

Palynological model of the Late Neogene sediments of Eastern Slavonia (Croatia)

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Abstract

By applying a palynological analysis of the Late Neogene sediments from one exploration well in the area of Eastern Slavonia, three vegetation zones (Z_1 , Z_2 , Z_3) as conditioned by climate sensitivity were set. On the basis of mutual percentage relations of the occurrence of individual form-species and grouping them according to the results of cluster analysis, these zones reflect the changes of warm-cold and variable humidity periods. The age of zones has been determined: zone Z_1 is Pontian, zone Z_2 is Pliocene and zone Z_3 is Pleistocene-Holocene. In the Pontian, 13 form-species of spores were determined that do not cross the Miocene/Pliocene boundary. In the Pliocene, 4 index form-species of spores were determined that were not found in the Quaternary in the study area. In the youngest sediments of the study area, i.e. Pleistocene and Holocene, 7 index form-species of spores were determined. Together with well logging (gamma ray and specific resistivity logs) of the formation, a model was constructed for the local routine provision of age in the study area. The results are generally consistent with other results obtained from Early Neogene sediments in adjacent areas in the central part of Paratethys, and may serve as a model for the correlation of contemporaneous sediments in other areas of Croatia, e.g. Sava and Drava Depressions, which in effect may contribute to the more efficient investigation of potential hydrocarbon reservoirs.

Keywords

Eastern Slavonia, Neogene, pollen, spores, climate, vegetation zones

1. Introduction

The area of Eastern Slavonia includes the southern part of the Pannonian Basin System (the eastern part of Drava and part of the Slavonia–Srijem Depressions) and it is one of the richest oil and gas fields in Croatia (**Figure 1**). The problem in the dating of Neogene sediments in further hydrocarbon exploration is always actual, because of the nature of their origin, as a consequence of environmental conditions of the sediment deposition and tectonic events at those times. The knowledge of the age of sediments which are reservoirs of hydrocarbons is the condition without which it is not possible to correlate contemporaneous layers, and thus define the potential of a petroleum system. During Neogene, the Paratethys area, because of tectonic movements, small grounding sedimentary basin systems were created with local environmental features, for example variability in the decrease of salinity degree, which resulted in endemism. Due to this fact, it is difficult or almost impossible to use index fossils characteristic of large, primarily marine depositional settings as a correlation tool of these isolated, more or less low salinity-brackish-freshwater environments. Due to the fact that spores and pollen are regionally distributed and they do not directly depend on the facies of depositional settings, palynology is the only tool in biostratigraphic correlation of sediments deposited in different continental and aquatic facies.

In terms of structural-tectonic and lithological features, the exploration area is quite complex. Many authors have dealt with this complex geological structure (e.g., **Kranjec, 1972; HERNITZ, 1983; Pamić, 1997; Pavelić, 2001, 2002, Saftić et al., 2003; Malvić & Velić, 2011**).

Igneous, metamorphic and sedimentary rocks of the Paleozoic, Mesozoic (locally possible and Palaeogene) are present in the explored area, and they represent the base of the Neogene sediments. Although the opening of the Pannonian Basin System (**Rögl & Steininger, 1984**) started in Early Miocene as a result of the collision of two tectonic plates (the Eurasian and African plates), the evolution of most of its south-western and southern parts, including Eastern Slavonian part, started

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in the Lower Miocene (Ottungian–Carpathian) triggered by strong extensional tectonics, volcanic activity and locally predetermined by the deposition of uneven lithological composition, varying, at first from freshwater to transitional and then to Badenian marine environments. Along with a variety of volcanic rock, the coarse freshwater sediments, breccia, conglomerate, sandstone, marl and limestone are deposited (Lučić et al., 2001; Pavelić et al., 2003). During the Middle Miocene in the shallow marine environment, mostly biogenic limestone and coarse-grained clastics were deposited, while in somewhat deeper environments, fine-grained sandstone, clay-marl and argillaceous limestone were deposited. In the Sarmatian, at the end of the Middle Miocene, the link between marine Paratethys and the great Mediterranean Sea (Tethys) breaks. The terrestrial influence caused the decrease of salinity and the deposition of a thin layered marl occurred. Upper Miocene sequence of sediments is characterized by a further gradual decrease of salinity and the deposition of a thick series of marl and sandstone. In the Pliocene, mostly sandy-clay sediments were deposited, and the succession ends by a deposition of Quaternary sediments represented by gravel, sand, clay and loess.

The aim of this study is to contribute to the more precise dating of the targeted sediments, in addition to the existing palynological results (dinospore dinoflagellate cysts), by reconstructing the terrestrial vegetation, using spores and pollen, which depended on the climate typical of certain geological periods. Standard palynological analysis, statistical methods of pollen analysis and well logging measurements of natural radioactivity and specific resistivity of the formation, were used. The results will serve as a local model for routine dating of these sediments in the study area.

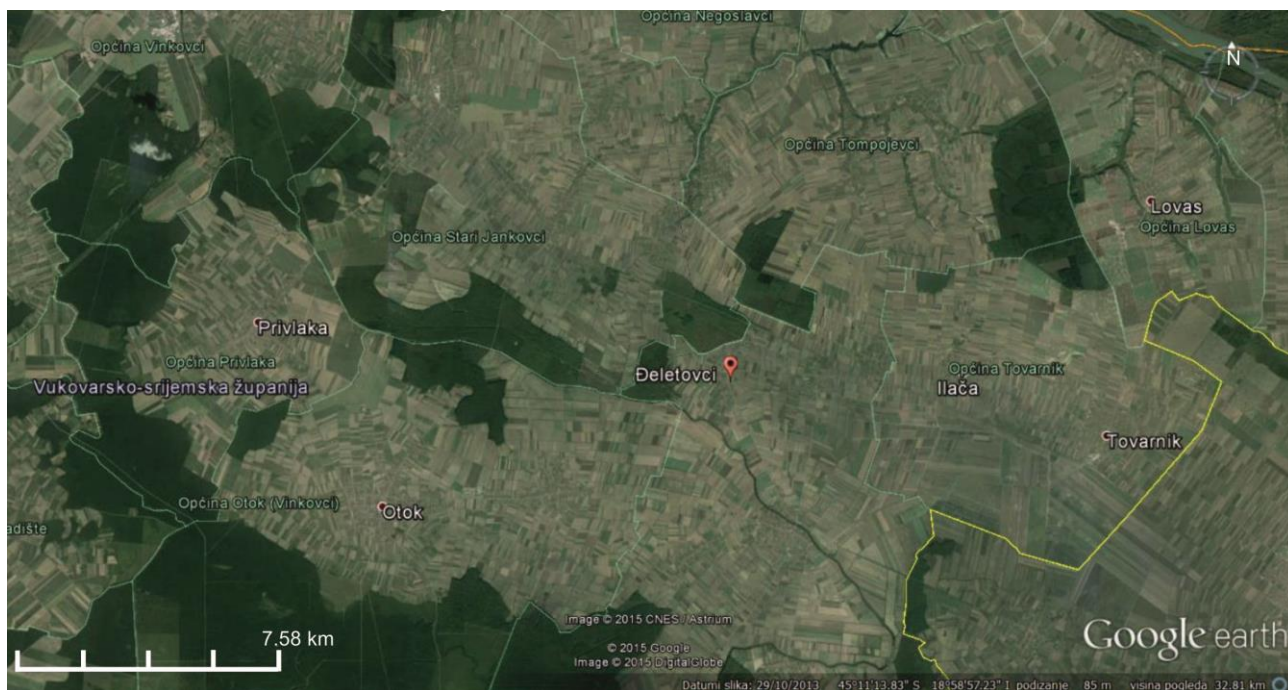


Figure 1. Geographic position of the study area (Modified from <http://maps.google.hr/>).

2. Material and methods

To create pollen diagrams, samples of debris from mud deep wells for the exploitation of hydrocarbons in Eastern Slavonia were used. The samples were taken every 30 m from the depths of 190 m to 1050 m for maceration. Maceration was performed according to the standard method (Kummel & Raup, 1965) used in INA d.d. Washed samples were first treated with 18 % hydrochloric acid (HCl) to dissolve the carbonate, and after washing, the residue was treated with 40 % hydrofluoric acid to dissolve silica. The residue obtained by chemically dissolving the rock sample is further processed in (ZnCl₂) heavy liquid ($\rho = 2.1 \text{ kg/l}$). The heavy liquid is used to extract the organic material from the mineral. The supernatant from the organic residue is sieved through a 15 μm sieve. The residue organic material was washed from the sieve, and centrifuged at 3600 rpm for 10 minutes. The residue from the casting ring is applied to a glass slide, dried, and after the addition of glycerine gelatine, it is covered with a cover slip. A transmitted light microscope (Olympus BX51) x 600 and x 1000 (oil immersion) was used for identification and x 400 was used for the counting of pollen and spores. Pollen and spore identification was accomplished using a computer program with a key to pollen and spore classes and a pollen database (Brajković et al., 2004). Other published keys and pollen atlases were also used as well as atlases of

recent pollen (Reille, 1992, 1995), the key for recent pollen detection with pictures (Moore, 1991), and the Atlas of form-species of fossil spores and pollen (Nagy, 1969; Planderová, 1990; Stuchlik et al., 2001). For the statistical analysis and preparation of pollen diagrams, computer software POLPAL was used (Walanus & Nalepka, 1999).

