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AHMED MAHMOOD[1]

# PETROLOGY OF THE TESCHENITIC ROCK SERIES FROM THE TYPE AREA OF CIESZYN (TESCHEN) IN THE POLISH CARPATHIANS

(Pl. XVII—XVIII and 7 Figs.)

# *Petrologia skał cieszynitowych z okolic Cieszyna*

*(Tabl. XVII—XVIII i 7 fig.)*

## INTRODUCTION

The region of Beskidy at the foot of the Western Carpathians in Silesia and Moravia is characterized by many small outcrops of eruptive igneous rocks. Hohenegger (1861), who was first to describe these rocks, introduced the term „teschenite" for all the granular rocks of the region. Later Tschermark, Mohl, Rohrbach and Kalvana (reported by Smulikowski, 1929) furnished a great deal of information on the chemistry and petrography of these rocks. The most authentic accounts are, however, due largely to the studies of Smulikowski and Pacak. Pacak's study (1926) was confined to Moravia. Smulikowski (1929), in two separate accounts, described the region as a whole, and various outcrops in the Cieszyn Silesia individually. The present study is almost entirely focussed on the easternmost part of the area in which the teschenitic rocks occur, covering outcrops only of the Polish territory. Specimens were collected mainly from the environs of Cieszyn, Żywiec and Bielsko-Biała (see Fig. 1). Many outcrops which were accessible to provious investigators are now covered with land-slides. Great difficulty was encountered in finding fresh samples. Extensive petrographical, mineralogical and chemical studies were made to work out the genesis of these rocks.

## GENERAL GEOLOGY

The area studied lies in the most western part of the Polish Flysch Carpathians. This particular part of the Flysch Carpathians is built up

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[1] Department of Earth Sciences. The University. P. O. Box 1090. Islamabad, Pakistan.

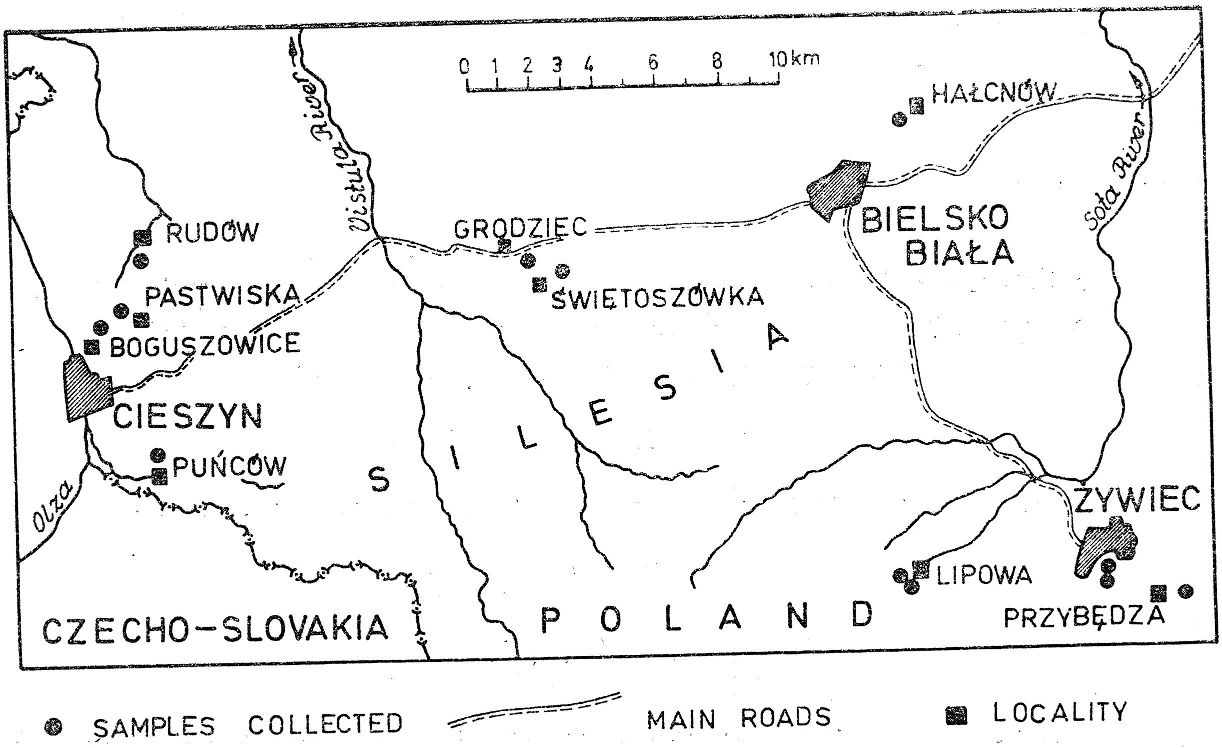

Fig. 1. Locality map of the area

of the Cieszyn nappe consisting mainly of Cretaceous beds. The Cieszyn nappe displays disharmonic folding and together with the overlying Godula nappe forms a bigger unit, i. e. the Silesian nappe. Geological map (Fig. 2) of the Silesian Carpathians by **Burtanówna**, **Konior** and **Książkiewicz**, (1937) covers the entire area. Stratigraphy and tectonics of the region have been studied by many authors (e. g. No-

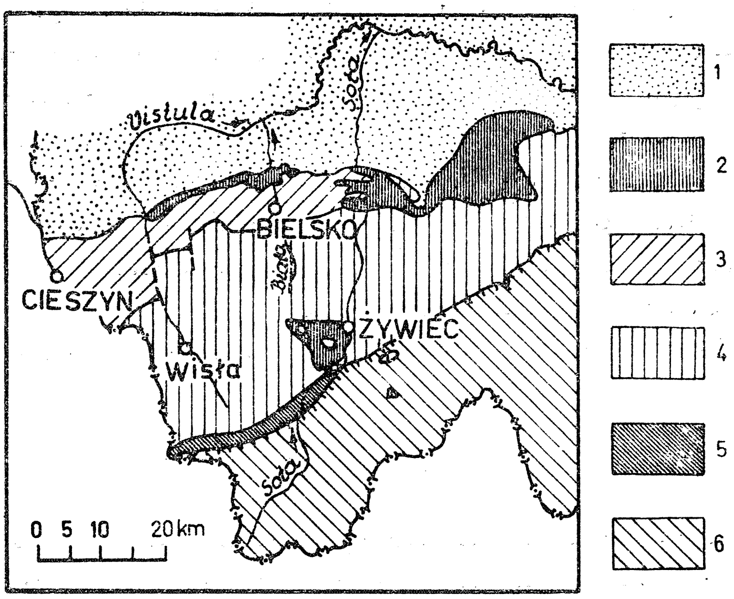

Fig. 2. Geological map of the area: 1 — Upper Tertiary; 2 — Sub-Silesian nappe; 3 — Cieszyn nappe; 4 — Godula nappe; 5 — Pre-Magura scales; 6 — Magura nappe (adapted from **Geroch** et al., 1967, p. 187). Boundary of the Cieszyn nappe marked approximately

wak, 1927; Świdziński, 1948; Książkiewicz, 1956 a and 1964; Geroch et al., 1967). The bulk of the eruptive igneous rocks of the Cieszyn area lies within the Cieszyn nappe. At Żywiec these rocks outcrop in the border zone of a tectonic window in the Silesian nappe exposing the underlying Sub-Silesian series.

Teschenites and their related rocks mostly outcrop in the lowermost three stratigraphic units of the Tithonian-Lower Cretaceous of the Silesian unit, forming the above mentioned Cieszyn nappe. These stratigraphic units are: Lower Cieszyn Shales, Cieszyn Limestones and Upper Cieszyn Shales. The area presents a complicated tectonic set-up. The Miocene folding produced several tectonic units which are thrust one upon another to a considerable extent and for that reason have been termed as 'nappes'. An interpretation of the tectonics of the Cieszyn zone was given by Książkiewicz (1956 a and 1964). According to his study the teschenites are pre-tectonic, since they never follow thrust planes and faults, and teschenite sills seem to be folded together with the sedimentary rocks. The teschenite sills are from a few centimeters to several meters thick.

## ROCK CLASSIFICATION AND PETROGRAPHY

A detailed and comprehensive classification scheme was given by K. Smulikowski (1929). According to this classification, all the rocks of the Sub-Beskidian region are divided mainly into three groups, namely the melanocratic, the mesocratic, and the leucocratic. A further division is based on the grain size and subsequently each of the three major groups is subdivided into the phaneritic and aphanitic varieties. Classification at the third place is mineralogical. Thus both the phaneritic as well as aphanitic melanocratic rocks are classified into olivine rich varieties (picrites; and olivine monchiquites and olivine ankeritites respectively) and olivine poor varieties (melanocratic bekinkites; and melanocratic fourchites and ouachitites, and augitites respectively). The phaneritic varieties of mesocratic and the leucocratic rocks are distinguished into feldspathoidal and non-feldspathoidal types. In all, the classification scheme took notice of possibly the minutest mineralogical and textural differences to evolve an intricate rock terminology to cover a widespread petrologic province. It was in itself a classical account. But despite its highly descriptive nature the classification scheme is not fully followed here due to the following reasons which are also to form the basis of present classification:

1) The present work covers only a part of the whole of the petrologic province which was under study of the previous work. Therefore, in following this previous classification, some gaps for the rocks which were presently not encountered will be left. A classification which

exclusively adjusts to the part of the petrologic province under present study is pursued. For example, no olivine-rich varieties like picrites and peridotites were collected from the investigated area. Even the inclusion of these highly magnesian varieties in the teschenitic petrologic province fell to doubt when subjected to the statistical tests. These picritic and peridotitic varieties taken from Smulikowski's study formed detached population groups on the statistical histograms.

2) Since the previous work a great tendency has developed among the petrologists to simplify rock classification. This fact can also be reasoned on the ground that previously a particular petrographic term was nowhere precisely defined. For example, terms like monchiquites, ouachitites, camptonites, etc. loose their meaning when not described as only dark, mostly melanocratic, lamprophyric rocks. It will be, therefore, not convenient to accept the repetition of these terms in mesocratic group as well, for which the colour index in no case exceeds 65%.

3) The present study revealed that, a mineralogical difference would be a vague basis to separate the rocks from each other. Some of the secondary processes such as analcitization of feldspars, amphibolization of pyroxenes, etc. are widespread. It would be difficult to assign a new name to the rock showing the same basic mineralogy but in different mineralogical proportions due to varying degree of the alterations mentioned above. Moreover, due to frequent occurrence of a glassy and zeolitic mesostasis, in part or wholly replacing the granular felsic components of the rocks, it is not very much possible to establish a passage and draw lines between different rock names, as attempted by the previous classification, particularly in the case of mesocratic varieties. A new name, in the present case, should be given only where there is a wholesale change in mineralogy accompanied by a clear change in texture.

4) The present study is greatly augmented with geochemistry. It is, therefore, desired to keep the petrographic grouping of the rocks as simple and concise as possible to make the geochemical work more meaningful and representative.

In the case of the Black Jack Sill, Austrialia, Wilkinson (1958) has divided the different rocks of the teschenitic association on textural basis into three groups, following Walker (1923b). The textural classification of the rocks of the Black Jack Sill, however, first takes into consideration two generalizations similar to those underlined in the case of the tholeiitic Skaergaard intrusion (Wager and Deer 1939), in order to simplify the petrography. The two generalizations are: „(1) rocks of the same horizon are similar, except for occasional differences in relative abundance of the minerals, and (2) the difference between average rocks of different horizons is a gradual one, being a function of the height of the rocks in the intrusion". In the present case, where the occurrence of the rocks under study is in the form of thin bodies of sills spread over a large area, the facility of a single column, where height plays an important role, is missing. However, the above mentioned two generalizations will prove equally useful for the present case if modified to the above mentioned effect as following: (1) rocks representing the magma fraction from the same horizon of the magma chamber feeding the various sills, or the rocks from the different sills but having undergone the same degree of main magmatic changes are basically similar; (2) the difference between average rocks of different horizons of the magma chamber or of different degree of main magmatic changes within a single body, i. e. a sill, is a gradual one. The position of a rock in a sill may or may not come into effect for our present purposes, since in the field, except for two sills, not the whole of the bodies of the sills were exposed due to alluvium covers caused by slumpings, etc.

Now, it will be seen that two rock varieties from two different bodies in the field can be correlated in showing not only the same basic mineralogy but also similar textural features. Even the end-members, between which these two rock species provide a passage, would be similar to each other. The present study, thus, provides a threefold classification, simultaneously based on texture and mineralogy, i. e. percentage of light and dark-coloured minerals, which is here referred to as „colour index". The colour index scheme is that proposed by Shand (see Williams, Turner and Gilbert, 1954).

Group 1: Melanocratic (colour index more than 60); texturally porphyritic or vitriophyric (depending upon the amount of glass).

Group 2: Mesocratic (colour index between 30 and 60); texturally coarse gabbroic or sub-ophitic to sub-hyaloophitic (depending upon the amount of glass).

Group 3: Leucocratic (colour index less than 30); texturally intergranular to intersertal (depending upon the amount of glass).

Basing on this classification scheme, the different rocks distinguished in the area are as follows:

Group 1: Limburgite 'porphyries'.

Lamprophyres: {
- Monchiquites
- Fourchites
- Camptonites

Group 2: Teschenites
Diabases

Group 3: Syenitic vein rocks.

The term syenite has been arbitrarily used for expressing the mineralogical and textural features of the leucocratic rocks of the area. The misleading character of this term is however fully realized and for that reason later in this study the term syenite has always been put in italics. However, this term has been frequently used representing the composition of leucocratic vein-rocks and schlieren (Yagi, 1953) and even thin veinlets of analcitic mesostasis in teschenite (Wilkinson, 1958). Quite a few more examples of the kind in alkali diabasic rocks have been collected by Turner and Vorhogen (1960, pp. 176—183).

Norms are calculated in cation per cents (see Barth, 1962, p. 69).

## MELANOCRATIC ROCKS

### Limburgite „porphyries"

(chemical analyses nos. 5 and 6)

The rock-specimens were collected from Pastwiska near Cieszyn. The centre of the sill under mention exhibits these highly melanocratic varieties. In hand-specimen, the rock is not so dark and has a greenish colour.

Under microscope, the porphyritic texture is developed on a medium-grained scale. The phenocrysts are those of saponitic pseudomorphs after olivine and of titanaugite embedded in a matrix of microcrystalline groundmass of titanaugite, soda augite and aegirine. Isotropic glassy groundmass, altering to chlorite and saponite, fills the interstitial spaces of the grains. Ti-biotite forms long well-developed flakes. The pseudomorphs of olivine are the largest of all the phenocrysts. The rock is completely devoid of feldspars. The pyroxene grains are euhedral while saponitic pseudomorphs are subhedral. The biotite flakes, at places, show a preferred orientation and include pyroxene inclusions, both parallel and perpendicular to the orientation of the flakes. The iron ore, almost always containing a central translucent cavity, is evenly distributed in the rock in the form of small specks.

A medium-grained porphyritic texture with an over-all abundance of pyroxene, olivine being an important associate and a complete absence of amphibole distinguishes this rock from the rocks of the lamprophyric group which is an important group in this area. The limburgitic rock grades into monchiquitic lamprophyre by a partial replacement of pyroxene by amphibole, and diminishing in the amounts of olivine either to the status of an accessory or a complete disappearence. These limburgitic members of the teschenitic rock series, in the case of the investigated petrologic province, constitute the earliest magma fractions which once injected in the form of sills were subjected to a chain of magmatic changes. A rather low amount of iron ore as compared to that of the normal teschenites indicates iron present in such a state as to be largely incorporable in the pyroxene structure leaving behind a little to crystallize as pure ore. Its even distribution in the rock is another indication of the fact that only the excess of iron left after the crystallization of pyroxene crystallized as ore. The limburgites are also the most magnesium-rich rock varieties collected from the area. These facts sufficiently indicate a fairly early period of crystallization of these limburgites. Below, two chemical analyses of the limburgites are calculated into norms and compared with their modal composition. The norms are in cation per cents.

Sample no. 5

| Norm (cation %) | | Mode (vol. %) |
|---|---|---|
| Orthoclase... | 4.05 | |
| Albite....... | 8.40 | Saponitized, chloritized, and zeolitized + analcitized matrix = 27.7 |
| Nepheline.... | 5.46 | |
| Anorthite.... | 8.27 | |
| Felsics...... | 26.18 | |
| Wollastonite | 24.00 | |
| Enstatite... | 23.36 | |
| Ferrosilite | 0.64 | Ti-augite = 42.3 |
| Diopside..... | 48.00 | |
| Forsterite.. | 11.53 | Ti-biotite = 8.4 |
| Ilmenite.... | 1.62 | |
| Magnetite... | 7.30 | Serpentinized olivine = 14.5 |
| Mafics...... | 68.45 | Iron ore = 5.1 |
| Apatite..... | 2.18 | Apatite = 2.0 |
| Calcite..... | 3.40 | |

Sample no. 6

| Norm (cation %) | | Mode (vol. %) |
|---|---|---|
| Orthoclase... | 6.00 | |
| Albite....... | 6.00 | Saponitized, chloritized, and zeolitized + analcitized matrix = 32.9 |
| Anorthite.... | 22.70 | |
| Felsics...... | 34.70 | |
| Wollastonite | 16.72 | |
| Enstatite... | 15.05 | |
| Ferrosilite | 1.67 | Ti-augite = 42.0 |
| Diopside..... | 33.44 | |
| Enstatite... | 19.16 | |
| Ferrosilite | 0.40 | Ti-biotite = 8.4 |
| Hypersthene | 19.56 | |
| Total pyrox. | 53.00 | Saponitized olivine = 7.2 |
| Olivine..... | 4.64 | |
| Ilmenite.... | 1.56 | Iron ore = 6.5 |
| Magnetite... | 3.93 | |
| Calcite..... | 1.68 | |
| Apatite..... | 2.24 | Apatite = 2.8 |

The two specimens differ in one being rich in olivine and other poor in olivine. Moreover, the isotropic vitreous matrix in the case of sample no. 6 is more in amount.

## The lamprophyres

The melanocratic rocks of the Cieszyn area with a marked lamprophyric character can be divided, mineralogically, into three groups.

## Monchiquites
(chemical analyses nos. 32 and 40)

A distinguishing property of the monchiquites is the idiomorphic character of the main granular constituent, i. e. titanaugite. A typical rock specimen from a road section at Hałcnów is being described here. The porphyritic texture is developed on a medium-grained scale. Medium phenocrysts of pyroxene and comparatively coarse phenocrysts of amphibole lie in an isotropic matrix which is greyish in colour. Long needles of apatite are frequently found in the isotropic glassy matrix. Very rarely, big laths of plagioclase are also seen embedded in the matrix. Small aggregates of pyroxene microlites are also scarcely distributed in the groundmass. The pyroxene grains show envelops of amphibole, brown hornblende, frequently developing parallel to their outlines. The iron ore, ilmenite, occurs in skeletal form. It is, however, not a homogeneous phase. The central parts of the grains are either translucent or have a characteristic reddish lustre in the reflected light. The margins are completely opaque. The iron ore is essentially associated with the amphibole as a by-product of its alteration to biotite and chlorite. It is inferred that the central part of the iron ore grains is rich in Ti-component and the margins in iron.

Sample no. 40

| Norm (cation %) | | | Mode (vol. %) |
|---|---|---|---|
| Orthoclase...... | 2.50 | | |
| Albite.......... | 5.00 | | |
| Nepheline....... | 13.20 | | Matrix = 44.0 (with microlites of pyroxene) |
| Anorthite....... | 15.00 | | |
| Isotropic matrix | 35.70 | (Felsics) | |
| Wollastonite.... | 25.00 | | |
| Enstatite....... | 24.30 | | |
| Ferrosilite..... | 0.70 | | Ti-augite = 37.3 |
| Diopside........ | 50.00 | | Brown hornblende = 7.2 |
| Forsterite...... | 2.80 | | |
| Fayalite........ | 0.07 | | |
| Olivine......... | 2.87 | | Saponitized olivine = 4.7 |
| Magnetite....... | 6.70 | | |
| Ilmenite........ | 2.20 | | Iron ore = 4.9 |
| Mafics.......... | 61.77 | | |
| Apatite......... | 2.40 | | Apatite = 2.1 |
| Calcite......... | n.d. | | |

Titanaugite alters to calcite and quartz. The cracks in the grains are filled with chlorite. The edges of the grains of titanaugite are stained grassy green. The amount of olivine in monchiquites is small.

