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Lithofacies and Thickness Maps of Pannonian and Pontian–Pliocene

Alexander NAGY (ed.)[1]
Zsolt PEREGI[2]
Paul HERRMANN[3]

Introduction
Pannonian
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[1]Geological Survey of Slovak Republik
Mlynská Dolina 1, 817 04 Bratislava

[2]Geological Institute of Hungary
H–1143 Budapest, Stefánia út 14.

[3]Geological Survey of Austria
Rasumofskygasse 23, A–1031 Vienna

Introduction

The stratigraphic division and nomenclature having been different in several aspects in Hungary, Slovakia and Austria at the time of the compilation of the maps.We have adopted a tentative solution to overcome the difficulties that has been collectively accepted by all parties. In observance of this agreement we are using the term Pannonian stage instead of Lower Pannonian (*s.l.*) and Pontian–Pliocene stages instead of Upper Pannonian (*s.l.*) as it is conventional in Hungary.

Beds shown as Pontian in the DANREG area lately are considered in Austria to be older than the type Pontian, and so in Austria they are called Upper Pannonian again (RÖGL *et al.* 1994), in a similar way as in Hungary, nonetheless for this paper the above mentioned technical solution remained in effect.

The Hungarian palaeogeographic — facial subdivision used in the facies maps has not been fully identical with the ones adopted by Austria and Slovakia, because in those countries borehole logging-, sequence- and seismostratigraphic methods have not yet been as widely introduced as in Hungary in the classification of Neogene strata in relation with the oil exploration of large sedimentary basins (POGÁCSÁS & RÉVÉSZ 1987, MATTICK *et al.* 1988). At the same time mutual understanding has been achieved to present as much of these research results as possible on the present level of knowledge. This, in turn, may result in certain inhomogeneity in the developmental concepts of the different areas as shown in our maps and reflected also by the explanatory text.

A considerable number of geological, geophysical, hydrogeological maps and studies exist in all three partner countries to characterize at least partially the geological features of the study area. They have been made as part of geological research and prospection programmes, mainly to assess oil and natural gas potential, lignite and geothermal energy prospects. Within the central part of Ásványráró–Gabèíkovo depression, in which most boreholes ended in the higher zones of the Pannonian sequence, the thicknesses of Pannonian sediments have been calculated on the basis of geophysical data, especially of seismic sections. In the other regions the isopach lines showing the thickness of the sediments on both map versions have been drawn by using computer extrapolation together with the data obtained from wells and seismic sections. In Hungary the work of CSÍKY *et al.* (1987) should be mentioned.

Since in the map it would be rather difficult to show in technical terms all the lithological features of a sedimentary column as much as 2500 m thick, we had to select the major rock types predominating in the respective facies zones. Where the alternation of different types occur, or they are overlain by another lithotype, we used a system of horizontal and vertical combination of colours, respectively.

The scale 1: 200 000 was chosen to make the lithofacies and thicknesses maps still easily legible.

Pannonian

During the Neogene geological development phase of the Carpathian Basin the earlier started subsidence of the Pannonian depression continued and at the beginning of the Pannonian stage locally even grew faster, although the intensity of the movements often showed considerable differences even among relatively close structural blocks.

The Danube Basin (Slovak territory) is a northern part of Pannonian back-land Carpathian arc stretching over Hungarian territory (VASS 1981). The Pannonian back-land arc was developed in the Pannonian starting at the end of the Miocene. Since then the shape of the basin changed to take a dish-like character with the centre of its subsidence in the Ásványráró–Gabèíkovo depression where the depth of the pre-Pannonian basement reached of some 5500 metres. It is filled by Pannonian to Pliocene sediments. The Quaternary sediments which developed in its central part reach the thickness up to 500 m.

The bulk of information comes from works of FRANKO *et al.* (1984), GAΩA *et al.* (1985), KEITH *et al.* (1989), HRUπECK″ *et al.* (1990) and NAGY *et al.* (in TKÁÈOVÁ *et al.* 1996).

