

*Тяжело*

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[http://www.susu.ac.ru/ru/dissertation/d-21229804/trofimov-evgeniy-alekseevich.](http://www.susu.ac.ru/ru/dissertation/d-21229804/trofimov-evgeniy-alekseevich)

454080, . 2 ., . . . . , 76, « » ( ),

e-mail: lilia.if@mail.ru

.: (351)267-91-23.

\_\_\_\_\_ 2014 .



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( 2.1.2/375, 1540 2448),  
 ( 04-03-32081- , 07-08-00365- , 07-08-12092- ,  
 10-03-96061- \_ \_ , 11-08-12046- - -2011, 13-08-00545- 13-03-00534- ).

1.

( , ) .

2.

“ — ”

3.

“ — ”

4.

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6.

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1)

, “ — ”

2)

, — ”;

3)

—  $Cu_2O-R_nO_m$  (  $R_nO_m$  — NiO, SnO<sub>2</sub>, ZnO, CoO, FeO, Fe<sub>2</sub>O<sub>3</sub>, PbO, As<sub>2</sub>O<sub>3</sub>, Sb<sub>2</sub>O<sub>3</sub>, Bi<sub>2</sub>O<sub>3</sub>, P<sub>2</sub>O<sub>5</sub>, SiO<sub>2</sub>, MgO, CaO, Al<sub>2</sub>O<sub>3</sub>), Cu<sub>2</sub>O–FeO–Fe<sub>2</sub>O<sub>3</sub>, Cu<sub>2</sub>O–SnO<sub>2</sub>–PbO, Cu<sub>2</sub>O–SnO<sub>2</sub>–PbO–ZnO, AlCl<sub>3</sub>–NaCl, AlCl<sub>3</sub>–KCl, AlCl<sub>3</sub>–MgCl<sub>2</sub>, AlF<sub>3</sub>–NaF, NiO–CaO, NiO–SiO<sub>2</sub>, — Cu–Ni, Sn–Al, Sn–Sb, Al–Sb Cu–Cu<sub>2</sub>O Ni–NiO;

4)

Cu–R–O ( R — Ni, Sn, Zn, Co, Fe, Pb, As, Sb, Bi, Si, Al, Ca, Mg, S, P), Cu–Pb–Sn–O, Cu–Pb–Sn–Zn–O, Cu–Fe–Si–O, Cu–Zn–P–O Cu–Ni–S–O;

- Al-Mg-O, Al-Mg-Na-O, Al-Mg-Na-K-O, Al-Me-Cl (Me - Na, Mg, K), Al-Na-F, Al-Mg-F, Al-Mg-Na-F;  
 Co-C-O, Co-Si-O, Co-Al-O, Co-Si-C-O; - Ni-O,  
 Ni-Ca-O, Ni-Al-O, Ni-Si-O, Ni-Ca-C-O, Ni-Al-C-O, Ni-Si-C-O;  
 - Pb-Ag-Zn, Pb-Au-Zn, Pb-Cu-S, Pb-Zn-O Pb-Sb-O;  
 - Sn-Al-Sb; - Bi-Ag-Zn;

5)

Cu-R-O  
 ( R - Ni, Sn, Zn, Co, Fe, Pb, Sb, Bi, Si, Mg, Al, S, P), Cu-Pb-Sn-O, Cu-Pb-Sn-Zn-O,  
 Cu-Fe-Si-O, Cu-Ni-S-O, Ni-R-O ( R - Cr, Fe, Mn, Nb, Pb, Bi, S, Sb, Sn, Ti, W);  
 Ni-R-Bi ( R - Pr, Er, Dy, Nd); Al-Mg-O, Pb-Ag-Zn, Pb-Cu-S, Pb-Zn-O,  
 Pb-Sb-O, Sn-Al-Sb, Bi-Ag-Zn, Bi-Pb-S, Bi-Cu-S, Bi-Pb-O Bi-Sn-O;

6)

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 1. “ -  
 - ” .

2.

3.

4.

5.

6.

Cu-R-O ( R -Ni, Sn, Zn, Co, Fe, Pb, Sb, Bi, Si, Mg, Al, S, P), Cu-Pb-Sn-O, Cu-Pb-Sn-Zn-O, Cu-Fe-Si-O, Cu-Ni-S-O, Cu-Ni-Si, Cu-Ni-Si-O, Ni-R-O ( R - Cr, Fe, Mn, Nb, Pb, Bi, S, Sb, Sn, Ti, W); Ni-R-Bi ( R - Pr, Er, Dy, Nd); Al-Mg-O, Pb-Ag-Zn, Pb-Cu-S, Pb-Zn-O, Pb-Sb-O, Sn-Al-Sb, Bi-Ag-Zn, Bi-Pb-S, Bi-Cu-S, Bi-Pb-O Bi-Sn-O.

7.

X, XI, XII XIII “ ( , 2001, 2004, 2008, 2011); XI, XII, XIII XIV - “ ( , 2001, 2004, 2007, 2010); “300 ”, - “ ( , 2001); VII, VIII, IX, X XI “ ( , 2004, 2006, 2008, 2010, 2012); “ - 2008” ( , 2008); 1- “M - ” ( , 2008); XIII (LAM-13, LAM- XIV 14) ( , 2007, , 2010); 2 - “ ( ) ” ( , 2007); - “ ( , 2011); 8, 9 10 “ ( )” ( - , 2009, 2011, 2013); - “ ( ’10 ’12)” ( - , 2010, 2012); XIX “ ( , 2011); “ ( - , 2012); ( ’12) ( , 2012); « - 2012» ( - » ( , 2012); IV « - 2012» ( -

, 2012); (RTAC-2013)” ( , 2013); XV, XVI, XVII, XVIII XIX  
 ( , 2005;  
 , 2007; , 2009; , 2011; , 2013).  
 127 , 54  
 2  
 559 4 , 6 , 364  
 , 271 31 .

1.

2.