The monchiquitic variety from Puńców presents some striking textural differences with the typical one described above. This monchiquite is coarse-grained vitrophyric. The glassy matrix, which is less in amount than the granular mafic part, is accompanied by chlorite. Titanaugite, the main mineral component, does not always form idiomorphic outlines. Amphibole both barkevikite and lamprobolite, normally surrounds the big titanaugite phenocrysts. In its coarser somewhat allotriomorphic texture, the Puncόw monchiquite closely resembles pyroxenite. The norm and mode are given below.

Sample no. 32

| Norm (cation %) | | | Mode (vol. %) |
|---|---|---|---|
| Leucite | 2.00 | | |
| Kaliophilite | 4.50 | | |
| Nepheline | 11.40 | | Analcitized and chloritized. |
| Anorthite | 23.75 | | |
| Isotropic matrix | 41.65 | (Felsics) | Matrix = 27.0 |
| Wollastonite | 19.60 | | |
| Enstatite | 18.20 | | |
| Ferrosilite | 1.40 | | |
| Diopside | 39.20 | | Ti-augite = 57.9 |
| Forsterite | 5.10 | | Brown hornblende = 10.6 |
| Fayalite | 0.30 | | |
| Olivine | 5.40 | | Olivine : accessory |
| Ilmenite | 1.50 | | |
| Magnetite | 7.20 | | Iron ore = 4.3 |
| Calcite | 5.00 | – note: calcite occurs as an alteration product of Ti-augite | |
| Mafics | 58.30 | | |
| Apatite | 0.61 | | Apatite : accessory |

## Camptonites

The rock-specimens were collected from a road section at Hałcnów near Bielsko Biała. The camptonite is in the form of fine to medium-grained vein-rock in coarse, almost pegmatoidal, teschenite. The other occurrence is at Pastwiska. The rock is closely jointed. In hand-specimen, the colour index is much lower.

The porphyritic texture is implied in the form of euhedral phenocrysts of amphibole, which is the chief mineral component, in a hypocrystalline matrix. The pyroxene, titanaugite, is apparently of two generations: the microcrystalline matrix and the large euhedral phenocrysts. The components of the hypocrystalline part are the unclear analcitic matrix and the big andesine laths (An$_{62}$ An$_{38}$). The andesine laths are, however, embedded in the analcitic matrix, and are always partially visible. The iron ore is ,typically, evenly distributed in the form of droplets. At places amphibole envelops a small central part of pyroxene. This shows that the present rock variety owes its formation to a large scale amphibolization of pyroxene. In this sense, camptonites succeede other lamprophyres like monchiquites. A distinctly two-generational nature of the pyroxene, however, distinguishes this variety from the monchiquite, and suggests the introduction of pyroxene phenocrysts into a magmatic fraction where there was a simultaneous crystallization of pyroxene and amphibolization of these phenocrysts. A frequent eating-up of the plagioclase by glass and microcrystalline nature of the pyroxene suggest a rapid cooling for this particular magma fraction. Olivine and biotite are absent.

Accessories in both the two cases are: calcite, quartz and chlorite--all occurring as alteration products of the primary minerals.

| | Sample no. 38 | Sample no. 39 |
|---|---|---|
| | Mode (vol. %) | Mode (vol. %) |
| Feldspathic and isotropic matrix | = 44.1 | = 38.5 |
| Ti-augite | = 20.3 | = 15.1 |
| Brown hornblende | = 31.3 | = 39.9 |
| Iron ore | = 4.7 | = 6.4 |

note: In both the two cases the matrix includes broken and microlitic grains of the mafic minerals.

### Fourchites
### (chemical analysis no. 37)

Lamprophyres devoid of olivine were collected from Żywiec in the valley of the river Soła and from Boguszowice. At Żywiec the rock-type occurs in the form of parallel placed narrow sills. The study of this variety was greatly handicaped by its extremely altered state. In hand-specimen, it is green, soft, and fine to medium grained.

Under microscope the mineralogy is almost completely obliterated due to alteration of the chief minerals. The chief mineral component is pyroxene, titanaugite (?). It is mostly altered to a mass of chlorite and calcite, and quite frequently only pseudomorphs of these secondary minerals are left. The unclear matrix is green, cryptocrystalline, and contains chlorite, analcite, and calcite. In fact, at places it is difficult to separate the matrix from the pyroxene pseudomorphs. Among the alteration products of the pyroxene, quartz is also rarely present. Apatite needles are found embedded in the matrix criss-crossing the other minerals. Iron ore, in the form of small grains, is evenly distributed. The central parts of the iron ore grains are filled with sphene, so that, at places, only a mantle of opaque iron ore is left around sphene. Iron ore grains also show central cavity without sphene and instead a hollow space. In this latter case, iron ore displays loose aggregates of small specks.

Sample no. 37

| Norm (cation %) | | Mode (vol. %) | |
|---|---|---|---|
| Leucite | 3.2 | Chloritized and analcitized matrix containing calcitic pseudomorphs after pyroxene | = 43.0 |
| Nepheline | 16.8 | | |
| Anorthite | 22.0 | | |
| Felsics | 42.0 | | |
| Wollastonite | 22.0 | | |
| Enstatite | 20.8 | Pyroxene (Ti-augite) | = 28.0 |
| Ferrosilite | 1.2 | | |
| Diopside | 44.0 | Biotite | = 19.0 |
| Ilmenite | 3.60 | Iron ore | = 6.9 |
| Magnetite | 7.54 | | |
| Mafics | 55.14 | | |
| Apatite | 1.30 | Apatite | = 3.3 |
| Calcite | 2.00 | | |

Note: Calcite is to be distributed equally between the felsic and mafic parts.

A striking feature of these highly altered olivine-free lamprophyres is the absence of amphibole. These, therefore, are the only example of the rocks, under present study, which are devoid of amphibole. It is in these lamprophyres that sometimes abnormally large amounts of biotite are recorded to warrant the change of the name of these lamprophyres to "Ouachitite". As shown by the chemical analysis (not produced here), the biotite is not in its pure form. Potash in this biotite is low and it is a magnesium-rich variety. It occurs in the form of big flakes. The flakes are, however, not compact and show swelling, so that inclusions like those of quartz, chlorite, and pseudomorphs of pyroxene are arranged parallel to the orientation of the flakes in the spaces thus made between the cleavages of the flakes. The flakes are sometimes almost colourless, and if slightly coloured then very feebly pleochroic in the shades of brown and green. Another characteristic feature of these flakes is their felted nature which is, however, associated with the swelling.

Biotite thus appears to be breaking down to the minerals of hydrobiotite and vermiculite group.

Both in the typical as well as in ouachititic fourchites a green pyroxene in the form of small grains is frequently found.

Below, a chemical analysis of ouachititic fourchite is calculated into its norm in cation per cent, and is compared with the mode in vol. percent.

## MESOCRATIC ROCKS

### The Teschenites

Ever since the introduction of the term, it has been variously described. Hohenegger (1861) who introduced the term meant it for the crystalline rocks of the „sub-Beskidian" region of the Flysch of the Western Carpathians. The name was, however, used in general terms for all the mineralogical and textural varieties of the igneous rocks of the region. Since then various writers have defined the term differently both on the textural and mineralogical basis.

According to Johannsen,[1] the texture of teschenites is coarse gabbroic to ophitic to fine granular; olivine is apparently not essential while barkevikite is an essential constituent. Holmes recognizes teschenites in similar terms with idiomorphic nature of the pyroxenes. Harker (1895)[1] disagrees with these two authors, inasmuch as the pyroxene is typically non-ophitic.

On zeolitization, Walker (1923)[1] observes analcite occurring as an alteration product of plagioclases instead of being related to higher primary analcite contents, as inferred by Tyrell (1923)[1]; and Eyles, Simpson and MacGregor (1929)[1].

In the case of the teschenites of the Cieszyn area two varieties were encountered in the field: a medium grained, and a semi-pegmatitic coarse-grained. Where there is no crystalline feldspathic phase, the colour of the rock is dark green and the pyroxene euhedrae are not visible in hand-specimen. Normally elongated pyroxene grains, greenish-black in colour, are well distinguishable against a white analcitized feldspathic ground. The coarser varieties are friable, soft and less compact.

The teschenite samples were collected from Pastwiska, Rudów, Punców and Hałcnów, near Bielsko Biała. At Punców, the sill is well-stratified into coarse pegmatoidal teschenitic layers and medium-grained teschenitic and lamprophyric layers. At Hałcnów, where there was only three meters of another exposure, the grain size increases upwards. How-

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[1] References taken from Wilkinson, 1955.

ever, fine to medium-grained lamprophyric rocks often form autoliths in the coarse varieties of teschenite.

Under microscope, the texture of the teschenites ranges form coarse gabbroic to subophitic. Where there is only isotropic (analcitic or glassy) matrix, the pyroxenes appear in idiomorphic forms in this isotropic matrix. Such a case is observed at Pastwiska.

Smulikowski (1929) classifies the teschenites into three groups, namely theralitic, essexitic, and monzonitic, basing on the relative amounts of plagioclase and alkali feldspars. Under microscope, it was found difficult to establish the nature of the feldspars very accurately due to extensive alternation of these. Moreover, persistent occurrence of a glassy mesostasis, mostly altered to analcite, hampered a study for the true nature of the feldspars. It was, therefore, possible only by means of chemical analyses that a more accurate assessment of the teschenites could be made as regards their feldspars. Such an assessment necessitated the simplification of the classification only to two kinds, i.e. type theralitic, in which there is a preponderance of anorthitic molecule over the other feldspars; and type monzonitic, in which the anorthite molecule is subdued as compared to the other feldspars.

In a more recent classification, Williams, Turner, and Gilbert (1954) accept the name teschenite for such a rock as having the following mineralogy: plagioclase 30 vol. % (laths showing normal zoning from labradorite to andesine or oligoclase. Many of these laths are mantled by orthoclase); Ti-augite 45 vol. %; barkevikite; olivine 10 to 15 vol. %; accessories: ilmenite, apatite, pyrite, and titanomagnetite. This mineralogical scheme suits well to the teschenites of the Cieszyn area, except for the fact that olivine is the least important mineral, i.e., either it is absent or present in very small amounts.

### Theralitic Teschenites
(chemical analyses nos. 9, 10 and 12)

The texture is coarse-to medium-grained, gabbroic or sub-ophitic to hyaloophitic (depending upon the amount of glass). Coarse plagioclase laths are extensively analcitized and only parts of these laths are visible. The mafic minerals, and particularly amphiboles, form the idiomorphic grains.

The composition of the plagioclase is mostly andesine to labradorite ($An_{40}$ to $An_{54}$). Analcite also occurs independently as subhedrae. Plagioclase is seen to break down to a mass of sericite and calcite. The automorphic grains of Ti-augite, purplish red in colour and showing well-developed hour-glass structure, is the chief mineral component. Lamprobolitic hornblende is developed around Ti-augite nuclei. The amphibolization of the pyroxene starts from the margins and sometimes the whole

Sample no. 9

| Norm | cation % | Mode vol.% |
|---|---|---|
| Orthoclase | 8.40 | Analcitized, |
| Leucite | 2.37 | zeolitized,and |
| Nepheline | 15.51 | calcitized |
| Anorthite | 21.65 | |
| Felsics | 47.93 | matrix = 50.9 |
| Wollastonite | 18.52 | Analcite |
| Enstatite | 15.72 | grains = 4.7 |
| Ferrosilite | 2.80 | Ti-augite = |
| Diopside | 37.04 | = 27.2 |
| Forsterite | 1.80 | Brown |
| Fayalite | 0.30 | hornblende = |
| Olivine | 2.10 | = 8.2 |
| Ilmenite | 1.76 | Iron ore = |
| | | = 6.8 |
| Magnetite | 7.14 | |
| Mafics | 48.04 | |
| Apatite | 0.53 | Apatite = |
| Calcite | 3.76 | = 1.4 |

Accessories: Olivine, sphene.

Sample no. 10

| Norm | cation % | Mode vol.% |
|---|---|---|
| Orthoclase | 11.50 | Fresh and |
| Albite | 3.95 | zeolitized |
| Nepheline | 10.83 | plagioclase = |
| Anorthite | 31.00 | = 48.8 |
| Felsics | 57.28 | |
| Wollastonite | 11.00 | Ti-augite = |
| Enstatite | 10.09 | = 26.4 |
| Ferrosilite | 0.01 | |
| Diopside | 22.00 | |
| Forsterite | 5.34 | Brown |
| Fayalite | 0.60 | hornblende = |
| Olivine | 5.94 | = 16.2 |
| Ilmenite | 3.20 | Iron ore = |
| | | = 4.0 |
| Magnetite | 6.90 | |
| Mafics | 38.04 | |
| Apatite | 3.70 | Apatite = |
| | | = 3.9 |

Sample no. 12

| Norm | cation % | Mode vol.% |
|---|---|---|
| Orthoclase | 11.00 | Fresh and |
| Albite | 15.10 | zeolitized |
| Nepheline | 9.54 | plagioclase = |
| Anorthite | 19.75 | = 58.4 |
| Felsics | 55.39 | |
| Wollastonite | 12.36 | Ti-augite = |
| Enstatite | 9.76 | = 17.1 |
| Ferrosilite | 2.60 | |
| Diopside | 24.72 | |
| Forsterite | 2.43 | Brown |
| Ilmenite | 3.40 | hornblende = |
| Magnetite | 6.90 | = 19.7 |
| Mafics | 37.45 | Iron ore = |
| | | = 2.9 |
| Apatite | 3.47 | Apatite = |
| Calcite | 3.60 | = 1.9 |
| | | Accessories are: Perovskite, biotite and saponitic pseudomorphs after olivine |

of the grains is amphibolitized. In such a case a remnant of Ti-augite is seen in the centre of a big lamprobolite grain. The amphibole automorphs are broken and their alteration to biotite and iron ore is observed. Lamprobolite grains, apart from the pyroxenes, have hexagonal apatite and iron ore inclusions. Apatite is widespread and occurs as inclusions in almost all the chief minerals. The amount of alkali feldspar, forming small laths on Carlsbad twins, is very small.

In this class, the teschenitic sample from Pastwiska is also included. Due to the absence of any feldspathic phase, it was difficult to classify this rock on the basis of feldspar. However, the chemical analysis and the norm revealed a dominance of the anorthitic molecule. Here, the automorphs of titanaugite and brown lamprobolitic hornblende lie in an isotropic vitreous matrix containing abundant analcite. Analcite, in the form of rounded grains, is evenly distributed in the rock. Calcite is also widespread in the isotropic matrix. There is an abundance of iron ore. Lamprobolitic grains, being soft and altered to chlorite, etc., disintegrate and at places hollow spaces are left after these in the isotropic matrix.

Perovskite is a prominent accessory. It has high relief, is nearly isotropic; and is associated with biotite. At places, Ti-augite also alters at the margins into a reddish brown material similar to perovskite.

A thin marginal alteration of titanaugite into green aegirinic pyroxene is quite common. Three chemical analyses are calculated into their norms. Sample no. 9 is from Pastwiska.

## Monzonitic Teschenites

(chemical analyses nos. 11 and 30)

The texture of this variety of rock is subophitic or hyalo-ophitic, as the case may be with the amount of glass. However, microlitic segregations of plagioclase feldspar is a common feature of the felsic components of this rock. The chief feldspar is orthoclase, but it is very strongly altered to analcite. Ti-augite forms big, mostly unamphibolized euhedral grains. The amphibole, hexagonal in outline, occurs as independent grains. Both these two primary mafics, in case of the sill at Puńców, show spots or tongue-like patches of a colourless highly birefrengent alteration product recognized as thomsonite (Pl. XVII, Figs. 3, 4). Sometimes, complete thomsonitic perimorphs of amphibole occur and only a remnant of the primary mineral can be seen in the middle. Among the accessories, apatite plays the most prominent role; others are sphene, biotite, and iron ore. Glassy matrix is mostly altered to analcite, natrolite and saponite or a dull green undistinguishable cryptocrystalline mass.

The monzonitic variety of teschenite collected from a quarry at Puńców differs from the above mentioned description in having a higher amount of alkali feldspar. Besides the water-clear alkali feldspar, there is also a rare cryptoperthitic unclear intergrowth. Alkali feldspar is also seen mantling the plagioclase.

Sample no. 11

| Norm (cation %) | | Mode (vol. %) | |
|---|---|---|---|
| Orthoclase | 33.50 | | |
| Albite | 17.90 | Semi-zeolitized felsic minerals | = 58.3 |
| Nepheline | 11.76 | | |
| Anorthite | 3.60 | | |
| Felsics | 66.66 | | |
| Wollastonite | 13.26 | | |
| Enstatite | 10.26 | Ti-augite | = 25.7 |
| Ferrosilite | 3.00 | | |
| Diopside | 26.52 | Brown hornblende | = 10.3 |
| Ilmenite | 2.60 | | |
| Magnetite | 3.15 | Iron ore | = 4.1 |
| Mafics | 32.27 | | |
| Apatite | 1.06 | Apatite | = 2.0 |

## Diabase

(chemical analyses, diabase at Lipowa: 23, 24, 25, 27, 28, and 29)

This variety of rock is not very common in the area. The present study is based on two of its occurrences, i.e. at Boguszowice and Lipowa. The rock-specimens from Boguszowice hold a direct textural and mineralogical evidence of their being coarse diabasic. The sill at Lipowa, however, exhibits the diabase in a completely altered form. The two occurrences are, therefore, described separately.

The sill at Boguszowice is 20 meters thick with leucocratic and aphanitic veins. The main sill body is a green medium-grained diabase. It clearly differs from a typical teschenite in not exhibiting the well projected titanaugite needles against a white analcitic or analcitized glassy matrix.

Under microscope, the texture is generally subophitic. The big automorphic grains of pyroxene occur partly enclosing the plagioclase laths.

Plagioclase in the form of coarse laths is frequently zoned (centre $An_{64-70}$ margin $An_{43-50}$). At places a thin rim of alkali feldspar is formed around polysynthetically twinned plagioclase. Polysynthetic twinning is mostly on albite law; but pericline twinning is also seen. Plagioclase is frequently proxied by glassy matrix. At places the whole of a plagioclase grain may be pseudomorphosed to cryptocrystalline sericitic material.

Pyroxene grains are mostly fresh and colourless. These do not show an intense hour-glass structure. The pyroxene grains, as against the pyroxenes of the teschenites, are free from apatite inclusions. Chlorite occurs on the surface of the pyroxene grains as the only alteration product.

Olivine is much smaller in amount as compared to pyroxene. It forms equally big grains. At places saponitic pseudomorphs of olivine, similar to those found in limburgite, are found.

Ilmenite occurs in skeletal form and is altered to leucoxene.

Besides the above described mineral assemblage, the interstitial spaces of the grains are filled by a chloritized material, presumably occurring after glass (or primary feldspathic minerals). The abundance of this chloritic material is responsible for the greenish colour of the rock in hand specimen.

The second occurrence, i.e. at Lipowa, displays a diabase of green colour, similar to that described above. The rock is medium-grained. Due to extremely altered nature of the diabase, both the mineralogical as well as chemical studies were handicaped. The outline of the grains are completely obliterated to be easily mixed up with the cryptocrystalline matrix, thus making it difficult to determine the mode by means of a point counter. Chlorite and calcite, evidently occurring after the primary minerals, are the most abundant minerals. Feldspar, in addition to its alternation to calcite, is at many places replaced by an unclear isotropic glassy matrix. However microlites of plagioclase can still be seen sticking in the isotropic matrix. In other cases fine plagioclase laths are frequently found, holding sufficient evidence of their ophitic relationship with the pyroxene. Pyroxene is mostly completely pseudomorphosed to chlorite. Iron ore, the by-product of the alteration of pyroxene to chlorite, occurs in the form of streaks on the surface of pyroxene and is arranged perpendicular to the outline of the grains. As evidenced from the calculation of the norm, the pyroxene of the diabase differs from that of the teschenite in having a low wollastonite molecule and a surplus hypersthene one. This fact combined with the ophitic texture of this rock variety serves a very concrete basis for naming it as diabase.

The diabase is marked with a later stage of crystallization of iron-rich pyroxene. This grassy green pyroxene, strongly pleochroic, occurs both as a magmatic alteration product of the main diabasic pyroxene on the wedge shaped margins of the grains, as well as independent grains. This later phase of pyroxene crystallization is accompanied by biotite. Biotite very selectively alters to hydrobiotite and vermiculite. Iron ore is again an alteration product of biotite; here it occurs in the form of larger grains within which, sometimes, biotite breaking down to hydrobiotite and vermiculite can be seen.

Other alteration products of this rock variety are natrolite and saponite. Quartz is rare. The diabase is rich in accessory apatite.

Sample 23 from Lipowa was the only sample fresh enough to establish its mode under the point counter and compare it with the norm.

