THE AGRO PONTINO SURVEY PROJECT

Methods and preliminary results

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FAULTED LAND: THE GEOLOGY OF THE AGRO PONTINO

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SUMMARY

The mountains surrounding the Agro Pontino mainly consist of limestone and were formed during the Mesozoic. The tuffs in the northwestern part of the Agro Pontino date to the early Middle Pleistocene. The Agro Pontino is a graben, which is part of a horst-and-graben system, formed mainly during the Middle Pleistocene. Its formation was accompanied by much volcanic activity. On the basis of soil surveys four marine terraces have been distinguished along the Tyrrhenian coast. Each terrace consists of a sandy beach ridge and a clayey lagoon, representing different sea level changes during the Pleistocene (isotope stages 13/14, 5e, and 5b/c) and the Holocene.

1 INTRODUCTION

The natural factors in the landscape that can affect cultural processes fall into biotic and abiotic categories. The abiotic, or physical, factors are climate, geology, relief, and soils. These factors vary through time and cause changes in the landscape. Research of the geological, physiographic, and pedological factors makes it possible to reconstruct the various stages in the development of the landscape.

In the framework of the Agro Pontino project particular attention is paid to those changes in the landscape that occurred during the period of human occupation. The earliest indications of human activity in the Agro Pontino stem from the Middle Palaeolithic, although earlier occupation cannot be ruled out.

The description of the development of the landscape provided here is based on geological, geomorphological, and pedological data, supplemented by palaeoclimatic, biological, and archaeological data where necessary. Following a brief review of events that occurred before the Quaternary is a description of the situation at the beginning of the Pleistocene, which is the basis for the development of the landscape during the Late Pleistocene and Holocene.

2 PRE-QUATERNARY

The Apennines in Central Italy consist of a number of parallel mountain chains with a northwestern-southeastern orientation. They have been subdivided into the Anti-Apennines, the Pre-Apennines, and the Apennines. The Monti Ausoni and the Monti Lepini, ranges bordering the northeast of the Agro Pontino, are part of the Volsci chain, which is part of the Anti-Apennines. Monte Circeo, a separate mountain at the southern end of the Agro Pontino plain, is considered to be an isolated part of the Apennines. It is generally accepted that the Apennines resulted from a tectonic wave, running from SW to NE. During the Middle and Late Miocene this orogenic wave folded and overthrusted a thick complex of Mesozoic sediments (Upper Triassic to Paleocene), resulting in the formation of a number of NW-SE running ridges (Sestini 1970). Opinions differ about the period when the Anti-Apennines in this part of Italy were uplifted. Parotto and Praturlon (1975) maintain that the major uplifting took place during the Upper Messinian (Early Miocene). Accordi (1966), however, assumes that the mountains were formed during the early Middle Pliocene. The Mesozoic limestone that constitutes the Volsci chain was displaced 50 to 60 km in a north-northeasterly direction during the orogenic period. Monte Circeo has also been displaced, but it is not understood in what direction or over what distance this took place (Accordi 1966).

