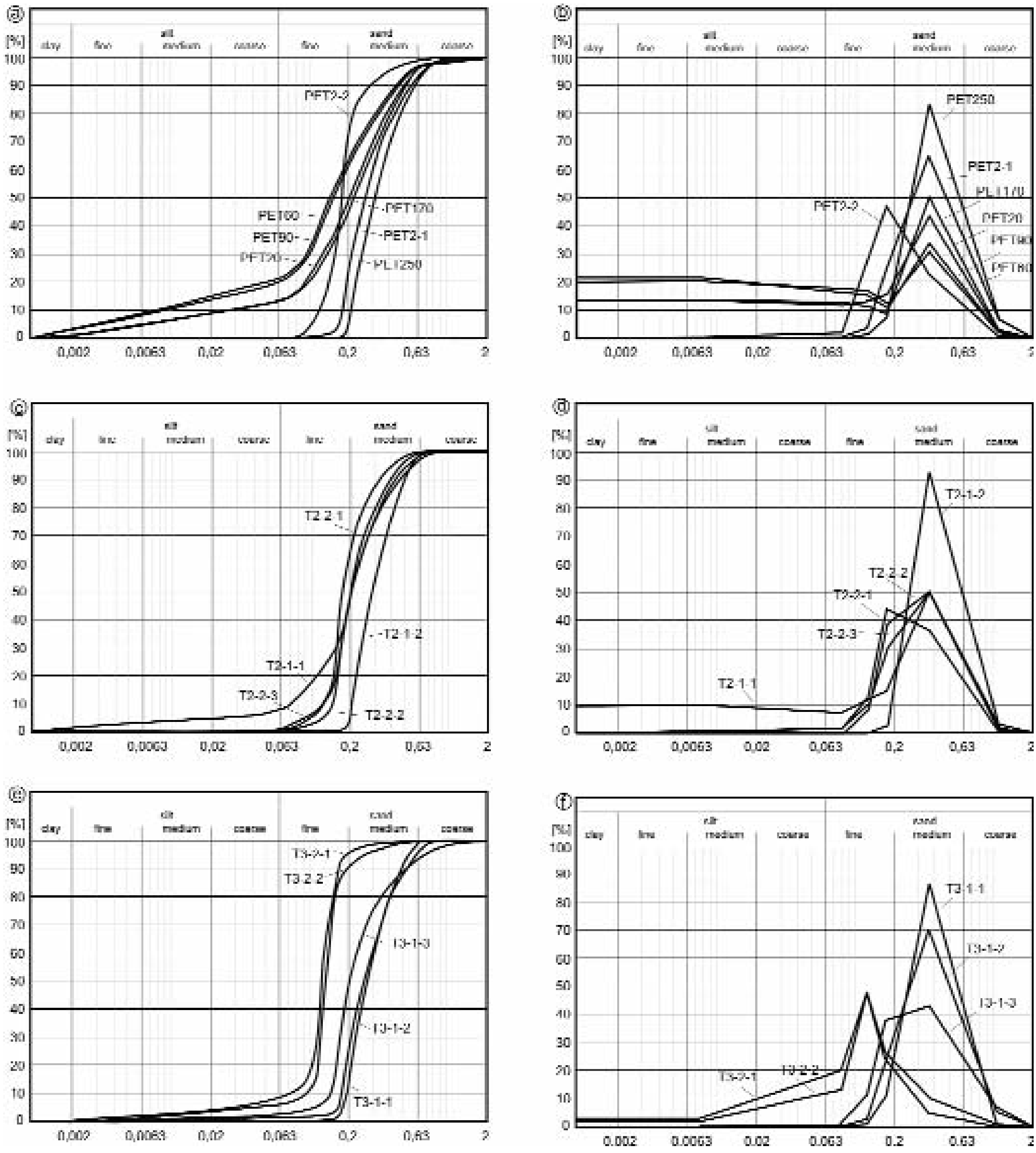


FIG. 5 - Grain size distribution and cumulated grain size curves of samples used for dating from Petrulla (top), San Teodoro I (middle) and San Teodoro II (below).

FIG. 6 - Upper part of San Teodoro I (T2) profile. 60-70 cm thick fine grain cover sediments (Tcs-2 or Ss and Cc) overlie the main gravel layer of terrace T2 (MTsbd-2 or Si, Ags and Pds). Scale: 1.50 m.

of the feldspar family, the main peaks of sanidine and microcline intersect; whereby, a reliable identification and quantification of sanidine in the feldspar fraction is rarely possible. Therefore, a minor sanidine content in our samples cannot be excluded. However, due to the low luminescence intensity characteristic of sanidine and the abundant occurrence of orthoclase, a negative influence on the feldspar IRSL signal is unlikely.

In addition, the x-ray diffraction analysis indicated an excellent mineral separation by density. Besides potassium feldspars, albite from the plagioclase mixed crystal series and quartz are verifiable in the samples. The ubiquitous mineral quartz has a wide density range and cannot be completely removed from the feldspar fraction by density separation. However, quartz has no IRSL signal; hence, it does not affect the feldspar luminescence signal. If heavy liquid of 2.58 g cm^{-3} is used, small quantities of albite (2.61-2.77 g cm^{-3}) within the potassium feldspar samples cannot be avoided because of density variations (2.55 g cm^{-3} for potassium feldspars). This contamination leads to

