

553.435+551.24(470.5)

456301,

E-mail: zaykov@ilmeny.ac.ru

23 2004 .

() (). (),
Co-Ni-Fe-
Bi Te (),
Co-Ni-Fe-
: I II – 150-350° , III – 200-300° 600° IV – 300° 460° .
(> 0,6)

**COBALT-BEARING MASSIVE SULFIDE DEPOSITS
ASSOCIATED WITH UTRAMAFITES OF THE ACCRECIIONARY PRISM
OF THE WEST-MAGNITOGORSK PALEOISLAND ARC**

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Main Urals Fault zone hosts three Co-bearing massive sulfide deposits associated with ultramafites – Ishkinino, Ivanovka, and Dergamysh. In result of analysis of their geological setting authors have concluded that ore fields belong to the Lower Devonian accretionary prism of the West-Magnitogorsk paleoisland arc represented by the assemblage of ophiolite and island arc tectonic units. In the modern structure ore fields comprise sinform (Dergamysh), antiform (Ishkinino) and block melange (Ivanovka). It was established that primary ores of deposits have been formed at sub/seafloor conditions in the accretionary prism of the island arc stage. They are represented by massive, veined-disseminated and clastogene textures with two mineral assemblages of sulfides and oxides. Ore field structures were formed in collision stage of fold belt development. Late veined-disseminated mineralization, also connected with collision stage, comprise Co-Ni-Fe-arsenides and sulfarsenides, native gold and Bi-Te-minerals (third assemblage) with late sulfides and oxides (fourth assemblages). Co-Ni-Fe-diarsenides – 1 lin-

gite, safflorite, rammelsbergite and krutovite – have been firstly established for the Urals massive sulfide deposits. Temperatures of ore assemblages formation have been estimated by comparison of natural and synthetic textures and compositions: I and II – 150-350° , III – from 200-300° up to 600° and IV – from 300° up to 460° . Chromites from the rocks and ores by their chemistry correspond to those from suprasubduction ultramafites, then we have suggested that discoveries of sulfide ores could be possible in accretionary prisms of the modern island arcs with ultramafic rocks.

Key words: *South Urals, Main Urals fault zone, accretionary prism, ultramafites, massive sulfide deposits, copper, cobalt, nickel, gold, sulfides.*

1927 .

1929

1933 .

1940-1942 .

[, 1991; , 2003].

[, 2003].

[Tesalina et al., 2003; Jonas, 2003].

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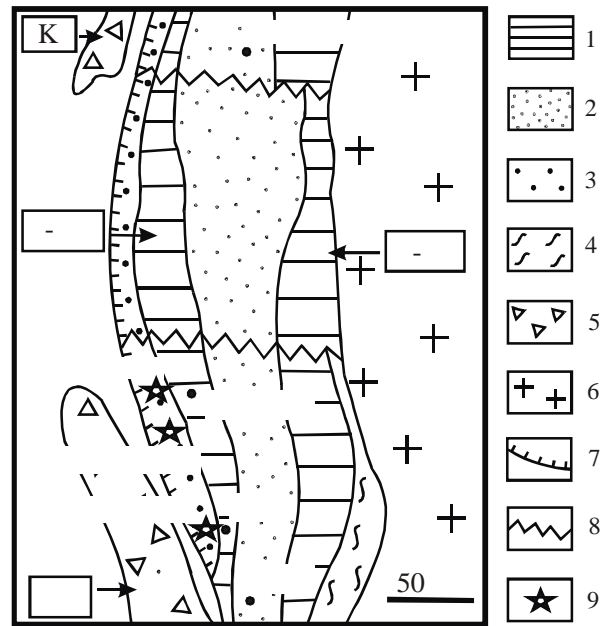
1954 10

1959 1961

1964-1966 .

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 ([, 1991]).
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 ; 7 - ;
 ; 8 - ;
 9 - .



([, 1997; 2000; , 2002]).
 [1970], [1962], [1962], [1969, 1975].
 1998 .
 [, 2001; , 2003].
 1 : 10 000 1 : 500.
) 2 (),
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 10-20
 , 1942, [, 1970] ([, 1991].
 [, 1969].

([, 1997; 2000; , 2002]).
 [1970], [1962], [1962], [1969, 1975].
 1998 .
 [, 2001; , 2003].
 1 : 10 000 1 : 500.
) 2 (),
 « » 1999
 10-20
 , 1942, [, 1970] ([, 1991].
 [, 1969].

... , ...

35-50°

[., 2003].

., 2003]: [., 2000; (O-S), «».

(D₁₋₂)

(D₃₋₁),

1991; , 1996; 1999; , 2000].

