# ESTIMATION OF MEAN ANNUAL TEMPERATURES IN OCNA DEJ FORMATION (MIDDLE BADENIAN) AT PRAID BASED ON COEXISTENCE APPROACH METHOD

**OTTILIA RUSZ, VLAD CODREA, OVIDIU BARBU**

**Abstract.** *A line for paleoclimate reconstructions based on quantitative pollen data is the coexistence approach (CA), firstly used by MOSBRUGGER & UTESCHER (1997). For a fossil assemblage and a certain climatic parameter, one looks for the suitable interval inside which all the actual correspondents of the fossil taxa could coexist. We used CA for interpreting the Middle Badenian flora documented by pollen in the salt from Praid (Basin of Transylvania). The results indicate 16.6-17°C mean annual temperature, according with the data already issued from other Central Paratethys Badenian deposits. It also reflects the climate turnover occurred soon after the Mid-Miocene Climatic Optimum event, when the climate worsened.*

**Keywords:** *Rumania, Basin of Transylvania, Middle Miocene, Badenian, flora, salt, Praid.*

**Rezumat. Estimări ale temperaturilor medii anuale în Formaţiunea de Ocna Dej (Badenian mediu) de la Praid pe baza metodei coexistence approach.** *O metodă pentru reconstiturile paleocliclimatice cantitative o reprezintă metoda Coexistence Approach (CA), aplicată pentru prima oară de MOSBRUGGER & UTESCHER (1997). Pentru o floră fosilă dată şi pentru un anumit parametru climatic se caută acel interval pentru care toţi corespondenţii actuali ai florei fosile pot să coexiste. Am folosit această metodă pentru microflora Badenianului cu sare de la Praid (Formaţiunea de Ocna Dej) şi am stabilit un interval pentru temperatura medie anuală cuprins între 16,6-17°C. Valorile sunt asemănătoare celor estimate Badenianul altor regiunil corespondente din Paratethys. Datele reflectă o tranziţie de la temperaturile mai ridicate din Optimumul Climatic Miocen Mediu, spre temperaturi mai scăzute ce au urmat acestui eveniment, indicând degradări climatice.*

**Cuvinte cheie:** *România, Bazinul Transilvaniei, Miocen mediu, Badenian, floră, sare, Praid.*

## INTRODUCTION

The Miocene means a geologic time span including several geologic and climatic events. Among others, it was also the last really warm episode-Mid-Miocene Climatic Optimum-(BÖHME, 2003; MOSBRUGGER et al., 2005; KOVAÇ et al., 2007; ZACHOS et al., 2007) before the Late Miocene, Pliocene and especially Pleistocene cooling.

The pollen studies carried out on Miocene sediments in Central Paratethys, in spite of an apparent abundance, are far to be enough and some of them (e.g. PLANDEROVÁ, 1990; NAGY 1991, 1992, 1999) are now considered as inconclusive, devoid of convenient method (e.g. JIMENEZ-MORENO et al., 2005).

The pollen taxonomy is helpful to better know the ancient plant assemblages, environments, or climate. Rich such data concern the Miocene and Pliocene. Starting with the Eocene, the majority of actual plants is already known in the geological records, thus facilitating a better understanding, trough direct comparisons.

Once, for paleoclimate evaluations based on microfloristic data, the ratio between thermophile: intermediary: temperate representatives had been used. In more recent contributions on climate reconstructions based on pollen data, the most used methods are *Coexistence Approach* (**CA**; MOSBRUGGER & UTESCHER, 1997) and *Climatic Amplitude Method* (**CAM**; FAQUETTE et al., 1998).

**CA** is reliable for quantitative Cenozoic non-marine climatic reconstructions. It is based on the presumption that the ancient Cenozoic plants had the same climatic requirements as their actual correspondents. The method's aim is the following: for a Cenozoic fossil flora and for a climate parameter, it had to be found the climate realm where all actual plant taxa could coexist.

For the marine Cenozoic, there are several quantitative estimative methods, the most common being the one based on stable isotopes. But, for the terrestrial environments, the carbon and oxygen isotopes are less useful for the climate reconstructions, due to difficulties rose in interpreting such data.

