STRATIGRAPHY AND RADIOMETRIC DATING S OF A MID-PLEISTOCENE TRANSgressive COMPLEX IN THE AGRO PONTINO (CENTRAL ITALY)

The coastal zone of central Lazio (W. Italy) is noted for its Pleistocene coastal complexes. To the South of the Tiber the chronostratigraphy, in particular of the older complexes, is still uncertain and has been largely based on soil chronosequences.

In the Borgo Montello area outcrops of the mid-Pleistocene Latina Complex, the largest transgressive complex in the Agro Pontino, were found to have intercalations of volcanites from the Vulcano Laziale. Detailed paleogeographic studies showed that this Latina Complex was formed during one single transgressive phase.

K-Ar and fission track datings were carried out on the intercalated volcanites, which belong to the “Complesso dei TuFi Inferiori”. The results of both methods are discussed on the basis of the analytical data. The methods yield an age of 0.57 to 0.56 Ma respectively. Based on these datings the Latina Complex can be correlated with isotopic stage 15. The next younger transgressive complex in the Agro Pontino (the Minturno Complex), which reaches considerably lower altitudes, has been dated at approx. 0.12 Ma (isotopic stage 5). This implies that a major stratigraphic hiatus exists between the two complexes. Apparently high sealevel stages of intermediate age (isotopic stages 13, 11, 9 and 7) left no traceable records in the form of marine terraces. This hiatus is reflected in the soil chronosequence established for the area.

Introduction

The coastal area of Central Lazio (Italy) is occupied by a large complex of Pleistocene coastal sediments, which extends over a distance of about 130 Km from the Tolfa Mountains near Civitavecchia (N of Rome) to the Agro Pontino in the South. Thusfar the stratigraphy of the superficial deposits South of the Tiber has been largely based on soil chronosequences (Agro Romano: Dai Pra & Arnoldus-Hutzendfeld, 1984; Agro Pontino: Sevink et al., 1982 and 1984, see also Table 1), which have only been calibrated for the Late Pleistocene (Hearty & Dai Pra, 1986).

The age and stratigraphy of the Latina complex, which represents the major marine terrace in the Agro Pontino, remained uncertain. In the area investigated by Sevink et al. (1984) it lacked fauna and intercalated volcanites and therefore could not be dated. However, during recent research tuff intercalations were found in the Borgo Montello area (see Fig. 1), stemming from the nearby Vulcano Laziale (Fornaseri et al., 1963; geological map sheet 158). These are intercalated in sandy deposits, which formerly were grouped with the “Duna Antica”, but are part of the Latina Complex (Sevink et al., 1984). Three different tuff intercalations could be identified, which can be used as markerbeds and for radiometric datings.

The question, whether the tuffs form intercalations in a continuous sedimentary sequence or are separating different transgressions is crucial for the dating of the Latina complex. Therefore considerable attention has been paid to the stratigraphy and paleogeographical history of the Borgo Montello area.

The dating of the Latin complex enables a further calibration of the existing soil chronosequences and thus a more reliable correlation of the older coastal deposits in this part of Italy.

General stratigraphy

Figure 1 shows that the Borgo Montello area is situated in the transitional zone between the volcanic deposits of the Vulcano Laziale and the terrigeneous coastal deposits of the Duna Antica. In the southern Agro Pontino the Duna Antica unit has been subdivided into complexes of predominantly littoral and lagoonal deposits, all of Pleistocene age; see Table 1 (Sevink et al., 1982 and 1984). In the northern part of the Agro Pon-
The volcanic units in the Borgo Montello stratigraphy belong to the "Complesso dei Tuﬁ Inferiori", which represents the second cycle of activity of the Volcano Laziale (Fornaseri et al., 1963). The complesso was deposited from a series of pyroclastic ﬂows which were generated by explosive (Plinian) eruptions, prior to caldera collapse of the Volcano Laziale (summarized by Fornaseri, 1985). Datings of the "Tuﬁ Inferiori" range widely (from 0.68 to 0.338 Ma: Pichler, 1970; Caputo et al., 1974; Locardi et al., 1976; Biddittu et al., 1979, Radicati di Brozolo et al., 1981). More recently an upper age limit of 0.338 Ma was broadly accepted (Volcano Laziale datings are summarized by Fornaseri, 1985).

