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ELECTRON MICROPROBE STUDIES ON THE TRANSFORMATION OF TITANOMAGNETITE OCCURRING IN THE CIESZYN SILESIA TESCHENITES

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Abstract. The present work discusses the presumable mechanism of transformation of titanomagnetite to titanite. At the first stage titanomagnetite is oxidized to titanomaghemite, the diffusion of Ti^{4+} cations into titanomaghemite crystal lattice accompanying the process of oxidation. At the second stage, titanomaghemite is transformed into phases with the decreasing Fe and increasing Ca, Si, Ti content. This is due to the diffusion of Ca^{2+} , Si^{4+} and Ti^{4+} cations from the surrounding minerals and simultaneously the diffusion of Fe^{3+} ions from the mineral to the surroundings. The said cation translocations ultimately lead to the transformation of titanomaghemite to titanite.

INTRODUCTION

The name titanomagnetite refers, strictly speaking, to magnetite-ulvöspinel monophase solid solutions characterized by the spinel structure with a general formula $(1 - x)Fe_3O_4 - xFe_2TiO_4$ or $Fe_{1+x}^{2+}Fe_{2-2x}^{3+}Ti_x^{4+}O_4$. In certain publications, however, titanomagnetite is also understood to mean magnetite containing inclusions of titanium minerals: ilmenite, ulvöspinel, rutile, perovskite, and others. These inclusions are for the most part the products of decomposition and transformation of magnetite-ulvöspinel solid solutions. In the present paper the name titanomagnetite is used in its strict sense. Katsura and Kushiro (1961) have shown that titanomagnetites in igneous rocks may undergo oxidation to phases with defect spinel structure; these phases have been called titanomaghemites. The oxidation of titanomagnetite to titanomaghemite can be clearly seen under the microscope in reflected light since titanomaghemite, forming at the expense of titanomagnetite, has a higher reflectivity and different colour. The separation of the two minerals is impossible

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considering similar physical and chemical properties and their intergrowing. Therefore, electron probe X-ray analysis alone can explain the changes that occur during the transformation of titanomagnetite into titanomaghemite.

PRELIMINARY ANALYSES

The analyses were made on grains of titanomagnetite occurring in a rock sample collected in an old quarry at Puńców. The petrography of this rock and other intrusive igneous rocks in the Cieszyn Silesia has been described by Smulikowski (1929). Preliminary examination results of titanomagnetites in teschenites have been furnished by M. Hubicka-Ptasińska (1971).

Optical examinations in reflected light as well as X-ray and chemical analyses (Table 1) of the magnetic concentrate have shown in the discussed rock the presence of titanomagnetites partly oxidized to titanomaghemites. Their position in the ternary FeO—Fe₂O₃—TiO₂ system was established on the basis of chemical analyses (Fig. 1). It appears that just like the titanomaghemites described by Basta (1959) and Katsura and Kushiro (1961) they are situated near the FeTiO₃—Fe₂O₃ line. The value of the lattice constant, amounting to 8.366 ± 0.005 Å, also agrees with that given for titanomaghemites by these authors.

Table 1
Chemical composition of the
magnetic concentrate

Component	Weight, %	Mol, %
FeO	13.88	23.78
Fe ₂ O ₃	57.22	44.07
TiO ₂	20.85	32.15
Total	91.95	100.00

The discussed results of mineralogical examinations indicate that the process of titanomagnetite maghemitization comes into play, but they fail to show its mechanism.

ELECTRON MICROPROBE X-RAY ANALYSIS

Experimental conditions. The analysis was performed on MS-46-Cameca electron microprobe X-ray analyzer, an accelerating voltage being 20 KV, beam current — 150 μA, sample current — 15 μA. The sample was coated with copper. Metallic Fe, Si, Al, Mn, Cr, Zn, Ti, Mg as well as magnetite, fluorite and titanite were used as standards.

In quantitative analyses, absorption corrections for Ti, Si, Al and Mg according to Philibert's formula were taken into account. Vanadium occurring in titanomagnetites was not examined because of the coincidence of the V-K_α line (2.505 Å) with the Ti-K_β lines (β₁ = 2.514 Å, β₂ = 2.498 Å).