The method is based on some suppositions: for the fossil taxa one can identify the actual correspondents, with systematic close affinities; the exigencies of a fossil taxon are very similar with the one of the actual correspondent; the climate exigencies and tolerance of an actual plant, as well as the ones of its fossil correspondent, could be deduced from their spreading areas. At the same time, one can presume that the meteorological stations are yielding reliable data for describing the climatic tolerances of an actual taxon.

MOSBRUGGER & UTESCHER (1997) underlined that the basics of this methods are not news, but in its philosophic "classical" approach of the actual correspondent (i.e. **NLR**= nearest living relative) one used once only few of the fossil taxa, leading to incertitude and gaps in knowledge. For example, a taxon occurrence or extinction is not due to climate changes in all situations, but also to taphonomic, edaphic, paleogeographic etc. reasons. Resuming the interpretations only on some taxa, one cannot reach to a maximum appropriate climate resolution, the results being influenced by the taxa selection.

Another cumulative method is based on plant morphology, i.e. *Climate Leaf Analysis Multivariate Program* (**CLAMP**). However, MOSBRUGGER & UTESCHER (1997) are considering that **CA** is more correct than **CLAMP.** On the Middle Miocene macro-and microflora in Schrotzburg (South Germany), the **CA** estimations were similar with the ones issued from Leaf Margin Analysis (**LMA**) or with another method, **ELPA**. On the opposite, **CLAMP** lead to different results (UHL et al., 2006).

**CAM** was firstly applied in interpreting the Pliocene from the Mediterranean area. Eight hundred actual pollen spectra had been used. For each spectrum, the frequency of pollen grains of a taxon was reported to the total quantum of pollen, excepting for the water plants and spores. Six climatic parameters were considered. The actual climate amplitude allowed by each plant taxon was established by representing the actual pollen frequencies in the actual pollen spectra in relationship with each climatic parameter (FAQUETTE et al., 1998).

Ultimately, another method based on nearest living relatives too is Overlapping Distribution Analysis (**ODA**). It was applied-besides other methods-in Shanwang Basin (China) and it is based on the explicit local distribution of plants taxa, but also on the associated meteorological stations (YANG et al., 2007).

## INTERPRETATIONS BASED ON POLLEN DATA CONCERNING THE MIDDLE BADENIAN FROM THE TRANSYLVANIAN BASIN

The Miocene pollen data in Europe outlined various floras, which evolved in different climates. The compositions of the flora assemblages were controlled mainly by altitude and latitude. In the Basin of Transylvania, the evaluation of the salt and gypsum Badenian deposits (i.e. Ocna Dej and Cheia formations) is of interest because it coincides with the end of the Mid-Miocene Climate Optimum (**MCO**) event.

In this basin, several pollen analysis were carried out for the Badenian salt deposits, as in: Sărățel (PETRESCU et al., 2001), Ocna Dej (PETRESCU & MESEŞAN, 1993), Turda (PETRESCU & BICAN-BRIŞAN, 1997), Praid (PETRESCU & BICAN-BRIŞAN, 2005). These studies pointed out the transition condition of the floras in middle Badenian (Wieliczian), between the Moravian ones and the subsequent Kosovian assemblages. Across this time span, one can outline a decreasing tendency of the thermophile representatives and the increase of the temperate taxa.

For the pollen assemblage found into the salt in Praid we used several data issued from the already done analysis (PETRESCU & BICAN-BRIŞAN, 2005), interpreting them by the **CA** method. In order to establish the actual correspondents (**NLR**) of the Middle Badenian taxa, as well as for the mean annual temperatures (MAT) optimal for these plants, we used the website www.palaeoflora.de

Table 1. Relationships between the middle Badenian taxa in Praid, their actual correspondents (**NLR**) and the mean annual temperatures (MAT in °C).
Tabel 1. Relațiile dintre taxonii din Badenianul mediu de la Praid, corespondenții actuali (**NRL**) şi temperaturile medii anuale (TMA în °C).