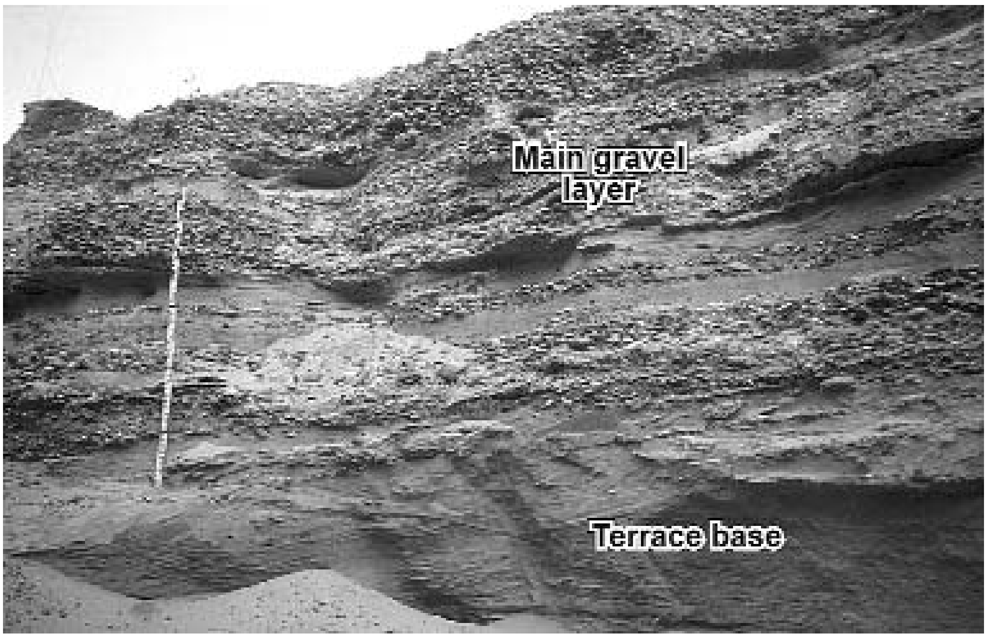
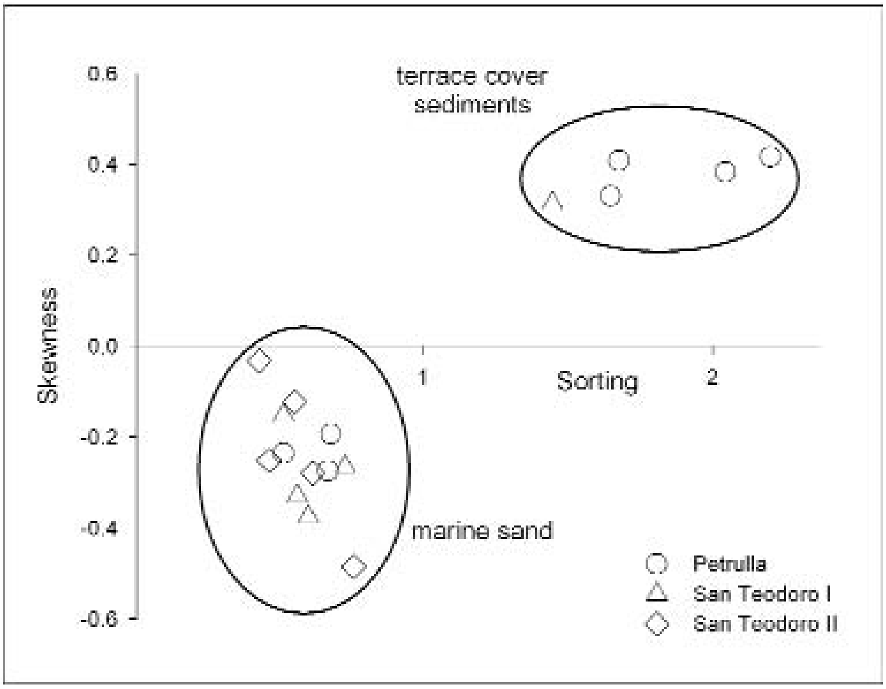


FIG. 7 - Lower part of the San Teodoro I (T2) section. Main gravel layer (MTsbd-2 or Si, Ags and Pds) on top of sandy terrace base (MTsb or Cb). Scale: 1.50 m.

FIG. 8 - Sorting and skewness calculations from the Metapontino using the equations of Folk & Ward (1957). The distributions show a distinct grain size differentiation between the terrace cover sediments on the one hand, and the marine sand extracted from the main gravel layer and the terrace base of the three profiles on the other.



difficulties because of problematic dating properties of the sodium feldspars (Clarke & Rendell, 1997).

LUMINESCENCE DATING

a - *Introduction*

Luminescence dating techniques determine the time of the last exposure of sediments to light (Aitken, 1998; Duller, 1995, 1996; Prescott & Robertson, 1997; Stokes, 1999; Wintle, 1993, 1997). It is an implicit assumption of the dating method that during sediment erosion, transportation and deposition every latent luminescence signal is substantially removed. Incomplete bleaching of sediments leads to age overestimation. As demonstrated by Godfrey-Smith & *alii* (1988), OSL signals are depleted after few minutes of sunlight exposure.

In fluvial or littoral environments the water absorbs a considerable portion of the light spectrum; hence, subaquatic bleaching of the natural luminescence signal takes more time. The time for a complete bleaching depends on turbulence, thickness of water column and concentration

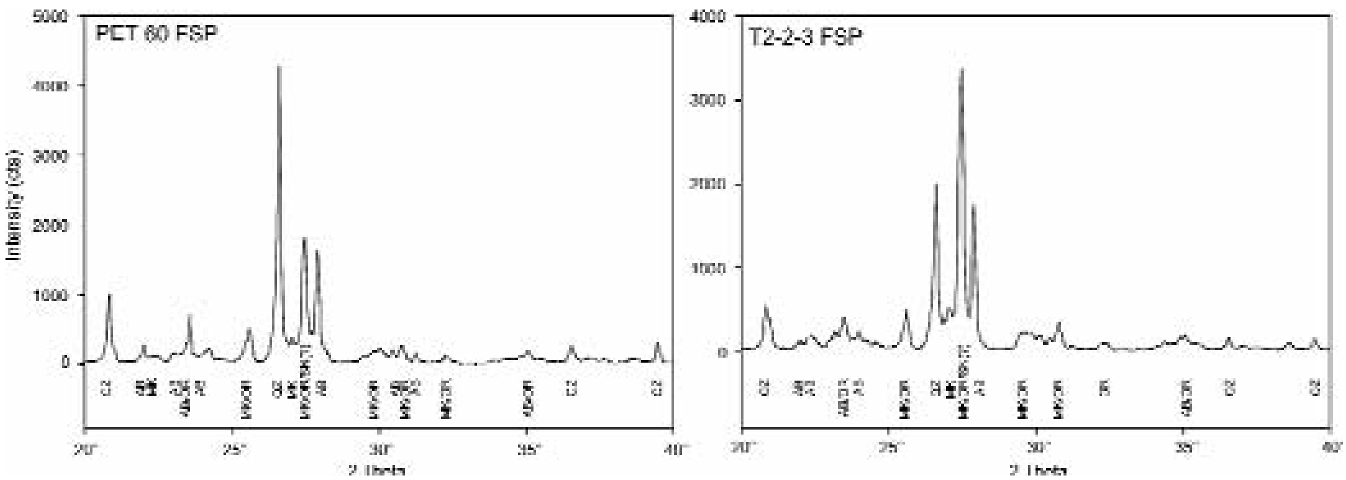


FIG. 9 - X-ray diffraction analysis of potassium feldspar samples extracted from Petrulla (left) and San Teodoro I (right). QZ = quartz, AB = albite, MK = microcline, OR = orthoclase, SN = sanidine.

