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The pressure character of the Hercynian metamorphism in the Gemericum (West Carpathians, Czechoslovakia)

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ABSTRACT. — The pressure character of the Hercynian metamorphism in the Czechoslovak West Carpathians was estimated in the Gemericum tectonic unit, which is the uppermost one. The Hercynian age of the low-temperature greenschist facies metamorphism in the considered areas is sufficiently supported by the available data. The geobarometric estimations were based on the criteria proposed by SASSI (1972) and developed by SASSI & SCOLARI (1974) and GUIDOTTI & SASSI (1976, 1986).

244 samples of graphite-bearing quartz phyllites from three rock formations in four areas (Fig. 1) were considered. They can be divided into two subgroups: paragonite-free and paragonite-bearing quartz phyllites (Fig. 2). The analytical results (Fig. 3), summarized in Table 1, indicate that the Hercynian metamorphism in the Gemericum took place under low-pressure conditions. A metamorphic thermal gradient of approx. 40°C/Km was estimated (Fig. 5).

The systematic differences between b_o values encountered in the paragonite-free and in the paragonite-bearing mineral assemblages (Fig. 4) supply a contribution towards a calibration of the b_o method in the Ms-Pg-Ab limiting assemblage. A comparison with other b_o data from Austria, Hungary, Italy and Romania (Table 2) suggest that, when geodynamic models of the Hercynian event are proposed, two facts must be taken into account the widespread low-pressure conditions prevailing throughout the Hercynides, and the very local prevalence of higher pressure values.

Key words: Hercynian metamorphism, pressure character, muscovite b_o method, West Carpathians.

RIASSUNTO. — È stato stimato il carattere geobarico del metamorfismo ercinico dei Carpazi Occidentali cecoslovacchi nell'unità tettonica Gemerica, che è la più alta dell'edificio alpino.

L'età ercinica del metamorfismo in facies degli scisti verdi (parte di più bassa temperatura) nell'area considerata è sufficientemente provata. Le stime geobarometriche sono state basate sui criteri proposti da SASSI (1972) e sviluppati da SASSI & SCOLARI (1974) e GUIDOTTI & SASSI (1976, 1986).

Sono stati presi in considerazione 244 campioni di filladi quarzifere carboniose di tre diverse formazioni nell'ambito di 4 distinte aree (Fig. 1). Essi possono essere classificati in due sottogruppi sulla base della presenza o assenza di paragonite (Fig. 2). I risultati analitici (Fig. 3), riassunti in Tab. 1, indicano che il metamorfismo ercinico nel Gemerico si sviluppò sotto basse pressioni. I dati analitici indicano un valore del gradiente termico metamorfico di circa 40°C/km (Fig. 5).

Sono state notate differenze sistematiche dei valori di b_o della muscovite fra i campioni con paragonite e quelli privi di paragonite (Fig. 4). Queste differenze sistematiche consentono di fare un primo passo verso la calibrazione del metodo geobarometrico del b_o nell'associazione limitante Ms-Pg-Ab.

Sono stati infine effettuati confronti fra i risultati ottenuti e quelli disponibili per altri complessi rocciosi circostanti, in Austria, Italia, Romania, Ungheria (Tab. 2). Questi confronti suggeriscono che, nel formulare modelli geodinamici dell'Evento Ercinico, è necessario tener conto di due fatti: la generale prevalenza nelle Ercinidi di condizioni di bassa pressione, e la locale presenza di situazioni di più alte pressioni.

Parole chiave: metamorfismo ercinico, carattere geobarico, metodo del b_o della muscovite, Carpazi Occidentali.

Introduction

The Hercynian metamorphism in the Gemericum generally displays low-grade features. The only exception is represented by the amphibolites and related gneisses which occur as large tectonic slices within the metabasalt-phyllite belt of the Rakovec Group. Minerals and mineral assemblages which may be used as pressure indicators are completely lacking, both in the greenschist facies rocks and in the tectonically boundaried amphibolite facies rocks.