Sample no. 23

| Norm (cation %) | | Mode (vol. %) | |
|---|---|---|---|
| Orthoclase | 6.50 | | |
| Albite | 16.50 | Calcitized and chloritized | |
| Anorthite | 16.75 | feldspars + matrix | = 50.0 |
| Felsics | 39.75 | | |
| Wollastonite | 8.22 | | |
| Enstatite | 7.77 | (quartz grains also included) | |
| Ferrosillite | 0.45 | Chloritic pseudomorphs of | |
| Diopside | 16.44 | pyroxenes | = 40.6 |
| Enstatite | 14.44 | | |
| Ferrosilite | 0.86 | | |
| Hypersthene | 15.30 | Biotite | = 1.9 |
| Magnetite | 9.45 | Iron ore | = 6.1 |
| Ilmenite | 2.80 | | |
| Mafics | 43.99 | | |
| Apatite | 1.04 | Apatite | = 1.6 |
| Calcite | 12.40 | | |
| Quartz | 2.30 - (secondary) | | |

## LEUCOCRATIC ROCKS

### *Quartz Syenite*

chemical analysis no. $G_1$

It is the only example of a Si-oversaturated rock in the whole of the area. The sample described is from Przybędza (near Żywiec).

The rock is even-grained. Albite and sodic orthoclase play the dominant rôle. In hand-specimen it is dark greenish in colour. Under microscope, however, its highly leucocratic nature is revealed. The feldspars constitute 80% of the rock. The interstitial spaces of the feldspars are filled by sparsely distributed biotite. Sodic orthoclase mantling the albitic plagioclase is the commonest feature of this rock variety (Pl. XVIII, Fig. 3). The central albitic parts of the grains are frequently altered to sericite and zeolite, while the outer parts of the alkali feldspar grains are fresh. Albite is well recognizable due to its fine polysynthetic twin lamellae. Twinning is on the albite and pericline laws. Quartz forms medium anhedral grains. Its amount is, however, small.

Biotite is extremely susceptible to alteration, and normally it is seen to break down to chlorite. In some other cases it looses its colour and seems to be changing to hydrobiotite and vermiculite. At places only chloritic pseudomorphs of biotite are left. The secondary chlorite also occurs in the form of large anhedral patches. These patches have spaces within them which are filled with calcite. The patchy chlorite does not bear any relationship to the flaky habit of biotite as to represent an alteration product of biotite. It is suspected that the patchy chlorite is occurring after some other primary mineral such as pyroxene. This inference, however, can not be confirmed due to lack of direct evidence. But pyroxenes pseudomorphosed to chlorite are observed in the case of other *syenites.*

Iron ore, in the form of minute rounded grains, is small in amount and is essentially an alteration by-product of biotite.

Sample no. $G_1$

| Norm (cation %) | | Mode (vol. %) | |
|---|---|---|---|
| Orthoclase......... | 6.35 | | |
| Albite............. | 43.00 | Alkali feldspars | = 66.1 |
| Anorthite.......... | 22.57 | | |
| Felsics............ | 71.92 | | |
| Wollastonite....... | 4.00 | | |
| Enstatite.......... | 2.70 | Patchy chlorite | = 3.2 |
| Ferrosilite........ | 1.30 | (altered pyroxene ?) | |
| Diopside........... | 8.00 | | |
| Enstatite.......... | 5.30 | Biotite | = 18.0 |
| Ferrosilite........ | 2.70 | | |
| Hypersthene........ | 8.00 | | |
| Magnetite.......... | 3.60 | Iron ore | = 2.9 |
| Ilmenite........... | 2.00 | | |
| Mafics............. | 21.60 | | |
| Quartz............. | 6.46 | Quartz | = 8.9 |

note: Calcite was not calculated. Therefore, all the calcium is shown in the anorthite

## *Analcitic Sodic Syenite*

Previously, this rock-type was described from Grodziec. Unluckily, on the present trip no fresh specimens could be found there. The sample, presently described is from Pastwiska. Here, a very thin vein of leucocratic rock was found at the contact of a teschenite sill with the country rock.

Under microscope, the texture is typically interstitial, whereby altered grains of pyroxene and biotite occur in the spaces between the feldspar grains. Spaces between the feldspar grains are also filled by profusely mixed up calcitic and zeolitic material. Analcite, more frequently, occurs on the surface of the albite grains as its alteration product. Chief feldspar is a low temperature albite, as determined on the universal stage through the study of twinning. The accompanying orthoclase forms comparatively coarser laths than albite. Orthoclase mantling albite is a common feature of this rock variety.

Among the mafics, pyroxene is the most abundant and forms well developed euhedral grains. The study of the nature of the pyroxene was, however, made difficult by their extensive chloritization. At places complete chloritic pseudomorphs after pyroxene occur. The iron ore is frequently completely leucoxinized. Brown Ti-biotite forms fresh, well developed flakes and resembles Ti-biotite of the limburgites. At places irregular patches of saponite are also found. It is, however, difficult to name the mineral after which these occur.

Sample no. 7

Norm (cation % )

| | | | |
|---|---|---|---|
| Orthoclase.... | 37.00 | Fayalite....... | 1.74 |
| Albite........ | 11.00 | Forsterite..... | 5.73 |
| Nepheline..... | 21.00 | Olivine........ | 7.47 |
| Anorthite..... | 12.50 | Ilmenite....... | 1.20 |
| Felsics....... | 81.51 | Magnetite...... | 3.75 |
| Wollastonite... | 0.40 | Mafics........ | 13.22 |
| Enstatite..... | 0.30 | | |
| Ferrosilite... | 0.10 | Calcite........ | 5.50 |
| Diopside...... | 0.80 | | |

Among the secondary minerals natrolite is easily recognizable due to its radiating fibrous form.

Owing to fine, nearly microlitic, nature of the mineralogy of this rock, and an overwhelming occurrence of the secondary cryptocrystalline mass, it was not possible to determine the modal composition by point counter. Since in calculating the norms of the rocks the deficiency of $SiO_2$ was compensated always by first transforming albite into nepheline, in the present case the albite component (in cation percent) is greatly reduced while the orthoclase component (in cation percent) remains unduly large. Actually, source of most of the K in this *syenite* is the secondary analcite, and the $SiO_2$ deficiency is caused by this undersaturated mineral.

## *Nepheline Syenite*

This rock-type occurs at Punców. The rock specimens were collected from the margin of a thick teschenite sill, where the *nepheline syenite* is in the form of a leucocratic vein. In hand specimen, it is medium-grained, light coloured with green needles of „ferriferrous" augite.

Microscopically, the interstitial to intersertal texture is shown by the occurrence of small needle like grains of green augite in the angular spaces of feldspar laths. At places prehnite also occurs in the intergranular spaces of the feldspars. In the present case only one kind of pyroxene, i. e. the green ferriferrous augite, was recorded. The feldspar is mostly ortoclase but albite is also found. Orthoclase may be fresh or completely altered to analcite.

Prehnite is a very important mineral in this *nepheline syenite*. It is present in varying amounts, and in certain cases it may constitute nearly 25 to 30% of the rock. Other accessory minerals are: biotite, sphene, iron oxide, and apatite.

The rock-type under study represents late stage magmatic liquids at the end of crystallization of á differentiating teschenitic magma. The occurrence of this rock in the form of thin veins also indicates the squeezing out of these late-stage magmatic liquids into the crevices or margins of a solidified or semi-solidified main body.

Sample no. 31

| Norm (cation %) | | | Mode (vol. %) | |
|---|---|---|---|---|
| Orthoclase.... | 41.00 | | | |
| Albite........ | 6.50 | | Fresh and analcitized alkali feldspars | = 51.5 |
| Nepheline..... | 14.70 | | | |
| Anorthite..... | 17.70 | Prehnite + Zeolites = 26.30 | Nepheline pseudo-morphs | = 9.6 |
| Wollastonite.. | 8.60 | | Prehnite | = 25.3 |
| Wollastonite.. | 3.20 | Pyroxene = 6.40 | | |
| Enstatite..... | 3.20 | | Green ferriferrous augite | = 11.4 |
| Magnetite..... | 4.70 | | | |
| Ilmenite...... | 0.46 | | Iron ore | = 2.0 |

The norm shows a surplus wollastonite molecule over the diopsidic one. It is accompanied by a large quantity of anorthite, whereas in the actual composition the amount of Ca-rich plagioclase is negligible. The present normative mineral combination can be explained by the fact that free wollastonite+anorthite stands for abnormally large quantities of prehnite in the actual composition. In the case of *nepheline syenite* under discussion the amount of prehnite varies from specimen to specimen. Prehnite, owing to its typical hydrothermal nature, forms still thinner veins and horizons within the *nepheline syenite*.

According to Smulikowski (1929), a major part of anorthite in the norm belongs to zeolitic aggregates associated with analcite. This zeolitic mass, which also makes up the pseudomorphs of nepheline in the present case, is supposed to be occuring after primary plagioclase which was completely transformed during prolonged consolidation at low temperature of the squeezed out late-stage magma fractions. In so far as the zeolitization is an important contributor alongwith prehnite for the large quantity of normative anorthite, the present study aggrees with Smulikowski's findings. The basis of this aggreement is the zeolitized nature of the plagioclase, as against the fresh ortoclase which frequently mantles the altered plagioclase in other *syenites*. Sphene is a very prominent accessory in this rock.

### Alkali Syenite

The thick diabasic sill at Buguszowice displays leucocratic veins and patches. This leucocratic variety was named by Smulikowski (1929) as alkali syenite. The present study aggrees upon the terminology, since the rock is predominantly marked by the presence of alkali feldspar, and the absence of primary feldspathoidal minerals, although hydrothermal analcitic veins traverse the albite. This leucocratic variety, like the leucocratic feldspathoidal variety of the Punców sill, originated during the final stages of crystallization of a differentiating magma, and was superimposed by calcite — and analcite — producing hydrothermal stage.

Microscopically, the chief mineral component is orthoclase. Normally, orthoclase encloses a core portion of albite. Calcite forms patches within the alkali feldspar. Accessories are: chlorite (in aggregates), sphene, biotite and pyrite.

Mode (vol. %)

| | |
|---|---|
| Orthoclase | 45.3 |
| Albite (with a few analcite veins) | 37.2 |
| Biotite | 1.2 |
| Calcite | 11.0 |

The rest consists of pyrite, sphene and chlorite.

## PETROGRAPHY OF THE SILL MARGINS AND APOPHYSES

Besides the leucocratic veins, the margins of the sills are marked by thin fine-grained contact zones and apophyses. Here, the examples of three big sills at Pastwiska, Rudów, and Puńców are quoted. At Pastwiska a thick teschenite sill at the upper margin displays an extremely fine-grained, hard rock. A similar kind of rock variety is found at Puńców in the form of a thin vein at the contact of another thick sill lying parallel with a leucocratic vein. At Rudów, however, the rock-type under mention occurs in the form of an off-shoot from the main sill body at the roof of it. Evidently, the passage between the main sill body and the rock-type under study is somewhat transitional in the case of the sill at Pastwiska, while at the other two places these are independent and have sharply bordered zones.

In case of all the three examples these marginal rock facies consist of hard, dark, fine-grained rock variety in which the individual minerals are difficult to discern in hand-specimen. At Rudów, however, the rock is slightly softer than at the other two places, lighter in colour, and has a characteristic spotty appearance, as shown by volcanic types due to sudden release of gases under rapid cooling.

Under microscope, all the three types have, basically, the same texture and mineralogy. The texture is characterized by fine microlitic nature of the chief mineral component, i. e. pyroxene. At Pastwiska, the grain size of the rock is slightly coarser as compared with the other two examples. This is (mentioned earlier as well) due to the fact that at Pastwiska the rock-type is simply a chilled margin of the sill with a gradual passage between the margin and the main body, and, as a result, exihibits gradual decrease in grain size. The pyroxene in all the cases forms needle-like grains which are haphazardly arranged. Between the needles lie more or less fresh, but cryptocrystalline, felsic mass. At Puńców and Rudów the microcrystalline mafics constitute 2/3rd of the rock, whereas at Pastwiska felsics and mafics are nearly equal in amount.

Another difference between the Punców and Rudów type and the Pastwiska type is the stronger amphibolization of the pyroxenes in the last case, so that amphibole also occurs as independent grains and constitutes 1/3rd of the total mafics.

Samples from Rudów and Pastwiska were chemically analysed and the two chemical analyses are calculated into their norms. The norms, however, could not be compared with the modes, because the microlitic nature of the grains in the form of clusters prevented the use of point counter, the only means available for determining the modal composition.

A feature which has an important bearing on the genesis of this rock-type is the occurrence of big phenocrystal grains of Ti-augite (Pl. XVII, Figs. 1, 2). The phenocrystal grains are a few in number in each of the three examples. There is every evidence of the xenocrystic nature of these crystals; as shown by their sharp euhedral outlines, and their many times larger size than that of the indigenous grains, what makes them stand out against a microcrystalline mozaic of the pyroxene needles. The needles of the pyroxene either abut against or lie alongside the walls of the phenocrysts. The phenocrysts completely resemble the Ti-augite grains of the teschenites. In case of an apophysis, for example at Rudów, the chilling is more intense since here the magma was injected in the form of an off-shoot sandwitched between two cold chunks of the country rock.

| Sample no. 8<br>Norm (cation %) | |
|---|---|
| Orthoclase...... | 8.65 |
| Albite.......... | 13.05 |
| Nepheline....... | 8.70 |
| Anorthite....... | 24.20 |
| Felsics......... | 54.60 |
| Wollastonite.... | 6.74 |
| Enstatite....... | 5.84 |
| Ferrosilite..... | 0.90 |
| Diopside........ | 13.48 |
| Forsterite...... | 15.72 |
| Fayalite........ | 1.77 |
| Olivine......... | 17.49 |
| Ilmenite........ | 1.82 |
| Magnetite....... | 4.80 |
| Mafics.......... | 37.59 |
| Apatite......... | 1.49 |
| Calcite......... | 5.57 |

| Sample no. 13<br>Norm (cation %) | |
|---|---|
| Orthoclase...... | 1.65 |
| Albite.......... | 1.85 |
| Nepheline....... | 9.69 |
| Anorthite....... | 22.67 |
| Felsics......... | 35.86 |
| Wollastonite.... | 16.94 |
| Enstatite....... | 16.94 |
| Diopside........ | 33.88 |
| Forsterite...... | 14.29 |
| Ilmenite........ | 3.40 |
| Magnetite....... | 8.40 |
| Mafics.......... | 59.97 |
| Apatite......... | 3.70 |
| Calcite......... | 1.20 |

It should be noted that compositionally sample no. 8 is a mesocratic rock—theralitic teschenite; whereas no. 13 is melanocratic, approximating monchiquite in composition.

## MINERALOGY

The mafic and felsic minerals are described separately. The mafic minerals predominate the felsic. Replacement of granular felsic minerals such as feldspars by analcite or analcitized glassy mesostasis is very common in the rocks of the Cieszyn area. The mafic minerals are described in the order of their abundance.

### The Pyroxenes

Pyroxene constitutes nearly 60% of the whole of the mafic portion of the rocks under study. There are mainly three kinds of pyroxene, namely the common augite, titanaugite, and ferriferrous augite. In addition to these three, there are frequently found thin rims of aegirine on large phenocrysts of titanaugite. The common augite is confined to typical diabasic rocks of the area. Titanaugite is the chief mineral component of all the melanocratic rocks and the teschenites. The third pyroxene, i. e. ferriferrous augite, is a new variety of pyroxene which has so far not been reported in the mineralogical literature. The green-coloured ferriferrous augite is found in the *nepheline syenite* veins in the thick teschenite sill at Puńców. The most characteristic feature of this highly iron-rich, Si-deficient pyroxene is the high $Fe^{3+}/Fe^{2+}$ ratio. Despite high content of $Fe^{3+}$, the amount of alkalies mainly sodium, is as low as that of a ferroaugite. Basing on the structural formula, it is concluded that the rôle of $Fe^{3+}$ in the ferriferrous augite is mainly twofold: 1) substituting alongwith Al and Ti for Si at the tetrahedral site, and 2) balancing the charge at the octahedral site for the incoming of trivalent elements at the tetrahedral site. As will be seen later, the formation of such a variety of pyroxene in the later stages of differentiation of the Cieszyn magma is well justified in view of the conditions of crystallization. A study on the physical and chemical properties, and the course of crystallization of the pyroxenes of the teschenitic rocks of the Cieszyn area has already been published (Mahmood, 1970) and it is intended to augment this study by X-ray and microprobe investigations.

## The Amphiboles

Amphibole after pyroxene is the next most important mafic mineral in the rocks under study. Amphibole is either basaltic hornblende, namely lamprobolite, or barkevikite. A detailed optical study revealed that the amphibole of such melanocratic rock species as camptonites, monchiquites, etc. is barkevikitic, while that of the teschenites is lamprobolitic.

Under microscope, amphibole occurs as large, euhedral grains several mms. across. The crystal faces normally met in the order of abundance are: (010), (001), (110), (100), and (101). The pleochroic scheme is as follows:

$\alpha$=pale yellowish-brown, $\beta$=brown, $\gamma$=dark reddish-brown, except for the deep green margins of some of the grains, which is an effect produced by the iron and alkali enrichment of the margins causing smaller optic axial angles than in the central portion of the grains. Similar phenomenon is observed in pyroxenes as well. Absorption is $n_\alpha < n_\beta < n_\gamma$

Some of the optical properties are tabulated below from where the important difference between lamprobolite and barkevikite can be noted.

Extinction angle ($\gamma : Z$) is the most variable property. Normally, lamprobolite has a lower extinction angle than barkevikite. Due to unequal distribution of the chemical elements, extinction within a grain is somewhat gradual from the margin to the centre.

2V is a stronger criterion to distinguish between the lamprobolite and barkevikite; it is smaller in the case of barkevikite. Refractive indices are, however, higher in the case of barkevikite. Dispersion proves as the ultimate confirmatory optical test for the two kinds of amphibole.

| | Lamprobolite | | | | | Barkevikite | |
|---|---|---|---|---|---|---|---|
| **Sample nos.** | 9 | 10 | 12 | 11 | 30 | 32 | 38 and 39 |
| | Theralitic Tesch. | | | Monzonitic Tesch. | | Monchiquite | Camptonites |
| $\gamma : Z$ | 4° | 7° | 10° | 11° | - | 13° | 15° |
| $2V_\alpha$ | 76° | 80° | 76° | 70° | 80° | 66° | 60° to 64° |
| R. I. (minimum) $N_\alpha$ | 1.686 | - | - | - | 1.687 | - | 1.691 |
| R. I. (maximum) $N_\gamma$ | 1.702 | - | - | - | 1.701 | - | 1.705 |
| Dispersion | $r < v$ | $r < v$ | $r < v$ | $r < v$ | $r < v$ | $r < v$<br>$r < v$ | $r > v$ |

Birefringence is quite low in the three quoted cases, and is in the range of 0.014—0.035.

Though no true zoning was observed yet thin marginal parts of most of the coarse amphibole grains in teschenites exhibit slightly different optical properties than the main part of the grains.

$\gamma : Z$ (on (010)) and $2V_\alpha$ are as follows:

Twinning is a very characteristic property of the amphiboles (Pl. XVII, Fig. 1). Sometimes, in coarse-grained rocks, many pinacoidal (010) and (001) grain-section show twinning. The twins are sharp, only rarely the twin plane is marked by a bright seam. The (100) twin meets the cleavage, as seen on c (001), sections at an acute angle of ca 20°.

| | $\gamma : Z$ (in dgrs.) | | | | |
|---|---|---|---|---|---|
| Margin | 8 | 3 | 0 | 0 | 0 |
| Centre | 17 | 8 | 4 | 6 | 5 |

| $2V_\alpha$ (in dgrs.) | | |
|---|---|---|
| 70 | 69 | 69 |
| 76 | 76 | 76 |

The common alteration product of the amphibole is chlorite. In the case of monzonitic teschenite from Rudów, large euhedral grains show within their boundaries thomsonitic alteration product in the form of patches (Pl. XVII, Figs. 3, 4). In this way, the margins of the grains are left intact. Sometimes, only a skeletal amphibole grain is seen in thomsonite. The feature, although observed in the pyroxene as well, is more intense in the case of amphibole. It is inferred that the hydrothermal solutions attacked these grains by seeping along the lattice defects within the walls of the grains.

Larger grains of lamprobolite show peripheral resorption effects, and the crystal margins are dusty with fine iron ore specks (Pl. XVIII, Fig. 2). Instances of more intense marginal resorption are also observed, whereby the grains are completely replaced by iron ore.

Another characteristic feature, particularly of the lamprobolite of coarse teschenites, is poikilitic nature of the grains. The commonest inclusions are those of apatite (Pl. XVIII, Fig. 1).