Cu-Ni-O

$$\begin{cases}
 n_1 \lg a_{[R]} + m_1 \lg a_{[X]} = \lg K_1 \\
 n_2 \lg a_{[R^*]} + m_2 \lg a_{[X]} = \lg K_2 \\
 n_3 \lg a_{[R^{**}]} + m_3 \lg a_{[X]} = \lg K_3 \\
 a_{[R]} = f(C_{[R]}) \\
 a_{[R^*]} = f(C_{[R^*]}) \\
 a_{[R^{**}]} = f(C_{[R^{**}]}) \\
 a_{[X]} = f(C_{[X]}) \\
 C_{[R]} + C_{[R^*]} + C_{[R^{**}]} + C_{[X]} = 100\%
 \end{cases}$$

$$R_n X_m = n[R] + m[X],$$

100%.

$$(R_n X_m) = n[R] + m[X],$$





a Q - ( Cu<sub>2</sub>O v = 2, NiO v = 1), x<sub>1</sub> x<sub>2</sub> - Cu<sup>+</sup> Ni<sup>2+</sup>,

1)

2)

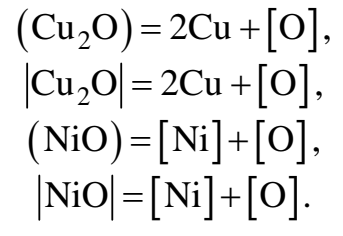
3)

4)

5)

6)

Cu-Ni-O,



1)

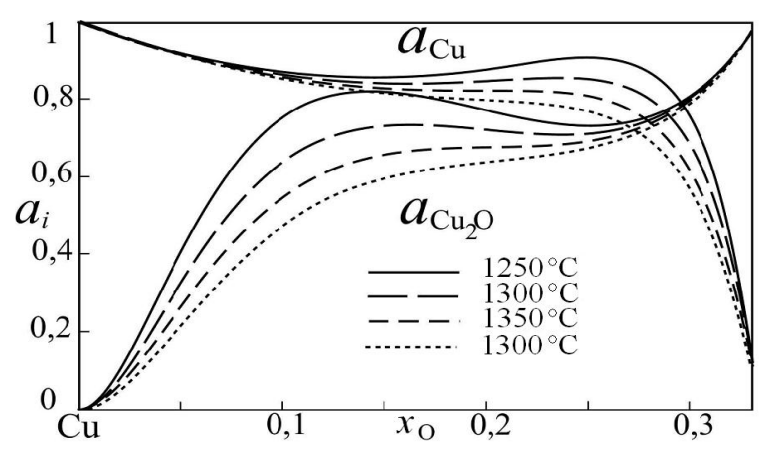
2)

3)

Cu<sub>2</sub>O-NiO.

Cu-Ni, Cu-Cu<sub>2</sub>O, Ni-NiO, Cu<sub>2</sub>O-NiO.

Cu-Cu<sub>2</sub>O ( . 1),



Mathcad

. 1.

Cu-Cu<sub>2</sub>O

Mathcad.

Mathcad

( )

“ ”

( “ ”)

Cu-Ni-O ( . 2).

(Cu<sub>2</sub>O, NiO).

I

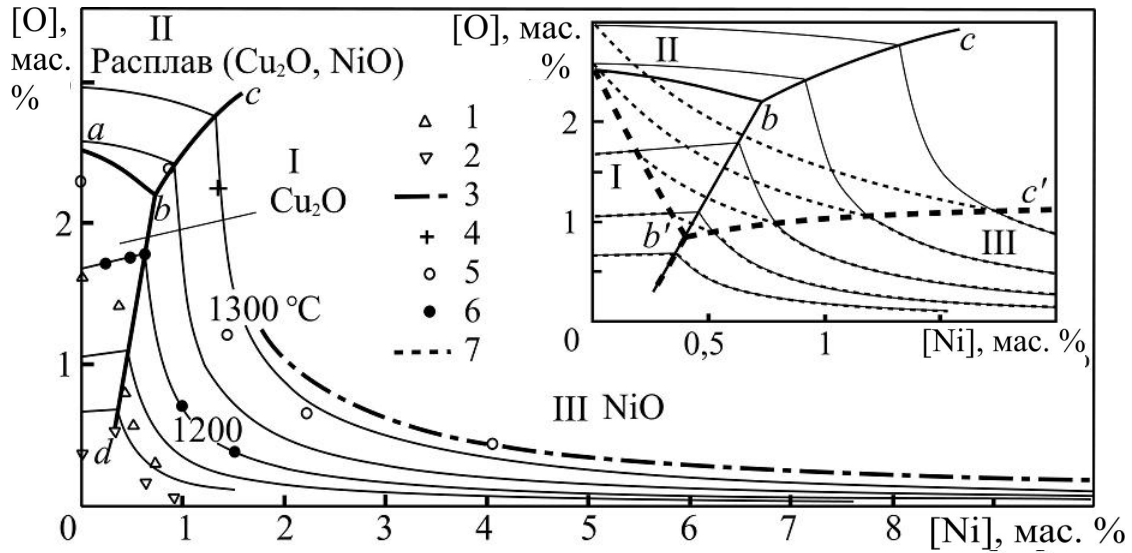
II

bc

III  
NiO.

bd

bc bd

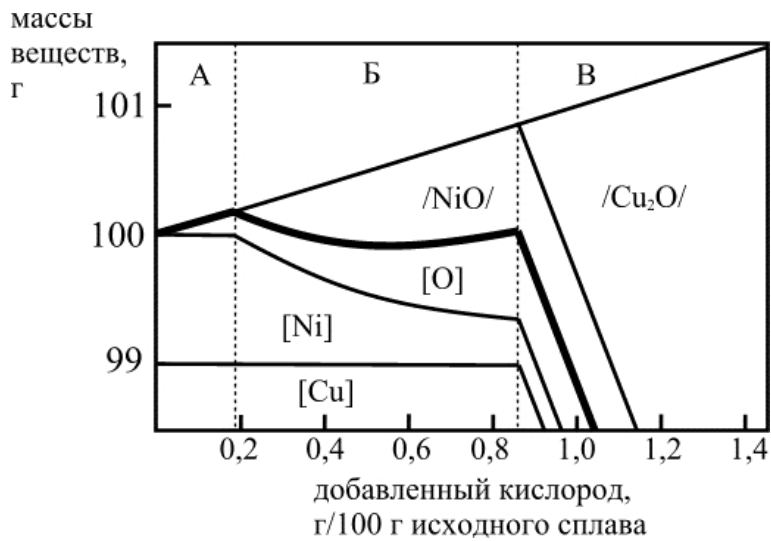


Cu-Ni-O:  
 1 - , 1194 ° ; 2 - , 1124 ° ;  
 3 - , 1200 ° ;  
 4 - Leitgeb W., 1250 ° ; 5 - , 1250 ° ; 6 - , 1200 ° ;  
 7 -

FactSage,

CALPHAD.

