Pyroclastic flow sediment (ignimbrite) in Miocene Tar Formation, Drava Depression

D. Bigunac, K. Krizmanić, B. Sokolović and Z. Ivaniček

PRELIMINARY COMMUNICATION

In the 2009 one of the exploration wells near Croatian-Hungarian borderline instead of prognosed primary target (Miocene barrier bar composed of sandstones, biogenic limestones and clayey limestones) 72 m shallower drilled through massive, 88 m thick pyroclastic flow sediment. Petrological analyses had been done on core as well as on drilling cuttings and the sediment is described as devitrified vitroclastic welded tuff, i.e. ignimbrite. As a result of micropaleontological and palynological analyses from overlying and underlying deposits, the age of the pyroclastic flow sediment was determined as the most probably Badenian. Lithostratigraphically that ignimbrite belongs to the Tar Formation.

Key words: pyroclastic flow, ignimbrite, Tar Formation, Miocene, Drava Depression

1. INTRODUCTION

In order to explore hydrocarbon potential in the Drava Depression, near Croatian-Hungarian border, INA and MOL during 2007 and 2008 acquired 189 km² of 3D seismic, both on the Hungarian and Croatian side. Assigning of well location was based on interpretation of 3D seismic data. Geochemical analyses were performed on cuttings and cores of nearby wells. In the Early-Middle Miocene rocks of those wells gas-prone source rocks with low generating potential were found. However, hydrocarbon shows are registered in the area, what proved the lateral secondary migration. Based on previous results the new exploration well, here named AA-1(Figure 1), was drilled in the 2009 on Hungarian side.

The main objective was to verify hydrocarbon presence in two predicted reservoirs of Miocene. Those are barrier bar and coarse clastic series. According to seismic image, lenticular depositional body near AA-1 well was interpreted as barrier bar. However, that well drilled massive, not-bedded pyroclastic flow sediment, i.e. ignimbrite, which belongs to Miocene Tar Formation (Figure 2). This formation belongs to Hungarian lithostratigraphic nomenclature and is dated in Karpatian–Badenian period, i.e. time span 17.5-14.79 Ma (e.g. references[4, 5, 15]). Tar Formation comprises variable pyroclastic facies, it can occur as stratified and as unstratified, ignimbritic as described in north, middle and south-west Pannonian Basin (e.g. references[3,5, 15,17]).

Pyroclastic rock drilled by AA-1 well is interpreted as the deposit of volcanically produced hot, gaseous density current, i.e. pyroclastic flow, that frequently develop from explosive volcanic eruptions, when hot masses composed of pyroclastic fragments and ash with high gas content flow, roll and travel downhill driven by mechanisms similar to gravity mass flows (e.g., references[2,18]). The speed of those fast moving fluidized bodies of pyroclasts depends on gradient of the slope and the size of the flow. High velocities and ability of flows to move over and around obstacles testifies to their great mobility, but most impressive are the distances (more than 100 km) over which ignimbrites have been traced and heights (over 600 m) that they can surpass. Pyroclastic flows originate from different tectonic settings and eruptions producing them may vary in volume from less than 1 km³ to more than 1000 km³ . Genesis[2] of

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

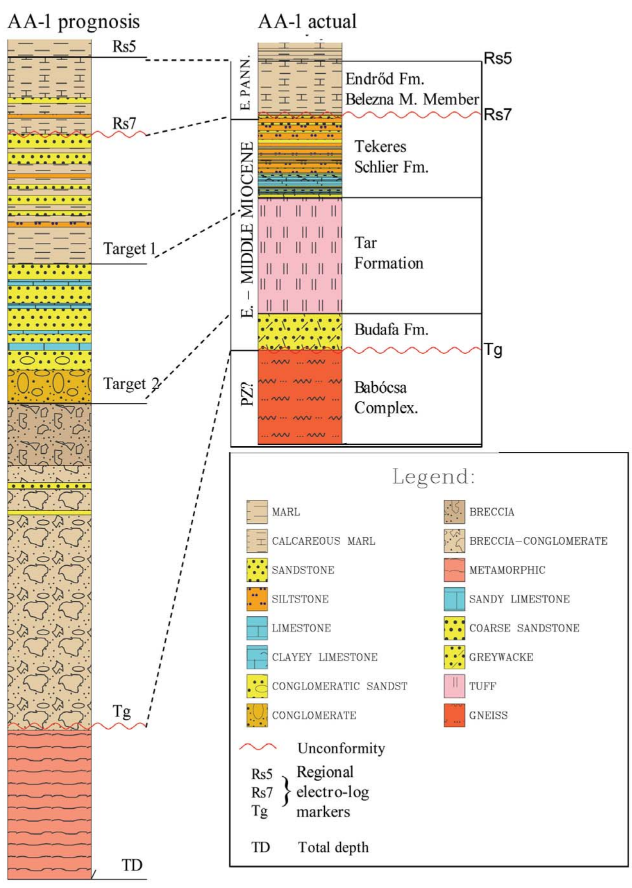


Fig. 2. The AA-1 well geological column (from Lower Pannonian to well depth - actual (right) and prognosed (left). Hungarian lithostratigraphical nomenclature is applied.

