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Recognition of the Pressure Character in Greenschist Facies Metamorphism

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With 3 figures

Abstract

The possibilities offered in the lowest temperature part of the greenschist facies by the b_0 geobarometric method are discussed on the basis of approx. 2000 b_0 values of white K-micas, coming from several metamorphic regions of different age and pressure. The main conclusion is that the phyllitic terrains can supply, by means of this very rapid method, more detailed information on the pressure conditions of metamorphism than the high-grade terrains. Therefore, the phyllitic regions are worth taking into consideration in research concerning the distribution of the P/T metamorphic regimes in space and time.

Low-temperature metamorphic terrains (greenschist facies) are difficult to analyze geobarometrically using traditional methods, due to the lack of minerals or mineral assemblages useful for monitoring the pressure conditions. Only the occurrence of glaucophane (and related minerals) is useful for this aim, but it supplies only a twofold, rigid classification. This fact simulates the existence of two preferential pressure situations or sets of situations, in contrast to the theoretical expectations which obviously imply that all pressure values falling within a given range (e.g. between 2 and 10 kb) can prevail during regional metamorphic processes, depending on the geodynamic situation. In conclusion, the geobarometry of phyllitic terrains based on traditional criteria is lacking or, in the best conditions, is quite poor.

However, in the last few years a method for geobarometric analyses valid for low-grade metapelites (lowest-temperature part of the greenschist facies) has

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been developed (SASSI, 1972; SASSI and SCOLARI, 1974; GUIDOTTI and SASSI, 1976). Its advantages include:

— it is applicable to rock-types which are common in any low-grade metamorphic terrains;
— it utilizes a parameter, the b_0 spacing of the white K-micas, which changes with pressure in a continuous way.

The method is based on the following developments: 1. other conditions being constant, the muscovite solid solution towards celadonite is a function of pressure (as shown by the experimental work of VELDE, 1965, 1967); 2. the b_0 spacing is a measure of the celadonite content of white K-micas in most natural cases (as developed by CIPRIANI et al., 1968; see further discussions in GUIDOTTI and SASSI, 1976); 3. consequently, the b_0 values allow a comparative estimation of the pressure conditions of metamorphism (SASSI, 1972).

Deferring to the above-quoted papers as regards the detailed grounds of the method and the criteria to be followed for correct sampling (only samples of a given compositional and thermic range must be taken into consideration), it should be stressed here that:

— the most suitable and sensitive samples should be those bearing "limiting assemblages", i.e. mineral assemblages in which the number of phases equals the number of components: as a consequence, the celadonite content of white K-mica depends on intensive parameters (T, P, aH_2O) and is independent of the bulk composition (GUIDOTTI and SASSI, 1976). As regards the low-grade metapelites, these conditions are encountered in the three phase fields of the AKNa diagram shown in Fig. 1 (compositions W or X or Z);

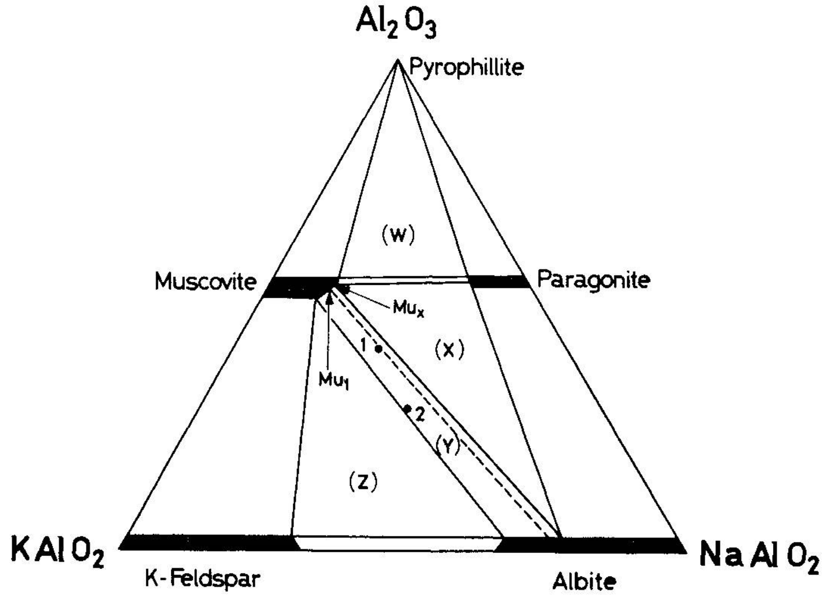


Fig. 1. Schematic AKNa diagram showing the mineral compatibilities for pelitic schists at low temperatures.