In the case of the petrologic province under investigation amphiboles are both primary as well as secondary. When secondary, these are exclusively developed around the pyroxene nuclei. In some cases (e.g. camptonites) the amphibole is of both the two kinds. In this rock the coarser phenocrystal grains are evidently after pyroxene, as inferred from a pyroxene centre. Under the aspect of amphibolization, the common structural relationship between these two mafics is that of amphibole mantling pyroxene. However, in the case of large elongated prismatic grains, amphibole is developed alongside pyroxene and extends into the host in the form of tongue-like patches.

## Iron Ore

Until the present study was carried out, titanomagnetite was thought to be the chief iron ore of the teschenitic rock series of the Cieszyn area. The present study however revealed that maghemitization of some original titanomagnetite was widespread in these rocks. Sometimes titanomaghemite grains without any relicts of titanomagnetite can be found in the teschenites. A detailed study on the maghemitization of titanomagnetite of the investigated rock series has been made (Harańczyk et al, 1971). Besides titanomagnetite or titanomaghemite, ilmenite is also very rarely found in the rocks of the Cieszyn area.

## Biotite

Biotite in the present case occurs either in the melanocratic or in the leucocratic rocks and is normally not found in the mesocratic rocks. In the mesocratic rocks, however, it may sometimes occur as an incipient alteration product of amphibole.

Fresh grains of biotite are found in the limburgites only. Here, it forms long slender flakes showing a slight preferred orientation. Pleochroism scheme is as follows: $\alpha =$ nearly colourless to pale brown, $\beta =$ $=$brown, $\gamma =$dark reddish-brown — a pleochroic scheme which agrees with that for the Ti-rich biotites (Hayama, 1959). Birefringence is strong (0.030 to 0.035). Optic axial angle is 0°. There is clear evidence of biotite in these limburgites having crystallized later than the pyroxenes, as shown by the pyroxene inclusions in biotite and the frequent abutting of the biotite flakes against the walls of pyroxene grains.

In the case of ouachititic fourchites, in which phlogopitic biotite is quite abundant, it is mostly altered to vermiculite and hydrobiotite. In this rock variety, it occurs in the form of thick flakes. The pleochroic scheme is as follows: $\alpha$=colourless or pale brown, $\beta$=brown, $\gamma$=deep brown. Absorption is weaker than in case of Ti-biotite of the limburgites; birefringence is, however, equally strong. 2V is also zero. The biotite flakes are broadly parted along the cleavage and inclusions like those of quartz and apatite arranged parallel to the elongation of the flakes can be seen. Such a swelling of the biotite flakes is owing to their breakdown to vermiculite through the stage of hydrobiotite.

In leucocratic rocks (e.g. *quartz syenite*) biotite is equally susceptible to alteration. Alteration in this case is, however, to both chlorite and vermiculite. Biotite flakes are shorter and absorption is less strong than in Ti-biotite of the limburgites. Pleochroism scheme is also somewhat different for having greyish-brown instead of reddish-brown tinge in $\beta$ and $\gamma$ positions. Very frequently the cleavages of the altered biotite flakes are lined with minute droplets of iron ore. This iron ore is evidently a product of biotite → chlorite alteration.

## Olivine

The rocks of the part of the Cieszyn area presently studied are particularly poor in olivine. The maximum amount of olivine was recorded in the case of limburgite no. 5, in which it is as much as 15%. Significant amount of olivine is also found in monchiquites. In the mesocratic rocks on the other hand its amount is negligible. Olivine rarely occurs in fresh grains. In the present case the alteration product of olivine is saponite. In limburgites, only saponitic pseudomorphs of olivine are found. The saponitic pseudomorphs of olivine are oval in shape, grassy green in colour and nearly non-pleochroic. The positive relief is medium. Birefringence is moderately strong and the maximum interference colours are of middle second order. Extinction is essentially straight and $2V\alpha$ is 44°.

The green alteration product, commonly found after olivine or orthopyroxenes, has been variously named as serpentine, chlorite, bowlingite and saponite. The first two, as evident from the optical properties and the form of occurrence in the rock, are out of question. X-ray and thermal studies by Caillère and Henin (1951) on four saponites, which were chemically analysed as well, indicated a montmorillonite type of structure for the green alteration product under mention, and this combined with the chemical composition led the authors to redefine bowlingite as saponite.

According to Ross and Shanon, as quoted by Willshire (1958), during alteration of olivine Mg is leached. Since the alteration is pseudomorphic, volume relations require removal of material, which involves selective leaching of Mg. The fact that the accompanying titanaugite, in the present case, is nearly unaffected by this alteration is simply due to the reason that this Mg-poor, Al-saturated mineral presented less attractive nuclei for the above argued alteration than the Mg-rich olivine.

No fresh grains of olivine were found to carry out a detailed mineralogical study.

## Alkali Feldspar

Alkali feldspar occurs only in monzonitic teschenite or in leucocratic rocks. In leucocratic rocks, except for the *nepheline syenite*, it is normally associated with plagioclase. In the case of the *quartz syenite* euhedral laths of albite are bordered by alkali feldspar.

Normally it forms subhedral grains. Relief is low. As in the case of *nepheline syenite* of Puńców, the alkali feldspar has cloudy surfaces. The cloudiness of the grains is attributed, partially, to their incipient alteration to sericite. Sometimes only pseudomorphs of analcite after the alkali feldspar are left. Due to unclear surfaces of the grains, cleavage is not easily seen; (001) cleavage is only rarely prominently displayed.

Compositionally, it is mainly orthoclase. In the *nepheline syenite* orthoclase has 2V 60° and extinction angle as measured on (010) is 1°—3°. In the *quartz syenite*, orthoclase is much more fresh. However, due to the absence of suitable cleavage-showing grains extinction angle could not be measured. 2V is slightly lower than in the previously mentioned case. This might be due to lesser soda enrichment of the alkali feldspar in this case.

In the mesocratic rocks, e.g. monzonitic teschenite, very few fresh grains of alkali feldspar are found. A characteristic feature of the alkali feldspar of this rock is its cryptoperthitic nature which is observed in a majority of grains. The cryptoperthitic intergrowths occur in the form of small stringlets (see Alling, 1938). Such cryptoperthitic intergrowths are also rarely seen in *syenites*. In the case of the *quartz syenite*, the central part of a zoned grain, which is otherwise occupied by pure albite, displays the cryptoperthite on an extremely fine scale.

## Plagioclase

The plagioclase may be grouped into three categories, namely that of the mesocratic rocks other than diabase; that of the leucocratic rocks; and the diabasic. Plagioclase always occurs in the form of coarse laths and is extensively analcitized, so that sometimes only pseudomorphs are present.

In the teschenites and camptonites, an exception among the melanocratic rocks for being feldspar-bearing, it forms big polysynthetically twinned laths. Twinning is mostly on the albite law. The composition is of andesine ($Ab_{62}$ $An_{38}$ to $Ab_{72}$ $An_{28}$). Due to extensive zeolitization accompanied by calcitization, resulting in extreme diminishing of the amount of fresh plagioclase, some earlier writers were constrained to name some of the teschenites as lugarites, etc. These secondary precesses have hardly any significance in the matters of terminology, since these processes essentially occur in place of plagioclase. There is clear evidence for this argument, in that complete zeolitic pseudomorphs after plagioclase retain the euhedral lath-like form of the feldspar.

Plagioclase of diabase is more or less fresh. It is rarely altered to calcite and, subordinately, to analcite. It forms very coarse laths. Compositionally it is labradorite ($An_{60}$—$An_{65}$). Though there is no direct evidence of zoning yet the grains show a wavy extinction from core to margin.

In leucocratic rocks the plagioclase is exclusively albite. In the *quartz syenite* albite forms small plates and laths. (001) cleavage is well visible. Twin lamellae, both on albite and pericline laws, are extremely fine. Zoning with orthoclase margin around a sericitized albite core is a common feature (Pl. XVIII, Fig. 3).

The albite of the *analcitic syenite* is in the form of microlites and is thoroughly mixed with analcite, calcite, and natrolite. The plagioclases of the *analcite syenite* and of the albite+prehnite veins are similar in properties. These veins represent low-temperature crystallization conditions. U-stage study supported the fact, as shown by the low-temperature nature of the albite of these veins.

## Nepheline

Nepheline is not commonly found in the investigated rocks. Its maximum amount was recorded in the *nepheline syenite,* but it also occurs in extremely small amount in mesocratic rocks. Nepheline is always altered (chiefly to natrolite). The pseudomorphs after nepheline retain their original automorphic forms. In the more altered rocks the pseudomorphs disappear in the zeolitic mass. Natrolite, occurring after nepheline is often mixed with some fibrous unrecognizable material.

## Analcite and Zeolites

The rôle of analcite in the rocks covered under the present study is variable. Generally, it has three different modes of occurrence: as a filling material, accompanying glass, calcite and other zeolites; as an alteration product of feldspars; and as a primary mineral in the form of irregular patches or rounded to subrounded grains. The third mode of occurrence is rare while the first two are quite commonly met. Due to the varying nature of analcite and its thorough mixing with other secondary minerals, it was not possible to separate it in pure state for detailed mineralogical investigation.

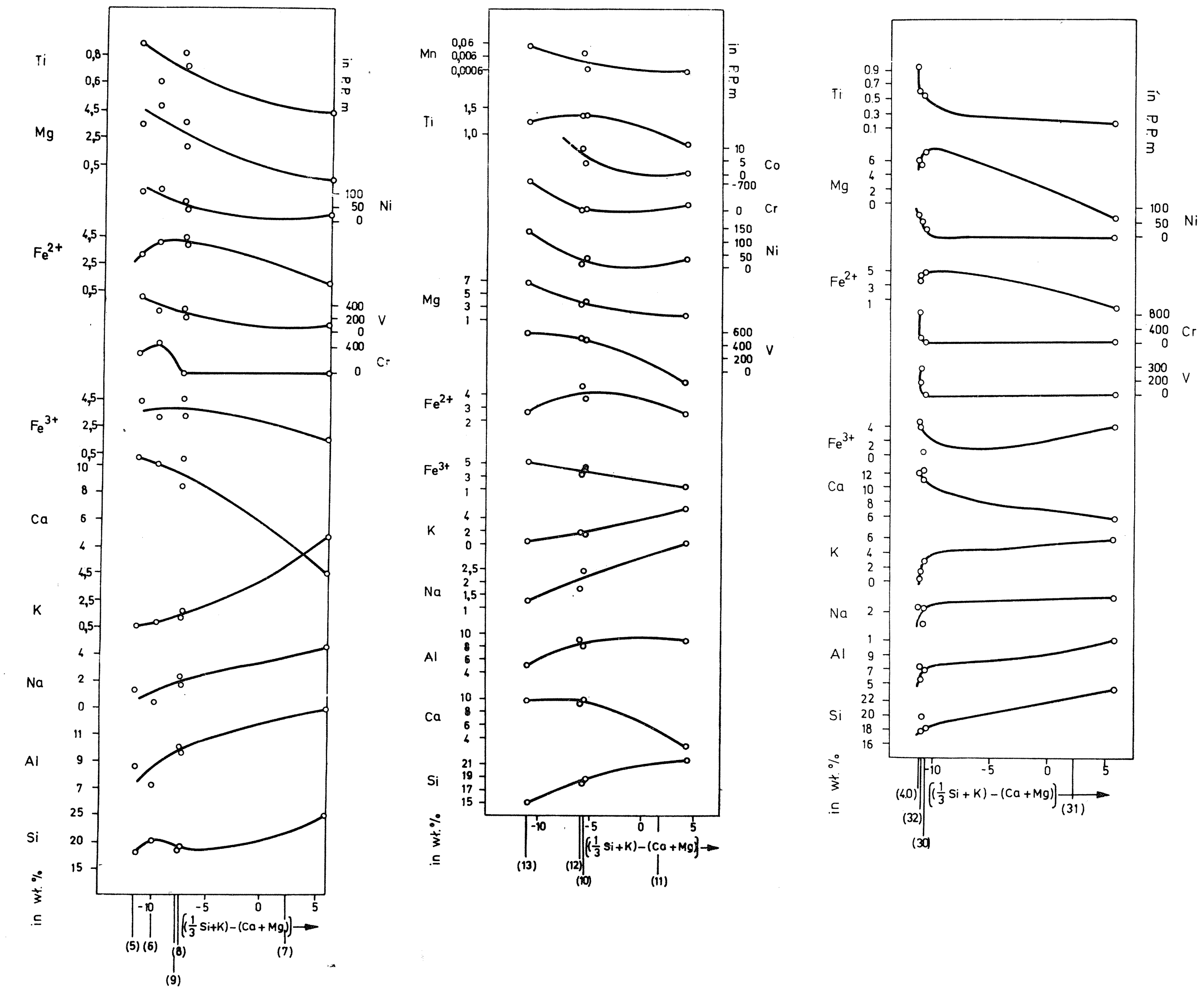

Fig. 3. Variation in the major and trace elements of the Cieszyn rock series: a — Pastwiska Sill; b — Rudów Sill; c — Puńców Sill

Under microscope, it is grey to dirty grey in colour. Relief is moderate. The mineral is isotropic and no bireferingence was observed. In the irregular patches of analcite, inclusions of augite, biotite, hornblende and apatite are found. These patches of analcite are upto several mm. in diameter. As stressed by K. Smulikowski (1929), this patchy analcite is primary in nature. It is also worth noticing that these patches occur alongwith secondary analcite after glass and calcic feldspars. The borders of these patches are sharp and not always irregular, since quite frequently their perfect rounded forms are found in teschenites like the one from Pastwiska. In the forementioned teschenite, analcite grains are embedded in an isotropic matrix which in all probabilities replaces plagioclase, because at times, in very thin sections, fresh parts of plagioclase can be seen. This isotropic matrix contains abundant calcite. The borders of analcite grains are sometimes corroded and subsequently filled by calcite which also spreads to the centre of the grains.

Besides the analcite discussed above, there is also secondary analcite formed as a result of hydrothermal metasomatism of feldspars, especially plagioclase. The feldspars are almost always transected by thin veins of analcite, or these, may be completely transformed to analcite, as is the case with alkali feldspar of the *nepheline syenite* at Puńców. The most abundant zeolite found in the rocks of the area is natrolite. It has weak to moderate birefringence. It is normally found in fibrous forms with positive elongation and parallel extinction. Natrolite is a product of transformation of nepheline, and less frequently of alkali feldspar. Fibrous mass of natrolite enclosing alkali feldspar is a feature commonly found in the *analcite syenite*. In such a case, as postulated by Smulikowski too, it may be a product of consolidation at low temperature and under hydrous conditions.

Another zeolite found in the rocks covered under the present study is thomsonite. Its occurrence as a perimorphic replacement product of amphiboles and pyroxenes has been discussed earlier. Optical properties: relief low, $n \leqslant$ balsam; maximum interference colours are blue and green of 2nd-order; $2V\gamma = 48'^{\circ}$.

## Prehnite

Prehnite occurs in sufficiently large amount in the *nepheline syenite* veins at Puńców. However, its distribution in this rock variety is quite irregular. In some rock-specimens its amount is as much as 25% of the whole rock, while in others it is just an accessory mineral. Prehnite was separated from its host rock and a detailed mineralogical and chemical study was made on it. For complete data, i. e. physical, optical, X-ray, chemical, infra-red absorption, DTA and TG, see Mahmood, 1971.

## GEOCHEMISTRY

### PLAN AND METHODS

The geochemical behaviour of the igneous rocks of the Cieszyn area is described on three kinds of variation diagrams. In the first part of this section the trends of both major and minor chemical components of the rocks from three differentiated sills — at Pastwiska, Puńców and Rudów — are plotted against the value (1/3(Si+K) — (Ca+Mg). Figs. 3a, b, c. Due to closeness in the chemical compositions of the melanocratic and mesocratic rocks of the Puńców sill there is a wide gap between the three points representing compositions of these and a solitary point marking the composition of the leucocratic variety, i. e. „nepheline syenite". At first this variation diagram looks superfluous but when considered in conjunction with the more elaborate diagrams for Pastwiska and Rudów sills, it will be seen that the variation trends of chemical elements in the three variation diagrams are, generally, the same.

The diabasic sill at Lipowa afforded the only opportunity in the area to study a profile where both the upper and lower contacts were visible. Sampling across the whole outcrop, about six meters thick, was carried out. Chemical analyses of the samples from the various heights of the sill were made (table 11). Chemical study revealed that the sill was undifferentiated. The function (1/3 Si + K) — (Ca + Mg), however, feebly increases from the centre outward, specifically toward the upper contact. A typical and sufficiently fresh sample of the diabase from Lipowa is given place on the crystallization index (CI) diagram (Fig. 5a) which takes into account all the rock-types of the area.

Individual differentiation trends of the above mentioned three differentiated sills, which are generally the same, are combined on a single diagram plotted against the „Mafic Index" (M) and the result is a confirmation of the general trends of the chemical components of the rocks of the Cieszyn area.

$SiO_2$ was determined gravimetrically.

$Al_2O_3 + TiO_2$, MgO, CaO and total iron were determined by complexometric titrations. $TiO_2$ alone, $P_2O_5$, MnO and all the trace elements were determined colorimetrically. Flame photometry was made use of in determining alkalies. $CO_2$ determinations were carried out following Schein's and Rogows method (Teleshova, 1964).

The chemical analysis-numbers are the same as sample-numbers in the petrographic portion.

### MAJOR AND TRACE ELEMENTS

The variations in the amounts of major and trace elements with differentiation are generally the same as those shown by the rocks of Scottish Tertiary alkali series, the alkali rocks of Hawaiian Islands, the alkali igneous rocks of Polynesian Islands (Nockolds and Allen, 1954), and the teschenites of the Black Jack Sill (Wilkinson, 1959).

Silica and aluminium have an ascending trend with increasing (1/3 Si + K) − (Ca + Mg). Aluminum increases in amount more rapidly in the case of three sills of the Cieszyn area, for which the variation trends are drawn here, than is the case with the other alkali rock series.

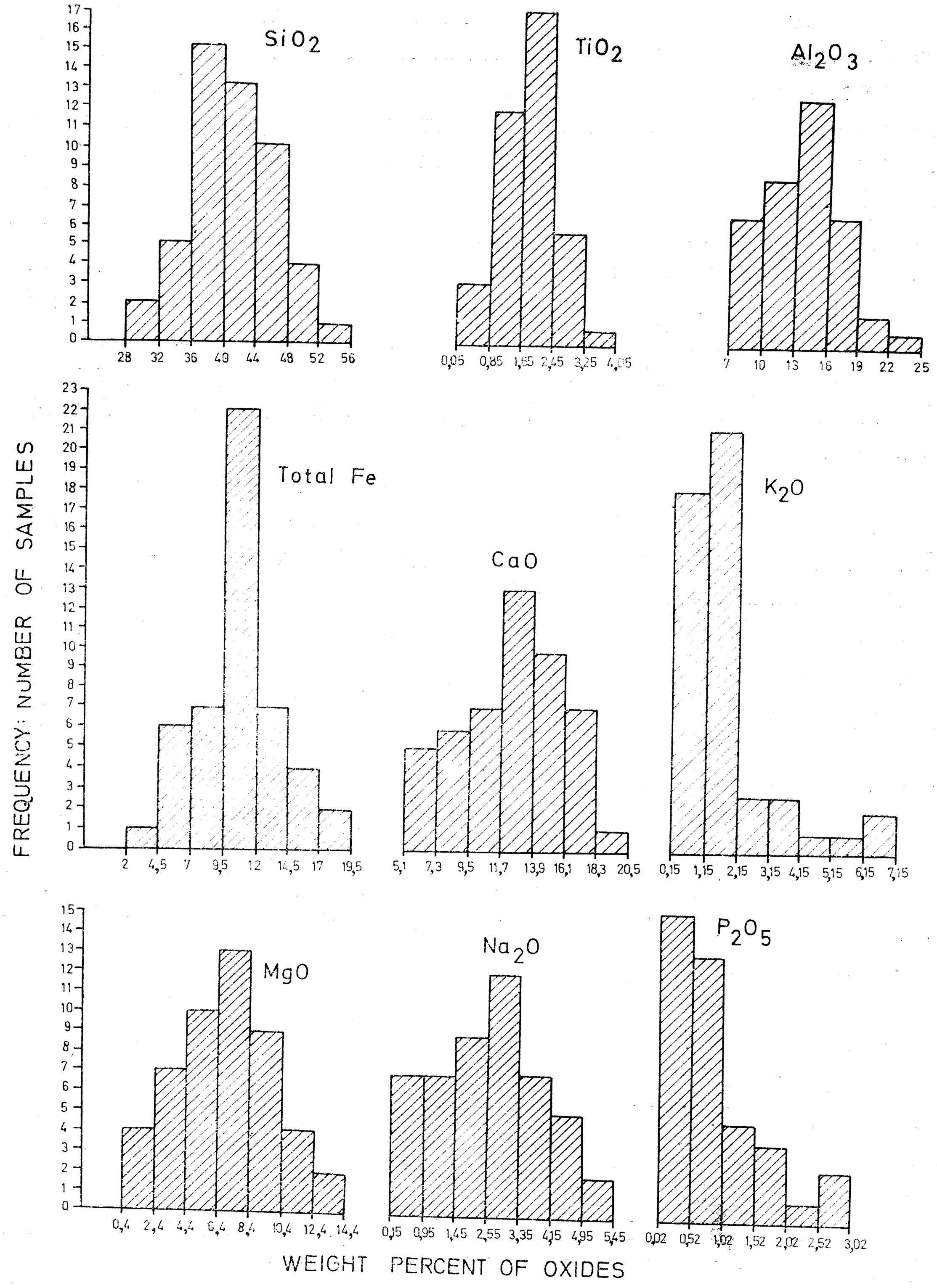

Fig. 4. Histograms of the major chemical components of the Cieszyn rock series

Iron and magnesium decrease with differentiation. $Fe^{3+}$ and Mg are more persistent in their falling trends while $Fe^{2+}$ first rises owing to $Mg \rightarrow Fe^{2+}$ subsitution but later falls towards the more mesocratic and leucocratic rocks.

