ALKALI AMPHIBOLES OF THE LOW GRADE METAVOLCANIC ROCKS OF KACZAWA MTS, WEST SUDETEN, POLAND

Alkaliczne amfibole w skałach metawulkanicznych o niskim stopniu zmetamorfizowania z obszaru Gór Kaczawskich, Sudety Zachodnie, Polska

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CONTENTS

SUMMARY. Alkali amphiboles mainly of glaucophane and crossite composition (electron probe analyses) have been found in 54 metabasites and 3 keratophyres, in all structural units of Kaczawa complex. They may indicate the higher pressure regime of greenschist facies metamorphism. Metaso-matism and variation in oxygen fugacity could affect the compositions of amphiboles and their significance as pressure indicators is limited. The large scale tectonic conclusions concerning Kaczawa complex based on alkali amphibole geobarometry should be taken cautiously.

GENERAL INFORMATION

The object of interest of this paper is the Variscan structural stage of Kaczawa Mts built up of low grade metamorphic sedimentary and volcanic rocks of Cambrian, Ordovician, Silurian, Devonian and lower Carboniferous. They are called together the Kaczawa complex. The youn-ger Laramian structural stage is built up of non-metamorphic rocks from upper Carboniferous to Cretaceous.

The investigations reported in this paper co-vered the hilly area of the eastern part of Kacza-wa complex (Fig. 1 and 2). Its western part, i.e.
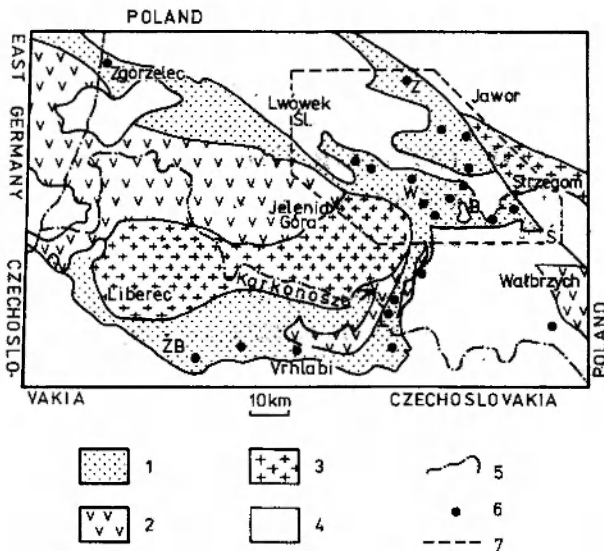
Fig. 1. Geological sketch map of Karkonosze-Izera block and neighbouring areas with locations of alkali amphiboles. *1* — metasediments and metavolcanics; *2* — gneisses, migmatites and older granitoids (Lausatian); *3* — Variscan granites; *4* — other formations younger than Silurian except those of Kaczawa complex; *5* — state borders; *6* — alkali amphibole locations; *7* — contour of geological map of Kaczawa Mts. (Fig. 2); B — Bolków; Ś — Świebodzice; W — Wojcieszów; Z — Złotoryja; ŻB — Żelezny Brod

Szkic geologiczny bloku karkonosko-izerskiego i obszarów przyległych z miejscami występowania alkalicznych amfiboli. *1* — metaosady i metawulkanity; *2* — gnejsy, migmatyty i starsze granitoidy (łużyckie); *3* — granity waryscyjskie; *4* — inne utwory geologiczne młodsze niż sylur z wyjątkiem utworów należących do kompleksu kaczawskiego; *5* — granice państw; *6* — miejsca występowania alkalicznych amfiboli; *7* — kontur mapy geologicznej Gór Kaczawskich (fig. 2); B — Bolków; Ś — Świebodzice; W — Wojcieszów; Z — Złotoryja; ŻB — Żelezny Brod
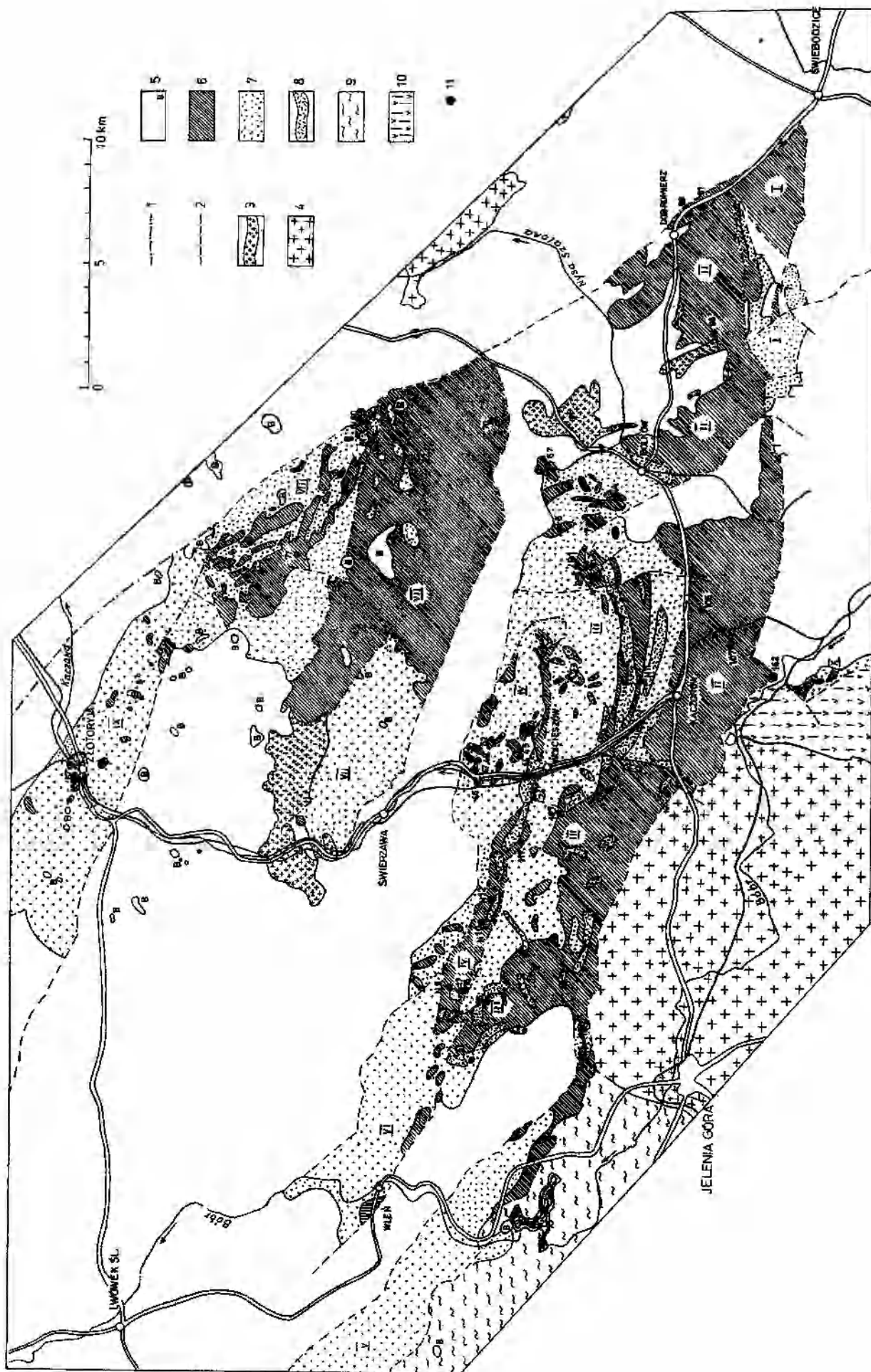
between Jelenia Góra and Zgorzelec, was in many places examined by the author (W. Smulikowski 1972) and no alkali amphiboles were noted.

A little less than half of Kaczawa complex consists of volcanic and subvolcanic rocks of basaltic (spilitic) composition for which the term metabasites is used. Rocks of rhyolite to dacite composition called keratophyres are present in relatively small amounts. The fresh rock outcrops are not common. They are mainly road cuts and small quarries, some natural cliffs are also present. In the area of 190 square kilometres of metabasites and keratophyres 41 localities were found where alkali amphiboles were observed. They are usually a minor or accessory constituent of a rock, never identifiable with the naked eye or hand lens while easily seen under the microscope in a thin section. About 340 thin sections from somewhat lower number of localities were examined. More alkali amphiboles will certainly be discovered with the further studies, both in metabasites and keratophyres.

In the area in question the term alkali amphibole covers in practice pure sodic amphibole of glaucophane - ferroglaucophane - magnesioriebeckite-riebeckite group. The content of potassium is always below 0.02 in the formula calculated for 23(0) and calcium only in two cases reached 0.4. However the term alkali amphibole not more appropriate sodic amphibole is used to follow strictly the recommendations of the Subcommittee on Amphiboles I.M.A. (Leake 1978).

Fig. 2. Simplified geological map of Kaczawa Mts (based on Sawicki 1966; H. Teisseyre 1967; Baranowski *et al.* 1981) with locations of alkali amphiboles. *1* — boundaries of tectonic units; *2* — other dislocations; *3* — acid volcanic rocks (Permian or Carboniferous); *4* — Variscan granites: Strzegom (Permian), Karkonosze massif (Westfal); *5* — other formations younger than Silurian except those of Kaczawa complex, B — Tertiary basalts; *6* — metabasites (Kaczawa complex); *7* — metasediments (Kaczawa complex); *8* — keratophyres (Kaczawa complex); *9* — Izera gneiss complex; *10* — E Karkonosze metamorphic series (mainly amphibolites, mica schists and gneisses); *11* — locations of alkali amphiboles, B in front of figures means sample collected by Z. Baranowski, N — W. Narębski, M — probable location of Maciejewski's (1954) sample, A — of Ansilewski's (1954); I — Cieszów unit; II — Dobromierz unit; III — Bolków unit; IV — Świerzawa unit; V — Pilchowice unit; VI — Wleń unit; VII — Rzeszówek-Jakuszowa unit; VIII — Chełmiec unit; IX — Złotoryja-Luboradz unit; X — Przybkowice element

Uproszczona mapa geologiczna Gór Kaczawskich zestawiona na podstawie map Sawickiego (1966), H. Teisseyre'a (1967), Baranowskiego *et al.* (1981) z miejscami występowania alkalicznych amfiboli. *1* — granice jednostek tektonicznych; *2* — inne dyslokacje; *3* — kwaśne skały wulkaniczne (permskie lub karbońskie); *4* — granity waryscyjskie: strzegomski (perm), karkonoski (westfal); *5* — inne utwory geologiczne młodsze niż sylur z wyjątkiem utworów należących do kompleksu kaczawskiego, B — bazalty trzeciorzędowe; *6* — metabazyty (kompleks kaczawski); *7* — metaosady (kompleks kaczawski); *8* — keratofiry (kompleks kaczawski); *9* — gnejsowy kompleks izerski; *10* — serie metamorficzne wschodnich Karkonoszy (głównie amfibolity, łupki łyszczykowe i gnejsy); *11* — miejsca występowania alkalicznych amfiboli, B — przed numerem oznacza próbki pobrane przez Z. Baranowskiego, N — przez W. Narębskiego, M — przypuszczalne miejsce pobrania próbki przez Maciejewskiego (1954), A — przez Ansilewskiego (1954); I — jednostka Cieszowa; II — jednostka Dobromierza; III — jednostka Bolkowa; IV — jednostka Świerzawy; V — jednostka Pilchowic; VI — jednostka Wlenia; VII — jednostka Rzeszówek-Jakuszowa; VIII — jednostka Chełmca; IX — jednostka Złotoryja-Luboradz; X — element Przybkowic

Legenda: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11

ZŁOTORYJA · LWÓWEK SL. · WLEŃ · JELENIA GÓRA · ŚWIERZAWA · BOLKÓW · ŚWIEBODZICE

10 km

PREVIOUS WORKS ON ALKALI AMPHIBOLES
IN KACZAWA MTS

The oldest note that may refer to alkali amphiboles in Kaczawa Mts. was made by Zimmermann and Kühn (1919, p. 30–31). The radially arranged blue-green hornblende needles were found in the diabase near Złotoryja. Zimmermann described later a few times the "blue glaucophane-like hornblende" from diabases and greenschists and once also from keratophyres (Zimmermann, Mühlen 1933, p. 12; Zimmermann, Haack 1935, p. 15, 20; Zimmermann 1938, p. 22; Zimmermann, Berg 1941, p. 26, 39). Łydka and Turnau-Morawska in the unpublished reports of 1953 on diabases of Bolków area refered by Juskowiak (1957) and H. Teisseyre (1977) mentioned "glaucophane" as an accessory constituent of these rocks. No chemical or optical data of this mineral except pleochroic colours were given. Maciejewski (1954) saw "glaucophane" in amygdales in the greenstone near Rochowice Nowe. Probably to the same locality refer Borkowska and K. Smulikowski (1973, p. 300). Ansilewski (1954) described "riebeckite" in the keratophyre N of Bolków and considered it as an originally magmatic mineral. Jerzmański (1965, 1969) and H. Teisseyre (1977) refer to the unpublished Maciejewski's report of 1955. He described "glaucophane" in the greenstones and "epidiabases" belonging to Chełmiec unit and Rzeszówek-Jakuszowa unit giving sometimes its pleochroic scheme and extinction angle Z/γ [1]. He also observed there under the microscope the "bluish actinolite". The presence of "glaucophane" was also confirmed by H. Teisseyre in the greenstones of the eastern part of Rzeszówek-Jakuszowa unit (Kural, H. Teisseyre 1978). Narębski (1964) described "glaucophane" in the pillow lava of Świerki hill from Świerzawa unit giving some of its optical data. The "amphibole resembling glaucophane" was also described from Chrośnica greenstones (compare locality 17 of this paper) and its presence was considered to be characteristic of Świerzawa unit (Baranowski et al. 1981).

Kryza and Muszyński (1987b) published the first paper on Kaczawa Mts area in which the authors at least refer to chemical compositions (electron probe analyses) of alkali amphiboles. It deals with diabase sills from vicinity of Wojcieszów (compare localities 45, 50 and 52 of the present paper). Unfortunately the unclear way of presenting results, lack of amphibole, biotite, and "stilpnomelane?" analyses, lack of information how the probe analyses were interpreted especially in respect of Fe^{3+}/Fe^{2+} ratio make the use of this paper for further considerations very limited. Knowing probably more than the reading public they however conclude on the basis of amphiboles relationship that two episodes of metamorphism have taken place: first — "high pressure metamorphism" documented by the presence of glaucophane, and later — "low/medium grade metamorphism with moderate pressure" when "barroisitic hornblende" was originating. As a further consequence they tend to apply the view of Wieser (1978) concerning East Karkonosze and that of Guiraud and Burg (1984) concerning South Karkonosze (Chab and Vrana 1979 should have been also mentioned) to Kaczawa complex that high pressure regime was due to subduction as a result of plate collision.