((₂-P₁) -)

«»

«...»

(

(?)...» [..., 1999, . 24].

1993;

., 2001].

(Ssk).

300

[., 1995].

[..., 1993].

[C ..., 1993].

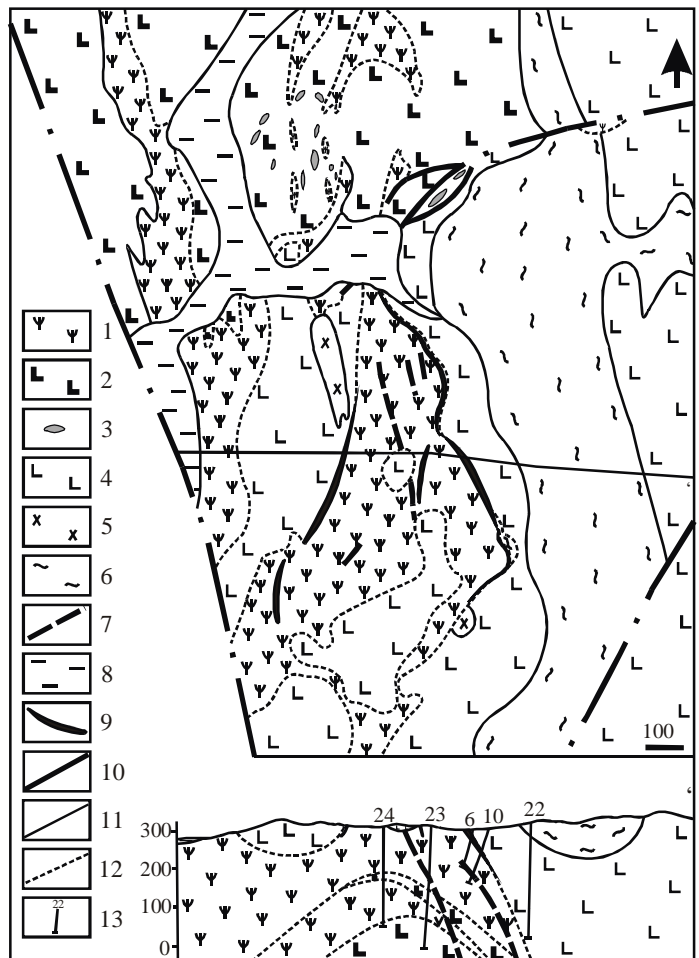
(. 2),

(. 2),

[C (...), ..., 1993].

. 2.

1 - $(O_2-S_1?)$; 2 - (Ssk) ; 3 - $(v\mu S)$; 4, 5 - (D_1b-br) ; 4 - $(\delta, v\delta D_1)$; 5 - $(v\mu D_1)$; 6 - (D_2ish) ; 7 - $(?) (v \rho)$; 8 - (Q_{IV}) ; 9 - (\dots) ; 10 - (\dots) ; 11 - (\dots) ; 12 - (\dots) ; 13 - (\dots)



33

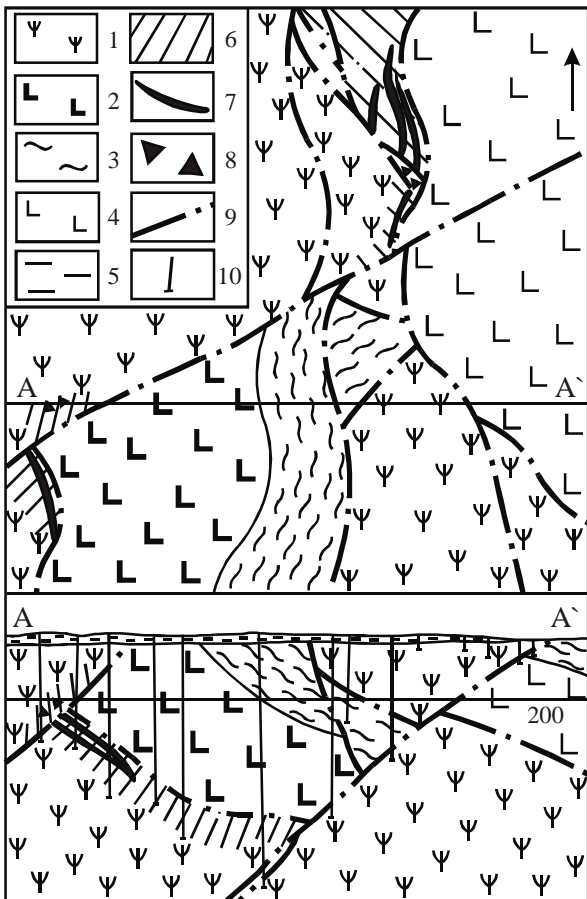
0,3-5,5
0,5-2 65-163

- 13-60

[, 2003].