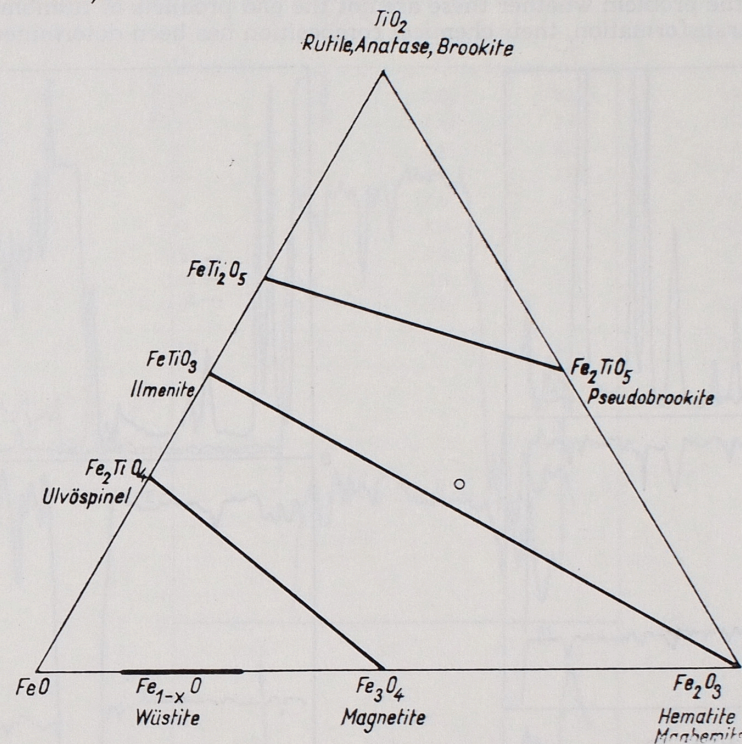


Fig. 1. Phases in the system FeO—Fe₂O₃—TiO₂, showing the major solid solution series magnetite-ulvöspinel, hematite-ilmenite and pseudobrookite—FeTi₂O₅. Mole per cent

The position of the analyzed magnetic concentrate is marked with a circle

Results. A microscopic picture of titanomagnetite undergoing maghemitization is represented on Phot. 1. Titanomagnetite (designated as *T*) is grey with a pink tinge, its reflectivity being about 18 per cent. Titanomaghemite (denoted as *M*) is grey with a blue tinge, its reflectivity approximating 24 per cent. There can be frequently observed a transformation of titanomaghemite on the whole grain surface to a submicroscopically grained mineral, grey in colour, with reflectivity of 10—15 per cent. This process sometimes goes so far that the secondary phase prevails and titanomaghemite appears in relict form. The areas where titanomaghemite transformations can be observed are marked with *P* on Phot. 1; they are also visible on Phot. 6.

All the above mentioned phases are isotropic. Attention has been also paid to the phases accompanying titanomagnetite-titanomaghemite grains with the reflectivity amounting to 10 per cent and revealing birefractance and distinct anisotropy. The phases have been designated as *F* on Phot. 1; they are also shown in the upper portion of the grain on Phot. 6. To clear the problem whether these are not the end products of titanomaghemite transformation, their chemical composition has been determined.

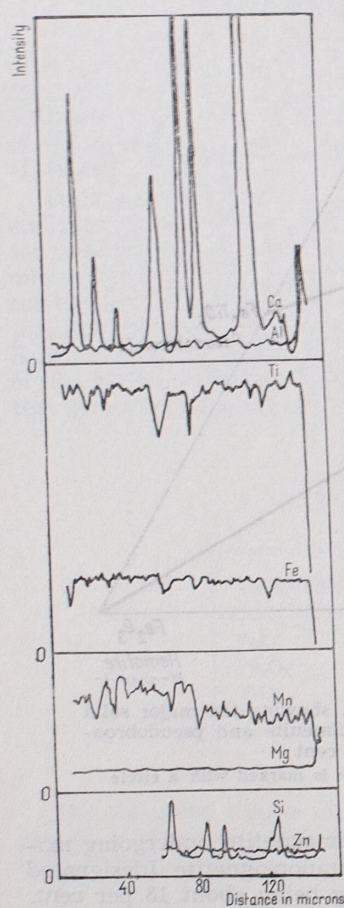


Fig. 2. Fe, Ti, Mn, Mg, Al, Ca, Si, Zn distribution along the A-A line shown on the electron image (Phot. 2)

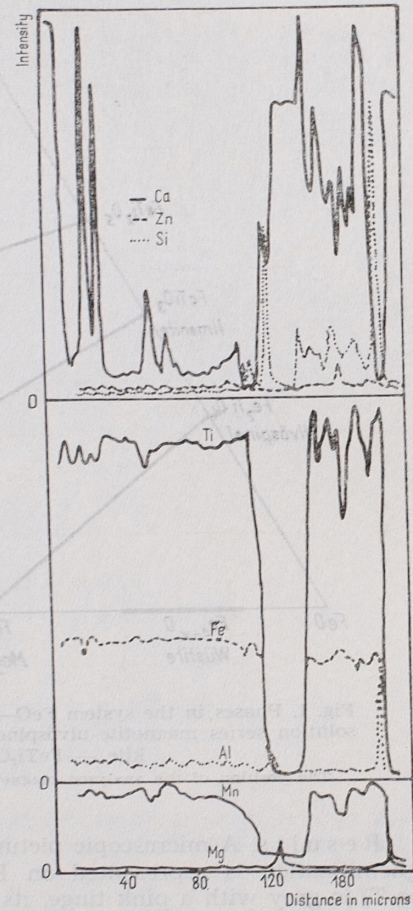


Fig. 3. Fe, Ti, Al, Ca, Zn, Si, Mn, Mg distribution along the B-B line shown on the electron image (Phot. 2)

The results of electron microprobe X-ray analyses of titanomagnetite (*T*), titanomaghemite (*M*), *P* phases and *F* phases (Photos. 1—5) are shown on Photos. 2—4, 6—10, Figs. 2—4 and Tables 2 and 3.