3. Results and discussion

A total of 35 samples (every 30 m) were analyzed, of which 30 (190-1050 m) contained palynomorphs (spores, pollen and dinocysts). Based on these, over 9000 pollen grains and spores (about 300 grains per sample) 96 taxa were determined, they were statistically processed and presented in the block diagram of the pollen, which consists of EK charts with a lithological column, a view of the development of each species in the study area during the time from the upper part of the Pontian (Stevanović, 1989) to the Holocene, cluster analysis and a chart of the relations of "warm and cold" species. The following results were obtained.

3.1. Vegetation zones

Three vegetation zones (Z_1 , Z_2 and Z_3) were determined on the basis of mutual percentage relations of the occurrence of individual species and grouping them according to the results of cluster analysis (Appendix 2). The biostratigraphical zone Z_1 is characterized by the dominance of pollen Taxodiaceae with a percentage up to 24 %, *Alnus* up to 11 % and *Ulmus* up to 9 %, indicating a warm and humid climate. At the top of the zone, at the turn of the Upper Pontian in the Pliocene, the percentage of Taxodiaceae are still high, while the percentage of Poaceae is markedly increasing (up to 22 %), indicating a still moist but significantly colder climate. In the zone Z_2 the percentage of Taxodiaceae has declined, while the percentage of *Alnus* and *Ulmus* remains largely the same. The increase in the proportion of *Cathaya* (up to 4.5 %) and Asteraceae (up to 8 %) is remarkable. The turn of Z_2 into Z_3 is characterized by an increase in the percentage of *Sciadopitys* (up to 13 %) and *Tsuga* (up to 9.5 %). The zone Z_3 is characterized by further cooling with the increasing percentage of Poaceae pollen (up to 17 %), *Picea* (up to 8 %), *Tsuga* (up to 8 %) and *Abies* (up to 6 %). This zone is divided into two sub-zones Z_{3a} and Z_{3b} . The zone Z_{3a} is characterized by a significant percentage of pollen genus *Tilia* (up to 6 %), *Quercus* (up to 5 %), and *Fagus* (up to 4.5 %), while in the zone Z_{3b} after the complete termination, the reappearance of Taxodiaceae pollen and Cupressaceae, *Carya* and *Pterocarya* is occurring, which are typical of riparian forests. This pollen diagram indicates a general cooling from Late Miocene to Quaternary, with distinct peaks on the border Pontian/Pliocene, Pliocene/Pleistocene and the end zone Z_{3a} , and re-warming in zone Z_{3b} . Similar climatic events were registered in other parts of the central Paratethys. Vegetation in the Pontian in the Danube basin system indicates a more continental climate with less rainfall and higher humidity at the beginning of Pliocen (Kováč et al., 2006). In the area of the Forecarpathian Basin System in Northwestern Bulgaria (Ivanov et al., 2002) as well as in Serbia (Utescher et al., 2007) and Southeast Europe (Ivanov et al., 2011) and in the study area of Eastern Slavonia, at the time of the Pontian, vegetation of the riparian forest and the similar composition of plant communities indicates an identical climate picture. Further to the north, in the Pannonian Basin System in Southern Hungary, at the end of the Pleistocene the basal red clay was deposited (Kovács et al., 2011), and its mineral composition shows extreme cooling which is also registered in the pollen diagram from Eastern Slavonia.

3.2. Age

The age zone of Z_1 , based on the dinocyst *Galeacysta etrusca* CORRADINI & BIFFI (Plate 1) has been defined as Pontian. Zone Z_2 has been defined as Pliocene and zone Z_3 as Quaternary, or Pleistocene and Holocene respectively. In this study, they were determined by reconstructing the climate based on the mutual percentage ratio of individual species over time, and comparing diagram relations of "warm and cold" species (Appendix 2) with Haq's curve (Haq et al., 1987, 1988) changes of the sea level that considers global cooling and warming of the earth and a comparison with the method of oxygen isotopes ($\delta O18$) that considers global climate changes (Emiliani & Edwards, 1953). The block diagram of the pollen samples from the borehole shows three distinct cooling periods corresponding to the events on the border of Miocene / Pliocene (approx. 660 m), Pliocene/Pleistocene (approx. 440 m) and Quaternary (Pleistocene+Holocene) (260 m) (Appendix 2).

3.3. Index of fossil spores

In the study area, the 44 form-taxa of spores were determined, 12 of which were form-genus and 32 form-species (**Appendix 1**). For each form-taxa the range of appearance has been determined within the investigated sediments (**Appendix 3**). Within each zone, the form-species of spores were determined, that appear only inside them, as possible index form-species for routine determination of age sediments in Eastern Slavonia. In the Pontian, 13 form-species of spores were determined, which do not cross the boundary Miocene/Pliocene (**Plate 1**). These are: *Echinatisporis longechinus*, *Echinatisporis miocenicus*, *Laevigatosporites gracilis*, *Leiotriletes triangulus*, *Retitriletes pseudoclavatus*, *Retitriletes punctoides*, *Stereisporites cyclus*, *Stereisporites pseudopsilatus*, *Stereisporites stereoides*, *Stereisporites stictus*, *Verrucatosporites favus*, *Verrucatosporites megabalticus* and *Verrucatosporites megafavus*. In the Pliocene, the 4 possible index form-species of spores were determined, that were not found in the Quaternary in the study area (**Plate 2**). These are: *Distancoraesporis silesicus*, *Selagosporis selagoides*, *Verrucatosporites alienus* and *Verrucatosporites histiopteroides*. The youngest sediments of the study area, the Pleistocene and Holocene, contain 7 possible index form-species of spores (**Plate 2**): *Camarozonosporites minoris* (*Lycopodiella* sect. *Campylostachys*), *Corrugatisporites microvallatus* (*Lygodium*), *Leiotriletes microlepioidites* (Dennstaedtiaceae, *Microlepia* ?), *Leiotriletes neddenioides* (Lygodiaceae? Cyatheaceae?), *Polypodiaceoisporites saxonicus* (*Pteris*), *Retitriletes rotundoides* (*Lycopodium*) and *Segmentizonosporites paucirugosus* (Pteridaceae). The confirmation of the above form-species is to be expected in future analyses of this study area.

3.4. Lithology and EK markers

The comparison of the pollen diagrams with logging diagrams should enable the determination of the exact depth of the above geological boundaries, i.e. the position of the logging rappers α , h and Q (**Hernitz, 1983**) (**Figure 2**). The youngest lithostratigraphic formation in Eastern Slavonia is the Vuka Formation (**Šimon, 1966**). It includes the interval above the logging marker alpha (α) to the surface. Based on lithological features, we can distinguish three parts of the Vuka Formation, which **Batušić & Urbih** (**1979**) called "operational units" A, B and C (from oldest to youngest) (**Figure 2**). In zone C, which goes back to the surface, there is clay, loosely packed sandstones, gravel, loess and humus. In some places there are layers of poorly carbonized coal and peat (porosity sands is around 10 %, and the salinity of formation water does not exceed 0.5 g NaCl/dm³).

Ek marker "Q" divides zones B and C. Zone B is dominated by fine-grained sands with layers of clay of low plasticity (porosity sands is around 30 %, and the salinity of formation water 0.5-1 g NaCl/dm³). Ek marker "h" divides zones A and B. In zone A, there is clay and fine-grained sands (25-30 % porosity and formation water salinity of 1-3 g NaCl/dm³). The transition from the Vera to Vuka Formations is characterized by a sudden increase in the value of specific resistance of formation (usually over 20 ohm x m) which is associated with the formation water salinity change which rapidly decreases (EK marker alpha). The central part of the Vuka Formation is separated from the lower part (B/A) by the logging marker "h". The values of specific resistance formations are more "jagged" in zone B than in Zone A (particularly in sandstones and sands) (**Figure 2**).