There is no doubt that Kryza and Muszyński could have arrived at these conclusions independently using the well established but a little primitive scheme: glaucophane — high pressure — subduction. The possibility of such interpretation was mentioned by the present author in written anual reports 1984 and 1985 of the MR.I. 16 and 1986 of the CPBP 03.04 research programmes sponsored by the Polish Academy of Sciences. In these reports the rocks containing alkali amphiboles in Kaczawa Mts were described including the area near Wojcieszów, localities and rocks which are the subject of Kryza and Muszyński study. Kryza and Muszyński take part in the same research programme. They knew about the reports and they could easily have had an access to them. The same authors a year later together with two French coleagues (Kryza et al. 1988) published the mineral formulas of the amphiboles of the same rock which are: kaersutite, glaucophane, winchite and actinolite. This time "barroisitic hornblende" was not mentioned, but crossite was, while its formula was not given. It is not known either whether the published formulas are results of single spot probe analyses or averages of more analyses of one amphibole zonal microstructure or of separate grains of one or more samples. Judging from comparison of the two papers all probe analyses were made in two

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[1] X, Y, Z — crystallographic axes, α, β, γ — vibration directions.

samples from one locality (no. 2), but it was not stated explicitly. The authors probably reserve more details for the third paper on the same subject. They do not however hesitate to suggest the existence of "blueschist facies" in "the rocks of Variscan basement of Kaczawa Mts" i.e. Kaczawa complex.

Summing up the previous works it appears that for many years various people have been observing scarce, blue in a thin section, alkali amphiboles in metavolcanic rocks of Kaczawa complex. Their composition, paragenesis, origin and geological significance have been discussed only in one locality. The present paper is intended to throw more light on this subject for as much as possible the whole Kaczawa complex.

OTHER OCCURRENCES OF ALKALI AMPHIBOLES IN KARKONOSZE-IZERA BLOCK

Alkali amphiboles in the whole Sudeten Mts are even more scarce and all of them except two localities were reported from Karkonosze-Izera block. One is an interesting riebeckite in lower Permian altered lava (melaphyre) near Łomnica described by Nowakowski (1957, 1976). Olivine as well as biotite and chlorite pseudomorphs after olivine and augite are transformed into riebeckite. Augite grains are transformed into riebeckite either directly or pale ordinary hornblende replaced augite and was in turn replaced by riebeckite. Riebeckite was also observed on or around the epidote grains. The origin of riebeckite and simultaneous albitization were caused by sodium metasomatism resulted by post-volcanic alkaline emanations.

On the eastern side of Karkonosze-Izera block the well described occurrence of glaucophane on Kopina Mt is known (Juskowiak 1957; Wieser 1978). The present author knows another 8 localities in the Lasocki Range, where Kopina Mt is situated, where alkali amphiboles, mainly crossite, were observed (W. Smulikowski 1987). In the same area bluish green amphiboles described usually as barroisitic hornblende are present. Wieser (*op. cit.*) described two samples where glaucophane[2] coexists with epidote, garnet[3] chlorite, albite, quartz, sphene and a little of barroisitic actinolite-hornblende[4]. He ascribed the rocks to glaucophane schist facies and explained their high pressure metamorphism as the result of subductional thrusting.

On Czechoslovak side of Karkonosze-Izera block the alkali amphiboles were reported from various localities i.e. from Rychorskie Mts (Ham-

pel 1911; Berg 1912), in Laba valley — Horni Vrchlabi (Pelikan 1928; Watznauer 1930) where probably crossite was found forming zonal microstructures with green hornblende, in Vichove NNW of Jilemnice — also crossite (Tucek 1949).

Fediuk (1953, 1962) described metavolcanic rocks of Železný Brod area which to large extent resemble the Kaczawa Mts rocks. Alkali amphiboles namely "glaucophane via crossite (most frequent cases) up to bababudanite[5]" may be found even in the same outcrop. They sometimes form reaction rims on pyroxenes, brown hornblende and also actinolite while riebeckite was mentioned as present in amygdales. All these resemble very much the microstructures observed in Kaczawa Mts. Stilpnomelane has been observed in some glaucophane bearing rocks. Fediuk (1962, p. 112) is of the opinion that all the rocks, also those including the alkali amphiboles, belong to greenschist facies but he does not satisfactorily explain the origin of these minerals.

From two localities of this area: Roprachtice (two glaucophanitic schist) and Tepere (two metagabbro samples) the amphiboles were analysed by the electron probe (Cháb, Vrána 1979). The alkali amphiboles corresponding to crossite are replaced by actinolite while in between the amphibole of intermediate composition crossite/actinolite is observed. On this basis the authors drew the conclusion that two stages of metamorphism: the earlier corresponding to blueschist facies and the later corresponding to greenschist facies took place but the pressure decreased gradually (compare Kryza and Muszyński 1987b). According to Cháb and Vrána (*op. cit.*) the high pressure metamorphism took place in the lower part of the sequence of thrusts and nappes during the collision of segments of the continental crust. Gui-

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[2] Wet chemical analysis corrected for inclusions of sphene and epidote on microscope-planimetric basis.

[3] Analysed chemically: $Fe^{2+} = 1.82$, $Mn = 0.45$, $Ca = 0.66$ in the formula.

[4] No chemical analysis, optical determinations only.

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[5] The old name of magnesioriebeckite.

raud and Burg (1984) on the basis of one sample from the same locality (Roprachtice) with ten amphiboles analysed by the electron probe arrived at similar conclusions.

It is worth to note that in a sample given to me by J. Gorczyca-Skala of the diabase found within Lausatian greywackes and slates in Jędrzychowice (N of Zgorzelec), which may be considered as western prolongation of Kaczawa complex, dark blue amphibole is present most probably of crossite/riebeckite composition. Its grains are too small even for microprobe analysis.

GENERAL GEOLOGY OF KACZAWA COMPLEX WITH SPECIAL EMPHASIS ON VOLCANOGENIC SERIES

The Kaczawa complex part of which is the subject of the present studies appears in both northern and southern „branches" of Kaczawa Mts divided by Świerzawa graben.

In the northern branch Jerzmański (1965) distinguished 3 units (from N to S): Złotoryja-Luboradz unit, Chełmiec unit and Rzeszówek-Jakuszowa unit (fig. 2).

In the southern branch H. Teisseyre (1956, 1967) distinguished Świerzawa unit being the lowest one and the core of the large anticline called Bolków-Wojcieszów saddle and 3 other units thrusted one against the other, from N to S: Bolków unit (lower), Dobromierz unit (middle) and Cieszów unit (the highest). In spite of various reservations, especially if the units should be considered as nappes, this distinction of units is still being used.

The most recent and brief summary of stratigraphy and lithology of Kaczawa complex is given by Baranowski et al. (1987). According to them if at all Cambrian is present in the complex it may be represented by some limestones and associated with them greenschists and greenstones[6] of Świerzawa and Bolków units. These metabasic rocks are metamorphosed toleite and alkali basalt tuffs and lavas originated in a shallow sea (Baranowski, Lorenc 1981). They often show pillow lava structures.

Ordovician having some conodont dating is represented by slates and schists being low grade metamorphic sandstones, siltstones and clay shales altogether about 1 km thick. Within the lower part of these sediments small sills of diabases are present described by Kryza and Muszyński (1987b) in the vicinity of Wojcieszów.

They suggest that intrusions were almost simultaneous with the sedimentation i.e. probably lower Ordovician and older than major volcanogenic series of Świerzawa unit which would be in this case upper Ordovician. This age was confirmed by a single and preliminary isotope dating of zircon from a keratophyre belonging to the upper part of volcanogenic series giving 460 ± 10 m yr (Kryza, Muszyński 1987a). The volcanogenic series is represented by greenstones, greenschists and keratophyres[7]. Pillow lava, subaeral lava flows tuffs and pyroclastic flows were recognised by Kryza and Muszyński (op. cit.).

There is a wide chemical variation within this series. Apart from the presence of basic, intermediate and acid volcanic rocks the basic ones may correspond to toleite-basalts, "transitional" and alkali-basalts. The major and minor element studies of many authors (Narębski 1964, 1980, 1981; Narębski et al. 1982, 1986; Baranowski et al. 1984; Kryza, Muszyński 1987a, b) in spite of somewhat diversified opinions seem to indicate the interplate character and possible ocean island environment.

Correlation of geological profiles from various places of Kaczawa complex, assuming after Oberc (1967) that Dobromierz unit is the prolongation of Rzeszówek-Jakuszowa unit allowed Haydukiewicz (1987) to see the possibility that almost all volcanites of Kaczawa Mts, except those mentioned above associated with possibly Cambrian limestones, are of Ordovician age. This would be an important statement but it is not satisfactorily documented yet.

Silurian in Kaczawa complex is represented by dated with graptolites predominantly black siliceous and clay slates, graphite slates and lydites. Some greenstones, e.g. the ones that built up the eastern part of Rzeszówek-Jakuszowa unit,

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[6] There is a lot of reservation of using the term "greenstone" as a rock name. This regionally well established term will be used here for non schistose greenschist facies rocks of bulk chemical composition close to basalts. Rocks of similar mineral and chemical composition but schistose are "greenschists".

[7] Keratophyre is traditionally used in this area term for volcanogenic metamorphosed light rock often corresponding to rhyolite or rhyodacite.

were considered by some authors as Silurian (Baranowski 1975).

Devonian and Carboniferous do not include volcanogenic series and are represented mainly by various slates or phyllites, in lower Carboniferous also by limestones.

An important new discovery of conodont fragments within Radzimowickie schists is revolutionary. Until now these predominantly quartz-muscovite albite schists or phyllites were considered as a lowermost probably Eocambrian member of Kaczawa complex (Baranowski *et al.* 1987). Now they have to be considered as younger.

Summing up their impressive achievements of last years the same authors (Baranowski *et al.* 1987) point out the following:

1. Tectonic elements having shape of flat bodies divided from each other by thrust planes contain rocks which originated in two different environments.

2. The sedimentary-volcanic sequence from Cambrian (?) to Devonian which builts up some of the elements called "scales" originated in the open sea basin analogous to an ocean. The volcanic sequence may be related to interplate rift or ocean islands environment.

3. The group of rocks including Radzimowickie schists, some of the rocks being part of melanges, slates and limestones from Rząsiny and Lubań were deposited in a basin of ocean trench type possibly in its various zones.

The authors tend to understand the structure of Kaczawa complex as an accretion prism even if not all characteristic features of this structural model can be detected.

DISTRIBUTION OF ALKALI AMPHIBOLES IN KACZAWA COMPLEX AND PETROGRAPHY OF ALKALI AMPHIBOLE BEARING ROCKS

As shown on the map (Fig. 2) the alkali amphiboles have been found in many places and in various rock types of the volcanogenic series. These minerals are noted in all tectonic units of eastern Kaczawa complex.

Due to the varying number of outcrops the whole area of Kaczawa complex was not uniformly covered by the investigations. Therefore the concentrations of points on the map, e.g. NW of Bolków, N of Wojcieszów, in Chrośnica, do not necessarily mean that these areas are especially enriched in alkali amphiboles. They may however be so.

Among the 57 rock samples containing at least a little of alkali amphiboles there are 20 diabases, 25 greenstones, 9 greenschists and 3 keratophyres. As much as possible the samples were taken from outcrops. In the areas where outcrops are scarce they were also taken from loose blocks.

The distinction between greenstones and greenschists is made simply on the fabric[8] basis.

If the green rock is distinctly schistose it is greenschist. If the directional fabric is not so predominant, weakly pronouced or not seen at all and the average grain size is less than 2 mm across the rock it is called greenstone. It is obvious that all transitions between greenschist and greenstone are possible but usually these two rock types differ also in mineral composition.

More difficult or actually impossible is the distinction between greenstone and diabase in a hand specimen. It is the geological occurrence e.g. a shape of the body, kind of surrounding rocks as a consequence of the way of emplacement and not the texture and composition of the rock itself that is used for the distinction. In some places where the geological situation is clear enough like in the case of subvolcanic sills NE of Wojcieszów Dolny the term diabase is perfectly adequate. The grain size of these diabases in most cases is above 2 mm across. In practice for the rocks with not clear geological position all mafic non-schistose rocks of Kaczawa complex having grain size above 2 mm were called diabases, the other finer grained were greenstones. All pillow lavas belong to greenstones.

The *PT* conditions of metamorphism of greenstones and diabases were roughly the same. However, the coarser grained rocks, i.e. diabases, contain usually much more textural and mineral relics of magmatic protolith therefore their mag-

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[8] There are not widely internationally accepted definitions of the terms. In the present paper they will be used as follows: Fabric = crystallographic and/or shape orientation of grains or grain aggregates e.g. directional fabric. Texture = geometric interrelationships between grains e.g. ophytic, amygdaloid, porphyroblastic texture. Microstructure = a single microscope scale structure of a mineral grain or a group of grains e.g. zonal microstructure of amphibole or plagioclase.

matic name "diabase" seems to be justified.

The difficulties with this arbitrary distinction between greenstone and diabase were probably the reason why H. Teisseyre (1969, 1974), H. Teisseyre and Gawroński (1965), Kural and H. Teisseyre (1975) did not distinguish on their maps diabases even if on the older maps (Zimmermann, Haack 1929; Zimmerman, Kühn 1929a,b; Zimmerman, Berg 1932) they were separated from greenstones. Jerzmański (1954-55), Jerzmański and Kural (1956) on their maps distinguished greenstones and "epidiabases". The prefix "epi" does not mean that they are different from the others.

DIABASES

They are medium- and only seldom coarse-grained[9] dark greyish-green rocks. Usually no directional fabric is present, however locally some foliation may be seen due to tectonic deformation.

Diabases usually contain the following minerals: albite, epidote, calcite, apatite, leucoxene and/or sphene, Fe-oxides and/or ilmenite, clinopyroxene, chlorite, actinolite or actinolitic hornblende, sometimes brown or green hornblende, and only sometimes alkali amphiboles.

The most coarse-grained diabase sample no. 50[10] (for detailed localisation, composition of minerals, whole rock compositions see Tables 1, 2, 3, 5 and Figures 2 and 10) contains clinopyroxene short prisms up to 8 mm long. Their margins are darker brownish under the microscope with lower birefrigence and higher Z/γ angle than the centre[11]. The margins contain more Ti, Al, Fe and less Mg, Cr, Si than the centres. Whole smaller grains correspond in the composition to marginal parts of the bigger grains. Dark brown hornblende — kaersutite is very often associated with clinopyroxene. The brown amphibole in this rock is always surrounded by blue-purple alkali

amphibole, usually forming central relicts in zoned amphibole grains. At the boundary with the brown hornblende alkali amphibole shows distinctly darker colours. In some places outside the alkali amphibole, especially at the ends of prisms, another amphibole is present. It is light green showing sometimes somewhat blueish colouration.

