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PLURIFACIAL ALPINE METAMORPHISM IN THE EASTERN BETIC CORDILLERAS (SE SPAIN), WITH SPECIAL REFERENCE TO THE GENESIS OF THE GLAUCOPHANE

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Zusammenfassung

In mehreren verschiedenen Fazies metamorphosierte Gesteine brauchen nicht polymetamorph zu sein, und werden als plurifazielle Gesteine bezeichnet. Folgende zeitliche Abfolge metamorpher Fazies alpinen Alters wird beschrieben: 1. Glaukophanschieferfazies, 2. Albit-Epidot-Amphibolitfazies, 3. Almandin-

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Amphibolitfazies. Es gab einen Übergang von kinematischen zu statischen Bedingungen. Die beschriebene alpine Metamorphose scheint unter einer Deckenlast vor sich gegangen zu sein. Der zeitliche Fazieswechsel wurde z. T. von einer beträchtlichen Temperatursteigerung bedingt.

Abstract

Rocks metamorphosed in two or more different facies are not necessarily polymetamorphic and are termed plurifacial rocks. The following age sequence of metamorphic facies of alpine age is reported: (1) glaucophane-schist facies; (2) albite-epidote-amphibolite facies; (3) almandine-amphibolite facies. There was a transition from kinematic to static conditions. The alpine metamorphism described seems to have proceeded under a pile of overthrust sheets. The change in metamorphic facies was in part due to a considerable rise of the temperature.

Résumé

Les roches montrant plus d'un seul faciès métamorphique ne sont pas nécessairement polymétamorphiques et sont dénommées plurifacielles. Quant au métamorphisme alpin, l'ordre suivant de succession chronologique des faciès fut constaté: (1) le facies à glaucophane, (2) le faciès amphibolite à albite-epidote, (3) le faciès amphibolite à almandin. Des conditions de métamorphisme cinématiques ont été suivies par des conditions statiques. Il paraît que le métamorphisme alpin décrit s'est effectué dans un géosynclinal de nappes. Le changement de faciès métamorphique dans le temps était partiellement dû à une augmentation considérable de la température.

Краткое содержание

Описаны метаморфные горные породы альпийского возраста. Дискутируются различные процессы, приведшие к преобразованию этих пород и образованию новых минералов.

Introduction and geological setting

Since the beginning of the summer of 1958 a geological team of the University of Amsterdam has been engaged in the detailed investigation of part of the eastern Betic Cordilleras. A summary of the geology of this region has been given by EGELER (in press). Its structure is essentially the result of large-scale overthrusting of alpine age. The individual overthrust units may be roughly divided into three major groups, the rocks of each of these groups showing a different degree of alpine metamorphism. Thus, the Betic of Málaga, which has hardly, if at all, suffered metamorphism of alpine age, is generally found to overlie the complex of the Alpujarride nappes, in which the alpine metamorphism is of a low grade. The Alpujarride nappes, apart from more local complications, in their turn overlie the complex of the Nevado-Filabride units (EGELER, in press), characterized by medium-grade metamorphism of alpine age. These Nevado-Filabride units comprise both the so-called mixed zone („Mischungszone") and the so-called "crystalline schists of the Sierra Nevada" of former authors. The present study bears upon the alpine metamorphism and therefore will only deal with the rocks of the Alpujarride nappes and those of the Nevado-Filabride units.

Since the number of samples subjected to detailed investigation is still limited, most of our petrological conclusions are as yet of a preliminary character. Unequivocal results, however, appear to have been obtained concerning the age sequence of several different stages of alpine metamorphism in a rather large region comprising the area S of Lubrín (prov. Almeria), each of these stages being characterized by a different metamorphic facies (DE ROEVER, EGELER & NIJHUIS, 1961).