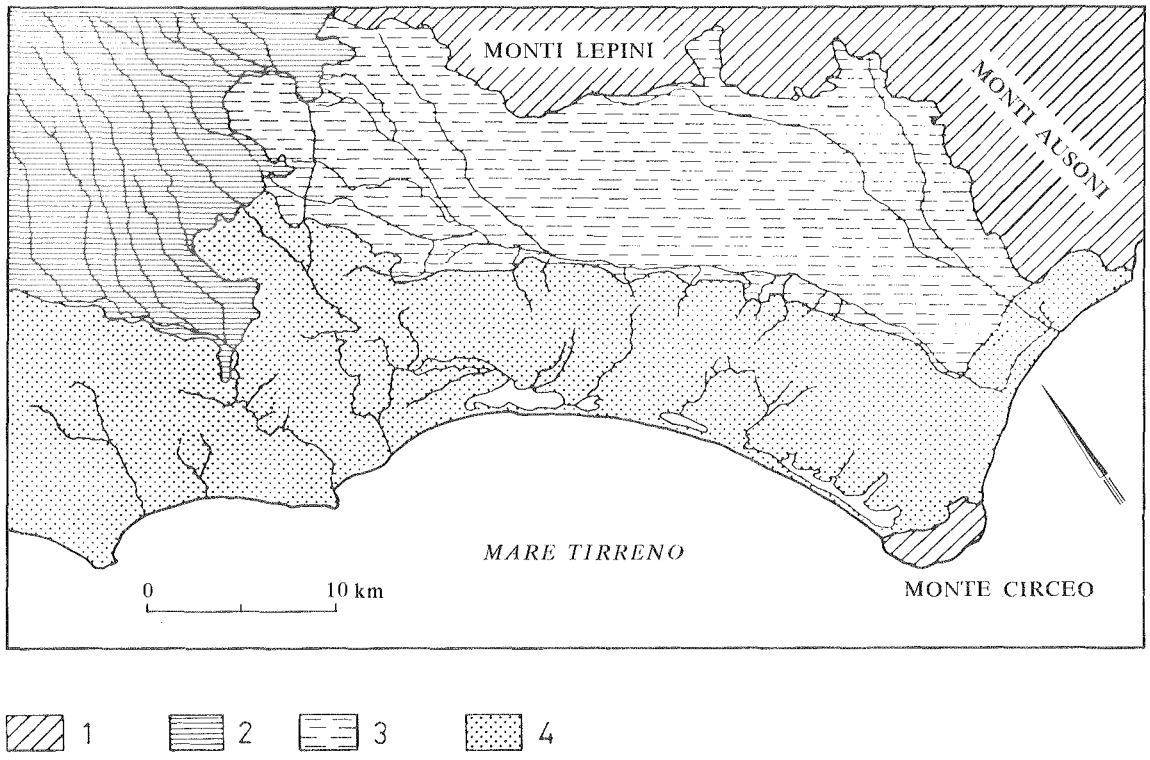

Figure 1. Physiographic map of the Agro Pontino. (after Blanc 1937) 1: calcareous mountains; 2: tuff-covered hills; 3: peat and clay filled graben; 4: sandy-clayey marine terraces.

3 OUTLINE OF THE QUATERNARY OF THE AGRO PONTINO

The Agro Pontino can be simply described as a large graben filled with Quaternary sediments, the upper strata of which have a largely marine-aeolian origin. In the northwest this formation merges with the dissected lower slopes of the Volcano Laziale, and to the north and east it is bordered by a large limestone massif, which rises abruptly above the plain (Figure 1).

This outline focuses on the local tectonics and volcanism and attempts to provide a concise description of the superficial geology. Particular attention is paid to the dating of the marine and aeolian sediments. A full description of their characteristics is presented in the following paragraphs.

3.1 Faulting and volcanism

Faulting and volcanic activity are characteristic for the Pleistocene in this part of Italy. The major fault lines in the Agro Pontino are oriented NW-SE, and vertical movements along these faults were responsible for the formation of a stepped graben which embraces the entire Agro Pontino. The northeastern part, parallel to the mountains, is somewhat lower than the area along the southwest coast, and is designated 'the graben' in this paper (Figure 1).

Faulting seems to have begun when the Volcano Laziale became active at the end of the Early Pleistocene. There seem to have been few or no displacements along the faults during the Late Pleistocene; a slight uplift of the northwestern part of the Agro Pontino apparently occurred during the early Würm (Sevink *et al.* 1982).

The Volcano Laziale was most active between 700 and 350 Kyr BP (1 Kyr = 1000 years). The tuff that is widely distributed all over the northwestern part of the Agro Pontino dates to this period (X on Figure 3). Near the Volcano Laziale the tuff deposits are very thick and heavily incised. To the south the sharply dissected tuff-landscape becomes gradually less pronounced and finally plunges beneath the younger sediments of non-volcanic origin. The most southerly outcrops of this older landscape appear near Borgo Montello where they are intercalated with sediments of the Latina level (see below). The fluvio-lacustrine tuffs, which appear in places in the northwestern part of the area, are younger and presumably date to the Middle Pleistocene.

