

Table 1. Chemical composition of surface facies, structural weathering crusts and sideritic carbonatites of the Seis Lagos deposit (wt. %) (Giovannini et al., 2013)

Components	Surface facies of KV					Structural KV		Siderite carbonatites
	1	2	3	4	5	6	7	
SiO ₂	0.56	0.53	0.31	0.16	0.42	0.48	1.04	0.66
Al ₂ O ₃	1.95	1.70	2.51	0.47	0.40	0.33	0.46	1.17
Fe ₂ O ₃ (total)	77.63	80.87	74.23	85.59	57.76	82.40	82.22	52.46
MgO	□	□	0.01	0.01	□	0.01	0.01	3.04
CaO	□	□	0.01	0.01	□	0.01	0.01	0.22
Na ₂ O	0.02	□	0.02	0.01	0.01	0.01	0.01	0.01
K ₂ O	0.01	□	0.01	□	0.02	0.03	0.01	0.06
TiO ₂	5.52	1.08	6.63	4.99	0.45	2.69	0.91	0.18
P ₂ O ₅	0.44	0.58	1.72	0.34	0.16	0.22	0.39	1.30
MnO	0.04	0.00	0.10	0.27	26.65	0.90	0.32	7.72
calcination losses	10.10	9.93	10.33	5.30	8.72	9.15	10.96	
CO ₂								24.38
BaO	0.04	0.04	0.09	0.06	3.23	0.23	0.11	4.28
Nb ₂ O ₅	1.59	0.89	1.76	0.99	0.22	1.97	1.34	0.15
La ₂ O ₃	0.04	0.07	0.15	0.03	0.02	0.10	0.12	
Ce ₂ O ₃	0.15	0.19	0.35	0.26	0.74	0.48	1.16	0.86
The amount	98.07	95.90	98.24	98.46	98.80	98.99	99.07	96.48

Note. 1–5 – surface facies: 1 – pisolith crusts (average of 2 analyses), 2 – fragmental crusts (average of 3 analyses), 3 – spotted crusts (average of 3 analyses), 4 – oolitic crusts (average of 4 analyses), 5 – manganese crusts (average of 5 analyses); 6, 7 – structural crusts: 6 – red ochres (average of 2 analyses), 7 – brown ochres (average of 5 analyses); 8 – sideritic carbonatites (average of 4 analyses). *Here and below:* dash – not detected, empty cell – not determined.

Table 2. Chemical composition of lateritic ochres (analysis 1) and products of their epigenetic transformation: zone of ochre bleaching, rich ores (analysis 2); limonite-siderite rocks (analysis 3) (Tomtor, wt. %)

Components	1	2	3
SiO ₂	3.82	8.70	3.92
TiO ₂	1.42	7.30	1.40
Al ₂ O ₃	1.66	15.25	2.55
Fe ₂ O ₃	49.72	9.01	30.63
FeO	5.46	5.90	19.72
MnO	4.64	0.61	4.30

MgO	0.72	0.25	0.80
CaO	5.93	3.04	5.36
K ₂ O	0.05	0.31	0.12
Na ₂ O	0.17	0.20	0.14
P ₂ O ₅	6.24	13.90	4.85
SO ₃	0.25	0.63	0.28
CO ₂	5.16	2.70	13.71
Nb ₂ O ₅	1.54	4.70	1.22
TR ₂ O ₃	4.50	10.72	
The amount	91.28	83.22	88.99

Table 3. Results of microanalysis of the manganese-rich (hollandite) (analyses 9, 13) and iron-rich (goethite) (analysis 14) phases in liquid separation structures (Chuktukon, wt. %)

Components	Liquid Separation structures		
	Mp- and Fe-phases in brown ironstone		
	3a*	3e	9
Na ₂ O			<0.05
BaO	12.64	0.19	13.10
PbO			0.19
SLn ₂ O ₃	0.20		
Nb ₂ O ₃	0.27	0.26	
ZrO ₂			0.13
Fe ₂ O ₃	4.93	78.04	0.12
MnO ₂	82.63	3.39	86.39
Al ₂ O ₃	0.07	2.88	0.05
V ₂ O ₃			0.04
P ₂ O ₅	0.07	0.17	
SiO ₂	0.07	2.14	
The amount	100.87	87.08	100.03

Note. * – analyzed areas of aggregates shown in Fig. 3a, e; analysis numbers correspond to point numbers in Fig. 3a, e.