The example of unusually complete zoning is shown in Fig. 3 where clinopyroxene centre surrounded by brown hornblende and zones dark blue, light blue and light green amphibole were observed[12].
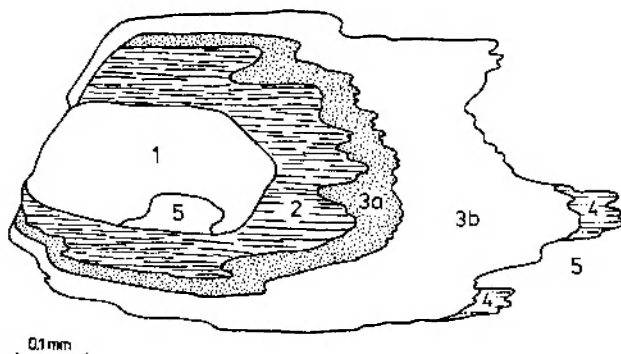

Fig. 3. Clinopyroxene-amphibole zonal microstructure of diabase sample no. 50. *1* — clinopyroxene; *2* — brown hornblende (kaersutite); *3a* — alkali amphibole showing dark blue-purple pleochroic colours (probably crossite); *3b* — alkali amphibole showing similar but pale colours (glaucophane); *4* — light green amphibole (actinolite); *5* — chlorite

Klinopiroksenowo-amfibolowa pasowa mikrostruktura w diabazie, próbka nr 50. *1* — piroksen jednoskośny (klinopiroksen); *2* — brunatna hornblenda (kaersutyt); *3a* — alkaliczny amfibol o ciemnych barwach pleochroicznych od niebieskiej do fioletowej (prawdopodobnie krossyt); *3b* — alkaliczny amfibol wykazujący podobne, lecz jasne barwy (glaukofan); *4* — jasnozielony amfibol (aktynolit); *5* — chloryt

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[9] The following designations of the average grain size of a metamorphic rock are used: very fine-grained $\langle 0.1$ mm, fine-grained 0.1–1 mm, medium-grained 1–4 mm, coarse-grained 4–16 mm, very coarse-grained $\rangle 16$ mm.

[10] The figures refer to locality nos. shown in the map (Fig. 2), letters following the figures — to samples, if more than one taken from the same locality. Capital letters in front of figures mean: B — collected by Z. Baranowski, N — by W. Narębski, A — described by Ansilewski (1954), M — described by Maciejewski (1954).

[11] Margin $Z/\gamma = 49°$; centre $Z/\gamma = 44°$ and $39°$, $2V_\gamma = 47°$.

[12] In spite of a relatively coarse grain of the rock (sample no. 50) homogenous parts of crystals of amphiboles are too small for detailed optical determinations and the optical data are rather incomplete. They are as follows (pleochroic colours in normal, about 0.25 mm thick, thin section): Brown hornblende (kaersutite): Z/γ angle about 12°, $2V_\alpha$ about 40°, pleochroic colours $\gamma = \beta > \alpha$, α — light golden brown, $\beta = \gamma$ — dark redish brown. Dark blue alkali amphibole (crossite?): α — light greyish yellow, β — dark blue (approximately parallel to Z), γ — violet, $2V_\alpha$ — probably 10–30°. Light blue alkali amphibole (glaucophane): α — light yellow almost colourless, β — light purple, γ — light blue (approximately parallel to Z), $2V_\alpha$ — small approaching 0°. "Black" alkali amphibole (riebeckite): greenish grey (γ?) through dark greyish blue to almost opaque (α?). Light green amphibole (actinolite or actinolitic hornblende): α — light yellow almost colourless, β and γ light green or green with blueish tint. The darker varietes may correspond to actinolitic hornblende but only actinolite was confirmed with the electron probe.

Table 1. Informations on analysed samples (see also Fig 2 and Table 5)

Informacje o analizowanych próbkach (patrz fig. 2 i tab. 5)

Sample no. Próbka nr	Locality Lokalizacja	Taken from pobrana z	Unit after H. Teisseyre (1967) Jednostka	Rock name Nazwa skały	Mineral composition* Skład mineralny*	Analysed minerals Minerały analizowane	Other remarks Inne uwagi
6 a	the road from Kaczorów–Bolków highway to village Jasirowiec, on the flat hill / droga od szosy Kaczorów–Bolków do wsi Jasirowiec na płaskim wzgórzu	block / blok	Bolków	greenschist (yellowish-green with black dots) / łupek zieleńcowy (żółtozielony z czarnymi plamkami)	albite, chlorite, leucoxene, glaucophane Fe-oxides, epidote	glaucophane (tab 2)	
17 j	Chrośnica, above the church, from the top of the cliff / Chrośnica, powyżej kościoła, ze szczytu skałki	outcrop / odkrywka	Świerzawa	green, plagioclase-free quartz chlorite schist / zielony łupek kwarcowo-chlorytowy, bez plagioklazu	Chlorite, quartz, calcite, crossite, sphene and leucoxene Fe-oxides, epidote, actinolite	2 crossites (tab. 2), chlorite	see Fig 8
45	small quarry about 1 km E of Wojcieszów Dolny / mały kamieniołom około 1 km na E od Wojcieszowa Dolnego	quarry / kamieniołom	Świerzawa	medium-grained, clino-pyroxene-free diabase / średnioziarnisty, bezpiroksenowy diabaz	chlorite, albite, calcite glaucophane and crossite sphene and leucoxene epidote, Fe-oxides actinolite hornblende and actinolite, apatite, kaersutite	crossite (Tab 2), glaucophane (Tab. 2), chlorite (Tab. 3)	see Fig 7
50	hill 405.1 m, E of Wojcieszów/Stara Kraśnica border / w górze 405.1 m, na E od granicy miejscowości Wojcieszów i Stara Kraśnica	outcrop / odkrywka	Świerzawa	coarse-grained diabase / gruboziarnisty diabaz	clinopyroxene, chlorite, albite, calcite sphene and leucoxene, Fe-oxides, glaucophane, kaersutite, epidote actinolite crossite riebeckite, magnesioriebeckite/crossite, apatite	kaersutite (Tab. 2), riebeckite (Tab. 2), glaucophane (Tab. 2), magnesioriebeckite/crossite (Tab. 2), actinolite (Tab. 2), 2 clinopyroxenes (Tab. 3), chlorite (Tab. 3)	see Fig 3 and 4
52	appr. 250 m N of hill 400.1 m, E of Wojcieszów/Stara Kraśnica border / w przybliżeniu 250 m na N od wzgórza 400.1 m, na wschód od granicy miejscowości Wojcieszów i Stara Kraśnica	block / blok	Świerzawa	medium-grained diabase / średnioziarnisty diabaz	albite, chlorite, clinopyroxene epidote, sphene and leucoxene serpentine aggregates, green hornblende glaucophane crossite, calcite Fe-oxides, actinolite ferroglaucophane/crossite, kaersutite, apatite, pyrite	glaucophane/crossite (Tab. 2), ferroglaucophane/crossite (Tab. 2), actinolite (Tab. 2), clinopyroxene (Tab. 3)	see Fig 5
98	Sady Górne village, on the sharp bend of the road, high outcrop of sericite schist with greenschist layers; sample from appr. 5 cm thick greenschist layer / wieś Sady Górne, na ostrym zakręcie szosy, wysoka odkrywka łupków sericytowych z wkładkami łupków zieleńcowych; próbka z ok. 5 cm grubej wkładki łupku zieleńcowego	outcrop / odkrywka	Dobromierz	clinopyroxene bearing greenschist / łupek zieleńcowy z klinopiroksenem	chlorite, clinopyroxene, albite, epidote leucoxene, Fe-oxides crossite, actinolite	2 crossites (Tab 2)	

* In order of decreasing amounts — w kolejności malejących zawartości.

Table 2 Chemical compositions and mineral formulas of alkali amphiboles, kaersutite and actinolite

Skład chemiczny i formuły mineralne alkalicznych amfiboli, kaersutytu i aktynolitu

No of sample/analysis	6a/1	17j/1	17j/3	45/1	45/2	50/2	50/3	50/4	52/1	52/4	98/1	98/2	50/1	50/5	52/2
Mineral name	glaucophane	crossite/glaucophane	crossite (close to glaucophane)	crossite	glaucophane	riebeckite	glaucophane	magnesioribeckite/crossite	glaucophane/crossite	ferroglaucophane/crossite	crossite	crossite	kaersutite	actinolite	actinolite
SiO_2	48.43	59.51	57.90	55.55	57.04	54.03	57.26	51.36	54.73	55.85	54.58	54.67	<0.05	55.49	52.51
Al_2O_3	9.96	5.83	5.42	6.61	9.55	1.81	8.61	3.10	10.34	8.57	5.85	6.36	10.02	1.16	2.52
Fe_2O_3	1.70	4.31	7.22	10.04	3.05	6.51	1.80	17.71	6.50	0.10	5.30	4.22	1.21	3.19	8.10
FeO	12.79	12.01	12.19	11.53	13.60	18.49	12.52	5.88	9.28	18.20	17.16	17.30	9.46	10.66	9.33
MgO	7.45	9.51	9.05	7.96	7.63	6.89	9.44	11.42	9.55	5.47	6.45	7.35	14.31	14.93	14.03
TiO_2	0.18	0.05	0.07	0.32	0.36	1.51	0.05	0.03	0.37	0.38	0.01	0.03	6.13	0.02	0.28
MnO	0.14	0.15	0.16	0.12	0.13	0.10	0.12	0.14	0.19	0.17	0.11	0.11	0.16	0.26	0.35
CaO	0.52	-0.74	0.45	0.47	0.77	0.12	0.71	2.58	0.74	0.71	2.04	2.80	11.15	9.73	10.99
Na_2O	6.13	7.11	7.76	7.49	7.30	9.04	8.21	5.62	8.25	7.16	6.30	7.00	2.87	1.71	0.45
K_2O	0.01	0.11	0.01	0.03	0.01	0.08	0.03	0.06	0.02	0.12	0.02	0.02	1.39	0.11	0.18
Total	97.71	99.51	100.23	100.09	99.44	98.58	98.75	99.90	99.97	97.63	98.72	99.86	96.73	97.26	98.74
Si	8.116	8.218	8.048	7.792	7.917	7.914	7.971	7.863	7.556	8.035	7.907	7.824	6.006	7.967	7.531
^{iv}Al	—	—	—	0.208	0.083	0.016	0.029	0.137	0.444	—	0.093	0.176	1.771	0.033	0.426
^{vi}Al	1.631	0.959	0.888	0.885	1.479	0.299	1.384	0.373	1.219	1.413	0.906	0.897	—	0.161	0.874
Fe^{3+}	0.178	0.451	0.775	1.057	0.319	0.724	0.189	1.479	0.675	0.09?	0.578	0.4?4	0.137	0.34?	1.119
Fe^{2+}	1.486	1.392	1.417	1.353	1.579	2.285	1.458	0.803	1.012	2.190	2.115	2.0?1	1.136	1.28?	—
Mg	1.542	1.965	1.575	1.464	1.578	1.517	1.558	2.374	1.935	1.173	1.393	1.?58	3.198	3.191	2.999
Ti	0.040	0.006	0.007	0.034	0.038	0.163	0.205	0.003	0.018	0.011	0.001	0.003	0.6?1	0.00?1	0.030
$\tfrac{1}{2}$Mn	0.008	0.009	0.010	0.007	0.008	0.007	0.007	0.009	0.011	0.011	0.007	0.007	0.010	0.015	0.022
$\tfrac{1}{2}$Mn	0.008	0.009	0.002	0.007	0.007	0.007	0.007	0.008	0.011	0.011	0.006	0.006	0.010	0.015	0.021
Ca	0.092	0.109	0.067	0.071	0.115	0.01?	0.106	0.386	0.109	0.10?	0.410	0.429	1.738	1.497	1.669
Na	1.678	1.882	1.924	1.922	1.878	1.97?	1.887	0.550	1.830	1.881	1.584	1.565	0.212	0.475	0.125
Na	—	0.022	0.167	0.115	0.087	0.615	0.329	—	0.328	0.172	0.186	0.377	0.633	—	—
K	0.002	0.002	0.202	0.005	0.002	0.015	0.005	0.011	0.004	0.04	0.004	0.004	0.266	0.020	0.013

For locations, rock names and mineral compositions of samples see Table 1.

Fe^{3+} and Fe^{2+} calculated assuming that $Si + Al + Fe^{3+} + Fe^{2+} + Mg + Ti + \tfrac{1}{2}Mn = 13$.

Formulas calculated on the basis of 23 (O).

For alkali amphibole mineral names compare Fig. 10.

Lokalizację, nazwy skał i składy mineralne podane w tab. 1.

Fe^{3+} i Fe^{2+} obliczone przy założeniu, że $Si + Al + Fe^{3+} + Fe^{2+} + Mg + Ti + \tfrac{1}{2}Mn = 13$.

Formuły mineralne obliczone na podstawie 23 (O).

Dla nazw alkalicznych amfiboli porównaj fig. 10.

Electron probe microanalyses by Institute of Material Science, Technical University, Warsaw (1987).

Analizy wykonane mikroanalizatorem rentgenowskim przez Instytut Inżynierii Materiałowej Politechniki Warszawskiej w 1987 r.

Table 3. Chemical composition and mineral formulas of clinopyroxenes and chlorites

Skład chemiczny i formuły mineralne piroksenów jednoskośnych i chlorytów

Nos. of sample/analysis	50/7	50/8	52/3	17j/3	45/3	50/6
Mineral name	clinopyroxene** (core)	clinopyroxene** (margin)	clinopyroxene**	chlorite***	chlorite***	chlorite***.
SiO$_2$	48.77	45.90	50.45	28.65	36.68	27.71
Al$_2$O$_3$	3.38	5.74	3.35	17.90	24.75	18.32
Cr$_2$O$_3$	0.72	0.04	0.19	—	—	—
FeO*	5.34	6.94	7.32	18.95	15.61	19.84
MgO	14.99	13.73	14.85	22.12	12.26	21.28
TiO$_2$	1.90	3.39	1.60	0.01	0.04	0.04
MnO	0.11	0.11	0.16	0.30	0.17	0.30
CaO	21.76	21.82	21.77	0.08	0.10	0.17
Na$_2$O	0.93	1.31	0.26	0.29	0.07	0.71
K$_2$O	0.01	0.01	tr.	0.02	0.51	0.03
Total	97.91	98.99	99.95	88.32	90.19	88.40
Si	1.849 ⎱ 2.000	1.743 ⎱ 2.000	1.876 ⎱ 2.000	5.797 ⎱ 8.000	6.888 ⎱ 8.000	5.652 ⎱ 8.000
^{IV}Al	0.151	0.257	0.124	2.203	1.112	2.348
^{VI}Al	—	0.001	0.024	2.067	4.367	2.055
Cr	0.022	0.002	0.006	—	—	—
Fe^{2+}*	0.170	0.221	0.228	3.207	2.451	3.385
Mg	0.847	0.777	0.823	6.670	3.431	6.468
Ti	0.055 ⎰ 2.052	0.098 ⎰ 2.087	0.046 ⎰ 2.010	0.002 ⎰ 12.133	0.006 ⎰ 10.447	0.007 ⎰ 12.291
Mn	0.004	0.004	0.006	0.051	0.026	0.052
Ca	0.884	0.888	0.868	0.017	0.020	0.035
Na	0.069	0.096	0.019	0.115	0.026	0.281
K	0.001	—	—	0.004	0.122	0.008

* Fe total as Fe^{2+}. For locations of samples, rock names and mineral compositions see Table 1. Electron probe microanalyses by Institute of Material Science, Technical University, Warsaw 1987.