In the Borgo Montello area, the "Pozzolane Medie" (de Wit, 1982), the "Tufo Lionato" and the "Pozzolane Superiore" (cf. geol. map of Lazio) could be identiﬁed. All three units are of (tephritic)-leucitic composition, with few phenocrysts of which leucite/analcite, augite, hornblende and biotite are the most common. The pozzolane (granular cinder tuffs) are medium to well bedded and show many features indicative of a pyroclastic ﬂow origin, such as internal truncation, undulating parallel lamination and graded sequences, together with variations in matrix content and sorting. The Tufo Lionato, in most outcrops in the Borgo Montello area, is homogeneous ﬁne grained, of a conspicuous orange colour and contains less that 5 volume percents of small, angular cinder fragments. Generally the Tufo Lionato is strongly lithoid and therefore resistant against weathering. According to Fornaseri et al. (1963), the tuff has been deposited from a glowing avalanche (hot pyroc-

![Fig. 1 — Simpliﬁed geological map of central Lazio, showing the investigated Borgo Montello area.](image)

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Table 1 — Table of the coastal complexes of Central Lazio (from Sevink et al., 1982).

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<thead>
<tr>
<th>Phases</th>
<th>Sediments</th>
<th>Soils in sandy deposits (with thickness of solum and hue)</th>
<th>Tentative age</th>
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<tr>
<td>Transgression (k)</td>
<td>Terracina Complex</td>
<td>Calcaric Regosols (0.5 m, 10 YR)</td>
<td>Holocene</td>
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<td>Major regression (j) and several phases of eolian activity (i)</td>
<td>Eolian sands</td>
<td>Cambic Aerenosols (0.5-1 m, 10 YR) to Chromic Luvisols (1 m, 7.5 YR)</td>
<td>Würmian</td>
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<td>Minor regression, possibly of tectonic origin (h), Transgression (g)</td>
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<td>Chromic Luvisols (2 m, 7.5 YR)</td>
<td>Tyrrenian III</td>
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<td>Late minor ﬂuctuations (e)</td>
<td>Minturno Complex</td>
<td>ferric Luvisols (4 m, 5 YR)</td>
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<td>Transgression (d)</td>
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<td>Tyrrenian II</td>
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<td>Late minor ﬂuctuations (h)</td>
<td>Latina Complex</td>
<td>Albic Glycic Luvisols (± 4 m, 5-7.5 YR)</td>
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Translation of the Italian text:

- Caratteristiche dei complessi costieri del Lazio centrale (da Sevink et al., 1982).
lactic flow). Its lithoid character is ascribed mainly to postdepositional auto-cementation (zeollitization). Exceptions to the uniform character of the Tufo Lionato are present in the Borgo Montello area. As will be discussed below, these can be related to deviant depositional conditions.

The terrigenous sediments, in which the tuffites are intercalated, are grouped together as the Latina Complex, which may be subdivided into two members: a lower (Latina I) and an upper (Latina II) member, separated by the Tufo Lionato. At the base of the Latina I member, the "Fox Sands" consist of light coloured, well sorted fine to very fine sands, which show vague wavy parallel and low angle cross lamination in a number of sections. The high quartz content and good rounding of the grains indicate a relatively high maturity. An eolian origin of these sands is inferred. The Fox Sands are locally truncated by medium grained sands, low in augite. These sands are of littoral or transitional origin (see further).

The "Augitic Sands" of the Latina II member are named after their variable but at every location and interval distinctive content of subhedral augite crystals. These are of volcanic origin and, upon weathering, cause strong red staining of the sands. Grain size distribution and sedimentological structures of the augitic sands vary throughout the area. In general, they are fine to very coarse grained and show many features of subaquatic deposition. Fine grained sands are parallel to low angle crosslaminated. Coarse to very coarse sands are troughshaped megacrossbedded, with foresets uniformly dipping NE and on some occasion containing medium coarse gravel. Only in lower parts of some sections re-deposited tuff lenses occur, which contain moulds of ribbed bivalves. Hence, the unit is interpreted to represent a littoral facies.

Besides augitic sands the Latina II member comprises lagoonal clays. These constitute the uppermost stratum of the Latina II member, rarely exceeding a thickness of a few metres (see also Fig. 3c).

The Latina transgression

The Latina I member represents the onset of a marine transgression coming from the South West. In section 1 (Fig. 2) a gradual transition can be observed from (bottom to top): non-augitic littoral sands of the Latina I member, re-worked Tufo Lionato, low-augite sands with tuffitic intercalations, to the highly augitic upper littoral sands of the Latina II member. Truncating the (colian) Fox Sands, sedimentation from this transgression had just reached the southern parts of the Borgo Montello area when it was interrupted by catastrophic deposition of the Tufo Lionato. Further inland non-depositional conditions prevailed, as is reflected in the presence of a paleosol in deposits of the Pozzolane Medie (de Wit, 1982). The Latina I deposits to the South and the (paleosol in) the Pozzolane Medie further North (Fig. 3a) both are buried directly by the Tufo Lionato. Inferred from the paleosol, the Pozzolane Medie will be older than the Latina I sands, and the Tufo Lionato is a common upper boundary to both.

