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Quaternary Deposits as the Hydrogeological System of Eastern Slavonia

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Key words: Hydrogeological system, Watershed, Lithological continuity, Fault zones, Transmissivity, Plateau, Eastern Slavonia, Croatia.

Ključne riječi: hidrogeološki sustav, razvodnica, litološki kontinuitet, rasjedne zone, transmisivnost, ravnjak, istočna Slavonija, Hrvatska.

Abstract

The area of eastern Slavonia, situated between the Drava and Sava rivers, comprises three geotectonic units: the eastern part of the Drava depression in the north, part of the Slavonia-Srijem depression in the south and the central Đakovo-Vinkovci plateau together with the Vukovar plateau. These units are separated by deep faults that reach the base of the Tertiary sediments. The first 200 m of Quaternary deposits are saturated with fresh water. The aim of this study was to find out whether the faults form impermeable boundaries separating the waterbearing deposits into independent hydraulic systems, or if a singular hydraulic entity exists. Results of the analysis indicate that lithological continuity of the aquifers exists along the fault zones on the margins of the Đakovo-Vinkovci and the Vukovar plateaux, which means that there is no impermeable hydraulic boundary on the watershed between the Sava and Drava river valley. The part of eastern Slavonia between the Sava and Drava rivers is one hydraulic system consisting of zones with different transmissivity values. In the zones of reduced transmissivity, the hydraulic connections are weakened, but not broken. Such zones exist not only along the fault zones of the Đakovo-Vinkovci plateau and the Vukovar plateau, but also within the Sava and Drava depressions. The terrain morphology influenced formation of both the surface and the underground watershed, parallel to the extension of the Đakovo-Vinkovci and Vukovar plateau. Therefore, within this single hydraulic entity, when the drawdown reaches the watershed due to excessive pumping, the watershed will be displaced from its natural position.

Sažetak

U prostoru istočne Slavonije, između Save i Drave nalaze se tri geotektonske jedinice i to na sjeveru istočni dio Dravske potoline, na jugu dio Slavonsko-srijemske potoline, a između njih Đakovačko-vinkovački i Vukovarski ravnjak. Ravnjaci su u morfološkom i strukturno-tektonskom pogledu složene timorske strukture, koje su od susjednih potolina odvojene sistemima dubokih rasjeda koji zadiru u podlogu tercijarnih sedimenata. Zbog morfologije terena se duž pružanja Đakovačko-vinkovačkog i Vukovarskog ravnjaka proteže površinska i podzemna razvodnica koja istraživani prostor dijeli u dva sliva: Dravski na sjeveru i Savski na jugu. Cilj ovog rada bio je istražiti da li rasjedne zone između ravnjaka i potolina predstavljaju nepropusnu granicu koja naslage dijeli u dva odvojena hidraulička sustava ili one čine jednu hidrauličku cjelinu. Analizom su obuhvaćene kvartarne naslage koje sadrže vodu pogodnu za vodoopskrbu, a koje zaliježu do dubine od 200 m. Rezultati analize pokazali su da litološki kontinuitet vodonosnih slojeva duž rasjednih zona Đakovačko-vinkovačkog i Vukovarskog ravnjaka nije prekinut, te da na razvodnici savskog i dravskog sliva ne postoji nepropusna hidraulička granica. Prostor istočne Slavonije između Drave i Save smatra se jednim hidrauličkim sustavom unutar kojeg postoje zone s različitim vrijednostima transmisivnosti. Duž zona smanjene transmisivnosti hidrauličke veze su oslabljene, ali nisu prekinute. Takve zone nisu prisutne samo duž rasjednih zona Đakovačko-vinkovačkog i Vukovarskog ravnjaka nego i unutar pojedinih depresija. U slučaju da sniženje uzrokovano crpljenjem dosegne razvodnicu započinje dotok vode iz područja s druge strane razvodnice, tj. razvodnica se premiješta u odnosu na prirodni položaj udaljavajući se od mjesta crpljenja.

1. INTRODUCTION

The eastern part of the Drava depression in the north and part of the Slavonia-Srijem depression in the south, divided by the central Đakovo-Vinkovci plateau together with the Vukovar plateau, are deeply subsided structural depressions which were formed along regional faults characterised by the horizontal displacement and movement of coherent tectonic blocks to the northeast, which influenced the formation of large extension zones. The plateaux have the morphology and structure of complex horst structures, that are separated from the neighbouring depressions by systems of deep faults (Figs. 1 and 2). With respect to the surface water and groundwater, two drainage areas are defined - the Drava drainage area in the north and the Sava drainage basin in the south. The surface and subsurface watersheds between these two areas are located on the Đakovo-Vinkovci and the Vukovar plateaux.

For construction of the geological map shown in Fig. 1, the following sheets of the Basic Geological Map of SFRJ Scale 1:100,000 were used: Donji Miholjac (HEĆIMOVIĆ, 1985), Našice (KOROLIJA & JAMIČIĆ, 1989a), Osijek (MAGAŠ, 1987a), Odžaci (TRIFUNOVIĆ & STOJADINOVIĆ, 1985), Slavonski Brod (ŠPARICA, 1987), Vinkovci (BRKIĆ et al., 1989), Bačka Palanka (ČIČULIĆ-TRIFUNOVIĆ &