Cu-Ni-O.



3.  
 Cu-Ni-O  
 T=1100 °

- 1 . %

1100 ° .

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Cu-Ni-O.

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3.

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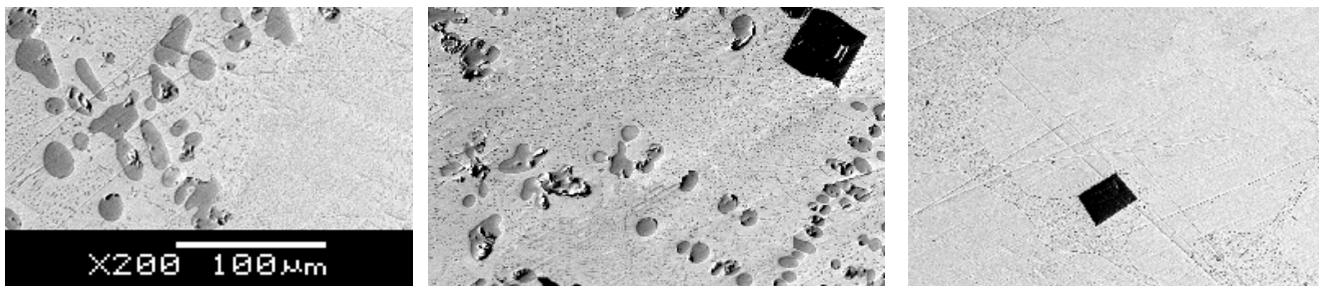
,

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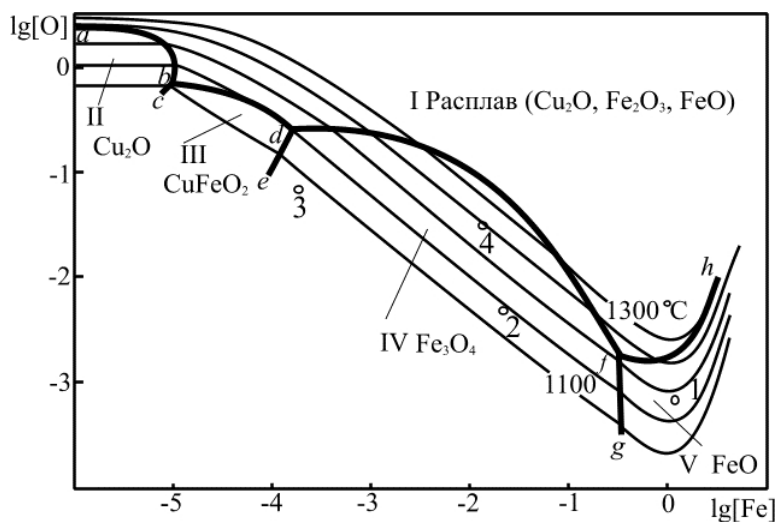
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1



4.  
 Cu-Ni-O,  $T=1200\text{ }^\circ\text{C}$ :  
 I (0.2, [Ni]=0.25 %),  
 - [Cu]=67.84 %, [O]=32.16 %;  
 I III (0.2, [Ni]=0.62 %),  
 - [Cu]=66.65 %, [O]=33.35 %.,  
 - [Ni]=49.97 %, [O]=48.32 %, [Cu]=1.72 %;  
 III (0.2, [Ni]=1.5 %),  
 - [Ni]=49.71 %, [O]=48.49 %, [Cu]=1.80 %

Cu-Co-O, Cu-Fe-O, ( Cu-Sn-O, Cu-Zn-O, Cu-Ni-O)



Cu-Ni-O

Cu-Fe-O (0.5).

5.

Cu-Fe-O

II  
 III - CuFeO<sub>2</sub>,

IV - Fe<sub>3</sub>O<sub>4</sub>,

V - FeO.

Cu<sub>2</sub>O,

= 1200 )

Cu-Fe-O (

( Cu-Pb-O, Cu-As-O, Cu-Sb-O, Cu-Bi-O)

- Cu-Sn-Pb-O Cu-Sn-Pb-Zn-O.

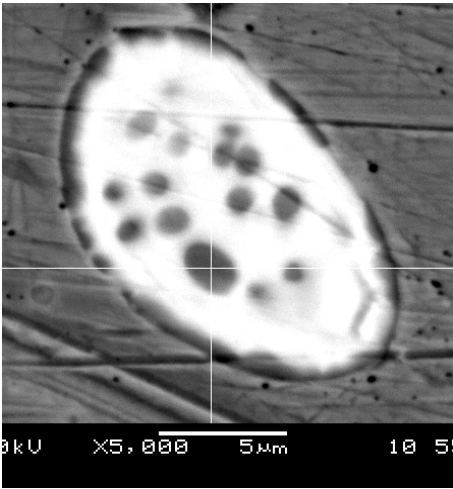
Cu-Sb-O,

(.6).

Cu<sub>2</sub>O-Sb<sub>2</sub>O<sub>3</sub>.

(84 . % Sb<sub>2</sub>O<sub>3</sub>)

Cu<sub>2</sub>O-Sb<sub>2</sub>O<sub>3</sub>.



(SiO<sub>2</sub>)

Cu-Si-O, Cu-Ca-O, Cu-Mg-O Cu-Al-O.

.6.

Cu-Sb-O ([Sb] = 1 % .)

.7

Cu-Fe-Si-O 1250 ° .

SiO<sub>4</sub><sup>4-</sup>;

IV -

.7 7

ab

.7.