In the eastern Borgo Montello area the lithoid Tufo Lionato reaches thicknesses up to 10 metres; therefore it can be reasonably assumed that its deposition at the paleo-coast will have interrupted the onlap of the transgression. The distribution pattern of coastal versus continental deposits (see Fig. 3a) illustrates how far onlap had proceeded at the time of emplacement of the Tufo Lionato.

Continuation of the transgression resulted in deposition of the Latina II member which at many places overlies thick outcrops of lithoid Tufo Lionato. In the lower part of the Latina II sands a next younger volcanic intercalation of lesser magnitude occurs. The volcanites, part of the Pozzolane Superiore, allow correlation of contemporaneous coastal and continental facies of the early Latina II phase (Fig. 3b). From this lower part upwards, the Latina II member is very uniform. It consists of augitic sands, bearing littoral facies characteristics. These sands cover a vast area between Borgo Montello and the Colli Albani (the former Volcano Laziale) to the North West (partially replacing the Duna Antica, Fig. 1). Figure 3c shows the distribution pattern of coastal, continental and transitional deposits, reflecting the highest stage of the transgression as preserved in the Borgo Montello area.

Stratigraphical and sedimentological evidence

Paleogeography before and at the time of deposition of the Tufo Lionato (Latina I transgressive phase)

In sections 2, 3, 5 and 6 the Fox Sand is the oldest member exposed. Apart from lithological criteria, good evidence for its eolian origin can be found at location 3. Here, catastrophic deposition of the Tufo Lionato on top of the Fox Sand has caused perfect preservation of the topography of an eolian dune, whereby plant frag-
ments have been incorporated in the lowermost levels of the tuff.

At the southernmost locations 1 and 2 the Fox Sand is truncated at its top by littoral deposits. These comprise both sands and volcanics, which have been reworked in a subaqueous environment. The alternately fine and coarse grained sands are low angle cross laminated. They are mixed with an upward increasing amount of tuff. The reworked volcanics are not lithoid, but can be recognized by their bleached orange colour and their content of hard, angular cinder fragments, which in this area are unique characteristics of the Tufo Lionato. Lenses of tuff are cross laminated and on some occasions contain moulds of ribbed bivalves (*Pecten*?). Aquatic deposition is evidenced by the presence of burrows; littoral (re-)deposition is expressed as thin toe sets in the sands enriched in (heavy) augite crystals.

At the northern locations (e.g. location 8, 15 and 16), the oldest outcropping formation is the Pozzolane Mediceo. It has been exposed to soil forming processes for a prolonged period (De Wit, 1982). Soil formation must have taken place before burial by the Tufo Lionato, the latter at the same locations having remained lithoid, unweathered and highly impervious. In spite of the
Fig. 2 — Representative sections from the Borgo Montello area. Left to right is roughly SW-NE; locations of sections are indicated in figures 3 a-c. The lower and middle correlation lines connect the base and top respectively of the different Tufo Lionato outcrops; thus the lower line represents the paleogeography at the moment the Tufo Lionato was catastrophically deposited (note that the sections are not drawn at true elevations). The upper correlation line reflects the final truncation of all older deposits (earlier Latina I phase transgression, pre- to post Tufo Lionato continental deposits, and the Tufo Lionato itself) by continuous onlap of the Latina II transgression. Locations 15 and 16 were never reached by the Latina transgression (cf. Fig. 3c).

— Sezioni stratigrafiche rappresentative dell’area di Borgo Montello. Da sinistra verso destra si procede grosso modo in direzione SW-NE; la posizione delle sezioni è indicata nelle figure 3a-c. Le due linee di correlazione inferiore e intermedia si riferiscono rispettivamente alla base e al tetto dei differenti affioramenti di Tufo Lionato; di conseguenza la linea inferiore rappresenta la superficie paleogeografica al momento della deposizione del Tufo Lionato (si tenga presente che nelle sezioni le quote non sono allineate). La linea di correlazione superiore rispecchia la troncatura finale di tutti i depositi più vecchi (fase trasgressiva Latina I, depositi continentali pre- e post-Tufo lionato e Tufo Lionato stesso) da parte della coltre continua di sedimenti della fase trasgressiva Latina II (vedi figura 3c).

soil formation, in the Pozzolane Medie primary depositional characteristics still can be recognized. These comprise stratification and ill sorted textures, especially in the coarser grained basal parts of the deposits, pointing to deposition from the non-sorted, central part of a pyroclastic flow (lobe) (see e.g. Sparks, 1976; Fisher, 1979). Significantly, no resedimentation structures occur in the Pozzolane Medie (in contrast to the intercalated tuff lenses in southern sections). Therefore it is concluded that at northern locations both the Pozzolane Medie and the Tufo Lionato were emplaced in a continental environment.