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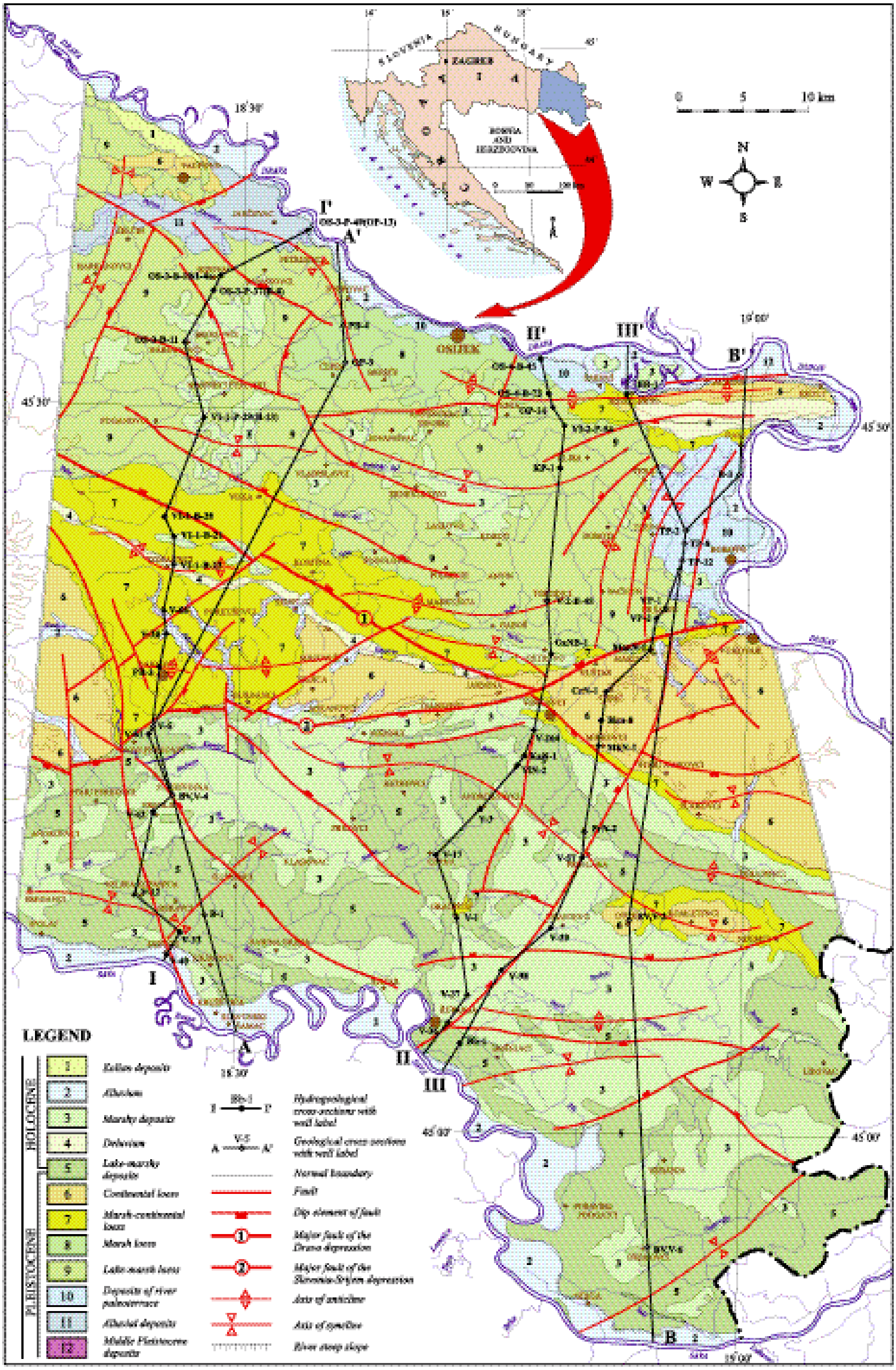

Fig. 1 Geological map.

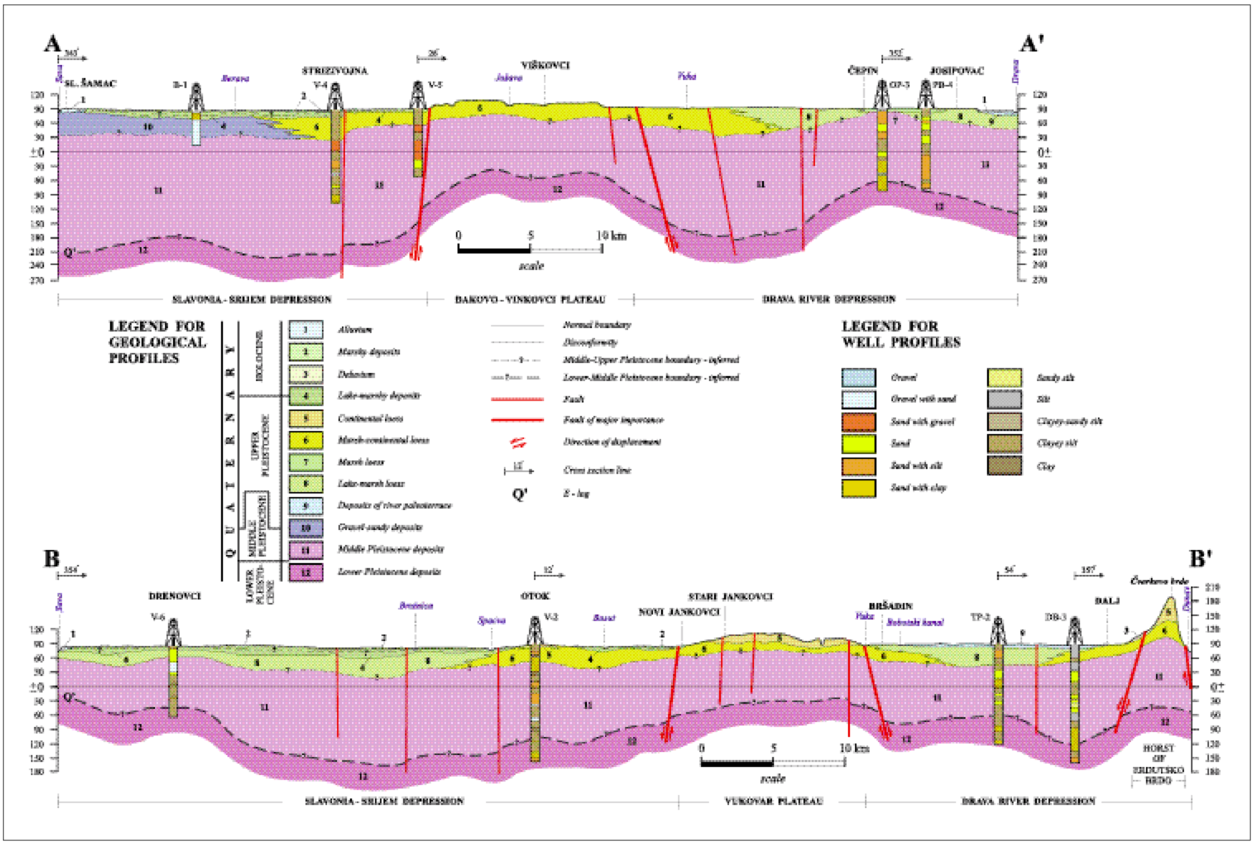

Fig. 2 Geological cross-sections A-A' and B-B'.

GALOVIĆ, 1985a), Brčko (BUZALJKO et al., 1987) and Bijeljina (VRHOVČIĆ et al., 1986). The structures and other tectonic data were compiled after the works of HERNITZ (1983) and PRELOGOVIĆ et al. (1995).