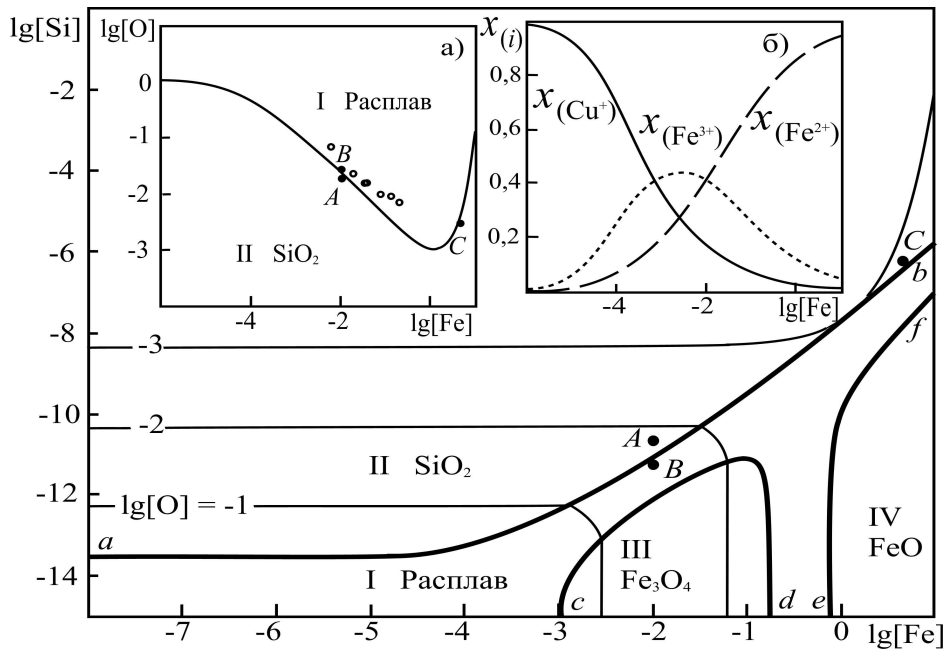
1250 ° .

I

Cu<sup>+</sup>, Fe<sup>2+</sup>, Fe<sup>3+</sup>, O<sup>2-</sup>,

III -

.7



. 7.  
Cu-Fe-Si-O  
= 1250 ° :  
o -

Cu-S-O    Cu-P-O,

(Cu-Ni-S-O, Cu-Zn-P-O    Cu-Pb-P-O).

Cu-Zn-P-O

. 8

1200 ° .

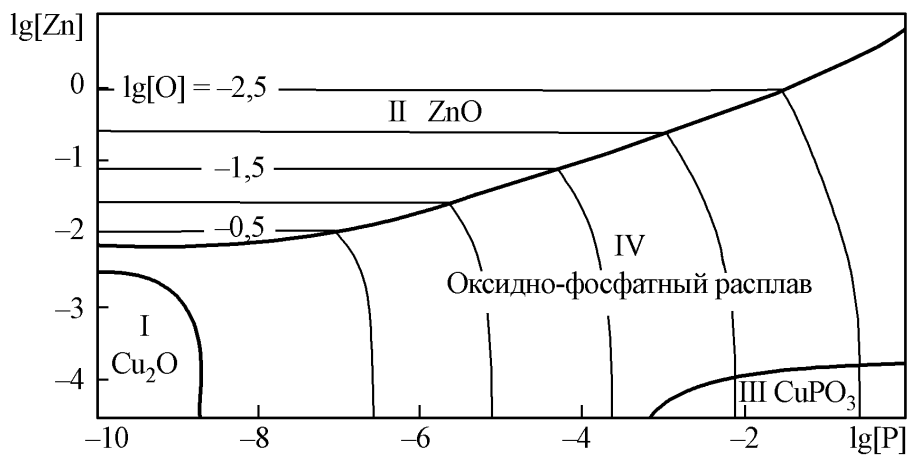
I

II - c

III - c

CuPO<sub>3</sub>,

IV - c



. 8.

Cu-Zn-P-O  
= 1200 °

( , ) ”.



Cu-Al-O ( )

4.

NiO-SiO<sub>2</sub>.

Co-Si-O, Co-Al-O, Co-Si-O

1500-1600 °

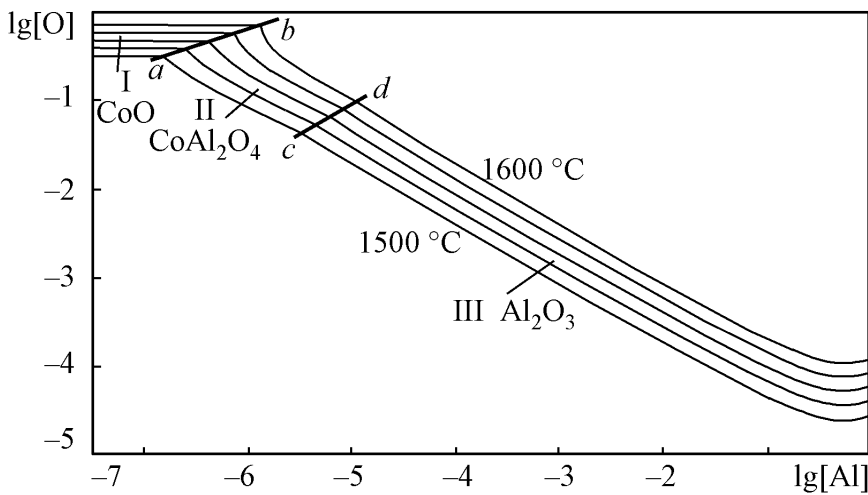
Ni-Ca-O Ni-Si-C-O

1500-1800 °

Ni-R-O ( R - Cr, Fe, Mn, Nb, Pb, Bi, S, Sb, Sn, Ti, W)

Ni-R-Bi ( R - Pr, Er, Dy, Nd)

Co-Al-O.



*ab*  
CoO

(CoAl<sub>2</sub>O<sub>4</sub>).

I

CoAl<sub>2</sub>O<sub>4</sub>.