In all outcrops where the Tufo Lionato represents a continental facies, it is invariably lithoid. Such outcrops proof to be very weathering-resistant: delithification can only proceed slowly and slowly in the tuffbed. Direct superposition of littoral deposits upon lithoid Tufo Lionato (e.g. location 7) points to marine submersion of the Tufo after its deposition. Even this has not obliterated its lithoid character. As a consequence, lithification reasonably can be regarded to be directly dependent on subaerial circumstances at primary deposition.

Conversely, all outcrops of Tufo Lionato deposited in a subaquatic environment (inferred
from circumstantial evidence) are non-indurated, of a bleached (orange) colour and little weathering-resistant. Therefore it can be similarly argued that outcrops of non-lithoid Tufo Lionato represent a subaerobic depositional environment, although further facies characteristics may lack. Outcrops of subaerobic Tufo Lionato are present at locations 1, 2, 4, 5 and 9.

The southernmost boundary of lithoid outcrops of the Tufo Lionato, as generally accepted (geol. map of Lazio and FORNASERI et al., 1963), perfectly coincides with the proposed paleoshoreline as inferred from the various continental and littoral deposits directly underlying the Tufo (Fig. 3a). Number and thickness of (marine-deposited) Tufo Lionato outcrops quickly diminish South of this boundary (also on Fig. 3a). Both phenomena can be explained adequately by interpretation of this line as a continental-littoral facies boundary at the time of deposition of the Tufo Lionato, i.e. as the paleo-shoreline.

Paleogeography after deposition of the Tufo Lionato (Latina II transgressive phase)

At different locations in the investigated area, different lithological units overlie the Tufo Lionato (Fig. 3b). The general succession of deposits with continental, transitional and littoral facies characteristics can be related to continuous onlap of the Latina transgression.

To the South, section 1 (Fig. 2) clearly evidences continuous deposition of the Latina I and Latina II members, whereby the Tufo Lionato and minor younger volcanites (of the Pozzolane Superiore) are intercalated as lenses in the littoral sands. In sections 1, 2, 4, 5 and 9 marine conditions caused a non-indurated and bleached character of the Tufo Lionato. Marine conditions also are clearly expressed in the overlying deposits. These younger deposits are made up of fine to medium sands, which are part of the Latina II member, characterized by a distinctive augite content. They contain various amounts of reworked tuffs and pozzolane. In the lowermost parts of the Latina II sands in section 1, augite content and red staining are least, in accordance with an expected poor preservation of off-shore deposited volcanites. In most sections mentioned, the lower sands are cross laminated (foresets alternatively dipping NE-SW, at angles of 12-20 degrees) and contain variable amounts of gravel, mostly in lag deposits or in separate layers. Fine to medium gravel also is present in the foresets. In section 1, possible wave ripples can be detected.

Tuffs intercalated in the early Latina II phase are homogeneous fine grained and contain concentric lapilli in nearly every outcrop. This greatly helps correlations, which in turn leads to identification of the Pozzolane Superiore (geol. map and FORNASERI et al., 1963). The intercalations form isolated lenses or separate beds, or the tuffs are completely mixed with the sand. In the southern Borgo Montello area (sections 1, 2 and 4), small Pozzolane Superiore lenses are nearly all cross-laminated similarly to the sands, and contain gravel. They also contain quite a number of moulds of ribbed bivalves and few calcareous concretions which have replaced the bivalves. Such outcrops with unambiguous littoral facies characteristics are indicated in Fig. 3b. Landward, i.e. NE of the limit of littoral deposits, strong soil formation or erosion have nearly obliterated the Pozzolane Superiore deposits together with the top of continental type Tufo Lionato (sections 8, 15, 16). A permanent continental environment is inferred.

Facies characteristics of the different deposits are not always unambiguous at all locations. For instance, beds of fine to medium grained augitic sands at many places underly the littoral augitic sands (Fig. 2 and 3b), and also are exposed East of the ultimate paleo-shoreline related to the highest stage of the Latina transgression (Fig. 3c). Depositional structures in these sands are restricted to parallel- to low angle cross lamination. Affinity of such outcrops to comparable sands of eolian origin (cf. lower part of sect. 3) as well as of littoral origin (sect. 6), could lead to distinction of a transitional (possibly backshore) sand facies.

A second type of deviant facies could be established in the Pozzolane Superiore sequence at locations 8 and 9. At these sites the volcanites are free of admixed or interbedded littoral sands, in contrast to outcrops further South. At location 9, the non-lithoid Tufo Lionato and the base of the overlying pozzolane and lapilli tuffs are intensely burrowed. The latter contain few bivalves (unspec.) and several layers rich in tree-leaf imprints. These, in turn, are overlain by a thin bed of non-volcanic, homogenee clay. At location 8, 200 m further East, the Pozzolane Superiore deposits (directly overlying lithoid Tufo Lionato) are less thick and strongly decayed by soil formation. The simultaneous occurrence at close distance of subaerobic (section 9) and continental (section 8) facies points to a transitional environment. The configuration resembles a lagoonal inlet (Fig. 3b).