Sl. 2. AA-1 geološki stup (od donjeg panona do konačne dubine) - ostvareni (desno) i prognozirani (lijevo). Prikazana je mađarska litostratigrafska nomenklatura.

such flow is most frequently connected to collapsing of eruptional column, which initiates processes of forming pyroclastic flow that finally form pyroclastic flow deposits (e.g. ignimbrites). Such volcanic products could be formed during hours and weeks, i.e. during instantaneous geologic events.[3]

The term ignimbrite is used for deposits of pumice-rich pyroclastic flow deposits whether welded or unwelded and because of many transitional varieties it is recommended to be used for all deposits formed by the emplacement of pyroclastic flows.[2] Welding of glass shards is one of the most characteristic features of ignimbrites deposited at high temperatures. The degree of welding depends on number of factors e.g. temperature, viscosity that develop during movement of pyroclastic flow and gas content.[2]

The range of silica content (Table-1) exhibited by the rock from AA-1 core is from 71-73%. In the base of analysed ignimbrite there is "transitional" zone consisting of pyroclastics in alteration with volcanic greywackes or conglomerates. That interval also probably belongs to Middle Miocene as the analysed part of the Tar Formation, i.e. is part of the Budafa Formation (Figure 2). The deepest drilled rocks are gneiss, chronostratigraphically probably of Palaeozoic age, i.e. lithostratigraphically of the Babócsa Complex Group.

Two cores (18 m each) were planned in prognosed reservoirs, but eventually one (6 m planned, 5.6 m obtained) was taken in welded tuff (Tar Formation). Gas shows are registered. Also cutting samples had been collected from this interval and from overlying and underlying rocks.

2. GEOLOGY OF THE ANALYSED AREA

In this chapter the complete review of regional geological settings is given. It comprises the short stratigraphical and structural evolution.

2.1. Stratigraphy

The oldest rocks belong to crystalline basement. Those are low to middle grade gneiss, mica, i.e. mica-quartz schist and amphibolite. Chronostratigraphic age is not determined.

Depending on paleorelief, Miocene sediments were deposited on Mesozoic carbonates or Palaeozoic magmatic or metamorphic rocks. Sediments are heterogeneous: conglomerates, breccias, sandstones, marls and of volcanic origin. Volcanic activity that started in early Miocene occurred throughout Pannonian Basin (e.g., references [1, 12, 14, 16]).

Pannonian and Pontian are characterized by alteration of sandstones and marls due to successive turbidite events in Croatian part[9] that were periodically interrupted by hemipelagic sedimentation.

Late Pliocene and Quaternary sediments are represented by terrestrial lithofacies.

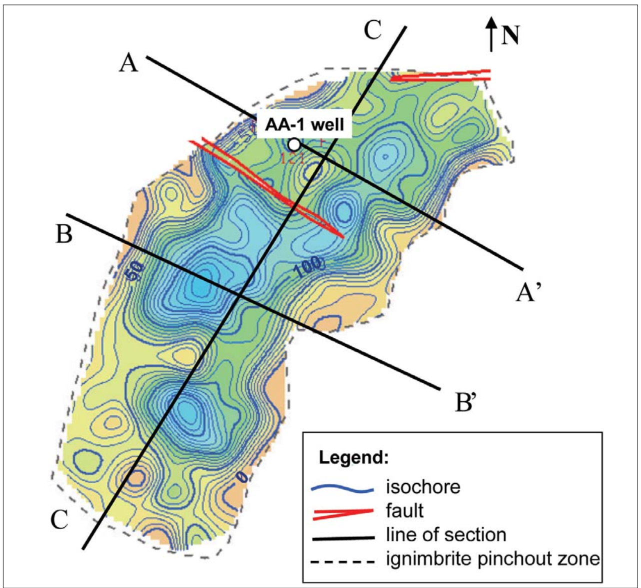


Fig. 3. Ignimbrite thickness map with lines of sections shown on Figures 4, 5 and 6

Sl. 3. Karta debljina ignimbrita s označenim geološkim profilima prikazanim na slikama 4,5 i 6