The aim of the study was to determine whether the fault zones between the plateaux and depressions constitute an impermeable zone that separates the Sava and Drava drainage area into two hydraulic systems, or whether a singular hydraulic entity exists. The shallowest 200 metres of sediments favourable for water-supply were explored.

2. DATA-SETS AND METHODS

The work is largely based on the analysis of geological and hydrogeological data that were published in scientific and professional papers and books, as well as on the numerous reports in the archives of several companies and scientific institutions. These data were interpreted together with fieldwork and laboratory investigations of the sediments drilled in 518 wells. The most important data obtained from the wells were the total depth, depth-intervals of permeable layers and the ratio of the thickness of permeable and impermeable layers. The following hydrogeological parameters of the wells were calculated: average hydraulic conductivity, transmissivity, storage coefficient and leakage coefficient. The drilling data and the well-logs (primarily the E-logs and the radioactive logs) were correlated in a north-south direction in order to depict the lateral relationships of the plateau sediments to the depressions. Due to the fact that there is a limited number of wells in the marginal zones, the data set was complemented with interpretation of geoelectric measurements. The results obtained by utilisation of the mathematical models that covered the marginal zone were also taken into account.

3. RESULTS

The results of comprehensive analyses of all the data that were at our disposal, originating from the sources mentioned above, can be grouped in accordance to the scientific disciplines - geological (stratigraphic, tectonic and palaeogeographic), hydrogeological and hydraulical data. Their synthesis solved the problem of the continuity of the aquifer layers in the studied area of a relatively complex geological structure.

3.1. QUATERNARY GEOLOGICAL EVOLUTION

In view of the water-supply possibilities, the most interesting sediments were deposited during the Middle and Upper Pleistocene. This is the reason why this overview of the geological history only covers the Quaternary period.

In northern Croatia, there is a continuation of like depositional environments between the Pliocene (Uppermost Tertiary) and the Quaternary, the Pliocene being characterised by large aquatic areas with sediments of significant thickness, especially in the subsiding depressions. It also means that the Pliocene - Pleistocene boundary has not yet been defined with confidence. Subsequent to the strong tectonic events between the Pliocene and Quaternary, and to the breakthrough of the Danube in the Đerdap canyon, the lakes and swamps gradually dried up, followed by formation of the drainage pattern. There are only scarce data on the **Lower Pleistocene** of the explored area. There are no outcrops. The age was proved by fossil findings in a small number of wells - in Otok (SOKAČ, 1976), Vinkovci (SOKAČ & HARTEN, 1978), Trpinja (MAGAŠ, 1987b; MUTIĆ, 1989), in Vladislavci and Osijek (MAGAŠ, 1987b), in Erdut and Dalj (SOKAČ et al., 1982) and also in Valpovo (KOROLIJA & JAMIČIĆ, 1989b). The Lower Pleistocene sediments are mostly clay, silt and some sand. Due to the fact that their contact with the Pliocene is not defined, it is also impossible to tell the thickness of these sediments. The Lower Pleistocene - Middle Pleistocene boundary is defined on the conditional E-log marker Q' (Fig. 2). Above the Q' marker horizon, there is a domination of permeable sediments, sand with some gravel, while underlying sediments are of low permeability - silt and clay (URUMOVIĆ et al., 1976, 1978). In the uplifts of the Đakovo-Vinkovci and the Vukovar plateaux, the Q' horizon lies at depth of approximately 150 m, while in depressions it is mostly below 200 m, sometimes even 300 m (HERNITZ, 1983).

The **Middle Pleistocene** sediments are also buried, apart from a small outcrop on the northern slope foothills of the Erdut hill (Fig. 1, TRIFUNOVIĆ, 1985). Nevertheless, these sediments are well studied due to the large number of water exploration wells, some of them drawn on the geologic cross-sections (Fig. 2). It was during the Middle Pleistocene that the main mass of the hydrogeologically interesting permeable sediments were deposited. The eastern Slavonia area was then covered by shallow lakes and swamps and the neighbouring Bosnian and Slavonian mountains were land areas exposed to strong denudation. The transport and deposition of clastic material, respectfully several cycles of redeposition, was also very dependent on the palaeoclimate. The most significant palaeoclimate characteristic was the alternation of the warm and humid periods with cold and very dry periods. During the warmer interglacial periods, the high waters of surface streams transported a lot of the coarse-grained clastic material and deposited it in the swamps and lakes. At the same time, the level of stagnant waters rose, so the swamps and lakes grew and covered a bigger area, until eventually they became interconnected. In contrast, the glacial periods are characterised by a draw-back of the surface streams into their river-beds, a reduction of their transport capabilities, and by the shallowing of the depositional area. The wind forces took the dominant role in the transport of sedimentary material, while silt and clay were deposited in the remaining lakes and swamps. In some places, the aquatic environments totally dried up which enabled the formation of palaeosols. The related palaeogeomorphological circumstances are explored, documented and explained in the works of VELIĆ & DURN (1993) and VELIĆ & SAFTIĆ (1996).

The aforementioned depositional environments are confirmed by fossil findings. The ostracods significant for the shallow stagnant waters were determined by SOKAČ (1976), SOKAČ & HARTEN (1978), SOKAČ et al. (1982) and URUMOVIĆ & SOKAČ (1974). The characteristic malacological community of the swamp biotope was interpreted by TRIFUNOVIĆ (1985), and the important biotope for the fluvial-paludal environment was discovered by ČIČULIĆ-TRIFUNOVIĆ & GALOVIĆ (1985b). Terrestrial species were determined by POJE et al. (1995) and by MALEZ (1970, 1971, 1978).

The majority of the clastic material was transported in the Slavonia-Srijem depression by the rivers and streams from the Bosnian mountains and from Mt. Dilj. This is confirmed by the mineral composition of fluvial sediments which originated from the serpentine zone in Bosnia (MUTIĆ, 1993). The main direction of transport from south to north correlates with reducing proportions of the coarse-grained clasts and grain size in the same direction (URUMOVIĆ et al., 1978). In this way, in the southern part, along the Sava river, gravel was predominantly deposited, and in the northern sections sand (MILETIĆ et al., 1986a).

The Drava river and the streams flowing down the slopes of Mt. Krndija are the main distributors of clastic material in the Drava depression. The Drava river transports the material eroded in the area of the Central Alps, on the Pohorje and Kozjak massifs and from the Slavonian mountains (BABIĆ et al., 1978; MUTIĆ, 1989). In eastern Slavonia the river mostly deposits sand. The more frequently occurring gravel along the western margin of the study area was brought by the Mt. Krndija streams (URUMOVIĆ, 1982). Apart from the rivers and streams, MAGAŠ (1987b) discovered the traces of lakes by the rivers and deep pools. In the Erdut area, large shallow marshes existed where rivers deposited sand in the high-water periods (VELIĆ et al., 1985).