*cd*

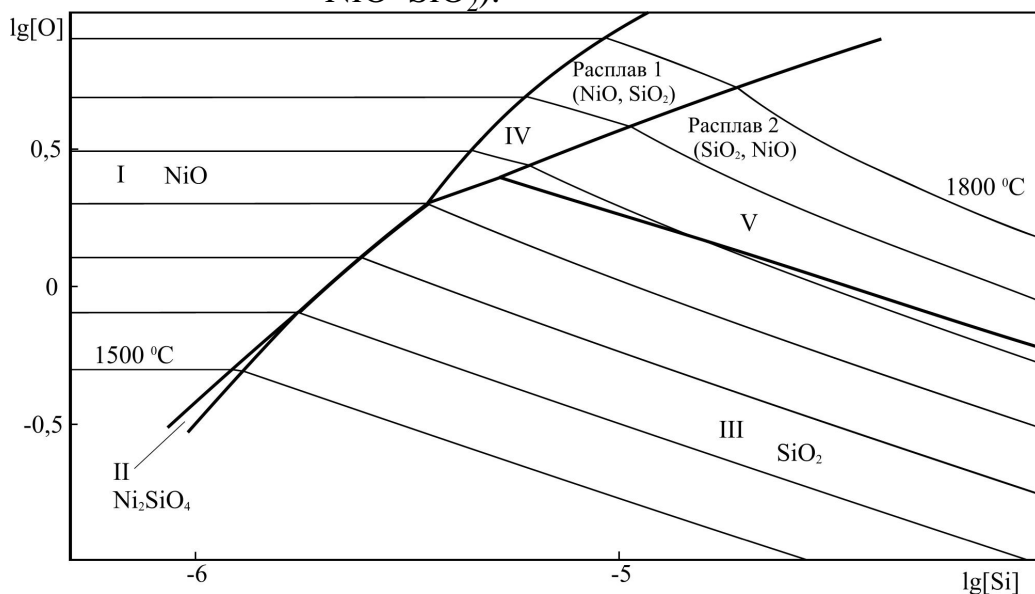
II -

III  
Al<sub>2</sub>O<sub>3</sub>.

Ni-Si-O Ni-Si-O. 10  
 Ni-Si-O,

I  
 II -  
 III  
 IV V  
 IV -

NiO-SiO<sub>2</sub>, V -  
 ( NiO-SiO<sub>2</sub>).

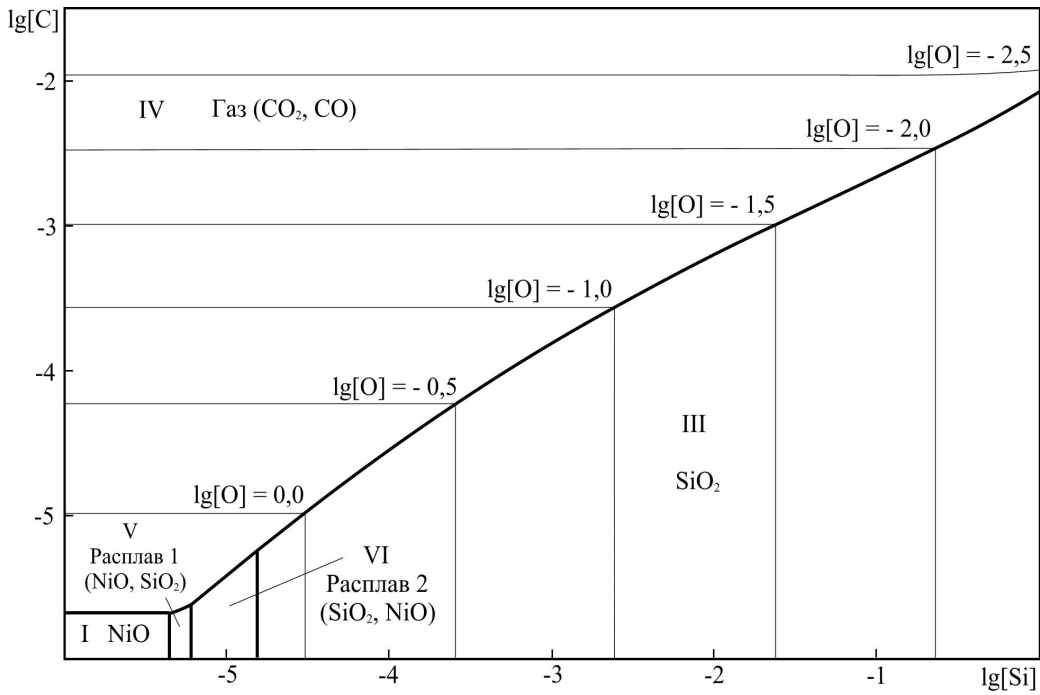


. 10.  
 Ni-Si-O

Ni-Si-O

. 11  
 1700°

1

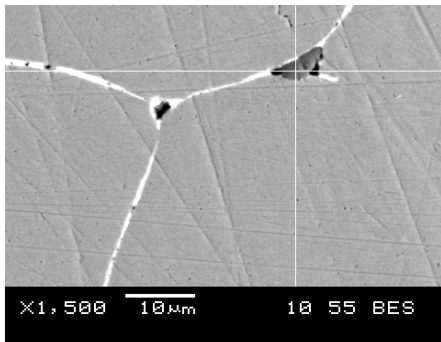


. 11.  
Ni-Si-C-O  
0,1013 M  
= 1700°

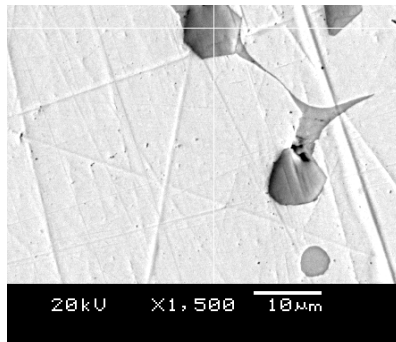
Ni-R-O ( R – Cr, Fe, Mn, Nb, Pb, Bi, S, Sb, Sn, Ti, W).

( . 12), ( . 13), ( . 14)

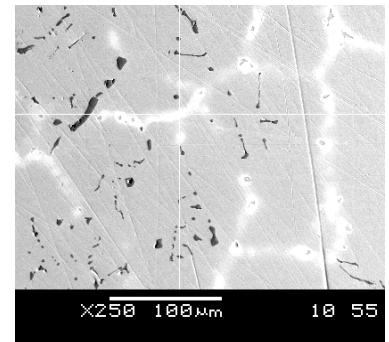
SO<sub>2</sub>,



. 12. Ni-Pb-O.



. 13. Ni-S-O.



. 14. Ni-Sb-O.

- NiO,  
(~ 40 – 80 %)

( NiO)

( – Cr, Fe, Mn, Nb, Ti, W).

(Pr, Er, Dy, Nd).

Ni–Bi–Pr

PrBi, Pr<sub>5</sub>Bi<sub>3</sub>, Pr<sub>4</sub>Bi<sub>3</sub>.

5.