, 2003].

, 1975; (. 3) [, 2001].

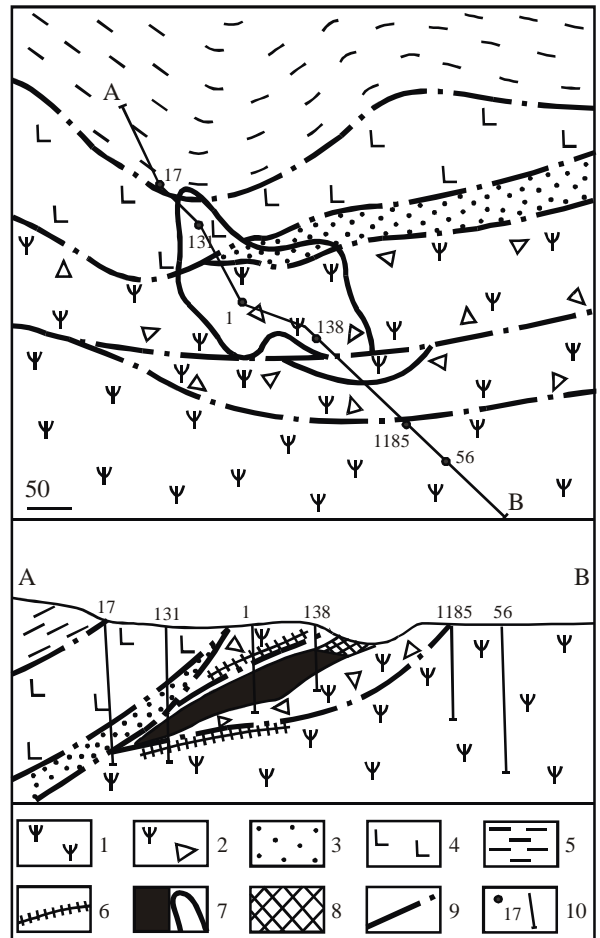


200

1 - (O₂-S₁?); 2-3 -
(?) (Ssk); 2 - , 3 -
; 4 - (D₁b-br);
, ; 5 - (Q_{IV});
6 - ;
; 8 - (7, 8 -
); 9 - ; 10 -

2 , Mg-
 , Mg, Si-
 [Tesalina et al., 2003].
 450
 102
 46
 [
 1975].
 [, 1970].
 , 1975].
 2 , 190 ,
 1/3
 13
 22
 . 4.
 (.)
 1 - (O₂-S₁?); 2 -
 ; 3 -
 (?) (Ssk):
 ; 4 -
 (D₁b-br):
 ; 5 -
 ; 6 - , - ; 7 -
 , b -
 8 -
 10 -

., 2001; Tesalina et al., 2003].
 :
 «
 », 2
 ;
 ;
 [, 1970;
 20 ; 1975; ., 2001; , 2005].
 (. 4) [., 2001].



... ; -
... ,
... [, 1962; , 2001].

...
... [, 2000].

30-35°

130

6,5

40

150-200

2-3

;

1 (1999 .),

78

(.4) [, 2001].

5

(.2, 5).

), « »

700

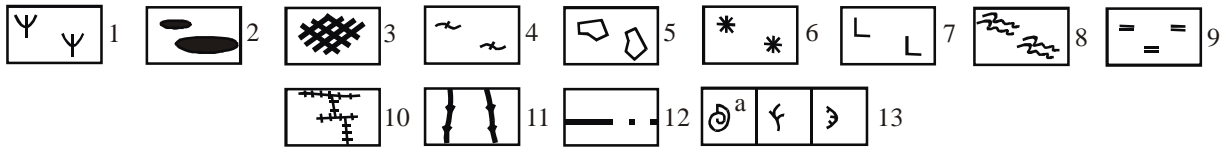
300-

..., 1993].