In the Pliocene, the Đakovo-Vinkovci and the Vukovar plateaux were mostly submerged uplifts characterised by the deposition of mixed sedimentary material. One of components was transported from the north, respectfully the north-west, and another from the south or the south-west. In the Vukovar plateau area, the fluvial, lacustrine and marsh sediments were determined (ČIČULIĆ-TRIFUNOVIĆ & GALOVIĆ, 1985b).

Apart from the palaeoclimate conditions, sedimentation was influenced by tectonic movements which are still active in eastern Slavonia. The most important tectonic displacement is on the main faults that follow the northern and southern margin of the plateau and on the secondary parallel faults of the WNW-ESE system. There is also a marked displacement on the faults of the NNE-SSW system (HERNITZ, 1983). This system has an especially pronounced horizontal character of displacement (PRELOGOVIĆ & VELIĆ, 1992).

In the beginning of the **Upper Pleistocene** similar sedimentary conditions were preserved. The Riss-Würm interglacial was still characterised by an influx of coarse-grained clastic material, which is proved by palaeontological investigation of the topmost part of the gravely aquifer close to the Sava river (MUTIĆ, 1993). It seems that the extensive transport of the coarse-grained clastic material by surface waters stopped with the beginning of the last ice age - the Würm glacial.

The most remarkable Würm facies are the loess deposits that also cover a significant part of the study area. Transported by strong winds, the loess grains were deposited everywhere - in the lakes, pools and shallower marshes as well as on the mild morphologic land uplifts. In respect to that, the lake-marsh, marsh, marsh-continental and continental loess is differentiated (Figs. 1 and 2). Different types of loess at the same time depict the contemporary distribution of the land and water, which is of special importance for the reconstruction of the evolution of the plateaux.

The typical continental loess is found only in the area of the Vukovar plateau, Erdut uplift and in the restricted area near the Otok and Komletinci. This means that land existed only in these areas at the time. The loess on the Đakovo-Vinkovci plateau was contemporaneously deposited in an aqueous environment. The following tectonic movements led to the uplift of the Vinkovci area so that the loess that was in the beginning deposited in water was gradually covered by continental loess (GALOVIĆ & MUTIĆ, 1984; MUTIĆ, 1990). The contact between the aqueous and continental loess can be clearly observed in the quarry of the Vinkovci brick-factory. During the entire Upper Pleistocene, in the western part of the plateau (the Đakovo part) the wind-blown grains were deposited in the shallow water environment. Due to neotectonic activity, this part of the plateau became land only in the Holocene (MUTIĆ, 1990).

In addition to the loess, the Upper Pleistocene sediments in the Drava depression are represented by river palaeoterraces and alluvial sands. The terraces are identified on the surface along the Drava flow between the Osijek and Sarvaš and along the Danube from Dalj to Vukovar, and the alluvial sand deposits lie in the marginal north-western part of the explored area (Figs. 1 and 2).

A large part of the Sava depression area is covered by marshy-lacustrine sediments of Upper Pleistocene age, deposition of which continued into the Holocene. Frequently, they are complicated to differentiate in the field from the marsh loess (ŠPARICA et al., 1987). Due to the lack of organic matter, it is interpreted that these sediments were deposited in relatively clean water. The analyses of malacologic assemblages resulted in interpretation of the water environment with land nearby and marked oscillation of water level which produced repeated floods and drying-up periods (GALOVIĆ et al., 1989).

Warming at the Pleistocene - Holocene boundary caused a change in composition of vegetation cover. The steppe was gradually replaced by woods (POJE, 1986). Changes in wildlife are also documented. In the early Holocene there are still grazing herds of North-European moose (*Alces Alces*), gigantic deer (*Megaceros*) and European bison (*Bison priscus*), and during the Boreal there were common deer (*Cervus elaphus*), wild oxen (*Bos primigenius*), bear (*Ursus arctos*), wolf (*Canis lupus*), lynx (*Felis*) etc. Domestication of some animals started in the Boreal. It was firstly the dog, then the goat, sheep, oxen and some other animals. In the Neolithic and the Bronze ages, it was the horse, donkey, hen etc. (MALEZ, 1979).

The climatic changes at the end of the Würm and the beginning of the Holocene caused the melting of ice in the alpine and perialpine area and inflow of large masses of water in and around the study area. Deposition of fluvial sediments started, followed by formation of river terraces.

There are four genetic types of **Holocene** sediments: river and creek alluvium, proluvial deposits, aeolian sands and marsh sediments (Fig. 1).

The river and creek sediments are found in the river channels of the Sava, Drava and Danube, and of their larger tributaries.

Proluvial deposits cover the southern slopes of the Erdut hill, as well as the northern margin of the Đakovo-Vinkovci plateau. They were formed by the surface erosion of the continental loess and accumulation of the eroded material in the area of contact with the aquatic loess. The proluvial deposits are thin and made of loose silt containing limestone concretions.

Aeolian sands are determined in the surroundings of Valpovo, in the marginal north-western part of the studied area. Actually, the sediments of this genetic type are very common in the Drava valley west of the studied area, and it is only the tract with a maximal eastward reach that is encountered here.

Although less than 2 metres thick, the *swamp deposits* cover large areas in the Brodsko Posavlje region and in eastern Posavina. They represent the final phase of deposition of the lacustrine-marsh genetic type of sediments. In the Drava area, these sediments infilled the larger and smaller forms of negative relief, that were due to the stagnant water transformed into the swamps or swamp forests. In fluvial seasons, some of the dried parts were again filled with water, and the depositional process renewed. This is ongoing today. The swamp deposits consist of the humus-peat enriched silt and silt with some sand, as well as of the silty clay.

