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Alternating Lacustrine-Marsh Sedimentation and Subaerial Exposure Phases During Quaternary: Prečko, Zagreb, Croatia

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Key words: Pleistocene, Holocene, Limnic, Paludal and fluviatile deposits, Loessoid, Palaeoclimate, Palaeosol, Conditional marker horizon Q', Prečko, Zagreb

Ključne riječi: Pleistocen, holocen, limničke, paludalne i fluvijalne taložine, lesoid, paleoklima, paleotlo, uvjetni reper Q', Prečko, Zagreb

Abstract

West of Zagreb, within an area of 6 ha, four units totalling 60 m thickness have been recognized on the basis of core analysis, geological mapping, geophysical measurements in exploration wells and laboratory analyses. The deepest situated unit (Unit I) accumulated during the Lower Pleistocene. It is interpreted to have formed by accumulation of loess mixed with local materials (loessoid). Unit II is considered to be Middle Pleistocene in age. While in its lower and middle part fluviatile-lacustrine sediments are recognized, in the upper part aeolian material contributed to the composition of the sediments. This unit is overlain by Unit III which is considered to be Upper Pleistocene in age. The composition of the unit is dominated by material of loess origin, and is interpreted to have formed in a marshy environment. The youngest unit (Unit IV) is composed of Holocene fluviatile sediments. The upper parts of Units I, II and III display palaeosol features indicating that were subjected to the action of soil forming processes during phases of subaerial exposure. These occured as a result of lake/marsh infilling which happened during the cold and dry glacials and probably lasted during the older periods of interglacials. Resumption of shallow and quiet water environments during the younger periods of interglacials is congruous with the increased influence of humidity. The formation of both, specific sedimentary environments and phases of subaerial exposure was also influenced by differently displayed neotectonic activity which was only partly compensated for by sedimentation and denudation respectively.

Sažetak

Zapadno od Zagreba, na površini od 6 ha na osnovi rezultata bušenja, geofizičkih mjerenja u bušotinama, terenske determinacije i laboratorijskih analiza, razlučene su četiri jedinice do dubine od 60 m. Najdublja, jedinica I nastala je tijekom donjeg pleistocena nakupljanjem lesa uz miješanje s lokalnim materijalom (lesoid). Jedinica II je srednjopleistocenska. U donjem i srednjem su dijelu zastupljeni riječno-jezerski, a u gornjem sve više i eolski sedimenti. Slijedi jedinica III, gornjopleistocenska, dominantno lesnog podrijetla, akumulirana u močvari. Najmlađa je jedinica IV, izgrađena od holocenskog riječnog nanosa. Vršni dijelovi jedinica I, II i III imaju značajke paleotala budući su bili izloženi pedogenezi. Kopnene faze su rezultat zapunjavanja jezera/močvara tijekom hladnih i suhih glacijala, a trajale su i stanovito vrijeme kroz starija razdoblja interglacijala. Sukladno sve većem utjecaju humiditeta, u mlađim razdobljima interglacijala obnavljane su plitke, mirne vodene sredine. Na tip naslaga i pojavu kopnenih faza utjecala je i različito izražena lokalna neotektonska aktivnost koja je samo djelomice kompenzirana sedimentacijom, odnosno denudacijom.

1. INTRODUCTION

Drilling and geophysical measurements undertaken within an area of 6 ha south of Prečko (Western Zagreb, Fig. 1) have allowed the study of the lithological composition, paleoenvironmental reconstruction and stratigraphic relationships of the deposits. In part, this paper represents an expansion of investigations carried out by VELIĆ & SAFTIĆ (1991) 10 kilometer westwards, along the left bank of the Sava river, in the vicinity of its confluence with the Krapina river. They defined the conditions and processes of formation of the Middle Pleistocene fluviatile-lacustrine and Holocene fluviatile deposits.

Many reconstructions, especially for the Late Quaternary, based on continental hydrolysis, sea water and general temperature are available for marine records (e.g. ROTSCHY et al., 1972). Compared to the continental environments, such as cave fillings, fluvioglacial, or fluvio-limnic deposits, they indicate a clear sequence of depositional history. Although mainly of local significance, results based on the investigation of specific continental environments, accompanied with observed lateral and vertical changes can undoubtedly increase a level of knowledge of events that have taken place during Quaternary.

The area of investigation represents a lowland, averaging 120 m above sea-level, covered by meadows and arable land. Seven exploration wells were drilled: four

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Fig. 1 Location map.
Sl. 1 Položajna karta.

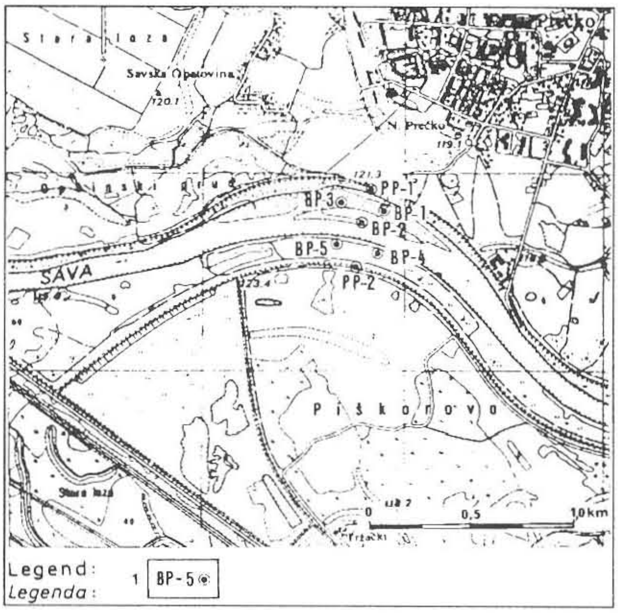


Fig. 2 Location map of wells. Legend: 1=well.
Sl. 2 Karta rasporeda bušotina. Legenda: 1=oznaka za bušotinu.

along the left bank and three along the right bank of the Sava river (Fig. 2). A total of 390 m of exploration core material was extracted and analysed. More than 30 samples were collected for laboratory investigations. Natural and induced radioactivity measurements were also undertaken.

Geophysical measurements conducted in the study area indicate the existence of four distinctive units which correspond with the lithologies ascertained from field and drill core mapping. Zones with features indicating the influence of soil forming processes can be defined. It has to be stressed that these zones are closely related to the boundaries which were observed between the units. The related units are characterized by specific granulometric composition, pebble lithologies, relative frequencies of occurrence of selected heavy minerals and, partly, bulk mineral composition of sands, silts and silty-clays. The study recognises specific characteristics as the consequence of sedimentation in different environments and paleoclimatic conditions and, postsedimentary processes during the phases of subaerial exposure.

2. REVIEW OF RESULTS ACHIEVED BY PREVIOUS STUDIES

Already at the beginning of century the idea was stated that yellow and grey coloured diluvium deposits of the Sava plain represented sediments of marsh or lake environments that had existed since the Upper Pliocene (GORJANOVIĆ-KRAMBERGER, 1908). After 1908, investigations of the Quaternary sediments, located in the Zagreb environs, proceeded in two directions. Hydrogeological investigations (MILETIĆ & BORČIĆ, 1967; NOVINSKA et al., 1967; BORČIĆ et al., 1968; ČAKARUN et al., 1987) focused on gravel horizons while others concentrated on petrological and stratigraphical problems.

It has been established that in the vicinity of Prečko, the sandy-silty-clayey, meter thick superficial deposit is underlain by several formations; an approximately 10 m thick, predominantly coarse-grained gravel overlies a brown, gravelly-clay and underlying, greasy, greyish-blue clay, similar to the Young Pliocene and the Zagreb Pleistocene terrace deposits. CRNKOVIĆ & BUŠIĆ (1970) pointed out the clear dependence of the mineralogical-petrographical composition of the Sava river deposits on the lithological composition of the drainage area. Between Zaprešić and Rakitje, cobbles of mainly dolomite-limestone composition are found, while due east, with the appearance of greenschists from Mt. Medvednica, the composition of cobbles changes, with quartz being more frequent. Using factor analysis, RAFFAELLI & MUTIĆ (1982) separated heavy mineral assemblages and concluded, that the material, sampled in the Upper Pliocene-Pleistocene deposits, 15 km due southeast of Prečko, predominantly originated from the metamorphic rocks of, most likely, Mt. Moslavačka Gora and is partly of aeolian origin. Sedimentation of the material took place in a quiter environment.

The most detailed study on the Quaternary sediments situated in the Zagreb environs is that of ŠIMUNIĆ & BASCH (1975). In 120 m exploration core material, they recognized four horizons of marshy-loess and three horizons of fluviatile deposits which are considered to be from the Riss to the III Würm stadial in age. ŠIKIĆ et al. (1979) and ŠIKIĆ & BASCH (1975) consider that detailed division of the Pleistocene deposits of the western part of the Zagreb environs is impossible, apart from division into genetic types, which are pondy-loess, continental loess without carbonates, alluvial deposit of the third Sava river terrace and cave-fillings. During the Pleistocene, pondy-loess was deposited in lake-remnants and/or ponds with a periodical fluvial inflow.

The Quaternary deposits investigated in Prevlaka, along the Sava river, located about 45 km due west of Prečko, are also documented in detail. Although located distant to the position of the present study, this area must be discussed. While HERNITZ et al., (1981) emphasized that the Holocene and Upper Pleistocene deposits together, are less than 20 m thick, ŠIMUNIĆ et al. (1988) pointed out that 73 m of Upper Pleistocene deposits are overlain by 2 to 3 m thick Holocene sediments. Results of the investigations performed underline the difficulties and dilemmas concerning the chronostratigraphic subdivisions.

3. METHODOLOGY

On the basis of descriptions performed and intervals observed, a quite limited number of representative samples were taken and subjected to different types of analysis. Granulometric analyses were obtained by wet sieving and sedimentation balance. Petrographic determinations of sandy-gravels and gravelly-sands (17 samples) were achieved by establishing relative frequencies of occurrence of clast lithologies in the fraction > 4 mm. In addition, thin-section analyses of selected pebbles were performed. The 71 to 125 μm fraction of the selected silty-sands and silts (15 samples) was quantitatively separated into heavy and light fractions using bromoform. In order to determine the relative frequencies of occurrence of the minerals, counts of the grains were made microscopically. XRD-data of selected sands, silts and silty-clays (13 samples) were obtained using a Phillips X-ray diffractometer unit, with Cu K α radiation generated at 34 kV and 18 mA. Semiquantitative estimation of mineral content was performed as well. Micropalaeontological investigations of selected silty-sands were also undertaken.

During exploration, wells were measured for natural and induced radioactivity. In addition neutron log measurements were performed. While an excellent vertical resolution has been achieved with the natural radioactivity measurements, only the neutron curve confirmed the existence of some horizons on a limited scale, with increased moistness or ground-water saturated horizons.

Although the limited number of samples and analyses made interpretation sporadically difficult, it has been compensated for by an interdisciplinary synthesis of the results obtained.

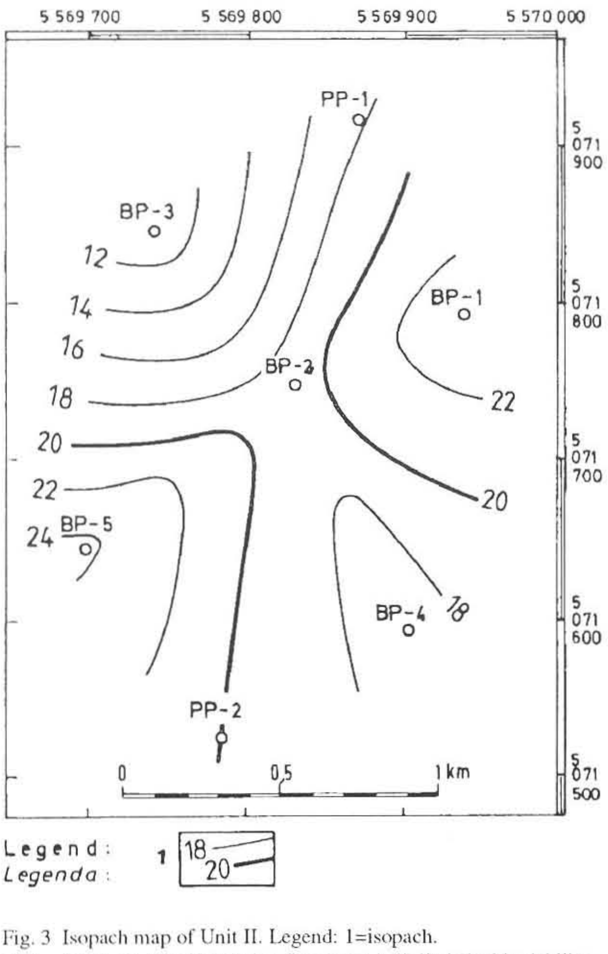


Fig. 3 Isopach map of Unit II. Legend: 1=isopach.
Sl. 3 Karta debljine II jedinice. Legenda: 1=linije jednakih debljina.

