

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 | 0.86 |
| Ce ₂ O ₃ | 0.15 | 0.19 | 0.35 | 0.26 | 0.74 | 0.48 | 1.16 | |
| 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)

Добавлено примечание ([ДАГ1]): Указать сумму

| 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 |

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 |
| Novopolavskoye, 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.