Although the Volcano Laziale was active until 45 Kyr BP (Parotto and Praturlon 1975), no volcanic sediments from the more recent past can be traced to this volcano.

Recent evidence shows that volcanic sediments of a relatively more recent age appear in the Agro Pontino (Eisner *et al.* 1986), which presumably come from the Campo Fegreii (Sevink and Paris 1989). Two tuff layers were found in a pollen core taken from the graben in the area of La Mezzaluna; the layers were 5.45 and 4.65 m below the modern sea level, and their dates are 12.5 Kyr and 10 Kyr BP, respectively.

3.2 Sedimentation and erosion

At several places at the foot of the limestone mountains that border the Agro Pontino are debris slopes or fans, which extend onto the plain. These sediments, a complex result of alternating deposition and erosion phases, were formed during different periods. Today the surfaces of these deposits continue to be unstable, that is, they are subjected to sedimentation and erosion.

Much of the Agro Pontino consists of Pleistocene and Holocene marine, fluviatile, and aeolian deposits. Initially, the area was divided into two parts (Blanc 1937): a low part at the foot of the Monti Lepini and Monti Ausoni with fluviatile and aeolian deposits and a higher part along the sea consisting of sandy, principally aeolian, deposits. A completely different picture, however, emerged from the pedological research of the 70s and 80s (Sevink *et al.*, this volume).

The higher part consists of a series of four well-developed marine terraces with a local aeolian cover. The marine terraces are called, from the highest to the lowest, and from oldest to youngest, the Latina level, the Minturno level, the Borgo Ermada level, and the Terracina level (Sevink 1977; Remmelzwaal 1978; Sevink *et al.* 1984). The youngest terrace, the Terracina level, is a simple and well-developed beach ridge-lagoonal system. The older terraces have been greatly affected by erosion and, for the most part, are more complex.

In the graben is an extensive complex of peaty and clayey Holocene sediments that cover older sediments and in places are more than 10 m thick. In the northwestern part Pleistocene clays, travertines, and tuff deposits appear at the surface and fluvio-colluvial deposits lie at the foot of the mountains (Duivenvoorden 1985; De Wit 1982). A more normal sequence of marine terraces is found along the coast between Terracina and San Felice Circeo, but this consists of only the two youngest terraces.

On the north side of the Agro Pontino the only evidence of marine sediments are extensive sandy deposits in the area south of Priverno, which are probably the remnants of a 40 m high marine terrace and associated aeolian sediments (Remmelzwaal 1978; Sevink *et al.* 1984).

The major cause for the development of marine terraces at different elevations are world-wide changes in sea level, which are related to the climatic fluctuations that occurred during the Quaternary. It is generally accepted that during the Pleistocene the relative sea level has gone down causing the formation of marine terraces that decrease in height as they decrease in age. The higher part of the Agro Pontino furnishes a good example. On a regional or even local level, however, other processes, such as tectonic

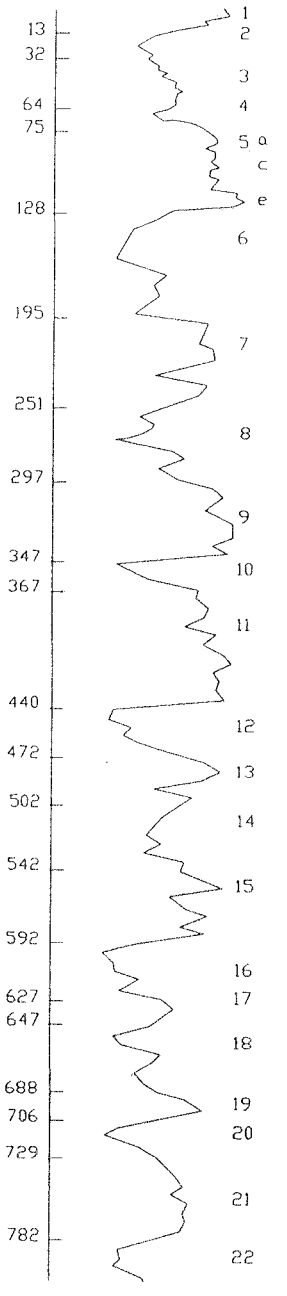

Figure 2. Oxygen isotope stratigraphy: Core V28-238, with stages 1-22, local names, and age estimates for stage boundaries. (after Shackleton and Opdyke 1973)

movements and compaction of sediments, also play a role. Because of these other factors, the local sea level fluctuations and the elevation of older marine sediments can strongly deviate from the general pattern. In the lower part of the Agro Pontino there is evidence for such deviations in the form of older marine sediments located at some depth below the present-day sea level.