4. LITHOLOGICAL DESCRIPTION OF UNITS

4.1. INTRODUCTION

Discrimination of units is based on all the field and laboratory data. On the basis of core determinations, results of applied laboratory analyses and average natural radioactivity, four units can be recognized.

A 13 to 25 meter thick interval of Unit I was encountered in all wells, but the base of the unit was never determined. During the field work, certain characteristics were noticed which clearly distinguish this unit from the overlying sediments. These are a grade of diagenesis, uniform granulometric composition and colour. The unit is composed of yellowish-orange, yellowish-red and yellowish-brown, semi-lithified , compact clayey-silts and silty-clays. Grey coloured or brown-mottled, meter thick interbeds are present, together with a few decimeter thick lenses of sand, and a minor amount of gravels.

Unit II is of relatively uniform composition. Ranging in thickness from 10.35 to 24.3 m (Figs. 3, 6 and 14), the lower part of the unit is predominantly composed of grey-coloured sands. Upwards, the content of silt and clay sized material becomes significant. Unit I is directly overlain by 0.5 to 2.5 m thick gravelly-sands, containing up to 33% gravels. Their base is sharp, and they pass upwards into sands with varying proportions of silt. In the middle part of Unit II, a 1.5 to 3 m thick, semi-lithified layer of normally graded gravelly-sand is present, which grades upward into fine sand. The upper part of the unit is dominated by grey-coloured or, less often, red to yellowish-brown mottled silt and clay sized material with weathered carbonate concretions.

Unit III is heterogeneous and varies in thickness between wells, as shown on Fig. 4. The minimum thickness of the unit was observed in exploration well BP-5 (6.5 m), while the maximum thickness was found in BP-3 (13.2 m). The oldest (and basal) member, a poorly sorted mixture of gravel, sand and silt, (~33:33:33%) was observed only in two wells. Elsewhere, the base of the unit is represented by clays and clayey-silts. In wells BP-2, BP-3, BP-4 and PP-1, these sediments are overlain by sands which become progressively more silty. In distinction from those previously described, in wells BP-1, BP-5 and PP-2 the lower part is silt dominated, while younger intervals are more sandy. The colour of the unit is not uniform. While the sands are predominantly grey-coloured, the silts and clays are often mottled yellow and brown. The uppermost, 10 to 70 centimetres of the unit, as observed in 6 wells, is rusty to yellowish-brown in colour, and the boundary with the overlying Unit IV is characterized by the abrupt appearance of gravels and sands (Figs. 6 and 14).

The youngest unit (Unit IV) varies in thickness from 6.6 to 7.7 m (Fig. 5) and is of a simple lithological composition. In wells PP-1, BP-3 and BP-5 carbonate gravels, comprising well rounded cobbles of up to 7 cm in diameter were recognized, accompanied by pale, yellowish-grey sands. Elsewhere gravels and sands are overlain by a greyish-brown, fine-grained silty-sand, less than 1 m thick, with rare cobbles of carbonate composition. The brownish colour is a consequence of the presence of carbonized plant remnants. The origin of a destroyed peat is possibly related to the adjacent subrecent marshy areas which were incorporated into a fluviatile-type environment.

The general lithological characteristics of the units described above correspond to, and are reflected in the geophysical signatures of the sediments (Figs. 6 and 7). However, traces observed from different well-logs can indicate mutually opposing trends for zones of similar age e.g. Unit III, wells BP-5 and BP-2 (Fig. 6). In addition, the pattern of the gamma log can, in some instances, be directly related to the lithological composition. For example, these traces in Unit III (see well BP-5, Fig. 6) form a funnel-like pattern in the lower part of the unit, diverging into a bell-shaped pattern in the upper part. These patterns corresponds to increasing gravel content in the lower part of Unit III, and the higher sand, silt and clay content of the upper part of the unit.

As observed in Figs. 6 and 7 the boundaries

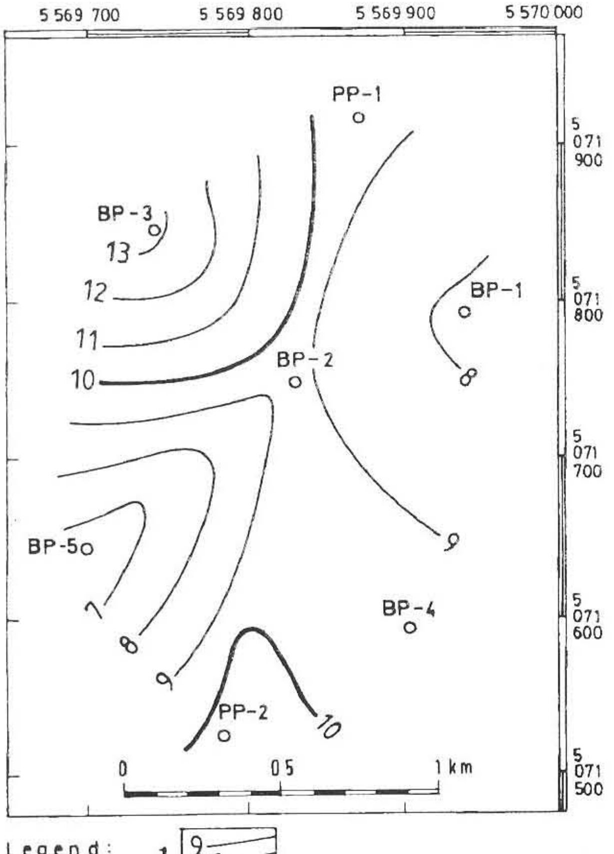


Fig. 4 Isopach map of Unit III. Legend: 1=isopach.
Sl. 4 Karta debljine jedinice III. Legenda: 1=linije jednakih debljina.

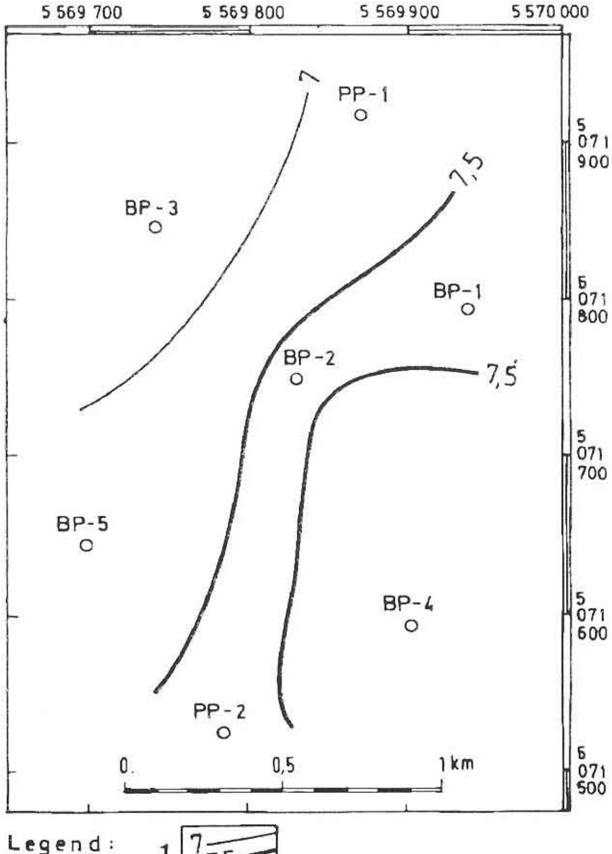


Fig. 5 Isopach map of Unit IV. Legend: 1=isopach.
Sl. 5 Karta debljine jedinice IV. Legenda: 1=linije jednakih debljina.

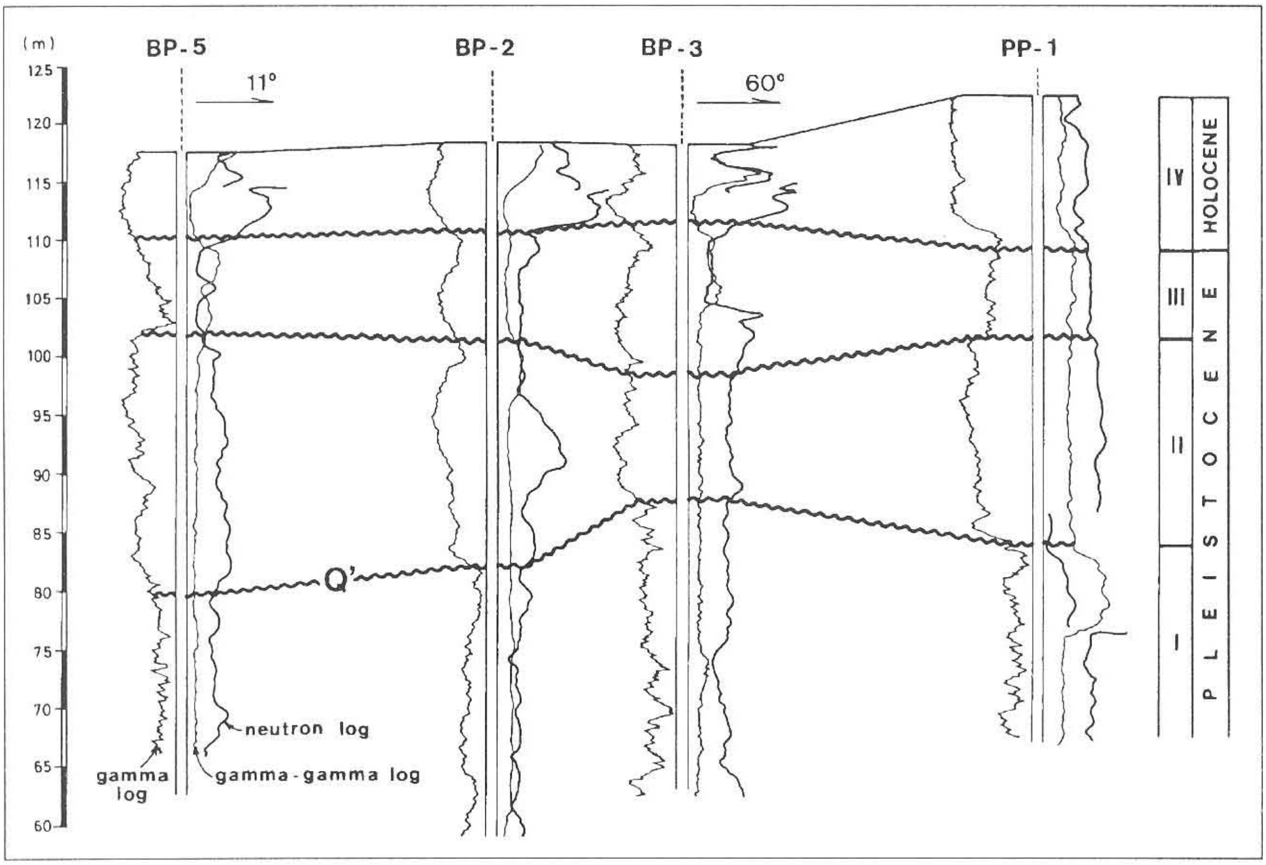


Fig. 6 Well-logs cross-correlation BP-5 - BP-2 - BP-3 - PP-1.
Sl. 6 Shematski korelacijski profil BP-5 - BP-2 - BP-3 - PP-1.

