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The shell morpho-thermometer method and its application in palaeoclimatic reconstruction

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(with 3 figures and 4 tables)

Abstract

We estimated the palaeotemperature of *Granaria frumentum*-containing Upper Pleistocene layers from Katymár and Császártöltés using the shell morpho-thermometer and the malaco-thermometer method and compared the results. We tested and calibrated the two methods with recent climatic and faunistical data.

Key words: palaeoclimatology, Gastropoda, morphometry, actuopalaeontology

Introduction

Comparing terrestrial gastropods (Mollusca) to other taxons of organisms they have some preferable features: gastropod shells have good fossilization ability that allows the identification to the species level (KROLOPP, 1983), the fossil asseblages from terrestrial layers are autochtonous (EVANS, 1972), and about 80 percent of the Quaternary mollusc fauna of the Carpathian Basin have been persisting up to the present (FŰKÖH et al., 1995). Hence we can use modern analogues to reconstruct the palaeo-environment of the fossil assemblages, according to the principle of actualism (LYELL, 1833). In a statistical point of view this possibility can be used as transfer function (ROUSSEAU, 1991).

The need for a palaeotemperature reconstruction method based on the mophological properties of mollusc shells is a classical problem. ROTARIDES (1931) wrote about *Chondrula tridens* in his paper that "if we had many recent and fossil populations, their statistical comparison would enable us to draw conclusions as to the climatic conditions of the loess period", and these words are true even nowadays. Later DOMOKOS studied fossil (DOMOKOS, 1982) and recent (DOMOKOS & FŰKÖH, 1984) *Granaria frumentum* populations and he subsequently developed the shell morpho-thermometer method for local (micro) environmental reconstruction of Horváti Cave in Uppony Valley (DOMOKOS, 1985). Our aim was to carry on investigating the use of morpho-thermometer in a higher spatial scale.

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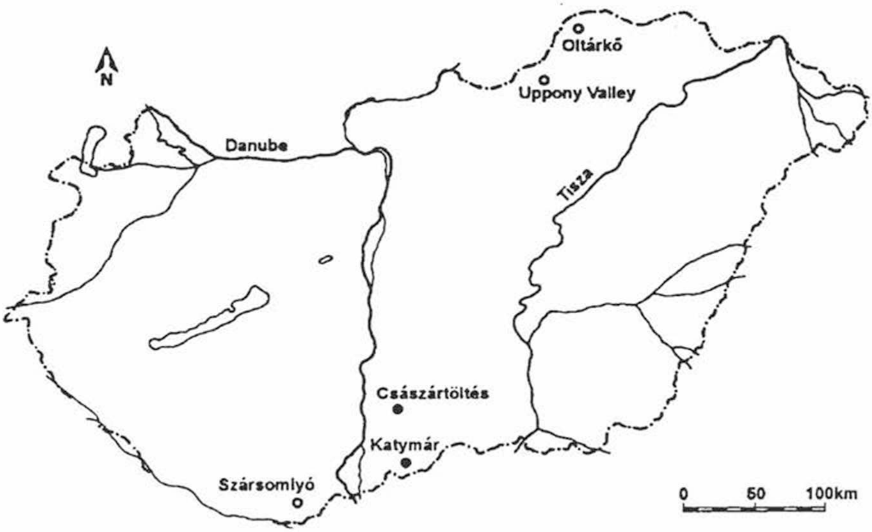

Fig. 1. Location of the stratigraphic profiles (filled circles) and sampling areas (empty circles).

