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An-Variation and Intergrowths of Plagioclases in Banded Metamorphic Rocks from Val Carecchio (Central Alps)

By *E. Wenk**) and *H.-R. Wenk***)

Abstract

In a highly diverse banded series from a single outcrop in the zone of partial anatexis of the Central Alps, the plagioclase composition changes stepwise from An 18–25 in leucocratic gneiss to An 90 ± 3 in marble bands. The general increase is a response to changing rock composition from salic to mafic and from sodic to calcic types. But the stepwise change, with preferred plagioclase compositions and gaps between, is controlled by discontinuities in the crystal structure.

Microscopic intergrowths of andesine An 33 ± 6 with labradorite An 67 ± 5 and of labradorite An 62–70 with bytownite/anorthite An 88–92 show the important growth faces $(1\bar{1}0)$, (110), (001), $(0\bar{2}1)$ and (010) as contact planes.

In one sample three plagioclases are intergrown: anorthite-bytownite crystallizes in the primitive anorthite structure with sharp *b*- and *c*-reflections, labradorite exhibits intermediate plagioclase structure with *e*-satellite reflections oriented as in igneous andesine. Andesine which occurs as fine lamellae does not show any superstructure even in strongly exposed X-ray photographs. We describe a hiatus between An 18–25 and An 28–35 which is present in the general distribution as well as in intergrowths with andesine grains showing isolated patches of oligoclase.

The results are compiled in a tentative diagram showing the variation of plagioclase composition as a function of metamorphic grade and rock composition. Fig. 6 may be compared with published phase-diagrams for the subsolidus range.

1. INTRODUCTION

In metamorphic rock series, the An-content of plagioclase changes in response to metamorphic grade as well as to rock composition and paragenesis. This was postulated early in this century, among others by F. Becke (1903), who realized the need to improve microscopic determination methods for

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feldspars and took an active lead in it. But it was not until the refinement of U-stage techniques (from DUPARC-REINHARD, 1924 onward) and of optical determination tables that extensive series of plagioclases could be investigated, and that Becke's postulate could be tested.

U-stage studies, and more recently, microprobe analyses, have now established that in metamorphic terrains the An-content of plagioclase is constant in isochemical rocks which crystallize at the same physical conditions. But it increases within the same metamorphic environment with rising normative An-content of the rock. Variations in An-content can be interpreted as a response to changing physico-chemical conditions. The reactions are complex, however, because a great number of phases are involved.

Growing evidence showed that both types of variation of An – in isochemical rocks with rising grade and in isophysical rocks with changing composition – are discontinuous, with gaps and prefered compositions, i.e. that under conditions of regional metamorphism the plagioclase series does not constitute a continuous solid solution series. Statistic microscopic analysis of metamorphic rock suites on a regional scale located steps near An 4, 17, 30, 60–70 and 85–90 and showed coexistence of two plagioclases often in crystallographic intergrowth. These characteristics of metamorphic plagioclases are reflecting the *discontinuities in the crystal structure*, explored in the past 25 years, and the complex *stability relations of the series at subsolidus conditions* which are still insufficiently known[1]). The following study is concerned with the variability of plagioclase composition in a highly diverse rock series at a single outcrop where mineral assemblages recrystallized simultaneously and at similar temperature-pressure conditions.

2. OCCURRENCE

The outcrop of the rocks described is situated in a side valley of Val Verzasca in the Central Alps, at coordinates 721.05/124.0 (map sheet Osogna 1 : 50000) and at an altitude of 1170 m; it covers roughly 300 m^2. The locality is reached from Lavertezzo along the trail to the abandoned Alpe Carèch. The rocks exposed in an average thickness of 25 m belong to the Castione zone, and constitute presumably metamorphic mesozoic sediments. The well-banded and folded series consists mainly of metapelites, subordinately of marbles and CaMg-silicate rocks (samples 593 and 746) and is bordered by huge masses of leucocratic gneiss (5931, 753, 746c). Amphibolites and related rocks (samples 697–700) derive from the WNW continuation of the same narrow zone, in direction of Monte Eus.

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[1]) For references and details see SMITH (1974).

The regional metamorphism at the exposure reached conditions of amphibolite facies in Miocene times. Kyanite is a typical index mineral of this zone. Amphibolites contain andesine and sporadically more calcic plagioclase, and clinopyroxene. The locality lies in the border zone of partial anatexis of the Lepontine Alps. Visitors who care to study the magnificent river outcrops between Lavertezzo and the type-section Carecchio are impressed by the common occurrence of knots, lenses, bands, veins and dikes of quartz-feldspar mobilisate, and of veined gneisses. Further NE, in the Cima Lunga synform at higher altitudes, the phenomena of quartz-feldspar mobilization disappear. Based upon mineral assemblages, the temperature of regional metamorphism may have reached 650°C and the pressure approximately 6 Kbar (Wenk et al. 1974).

3. VARIATION OF An-CONTENT

In Fig. 1, estimated modes and An-contents of plagioclase (U-stage and microprobe) of twenty representative rocks are displayed. On the left, eleven carbonate-free gneisses, schists and amphibolites are arranged in order of increasing color index. On the right are nine calcite-bearing samples in order of increasing An-content. The narrow, anorthite-rich bands of the outcrop are quantitatively overrepresented in the graph, as they are of special interest for this study, and the common leucocratic gneisses are underrated. Fig. 1 illustrates clearly that at a single outcrop, the An-content increases *stepwise* from salic to mafic, and from sodic to calcic rocks, with *pronounced discontinuities.*

As a function of paragenesis and mode, the An-content of plagioclase varies in the Carecchio rocks in the following way:

Albite is not observed, because leucocratic gneisses rich in sodium and very poor in calcium do not occur at the outcrop.

The most sodic plagioclase at Carecchio is *oligoclase* An 18–25 which is common in leucocratic alkalifeldspar-gneisses of granitic to granodioritic composition.