A	B	C	D	E
	D ₃ -C ₁	> 30	= = =	⇒
III	D ₂ ish	200		⇒
	D ₁ b-br	300		
II	σO-S ₁	200-400		
I	Ssk	>270		
	σO-S ₁	>300		

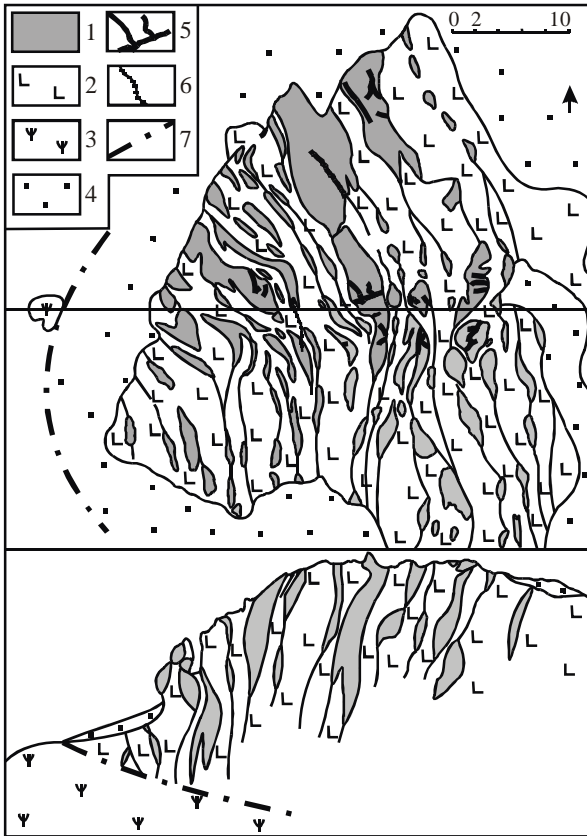
A	B	C	D	E
VI	D ₃ -C ₁	>300	= = =	⇒
V	D ₁ b-br	100-150		
IV	Ssk(?)	>70		
III	σO-S ₁	50-100		
II	σO-S ₁	300-400		
I	D ₁ b-br(?)	300-500		
	σO-S ₁	>500		

A	B	C	D	E
IV	D ₁ b-br(?)	>200		
III	σO-S ₁	100-200		
II	Ssk(?)	400		
I	σO-S ₁	>250		
	Ssk	300		



. 5. (, E - . . .).
 A - , B - , C - , D - , E - .
 1 - (O₂-S₁?); 2 - - -
 ; 3 - - - -
 ; (Ssk): 4 - , (D₁b-br): 5 -
 , 6 - , 7 - - ; -
 (D₂ish): 8 - ;
 (D₃-C₁): 9 - , ; 10 - ; 11 - -
 ; 12 - ; 13 - : a - , - , - .

-
 -
 - 1 12 .
 -
 - :
 - ,
 - 200-400
 -
 - (. 6),
 - 300
 -
 - [., 2000],
 -
 -



. 6. (1 - ; 2 - ; 3 - ; 4 - ; 5 - ; 6 - ; 7 -)

(. 7). [, , 2004].

50-400 (. 5).

[, 2004],

Polygnatus ex gr. costatus, P. aff. pseudofoliatu [..., 1993].

[, 2000].