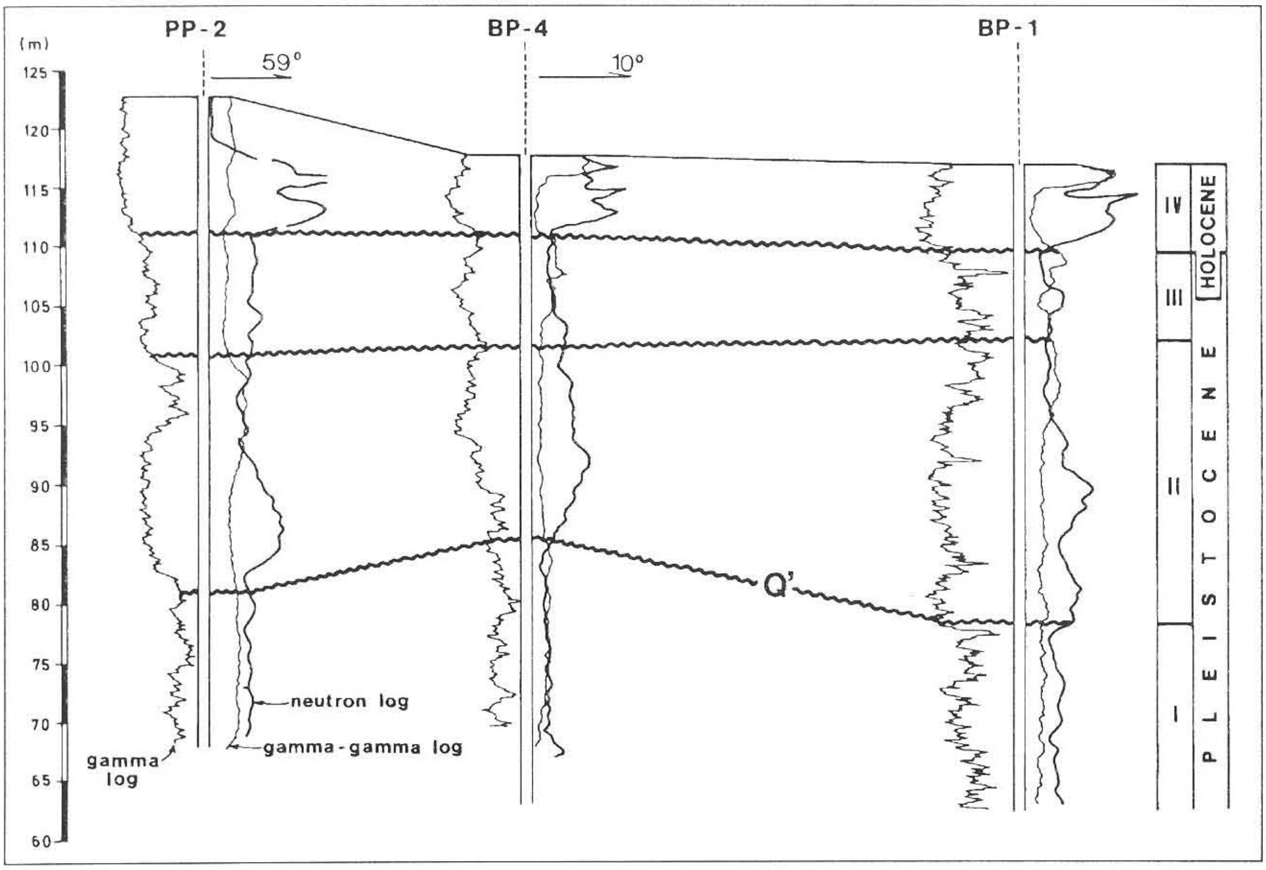


Fig. 7 Well-logs cross-correlation PP-2 - BP-4 - BP-1.
Sl. 7 Shematski korelacijski profil PP-2 - BP-4 - BP-1.

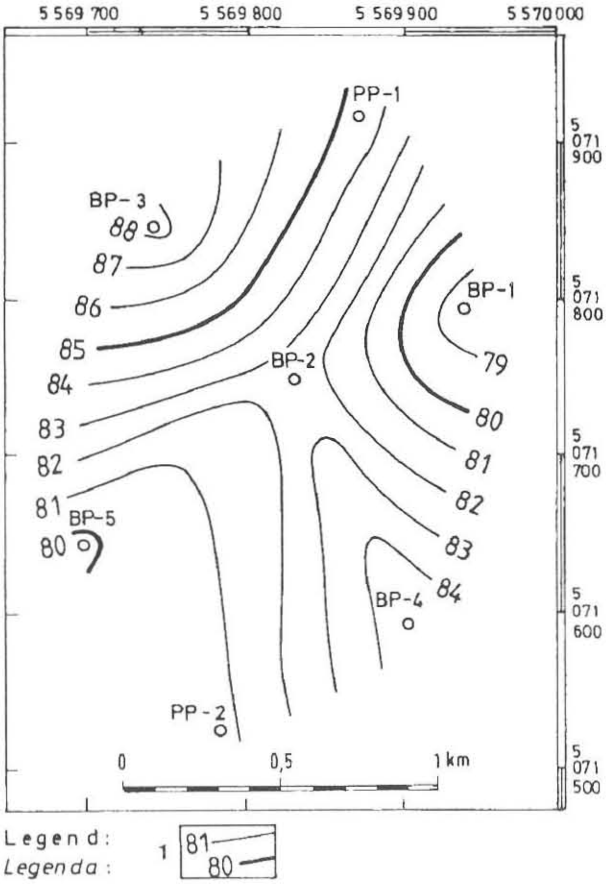


Fig. 8 Contour map - base of Unit II. Legend: 1=isohypse.
Sl. 8 Karta podinske plohe jedinice II. Legenda: 1=linije jednakih apsolutnih visina.

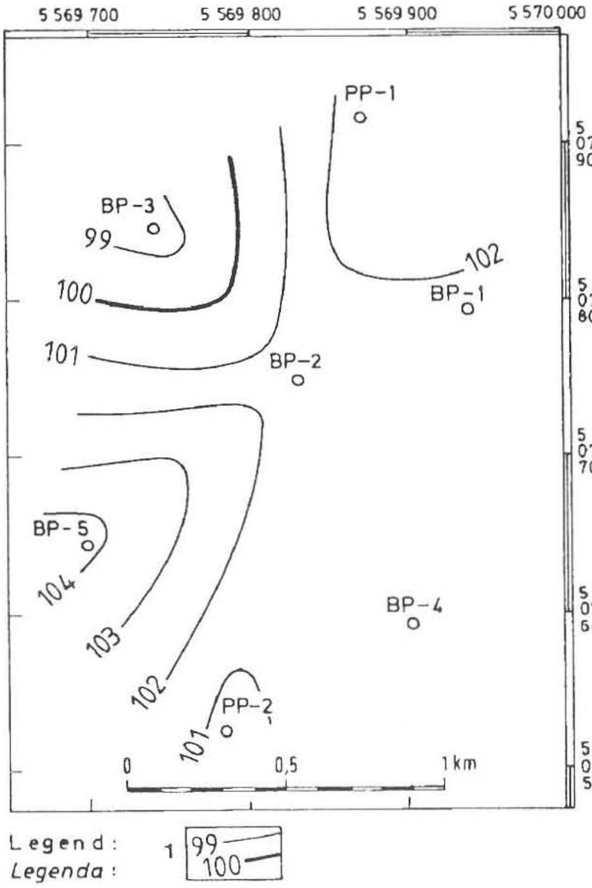


Fig. 9 Contour map - base of Unit III. Legend: 1=isohypse.
Sl. 9 Karta podinske plohe jedince III. Legenda: 1=linije jednakih apsolutnih visina.

between units are not parallel, reflecting lateral thickness variation of the units. This is also clearly seen in contour maps of the boundaries (Figs. 8, 9 and 10). The steepness of the slope of the boundaries (reflected by the spacing of the contours) decreases for progressively younger boundaries (compare Figs. 8, 9 and 10). This is the consequence of a number of factors, including sedimentary environments, sedimentation and denudation processes, and tectonic processes, and is discussed further below.

4.2. DETAILED DESCRIPTION OF UNITS IN DRILL CORES BP-1 AND BP-4

After the detailed analysis of drill cores, wells BP-1 and BP-4, characterized the most obvious lateral changes between contemporary units and were chosen for comparison. While drill core BP-2 displayed quite a high degree of similarity on granulometric and mineral characteristics with drill core BP-1, drill core PP-2 displayed the same with drill core BP-4. These facts were used in order to supplement and expand the data.

Unit I

BP-1 drill core was terminated in Unit I at a depth of 39.2 m recording a thickness of 15.8 m, but the base of the unit was not determined (Fig. 13). In ascending order the unit consists of:

55.0 - 53.9 m, predominantly yellowish-brown mottled, grey-coloured clayey-silt with sporadic quartzite and sandstone granules.

53.9 - 50.0 m, yellowish-brown clay and yellowish-brown mottled silty-clay with sporadic pebbles.

50.0 - 49.6 m, predominantly yellowish-brown mottled grey clayey-silt.

49.6 - 47.4 m, yellowish-red silty-clay with sporadic granules in the lower part of the level and abundant quartzite and sandstone pebbles in the upper part.

47.4 - 45.3 m, yellowish-red, silty-clay to clayey-silt with sporadic quartzite and sandstone pebbles. A thin interbed in the lower part of the level represents greenish-grey to brown, poorly sorted gravelly to silty clay. The fraction >4 mm contains mainly quartzite (68 %) and sandstone pebbles (26 %). Extrusive rocks, tuffs and schists contribute a few per cent each. The Heavy mineral fraction contains opaques (62%), epidote (23%), zoisite (7%), tourmaline (3%), disthene (2%), zircon, garnet and apatite (1%).

45.3 - 39.2 m, yellowish-red mottled silty-clay with sporadic limonitic sandstone pebbles. The mottles mentioned are mostly associated with the upper part of the level. XRD-analysis showed that the yellowish-red

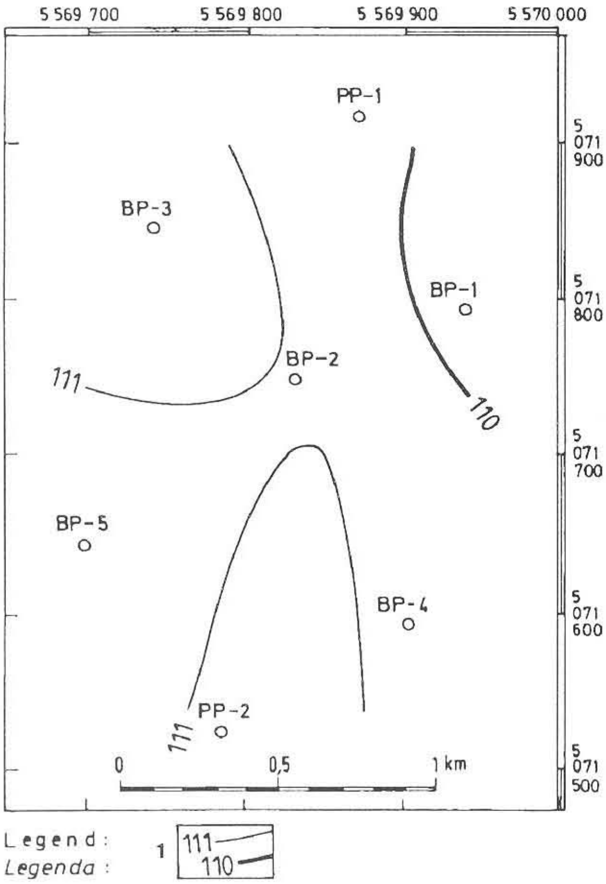


Fig. 10 Contour map - base of Unit IV. Legend: 1=isohypse.
Sl. 10 Karta podinske plohe jedinice IV. Legenda: 1=linije jednakih apsolutnih visina.

mottled silty-clay consists of quartz (38%), micaceous minerals (23%), K-feldspar (2%), chlorite, unidentified mixed-layer clay mineral, kaolinite and goethite.

In drill core BP-4 Unit I is 22 m in thickness, but the base of the unit was not determined (Fig. 14). It consists of:

55.0 - 54.2 m, predominantly yellowish-brown mottled, dark grey silt with sporadic quartzite pebbles.

54.2 - 53.8 m, dark grey-greenish silt to fine grained sand.

53.8 - 53.3 m, dark grey coloured, sandy matrix supported breccia-conglomerate.

53.3 -52.8 m, fine-grained yellowish-brown mottled sand, fining upwards to grey silt.

52.8 - 43.0 m, yellowish-brown clayey silt with grey mottles

43.0 - 40,0 m, yellowish-red silty-clay to clayey-silt with sporadic grey mottles.