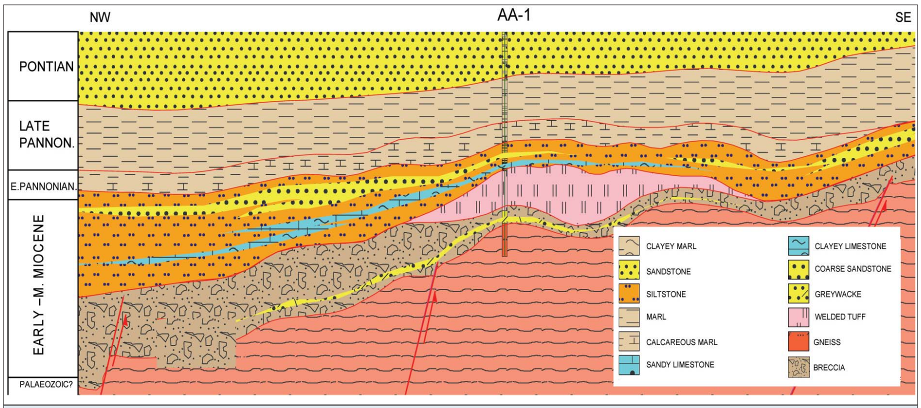


Fig. 4. Cross-section A-A' (strike is given on Figure 3)
Sl. 4.Geološki profil A-A' (položaj je prikazan na slici 3)

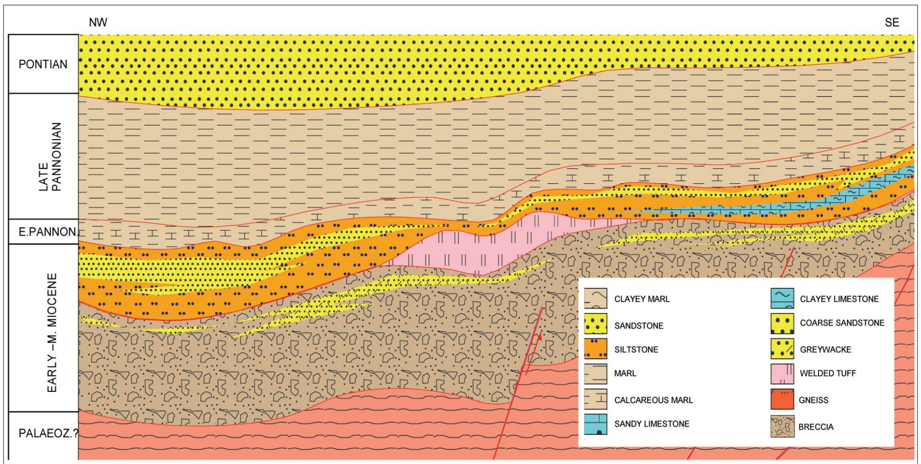


Fig. 5. Cross-section B-B' (strike is given on Figure 3)
Sl. 5. Geološki profil B-B' (položaj je prikazan na slici 3)

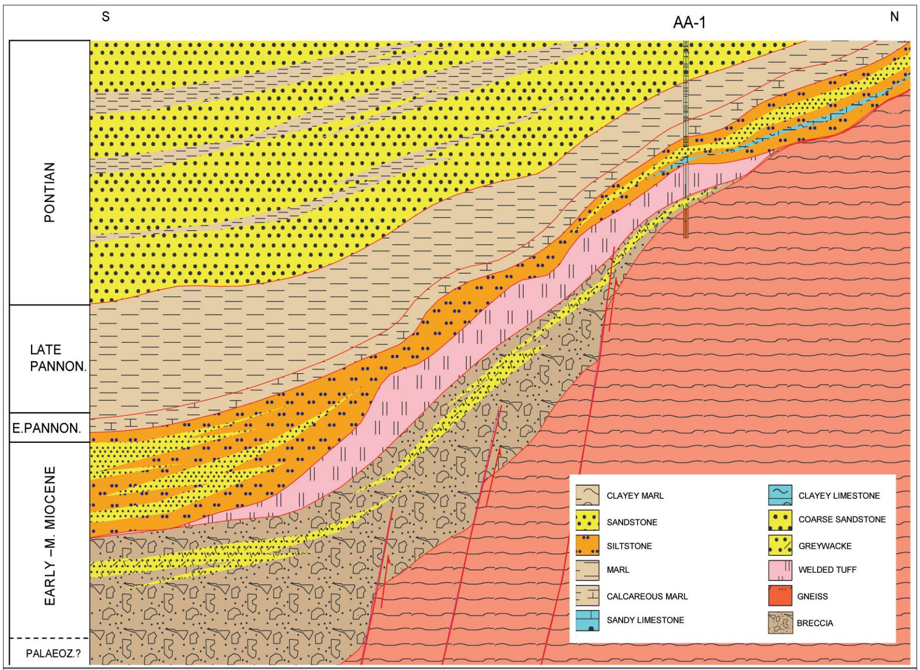


Fig. 6. Cross-section C-C' (strike is given on Fig. 3)
Sl. 6. Geološki profil C-C' (položaj je prikazan na slici 3)