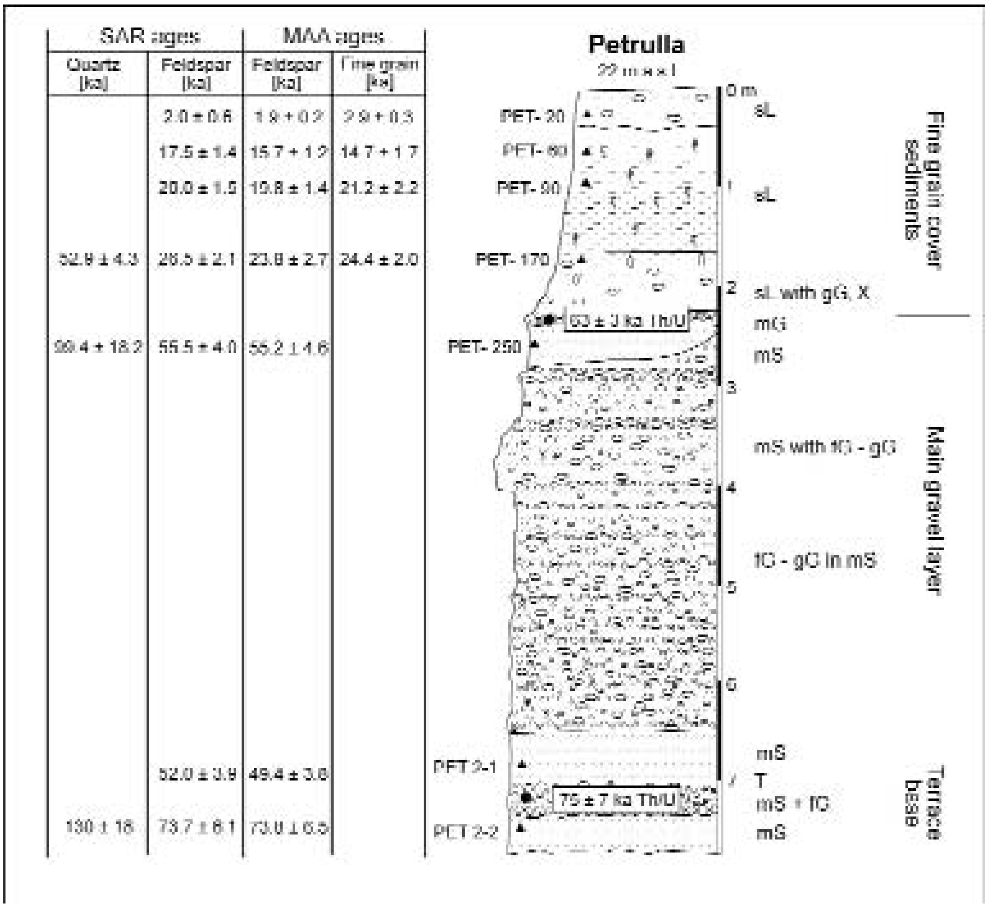


FIG. 10 - Petrulla profile from terrace level T1. Luminescence age estimates are given for quartz, feldspar and fine grain samples in kiloyears (ka). SAR = single aliquot regeneration protocol, MAA = multiple aliquot additive protocol.

of suspended material (Ditlefsen, 1992). A scan for the degree of bleaching of littoral sediments can to some extent be made by dating modern material from similar sedimentary settings. If samples from the present coastal sandbar provide very recent age estimates or even zero ages, they may serve as evidence that sediments from older coastal sandbars were likewise sufficiently bleached. To verify this assumption for the given case, two samples were taken from the current beach a few meters from the shoreline and from the modern cliff northeast of Metaponto.

b - Laboratory procedures and measuring protocols

Luminescence sample preparation was carried out under subdued red light (610 ± 45 nm) after Zimmermann (1971) and Frechen & *alii* (1996). Carbonates and organic components were removed by hydrochloric acid (10% and 35%, respectively) and hydrogen peroxide (30%). Subsamples for coarse grain dating preparation were first wet sieved (63-150 µm, 100-200 µm and/or 200-250 µm) and then submitted to the same chemical treatment. Sodiumpolytungstate solutions of densities 2.62 g cm^{-3} and 2.70 g cm^{-3} were used for quartz separation and 2.58 g cm^{-3} for feldspar separation. Thereafter, the quartz fraction was etched by hydrofluoric acid (40%) for 40 min and sieved again to remove remaining feld-spar and smaller quartz fragments. An IR test was run on all samples to prove purity (Short & Huntley, 1992; Stokes, 1992).

Determination of the equivalent doses (D_e) were accomplished by multiple aliquot additive procedures (MAA) on fine grain samples and a single aliquot regeneration protocol (SAR) on coarse grain quartz and feldspar (after Murray & Wintle, 2000; Wallinga & *alii*, 2000a). Infra-red stimulated luminescence dating (IRSL) was used for feldspar and polymineral fine grain samples (4-11 µm), and green light stimulated luminescence (GLSL) for quartz dating. All measurements were carried out on a Risø TL/OSL DA 15-reader at the Marburg Luminescence Laboratory (Faculty of Geography, University of Marburg), with integrated IR diodes (880 ± 80 nm) and a filtered halogen bulb (420-550 nm) for green light stimulation. The detection spectrum for IRSL measurements was defined by a filter combination of BG3, GG400 and BG39, allowing a transmission of 390-450 nm. GLSL measurements were carried out using a filter combination of Hoya U340 and HA3 enabling detection from 300-380 nm.

Polymineral fine grain samples and coarse grain feldspar samples were measured by MAA protocol. After a short IR stimulation (0.3 s IR) for normalisation, 8 subsets with 5 aliquots each were gradually beta irradiated to a maximum of 800 Gy. Natural luminescence was determined from 8 aliquots. After 4 weeks storing at ambient temperature the samples were preheated in the Risø reader for 5 min at 220 °C and IRSL was recorded for 100 s. After background subtraction (90-100 s) equivalent doses were determined using the maximum integral which was defined over the stable D_e plateau.

Single aliquot dating was accomplished using a modified SAR protocol after Murray & Wintle (2000) for quartz and an adapted protocol for feldspars after Wallinga & *alii* (2000a). Natural samples and regenerated cycles were preheated at 290 °C for 10 s and subsequently measured 100 s at 125 °C (quartz) and 200 s at 50 °C (feldspar), respectively. Test dose cycles were heated to 160 °C (quartz) and 210 °C (feldspar). After background subtraction, equivalent doses were determined, integrating the first 0.8 s of the shine down curves.