Initially, at the beginning of the Pannonian age, the Danube Basin was a brackish inland sea, which grew gradually fresher due to the increasing activity of fluvial deltas advancing mainly from the the NW and from surrounding core mountains, only to become an almost freshwater sedimentary basin by the end of Pannonian stage. This also complies with the lithological features of the sediments.

Excepting the area east of the Hron fault system (North–South direction) the Pannonian sediments in the area under study stretch over the entire Danube Basin. They overlie Sarmatian sediments, however, in the broader surroundings of Komárno they overstep the Mesozoic basement and in the area of Trnava (well Tr–1) they were even deposited directly on the Lower Palaeozoic (BUDAY & ˇPIÈKA 1967). Their maximum thickness, as intersected in the well Kol–2 near Kolárovo, is 1355 metres and the minimum thickness, observed in the well Sb–1 near Patince, is 93.8 metres. On the basis of computerized extrapolation and seismic sections the overall thicknesses of Pannonian sediments in the centre of Ásványráró–Gabèíkovo Depression should be of the order of 2500 metres. As observed in the wells north of the line connecting roughly Dobrohoπ∫–D. Streda–Rastislavice and in its south-eastern part north of the line roughly ˇurany —N. Zámky— Kamenica the thicknesses of the Pannonian sequence reach 1000 metres at the margins of the Danube Basin.

The lithological character of the Pannonian succession both vertically and horizontally varies considerably. It is not possible to characterize unequivocally the type of sedimentation in discrete parts of the basin. But data from wells allow to make an overall assessment of the lithofacies distribution. Thus, we could single out predominantly deep water areas from the areas with predominatly marginal, or shallow water facies. Deep water facies occur in the central part of the region. In the northern part they continue as far as the Zlaté Moravce bay, or the Komjatice depression. The Pannonian sediments in the central parts of the basin cover the Sarmatian sediments developed in basin facies. The basinal facies, although not intersected by wells in Slovak territory, in the northern Hungarian territory is known from a number of boreholes (Gönyû–1, Pér–1, Gysz–3, Tét–1, *etc.*). It is composed, mainly in its lower parts, of grey limy clay or clay-marl with rare sandy intercalations and reaches a total thickness of some 900 m.

The silt and fine-grained sandstone with scarce microconglomerate intercalations, composed mainly of quartz, begin to predominate over clay towards the hanging wall (divided only in the Hungarian part). Subordinate thin intercalations of coaly clays and lignite also begin to appear. In the surroundings of the NV–1 well (Nová Vieska) clayey sediments occur with redeposited tuffitic admixture.

The carbonate content in the above mentioned Pannonian sediments ranges between 1.06% and 41.7%. Of the clay minerals illite and the montmorillonite were observed in them. The content of heavy minerals among which predominate garnet, chlorite, biotite and pyrite (PRIECHODSKÁ & VASS 1986) ranges between 0.3% and 22.2%. The clastic sediments mentioned probably developed due to the advancement of distal and late proximal turbidites heralding the delta facies.

As the shallowing progressed, in the upper part of the Pannonian a monotonous sequence of grey, non carbonate to slightly carbonate, micaceous, poorly sorted sand prevailed, alternating with grey clay with sandy admixture, or with silt and rare sandstone beds. Fine gravel intercalations occur in the uppermost parts. These, already less pelitic sediments, overlie the two lower facies of Pannonian sediments and occur throughout the central and eastern part of Slovak territory. They may be interpreted as the product of prodeltaic and deltaic sedimentation of palaeorivers running down mainly from NW but also from other surrounding emerged core mountains into a freshening and progressively more and more isolated basin.

The marginal facies with typical coarse clastic sediments are widespread in the north-western part of the Danube Basin. In the first place this is in relation with their transgressive character, and in the second place due to the immediate proximity of core mountains, which served as source areas for the sedimentary material. Since the depocentre was in the area of Ásványráró–Gabèíkovo depression, in these outlying areas only the marginal, shallow water facies developed. The sediments are made up predominantly of coarse conglomerate (up to 30 cm diameter), gravel and coarse-grained sandstone. Petrographically, they are magmatic and carbonate rocks of Malé Karpaty Mts, PovaΩsk˝ Inovec Mts and Biele Karpaty Mts. In the north the sedimentary filling of both partial depressions is characterized by the alternation of coarse detritic facies with sandy-clayey one.