3.3 Dating of the marine terraces

There are several ways to date marine terraces. First, one can infer relative age from the degree of soil development. In the Mediterranean part of Italy no periglacial conditions, which destroy soils through such processes as solifluction, occurred during the glacial periods. This means that the age of a land surface with relatively little relief, which is not heavily influenced by wind and water erosion, can be interpreted from the degree of soil development. By comparing the degree of soil development in locally stable areas, it is possible to set up a chronological sequence of soils that allows relative dating of the terraces. Comparison with similar soil sequences from dated contexts elsewhere provides a more trustable date.

The four marine terraces in the Agro Pontino consist of a more or less eroded beach ridge with associated aeolian deposits, both very porous sediments, and a lagoon, with predominantly heavy, rather poorly-drained clays. Differences in soil development that are related to time are most clear in the sandy deposits. Soil formation in clays is strongly determined by drainage conditions and shows less differentiation through time.

A second method of dating the marine terraces is through fossils found in their sediments. The mollusc *Strombus bubonius*, found today in Senegal, is an indicator of warm periods. This method is not very useful on the Agro Pontino since *Strombus bubonius*, as far as I know, is mainly found secondarily deposited in fluviatile sediments (Blanc 1935; Dai Pra and Arnoldus-Huyzendveld 1984; Hearty and Dai Pra 1986). Apart from this, dating with *Strombus bubonius* has various other problems, so that the method has to be considered unreliable.

Archaeological artifacts have also been regarded as fossils and used for dating by providing a *terminus ante quem*. The artifacts found in the geological contexts of interest are compared with chronotypologies based on archaeological materials taken from stratified sites in caves in Monte Circeo, the Monti Lepini, and the Monti Ausoni. In some cases strata in the caves have been dated by radiocarbon. This method is also very inexact.

A third method is correlation with terraces elsewhere that have the same elevation and have been dated with absolute methods. Terraces on the Agro Pontino have been correlated with those in North Latium (Sevink 1977; Remmelzwaal 1978; Sevink *et al.* 1982, 1984). Italian geologists (Bigazzi *et al.* 1973) described a sequence of marine terraces in North Latium whose elevations were 2-3 m, 10-15 m, 18-22 m, and 39-48 m

above sea level. These terraces are dated by radiometric measurements (fission track and K/Ar). Through correlation with this sequence the Minturno level (16 m) is dated 127 ± 13 Kyr BP (isotope stage 5e) (Figure 2), the Borgo Ermada level (6 m) 90 ± 18 Kyr BP (isotope stage 5c) and the Terracina level post-Würm. The Latina level is considerably lower than 39-48 m above sea level. Sevink *et al.* (1982) point out that the Latina level may not even correlate with the 39-48 level in North Latium since other marine terraces could have existed between the Minturno and the Latina levels. Remmelzwaal (1978) correlates the Latina complex with the 39-48 m level in North Latium on the basis of their similarity in volcanic minerals. The 48 m Tarquinia level is dated to the Milazzian (isotopic stage 13/14, 500 Kyr BP). This correlation method in such a tectonically active area as Central Italy, is not trustworthy, particularly for the older terraces.

The final possibility is an absolute dating method. Tuffs within the Latina level have been dated by K/Ar and fission track. The K/Ar dates averaged 570 ± 8 Kyr BP, and the fission track dates 560 ± 14 Kyr BP. Together these give a date of 560 ± 10 Kyr BP (De Wit *et al.* 1987), which would place the Latina level in isotope stage 15.