* Fe całkowite jako Fe^{2+}. Lokalizacje, nazwy skał i składy mineralne podane w tabeli 1. Analizy wykonane mikroanalizatorem rentgenowskim przez Instytut Inżynierii Materiałowej Politechniki Warszawskiej w 1987 r.

** Formulas calculated on the basis of 6(O). Formuły mineralne obliczone na podstawie 6(O).

*** Formulas calculated on the basis of 28(O). Formuły mineralne obliczone na podstawie 28(O).

In the sample no. 50 still more complicated and extraordinary zonal microstructure was observed (Fig. 4). The mineral zones were analysed with the electron probe (Tables 2 and 3). Here zones of the following amphiboles were identified: 1) brown hornblende − kaersutite, 2) "black" alkali amphibole − riebeckite, 3) light blue-purple alkali amphibole − glaucophane, 4) narrow stripe of a similar to no. 2 but not quite "black", rather very dark blue amphibole which composition corresponds to magnesioriebeckite or nearby crossite, 5) light green amphibole − actinolite relatively rich in sodium. In this microstructure dark blue-purple crossite is not seen.

Similar to presented in Fig. 4 zonation of amphiboles can be observed in other places of the same rock (sample no. 50) but some members are missing. Amphibole grains showing zones 1–2–3, 1–3–5, 1–3, 3–5 were observed. The least common are riebeckite and magnesioriebeckite

nos. 2 and 4, also green amphibole is present in a relatively small amount.

The relationships of mafic minerals in diabases are very diversified. In medium grained diabase of locality 52 the clinopyroxene is seldom preserved in its original magmatic form and is replaced by chlorite and calcite. Sometimes within clinopyroxene grains inclusions of brown hornblende (kaersutite) are present. This hornblende very seldom forms its own separate grains. There is however another hornblende green in colour [13] which does not form inclusion in clinopyroxene but numerous own grains. Due to the fact that it is somewhat inhomogeneous and aggregatic no proper fully quantitative analyses was made. Its composition may correspond to common green hornblende. Its size and shape often

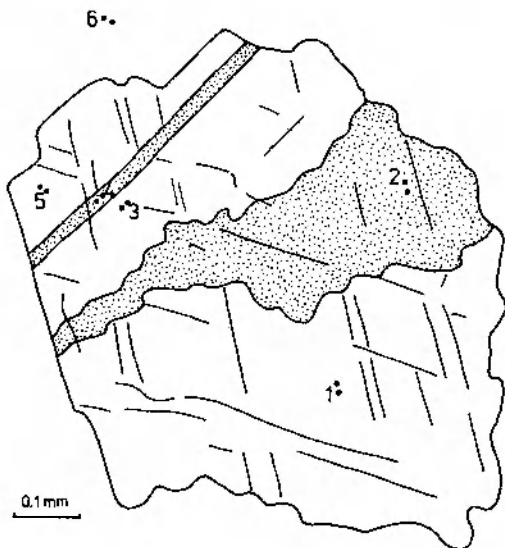[13] α − yellow, β = γ − dark green.

Fig. 4. Analysed with electron probe amphibole zonal micro-structure of diabase sample no. 50 (see Tables 1, 2 and Fig. 10). *1* — brown hornblende (kaersutite); *2* — "black" alkali amphibole (riebeckite); *3* — light blue-purple alkali amphibole (glaucophane); *4* — similar to no. 2 very dark blue almost black alkali amphibole (magnesioriebeckite/crossite); *5* — light green amphibole (actinolite); *6* — chlorite. Dots represent analysed spots

Analizowana za pomocą mikroanalizatora rentgenowskiego pasowa mikrostruktura amfiboli w diabazie, próbka nr 50 (patrz tabele 1, 2 i Fig. 10). *1* — brunatna hornblenda (kaersutyt); *2* — „czarny" alkaliczny amfibol (riebeckit); *3* — jasny, niebieskofioletowy alkaliczny amfibol (glaukofan); *4* — podobny do numeru 2 bardzo ciemnogranatowy, prawie czarny alkaliczny amfibol (magnezioriebeckit/krossyt); *5* — jasnozielony amfibol (aktynolit); *6* — chloryt. Kropki oznaczają punkty analizowane

euhedral may indicate that this is also together with clinopyroxene and brown hornblende a primary magmatic constituent and not a metamorphic mineral. It may represent the lower temperature stages of magma consolidation than the brown hornblende. There is also light green actinolite in the same rock forming parts of amphibole grains (Table 2, anal. 52/2).

Both the brown and green hornblende are replaced by alkali amphibole (Fig. 5) which shows two varieties dark (ferroglaucophane/crossite) and light (glaucophane/crossite) (see anal. 52/4 and 52/1, Table 2 and Fig. 10). The dark one is present at the boundaries with hornblende, clinopyroxene and also sometimes with chlorite, Fe-oxides and epidote. It seems that iron could have migrated into alkali amphibole during its growth from these iron containing minerals. Often fine alkali amphibole prisms are present in chlorite aggregates, together with chlorite inside the clinopyroxene grains usually following the
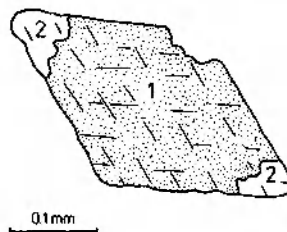

Fig. 5. Olive green hornblende (*1*) and light blue-purple alkali amphibole (glaucophane/crossite) (*2*) of diabase sample no. 52
Oliwkowo-zielona hornblenda (*1*) i jasny, niebieskofioletowy alkaliczny amfibol (glaukofan/krossyt) (*2*) w diabazie, próbka nr 52

cleavage planes. Similar fine alkali amphibole prisms are also present within albite grains.

The medium grained diabase from the quarry 1 km S of Pogwizdów village (locality 67) is different from most of other diabases. The texture of the rock may be considered as porphyritic with large amount of phenocrysts and only very little of interstitial matrix. The striking feature of the rock is the presence of long (up to 5 mm) and thin prisms of ilmenite with leucoxene. Elongated plagioclase laths have the composition of pure albite. The clinopyroxene grains are often replaced by chlorite and also fine aggregate consisting probably of epidote and sphene. The hourglass microstructure may sometimes be recognised.

Like in other diabases the most interesting are amphiboles. The following four varietties can be distinguished (Fig. 6):

1) hornblende showing pleochroic colour from light brown olive to light greenish olive and high birefrigence;
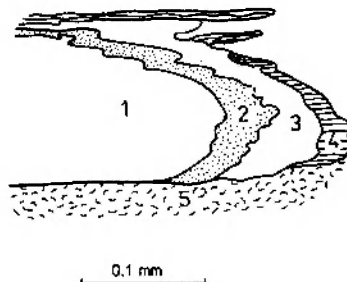

Fig. 6. Amphibole zonal microstructure of diabase sample no. 67. *1* — light brown to olive hornblende; *2* — green with emerald tint actinolitic hornblende; *3* — light green almost colourless actinolite; *4* — intense blue-purple alkali amphibole (crossite?); *5* — chlorite aggregate

Pasowa mikrostruktura amfiboli w diabazie, próbka nr 67. *1* — jasnobrązowooliwkowa hornblenda; *2* — zielona ze szmaragdowym odcieniem hornblenda aktynolitowa; *3* — jasnozielony, prawie bezbarwny aktynolit; *4* — intensywnie niebieskofioletowy alkaliczny amfibol (krossyt?); *5* — agregat chlorytowy

2) hornblende — light green with blueish tint to very light green showing lower birefrigence;

3) actinolite — very light greyish green to almost colourless with still lower birefrigence;

4) alkali amphibole probably crossite — intense blue, purple to light greyish yellow with the lowest birefrigence.

In this rock alkali amphibole forms fine rims and fills the fissures and must have crystallized as the last of all amphiboles.

The amphiboles often form zonal microstructure similar to that shown in Fig. 6. Actinolite may be present also as its own separate prisms.

If any of the examined rocks have effects of heating later than metamorphism resulted by Permian igneous activity that should be the one from locality 67. The Permian rhyolites outcrop only about 75 m away. The light mainly quartz veins containing fine flakes of greenish brown biotite, which is rather unusual of Kaczawa Mts metabasites, might be considered as the rhyolite effect.

In the rock mass biotite is not present but two kinds of chlorite can be distinguished. One forms aggregates often replacing clinopyroxene, it is light green with low interference colours sometimes abnormal blue. The other variety forms also coarse flaky aggregates, shows higher birefrigence and distinct pleochroism from dark green to light golden brown.

Similar mineral examined with the electron probe in the sample 6a proved not to contain potassium and to be an iron-rich chlorite. The golden brown colour may be partly due to weathering.

The two different chlorites in a metabasite of Kaczawa Mts were identified with the use of XRD by Narębski (1964). The light green forming usually bigger scales of lower birefrigence belongs to pennine-delessite series and aggregatic yellow green of higher birefrigence is rich in Fe ripidolite-afrosyderite.

The existence of two kinds of chlorite of different composition in the same rock is not very unusual. It was well documented with the electron probe analyses in a metabasic complex of West Spitsbergen (W. Smulikowski 1977).

The medium grained diabase from locality 45 (see Tables 1–3 and 5) shows exceptionally big prisms of alkali amphibole which may reach the size of 0.3 × 0.8 mm. They are not uniform. There are dark (crossite) and light (glaucophane) varieties and inside the prisms some parts are rich in fine inclusions of Fe-oxides and Ti minerals (Fig.
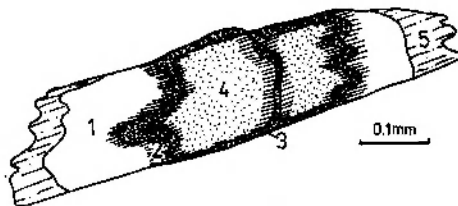

Fig. 7. Alkali amphibole prism in diabase sample no. 45. *1* — clear light blue-purple alkali amphibole (glaucophane); *2* — dark blue-purple alkali amphibole (crossite); *3* — strongly dusty (rich in fine inclusions) relict zones; *4* — dusty light alkali amphibole (glaucophane); *5* — green amphibole (actinolite or actinolitic hornblende)

Słupek alkalicznego amfibolu w diabazie, próbka nr 45. *1* — czysty, jasny, niebieskofioletowy amfibol alkaliczny (glaukofan); *2* — ciemny, niebieskofioletowy alkaliczny amfibol (krossyt); *3* — bogate w drobne wrostki strefy reliktowe; *4* — przyprószony drobnymi wrostkami alkaliczny amfibol (glaukofan); *5* — zielony amfibol (aktynolit lub hornblenda aktynolitowa)

7). They represent remnants of a pre-existing mineral most probably brown hornblende — kaersutite, of which very fine relicts may still be found.

The optical determinations of the dark alkali amphibole were not possible due to the numerous inclusions and too small uniform areas. The light variety shows also some zonation and inhomogenity therefore the optical data show variation within large limits [14].

The rock does not contain clinopyroxene, instead the pseudomorphs of light green chlorite +calcite+Fe-oxides+Ti-minerals (leucoxene) are present. An aggregate of a green mineral resembling (under the microscope) hornblende or biotite appeared to be chlorite when analysed with the electron probe (Table 3, anal. 45/3).

Most probably from the same locality 45 Kryza and Muszyński (1987b) — their locality no. 2 — described the coarse-grained diabase rich in clinopyroxene. They described also zonal microstructures of amphiboles similar to those of sample no. 50, but riebeckite and magnesioriebeckite were not observed. The most outer amphibole zone in their case was "light green barroisitic hornblende" (barroisitic hornblende should have been distinctly blueish-green). In the next paper (Kryza *et al.* 1988) concerning most probably the

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[14] Z/γ angle = 0, 3, 4, 6, 7, 9, 11 (average 5.7)°. $2V_\alpha$ angle = 30, 20, 20, 10 (average 20)°. Pleochronic colours: parallel to elongation of prisms γ — blue with slight purple tint, perpendicular to elongation of prisms β — violet purple, perpendicular to elongation of prisms α — light yellow to colourless.

same locality zones of kaersutite (centre), sodic-, sodic-calcic and calcic-amphiboles were mentioned and mineral formulas calculated from the electron probe analyses of kaersutite, glaucophane, winchite (at the border with actinolite) and actinolite were given. This time "barroisitic hornblende" was not mentioned. In the same rock greenish biotite was identified.

In all diabases plagioclase is of albite composition. As a rule it contains fine inclusions of epidote or clinozoizite and obviously its original composition was more calcic. Sometimes distinct sericitization can be observed.

In the rocks belonging to Świerzawa and Bolków units, especially in diabases, the crystals of alkali amphiboles are more common and bigger than in the other units. Therefore most of optical and chemical data were collected from these rocks. The diabases containing alkali amphiboles were also found in many other places. They all, including so-called "epidiabases" of northern branch of Kaczawa Mts (Jerzmański 1965), have similar mineral composition and textural position of alkali amphiboles. Most of the diabases contain primary magmatic minerals i.e. clinopyroxene and hornblende.

GREENSTONES

The mineral composition of greenstones is roughly the same as that of diabases. They contain albite with numerous inclusions of minerals of epidote group and some sericite. Epidote is commonly present as independent bigger grains Sphene sometimes with ilmenite relicts in centres is a common mineral. Accessory apatite is always present in small amounts. Quartz is sometimes observed rather as secondary veins or nests. Calcite is common. Chlorite is usually the most important mafic mineral. Sometimes like in some diabases two varieties of chlorite may be observed in one rock. The major mineralogical difference as compared with diabases is that primary magmatic minerals are usually less common in greenstones. Clinopyroxene similar to that of diabases is sometimes observed (e.g. samples 70, 77, 91b, 107b). Around clinopyroxene grains and in cracks in them chlorite is always present ·and often also actinolite. These two minerals grew at the expense of the decomposing clinopyroxene. The primary hornblende like the one seen in diabases was observed only in the greenstone sample no. 91b.

Quite common are textural relics. Ophitic or intergranular textures — arrangements of plagioclase laths and pyroxene or post-pyroxene chlorite — have been observed in many places, e.g. samples 70, 77, N11. In some greenstones amygdaloidal texture is seen megascopically and under the microscope. In the rock collected by W. Narębski no. N11 from the hill Grodzik amygdales are filled mainly with calcite. Fe-oxides group both in their centres and at the boundaries of amygdales and a rock mass. Small amounts of chlorite, epidote and albite are also present in amygdales. In the same rock there are also sharp angular concentrations of coarse crystals of calcite. They could have originated by replacing a deformed short-prismatic mineral, possibly clinopyroxene. These concentrations contain also albite, epidote, more than amygdales of chlorite, dark olive biotite plates and fine sphene grains. There is also an alkali amphibole in them forming fine radially distributed prisms showing pleochronic colours from light yellow ·through greyish blue to dark blue with some emerald tint, oblique extinction and distinct dispersion. This is a kind of alkali amphibole somewhat different from the others identified in Kaczawa complex possibly transitional to barroisitic hornblende. The crystals are too small for more detailed optical determinations and no sample was available for probe analysis.