In the Pannonian sediments abundant macrofauna appears in Pannonian sediments, especially in their higher horizons. Microfauna, such as ostracods occurs throughout the sequence, like those known from the other parts of the Pannonian Basin.

The described sediments represent the Ivánka Formation (PRIECHODSKÁ *et al.* 1988).

In the southern part of the Vienna Basin in the area between Zohor and Morava rivers the Pannonian sediments develop gradually from the underlying Sarmatian sequence. They are composed of green–grey, limy clay of basin facies with variable amounts of sandy admixture and occassional beds of limy sand. In the upper part there are limy, pale-grey claystone and clay. They are facially identic with the sediments of the central part of the Danube Basin. The thickness of the Pannonian beds here does not exceed 500 m. Only a few Cardium horizons and occasional occurrences of ostracods allow a precise dating of the strata.

The reported sediments were referred to as the Záhorské Formation (BARTEK 1987, unpublished proposal).

The sedimentary basin south of the River Danube (Hungarian territory) has been divided by a ridge between Mihályi and Rajka into two deeper sub-basins characterised both by the deposition of thick sedimentary sequences. The western one has elongated shape in North–South direction, with its central depression extending along the zone of Csapod, Agyagosszergény and the Austrian village of Wallern, where the Pannonian sediments are about 800–1300 m thick. The deepest, central part of the much larger eastern basin of almost isometric form is probably in the region of Ásványráró extending in direction to Gabèíkovo where the Pannonian sedimentary sequence can reach almost 2300 metres thickness or more. Interestingly enough above the blocks of Mihályi and Pásztori, relatively at close quarters to the central zone, merely 100–200 m of Pannonian sediments have been deposited.

Concerning the stratigraphy and regional geology of the Pannonian (*s.l.*) sedimentary sequence the works of JÁMBOR (1980b, 1985, 1988) should be especially mentioned. According to these within the study area the south-eastern and south-western rims of the Pannonian Basin as well as the marginal zone of the Zsámbék embayment are characterised by the sedimentation of basal layers of abrasional gravel and sand (Kisbér and Zámor formations) which rarely surpass 10 metres thickness. In some areas the clastic sediments may even be entirely missing. According to data from Slovakia a similar marginal facies extends to the northern Hungarian part of the Rajka–Mihályi ridge. Abrasional gravel, sand and conglomerate layers (Mihályi Formation) are also present in the interior of the sedimentary basin in the Mihályi uplift and in the Mosonszentjános region (borehole Mos–1) situated in the southern part of the Rajka ridge. There, in early Pannonian time the most elevated tectonic blocks of the crystalline basement seem to have formed islands and cliffs with at least some parts of them getting above the sea level.

In different territories the ages of the basal layers may be considerably different from one another as their deposition started earlier in the deeper basin areas and with the advancing transgression it edged gradually ahead into the marginal zones towards the landmasses. In addition to the characteristic sand–quartzite gravel deposits at the eastern basin margin where the dominant facies is the well rounded, so called "pea gravel" of polished pebble surfaces, in the Mihályi elevation a coarse conglomerate has been revealed in the boreholes drilled for hydrocarbon exploration (Békés Conglomerate Formation). The latter is made up almost entirely of metamorphic pebbles originating from the crystalline basement, embedded in sandstone matrix. As for age the Békés Conglomerate is regarded to be the oldest (JÁMBOR 1989), while the Pannonian Kisbér Gravel (its deposition migrating in space and time) may have a transition into the Kálla Gravel Formation at the north-eastern basin margin, which is thought to be Upper Pannonian *s.l.* (KORPÁS-HÓDI 1993) *i.e.* Pontian–Pliocene.