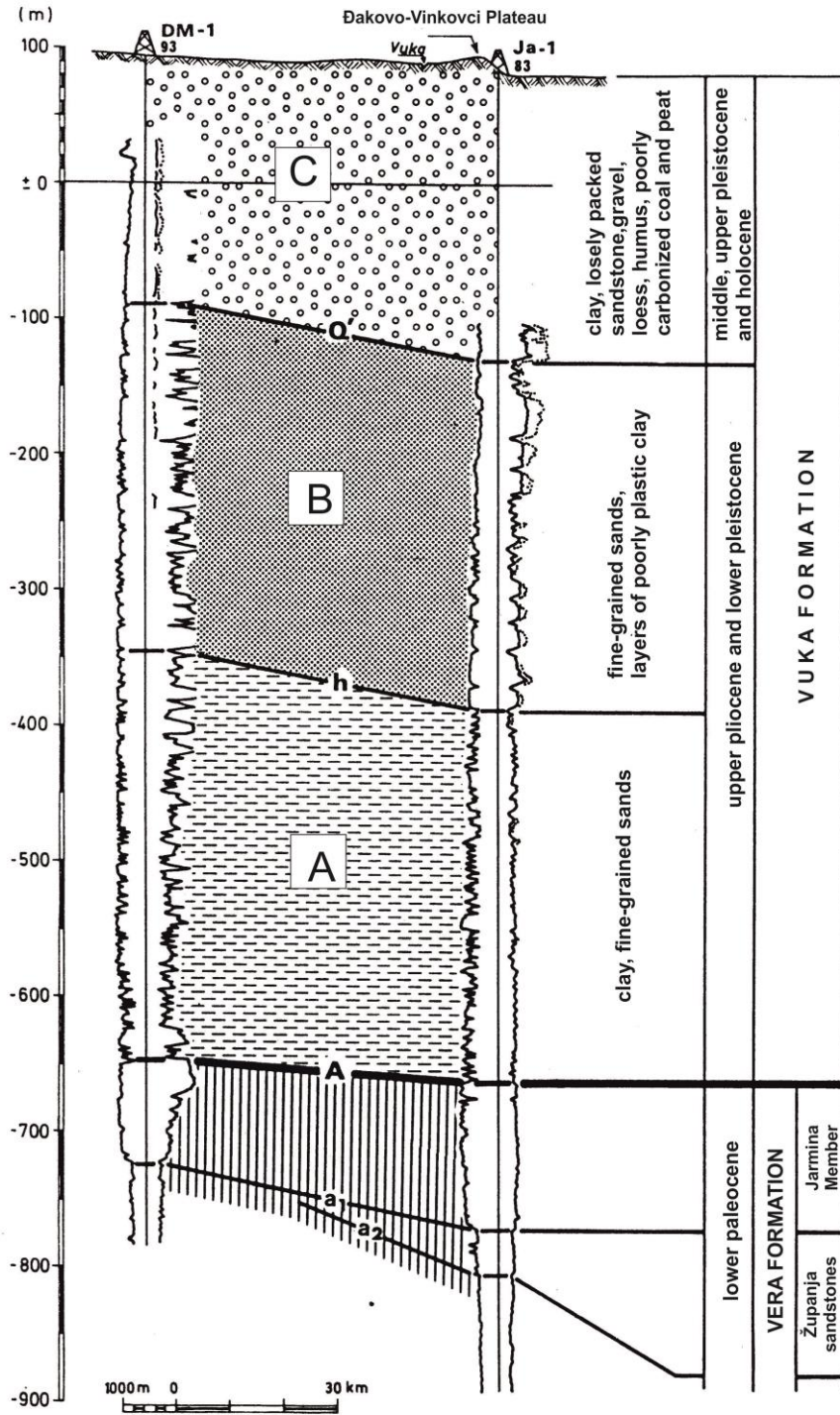


Figure 2. Classification of the Vuka Formation (modified from HERNITZ, Z. 1983)

4. Conclusion

From the debris of rocks obtained during the drilling of deep exploration wells in Eastern Slavonia, the pollen analyses were conducted and the pollen diagram was made showing the representation of certain plant species that existed in the area at the time of the uppermost Miocene to Quaternary. Three vegetation zones (Z_1 , Z_2 and Z_3) and two sub-zones (Z_{3a} and Z_{3b}) were set.

Determined plant species were grouped according to environmental requirements in three groups - hot, cold and ubiquitous - that have a wide range of tolerance to climate change, primarily temperature. Their comparison led to determining the periods of extreme cooling in the study area throughout the observed time. The comparison with Haq's curve of global changes in sea level, and the comparison with the method of oxygen isotopes ($\delta O18$) that shows global climate changes, led to determining the geological age of the established cooling periods.

The correlation of the results with curves EK measurements of the well, whose rock material was analyzed, led to the determination of accurate geological boundaries (Miocene/Pliocene and Pliocene/Quaternary) by using EK markers.

By precise provision of a range of occurrence of some form-species of spore, species that appear within a limited time period were set as possible index species for these geological periods in Eastern Slavonia. As such, they represent a valuable material for the routine determination of geological age in the study area.

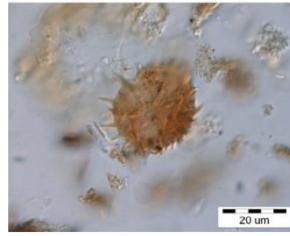
Considering the specific development of the Miocene and Pliocene in the area of Central Paratethys, this model of research would be useful in other parts of the Pannonian Basin System.

Acknowledgment

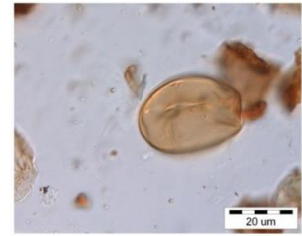
We are grateful to Koraljka Bakrač and Georg Koch for carefully reviewing the manuscript and enabling us to significantly improve it.



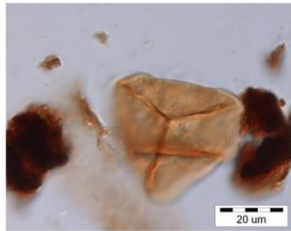
Echinatisporis longechinus



Echinatisporis miocenicus



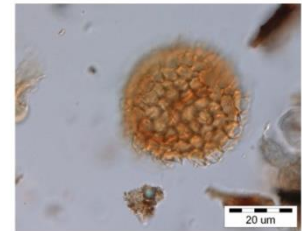
Laevigatosporites gracilis



Leiotriletes triangulus



Retitriletes pseudoclavatus



Retitriletes punctoides



Stereisorites cyclus



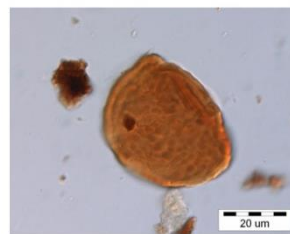
Stereisorites pseudopsilatus



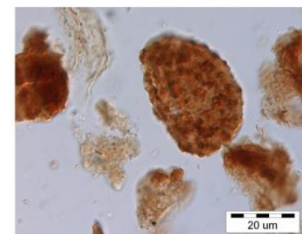
Stereisorites stereoides



Stereisorites stictus



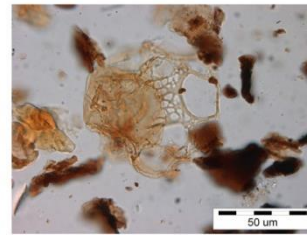
Verrucatosporites favus



Verrucatosporites megabalticus



Verrucatosporites megafavus

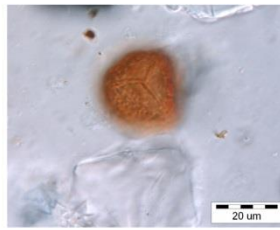


Galeacysta etrusca

Plate 1.



Distancoresporis silesicus



Selagosporis selagoides



Verrucatosporites alienus



Verrucatosporites histiopteroides



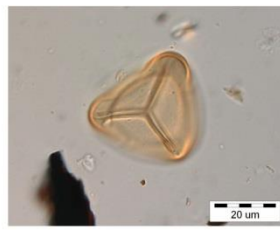
Camarozonosporites minoris



Corrugatisporites microvallatus



Leiotriletes microlepioidites



Leiotriletes neddenioides



Polypodiaceosporites saxonicus



Retitriletes rotundoides



Segmentizonosporites paucirugosus

Plate 2.