It should be mentioned that the authors made use of preliminary results of investigations by O. J. SIMON, P. H. M. BRAAM, H. HELMERS, R. J. SNEPVANGERS, A. L. J. STOFFELS, and H. P. ZECK. The data on the plurifacial metamorphism in the investigated region are mainly derived from studies by the junior author (H. J. NIJHUIS) in the area S of Lubrín, which will be more elaborately dealt with in his thesis.

The alpine metamorphism in southeastern Spain

The eastern Betic Cordilleras consist in part of polymetamorphic rocks that not only have been affected by metamorphism of alpine age, but also have been metamorphosed during an older orogenic cycle. In order to avoid misinterpretations of the age of metamorphic minerals occurring in such polymetamorphic rocks, we will confine ourselves in the present paper to the characteristics of those rocks which have only been affected by metamorphism of alpine age (cf. CHATTERJEE, 1961).

Besides of polymetamorphic rocks of the type mentioned above the Alpujarride nappes mainly consist of Triassic sediments affected by low-grade metamorphism of alpine age. The study of this metamorphism has not yet yielded any important results.

Pumpellyite and glaucophane[2]), however, have been found in metadiabases that are intrusive in metamorphosed, in part fossiliferous, Triassic rocks belonging to the rather enigmatic low-grade metamorphic rock-sequence of the Sierra de Almagro studied by Mr. O. J. SIMON. The latter mineral obviously belongs to the world-wide glaucophane belt of Tertiary and Mesozoic age, a map of which — partly based on numerous data compiled by the senior author of the present paper — was recently given by VAN DER PLAS (1959).

In the tectonic units below the Alpujarride nappes — that is, in the Nevado-Filabride units, which comprise both the so-called "Mischungszone" and the "crystalline schists of the Sierra Nevada" — the alpine metamorphism reached a medium grade. Since in these medium-grade rocks no fossils have yet been found, a selection of the rocks only affected by metamorphism of alpine age is not so easily made. However, it may be concluded from a lithological comparison with the low-grade metamorphic rocks of the Alpujarride nappes as well as of other units, that we are dealing here with a repeated alternation of younger, in part Triassic rocks with older, polymetamorphic rocks that have also been meta-

[2]) Not crossite as erroneously described by SIMON, Thesis Amsterdam, 1963 (note added in proof).

morphosed during an older, pre-Alpine orogenic cycle. The most important representatives of this group of polymetamorphic rocks are graphite-rich schists with intercalated quartzites and marbles, and tourmaline-rich gneisses. A Triassic age, on the other hand, is attributed to the gypsum[3]) and the accompanying calcareous or dolomitic marbles, calcareous micaschists, and amphibole-micaschists; a similar or perhaps in part younger age may be assumed for various types of closely associated metabasites. The principal metamorphic minerals hitherto recognized as constituents of these younger rocks are, in alphabetic order: actinolite-tremolite (in the marbles and dolomites only), albite, blue-green amphibole, biotite, calcite, chlorite, chloritoid, dolomite, epidote, garnet, glaucophane, muscovite, oligoclase, oligoclase-andesine, phengite, sodium-rich pyroxene, quartz, and zoisite[4]). Since the rocks containing these minerals are considered to be of Triassic or younger age, all these minerals are inferred to have been formed during the alpine metamorphism. This conclusion is confirmed by the fact that glaucophane is among the oldest of the above-mentioned minerals (see below), and that glaucophane also occurs in metamorphosed intrusive diabases amidst Triassic rocks of the Sierra de Almagro, as mentioned above.

It is in the rocks under consideration, which were only affected by metamorphism of alpine age — that is, in the Triassic or perhaps in part younger rocks of the Nevado-Filabride units — that we found the above-mentioned age sequence of several different stages of metamorphism, each characterized by a different metamorphic facies. In current literature such rocks affected by metamorphism in several different facies have repeatedly been designated with the term "polyfacial". It is proposed here to avoid this hybrid word derived from a Greek and a Latin stem, and to designate all rocks affected by metamorphism in two or more different facies as "plurifacial" rocks, which designation has the advantage that it does not convey the impression that such rocks would necessarily be polymetamorphic as well. In many instances this is not the case, if at least the term "polymetamorphic" is reserved for rocks with a metamorphic history consisting of "two or more unified acts that are separable from one another and present no obvious genetic connexion" (READ, 1949, p. 130).