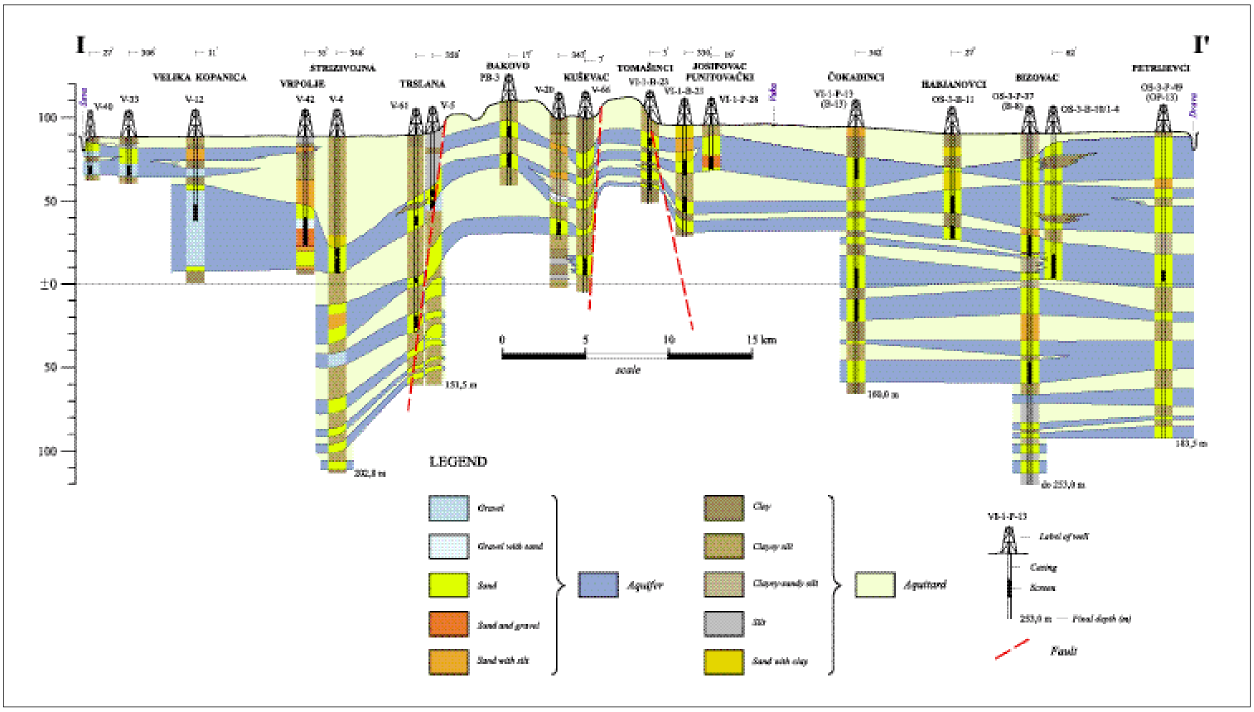

Fig. 3 Hydrogeological cross-section I-I'.

About a century ago, when the struggle for reclamation of this swampy land began, the lowest parts of the Sava and Drava depression were still covered by pools and swamps. There are works of PILAR (1876) on the swamps south-east of Osijek, and of BÖSENDORFER (1952) on the pools and swamps in the areas of Karašica, Vuka and Vučica rivers, in the Biđ-Bosut depression, and in the areas of Berava, Spačva and Studva. They all had their maximal extent during the high waters of the Drava and Sava rivers.

There are also the archaeological findings that are worth mentioning, because they indirectly depict the distribution of aquatic surfaces. The oldest settlements at present that were found in eastern Slavonia are from the Younger Stone Age - the Neolithic (6,000-3,500 B.C.) and pertain to the cultural layers named Starčevac and Sopot. These are the oldest settlements of farmers that were located in groups on the more elevated dry terrain along the rivers and lakes, but out of the reach of floods (MINICHREITER, 1992a, b). The remains of these cultures are found near the Stari Perkovci, Vrpolje, Đakovo, Vinkovci, Vukovar, Otok, Erdut hill and near Osijek.

3.2. HYDROGEOLOGICAL CHARACTERISTICS

The permeable sediments saturated with drinking water were deposited during the Middle Pleistocene and part of the Upper Pleistocene, under conditions of cyclic sedimentation followed by tectonic movements. These depositional conditions resulted in pronounced lithological heterogeneity in both the horizontal and vertical directions.

According to core determination of the shallowest 200 m of sediments in the stratigraphic column, five to seventeen permeable layers can be discerned in the Drava depression. The number of layers depends on location, while some of them reach the maximal thickness of 40 m (Figs. 3, 4 and 5). These permeable layers are mostly composed of fine- to medium-grained sands with some gravel occasionally, (usually encountered in the basal parts of thicker sandstone layers). Hydraulic conductivity is commonly in the range of 10-20 m/day, with the exception of some of the wells in Osijek, where over 40 m/day was determined, and, in contrast wells in Ostrovo, Korog and Borovo which have less than 10 m/day. The storativity is in the range of 4×10^{-5} to 3×10^{-3} while the transmissivity depends on the depth of drilling and is in a wide range of 70-1000 m^2/day. The distribution of the net thickness of permeable layers in the entire studied area is shown in Fig. 6, where it clearly depicts the depositional conditions as described above.

The sediments of the Sava depression can be divided into two units with essentially different hydrogeological properties. The first unit that lies in the south, along the Sava, consists of a single gravel aquifer (Fig. 2) with a maximal thickness exceeding 100 m. The lithological composition is dominated by fine- to medium-grained gravel with 10-50 wt. % of sand. This layer has the most favourable hydrogeological characteristics in the triangle between the Velika Kopanica, Gundinci and Kruševica. In this area, the gravel rarely contains more than 20 wt. % of sand, and the thinner beds of finer material appear only sporadically. The more pronounced lithological inhomogeneity is found in the area