Table 4. Chemical composition of hollandite from manganese horizon of the weathering crust of sideritic carbonatites from the Seis Lagos deposit (Giovannini et al., 2017) (wt. %)

Components	13.01	13.02	15.01	15.02	15.03	15.04	15.05	17.01
K ₂ O	0.07	0.05	0.01	0.11	0.07	0.08	0.16	0.19
BaO	17.22	14.66	17.59	16.88	16.43	15.94	16.52	14.62

PbO	0.03	0.20	□	0.04	□	□	□	0.13
MnO	6.46	6.50	2.72	7.15	7.05	6.53	7.35	6.66
MnO ₂	70.99	75.89	67.47	73.24	73.30	73.73	73.51	75.74
Al ₂ O ₃	1.10	0.43	2.22	0.72	0.46	0.50	0.40	0.17
Fe ₂ O ₃	1.82	0.18	8.72	0.58	0.62	1.24	0.31	0.38
The amount	97.69	97.91	98.73	98.72	97.93	98.02	98.24	97.89

Table 5. Chemical analyses of carbonated (siderite) laterite weathering crusts based on 10-m group samples of borehole 3665 (Tomtor ore field)

Analysis No.	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	Fe ₂ O ₃	MnO	MgO	CaO	K ₂ O	Na ₂ O	P ₂ O ₅	SO ₃	CO ₂	calcination losses
1	0.80	0.67	7.00	4.75	25.87	15.80	0.50	3.00	0.05	0.08	2.98	7.10	19.15	9.70
2	1.60	0.16	0.10	12.29	3.52	30.30	1.75	9.12	0.05	0.08	2.58	0.01	27.88	4.09
3	3.60	0.67	0.10	14.09	3.88	21.60	1.87	1.00	0.05	0.08	3.75	0.01	22.72	8.49

Добавлено примечание ([ДАГ1]: Указать сумму

Table 6. Results of microanalysis of Nb-rutile of the first generation (an. 2-9) and the second generation (an 1.10-12) Tomtor array (mass%)

Components	1	2	3	4	5	6	7	8	9	10	11	12
Al ₂ O ₃	0.16	0.05	0.06	0.06	и.о.	0.21	0.88	1.58	0.12	0.17	0.20	0.20
SiO ₂	0.53	0.42	0.54	0.29	0.40	0.53	0.24	0.45	0.41	1.12	0.98	0.90
TiO ₂	60.14	78.66	80.69	81.90	79.29	69.24	74.60	60.80	66.41	53.41	47.16	47.36
V ₂ O ₃	1.29	1.28	0.84	1.44	1.06	1.51	0.97	1.27	2.50	1.64	1.58	2.03
Fe ₂ O ₃	6.61	4.78	4.84	3.55	4.82	3.91	3.07	3.10	4.45	7.15	9.03	8.10
Nb ₂ O ₅	28.96	14.59	13.59	13.49	15.34	17.01	10.38	12.19	17.64	30.17	37.12	30.21
The amount	97.66	99.78	100.52	100.72	100.91	92.41	90.15	79.39	93.06	93.67	96.07	89.80

Note. The amounts of some analyses (8-10) are significantly lower than 100%, since minerals contain additional Na₂O – 0.21, CaO – 0.17, P₂O₅ – 0.33, MnO – 0.09, BaO – 0.30, Y₂O₃ – 0.34, Sc₂O₃ – 0.09 wt.%; SrO, Ta₂O₅ – not detected.