40.0 - 33.0 m, grey silty-clay to clayey-silt with yellowish-red mottles. A sample taken from the upper part of the level contains quartz (20%), micaceous minerals (30%), dolomite (15%), calcite, chlorite, smectite, mixed layer clay mineral and kaolinite.

Unit II

In drill core BP-1 Unit II is 23.8 m thick. Contact with the underlying Unit I is sharp and is characterized by an abrupt change in granulometric composition and colour.

39.2 - 32.8 m, grey gravelly-sand and silty-sand, grading upwards to sandy-silt and sandy-clayey-silt. The heavy mineral fraction of the silty-sand contains opaques (78%), garnet (7%), epidote (5%), zircon (3%), titanite, chlorite, disthene, apatite, zoisite and tourmaline (1%). A sample of the sandy-clayey-silt consists of quartz (28%), micaceous minerals (20%), dolomite (15%), plagioclase (8%), calcite (7%), chlorite, smectite, mixed-layer clay mineral, kaolinite and, possibly siderite[1].

32.8 - 27.0 m, grey sandy-silts overlain by alternating dm sized gravelly-sand layers and cm-dm sized layers containing silty-sands. The gravelly-sand contains pebbles of quartzite (53%), sandstone (17%), chert (14%), limestone (5%), dolomite (4%) and conglomerate-breccia (3%). Also observed extrusive rocks, tuffs, and acid intrusive rocks contribute a few per cent together.

27.0 - 21.5 m, grey silty-sand. Consists of quartz (30%), dolomite (28%), micaceous minerals (12%), calcite (8%), plagioclase (5%), K-feldspar and chlorite. Heavy mineral fraction contains opaques (62%), garnet (12%), epidote (9%), zoisite (6%), chlorite (5%), zircon, amphibole, disthene, apatite and titanite (1%).

21.5 - 19.9 m, yellowish-grey sandy-silt with thin interbeds of silty-clay. One of the interbeds contains quartz (22%), micaceous minerals (25%), dolomite (20%), calcite (5%), K-feldspar (3%), chlorite, smectite and mixed-layer clay mineral.

19.9 - 19.0 m, greenish-grey sandy-clayey silt with carbonate concretions.

19.0 - 18.0 m, predominantly grey clayey-silt with yellowish-brown mottles, carbonate concretions and remains of Rhisoconcretions.

18.0 - 15.4 m, yellowish-brown mottled clayey-silt with carbonate concretions.

In drill core BP-4, Unit II is 16.6 m thick. Contact with the underlying unit is not sharp but distinguishes itself with a marked change in colour.

33.0 - 31.0 m, grey sandy-silt

31.0 - 28.0 m, light grey sandy-silt with rare pyrite crystals. This passes upwards to gravelly-sandy-silt with thin greenish-grey interbeds of silt. A silt sample contained quartz (16%), micaceous minerals (10%), dolomite (30%), calcite (15%), plagioclase (3%), chlorite, mixed-layer clay mineral and, possibly siderite.

28.0 - 26.4 m, grey silty-sandy gravel. The fraction > 4 mm contains pebbles of sandstone (36%), quartzite (49%) and chert (12%). Pebbles of extrusive rocks, tuffs, acid intrusive rocks and schists, contribute together a few per cent.

26.4 - 22.9 m, grey silty-sand. The heavy mineral

[1] According to XRD data, observed unidentified carbonate minerals, noticed in some samples can be refered to siderite in which iron is partly replaced with calcium and manganese (Prof. D.Slovenec, personal communication). In the further text, term possible siderite will be used.

fraction is composed of opaques (79%), epidote (7%), zoisite (5%), garnet (4%), zircon (3%), tourmaline (1%) as well as apatite, chlorite and disthene (contributing less than a per cent each). The mineralogical composition of the upper part includes quartz (40%), micaceous minerals (8%), dolomite (28%), calcite (6%), plagioclase (5%), K-feldspar (3%) and chlorite.

22.9 - 19.7 m, as the underlying material but with an increased silt content and thin sandy-silt interbed.

19.7 - 16.4 m, greenish-grey sandy-clayey silt with sporadic pebbles and irregularly distributed carbonate concretions.

Unit III

In drill core BP-1, Unit III is 7.7 m in thickness. The boundary with the underlying unit is emphasized with a marked change in colour.

15.4 - 14.7 m, greenish-grey sandy-clayey-silt.

14.7 - 12.7 m, greenish-grey clayey-silt. The mineral composition includes quartz (38%), micaceous minerals (25%), plagioclase, chlorite, smectite, mixed-layer clay minerals and kaolinite.

12.7 - 11.2 m, greenish-grey sandy-clayey silt with sporadic plant fragments.

11.2 - 9.5 m, grey sandy-silt with ostracodes and remains of *Lithoglyphus* situated near the top of the sequence.

9.9 - 8.7 m, yellowish-grey silty-sand.

8.7 - 8.4 m, grey silty-sand.

8.4 - 7.8 m, silty-sand, yellowish-brown mottled in the upper part, yellowish-brown in the lower part. The heavy mineral fraction contains opaques (43%), garnet (25%), epidote (9%), zoisite (5%), chlorite (5%), apatite (4%), zircon (3%), tourmaline (1%) as well as disthene, rutile, titanite, staurolite and sillimanite.

In drill core BP-4, a 9.6 m thick Unit III was encountered. The boundary with the underlying unit is sharp and marked by an abrupt change in granulometric composition and a slight change in colour.

16.4 - 15.4 m, grey, ungraded, sand dominated mixture of gravel, sand, silt and clay with a pyritized fragment of wood.

15.4 - 15.0 m, grey silty-gravelly-sand with pebbles of dolomite (3%), sandstone (25%), quartzite (45%), extrusive rocks and tuffs (6%), chert (13%), and some acid intrusive rocks and schists.

15.0 - 10.4 m, grey silty-sand with a brown coloured interbed containing plant remnants and fragments of wood.

10.4 - 7.5 m, grey silty-sand.

7.5 - 7.1 m, greenish-grey clayey-silt with irregularly distributed carbonate concretions.

7.1 - 6.8 m, silty-sand with pebbles in the upper part.

Unit IV

Unit IV, composed of sandy-gravels, ranging in thickness from 6.6 to 7.7 m, sharply overlies Unit III. Distributed over the whole study area, sandy-gravels of grey, yellowish-grey and greyish-brown colour are composed of variety of rounded and subrounded pebbles set in a silty-sandy matrix. Pebble lithologies include limestones (49 - 55%), dolomites (5 - 21%), sandstones (11 - 23%), quartzites (8 - 13%), cherts (2 - 8%), extrusive rocks and tuffs (up to 5%), and conglomerates, breccias, acid intrusive rocks and schists (contributing a few per cent each).

5. RESULTS

5.1. GRANULOMETRIC ANALYSES

Unit I is laterally uniform and composed of silty-clays and clayey-silts, with randomly distributed granules and pebbles. In the lower and middle parts of the unit, few sandy and gravelly-sandy layers were observed. Unfortunately, only a small number of samples were analyzed, so, the description of Unit I is based mainly on field observations.

The results of particle size determinations of Units II, III and IV, in drill cores BP-1 and BP-4 are shown on Figs. 13 and 14. Unit II is laterally homogenous and characterized by the presence of one or two gravelly-sand sequences. In the upper part of the unit, abundant silt size material, accompanied by an increasing clay content is observed. Unit III displays more lateral variation. While drill core BP-4 is dominated by sand size material, in drill core BP-1, the lower and middle part is characterized by a high silt content. Unit IV is laterally uniform and composed of sandy gravels.

The predominant occurrence of silt size material, observed in certain intervals of Units I, II and III, raises the possibility of loess contribution to the sedimentary basin. For the determination of sedimentary environments based on particle-size distribution, the correlation of the parameters median, coefficient of sorting and skewness have proved convenient (KUKAL, 1971). According to KUKAL (1971), the median (Md) of loess is usually 0.06 - 0.02 mm, the coefficient of sorting as Phi Deviation is 1-3 and Phi Skewness is in most cases slightly positive. In his figures, the coefficient of sorting and skewness of the sediments are compared with their median. The statistical parameters of the silt samples are plotted in Fig.12. The diagram is modified after KUKAL (1971) and NIHLÉN & SOLYOM (1986).

It is obvious that the loess influence can not be neglected. Sand, or clay sized material can be attributed to the mixing with local materials or to pedogenic processes. According to PYE (1987), the term "loessoid" can be used to describe sediments composed of mixtures of deposited dust and other (local) sediments (such as dune sand, soil, alluvial fill). He also emphasized that the term "loess-like deposits" can be used for sediments which possess many of the sedimentological properties of aeolian loess but which have not been transported by the wind at any stage in their history (such as overbank silts and some colluvial deposits). Loess is frequently but very often a mis-used term in our literature. In this paper, for sediments having the properties of loess (mainly based on particle size analyses and analogy with the literature), reworked loess and resedimented loess, the term loessoid sediment is used.

5.2. PEBBLE LITHOLOGIES

On the basis of pebble lithologies, two different types of gravelly sediments can be recognized. Type 1 includes the silty-gravelly sands of Unit III, gravelly-sands and sandy-silty gravels of Unit II and gravelly-sandy interbeds of Unit I. They are of siliciclastic composition, comprised mainly of quartzite and sandstone granules and pebbles set in a clayey-silt to sandy matrix. While in Units II and III a few pebbles of limestone and dolostone were found, no trace of carbonate pebbles was observed in Unit I. Type 2 deposits are represented by the sandy gravels of Unit IV, composed of rounded and subrounded pebbles of predominantly carbonate composition (limestones and dolostones) in a silty-sandy matrix.

The difference, emphasized by the pebble lithologies of the two types suggests that during their formation, distinct source rocks were exposed to erosion and weathering. In addition, it can be stressed that, generally, more limestones and dolostones were eroded, acting as a progressively dominant source of pebbles for sediments of increasingly younger age.

5.3. HEAVY AND LIGHT MINERAL COMPOSITION

The heavy mineral assemblages are comparatively simple. Samples selected from Units I, II and III contain opaques, epidote, garnet, zoisite, chlorite and zircon with small amounts of tourmaline, apatite, amphibole, disthene, titanite, staurolite, biotite and sillimanite. A complete absence of pyroxenes, together with the scarsity of amphiboles may indicate that intensive abrasion and/or weathering have taken place, suggesting that sediments are reworked. In addition, it is possibile that the source rocks did not contain these minerals in any distinctive percentage.

Heavy mineral percentages in a particular unit are comparable for equivalent depths. A difference between the garnet and epidote content among the units was observed. In order to compare the heavy mineral composition among the units, data are plotted in relation to epidote, zircon + tourmaline and garnet (Fig. 11). The formation of three distinct groups suggest, that, possibly, different source areas and/or different transport factors were involved.

The light mineral fraction consists of variable portions of quartz, feldspars (mainly albite, rarely K-feldspar), muscovite and calcite (as mineral and limestone fragments). It is necessary to stress that in the yellowish-red mottled silty-sands of Unit I, calcite was not found.

5.4. PALAEOSOLS

"Palaeosols are soils that formed in the past on portions of land surfaces that were sufficiently stable for variable lengths of time to receive and retain imprints of soil forming factors" (LECKIE et al., 1989). EINSELE (1991) stated that lake deposits are frequently associated with fossil soils. According to KRAUS (1987), palaeosols in alluvial sediments are powerful indicators of paleoclimate, floodplain drainage and pauses of sedimentation.

In order to establish whether certain intervals represent palaeosols, the following criteria were used:

- different colour compared to the overlying and underlying material,
- presence of mottles,
- presence of concretions and nodules,
- evidence of progressive weathering of minerals,
- presence of roots and organic matter fragments.

On the basis of the above criteria, at least three intervals are of possible pedogenic origin. These intervals are closely related to the observed unit boundaries. They indicate that the upper parts of the units were subjected to soil forming processes. However, it should be noted that some diagenetic features (for instance, burial gleying) closely resemble that of soils.