South of the River Danube, in the deepest parts of the basin the Pannonian strata overly conformably (with continuous sedimentation) the Sarmatian formations, while in the marginal areas they are found in unconformable position above the underlying formations of the same age or older (Tertiary, Mesozoic, Palaeozoic).

At the beginning of the Pannonian in the interior of the basin monotonous layers of grey clay-marl and marl (Endrõd Marl Formation, Nagylengyel, Belezna Members) were deposited in open, hemipelagic environment, with a laminated clay/marl, marl and silt sequence. This is considered to be the transitory formation of the continuous Sarmatian-Pannonian boundary (JÁMBOR 1989). The Belezna Calcareous Marl is a fine sandy, pyrite bearing rock sequence while the Nagylengyel Member is characterised by micaceous claymarls containing pyrite nodules and clasts of organic origin, 20–200 metres thick.

In the upper part of the open marine, pelitic sedimentary sequence sandstone intercalations are appearing with ever increasing frequency and thickness. This can be interpreted as the arrival of the distal and proximal turbidites of the prograding deltas (JUHÁSZ 1992a, 1994) coming from the neighbouring landmasses (Szolnok Sandstone Formation). The terrigeneous material reached the Pannonian sedimentary basin of the Little Hungarian Plain from the north-west. This Gilbert-type delta (JUHÁSZ 1992b) had steep slopes and well developed mouth bars. Its fine-grained sediments may have been transported relatively fastly towards the interior of the basin.

The Tófej Member, about 800 m thick as a maximum, is characterised by the frequent alternation of thin sandstone, silt and claymarl strata rich in carbonised plant remnants (KÕRÖSSY 1987). In some places inside the pelitic sequence sandstone interbeddings may reach over 10 metres thickness but this is not a frequent case. Generally the sedimentary structure, like contorted bedding, mudstreams, convolute bedding, etc. that are characteristic of turbidites, can easily be recognised.

The upper part of the Pannonian sequence is generally well developed all over the study area south of the River Danube. It is built up mainly of silt and claymarl layers with some rare sandstone interbeddings the deposition of which is considered to be related to the gradually advancing pro-delta and delta slope facies (Algyõ, Csákvár, Szák, Csór Formations). Similar deposits may have also been formed in the remaining shallow sedimentary basins between the distributary channels of the gradually extending delta.

The Algyõ Formation, almost omnipresent in the basin of the Little Hungarian Plain, is built up mainly of claymarl and in places of micaceous silty claymarl. This sequence may contain also occasional crosbedded clayey sandstone intercalations. In the deeper parts of the basin its thickness may exceed 800 m. The basin margin formations of similar age and petrographic character have been named locally as the Csákvár, Szák and Csór Formations.

The Mihályi, Rajka and Pásztori basement elevations have only been inundated completely in the last phase of the Pannonian development stage, whereas in the deeper regions of the same ridges the sedimentation started already with the turbiditic sequence.

In this area relatively few data of magmatic activity have been recorded. At Pásztori and Bõsárkány, in the lowermost, marl containing parts of the Pannonian sedimentary sequence carboandesite and carbotrachyte agglomerates as well as tuff interbeddings are known (Pásztori Trachyte Formation), while at Tét, also in the lower part of the Pannonian sequence, the volcanic activity is marked by andesitic tuff layers. The volcanism started still in the Miocene and was going on in the Pannonian.

In the area of Zsámbék, Budajenõ and Bicske an earlier formed intramontane sedimentary sub-basin was still in existence during the Pannonian age, but it was significantly smaller than the other ones discussed earlier. It was separated from the basin of the Little Hungarian Plain by the central Transdanubian ridge. There, above the basal gravel (Zámor Gravel Formation) clay-marl of epicontinental sea, lagoon facies has been deposited (Csákvár Clay Marl, Csór Silt Formations) which only in a few places exceeded 200 m of thickness. The Strázsahegy Limestone Member (Csákvár Formation) may have been formed by local precipitation of carbonatic materials in springs and freshwater puddles. In the Zsámbék Marl a few millimetres thick rhyodacite tuff laminae have been mentioned in the Bicske, Herceghalom, Mány and other regions (JÁMBOR 1980a).