Using the Pozzolane Superiore as a markerbed for the lower Latina II member, the littoral facies to the South can be linked via this transi-
Fig. 3 — a) Partition of deposits with littoral/aquatic and continental facies characteristics in the Borgo Montello area. Only the Tufo Lionato and older deposits are included; hence the figure reflects the paleogeography immediately after deposition of the Tufo Lionato. b) As fig. 3a; now only the lower Latina II transgressive sediments and the Pozzolana Superiore are depicted, representing the situation when the Latina transgression resumed after deposition of the Tufo Lionato. This figure confirms the inferred paleogeography of fig. 3a. c) The paleogeography of the Borgo Montello area at the highest stage of the Latina transgression. Roughly half of the area is covered by the augitic sands of the Latina II member (the former Duna Antica unit). To the SW the sands clearly are of littoral origin. Only in the central part of the area the sands are designated as transitional facies, and indeed could be eolian. The lagoonal clays, part of the Latina complex, are found due behind these sands. More inland strictly continental deposits are found.

— a) Distribuzione dei depositi di facies subacquea-litorale e continentale nell’area di Borgo Montello. Sono rappresentati solo Tufo lionato e depositi più antichi, per cui la figura suggerisce l’aspetto paleogeografico dell’area subito dopo la messa in posto del Tufo lionato. b) Come in 3a; sono rappresentati solo i sedimenti della fase trasgressiva Latina II e le Pozzolane superiori, per cui quella illustrata è la situazione alla ripresa della trasgressione di Latina, dopo la deposizione del Tufo lionato. Questa figura conferma il quadro paleogeografico ipotizzato nella figura 3a. c) Paleogeografia dell’area di Borgo Montello nel momento della massima avanzata della fase trasgressiva Latina II. Circa metà dell’area risulta coperta dalle sabbie augitiche del membro Latina II (= unità della Duna antica Auct.). Verso SW le sabbie sono indicate come di facies di transizione e potrebbero essere eoliche. Le argille lagunari, parte del complesso di Latina, si trovano subito a rido sotto di queste sabbie. Depositi decisamente continentali si trovano più all’interno.
tional facies to a continental facies at northern locations, which is characterized by non-deposition and well developed paleosols (see further).

The upper part of the Latina II member in all southern and central sections in the Borgo Montello area (Fig. 3c, loc. 1-12) consists of strongly augitic sands. Thick outcrops of these sands extend far to the west of Borgo Montello over the coastal area of central Lazio. In sections 1 and 4 it can be seen that the littoral deposits of the early Latina II phase regularly grade up into the augitic sands.

At their base the augitic sands are coarse grained and contain medium coarse gravel, in the foresets and as lag deposits. The sands are trough-shaped mega crossbedded with foresets uniformly dipping 050-060 NE, at high angles. Towards their top the sands are medium coarse grained and less distinctly crossbedded, at lower angles. By these features, in cliffs at locations 1, 3, 4 and 5, large outcrops of the augitic sands could be identified as coastal barrier deposits.

The north-eastern delimitation of the Latina II sands in the Borgo Montello area is interpolated along superficial outcrops between well exposed sections. This line, depicted in Fig. 3c, can be regarded to represent the paleo shoreline, since it trends perpendicular to the uniform foreset direction measured in the coastal barrier sands. East of this line the earlier mentioned transitional/collion sands and lagoonal clays are found. These lagoonal clays also form part of the Latina Complex (Sevink et al., 1984) and their top corresponds to the highest stage of the Latina transgression.

**Paleogeography after the Latina transgression**

To the North-East of Borgo Montello the continental volcanic deposits (including the Tufo Lionato) and the Latina Complex are non-conformably covered by dense black clays and coarse textured channel fills. The clays reach a thickness of 2 to 3 metres and contain numerous pedogenic calcareous nodules. The channel fills consist of redeposited non-sorted volcanic material (cf. section 16, Fig. 2) and are known as the “Formazione Tuftistica Fluviolacustre” (unit Tq of the geol. map of Lazio). They contain mammal bones and freshwater ostracods, and again represent a continental facies.

Maximum altitudes reached by these deposits are below the top of the Latina Complex (cf. contours of Fig. 3c), evidencing that after the Latina transgression, in the Borgo Montello area conditions remained continental (the Latina transgression reaching higher altitudes than any of the subsequent transgressions in the area; see below). Stable continental conditions are further evidenced by the strong development of the (non-croded) soils in the Latina sands and the tuffitic deposits (Luvisols and Nitrosols, de Wit, 1982; Duivenvoorden, 1985), which points to a prolonged period of subaerial exposure.