Absolute dates for the Minturno and Borgo Ermada levels have also been recently obtained with amino acid racemization on three species of shell, *Glycymeris*, *Arca*, and *Cerastoderma* (Hearty and Dai Pra 1986). Samples were collected from six places on the Agro Pontino. The authors distinguished three amino zones and the two youngest ones could be geomorphologically and stratigraphically associated with the Minturno and Borgo Ermada complexes. Both complexes have been compared with deposits elsewhere in the Mediterranean where dates from amino acid racemization have been calibrated with U-series dates on coral (Hearty 1986). The Minturno and Borgo Ermada levels are dated to ca. 125 Kyr BP (isotope stage 5e) and 90 ± 15 Kyr BP (isotope stage 5c), respectively. The size of the standard deviation in the date for the Borgo Ermada level means that it could just as well be placed in isotope stage 5b. These dates agree well with those proposed by Sevink *et al.* (1982) on the basis of soil formation in and elevations of the marine terraces.

4 *THE MIDDLE PLEISTOCENE: THE LATINA TERRACE*

The oldest dated sediments on the surface in the Agro Pontino belong to the Latina level and were probably deposited during the transgression phase of isotope stage 15. They consist of marine and aeolian deposits and associated tuffs. Given the age of this formation, the occurrence of Early Palaeolithic artifacts on its surface cannot be excluded.

Except in the northwestern part of the Agro Pontino the Latina level has an average elevation of ca. 25 m. It consists of rather poorly drained, lagoonal deposits and well-drained sandy beach deposits. In the north the Latina level sediments are uplifted. Remnants of the fossil beach ridge and coastal dunes are found only between the Astura and the Fosso di Moscarello in the northwestern part of the Agro Pontino (VII on Figure 3). Layers with gravel, much of it being flint gravel, appear in places. In other parts of the Agro Pontino all of the sandy deposits and part of the lagoonal sediments have been eroded away during one or more sea transgressions. The lagoonal sediments of the Latina level are particularly extensive (VIII on Figure 3). They consist of a clay layer, several meters thick, overlying a thick layer of well-sorted, generally fine sands. These sands surface on hillsides and in valley slopes.

The oldest archaeological artifacts on the Latina level are from the Middle Palaeolithic (older than 35 Kyr BP).

In the surroundings of Fossanova tuffs intercalated in lagoonal sediments give, on the basis of a K/Ar, a date of 470 Kyr. Therefore, these sediments and the aeolian sands above them (IX on Figure 3) can be considered part of the Latina level complex. Within the aeolian sands in this area, however, more than one phase of aeolian deposition can be

Figure 3. The major sedimentary complexes in the Agro Pontino. (adapted from Duivenvoorden 1983, 1985; Van Huissteden 1983; Kamermans 1980; Sevink et al. 1982, 1984; drawing IPP)

I	*beach ridge deposits, Terracina level*	*VIII*	*lagoonal deposits, Latina level*
II	*lagoonal deposits, Terracina level*	*IX*	*aeolian deposits*
III	*beach ridge deposits, Borgo Ermada level*	*X*	*tuff deposits*
IV	*lagoonal deposits, Borgo Ermada level*	*XI*	*travertine*
V	*beach ridge deposits, Minturno level*	*XII*	*alluvial and colluvial deposits*
VI	*lagoonal deposits, Minturno level*	*XIII*	*recent colluvio-alluvial valley fills*
VII	*beach ridge deposits, Latina level*		

differentiated and some of the sands may have blown in more recently (Arnoldus-Huyzendveld *et al.* 1985). No sediments of the Latina level appear at the surface in the lower part of the graben.

No surface remains of terraces that were formed between the development of the Latina level (isotope stage 15, 560 Kyr BP) and the Minturno level (isotope stage 5e, 125 Kyr BP) have been preserved in the Agro Pontino. Subsurface deposits show that there was sedimentation during the later Middle Pleistocene sea transgressions and that marine terraces were formed (Hearty and Dai Pra 1986). That there is no outcrop of these terraces in the Agro Pontino may be due to heavy erosion during the Late Pleistocene isotope stage 5e transgression.