In the western part of the DANREG area (Austrian territory), three structural units can be distinguished:

— The Seewinkel area and the area south of Sopron are parts of the Little Hungarian Plain. There the Pannonian sequence transgressed partially over thin sediments of older Miocene formations, but also in wide zones on the surface of pre-Tertiary rocks. The thickness of the Pannonian is as a rule less than that of the Pontian–Pliocene.

— The area northwest of the Hainburger Berge and the Leithagebirge belongs to the Vienna Basin having thick layers of Badenian and Sarmatian sediments. There, in the deeper parts of the basin, the Sarmatian sequence develops into the Pannonian without a hiatus, and the Pannonian transgression never exceeds that of the Badenian.

— lastly, there is the small Eisenstadt Basin, located between the Leithagebirge, the Ruster Bergland, Brennberg village and the Rosaliengebirge (this western boundary of the Eisenstadt Basin is outside the DANREG area). It is filled mainly with sediments of the Badenian and Sarmatian. In the inner parts of the basin these are overlain a by thin Pannonian sequence (FUCHS 1980).

Pontian–Pliocene

To serve the purpose of this paper and to comply with the works of Slovak, Austrian and Hungarian geologists we describe the Pontian–Pliocene (Dacian and Romanian) stages together.

At the beginning of Pontian Stage in the northern part of the studied area (Slovak territory) the Danube Basin changed into a marginal bay with sedimentation, especially during the Pliocene, taking place already in freshwater.

The Pontian–Pliocene sediments have the same territorial extension as the Pannonian ones. Overlain by Quaternary sediments, they are exposed only in the area of Bernolákovo and Senec and in the eastern part of the region. The dish-like structure of Danube Basin is especially well observable when we look at the distribution of Pontian–Pliocene sediments, which thicken from margins towards the centre of the Ásványráró–Gabèíkovo depression to attain a thickness of some 2300 metres. The Pontian–Pliocene lithological sequence is much more variable than the Pannonian one. Apparently, the deep water facies cannot be found anymore.

A monotonous sequence of irregular beds of grey silt and sandy clay alternating with fine to medium grained sand to desintegrating sandstone developed in the central parts of the region. Generally sandy pelite predominates over sand. The carbonate content ranges from 0.77% to 41.7% and the content of heavy minerals, among which predominate chlorite, biotite, garnet, tourmaline, pyrite and magnetite (PRIECHODSKÁ & VASS 1986) from 0.01% to 8.5%. It is probably a pelitic-sandy facies, which has been deposited in delta front.

Throughout the region under study the facies mentioned above is overlain by variegated sediments, which change very rapidly both vertically and horizontally. It consists of irregularly alternating grey, grey–green, yellow, brown–yellow mottled clay with variable sandy admixture and sandy intercalations. Towards the margins of the sedimentation area beds of coarse grained gravels prevail, composed exclusively of the material from the core mountains. Coaly clay and lignite occur throughout the sequence, but mainly in the eastern foothills of the Malé Karpaty Mts and in the eastern part of the region, between Pozba and Gbelce. They belong mostly to Beladice Formation of Pontian age.

The reported sediments represent a shallow water sedimentation with features of fluvial, delta plain, lacustrine and paludal facies. Together they represent the Beladice, Volkovce and Kolárovo formations.

The Pontian–Pliocene sediments contain no key fossils. The general determination of Pontian, Dacian and Rumanian ages was achieved on the basis of heavy mineral analyses only (reports of PRIECHODSKÁ, referred to in the paper of PRIECHODSKÁ *et al.*1988).

The distribution of Pontian–Pliocene beds in the southern part of the Vienna Basin resembles that of the Pannonian — the thickness of sediments slowly rises towards the basin centre to reach a total thickness of 600 metres. The lithological filling, as well as the content of rare, biostratigraphically irrelevant organic remnants, remind of the Danube Basin sediments. The Pontian–Pliocene is represented by the Èáry, Gbely and Brodské formations.