The rocks under consideration, which have only been affected by metamorphism of alpine age, most distinctly show a metamorphism in the albite-epidote-amphibolite facies, with blue-green amphibole. It may be mentioned that this facies is included in the greenschist facies by TURNER and VERHOOGEN (1960), under the name of quartz-albite-epidote-almandine subfacies.

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[3]) For a recent discussion of the age of the gypsum see FALLOT, FAURE-MURET, FONTBOTÉ & SOLÉ SABARIS, 1960, p. 507.

[4]) It is recommended to give such a list of metamorphic minerals in every paper on a metamorphic region, in order to facilitate studies concerning the regional distribution of metamorphic minerals and metamorphic facies.

Moreover, many rocks contain armoured relics of an older metamorphic facies that are commonly enclosed in single crystals of garnet or blue-green amphibole. It is not possible to decide, whether the metamorphism in the albite-epidote-amphibolite facies or that in this older facies represents the main phase of alpine metamorphism, since it is not known to which extent the older phase has been obscured by the younger one. Characteristic minerals of the older facies are glaucophane and sodium-rich pyroxene, which are accompanied by syngenetic epidote, garnet, and chloritoid, but not by lawsonite or pumpellyite. The occurrence of veinlets of blue-green amphibole in the glaucophane indicates that we are not dealing here with a later glaucophanization in the cores of crystals of green amphibole, as assumed to occur in the region of Gran Paradiso and Sesia-Lanzo by MICHEL (1953). These older minerals are indicative of the glaucophane-schist facies as originally defined by ESKOLA (1929). TURNER and VERHOOGEN (1960, p. 543) proposed to restrict this facies to "the paragenesis in which glaucophane schists are associated with assemblages containing lawsonite, jadeite-quartz, aegirine, or pumpellyite — typically all four", while they assigned the remaining glaucophane schists to the greenschist facies, but there are several arguments to reject this proposal. Firstly, it implies that the occurrence of glaucophane schists would not be characteristic of the glaucophane-schist facies; a facies as defined by TURNER and VERHOOGEN should bear another name. Further, the absence of glaucophane in almost all regions with true greenschists is not adequately reflected by a classification, according to which glaucophane schists not associated with assemblages containing lawsonite, jadeite-quartz, aegirine, or pumpellyite, are assigned to the greenschist facies. The restriction proposed by TURNER and VERHOOGEN would also imply an artificial partition of the world-wide glaucophane belt of Tertiary and Mesozoic age (cf. VAN DER PLAS, 1959). Moreover, according to ERNST (1959 a and b) the formation of, for instance, glaucophane schists with colourless mica from greenschists or rocks of the albite-epidote-amphibolite facies also implies a volume reduction, similarly as that of glaucophane schists with lawsonite, etc. The older minerals in the rocks under consideration are therefore classified in the glaucophane-schist facies, viz. in a subfacies characterized by the plentiful production of garnet, epidote, and sodium-rich pyroxene, but not of lawsonite or pumpellyite.

The rocks under consideration furthermore contain hysterogene mineral associations, which have been produced after the metamorphism in the albite-epidote-amphibolite facies. The most characteristic mineral of these younger associations is calciferous plagioclase, commonly represented by oligoclase or oligoclase-andesine which occurs as rims around older albite. This hysterogene calciferous plagioclase obviously belongs to the almandine-amphibolite facies. Thus, in the rocks under consideration the enumerated facies of the alpine metamorphism show the following age sequence:

(1) Glaucophane-schist facies (relics)
(2) Albite-epidote-amphibolite facies
(3) Almandine-amphibolite facies (hysterogene).

In several instances characteristic minerals of each of these facies showing the above age sequence have been observed in one thin section, so that we are dealing here with a real age sequence applying to one and the same locality.