Study area

We investigated *Granaria frumentum*-containing layers of the stratigraphic profiles of Katymár and Császártöltés (Fig. 1) in order to compare the estimated values of morpho- and malaco-thermometer methods. Császártöltés layer belongs to Mende Upper Soil Complex formation (5.75-6.25 m, age: 31,300 ± 330 yr BP, deb-1484) and this layer is the locus typicus of *Granaria frumentum-Vallonia enniensis zonule* (KROLOPP & SÜMEGI, 1995). Katymár I. layer belongs to Mende Upper Soil Complex formation as well as Császártöltés (9.00-9.25 m, age: 29,828 ± 554 yr BP, deb-3058) does. Katymár II. layer belongs to Dunaújváros-Tápiósüly Loess Complex, humic level 1 (6.00-6.25 m, age: 23,749 ± 360 yr BP, deb-3064). The radiocarbon age of the layers were measured with high precision radiocarbon dating system (HERTELENDI et al., 1989).

For testing the validity of the temperature estimation methods we used recent faunistical data from Szársomlyó located in the Villány Hills, S Hungary (SÓLYMOS, 1996, SÓLYMOS & NAGY, 1997), and from Uppony Valley (Simakő and Kereszteskő) located in the Mid-Mountain Range, N Hungary (FŰKÖH, 1980). We also used microclimatological data fom Szársomlyó (SÓLYMOS & NAGY, 1997), Uppony Valley (DOMOKOS & FŰKÖH, 1984), and Nagyoldal (Oltárkő) (JAKUCS, 1954) (Fig. 1).

Material and methods

Granaria frumentum is mostly a xerophilous species living in rocky and short grasslands (SOÓS, 1943, KERNEY et al., 1983). AGÓCSY (1965) considers the species as very variable with a big geographical range occuring several macroclimatic areas of Hungary.

DOMOKOS (1982) gives 30 for the minimal number of cases that is representative for the derived data of the *G. frumentum* populations. The above three layers contained enough *G. frumentum* individuals for the statistical evaluation of the morphometrical attributes (Table 1). We used full-blown and entire shells for the measuring of the height (H) and width (W) of shells in mm with 0.1 mm precision (max 5% measuring error). We calculated elongation index (H/W) for the data pairs, and arithmetic mean, mode, median, standard deviation, minimum value, maximum value, range of measuring for the *G. frumentum* populations came from the three different layers (Table 1). Fig. 2 shows the interclass distribution curves of height values came from the three layers.

The shell morpho-thermometer is based on the connection between the shell morphometry of *Granaria frumentum* and climatic factors as temperature and humidity. DOMOKOS & FŰKŐH (1984) found that higher mean temperature promoted the development of higher and wider shells within the studied temperature range (19.7-22.8 °C). The shell morpho-thermometer method was developed for local (micro) environments at Horváti Cave in Uppony Valley by DOMOKOS (1985). Here we present the application of the method in a higher spatial scale according to the postulated connection between macroclimate and shell morphometry of *G. frumentum* (SÓLYMOS & DOMOKOS, 1998). We calibrated the morpho-thermometer with recent investigations so the method combines fossil and recent data either and have to be considered as absolute estimation of the palaeotemperature. Methods without the recent calibration are have to be considered as relative estimation of the palaeotemperature (see eg. NYILAS & SÜMEGI, 1991).

Layer		AM	MO	ME	SD	Min	Max	d
Katymár I.	H	7.2	7.1	7.1	0.47	6.4	8.0	1.7
N=33	W	2.6	2.5	2.6	0.11	2.5	3.1	0.6
29,828 yr BP	H/W	2.73	2.70	2.71	0.202	2.05	3.10	1.05
Katymár II.	H	7.1	7.2	7.1	0.39	6.2	7.9	1.7
N=30	W	2.7	2.7	2.7	0.12	2.5	3.1	0.6
23,749 yr BP	H/W	2.59	2.90	2.58	0.207	2.04	3.11	1.06
Császártöltés	H	7.3	7.1	7.4	0.29	6.7	7.9	1.2
N=28	W	2.7	2.7	2.7	0.08	2.5	2.8	0.3
31,300 yr BP	H/W	2.72	2.71	2.71	0.110	2.50	2.96	0.47

Table 1. Size distribution characteristics of the measured *Granaria frumentum* populations. N: number of cases, H: height, W: width, H/W: elongation index, AM: arithmetic mean, MO: mode, ME: median, SD: standard deviation, Min: minimum value, Max: maximum value, d: range of measuring.