Fading tests at feldspar and fine grain samples were accomplished following Godfrey-Smith (1994), yielding no evidence for fading. A long time fading experiment over a period of 11 months was accomplished on 2 feldspar samples from San Teodoro I and II (T2-2-2 and T3-2-2). Ten aliquots of each sample were prepared and five of them irradiated with a 115 Gy beta dose in January 2001. Subsequently, all aliquots were stored at ambient temperature for 11 months. The five remaining natural aliquots were then irradiated with the same dose and all discs were again stored at room temperature. After 4 weeks, all subsamples were preheated at 290 °C for 10 s and IRSL was measured at 50 °C for 100 s. All samples were then normalised by second glow normalisation. None of them displayed a significant signal instability over the time of 11 months. The differences between both subsets were less than 3% and hence lie within reproducibility range.

Natural sediment dose rate was determined by gamma spectrometry at the Institute of Geography, University of Cologne (Preusser & Kasper, 2001) (tab. 1). With reference to Huntley & Baril (1997), internal potassium contents of 12.0 ± 0.5% were assumed for the feldspar samples. Cosmic dose was estimated after Aitken (1985) and Lang (1996).

c - OSL dating results

The modern samples («beach» and «cliff») from the present beach east of Metaponto (cf. fig. 1) were both measured using SAR protocols. Sample «beach» from the shoreline gave an age of 30 ± 30 years (quartz) and sample «cliff» from the modern backbeach cliff yielded 190 ± 50 years for feldspar and 290 ± 30 years for quartz. These dating results suggest a sufficient sunlight exposure during littoral deposition to bleach the sand size minerals completely. This demonstrates the suitability of littoral deposits for luminescence dating. Sediments from comparable environmental conditions deposited during earlier interstadials and the last interglacial may have had similar bleaching probabilities and may have reached a similar bleaching level. Therefore, the fundamental requirements for luminescence dating are fulfilled.

As described in Chapter 3, seven samples were taken for OSL dating from the Petrulla profile (terrace level T1) (cf. figs. 3 and 10). In accordance with grain size analyses, the sediment dose rates (tab. 1) indicate a major facies change between the overlying fine grained cover sediments

TABLE 1 - Dosimetry data obtained by gammaspectrometry and results of palaeodose determinations using single aliquot regeneration (SAR) and multiple aliquot additive (MAA) protocols. Grain sizes used for coarse grain dating are given in column 3. Fine grain dating was carried out on the 4-11 µm fraction. Dose rates were calculated for dated samples only, using an average water content of 12 ± 5% and an internal potassium content of 12 ± 0.5% for coarse grain feldspar

Sample	Lab number	Grain size [µm]	Uranium [µg g^{-1}]	Thorium [µg g^{-1}]	Potassium [%]	*D* Quartz [Gy ka^{-1}]	*D* Feldspar [Gy ka^{-1}]	*D* Fine grain [Gy ka^{-1}]	D_e Quartz SAR [Gy]	D_e Feldspar SAR [Gy]	D_e Feldspar MAA [Gy]	D_e Fine grain MAA [Gy]	OSL QZ-SAR [ka]	IRSL age FSP-SAR [ka]	IRSL age FSP-MAA [ka]	IRSL age FK-MAA [ka]
PET-20	MR0054	100-200	1.19 ± 0.06	5.29 ± 0.27	1.17 ± 0.06	—	2.5 ± 0.2	2.3 ± 0.2	—	4.3 ± 0.6	4.7 ± 0.5	6.9 ± 0.6	—	2.0±0.6	1.9±0.2	2.9±0.3
PET-60	MR0055	63-150	1.39 ± 0.07	6.52 ± 0.32	1.13 ± 0.06	—	2.4 ± 0.2	2.5 ± 0.2	—	42.4 ± 1.8	38.0 ± 1.5	36.4 ± 3.1	—	17.5±1.4	15.7±1.2	14.7±1.7
PET-90	MR0056	63-150	1.56 ± 0.08	7.27 ± 0.36	1.17 ± 0.06	—	2.5 ± 0.2	2.6 ± 0.2	—	50.6 ± 1.9	50.2 ± 1.0	56.1 ± 3.8	—	20.0±1.5	19.8±1.4	21.2±2.2
PET-170	MR0057	63-150	1.52 ± 0.08	7.45 ± 0.37	1.14 ± 0.06	2.0 ± 0.1	2.5 ± 0.2	2.6 ± 0.2	104 ± 4	66.1 ± 2.5	59.4 ± 5.3	63.5 ± 1.4	52.9 ± 4.3	26.5±2.1	23.8±2.7	24.4±2.0
PET-250	MR0058	150-250	0.47 ± 0.02	1.36 ± 0.07	0.78 ± 0.04	1.1 ± 0.1	1.6 ± 0.1	—	104 ± 18	88.2 ± 2.7	87.8 ± 4.7	—	99.4 ± 18.2	55.5±4.0	55.2±4.6	—
PET2-1	MR0059	150-200	0.48 ± 0.02	2.07 ± 0.10	0.91 ± 0.05	—	1.7 ± 0.1	—	—	86.4 ± 2.9	82.7 ± 3.0	—	—	52.0±3.9	49.4±3.8	—
PET2-2	MR0060	150-200	0.39 ± 0.02	1.25 ± 0.06	0.57 ± 0.03	0.8 ± 0.1	1.3 ± 0.1	—	99.1 ± 12.1	95.3 ± 3.5	95.5 ± 4.6	—	130 ± 18.2	73.7±6.1	73.8±6.5	—
T2-1-1	MR0061	100-200	1.08 ± 0.05	6.84 ± 0.34	1.16 ± 0.06	—	2.4 ± 0.2	2.3 ± 0.2	—	127 ± 3.9	127 ± 7.2	129 ± 12.4	—	52.8± 4.3	53.1±5.0	54.7±6.7
T2-1-2	MR0062	150-200	0.55 ± 0.03	1.67 ± 0.08	0.44 ± 0.02	0.8 ± 0.1	1.3 ± 0.1	—	112 ± 18.5	106 ± 3.7	78.1 ± 3.4	—	145 ± 25.7	81.4±7.2	59.8±5.5	—
T2-2-1	MR0063	150-200	0.49 ± 0.02	1.98 ± 0.10	0.93 ± 0.05	1.1 ± 0.1	1.7 ± 0.1	—	169 ± 3.5	118 ± 3.7	126 ± 11.1	—	149 ± 11.3	70.0±5.2	74.6±8.3	—
T2-2-2	MR0064	150-200	0.54 ± 0.03	1.82 ± 0.09	0.98 ± 0.05	1.2 ± 0.1	1.7 ± 0.1	—	146 ± 15.1	134 ± 4.8	130 ± 6.5	—	124 ± 15.7	69.5±5.2	75.6±6.2	—
T2-2-3	MR0065	150-200	0.59 ± 0.03	2.32 ± 0.12	0.95 ± 0.05	—	1.7 ± 0.1	—	—	120 ± 3.8	134 ± 4.9	—		69.1±5.0	76.6±5.8	—
T3-1-1	MR0066	150-250	0.48 ± 0.02	1.97 ± 0.10	0.79 ± 0.04	1.1 ± 0.1	1.7 ± 0.2	—	154 ± 9.6	120 ± 4.1	120 ± 6.5	—	139 ± 12.6	69.7±7.4	69.5±7.9	—
T3-1-2	MR0067	150-200	0.49 ± 0.02	1.98 ± 0.10	0.80 ± 0.04	1.1 ± 0.1	1.7 ± 0.1	—	148 ± 1.9	136 ± 4.8	134 ± 8.1	—	134 ± 9.0	82.3±6.0	81.2±7.2	—
T3-1-3	MR0068	150-200	0.68 ± 0.03	2.71 ± 0.14	0.78 ± 0.04	1.2 ± 0.1	1.7 ± 0.1	—	174 ± 10.3	132 ± 4.8	144 ± 8.8	—	151 ± 13.5	77.8±5.6	83.7±7.4	—
T3-2-1	MR0069	150-200	1.03 ± 0.05	4.04 ± 0.20	1.09 ± 0.05	—	2.1 ± 0.1	—	—	155 ± 6.3	146 ± 9.5	—	—	74.3±5.5	70.1±6.3	—
T3-2-2	MR0070	100-150	0.96 ± 0.05	3.97 ± 0.34	1.09 ± 0.06	—	1.9 ± 0.1	—	—	157 ± 5.9	167 ± 12.5	—	—	80.8±6.2	86.2±8.6	—
Cliff	MR0071	100-200	0.83 ± 0.09	2.61 ± 0.26	0.61 ± 0.05	1.2 ± 0.1	1.6 ± 0.2	—	0.34 ± 0.04	0.31 ± 0.07	—	—	0.29 ± 0.03	0.19±0.05	—	—
Beach	MR0072	200-250	0.49 ± 0.05	1.11 ± 0.11	0.66 ± 0.06	1.0 ± 0.1	—	—	0.03 ± 0.03	—	—	—	0.03 ± 0.03	—	—	—