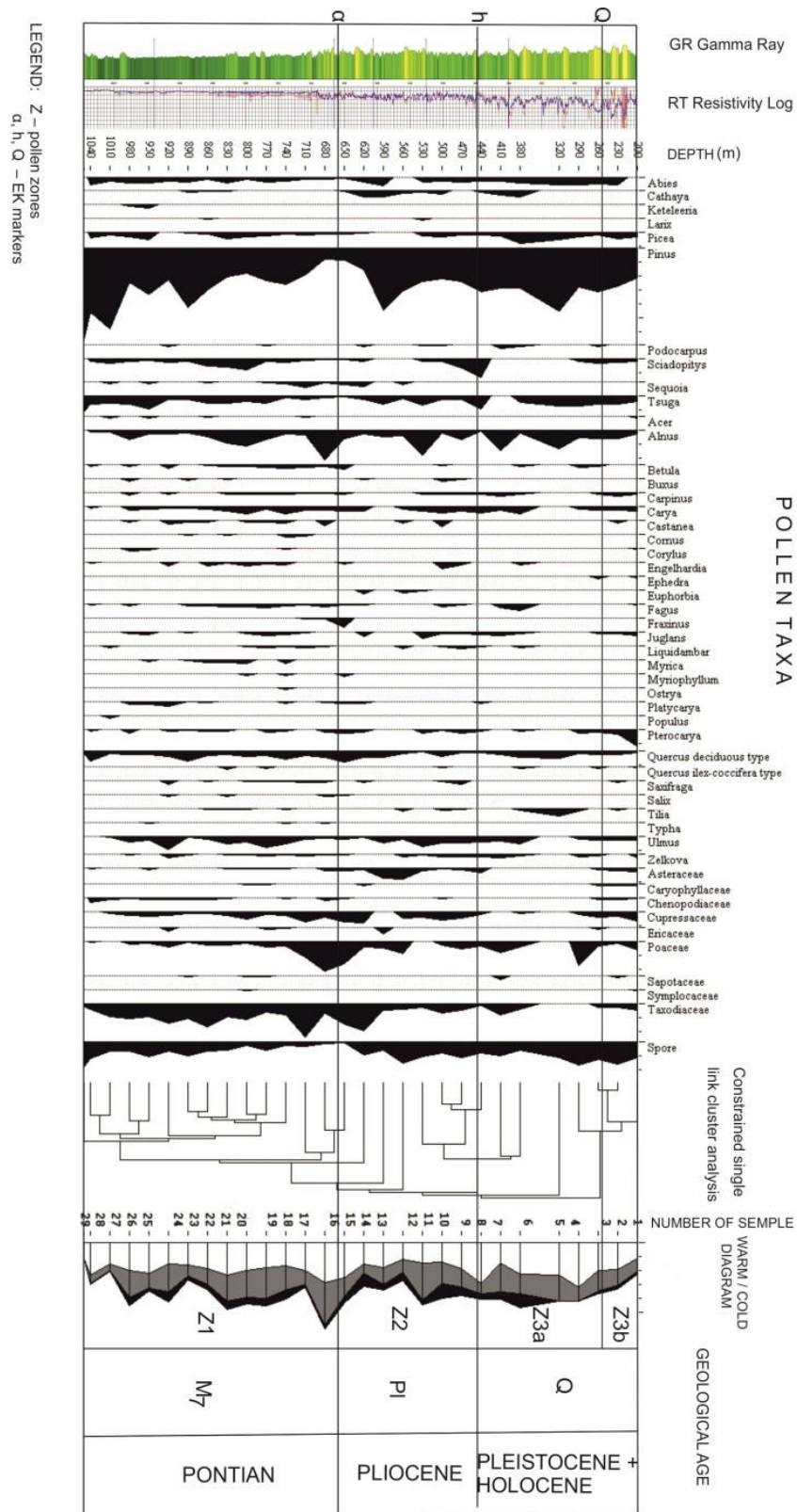
Appendix 1

List of form-species of spores

1. *Baculatisporites* sp.
2. *Baculatisporites nanus* (Wolff 1934) Krutzsch 1959
3. *Baculatisporites ovalis* Kedves 1973
4. *Baculatisporites primarius* (Wolff 1934) Pflug & Thomson in Thomson & Pflug 1953
5. *Camarozonosporites minoris* Krutzsch 1963
6. *Contignisporites* sp.
7. *Corrugatisporites* sp.
8. *Corrugatisporites microvallatus* (Krutzsch 1967) Nagy 1985
9. *Distancoraesporis silesicus* (Krutzsch 1963) Grabowska 2001
10. *Echinatisporis* sp.
11. *Echinatisporis longechinus* Krutzsch 1959
12. *Echinatisporis miocenicus* Krutzsch & Sontag in Krutzsch 1963
13. *Echinosporis fotensis* Nagy 1985
14. *Laevigatosporites* sp.
15. *Laevigatosporites gracilis* Wilson & Webster 1946
16. *Laevigatosporites haardti* (Potonié & Ventiz 1934) Thompson & Pflug 1953
17. *Leiotriletes* sp.
18. *Leiotriletes microlepidoidites* Krutzsch 1962
19. *Leiotriletes neddenioides* Krutzsch 1962
20. *Leiotriletes triangulus* (Mürriger & Pflug ex Krutzsch 1959) Krutzsch 1962
21. *Neogenisporis* sp.
22. *Polypodiaceoisporites* sp.
23. *Polypodiaceoisporites saxonicus* Krutzsch 1967
24. *Retitriletes* sp.
25. *Retitriletes pseudoclavatus* Krutzsch 1963
26. *Retitriletes punctoides* Krutzsch 1963
27. *Retitriletes rotundoides* Krutzsch 1963
28. *Segmentizonosporites paucirugosus* (Nagy 1985) Stuchlik 2001
29. *Selagosporis selagoides* Krutzsch 1963
30. *Stereisporites* sp.
31. *Stereisporites cyclus* Krutzsch 1963
32. *Stereisporites pseudopsilatus* Krutzsch 1959
33. *Stereisporites stereoides* (Potonié & Ventiz 1934) Thompson & Pflug 1953
34. *Stereisporites stictus* (Wolff 1934) Krutzsch 1963
35. *Toroisporis* sp.
36. *Toroisporis stuchlikii* Planderová 1990
37. *Triplanosporites* sp.
38. *Verrucatosporites* sp.
39. *Verrucatosporites alienus* (Potonié 1931) Thompson & Pflug 1953
40. *Verrucatosporites balticus* (Krutzsch 1962) Krutzsch 1967
41. *Verrucatosporites favus* (Potonié 1931) Thompson & Pflug 1953
42. *Verrucatosporites histiopteroides* Krutzsch 1962
43. *Verrucatosporites megabalticus* Krutzsch 1967
44. *Verrucatosporites megafavus* Krutzsch 1967

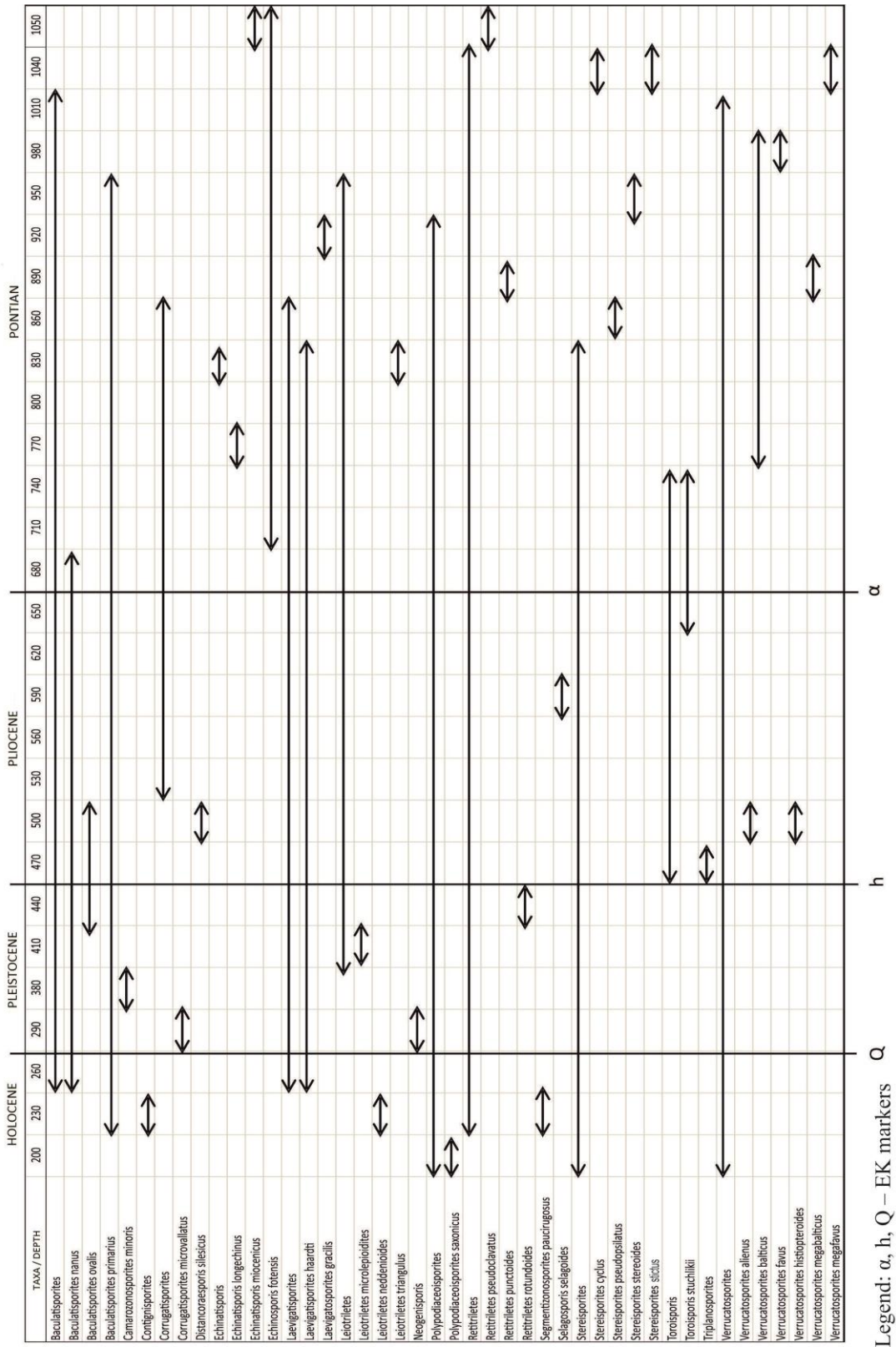
Appendix2

Pollen diagram of exploration well from Eastern Slavonia



Appendix3

Range of local index fossil spores



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Palinološki model mlađih neogenskih naslaga Istočne Slavonije (Hrvatska)

Izvorni znanstveni rad



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Sažetak

Palinološkim analizama naslaga mlađeg neogena iz eksploatacijske bušotine u prostoru Istočne Slavonije postavljene su 3 vegetacijske zone (Z_1 , Z_2 , Z_3) koje su uvjetovane klimatskim odrednicama. Na osnovi međusobnih postotnih odnosa pojavljivanja pojedinih svojti i njihovih grupiranja prema rezultatima klsterske analize te zone oslikavaju razdoblja zahladnjenja i zatopljenja uz promjenjivu vlažnost. Određene su starosti zona: zona Z_1 pont, zona Z_2 pliocen i zona Z_3 kvartar (pleistocen i holocen). U pontu je određeno 13 form-vrsta spora koje ne prelaze granicu miocen/pliocen. U pliocenu su određene 4 provodne form-vrste spora koje nisu nađene u kvartaru na istraživanome području. U najmlađim naslagama istraživanoga područja (pleistocen i holocen), utvrđeno je 7 provodnih spora. Zajedno s elektrokarotaznim mjerenjima (prirodna radioaktivnost i specifična otpornost) načinjen je model za lokalnu rutinsku odredbu starosti na istraživanome području. Dobiveni rezultati generalno se podudaraju s drugim rezultatima dobivenim iz sedimenata mlađega neogena u susjednim područjima Središnjega Paratethysa, te mogu poslužiti kao model za korelaciju istovremenih sedimenata i u drugim područjima (kao što su Savska i Dravska depresija) što doprinosi učinkovitijem istraživanju potencijalnih ležišta ugljikovodika.