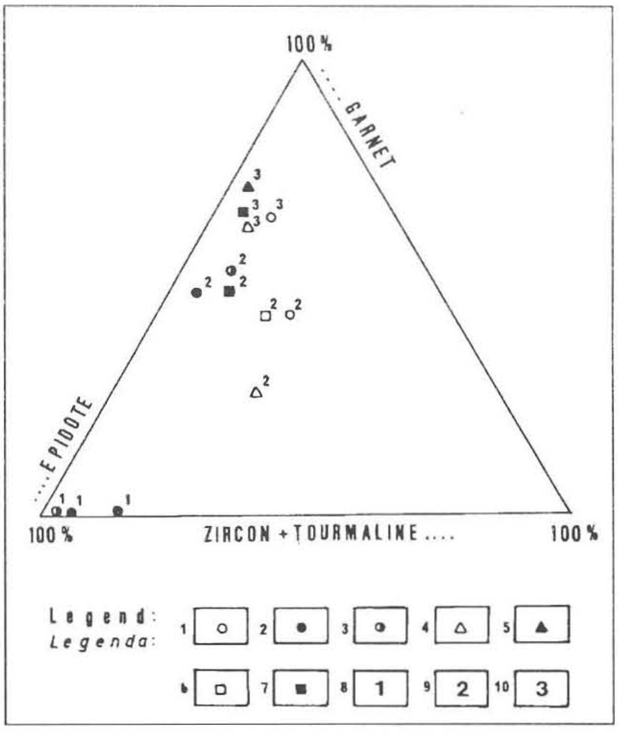


Fig. 11 Composition of selected heavy minerals.
Legend: 1=well BP-1; 2=well BP-2; 3=well BP-3; 4=well BP-4; 5=well BP-5; 6=well PP-1; 7=well PP-2; 8=Unit I; 9=Unit II; 10=Unit III.

Sl. 11 Sastav izabranih teških minerala.
Legenda: 1=bušotina BP-1; 2=bušotina BP-2; 3=bušotin BP-3; 4=bušotina BP-4; 5=bušotina BP-5; 6=bušotina PP-1; 7=bušotina PP-2; 8=jedinica I; 9=jedinica II; 10=jedinica III.

5.5. GEOPHYSICAL WELL LOGS

The gamma log trace represents a lithological indicator as well as a method of performing correlations. For the Quaternary sediments in North Croatia, this method is suitable both for cased and uncased wells. It facilitates very good general discrimination of clayey-silts, sands and gravels respectively: the first are recognized due to high radiation, due to the presence of potassium from feldspars and micaceous minerals (grains and clasts of source rocks), the second are identified by medium radiation brought out by the damping influence of non-radioactive quartz and the third produce very low levels of radiation from carbonates which constitute the majority of pebbles in the youngest gravels.

The gamma log traces, obtained from seven exploration wells, corroborate the existence of four units. This can be clearly seen in exploration well PP-1 (Fig. 6). The oldest unit is characterized with an average of 30 Counts Per Minute (CPM), Unit II with an average of 15 CPM (except in levels with high sand content, having 8 CPM), Unit III with an average of 20 CPM and Unit IV, in general, with 5 CPM.

The shape of the neutron log reflects the quantity of hydrogen in rocks penetrated by exploration well. Therefore, the neutron log is used for measuring moisture above the water table and total porosity below the water table. The highest results, as shown in Count Per Second units (CPS), coincide with water-bearing gravels of Unit IV and moist, sandy intervals of Unit II (Figs. 6 and 7).

6. INTERPRETATION

6.1. SEDIMENTARY ENVIRONMENTS AND PHASES OF SUBAERIAL EXPOSURE

The evolution of the units investigated was undoubtedly dependent upon glacial/interglacial cycles. It is a common belief that during the glacial periods, a large amount of wind borne silt material (loess) was blown out and accumulated south of the glaciated regions, building extensive aeolian loess deposits.

As silt size material is predominant in the cores investigated, an attempt was made to find out whether the sediments of Unit I were partly composed of loess. Slightly too high coefficients of sorting compared to the average values (Fig. 12), possibly indicate the mixing of loess with local materials (loessoid sediment). However, very similar grain size parameters were found for flood plain basins (KUKAL, 1971) which during a wet and humid climate include large vegetated marshes or swamps and permanent lakes and ponds (ALLEN, 1971). Although genetically related to glacials, during the more humid periods, loess is easily eroded by running water and fluvial action and transported as a reworked sediment to an accessible sedimentary basin. During transport, as well as deposition,

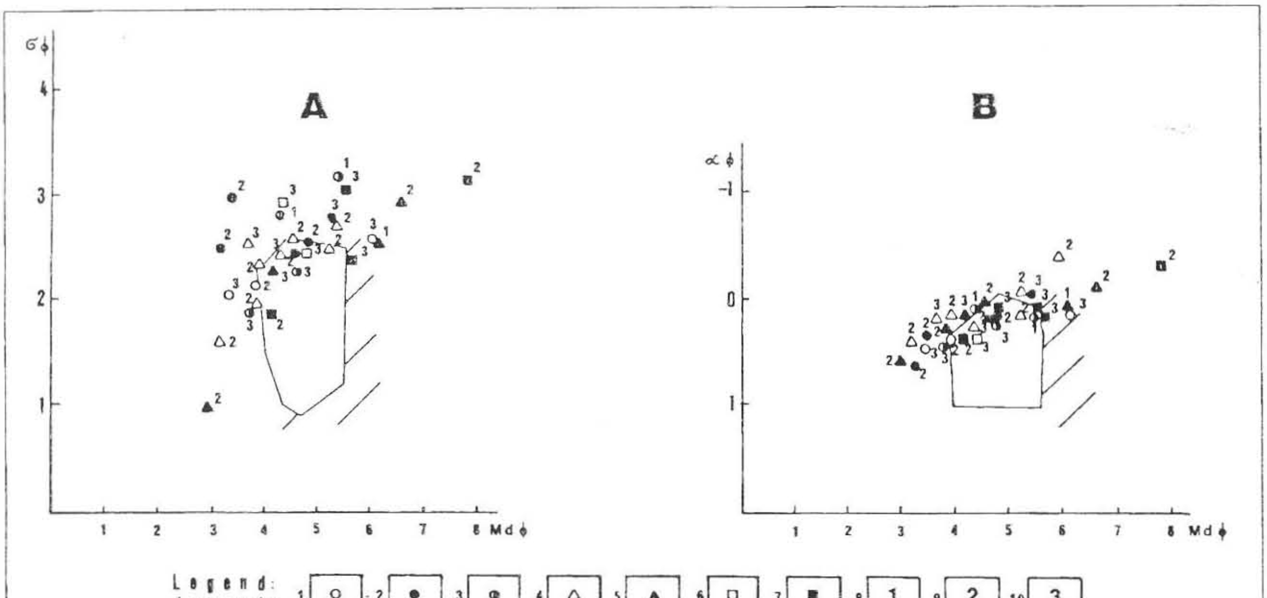


Fig. 12 A. Relation between median and the coefficient of sorting.
B. Relation between median and skewness. Outlined and dashed zones indicate areas with typical loess deposits ratios.
(modified after KUKAL, 1971 and NIHLÉN & SOLYOM, 1986)
Legend: 1=well BP-1; 2=well BP-2; 3=well BP-3; 4=well BP-4; 5=well BP-5; 6=well PP-1; 7=well PP-2; 8=Unit I; 9=Unit II; 10=Unit III.

Sl. 12 A. Odnos između medijana i koeficijenta sortiranja.
B. Odnos između medijana i koeficijenta asimetrije. Uokvirene i iscrtkane zone indiciraju područja unutar kojih se nalaze odnosi koeficijenata za tipične naslage lesa.
(modificirano prema KUKAL, 1971 i NIHLÉN & SOLYOM, 1986)
Legenda: 1=bušotina BP-1; 2=bušotina BP-2; 3=bušotina BP-3; 4=bušotina BP-4; 5=bušotina BP-5; 6=bušotina PP-1; 7=bušotina PP-2; 8=jedinica I; 9=jedinica II; 10=jedinica III.

this resedimented material can easily mix with other materials. Undoubtedly, loess could have been blown directly to a sedimentary basin (lake, marsh, pond, river). Wind blown dust and sand contribute to the composition of various types of sediments which ultimately accumulate in fluvial or subaquatic environments (EINSELE, 1991).

The heavy mineral composition shows that, compared to the younger units, Unit I is depleted in its garnet content (Fig. 11). This almost complete lack of garnet can be related to the source area. If we assume dominant loess origin of the unit, the difference in garnet content can also be related to transport. Namely, the lack of the heavier garnet, compared to the much more abundant lighter epidote may imply that the source area was situated far away from the depositional basin.

With the exception of the silty-clays, a dominant characteristic of Unit I, at least in its upper part, is the predominantly yellowish-red and yellowish-brown appearance of the sediments. XRD-diffractograms show that the yellowish-red mottled silty-clay, situated in the upper part of the unit in the drill core BP-1 contains, among other minerals, goethite. The presence of goethite indicates that the sediment has been oxidized. The occurrence of more than 10 m thick yellowish-red sediment in places may suggest that the colour of the sediment: (1) is original, implying that the sediment was deposited in a well oxygenated environment, (2) reflects post-burial, post-depositional oxidation processes, (3) reflects post-depositional weathering.

Together, the yellowish-red mottled appearance, lack of carbonates and presence of goethite suggest that the upper part of the unit in the drill core BP-1 was influenced by weathering, i.e. soil forming processes. According to RETTALACK (1990), the geomorphic setting of palaeosols may not always be obvious, but their relationship to the water table often is discernible and has a clear bearing on their position in the landscapes of the past. The presence of yellowish-red mottles in the predominantly grey silty-clay, noticed in the upper part of the unit in the drill core BP-4, indicate that the paleosol (and underlying sediment) had been partly within the zone of water table fluctuation. Compared to the well drained yellowish-red palaeosol observed in the drill core BP-1, the grey one contains calcite, dolomite and smectite and lacks goethite (except in mottles). We suppose that, during the wet season, palaeosol was affected by gleying processes. During the dry season (lower water table), liberated ferrous iron was oxidized and fixed as goethite on yellowish-red mottles. It is necessary to stress that the features implying waterlogged conditions were noticed at different levels through the prevailingly yellowish-red Unit I. The origin of these features is disputable.

Although indisputable evidence for the prevailing yellowish-red appearance of Unit I is not available, existing facts are sufficiently convincing and imply that at least the upper part of the unit represents a palaeosol. In addition, waterlogged features may indicate that several stages of weathering or post-burial processes were involved. Nevertheless, the preserved yellowish-red appearance implies that oxidizing conditions within the unit were maintained because little or no organic mater or reducing pore waters were available to convert the iron from a ferric to ferrous state (EINSELE, 1991).

According to KARLSTROOM (1991), much evidence suggests that late Tertiary and Pleistocene interglacials in upper-middle latitude continental regions were characterized by warm-temperate, subtropical and/or Mediterranean climates. At that time, different types of interglacial soils developed. As palaeosols generally bear the imprint of the strongest environment affecting their development (MORRISON, 1978), we attribute the observed paleosol and upper parts of the unit to be influenced by an interglacial climate.

The presence of pyrite and, possibly siderite, as well as the grey colour of Unit II undoubtedly indicates that the sediment has been affected by reducing conditions. In addition, in drill core BP-5 the lower gravelly-sandy interbed contains very well preserved wood fragments with abundant pyrite crystals. While in the middle part of the unit limestone and dolomite pebbles can be found, in the sandy-gravels, in the lower part no pebble of carbonate composition has been observed. A characteristic feature of the unit is the presence of a uniform, 3.4 m (BP-4) to 5.5 m (BP-1) thick, grey silty-sand which overlies the gravelly interbeds. Although the upper part of unit is characterized by the silt dominated, fining upwards sequence, differences in colour, thickness and granulometric composition of the uppermost part of unit, has been observed between cores. Grain size parameters of the uppermost part of the unit (Fig. 12) indicate loessoid sediments and a lacustrine-marsh type depositional environment.

In the drill core BP-1, the uppermost part of the unit in decreasing vertical order is composed of yellowish-brown mottled clayey-silt with carbonate concretions, underlain by grey clayey-silt with yellowish-brown mottles, carbonate concretions and remnants of Rhisoconcretions, and greenish-grey clayey- silt with carbonate concretions. The clay content decreases downwards.