On the other hand, numerous data exist in the recent literature demonstrating that the pressure character of the metamorphism and its variations are important elements for interregional comparisons and geodynamic interpretations.

measurements. The analytical procedures and criteria were those proposed by SASSI (1972) and developed by SASSI & SCOLARI (1974) and GUIDOTTI & SASSI (1976; 1986). It is opportune to point out here that the specific procedure followed in sample preparation for b_o measurements (rock slices cut perpendicularly to the foliation) is such that the intensity of the 060 peak is strongly enhanced, while that of the 331 and $\bar{3}31$ reflections significantly lowered. The measurements of the d_{060} spacing and calculation of the b_o values are

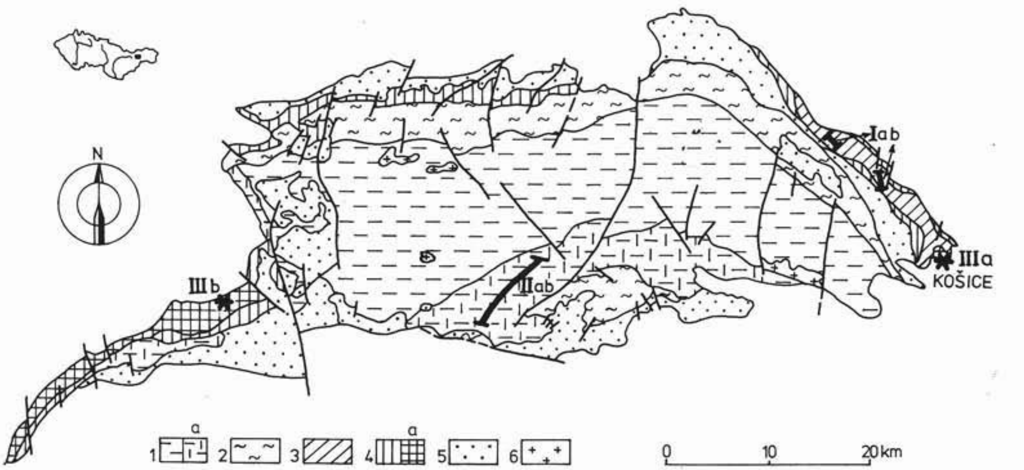

Fig. 1. — Geological sketch of the Gemericum (taken from Bajanik et. al., 1984). The two asterisks and the two heavy segments represent the location of sample populations taken into consideration for muscovite b_o measurements (Table 1). 1: Gelnica Group; 1a: Drnava Formation; 2: Rakovec Group; 3: Crmel Group; 4: Dobsina Group; 4a: Ochtina Formation; 5: Late Paleozoic and Mesozoic sequences; 6: Granitoids of Late Paleozoic-Mesozoic age.

For these reasons, the present research was planned by the authors as the first step of a research collaboration program on the pre-Alpine metamorphism(s) in the Alpine area of Czechoslovakia. It is aimed at establishing the pressure character of the Hercynian metamorphism in this part of the Alpine-Carpathian belt, supplying the literature with data which are already available both on the more westerly mountain chain of the Eastern Alps (SASSI, 1972; BÖGEL et al., 1979; BECKER et al., 1987) and in the Romanian South (KRÄUTNER et al., 1976) and East (KRÄUTNER et al., 1975) Carpathians.

The method utilized is based on the muscovite composition in greenschist facies metapelites, estimated by means of b_o

therefore not affected by any ambiguity: the risk emphasized by FREY et al. (1983) consequently does not occur when the above procedure is followed.

The goebarometric estimations were based on three sample populations, respectively belonging to the Gelnica Gruop, the Crmel Group and the Ochtina Formation (Fig. 1).

Geopetrological frame

The Gemericum is the uppermost tectonic unit of the Alpine structure of the Slovak West Carpathians. The regional Alpine metamorphic overprint occurs only locally and is significantly lower than in the other West Carpathian tectonic units.