| Badenian taxa | NLR | MAT |
|---|---|---|
| *Polypodiaceoisporites torosus* | *Pteris* sp. | 2.0- 21.7 |
| *Abiespollenites* sp. | *Abies* sp. | -6.7- 27.4 |
| *Pityosporites microalatus Pityosporites alatus* | *Cathaya* sp. | 17.0- 22.2 |
| *Pityosporites labdacus pseudocristatus* | *Pinus silvestris* | -9.2- 10.8 |
| *Piceapollis* sp. | *Picea* | -8.9- 21.7 |
| *Cedripites miocaenicus* | *Cedrus* sp. | 11.6- 18.4 |
| *Podocarpidites libellus* | Podocarpaceae | 11.0- 27.7 |
| *Zonalapollenites igniculus*<br>*Zonalapollenites maximus* | *Tsuga* sp. | 1.8- 21.9 |
| *Sciadopityspollenites* sp. | *Sciadopitys verticillata* | 7.4- 16.6 |
| *Cupressacites insulipapillatus* | Cupressaceae<br>(*Cupressus, Chamaecyparis*)<br>Cupressaceae<br>(*Austrocedrus,Libocedrus*, *Papuacedrus*) | 1.8- 21.7<br><br>8.2- 26.5 |
| *Sequoiapollenites gracilis*<br>*Sequoiapollenites polymorfosus* | Taxodiaceaee | 9.1- 25.0 |
| *Sparganiaceaepollenites sparganioides* | *Typha* sp. | 8.2- 25.7 |
| *Moncolpopollenites* sp. | Palmae | 13.3- 27.7 |
| *Arecipites* sp. | *Arecoideae* sp. | 13.5- 27.7 |
| *Triatriopollenites bituitus* | *Myrica* | -6.9- 28.1 |
| *Momipites* sp. | *Engelhardtia* sp. | 15.6- 27.0 |
| *Caryapollenites simplex* | *Carya cordiformis* | 6.6- 21.3 |
| *Pterocaryapollenites stellatus* | *Pterocarya* sp. | 7.6- 24.2 |

| | | |
|---|---|---|
| Ulmaceae | Ulmaceae | 3.4- 27.7 |
| *Alnipollenites verus* | *Alnus* sp. | -13.3- 27.4 |
| *Intratriporopollenites instructus* | *Tilia* sp. | 2.5- 20.8 |
| *Tricolpopollenites liblarensis* | Fagaceae | -1.1-27.9 |
| *Nyssapollenites* sp. | *Nyssa* sp. | -1.1- 23.9 |
| *Cyrillaceaepollenites megaexactus* | Cyrillaceae | 13.6- 25.4 |
| *Ericipites baculatus*<br>*Ericipites callidus*<br>*Ericipites ericius* | *Erica arborea*<br>Ericaceae<br>*Erica tetralix* | 13.1- 18.6<br><br>4.6- 18.8 |
| *Chenopodipollis multiplex* | Chenopodiaceae | -7.6-27.7 |