The vertical section described, and features mentioned strongly suggest that the upper part of the unit was subjected to water - table fluctuations. While the yellowish-brown mottled clayey-silt accompanied with carbonate concretions resembles well drained soils, the underlying grey clayey-silt with yellowish-brown mottles and carbonate concretions indicates seasonally wet conditions. According to EINSELE (1991), carbonate nodules originating from near surface carbonate dissolution and reprecipitation are similar to the formation of caliche. RETALLACK (1990) stated that calcareous concretions are thought to have accumulated under alkaline conditions of dry periods. Rhisoconcretions (observed in grey clayey-silt) form in soils because of the special local environment created by roots (RETALLACK, 1990). As the result of repeated cycles of wetting and drying, roots may become heavily encrusted with concentric layers of very-fine grained low-magnesium calcite. The presence of Rhisoconcretions suggest that the sediment was subjected to repeated cycles of wetting and drying. Although the appearance of carbonate concretions can be attributed to the same phenomenon, their possible diagenetic origin can not be neglected. Nevertheless, the fact that yellowish - brown mottled clayey-silt undoubtedly developed above the water table indirectly implies that it was subjected to soil forming processes.

Unit II probably developed in a shallow, oxic lacustrine to marshy environment with periodic fluvial influence during the lower and middle parts of the unit. In the upper part of the Unit, loess contributed to the local material. As a result of increased sediment supply, or reduced subsidence, or changing climate, the sedimentary basin became a seasonally dry marsh (fluctuating water table and gleying phenomena) which successively dried up (yellowish-brown mottled well drained appearance). In the drill core BP-4, the greenish-grey sandy clayey silt with sporadic pebbles, irregularly distributed calcite, possible siderite concretions, and lack of yellowish-brown mottled appearance can be attributed to processes of burial diagenesis. RETTALACK (1990) states that a serious complication for the interpretation of seasonality in swamp soils is the tendency of such lowland regions to be slowly subsiding sedimentary basins. As a result, a seasonally dry swamp may subside below the water table to become a permanently waterlogged soil. In addition, soil can be strongly reduced upon burial and subsidence into a biologically active water table.

While in drill core BP-1, the boundary of Unit III with the underlying unit is emphasized by a marked change in colour, in the drill core BP-4, the contact is sharp and marked by an abrupt change in granulometric composition and slight change in colour.

In drill core BP-1, the lower part of the unit is composed of greenish-grey sandy-clayey silt to clayey-silt with sporadic plant remains. The grain size parameters (Fig. 12) of the greenish-grey sequence suggest a loessoid origin. The lower part of the unit in the drill core BP-4 is composed of an ungraded, sand dominated mixture of gravel, sand, silt and clay. Such a lateral difference can possibly be attributed to the position in the sedimentary basin, probably related to the proximity of land or a fluvial inflow in the sediments of Unit III (drill core BP-4).

The greenish-grey to grey colour, accompanied by plant remains (e.g. BP-1) and pyritized wood fragments (e.g. BP-4) together with a lack of carbonates, strongly suggest that the sediment was developed in a reducing, acidic, probably marshy environment. The presence of ostracodes and remains of *Lithoglyphus* in the grey sandy silt above the marshy, greenish-grey clayey-silt, indicates a fresh water inflow, which resulted in the less acidic conditions necessary for the preservation of calcite and dolomite (in drill core PP-2).

Above the fossiliferous grey sandy-silt is a yellowish-grey to grey silty-sand, overlain by yellowish-brown mottled silty-sand palaeosol. Furthermore, the upper part of the unit is characterized by the presence of greenish-grey clayey-silt in the drill core BP-4, and yellowish-brown clayey-silt in the drill core PP-2, both with the abundant carbonate concretions. Observed lateral changes, mainly related to colour and the presence/absence of carbonate concretions can be attributed to a flucculating water table, both, during palaeosol formation and after burial.

Unit IV is composed of sandy gravels. We interpret this unit as a fluvial deposit.

No distinctive conclusion on source material can be drawn from clay mineral assemblages (Figs. 13 and 14). In clastic sediments of Pleistocene age, situated along the southern slopes of Mt. Medvednica, the main clay minerals besides illite are vermiculite and smectite (SLOVENEC & ŠIFTAR, 1991). Kaolinite is observed as well. While chlorites in low-metamorphic rocks of Mt. Medvednica were the minerals, out of which vermiculite and smectite were formed during the weathering processes, the problem of the origin of kaolinite remains to be resolved.

Clay minerals in most clastic lakes are detrital and reflect the composition of the source rocks and there is no exclusive phylis suite (WEAVER, 1989). CHAMLEY (1989) stated that a general correlation exists between the mineral composition of most freshwater lakes and the average clay mineralogy of rocks and soils in the surrounding drainage basins.

The use of clay minerals in palaeosol investigations, with a view to a climate reconstruction, assumes that soils form in equilibrium with the climate. If such soils are subjected to the action of erosion, are transported and deposited in a sedimentary basin (e.g. lake), the reworked sediments will bear traces of the mineral composition which actually expresses climate related weathering patterns.

For example, kaolinite from the paleosol situated at the top of Unit I probably formed by the action of soil forming processes, during a warm, moist interglacial. In well drained conditions, kaolinite is a stable mineral phase. During that period, kaolinite as a secondary mineral certainly developed on remaining continental surfaces. In subsequent periods, neoformed soils were exposed to the action of erosion processes and undoubtedly contributed to the composition of younger sediments. Using this mechanism, a presence of kaolinite in the lower parts of Units II and III could possibly be explained.

The fact that clay minerals have an important role in these kind of investigations is obviously important. Future investigations of the Quaternary sediments should include investigation of the clay mineral assemblages in related sediments, palaeosols and potential source rocks, respectively.

In order to evaluate the role of tectonic events on the development of the recognized units, the following must be stressed. The morphology of the base surfaces of Units II, III and IV are mutually different (Figs. 8, 9 and 10). In ascending order, they are more simple in appearance. When overlapped, maps in general show neither coincidence between uplifted nor depressed parts of the study area. This is, among others, a consequence of neotectonic movements. The area studied is situated at the mutual edge of two structures. West of Prečko, an uplifted structure, which was active during the Middle and Upper Pliocene and Quaternary was recognized, while due east, an inverse structure which subsided during the Pliocene and Quaternary was observed (VELIĆ, 1980). Local processes of tectonic uplift and subsidence were only partly compensated by sedimentation and denudation, respectively, which resulted in warping of the base surfaces.

6.2. CHRONOSTRATIGRAPHIC RELATIONSHIPS

Index fossils were not discovered and radiometric age determinations and paleomagnetic correlation were not performed, which has resulted in the problematic chronostratigraphic affiliation of the units recognized. By placing all of the relevant data into a generally accepted paleoclimatic framework of the Quaternary (MARKOV, 1970; ŠEGOTA, 1966, 1967), the following chronostratigraphic characterization is supposed. It has to be stressed, that during the investigation of stratigraphic relationships we used the terminology for glacial and interglacial sequences of the Alpe regions regardless the serious remarks concerning their scientific justifiability. Namely, the authors on papers dealing with the Quaternary in Croatia exclusively used the clasification mentioned. In order to correlate our results with results of adjacent areas, we used the same terminology. An identification according to the chronostratigraphic scale for Europe was performed after HARLAND et al. (1990), especially in division on the Lower (Early), Middle and Upper (Late) Pleistocene, and after NILSSON (1983).

The oldest Unit is Lower Pleistocene in age. Since of dominant loess origin, it is considered to have formed during the Menapian (Günz). This is also corroborated by the position of the conditional marker horizon Q', which was defined over a wider area of the Sava depression (HERNITZ et al., 1980) on the basis of logging, performed on cores from about a hundred locations around Zagreb, Sisak and Mt. Moslavačka Gora. This marker separates the Lower Pleistocene from the Middle Pleistocene, Upper Pleistocene and Holocene sediments, as documented by URUMOVIĆ et al. (1976). Above the Q' marker, the "unconsolidated material" of HERNITZ et al. (1981) is situated, which is, compared to the underlying, fine-grained, semi-lithified, impermeable sediments, mainly composed of permeable strata. On the basis of described characteristics, it is possible to recognize the Q' marker on the well-log traces which are shown on Figs. 6 and 7. Isopach map (HERNITZ et al., 1980, Fig. 11), showed that inferred thicknesses between the Q' marker and the ground surface, in the area of Prečko were lower than 50 m. Our results indicate that the maximum depth of the Q' marker is 40 m (well BP-1, Fig. 7)

Unit II is Middle Pleistocene in age. Contact with the underlying unit is sharp. In the lower part, Unit II is composed of grey, poorly sorted gravels and sands, deposited by running water entering a shallow lake or a marsh. We consider the lake formation to be related to the Holstein interglacial (Mindel/Riss), during which a moist, warm climate prevailed. The granulometric and bulk composition gradually changes upwards with increasing silts and clays, possibly indicating, that the transport mechanism also changes, probably with the incoming glacial, possibly Saalian (Riss). During the mentioned glacial at least two warming phases occured and therefore the lacustrine-marsh type sedimentation was probably maintained until the very end of Saalian. The increased loess contribution, accompanied by marked cooling and dryness during the last third of the Saalian glacial, resulted in long lasting aridity. Correlation with the results obtained in the vicinity of Podsused by VELIĆ & SAFTIĆ (1991), also suggests the Middle Pleistocene age of Unit II, as pebble lithologies at both localities are almost identical; sandstone and quartz/quartzite pebbles being predominant.

We consider Unit III to be of Upper Pleistocene age, (predominantly Lower to Middle Weichselian). Particle size analyses partly indicate a loess origin of the material. A marsh type environment is also documented. Marshes were possibly formed during the Upper part of the moist and warm Eemian interglacial (Riss/Würm). Compared to the Holstein (Mindel/Riss) interglacial, this was characterized by decreased humidity. Frequent lateral changes of lithological composition occur. Fluviatile gravels and sands, found in a small number of localities indicate the proximity of a coast line. In the upper part of Unit III varve were recognized in the field, as alternating millimetre thick, light-coloured, fine-grained sands and dark grey to black silts. They are a typical product of glacial conditions. Since the maximum Quaternary cooling began during the second half of the Weichselian (Würm), these sediments are comparable with the climatic conditions.

It has been previously stated, that pyroxene was not found in the heavy mineral fraction of Units I, II and III. This is in agreement with studies by RAFFAELLI & MUTIĆ (1982), who concluded, that the lack of pyroxenes is a typical characteristic of the Upper Pliocene-Pleistocene sediments, compared to the Sava sediments of Holocene age.

Unit IV is Holocene in age and of fluviatile origin. Well rounded pebbles of, predominantly carbonate composition, as well as the degree of sorting, correspond to the results, obtained from exploration wells situated slightly west of the study area (VELIĆ & SAFTIĆ, 1991).