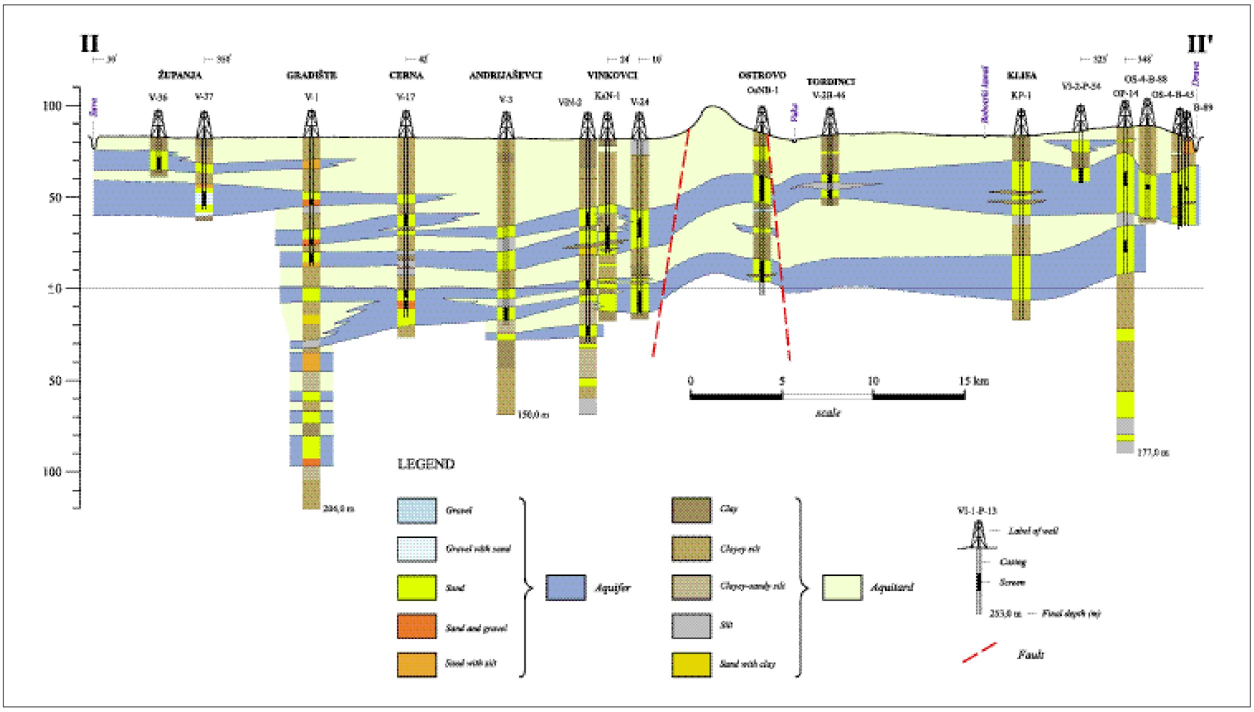

Fig. 4 Hydrogeological cross-section II-II'.

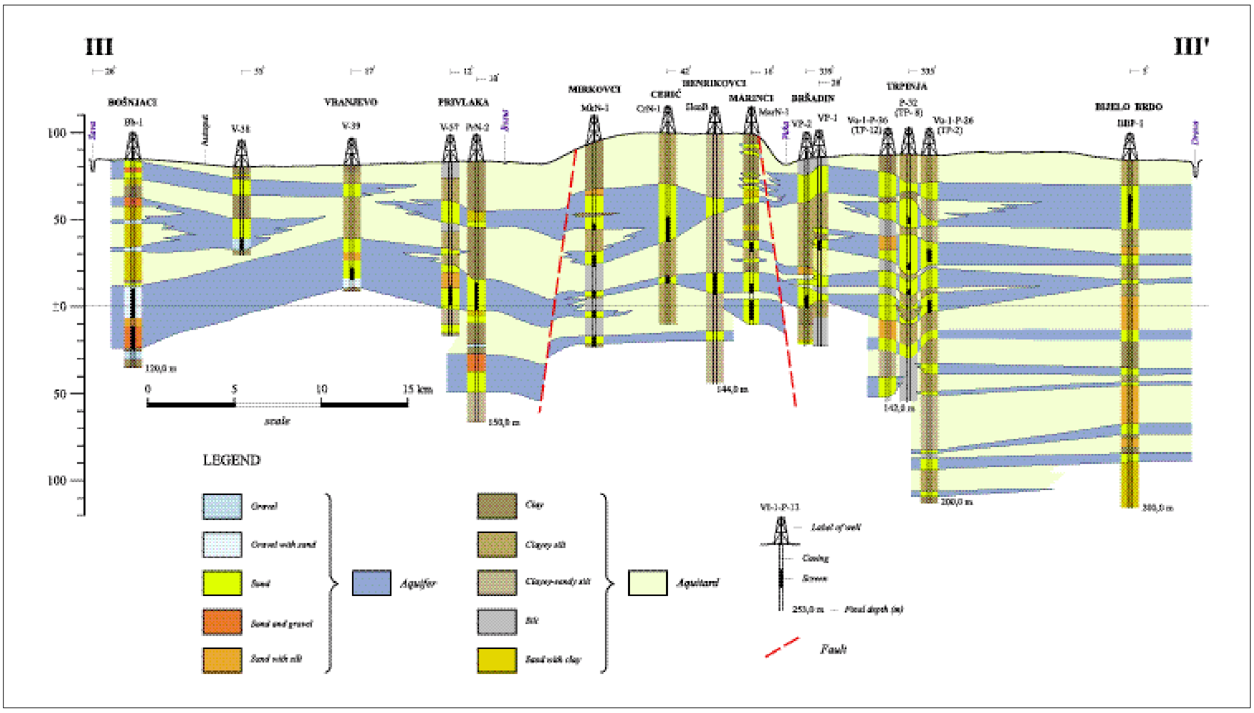

Fig. 5 Hydrogeological cross-section III-III'.

between the Babina Greda and Štitar and further to the east, where the gravel contains frequent interbeds of silty sand and clay. The mentioned aquifer has a hydraulic conductivity in the range of 30-≥200 m/day, the transmissivity is between 423-7344 m^2/day, and storativity between 1.7 x 10^{-4} and 8 x 10^{-3}.

To the north and east of the gravel aquifer, lies the second hydrogeological unit of the Sava depression. It consists of a system of sand aquifers that can number from 2 to 11 in the shallowest 200 m of sediments. The thickness of individual layers rarely exceeds 30 m. Layers are mostly composed of fine- to medium-grained sand and occasionally of coarse-grained sand. As in the Drava depression, the thicker layers of sand contain some gravel in their basal parts, especially in the eastern section, in the localities of Vranjevo, Otok and Slakovci. The hydraulic conductivity of these layers is in the range of 5.5-37 m/day, the transmissivity is