Ključne riječi

Istočna Slavonija, mlađi neogen, pelud, spore, klima, vegetacijske zone

1. Uvod

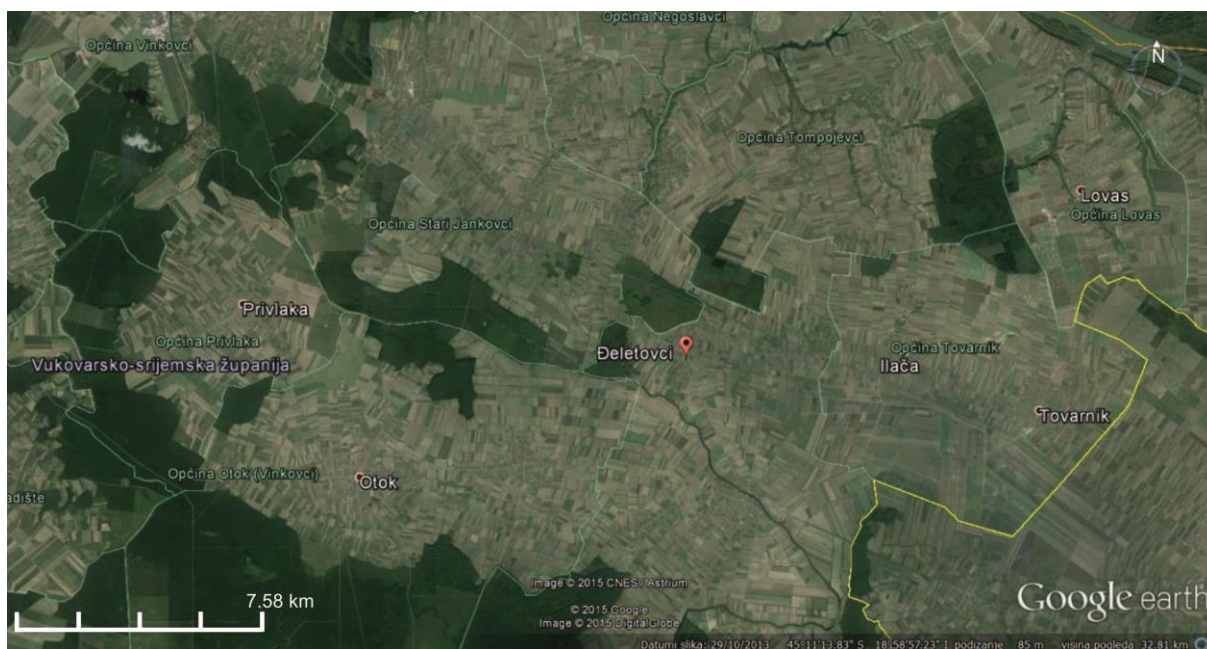
Područje Istočne Slavonije obuhvaća južni dio Panonskog bazenskog sustava (**slika 1**), odnosno, istočni dio Dravske te dio Slavonsko-srijemske depresije i jedno je od najbogatijih nalazišta ugljikovodika u Hrvatskoj. Problem odredbe starosti neogenskih naslaga u daljnjim istraživanjima ugljikovodika uvijek je aktualan zbog prirode njihova nastanka, što je posljedica okolišnih uvjeta taloženja sedimenata i tektonskih događanja toga vremena. Poznavanje starosti sedimenata koji su nosioci ugljikovodika uvjet je bez kojega nije moguće korelirati istovremene slojeve te na taj način definirati potencijale naftnoga, odnosno ugljikovodičnoga sustava. U doba neogena na području Paratethysa, zbog tektonskih pokreta stvaraju se manji uzemni sedimentacijski sustavi s lokalnim posebnostima, primjerice različit stupanj oslađivanja, što dovodi do razvoja endemizama. Zbog te činjenice teško je ili gotovo nemoguće iskoristiti provodne fosile karakteristične za velike, ponajprije morske, Zemljine površine kao sredstvo korelacije takvih novonastalih, više ili manje oslađenih uzemnih taložnih bazenskih sustava. S obzirom na činjenicu kako su spore i pelud regionalno distribuirani i ne ovise direktno o facijesima taložnih bazenskih sustava, palinologija je jedini alat u biostratigrafskoj korelaciji sedimenata taloženih u različitim kontinentalnim i akvatičkim facijesima.

U strukturno-tektonskome i litološkome smislu istraživano područje prilično je složeno. Mnogi su se autori bavili tom kompleksnom geološkom građom (npr. **Kranjec, 1972; Hertz, 1983; Pamić, 1997; Pavelić, 2001, 2002; Saftić et al., 2003; Malvić & Velić, 2011**).

Magmatske, metamorfne i sedimentne stijene paleozoika i mezozoika (lokalno možda i paleogena) prisutne su u istraživanome području i tvore podinu na kojoj se nalaze istraživani neogeni sedimenti. Iako se otvaranje Panonskoga

bazenskog sustava (Rögl & Steininger, 1984) događalo početkom miocena uslijed sraza dviju tektonskih ploča (euroazijske i afričke), evolucija većega dijela njegova jugozapadnog i južnog područja, pa tako i istočnoslavenskog dijela započinje u donjemu miocenu (otnang–karpat) snažnom ekstenzijskom tektonikom, vulkanskom aktivnošću i lokalno predodređenim taloženjem naslaga neujednačenoga litološkog sastava, isprva iz slatkovodnih, prijelaznih, a zatim od badena i marinskih okoliša. Uz različite vulkanske stijene talože se krupnozrnati slatkovodni sedimenti breče, konglomerati, pješčenjaci, lapori i vapnenci (Lučić et al., 2001; Pavelić et al., 2003). Tijekom srednjega miocena u plitkomorskim okolišima većinom se talože biogeni vapnenci i krupnozrnati klastiti, a u nešto dubljim prostorima sitnozrnati pješčenjaci, glinovito-laporoviti peliti i vapnenci. U sarmatu, krajem srednjega miocena, prekida se marinska veza između prostora Paratethysa i (Neo)Tethysa. Dolazi do oslađivanja okoliša i taloženja tanko uslojenih lapora. Gornjomiocenski slijed naslaga karakteriziran je daljnjim postupnim oslađivanjem i taloženjem debelih serija lapora i pješčenjaka. U pliocenu se talože većinom pjeskovito-glinoviti sedimenti, a sukcesija završava taloženjem kvartarnih naslaga šljunaka, pijesaka, glina i lesa.

Cilj je ovoga rada, uz već postojeće palinološke rezultate (dinosporinske ciste dinoflagelata) rekonstrukcijom kopnene vegetacije pomoću spora i peluda, koja je uvjetovana klimom karakterističnom za pojedina geološka razdoblja, pridonijeti preciznijoj odredbi starosti istraživanih sedimenata. Korištene su standardna palinološka analiza i statistička metoda peludnih analiza te elektrokarotazna mjerenja prirodne radioaktivnosti i specifične otpornosti. Dobiveni rezultati poslužiti će kao lokalni model za rutinsku odredbu starosti na istraživanome području.



Slika 1. Geografski položaj proučavanoga prostora (preuzeto iz <http://www.google.hr>)

2. Materijal i metode

Za izradu peludnoga dijagrama korišteni su uzorci krhotina iz isplake duboke bušotine za eksploataciju ugljikovodika na području Istočne Slavonije. Od dubine 190 m do 1050 m za maceraciju uzimani su uzorci svakih 30 m. Maceracija je rađena prema standardnoj metodi po Kummel & Raup (1965) koja se koristi u INA d.d. Oprani uzorci prvo se tretiraju s 18-postotnom solnom kiselinom (HCl) radi otapanja karbonata i nakon ispiranja ostatak se tretira s 40-postotnom fluorovodičnom kiselinom da se otope silikati. Ostatak dobiven kemijskim otapanjem uzorka stijene dalje se obrađuje u (ZnCl₂) teškoj tekućini ($\rho = 2,1 \text{ kg/l}$). Teška tekućina koristi se za izdvajanje organske tvari od mineralnoga ostatka. Supernatant s organskim ostatkom prosijava se kroz sito veličine otvora 15 μm . Ostatak organske tvari sa sita se ispire i centrifugira na 3600 okretaja 10 minuta. Talog iz kivete nanosi se na predmetno staklo, osuši i nakon dodavanja

glicerinske želatine prekrije se pokrovnim stakalcem. U ovome radu korišten je palinološki svjetlosni mikroskop s interferencijskim kontrastom i fluorescencijom maksimalnoga povećanja do 600 x, OLYMPUS BX51. Za analizu svojti korišteno je povećanje 1000 x s imerzijskim uljem, a za brojenje 400 x. Za klasifikacijsku odredbu korišteni su atlas recentnoga peluda (Reille, 1992, 1995), ključ za odredbu recentnoga peluda sa slikama (Moore, 1991), atlas form-vrsta fosilnih spora i peluda (Nagy, 1969; Planderová, 1990; Stuchlik et al., 2001) i baza podataka recentnoga peluda Hrvatske s ključem za odredbu (Brajković et al., 2004). Za statističku obradu i izradu peludnoga dijagrama korišten je računalni program POLPAL (Walanus & Nalepka, 1999).