During the late Neogene geological history of the area, coinciding with the subsidence of the western part of the depression terrigeneous material continued to arrive into the sedimentary basin. It somewhat levelled out the rough Pannonian basement morphology south of the River Danube (Hungarian territory). Nonetheless in the central area (Ásványráró, Gabèíkovo) the characteristics of the basin changed little. In shallow water and deltaic environment a thick sedimentary sequence accumulated which exceeded 2 500 metres.

In the marginal zones of the basin, in the forelands of Sopron, Kocs and Tata sand, silt, clay and claymarl strata were deposited (Somló Formation). In the inner parts sandstone bodies with different thickness developed, some reaching almost 10 metres, divided from one another by silt, clay and clay/marl layers (Újfalu Formation). Originally the Pontian–Pliocene sedimentary cover significantly exceeded the development area of the Pannonian sediments. In the regions of Almásneszmély, Süttõ, Sopronkövesd and Budapest it directly covers the pre-Pannonian basment. This lower part of the sedimentary sequence was deposited mainly in delta-front facies. It is supposed , however, that the sedimentation continued also in shallow, remaining basin parts which survived among delta bars under near equilibrium conditions where the sinking was exceeded only slightly by the sedimentation of terrigene material and by the filling up process. The sediments of the delta and of the shallow water basins are intertwined in such an intricate manner that they can not be separated either in facial sense or in space.

The Somló Formation is built up by alternating layers of grey clay/marl, silt and fine-grained sand, while the Újfalu Formation is characterised by a sequence of sandstone of varying hardness, silt and claymarl. The latter contains also plenty of carbonised plant remnants. The maximum thickness of the sequence can reach 600 metres.

In the late development phase of the Pontian–Pliocene sedimentary basin, as the filling up process advanced, the deposition of fluvial, flood plain and shallow basin sediments became characteristic (Tihany, Zagyva, Hanság Formations). The prevailing silt, sand, clay and clay-marl layers often contain thin lignite interbeds. In the upper part of the sequence mottled clay intercalations also appear. The ever more extensive occurrence of the latter indicates the increasing prominence of terrestrial areas.

The Tihany Formation, which is considered to be of delta plain origin, is built up mainly of silt and fine-grained sand layers containing numerous huminitic clay and thin lignite interbeds, while the Hanság and Zagyva Formations indcate an even more continental environment with alternating layers of flood channel and flood-plain deposits represented by sand, silt and clay, with thin lignite layers, occasional pebble and mottled clay intercalations.

In the Pontian–Pliocene development stage pyroclastic materials are known in the shallow water sediments at Mihályi and Dõr, represented by basalt tuff interbeds (Tapolca Formation). Similar tuff appears as a characteristic accessory material in the Hanság Formation, too.

In the Buda region, South of János Hill small exposures of sedimentary rocks can be found which are difficult to classify as they are only remnants of erosion with severely reduced thickness, composed of gravel, ochre and freshwater lime. They have presumably been deposited in a shallow-water inner basin of small territorial extension (Kálla Gravel ?, Nagyvázsony Limestone ?).

In the Pest Plain sediments of delta-front, delta-plain, riverbed and flood-plain facies were formed in the Pontian–Pliocene period. They were similar in many respects to the sediments of the Little Hungarian Plain and they have been tentatively classified as the Somló, Tihany, Zagyva and Nagyalföld Formations (DARIDA-TICHY — oral information). Owing to their marginal position they are less than 100 metres thick.

In the western part of DANREG area (Austrian territory) in the Seewinkel area the thickness of the Pontian–Pliocene sequence generally exceeds that of the Pannonian.

In the area northwest of the Hainburger Berge and the Leithagebirge the thickness of the Pontian–Pliocene is only sometimes greater than that of the Pannonian. In many cases it is even less.

In the small Eisenstadt Basin sediments of Pontian–Pliocene are not kown (FUCHS 1980).

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