It should be pointed out that quantitative analyses in the areas of titanomaghemite transformations (*P* phases) may lead to a large error due to a significant chemical inhomogeneity caused by the submicroscopic form of the secondary phase. This inhomogeneity is evident in the Fe, Ti, Ca, Si X-ray scan pictures (Figs. 3, 4).

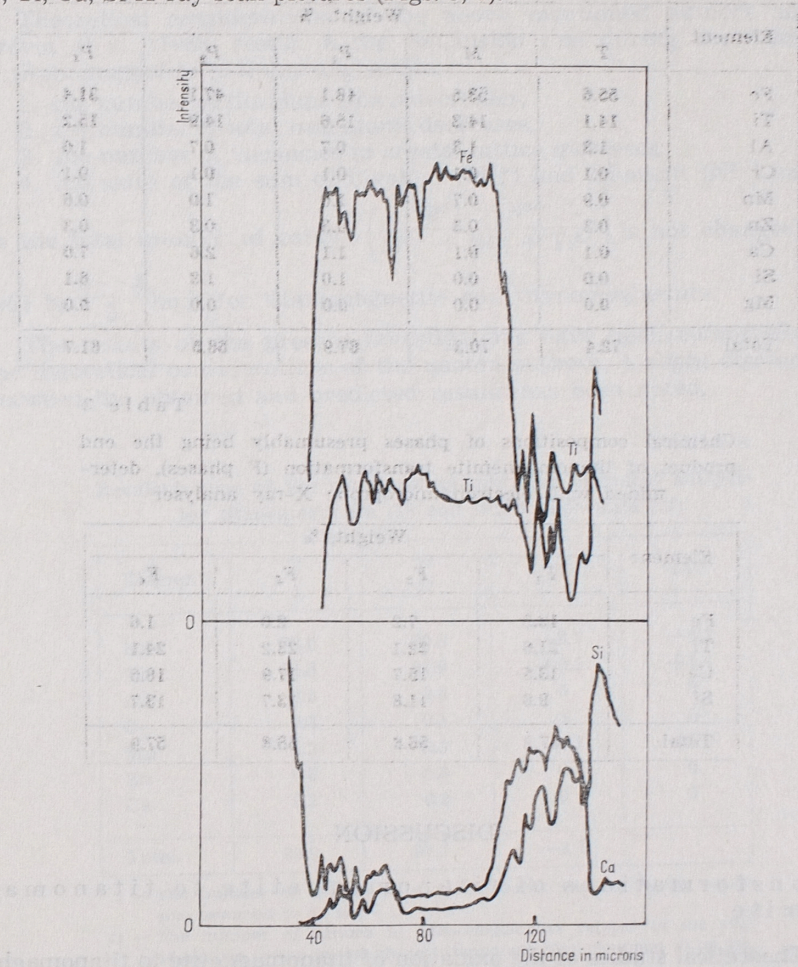


Fig. 4. Fe, Ti, Ca, Si distribution along the C-C line shown on the electron image (Phot. 6)

A scan along C-C line (Fig. 4) for the grain shown on Phot. 5, including *F* phase (the presumable end products of titanomaghemite transformation), has demonstrated a still greater inhomogeneity of chemical composition.

Table 2

Chemical compositions of titanomagnetite (*T*), titanomaghemite (*M*) and the phases formed by titanomaghemite transformation (*P*₁, *P*₂, *P*₃), determined with electron microprobe X-ray analyser

Element	Weight, %				
	<i>T</i>	<i>M</i>	<i>P</i> ₁	<i>P</i> ₂	<i>P</i> ₃
Fe	55.6	53.5	48.1	47.1	31.4
Ti	14.1	14.3	15.6	14.9	15.2
Al	1.3	1.3	0.7	0.7	1.0
Cr	0.1	0.1	0.1	0.1	0.1
Mn	0.9	0.7	1.0	1.0	0.6
Zn	0.3	0.3	0.3	0.3	0.3
Ca	0.1	0.1	1.1	2.6	7.0
Si	0.0	0.0	1.0	1.8	6.1
Mg	0.0	0.0	0.0	0.0	0.0
Total	72.4	70.3	67.9	68.5	61.7