According to results of investigations by the junior author (H. J. NIJHUIS) the character of the metamorphism shows a transition from kinematic to static during the sequence of metamorphic facies just mentioned. Many glaucophane crystals, for instance, have been broken and crystals of this mineral may also occur as inclusions in garnets that were rotated during their formation. The latter mode of occurrence also applies to part of the blue-green amphibole. On the other hand, a very distinct stage of static crystallization set in after the synkinematic crystallization in the albite-epidote-amphibolite facies. It is not yet known, whether the large crystals of muscovite, chlorite and albite produced during this static stage belong to the albite-epidote-amphibolite facies or to the greenschist facies in a restricted sense, i.e., to an additional facies. The large crystals of albite, again, in many instances show the above-mentioned rims of oligoclase or oligoclase-andesine belonging to the almandine-amphibolite facies. These relations will be more elaborately described in the thesis of the junior author.

The synkinematic stages of crystallization just mentioned have not yet been dated with respect to the formation of lineations, etc. Furthermore it may be mentioned that the occurrence of abrupt changes in the intensity of the alpine metamorphism at the boundary of the Nevado-Filabride units with the overlying Alpujarride nappes is indicative of comparatively late movements. On the other hand, the absence of conspicuous changes in the intensity of the alpine metamorphism along the boundaries of the deeper tectonic units seems to indicate that the metamorphism did not take place before the overthrusting, under a cover of rocks removed by erosion prior to the overthrusting.

Comparison with other regions affected by Tertiary or Mesozoic metamorphism

It is apparently due to the common occurrence of plurifacial metamorphism in the alpine orogenic belt, that the mapping of mineral zones in this belt was only successful at a much later date than that in, for example, the Caledonides. After this method was applied by the senior author (DE ROEVER, 1947) to material from the island of Celebes, comparable investigations by VAN DER PLAS (1959, partly based on numerous data assembled by the senior author of the present paper) and especially by ERNST NIGGLI (1960), WENK (1962 and earlier papers), and BEARTH (1962) have only recently led to very important advances of our knowledge of the Swiss and Franco-Italian Alps[5]). For this part of the alpine

[5]) As contended by CHATTERJEE (1961, see also VAN DER PLAS, 1959, p. 571), in evaluating the results of mapping of mineral zones due attention should be paid to the age-relations of the minerals under consideration.

belt, however, with the exception of a few studies, viz. those by the senior author's pupil VAN DER PLAS (1959) and by ELLENBERGER (1960), no attempts to a plurifacial analysis according to the facies principle of ESKOLA have yet been made. Consequently, material for comparison with the age sequence of the metamorphic facies in southeastern Spain is still rather limited. Therefore, a comparison with other parts of the alpine orogenic belt will also be made, in which we will confine ourselves to facies sequences of alpine age that include the glaucophane-schist facies. Different age sequences of the glaucophane-schist facies, the greenschist facies and a facies characterized by the plentiful production of pumpellyite — corresponding to the higher-grade part of COOMBS' (1960) prehnite-pumpellyite-metagreywacke facies (see also SEKI, 1961) — are known from Celebes (DE ROEVER, 1947, 1950) and Corsica (NETELBEEK, 1951; BROUWER & EGELER, 1952). In eastern Celebes, for instance, metamorphism in the glaucophane-schist facies is preceded, laterally accompanied at the low-grade side, and followed by metamorphism in the pumpellyite facies mentioned, while there is also a later metamorphism in the greenschist facies. Furthermore, in the Vanoise region (French Alps) ELLENBERGER (1960) found metamorphism in the glaucophane-schist facies to have been followed by metamorphism in the greenschist facies, while for the northern Adula region (Switzerland) VAN DER PLAS (1959) established the age sequence: (1) glaucophane-schist facies; (2) albite-epidote-amphibolite facies; (3) greenschist facies. In all instances cited the metamorphism in the glaucophane-schist facies is very early, a conclusion which seems to be of more general application. For no other region than southeastern Spain does it seem to have been established with certainty that later metamorphism in the almandine-amphibolite facies affected the same rocks that were earlier metamorphosed in the glaucophane-schist facies. However, according to recent results of investigations by BEARTH (1962), in part based on the work of WENK (1962 and earlier papers), a similar age sequence of metamorphic facies of alpine age would occur in the circumference of the Lepontine region near the Swiss-Italian frontier, i.e., in a region of great petrogenetic importance. An accurate determination of the age sequence of the metamorphic facies in the latter region, together with dating of the facies changes with the aid of lineations, etc., could lead to a very important advance of our knowledge of the alpine metamorphism.