Andesine An 28–38, in amphibolites up to An 48, and often with isolated patches An 20–25 in the center of the grain dominates in mesocratic plagioclase-gneisses, in mica schists and in amphibolites. From the chemical analysis of biotite-schist 593k the normative An-content 32 is calculated (range by optic methods An 28–38).

The feldspars of the alkalifeldspar-bearing amphibolite 698b were studied in some detail. Plagioclase in this sample is often inhomogeneous and patchy, with An ranging from 23 to 47; but without regular microscopic intergrowth of two plagioclase phases. The bulk of the optic measurements lies between An 36 and 45. The average value of

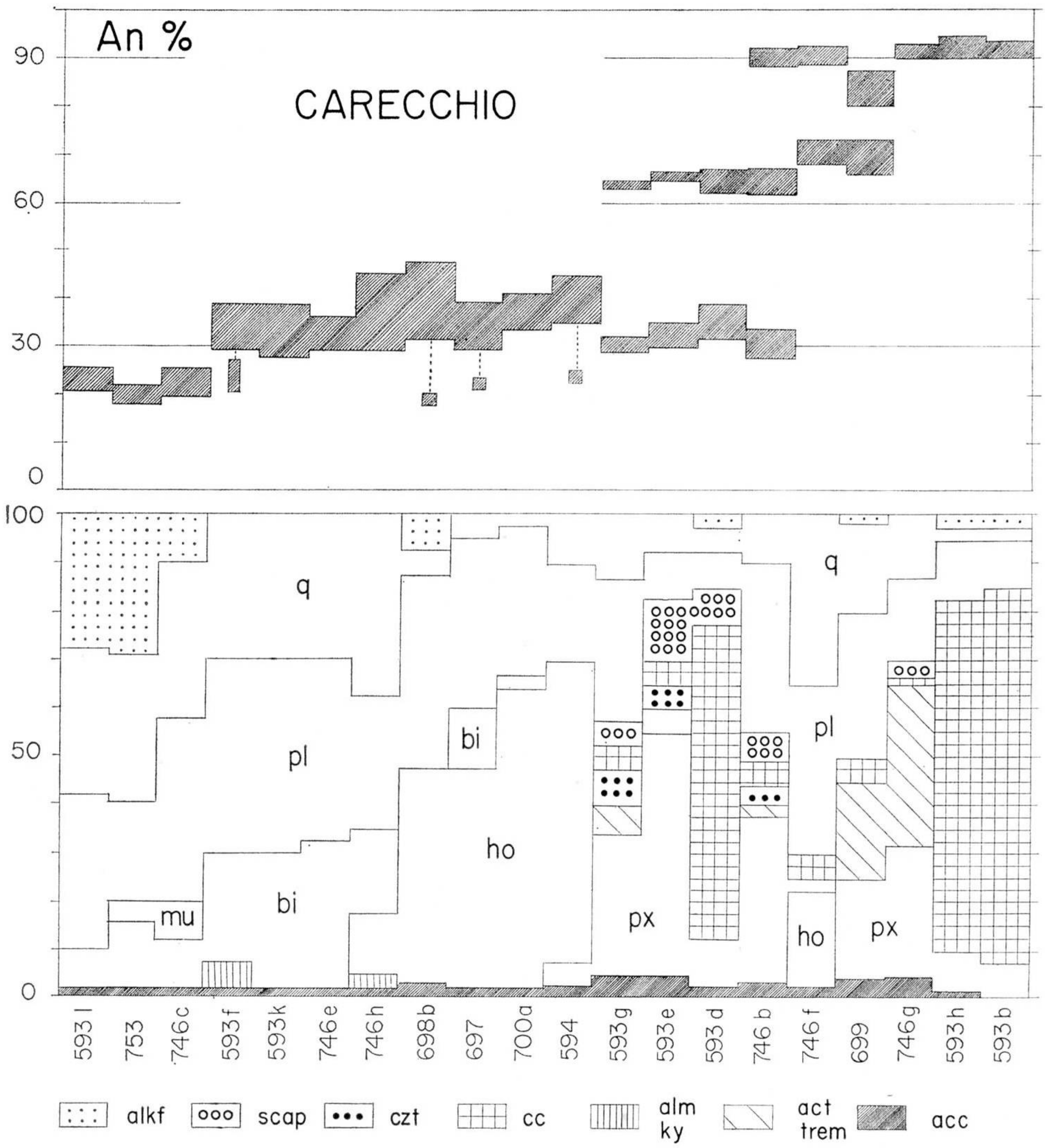

Fig. 1. An-content of plagioclase (U-stage and microprobe) and estimated modes of twenty rock samples from the banded metamorphic series of Val Carecchio, Castione zone.

15 microprobe determinations of basic host crystals gives Or 0.5, Ab 54.5, An 45.0. Oligoclase composition was found in the margins between andesine and interstitial K-feldspar, and in distinct rims around K-feldspar inclusions, as well as in irregularly distributed spots. The K-feldspar occurring as interstitial crystal as well as inclusions in plagioclase appears as finely twinned microcline of the composition Or 96 (93–99), Ab 3.5, An 0.5 (mean value of 10 microprobe-determinations). $2V_\alpha = 45°$, with a wide range from 30 to 58°. In these antiperthitic intergrowths mainly (001), (110) and $(1\bar{1}0)$ were determined as composition planes. These textures indicate simultaneous crystallization of plagioclase and K-feldspar. There is also convincing evidence that the potassium phase,

concentrated in the interstices and protruding along cracks into the plagioclase, continued crystallization after the formation of plagioclase. The presence of K-feldspar instead of biotite marks this rock as a very special amphibolite, mineralogically related to some amphibolites and tonalites in the Bergell Alps (Wenk et al., 1977).

Labradorite An 63–70 often with microscopic *lamellae of andesine* An 30–39, is common but confined to CaMg-silicate rocks containing meionitic scapolite, and to scapolite-marbles (Wenk et al., 1975). The following Euler angles could be derived for two labradorite host-crystals twinned after the Carlsbad law:

sample	Φ	Θ	Ψ	$2V_\gamma$	An
593d	50°	35°	25°	85°	64
593e	51.5°	37°	26.5°	87°	63–64

The narrow andesine lamellae An 35–40 in 593d and An 30–35 in 593e did not allow a reliable construction.