The only important exceptions are found

in the Late Paleozoic to Mesozoic rock sequences close to the northern and southern tectonic boundaries of the Gemericum: Alpine metamorphic overprints are important there, and may be related (at least partly: see KAMENICHY, 1957, and REICHWALDER, 1973, about the occurrence of glaucophane) to a shear zone metamorphism (BROWN, 1984). A different type of metamorphic overprint of Alpine age (VRANA, 1964; VOZAROVA & KRISTIN, 1985) may also be found locally elsewhere, as a thermal effect of granitoid intrusions (VOZAROVA & VOZAR, 1982; KANTOR, in Vozarova et al., 1979).

The Gemericum consists of several tectonic subunits. From the lithostratigraphic point of view, several groups and formations have been distinguished (BAJANIK, et al., 1984), armong which the Gelnica Group, the Crmel Group and the Ochtina Formation (Fig. 1) are those in which metapelites of suitable composition for this type of analysis are well represented.

Crmel Group

The sedimentation age of the Crmel Group is Lower Carboniferous. Graphite-bearing metapelites are repeatedly interlayered in all levels of the lithostratigraphic column. The above-mentioned sedimentation age ascertained by palynological data (SNOPKOVA, in Bajanik et al., 1986).

The age of metamorphism is certainly pre-Westphalian, considering that pebbles of the rocks occur within the well-dated Westphalian conglomerates (VOZAROVA, 1973). Therefore, the Hercynian age of this metamorphism is not yet radiometrically demonstrated but must be reasonably admitted, considering the Lower Carboniferous sedimentation age.

Fifty-one samples phyllites were taken as representative, under the considered point of view, of the Crmel Group. The location of this sample population is shown in Fig. 1.

The metamorphic mineral assemblage commonly found in these samples is represented in the AKNa diagram of Fig. 2 (open circle): it is the non-limiting muscovite-albite assemblage. Quartz and small amounts of chlorite and graphite are to be mentioned in addition. The widespread occurence of the latter mineral, although in commonly low quan-

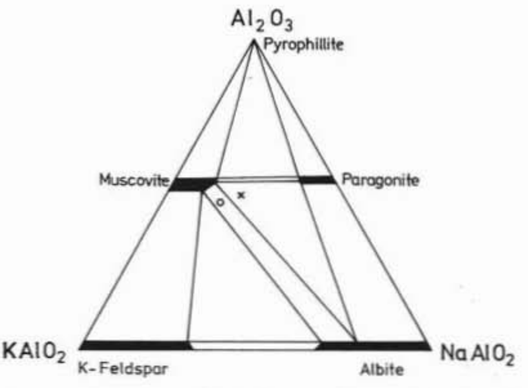

Fig. 2. — Schematic AKNa diagram showing the mineral compatibilities in the low temperature greenschist facies. The open circle indicates the common mineral assemblage in the Crmel quartz phyllites, while the cross that in the Gelnica and Ochtina quartz phyllites.

tities, ensures that fO_2 was buffered at low values: we may therefore admit that b_o values are controlled by the phengite s.s. rather than ferrimuscovite s.s. content.

The analytical results of the b_o measurements are shown by means of their frequency distribution in histogram *a* of Fig. 3, together with the mean b_o value (8,997 Å) and the standard deviation (0.003).

In addition to the above-examined samples, four Al-rich Crmel metapelites of identical metamorphic grade were considered. Evidence of paragonite occurrence was found in them by means of X-ray powder diffractometry. The mean b_o value obtained from these four samples was 8.983 Å (s = 0.002), a value which is significantly lower than that obtained from the 51 paragonite-free Crmel samples. This fact is clearly due to the rock bulk composition and consequently to the significantly different mineral assemblages: we are now dealing with an Al-richer limiting assemblage, muscovite-paragonite-albite, for which lower phengite s.s. contents are to be expected, both from the theoretical (GUIDOTTI & SASSI, 1976) and experimental (GOMEZ-PUGNAIRE et al., 1978) viewpoints.

Gelnica Group

In the ambit of the Gelnica Group, graphite-bearing metapelites are well represented in the Drnava Formation, which is the uppermost lithostratigraphic part of this group.