3. Rezultati i diskusija

Analizirano je 35 uzoraka (svakih 30 m) od kojih je 30 (190 – 1050 m) sadržavalo palinomorfe (spore, pelud i dinociste). Na osnovi analiziranih približno nešto više od 9000 peludnih zrna i spora (oko 300 zrna po preparatu) određeno je 96 biljnih svojti koje su statistički obrađene i prikazane u skupnome peludnom dijagramu koji se sastoji od karotažnih dijagrama s litološkim stupom, prikaza razvoja svake pojedine svojte na istraživanome prostoru u vremenu od gornjega ponta (Stevanović, 1989) do holocena, od klasterske analize i dijagrama odnosa „toplih i hladnih” svojti. Dobiveni su sljedeći rezultati:

3.1. Vegetacijske zone

Određene su 3 vegetacijske zone (Z_1 , Z_2 , i Z_3) na osnovi međusobnih postotnih odnosa pojavljivanja pojedinih svojti i njihovih grupiranja prema rezultatima klasterske analize (prilog 2). Za biostratigrafsku zonu Z_1 karakteristična je dominacija peluda Taxodiaceae s postotkom do 24 %, *Alnus* do 11 % i *Ulmus* do 9 %, što upućuje na topliju i vlažniju klimu. U vršnome dijelu zone, na samome prijelazu iz gornjega pontu u pliocen, postotak Taxodiaceae i dalje je visok, dok izrazito raste postotak Poaceae (do 22 %), što upućuje na još uvijek vlažnu klimu, ali znatno hladniju. U zoni Z_2 postotak je Taxodiaceae u padu, a postotak *Alnus* i *Ulmus* ostaje uglavnom isti. Karakteristično je povećanje udjela peluda *Cathaya* (do 4,5 %) i Asteraceae (do 8 %). Na prijelazu iz Z_2 u Z_3 karakteristično je povećanje postotka *Sciadopitys* (do 13 %) i *Tsuga* (do 9,5 %). Za zonu Z_3 karakteristično je daljnje zahladnjenje s povećanjem postotka peluda Poaceae (do 17 %), *Picea* (do 8 %), *Tsuga* (do 8 %) i *Abies* (do 6 %). Ta je zona podijeljena na dvije podzone Z_{3a} i Z_{3b} . U zoni Z_{3a} znatan je postotak peluda rodova *Tilia* (do 6 %), *Quercus* (do 5 %) i *Fagus* (do 4,5 %), dok se u zoni Z_{3b} nakon potpunoga prestanka ponovo javlja pelud Taxodiaceae i Cupressaceae, *Carya* i *Pterocarya*, koje su karakteristične za šume poplavnih ravnica. Takva slika peludnoga dijagrama upućuje na generalno zahladnjenje od kraja miocena do kvartara, s izrazitim pikovima na granici pont/pliocen, pliocen/pleistocen i na kraju zone Z_{3a} , te ponovno zatopljenje u zoni Z_{3b} . Slična klimatska događanja registrirana su i u ostalim dijelovima Središnjega Paratethys-a. Vegetacija u pontu Dunavskoga bazenskog sustava upućuje na više kontinentalnu klimu s manje oborina i većom vlagom s početkom pliocena (Kováč et al., 2006). U Pretkarpatskome bazenskom sustavu u sjeverozapadnoj Bugarskoj (Ivanov et al., 2002) te u Srbiji (Utescher et al., 2007) i jugoistočnoj Europi (Ivanov et al., 2011) u vrijeme pontu vegetacija šuma poplavnih ravnica i sličan sastav biljnih zajednica kao i na istraživanome području Istočne Slavonije upućuje na identičnu klimatsku sliku. Nešto sjevernije u Panonskom bazenskom sustavu na području južne Mađarske krajem pleistocena sedimentiraju se bazalne crvene gline koje svojim mineralnim sastavom upućuju na izrazito zahladnjenje (Kovács et al., 2011) koje je registrirano i na peludnome dijagramu iz Istočne Slavonije.

3.2. Starost

Starost zone Z_1 na osnovi dinocista – *Galeacysta etrusca* Corradini & Biffi (tabla 1) određena je kao pont. Zona Z_2 kao pliocen i zona Z_3 kao kvartar, odnosno pleistocen i holocen, određene su u ovome radu rekonstrukcijom klime na osnovi međusobnih postotnih odnosa pojedinih svojti kroz vrijeme i usporedbom dijagrama odnosa „toplih i hladnih” svojti (prilog 2) s Haqovom krivuljom promjena nivoa mora koja upućuje na globalna zahladnjenja i zatopljenja na Zemlji (Haq et al., 1987, 1988) i usporedbom s metodom kisikovih izotopa (δO^{18}) koja također upućuje na globalne izmjene klime (Emiliani & Edwards, 1953). Na skupnome peludnom dijagramu iz uzoraka iz bušotine uočena su tri izražena

zahladnjenja koja odgovaraju događanjima na granici miocen/pliocen (cca 660 m), pliocen/pleistocen (cca 440 m) i u kvartaru (pleistocen + holocen) (260 m) (**prilog 2**).

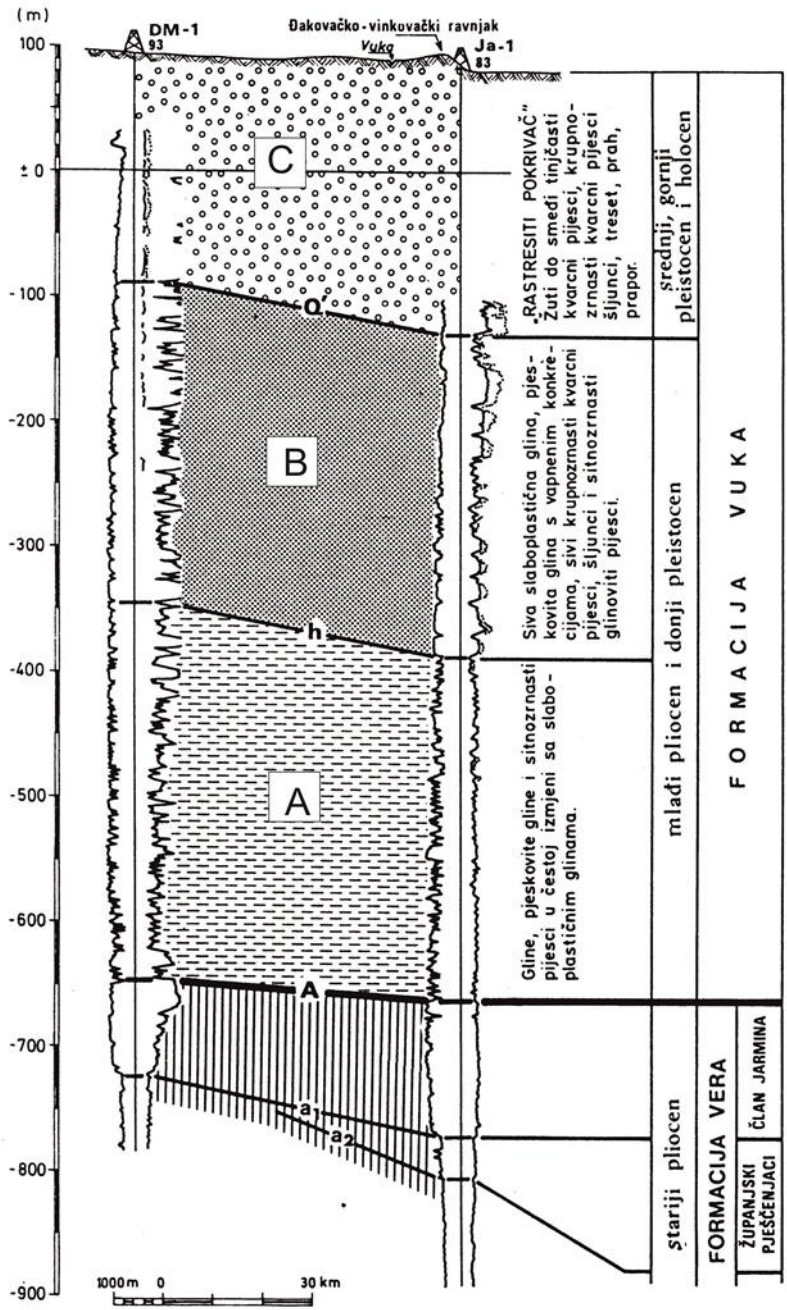
3.3. Provodne vrste

Na istraživanome području, određene su 44 morfosvojte spora, od kojih 12 form-rodova i 32 form-vrste (**prilog 1**). Takvi izrazi standardno se rabe u strukovnome izričaju hrvatskog jezika (**Koch, 1998**). Za svaku morfosvojtju utvrđen je raspon pojavljivanja u okviru istraživanih sedimenata (**prilog 3**). Unutar pojedinih zona određene su form-vrste spora koje se pojavljuju samo unutar njih, kao moguće provodne form-vrste za rutinsku odredbu starosti sedimenata na području istočne Slavonije. U pontu je određeno 13 form-vrsta spora koje ne prelaze granicu miocen/pliocen (**tabla 1**). To su: *Echinatisporis longechinus*, *Echinatisporis miocenicus*, *Laevigatosporites gracilis*, *Leiotriletes triangulus*, *Retitriletes pseudoclavatus*, *Retitriletes punctoides*, *Stereisporites cyclus*, *Stereisporites pseudopsilatus*, *Stereisporites stereoides*, *Stereisporites stictus*, *Verrucatosporites favus*, *Verrucatosporites megabalticus* i *Verrucatosporites megafavus*. U pliocenu su određene 4 moguće provodne form-vrste spora koje nisu nađene u kvartaru na ovome istraživanom području (**tabla 2**). To su: *Distancoraesporis silesicus*, *Selagosporis selagoides*, *Verrucatosporites alienus* i *Verrucatosporites histiopteroides*. U najmlađim naslagama istraživanog područja, dakle pleistocena i holocena, 7 je mogućih provodnih spora (**tabla 2**) koje, ako se potvrdi da pripadaju kvartaru, treba revidirati prema recentnoj nomenklaturi: *Camarozonosporites minoris* (*Lycopodiella* sect. *Campylostachys*), *Corrugatisporites microvallatus* (*Lygodium*), *Leiotriletes microlepidoides* (Dennstaedtiaceae, *Microlepidia*?), *Leiotriletes neddenioides* (Lygodiaceae? Cyatheaceae?), *Polypodiaceoisporites saxonicus* (*Pteris*), *Retitriletes rotundoides* (*Lycopodium*) i *Segmentizonosporites paucirugosus* (Pteridaceae). Potvrdu navedenih provodnih vrsta treba očekivati u budućim analizama ovoga istraživanog područja.