(Tcs) and the sandy terrace gravel (MTsbd). Owing to higher silt and clay content the upper 2 m yielded much higher dose rates than the underlying sandy gravel. The dose rates range between 2.4 ± 0.2 and 2.5 ± 0.2 Gy/ka for the cover sediments and between 1.3 ± 0.1 and 1.7 ± 0.1 Gy/ka for the sandy layer within the gravel deposits (tab. 1).

Within the margin of error, SAR feldspar ages are in agreement with MAA feldspar results (fig. 10). They indicate a deposition of the fine grain cover sediments (Tcs) between 15.7 ± 1.2 and 26.5 ± 2.1 ka, i.e. in MIS 2 around the last glacial maximum (LGM). Fine grain dating results reach from 14.7 ± 1.7 to 24.4 ± 2.0 ka and confirm this age range.

During the LGM (around 20 ka ago), global sea level was about 125 m lower than today. Even at the beginning of the Holocene it was ca. 40 m below the present level (Lambeck & Bard, 2000; Lambeck & *alii*, 2004). Shallow marine deposition in a small creek or a lagoon is therefore unlikely for the Tcs represented by reddish silty-sandy cover sediments. Good agreement between the coarse grain and fine grain dating results, as well as the grain size distribution, support the assumption of a primarily aeolian transport. Nevertheless, subsequent reworking is likely because of numerous pebbles intercalated in the lower part of the cover sediments. The comparably young age obtained for the uppermost sample – ca. 2-3 ka BP – may be attributed to anthropogenic influence (i.e. disturbance by ploughing, Ap horizon).

The main gravel formation (MTsbd) was not sampled due to its inhomogeneous and coarse composition. Sandy layers of the sandy terrace base (MTsb), at about 15-20 m a.s.l., yielded feldspar ages between 49.4 ± 3.8 ka and 55.5 ± 4.0 ka, suggesting high accumulation rates at the beginning of MIS 3. However, mollusc bivalves from the lower part of the terrace base yielded Th/U ages of 75 ± 7 ka and 63 ± 3 ka (Brückner, 1980a), suggesting a deposition during late MIS 5 and early MIS 4. This contradicts the luminescence dating results (fig. 10).

While the lower Th/U age confirms the expected age range of MIS 5.1, the upper date underestimates this range. IRSL ages from feldspar of about 74 ± 6 ka agree with the lower mollusc shell Th/U age of 75 ± 7 ka. In summary, there is evidence for a deposition of this terrace during MIS 5.1, but dating results are controversial.

SAR measurements applied on three quartz samples yielded significantly higher age estimates in average compared to the feldspar results. Quartz OSL ages for the sandy horizon from the upper main gravel layer and the lower sandy terrace base are 99.4 ± 18.2 ka and 130 ± 18 ka, respectively. These quartz dates place the main gravel layer in MIS 5.3 rather than in MIS 5.1 and the terrace base at the beginning of MIS 5.5. However, the quartz dates have a large uncertainty and a high error deviation, thus only allowing the statement «presumably within MIS 5».

Error deviations up to 20% obtained for the quartz measurements from Petrulla as well as from the other two profiles (cf. figs. 12 and 13) are due to low reproducibility, non-linear shape of growth curves and the resulting high individual D_e uncertainties (fig. 11). The strong exponential shape of the growth curves indicates a low quartz saturation level. In consequence, the age estimates obtained for quartz are questionable.

Close to the village of San Teodoro two profiles, which are correlated with terrace levels T2 and T3, were sampled for OSL dating with 5 samples each. For profile San Teodoro I (fig. 12), linked with level T2, dose rates are inhomogeneous within the sediment record. Hence they indicate pronounced facies changes (tab. 1). The dose rate (2.4 ± 0.2 Gy/ka) of sample T2-1-1 extracted from the fine grained cover sediments (Tcs) is almost twice as high as for sample T2-1-2 from the main gravel layer (MTsbd). Three samples taken from the more homogeneous terrace base (MTsb; well sorted sand with few thin intercalated gravel horizons) give uniform dose rates of 1.7 ± 0.1 Gy/ka. The 2 m thick sandy layers at the terrace base show no significant age increase with depth.