Table 7. Chemical composition of Nb-rich rutile from the weathering crusts of sideritic carbonatites from the Seis Lagos deposit (Giovannini et al., 2017) (wt. %)

Components	4.1	6.1	6.2	6.3	6.4	6.5	12.1	34.1	34.2	34.3	34.4	34.5
Fe ₂ O ₃	8.96	12.18	13.94	11.12	14.95	10.52	17.78	14.92	11.64	11.67	11.18	12.43
SiO ₂	□	1.09	0.45	0.63	0.62	0.52	1.00	0.33	0.27	0.34	0.30	0.28
TiO ₂	80.92	70.73	68.92	72.45	66.26	74.08	57.84	58.26	67.34	68.66	66.92	57.86
Nb ₂ O ₅	11.26	16.59	19.08	16.71	18.89	14.89	22.23	25.46	19.16	17.47	20.28	27.61
WO ₃	0.16	0.35	0.31	0.70	0.33	0.64	1.27	0.20	0.33	0.19	0.85	0.62
The amount	101.30	100.94	102.70	101.61	101.05	100.65	100.12	99.17	98.74	98.33	99.53	98.80

Table 8. Chemical composition of Nb-rich brookite from the weathering crusts of sideritic carbonatites from the Seis Lagos deposit (Giovannini et al., 2017)

Components	10.1	10.2	10.3	12.1	12.2
Fe ₂ O ₃	12.08	12.53	9.86	10.89	10.69
SiO ₂	0.97	1.24	0.64	0.72	0.78
TiO ₂	69.60	73.45	76.68	76.93	78.02
Nb ₂ O ₅	16.03	12.09	11.77	10.75	10.43
WO ₃	0.69	0.32	0.74	1.10	0.80
The amount	99.37	99.63	99.69	100.39	100.72

Table 9. Chemical composition (EPMA) of vanadium compounds {Tomtor, wt. %)

Components	1	2	3	4	5
V ₂ O ₅	19.08				
V ₂ O ₃		10.93	11.14	15.39	15.85
PbO	49.67			0.19	0.05
Fe ₂ O ₃		54.95	53.28	51.54	49.18
FeO	4.51				
Nb ₂ O ₅	0.55	8.24	5.34	3.41	5.19
Al ₂ O ₃	2.4	1.86	2.10	2.76	1.93
SiO ₂	4.47	3.03	3.21	3.82	3.40
TiO ₂	2.38	3.32	4.05	3.84	3.36
BaO	0.49	0.50	0.20		
SrO	0.57				
P ₂ O ₅	1.42				
SO ₃	4.85	3.88	3.88	1.54	1.91
The amount	90.39	86.68	83.21	82.49	80.37

Table 10. Distribution of manganese in the hypergenic complex by wells of the Severny part of Tomtor ore field

Drilling well №	Thickness, m	Average content MnO %
101	28.4	11.71
105	110	13.75
108	40	10.58
111	13	12.25
3665	30	22.57
4465	70	12.72
Average by wells	48.6	12.83

Добавлено примечание ([ДАГ2]): Общее железо? Указать

Добавлено примечание ([ДАГ3]): Общее железо? Или определялось химией? Указать
И.М.Куликова,Р.Л.Баринский Микрорентгеноанализ содержания ионов переходных элементов разной валентности в минералах//ЗВМО,1998,№2, 115-119

Table 11. Forecast resources of manganese oxide in laterite weathering crusts of the Severny section of the Tomtorsky ore field.

The area of the ore-bearing site, thousand m ²	Average ore capacity, m	Ore volume million m ³	Volume weight of ore, t/m ³	Ore volume, mln.t.	Average content of MnO in ore, %	Ore resources, million tons
1550.6	23	35.7	3.8	135.5	12.83	17.4