Bytownite An 80–87 (up to 90?) with microscopie *lamellae of labradorite* An 65–73, grading into submicroscopic intergrowth, was discovered in calcite-bearing CaMg-silicate rocks free of scapolite (see Fig. 3).

Anorthite An 90–93 is common in diopside marbles which often contain K-feldspar. It also is a component of veins in the scapolite-bearing diopside-actinolite schists such as samples 746b and g.

Fig. 2 shows the variation of plagioclase and rock composition in adjacent bands of a 25.5 cm long rock sample (Vz. 746m), examined in seven successive thin sections cut perpendicular to the foliation. The graph confirms the facts mentioned above, but gives additional information on the often very pronounced An-variation between neighbouring rock layers of contrasting composition. The most calcic plagioclases are found in calcsilicate rocks and marbles. Intergrowths of andesine and labradorite are confined to scapolite-marbles; but within these rocks plagioclase grains, mantled by calcite, diopside and clinozoisite, are anorthites. The succession of Ca-rich bands in Fig. 2 is on both sides bordered by thick layers of mesocratic biotite-andesine-gneiss which are better represented in Fig. 1. The average normative An-content calculated from the chemical analysis of the 10 cm broad marble band in Fig. 2 is An 80.

4. INTERGROWTHS OF TWO AND THREE PLAGIOCLASES

As illustrated in the previous paragraph, the variation in An-content is *discontinuous*. An 20–25, An 28–40 (–48), An 62–70 (–75) and An 85–92 are the dominant compositions, and these preferred plagioclase types are also observed in crystallographic intergrowths. In the intergrowths, the phases are in the same crystallographic orientation not considering minor adjustments due to

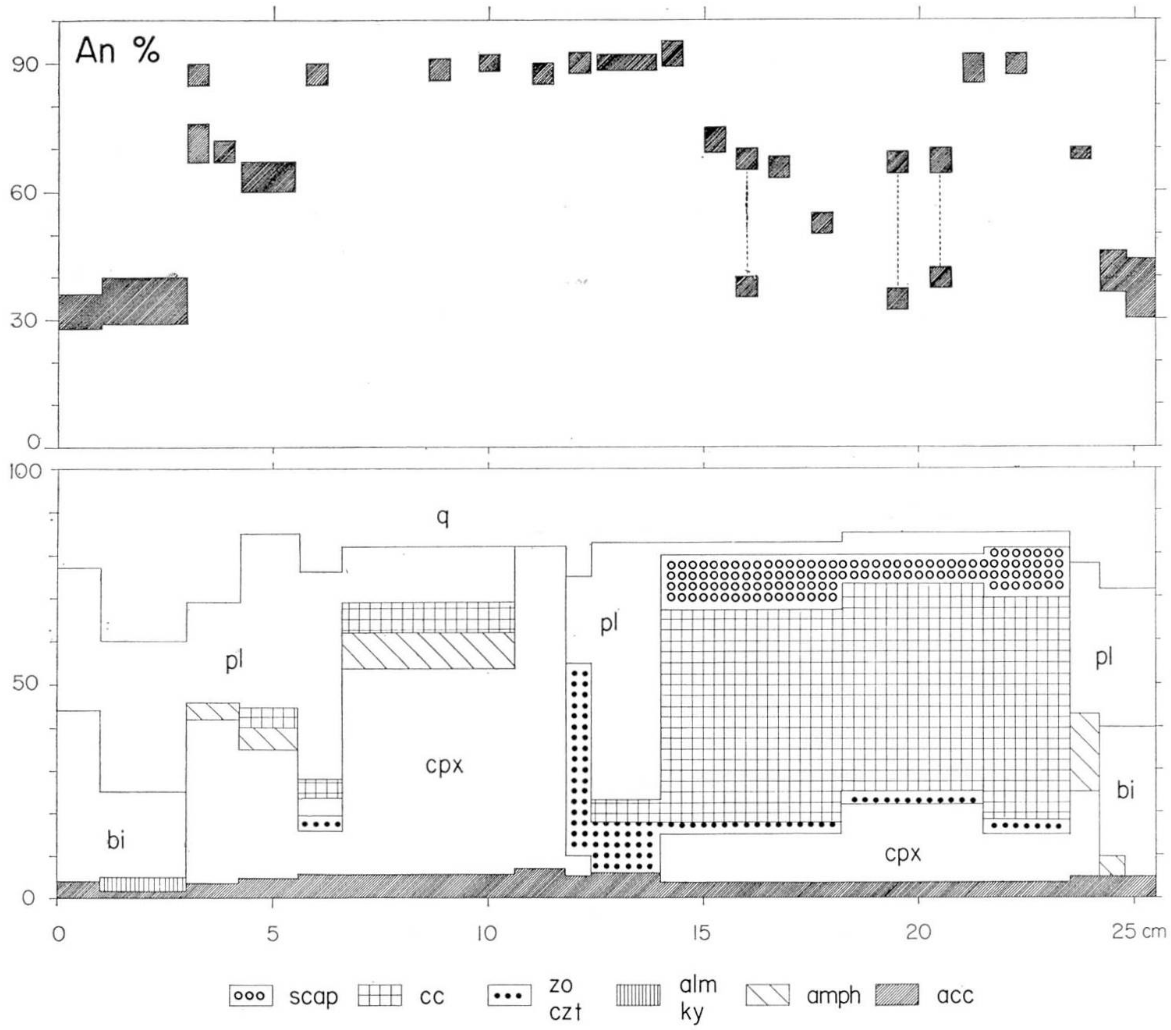

Fig. 2. Variation of plagioclase composition and of mode across the 25.5 cm long banded rock sample Vz. 746 m, examined in seven thin sections cut perpendicular to the foliation. Outcrop Carecchio in main river on northern shore, coordinates 712.25/123.93. Intergrowth of labradorite and andesine is marked by dotted line. Anorthites found in scapolite-marble concern grains surrounded by calcite, diopside and clinozoisite. As accessory mineral sphene is more common than ore minerals.