From the Borgo Montello area to the present coast (several kilometers W of Borgo Montello, trending NW-SE) each of the coastal barrier complexes, related to post-Latina high sea level stages (see Table 1), was deposited at a lower topographic level. The next, younger, Minturno

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**Fig. 4 — Plot of the different Agro Pontino transgressive phases in the curve of δ18O isotope fluctuations which define high and low eustatic sea level stages (after Shackleton & Opdyke, 1976).**

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**Posizione delle diverse fasi trasgressive dell’Agro Pontino nella curva delle variazioni dell’isotopo δ18O, che definisce stadi di sollevamento e abbassamento eustatici del livello del mare (Shackleton & Opdyke, 1976).**
Complex rests at c. 15 m asl, some 15 m lower than the Latina Complex. Contacts between the Latina and Minturno complexes are not exposed. However, their boundary is morphologically well expressed and near Latina (to the SE), takes the shape of a steep cliff. It moreover clearly shows up as a soil boundary, separating soils with markedly different soil development (see Table 1).

**Analytical procedures and age determinations**

Samples for radiometric datings were taken from the Pozzolane Medie, the Tufo Lionato and the Pozzolane Superiore, from positions indicated in Figure 2. The radiometric datings (Table 2) were carried out on separates of biotite phenocrysts (K-Ar) and of apatite (fission track) at the ZWO Laboratory of Isotope Geology, Amsterdam. Standard laboratory techniques were applied for the separation of biotite and apatite. K contents were determined by flame photometry with a lithium internal standard and caesium chloride-aluminium nitrate buffer. Ar was extracted in a resistor-heated all-metal vacuum furnace and analysed by isotope dilution techniques using a 38Ar-spark; the measurements were made by the static method with a modified MAT 111 mass-spectrometer. Fission track dating technique is according to ANDRIESEN & Bos (1986), using the population method on apatite and applying a Zeta calibration factor of 308.1 ± 18.

The analytical accuracy for the K concentrations is estimated to be within 1%. The external precision for the 40Ar/39Ar ratio of atmospheric argon is 0.2% (1 sigma). The analytical precision is calculated on the basis of the 1 sigma precision. The uncertainty of the argon-spark calibration is estimated to be within 2%. The errors for the fission track ages are calculated according to a Poisson distribution of the fission tracks.

**Discussion**

The onlap of the Latina transgression in the Borgo Montello area is reflected in a regular landward (NE) migration of the paleo-shoreline. In the sections, going from SW to NE, truncation of older deposits occurs at successively higher stratigraphic levels.

Section 1 reflects continuous littoral conditions whereby little Tufo Lionato has been preserved. In many other sections in the central part of the area, the co-occurrence of subaqueous characteristics of the Tufo Lionato and well defined littoral facies characteristics of the overlying sands is striking enough to suggest that the tuff was emplaced in the midst of a continuous transgression.

The paleogeographic reconstruction as outlined above and illustrated in Figures 3 a to c can account for fair detail for all observations made in the field. The reconstruction is simplest explained by assuming continuous onlap of one, undivided, Latina transgression. Hence the intercalated tuffs are excellent time markers for the Latina transgression.

Recently considerable attention has been paid to the reliability of radiometric age estimations of the volcanic rocks from the Volcano Laziale (for an overview, see FORNASERI, 1985). In particular K-Ar techniques were often found to produce erroneously high or conflicting ages. This was attributed to contamination during explosive eruption (with cognate and accessory lithics) and to the presence of trapped 40Ar, not derived from the decay of in situ 40K (PECCERILLO et al., 1984; LOCARDI, 1985 and pers. comm.). In particular in young tufts, like the ones studied, trapped 40Ar will seriously affect K-Ar datings. Since the three members of the Complesso dei Tufi Inferiori, present in the Borgo Montello area, also testify of an explosive and hence gas-rich origin, a cross-check of K-Ar and fission track datings was deemed necessary.

The K-Ar and fission tracks ages determinations, performed on the cogenetic minerals of three different tuff members of the Complesso dei Tufi Inferiori, are consistent and the two analytical techniques yield similar ages. The large error in the fission track dates prohibits a high age resolution and therefore excludes the detection of either cross-contamination within the formation or by other volcanic materials derived from elsewhere. However, the combination of induced track density and NBS glass density (see Table 2) can be used to estimate the U content of the mineral. Samples 3 and 4, both belonging to the Pozzolane Superiore, and sample 1 of the Pozzolane Medie have similar U contents. Sample 2 of the Tufo Lionato (continental) has a distinct higher U-content, differing 3 to 4 orders in magnitude. Cross contamination would certainly show up as a measure in the variance of the U-distributions, which is not the case. The consistency between K-Ar and fission track ages also contradicts the possibility of contamination.