Table 12. Weathering crust deposits of carbonatites

Deposit	Type of deposit; substrate*	Type of ore	Ore component	Average component content, %
1	2	3	4	5
Beloziminskoe, Russia	Hydrosilicic crust; K, AK	Apatite-pyrochlore in hydrosilicic ochres and loose particles	Nb ₂ O ₅ P ₂ O ₅	0.5 6.4-11.74
Novopolotskoye, Ukraine	The same; K, D, DC	The same	Nb ₂ O ₅ P ₂ O ₅	0.32 9.0
Tatarskoe I, Russia	The same; A	The same	Nb ₂ O ₅ P ₂ O ₅ vermiculite, hydrosilica	0.61 8.2 30.0
Anjico, Brazil	The same; K	Apatite with vermiculite in hydrosilicic ochres	P ₂ O ₅	15.4
Tatarskoe II, Russia	Laterite crust; A	Pyrochlore in laterite ochres Francolites in limonite-francolite rocks	Nb ₂ O ₅ P ₂ O ₅	1.2-2.5 23.7
Chuktukon, Russia	The same; K, AK	Pyrochlore-monazite-florencite in laterite ochres Francolites in limonite-francolite rocks	Nb ₂ O ₅ P ₂ O ₅ Y ₂ O ₃	1.0-1.48 5.0 0.23-0.34
Kovdor, Russia	Laterite crust; K	Apatite-francolite	P ₂ O ₅	15-20
Arasha (Bareiro), Brazil	The same; Δ	Pyrochlore with barite in laterite ochres Monazite in laterite ochres Francolites in limonite-francolite rocks	Nb ₂ O ₅ , BaSO ₄ TR ₂ O ₃ P ₂ O ₅	2.5; 20.67 13.5 15.01
Catalan I, Brazil	The same; K, Δ	Pyrochlore in laterite ochres Phosphate Rare earths Titanium	Nb ₂ O ₅ P ₂ O ₅ TR ₂ O ₃ TiO ₂	1.51 7.96 12.2 19.9
Catalan II, Brazil	The same; K, Δ	Pyrochlore in laterite ochres	Nb ₂ O ₅	2.18
Ceish Lagos, Brazil	The same; Φ	Ti-Nb-ores with Nb-rutile and Nb-brookite in ochres Hollandite in the surface facies of the crust including the rich Ferruginous oxide in ochres	Nb ₂ O ₅ TiO ₂ MnO ₂ Fe ₂ O ₃	2.81 12.0 61.6 80.0
Moro do Cerrote (Brazil)	The same; K	Apatite-francolite	P ₂ O ₅	29
Bingo, Zaire	The same; K	Пирохлоровые в латеритных охрах	Nb ₂ O ₅	2.86
Luesh, Zaire	The same; K, CK	Pyrochlorite in ochre-clay weathering products	Nb ₂ O ₅	1.34

Mrima, Kenya	The same; K, Δ	Pyrochlore-monazite in laterite ochres	Nb ₂ O ₅ TR ₂ O ₃	0.7 5.0
Mabouni, Gabon	The same; K, Δ	Pyrochlore in laterite ochres	Nb ₂ O ₅	1.5
Sokli, Finland	The same; K	Francolite with pyrochlore in limonite-francolite rocks	P ₂ O ₅ Nb ₂ O ₅ TR ₂ O ₃	17.8 0.46 0.35-0.94
Mount Weld, Australia	The same; K	Pyrochlore in laterite ochres	Nb ₂ O ₅ Ta ₂ O ₅	1.86 0.034
	The same; A	Monazite in laterite ochres	TR ₂ O ₃ including the rich TR ₂ O ₃ Y ₂ O ₃	11.2 23.6 0.33
Tomtor, Russia	Epigenetically altered laterite cortex (Buranny site); LO	Crandallite-monazite pyrochlorite in epigenetically altered ochres	Nb ₂ O ₅ TR ₂ O ₃ Y ₂ O ₃ Sc ₂ O ₃ V ₂ O ₅ SrO TiO ₂	4.93 12.8 0.87 0.06 1.0 3.9 7.0
	Laterite crusts (deposit as a whole); K, AK, A	Monazite-pyrochlorite in laterite ochres	Nb ₂ O ₅ TR ₂ O ₃	0.7-1.4 4.4
		Pyrochlore-francolite in limonite-francolite rocks	Nb ₂ O ₅ P ₂ O ₅	0.6 14-20

Note. *Rocks undergoing weathering or reductive epigenesis: K – calcitic, A – ankeritic, AK – ankerite-calcitic, D – dolomitic, DK – dolomite-calcite carbonatite, F – sideritic ferrocarbonatite, SK – syenite-carbonatite, LO – lateritic ochres. The table uses overview summary works "Deposits of carbonatite weathering crust" (Lapin, Tolstov 1995). "Minerageny of the weathering crust of carbonatites" (Lapin, Tolstov 2011), as well as original sources on individual deposits given in these summary works.