Palaeotemperature can be calculated using the equation of the regression line of the present time climatic data and arithmetic means of height of the recent *G. frumentum* populations (R=0.6848, R^2=0.4691, F(1.16)=14.137, p<0.0017, Standard error of estimate: 0.3932, see Fig. 3):

$$PT1 = \frac{AM - 2.1747}{0.2824}$$

where $PT1$ is the palaeotemperature calculated with morpho-thermometer method, AM is arithmetic mean. The connection between height and climatic factors is more detectable than the connection between width and the same climatic factors. So height values were used for the regression analysis correlated with mesoclimatic data determined after MAROSI & SOMOGYI (1990) and PÉCSI (1989).

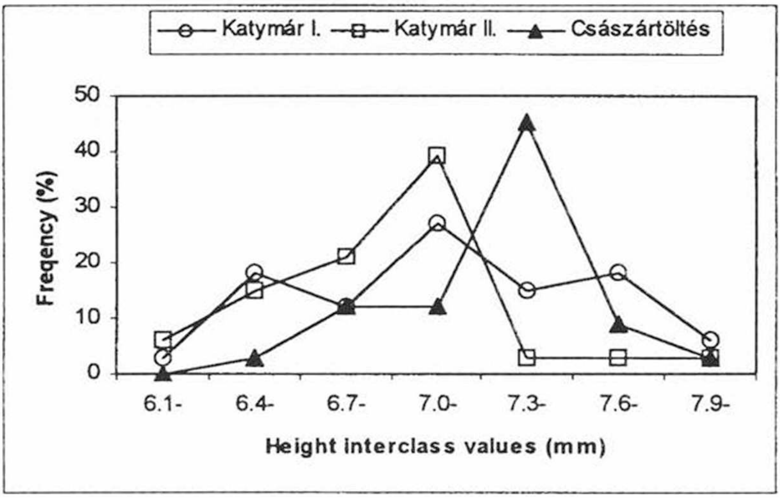

Fig. 2. Height distribution curves of the the different layers (Katymár I. and II., Császártöltés). We used 0.3 mm interclasses according to DOMOKOS (1982).

For testing the shell morpho-thermometer we used the malaco-thermometer method (SÜMEGI, 1989, 1996, HERTELENDI et al., 1992) that is based on recent arealgeographic patterns of some gastropod species dealing with a composite malacofauna. Using the data of climatic research stations, optimal climatic conditions for selected gastropod species can be determined including the minimal and maximal temperature (activity range) that these taxa tolerate (Table 2). Malaco-thermometer method is based on the following equation:

$$PT2 = \frac{\sum_{i=1}^{n} A_i T_i}{\sum_{i=1}^{n} A_i}$$

where $PT2$ is the palaeotemperature calculated with malaco-thermometer method, A_i is the abundance of a given i species in the sample, T_i is the optimum temperature of a given i gastropod species, n is the number of species used for the estimation.

Estimated palaeotemperature values are necessarily valid only for the vegetation period because the studied gastropod species are active only during certain times of the year (SÜMEGI, 1989, 1996, ROUSSEAU et al., 1994). So we compared July mean temperature values calculated by the morpho- and malaco-thermometer methods.

Results

We calculated July mean temperature values for the three layers (Table 3). In the case of Katymár I (29,828 yr BP) the morpho-thermometer underestimated the malaco-thermometer with 1.7 °C. In the case of Katymár II (23,749 yr BP) the morpho-thermometer also underestimated it with 0.5 °C. In the case of Császártöltés (31,000 yr BP) morpho-thermometer method overestimated the value of malaco-thermometer with 1.2 °C. These the differences are under 2.0 °C and 1.1 °C in average.