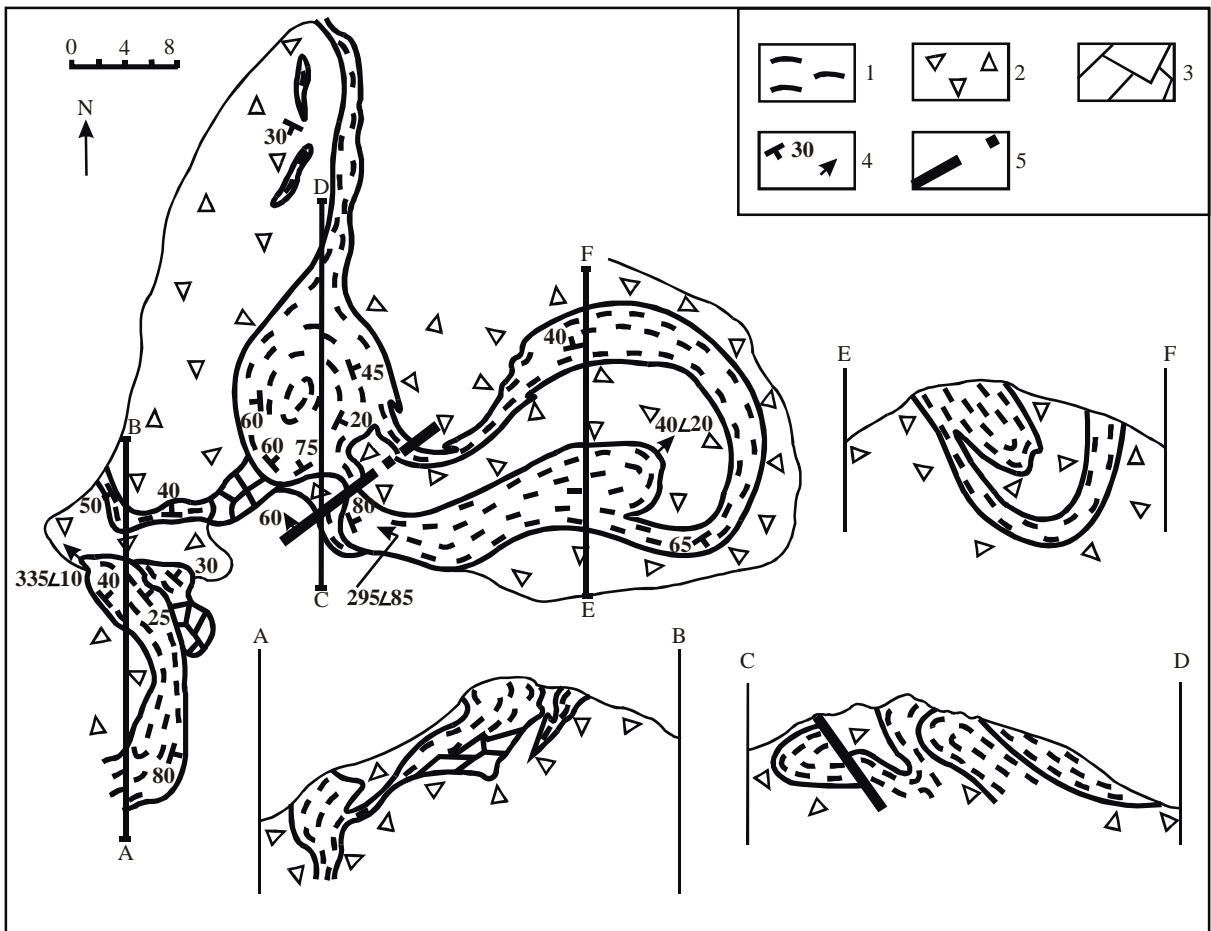
« »,

(),

6

[, 1975].

[, 1975].



.7.

(.) .

1 - ; 2 - ; 5 -

; 3 - ; 4 -

nas, 2003]

N-MORB.

400 (. 5). 100- 600 .

50-100

« » [. 2003]

[., 2002]. (, - ,)

(.%) SiO₂ – 54-61, Al₂O₃ – 12-13, MgO – 10-13, CaO – 5-11 [., 1999].

([. 2000].

MgO, TiO₂ – K₂O

[2003],

0,9-1,6 . % TiO₂ – 3,2-4,1 . %.

TiO₂ – FeO/MgO (–)

La/Yb Zr – Ti/100 MgO – SiO₂.

– Y×3 Zr – Ti/100 – Sr/2 (. 1988)

E-MORB. ()

Ni, V, Mn, Fe, Zn [., 2000; 2002].

(.%): SiO₂ – 45-51, TiO₂ – 1,1-2,1, K₂O – 0,2-0,4, Na₂O – 3,0-4,6. [Jo-

K_2O (0,97 . %) TiO_2 (α - ,) β - (
 1,15 . %) α - 1,5 [, 1978; , 2003].
 MgO) (20-35 %.
 [, 2003].
 200-350
 30
 Cr 0,05 0,77 . % [, 1978].
 Ni,
 50-200 - 0,19 0,15 . %
 Co 0,005 0,019 . % Ni
 [Jonas, 2003]. 0,42 . %.
 [, 1970; , 1975]. (1-3) 150 [, 2002].
 [, 1978].
 [, 2003],

(Cr₂O₃ – 52-64 . %)

0,7 2 [, , 2002]. (. %) Al₂O₃ – 6-13, MgO – 8-14.

[, , 2002, 2003; Tesalina et al., 2003]. (. %) Cr₂O₃ 51-53 58-60, MgO 9 14, Al₂O₃ – 6-12. MnO (1,32 . %). (16-20 . %), 1.