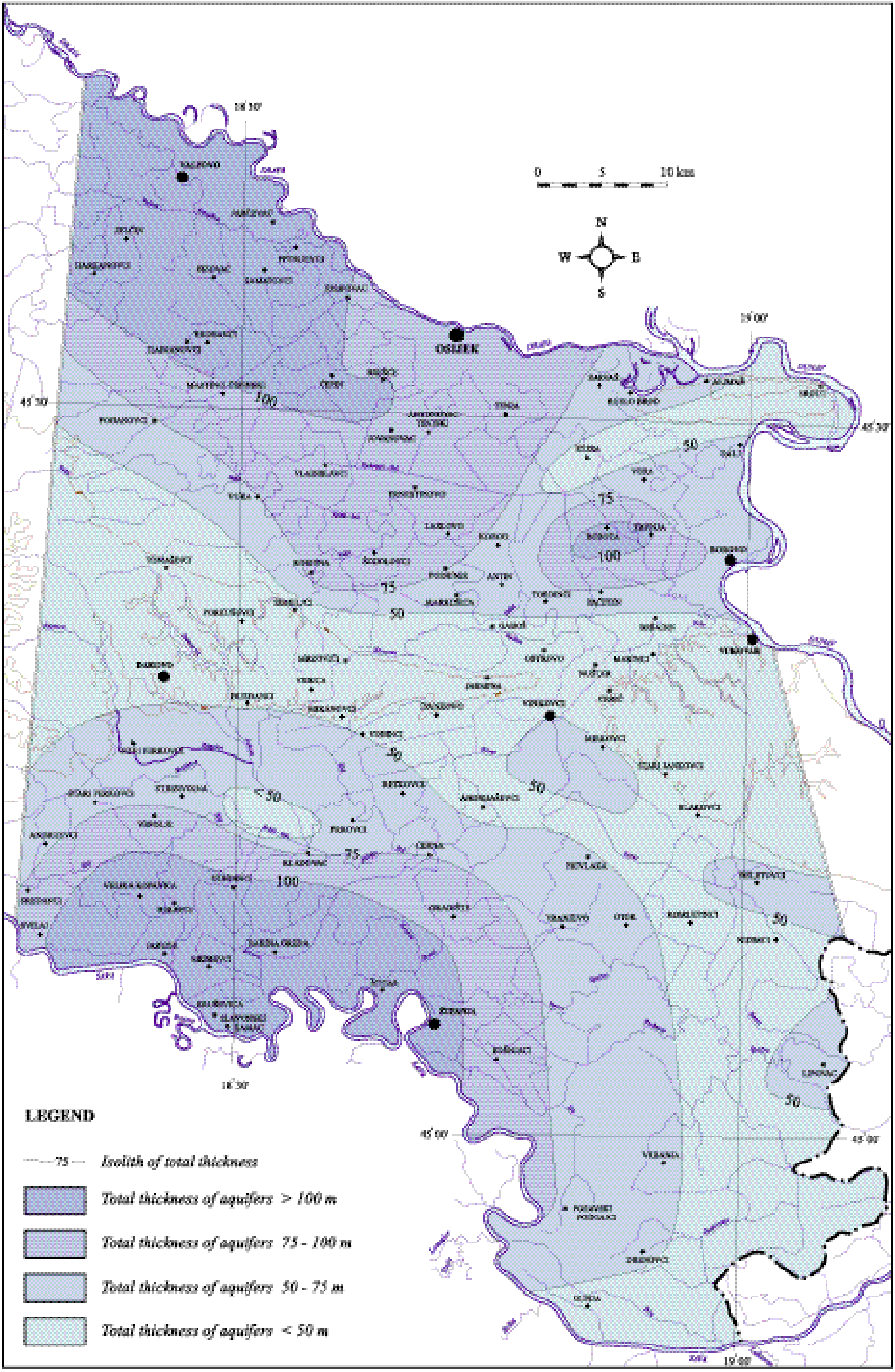

Fig. 6 Isolith map of permeable layers in the Quaternary aquifer system.

between 52-706 m^2/day, and storativity between 1.3×10^{-4} - 4.3×10^{-3}.

In the first 120 m of sediments drilled on the Đakovo-Vinkovci plateau, between 3 to 8 aquifers were determined in the stratigraphic column. Some of these layers were found to have a maximal thickness of 30 m (Figs. 3, 4 and 5). These aquifers are made of fine- to coarse-grained sand that often contains coarse-grained gravel, especially in the western part of the explored area. The hydraulic conductivity is in quite a wide range of 5-30 m/day, the transmissivity is between 52 and 413 m^2/day, and storativity between 1.9×10^{-4} and 4.4×10^{-3}.

The thickness of deposits that cover the eastern Slavonia aquifer system is shown in Fig. 7. The cover sediments over the entire area of eastern Slavonia are composed of silty-clayey deposits with lenses and interbeds of sand. The low-permeability sediments between the aquifers at depth are of the same lithological composition. The leakage coefficient there is in the wide range of 1.3×10^{-5} - 4.3×10^{-3} day^{-1}.

Over the entire study area, the groundwaters are recharged by the means of rainfall infiltration. The infiltration from the surface streams in natural conditions can practically be neglected in the Drava depression. The surface drainage pattern in the studied part of the Drava depression is such that it drains the groundwater both in periods of high and low waters. The situation in the Sava depression is somewhat different. The Sava river channel is cut into the gravel aquifer, thus putting it in direct hydraulic connection with the river. The high waters of the Sava are registered in the wells up to 5 km further north, as far as the area of Velika Kopanica. During the low waters, the river waters are below the groundwater level which means that the Sava drains the aquifer. Alternatively, in conditions of extensive exploitation of the gravel layer, the inflow of Sava waters would be the major recharge source. The rainfall infiltration on the plateaux is especially well developed in the eastern parts, because the aquifer system there is covered by the continental loess that has a significant vertical permeability.

Because of the terrain morphology, the hypsometric levels of groundwater are the highest in the area of Đakovo-Vinkovci and Vukovar plateau, which means that groundwater flows from the plateau in the directions of the north-east and south-east, and there is the watershed along the plateau.

3.3. HYDRAULIC FUNCTION OF THE PLATEAU

In order to enable the analysis of lateral changes of sediments, especially on the contact between the plateau and depressions, a number of the N-S striking hydrogeological cross-sections were constructed. The sections illustrate the results of comprehensive correlation of all the acquired drilling data and well-logs (mostly E-logs) in the area of Đakovo-Vinkovci and Vukovar plateau. Only characteristic sections are shown in Figs. 3, 4 and 5. The correlation of well data showed that the plateaux have undergone a spatially and temporally non-uniform uplift that resulted in differences of sediment deformation along the fault zones. The biggest displacements are registered on the southern fault zone, south of Đakovo (Fig. 3). Thicker aquifers are bent and thinned but their lithological (and hydraulic) continuity is not broken. It is noted that tectonics within the plateau itself contributed to sediment deformation even more than the northern fault zone near Tomašanci. Further to the east, in the area from Ivankovo to Vinkovci, the aquifer layers remained practically undisturbed along the fault zones, making the hydrogeological relations on the plateau the same as those in the depressions (Fig. 4). The correlation of wells across the Vukovar plateau showed a stronger deformation of sediments along the northern fault zone than on the southern one (Fig. 5). Some of the aquifers branch along the northern fault zone, but the continuity of the thicker layers is intact. While observing the cross-sections in Figs. 3, 4 and 5, a significant vertical exaggeration must be noted, because it gives an impression of a higher deformation of sediments than that which actually exists.