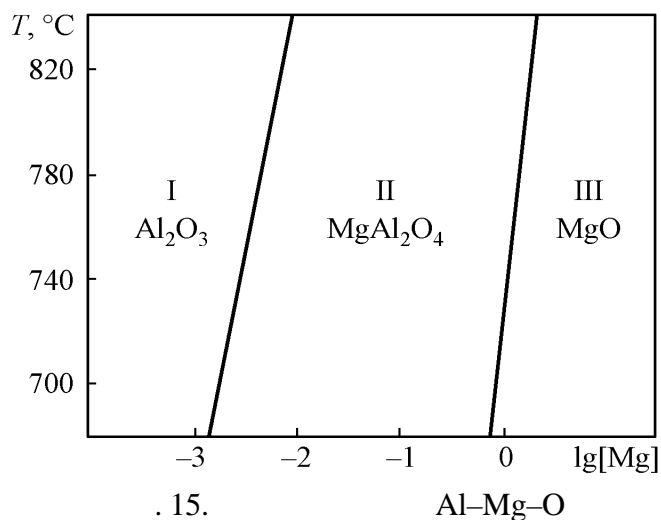
AlCl<sub>3</sub>–NaCl, AlCl<sub>3</sub>–KCl, AlCl<sub>3</sub>–MgCl<sub>2</sub>, AlF<sub>3</sub>–NaF.

– Al–Mg–O, Al–Mg–Na–O,  
Al–Mg–Na–K–O, Al–Me–Cl ( Me – Na, Mg, K), Al–Na–F, Al–Mg–F, Al–Mg–Na–F.

Al–Mg–O,

. 15 (

),



II –

(MgAl<sub>2</sub>O<sub>4</sub>),

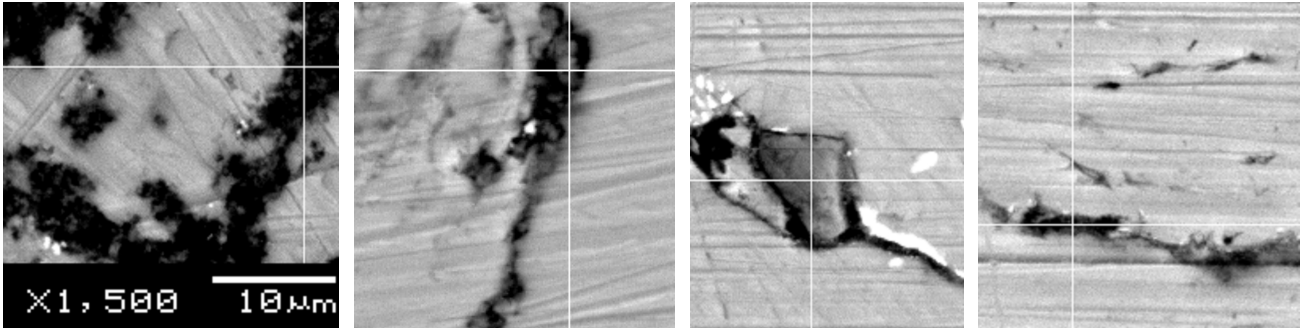
(MgO).

I

(Al<sub>2</sub>O<sub>3</sub>),

III –

Al-Mg-O



. 16.

-	MgO	6,0 .%
-	MgO	1,5 .%
-	MgAl <sub>2</sub> O <sub>4</sub>	0,25 .%
-	Al <sub>2</sub> O <sub>3</sub>	

. 17

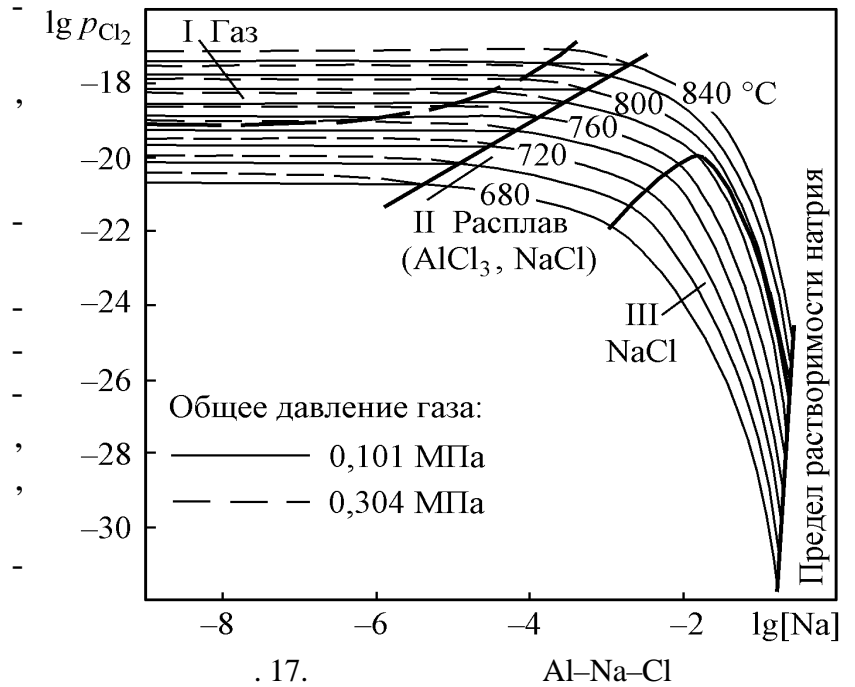
Al-Na-Cl.

NaAlCl<sub>4</sub> AlCl<sub>3</sub>

II -

III

(NaCl).



. 17.

Al-Na-Cl

II

I

. 17

0,101 ( ) 0,304 ( )

I II,

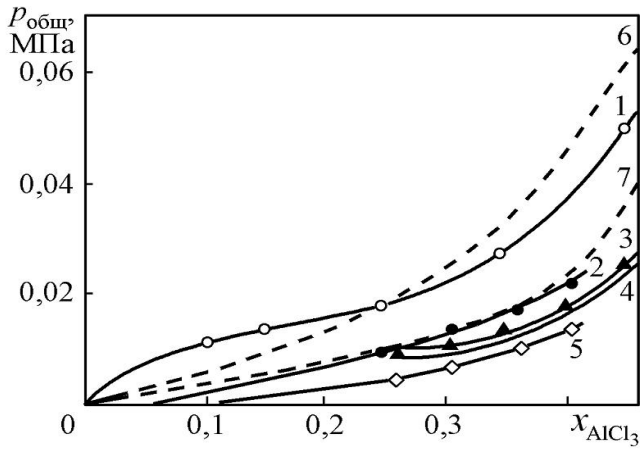
II III,

$\text{AlCl}_3\text{-NaCl}$ .