Zoned crystals of amphibole containing both blue and green, blue-green or colourless amphibole have also been reported from several regions in Japan (e.g., MIYASHIRO & BANNO, 1958, p. 107; SEKI, 1957, p. 369, and 1958, p. 240; SHIDÔ & SEKI, 1959, p. 676; IWASAKI, 1960 b, p. 625—626), while SEKI (1957, p. 370) described pseudomorphs of epidote, quartz, sericite, and albite after lawsonite from the Kantô region NW of Tokyo. Though IWASAKI (1960 a, p. 571—573; 1960 b, p. 629) ascribed the occurrence of zoned crystals of amphibole to changes in the conditions of metamorphism, it seems that the importance of the above-mentioned phenomena as indications of plurifacial metamorphism has generally been underrated by Japanese authors, which may in part be due to the fact that the Japanese sodium-amphibole in several instances is accompanied by older as well as by younger green amphibole. It is not impossible, therefore, that the two different subfacies of the glaucophane-schist facies proposed by MIYASHIRO and SEKI (1958) comprise mineral associations that in reality may have been produced during different stages of metamorphism, each characterized by a different metamorphic facies.

For the methods of plurifacial analysis reference may be made to papers by the senior author (DE ROEVER, 1947, p. 157—160 and 162), FYFE, TURNER and VERHOOGEN (1958, p. 14), and VAN DER PLAS (1959, p. 552—571); dating of the metamorphism in the different facies with the aid of linear structures, etc., may be done according to the methods described by, for instance, WUNDERLICH (1957, 1958), PLESSMANN (1957, 1958), and ZWART (1963).

As to the importance of plurifacial analysis, the following may be quoted from READ (1949, p. 104): „If we could be sure that, possibly over a somewhat restricted field, a metamorphic facies was peculiar to a given time in the development of the metamorphic rocks of that field, then the plutonic geologist would have gained a principle as valuable to him as WILLIAM SMITH's Second Law is to the stratigrapher."

Conclusions from experimental data on the conditions of formation of characteristic minerals of the glaucophane-schist facies

Only few experimental data are available concerning glaucophane itself. All natural glaucophane investigated by ERNST (1962), however, corresponded to a high-pressure — low-temperature modification of the artificial iron-free material that he likewise described under the name of glaucophane and which is stable over a wide range of physical conditions.

More distinct indications are obtained from the data available for some other minerals of the facies. For glaucophane schists with slightly acmitic jadeite accompanied by quartz, and associated with aragonite — which according to an unsuspected find by COLEMAN and LEE (1962) occurs as a metamorphic high-pressure mineral in lawsonite-bearing rocks — the experimental data indicate that confining pressures during their origination may have been 7—10 kilobars at 200° C., or, for instance, 10—14 kilobars at 400° C.