3.4. Litologija i EK markeri

Usporedbom peludnoga dijagrama s karotažnim dijagramima trebalo bi biti moguće odrediti točne dubine navedenih geoloških granica, odnosno poziciju karotažnih repera α , h i Q (**Hernitz, 1983**) (**slika 2**). Najmlađa litostratigrafska formacija u području istočne Slavonije jest formacija Vuka (**Šimon, 1966**). Ona obuhvaća interval iznad karotažnoga markera alfa (α) do površine zemlje. Temeljem litoloških značajki mogu se razlikovati tri dijela formacije Vuka koje su **Batušić & Urbiha (1979)** nazvali operativnim jedinicama A, B i C (od najstarije prema najmlađoj) (**slika 2**). U zoni C koja seže do površine zemlje ima glina, nevezanih pijesaka, šljunaka, prapora i humusa. Mjestimice se nalaze proslojci slabokarboniziranoga ugljena i treseta (poroznost pijesaka iznosi oko 10 %, a salinitet slojne vode ne prelazi 0,5 g NaCl/dm³).

EK marker Q dijeli zone B i C. U zoni B prevladavaju sitnozrnati pijesci s proslojcima slaboplastične gline (poroznost pijesaka iznosi oko 30 %, a salinitet slojne vode 0,5 – 1 g NaCl/dm³). EK marker h dijeli zone A i B. U zoni A nalaze se gline i sitnozrnati pijesci (poroznosti 25 – 30 % i saliniteta slojne vode 1 – 3 g NaCl/dm³). Prelazak iz formacije Vera u Vuku karakterizira nagli porast vrijednosti specifične otpornosti formacije (najčešće preko 20 ohm x m) koji je povezan s promjenom saliniteta slojne vode koji se naglo smanjuje (EK marker alfa). Središnji dio formacije Vuka odvojen je od donjega dijela (B/A) EK markerom h. Vrijednosti specifične otpornosti formacije jače su „nazubljene” u zoni B nego u zoni A (posebice u pješčenjacima i pijescima) (**slika 2**).



Slika 2. Podjela formacije Vuka (Hernitz, 1983)

4. Zaključak

Iz krhotina stijena dobivenih za vrijeme bušenja duboke istraživačke bušotine u Istočnoj Slavoniji načinjene su peludne analize i izrađen je peludni dijagram zastupljenosti pojedinih biljnih svojti koje su na tome području egzistirale u vremenu od najmlađega miocena do kvartara. Postavljene su tri vegetacijske zone (Z_1 , Z_2 i Z_3) i dvije podzone (Z_{3a} i Z_{3b}).

Determinirane biljne svojte grupirane su prema ekološkim zahtjevima u tri skupine, kao tople, hladne i ubikvisti, to jest one koje imaju širok dijapazon tolerancije na klimatske promjene, ponajprije temperaturne. Njihovom međusobnom usporedbom utvrđeni su periodi izrazitoga zahladnjenja na istraživanome prostoru kroz promatrano vrijeme. Usporedbom s Haqovom krivuljom globalnih promjena nivoa mora i usporedbom s metodom kisikovih izotopa ($\delta O18$) koja govori o globalnim izmjenama klime određena je geološka starost utvrđenih zahladnjenja.

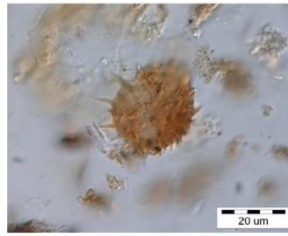
Korelacijom dobivenih rezultata s krivuljama elektrokarotaznih mjerenja bušotine čiji je stijenski materijal analiziran, utvrđene su EK markerima točne geološke granice (miocen/pliocen i pliocen/kvartar). Preciznom odredbom raspona pojavljivanja pojedinih form-vrsta spora, vrste čije je pojavljivanje ograničeno unutar jednoga razdoblja postavljene su kao moguće provedene vrste za navedena geološka razdoblja na području Istočne Slavonije. Kao takve vrijedan su materijal za rutinske odredbe geološke starosti na istraživanome području. S obzirom na specifičan razvoj miocena i pliocena na području središnjeg Parathetysa, ovakav model istraživanja bio bi koristan i u drugim dijelovima Panonskoga bazenskog sustava.

Zahvala

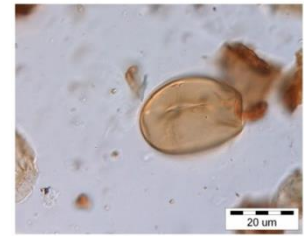
Za korisne savjete i nesebičnu pomoć zahvalni smo recenzentima dr. sc. Koraljki Bakrač i dr. sc. Georgu Kochu.



Echinatisporis longechinus



Echinatisporis miocenicus



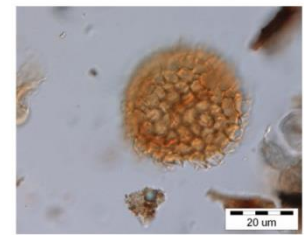
Laevigatosporites gracilis



Leiotriletes triangulus



Retitriletes pseudoclavatus



Retitriletes punctoides



Stereisorites cyclus



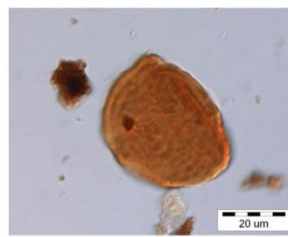
Stereisorites pseudopsilatus



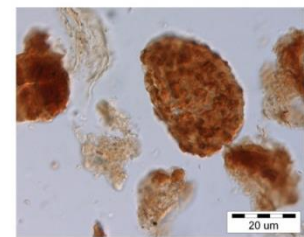
Stereisorites stereoides



Stereisorites stictus



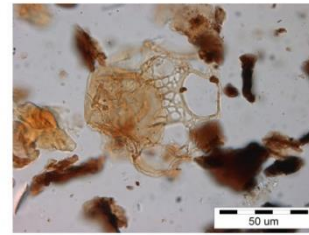
Verrucatosporites favus



Verrucatosporites megabalticus

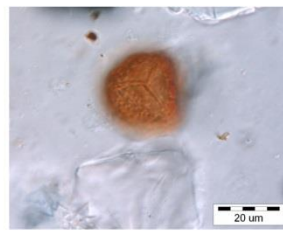
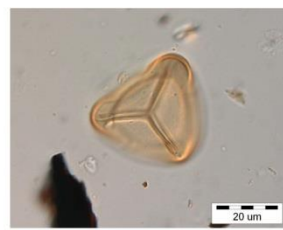


Verrucatosporites megafavus



Galeacysta etrusca

Tabla 1.

*Distancoresporis silesicus**Selagosporis selagoides**Verrucatosporites alienus**Verrucatosporites histiopteroides**Camarozonosporites minoris**Corrugatisporites microvallatus**Leiotriletes microlepidoidites**Leiotriletes neddenioides**Polypodiaceosporites saxonicus**Retitriletes rotundoides**Segmentizonosporites paucirugosus***Tabla 2.**