10-20 0,3 3 , Cr, Al Fe³⁺

1

	MnO	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	MgO	FeO	Al	Cr	Fe ³⁺	Fe ²⁺	Mg	Cr#	Mg#	Y Fe ³⁺	N
1	0,11	0,31	12,84	54,43	10,42	21,81	0,49	1,40	0,10	0,49	0,51	73,99	50,67	5,10	27
2	0,18	0,15	9,80	59,35	10,96	19,61	0,38	1,54	0,08	0,46	0,54	80,23	53,74	3,89	33
3	0,02	0,02	18,90	49,97	13,11	15,83	0,71	1,25	0,04	0,38	0,62	63,91	62,00	2,01	8
4	0,00	0,02	14,52	54,41	11,40	18,99	0,55	1,39	0,06	0,45	0,55	74,54	54,79	3,01	8
5	0,05	0,00	10,52	59,10	8,24	21,98	0,41	1,56	0,03	0,59	0,41	79,04	41,03	1,24	12
6	0,24	0,25	13,08	53,87	10,99	21,13	0,50	1,39	0,12	0,47	0,53	73,43	53,37	5,74	18
7	0,29	0,36	12,37	51,02	7,87	27,72	0,49	1,35	0,17	0,61	0,39	73,47	39,10	8,31	79
8	0,45	0,35	1,36	48,01	2,14	46,35	0,06	1,40	0,54	0,88	0,12	95,08	11,71	27,21	9
9	0,30	0,10	10,70	53,88	9,39	26,05	0,42	1,40	0,18	0,54	0,46	77,17	46,13	8,98	9
10	0,45	0,01	10,57	59,67	12,41	16,73	0,41	1,54	0,06	0,40	0,60	79,13	60,18	2,90	34
11	0,37	0,27	13,71	48,87	9,33	26,70	0,53	1,27	0,20	0,54	0,46	70,51	45,82	9,89	15
12	0,03	0,22	19,26	50,75	11,90	17,72	0,71	1,26	0,02	0,44	0,56	63,88	55,79	1,20	21

: 1, 2 – 3-5 – ; 6-8 – ; 9, 10 – ; 11 –

12 – JEOL JCSA-733 (; Cr# = Cr×100/(Cr+Al); Mg# = Mg×100/(Mg+Fe²⁺); Y Fe³⁺ – ; N –

TiO₂ Al₂O₃
menetsky et al., 2001],

, 2003].

[, 2005].

10-30°.

150-250 ,

[, 1999].

1

1999].

)

(50-75°).

« (2) » , (16-25 .%)

Bi Pb - Ni

Co -

29 , : - 12, - 5, - 2,

- 3, - 2, - 5, - 2.

[, (Au 88-91 .%).

1962; , 1970; 2003; Tesalina et al., 2003; , 2005].

Bi-Te-

. 2.

Co, Ni, Cr, Au

Ag

Co

(. 8).

10 , : (Au 71-75 .%, Ag 24-28 .%)

Ni

Co

Co Ni

Co (. 2),

I II

1)

-I

(. %; Au, Ag – /)

Co	: 0,1. . 0,02-0,03 (0,01-0,08*) : 1-10. . 0,67 (0,13-0,31*) : 0,05-0,18* : 0,01-0,12. . 0,05-0,06	: 0,01-0,2 : 0,03-0,04 : 0,02-0,11** : 0,02-0,04**	: 0,04-0,21 : 0,01 : 0,14***
Ni	: 0,2-0,3 (0,13-0,49*) : 0,1-0,4 (0,22-0,49*) : 0,21-0,31*	: 0,1-0,2 : 0,02-0,2 : 0,11-0,16** : 0,11-0,15**	0,05 (. .) : 0,02-0,06***
Cu	: 2. . 0,5-0,7 (0,36-6,90*) : 0,5-15. . 6,4 (3,92-9,29*) : 6,40-20,80* : 0,5-2. . 0,5-0,8	: 0,5 6-9 : 0,6-0,9 : 0,14-1,05** : 0,14-0,57**	: 0,5-6,6 . 1,38 : 0,12-0,59 . 0,17
Zn	: 0,4 . % (104-490 / *) : 2-270 / * : 243-860 / *	: 0,02-0,03** : 0,04-0,15**	: 0,12-2 : 0,12-0,69
Fe	: 45-64* : 39-55* : 49-53*	: 35-59 : 27	: 49,3 : 45,6
S	: 28-30 (23-31*) : 22-25* : 26-28*	: 31,5 : 20,4-31,1** : 16,5-26,3**	: 47 : 50,98
As	: 0,02-5,80* : 7,43-26,1* : 0,12-2,45*	-	0,02 (. .)
Cr	: 0,13-0,51* : 0,19-0,58* : 0,27-0,47*	-	-
Au	: 1,4 (3,7-16,9*) : 0,2-6,6* : 0,5-3,2*	0,22-0,54 (. .) 0,04-5,4**	, : 4 : 0,4-6,2***
Ag	: 4-6 (3,1-6,1*) : 0,8-5* : 3,8-11,6*	1,08-13,2 (. .)	

2T; *** -

1T.