2.2. Structural settings

The main geotectonic characteristic of the area of interest is normal faulting system related to strong tectonic activities during Alpine orogenesis that began during the late Eocene and Oligocene and continued throughout much of the Neogene accompanied by intensive volcanic activity. Exchange of deep depressions and elevated parts characterized palaeorelief. The deepest part is situated at the south-eastern part oriented NW-SE, while towards north studied area is uplifted along the numerous northwest-southeast trending normal faults that represent Early-Middle Miocene synrift extensional phase of Pannonian Basin.[9] Due to Late Badenian (postrift) compressional, or transpressional, tectonic event NE-SW directed reverse faults took place. Late Miocene slight compressional (uplifting) deformation is reflected by tilted blocks and NW-SE oriented small reverse faults. E-W directed steep normal faults situated in the northern area indicate Pliocene (– Quaternary?) transtensional – extensional tectonic phase that occurred locally during regional transpressional[9] tectonic phase.

Based on seismic interpretation and the corresponding well data, structural maps of Miocene barrier bar and coarse clastic series were interpolated and were base for location of the AA-1 well (e.g., references[6,7]). The two prognosed reservoirs were target. Exploratory well was drilled and the whole area was reinterpreted using new obtained data. Previously interpreted lenticular depositional body, after reinterpretation, maintained its shape and direction, but was located 72 m shallower, with different lithofacies (Figures 3, 4, 5 and 6).

The ignimbrite (Figure 3) covers 14 km^2. It is approximately 6 km long and 3 km wide body with its longer axis positioned in SW-NE direction. Maximum thickness is 190 m in the central part and it is thinning gradually toward margins with several smaller maximums.

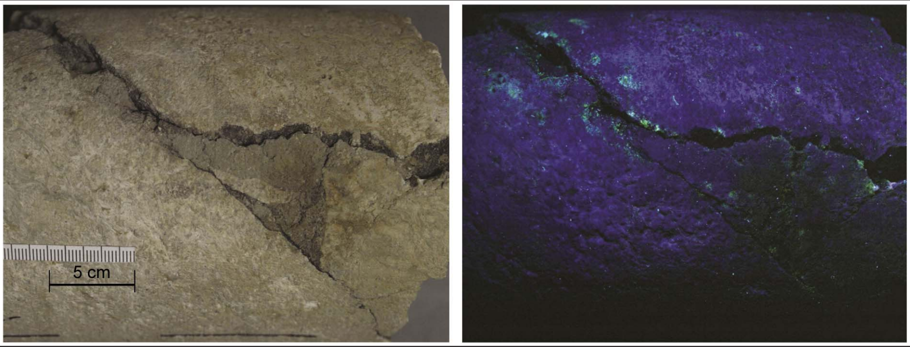


Fig. 7. Photos of sample exposed to normal (left) and UV (right) light
Sl. 7. Fotografija uzorka izoženog normalnom (lijevo) i UV (desno) svjetlu

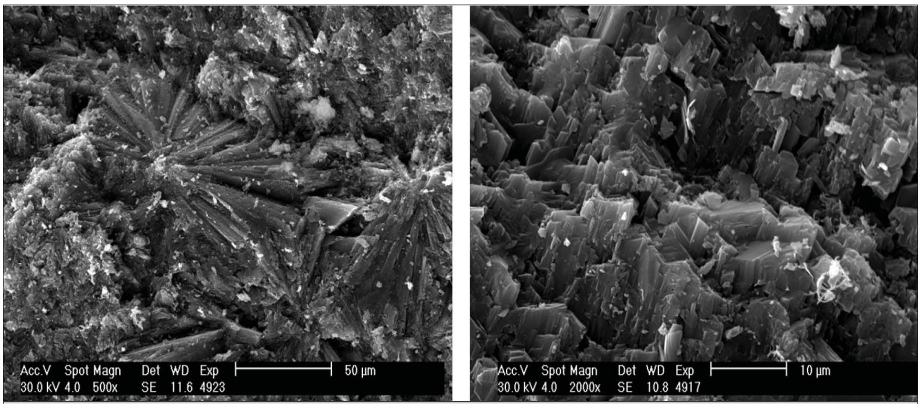


Fig. 8. SEM image of spherulites (left) and of inter-crystal pores (right)
Sl. 8. SEM fotografija sferulita (lijevo) te interkristalnih pora (desno)