5 *LATE PLEISTOCENE*

5.1 Eemian interglacial: the Minturno terrace

The Minturno terrace, which was formed during the last interglacial (isotope stage 5e), has an average elevation of about 16 m. The terrace has a rather simple structure, consisting of a large fossil beach ridge (V on Figure 3) in front of a strongly dissected lagoonal deposit (VI on Figure 3). The relief of the lagoonal deposit is level to hilly, and the upper layers are poorly drained clayey materials. In front of it and partly on top of it are level to slightly hilly, well-drained beach sediments. Gravelly deposits, with an average grainsize diameter of 3 cm, are found about 4 m below the surface. These deposits are the accumulated residue from abrasion of older gravelly deposits that occurred during transgression phases of the sea (Sevink *et al.* 1982). The primary source of these gravels are Tertiary deposits near Nettuno which contain much flint and have been eroded and transported along the coast (Sevink *et al.* 1982). Gravel from Tertiary deposits near Rome could also be present (A. Arnoldus-Huyzendveld, personal communication). A third possible source is a more westerly Apennine chain whose erosion produced gravels that were transported by the sea directly to the coast (A.G. Segre, personal communication).

Remnants of the original Minturno surface have been found in the lower part of the graben in the northwestern part of the Agro Pontino in the surroundings of Cisterna (VI on Figure 3). These are heavy clays deposited in a circumlagoonal environment with a level surface and poor drainage (Duivenvoorden 1985).

In the extreme northern part of the area are level travertine deposits (XI on Figure 3) which are partly covered by heavy circumlagoonal clays. Duivenvoorden (1985) shows that at least part of the travertines must date to an early stage of the transgression during which the Minturno terrace was formed (isotope stage 5e).

The oldest artifacts that occur on the Minturno terrace are also, typologically speaking, from the Middle Palaeolithic.

5.2 Würm: the Borgo Ermada terrace

Overall, during the Würm glaciation there was a pronounced lowering of the sea level and a concomitant fluvial dissection of the landscape. The sea level, however, underwent large fluctuations in the process of lowering, and a period with temporary high sea levels occurred during the early Würm. During this period, the Borgo Ermada terrace formed.

The Borgo Ermada terrace has an average elevation of ca. 6 m. It has a level to slightly sloping surface and consists of well-drained, sandy beach ridge sediments (III on Figure 3) in front of poorly drained, clayey, lagoonal deposits with a level relief (IV on Figure 3). In general, the Borgo Ermada level in and around the Agro Pontino is similar to the Minturno level, with lagoonal deposits lying behind beach ridge sediments (Remmelzwaal 1978; Conato and Dai Pra 1980; Sevink *et al.* 1984). Near Foce Verde, however, the terrace has a more complex structure, with a number of parallel beach ridges separated by lagoonal deposits. The complex of sandy beach ridges perhaps developed during a regression when a series of beach ridges formed at successively lower elevations. Possibly this regression was due to local uplifting (Sevink *et al.* 1982).

In the graben the Borgo Ermada deposits are extensive (IV on Figure 3). They are found mainly along the southwestern rim of the graben adjacent to deposits of the Latina level and in the northwest in the vicinity of Cisterna. These areas are almost completely flat and consist of poorly drained clays. Along the southeast coast both the beach ridge (III on Figure 3) and lagoonal (IV on Figure 3) deposits are present. Marine shells and fragments of them are found in these sediments, and the diatoms present indicate a marine to lagoonal environment (Sevink *et al.* 1984). In the extreme northwestern part of the Agro Pontino the Borgo Ermada deposits are fine, dark clays. From the very fine texture

of the clays and the broad depositional area, Duivenvoorden (1985) infers that these clays were deposited in a circumlagoonal environment. In such environments, much organic material gets incorporated into the sediments, which would explain the dark colour of the clay.