Mn, except for the case of Rudów Sill, does not show a curvilinear relationship with the function $(1/3\,Si + K) - (Ca + Mg)$. In association with $Fe^{2+}$, its amount decreases with progressive crystallization.

Cr, camouflaged by $Fe^{3+}$, has a falling trend which conforms to the trends of this element in the other alkali rock series. Chromium falls almost perpendicular to the abscissa as the value $(1/3\,Si + K) - (Ca + Mg)$ rises but later, and for most part of the course of crystallization, it runs parallel to the abscissa with amounts slightly rising above the sensitivity limit. This implies very effective ejection of Cr from the liquid phase as a result of its incorporation into the early crystallites. In this regard a comparison between the chilled marginal rock and the teschenite of the Rudów Sill and between the limburgites and the teschenite of the Pastwiska Sill can be made. It is interesting to note that at Pastwiska Cr-rich rock varieties surround the Cr-poor varieties. This fact has proved helpful in laying out the sequence of evolution of the sill.

Contents of nickell fall with increasing $(1/3\,Si + K) - (Ca + Mg)$. Its trend is more or less the same as that of chromium but the initial fall in the amount of Ni in the rocks of the Cieszyn area, unlike the other alkali rock series, is not as steep as in the case of Cr. In olivine-rich limburgites, Ni is twice as high as in teschenites. Despite small amounts of olivine recorded in sample no. 13 (the chilled marginal rock of the Rudów Sill), the Ni content of this rock sample is the highest. It may be that in the present case Ni in addition to substituting for Mg in olivine is involved in a similar relationship with $Fe^{2+}$ in pyroxene.

In passing along the differentiation series vanadium decreases in a manner not entirely consistent with the other alkali rock series. However, in all the alkali series presently considered, including the Cieszyn one, vanadium falls to very low values at a later stage than Ni and Cr. A constant decrease in vanadium in the rocks of the Cieszyn area is due to the incorporation of this element in the early crystallizing pyroxene and magnetite, thus substantially lowering the amount of this element available to these minerals crystallizing at later stages. In the fourchite and the *quartz syenite* vanadium replaces $Fe^{3+}$ presumably in biotite. Sample no. 30, a monzonitic teschenite, provides remarkable evidence for the strict association of vanadium with ferric-iron. This is the only sample of teschenite in the investigated area in which V is below the sensitivity limit, but such a low amount of vanadium is readily explained basing of the equally low amount of Fe$^{3+}$. In fact this teschenite displays the lowest Fe$^{3+}$/Fe$^{2+}$ ratio.

Distribution of copper in the rocks of the Cieszyn area is irregular. Its amount depends on the immiscible sulphide phase. The highest amount of Cu, i. e. 210 p. p. m., is found in sample no. 9. Ore-microscopic study revealed an abnormally high amount of pyrite and chalcopyrite in this rock sample.

Table 1

Chemical composition of rocks of the Pastwiska sill
Analyst: A. Mahmood

| wt.% | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|
| $SiO_2$ | 38.90 | 43.40 | 46.70 | 40.70 | 40.26 |
| $TiO_2$ | 1.50 | 1.03 | 0.78 | 1.37 | 1.23 |
| $Al_2O_3$ | 12.48 | 9.77 | 19.77 | 15.27 | 14.77 |
| $Fe_2O_3$ | 6.30 | 4.49 | 3.47 | 4.62 | 6.48 |
| FeO | 4.16 | 5.30 | 2.70 | 5.86 | 5.24 |
| MnO | 0.053 | 0.053 | 0.048 | 0.16 | 0.154 |
| MgO | 12.55 | 11.45 | 3.01 | 9.54 | 6.24 |
| CaO | 15.00 | 14.15 | 6.14 | 12.00 | 15.10 |
| $Na_2O$ | 1.76 | 0.597 | 5.10 | 3.08 | 2.71 |
| $K_2O$ | 0.664 | 0.93 | 6.20 | 1.50 | 2.01 |
| $P_2O_5$ | 1.00 | 0.46 | n.d. | 0.72 | 0.29 |
| Total $H_2O$ | 4.46 | 7.23 | 3.64 | 2.92 | 3.68 |
| $CO_2$ | 1.25 | 0.60 | 2.00 | 1.76 | 1.40 |
| Total | 100,07 | 99.46 | 99.55 | 99.50 | 99.56 |

5 and 6 - Limburgites; 7 - Analcite Syenite;
8 - Chilled rock from the margin of the sill;
9 - Theralitic Teschenite

Potassium and sodium increase with increasing (1/3 Si+K) − (Ca+ + Mg) at the same rate in the Cieszyn series as in the Scottish Tertiary, Hawaiian and Polynesian ones.

Co in the present case is low and its amount in many samples is below the sensitivity limit of the applied method. It appears that most of the Co was incorporated in the olivines. As postulated here, olivine separated from the magma during the early stages of crystallization differentiation and very little amount of this mineral crystallized in the sills. Therefore, a low amount of Co is related to a low amount of olivine in the teschenitic rock series under study. Co is principally

Table 2

**Chemical composition of rocks of the Rudów sill**

Analyst: A. Mahmood

| wt.% | 10 | 11 | 12 | 13 |
|---|---|---|---|---|
| $SiO_2$ | 38.60 | 45.69 | 39.54 | 32.36 |
| $FiO_2$ | 2.30 | 1.67 | 2.30 | 2.13 |
| $Al_2O_3$ | 16.90 | 17.30 | 14.16 | 9.19 |
| $Fe_2O_3$ | 4.67 | 2.57 | 6.32 | 7.34 |
| FeO | 5.88 | 4.29 | 4.55 | 3.68 |
| MnO | 0.02 | 0.008 | 0.01 | 0.07 |
| MgO | 5.95 | 3.15 | 6.13 | 10.83 |
| CaO | 13.26 | 6.52 | 13.36 | 13.37 |
| $Na_2O$ | 2.31 | 3.58 | 3.29 | 1.76 |
| $K_2O$ | 1.89 | 4.82 | 1.77 | 0.27 |
| $P_2O_5$ | 1.74 | 0.474 | 1.54 | 1.55 |
| Total $H_2O$ | 6.05 | 10.18 | 6.38 | 16.49 |
| $CO_2$ |  |  | 1.20 | 0.45 |
| Total | 99.57 | 100.25 | 100.55 | 99.49 |

10 and 12 - Theralitic Teschenites; 11 - Monzonitic Teschenite; 13 - Chilled rock from the margin of the sill

Table 3

**Chemical composition of rocks of the Puńców sill**

Analyst: A. Mahmood

| wt.% | 30 | 31 | 32 |
|---|---|---|---|
| $SiO_2$ | 39.30 | 48.50 | 39.03 |
| $TiO_2$ | 0.92 | 0.28 | 1.00 |
| $Al_2O_3$ | 13.20 | 18.60 | 13.80 |
| $Fe_2O_3$ | 0.81 | 4.61 | 6.69 |
| FeO | 6.18 | 1.91 | 5.14 |
| MnO | 0.001 | 0.05 | 0.085 |
| MgO | 11.45 | 1.06 | 8.92 |
| CaO | 15.46 | 8.90 | 17.17 |
| $Na_2O$ | 2.87 | 3.16 | 2.06 |
| $K_2O$ | 3.18 | 6.46 | 1.69 |
| $P_2O_5$ | 0.365 | 0.02 | 0.273 |
| Total $H_2O$ | 6.00 | 6.00 | 2.40 |
| $CO_2$ |  |  | 2.00 |
| Total | 99.73 | 99.55 | 100.25 |

30 - Monzonitic Teschenite; 31 - Nepheline Syenite; 32 - Monchiquite

Table 4

## Chemical composition of diabase of the Lipowa sill

**Analyst: A. Mahmood**

| wt.% | 23 | 24 | 25 | 27 | 28 | 29 |
|---|---|---|---|---|---|---|
| $SiO_2$ | 36.90 | 31.80 | 33.13 | 33.85 | 34.73 | 34.80 |
| $TiO_2$ | 1.80 | 1.61 | 1.64 | 1.65 | 1.38 | 2.50 |
| $Al_2O_3$ | 9.45 | 11.01 | 12.00 | 15.85 | 12.62 | 8.86 |
| $Fe_2O_3$ | 8.10 | 6.53 | 5.61 | 3.16 | 5.07 | 5.89 |
| FeO | 6.13 | 4.11 | 5.99 | 5.95 | 3.58 | 5.24 |
| MnO | 0.044 | 0.05 | 0.023 | 0.04 | 0.05 | 0.00 |
| MgO | 6.59 | 7.40 | 9.02 | 10.54 | 7.48 | 7.34 |
| CaO | 13.90 | 15.38 | 11.60 | 10.54 | 15.15 | 12.42 |
| $Na_2O$ | 1.68 | 1.75 | 0.58 | 0.18 | 2.01 | 2.82 |
| $K_2O$ | 0.98 | 1.19 | 1.08 | 0.29 | 0.99 | 0.95 |
| $P_2O_5$ | 1.38 | 2.72 | 2.74 | 2.84 | 2.13 | 4.09 |
| Total $H_2O$ | 8.73 | 9.09 | 11.54 | 11.66 | 7.39 | 8.95 |
| $CO_2$ | 4.50 | 7.90 | 4.70 | 3.90 | 7.10 | 6.00 |
| Total | 100.18 | 100.54 | 99.65 | 100.45 | 99.68 | 99.86 |

**From the lower to the upper contact of the sill the order of sampling is:** 27 - 28 - 25 - 24 - 23 - 29

Table 5

## Chemical composition of rocks

(discriptions at the foot of the table)

Analyst: A. Mahmood

| wt.% | 37 | 40 | $G_1$ |
|---|---|---|---|
| $SiO_2$ | 38.80 | 42.80 | 54.90 |
| $TiO_2$ | 2.49 | 1.60 | 1.36 |
| $Al_2O_3$ | 13.27 | 10.06 | 16.67 |
| $Fe_2O_3$ | 8.06 | 6.21 | 3.40 |
| FeO | 5.53 | 4.69 | 5.25 |
| MnO | n.d. | n.d. | 0.06 |
| MgO | 6.53 | 9.85 | 2.83 |
| CaO | 16.67 | 17.14 | 6.38 |
| $Na_2O$ | 3.02 | 2.92 | 4.60 |
| $K_2O$ | 0.65 | 0.45 | 0.68 |
| $P_2O_5$ | 0.622 | 1.06 | n.d. |
| Total $H_2O$ | 3.19 | 3.20 | 3.34 |
| $CO_2$ |  |  | - |
| Total | 98.83 | 99.98 | 99.47 |

37 - Fourchite from Żywiec; 40 - Monchiquite from Hałcnów; $G_1$ - Quartz syenite from Żywiec

Table 6

Trace elements of the rocks of the Cieszyn area

| Elements in p.p.m. | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 25 | 28 | 29 | 30 | 31 | 32 | 37 | 40 | $G_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| V | 520 | 285 | traces | 200 | 315 | 350 | 110 | 300 | 620 | traces | 120 | X | X | traces | 315 | 280 | 205 | 155 |
| Cr | 320 | 465 | X | 48 | traces | X | traces | X | 762 | 255 | 225 | 125 | traces | X | 115 | X | 895 | traces |
| Ni | 110 | 115 | X | 40 | 65 | 10 | 10 | 35 | 140 | 55 | 40 | 30 | 20 | traces | 55 | 70 | 75 | traces |
| Co | X | X | X | X | traces | 10 | 5 | traces | n.d. | traces | X | n.d. | X | 5 | n.d. | 5 | 10 | X |
| Cu | 110 | 45 | n.d. | 110 | 210 | 90 | 85 | 50 | 60 | 165 | 120 | 90 | 70 | 45 | n.d. | 65 | 35 | 80 |
| Ni x 1000/Mg | 1.4 | 1.7 | - | 0.7 | 1.7 | 0.3 | 0.5 | 0.9 | 2.1 | 1.0 | 0.9 | 0.7 | 0.3 | - | 1.0 | 1.8 | 1.3 | - |
| Ni x 1000/$Fe^{+2}$ | 3.4 | 2.8 | - | 0.9 | 1.6 | 0.2 | 0.3 | 1.0 | 4.9 | 1.2 | 1.5 | 0.7 | 0.4 | - | 1.4 | 1.6 | 2.1 | - |
| Cr x 1000/$Fe^{+3}$ | 7.3 | 15.0 | - | 15.0 | - | - | - | - | 15.0 | 6.5 | 6.4 | 3.0 | - | - | 2.6 | - | 4.8 | - |
| V x 1000/$Fe^{+3}$ | 12.0 | 9.1 | - | 6.3 | - | 10.7 | 6.2 | 6.8 | 12.0 | - | 3.2 | - | - | - | 6.7 | 50 | 20.5 | - |

x denotes amounts below the sensitivity limit

note: For sample and locality discriptions see tables 1 to 5 camouflaged by $Fe^{2+}$, but as shown by Le Bas (1970) it is relatively less acceptable in pyroxene than in olivine. In the case of rocks from the Cieszyn area, pyroxenes are even otherwise poor in $Fe^{2+}$ and have a high $Fe^{3+}/Fe^{2+}$ ratio.

Passing from the melanocratic to the mesocratic rocks the ratio Ni x 1000/Mg falls. However, the variation in this ratio is small. According to Wager and Mitchell (1959), if in a mineral or rock series ratio Ni x 1000/Mg shows little variation then there has probably been no appreciable fractionation. This fact supports the conclusion drawn later in this study that in the Cieszyn magma the fractionation of the ferromagnesian minerals was weak.

Table 7

Statistical data on the major chemical components of the rocks of the Cieszyn area

Normal Distributions

| Chemical Components | n | Sk | K | $\bar{X}$ | S | V % |
|---|---|---|---|---|---|---|
| $SiO_2$ | 49 | 0.13 | -0.27 | 41.22 | 5.24 | 12.7 |
| $Al_2O_3$ | 39 | 0.26 | -0.29 | 13.93 | 3.79 | 27.3 |
| Total iron | 49 | 0.10 | 0.19 | 10.71 | 3.20 | 30.0 |
| MgO | 49 | 0.06 | -0.46 | 6.88 | 3.05 | 44.3 |
| CaO | 49 | -0.30 | -0.70 | 12.49 | 3.28 | 26.0 |
| $Na_2O$ | 49 | -0.27 | -0.80 | 2.77 | 1.34 | 13.0 |
| $TiO_2$ | 39 | 0.61 | 0.05 | 1.95 | 0.88 | 45.1 |

Log-normal Distributions

| | n | Sk | K | $\tilde{X}$ | S | V % |
|---|---|---|---|---|---|---|
| $P_2O_5$ | 42 | -0.62 | -1.0 | 1.01 | 0.32 | 31.6 |
| $K_2O$ | 49 | -0.59 | +0.35 | 1.48 | 0.36 | 30.9 |

n - number of smaples; Sk - skewness; K - Kurtosis;
$\bar{X}$ - arithmatic mean; $\tilde{X}$ - geometric mean;
V - coefficient of variation; S - standard deviation

Critical values of Sk and K for a given number of data:

n = 49 : $Sk_{05} = 0.63$ and $Sk_{01} = 0.84$
$K_{05} = 1.11$ and $K_{01} = 1.50$
n = 39 : $Sk_{05} = 0.71$ and $Sk_{01} = 0.93$
$K_{05} = 1.31$ and $K_{01} = 1.78$

# A STATISTICAL STUDY ON THE MAJOR GEOCHEMICAL COMPONENTS OF THE ROCKS OF THE CIESZYN AREA

In tables 7 and 8 statistical data based on the chemical analyses (tables 1 to 5 and 9, 10, 11 in append.) on the geochemistry of the whole of the petrologic province of Cieszyn are given. It is beyond the scope and space of this study to take into consideration the lengthy statistical procedures used in preparing these tables. The reader, however, may be referred to Griffith (in Miller, 1962, chapter XVI) and Moroney (1962, chapter 16). By including the chemical analyses of the rocks from outside the area under study, the present thesis is escalated to the whole of the Cieszyn region. Some of the salient features of the statistical study are as follows:

1) The correlation coefficient is a mathematical expression of the degree of agreement or disagreement, i. e. positive or negative correlation, between the trends of any two elements, each represented by a curve on the variation diagram, during the course of crystallization. Correlation coefficient are therefore a good check on the trends drawn in the various diagrams. It can be noted that there exists a fair accord between a particular correlation coefficient and the two corresponding curves on any one for the variation diagrams (Figs. 3a, b, c, 5a, 6a), thereby establishing the authenticity of the results of author's geochemical study, confined otherwise to a limited area in the Cieszyn region, for the region as a whole.

Table 8

Linear correlation coefficients (r) between some of the major chemical components of the rocks of the Cieszyn area

|  | $SiO_2$ | $Al_2O_3$ | Fe total | MgO | CaO | $Na_2O$ | $TiO_2$ |
|---|---|---|---|---|---|---|---|
| $SiO_2$ |  | + 0.443 | - 0.19 | - 0.413 | - 0.614 | + 0.520 | - 0.37 |
| $Al_2O_3$ | + 0.443 |  | - 0.565 | - 0.676 | - 0.502 | + 0.768 | - 0.312 |
| Fe total | - 0.19 | - 0.565 |  | + 0.304 | + 0.295 | - 0.422 | + 0.528 |
| MgO | - 0.413 | - 0.676 | + 0.304 |  | + 0.435 | - 0.536 | - 0.03 |
| CaO | - 0.614 | - 0.502 | + 0.295 | + 0.435 |  | - 0.400 | + 0.224 |
| $Na_2O$ | + 0.520 | + 0.768 | - 0.422 | - 0.536 | - 0.400 |  | - 0.230 |
| $TiO_2$ | - 0.37 | - 0.312 | + 0.528 | - 0.03 | + 0.224 | - 0.230 |  |

$SiO_2$, total iron, MgO, CaO and $Na_2O$ : $n = 49$; $r_{05} = 0.277$; $r_{01} = 0.364$

$Al_2O_3$ and $TiO_2$ : $n = 39$; $r_{05} = 0.310$; $r_{01} = 0.407$

r is considered to be significant with 95% probability if it is higher than $r_{05}$ and with 99% probability if it exceeds the $r_{01}$ value for a given number of data

2) $K_2O$ and $P_2O_5$ display log-normal distribution (Fig. 4). While the log-normal distribution of the trace elements can, normally, be explained for their „localization" in specific minerals, the analogous statistical behaviour of these two major elements is interesting to note. „Log-normality" of $K_2O$ is due to incoming of alkali feldspar in the later stages of crystallization in excess of increasing amount of sodic zeolites and progressively Ab-enriched plagioclase. „Log-normality" in the case of $P_2O_5$ may be attributed to the abnormally high concentration of apatite in the diabase of Lipowa.

3) $Al_2O_3$ shows a high degree of correlation with all the other elements. This is due to marked increase in the contents of analcite mesostasis, feldspars, and feldspathoids in teschenites and leucocratic rocks and a corresponding decrease in the ferromagnesians, as shown by a fairly high negative correlation coefficient between $Al_2O_3$ and total iron, $Al_2O_3$ and MgO, $Na_2O$, and total iron, and $Na_2O$ and MgO.

4) $TiO_2$ shows a strong positive correlation with total iron as a result of their close association in iron-titanium oxides.