The sedimentation age of the Drnava Formation is Upper Silurian to Lower Devonian (SNOPKOVA & SNOPKO, 1979), as demonstrated by palynological data.

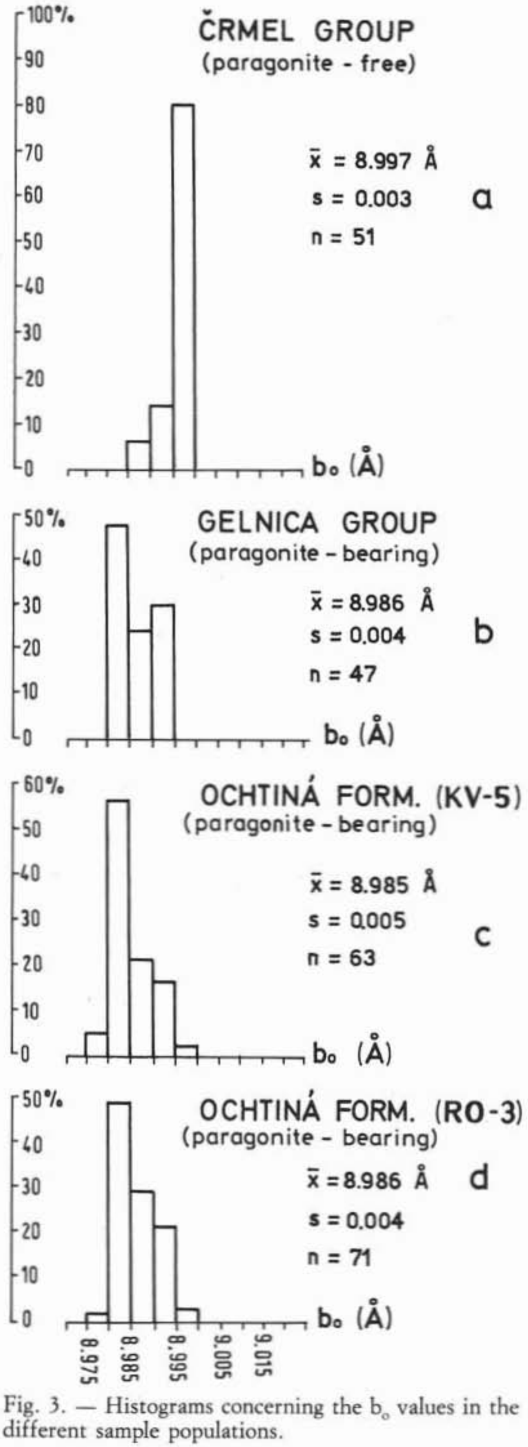

Fig. 3. — Histograms concerning the b_o values in the different sample populations.

As regards the age of metamorphism, radiometric age determination are not yet available. However, some geological constraints indicate that we are dealing with the Hercynian metamorphism: (i) pebbles of Drnava rocks occur in the Stephanian-Permian conglomerates (VOZAROVA, 1973), demonstrating a pre-Stephanian age of metamorphism; (ii) zircons 395-420 Ma old (U/Pb: in GRECULA & VARGA 1977), occur in the metarhyolitic tuffs which are intimately and repeatedly interlayered within the Drnava Formation, demonstrating a post-Silurian age of metamorphism.

Forty-seven samples of quartz phyllites from the Drnava Formation were considered for b_o measuremets. The location of this sample population is shown in Fig. 1.

The metamorphic mineral assemblage commonly found in them, also revealed by X-ray powder diffractometry, is muscovite-paragonite-albite (Fig. 2: cross); In addition to the represented mineral phases, small amounts of quartz and chlorite must be mentioned, as well as significant quantities of graphite. The latter mineral is more abundant in the Drnava phyllites than in the Crmel ones, and its presence indicates that fO_2 was buffered at low values.

Histogram *b* of Fig. 3 represents the frequency distribution of the b_o values obtained from the Drnava phyllites. The mean b_o vale turns out to be 8.986 Å (s = 0.004), a value which is substantially equal (within the limits of the analytical error) to that obtained from the four paragonite-bearing samples from the Crmel Group.