( . . ) ,

. 18

$\text{AlCl}_3\text{-NaCl}$ ,



. 18.

$\text{NaCl-AlCl}_3$

- 1, 2 – 827 ° ;
- 3, 4, 5 – 775 ° ;
- 6 – 840 ° ;
- 7 – 780 °

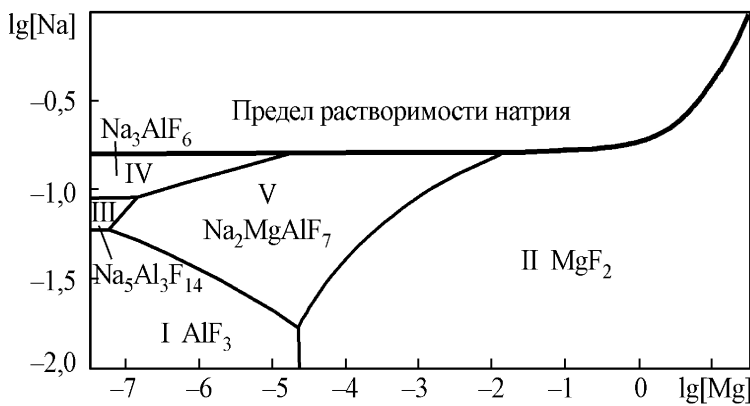
( $\text{Na}_3\text{AlF}_6$ ).

$\text{Al-Mg-Na-F}$ .

680 °

. 19.

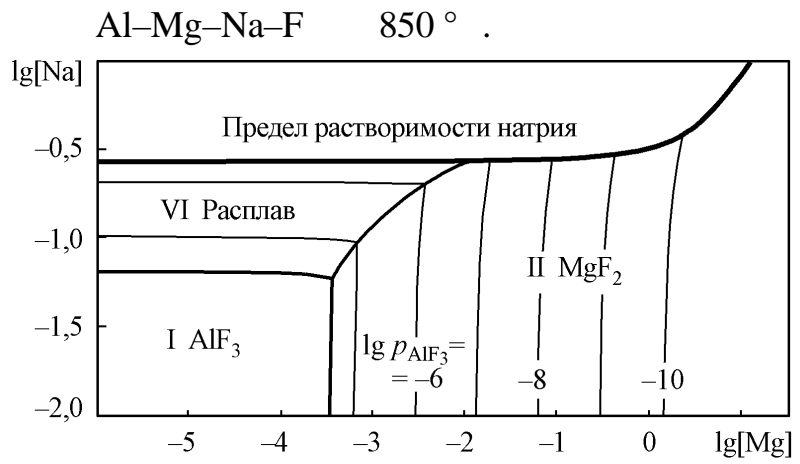
I



. 19.

$\text{Al-Mg-Na-F} = 680^\circ$

( $\text{Na}_2\text{MgAlF}_7$ ).



. 20.

Al-Mg-Na-F = 850 °

6.

(Pb-Ag-Zn, Pb-Au-Zn, Pb-Cu-S, Pb-Zn-O, Pb-Sb-O),  
(Bi-Ag-Zn) (Sn-Al-Sb).

Pb-Ag-Zn, Pb-Cu-S, Pb-Zn-O, Pb-Sb-O, Bi-Ag-Zn, Bi-Cu-S,  
Bi-Pb-S, Bi-Pb-O, Bi-Sn-O Sn-Al-Sb.

Pb - Ag - Zn

. 21.

I

II - AgZn

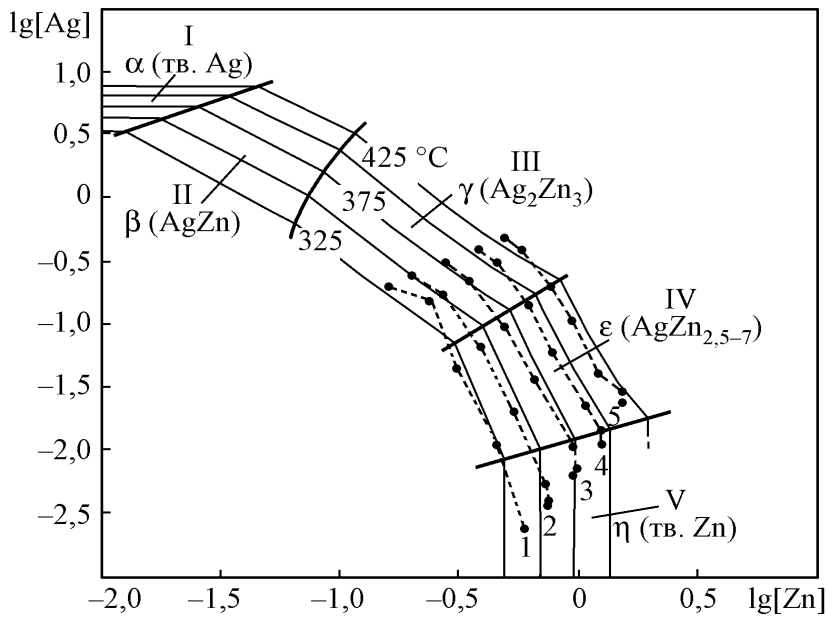
III

Ag<sub>2</sub>Zn<sub>3</sub> IV

ε -

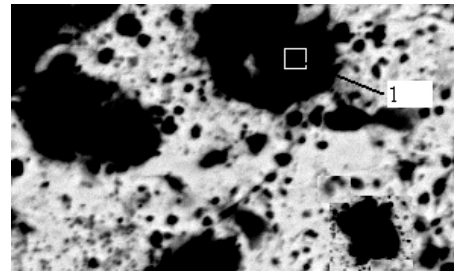
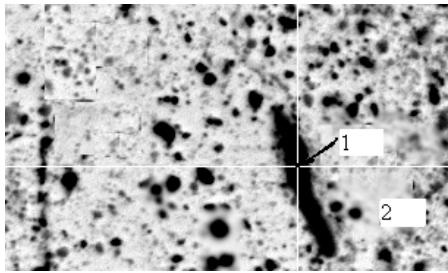
(AgZn<sub>2,5-7</sub>).

. 22.



. 21.  
Pb-Ag-Zn.