Pervasive 40Ar trapped in the minerals is highly unlikely, because the erratic quantity of trapped 40Ar would have resulted in different individual ages, not agreeing with the age of the cogenetic mineral apatite.

Considering the stratigraphic position of the
Fission-track analytical data

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<th>Sample nr (apatite)</th>
<th>$P_s$ (10^4 t/cm²)</th>
<th>$P_t$ (10^6 t/cm²)</th>
<th>$P_0$ (962) (10^5 t/cm²)</th>
<th>Age ± 1σ (10^6 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pozzolane Medie</td>
<td>0.48</td>
<td>0.80</td>
<td>3.688</td>
<td>0.68 ± 0.17</td>
</tr>
<tr>
<td>(45)</td>
<td>(677)</td>
<td>(4066)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 PozzolaneSuperiore</td>
<td>0.28</td>
<td>0.59</td>
<td>3.688</td>
<td>0.53 ± 0.15</td>
</tr>
<tr>
<td>(26)</td>
<td>(1391)</td>
<td>(4066)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 PozzolaneSuperiore</td>
<td>0.21</td>
<td>0.49</td>
<td>3.688</td>
<td>0.49 ± 0.15</td>
</tr>
<tr>
<td>(20)</td>
<td>(1155)</td>
<td>(4066)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Tufo Lionato</td>
<td>0.81</td>
<td>1.80</td>
<td>3.688</td>
<td>0.52 ± 0.10</td>
</tr>
<tr>
<td>(75)</td>
<td>(1505)</td>
<td>(4066)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) $P_s$: density of spontaneous tracks; $P_t$: density of induced tracks; $P_0$: density of NBS glass; in parentheses the number of tracks actually counted in 200 grains for the spontaneous tracks and 50 grains for the induced tracks.

K-Ar analytical data

<table>
<thead>
<tr>
<th>Sample nr (biotite)</th>
<th>K (%Wt)</th>
<th>Aliquot used for Ar determination (g)</th>
<th>Radiogenic $^{40}$Ar (10^-10 cm²/g NTP)</th>
<th>$^{40}$ArAfar (%)</th>
<th>$^{40}$ArTot (%)</th>
<th>Age (10^6 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pozzolane Medie</td>
<td>7.58</td>
<td>0.297776</td>
<td>0.190</td>
<td>97.1</td>
<td>97.3</td>
<td>0.64 ± 0.10</td>
</tr>
<tr>
<td></td>
<td>7.63</td>
<td>0.299601</td>
<td>0.217</td>
<td>97.3</td>
<td>97.6</td>
<td></td>
</tr>
<tr>
<td>3 PozzolaneSuperiore</td>
<td>7.81</td>
<td>0.599827</td>
<td>0.174</td>
<td>94.0</td>
<td>94.0</td>
<td>0.61 ± 0.06</td>
</tr>
<tr>
<td></td>
<td>7.83</td>
<td>0.583901</td>
<td>0.197</td>
<td>93.1</td>
<td>94.4</td>
<td></td>
</tr>
<tr>
<td>4 Pozzolane Superiore</td>
<td>7.78</td>
<td>0.299840</td>
<td>0.142</td>
<td>95.9</td>
<td>95.9</td>
<td>0.54 ± 0.07</td>
</tr>
<tr>
<td></td>
<td>7.78</td>
<td>0.600793</td>
<td>0.183</td>
<td>94.0</td>
<td>94.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.94</td>
<td>0.300741</td>
<td>0.161</td>
<td>94.8</td>
<td>94.8</td>
<td></td>
</tr>
<tr>
<td>2 Tufo Lionato</td>
<td>7.94</td>
<td>0.599071</td>
<td>0.142</td>
<td>91.0</td>
<td>91.0</td>
<td>0.50 ± 0.07</td>
</tr>
<tr>
<td></td>
<td>7.94</td>
<td>0.609765</td>
<td>0.154</td>
<td>89.6</td>
<td>89.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.601329</td>
<td>0.129</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\lambda^{40}_{K}\beta = 5.962 \times 10^{-10}$ a⁻¹, $\lambda^{40}_{K} = 0.581 \times 10^{-10}$ a⁻¹, abundance $^{40}$K = 0.01167 atom % total K.

Tab. 2 — Analytical results and K-Ar and fission track datings of the Borgo Montello samples.

— Dati analitici relativi alle datazioni con il metodo K-Ar e con quello delle tracce di fissioni, effettuate su campioni di Borgo Montello.

individual samples (see Fig. 2), their estimated ages and the error ranges of these estimations (see Table 2), the volcanitic members should be considered as one complex. The estimated K-Ar age of this complex ranges from 0.64 to 0.50 Ma, with a mean age of 0.57 ± 0.08 Ma and its fission track age from 0.64 to 0.49 Ma, with a mean age of 0.56 ± 0.14 Ma.