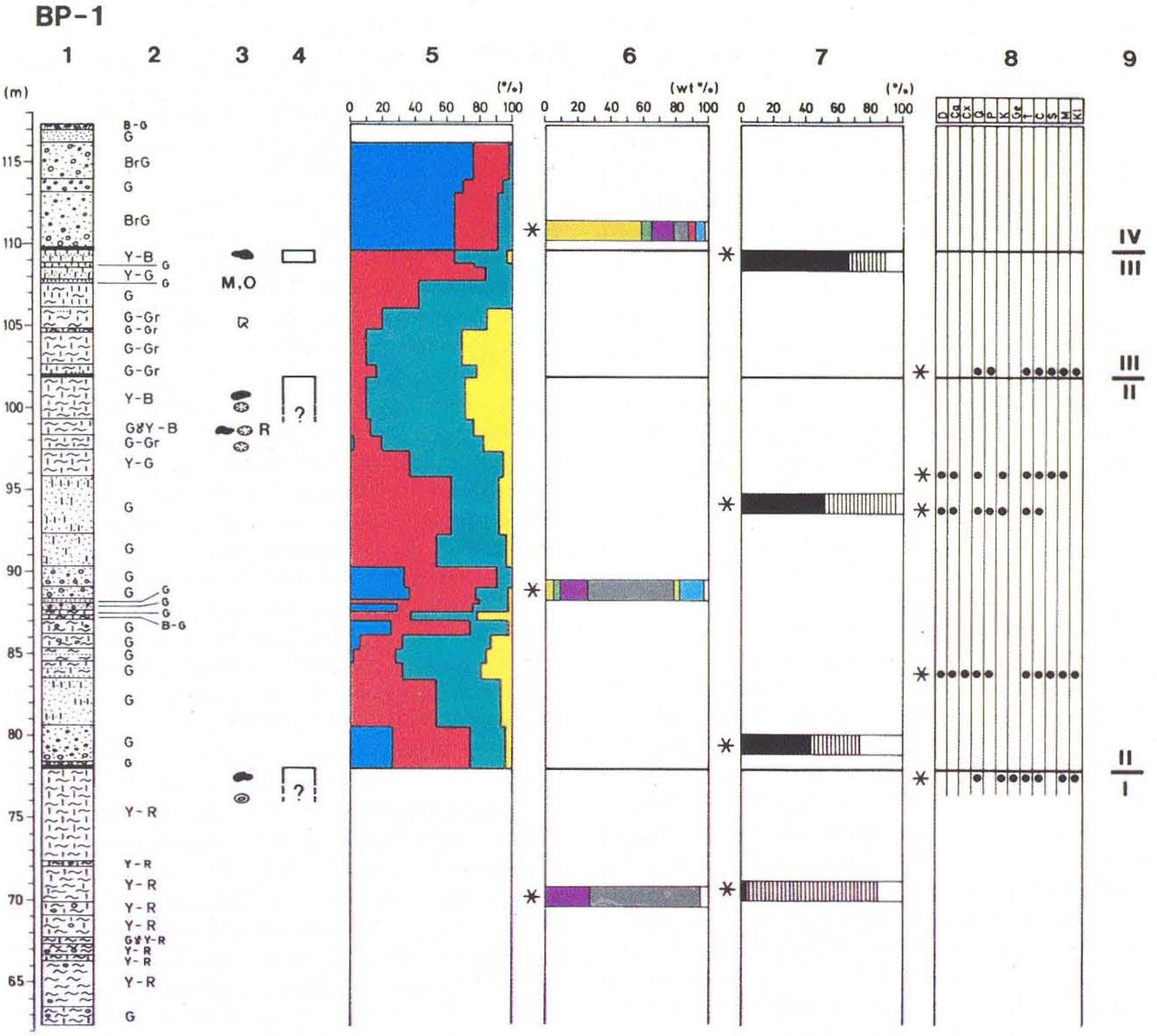
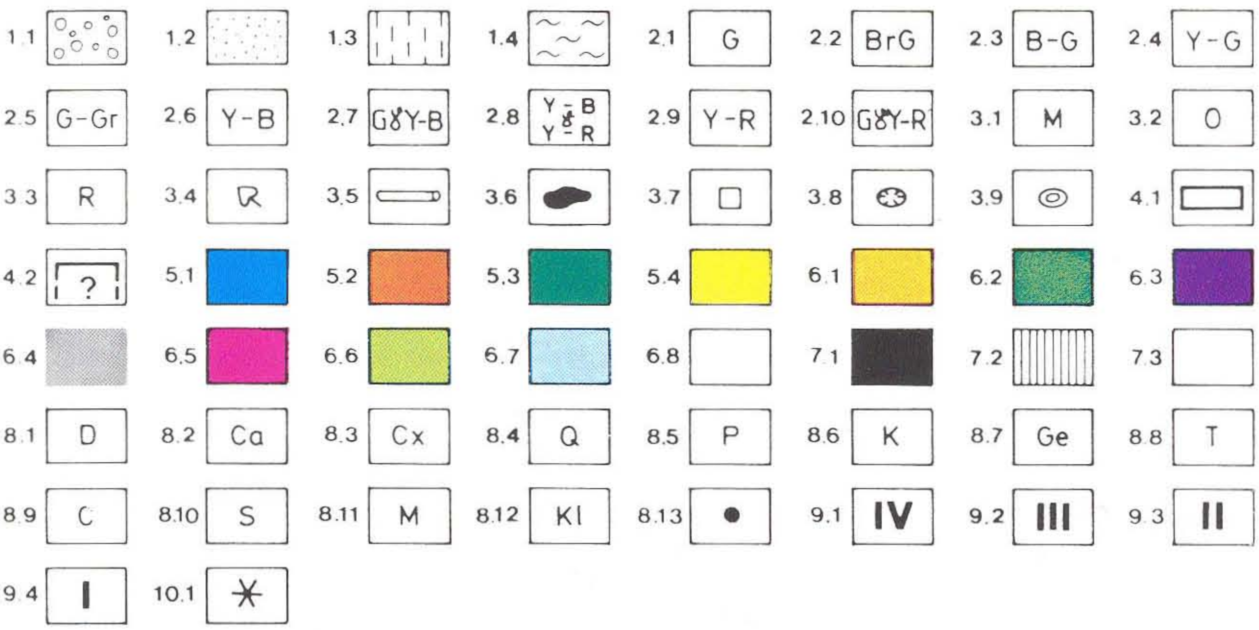


Fig. 13 Correlation of results of field and laboratory investigations, well BP-1.
Sl. 13 Korelacija rezultata terenskih i laboratorijskih istraživanja, bušotina BP-1.



Legend for Figs. 13 and 14.
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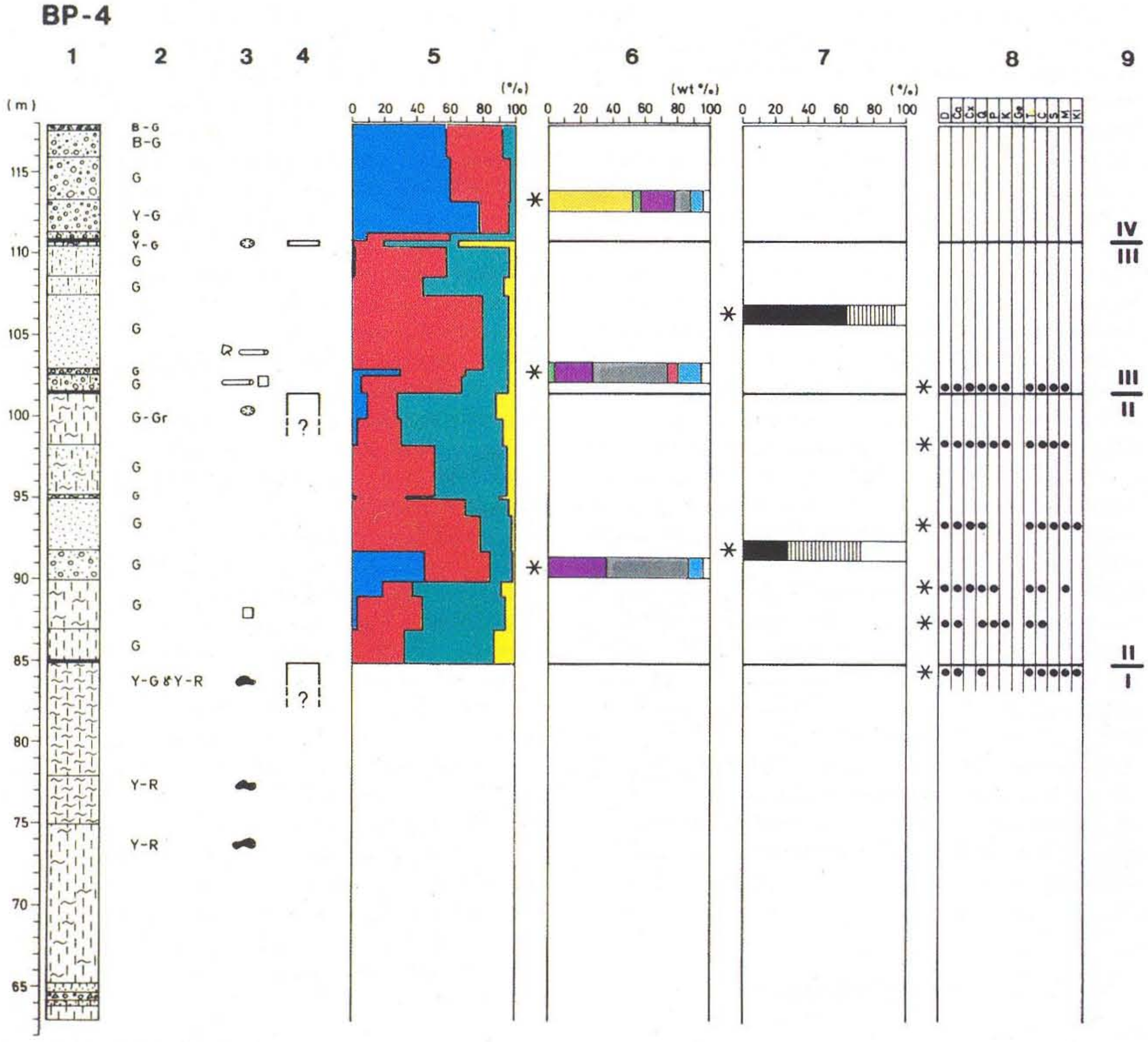

Fig. 14 Correlation of results of field and laboratory investigations, well BP-4.
Sl. 14 Korelacija rezultata terenskih i laboratorijskih istraživanja, bušotina BP-4.

1. Lithology: 1.1=gravel; 1.2=sand; 1.3=silt; 1.4=clay
2. Colour: 2.1=grey; 2.2=bright grey; 2.3=brownish grey; 2.4=yellowish grey; 2.5=greyish green; 2.6=yellowish brown; 2.7=grey and yellowish brown; 2.8=yelowish grey and yellowish red; 2.9=yellowish red; 2.10=grey and yellowish red
3. Palaeontological symbols and soil-forming/after burial features: 3.1=molusca fragments; 3.2=ostracods; 3.3=Rhizoconcretions; 3.4=plant fragments; 3.5=wood fragments; 3.6=mottles; 3.7=pyrite; 3.8=calcerous concretions; 3.9=limonitized rock fragment
4. Zones with features which indicate possible soil forming processes: 4.1=palaeosol; 4.2=undetermined lower boundary of a palaeosol
5. Grain size distribution: 5.1=gravel; 5.2=sand; 5.3=silt; 5.4=clay
6. Gravel composition (granules and pebbles): 6.1=limestones; 6.2=dolostones; 6.3=sandstones; 6.4=quartzites; 6.5=extrusive rocks and tuff; 6.6=conglomerates and breccias; 6.7=chert; 6.8=other rocks
7. Selected heavy minerals ratios: 7.1=garnet; 7.2=epidote; 7.3=zircon+tourmaline
8. Mineralogical composition of clay and silt rich materials: 8.1=dolomite; 8.2=calcite; 8.3= unidentified carbonate mineral (possibly siderite); 8.4=quartz; 8.5=plagioclase; 8.6=feldspar; 8.7=goethite; 8.8=mica; 8.9=chlorite; 8.10=smectite; 8.11=mixed-layer clay minerals; 8.12=kaolinite; 8.13=identified mineral constituent
9. Identified units: 9.1=Unit IV; 9.2=Unit III; 9.3=Unit II; 9.4=Unit I

10.1=Position of a sample.

1. Litološki sastav: 1.1=šljunak; 1.2=pijesak; 1.3=silt; 1.4=glina
2. Boja naslaga: 2.1=sivo; 2.2=svijetlosivo; 2.3=smedesivo; 2.4=žućkastosivo; 2.5=sivkastozeleno; 2.6=žućkastosmeđe; 2.7=sivo i žućkastosmeđe; 2.8=žućkastosivo i žućkastocrveno; 2.9=žućkastocrveno; 2.10=sivo i žućkastocrveno
3. Paleonotološke oznake i pedogenetske/dijagenetske pojave: 3.1=fragmenti ljuštura mekušaca; 3.2=ostrakodi; 3.3=rizokonkrecije; 3.4=biljno trunje; 3.5=ostaci drveta; 3.6=šare; 3.7=pirit; 3.8=karbonatne konkrecije; 3.9=fragmenti limonitiziranih stijena
4. Zone s pojavama koje ukazuju na procese stvaranja tla: 4.1=paleotlo; 4.2=paleotlo bez utvrđene donje granice
5. Granulometrijski sastav: 5.1=šljunak; 5.2=pijesak; 5.3=silt; 5.4=glina
6. Petrografski sastav valutica: 6.1=vapnenac; 6.2=dolomit; 6.3=pješčenjak; 6.4=kvarcit; 6.5=efuzivi i tuf; 6.6=konglomerati i breče; 6.7=čert; 6.8=ostale stijene
7. Odnos izabranih teških minerala: 7.1=granat; 7.2=epidot; 7.3=cirkon+turmalin
8. Mineralni sastav glina i siltova 8.1=dolomit; 8.2=kalcit; 8.3=nedefinirani karbonat (vjerojatno siderit); 8.4=kvarc; 8.5=plagioklas; 8.6=feldspat; 8.7=getit; 8.8=tinjci; 8.9=klorit; 8.10=smektit; 8.11=miješano-slojni minerali glina; 8.12=kaolinit; 8.13=identificirani mineral
9. Razlučene jedinice: 9.1=jedinica IV; 9.2=jedinica III; 9.3=jedinica II; 9.4=jedinica I

10.1=Položaj uzorka.