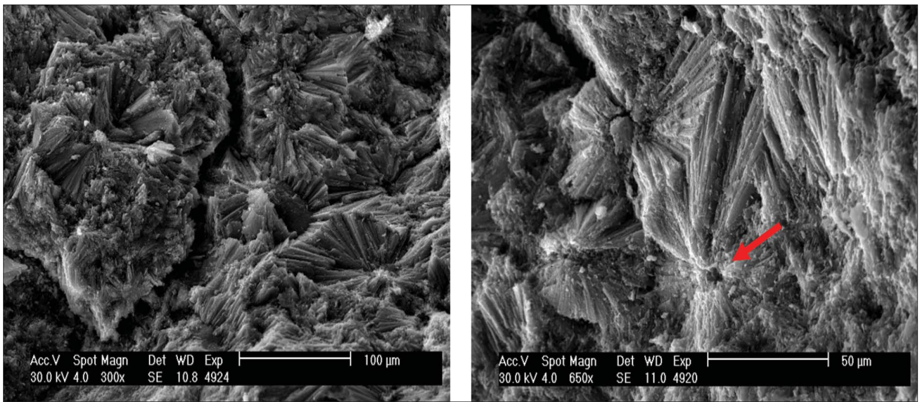


Fig. 9. SEM image (left) of open fracture and of lithophysae (red arrow), central vug in spherulites (right)
Sl. 9. SEM fotografija (lijevo) frakture i litofize (crvena strelica), centralne šupljine u sferulitu (desno)

3. PETROGRAPHIC AND BIOSTRATIGRAPHIC ANALYSES AND INTERPRETATION

Analyses of the core and drill cuttings from ignimbrite and its top and bottom included the following procedures: detailed macroscopic description, inspection under ultraviolet light (Figure 6), SEM (Scanning Electronic Microscope) analyses, various petro-physical measurements and geochemical analyses. Pyroclastic deposits were classified according to the size of component particles after.[8] Chemical analyses were done according to.[11] Biostratigraphic analyses (palynological and micropaleontological) of drill cuttings from overlying and underlying deposits of the pyroclastic interval were carried out in effort to define age and depositional context of ignimbrite. Dinoflagellatae cysts were determined according to[19] and findings of pollen according to.[13]

3.1. Petrographic analyses and interpretation

Macroscopic appearance of core samples (Figure 7, Figure 10 a) is very light gray to medium light gray and structure is massive. Core samples show zones of strong tectonic (fracturing) and chemical compaction (stylolites, Figure 10 e). Fracturing and vuggy (secondary) porosity is result of tectonics and dissolving. Treated with chloroform, core sample emanate pale yellow colour long fractures and vugs under UV light (Figure 7).

Geochemical analyses showed that core contains mature bitumen, dominantly from algal precursor with some indices of terrestrial material. Petrophysical