According to investigations by BIRCH and LECOMTE (1960), the reaction albite = jadeite + quartz requires confining pressures of about 10 kilobars at 200° C., or about 14 kilobars at 400° C. to proceed to the right. This reaction was studied between 15 and 25 kilobars, 600° and 1000° C. Two systems of generating pressure were used, with mutually consistent results: a „simple squeezer", and a nitrogen system with hydrostatic pressure. The equilibrium line is given by the relation, $P = 6000\ (\pm 500) + 20\ (\pm 2)\ T$, where P is in bars, T in degrees Celsius. This was said to be in good agreement with the curve of KELLEY and others based on thermochemical data. The equilibrium curve was sought from both sides, by causing albite to break down to jadeite + quartz, and by causing charges of jadeite + quartz to form albite. At a temperature between 840° and 863° C., for example, jadeite and quartz were partially converted into albite at a pressure of 21.28—21.76 kilobars (run 100, duration 11 hours); further, at a temperature of 800° C., a charge consisting of jadeite, quartz and silicic acid partially reacted to form albite at a pressure of 21 kilobars (run 66, duration 1 hour), whereas at the same temperature and a pressure of 23.4—23.44 kilobars albite was partially converted into jadeite and quartz (run 103, duration 3 hours). Similarly, at a temperature of 600° C., a charge consisting of jadeite, quartz and silicic acid was partially converted into albite at a pressure of 15 kilobars (run 51, duration 22 hours), whereas at the same temperature and a pressure of 18 kilobars jadeite and quartz were produced in a charge of albite and silicic acid (run 50, duration 21 hours). The natural jadeite from Burma used in these experiments is comparatively pure, having only a very slight content of diopside and acmite. According to Brown, Fyfe, and Turner (1962, p. 581), at a given temperature the pressure for equilibrium between jadeite + quartz and albite would be lowered by the iron content of the jadeite (see also Miyashiro & Banno, 1958, p. 104).

The polymorphic transition calcite—aragonite according to investigations by Jamieson (1953), Clark (1957), and Goldsmith (1959) requires about 7 kilobars at 200° C., or about 10 kilobars at 400° C [6]). The most extensive studies of this transition are those by Jamieson, G. J. F. MacDonald (1956), and Clark. Mac Donald's equilibrium curve, determined by direct experiment with a „simple squeezer" in the temperature range 200° to 600° C., is at a pressure about 1½ kilobars lower than the curve obtained by Jamieson on the basis of a thermochemical study at temperatures between 25° and 80° C. Jamieson calculated an equilibrium pressure of 3920 kg/cm² for 298.1° K. Since the state of stress to which the sample is subjected in a „simple squeezer" is not susceptible to direct determination, Clark (1957) made a number of runs — between 410° and 575° C. — in a different type of apparatus in which the pressure was truly hydrostatic. At a temperature of 575° ± 10—15° C., for example, Clark found synthetic calcite to convert into aragonite at a pressure of 13,200 ± 100 bars (run 129, duration 2¼ hours), and synthetic aragonite into calcite at 12,700 ± 100 bars (run 130, duration 2 hours). Clark's results are in excellent agreement with those of Jamieson. Clark also reported: „Professor Kennedy, in whose laboratory MacDonald's work was done, has informed me that the accuracy of his determinations of pressure in the simple squeezer have recently been improved, and that further work on this reaction is in good agreement with the results presented here." Goldsmith (1959) extended the equilibrium curve to approximately 16,000 bars at 800° C., again in good agreement with the findings of Clark. The low-temperature part of the curve was roughly checked by Dachille and Roy (1960, fig. 2), under the addition of displacive shear which itself did not alter the equilibrium relations between the phases to a measurable extent (see also Griggs, Turner & Heard, 1960, p. 97—99). The experiments by Dachille and Roy on calcite at room temperature and 4—5000 bars, for instance, showed plainly the formation of over 50 per cent aragonite in only 16 hours; similar experiments on aragonite in the calcite field were successful at 200° C. and above.