The interrelations of amphiboles in greenstones are similar to that of diabases. As it was mentioned before the only greenstone where primary magmatic hornblende was observed is sample no. 91b. Actinolite is common in these rocks often observed together with chlorite associated with decomposing clinopyroxenes. Alkali amphibole most often of probably glaucophane/crossite composition appears in various relations to other minerals. It may form on the margins of actinolite grains (e.g. sample no. 70) or vice versa is rimmed by actinolite forming central parts of prisms (e.g. 15a, 15b, 107b). Often light green amphibole, probably actinolitic hornblende, forms rims around alkali amphibole which is especially well seen at the ends of prisms (e.g. 24, N12a). Commonly both amphiboles are covered by chlorite. In many places alkali amphibole seems to be replaced by chlorite, in any case these two minerals are often mixed together.

GREENSCHISTS

The compositional variation of these rocks is very wide. They may have originated from

strongly deformed basic lavas, tuffs, tuffs mixed with pelitic material etc. Some acid volcanic admixture cannot be excluded either. The minerals present in greenschists are mainly the same as in greenstones but their proportions may be different. Quartz seems to be more common in greenschists.

The only greenschists in which clinopyroxenes are present is the one forming about 5 cm thick layer within sericite schists in locality 98 (see Tables 1, 2, 3, 5 and Fig. 10). Within bands of chlorite with some sphene, epidote and albite "augen" shaped pyroxenes 0.2–0.3 mm across are present. Alkali amphibole (crossite close to ferroglaucophane, note relatively high Ca content) up to 0.1 mm across is associated with pyroxene and chlorite. At its margins sometimes actinolite is present. Greenschists often contain muscovite usually mixed with chlorite. In places their mixture resembles fine biotite flakes. Quartz is usually present in small amounts. Epidote, sphene and Fe-oxides are always present. Plagioclase is always a pure albite, sometimes clear, sometimes with sericite and fine other inclusions like epidote, chlorite and sometimes alkali amphibole.

In the localities B5 and B6 alkali amphiboles form bigger than average often euhedral phenoblasts. They may reach even the size 1.2 × 0.5 mm. They are light blue to purple but sometimes show dark thin rims. They are always surrounded by chlorite. In one case (B6) chlorite pseudomorph after alkali amphibole was observed. Fine relicts of alkali amphibole and typical of amphiboles oblique cleavages still seen in the chlorite aggregate are present. An interesting fact is that the dark alkali amphibole probably crossite rim is much better preserved than the centre built up of light alkali amphibole variety probably glaucophane. It appears that crossite was still stable when glaucophane was decomposed and replaced by chlorite. This would be the evidence of a well known fact that alkali amphiboles containing riebeckite or magnesioriebeckite molecule are stable in lower pressure and higher temperature conditions as compared with pure glaucophane.

In another rock (B5) inside the alkali amphibole phenoblast very light green actinolite was observed as probably a relict. It is probable that the alkali amphibole like in diabases originated by replacing the pre-existing amphibole. In this case it was actinolite. Besides the bigger phenoblasts the alkali amphibole forms sometimes very fine prisms in albite and chlorite aggregates. The optical data of alkali amphiboles from

greenschists are far from being complete[15].

All diabases, greenstones and greenschists described until now in which alkali amphiboles have been found contain albite as a major constituent. In the profile above the church in the village Chrośnica, described by Baranowski et al. (1981), where they mentioned the presence of "glaucophane", a green plagioclase free chlorite-from quartz schist containing appreciable amount of calcite, with alkali amphibole have been found. The sample from this locality, given to me by Z. Baranowski belongs to this category. The schist is composed of separate patches of chlorite with Fe-oxides and leucoxene and sometimes epidote, quartz with some chlorite and calcite and calcite-rich containing all other minerals.

The alkali amphibole (crossite close to glaucophane — see Table 2 and Fig. 10) is present in these schists as small prisms and needles in opening fissures filled with quartz in chlorite (Fig. 8), in quartz and quartz-calcite patches. It crystallized usually near the boundaries between chlorite and quartz or chlorite and calcite.

The microstructures resemble to some extent the crystallization in "pressure shadows". Bigger prisms of crossite[16] may reach the size 0.2 × 0.9 mm. The rock sample 17j is so rich in crossite that should be named chlorite-quartz-calcite-crossite schist. Around crossite especially at the ends of prisms a little of green amphibole being probably actinolite or actinolitic hornblende is present.
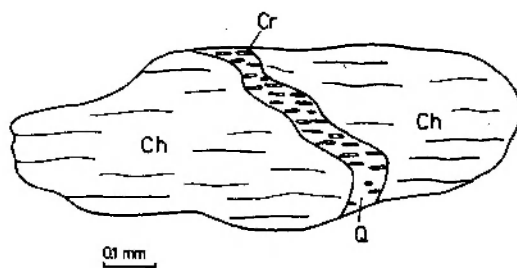

Fig. 8. Fine alkali amphibole (crossite) prisms within quartz "vein" cutting chlorite cluster in plagioclase free green schist sample no. 17j. Q — quartz; Ch — chlorite; Cr — crossite
Drobne słupki alkalicznego amfibolu (krossytu) w „żyle" kwarcowej przecinającej pakiet chlorytu w bezplagioklazowym zielonym łupku, próbka nr 17j. Q — kwarc; Ch — chloryt; Cr — krossyt

[15] Pleochroic colours: α — light yellow to colourless, β — purple, γ — blue. Birefrigence low to intermediate, lighter varieties show higher birefrigence. $2V_\alpha$ angle — small.

[16] Crossite pleochroic scheme: α — almost colourless, β — blue, γ — purple.

In this rock in the absence of plagioclase the only Na mineral is crossite. The whole rock chemical analysis (Table 4) shows that sample 17j has very low Na_2O ($0.53^o/_o$) content and high CaO and CO_2 content due to the abundance of calcite.

Table 4. Ferric/ferrous ratios of alkali amphiboles based on published wet chemical analyses (mainly Deer *et al.* 1963) Fe^{3+}/Fe^{2+} w alkalicznych amfibolach na podstawie publikowanych analiz chemicznych (głównie Deer *et al.* 1963)

	Fe^{3+}/Fe^{2+}	
	min.	max.
Glaucophane, ferroglaucophane and adjacent crossite ($Al^{total} > 1.2*$)	0.20	0.70
Riebeckite and adjacent crossite (Mg < 1.2, Al < 0.7*)	0.30	0.80
Magnesioriebeckite and adjacent crossite (Mg > 1.0, Al < 0.7*)	0.30	2.00

* Usually in the formula.

In other layers of the same outcrop similar green schists contain albite and white mica but alkali amphibole is lacking. It is a seeming contradiction that Na-amphibole appears in the Na-poorest layers. As the *PT* conditions were approximately the same in all neighbouring layers of the same outcrop the presence or absence of alkali amphibole should depend on the differences of mineral and/or chemical compositions of the rock layers. It appears however, that it may also be related to other not easily definable factors like fissility for solutions, possibly depending on the degree of deformation, giving rise to metasomatic phenomena.

KERATOPHYRES

In the same profile of Chrośnica village below the outcrops of greenschists (loc. no. 17) the keratophyres are present (no. 18). Nearest to the greenschist the nodule keratophyre is outcropping. It consists of a little of green schistose matrix in which dark grey massive, non directional nodules are present 1 to 10 cm across. The matrix is a light-mica schist with some knots of sphene, epidote and Fe-oxides, blasts of albite showing helicitic microstructure are also present. The matrix does not contain alkali amphiboles. The nodules consist mainly of quartz, albite, K-feldspar and a little of green biotite, light-mica,

sphene-leucoxene, epidote, Fe-oxides and apatite. It is worth to note that if potassium is abundant biotite not chlorite is stable in the rock. In this rock small prisms of alkali amphibole tend to group in the quartz nests and veins. Both in previously described green schist (no. 17j) and in the keratophyre this common coexistence of quartz and alkali amphibole is quite clear. The prisms of alkali amphibole were too small for accurate optical determinations and even for microprobe analysis.

As mentioned at the beginning of this paper Ansilewski (1954) described alkali amphibole in the keratophyre NNW of Bolków (loc. no. A1). On the basis of optical data [17] he identified it as riebeckite and considered it as a primary magmatic mineral. The samples collected by the present author from probably the same locality do not contain any alkali amphibole which means that alkali amphibole is not a common mineral of these keratophyres. It seems probable that the origin of this alkali amphibole is similar to other alkali amphiboles of Kaczawa complex and not necessarily a magmatic one.

About 1.5 kilometer NW, in locality no. 7 two samples of alkali amphibole bearing felsic rock corresponding to keratophyre were taken from loose blocks. In the aphanitic grey matrix elongated yellow feldspars of 2–4 × 5–10 mm size are seen. The rock has somewhat gneissic appearance. The feldspars are albites. They could have been originally bigger, later destroyed by deformations. In general the rock has in its parts mylonitic appearance. Quartz forms various nests and veins. In the sample 7d many quartz aggregates are circular in the thin section which resemble quartz amygdales. In the same rock pseudomorphs after a prismatic mineral filled with light mica and a little of green biotite could be met. Numerous Fe-oxides, some sphene and epidote as well as probably a little of allanite [18] are present. The alkali amphibole forms thin needles too small for proper optical determinations. In some places they are light in other dark blue and purple. They probably correspond to crossite. Only seldom the ends of prisms show slight greenish colouration.

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[17] Pleochroic colours $\alpha > \beta > \gamma$: α — "ink" blue, β — blueish grey, γ — greenish yellow, very low birefrigence and straight extinction.

[18] Pleochroic colours from light grey to greyish brown, intermediate to high birefrigence, biaxial.

MINERAL REACTION SCHEME
OF METABASITES OF KACZAWA COMPLEX

On the basis of the described above various textural relations of the minerals of diabases, greenstones and greenschists an attempt has been made to present the mineral reactions that took place in various rocks on a single diagram.

If one mineral forms a rim, even irregular and not complete, on another mineral it is in most cases reasonable to assume that the rim originated later. It could happen either when new mineral grew at the expense of the former one replacing it or when new mineral grew during the metamorphism on the former one without its decomposition using it only as a nucleus. In both cases the mineral changes reflect the change of *PTX* conditions of crystallization. The zonation apart from being the replacement and/or growth feature may also partly be result of a diffusive exchange between zones of different compositions (Holland, Richardson 1979). In some cases all three processes could have taken place in one rock. The distinction between them on the basis of microscope observation is often not sure, sometimes impossible.

In the case of the often observed pseudomorphs of chlorite or chlorite and calcite, with inclusions of Ti-minerals, showing the shape of short prisms after clinopyroxene and still containing some clinopyroxene relicts the replacement process seems to be satisfactorily documented.

The interpretation is not so clear in the case of zonal microstructures so well developed in diabases (Figs. 3 and 4). The zone of kaersutite around clinopyroxene core (Fig. 3) seems to be the overgrowth during crystallization from a melt. The zone of alkali amphibole mantling the kaersutite may be partly the result of replacement of kaersutite (where inclusions of Ti-minerals in alkali amphibole are numerous) and partly of the further metamorphic growth. The same applies to actinolite zone around alkali amphibole.

The thin rim in sample 52 of darker alkali amphibole (ferroglaucophane/crossite) between magnetite or epidote and lighter alkali amphibole (glaucophane/crossite) may easily be the result of a diffusive exchange of neighbouring minerals. This may also apply to presence of crossite thin rims between kaersutite and glaucophane in other samples.

Even if the process of crystallization of minerals is not fully explainable the zonal microstructures usually allow to trace the order of mineral

crystallization which may be interpreted as a record of changing metamorphic conditions.

On the diagram (Fig. 9) the solid arrows mean that this order of crystallization is commonly observed. The dashed arrows represent
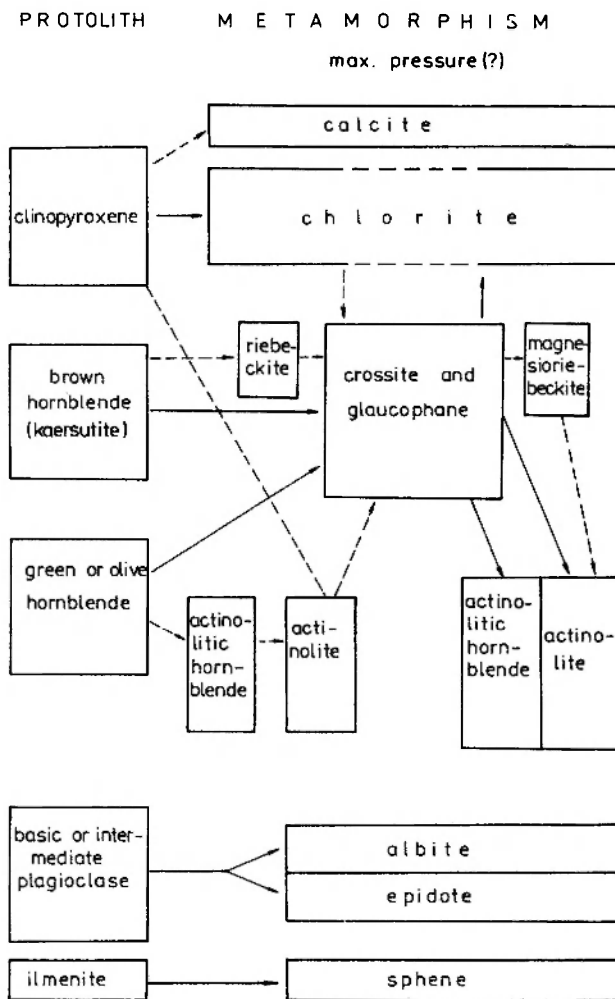

Fig. 9. Mineral reaction scheme of metabasites of Kaczawa complex. Solid arrows — commonly observed; dashed arrows — sometimes observed; other explanations in the text

Schemat reakcji mineralnych w metabazytach kompleksu kaczawskiego. Strzałki ciągłe — obserwowane często; strzałki przerywane — obserwowane czasami. Inne objaśnienia — w tekście

those observed only sometimes. On the left side of the diagram are the minerals which were present in a primary igneous rock — the protolith. Their relicts are often observed in diabases and greenstones. In case of plagioclase no relicts of basic or intermediate members were detected.

In the centre and right the metamorphic minerals are presented. Most of chlorite is the result

of transformation of clinopyroxene. It could eventually happen in an early stage of metamorphism when also small amount of actinolitic hornblende and actinolite sometimes originated from olive green hornblende and also some actinolite directly from clinopyroxene. But most of chlorite originated later when not only clinopyroxene but also part of alkali amphibole were converted into it.

Alkali amphiboles originated mainly by replacement of pre-existing amphiboles. This is clearly seen in diabases in respect of brown and green hornblende, not so common in respect of actinolite. The separate small prisms of crossite or glaucophane present within or near chlorite aggregates show that they could grow independently not replacing any particular mineral, being probaly at certain stage of metamorphism in equilibrium with albite and chlorite. This applies also to alkali amphiboles present in keratophyres though they are not presented in Fig. 9. In other places the replacement of alkali amphibole by chlorite seems to be very probable.