Table 3

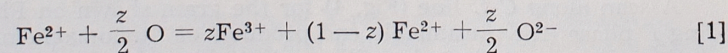
Chemical compositions of phases presumably being the end product of titanomaghemite transformation (*F* phases), determined with electron microprobe X-ray analyser

Element	Weight, %			
	<i>F</i> ₁	<i>F</i> ₂	<i>F</i> ₃	<i>F</i> ₄
Fe	12.3	7.2	2.0	1.6
Ti	21.6	22.1	23.2	24.1
Ca	13.5	15.7	17.9	18.5
Si	9.8	11.8	13.7	13.7
Total	57.2	56.8	56.8	57.9

DISCUSSION

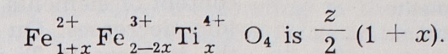
Transformations of titanomagnetite to titanomaghemite

Theoretical studies of the oxidation of titanomagnetite to titanomaghemite have been carried out by O'Reilly and Banerjee (1966), who assumed that titanomaghemite has the spinel structure. Introducing parameter *z* for the oxidation state of Fe²⁺, they have given the following formula for titanomagnetite oxidation reaction:



where $0 \leq z \leq 1$

It appears from the reaction that the number of oxygen atoms introduced additionally into titanomaghemite with the formula



Theoretical considerations of the above mentioned authors and of Prevot et al. (1968) result in the conclusion that during the oxidation of titanomagnetite to titanomaghemite:

1. the number of titanium atoms decreases,
2. the number of total iron atoms decreases,
3. the number of vacancies in crystal lattice increases,
4. the ratio of the sum of bivalent (*M*²⁺) and trivalent (*N*³⁺) cations

to the total number of cations $\left(\frac{M^{2+} + N^{3+}}{M^{2+} + N^{3+} + \text{Ti}^{4+}} \right)$ is not changed; it will be $\frac{3-x}{3}$ both for titanomagnetite and titanomaghemite.

The results of the present investigations have been compared with the theoretical considerations of the quoted authors. A slight discrepancy between the obtained and predicted results has been noted.

Table 4

Recalculations of the results of quantitative chemical analysis for titanomagnetite (*T*) and titanomaghemite (*M*)

Element	<i>T</i>	<i>M</i>	<i>III</i>	<i>IV</i>
	<i>I</i>	<i>II</i>		
Fe	73.0	70.3	-2.7	-3.7
Ti	21.6	21.9	+0.3	+1.4
Al	3.5	3.5	0	0
Cr	0.1	0.1	0	0
Mn	1.2	0.9	-0.3	-2.5
Zn	0.3	0.3	0	0
Ca	0.2	0.2	0	0
Total	99.9	97.2	-2.7	

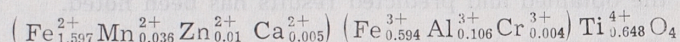
- I* — The number of cations in titanomagnetite respect to the cation sum assumed to be 100,
II — The number of cations in titanomaghemite related to the sum of cations in the initial phase (titanomagnetite) assumed to be 100,
III — Difference between columns *II* and *I* (*II*-*I*),
IV — Relative change in the percentage of cation content in relation to the content given in column *I*.

Recalculations of *T* and *M* phase chemical analyses (Table 2), made according to the interpretation of Prevot et al. (1968) and presented in Table 4, indicate an evident cation deficiency manifested in the increase of vacancies in titanomaghemite. In accordance with the predictions, the

Theoretical oxide composition of titanomagnetite

Component	Weight, %
FeO	52.1
Fe ₂ O ₃	21.5
TiO ₂	23.5
Al ₂ O ₃	2.5
Cr ₂ O ₃	0.1
MnO	1.2
ZnO	0.4
CaO	0.1
Total	101.4

Basing on this value, the following theoretical formula of the analyzed titanomagnetite has been obtained:



The theoretical titanomagnetite oxide composition derived from the above formula is given in Table 5.

According to theoretical predictions (item 4), the ratios of the sums of M^{2+} and N^{3+} cations to the total number of cations for titanomagnetite and the forming titanomaghemite should agree. The noted slight discrepancy (Table 6) is very likely due, as has been said, to the diffusion of

Table 6

Recalculations of the results of quantitative chemical analyses for the phases formed by titanomaghemite transformation (P phases) in relation to titanomagnetite (T)