## DIFFERENTIATION TRENDS OF THE CIESZYN MAGMA

The foregoing petrographic account portrays a great variety of rocks comprising the petrologic province of Cieszyn. Through the usage of the term „province" the writer commits himself to a common parental magma for all these mineralogically diverse rocks. As a consequence of mineralogical diversity, the chemical composition in terms of major oxides normally exhibits a considerable variation between two different rock-types. The purpose of the following study is to show concisely by means of variation diagrams the trends of different oxides, from the beginning to the end of crystallization period, plotted against a suitable parameter of igneous differentiation. The choice for the construction of a simple binary diagram for showing crystallization trends of the rocks of the Cieszyn area fell on Poldervaart's and Parker's crystallization index CI for its advantageous application at the onset of crystallization (Poldervaart and Parker, 1964, p. 281). This crystallization index should prove a very useful criterion for elaborating the differentiation of the Cieszyn magma, where 80% by vol. of the whole rock exposure is covered by melanocratic and mesocratic varieties representing compositions closer to that of the source magma. Moreover, by taking into account the amount of normative anorthite, a substitution of lime by alkalies in basaltic magma at the later stages can also be comprehended.

CI is calculated from the normative compositions as sum of $An' + Di' + Fo' + Sp'$ (see Poldervaart and Parker, 1964). Sp in the present case is negligible. Since the norms of the Cieszyn rocks are

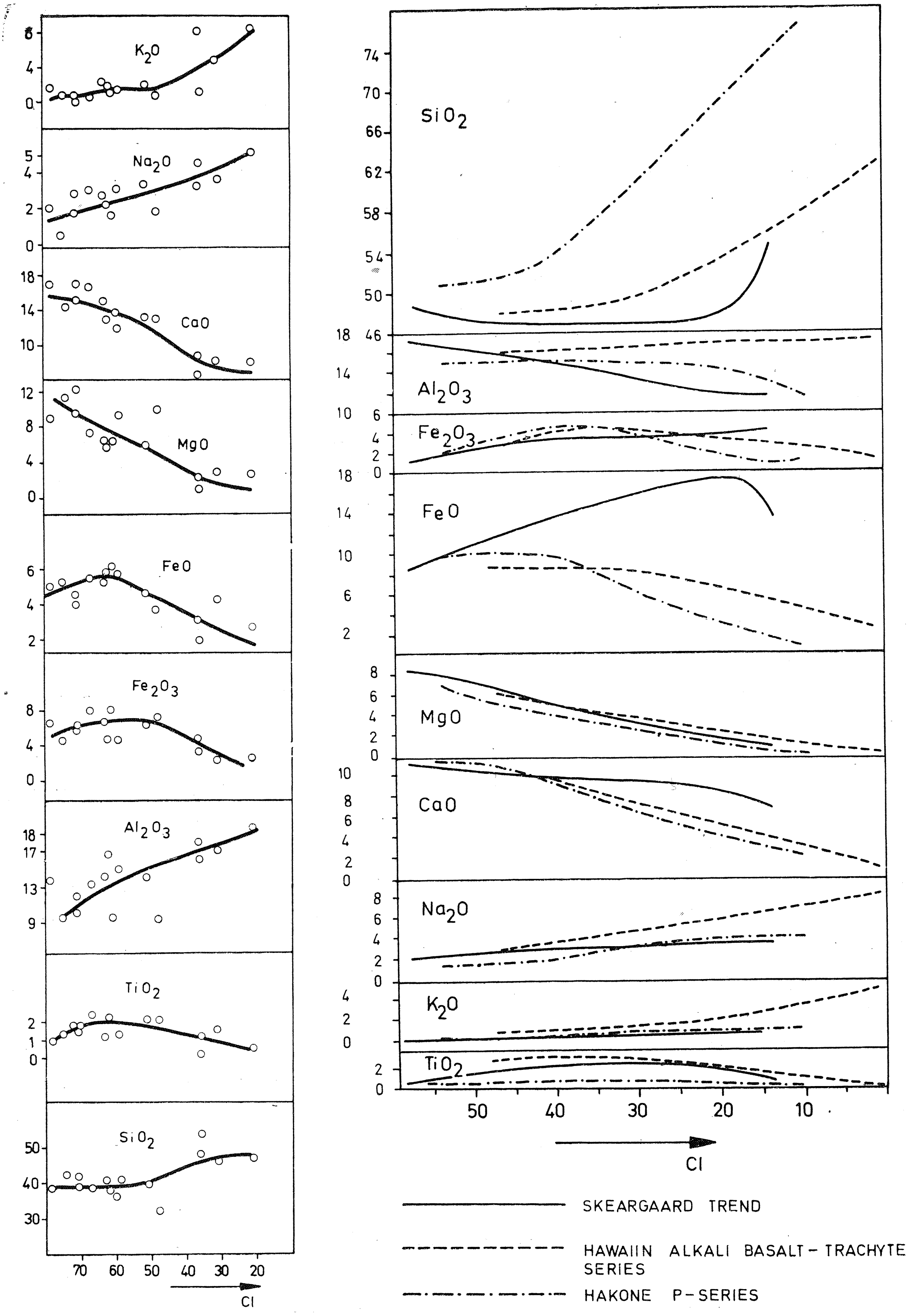

Fig. 5. Differentiation trends on CI diagram: a — Cieszyn rock series; b — Three contrasting basaltic series (after Poldervaart and Parker, 1964, p. 286)

calculated on the basis of cation percents, the method proposed by Narębski (1966) is followed. All the chemical analyses for which the norms are given in the petrographic portion of this study are used of in the construction of the variation diagram (Fig. 5a).

The variation diagrams given by the above mentioned two authors for the three contrasted basaltic provinces, namely Skaergåard partial magma; Hawaiian alkali basalt — trachyte series; and Hakone P-series are drawn here for comparison (Fig. 5b). The curves for the rocks of the Cieszyn area accord well with those for the Hawaiian alkali-trachyte series. It is interesting to note that both these two series of rocks are characterized by an alkali enrichment with progressive crystallization, whereas Skaergaard partial magma and Hakone P-series proceed to iron and silica enrichment respectively. The curves for the rocks of the Cieszyn area represent broadly the same trends as for the Hawaiian series drawn by Kuno, Yamasaki, Iida, and Nagashami (1957) but with a different crystallization index (SI : $MgO \times 100/MgO + FeO + Fe_2O_3 + Na_2O + K_2O$). A common feature of the two identical basaltic series, the Cieszyn and the Hawaiian, is a steady rise in alumina. Contrarily, Skaergaard partial magma and Hakone P-series show progressive decrease in the content of this element. This fact stresses a close sympathetic relationship between alkalies and $Al_2O_3$. A rise in the contents of these elements is due to abundant formation of low-temperature alkali feldspars in the late stages of crystallization. A drastic increase in alkalies, unlike Skaergaard and Hakone P-series, caused alumina to maintain a steady general ascending trend. In the present case curve for alumina is even somewhat steeper. This is because of predominance of the mafics, i. e. olivine, pyroxene, amphibole, etc., over the felsics, i. e. plagioclase, during most of the sequence of crystallization.

$SiO_2$ remains more or less at a constant level throughout the zone of melanocratic and mesocratic rocks and rises abruptly towards the leucocratic zone.

Both FeO and $Fe_2O_2$ gently rise from the melanocratic to the mesocratic rocks and from then onward there is a steady fall. FeO rises at the expense of MgO and decrease in the amount of MgO is further accentuated by a thorough separation of olivine at the beginning of crystallization differentiation. In the teschenites, the amount of olivine is very small and this mineral rarely occurs. Rise in the content of $Fe_2O_3$ is due to the precipitation of iron oxide in large quantities in teschenites and the other mesocratic rocks covering the middle stages of crystallization.

CaO decreases, first gently and then abruptly. A decline in the content of CaO is mainly due to diminishing, and even complete disappearance, of calcium-rich titanaugite beyond the stage of crystallization of teschenites. However, substituiton of CaO by alkalies is also substantially responsible for the decrease in CaO.

$TiO_2$ like $Fe_2O_3$ shows a gentle increase towards the middle of the diagram and then falls. A similar trend in the case of Skaergaard intrusion has been noted by Wager (1960). $TiO_2$ rises up to the upper limit of the lower zone of the Skaergaard intrusion where a maximum is reached coinciding with the precipitation of titanomagnetite. The difference in the amount of iron ore in the lamprophyres on one hand and the teschenites on the other, in the investigated rocks, is considerably large. Titanium seems to have entered the crystal structure of the magnetites in considerable amount only in the teschenites, while in the melanocratic rocks, as evident from the physical character of the grains, the iron ore is richer in magnetite. Ilmenite occurs in small amounts in the melanocratic rocks. Large patchy aggregates of iron ore are characteristic of the teschenites only.

Differentiation trends of the Cieszyn magma can be taken in further detail by making a comparison with differentiation trends of the Black Jack Sill, New South Wales, Australia, the only other teschenitic locality thoroughly studied (Wilkinson, 1958). Wilkinson plotted the weight percent of the principal oxides against the ratio

$$\frac{FeO + Fe_2O_3}{FeO + Fe_2O_3 + MgO} \times 100$$

(see Wager and Deer, 1939, and Walker and Poldervaart, 1949), i. e. the Mafic Index (M) of Simpson (1954). According to Walker (1953), this ratio is a measure of differentiation of basaltic magma and yields the best results in the early and middle stages of differentiation. For this comparative study the three differentiated sills, namely the Pastwiska, the Rudów, and the Puńców are considered on a combined variation diagram (Fig. 6a). The leucocratic, mesocratic, and melanocratic zones are marked on the abscissa. With the exception of sample no 30, a monzonitic teschenite, the three zones in that order follow a line of increasing mafic index. Whereas the upper "M" values for these two teschenitic rock series are comparable, the lower ones in the case of the rocks of the Cieszyn area are much lower than those for the Black Jack Sill. This indicates that the initial magma fractions which crystallized near the surface and were later subjected to differentiation, in the case of the rocks of the Cieszyn area, are compositionally closer to the source magma. Moreover, the range of differentiation and consequently the diversity of the rock-types is larger in this case.

$SiO_2$ and alkalies have similar trends in both the two cases. It is interesting to note that in either case potash increases at a more rapid rate than soda. It is as a result of incoming of alkali feldspar in excess of increasing amount of soda zeolites and a progressively Ab-enriched

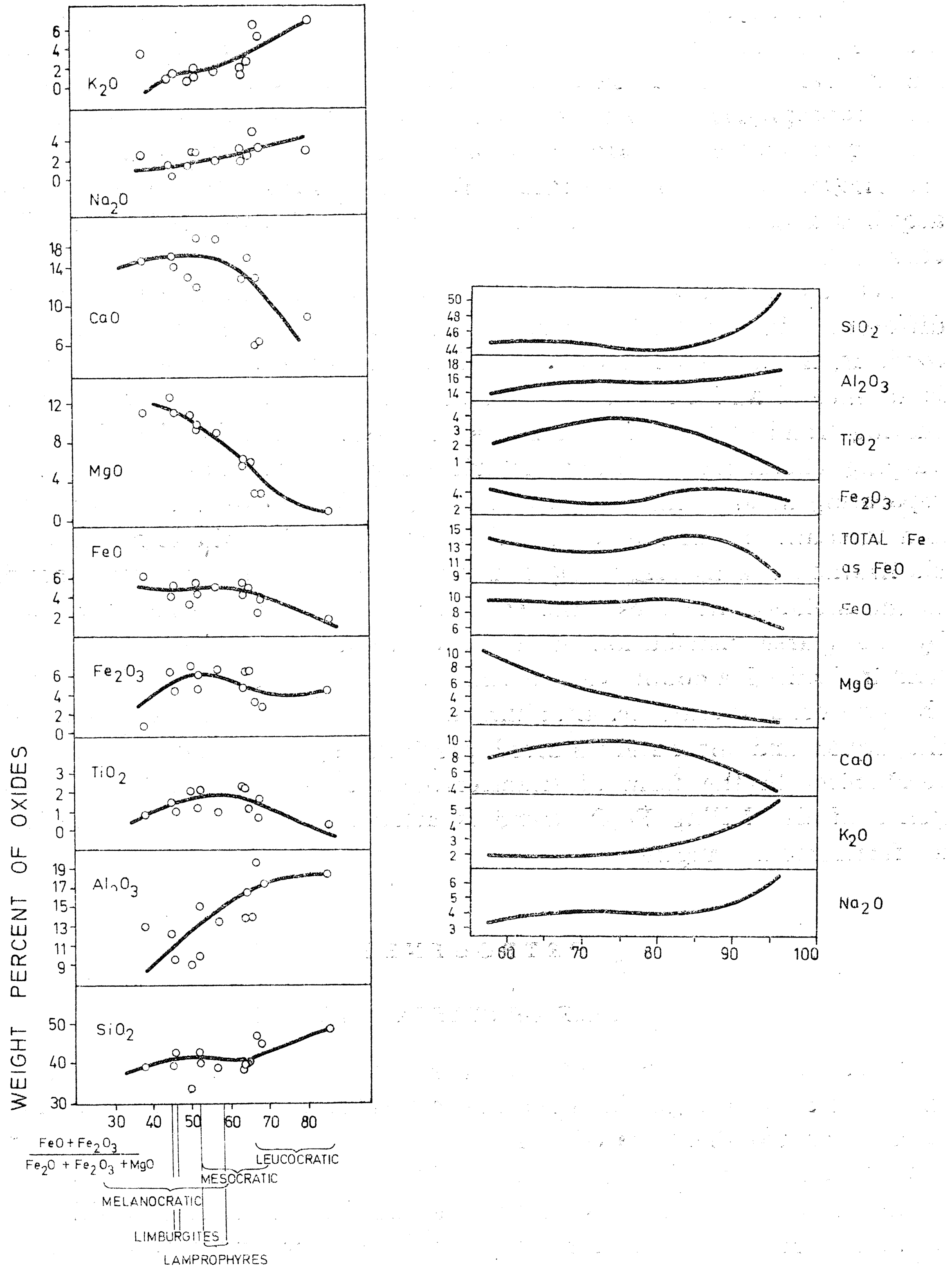

**Fig. 6. Differentiation trends drawn against the „Mafic Index" (M): a**— Cieszyn rock series; **b — Black Jack** teschenites

plagioclase. $TiO_2$ is another element with identical trend in the two rock series.

The two $Al_2O_3$ trends differ. In the rocks of Cieszyn area $Al_2O_3$ shows a more pronounced ascending course. This is due to the absence of a crystalline felsic phase from such earlier differentiates as limburgites and the lamprophyres. It is only in teschenites that plagioclase appears, excepting of course the rare camptonitic rock variety. It can be seen from the diagram that from the mesocratic zone onward, the curve for $Al_2O_3$ acquires a gentle slope more or less concordant with that of the Black Jack Sill.

FeO has a similar trend in the two series. $Fe_2O_3$, however, proceeds differently in the present case, when compared with the trend of this oxide in the Black Jack Sill. A conspicuous difference between the two is absence of an initial decrease in the rocks of the Cieszyn area. A fluctuating trend of $Fe_2O_3$ in the Black Jack Sill is correlated both with the varying chemistry of titanomagnetite and the amount of the mineral separating at any time, (Wilkinson, 1958). In the present case there is a constant rise in the content of $Fe_2O_3$ up to the middle stages of crystallization. During early stages of crystallization, i.e. those corresponding to the melanocratic rocks, the conditions were quite reducing, as shown by the sparse distribution of the iron ore in limburgites, etc. Large Ti ions in limited amount were permitted in titanaugite only. In this way the two constituents, i.e. titanium and ferric iron were concentrated in the liquid and ultimately started precipitating in abundant quantity in teschenites in the form of titaniferrous magnetite. A late-stage resurgence of the falling $Fe_2O_3$ trend is attributed to the crystallization of a „ferriferrous" augite.

## PETROGENESIS

### COURSE OF CRYSTALLIZATION

Chemical composition of the rocks of the Cieszyn area is plotted in the total Iron-MgO-Alkalies diagram (Fig. 7). To avoid confusion of points, the undifferentiated sill of altered diabase of Lipowa is represented by a zone ("A" on the diag., Fig. 11). The points representing the chemical compositions of various rocks in the differentiated sills lie on a smooth curve, except for sample no. 30. The curve illustrating the course of crystallization is concave downward. Basically it is similar to crystallization curves of Insizwa rocks (Walker and Polderwaart, 1949); Scottish alkali basalt-trachyte series, Hawaiian alkali basalt series, Polynesian alkali basalt series, Easter Island basalt-alkali rhyolite series (Nockolds and Allens, 1954); Morotu alkali rocks (Yagi, 1953), and teschenitic rocks of the Black Jack Sill (Wilkinson, 1958).

A common feature of these rock series is that they do not show any distinct iron enrichment. On a closer examination, it will be noted that the course of crystallization of the rocks of the Cieszyn area presents maximum similarity with that of the Insizwa rocks (Walker and Poldervaart, 1949, p. 657). Both the two series of rocks have initial compositions which lie closer to the MgO — FeO (total) join. In both the series, differentiation starts from the ultramafic varieties and therefore the crystallization course in these two does not commence from the middle of the triangular diagram, as is the case with the other examples cited above.

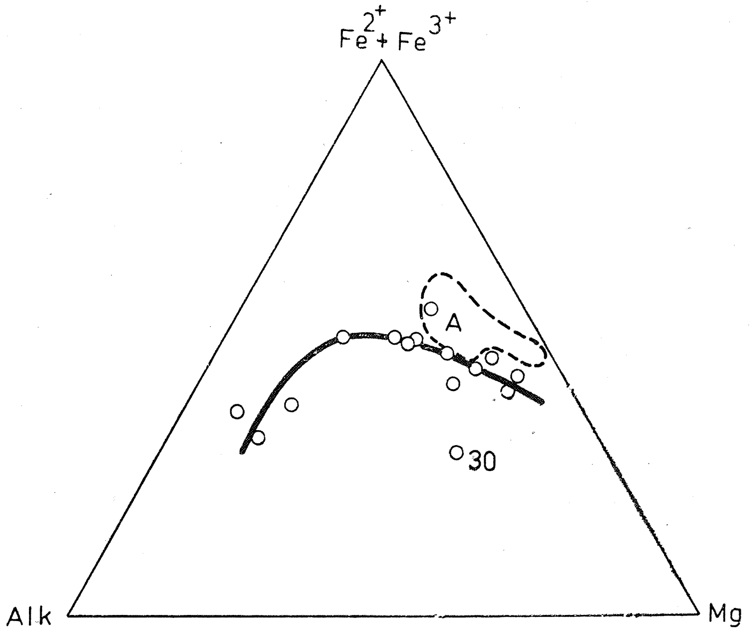

Fig. 7. Course of crystallization of the Cieszyn rock series on FMA triangular diagram. Points for the altered diabase from Lipowa (table 11) lie in the zone "A"

In the case of the rocks of the Cieszyn area the course of crystallization in the early and middle stages of crystallization is sub-parallel to the base of the triangle. Cieszyn magma thus shows the lowest iron enrichment of all the above mentioned rock series. An initial iron enrichment is normally due to the composition of olivine varying from more forsteritic to more fayalitic; in the rocks of the Cieszyn area which crystallized in sills under the near surface conditions, this generalization, due to paucity of olivine, is not valid and the course of crystallization is mainly controlled by an ever-increasing amount of felsics over mafics. The composition of the Cieszyn magma in terms of MgO/FeO ratio seems to have been fixed at the beginning of the crystallization differentiation, with the result that the crystallization curve was prevented from acquiring a maximum in the middle of the diagram.

Enrichment in alkalies is shown by the crystallization course plunging toward the alkalies end on the triangle. Supported by the mineralogical evidence, it appears that fractionation of ferromagnesian minerals once the magma had been injected into the individual sills was weak.

The problem of iron enrichment in basaltic magma has engaged the attention of petrologists for a very long time. Bowen favours alkali and silica enrichment, with the production of dioritic and granitic partial magma, while Fenner has been a staunch protagonist of iron enrichment. Wager and Deer (1939), confirming Fenner's views, showed, in the strongly fractionated Skaergaard magma, that absolute iron enrichment continued through 95% of the crystallization, but that during the crystallization of the remaining 5% the differentiation trend changed abruptly, producing residue rich in silica and alkalies. Edward (1942) also was convinced of ultimate iron enrichment as the normal trend of differentiation of the basaltic magma.

Walker and Poldervaart (1949) and some later writers (e.g. Yagi (1953), Kennedy (1955), Wilkinson (1958), Hamilton (1964), etc.) however take a more flexible view of the final course of crystallization of basaltic magma.