One would expect to find Pontinian artifacts (late Middle Palaeolithic) on the Borgo Ermada terrace. In the circumlagoonal deposits, many are found, but on the Borgo Ermada beach ridge between San Felice and Terracina, Middle Palaeolithic artifacts are very rare. The reason for this could be a difference in age between these coastal deposits and the circumlagoonal deposits, uplifting in the northern part of the Agro Pontino, but not in the southern part, or later erosion of part of the terrace near the coast.

The southern part of the complex of marine terraces has a later aeolian cover, which, according to Sevink (Sevink *et al.* 1984), was deposited in the period from the Würm to the early Holocene.

The pollen core from La Mezzaluna, near Sezze, gives an impression of the conditions in the graben during the Würm. Seven meters beneath the present-day sea level are sandy deposits with fragments of shell (Eisner *et al.* 1986). The dating of this deposit, if it is the result of a sea transgression, poses serious problems. The clayey peat layer above the sand layer has been dated to 15,850 ± 500 BP and the clay layer under the sand layer yielded a date of 34,650 ± 950 BP. This would indicate a sea level at least 7 m below the present-day sea level during the last ice age. Given the subsidence of the graben, an even higher sea level would need to be postulated. It is generally accepted, however, that during the coldest period of the last ice age the sea level was from 100 to 150 m below that of today (Peterson *et al.* 1979). There appear to be three ways to explain the 'transgression deposits'. The first is to suppose that there was a tectonic uplifting of the sandy deposits of nearly 100 meters! The second is that the deposits come from much older, reworked marine levels. And the third is to interpret the sandy layer not as a 'transgression deposit' but as a fluviatile sediment (see also Hunt and Eisner, this volume).

6 *HOLOCENE*

The youngest terrace, the Terracina terrace, was formed in the Holocene and has a simple structure with a row of coastal dunes in front of a lagoonal lake or lagoonal deposits (II on Figure 3). The terrace is slightly above present-day sea level and the dunes exhibit strong relief (I on Figure 3). The dunes consist of well-sorted, well-drained, calcareous sands. The lagoonal deposits (II on Figure 3), which in some places are anthropogenic, consist of non-calcareous clays, peaty clays, and peats. In places aeolian sands lie over the lagoonal deposits.

The young coastal dunes (I on Figure 3) between Terracina and San Felice and the lagoonal deposits behind them (II on Figure 3) are also part of the Terracina level.

The oldest archaeological materials that have been found on the coastal sediments of the Terracina level date to the Bronze Age (Blanc and Segre 1953).

The Holocene peaty and clayey sediments in the lowest part of the graben northeast of Pontinia are part of the lagoonal deposits of the Terracina level (II on Figure 3). Before the reclamation of the 30s, the graben was cut off from the sea by the two youngest marine terraces and this part was a marsh. The surface of the deposits is flat and they are poorly drained; the uppermost meters are composed mainly of peat and clayey peat. The pollen core taken in La Mezzaluna in the graben shows no discontinuity in sedimentation from 50 cm to 770 cm below the surface. The average rate of sedimentation has been calculated at 5.8 cm per century. From 16,000 to 11,590 BP, the rate was about 3.5 cm per century, between 11,590 and 9860 BP it averaged 8.6 cm per century, between 9860 and 6450 BP it was 6.1 cm per century, and in the period between 6450 and 4730 BP it was 8.7 cm per century.

In some places in this part of the graben are calcareous, travertine-like deposits, which form from the influx of calcic waters from springs or from streams running down from the mountains (Sevink *et al.* 1984).

A large part of the lagoonal sediments in the graben are covered by a layer of younger alluvium or colluvium (XII on Figure 3). Sevink *et al.* (1984) initially explained the alluvium in the graben to be the residue of irrigation and drainage channels since most of them were more or less rectilinear deposits of sand and gravel. Later, Sevink (1985) referred to them as "colmatage" deposits, i.e. sediments resulting from deliberate silting up of the lower, swampy areas of the Agro Pontino. He dates them to the pre- or Early-Roman period.

The valleys of the Fiume Astura and the Fosso di Moscarello, in the western part of the Agro Pontino, contain recent colluvio-alluvial deposits (XIII on Figure 3). Such deposits also occur to the south in channels which cut through the complex of marine terraces.

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