This identity may be used as an indication of identical pressure values prevailing during the Hercynian metamorphism in the Crmel and Gelnica Groups. The demonstration of pressure identity was obtained by measuring the b_o values of eight paragonite-free samples from the Gelnica Group, of the same metamorphic grade. The mean b_o value of 8.999 Å (s = 0.002) is substantially equal to that obtained from the 51 paragonite-free samples from the Crmel Group, within the limits of analytical error.

Ochtina Formation

The Ochtina Formation is the youngest among the Paleozoic formations in the Gemericum. Its age is Lower Carboniferous (including the Serpuchovian) as established by palynological data (PLANDEROVA, 1982; BAJANIK & PLANDEROVA, 1985) as well as macrofauna (BOUCEK & PRIBYL, 1960) and conodonts (KOZUR et al., 1976).

Two sample populations were taken into consideration for the present research: one from the Kosice area (borehole KV-5), the other from the Rochovce area (borehole RO-3). The locations of both boreholes are shown in Fig. 1.

In the Kosice area, graphite-rich phyllites are the most abundant rock type in the silicate part of the rock sequence crossed by the borehole. The Hercynian age of the metamorphism has not yet been demonstrated in this area, but is assumed on the basis of regional correlations (fragments of these rocks occur in Permian conglomerates: BAJANIK, 1965).

The Lower Carboniferous rock sequence is more complete in the Rochovce than in the Kosice area, and graphite-rich phyllites are repeatedly interlayered in several levels of the whole rock sequence. Intruded Alpine granitoids were found at the bottom of the Rochovce borehole, 500 m below the lowermost phyllites analysed for b_o values of muscovites.

As regards the age of the Ochtina Formation in the Rochovce area, direct radiometric evidence is available: a K/Ar age value of 340 ± 27 Ma obtained from an amphibole in a low-grade metagabbrodiorite from the Jelsava area (SE of Rochovce: KANTOR & DURKOVICOVA, 1980).

The b_o value of muscovite was measured in 71 samples from the Rochovce borehole and in 63 from the Kosice borehole. The mineral assemblage ascertained in thin section in these metapelites is muscovite-albite, but the additional occurrence od paragonite was detected in numerous samples by of X-ray powder diffractometry. The common mineral assemblage in the Ochtina phyllites is consequently muscovite-paragonite-albite, i.e., the limiting assemblage shown in Fig. 2 by a cross. Therefore, assuming that the pressure conditions of the Hercynian metamorphism were the same as in the Gelnica and Crmel Group, very low b_o values close to those found in the paragonite-bearing Gelnica (mean b_o = 8.986 Å) and Crmel (mean b_o = 8.983 Å) quartz phyllites are to be expected. Figs. 3c and 3d show that this expectation is fulfilled: the Octina mean b_o values are identical to those quoted above, both in the Rochovce (mean b_o = 8.986 Å; s = 0.004) and in the Kosice (mean b_o = 8.895 Å; s = 0.005) quartz phyllites. The distribution pattern is identical in the two populations, indicating identical pressure conditions notwithstanding the distance (about 80 km) separating the two boreholes.

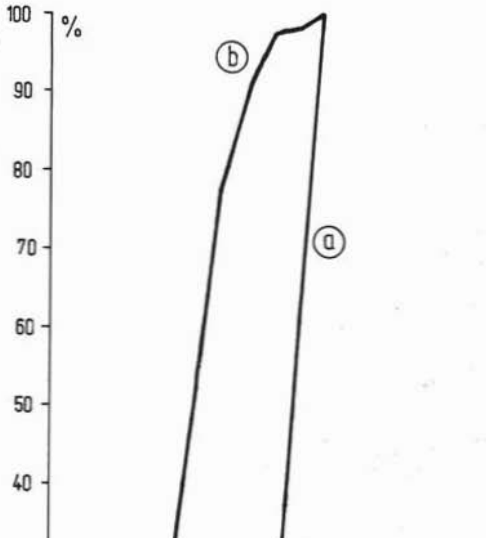

Fig. 4. — Cumulative frequency curves of paragonite-free quartz phyllites (curve a: sample populations Ia and IIa, in Table 1) and in paragonite-bearing quartz phyllites (curve b: sample populations Ib, IIb, IIIa, b, in Table 1). The two arrows along the abscissa indicate the mean b_o values, and the orizontal segments at their basis represent the corresponding confidence ranges 95% probability level.