According to Walker and Poldervaart (1949) iron enrichment in crystallizing basaltic magmas means that fractionation affected ferromagnesian minerals more than the feldspars. The reverse may, however, be the case in suites richer in $Fe_2O_3$ and poorer in FeO. Stronger fractionation of feldspars than of the ferromagnesian minerals, producing alkali enrichment throughout the crystallization period is more characteristic of differentiation in calc-alkali provinces or in basic volcanic associations (Kennedy and Anderson, 1938; Walker and Poldervaart, 1949), the Cieszyn magma being a case in point. Kennedy (1955) takes a similar viewpoint. According to him the same basalt could be made to follow a Bowen trend of differentiation, enrichment in alkalies, and silica, or could be made to follow a Fenner trend with enrichment in iron, depending upon the partial pressure of oxygen under which the melt is crystallized.

„If the basalt crystallized under modest oxygen pressure, much of the iron in the basalt would be converted from ferrous to ferric, and the first phase to appear, at approximately 1280°C, is a spinel. This spinel comes out early and in great abundance, impoverishing the liquid in both iron and magnesium;" the crystallization trend is thus set in the direction Bowen advocates. "If, on the other hand, the crystallization is carried out in a near vacuum or in a slightly reducing environment, where partial pressure of oxygen is extremely low, no $Fe_2O_3$ and thus no early spinel is formed. Olivine very rich in magnesian appears at about 1240°C;" in this case crystallization will follow a Fenner trend.

In the present case there is a need to draw distinction between the conditions of crystallization in the deep-seated magma chamber and in the various sills. The first part of Kennedy's statement is valid for the latter and the second part of his statement for the former. Sparse distribution of iron ore in some of the earliest differentiates such as limburgites, monchiquites, etc., the rocks which immediately succede the varieties occurring beneath the surface, is suggestive of low oxygen partial pressure (but not entirely reducing or that of a vacuum), since spinel is not found in any of the rock-specimens collected from the area and olivine was instead the first mineral to separate out. But soon after the Cieszyn magma came in contact with the country rock near the surface the oxygen pressure changed drastically. The chief source of oxygen was through the decomposition of $H_2O$. Hydrogen thus produced would diffuse out of the magma into the adjacent rocks, a process analogous to the technique for buffering the oxygen fugacity of hydrothermal equilibrium experiments in the laboratory (Eugster, 1957; Chinner, 1960; and Osborn, 1959). In this way, keeping the $H_2O/H$ ratio high, the iron enrichment is suppressed (Presnall, 1966). Osborn (1959) envisages change of oxygen pressure during fractional crystallization of basaltic magma as the chief control determining whether liquids move toward high silica and lower iron oxide content (calc-alkaline trend), or toward higher iron oxide content with little change in silica (tholeiitic trend). The former occurs where $Po_2$ (oxygen partial pressure, Osborn, 1958, p. 612) remains about constant or increases, and this entails introduction of oxygen to the system, and the latter where crystallization proceeds under conditions of constant total composition, in which case $Po_2$ decreases. Osborn states, „the conditions of constant or increasing $Po_2$ may be approached where sufficient water or carbon dioxide is present in the magma to give an appropriate $Po_2$ and to serve as a reservoir of oxygen to donate or accept oxygen from the liquid and crystalline phases without greatly changing its $Po_2$".

An early widespread amphibolization of pyroxene, appearance of amphibole during the early stages of crystallization, a rapid and marked increase in the analcitic mesostasis of the rocks, all point to a fairly high water-content of the Cieszyn magma for maintaining a constant and even rising $Po_2$. The water requirements of the Cieszyn magma should have been mainly fulfilled through the agency of wet flysch sediments in which it was injected. Consequently the trend of crystallization, whatever it had been in the deep-seated magma reservoir conditions, was decisively driven in the direction of non-iron enrichment or calc-alkaline type or silica enrichment, as Osborn argues, once the magma was injected near the surface. We however find that the crystallization trend of the Cieszyn magma, if not of iron enrichment, was not of silica enrichment either. It seems that the Cieszyn magma maintained its genetic silica-undersaturation throughout the course of crystallization, and, compared with calc-alkaline types, there was a little increase in silica in the residual solutions. The timing of the separation of amphibole in the crystallization sequence, mentioned before, is also of certain significance. Aoki (1970) believes, that at the same pressure and temperature conditions amphibole would crystallize at an earlier stage of fractionation from a silica-undersaturated magma than from an oversaturated one. A genetic silica-undersaturation, reported already by Smulikowski (1929), is well understood while keeping in view the fact that some of the earliest rocks of the area, e.g. limburgites, which served as parental types for the typical teschenites, are known to be the most silica-undersaturated rock-types. Limburgites at the same time are the most olivine-rich rocks in the area. In order to account for the considerably large amount of olivine in limburgites, it is postulated that olivine was carried from below by the magma injection in solid state and the limburgites owe their origin to a crystal-liquid mush. After the injection of the magma in the form of sills very little olivine crystallized. This early separation of olivine played a dual role: 1) it perpetuated an initial state of silica-undersaturation of the magma (Tilley and Yoder, 1962), and 2) it ensured against any decline in the oxygen fugacity of the magma (Wilkinson and Nash, 1970), thus maintaining a high $Fe^{+3}/Fe^{+2}$ ratio. Once the possibilities of silica enrichment are also excluded, the course of crystallization of the Cieszyn magma was precisely the one of ultimate enrichment in alkalies.

Only one example of silica-saturation is found in the whole of the area. It is *quartz syenite* from Żywiec. The melanocratic variety here is fourchite. Fourchite-quartz syenite is an off-shoot of the main magma course. The fourchite sometimes has large amounts of biotite. Amphibole is not found in this rock variety and therefore biotite is the chief mafic partner of pyroxene. In this regard, fourchites and their subsequent derivates seem to have crystallized under more silica-saturated and hydrous conditions than those prevalent upon the main Cieszyn magma. That the $P_{H_2O}$, and only with some temperature restrictions the $PO_2$ as well, increased is shown by a general deuteric breakdown of biotite into vermiculite and hydrobiotite. The higher the $PO_2$ or $P_{H_2O}$ the higher the degree of silica-saturation reached by a magma. That is why the silica oversaturation of granitic magmas is related to their more hydrous nature compared with undersaturated basaltic magmas. Yoder and Tilley (1962) have also inferred from their experimental studies that „oxidation may bring about the passage of the bulk composition of the liquid through the critical plane of undersaturation, hence leading to silica derivates rather than nepheline derivates".

## GENERALIZED OUTLINE OF THE EVOLUTION OF THE SILLS

After the injection of magma into the cold country rock, formation of chilled margins occurred in most of the sills. The intensity of chilling depended upon the rate of dissipation of heat into the surrounding country rock and upon the thickness of the sill. The chilled margins are, at the maximum, two feet thick. Crystallization commenced at a fairly rapid rate but was soon retarded by the increasing water and other volatile contents of the magma. There is thus a marked coarsening of the grain size in the teschenites, which are in parts coarsely gabbroic to pegmatoidal. The porphyritic texture of the melanocratic rocks is due to the semi-solidified nature of their magma fraction. The stratified nature of the outcrop at Hałcnów is a reflection of different rates of cooling associated with different horizons of the sill. Since the difference between any two horizons is purely textural, it is unlikely that the contrasted types were the product of periodic injections of magma of varying compositions.

The Cieszyn magma was not emplaced passively by flowing into zones of low pressure: it rather moved under the influence of internal pressure of the magma by wedging the sediments apart. A forceful injection of magma is seen from the apophyses, discordant with the bedding, which extend from the main sill bodies.

At quite a few localities the Cieszyn magma caused metamorphism of the country rock at the contact. The metamorphic zones are, however, thin, and the metamorphic effects are weak. Metamorphism did not involve any appreciable change in the chemical composition of the country rock, other than addition of water, silica, iron, etc., to give diopside-bearing hornfelses and marbles (see also Smulikowski, 1929, pp. 752—3). According to Wieser (1971), however, the contact metamorphic alterations in the case of the teschenites under study are not restricted to decalcification of marls and recrystallization of limestones into marbles only, but they embrace paragenetic contact metamorphic assemblages, namely grossularite — dolomite — calcite — sericite — chlorite as well as diopside — albite — sanidine — quartz — dolomite, too.

## THE DIFFERENTIATION MECHANISM

All the scattered outcrops of the area are the result of a single episode of igneous activity. Each of the outcrops, however, represents a surge of magma from a particular horizon of the magma chamber. Some of these magma injections were capable of undergoing further differentiation while the others were „inert" regarding any further splitting into fractions of contrasted composition. For example, the diabasic sill at Lipowa is undifferentiated; the teschenitic sill at Rudów is weakly differentiated; and the sills at Puńców and Pastwiska are strongly differentiated. It is believed that fractional crystallization, i.e. the separation of successive crystal fractions from liquids of ever-changing composition is, from the mineralogical and chemical evidence, the chief differentiation mechanism in the cases under consideration. Presnall (1966) considers, in the case of the ultramafic bodies of Alaska and British Columbia, that under conditions of buffered oxygen fugacity, fractional crystallization is chemically the most suitable mechanism of differentiation.

Pyroxene, a titanaugite, was the first mineral to crystallize in considerable volume after the injection of the magma in the form of sills. It was accompanied, subordinately, by olivine which had otherwise nearly completed its crystallization before the intrusion of at least such a magma fraction as was capable of undergoing further differentiation. Only a short period of crystallization of olivine elapsed in the sills. In the earliest stages pyroxene was also accompanied by small amount of magnetite and biotite. In some other rocks, e.g. the camptonites, plagioclase co-precipitated with pyroxene and soon afterwards amphibole started crystallizing in large amounts. Yoder and Tilley (1962) have shown experimentally that amphibole appears above 5,300 bars and may appear earlier than olivine above 11,100 bars water pressure.

Even in the early stages of crystallization, a highly alkaline residuum was produced which either crystallized interstitially as a microcrystalline mesostasis, or precipitated analcite and other zeolites. The migration of this alkaline residuum, by a process of filter-pressing, resulted in the formation of the leucocratic veins (Smulikowski, 1929). These alkali-rich solutions (s. lato) might also have attained a great deal of mobility due to their volatile contents. Both in the Black Jack Sill and the Cieszyn cases, such secondary changes as the analcitization of plagioclase feldspar, the formation of biotite marginal to magnetite, the leucoxenization of the iron ore, and the development of minor rims of green sodic clinopyroxene around titanaugite, similarly provide evidence for the activity of these sometimes iron-rich late magmatic solutions.

Apatite, although a fairly persistent accessory mineral, is not particularly so in regard to its amount in the various rock types. The undifferentiated sill at Lipowa is abnormally rich in apatite. The liquids of this sill seem to have arisen from some upper horizons of the magma chamber where concentration of phosphorus, alongwith volatiles, had occurred. According to Philpot (1957), oxide-apatite rocks are the result of immiscible liquids which separated from a magma that underwent strong differentiation. In alkali igneous complexes, the magmas are generally richer in phosphorus than other common magmas and therefore it is quite possible that fractional crystallization may lead more easily to conditions of immiscibility.

It has been a common practise amongst petrologists to include a discussion on the possible rôle of gravity accumulation of early formed crystals from basaltic magma. The formation of picritic magma through fractional crystallization of the Hawaiian basaltic magma and settling of olivine crystals is now a familiar concept as a result of studies by Macdonald (1964); Powers (1955); Muir, Tilley and Scoon (1957); and Murata and Richter 1961). In view of the small thickness of the Cieszyn sills, the question of gravity accumulation having played any significant role is highly doubtful. Moreover, frequent landslides have covered the contacts of most of the sills in the field and it was difficult to decide upon the actual structure of the sills, as well as to carry out systematic sampling. Only at Pastwiska was it possible to delineate, approximately, the shape of the body. This sill has an arched upper contact. From the core outward, the succession is limburgite — teschenite — leucocratic vein rock. Under this setting, the differentiation appears to have taken place from core to margin. It would therefore be highly relevant to consider the rôle of the „flow differentiation mechanism". The mechanics of flow differentiation in ultramafic and mafic sills has been studied by Bhatacharya (1967) on experimental scale models using a solid-fluid mixture. In broad terms, his hypothesis states that the phenocryst-rich core of a sill might be formed by the concentration of intra-telluric crystals toward the center of the flowing magma which contains both solid and fluid phases. „The crystals can segregate to form mineral accumulates due to inherent flow properties of the magma. Such segregation takes place away from the walls and toward the center of the flowing magma". The phenomenon takes into account the formation of porphyritic cores in sills, sheets, and dykes. The model experiments have also revelaed that the continuity of flowing magma in the vicinity of a boundary results in a centripetal radial force acting on the crystals, which is sufficiently strong, even at low magma viscosities, to produce crystal segregation from the walls inward.

A flow-differentiation, when applied to sills such as that of Pastwiska which shows differentiation from the core to the margin, helps us explain the formation of a porphyritic core in sharp contrast to the non-porphyritic outer parts of the sill. In the case of the Pastwiska sill, it also confirms that the magma consisted of a crystal-liquid mush (the basic requirement for the mechanism to be operative). The solid phase was mainly of olivine, since the phenocryst are mostly of altered olivine. Furthermore, this mechanism provides an important explanation for the occurrence of large phenocrysts, only a few in number, in the chilled margins of the sills. These „stranded" phenocrysts represent the solid phase of the original crystal-liquid mush which were ultimately to be transferred, during flow, to the inner parts of the sills.

## PARENTAL MAGMA

A common parentage for the various rocks of the Cieszyn region has already been accepted by Smulikowski (1929). According to him the Cieszyn rocks form a lithologic series which is continuous, ranging from the melanocratic to the leucocratic rocks. A two-stage differentiation, namely one in the deep-seated magma chamber and the second in the individual sills, as postulated earlier in this study, is in agreement with Smulikowski's findings. The first stage took place at depths inside a magma chamber. The partially differentiated magma penetrated the Cretaceous sediments of the Carpathians geosyncline, forming sill-like intrusions. The second stage took place within these sills. It is postulated that the first stage of differentiation split the magma chamber into horizons of varying compositions. A general scarcity of olivine in the outcrops, for instance, shows that olivine might have sunk to lower levels of the magma chamber, from where the energy of the magma was not high enough to propel olivine-rich liquids toward the surface.

## CONCLUSIONS

A great variety of rocks in the area, from the lamprophyres to the „syenites", is attributed to a two-stage differentiation — in the deep-seated magma chamber and in the individual sills near the surface — chiefly through the mechanism of fractional crystalization of the Cieszyn magma. The differentiation trend conforms, fundamentally, to that of the alkaline olivine-basalt magmas, as shown by the help of comparison with the Hawaiian alkali basalt — trachyt series. The more specific character of the Cieszyn magma as a basic representative of the alkaline olivine-basalt magma lies in its sharing with the other alkali diabasic rocks the common feature of alkali enrichment. In terms of Fe-Mg enrichment trend the Cieszyn magma presents a unique case, in that it shows very little iron enrichment, when compared with the alkali diabasic rocks of the other reported localities. Iron enrichment in the present case was overwhelmingly suppressed by a coordinated rôle of water, high $PO_2$ and alkalies. Formation of a ferriferrous augite in the late-stage leucocratic rocks such as the „nepheline syenite", instead of ferroaugite; maghemitization of titanomagnetite, so much so that in the one case reported herein pure titanomaghemite grains without any relicts of titanomagnetite occur, ever increasing amount of analcite mesostasis and other zeolites; and formation of prehnite veins in the final stages of crystallization provide convincing evidence for the prevelance of the three above mentioned agencies during the crystallization of the Cieszyn magma.

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*Department of Mineralogy and Petrography*
*of the Jagellonian University Kraków*

## APPENDIX

Table 9

Chemical analyses of the rocks of the Cieszyn area for statistical study. Analyst I. Gucwa

| Wt.% | 1P | 2P | 7P | 8P | 5R | 6R |
|---|---|---|---|---|---|---|
| $SiO_2$ | 43.65 | 43.03 | 44.38 | 44.43 | 43.46 | 41.10 |
| $TiO_2$ | 1.65 | 2.26 | 1.80 | 1.83 | 2.12 | 1.43 |
| $Al_2O_3$ | 18.45 | 11.75 | 14.08 | 8.67 | 11.80 | 16.20 |
| $Fe_2O_3$ | 6.12 | 9.79 | 7.71 | 10.42 | 11.58 | 8.46 |
| FeO | 6.27 | 6.82 | 3.74 | 4.16 | 6.10 | 5.97 |
| MnO | 0.15 | 0.15 | 0.14 | 0.15 | 0.15 | 0.13 |
| MgO | 3.96 | 3.85 | 4.97 | 7.87 | 5.08 | 6.68 |
| CaO | 10.07 | 10.29 | 14.25 | 16.21 | 10.22 | 13.10 |
| $Na_2O$ | 2.07 | 2.10 | 1.19 | 0.62 | 3.31 | 1.75 |
| $K_2O$ | 3.03 | 3.18 | 2.67 | 1.69 | 1.78 | 1.45 |
| $P_2O_5$ | 0.15 | 0.18 | 0.09 | 0.08 | 0.19 | 0.11 |
| $H_2O-$ | 0.87 | 0.43 | 0.97 | 1.50 | 1.37 | 0.34 |
| $H_2O+$ | 3.77 | 3.46 | 3.55 | 2.56 | 3.27 | 1.78 |
| $CO_2$ | 0.14 | - | 0.84 | 0.25 | 0.25 | 1.27 |
| Total | 100.35 | 99.29 | 100.38 | 100.44 | 100.68 | 100.77 |
| in P.P.m. | | | | | | |
| V | traces | 8 | 9 | 18 | 10 | 300 |
| Cr | - | traces | 200 | 346 | traces | - |
| MO | 6 | traces | traces | traces | traces | traces |
| Ni | 10 | 11 | 61 | 47 | traces | traces |
| CO | 19 | - | 14 | - | 8 | - |
| Cu | 7 | 13 | 5 | 3 | 21 | 151 |

Samples "P" from Punców; Samples "R" from Rudów

# A P P E N D I X

Table 10.