Element	T	P ₁				P ₂			P ₃		
	I*	II*	III*	IV*	II	III	IV	II	III	IV	
Fe	73.0	63.2	-9.9	-13.5	62.4	-10.6	-14.6	41.2	-31.8	-43.5	
Ti	21.6	23.9	+2.3	+10.6	22.8	+1.2	+5.5	23.3	+1.7	+7.8	
Al	3.5	1.9	-1.6	-45.7	1.9	-1.6	-45.7	2.7	-0.8	-22.8	
Cr	0.1	0.1	0	0	0.1	0	0	0.1	0	0	
Mn	1.2	1.3	+0.1	+8.3	1.3	+0.1	+8.3	0.8	-0.4	-3.3	
Zn	0.3	0.3	0	0	0.3	0	0	0.3	0	0	
Ca	0.2	2.0	+1.8	+900	4.7	+4.5	+2250	12.9	+12.7	+6350	
Si	0.0	2.6	+2.6		4.7	+4.7		15.9	+15.9		
Total	99.9	95.3	-4.7		98.2	-1.7		97.2	-2.7		

* Explanations: see Table 4.

quantity of Fe decreases and so does the Mn content. This shows that the content of elements subject to oxidation decreases. On the other hand, the increase in Ti content has been noted contrary to the theoretical predictions of O'Reilly and Banerjee (1966). This phenomenon is very likely due to the diffusion of Ti⁴⁺ cations from the surrounding minerals to titanomaghemite, the cations occupying vacancies in the defect spinel structure of titanomaghemite.

Using the data compiled in Table 4 column I and having assumed the theoretical sum of cations as 3, the value of x has been calculated and found to be 0.648 ($x = 3 \cdot 0.2147$).

theoretical formula of the analyzed

titanium cations to titanomaghemite. The observed relative decrease in the content of iron atoms in titanomaghemite is far from the possible theoretical decrease (12.7%) corresponding to the complete oxidation of titanomagnetite (for $z = 1$ of reaction 1), as it amounts to 3.7 per cent only (Table 4 column IV). The possible theoretical decrease can be calculated as follows (Prevot et al. 1968):

$$\frac{n_0 - n_1}{n_0} = \frac{-x^2 + 2x + 3}{-x^2 - 6x + 27} \cdot 100 = 12.7\%$$

where:

n_0 — the number of Fe atoms in titanomagnetite (for $z = 0$)

n_1 — the number of Fe atoms in the completely oxidized titanomaghemite (for $z = 1$).

Titanomaghemite transformations

As can be seen from the results of spot analyses (Table 2) and those performed along a line (Figs. 3, 4), the phases P_1 , P_2 , P_3 forming in titanomaghemite are characterized by a significant variability in their chemical composition. On the basis of a dozen or so analyses, however, it was found that all the phases reveal a considerable decrease in Fe and a slight decrease in Al content with a simultaneous increase in Ca, Si and Ti content. The calculations of cation numbers in these phases as related to the sum of titanomaghemite cations are given in Table 6. Column II in Table 6 indicates that these phases are also characterized by cation site vacancies in relation to titanomagnetite. The relative changes in Fe content given in column IV with reference to the values listed in column I reveal the decrease in Fe exceeding the theoretical value (12.7%). The noted decrease is partly apparent, since it may result from the increase in Ca²⁺ and Si⁴⁺ content in the areas of titanomaghemite transformations. It is difficult to find to what extent this is due to Fe²⁺ oxidation and to what extent to the migration of Fe²⁺ or Fe³⁺ cations to the surrounding minerals.

Worthy of note is a comparison (Table 7) of the ratio of the sum of M^{2+} , N^{3+} and Si⁴⁺ cations to the total sum of cations (R) and the ratio

Table 7

Cation ratios in titanomagnetite (T), titanomaghemite (M), P phases and the magnetic concentrate

	T	M	P ₁	P ₂	P ₃	Magnetic concentrate
$R' = \frac{\text{Fe}}{\text{Fe} + \text{Ti}}$	0.772	0.762	0.725	0.732	0.639	0.776
$R = \frac{M^{2+} + N^{3+} + \text{Si}^{4+}}{M^{2+} + N^{3+} + \text{Si}^{4+} + \text{Ti}^{4+}}$	0.784	0.785	0.750	0.768	0.761	

**BADANIA NAD PRZEOBRAŻENIEM TYTANOMAGNETYTU
WYSTĘPUJĄCEGO W CIESZYNITACH ŚLĄSKA CIESZYŃSKIEGO
ZA POMOCĄ MIKROANALIZATORA RENTGENOWSKIEGO**

Streszczenie

W pracy przedstawiono przypuszczalny mechanizm przeobrażenia tytanomagnetytu w tytanit. W pierwszym stadium następuje utlenienie tytanomagnetytu, co prowadzi do powstania tytanomaghemitu, przy czym utlenieniu żelaza towarzyszy również przenikanie kationów Ti^{4+} do tytanomaghemitu. W drugim stadium tytanomaghemit ulega przeobrażeniu w fazy o coraz mniejszej zawartości Fe i coraz większych zawartościach Ca, Si, Ti. W miarę utlenienia następuje bowiem dyfuzja kationów Ca^{2+} , Si^{4+} i Ti^{4+} z otoczenia, której towarzyszy równoczesne przenikanie jonów Fe^{3+} do otoczenia. Te przemieszczenia kationów w końcowym efekcie doprowadzają do przeobrażenia tytanomaghemitu w tytanit.