1 - 330; 2 - 350;  
3 - 375; 4 - 400;  
5 - 425 °C



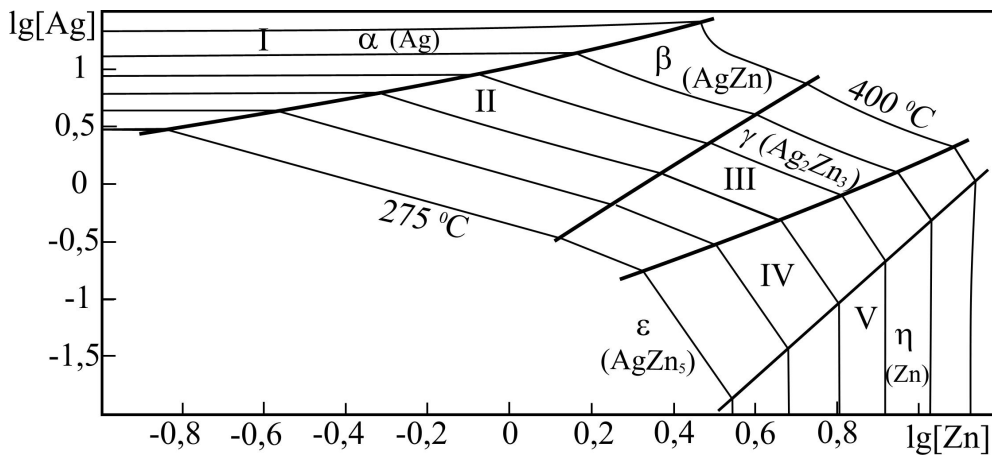
. 22.

Pb - Ag - Zn

( - AgZn, - Ag<sub>2</sub>Zn<sub>3</sub>)

Bi-Ag-Zn

. 23.



. 23.

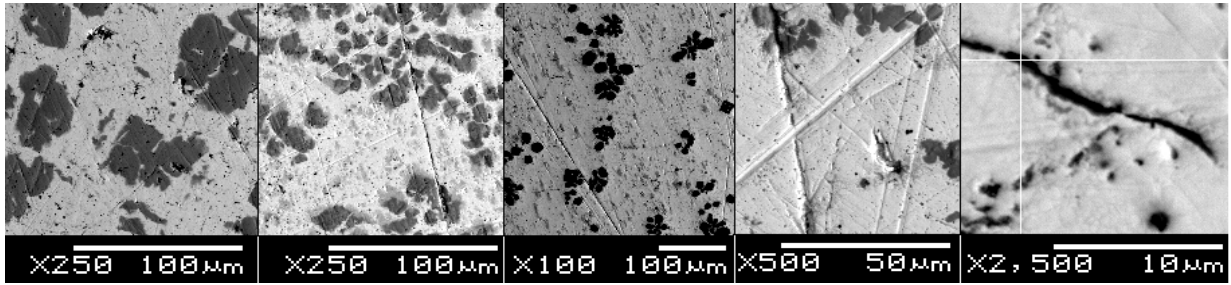
Bi-Ag-Zn

I  
AgZn  
II -  
III -  
IV  
Ag<sub>2</sub>Zn<sub>3</sub>.  
IV  
ε-  
IV  
V  
(AgZn<sub>2,5-7</sub>).  
V



Ag-Zn,

. 24.



. 24.

Ag-Zn,

Bi-Ag-Zn

1.

2.

3.

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1000 °

(

).





Co-Al-O, Co-Si-C-O; - Ni-O, Ni-Ca-O, Ni-Al-O,  
 Ni-Si-O, Ni-Ca-C-O, Ni-Al-C-O, Ni-Si-C-O; -  
 Pb-Ag-Zn, Pb-Au-Zn, Pb-Cu-S, Pb-Zn-O Pb-Sb-O; -  
 Sn-Al-Sb; - Bi-Ag-Zn.

11. -

12. -

Cu-R-O ( R -Ni, Sn, Zn, Co, Fe, Pb, Sb, Bi, Si, Mg, Al, S, P), Cu-Pb-Sn-O,  
 Cu-Pb-Sn-Zn-O, Cu-Fe-Si-O, Cu-Ni-S-O, Ni-R-O ( R - Cr, Fe, Mn, Nb, Pb, Bi,  
 S, Sb, Sn, Ti, W), Ni-R-Bi ( R - Pr, Er, Dy, Nd), Al-Mg-O, Pb-Ag-Zn, Pb-Cu-S,  
 Pb-Zn-O, Pb-Sb-O, Sn-Al-Sb, Bi-Ag-Zn, Bi-Pb-S, Bi-Cu-S, Bi-Pb-O Bi-Sn-O.

13. -

Cu-Al-O ( ),

14. -

1. / . . . ,

2. // . . . - . - 2002. - 2 - .10-13. , -

. - 2003. - 3 - .9-12. / . . . , . . . // . . .

3. Cu-Pb-Sn-O 1100 – 1300 ° / . . . , . . . // . -  
2004. – 6 – .23–31.
4. Cu-P-O  
1100 – 1300 °C / . . . , . . . // - -  
: . - 2004. – 8(37) – .31–33.
5. Cu-S-O  
1100–1300 ° / . . . , . . . // . - 2005. –  
1 – .4–9.
6. Pb-Ag-Zn / . . . -  
, . . . // : -  
. - 2005. – 3(43) – .60–62.
7. / . . . , . . . // . - 2005. –  
4 – .82–85.
8. Al-Na-Cl, Al-Mg-Cl, Al-K-Cl Al-Mg-Na-Cl 680 – 840 ° / . . . //  
. - 2005. – 6 – .36–44.
9. Al-Mg-Na-K-O 680 – 840 ° / . . . , . . . // . -  
2006. – 4 – .23–29.
10. Cu-Fe-O, Cu-Fe-Si-O / . . . , . . . -  
// : . -  
2006. – 10 (65) – .11–14.
11. Co-Si-O, Co-Al-O Co-Si-O / . . . -  
, . . . // : -  
. - 2006. – 10 (65) – .15–18.
12. / . . . // . - 2006. – 3. – .84–90.
13. Cu-Zn-P-O Cu-Pb-P-O 1100...1300 ° / . . . , . . . //  
- : . - 2006. –  
10(65) – .7–10.
14. Cu-Pb-O, Cu-Sn-O, Cu-Sn-Pb-O / . . . , . . . -  
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