TABLE 1

Summary of the muscovite mean b_o values ($\bar{x}$), standard deviation (s) and number of samples (n) of different sample populations from the Gemericum (West Carpathians, Czechoslovakia)

		Sample Populations	$\bar{x}$	s	n
paragonite-free	quartz phyllites	Ia : ČRMEL GROUP	8.997 Å	0.003	51
		IIa : GELNICA GROUP	8.999 Å	0.002	8
		total	8.997 Å	0.003	59
paragonite-bearing	quartz phyllites	I b: ČRMEL GROUP	8.983 Å	0.002	4
		II b: GELNICA GROUP	8.986 Å	0.004	47
		IIIa,b: OCHTINÁ FORMATIONS	8.986 Å	0.005	134
		total	8.986 Å	0.004	185

Goebarometric interpretation

Any geobarometric interpretation of the b_o values obtained in the present research must be based on the average values summarized in Table 1.

The first consideration to be made is that all muscovite b_o values either fall around 8.986 Å or close to 8.997 Å. This systematic difference, which is easily detectable in Fig. 4, is to be related to the different mineral assemblages: muscovite-paragonite-albite in the quartz phyllites from which b_o values around 8.986 Å were obtained, muscovite-albite in the other quartz phyllites. This behaviour is consistent with both theoretical expectations (GUIDOTTI & SASSI, 1976) and available analytical data (GOMEZ-PUGNAIRE et al., 1978).

Taking into account the fact that all geobarometric estimations based on the b_o method carried out in different parts of the world are based on muscovites in the non-limiting muscovite-albite mineral assemblage, only the mean b_o value of 8.997 Å obtained from the 59 paragonite-free quartz phyllites can be cosidered.

Comparing this value with those given by SASSI & SCOLARI (1974) and GUIDOTTI & SASSI (1986), the Hercynian metamorphism in the Gemericum clearly falls in the realm of low-pressure metamorphisms and is comparable to the Bosost metamorpism in the Pyrenees (average b_o value: 8.986 Å) and the Buchan metamorphism in eastern Scotland (average b_o value: 8.992 Å).

The same mean b_o value may be used for an attempt at estimating the metamorphic thermal gradient prevailing during the climax of the Hercynian metamorphism in the Gemericum. The basis of this attempt is the diagram proposed by GUIDOTTI & SASSI (1986) concerning the pattern of b_o values in the PT field, as reworked by SASSI (1987, p. 449). Considering that biotite and Al_2SiO_5 phases are not stable in these rocks, a relatively narrow thermal range of approximately 350-370°C may be reasonably assumed along the iso-b_o line of 8.997 Å (Fig. 5). A value of approximately 40°C/km is consequently obtained for the Hercynian metamorphism in the Gemericum.

A further consideration may be made on the systematic b_o difference of muscovites between the paragonite-free and paragonite-bearing quartz phyllites. The data available in the literature are summarized below:

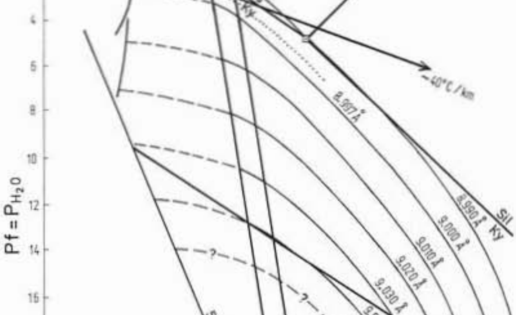

Fig. 5. — Graphical estimation of the Hercynian metamorphic thermal gradient in the Gemericum (approx. 40°C/km) based on the mean b_o value (8.997 Å) and the T range desumed from the mineral assemblages (black rhomboid). Curve 1: Kaol + Qtz = Pyroph + H_2O; 2: Pyroph = Al-silicate + Qtz + H_2O; 3: (NaPhl-Tlc) s.s. + Ab = Glaucophane (CARMAN & GILBERT, 1983). The diagram is that proposed by *Guidotti & Sassi* (1986), with the b_o contours as modified by SASSI (1987, p. 449).