OBJASNIENIA FIGUR

- Fig. 1. Fazy układu $FeO-Fe_2O_3-TiO_2$, pokazujące główne serie roztworów stałych: magnetyt-ulvospinel, hematyt-ilmenit i pseudobrukite- Fe_2TiO_5 . Procenty molowe
Kółkiem oznaczono położenie analizowanego koncentratu magnetycznego
- Fig. 2. Rozmieszczenie Fe, Ti, Mn, Mg, Al, Ca, Si, Zn wzdłuż linii A—A widocznej na obrazie elektronowym fot. 2
- Fig. 3. Rozmieszczenie Fe, Ti, Al, Ca, Zn, Si, Mn, Mg wzdłuż linii B—B widocznej na obrazie elektronowym fot. 2
- Fig. 4. Rozmieszczenie Fe, Ti, Ca, Si wzdłuż linii C—C widocznej na obrazie elektronowym fot. 6

OBJASNIENIA TABEL

- Tab. 1. Skład chemiczny koncentratu magnetytowego
- Tab. 2. Skład chemiczny tytanomagnetytu (T), tytanomaghemitu (M) oraz faz powstających z przeobrażenia tytanomaghemitu (P_1, P_2, P_3) oznaczony na mikroanalizatorze rentgenowskim
- Tab. 3. Skład chemiczny faz stanowiących przypuszczalny końcowy produkt przeobrażenia tytanomaghemitu (fazy F) oznaczony na mikroanalizatorze rentgenowskim
- Tab. 4. Przeliczenie wyników ilościowej analizy chemicznej dla tytanomagnetytu (T) i tytanomaghemitu (M). I — udział liczby kationów tytanomagnetytu w odniesieniu do sumy kationów przyjętej za 100; II — udział liczby kationów tytanomaghemitu odniesiony do sumy kationów fazy wyjściowej (tytanomagnetytu) przyjętej za 100, III — różnica między kolumnami II i I (II—I), IV względna zmiana w procentach zawartości kationów w odniesieniu do zawartości podanych w kolumnie I
- Tab. 5. Teoretyczny skład tlenkowy tytanomagnetytu
- Tab. 6. Przeliczenie wyników ilościowych analiz chemicznych dla faz powstających z przeobrażenia tytanomaghemitu (fazy P) w odniesieniu do tytanomagnetytu (T)
- * Objasnienia kolumn zob. tab. 4
- Tab. 7. Stosunki kationów w tytanomagnetycie (T), tytanomaghemicie (M), w fazach P i koncentracje magnetycznym

of total Fe to the sum $Fe + Ti$ (R'). A significant increase in the values of R' ratio may be ascertained for P phases when compared with titanomaghemite. As appears from Table 6, this is due to cation translocations. The ratio R, on the other hand, is only slightly lowered. A certain number of vacancies occur in the analyzed titanomaghemite (Table 2, M phase), but there is no Si^{4+} and very little Ca^{2+} in it. As titanomaghemite oxidation progresses, diffusion of Si^{4+} and Ca^{2+} from the surrounding minerals commences. Due to this process, the ratio R is only slightly changed.

The end product of titanomaghemite transformation is presumably a phase visible in the upper portion of the grain shown on Phot. 6. Relicts of titanomaghemite that can be observed in this area seem to point to this effect. The presented spot analyses of the main components performed in this area have demonstrated the chemical composition of this phase, though considerably inhomogeneous, to approximate the composition of titanite with a variable Fe content.

CONCLUSIONS

The performed electron microprobe X-ray analyses lead to the following conclusions:

1. Titanomagnetite maghemitization is not merely a simple process of Fe^{2+} oxidation; it is accompanied by the diffusion of Ti^{4+} cations, which occupy vacancies in the defect titanomaghemite structure.
2. A theoretically possible number of vacancies in titanomaghemite structure is never reached.
3. Fe^{2+} being completely oxidized, the resultant Fe^{3+} cation, possessing a smaller ionic radius and, in consequence, a greater mobility, presumably begins to diffuse to the surrounding minerals. This process is most likely accompanied by the diffusion of Ca^{2+} and Si^{4+} from the surrounding minerals. The two processes ultimately lead to the transformation of titanomaghemite to submicroscopically dispersed titanite.

The performed analyses have thus permitted the explanation of the transformation of titanomagnetite through titanomaghemite to titanite.