The same results were obtained by interpretation of geoelectrical measurements that were performed on a number of occasions by the Geoelectrical Department of the "Geofizika" company from Zagreb. On the fault zones, a few cross-sections have a characteristic reduction of the electric resistivity to a level of 5 Ωm. There are bigger differences on the plateau itself. In the shallowest 100 m the zones were measured with resistivity under 20 Ωm, and those with more than 65 Ωm.

In order to determine the hydraulic role of fault zones between the plateaux and depressions, the results of mathematical models that encompassed the plateau areas were analysed. Two models were calculated (MILETIĆ et al., 1986b, 1993), both of which tested the shallowest aquifer. In both cases, the model results showed that there is no hydraulic barrier along the fault zones. Namely, the simulated and measured drawdowns correspond only in the case of the supposed continuity of the aquifer. Putting the flow barrier along the fault line in the model, or even the reduced transmissivity, would result in unrealistically large simulated drawdowns in respect to the measured ones.

4. CONCLUSION

Based on the analysis of all the acquired geological and hydrogeological data, it must be concluded that there is lithological continuity of the aquifer layers across the fault zones of the Đakovo-Vinkovci and Vukovar plateaux, which means that there is no hydraulic barrier on the watershed between the Sava and Drava alluvial valley.

The area of eastern Slavonia between the Drava and Sava rivers is regarded as one hydraulic system that contains zones of different transmissivity. Along the

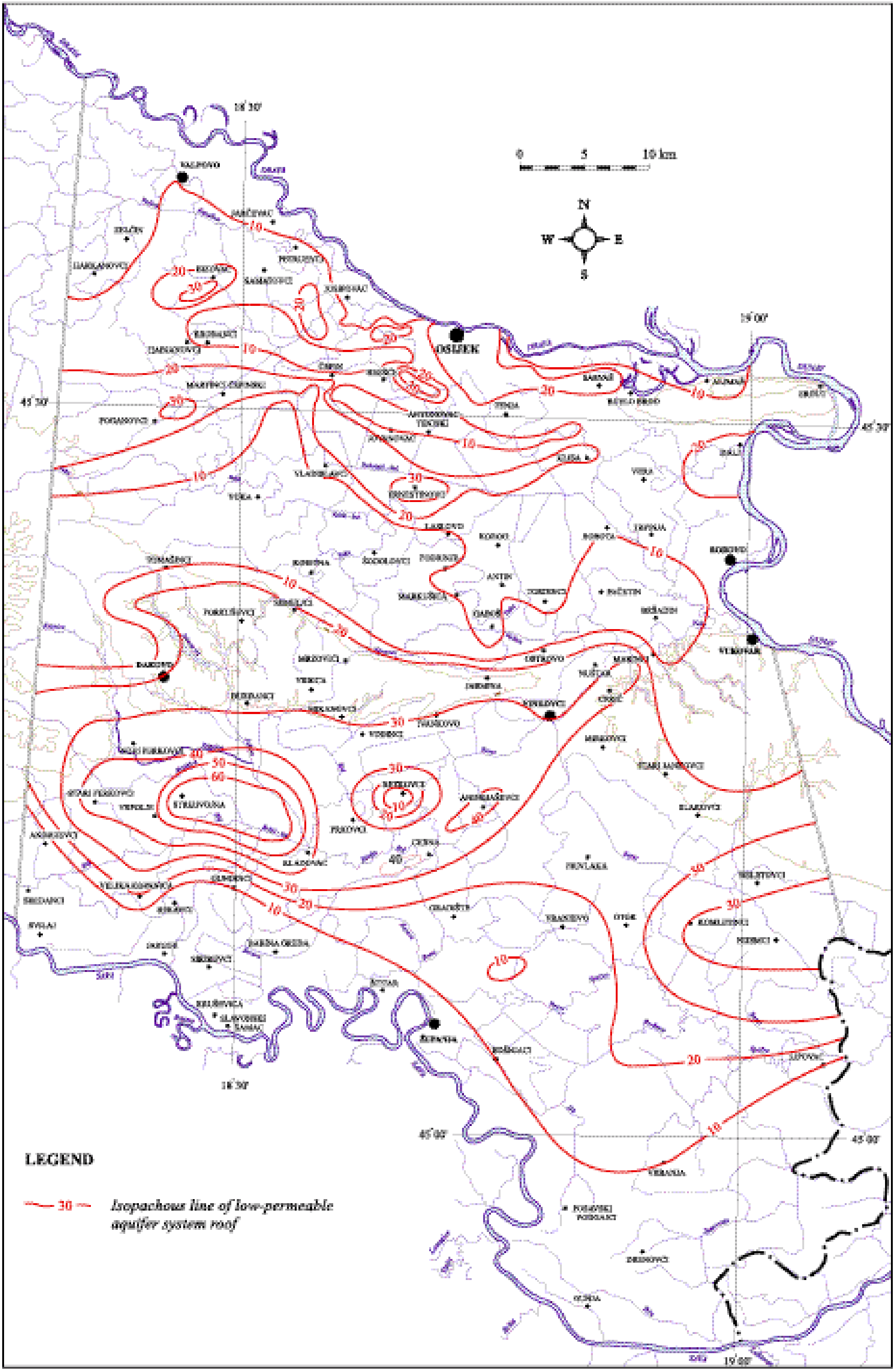

Fig. 7 Isopach map of low-permeable aquifer system roof.

zones of reduced transmissivity, the hydraulic connections are weakened, but not broken. Such zones exist not only along the fault zones of the Đakovo-Vinkovci and Vukovar plateau, but within the depressions and the plateau itself.

The terrain morphology influenced the formation of both the surface and the underground watershed, parallel to the extension of the Đakovo-Vinkovci and Vukovar plateau. In a hydraulic sense, the watershed represents a streamflow line. That is why, in order to construct a mathematical model of a certain drainage area (or of a part of the drainage area) with a marginal line along the watershed, the watershed has to be defined as a "zero flow boundary". Because of the single hydraulic entity, in the case of the draw-down reaching the boundary due to the excessive pumping, the groundwater will start flowing over the margin of the model. The bigger the draw-down at the margin, the bigger the flow, making the watershed more displaced from its natural position.

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