Summing up we can conclude that the feldspar MAA dating results are consistent with stratigraphic order and yield ages between 53.1 ± 5.0 ka and 76.6 ± 5.8 ka for the T2 sediments. With reference to these age estimates the main gravel layer (MTsbd-2) was deposited during early MIS 3; but, this is the same age range as achieved from the main gravel layer of terrace level T1 at Petrulla (MTsbd-1). Since terrace T2 has a higher geomorphologic position and higher proposed age, increasing age underestimations occur with increasing deposition age for IRSL feldspar dating of these littoral deposits.

Only sample T2-1-1 from the reddish-brown cover sediments, the Tcs-2, provided enough fine silt to carry out fine grain MAA dating. The resulting age of 54.7 ± 6.7 ka correlates well with MAA coarse grain dating on feldspar. Within the error margin, SAR data are in good agreement with MAA data – except for sample T2-1-2. There is no reason for the exception concerning this specific sample (cf. fig. 12). SAR dating of the quartz fraction reveals simi-

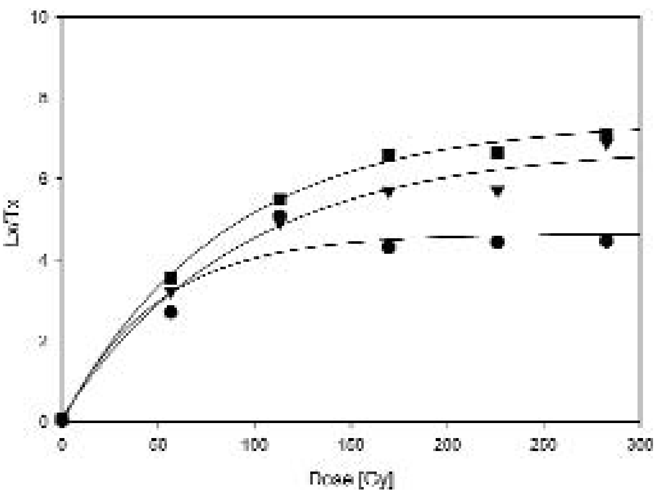
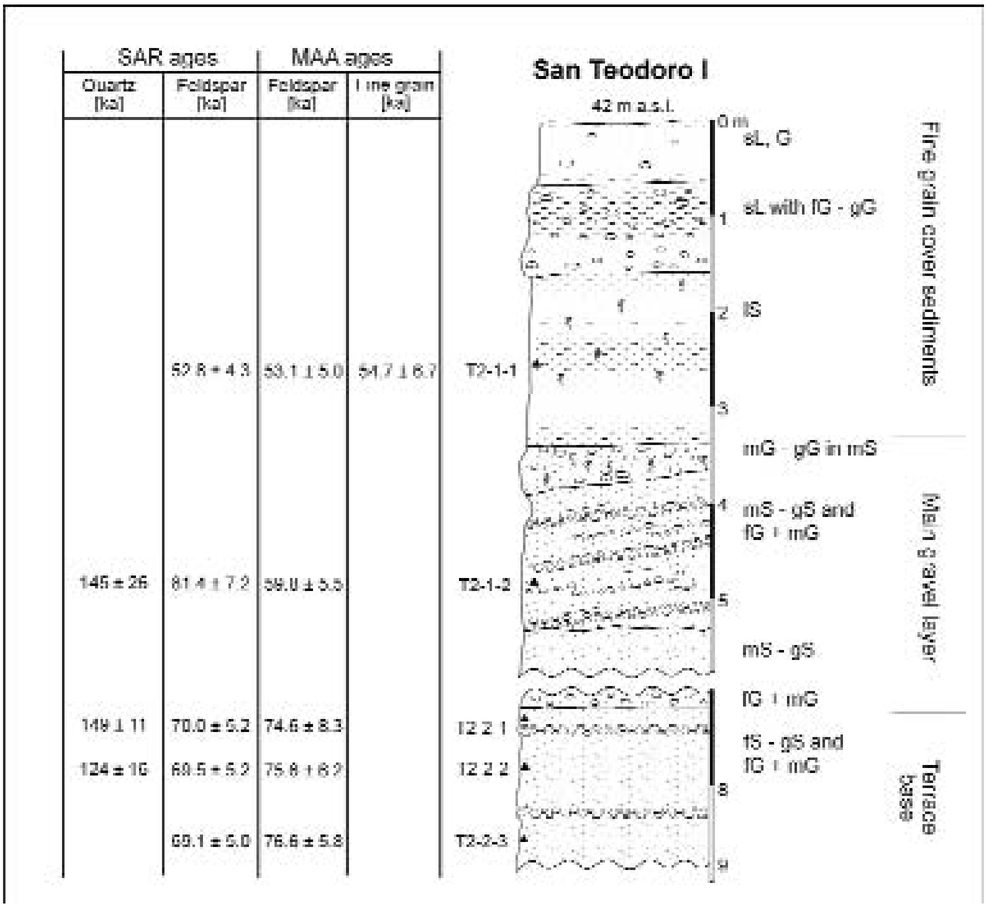


FIG. 11 - Saturating growth curves from sample PET-250 (triangle and circle) and T2-2-2 (squares). Maximum radiation dose is ~282 Gy.

FIG. 12 - San Teodoro I profile from terrace level T2. Luminescence age estimates for quartz, feldspar and fine grain samples are given in kiloyears (ka). SAR = single aliquot regeneration protocol, MAA = multiple aliquot additive protocol.



lar difficulties as the samples from Petrulla. Age estimates range between 124 ± 16 ka and 149 ± 11 ka but they are not in stratigraphic order.

Similar deviations between the applied methods occurred for the profile San Teodoro II from terrace level T3 (fig. 13). All five MAA feldspar ages vary between 69.5 ± 7.9 ka and 86.5 ± 8.6 ka. They are not consistent within their stratigraphic position and exhibit no age increase with depth. On the other hand the accompanying palaeodoses show a continuous increase with depth (cf. tab. 1). As derived from gammaspectrometry the dose rates in the sediment record vary considerably. This could either refer to post-sedimentary processes or to sedimentary facies changes. Indicators for secondary chemical processes are not evident in the homogeneous laminated fine sand, but facies changes can be determined from granulometry. However, the latter does not explain the substantial age underestimation.