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ИССЛЕДОВАНИЕ ИЗМЕНЕНИЙ ТИТАНОМАГНЕТИТА В ТЕШЕНИТАХ ЦЕШИНСКОЙ СИЛЕЗИИ С ПОМОЩЬЮ РЕНТГЕНОВСКОГО МИКРОАНАЛИЗАТОРА

Резюме

В работе описан предполагаемый механизм превращения титаномагнетита в титанит. В первой стадии происходит окисление титаномагнетита до титаномаггемита, причем окисление железа сопровождается диффузией катионов Ti^{4+} в титаномаггемит. Во второй стадии титаномаггемит переходит в фазы, характеризующиеся все меньшим содержанием железа и все большим содержанием Ca, Si, Ti, так как при окислении поступает диффузия ионов Ca^{2+} , Si^{4+} и Ti^{4+} из окружающей среды и одновременно происходит диффузия ионов Fe^{3+} в окружающую среду. Такая перестановка катионов приводит в конечном итоге к превращению титаномаггемита в титанит.

ОБЪЯСНЕНИЯ К ФИГУРАМ

- Фиг. 1. Фазы в системе $FeO-Fe_2O_3-TiO_2$, показывающие главные группы твердых растворов: магнетит — шпинель, гематит — ильменит, псевдобрукит — Fe_2TiO_5 . Молярные проценты. Кружком показано расположение исследованного магнитного концентрата.
- Фиг. 2. Распределение Fe, Ti, Mn, Mg, Al, Ca, Si, Zn вдоль линии A—A, наблюдающейся на электронном изображении (фото 2).
- Фиг. 3. Распределение Fe, Ti, Al, Ca, Zn, Si, Mn, Mg вдоль линии B—B, наблюдающейся на электронном изображении (фото 2).
- Фиг. 4. Распределение Fe, Ti, Ca, Si вдоль линии C—C, наблюдающейся на электронном изображении (фото 6).

ОБЪЯСНЕНИЯ К ТАБЛИЦАМ

- Табл. 1. Химический состав магнетитового концентрата.
- Табл. 2. Химический состав титаномагнетита (T), титаномаггемита (M) и фаз преобразования титаномаггемита (P_1, P_2, P_3), определенный на рентгеновском микроанализаторе.
- Табл. 3. Химический состав фаз, представляющих предполагаемый конечный продукт преобразования титаномаггемита (фазы F), определенный на рентгеновском микроанализаторе.
- Табл. 4. Пересчет данных количественного химического анализа для титаномагнетита (T) и титаномаггемита (M).
I — отношение катионов титаномагнетита к сумме всех катионов, принятой за 100, II — отношение катионов титаномаггемита к сумме всех катионов исходной фазы (титаномагнетита), принятой за 100, III — разница между числами II и I, IV — относительное процентное изменение содержания катионов по отношению к содержаниям, приведенным в столбике I.
- Табл. 5. Теоретический окисный состав титаномагнетита.
- Табл. 6. Пересчет данных количественных химических анализов фаз, возникающих вследствие преобразования титаномаггемита (фазы P), по отношению к титаномагнетиту (T).
Объяснения см. табл. 4.
- Табл. 7. Соотношения катионов в титаномагнетите (T), титаномаггемите (M) в фазах P и в магнитном концентрате.

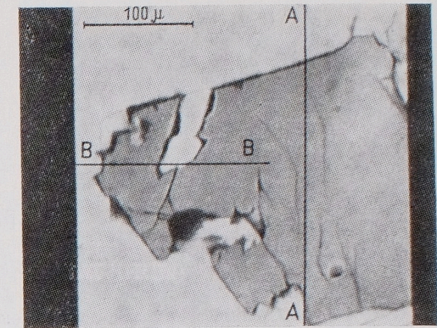
PLATES, (PLANSZE, ТАБЛИЦЫ)

PLATE I (PLANSZA I, ТАБЛИЦА I)