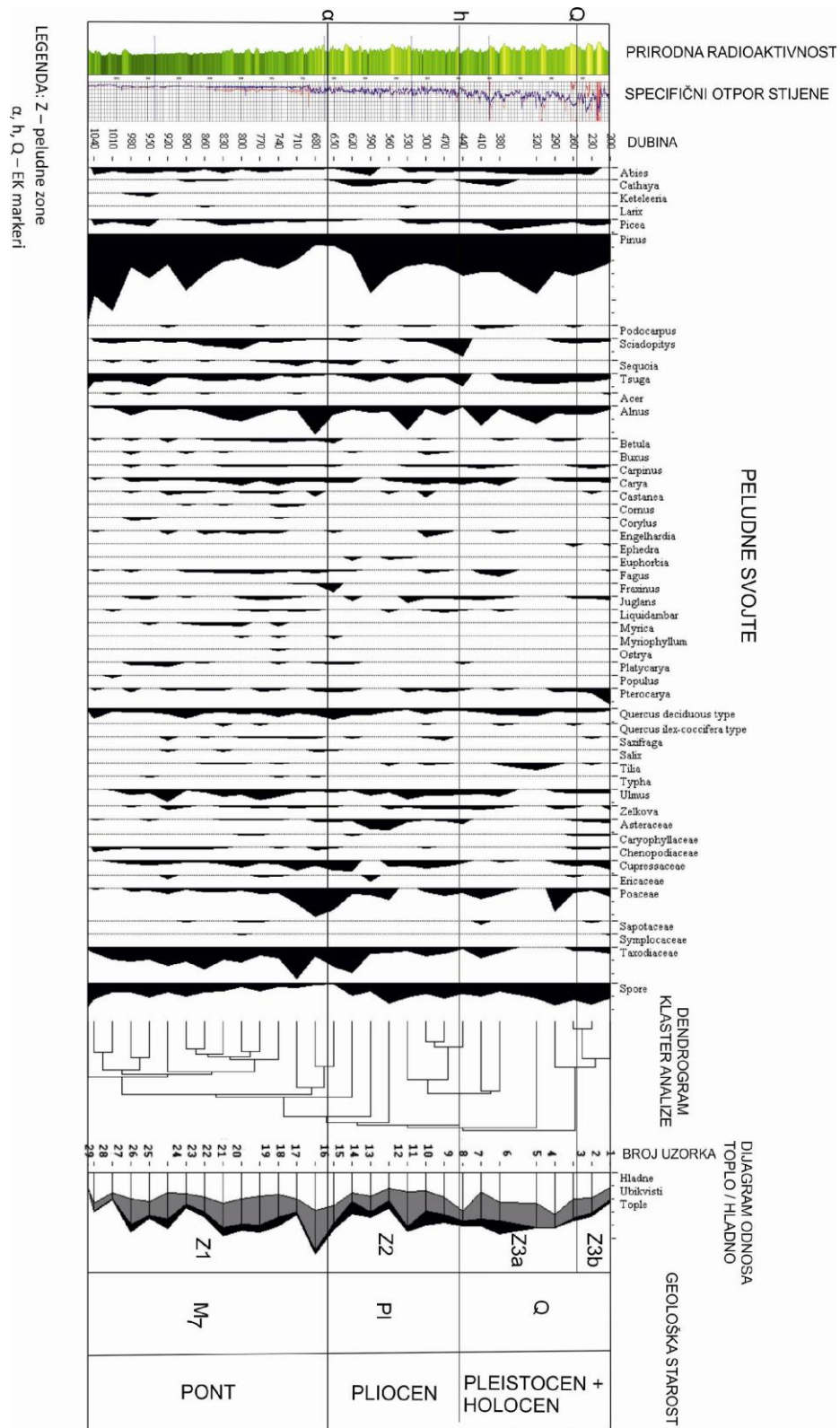
Prilog 1

Popis form-vrsta spora određenih u ovome radu

1. *Baculatisporites* sp.
2. *Baculatisporites nanus* (Wolff 1934) Krutzsch 1959
3. *Baculatisporites ovalis* Kedves 1973
4. *Baculatisporites primarius* (Wolff 1934) Pflug & Thomson in Thomson & Pflug 1953
5. *Camarozonosporites minoris* Krutzsch 1963
6. *Contignisporites* sp.
7. *Corrugatisporites* sp.
8. *Corrugatisporites microvallatus* (Krutzsch 1967) Nagy 1985
9. *Distancoraesporis silesicus* (Krutzsch 1963) Grabowska 2001
10. *Echinatisporis* sp.
11. *Echinatisporis longechinus* Krutzsch 1959
12. *Echinatisporis miocenicus* Krutzsch & Sontag in Krutzsch 1963
13. *Echinosporis fotensis* Nagy 1985
14. *Laevigatosporites* sp.
15. *Laevigatosporites gracilis* Wilson & Webster 1946
16. *Laevigatosporites haardti* (Potonié & Ventiz 1934) Thompson & Pflug 1953
17. *Leiotriletes* sp.
18. *Leiotriletes microlepidoidites* Krutzsch 1962
19. *Leiotriletes neddenioides* Krutzsch 1962
20. *Leiotriletes triangulus* (Mürriger & Pflug ex Krutzsch 1959) Krutzsch 1962
21. *Neogenisporis* sp.
22. *Polypodiaceoisporites* sp.
23. *Polypodiaceoisporites saxonicus* Krutzsch 1967
24. *Retitriletes* sp.
25. *Retitriletes pseudoclavatus* Krutzsch 1963
26. *Retitriletes punctoides* Krutzsch 1963
27. *Retitriletes rotundoides* Krutzsch 1963
28. *Segmentizonosporites paucirugosus* (Nagy 1985) Stuchlik 2001
29. *Selagosporis selagoides* Krutzsch 1963
30. *Stereisporites* sp.
31. *Stereisporites cyclus* Krutzsch 1963
32. *Stereisporites pseudopsilatus* Krutzsch 1959
33. *Stereisporites stereoides* (Potonié & Ventiz 1934) Thompson & Pflug 1953
34. *Stereisporites stictus* (Wolff 1934) Krutzsch 1963
35. *Toroisporis* sp.
36. *Toroisporis stuchlikii* Planderová 1990
37. *Triplanosporites* sp.
38. *Verrucatosporites* sp.
39. *Verrucatosporites alienus* (Potonié 1931) Thompson & Pflug 1953
40. *Verrucatosporites balticus* (Krutzsch 1962) Krutzsch 1967
41. *Verrucatosporites favus* (Potonié 1931) Thompson & Pflug 1953
42. *Verrucatosporites histiopteroides* Krutzsch 1962
43. *Verrucatosporites megabalticus* Krutzsch 1967
44. *Verrucatosporites megafavus* Krutzsch 1967

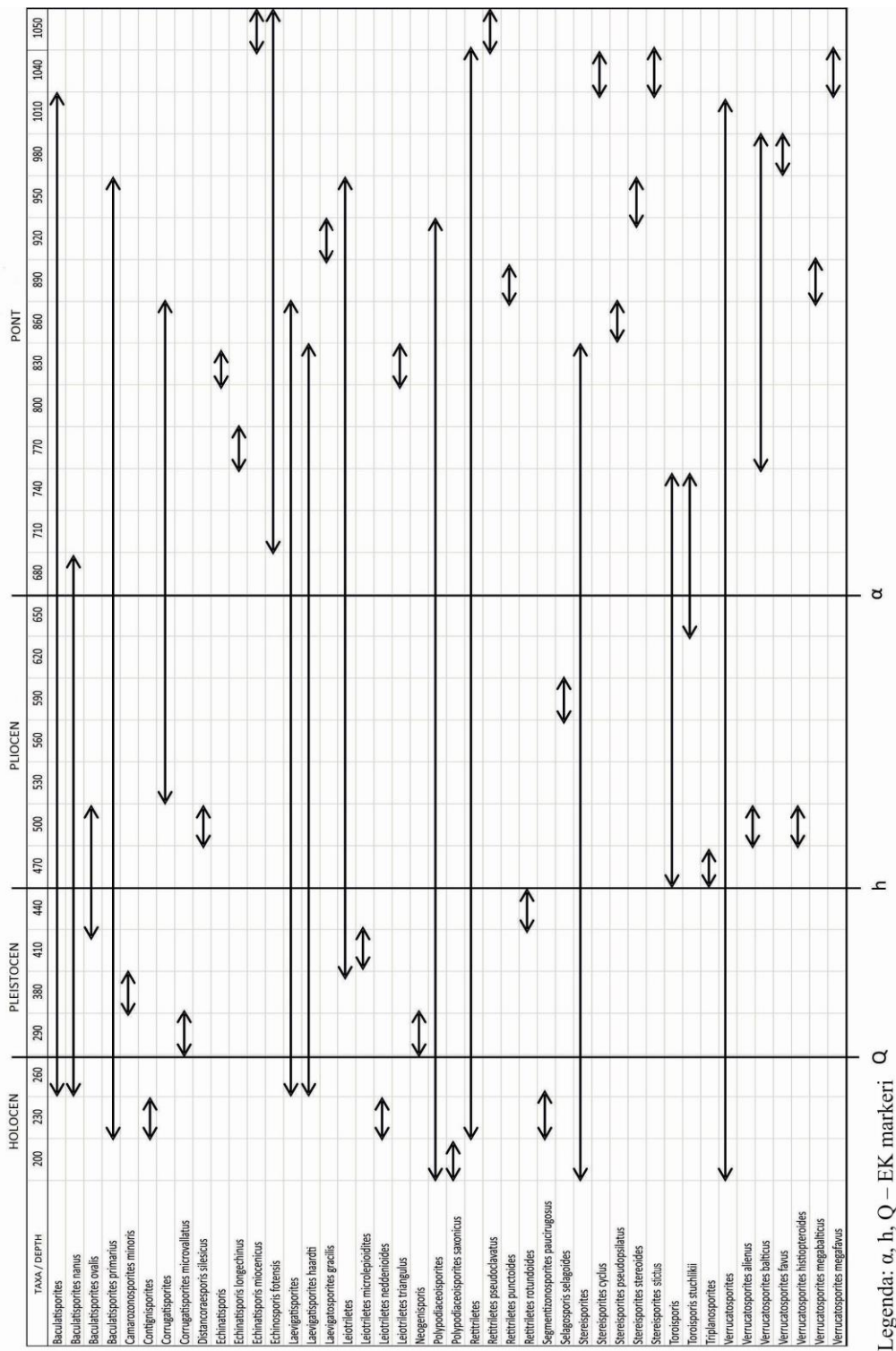
Prilog 2

Peludni dijagram duboke bušotine u istočnoj Slavoniji



Prilog 3

Prikaz raspona mogućih lokalnih provodnih vrsta spora



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