Overlying palaeosols indicate phases of subaerial exposure. Units II, III and IV overlie palaeosols, indicating that the uppermost parts of Units I, II and III were exposed to the action of pedogenesis. Three palaeosols occur in a 60 m thick interval of sediments. While the oldest palaeosol displays the greatest thickness (in some cores more than 10 meters), the youngest is the thinnest, ranging in thickness from 0.1 to 0.7 m. Their formation is closely related with palaeoclimatic conditions implying that warm periods of specific humidity and duration are required. Since the differences among interglacial mean annual temperatures are relatively small (EMILIANI & SHACKLETON, 1974), the differences in palaeosol thickness were undoubtedly influenced by the duration of sediment exposure to soil forming processes. Nevertheless, it has to be stated that some authors assume that strongly developed pre-Würm paleosols formed under long intervals with climate similar to the present (e.g. BOARDMAN, 1985), while others (e.g. KARLSTROM, 1991) find that the mean temperature and precipitation during formation of the paleosols was at least 6-8°C warmer and 40 cm higher than present. During approximately 200,000 years of the Cromerian and Elsterian, almost the complete drilled interval of Unit I was subjected to the action of soil forming processes. In the Eemian interglacial, which lasted slightly less than 100,000 years, up to 2.6 m of the uppermost part of Unit II was affected by pedogenesis. A palaeosol, approximately 0.5 m thick, formed in the top part of Unit III, during the period of 4000 to 6000 years in late Weichselian and, possibly, early Holocene.

7. CONCLUSIONS

On the basis of performed field and laboratory investigations accompanied by natural-gamma radioactivity measurements four units are recognized (Figs. 6, 7, 11, 12, 13 and 14). Unit I is predominantly composed of yellowish-red, yellowish-orange and yellowish-brown, poorly-moderately cemented, dense, clayey-silts/silty-clays. Sporadic lenses and interbeds of gravelly-sands, up to a few dm thick also occur. Highly variable coefficients of sorting, compared to the average values (Fig. 12) possibly indicate that loess, mixed with local materials (loessoid) has contributed to sediment composition. The almost complete absence of garnet may be a consequence of aeolian transport. Unit I is Lower Pleistocene in age and is considered to have formed during the Menapian. This is substantiated by the correlation between the conditional marker horizon Q and the unconformity which separates Unit I from Unit II. In addition, earlier investigations showed that inferred thicknesses between the Q' marker and the ground surface, in the area of Prečko were lower than 50 m, while, according to the present study, the maximum value is 40 m.

Unit II ranges in thickness from 10.35 to 24.3 m (Fig. 3) and is interpreted to be Middle Pleistocene in age. The unit is relatively uniform in composition: while the lower and middle part is predominantly composed of grey coloured sands, the upper part comprises grey coloured or red to yellowish-brown mottled silt and clay sized material. Coarse-grained sediments in the lower and middle part of the unit are poorly sorted. The high matrix content indicates that they were rapidly deposited in a quier-water environment i.e they were deposited from running water at the point of entry into a shallow lake or a marsh. The lake was formed in a humid climate, during the Holstein interglacial. With the incoming glacial, possibly Saalian, the granulometric and bulk composition gradually changes upwards indicating that the transport mechanism also changes. As the result of increasing loess accumulation accompanied by a marked cooling and dryness, the lake/marsh dried out.

Unit III is heterogeneous and ranges in thickness from 6.15 to 13.2 m (Fig. 4). The unit is characterized by frequent lateral changes of gravels, sands, silts and clays. While the sands are predominantly grey coloured, the silts and clays are often mottled in yellowish and brownish shades. In the upper part, varve are recognized, as alternating, millimetre thick light coloured, fine-grained sands and dark grey to black silts. While particle size analyses partly indicate a loess origin of the unit, some recognized features suggest that the sediment was accumulated in a marsh type environment. Resumption of a quier and shallow water environment corresponds with the upper part of the moist and warm Eemian interglacial. Consequently, we consider Unit III to be Upper Pleistocene, principally Lower to Middle Weichselian in age.

Unit IV varies in thickness from 6.6 to 7.7 m (Fig. 5) and is Holocene in age. It is composed of pale, yellowish-grey coloured gravels and sands in which limestone cobbles prevail.

The upper parts of Units I, II and III were exposed to the action of soil forming processes during phases of subaerial exposure. At least three zones with palaeosol characteristics were recognized. The criteria used to recognize the palaeosols were: (1) different colour compared to the overlying and underlying material, (2) presence of mottles, (3) presence of concretions and nodules, (4) evidence of weathering of minerals (goethite) and (5) presence of roots and organic matter fragments. These zones are closely related to the observed unit boundaries. While the oldest palaeosol (Unit I) displays the greatest thickness (in some cores more then 10 m), the youngest paleosol (Unit III) ranges in thickness from 0.1 to 0.7 m. Their formation required warm periods of specific humidity and duration. We consider these periods to be related with the Cromerian and Elsterian, Eemian, and late Weichselian and, possibly early Holocene respectively.

The occurence of both specific sedimentary environments and phases of subaerial exposure was also influenced by tectonic processes. The morphology of the base surfaces of Units II, III and IV are mutually different (Figs. 8, 9 and 10). In ascending order they are more simple in appearance. This is, among others a consequence of neotectonic movements. Namely, the area studied is situated at the mutual edge of two structures which have been active till Quaternary. Local processes of tectonic uplift and subsidence were only partly compensated for by sedimentation and denudation respectively.

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Izmjena jezersko-močvarne sedimentacije i kopnenih faza tijekom kvartara na lokaciji Prečko (Zagreb)

J. Velić i G. Durn

Na lokaciji Prečko površine od 6 ha (sl. 1) proučene su taložine u prvih 60 m dubine. Izrađeno je sedam bušotina; četiri na lijevoj i tri na desnoj obali Save (sl. 2). Izvučeno je ukupno 390 m jezgre. One su na terenu determinirane te je prikupljeno i više desetaka uzoraka za laboratorijsku i kabinetsku obradu. U bušotinama su obavljena geofizička snimanja prirodne i izazvane radioaktivnosti.

Tijekom studiranja stratigrafskih odnosa djelomice su korišteni nazivi glacijalnih i interglacijalnih sekvencija za područje Alpa bez obzira na ozbiljne primjedbe glede njihove znanstvene utemeljenosti. Naime, autori kvartaroloških radova o terenima Hrvatske rabili su isključivo spomenutu klasifikaciju pa smo korelirajući naše s rezultatima za susjedna područja i mi morali tako postupiti. Identifikacija s kronostratigrafskom skalom za Europu obavljena je prema HARLAND et al. (1990) - naročito u podjeli na donji (rani), srednji i gornji (kasni) pleistocen, te prema NILSSON (1983).

Na temelju svih terenskih i laboratorijskih podataka te prosječne prirodne gama-radijacije (sl. 6, 7, 11, 12, 13 i 14) razlučene su četiri jedinice. Jedinica I izgrađena je pretežito od poluvezanih, gustih glinovitih siltova/siltoznih glina karakteristične žutonarančaste (crvene) ili žutosmeđe boje. Sporadično su prisutne leće šljunkovitih pijesaka debljine nekoliko decimetara. Malo povišene vrijednosti koeficijenta sortiranja u odnosu na srednje vrijednosti (sl. 12) ukazuju da se vjerojatno radi o lesu pomiješanom s lokalnim materijalom (lesoid). Gotovo potpuna odsutnost granata moguća je posljedica eolskog transporta čestica. Spomenuti krupnozrnasti klastiti ukazuju pak i na donos vodama tekućicama, najčešće bujicama u plitku slatkovodnu sredinu. Jedinica je donjopleistocenske starosti. Pretpostavljamo da je nastala tijekom menapiana (günz). U prilog takvog tumačenja ubraja se i podudaranje krovine ove jedinice s uvjetnim reperom Q' kao i ranijim istraživanjima pretpostavljene debljine stijene od repera Q' do površine terena - manje od 50 m, ovdje konkretno određeno 40 m.

Jedinica II debljine 10,35 do 24,3 m (sl. 3) interpretirana kao srednjepleistocenska, jednoličnog je sastava: u donjem i srednjem su dijelu uglavnom pijesci sive boje, a u gornjem sve više ima siltova i glina, sivih ili "šarenih" s mrljama crvene do žutonarančaste boje. Krupnozrnasti klastiti donjega i srednjega dijela loše su sortirani. Visoki udjel glinovito-siltnog matriksa u njima ukazuje da su taloženi u uvjetima brze sedimentacije u vodenoj sredini niske energije, tj. da su nastali akumulacijom iz voda tekućica prigodom utoka u jezero ili močvaru. Jezero je formirano u mlađem holsteinu (mindel/riss interglacijal) zahvaljujući prvenstveno humidnoj klimi. S nastupanje glacijala saale (riss) postupno se mijenjao sastav, veličina i način donosa čestica, tj. sve je izraženija i akumulacija lesa, što je uz zahlađenje i sušu prouzročilo presušivanje jezera/močvare.

Jedinica III karakteristična je po heterogenom sastavu i varijacijama debljine - od 6,15 do 13,2 m (sl. 4). Radi se o čestim bočnim izmjenama šljunaka, pijesaka, siltova i glina. Pijesci su uglavnom sivi, a siltovi i gline često mrljasti u nijansama žute i smeđe boje. U gornjem su dijelu uočene varve: milimetarske izmjene svijetlih sitnozrnastih pijesaka i tamnosivih do crnih siltova. Prema veličini čestica ova je jedinica dominantno lesnog podrijetla s obilježjima geneze u močvarnoj sredini što znači i unosa detritusa vodenim transportom. Obnavljanje mirne, plitke vodene sredine u korelaciji je s vlažnim i toplim interglacijalom eem (riss/würm) i to njegovim mlađim dijelom, dok je sedimentacija razmatrane jedinice gornjopleistocenske, pretežno starije do srednjoweichselske (würm) starosti.

Debljina jedinice IV kreće se od 6,6 do 7,7 m (sl. 5). Radi se o holocenskom šljunku i pijesku svijetle žućkastosive boje, standardnog petrografskog sastava savskih nanosa kod kojih su dominantne valutice vapnenaca.

Vršni dijelovi taložina I, II i III jedinice bili su izloženi procesima pedogeneze. Ustanovljena su barem tri nivoa sa značajkama paleotala. To su žutonarančasta-crvena-smeđa boja naslaga, prisutnost mrlja ili šara, konkrecija, nodula, korijenja te minerala trošenja (getit). Odnosni su nivoi usko povezani s granicama među jedinicama. Različito su izraženi. Obuhvaćaju od preko 10 m (jedinica I) do 0,1 m (jedinica III). Za njihovo je stvaranje bila potrebna topla klima određene vlažnosti i trajanja, čemu odgovaraju intervali od cromera do holsteina, zatim raniji eem i naposljetku kasni weichsel s eventualno starijim holocenom.

Na genetski tip naslaga i pojavu kopnenih faza utjecali su također i tektonski procesi. Oblici podinskih ploha jedinica II, III i IV (sl. 8, 9 i 10) uglavno se međusobno ne podudaraju, a idući prema mlađima razlučene jedince se rasprostiru unutar sve manjih visinskih intervala. To je posljedica različito izraženih lokalnih spuštanja i izdizanja u rubnim zonama nasljedne (na zapadu od Prečkog) i inversne (na istoku) strukture, aktivnih do u kvartar. Tektonski pokreti su očito samo djelomice kompenzirani sedimentacijom,

odnosno denudacijom.

I na kraju, ali ne i manje važno, jedna pripomena. Kako bi se izbjegle nedoumice, a omogućile stratigrafske usporedbe s Europskim i svjetskim postignućima, ubuduće svakako treba predvidjeti i obavljati radiometrijske analize (osim često primijenjivanu radiokarbonsku metodu i mjerenja na bazi dugoživućih radionukleida) uzoraka kvartarnih taložina s terena Hrvatske kao i paleomagnetne korelacije. To je jedini način da se dođe do kriterija za valjanu i općeprihvatljivu kronostratigrafsku klasifikaciju.

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