The estimated values and the complete malacofaunas of Katymár I and Császártöltés layer both indicate a climate similar to that of today of the Carpathian Basin at the begining of the Upper Würm period (32,000-27,000 yr BP). Katymár I and Császártöltés layer belong to the early phase of the Upper Würm *Granaria frumentum-Vallonia enniensis zonule* (KROLOPP & SÜMEGI, 1995). The xerophilous *Pupilla triplicata* is dominant with the mesophilous *Vallonia costata* and *Pupilla muscorum* in the Katymár I and Császártöltés layer. In this two layers the dominance of *Granaria frumentum* is relatively low. In the Katymár II layer the dominance of *Pupilla triplicata* is lower and *G. frumentum* is more abundant than in Katymár I. layer. The abundance of the subhygrophilous *Punctum pygmaeum*, *Euconulus fulvus*, and *Clausilia dubia* is higher indicating transitional covered vegetation and milder climate. The persistence of *Vallonia tenuilabris* indicates colder climate. The Katymár II layer shows the transitional period between the previous cold phase (*Vallonia tenuilabris zonule*, 25,000-22,000 yr BP) and the following mild and humid climatic phase (*Vallonia costata zonule*, 22,000-20,000 yr BP) with the presence of both mesophilous-subhigrophilous (*Vallonia costata*, *V. pulchella*, *Pupilla muscorum*) and frigophilous (*Vallonia tenuilabris*) species.

Using the values of the malaco-thermometer method, the cooling of the climate in the case of the Katymár layers is 1.6 °C. The values of morho-thermometer method show only 0.4 °C decrease of the July mean temperature. The cooling tendency of the climate is detectable by both methods but to a different extent.

Discussion

Before the interpretation of the results, we have to define some concept concerning climatic scales in the way we use here. Microclimate is the climate of the least ranged area that climate is different from the neighbouring microclimates (BACSÓ, 1970). Temperature is a continuous variable both in space and time so we have to use mean, minimum and maximum temperature that can be calculated from the data of a longer time period. The data of a single climate station represents a kind of microclimate on 1-2 m height. Mesoclimate temperature characteristics of a bigger area can be calculated using the data of several climate stations belonging to the area. So mesoclimate is the average of numerous microclimates of a given area and macroclimate is the average of numerous mesoclimates of a larger territory.

The Carpathian Basin has four main macroclimatic regions after Köppen: Carpathic-mountainuous climate region, moderate-warm oceanic climate region, forest-steppe steppe continental climate region, and submediterranean climate region (after DOBOSI & FELMÉRY, 1994). In a macroclimate we can find several different geomorphological features like hills and plains etc. In our oppinion, the climate of a mountain or a hill is mesoclimate with a lot of different microclimates. Microclimatic differences on the areas where from the recent *Granaria frumentum* samples were came out (Szársomlyó, Oltárkő, and Kereszteskő) are 1-4 °C according to the properties of the micro-habitat, vegetation structure (SÓLYMOS & NAGY, 1997), different exposures (STOLLÁR & ZSOLDOS, 1985, HORVÁT & PAPP, 1964), and height of themeasuring (JAKUCS, 1954, SÓLYMOS & NAGY, 1997). Micro scale temporal fluctuation of the temperature and the inertness of the measuring instruments can also reach 1-2 °C (DOBOSI & FELMÉRY, 1994).

We compared the measured microclimate data, the data of mesoclimatic research stations, and values of malaco-thermometer method dealing with the recent fauna of Szársomlyó and Uppony Valley. For Szársomlyó the malaco-thermometer method gave 20.9 °C July mean temperature, the recently observed July mean temperature is 20.8 °C (MAROSI & SOMOGYI, 1990, PÉCSI, 1989), and microclimatic measures gave 21.7 °C on 2 m height and 22.4 °C near the surface during a 24 hour period in southern exposure (SÓLYMOS & NAGY, 1997). For Uppony Valley the malaco-thermometer gave 20.7 °C July mean temperature, the recently observed July mean temperature is 18.0 °C (MAROSI & SOMOGYI, 1990, PÉCSI, 1989), and microclimatic measures gave 17.5 °C during one week quite rainy weather in different exposures (Kereszteskő is exposed to the south, Simakő is exposed to the north) (DOMOKOS & FŰKÖH, 1984).