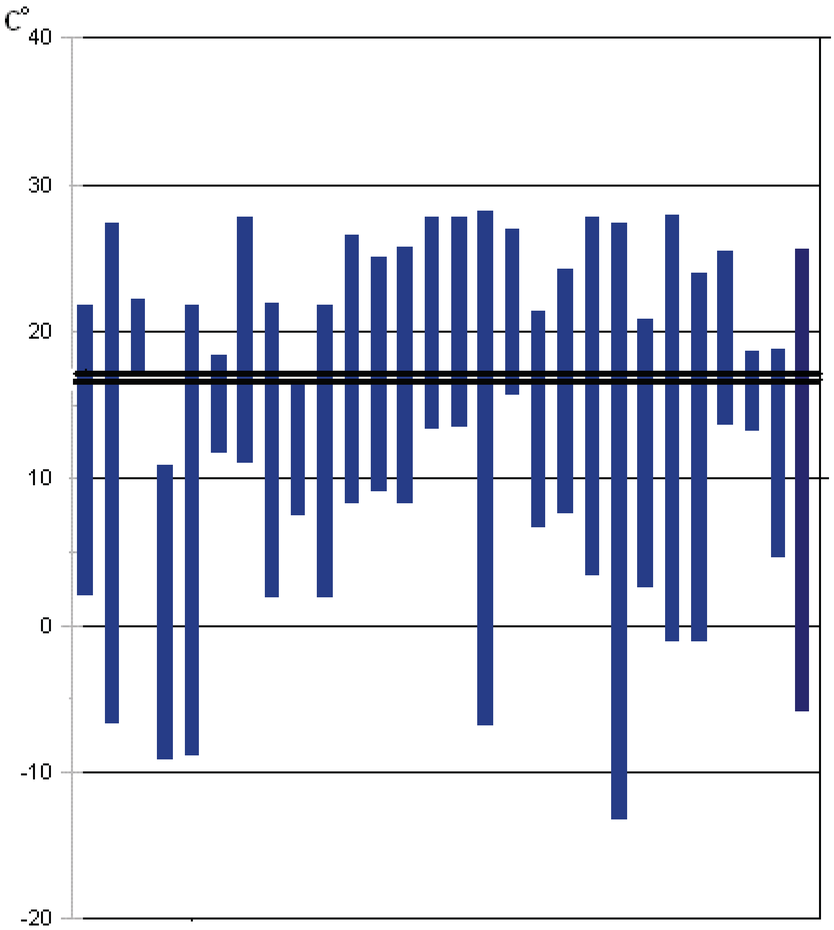


Figure 1. The coexistence interval for the MAT of the actual correspondents of the Badenian plant taxa in Praid. The MAT intervals for each taxon are represented in blue, and the coexistence interval is marked by the two horizontal black lines. The taxa, according Tabel 1, starting with *Polypodiaceoisporites torosus* at left.
Figura 1. Intervalul de coexistenţă pentru TMA a corespondenţilor actuali ai taxonilor de plante din Badenian de la Praid. Intervalele TMA pentru fiecare taxon sunt reprezentate cu albastru şi intervalul de coexistenţă este marcat de două linii negre orizontale. Taxonii, conform Tabelului 1, încep cu *Polypodiaceoisporites torosus* de la stânga.

In Fig. 1, there are the MAT for the actual taxa (in blue) and the coexistence interval (two black lines). The coexistence interval for the MAT in the Badenian in Praid is 16.6- 17.0 °C. One can observe an outlier corresponding to the MAT fitting with the actual *Pinus sylvestris*. The taxa which may coexist represent 96% (statistically significant are the calculated coexistence intervals, where 88-100% of taxa could be in coexistence). For comparison, actually, the MAT measured in two meteorological stations (where the climatic measurements cover more than thirty years) located next to Praid, in Odorheiu-Secuiesc and Târgu-Mureş, is of 8.0ºC and 8.6ºC (1961-2005; ***).

In Table 2, there is a comparison between the MAT in European Miocene localities, mainly in Badenian. One can observe a decreasing trend of the MAT from the Egerian until the Sarmatian.

Table 2. MAT (in °C) in some Miocene European localities, based on macro-and microflora and various methods.
Tabel 2. TMA (în °C) în câteva localități europene din Miocen, pe baza macro- şi micro-florei şi a altor metode.

| | | **Lăpugiu pollen (PETRESCU et al. 1990)** | **Bozovici pollen (PETRESCU & NICORICI, 1989)** | **Țebea pollen (PETRESCU & FAZECAȘ, 1989)** | **Hungary macroflora (ERDEI et al., 2007) CA** | **Hungary pollen (JIMENEZ-MORENO et al., 2007) CAM** | **Germany macroflora (BÖHME et al., 2007) CA** |
|---|---|---|---|---|---|---|---|
| Sarmațian | | | | | 14.0- 16.5 | 16.0 | |
| Badenian | upper<br>midd.<br>lower | | | 16-18. | 14.5- 16.5 | 18.0- 20.0 | |
| | | 17-18 | | | | | 15.7- 20.8 |
| Karpatian | | | | | 15.6- 16.6 | | 15.7- 20.5 °C |
| Ottnangian | | | | > 16 | | | 22.2- 24.2 |
| Eggenbur-gian | | | 16.-17 | | 16.5- 18.8 | | |
| Egerian | | | | | 13.3- 20.6 | | |

The MAT estimated for Praid resembles the ones reported for the Eastern and Central Paratethys (PETRESCU & NICORICI, 1989, PETRESCU & FAZECAȘ, 1989, PETRESCU et al., 1990, ERDEI et al., 2007, BÖHME et al., 2007, IVANOV et al., 2002, 2007). Larger values (18-20°C) are reported for the Badenian in Hungary, based on "Climatic Amplitude Method" (JIMENEZ-MORENO, 2006).

From the climate viewpoint, an important feature for the Middle Miocene is the **MCO** worldwide event. The deep drilling data (based on $\delta^{18}O$ and $\delta^{13}C$) estimated that this warm time lasted between 17-15 My BP and was followed by a gradual cooling and a recovering of the icecap in Antarctica (ZACHOS et al., 2001).