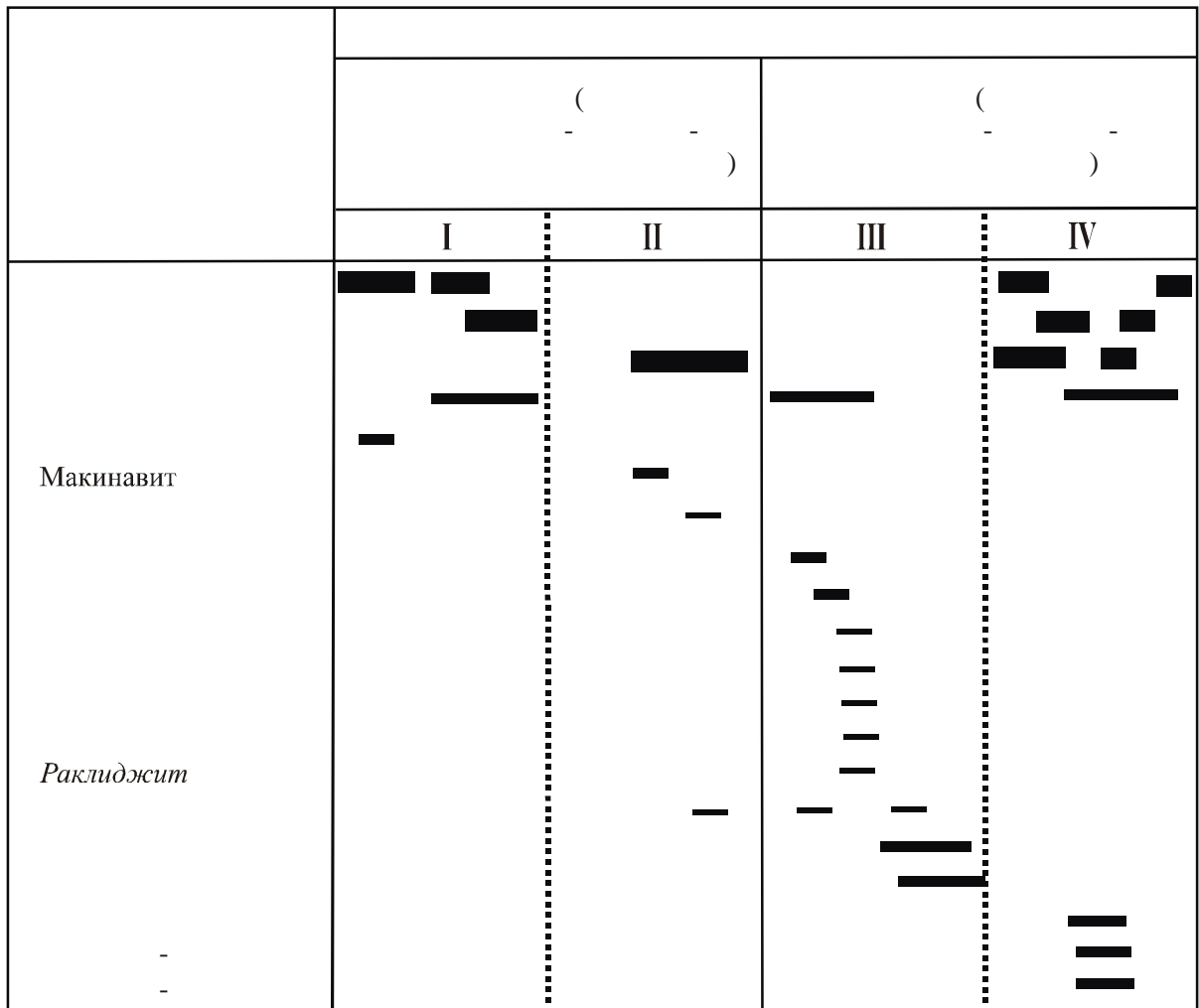
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I II

3)

2)

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 (III).
 -I
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 Ni Co
 , Au As [, 2001].
 [, 2005], ()
 As-
 Co Ni -



1 2 3

. 8.
 ([, 2003])
 I-IV - ; 1-3 - : 1- , 2- , 3-

2003]. , - , [, , , , , -
 FeAsS-CoAsS-NiAsS, ,
 500 650° -
 , Ni
 (Co/Fe , ,
). ,
 400-550°
 (D₁b-br D₂ish) - 450-500° ,
 - 400-590° ,
 500-590° . -
 Ni
 (IV):
 II III, -II III, -II III; FeAsS-CoAsS-NiAsS,
 -III, IV. 400 650° . -
 - 200-300
 625° . ,
 Ni- -
 / , -
 I II - , -
 ~ 150-350° , 600° . ,
 (I) - (II - : (1)
), , ; (2)
 ~ 150 350° ,
 [, - , 1984]. ,
 , Co, Ni, Fe, As S
 IV 300-460° -
 , ,
 , 460° , 300°
 , (.%): [Vaughan, Craig, 1985].
 - Ni (14,69),
 (14,66), (11,82)
 (10,08);
 - Co (12,68), Fe (18,53)
 Co (11,91);
 - S (12,77)
 (8,27).