differences in lattice constants. They are easily recognized in the petrographic microscope due to different extinction angles and contrasting relief (Figs. 3 and 4). While in the *oligoclase-andesine* pair, oligoclase appears only as small isolated inclusions, in the *andesine-labradorite* and in the *labradorite-anorthite* intergrowths lamellae are observed which are parallel to rational planes (in order of frequency: $(1\bar{1}0)$, (110), (001), $(0\bar{2}1)$, $(\bar{2}01)$ and (010), rarely planes with higher indices, all important growth faces). We noticed that the sodic phase is always the minor component in a calcic host. Lamellae running obliquely to a twin plane are often repeated symmetrically in the second individual. As illustrated by Figs. 3 and 4 alternating parallel lamellae may show buttress-like structure similar to oscillatory zoning observed in mag-

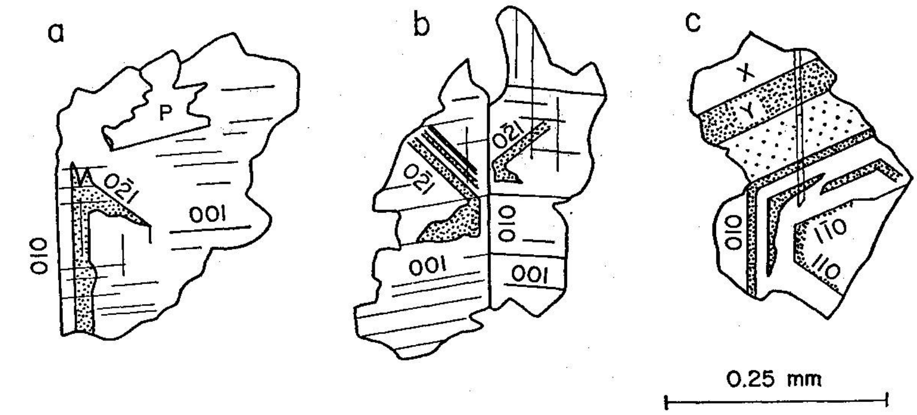

Fig. 3 a–c. Morphology of plagioclase crystals showing intergrowth of calcic labradorite (dotted) and bytownite, from CaMg-silicate rock Vz. 699, Monte Eus, Val Carecchio. (a) bytownite host crystal An 80–85 with pericline twin P, cleavages (001) and (010), and with lamella An 67–70 (U-stage). The fish-hook shaped inclusion is 0.2 mm long and 0.02 mm broad. Contact planes are (010) and (0$\bar{2}$1). (b) Simple albite-twin of bytownite An 80–85 (possibly 90) with cleavage (001) in both individuals and with thin lamellae An 70–75. Composition plane (0$\bar{2}$1). On the U-stage the optic orientation of the lamellae could be measured in the triangular part in the left hand individual, (c) crystal with alternating zones of basic labradorite/acid bytownite and of bytownite, occurring in about equal amounts and grading into submicroscopic intergrowth. The optic orientation relative to the albite lamella and the well pronounced zone boundaries could only be measured in areas x (An 80–85, possibly 90) and y (An 65–71). In the rest of the crystal the oscillatory zoning is very fine. The microprobe determined for x Or 0 Ab 17–20 An 80–83, for y Or 0.5 Ab 30–33.5 An 66–69.5, and for the adjoining lower part in Fig. 3c An-values ranging from 71 to 78. At one spot a potassium feldspar Or 96.5 Ab 3 An 0.5 was analyzed which is not visible in the microscope.

matic rocks. The feature is very conspicuous if microscopic repetition grades into suboptical intergrowth. These observations indicate that both phases grew alternately during metamorphism and are not due to secondary exsolution.

Of special interest is sample 746 b_2 which was studied in detail in several thin sections. Thin layers consisting mainly of diopside and anorthite alternate with those bearing clinozoisite and scapolite as main constituents. In these layers intergrowths of anorthite An 88–92 (U-stage 85), labradorite An 62–65 (U-stage 64–66) and andesine An 27–30 (U-stage 30–35) were observed (Fig. 4d). While the labradorite-andesine intergrowth is identical to the one described above with rational composition planes (110) and (1$\bar{1}$0), anorthite occurs in the center of larger crystals with sometimes locally corroded boundaries and myrmekite-like stringers of quartz. Anorthite in this sample could be a relict from a slightly earlier stage in the crystallization history. X-ray precession photographs and U-stage studies indicate that all three phases are nearly in the same orientation.

Studies in progress on a metamorphic series from the tectonic window of Bagni del Masino (Prov. Sondrio, Italy), in the base of the nappe-forming megacrystic Bergell granodiorite-gneiss, reveals some new aspects: There, in the sillimanite-cordierite zone and within the zone of anatexis, andesine coexists with predominant bytownite/anorthite in regular crystallographic intergrowth as well as with irregular contact between large anorthite grains and partial andesine rims, and also as separate grains. The metamorphic environment of Bagni del Masino is further characterized by the unusual frequency of Carlsbad-Roc Tourné-albite threelings and fourlings of basic plagioclase in the equigranular mosaic fabric of calcsilicate rocks.

The intergrowths of plagioclase reported in this paper are different from intergrowths described earlier in igneous rocks where submicroscopic lamellar structures were interpreted as exsolutions of two chemically different phases. The proposed compositional ranges, which could not be measured directly for peristerite (Böggild, 1924), labradorite (Böggild, 1924; Nissen, 1971) and bytownite (Huttenlocher, 1942, Nissen, 1968; Nord et al., 1972; Grove, 1976) intergrowths compare well with our determinations but the geometry of the intergrowth and the way of formation is entirely different.