Within error deviations, the SAR luminescence dates on feldspar are in good agreement with the MAA measurements, but not consistent with the stratigraphy. For the main gravel layer SAR feldspar results range between 82.3 ± 6.0 ka and 69.7 ± 7.4 ka. Like the MAA ages, they indicate deposition of this layer during MIS 5.1. Quartz datings carried out on three samples from the main gravel layer (MTsbd-1, 2, 3) provide the same age range as for profile San Teodoro I at terrace level T2. Age estimates between 151 ± 14 ka and 134 ± 9 ka suggest a deposition within the penultimate glacial (MIS 6) or in the early part of the last interglacial (MIS 5). However, because of the relative sea level low stand during MIS 6 (cf. Waelbroeck & *alii*, 2002) and the proposed average elevation rates of the area, the deposition of the marine terrace T3 during that time is not possible, as already noted by Brückner (1980a: tab. 17).

DISCUSSION

The three examined terrace profiles are related to the three youngest terrace levels T1, T2 and T3 in the Metapontino area. The correlation of the profiles with the marine oxygen isotope record is based on the chronostratigraphy established by Brückner (1980a). He gave three geological evidences: (a) The Brunhes/Matuyama palaeomagnetic boundary (~ 780 ka BP) is located between T11 and T10; (b) a 500-600 ka volcanic tephra covers terrace T8; (c) in accordance with Th/U datings and palaeontological data T1 is attributed to MIS 5.1. Considering these facts and using geomorphologic and pedologic criteria, Brück-

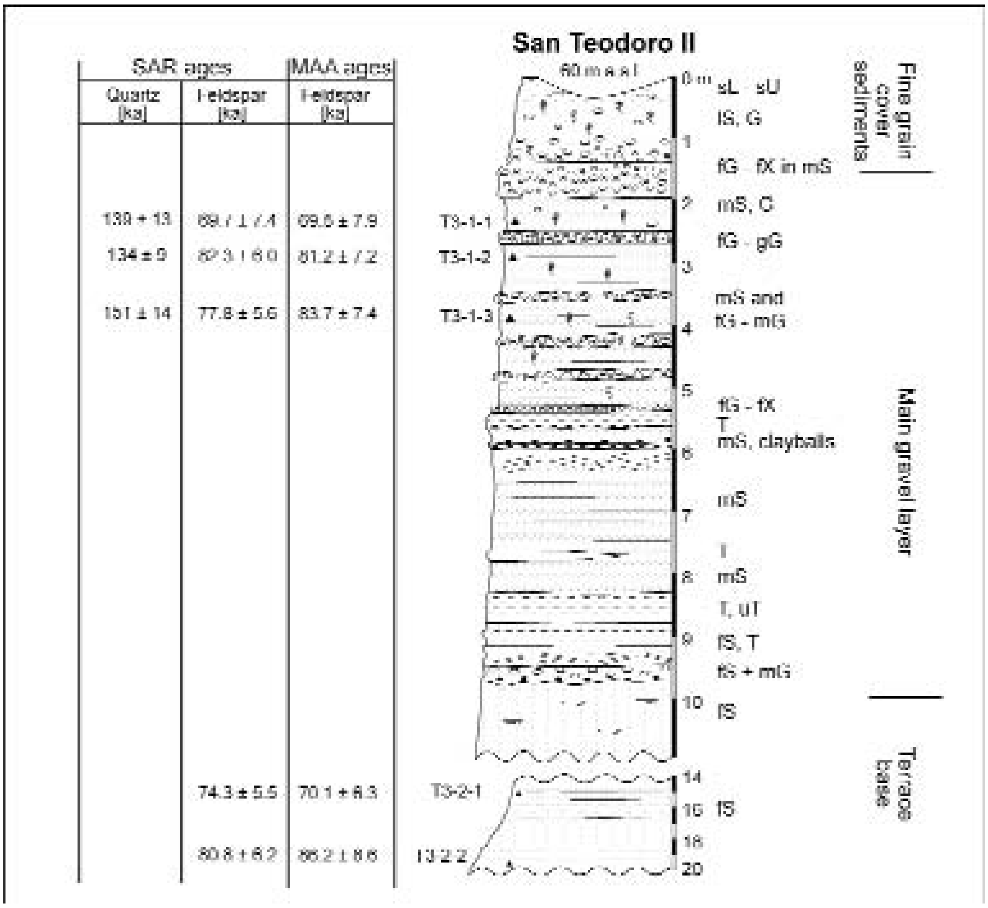


FIG. 13 - San Teodoro II profile from terrace level T3. Luminescence age estimates for quartz and feldspar samples in kiloyears (ka). SAR = single aliquot regeneration protocol, MAA = multiple aliquot additive dose protocol.

ner (1980a) associates the sediments of T1 with the sea-level highstand during MIS 5.1, T2 with the last interglacial sea-level highstand during MIS 5.5 and T3 with MIS 7. The occurrence of *Strombus bubonius*, a key fossil for the last interglacial in the Mediterranean Sea, on a raised marine terrace at about 40 m a.s.l. (Boenzi & *alii*, 1985; Caldara, 1987), supports the association of T2 with MIS 5.5. Nevertheless, this correlation is not certain because in this region of the Metaponto area the marine terraces are morphologically replaced by beach ridge systems (cf. Brückner, 1980a: Supplement I).

The above presented chronological correlation of the terraces cannot be verified with the obtained luminescence age estimates. The results of quartz dating suggest a correlation of the main gravel layers (MTsbd) of T1 and T2, respectively, with MIS 5.1 and MIS 5.5. However, from the methodological point of view, they are not reliable since the strong exponential shape of the D_e growth curve indicates a «close to saturation» level. Saturation dose experiments indicate that the quartz saturation doses vary between 150 and 200 Gy (cf. fig. 11).

The feldspar dating results from all three profiles considerably underestimate the quartz results; but, SAR and MAA ages show good agreement amongst themselves (fig. 14). From this assessment, one would conclude that the modified SAR protocol for feldspar dating after Wallinga & *alii* (2000a) provides reliable and comparable luminescence dating results on marine sediments. Methodologically induced affinity to age underestimations as described by Wallinga & *alii* (2000b) was not observed. Nevertheless, the feldspar results from the Metaponto area are far younger than expected from the regional stratigraphy. Compared to the younger T1 level exposed in Petrulla, the T2 level in San Teodoro shows no increase in age. For the T3 level at San Teodoro II, a small age increase is detectable compared to the two younger terraces but no age increase in the sediment record itself.

The missing age increase, which is particularly conspicuous in the two older marine terraces, and the obvious age underestimations in relation to chronostratigraphic expectations may point to unstable luminescence centres in the feldspars and fading effects (see also Visocekas 1985; Templer 1986; Spooner 1994; Lamothe & Auclair 1999). However, there is no explicit evidence.