Chemical analyses of the rocks of the Cieszyn area for statistical study
/from Smulikowski, 1929, p. 778 table I/

| | a | b | c | d | e | f | g | h | i | j | k | l | m | n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 38.72 | 38.9 | 39.05 | 39.20 | 39.75 | 40.65 | 40.79 | 41.35 | 42.15 | 44.39 | 44.65 | 47.41 | 47.62 | 48.18 |
| $Fe_2O_3$ | 6.30 | 4.9 | 8.16 | 8.80 | 7.58 | 4.88 | 3.52 | 8.24 | 4.94 | 6.69 | – | – | 4.91 | 9.79 |
| FeO | 6.14 | 7.0 | 6.25 | 5.08 | 8.57 | 8.30 | 6.39 | 7.13 | 7.30 | 4.60 | 11.65 | 10.21 | – | 5.90 |
| MgO | 18.59 | 23.6 | 8.89 | 6.49 | 6.17 | 18.05 | 23.34 | 8.79 | 3.74 | 3.59 | 6.52 | 5.06 | 4.74 | 6.05 |
| CaO | 10.37 | 6.0 | 14.02 | 14.45 | 12.65 | 8.05 | 8.48 | 11.65 | 9.75 | 9.28 | 13.70 | 7.17 | 7.39 | 7.50 |
| $Na_2O$ | 1.50 | 1.3 | 0.55 | 2.04 | 0.81 | 1.38 | 1.71 | 0.15 | 3.34 | 3.80 | 3.59 | 4.90 | 3.80 | 3.46 |
| $K_2O$ | 1.57 | 0.8 | 0.89 | 1.11 | 0.28 | 0.91 | 0.71 | 0.16 | 2.07 | 3.89 | 0.82 | 2.06 | 2.25 | 1.57 |
| $H_2O$ | 3.96 | 4.5 | 2.95 | 3.70 | 2.15 | 2.70 | 4.04 | 5.35 | 4.35 | 3.76 | 3.18 | 5.05 | 4.57 | 3.20 |
| $CO_2$ | 2.93 | 1.8 | 5.10 | 2.80 | 6.50 | 2.30 | trace | 2.70 | 3.10 | – | – | – | – | 0.71 |
| $P_2O_5$ | – | – | 0.55 | 1.18 | 0.71 | 0.64 | – | 0.22 | 0.58 | 1.25 | – | – | – | 0.49 |
| F | – | – | – | – | – | – | – | – | – | 0.38 | – | – | – | – |

note: $Al_2O_3$ not produced here

# APPENDIX

Table 11

## Chemical analyses of the rocks of the Cieszyn area for statistical study
/from Smulikowski, 1929, p. 779 table II/

| No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 39.38 | 39.78 | 40.20 | 39.52 | 43.30 | 31.28 | 39.73 | 43.55 | 41.42 | 49.00 | 42.46 | 47.20 | 50.41 |
| $Al_2O_3$ | 7.64 | 8.41 | 8.04 | 9.36 | 10.71 | 10.65 | 12.46 | 13.37 | 15.07 | 14.67 | 19.18 | 18.92 | 22.60 |
| $Fe_2O_3$ | 4.97 | 4.47 | 4.23 | 3.74 | 2.88 | 10.23 | 3.73 | 4.69 | 6.40 | 1.97 | 3.83 | 3.83 | 1.20 |
| FeO | 7.23 | 8.12 | 9.66 | 7.39 | 8.65 | 7.66 | 7.19 | 5.83 | 7.93 | 7.14 | 6.85 | 5.60 | 2.74 |
| MgO | 22.05 | 19.02 | 11.28 | 8.64 | 12.63 | 7.30 | 8.26 | 6.95 | 4.82 | 6.69 | 2.63 | 3.05 | 0.55 |
| CaO | 8.62 | 9.92 | 13.23 | 16.94 | 11.90 | 13.74 | 14.72 | 13.47 | 10.16 | 9.43 | 10.23 | 7.86 | 6.48 |
| $Na_2O$ | 0.43 | 1.66 | 2.00 | 1.49 | 2.17 | 2.22 | 2.39 | 1.87 | 4.00 | 3.56 | 4.38 | 4.45 | 4.23 |
| $K_2O$ | 1.12 | 0.74 | 1.58 | 1.63 | 1.21 | 2.11 | 1.83 | 3.17 | 1.98 | 1.88 | 3.13 | 2.80 | 5.75 |
| $H_2O+$ | 4.93 | 3.42 | 2.45 | 3.01 | 2.77 | 1.82 | 3.28 | 2.51 | 2.73 | 2.31 | 3.35 | 3.06 | 4.90 |
| $H_2O-$ | 0.95 | 1.01 | 0.70 | 0.97 | 0.70 | 0.75 | 0.29 | 0.23 | 0.27 | 0.32 | 0.59 | 0.34 | 0.26 |
| $CO_2$ | - | trace | 2.79 | 3.07 | 0.18 | 2.83 | 3.00 | 1.16 | - | 0.49 | - | - | - |
| $TiO_2$ | 1.73 | 2.39 | 2.48 | 2.75 | 2.10 | 4.01 | 2.15 | 2.63 | 3.14 | 2.28 | 2.24 | 2.22 | 0.55 |
| $P_2O_5$ | 0.44 | 0.48 | 0.81 | 1.36 | 0.59 | 5.04 | 1.00 | 0.52 | 1.57 | 0.39 | 0.78 | 0.69 | 0.16 |

**note:** S, Cl, F, MnO, NiO, BaO, $Cr_2O_3$ not produced here

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## STRESZCZENIE

Niniejsze studium jest poświęcone mineralogicznym, petrograficznym i geochemicznym badaniom cieszynitów i skał pokrewnych, występujących przeważnie w postaci drobnych ciał intruzywnych w karpackich osadach kredowych.

Skały te odsłonięte są przede wszystkim w trzech najniższych poziomach stratygraficznych jednostki cieszyńskiej (tyton — dolna kreda) tworzącej płaszczowinę cieszyńską. Są to: łupki dolno- i górnocieszyńskie. Skały regionu Cieszyna wykazują znaczne zróżnicowanie pod względem własności mineralogicznych i petrograficznych, dlatego też zaproponowano dość szeroką klasyfikację na podstawie składu mineralnego i własności strukturalnych skał.

Według tej klasyfikacji skały zostały podzielone na trzy grupy: melanokratyczne, mezokratyczne i leukokratyczne.

Dla skał melanokratycznych współczynnik barwy jest większy od 60, a struktura jest porfirowo-witrofirowa (zależnie od ilości szkliwa). Dla skał mezokratycznych współczynnik barwy waha się od 30 do 60, a struk-

tura staje się gruboziarnista gabroidowa lub subofitowa do subhialofitowa (zależnie od ilości szkliwa).

Dla skał leukokratycznych współczynnik barwy jest mniejszy od 30, natomiast struktura zmienia się od intergranularnej do intersertalnej (zależnie od ilości szkliwa).

Podział skał w obrębie jednej grupy opiera się na względnych proporcjach składników mineralnych.

Grupa skał melanokratycznych obejmuje porfiry limburgitowe i lamprofiry, których rozróżniamy trzy rodzaje, a mianowicie monczykity, kamptonity i furchity. Zdarza się, że te ostatnie zawierają większą ilość biotytu, przez co upodabniają się do ouachitytów. Grupa mezokratyczna obejmuje diabazy i cieszynity. Wśród cieszynitów, stanowiących główną podgrupę w badanych seriach skalnych, można wyróżnić cieszynity teralityczne, jeśli plagioklazy przeważają nad zasadowym skaleniem, oraz monzonityczne, gdy występuje relacja odwrotna. Głównym składnikiem mineralnym skał występujących w rejonie Cieszyna jest piroksen: zwykły augit, augit tytanowy i nowa odmiana zielonego augitu żelazawo-żelazowego. Sjenit nefelinowy, analcytowy, zasadowy i kwarcowy składają się na trzecią grupę skał leukokratycznych.

W grupie skał melanokratycznych kryterium rozróżniania skał stanowią głównie minerały ciemne, to jest przede wszystkim pirokseny, podczas gdy cieszynity, należące do skał mezokratycznych, sklasyfikowane są na podstawie zawartości jednego z rodzajów skalenia.

Pirokseny odegrały bardzo istotną rolę w procesie tworzenia się tych skał. Augit zwyczajny występuje tylko w diabazach, augit tytanowy jest szeroko rozpowszechniony jako podstawowy składnik wszystkich skał melanokratycznych i cieszynitów, a augit żelazawo--żelazowy, odmiana dotychczas nie opisana w literaturze, spotykany jest w żyłach sjenitu nefelinowego. Ten ostatni piroksen, charakterystyczny z powodu wysokiego stosunku $Fe_2O_3$ do $FeO$ i małej zawartości alkaliów, dostarcza, wraz z innymi składnikami mineralnymi, przekonywających dowodów do poparcia wniosków petrogenetycznych, do których doszedłem w wyniku przeprowadzonych badań. Augit żelazawo-żelazowy, podobnie jak poprzedzające go augity tytanowe, wykrystalizował z magmy nie nasyconej w krzem, w warunkach stopu uwodnionego, co sprzyjało utlenieniu. Niedostatek krzemu mógł być wobec tego skompensowany nie tylko przez Al i Ti, lecz również przez trójwartościowe żelazo, odgrywające z tego powodu głównie podwójną rolę w tym piroksenie:

1) Zastępuje ono krzem w koordynacji tetraedrycznej.

2) Stanowi czynnik kompensujący ładunek pozycji oktaedrycznych przy podstawianiu czterowartościowego krzemu w tetraedrach przy $Fe^{3+}$.

Amfibole stanowią drugi pod względem ważności ciemny minerał spotykany w badanych skałach. Występuje on w pokaźnych ilościach w kamptonitach a także w cieszynitach. Amfibole te powstały jako wynik amfibolizacji piroksenów. Pomimo że główną odmianą amfiboli w cieszynitach i niektórych lamprofirach jest lamprobolit, dla innych lamprofirów, na przykład kamptonitów, charakterystyczny jest barkewikit. Z przeprowadzonych badań wynika, że ruda żelaza, zasadniczo tytanomagnetyczna, jest często zmaghemityzowana, tak że w niektórych skałach, takich jak cieszynity, występuje wyłącznie maghemit tytanowy. Jeśli chodzi o biotyt, to natrafiamy na jego większe ilości jedynie w limburgitach, furchitach i sjenitach. Oliwin, zawsze przeobrażony w saponit, znajduje się tylko w limburgitach i monczykitach. Plagioklaz, o składzie wahającym się od andezytu do labradorytu jest najobficiej występującym jasnym minerałem skał melanokratycznych podczas gdy niskotemperaturowy albit jest najważniejszym skaleniem w skałach leukokratycznych. Może on występować samodzielnie lub w otoczeniu ortoklazów. Podobnie ortoklaz tworzy samodzielne, średnioziarniste skupienia w sjenicie nefelinowym. Jako podstawowy minerał nefelin pojawia się wyłącznie w tym sjenicie. Analcyt to jeden z najobficiej występujących minerałów w skałach badanego regionu. Jest on obecny w postaci pierwotnej a także jako wtórna analcytowa mezostasis zastępująca szkliwo, która zawsze zawiera dość dużo kalcytu i zeolitu. I tak na przykład często spotykamy w sjenitach większe ilości natrolitu. Prenit stanowi kolejny minerał znajdowany w dużych ilościach.

Krzywe zmienności składników chemicznych badanych skał w odniesieniu do wskaźnika Larsena, zmodyfikowanego przez Nockoldsa i Allensa, opracowano dla trzech sillów, to jest: Pastwiska, Rudów, Puńców. Pomijając drobne różnice, wszystkie trzy sille wykazują podobieństwo do krzywych zmienności składników chemicznych skał trzeciorzędowych serii alkalicznych Szkocji, hawajskich skał alkalicznych, alkalicznych skał ogniowych wysp polinezyjskich i cieszynitów z Black Jack Sill. Krzem i aluminium wykazują wzrost zawartości w ciągu krystalizacji, natomiast żelazo i magnez zmniejszenie koncentracji. Wapń i alkalia wykazują przebiegi przeciwne. Ilość alkaliów wzrasta a wapnia maleje ze wzrostem współczynnika krystalizacji. Jeśli chodzi o pierwiastki śladowe, to chrom i nikiel zachowują się identycznie. Początkowo ilość ich gwałtownie spada, lecz następnie w toku krystalizacji nie wykazują one większych zmian ilościowych. Krzywa dla wanadu przebiega tak samo, lecz załamuje się później niż krzywa dla niklu i chromu.

Przy przejściu od skał melanokratycznych do mezokratycznych stosunek niklu do magnezu spada. Mimo to zmienność tego stosunku jest mała. Według Wagera i Mitchela, jeśli w serii mineralnej lub skalnej stosunek ten wykazuje małą zmienność, to prawdopodobnie nie miała tam miejsca silniejsza frakcjonacja. Potwierdza to wniosek, że w skałach prowincji cieszyńskiej frakcjonacja minerałów femicznych była słaba, a to z kolei tłumaczy, dlaczego stosunek Fe/Mg pozostał prawie nie zmieniony, powodując zahamowanie wzrostu ilości żelaza w czasie krystalizacji. Jest to powód, dla którego petrologiczna prowincja cieszynitowa wykazuje szczególne podobieństwo do hawajskich serii bazalt alkaliczny-trachit, a różni się od serii P Hakone, które są przykładem prowincji bazaltów toleitowych, oraz intruzji Skaergaard, w których, w przeciwieństwie do serii skalnych okolic Cieszyna, obserwujemy wzbogacenie w żelazo. Najbardziej charakterystyczną cechą hawajskiej serii bazalt alkaliczny-trachit i serii skalnych okolic Cieszyna jest bliskie podobieństwo zachowania się glinu i pierwiastków alkalicznych, choć zawartość tych ostatnich wzrasta znacznie szybciej w toku krystalizacji niż ilość glinu. Przebieg krystalizacji skał prowincji cieszynitowej naniesiony na trójkątny diagram: Total iron — Total alkalies — MgO, wykazuje podobieństwo do ogólnie znanych serii bazaltów alkalicznych. Ze wszystkich wyżej wspomnianych bazaltów alkalicznych, skały okolic Cieszyna wykazują najmniejsze wzbogacenie w żelazo w toku krystalizacji, także we wczesnych i środkowych stadiach krzywa krystalizacji jest prawie równoległa do podstawy trójkąta. Stosunek Mg/FeO zdaje się być ustalony już w początkowym stadium krystalizacji. Wzbogacenie w żelazo jest powstrzymane w wyniku wysokiego ciśnienia parcjalnego tlenu, co powoduje wysoki stosunek żelaza $Fe^{3+}/Fe^{2+}$. Warunki mniej więcej stałego lub wzrastającego ciśnienia parcjalnego tlenu mogą być spełnione, jeżeli magma zawiera wystarczającą ilość wody lub $CO_2$. Warunki te spełnione są na ogół w bazaltowych magmach alkalicznych, zazwyczaj zasobnych w wodę. Macierzysta magma okolic Cieszyna zawierała szczególnie dużo wody. Należy przypuszczać, że źródłem tej niezwykle dużej zawartości wody były wilgotne osady fliszu, będące w stanie plastycznym w okresie intruzji magmy. Uważa się powszechnie, że źródłem tlenu był rozkład cząsteczek wody, przy czym uwolniony wodór dyfundował z magmy w warstwy sąsiednie. Według Presnalla, w przypadku wysokiego stosunku $H_2O/H$ wzbogacenie w żelazo zostaje zahamowane.

Hipoteza dwóch stadiów dyferencjacji magmy cieszynitowej, przedstawiona przez profesora K. Smulikowskiego znajduje pełne potwierdzenie w świetle badań autora. Częściowo zróżnicowana magma intrudowała następnie w osady kredowe. Niektóre z jej frakcji mogły ulec silnej dyferencjacji, inne pozostały nie zróżnicowane. Krystalizacja frakcjonalna, polegająca na sukcesywnym wydzielaniu się frakcji krystalicznych z cieczy o stale zmieniającym się składzie, jest w świetle badań chemicznych i mineralogicznych głównym mechanizmem różnicowania. Krystalizacja oliwinu zakończyła się niemal całkowicie przed ascenzją magmy ku powierzchni. Na skutek tego, mieszanina minerałów i cieczy w pobliżu granicy powstałej na zastygłych brzegach sillu poddana została działaniu siły dośrodkowej, wystarczająco silnej, nawet przy niskich lepkościach magmy, aby spowodować wydzielanie kryształów od ścian ku środkowi. Zjawisko to jest znane pod nazwą dyferencjacji przepływowej i wszystko wskazuje na to, że ten właśnie mechanizm działał w przypadku sillu w Pastwiskach, złożonego z porfirowego centrum i afirowych partii zewnętrznych. Dyferencjacja przepływowa wyjaśnia także pojawianie się dużych, choć nielicznych, fenokryształów w zamrożonych brzegach i apofyzach sillów. Wydzielanie się oliwitu z magmy cieszynitowej we wczesnym stadium krystalizacji grało dwojaką rolę:

1) Zapewniło ono stałość aktywności tlenu w magmie (jak wykazały badania doświadczalne Wilkinsona i Nasha), warunkującą utrzymanie się wysokiego stosunku $Fe^{+3}/Fe^{+2}$.

2) Utrwaliło początkowe stadium nienasycenia magmy w krzemionkę (Tilley i Yoder 62).

Należy zaznaczyć, że krańcowe niedosycenie magmy w krzemionkę jest najbardziej charakterystyczną cechą omawianej magmy cieszynitowej.

*Katedra Mineralogii i Petrografii*
*Uniwersytetu Jagiellońskiego, Kraków*

## EXPLANATION OF PLATES
## OBJAŚNIENIE TABLIC

### Plate — Tablica XVII

Fig. 1. and 2. Big "phenocrysts" of pyroxene in the chilled marginal rock. X. 37.
Fig. 3. and 4. Lamprobolite breaking-down to thomsonite. The margins of the lamprobolite grains are however preserved. X 37.

### Plate — Tablica XVIII

Fig. 1. Twinned lamprobolite grain. The (1z0) twin plane as seen on the (010) face meets the cleavage at an acute angle of 20°. Rounded white spots are inclusions of apatite. X 37.
Fig. 2. Peripheral resorption effects in lamprobolite. Iron oxide in the form of small specks occurs at the margins of the grains (top left). Bigger grains are those of titanaugite. X 37.
Fig. 3. Zoning in feldspars. Central parts of the grains are sericitized albite, which are surrounded by orthoclase. X. 93.
Fig. 4. Radiating flakes of prehnite in "nepheline syenite". The cloudy matrix is alkali feldspar. Dark grains are those of iron rich ferriferrous augite. X. 93

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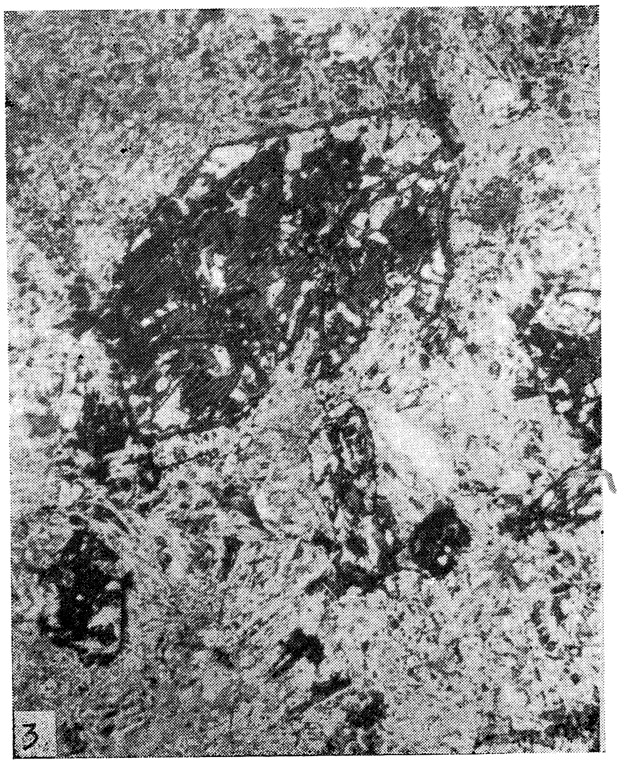

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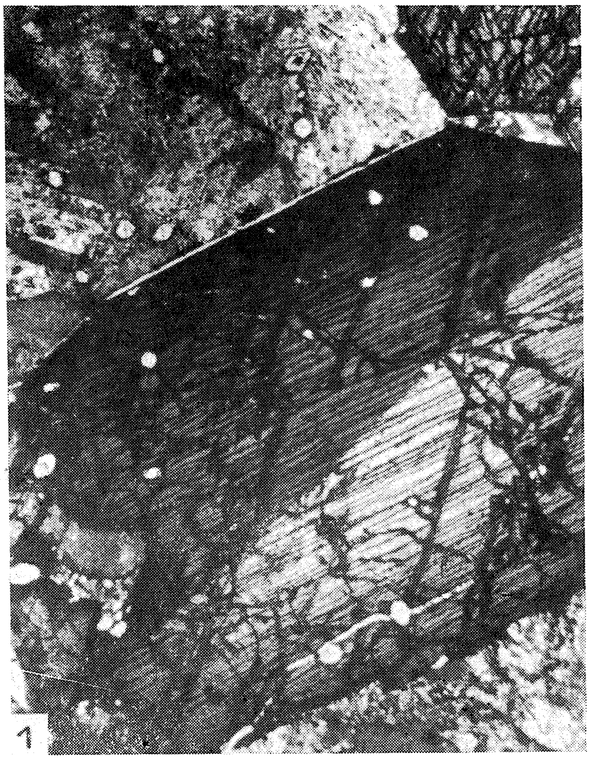
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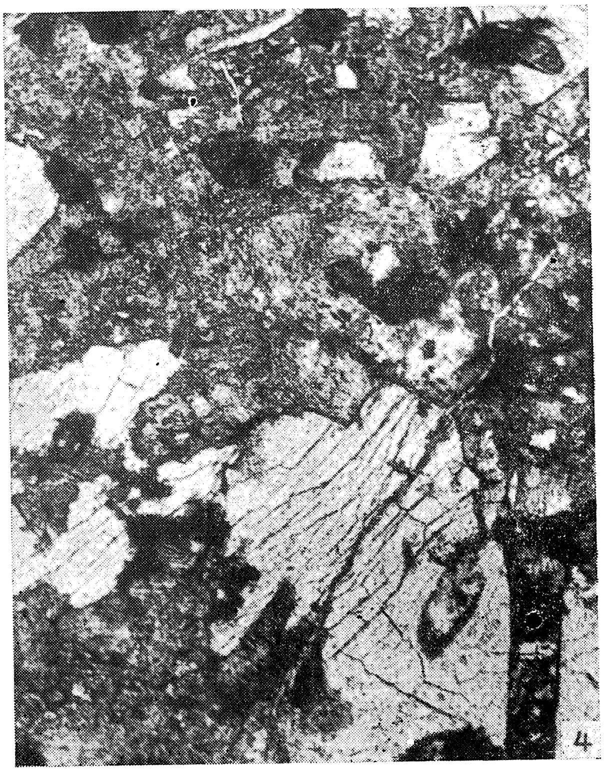
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