Table 1. Chemical analyses of core sample

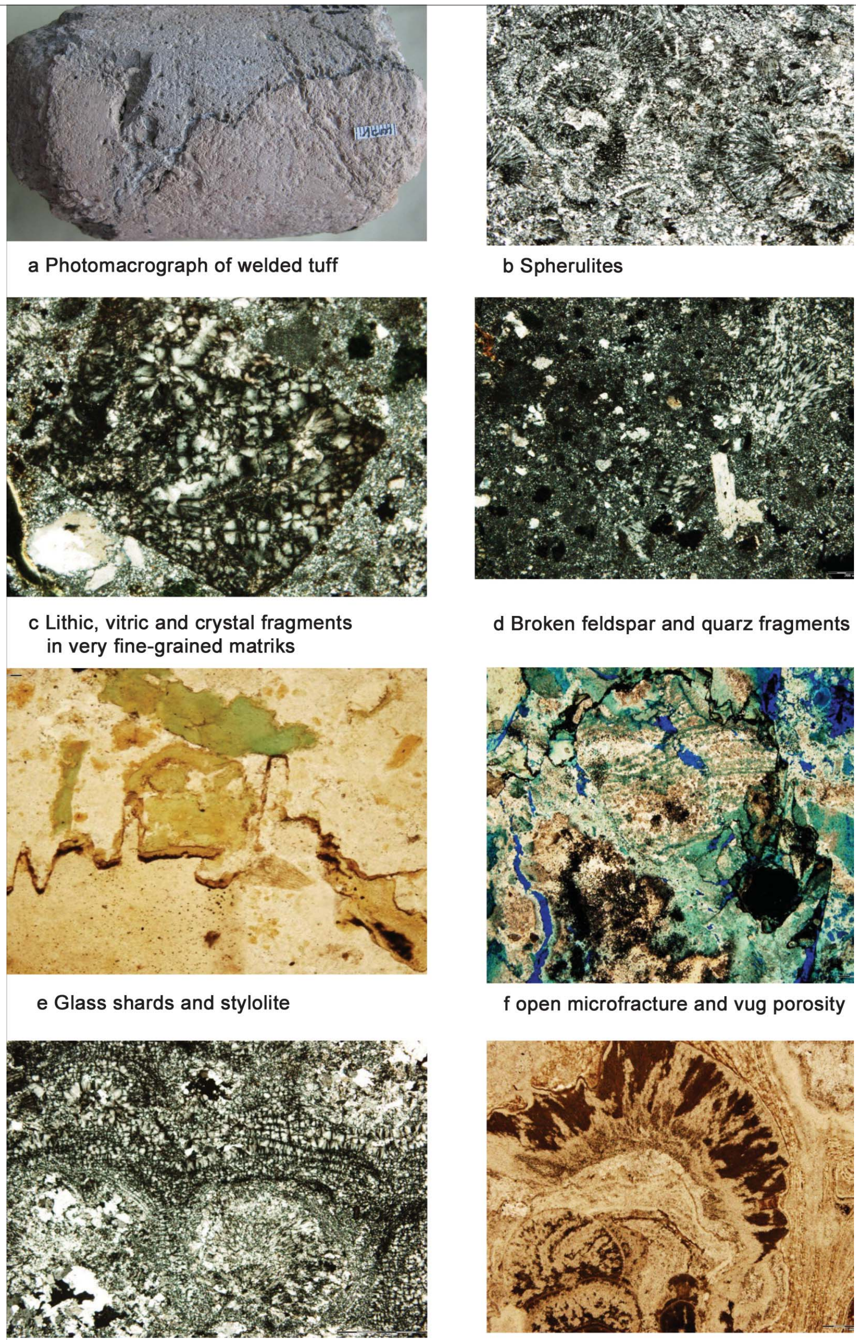
Samples	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)
AA-1 Core – 1, IV m	71.55	13.30	0.11	0.28	0.02	2.88	6.55
AA-1 Core – 1. IV m	71.65	13.34	0.25	0.15	0.07	3.15	5.28
AA-1 Core – 1. IV m	73.28	13.03	1.71	0.07	0.13	4.16	4.67

measurements showed high values of fracture porosity, but low permeability values.

Core samples represent pyroclastic sediment flow deposit - devitrified vitroclastic welded tuff which tends to develop from relatively high viscosity silicic (rhyolitic) magma. The whole-rock chemical analysis for described ignimbrite is given in Table 1.

Analyzed thin sections from AA-1 core consist of glass shards, pumice, crystals and lithic fragments. Devitrification, secondary process during cooling, is characterised by the formation of axiolithic and spherulitic (Figure 8, Figure 10 b,g,h) forms of radiating quartz and alkali feldspar crystal fibres with spherical, fan (fibres radiate from a point), axiolitic (fibres radiate from a line) and mosaic texture. Spherulites with various morphologies represent common product of high-temperature devitrification[10] of volcanic glass that consists of radiating arrays of crystal fibres where single crystals have slightly different crystallographic orientation form adjacent crystals. Lithic fragments as pyroclasts and crystal fragments are also present (Figure 10 c,d) as well as broken crystals which are common characteristics for ignimbrites. Chalcedonic aggregates (Figure 10 g) and pyrite crystals are also noticed in thin sections.

Porosity in thin sections is derived from micro fractures and vuggies (Figure 10 f). In SEM images such inter-crystalline (5-10 mm) pores and open fractures (Figure 9 left) are visible. Some spherulites (Figure 9 right) have a central vug, called lithophysae, while others are filled. It is because the internal crystal fibre structure can be re-crystallized to a quartz-feldspar mosaic as a result of later alteration. That can destroy or modify the original devitrification textures.



a Photomacrograph of welded tuff

b Spherulites

c Lithic, vitric and crystal fragments in very fine-grained matriks

d Broken feldspar and quarz fragments

e Glass shards and stylolite

f open microfracture and vug porosity

g Spherulites and chalcedonic aggregates

h Alteration of spherulites in clay minerals

Fig. 10. AA-1 core samples
Sl. 10. Uzorci jezgre iz AA-1

3.2. Biostratigraphical analyses and interpretation

Pyroclastics from core could not be biostratigraphically analysed. So, drill cutting samples from top (Figure 11) and base (Figure 12) of ignimbrite were palynologically and micropaleontologically analysed. Younger sediments are represented by fossiliferous, sandy and argillaceous micrite.