We believe that these mean ages represent the true age of the Complesso dei Tufi Inferiori of the Volcano Laziale. A quite younger age of 0.338 ± 0.008 Ma for the Tufo di Villa Senni Formation of the same complex has been reported by RADICATI DI BROZOLI et al. (1981). This age is an average of $^{40}$Ar-$^{39}$Ar analyses on leucite and biotite and Rb-Sr analyses of whole-rock/biotite pairs. The Tufo di Villa Senni lies between older tuffs dated at 0.5 Ma and more recent lava flows. In this respect both dates can be true and do not contradict, because the Tufo di Villa Senni is regarded to form the top formation of the Complesso di Tufi Inferiori (Fornaseri, 1985).

With the here presented data the discussion about Volcano Laziale volcanite-datations certainly will not be concluded. With regard to the stratigraphy of the Pleistocene coastal complexes in southern Lazio, it is evident that a major hiatus exists between the Latina Complex
and the younger coastal complexes present in the area.

Due to its monomictness, conspicuous lithoid character and unambiguous stratigraphic position, the Tufo Lionato would be the best time marker for the Latina transgression. However, as a result of the lack of resolution of the age estimations obtained, the mean age of the Tufo Lionato and the Pozzolane Superiore (both de facto intercalated in the Latina sands; stratigraphically the Pozzolane Medie clearly antedates the Latina transgression) is taken to date the Latina transgression at 0.56 ± 0.1 Ma. Assuming that this age is correct, the Latina transgression would correlate with isotopic stage 15, one of the main high seal levels stages in the lower Middle Pleistocene, established from deep-sea core V 28-239 (Shackleton & Opdyke, 1976; see Figure 4). The next younger Minturno Complex, which rests closer to the recent shoreline at a considerable lower elevation and is dated at 0.12 Ma, would correlate to isotopic stage 5.

Intermediate Mid-Pleistocene high seal levels stages (numbered 13, 11, 9 and 7) clearly left no traces in the form of marine terraces in the area studied. Either they were completely eroded during the Upper Pleistocene or Holocene, or are presently deeply buried under sediments, dating from the Minturno and more recent phases.

The foregoing implies that the soil-chronosequence from the Agro Pontino is incomplete. This was already indicated by the marked differences in soil development between the Latina and Minturno Complexes (Sevink et al., 1982 and 1984; see Table 1). As suggested by the study of Dai Pra & Arnoldus-Huyzendveld (1984), further study in the Agno Romano a more complete soil-chronosequence may exist. Study of that area seems promising and might provide additional information with regard to the Pleistocene development of the Latian coast.

Conclusions

The oldest outcropping coastal complex in the Agro Pontino, the Latina complex, originated from one single Mid-Pleistocene transgression. It was found that in the transgressive sediments, tuffs from the Volcano Laziale are intercalated. Radiometrically, the volcanics have to be considered as one complex, representing the Completo del Tufi Inferiori. By these volcanic intercalations, the Latina transgression was reliably dated at 0.56 ± 0.1 Ma and therefore correlates with isotopic stage 15. In the Agro Pontino, the next younger complex correlates with isotopic stage 5. This implies that in the soil-chronosequence, established for this area, four members are missing.

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RIASSUNTO

La zona costiera del Lazio centrale è ben nota per i suoi complessi costieri pleistocenici. Nelle aree a sud del delta del Tevere la cronostatigrafia, soprattutto nei complessi più antichi, è ancora incerta ed è stata basata ampiamente su cronosequenze di suoli.

Nell'area di Borgo Montello si trovano affioramenti del Compleso di Latina (Pleistocene medio), il complesso trasgressivo più esteso dell'Agro Pontino, con intercalazioni di vulcaniti del Vulcano Laziale. Dettagliati studi paleogeografici hanno mostrato che questo Compleso di Latino si è formato in un'unica fase trasgressiva.

Sono state effettuate datazioni con i metodi K-Ar e delle tracce di fisione su campioni delle vulcaniti, facenti parte del «Completa del Tufi Inferiori» Auct.: i metodi hanno dato rispettivamente un'età di 0,57 e di 0,56 Ma. Sulla base di queste datazioni il Compleso di Latina può essere correlato con lo stadio isotopo 15. Il successivo, più giovane, complesso trasgressivo nell'Agro Pontino (Compleso di Minturno), i cui depositi raggiungono notevolmente minori del precedente, è stato datato approssimativamente a 0,12 Ma (= stadio 5). Tra i due complessi esistene quindi una notevole lacuna stratigrafica. I sollevamenti eustatici di età intermedia (stadi 13, 11, 9 e 7) sembrano non aver lasciato tracce sotto forma di terrazzamenti marini. La lacuna è documentata nella cronosequenza dei suoli ricostruita per quest'area.

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BIBLIOGRAFIA