Comparing recent time July mean temperatures of mesoclimatic research stations and estimated temperature values of malaco-thermometer at Uppony Valley, the malaco-thermometer overestimated the measured data. Contrary to the 230 km latitudinal distance between the Szársomlyó and Uppony Valley, the values of the malaco-thermometer are quite the same with 0.2 °C difference. The very similar mollusc fauna and composition could contribute to the similar estimated temperature values.

According to the above we have to ask, where the border between climatic variability and difference is. Of course it depends on the spatial and temporal scale we use in our investigations. SÜMEGI (1989, 1996, HERTELENDI et al., 1992) used the averages of July mean temperatures of several localities to estimate the palaeoenvironment of the Great Hungarian Plain. The layers were synchronized by radiocarbon dating. Averages help us to reduce the error of extreme values caused by unacquainted special micro- and mesoclimatic conditions in the past.

Comparing estimation methods of other authors using different taxa (vole thermometer, Coleoptera thermometer, and pollen thermometer) the differences of July mean temperature are between 1-6 °C or higher. The different temperatures can be explained by the different location and the types of the investigated areas (marshes, dry habitats; for detail see HERTELENDI et al., 1992). Shell morpho- and malaco-thermometer methods gave very similar outcomes in a 1-2 °C range. This range is acceptable, because the error of the estimation of malaco-thermometer method is ±1-2 °C (see Table 2). Our outcome values appertain to the same layers of the same locations. The experienced differences between malaco- and morpho-thermometer are within this 1-2 °C deviation range.

Species	Optimum (°C)	Activity range (°C)
Pupilla muscorum	16 ± 1	10 – 22
Pupilla triplicata	20 ± 2	16 – 24
Vallonia costata	17 ± 1	10 – 24
Vallonia tenuilabris	9 ± 2	4 – 14
Granaria frumentum	21.5 ± 1	17 – 26
Clausilia dubia	16 ± 1	12 – 20
Punctum pygmaeum	16 ± 1	10 – 22
Vitrea crystallina	15 ± 1	11 – 21
Trichia hispida	15 ± 1	10 – 20

Table 2. Optimum temperatures and activity ranges of gastropod species used for palaeoclimatic reconstruction (SÜMEGI 1989, 1996).

Layers	*PT*1 (°C)	*PT*2 (°C)
Katymár I.	17.7	19.4
Katymár II.	17.3	17.8
Császártöltés	18.2	17.0

Table 3. Estimated July mean temperatures for the different layers with shell morpho-thermometer method (*PT*1), and with malaco-thermometer method (*PT*2) (SÜMEGI 1989, 1996).

Conclusions

Our further aim is to make the regression model of the morpho-thermometer more precise using more recent and fossil populations. It would lead to more precise estimation of palaeotemperature what is a fundamental demand of the better comparability. Actuopalaeontological investigations provide the basis of recent calibration of the thermometer methods. We are planning the morphometrical analysis of other widespread gastropod species (eg. *Pupilla muscorum*) as well, because the appearance of *G. frumentum* is occasional during the the warm periods of the Pleistocene in the Carpathian Basin (KROLOPP & SÜMEGI , 1995). Using more kinds of estimation methods can contribute to the more precise estimation of the palaeoenvironmental variables, because the methods can confirm and complete each other.