Volcanic feldspar minerals such as sanidine, which is known to show spontaneous signal loss (Spooner 1992; 1994; Wintle 1994), were not verifiable by x-ray diffraction analysis (cf. Chapter 4). Eleven months fading tests on feldspar and fine grain samples gave no indication for signal instabilities. Agreement between coarse grain and fine grain

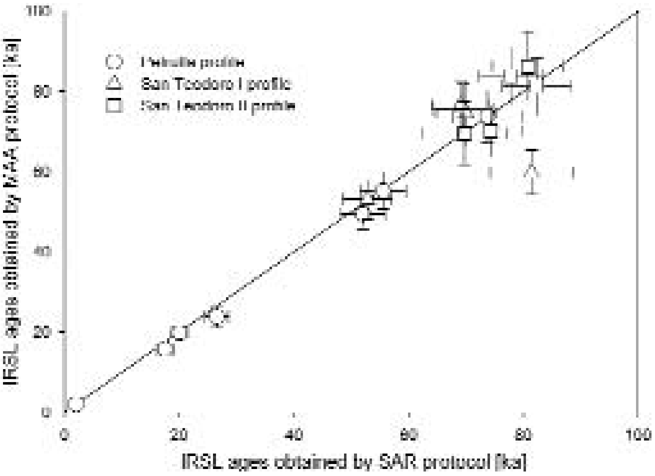


FIG. 14 - Comparison of IRSL feldspar ages obtained by MAA and SAR protocols.

results can also be regarded as an argument against fading, since the different grain sizes are assumed to originate from different sediment sources thus differing in their fading behaviour. A long time fading with slow signal loss is not provable by laboratory experiments («mid term fading» by Grün & *alii*, 1989; Xie & Aitken, 1991 or «long term fading» by Mejdahl, 1988). This could be considered the causal trigger. However, mid term fading is controversial as discussed in the literature (Wintle, 1991; Berger, 1994).

IRSL measurements on feldspars from the Tyrrhenian coast (Central Italy) using similar protocols (Mauz, 1999) resulted in stratigraphically consistent luminescence ages up to approximately 90 ka. On the other hand, dating of feldspars from the Crotone Peninsula in southern Italy (Mauz & Hassler, 2000) revealed significant underestimations which were attributed to signal instabilities. Similar results were obtained by Balescu & Lamothe (1994) for feldspar samples from Calabria. The authors then applied a correction model for long term fading after Mejdahl (1988; 1989) in order to relate to the expected ages. However, such mathematical corrections are regarded critically since computation of luminescence trap lifetimes include large uncertainties (Aitken, 1998). Correction procedures recently developed by Auclair & *alii* (2003) and Lamothe & *alii* (2003) are yet to be tested.

As deduced from fine grain and feldspar results, the terrace cover sediments of T1 (Tcs-1) were deposited in late MIS 3 and MIS 2. Grain size analysis revealed a substantial silt content. Both parameters – sedimentation age and silt content – indicate that a considerable fraction of the sediments had an aeolian origin. They were probably blown off the exposed marine shelf during MIS 2.

The entire succession of cover sediments with few basal pebbles in silty/sandy matrix leaves an impression of post-depositional reworking. Vertically standing pebbles in the fine grained matrix of the lower part of the T1 cover sediments were obviously dislocated after deposition (fig. 4). This could imply frost lifting requiring temporary ground frost. In this part of southern Italy these climatic conditions were restricted to LGM as deduced from the lacustrine sediments of the Lago Grande di Monticchio (Allen & *alii*, 2000; Allen & Huntley, 2000). Thus, a deposition and subsequent solifluction for at least the lower part of the cover sediments is probable in early MIS2. The upper ca. 1.7 m were accumulated later during MIS 2 as corroborated by the IRSL ages.

CONCLUSION

The luminescence dating approach carried out on the lowermost three raised marine terraces of the Metaponto area revealed that OSL dating of littoral sediments includes substantial complications, but is in general feasible (Mauz, 1999). Two of the most important requirements for a reliable and successful application of this dating method are (i) the adequate bleaching and resetting of the luminescence signal during sediment transport, and (ii) the stability of the luminescence signal over geologic time. Two samples from the recent cliff and the modern beach were examined to prove that the present sedimentological conditions meet these dating requirements. They resulted in a zero age for the beach and a near to zero age for the modern cliff. It can therefore be assumed that sediments from former shorelines and cliffs had similar accumulation conditions and hence became sufficiently bleached.

Considering the different methods applied, a good agreement between MAA and SAR dating results is apparent. Nevertheless, feldspar ages determined with both techniques significantly underestimate the expected age ranges – presupposing that the chronostratigraphy of the Metaponto area's terrace flight suggested by Brückner (1980a) is correct. Most probably, the T3 marine deposits were deposited during MIS 7. The lower T2 and T1 marine deposits are linked to two different periods of MIS 5, the MIS 5.5 and MIS 5.1 substages, respectively (Brückner, 1980a).

This model is concordant with the sequence of the raised marine surface in the Taranto area as described by Belluomini & *alii* (2002). Both areas are characterised by the lack of evidence for a marine deposit ascribed to MIS 5.3. An abrasion of MIS 5.3 deposits during the MIS 5.1 transgression is one possibility; another possibility is that sea level was too low during MIS 5.3. In fact, according to the most recent «global» sea level curve (Waelbroeck & *alii*, 2002) its maximum was about –15/–35 m lower than during the maxima of MIS 5.5 and MIS 5.1. To date, there are no areas along the northern part of the Gulf of Taranto where marine terrace sediments have been ascribed to MIS 5.3 using absolute age determinations.

From the obtained luminescence data set, it is not possible to validate this model. A major difficulty is the missing increase in the luminescence age estimates from terrace

T1 (22 m a.s.l.) to terrace T2 (42 m a.s.l.). The terraces can be clearly distinguished by geomorphological features as well as pedological criteria and by their altitude above sea level, but IRSL age estimates yielded the same deposition ages. Signal instabilities may explain the underestimation, but fading tests gave no indication of such occurrence.

As demonstrated on all three profiles, older quartz minerals from the Metaponto area are not well suited for luminescence dating. Small saturation doses between 150 and 200 Gy and the ensuing strong exponential shape of the growth curves result in large uncertainties.

Summing up the luminescence data set at hand, it is difficult to establish a reliable chronostratigraphic frame for the terrace flight of the Metaponto area. An additional independent age control by modern Th/U, AAR or ESR dating techniques would help to qualify and quantify the apparent age underestimations of the presented feldspar datings and would thus allow a more precise statement about the chronological record.

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