3.2.1. The ignimbrite top

Drill cuttings were treated by conventional method of maceration. In sediments overlying pyroclastic (top of ignimbrite) deposit organic matter is relatively well represented. In most of samples terrestrial material, which varies in size and type, prevail over amorphous organic

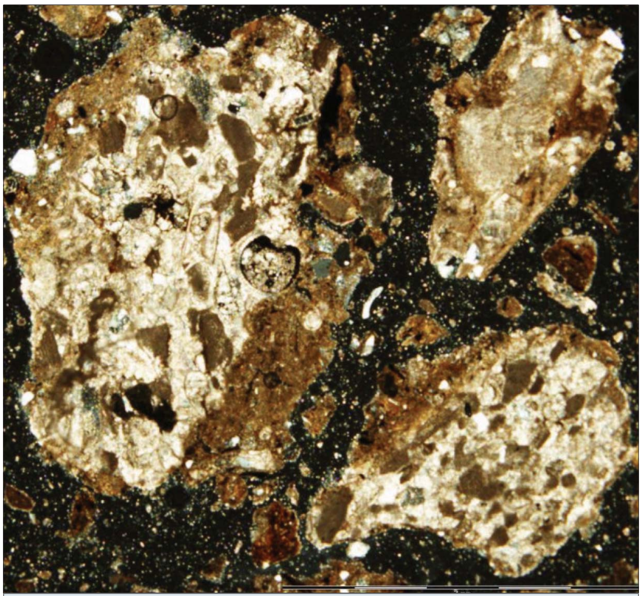


Fig. 11. Fossiliferous, sandy and argillaceos micrite
Sl. 11. Fosiliferni, pjeskoviti i glinoviti mikrit

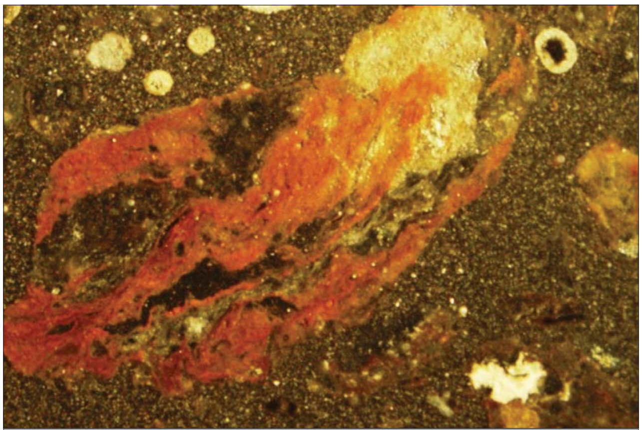


Fig. 12. Lithic greywacke with hematitic matrix
Sl. 12. Liična grauvaka s hematitiziranim matriksom

matter. Fossils are rare and generally represented by bisaccate, porate, colpate and other kinds of pollen grains together with some green algae remnants (*Botryococcus*). Macerals are biodegraded and mechanically re-worked. Sedimentation took place probably in marine environment, shallow (absence of dinoflagellates) and coastal environment (terrestrial organic matter and pollen grains). Micropaleontological analyses showed findings of planktonic foraminifera (*Orbulina* sp., *Globigerinoides* sp., *Globigerina* sp.) and remnants of algae Lithothamnium. All those facts indicated on marine depositional environment of Badenian.

3.2.2 The bottom of ignimbrite

However, the chronostratigraphic classification of the interval underlying the ignimbrite is uncertain regarding particular stage because of lack of index species. It is assigned to Budafa Formation with Middle Miocene age, probably Badenian. Lithologically, this interval is represented by pyroclastics, conglomerates (according to mud logging reports) and lithic greywacke (Figure 12) consisting of poorly sorted, sub-angular, sandy detritus in fine-grained matrix (silty to sandy, in places hematitic). The detritus consist of quartz, feldspar and rock fragments. Thin sections were micropaleontologically sterile, but palynological analyses have the following results:

Sporomorphes of the palynofacies is lacking in spores but rich in diverse pollen grains. Very often *Momipites* sp., *Myricipites* sp. (Figure 13) and *Engelhardtioidites* sp. (Figure 14) are identified. Bisaccate grains *Cathayapollenites* sp. (Figure 15), *Pinuspollenites mioceanicus* and many other are abundant. Besides some undefined pollen grains, following taxa have been determined: *Caryapollenites simplex*, *Tricolporopollenites* sp., *Monocolpopollenites* sp., *Alnipollenites* sp. and very rarely *Eucalyptus* sp.

Green algae of the genus *Botryococcus* sp. and following dinoflagellate cysts were determined: *Spiniferites mirabilis* (Figure 16), *Spiniferites* sp. (Figure 17), *Impagidinium* sp., *Impagidinium* cf. *patulum*, *Batiacasphaera sphaerica* (Figure 18), *Achomosphaera* sp.