— notwithstanding this fact, because limiting assemblages are very rare in low-grade terrains, the b_0 method has been developed for the very common assemblages Y (two-phase field muscovite-albite), in order to have the possibility of wide applicability to all metamorphic terrains. However, within this field Y, high Al samples were preferred (composition type 1 in comparison to type 2 in Fig. 1): in fact, muscovite is very abundant in them, and its Mu_1 composition approximates the Mu_X one for the three-phase limiting assemblage muscovite-paragonite-albite. Therefore, in the bulk compositional range in which method has been developed, some control of bulk composition on mica composition is to be expected, but its extent is low.

In conclusion, when several populations of isothermal Al-rich samples from the field Y are compared, the main b_0 differences certainly reflect differences in the pressure character of metamorphism, while the small differences may depend on bulk composition.

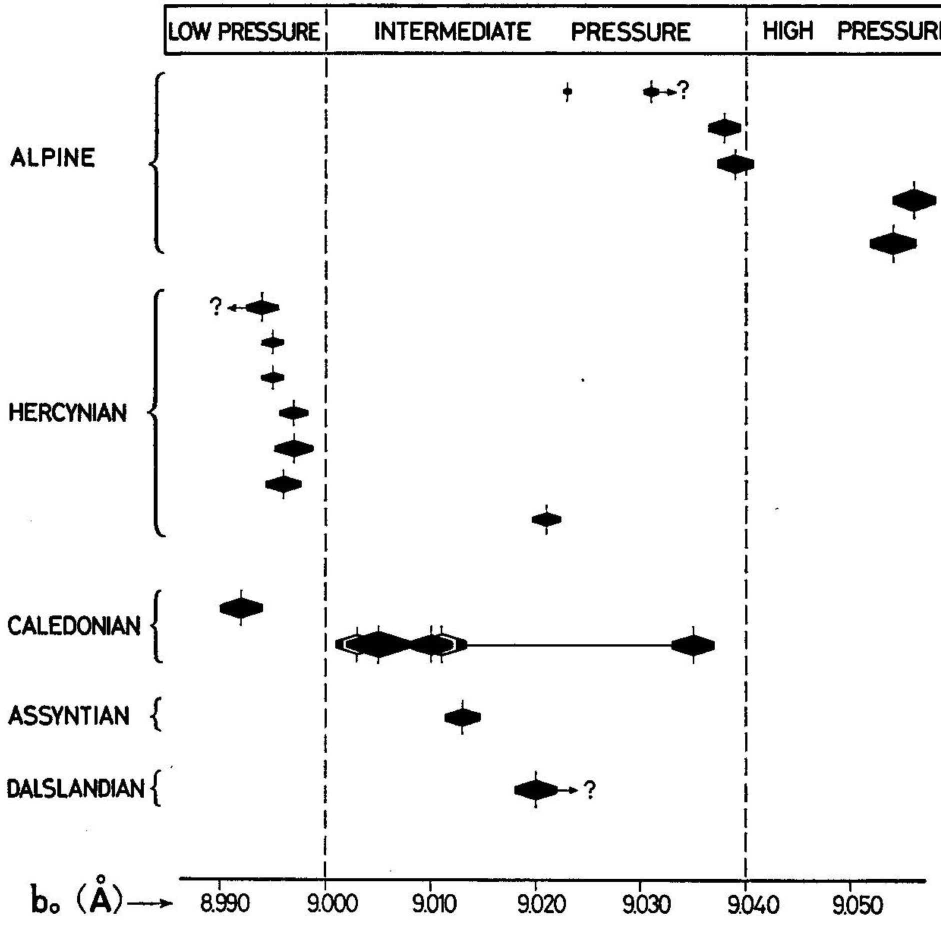
The b_0 geobarometric method has been utilized in numerous regions, so that approximately 2500 b_0 values are available at present. These numerous analytical data, which were all obtained using the same analytical procedures, allow us to attempt a general evaluation of the effective possibilities offered by this method as regards:

— the feasibility of truly discriminating different pressure types of metamorphism;
— contributing to the studies on the distribution of the different facies series in the earth's crust also by utilizing the phyllitic terrains, till now perforce disregarded.

The 1853 data relevant for this evaluation are shown syntetically in Fig. 2 by means of the mean value ($\bar{x}$), standard deviation (s), number of samples (n), confidence range at 95% (the longer diagonal of the rhombus-shaped symbol is twice 1.96 $s/\sqrt{n}$, left and right of the mean value). An asterisk marks those sample populations for which independent evidence (critical mineral assemblages) for the pressure character is available. Those populations which are not marked by asterisks were assigned to the low, intermediate and high pressure ranges by comparison of the b_0 values with the populations marked by asterisks.