In his elaborate study of Boehl's Butte anorthosites, Idaho, Nord (1973) described andesine An 40–45, labradorite An 60 and bytownite-anorthite An 80–97 in contact with each other and with similar crystallographic orientation. The microscopic contact planes are (010), (001) and probably (132). Two and three plagioclase assemblages are proposed to have resulted from incomplete metasomatic replacement of original labradorite. The intergrowths discussed by Nord differ in thin sections in dimension as well as in orientation from those described in this paper.

5. CHEMICAL COMPOSITION OF PLAGIOCLASE AND CRYSTAL STRUCTURE

Most chemical determinations were made with U-stage techniques, selecting plagioclase grains which showed twin-planes and cleavage. The curves of Burri, Parker, Wenk, 1967, were used for interpretation. This optical method supplies not only chemical data, but allows also indexing of the composition planes of intergrown plagioclase phases simultaneously. For special samples, we did a detailed survey with an 8-channel ARL microprobe analyzing for Si, Al, Ca, Na, K, Fe, Sr and Mg, or Ba. In none of the samples were the last four elements present in more than trace amounts ($MgO < 0.02$, $SrO < 0.15$, $BaO < 0.01$, $FeO < 0.04$ weight %). A very fine-focused beam was used to get maximum spatial resolution risking some alkali evaporation in the Na-rich plagioclases. Results of averages of point analyses are listed in Table 1. They confirm the U-stage analyses but add some additional data which are still puzzling but may by significant in the interpretation of intergrowth formation and establishment of the chemical environment. In plagioclase (Ca, Na, K) (Si, Al) Si_2AlO_8 the An-content can be calculated either as $(Al-1)/(Si+Al-3)$ or as $Ca/(Ca+Na+K)$. In a stoichiometric structure, both values should be identical, and we notice in our analyses that this is the case

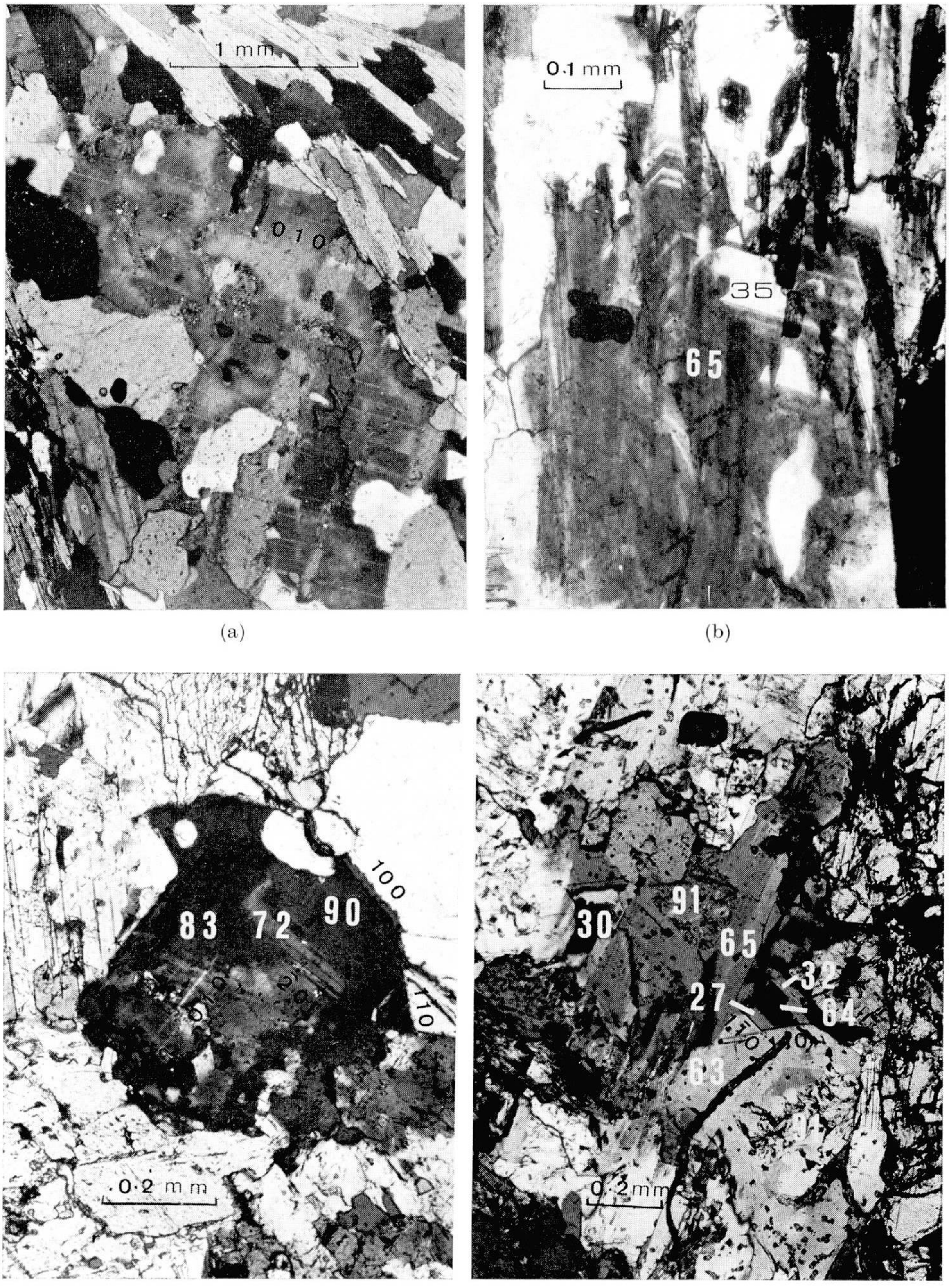

Fig. 4. Photomicrographs of plagioclase intergrowths. Composition is indicated, see Table 1, Miller symbols in black. (a) Andesine An 29–38 with oligoclase An 21–27 inclusions, sample Vz. 594f. (b) Buttress-like labradorite An 62–67-andesine An 31–37 intergrowth, sample Vz. 593d. (c) Inhomogeneous two-bytownite intergrowth, sample Vz. 699. (d) Anorthite, labradorite and andesine, sample Vz. 746 b_2.