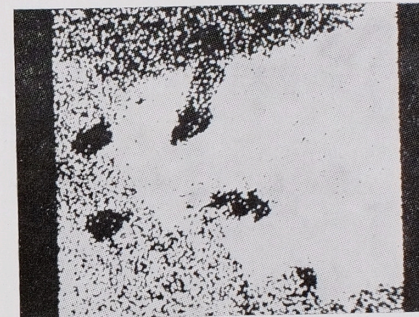
- Phot. 1. Photomicrograph. Reflected light. 250 \times . T — titanomagnetite, M — titanomaghemite, P — phases formed by titanomaghemite transformation
 Mikrofotografia. Światło odbite, pow. 250 \times . T — tytanomagnetyt, M — tytanomaghemit, P — fazy powstające z przeobrażenia tytanomaghemitu
 Микрофотоснимок. Отраженный свет. Увел. 250 \times . T — титаномagnetит, M — титаномagгемит, P — фазы преобразования титаномagгемита
- Phot. 2. Electron image of the grain shown on Phot. 1 A—A, B—B — lines of scanning
 Obraz elektronowy ziarna pokazanego na fot. 1 A—A, B—B analizowane profile
 Электронное изображение зерна, показанного на фото 1 A—A, B—B — анализированные профили
- Phot. 3. Fe K $_{\alpha}$ X-ray image of the grain shown on Phot. 1
 Rozmieszczenie Fe K $_{\alpha}$ w ziarnie pokazanym na fot. 1
 Распределение Fe K $_{\alpha}$ в зерне, показанном на фото 1
- Phot. 4. Ti K $_{\alpha}$ X-ray image of the grain shown on Phot. 1
 Rozmieszczenie Ti K $_{\alpha}$ w ziarnie pokazanym na fot. 1
 Распределение Ti K $_{\alpha}$ в зерне, показанном на фото 1
- Phot. 5. Photomicrograph. Reflected light. Immersion. 350 \times P — phases formed by titanomaghemite transformation, F — phases presumably being the end product of titanomaghemite transformation
 Mikrofotografia. Światło odbite, imersja, pow. 350 \times P — fazy powstające z przeobrażenia tytanomaghemitu, F — fazy stanowiące przypuszczalny końcowy produkt przeobrażenia tytanomaghemitu
 Микроснимок. Отраженный свет. Увел. 350 \times , иммерсия P — фазы преобразования титаномagгемита, F — фазы, представляющие предполагаемый конечный продукт преобразования титаномagгемита
- Phot. 6. Electron image of the grain shown on Phot. 5
 Obraz elektronowy ziarna pokazanego na fot. 5
 Электронное изображение зерна, показанного на фото 5



Phot. 1



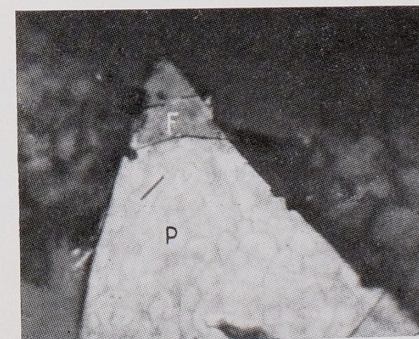
Phot. 2



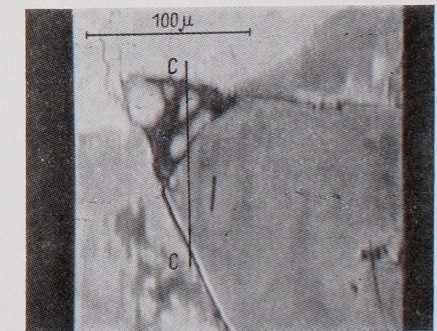
Phot. 3



Phot. 4



Phot. 5



Phot. 6

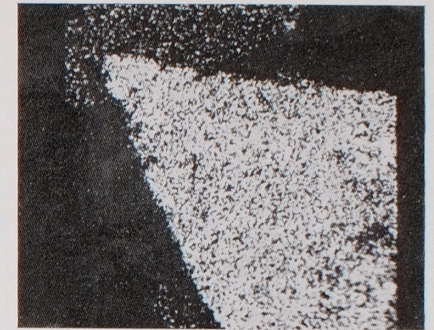
Maria HUBICKA-PTASINSKA, Stanisława JASIENSKA — Electron microprobe studies on the transformation of titanomagnetite occurring in the Cieszyn Silesia teschenites

PLATE II (PLANSZA II, ТАБЛИЦА II)

- Phot. 7. Fe K_{α} X-ray image of the grain shown on Phot. 5
 Rozmieszczenie Fe K_{α} w ziarnie pokazanym na fot. 5
 Распределение Fe K_{α} в зерне, показанном на фото 5
- Phot. 8. Ti K_{α} X-ray image of the grain shown on Phot. 5
 Rozmieszczenie Ti K_{α} w ziarnie pokazanym na fot. 5
 Распределение Ti K_{α} в зерне, показанном на фото 5
- Phot. 9. Ca K_{α} X-ray image of the grain shown on Phot. 5
 Rozmieszczenie Ca K_{α} w ziarnie pokazanym na fot. 5
 Распределение Ca K_{α} в зерне, показанном на фото 5
- Phot. 10. Si K_{α} X-ray image of the grain shown on Phot. 5
 Rozmieszczenie Si K_{α} w ziarnie pokazanym na fot. 5
 Распределение Si K_{α} в зерне, показанном на фото 5



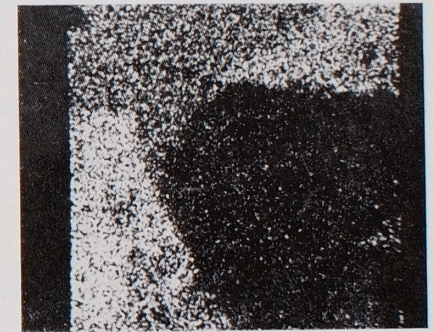
Phot. 7



Phot. 8



Phot. 9



Phot. 10