An analysis of these data allows us to make the following statements:

1. The three main types of metamorphisms – low-pressure type, intermediate-pressure type and high-pressure type, as defined respectively by the occurrence of andalusite, kyanite and glaucophane in the rocks of suitable bulk composition and temperature (MIYASHIRO, 1961) – are very well discriminated. Therefore, in classifying metamorphic terrains from the geobarometric viewpoint, the phyllitic terrains can be taken into account in the same way as the high-grade terrains.



AREA	SOURCE	$\bar{x}$	s	n
1-2–CALABRIA	(1)	9.023 9.031	0.003 0.005	297 174
*3 – E. ALPS	(2)	9.038	0.008	100
*4 – OTAGO	(3)	9.039	0.005	35
*5 – PONTIC RANGE (DADAY - BALLIDAG)	(3)	9.056	0.007	46
*6 – SANBAGAWA	(3)	9.054	0.006	34
*7 – BOSOST	(3)	8.994	0.009	132
8 – CALABRIA	(4,5)	8.995	0.006	139
*9 – E. ALPS (AUSTRIDES)	(2,6,7,8)	8.995	0.007	159
10 – E. ALPS (S. ALPS)	(9)	8.997	0.009	161
11 – E. CARPATHIANS	(10)	8.997	0.008	84
12 – PELORITANI	(11)	8.996	0.005	42
13 – S. CARPATHIANS (POIANA RUSCĂ)	(12)	9.021	0.008	129
*14 – E. SCOTLAND (BUCHAN)	(13)	8.992	0.007	44
*15-19 – SCOTLAND (BARROVIAN)	(13)			153
20 – E. CARPATHIANS	(10)	9.013	0.007	81
*21 – E. CARPATHIANS	(10)	9.020	0.007	43

Fig. 2. Confidence range 95% (rhombus-shaped symbol), mean b_0 value ($\bar{x}$), standard deviation (s) and number of samples (n) concerning 21 sample populations from different metamorphic regions. The total number of samples is 1853. Arrows show the possible shifting of a given population as proposed for some reason by the respective authors quoted in the "Source" column. *Sources:* 1 = DIETRICH et al. (1976); 2 = SASSI (1972); 3 = SASSI and SCOLARI (1974); 4 = PIERRO et al. (1973); 5 = PICCARRETA and ZIRPOLI (1974); 6 = GEYSSANT and SASSI (1972); 7 = SASSI and ZANFERRARI (1972); 8 = VISONÀ (1974); 9 = SASSI et al. (1974); 10 = KRÄUTNER et al. (1975); 11 = ATZORI and SASSI (1973); 12 = KRÄUTNER et al. (1976); 13 = FETTES et al. (1976). Asterisk marks the areas in which an independent evidence of the pressure character of metamorphism exists.

2. In the low-pressure and high-pressure ranges, the weak scattering of data could be devoid of significance and potentially confusing. In fact, as stressed above, the position of each population in Fig. 2 is controlled to some extent also by the rock bulk composition, because the samples are of type Y_1 in Fig. 1; consequently, the small differences encountered may depend entirely on the bulk compositional effect. However, as shown in Fig. 3, it is probably no mere