Table 1. *Average microprobe analyses of feldspars showing intergrowths.*

Major elements are indicated. Samples have also been analyzed for Fe, Mg, Ba, and Sr, but only traces were present (Bence-Albee correction applied). Analyst H. R. W.

Sample		Spot No.	weight percent oxides SiO_2	Al_2O_3	CaO	Na_2O	K_2O	formula based on 8 oxygens Si	Al	Ca	Na	K	An content $\frac{Al-1}{Si+Al-3}$	An content $\frac{Ca}{Ca+Na+K}$	no. of analyses
Vz 593		1	62.1	24.3	5.9	8.5	0.08	2.73	1.26	0.28	0.73	0.005	27	26	8
		2	62.8	23.7	5.1	8.9	0.10	2.76	1.23	0.24	0.76	0.005	24	23	16
		3	65.5	22.2	3.3	10.0	0.13	2.85	1.14	0.15	0.85	0.008	15	14	7
Vz 698		1	58.2	26.6	8.4	6.8	0.32	2.60	1.40	0.40	0.59	0.02	40	40	3
		2	58.7	25.2	7.3	7.3	0.41	2.65	1.34	0.35	0.64	0.02	35	34	10
Vz 699	Area 1	1	49.2	32.3	14.3	3.0	0.1	2.26	1.75	0.70	0.27	0.005	74	72	12
		2	46.9	34.3	16.6	1.9	0.05	2.16	1.86	0.82	0.17	0.003	84	83	16
	Area 2	3	49.9	31.1	12.9	3.3	0.5	2.32	1.70	0.64	0.30	0.04	69	66	12
		4	46.5	33.8	16.5	1.8	0.05	2.16	1.85	0.82	0.17	0.003	84	83	7
	Area 1/2	5	48.0	32.1	15.5	2.2	0.9	2.23	1.76	0.77	0.19	0.05	77	76	5
		6	47.1	33.4	16.7	1.9	0.3	2.17	1.82	0.83	0.17	0.02	83	81	12
		7	46.5	34.5	17.5	1.6	0.08	2.13	1.86	0.86	0.14	0.04	87	83	25
	Area 2	8	64.0	18.0	00.0	0.35	18.0	2.97	0.99	0.00	0.03	0.99	Kspar	Kspar	1
Vz 746 b_2	Area 1	1	59.1	26.2	5.7	7.0	0.17	2.66	1.39	0.27	0.61	0.10	37	28	7
		2	51.8	30.3	12.0	4.1	0.04	2.38	1.64	0.59	0.36	0.02	63	62	5
		3	45.7	34.5	17.8	1.2	0.04	2.12	1.88	0.88	0.10	0.02	88	88	9
	Area 2	4	60.1	26.3	5.2	7.0	0.13	2.69	1.38	0.25	0.61	0.07	36	27	4
		5	58.8	26.6	6.0	6.8	0.14	2.65	1.41	0.29	0.59	0.08	39	30	5
		6	52.1	31.1	12.3	3.9	0.05	2.36	1.67	0.60	0.34	0.02	65	63	6
		7	51.7	31.4	12.7	3.6	0.04	2.35	1.68	0.62	0.32	0.02	66	65	7
		8	46.5	35.1	18.0	0.95	0.02	2.12	1.89	0.88	0.08	0.01	89	91	5
Vz 746g			45.6	35.7	19.4	0.8	0.03	2.07	1.91	0.94	0.07	0.01	93	92	7

for most samples except andesine in 746b_2. This andesine is also unusual in its high K-content (Or 7–10%), resembling anorthoclase and Schiller labradorite (NISSEN et al., 1967) but this does not account for the nonstoichiometry. WENK and WILDE (1973) have designed a vector method to determine deviations from stoichiometry in plagioclase quantitatively. Using their vector plots (Fig. 5) we find that the surplus of Al (the framework is "too anorthite-like" for andesine) can either be explained by some Al occupying large cation sites or by a divalent cation which was not analyzed for substituting for Na and K. It definitely is not due to alkali evaporation during the analysis.

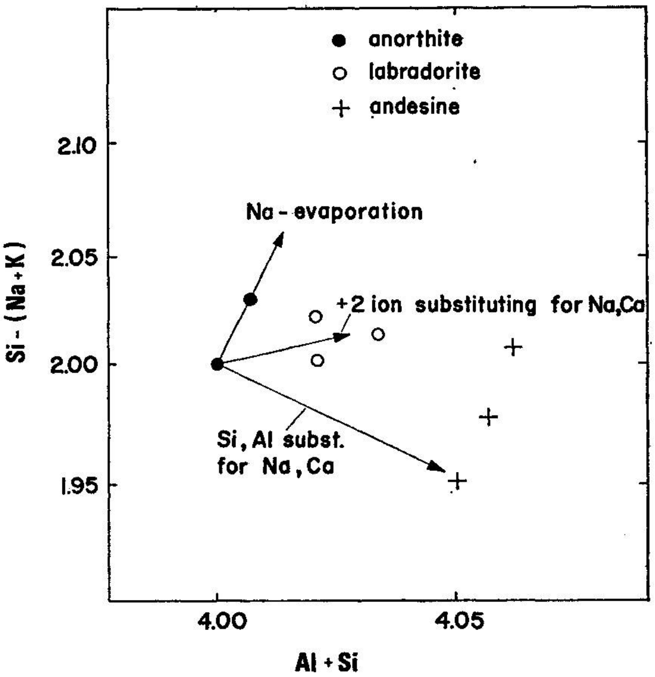

Fig. 5. Variation of Si-(Na+K) and Al+Si in 746b_2 intergrowth. Microprobe analyses of Si, Al, Ca, Na, K normalized to 8 0. Some substitution vectors are indicated. Their length corresponds to 0.05 formula units (compare WENK and WILDE, 1973).