Ratio between sporomorphs and phytoplankton as well as amount of terrestrial material varies from sample to sample, depending on palaeo-depth and distance from palaeo-land. Generally, it was high-energy environment (mechanically damaged fossils), marine, near-shore, relatively shallow, but deeper than environment of sediments deposited in the top of ignimbrite (dinoflagellates are observed). According to palynobiocenosis this sediment is of Badenian age, and belongs to the Budafa Formation.

Fig. 13. ***Myricipites*** **sp.; transmited light**

Fig. 14. ***Engelhardtioidites*** **sp.; transmited light**

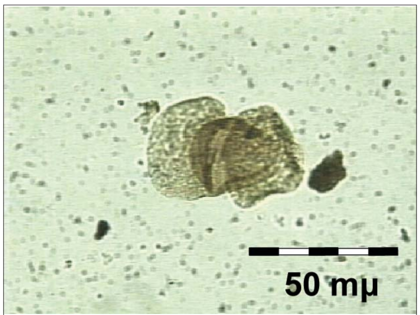


Fig. 15. ***Cathayapollenites*** **sp.; transmited light**

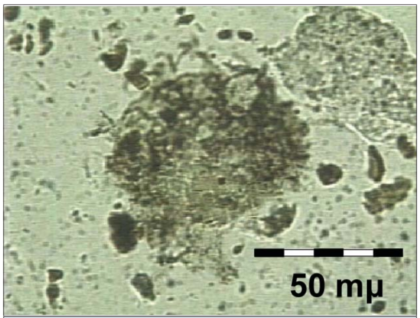


Fig. 16. ***Spiniferites mirabilis*; transmited light**

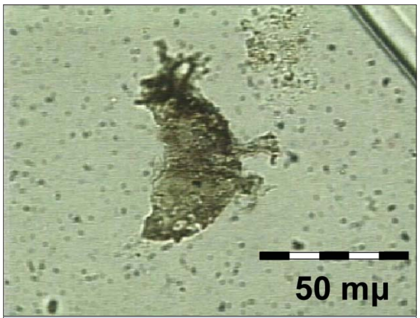


Fig. 17. ***Spiniferites* sp.; transmited light**

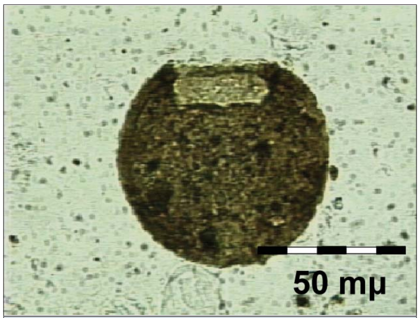


Fig. 18. ***Batiacasphaera sphaerica*; transmited light**

4. CONCLUSIONS

Described type of pyroclastic sediment flow deposit has not yet been observed on the outcrops or wells in this zone of the Drava Depression. More than 10 kilometres to the south-west, towards Virovitica (Figure 1) and to the south-east, evidences of Miocene volcanism in Croatia exist in the form of thick series of basic to intermediate effusive rocks commonly represented by basalts and andesites intercalated with marls or in form of thin pyroclastic fall deposits which are tuff layers within thick clastic sediments, drilled by several exploration wells, but pyroclastic flow deposits formed after explosive volcanic eruptions were not determined.

Moreover, pyroclastic flow deposits of the Tar Formation are described in numerous locations in Hungary. In analysed part of the Drava Depression (Figure 1) 88 m from pyroclastic interval had been drilled by the AA-1 well. That is lithologically defined as devitrified vitroclastic welded tuff, i.e. ignimbrite. Lithostratigraphically it belongs to the Tar Formation, and chronostratigraphically to Badenian.

Analysed ignimbrite did not show internal bedding. It is rich in glass shards, pumice, crystals and lithic fragments. The thickness of the mapped welded tuff is up to 190 m. The dominant component is ash-sized (<2mm), vitric, lithic and crystal fragments being set in very fine-grained matrix. Vitric particles, glass shards and pumice are abundant. Texture is granophyric and spherulitic. Lithic fragments as lithic pyroclasts and crystal fragments (commonly broken feldspar and quartz) are also present, as well as chalcedonic aggregates and pyrite crystals. Other characteristic features of this deposit are light colour and rhyolitic chemical composition. Basic structural features in the core are fractures, vugs and stylolites.

Micropaleontologically based ages of the top of the ignimbrite were concluded from foraminifera and algae findings and palynologically based ages from dinoflagellate cysts and findings of pollen. The top of analysed ignimbrite contained the Badenian marine microfossils. Samples from bottom are micropaleontologically sterile but palynobiocenosis determined from palynological analyses, also indicated on Badenian marine environment. Consequently, it is assumed that the ignimbrite had been created from pyroclastic flow in Badenian and into shallow, marine environment.

5. ACKNOWLEDGEMENTS

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