Species	Katymár I.	Katymár II.	Császár-töltés
Cochlicopa lubrica (MÜLLER, 1774)	-	-	0.20
Cochlicopa lubricella (PORRO, 1833)	-	-	0.70
Vertigo pygmaea (O.F. MÜLLER, 1774)	-	-	11.90
Pupilla triplicata (STUDER, 1820)	78.51	21.56	5.70
Pupilla muscorum (LINNAEUS, 1758)	6.37	4.25	23.60
Vallonia costata (O.F. MÜLLER, 1774)	10.57	24.56	21.70
Vallonia pulchella (O.F. MÜLLER, 1774)	-	-	11.90
Vallonia enniensis (GREDLER, 1856)	-	-	0.80
Vallonia tenuilabris (A. BRAUN, 1843)	-	0.34	-
Punctum pygmaeum (DRAPARNAUD, 1801)	0.34	26.63	0.40
Granaria frumentum (DRAPARNAUD, 1801)	0.17	8.83	1.70
Chondrula tridens (O.F. MÜLLER, 1774)	0.51	-	2.00
Vitrea crystallina (O.F. MÜLLER, 1774)	-	0.46	-
Helicopsis striata (O.F. MÜLLER, 1774)	0.85	1.44	0.10
Euconulus fluvus (O.F. MÜLLER, 1774)	0.17	4.25	0.10
Limacidae	2.39	1.15	0.10
Clausilia dubia DRAPARNAUD, 1805	0.06	0.11	-
Nesovitrea hammonis (STRÖM, 1765)	0.06	3.21	0.40
Trichia hispida (LINNAEUS, 1758)	-	0.11	0.40
Bradybaena fruticum (O.F. MÜLLER, 1774)	-	3.10	0.10

Table 4. Relative frequencies of the gastropod species found in the three different layers.

In conclusion we adopt the words of BIRKS & BIRKS (1980) that "Numerical methods provide a common language between different biological and environmental variables: a communication link between palaeoecologist and other scientists in related fields". Interdisciplinary research is needed in order to investigate and modelling past and future climate changes and make predictions both in local and global scale.

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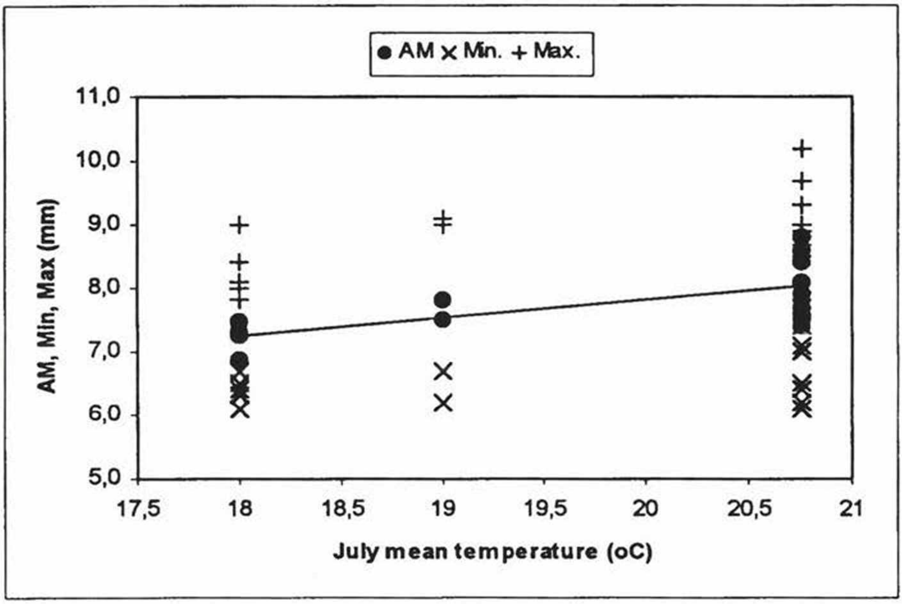

Fig. 3. Connection between macroclimatic factors and means of height (AM), mimimum (Min) and maximum (Max) values of recent *Granaria frumentum* populations from three sampling areas: Szársomlyó (July mean temperature is 20.8 °C), Oltárkő (July mean temperature is 19.0 °C), Kereszteskő (July mean temperature is 18.0 °C) (July mean temperatures after MAROSI & SOMOGYI 1990, PÉCSI 1989) (modified from SÓLYMOS & DOMOKOS 1998 in print).