Structural states of the various plagioclase phases were investigated with electron and X-ray diffraction methods. We found that anorthite-bytownite in 699, 746b and 746g crystallizes in the $P\bar{1}$ structure with strong *b*, *c*, and *d* reflections. Labradorite An 63–66 in 746b has an intermediate structure with strong *e*-satellites. Satellite positions were refined on a CAD 3 single crystal diffractometer using the automatic centering program SETANG. The values of $\Delta h = 0.080$ (7) $\Delta k = 0.031$ (8) $\Delta l = 0.261$ (10) and s = 26.7 (3) Å agree with the superstructure orientation found in other labradorite-andesine intergrowths (WENK et al., 1975) and are close to parameters determined for igneous andesine (BOWN and GAY, 1958). Variation in the long-range superstructure of these metamorphic plagioclases is clearly not only a function of An-content as suggested recently by SLIMMING (1975) but rather of all physico-chemical conditions of the system, including time. Comparing intensity of superstructure reflections, we notice that there is *no* correspondence between satellite reflections in labradorite (071 strong, $09\bar{5}$ medium) and *b*-reflections in anorthite (071 weak, $09\bar{5}$ strong) (cf. RAINEY and WENK, 1978). On the other hand, diffuse streaks in positions of *c*-reflections in labradorite correspond to strong *c*-reflections in primitive anorthite.

Lattice constants determined from automatic centering of *a*-reflections with the single crystal diffractometer in a labradorite-andesine intergrowth give for labradorite a = 8.149 (4) Å, b = 12.823 (6) Å, c = 14.181 (9) Å, α = 93.50 (2)°, β = 116.04 (2)°, γ = 90.21 (2)° and for a very small fragment of andesine a = 8.154 (2) Å, b = 12.839 (4) Å, c = 14.220 (4) Å, α = 93.64 (1)°, β = 116.31 (3)°, γ = 89.50 (3)°, which is consistent with values in the literature for these compositions (BAMBAUER et al., 1967). Even in very strongly exposed photographs of the andesine crystal we were unable to see any sign of satellite reflections. Thus andesine and oligoclase in medium grade metamorphic rocks may crystallize in albite structure.

6. DISCUSSION, A TENTATIVE STABILITY DIAGRAM FOR METAMORPHIC PLAGIOCLASES

Rock composition and paragenesis govern the general variation of An in the layered series of Carecchio, displayed in Figs. 1 and 2. The crystal structure and the stability conditions in the subsolidus range determine the stepwise character of the increase, ranging from An 20 to An 93. The same discontinuous sequence, with preferred An compositions and gaps between, is also found in feldspars of rocks with similar bulk composition, but with rising metamorphic grade, as described earlier for Alpine carbonate rocks by WENK (1962) and for amphibolites by WENK and KELLER (1970). For each metamorphic grade a maximum An-content exists which is usually observed in plagioclases of impure marbles or calcsilicate rocks. The diagram of Fig. 6 illustrating the occurrence of metamorphic plagioclase as a function of grade and An-content summarizes data obtained from the Carecchio series and inferences from other metamorphic rocks of the Central Alps (margarite-bearing rocks excepted, see FREY and ORVILLE, 1974):

In low-grade rocks *albite* is the only stable plagioclase phase, irrespective of rock composition. Minerals of the epidote group are the main CaAl-consumers. It must be emphasized, however, that albite is by no means restricted to greenschist facies rocks. It occurs in the amphibolite facies as well, but here the mineral is confined to rocks rich in Na and poor in Ca.

At slightly higher grade (biotite in, chlorite still present) albite and oligoclase An 17–25 crystallize simultaneously in Ca- and Al-rich rocks (e.g. amphibolites and calcareous schists). These two-plagioclase rocks, first reported by EVANS (1964) from New Zealand, are easily overlooked but they are of common