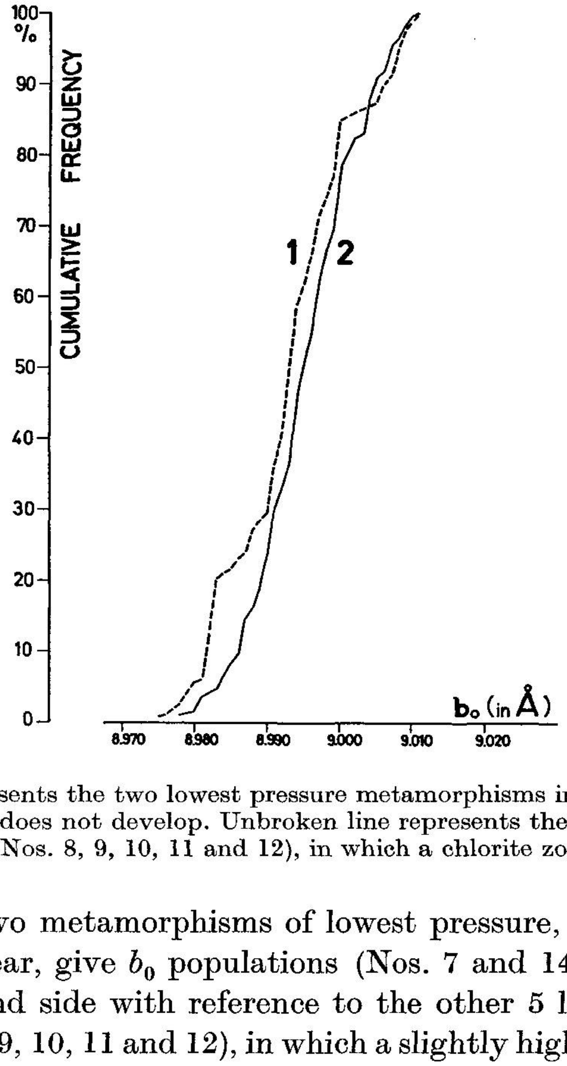


Fig. 3. Dashed line represents the two lowest pressure metamorphisms in Fig. 2 (Nos. 7 and 14), in which a chlorite zone does not develop. Unbroken line represents the five low-pressure metamorphisms in Fig. 2 (Nos. 8, 9, 10, 11 and 12), in which a chlorite zone is well developed.

accident that the two metamorphisms of lowest pressure, in which a chlorite zone could not appear, give b_0 populations (Nos. 7 and 14) which are shifted towards the left-hand side with reference to the other 5 low-pressure sample populations (Nos. 8, 9, 10, 11 and 12), in which a slightly higher pressure allowed the chlorite zone to develop very well.

3. More important scattering of the data occurs within the intermediate pressure range. In this case, the extent of the variation range and the amount of the scattering are so large that they cannot be entirely linked to the bulk compositional effect. On the other hand, the requisites of the sample populations exclude the responsibility of intensive variables other than pressure. The conclusion to be inferred is that this large variation range of b_0 values indicates a large range of pressure conditions.

Therefore, this method offers the effective possibility of distinguishing – within the ambit of the intermediate pressure range, i.e. within the field of Barrovian-type metamorphism – several baric types of metamorphisms. Consequently, the b_0 geobarometric method applied to greenschist facies terrains turns out to be more discriminatory than traditional methods applied to amphibolite facies terrains. In other words, the Barrovian-type metamorphism as defined by the occurrence of kyanite is too large and too comprehensive with respect to the requirements of modern Earth Sciences; the b_0 method seems to be the most simple, rapid and reliable way presentle available of distinguishing several pressure conditions in the Barrovian metamorphic range.

4. Highly discriminatory interregional comparisons and the detection of possible changes in pressure along or across a given metamorphic belt or during a given metamorphic event can easily be achieved by using the b_0 approach, and could be more rigorously demonstrated using limiting assemblages. These are results which traditional methods can generally only supply by means of sophisticated utilizations of the often unsteady stability curves. In particular, as regards glaucophanitic greenschist facies linked to subduction, the possibility exists of detecting differences in metamorphic pressure (different depths of subduction?) between apparently similar glaucophanitic belts, and a new, independent method for recognizing a polarity in them is available.

5. In Fig. 2 the b_0 data groups are arranged according to a chronologic order, but within the ambit of each group the order is only alphabetic. In this way, several considerations regarding the distribution of the P/T regimes in space and time can easily be made. For example, our b_0 data show that:

— high-pressure metamorphism occurs only in the Alpine belts (cfr. De Roever, 1972; Ernst, 1975);
— during the Alpine cycle, at least two metamorphic phases of different pressure developed in many regions, as in Calabria. In these cases, it is possible that the b_0 values around 9.030–9.035 Å represent the result of the younger phase (intermediate pressure: $b_0 \cong$ 9.020–9.025 Å) overprinted on older celadonite-rich micas crystallized during the early metamorphic phase (high pressure: $b_0 \cong$ 9.055 Å);
— Hercynian metamorphism is, as a rule, of low pressure, but in the South Carpathians a "Barrovian" situation has recently been detected by means of the b_0 method: a new "exception" to the well defined "Hercyno-type" character (Zwart, 1969);
— Caledonian metamorphism in Scotland developed under a very large range of pressure conditions, and a continuous change in facies series across the Scottish Dalradian has been detected;

— a similar situation probably occurred during the Dalslandian event, which, in the East Carpathians, turns out to be of "Barrovian type", while in Northern Europe it is of low pressure (ZWART, 1969).

Most of the conclusions we inferred from b_0 data in Fig. 2 have been known for a long time now. However, it is worth stressing the fact that the considerations inferred by means of the b_0 method are consistent with, and often more detailed than, those obtained using traditional methods on high-temperature rocks.

It is this very point which leads us to propose the widespread, systematic use of this method, certain that it can contribute very validly to our knowledge of the distribution of the metamorphic P/T regimes occurring in the Earth's crust in space and time.

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