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A héj morpho-hőmérő módszer és alkalmazhatósága őskörnyezeti rekonstrukciók során

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A csigák (Mollusca, Gastropoda) más élőlénycsoportokkal szemben számos előnyös tulajdonsággal rendelkeznek: jól fosszilizálódó héjuk faji szintű határozást tesz lehetővé, a héjak felépítésükből és méretükből következően az áthalmozódásra rendkívül érzékenyen „reagálnak", ezért szinte minden esetben az autochton módon, *in situ* felhalmozódott héjakat vizsgálhatunk a negyedidőszaki szárazföldi rétegekben. A Kárpát-medence belső területein található negyedidőszaki Mollusca fauna döntő része, mintegy 80%-a ma is él, ezért az aktualizmus elvének felhasználásával a recens klimatológiai, faunisztikai és biogeográfiai megfigyelések jól hasznosíthatók a kvartermalakológiai vizsgálatok során.

A morfo-hőmérő módszert DOMOKOS (1985) alkalmazta elsőként az Upponyi-szoros holocén üledékeinek vizsgálata során. Következtetései lokális vonatkozásúak voltak, mert a morfo-hőmérő „kalibrálását" az Upponyi-szoros recens faunisztikai és mikroklimatológiai adatai alapján (DOMOKOS & FŰKÖH, 1984) végezte el. A jelen dolgozatban bemutatott módszer több mikroklimatikusan is különböző területről (Upponyi szoros, Oltárkő, Szársomlyó) (1. ábra) származó recens *Granaria frumentum* populáció méretbeli változékonysága és mezoklimatikus-makroklimatikus tényezők (pl. júliusi középhőmérséklet) közötti kapcsolaton alapul (SÓLYMOS & DOMOKOS, 1998). Egy adott (fosszilis) populáció héjmagasságainak középértékét behelyettesítve a regressziós egyenes (2. ábra) egyenletébe, a júliusi középhőmérséklet becsülhető.

Három rétegsor (Katymár I., II., Császártöltés) fosszilis *G. frumentum* populációinak statisztikus elemzése után a héj morfo-hőmérő módszer segítségével becsültük az egykori júliusi középhőmérsékleteket. Az így kapott értékeket összevetettük SÜMEGI (1989, 1996) malako-hőmérő módszerével kapott eredményekkel. Az eltérések átlagban alig haladták meg az 1 °C-t (3. táblázat).

A morfo- és malako-hőmérő módszerek eredményei ugyanazokra a rétegsorokra vonatkoznak. A tapasztalt 1-2 °C eltérés elfogadható, mivel minden becslési eljárásnak van bizonyos sajáthibája, amivel a kapott eredmények értelmezése során mindenképpen számolni kell. A malako-hőmérő esetén ez a bizonytalansági tartomány 1-2 °C (ld. 2. táblázat). Más élőlénycsoportok felhasználásán alapuló őshőmérséklet becslő módszereket (pollen-, pocok-,

bogár-hőmérő módszerek) összehasonlítva azok egymástól való eltérése az általunk tapasztalt 1-2 °C eltérésnek többszöröse lehet (HERTELENDI et al., 1992).

A morfo-hőmérő módszer felhasználható paleoökológiai rekonstrukciók során az őshőmérséklet becslésére, más módszerekkel kapott adatok kiegészítése, alátámasztása. A recens analógiák felhasználása lehetővé teszi a módszerek „kalibrálását", így az aktuálpaleontológiai vizsgálatok elengedhetetlenek a becslés pontosságának növelése érdekében. Minél pontosabb paleoklimatológiai módszerek állnak rendelkezésre, annál pontosabb lehet az őskörnyezeti tényezők becslése, és ezáltal több adat válik összehasonlíthatóvá. A numerikus módszerek alkalmazása kommunikációs kapcsolatot jelent a paleoökológia és más tudományterületek között, ami segítséget nyújt a környezeti és éghajlati változások lokális és globális vizsgálata és modellezése során.