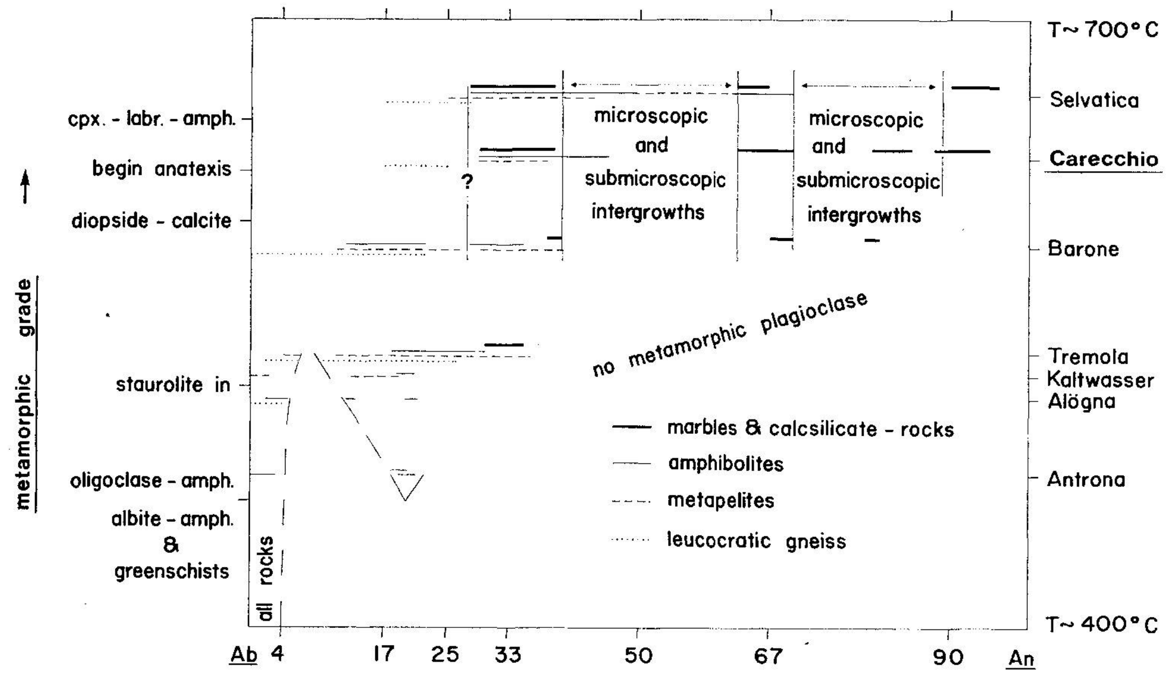

Fig. 6. Tentative diagram showing variation of plagioclase composition as a function of metamorphic grade and rock composition. The compositional range of Carecchio plagioclases (Figs. 1 and 2) is compared with the trends of An-variation observed at Selvatica (Gordemo-Fontöbbia) and on Pizzo Barone in Verzasca Valley (WENK 1962, SCHWANDER et al. 1967, WENK et al. 1969 and unpublished results). Data for the Tremola series are mainly from STECK (1976), those for Kaltwasser (Simplon) from STRECKEISEN et al. (1974), Alögna and Antrona from WENK and KELLER (1969). The special conditions reported by FREY and ORVILLE (1974) from margarite-bearing rocks in greenschist facies are not considered.

occurrence also in the Alps, e.g., in the Simplon area (STRECKEISEN and WENK, 1974), in the Gotthard massif (STECK, 1976); in upper Calanca and Mesolcina valleys (WENK and KELLER, 1970) and on the N-slope of Bergell valley. Albite is generally more abundant than oligoclase. Inverse zonal growth with narrow oligoclase rims around large albite cores, indicating a time sequence in crystallization, is common in this metamorphic zone.

The peristerite gap is closed in the staurolite zone. Microscopically and submicroscopically (X-ray) homogeneous plagioclases of the range An 5–17 are found in leucocratic gneisses poor in Ca from the upper reaches of Verzasca valley (e.g. P. BARONE, Corona di Redorta), in the host rocks of the well-known staurolite-kyanite-schists of Campo Tencia. Oligoclase An 17 from BARONE shows slightly diffuse but unsplit a-reflections, without e-satellites even in strongly exposed X-ray photographs.

Still within the staurolite-kyanite zone, but before the beginning of partial anatexis, *andesine* becomes the most calcic plagioclase first of carbonate-rocks and later on of amphibolites, while oligoclase is found in associated gneisses. There is a clear distinction between a rather homogeneous oligoclase group An 18–25 and a broader andesine group, as has been reported previously for metamorphic series (Wenk, 1936, Fig. 2; 1948 Fig. 2; 1958 Fig. 1 and Rein, 1952 Table 3). The acid end-member of the andesine-labradorite series is not identical with the calcic oligoclase so common in leucocratic gneiss. We have not yet studied the structural states of these phases and therefore do not venture an explanation for this apparent gap.

A considerably broader gap exists in the range An 35–63, observed in medium grade amphibolite facies rocks. In this range intergrowths of labradorite and andesine occur. If labradorite predominates andesine lamellae are usually on a microscopic scale. If andesine is the major phase we find fine submicroscopic intergrowth of the two phases. In the latter case patchy extinction or zoning may result.

At high grade amphibolite facies as it exists in the Bergell Alps we find in basic rocks generally homogeneous An 45–55 and more rarely a 2-phase An 30 and An 80 assemblage (Wenk et al., 1977). Thus at higher temperatures An 50 may be stable which would agree with the rather common occurrence of An 50 in anorthosites.

Apart from few exceptions microscopic intergrowth of andesine and labradorite is confined to the field in which the maximum anorthite content in associated silicate-marbles is higher than 85. These rocks are in amphibolite facies.

Data are not yet sufficient to decide if regular crystallographic intergrowth of andesine and labradorite, of labradorite and bytownite, or of all three phases sets in at the same or at different metamorphic grade.

Plagioclase An 65–76 is again a commonly occurring composition and has been shown in many examples to display intermediate plagioclase structure though generally with satellites closer to the orientation of igneous andesine than bytownite even where labradorite coexists with anorthite (746b).

There is a last gap between An 70 and An 90. A few representatives of An 85–90 are considered to be submicroscopic intergrowths. *Anorthite* An 90–100 crystallizes in $P\bar{1}$ structure. Compositions An 90–95 are common, pure anorthite is extremely rare in metamorphic rock (e.g. Bergell, Wenk and Trommsdorff, 1967, and A. Pasmeda, Predazzo-Monzoni).

The diagram of Fig. 6 should be compared with equilibrium phase diagrams with gaps in occurrence representing miscibility gaps corresponding to those of the perthites in alkalifeldspar. Due to sluggish kinetics, the compositional phase separation in plagioclase occurs only rarely during cooling by exsolution. It rather forms during growth in an environment of progressive regional metamorphism largely controlled by the chemical composition of fluid phases and in equilibrium with coexisting Ca-Al minerals such as scapolite and clinozoisite (Goldsmith and Newton, 1977).

The occurrence of an "abnormal" superstructure in metamorphic labradorite and absence of it in andesine opens the intriguing question about the origin of the still puzzling intermediate plagioclase structure which seems to be much stronger developed – and thus better ordered – in igneous plagioclase which cooled slowly below the liquidus. If the formation of the intermediate structure is the result of a spinodal-type decomposition at subsolidus conditions with periodic fluctuations in composition and/or ordering, then it is plausible that such a mechanism is favored at higher temperatures where diffusion is more intense than in the regime of amphibolite facies. The longest range and best ordered superstructure is observed in plutonic bytownites. With decreasing An content and decreasing temperature kinetics become more restricted and at conditions of greenschist and medium amphibolite facies no "structural decomposition" occurs in andesine. The influence of metamorphic grade on the wavelength of the *e* structure has recently been documented (H.-R. WENK, 1977).

The complicated stability relations of plagioclase are most significant for metamorphic petrology. In isochemical rock series of progressive metamorphism the discontinuities facilitate the drawing of isograds separating different plagioclase compositions. The advantage of iso-anorthite zoning lies in its general applicability in metamorphic terrain. It does not depend upon the occurrence of a rather rare rock-forming mineral such as chloritoid, staurolite or cordierite which are confined to rocks of special composition or upon a mineral reaction only sporadically indicated by textural relations in thin section.

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