For the Central Europe, the **MCO** was between 18 and 14.0 My BP (i.e. Ottnangian-Early/Middle Badenian). The MAT was between 17.4 °C and 20-22°C. Between 14.0-13.5 My BP an abrupt climate worsening occurred, the MAT being 15.4°C - 14.8°C. In these circumstances, the marine and terrestrial records are decaled (BÖHME, 2003).

For the analysis of the climate evolution in the Central Europe Cenozoic, forty-five floras had been studied, originating from various localities, interpreted trough **CA** (MOSBRUGGER et al., 2005).

The cooling tendency, which followed the **MCO** is recorded also in the middle Badenian foraminifers from western Transylvania. In these assemblages, the *Candorbulina* representatives are missing, being replaced by planktonic species, which evolved in cooler waters. This cooling tendency reported just in the middle of the salt-bearing formation, corresponds to a regressive episode, to a decreasing of the marine fauna diversity and extinction of subtropical representatives (FILIPESCU, 2001).

In the Wieliczka salt (Poland), Zabłocki made a first description of the flora (SZAFER & KOSTYNIUK, 1952). The climate was estimated as "mild", with taxa as *Taxodium distichum miocenum, Platanus, Magnolia, Liquidambar, Pinus, Carya, Juglans, Libocedrus, Engelhardtia, Magnolia, Castanopsis* etc. A revision of this flora outlined the dominance of arcto-tertiary representatives, only a third of taxa being paleotropical. The flora assemblages from Wieliczka comprised mesophytic forests, leaf trees, and evergreen shrubs, typical for a mastixian flora, including *Juniperus succinifera*. (LAŃCUCKA-ŚRODONIOWA & ZASTAWNIAK, 1997).

The pollen data issued from the Carpathian-Sarmatian cores originating from the Tengelic 2 borehole Hungary (Jimenez-Moreno, 2006) pointed out the existence of multi-staged forests, which evolved in a wet warm subtropical climate, illustrative for the **MCO**. The cooler and drier climate from the Late Badenian and Sarmatian was interpreted as a cool episode, correlative with "Monterey Cool Event".

## CONCLUSIONS

The Neogene evolution in the Basin of Transylvania interfered with the one of the surrounding mountains. The 15 – 5 My BP time span (including the Middle Miocene salt genesis) is also the one of the erecting Carpathian orogene. For the Eastern Carpathians, 2,500 m maximum height is estimated (SANDERS et al., 2002). Thus, geography may explain the presence of altitude representatives into the Badenian salt pollen spectra (large number of *Picea* pollen grains). The dominance in clay minerals of the illite-chlorite suggests also a source-area controlled by altitude (BICAN-BRIȘAN & HOSU, 2006).

A cool episode in the Central Paratethys can be obviously observed in the marine Late Badenian microfauna, even if the planktonic foraminifers are indicating even an earlier beginning of this event, to the end of Early Badenian. The biogeographical differentiation between the northern, northeastern, and southern basins became sharper in Late Badenian (KOVAÇ et al., 2007).

As concerning the climate during the Middle Miocene (13.6-13.4 My BP according BALINTONI & PETRESCU, 2002) salt genesis, it seems that it occurred in the cooler episode (14.0-13.5 My BP), which followed the **MCO**. On the other hand, this cooler episode may correspond to a change between anti-estuarine water movements with an estuarine one. But, the salt deposition should occur during the anti-estuarine movements, when the Mediterranean shallow waters invaded the Central Paratethys, while the bottom waters flowed to the Mediterranean Sea. This type of water circulation (implying also a heat mobilization) was dominating the middle Badenian, facilitating the deposition of evaporites (BÁLDI, 2006).

This is the first tentative in interpreting the Middle Badenian climate using the **CA** method in Rumania. Obviously, these data could be refined by future additional pollen analysis.

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*** www.palaeoflora.de

**Ottilia Rusz, Vlad Codrea, Ovidiu Barbu**
"Babeş-Bolyai" University, Faculty of Environmental Science
30, Fântânele Str., 400294, Cluj-Napoca
E-mail: ruszotti@freemail.hu
E-mail: vcodrea@bioge.ubbcluj.ro; codrea_vlad@yahoo.fr
E-mail: obarbu99@yahoo.com

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