The most complete series of zonal crystallizing/replacing amphiboles found in diabase sample no. 50 (Fig. 4) kaersutite — riebeckite — glaucophane — magnesioriebeckite — actinolite is also shown on the scheme.

CHEMICAL DATA OF MAFIC MINERALS, ANALYTICAL METHODS AND CALCULATIONS OF MINERAL FORMULA

The analyses were performed by the team from Institute of Material Science of the Technical University of Warsaw under the research programme CPBP 03.04 sponsored by the Institute of Geological Sciences of Polish Academy of Sciences. 12 alkali amphiboles, 3 Ca-amphiboles, 3 clinopyroxenes and 3 chlorites were analysed in 6 samples. The following elements were determined (in brackets the standards used): Na (jadeite), Mg (olivine), Al (corundum), Si (wollastonite), K (orthoclase), Ca (wollastonite), Ti (metal), Mn (metal), Fe (olivine) and in pyroxenes additionally Cr (metal). Analyses were made with the use of Jeol JXA-3A microanalyser with two WDS spectrometers. The ZAF corrections were applied.

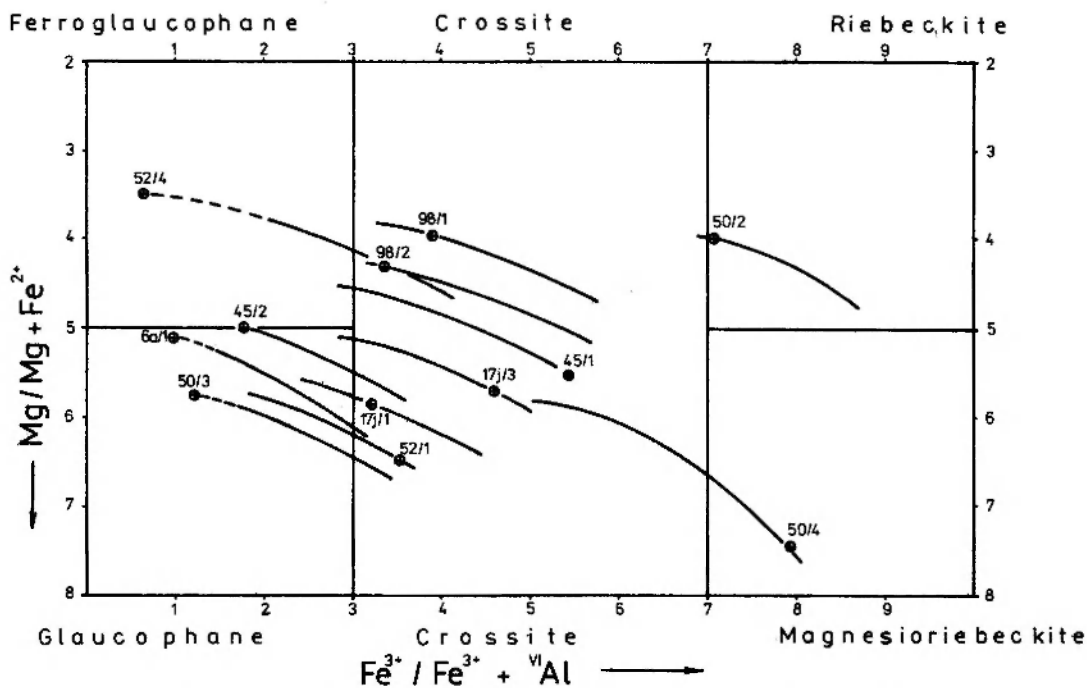To reduce the problem of matching the analy-

Fig. 10. Kaczawa Mts alkali amphiboles classification graph. Each analysis is represented by a section of curve corresponding to limit Fe^{3+}/Fe^{2+} ratios given in Table 4 (solid line) and a point corresponding to Fe^{3+} content calculated on the basis of 13 cations (see Table 2)

Wykres klasyfikacyjny alkalicznych amfiboli z Gór Kaczawskich. Każda analiza przedstawiona jest przez odcinek krzywej, odpowiadający granicznym wartościom stosunków Fe^{3+}/Fe^{2+} podanym w tabeli 4 (linia ciągła), i punkt odpowiadający zawartości Fe^{3+} obliczonej na podstawie 13 kationów (patrz tabela 2)

sed points for 5 runs photomicrographs were used for spot locating. The compositions reported are averages of 2 spot analyses located usually 10–15 μm from each other.

Calculations of amphibole formulas were made on the basis of 23 oxygens i.e. assuming $(OH)_2$ in the formula. The Fe_2O_3 and FeO contents (Table 2) were calculated assuming that

$$Si + Al + Fe^{3+} + Fe^{2+} + Mg + Ti + \tfrac{1}{2}Mn = 13.$$

This calculation of Fe^{3+}/Fe^{2+} ratios is not fully reliable because sometimes a small negligible error in one of major elements and lack of H_2O determination may influence the calculated ratio to large extent. In the classification of alkali amphiboles the Fe^{3+} content is very critical therefore each analysis was calculated for the limits of Fe^{3+}/Fe^{2+} ratios for three compositional groups of alkali amphiboles taken from wet chemical analyses found in the literature (mainly Deer et al. 1963). The limit ratios are given in Table 4. In this way each alkali amphibole analysis is represented on the classification graph (Fig. 10) by a section of curve corresponding to the limits of the Fe^{3+}/Fe^{2+} ratios given in Table 4 (solid lines) and a point corresponding to the Fe^{3+} content calculated on the basis of 13 cations (Table 2). In some cases the points do not lie within the limits.

CHEMICAL COMPOSITIONS AND CIPW NORMS OF ALKALI AMPHIBOLE BEARING ROCKS

For more complete documentation the alkali amphibole bearing rocks in which minerals were analysed by the electron probe were also analysed. The whole rock chemical analyses and the CIPW norms are given in Table 5.

The analytical results of major elements of only 6 samples do not allow for any generalizations but chemical study of whole rocks was not the objective of the present paper. The most recent report on paleotectonic setting of Kaczawa complex metavolcanics based on major and trace elements studies of Narębski (1964, 1980), Narębski et al. (1982, 1986), Baranowski et al. (1984) and Kryza and Muszyński (1987b) was given by the last authors (1987a).

The alkali amphibole bearing rocks do not show any enrichment in sodium in relation to other rocks of the same kind. It is worth to note that the greenschist sample 6a with its high content of normative quartz and albite does not correspond in composition to metabasic rock. On the other hand the quartz-chlorite schist 17j shows unusually low content of sodium. Among the analysed greenschists only sample no. 98 shows the composition of a proper metabasic rock.

Diabases 50 and 52 show rather low content of silica and their chemical composition is close to basanite. The third diabase 45 is distinctly carbonitized and chloritized which is reflected by its bulk chemical composition.

COMPARISON OF THE OCCURRENCES OF ALKALI AMPHIBOLES IN KACZAWA MTS WITH KOPINA MT (E KARKONOSZE) AND ŽELEZNÝ BROD (S KARKONOSZE) AREAS

The detailed microscope and electron probe study of alkali amphiboles of metavolcanic rocks of Kaczawa complex reveals that they belong to glaucophane—crossite—riebeckite series. Most often they are crossites and glaucophanes but ferroglaucophane, riebeckite and magnesioriebeckite were identified.

As it was mentioned before the alkali amphiboles are scarce in Kaczawa Mts. They were identified in relatively few samples and they are not attached to any particular rock type neither from textural nor mineralogical nor chemical point of view. They were identified in all metavolcanic rock types i.e. diabases, greenstones, greens-chists and keratophyres and their origin should be considered jointly in all rock types.

The occurrence of alkali amphiboles in Kaczawa complex is not related to any particular tectonic position. They are present in all tectonic units. They do not follow any zones or lines of whatever significance, or at least this kind of relationship was not detected.

The feature of alkali amphiboles which was often observed is their zonal microstructure. They usually grew on or at the expense of the pre-existing Ca-amphiboles (kaersutite, actinolite) and have rims of again Ca-amphibole (actinolite or actinolite hornblende).

Table 5. Whole rock chemical compositions and CIPW norms of alkali amphibole bearing metabasites in weight per cent

Analizy chemiczne całych skał i normy CIWP metabazytów zawierających alkaliczne amfibole w procentach wagowych

No. of sample		6a	17j	45	50	52	98
Rock name		greenschist	green quartz-chlorite schist	diabase	diabase	diabase	greenschist
SiO_2		64.55	41.54	38.28	42.52	45.99	44.72
Al_2O_3		14.70	8.46	12.13	10.02	14.70	15.42
Cr_2O_3		0.01	0.19	0.06	0.06	0.04	0.04
Fe_2O_3		3.78	7.09	5.70	6.22	4.81	10.83
FeO		1.44	5.48	7.15	7.03	6.35	4.16
MgO		2.24	9.71	9.79	12.43	6.62	5.95
TiO_2		1.24	2.62	3.80	3.67	3.40	2.06
MnO		0.05	0.20	0.18	0.18	0.16	0.27
CaO		1.42	11.57	8.75	12.25	8.51	8.73
Na_2O		5.78	0.53	2.10	1.40	3.04	2.46
K_2O		0.25	0.05	0.62	0.12	1.48	0.17
P_2O_5		0.35	0.18	0.27	0.17	0.24	0.05
CO_2		0.29	5.72	5.39	0.15	0.33	1.39
H_2O^+		3.46	6.54	6.14	4.24	3.85	4.20
Total		99.56	99.88	100.36	100.46	99.52	100.45
S		0.01	0.02	0.02	0.02	0.06	0.02
H_2O		0.74	0.87	0.50	0.30	0.23	1.08
Quartz	Q	26.42	16.08	4.97	—	—	7.12
Corrundum	C	3.98	0.13	5.53	—	—	—
Orthoclase	or	1.56	0.28	3.89	0.72	9.17	1.06
Albite	ab	50.78	4.82	18.80	12.26	26.87	21.63
Anorthite	an	3.14	21.64	8.09	21.52	23.01	31.65
Plagioclase	ab+an	53.92	26.46	26.89	33.78	49.88	53.28
an %		6	82	30	64	46	59
Diopside	di	—	—	—	30.87	13.64	3.05
Hypersthene	hy	5.83	26.02	28.49	10.35	8.15	14.03
Olivine	ol	—	—	—	6.75	3.57	—
Magnetite	mt	1.16	11.00	8.77	9.37	7.28	8.40
Chromite	cm	0.02	0.29	0.09	0.09	0.07	0.07
Haematite	hm	3.14	—	—	—	—	5.46
Ilmenite	il	2.45	5.34	7.66	7.24	6.75	4.07
Apatite	ap	0.82	0.43	0.66	0.43	0.59	0.13
Pyrite	pr	0.02	0.04	0.05	0.04	0.13	0.06
Calcite	cc	0.68	13.93	13.00	0.36	0.77	3.27
sal/Fem		6.08	0.75	0.73	0.53	1.44	1.59
(Q + F)/C		41.52	329.38	6.46	.	.	.
Q/F		0.48	0.60	0.16	0	0	0.13
$(K_2O' + Na_2O')/CaO'$		3.78	0.04	0.26	0.11	0.43	0.27
K_2O'/Na_2O'		0.03	0.05	0.19	0.06	0.32	0.05
(P + O)/M		0.86	1.56	1.72	2.87	1.80	0.95
P/O		.	.	.	6.11	6.10	
$(MgO' + FeO')/CaO'$		.	.	.	2.38	3.06	10.96
MgO'/FeO'		.	2 600.00	13.53	20.97	9.89	.
CIPW		II(I).4.2.5.	III(I).3.5.5.	III(II).4.4.4.	IV(II).2.2.1.	III(I).5.4.4.	III(I).5.4.5.

For location of samples and mineral compositions see Table 1. Analysed in Analytical-Department of the Katowice Geological Company.

Lokalizacja i składy mineralne podane w tabeli 1. Analizy wykonano w Wydziale Badań Analitycznych Katowickiego Przedsiębiorstwa Geologicznego.

The whole Kaczawa complex was metamorphosed under the conditions of greenschist facies. Except relict magmatic minerals (clinopyroxene, kaersutite, green hornblende, ilmenite) the most common minerals of metabasites are: albite (never more calcic plagioclase), chlorite, epidote, calcite, actinolite and sphene. Biotite was observed by the present author only in keratophyres and in veinlets in diabase, while Kryza and Muszyński (1987b) and Kryza et al. (1988) saw it also in diabase.

The described by Wieser (1978) glaucophane schist from Kopina Mt in Lasocki Range of E Karkonosze, including epidote, garnet, chlorite, albite and quartz, does not resemble any of Kaczawa Mts alkali amphibole bearing rocks. The glaucophane being the most important mineral of the rock (49 and 56 vol.$^{0}/_{0}$), what is never the case in Kaczawa Mts, and presence of garnet, again never noted in Kaczawa Mts, are the major differences.

The described by Fediuk (1962) occurrences of alkali amphiboles of varying composition from glaucophane to magnesioriebeckite of Železný Brod area resemble to some extent the rocks of Kaczawa Mts not being however identical.

The "glaucophane schists" known in Železný Brod area have never been described from Kaczawa Mts, but zonal microstructures in metagabbro from Tepere: brown amphibole (centre) — edenitic amphibole — glaucophane, or other microstructures: brown amphibole — actinolitic amphibole — glaucophane — edenitic amphibole, resemble generally the microstructures from Kaczawa Mts. Fediuk also saw riebeckite in keratophyres.

Fediuk's (op. cit.) scheme of mineral reaction is very similar to that presented in this paper. In Železný Brod area "common green hornblende" and "prasinite (barroisitic) hornblende" seem to be common. It is worth to remember that at that time Fediuk did not have electron probe analyses of amphiboles and determined them only optically.

Fediuk considered the whole Železný Brod area as belonging to greenschist facies and he did not distinguish glaucophane schists as separate glaucophane facies. He did not however explain the origin of alkali amphiboles. Suk (1983, p. 247–248) extends Fediuk's views and concludes that "the origin of alkaline amphibolites [19] resul-

ted from the supply of CO$_2$ which bound Ca from actinolite and epidote giving rise to carbonates". Both Fediuk and Suk felt that local presence of alkali amphiboles does not mean necessarily the high pressure metamorphism.

The newer works were published by Cháb and Vrána (1979), based on 4 samples from 2 localities described earlier by Fediuk (op. cit.), and Guiraud and Burg (1984) based on one sample from the locality described earlier by Fediuk and Cháb and Vrána (op. cit.). The minerals were analysed by the electron probe. The alkali amphiboles correspond mainly to crossite. Calcic amphibole is actinolite often with some edenite substitution. Part of the amphiboles from Železný Brod area show various proportions of Ca and Na and represented intermediate sodic-calcic amphiboles.