The question, whether at the given temperatures such high pressures can occur in nature, has recently been discussed by Coleman and Lee (1962), and by Brown, Fyfe, and Turner (1962). Brown, Fyfe and Turner made a number of experiments on the possibility of survival of aragonite and the corresponding incompleteness of the reverse trans-

[6]) Note added in proof: Slightly higher values were recently obtained by Simmons and Bell (Science, vol. 139, p. 1197—1198, 1963).

formation aragonite — calcite, and concluded that available experimental data are consistent with metamorphic temperatures between 200° and 300° C. and a geothermal gradient of about 10° C. per km, corresponding to a depth of metamorphism of more than 20 km. COLEMAN and LEE, on the other hand, suggested that in addition to load pressure a pressure of tectonic origin of about 3 kilobars was operative, the maximum possible magnitude of which is determined by the strength of the rocks in question. In this case, too, load pressures must still have been considerable, e.g., for a temperature of metamorphism of 200° C. corresponding to a thickness of the overburden of about 15 kilometres, which, if not due to sedimentation only, may have been reached in a „géosynclinal de nappes“ in the sense of ELLENBERGER (1952, 1958).

To our present knowledge, the metamorphism in the glaucophane-schist facies in southeastern Spain has not given rise to the production of jadeite-quartz and aragonite, and therefore apparently proceeded at lower pressures. Further quantitative indications concerning the magnitude of these pressures are not available. Anyhow, at a given temperature they must have been higher than those conducive to the origination of rocks of the greenschist facies or of the albite-epidote-amphibolite facies (ERNST, 1959a and b), the resulting combinations of temperature and pressure being so unusual that glaucophane has only scarcely been produced during pre-Mesozoic regional metamorphism (DE ROEVER, 1956). It seems, therefore, that the metamorphism in the glaucophane-schist facies in southeastern Spain has proceeded at appreciable depth. Since the thickness of the sediments here is not exceptionally great, it has apparently taken place in a „géosynclinal de nappes“, i.e., after the formation of a pile of overthrust sheets. The subsequent change of metamorphic facies in time, under waning tectonic influence, is in part to be ascribed to a considerable rise of the temperature, as can be inferred from the production of oligoclase and oligoclase-andesine during the latest stage of metamorphism recognized. Abrupt changes in the intensity of the metamorphism at certain nappe boundaries[7]) (see above) are apparently due to comparatively late movements, after the main period of overthrusting, but perhaps at least in part before the later, static phases of metamorphism (LEINE & EGELER, 1962).

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[7]) A comparable abrupt change in the intensity of the metamorphism, reported from the island of Kabaena near Celebes by the senior author (DE ROEVER, 1953), may similarly be due to comparatively late movements.

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Observation de M. LEMOINE à la suite des conférences de MM. EGELER et DE ROEVER:

Les précédents exposés de MM. DURAND-DELGA et MATTAUER nous ont déjà montré certaines analogies de structure — peut-être superficielles — des chaines du pourtour de la Méditerranée occidentale avec les Alpes Occidentales. Mais les très intéressants exposés de MM. EGELER et DE ROEVER sur la structure et le métamorphisme alpin de la partie orientale des cordillère bétique mettent en évidence une autre analogie, très importante: C'est le caractère nettement syn- et post-tectonique du métamorphisme alpin[8]), qui se traduit par la décroissance de son intensité au fur et à mesure que l'on l'élève dans l'édifice des unités tectoniques. Et, ici aussi, le problème de la surcharge se pose (la nappe de Malaga est beaucoup trop mince pour jouer ce rôle). Un hypothétique « géosynclinal de nappes », dont toutes les nappes se seraient « envolées » par la suite, est dans les deux cas une solution séduisante, mais également gratuite.

REMARQUES SUR LA TRILOGIE SERPENTINITES-GABBROS-DIABASES DANS LE BASSIN DE LA MÉDITERRANÉE OCCIDENTALE

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Zusammenfassung

Es wird eine Entwicklung der Anschauungen über die alpinen Diabase, Gabbros und Serpentinite während der letzten 35 Jahre gegeben. Die Diabase haben sich als submarine Lavaergüsse erwiesen. Die Stellung der Gabbros und deren Saussuritisierung bleibt noch unklar. Die Serpentinite werden von ultrabasischen Intrusiva abgeleitet. Ausführliche Diskussion von Beobachtungen; Vergleich von alten und neuen Hypothesen.

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