[Klemm, 1965; Radcliffe, Berry, 1968]

«
 [, 2000].
 U-Pb
 355±5
 ([Gannoun et al., 2003].
 Re Os
 366±2
 90- XX
 « »
 [Jonas,
 2003] [Nimis et al., 2004]
 « »
 [, 1987], [, 1997; , 2004]. [,
 [Stern, 2004].
 [, 2004].
 As-Bi-Au Co-Ni- 4He
 [, 2005].
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 Pal-
 365
 matolepis crepida),

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-2003. 2001. 315 .

: ,2003. .52-54.
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.2005. .47. 1. .16-50.
. . . //

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. II. ,1969. .53-55.
.2004. .46. 1. .74-87.
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1975. .105-110.
,1970. .114-125.
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,1978. 238 .
. . . ,1962. .74-97.
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-2000. ,
,2000. .103-110. : ,2001. .250-283.
. . . ,1997. 233 .
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-2005. I. 3. . : ,2003.
: ,2005. .183-187. .152-161.
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-2002. . : ,1984. 280 .
. . . //

: ,2002. .181-188. -2 : //
. . . .2003. 3. .304-328.
. . . .5.
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-2003. : ,1999. 348 .
,2003. .226-231.
. . . //

// 2004. . II. :
.2000. .42. 2. .177-190. ,2004. .232-252.
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. : ,1991. 206 .
. . . () . : ,2003. 122 .

1999. 436 .
- ()// -2005.
- 2003. : , 2005. . 90-97.
2004. . 118-123.
- : , 1992. 104 . ()// 12. : , 2002. C. 98-110.
- // *Dick H.J.B., Bullen T.* Chromite as a petrogenetic indicator in abyssal and alpine-type peridotites and spatially associated lavas // *Contrib. Mineral. Petrol.* 1984. 86. P. 54-76.
- : , 2000. 146 . *Gannoun A., Tessalina S., Bourdon B. et al.* Re-Os isotopic constraints on the genesis and evolution of the Dergamish and Ivanovka Cu (Co, Au) massive sulfide deposits, south Ural, Russia // *Chemical Geol.* 2003. 14160. P. 1-15.
- // . 2002. 3. . 19-37. *Jonas P.* Tectonostratigraphy of oceanic crustal terrains hosting serpentinite-associated massive sulfide deposits in the Main Uralian Fault Zone (South Urals). PhD thesis, Freiberg, 2003.
- . 2003. 3. . 42-64. *Kamenetsky V., Crawford A., Meffre S.* Factors controlling chemistry of magmatic spinel: an empirical study of associated olivine, Cr-spinel and melt inclusions from primitive rocks // *J. Petrol.* 2001. V. 42. P. 655-671.
-)// -2000. , , *Klemm D.* Synthesen und Analysen in den Dreiecksdiagrammen FeAsS-CoAsS-NiAsS und FeS₂-CoS₂-NiS₂ // *Neues Jb. Mineral. Abhandl.* 1965. Bd. 103. H. 3.
- : , 2000. . 174-181. *Mozgova N.N., Krasnov S.G., Batuev B.N. et al.* The first report of cobalt pentlandite from a Mid-Atlantic Ridge hydrothermal deposit // *Can. Mineral.* 1996. V. 34. Pt. 1. P. 23-28.
- // -2002. *Nimis P., Omenetto P., Tesalina S.G., Zaykov V.V.* Peculiarities of some mafic-ultramafic-hosted massive sulfide deposits from southern Urals. A likely forearc occurrence // *Mineral exploration and sustainable development.* Rotterdam: Millpress, 2003. P. 627-630.
- , 2002. . 17-26. *Radcliffe D., Berry L.G.* The safflorite-loellingite solid solution series // *Amer. Mineral.* 1968. V. 53. P. 1856-1881.
- , 1993. 217 c. *Stern R.J.* Subduction initiation: spontaneous and induced // *Earth Planet. Sci. Let.* 2004. V. 226. P. 275-292.
3. . 195-218. // . 1996. *Tesalina S.G., Nimis P., Auge T., Zaykov V.V.* Origin of chromite in mafic-ultramafic-hosted hydrothermal massive sulfides from the Main Uralian fault, South Urals, Russia // *Lithos.* 2003. 70. P. 39-59.
- : , 1995. 480 . *Vaughan D.J., Craig J.R.* The crystal chemistry of iron-nickel thiospinels // *Amer. Mineral.* 1985. V. 70. P. 1036-1043.
- ()// -2002. , 2002. . 188-191.