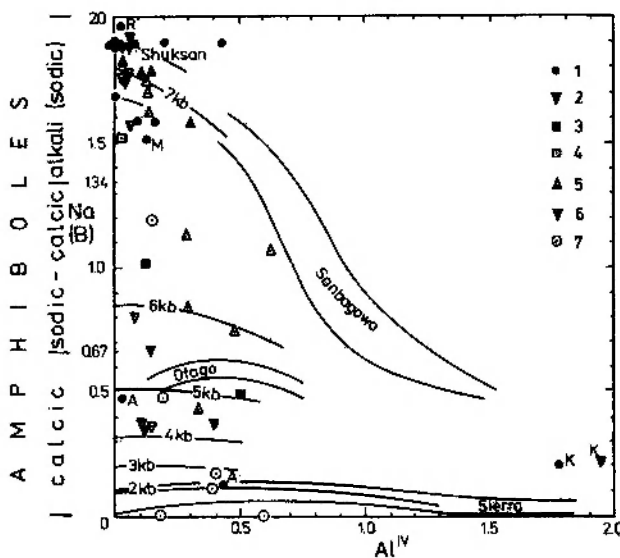The alkali amphiboles from Kaczawa Mts are in most cases either sodic or calcic ones. Interme-

Fig. 11. Tentative estimate of the relationship between pressure of metamorphism and Na (B) of amphiboles after Brown (1977). 1 — Kaczawa Mts (Table 2); 2 — Kaczawa Mts (Kryza et al. 1988); 3 — Ciechanowice, possibly from E Karkonosze (Smulikowski 1989); 4 — Kopina Mt, E Karkonosze (Wieser 1978); 5 — Roprachtice–Železný Brod (Cháb and Vrána 1979); 6 — Roprachtice (Guiraud and Burg 1984); 7 — Tepere–Železný Brod area (Cháb and Vrána 1979); R — riebeckite; M — magnesioriebeckite; K — kaersutite

Próba oceny zależności pomiędzy ciśnieniem w czasie metamorfizmu i Na (B) w amfibolach według Browna (1977). 1 — Góry Kaczawskie (tab. 2); 2 — Góry Kaczawskie (Kryza et al. 1988); 3 — Ciechanowice, przypuszczalnie E Karkonosze (Smulikowski 1989); 4 — góra Kopina, E Karkonosze (Wieser 1978); 5 — Roprachtice, koło Železnego Brodu (Chab i Vrána 1979); 6 — Roprachtice (Guiraud i Burg 1984); 7 — Tepere k. Železnego Brodu (Cháb i Vrána 1979); R — riebeckit; M — magnezioriebeckit; K — kaersutyt

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[19] Most probably he was thinking about alkali amphibole bearing amphibolites.

diate members are not known, if not taking into account the identified recently by Kryza et al. (1988) in a diabase the actinolite/winchite intermediate amphibole. It is interesting to note that amphiboles from amphibole schist found in the village Ciechanowice as a block derived probably from Culm conglomerate and indirectly rather from E Karkonosze complex represent intermediate sodic-calcic amphiboles (W. Smulikowski 1987). All analysed amphiboles from Kaczawa Mts, E Karkonosze and Železný Brod area are plotted on the graph (Fig. 11).

Magnesioriebeckite from sample no. 50, analysis 4, was analysed in a very narrow stripe. It is possible that a little of Ca and Mg came from neighbouring actinolite taken into analysed volume.

Both pairs of authors, i.e. Cháb and Vrána and Guiraud and Burg, have no doubts that alkali amphiboles of Železný Brod area document the high pressure regime of one stage of metamorphism and subduction/obduction model of early Variscan suture zone (G. & B., op. cit.) or "the lower part of a thrust-and-nappe sequence originated during the collision of continental crust segments of lithospheric plates along the previous convergent boundary" (C. & V., op. cit.) were used for its explanation. To what extent these explanations may be applied to Kaczawa complex will be discussed below.

SIGNIFICANCE OF ALKALI AMPHIBOLES AS PRESSURE INDICATORS

The significance of alkali amphiboles as pressure indicators has been a problem since long ago. Neither differential stress nor high pressure is necessary for the formation of glaucophane (Ernst 1961). Glaucophane is stable over the wide range of physical conditions if chemical conditions are appropriate i.e. rich in Na and Mg and poor in Ca in relation to Al. Such bulk chemical compositions of the rocks are very unusual and therefore glaucophane is not frequently present. The presence of glaucophane in the rocks of "normal" — i.e. commonly occurring in metabasites — composition may indicate the conditions different from widespread metamorphic facies like greenschist facies or epidote-amphibolite facies.

The excess of Na in relation to Al in the presence of Fe should favor the crystallization of intermediate and riebeckite rich members of glaucophane-riebeckite series i.e. crossites. Their formation is highly dependent on oxygen fugacity. Riebeckite is stable over the whole PT range from sedimentary to igneous rocks in Al-poor, Fe-rich rocks while the stability of crossites and transitional crossite-riebeckite members is not fully worked out. According to Miyashiro and Banno (1958) "the presence of riebeckite and magnesioriebeckite molecules in solid solutions extends the stability field of glaucophanic amphiboles in pressure and temperature".

Studying blueschist facies amphiboles from various localities Muir Wood (1980) noticed that pure riebeckite exists under low pressure but breaks down in normal blueschist facies; ferroglaucophane may exist at all except the lowest blueschist temperatures; magnesioriebeckite is stable at high temperature and low pressure and breaks down in the blueschist facies; glaucophane is stable only at high pressure. He also concludes that the study of stability of natural alkali amphiboles in temperature and pressure should be undertaken with the cautious approach to experimental analogy. The relatively recent experimental study by Maruyama et al. (1984) confirms the stability of blueschist and greenschist facies assemblages over a considerable range of P and T depending on the bulk composition.

Glaucophane and crossite commonly occur in blueschists associated with lawsonite, jadeitic pyroxene and aragonite. These last three minerals and not alkali amphiboles themselves are the true indicators of high pressure conditions. Even if alkali amphiboles alone do not strictly indicate the high pressure they are however considered in the rocks of "normal" — i.e. common in metabasites — composition as indicators of higher pressure conditions. For the rocks of greenschist facies containing alkali amphiboles and not lawsonite, jadeitic pyroxene or aragonite Winkler (1967) applied the term "glaucophanitic greenschist facies", which corresponds to the highest pressure greenschist facies (Fig. 12).

In newer works, e.g. Holland and Ray (1985), the composition of Ca-Na amphiboles is considered as potential geobarometer using the reactions analogous to the following: crossite + epidote + H_2O = Ca-amphibole + albite + chlorite + Fe-oxide. There are many limitations of this geobarometer which Brown (1977) discussed extensively.
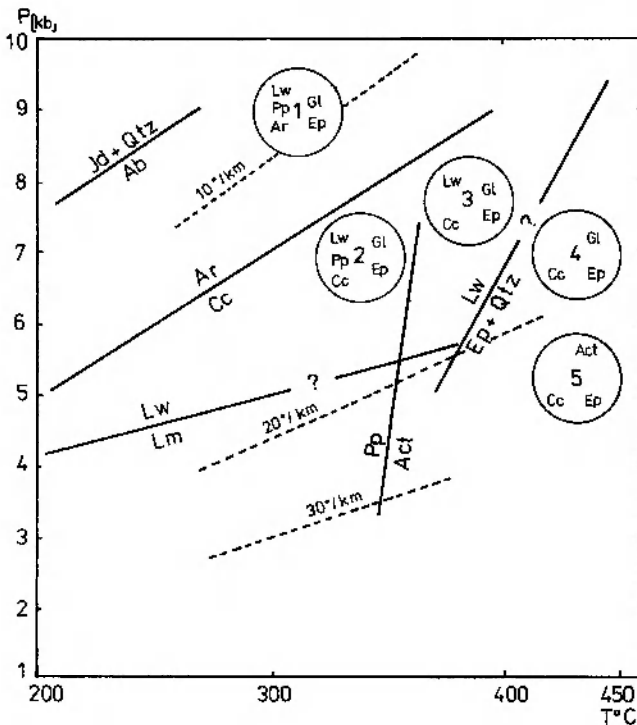
Fig. 12. Mineral assemblages of metabasites under conditions of low grade metamorphism. Compiled from Brown *et al.* (1981), Turner (1968), Winkler (1967). Albite, chlorite, Fe- -oxide and quartz may always be present. Ab — albite; Ar — arragonite, Act — actinolite; Cc — calcite; Ep — epidote; Gl — glaucophane; Jd — jadeite; Lm — laumontite; Lw — lawsonite; Pp — pumpellyite; Qtz — quartz. 1, 2, 3 — lawsonite glaucophane schist facies; 4 — glaucophane greens- chist facies; 5 — greenschist facies

Zespoły mineralne w metabazytach w warunkach niskiego stopnia metamorfizmu. Zestawiono na podstawie: Brown *et al.* (1981), Turner (1968), Winkler (1967). Albit, chloryt, tlenki Fe i kwarc mogą być obecne we wszystkich zespołach. Ab — albit; Ar — aragonit; Act — aktynolit; Cc — kalcyt; Ep — epidot; Gl — glaukofan; Jd — jadeit; Lm — laumontyt; Lw — lawsonit; Pp — pumpellinit; Qtz — kwarc. 1, 2, 3 — facja łupków lawsonitowo-glaukofanowych; 4 — facja glaukofano- wo-zieleńcowa; 5 — facja zieleńcowa

Sodic-calcic amphibole should be mixed in the greenschist facies as a single solid solution phase. When pressure increases the Na-amphibo- le component increases to the point, when the pressure is so high, that the amphibole is essen- tially the sodic amphibole. Thus according to Brown (*op. cit.*) the Na (M4) i.e. Na (B) content of actinolite is pressure dependent but only in assemblages which include albite, chlorite and magnetite. He calibrated his geobarometer on the empirical basis using various metamorphic com- plexes containing both sodic and/or sodic-calcic amphiboles and a possibility of independent eva- luation of the pressure. The three calibration terraines were:

Sierra Nevada (California) — 2 kb based on mineral stabilities and estimation of erosion since intrusions of plutons;

Western Otago (New Zealand) — 5-6 kb ba- sed on sphalerite geobarometer using experimen- tal data of Fe–Zn–S system;

Shuksan (North Cascades, Washington) — 7 kb based on albite present instead of jadeite +quartz, lawsonite and calcite with only one locality of aragonite.

Using these very far from being accurate data Brown (*op. cit.*) prepared the graph (Fig. 11). He was aware of the fact that this geobarometer provides only tentative estimation of pressure but he did not say explicitly that it may be applied only in some terraines while in the others the assesment of conditions may be complicated by other important factors mainly variation in oxy- gen fugacity.

Okay (1980) has shown that practically whole compositional range of sodic amphiboles in glau- cophane-lawsonite facies is stable. By analysing them with coexisting magnetite or haematite or both of them he noticed that the compositions of amphiboles are different. With haematite they are more towards magnesioriebeckite, with magnetite towards ferroglaucophane. The zoning of amphi- boles according to Okay (*op. cit.*) are best explai- ned by changes in oxygen fugacity during meta- morphism. As shown by Chinner (1960) oxygen fugacity during metamorphism is not externally but locally controlled.

This explanations seem to fit very well to the zonations of amphiboles from Kaczawa Mts es- pecially to the analysed sample 50.

As it was mentioned before the presence of riebeckite or magnesioriebeckite molecule in solid solutions of alkali amphibole are stable in a wider range of temperature and pressure as com- pared with glaucophane. The Na content in Ca- amphibole which is in general pressure controlled may have different significance depending on which of Na-amphiboles (glaucophane, ferroglau- cophane, magnesioriebeckite, riebeckite) forms so- lid solutions with Ca-amphibole. To make it still more complicated the effect of the composition of the Ca-amphibole taking part in the solid solu- tions (e.g. edenite or tchermackite substitution in actinolite) is not known either.

It appears from these considerations that the formation of sodic and sodic-calcic amphiboles is controlled by complicated combination of physi- cal conditions, chemical compositions and oxygen

fugacity. In addition to that, as it often happens in low grade metamorphism, metastable relicts and various local equilibria have to be taken into account. An univocal interpretation of rock textures, mineral and chemical compositions is difficult and in some cases may not be possible.

APPLICATION OF ALKALI AMPHIBOLE GEOBAROMETRY
TO KACZAWA MTS METABASITES

Having in mind all the reservations discussed in the previous chapter it is worth to try to apply the alkali amphibole geobarometry to Kaczawa complex. With their zonal microstructures and a few generations of relicts one of difficulties of Kaczawa Mts rocks is which of minerals present in the rock belong to the same equilibrium assemblage.

Another complication in using the Kaczawa complex alkali amphiboles for geobarometry illustrates the described outcrop no. 17 from Chrośnica, where crossite appears only in Na--poor, albite free chlorite-quartz schist layers while in albite (and Na) rich layers alkali amphibole is not present. The formation of almost Ca-free crossite in the sample 17j was probably the effect of a metasomatic process.

The mentioned before zonal amphiboles of sample 50 with zones of riebeckite and magnesio-riebeckite show most probably an effect of oxygen fugacity variation during the metamorphism, which provides another complication to alkali amphibole geobarometry.

The alkali amphiboles of Kaczawa complex, contrary to S Karkonosze (Železný Brod area) rather seldom show intermediate members of sodic-calcic amphiboles. According to Brown (1977) in very high pressure regimes, e.g. Franciscan, there may exist a miscibility gap in sodic-calcic amphiboles (Klein 1968), while in lower blueschist facies and greenschist facies terraines continuous series of solid solutions are observed. In the greenschist facies of Kaczawa complex one would expect continuous series of amphiboles from hornblende to glaucophane or crossite with the increasing pressure of metamorphism and from glaucophane or crossite to actinolite with the decreasing pressure. The abrupt changes of pressure are unlikely to have taken place. This may also be an argument that not only pressure and temperature controlled the growth of amphiboles of Kaczawa complex during the metamorphism.

The Kaczawa complex alkali amphiboles plotted on Brown's (*op. cit.*) diagram (Fig. 11) group in high pressure field.

Cháb and Vrána (1979) using the same graph (Fig. 11) obtained for Železný Brod area maximum pressure of 7 kb and intermediate values of 6 and 5 kb. Guiraud and Burg (1984) took for pressure estimations the outer rim of crossite and the neighbouring actinolite and obtained $T = 350-450°$ and $P = 6.5-7$ kb not clearly explaining how they arrived at these figures. Their amphiboles are also plotted in Fig. 11.

Not taking very strictly the values of pressure obtained from Brown's graph (Fig. 11) for Kaczawa complex rocks it seems reasonable to assume that at least some of the alkali amphibole containing assemblages may correspond to higher pressure regime of greenschist facies represented in Fig. 12 by assemblage no. 4. In later stages of metamorphism the decrease of pressure took place and assemblages of medium pressure greenschist facies corresponding to no. 5 were stable predominantly in the whole Kaczawa complex.

CONCLUSIONS

Even if taking into account that part of existing earlier alkali amphiboles was destroyed by later processes like replacement by chlorite or actinolite it is impossible to assume that there existed in Kaczawa Mts a large area built up of blueschists and that presently existing alkali amphiboles are only scarce remnants of them.