TABLE 2

Summary of the muscovite mean b_o values ($\bar{x}$), standard deviations (s) and number of samples (n) concerning Hercynian quartz phyllites from different areas in Austria, Czechoslovakia, Hungary, Italy and Romania

Sample Group	$\bar{x}$	s	n
GEMERICUM, WEST CARPATHIANS, Czechoslovakia (present paper)	8.997 Å	0.003	59
EASTERN ALPS (Austria and Italy): Austrides (Guidotti & Sassi, 1986)	8.995 Å	0.007	159
EASTERN ALPS (Italy): Southern Alps (Sassi et al., 1974)	8.997 Å	0.009	161
UPPONY Mts., Hungary (Lelkes-Felvari & Sassi, 1981)	8.996 Å	0.010	34
FOKAJAR area, Hungary (Lelkes-Felvari et al., 1982)	8.987 Å	0.004	38
TAZLAR area, Hungary (Arkai & Lelkes-Felvari, 1987)	8.998 Å	0.007	11
SZENDRŐ Mts., Hungary (Lelkes-Felvari & Sassi, 1981)	9.003 Å	0.007	64
EAST CARPATHIANS, Romania (Kräutner et al., 1975)	8.997 Å	0.008	84
POIANA RUSCA MASSIF, South Carpathians, Romania (Kräutner et al., 1976)	9.021 Å	0.008	129

1) Sierra de Baza area (Betui Cordilleres, Spain: GOMEZ et al., 1978): tha average b_o value in paragonite-bearing phyllites is 8.996 Å (s = 0.006, n = 28) versus 9.008 Å (s = 0.007, n = 35) in paragonite-free phyllites;

2) Gemericum data (present paper, Table 1): respectively 8.886 Å versus 8.997 Å.

In each of the above cases, the difference between the two average b_o is practically the same: 0.11 Å in the Gemericum and 0.12 Å in the Sierra de Baza area. Notwithstanding that only two cases can be considered from this point of view, the above systematic difference may represent a first step towards the calibration of the b_o geobarometric method in the muscovite-paragonite-albite assemblage.

Interregional comparisons

The b_o data obtained for the Hercynian metamorphism of the Gemericum may profitably be used for comparison with the b_o data available in the literature concerning the Hercynian metamorphism in other regions surrounding the Czechoslovak West Carpathians. These comparisons are proposed with the only aim of detecting similarities and differences in the pressure character of the Hercynian metamorphism, without any implication of geological correlation.

The areas in which b_o data are available in the literature belong to the Eastern Alps (Austria and Italy), Hungary, and the South and East Carpathians (Romania). The mean b_o values for each area are shown in Table 2, from which two main statements may be drawn:

(i) with only one exception (the Poiana Rusca Massif in the South Carpathians), all the sample populations supplied identical mean b_o values, within the range of analytical error, thus clearly indicating that identical low-pressure conditions prevailed during the Hercynian metamorphism over very large parts of the Hercynides, and completely supporting the ideas expressed by Zwart about twenty years ago (1969);

(ii) the exception found by KRÄUTNER at al. (1976) in the South Carpathians indicates that higher pressure values locally prevailed during the Hercynian metamorphism, because the number of samples, analytical procedures and b_o frequency distributions are such that the mean b_o value obtained from this area is unquestionable and significant for geobarometric purposes.

In conclusion, it should be noted that, when geodynamic models of the Hercynian event are proposed, two facts must be explained: the widespread low-pressure conditions prevailing throughout the Hercynides, and the very local prevalence of higher pressure values.

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