The origin of alkali amphiboles in Kaczawa complex was very selective. The higher pressure regime of greenschist facies certainly favoured the crystallization of alkali amphiboles. But under the same PT conditions in most of the complex, in spite of the existence of the required mineral phases and often nucleis of earlier amphiboles the alkali amphiboles did not occur. There must have been some other than temperature and pressure factors which affected and controlled their growth, like metasomatism and variation of oxy-

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ALKALICZNE AMFIBOLE W SKAŁACH METAWULKANICZNYCH O NISKIM STOPNIU ZMETAMORFIZOWANIA Z OBSZARU GÓR KACZAWSKICH, SUDETY ZACHODNIE, POLSKA

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Streszczenie

ABSTRAKT: Alkaliczne amfibole, głównie o składzie glaukofanu i krossytu (analizy mikroanalizatorem rentgenowskim), zostały znalezione w 54 metabazytach i 3 keratofirach. Występują one we wszystkich strukturalnych jednostkach kompleksu kaczawskiego. Mogą one wskazywać na metamorfizm odpowiadający wyżej ciśnieniowej części facji zieleńcowej. Znaczenie alkalicznych amfiboli jako wskaźników ciśnienia jest ograniczone, bowiem metasomatyzm i zmiany lotności tlenu mogły także wpływać na ich skład. Interpretacje tektoniczne dużej skali dotyczące kompleksu kaczawskiego, oparte na geobarometrze wykorzystującym alkaliczne amfibole, powinny być traktowane z rezerwą.

Waryscyjskie piętro strukturalne Gór Kaczawskich, zbudowane ze słabo zmetamorfizowanych skał osadowych i wulkanicznych wieku od kambru do dolnego karbonu, zwane jest kompleksem kaczawskim. Nieco mniej niż połowę tego kompleksu stanowią skały wulkaniczne i subwulkaniczne o składzie bazaltów (spilitów) o niskim stopniu zmetamorfizowania, dla których używany jest termin metabazyty. Towarzyszą im skały o składzie ryolitów i dacytów zwane keratofirami, które występują we względnie niewielkich ilościach.

Alkaliczne amfibole są na badanym terenie niemal wyłącznie czysto sodowymi amfibolami z grupy glaukofan — ferroglaukofan – magnezioriebeckit – riebeckit. Obecność alkalicznych amfiboli w metawulkanitach Gór Kaczawskich znana jest od dawna. Najstarsza wzmianka o nich pochodzi z 1919 roku (Zimmermann i Kühn). Najczęściej określane one były jako „podobna do glaukofanu hornblenda" lub „glaukofan". Dokładne analizy tych minerałów nie były jednak dotychczas publikowane. Dopiero ostatnio Kryza et al. (1988) podali wzory krystalochemiczne amfiboli, m. in. glaukofanu, z diabazu koło Wojcieszowa Dolnego.

Alkaliczne amfibole opisane były (fig. 1) w rejonie Grzbietu Lasockiego we wschodnich Karkonoszach, gdzie występuje glaukofan (Wieser 1978) i krossyt oraz w południowych Karkonoszach. Te ostatnie najlepiej zostały zbadane w okolicach Železnego Brodu (Fediuk 1962; Cháb, Vrána 1979; Guiraud, Burg 1984). Ich skład zmienny jest w szerokich granicach, lecz najczęściej zbliżony jest do krossytu.

H. Teisseyre (1956, 1967) i Jerzmański (1965) wyróżnili szereg jednostek tektonicznych w Górach Kaczawskich. Pomimo licznych wątpliwości dotyczących charakteru tych jednostek, podział ten ciągle pozostaje w użyciu. Najnowsze podsumowanie dotyczące stratygrafii, litologii i tektoniki kompleksu kaczawskiego dają Baranowski et al. (1987).

Na mapie (fig. 2) zaznaczone są miejsca pobrania prób zawierających alkaliczne amfibole. Występują one w różnych rodzajach skał w obrębie serii wulkanogenicznej we wszystkich jednostkach tektonicznych. Wśród 57 próbek zawierających alkaliczne amfibole było 20 diabazów, 25 zieleńców, 9 łupków zieleńcowych i 3 keratofiry.

Rozróżnienie pomiędzy zieleńcami i łupkami zieleńcowymi dokonane zostało na podstawie tekstury. Trudniejsze, a w skali pojedynczej próbki właściwie niemożliwe, jest rozróżnienie diabazu od zieleńca, bowiem to forma geologicznego występowania powinna decydować o tym, czy skałę można nazwać diabazem. Diabazy tworzące sille na NE od Wojcieszowa wykazują przeważnie ziarno wielkości powyżej 2 mm. W praktyce, gdy nie była znana dokładnie forma geologicznego występowania, skały o bezkierunkowej teksturze i ziarnie powyżej 2 mm nazywane były diabazami, a podobnie o ziarnie drobniejszym — zieleńcami. Temperatury i ciśnienia osiągnięte w czasie metamorfizmu obydwu rodzajów skał były zapewne zbliżone, jednak grubiej ziarniste odmiany, czyli diabazy, zawierają znacznie więcej strukturalnych i mineralnych reliktów magmowych i ich „magmowa" nazwa wydaje się uzasadniona.

Diabazy i zieleńce składają się (patrz tab. 1) z albitu, chlorytu, epidotu, kalcytu, aktynolitu lub hornblendy aktynolitowej, czasem brunatnej lub zielonej hornblendy i klinopiroksenu (relikty magmowe), a ponadto tytanitu i (lub) leukoksenu, tlenków Fe i (lub) ilmenitu i apatytu. Tylko rzadko dołączają się do tego zespołu alkaliczne amfibole. Kwarc jest czasem obecny, przeważnie — jak się wydaje — w formie późnych żyłek i gniazd.

Łupki zieleńcowe mają podobny skład mineralny. Kwarc jest jednak w nich przeważnie obecny, choć w niedużych ilościach. Częstym ich składnikiem jest również muskowit. Nie spotyka się natomiast nigdy reliktów brunatnej hornblendy, a klinopirokseny napotkano tylko w jednej próbce 98.

Alkaliczne amfibole nie dają się identyfikować megaskopowo. Mikroskopowo najlepiej widoczne są natomiast w diabazach ze względu na grubsze ziarno skały (fig. 3–7). Ziarna amfiboli wykazują przy tym często budowę pasową: brunat-

na hornblenda (centrum), krossyt, glaukofan, aktynolit lub hornblenda aktynolitowa (fig. 3). Figura 4 przedstawia raczej wyjątkową mikrostrukturę pasową: brunatna hornblenda (kaersutyt), riebeckit, glaukofan, magnezioriebeckit na pograniczu krossytu, aktynolit. W zieleńcach i łupkach zieleńcowych alkaliczne amfibole tworzą mniejsze ziarna, często trudne do dokładniejszego oznaczenia (fig. 8).

W keratofirach, w których napotkano alkaliczne amfibole, obecne są kwarc i albit, a ponadto skaleń potasowy, trochę zielonego biotytu i jasnego łyszczyku.

Na podstawie obserwacji wzajemnych zależności strukturalnych minerałów podjęto próbę przedstawienia schematu reakcji mineralnych w metabazytach kompleksu kaczawskiego (fig. 9).

Analizy minerałów (tab. 2 i 3) zostały wykonane mikroanalizatorem rentgenowskim Jeol JXA-3A. Zastosowano poprawki ZAF. Wzory krystalochemiczne amfiboli (tab. 2) obliczono na 23 tleny, a zawartości FeO i Fe_2O_3 kalkulowano komputerowo na sumę 13 kationów włączając w nią $\frac{1}{2}$Mn. Tego rodzaju obliczenia obarczone mogą być pewnym błędem i dlatego wzory krystalochemiczne alkalicznych amfiboli zostały obliczone również dla wartości granicznych stosunku Fe^{3+}/Fe^{2+} zaczerpniętych z literatury (tab. 4) dla poszczególnych rodzajów tych amfiboli. Możliwe zakresy składu zanalizowanych alkalicznych amfiboli przy takiej zmienności stosunku Fe^{3+}/Fe^{2+} przedstawione zostały na wykresie (fig. 10).

Tabela 5 podaje globalny skład chemiczny i normy CIPW skał, z których analizowane były minerały.

Alkaliczne amfibole występują w skałach kompleksu kaczawskiego w niewielkich ilościach. Najczęściej spotykano krossyty, rzadziej glaukofany, ale ferroglaukofan, riebeckit i magnezioriebeckit też były oznaczane.

Obecność alkalicznych amfiboli nie jest związana z żadnym szczególnym rodzajem skały lub specjalną sytuacją tektoniczną. Występują one, jak już wspomniano, we wszystkich jednostkach tektonicznych i nie układają się w żadne strefy.

Opisane przez Wiesera (1978) łupki glaukofanowe, obecne w formie cienkiej wkładki na zboczu góry Kopina w Grzbiecie Lasockim we wschodnich Karkonoszach, zawierają około $50^0/_0$ glaukofanu i granat, czym różnią się w znaczący sposób od skał kaczawskich.

Opisane natomiast przez Fediuka (1962) skały zawierające alkaliczne amfibole z okolic Żeleznego Brodu w południowych Karkonoszach w znacznym stopniu przypominają skały kaczawskie. Nowsze prace (Cháb, Vrána 1979; Guiraud, Burg 1984) z tego samego terenu podają skład chemiczny alkalicznych amfiboli oznaczony za pomocą mikroanalizatora rentgenowskiego. Są one przeważnie krossytami, lecz obecne są również pośrednie sodowo-wapniowe amfibole (patrz fig. 11). Wymienieni autorzy, podobnie jak Wieser (op. cit.), są zdania, że amfibole te powstały w warunkach wysokociśnieniowego metamorfizmu w wyniku zjawisk związanych z subdukcją na granicy płyt litosferycznych.

Znaczenie alkalicznych amfiboli jako wskaźników ciśnienia nie jest jeszcze w pełni zbadane. Na przykład z prac eksperymentalnych wynika, że glaukofan jest trwały w szerokim zakresie ciśnień i temperatur przy pewnych rzadko spotykanych składach chemicznych skał: „ubogich w Ca a bogatych w Na i Mg względem Al" (Ernst 1961). Glaukofan i krossyt występują jednak często w łupkach niebieskich (porównaj Muir Wood 1980) w towarzystwie lawsonitu, jadeitowego piroksenu i aragonitu, a te ostatnie trzy minerały są prawdziwymi wskaźnikami wysokociśnieniowego metamorfiz-

mu. Jeśli zatem alkaliczne amfibole nie są ściśle biorąc bezwzględnym wskaźnikiem wysokich ciśnień, to w skałach o „normalnym" — powszechnie spotykanym w metabazytach — składzie wskazują na działanie wyższych ciśnień. Dla skał facji zieleńcowej, zawierających alkaliczne amfibole, a nie lawsonit, piroksen jadeitowy i aragonit, Winkler (1967) zastosował termin „glaukofanowa facja zieleńcowa", która odpowiada zakresowi najwyższych ciśnień facji zieleńcowej (fig. 12).

W nowszych pracach skład sodowych i sodowo-wapniowych amfiboli jest uważany za potencjalny geobarometr, np. Maruyama et al. (1984). Według Browna (1977) zawartość Na (B) w aktynolicie zależy od ciśnienia w skałach zawierających albit, chloryt i magnetyt. Jego geobarometr kalibrowany w sposób empiryczny w oparciu o różne kompleksy metamorficzne, w których obecne są sodowo-wapniowe lub sodowe amfibole i w których warunki ciśnienia mogły być oznaczone innymi metodami, jest przedstawiony na figurze 11. Na ten wykres naniesione są amfibole z kompleksu kaczawskiego oraz wschodnich i południowych Karkonoszy. Brown (op. cit.) zdawał sobie sprawę, że jego wykres może dawać tylko przybliżoną, obarczoną dużymi błędami ocenę ciśnienia. W niektórych kompleksach jednak występują dodatkowe komplikacje, związane między innymi często ze zmianą lotności tlenu w czasie metamorfizmu (Okay 1980), co znacznie obniża dokładność barometrycznych szacowań.

Okay (op. cit.) uważa, że budowa pasowa amfiboli może być wytłumaczona najlepiej właśnie zmiennością lotności tlenu. Takie tłumaczenie dobrze odpowiadałoby pasowym strukturom amfiboli w diabazach kompleksu kaczawskiego, a szczególnie w próbce nr 50 (fig. 4).

Wydaje się zatem, że powstawanie alkalicznych (sodowych) i sodowo-wapniowych amfiboli zależy od skomplikowanej kombinacji warunków ciśnienia i temperatury, składu chemicznego środowiska blastezy i lotności tlenu, przy czym muszą być brane pod uwagę różne metastabilne relikty i lokalne równowagi.

Alkaliczne amfibole pochodzące z kompleksu Kaczawskiego grupują się na diagramie Browna (1977) na figurze 11 w polu wysokich ciśnień, brak natomiast (z jednym podanym przez Kryzę et al., 1988, wyjątkiem aktynolitu/winchitu, tj. z pogranicza amfiboli wapniowych i sodowo-wapniowych) pośrednich amfiboli sodowo-wapniowych, których należałoby tu oczekiwać.

Pamiętając o wyżej wymienionych zastrzeżeniach i niskiej precyzji oszacowań barometrycznych uzyskanych metodą Browna (fig. 11), należałoby sądzić, że przynajmniej niektóre zespoły mineralne zawierające alkaliczne amfibole w obrębie kompleksu kaczawskiego powstały w warunkach wysokociśnieniowej części facji zieleńcowej (nr 4 na fig. 12). W późniejszych stadiach metamorfizmu nastąpił spadek ciśnienia i powstały zespoły mineralne odpowiadające średniociśnieniowej facji zieleńcowej (nr 5 na fig. 12). Te ostatnie zespoły mineralne panują w całym kompleksie kaczawskim.

Jak się wydaje, alkaliczne amfibole w kompleksie kaczawskim powstały w bardzo nielicznych miejscach i bardzo selektywnie. Nie można tu w żadnym razie mówić o większym terenie objętym metamorfizmem w facji łupków niebieskich. Niewątpliwie warunki wysokociśnieniowej części facji zieleńcowej ułatwiały krystalizację alkalicznych amfiboli. Jednak w tych samych warunkach ciśnienia i temperatury panujących w większości kompleksu kaczawskiego nie powstały nigdy alkaliczne amfibole, mimo że istniały odpowiednie fazy mineralne i często zarodki krystalizacyjne w postaci wcześniejszych amfiboli. Musiały być zatem jeszcze inne niż ciśnienie i temperatu-

ra czynniki, które warunkowały powstanie alkalicznych amfiboli, takie jak metasomatyzm i zmienność lotności tlenu.

W świetle powyższych rozważań występowanie alkalicznych amfiboli i ich skład chemiczny nie są jednoznacznymi i wystarczającymi wskaźnikami niskotemperaturowego meta-morfizmu wysokich ciśnień odpowiadającego facji łupków niebieskich. Oparte na obecności alkalicznych amfiboli interpretacje tektoniczne w wielkiej skali powinny być traktowane z dużą ostrożnością.