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GEOCHEMISTRY

Age and Sources of Dunite from the Konder Massif (Aldan Shield)

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Abstract—The Sm–Nd and Rb–Sr isotope characteristics were studied in clinopyroxenes (Cpx) of ultrabasic rocks (dunite, wehrlite, pyroxenite, and kosvite) from the Konder massif, which is a source of a unique placer platinum deposit. The chemical composition of the clinopyroxenes studied provides evidence for their crystallization from a single melt in the course of magmatic differentiation. The Sm–Nd isotope characteristics of Cpx in dunite from the Konder massif correspond to the regression with an age of 128 ± 40 Ma, which provides evidence for the same age of rocks of the "dunite core," wehrlite, pyroxenite, kosvite, and alkaline rocks of the subsequent intrusive stage in the Konder massif. Variations in the Sr and Nd isotope characteristics in dunite, wehrlite, pyroxenite, and kosvite result from contamination of the picritic melt with rocks of the continental crust in the course of its cumulative evolution, which allows us to exclude the model of diapiric intrusion of mantle dunite.

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Several massifs of ultrabasic and alkaline rocks with associated placer deposits and ore occurrences, such as Konder, Chad, Inagli, Sybakh, and others [1], were discovered on the Aldan Shield in the middle of the last century. All of them have a concentrically zoned structure with a "dunite core." The resources of the Konder placer deposit exceed 100 t Pt [2]. Detailed study of ultrabasic rocks from the Konder massif has been carried out in order to predict similar giant PGE deposits of the placer and original types on the platforms [1]. However, their age and sources have been not defined reliably. To solve this task, we carried out Rb–Sr and Sm–Nd isotope–geochemical studies of dunite and pyroxenite from the Konder massif.

The Konder massif is located within the Batomga geoblock of the Aldan Shield. This massif is composed of ultrabasic rocks (dunite, wehrlite, pyroxenite, and kosvite), as well as hornblendite, gabbro, alkaline syenite, alkaline pegmatite, monzodiorite, subalkaline diorite, and subalkaline granite (Fig. 1). They intrude Archean crystalline rocks and Proterozoic terrigenous rocks and form a single ring structure with the central "dunite core." The influence of basic and alkaline melts on the "core" rocks and their metasomatic alterations resulted in the formation of clinopyroxene, apatite–titanomagnetite–biotite–amphibole–clinopyroxene, and amphibole rocks, as well as serpentinite.

Ideas on the age of ultrabasic rocks of the Konder massif are contradictory: Proterozoic or Mesozoic. Attempts to estimate the age of dunite by the K–Ar, Rb–Sr, and Sm–Nd isotope methods provided either a wide range of age values obtained or a huge error [3]. Age estimations for zircons and baddeleyites from dunite by the U–Pb method provided significantly different and contradictory results as well (from 2477 to 125 Ma) [4, 5]. The age of other rocks from the Koder massif was defined as Early Cretaceous (110–130 Ma) [3, 6]. In addition, the problem of petrogenesis of ultrabasic, basic, and alkaline rocks of the massif is debatable. Most researchers adhere to the ideas of the intrusive origin of ultrabasic rocks of the massif ([1, 7] and others). At the same time, dunite of the massif is interpreted as a mantle protrusion [4, 8].

Ultrabasic rocks are characterized by an extremely low concentration of rare elements including the components of the Sm–Nd, Rb–Sr, and U–Pb radiogenic isotope systems, which make it extremely difficult to carry out isotope–geochemical studies. In addition, the Sm–Nd, Rb–Sr, and U–Pb isotope systems of ultrabasic rocks are very sensitive to overprinted alterations.

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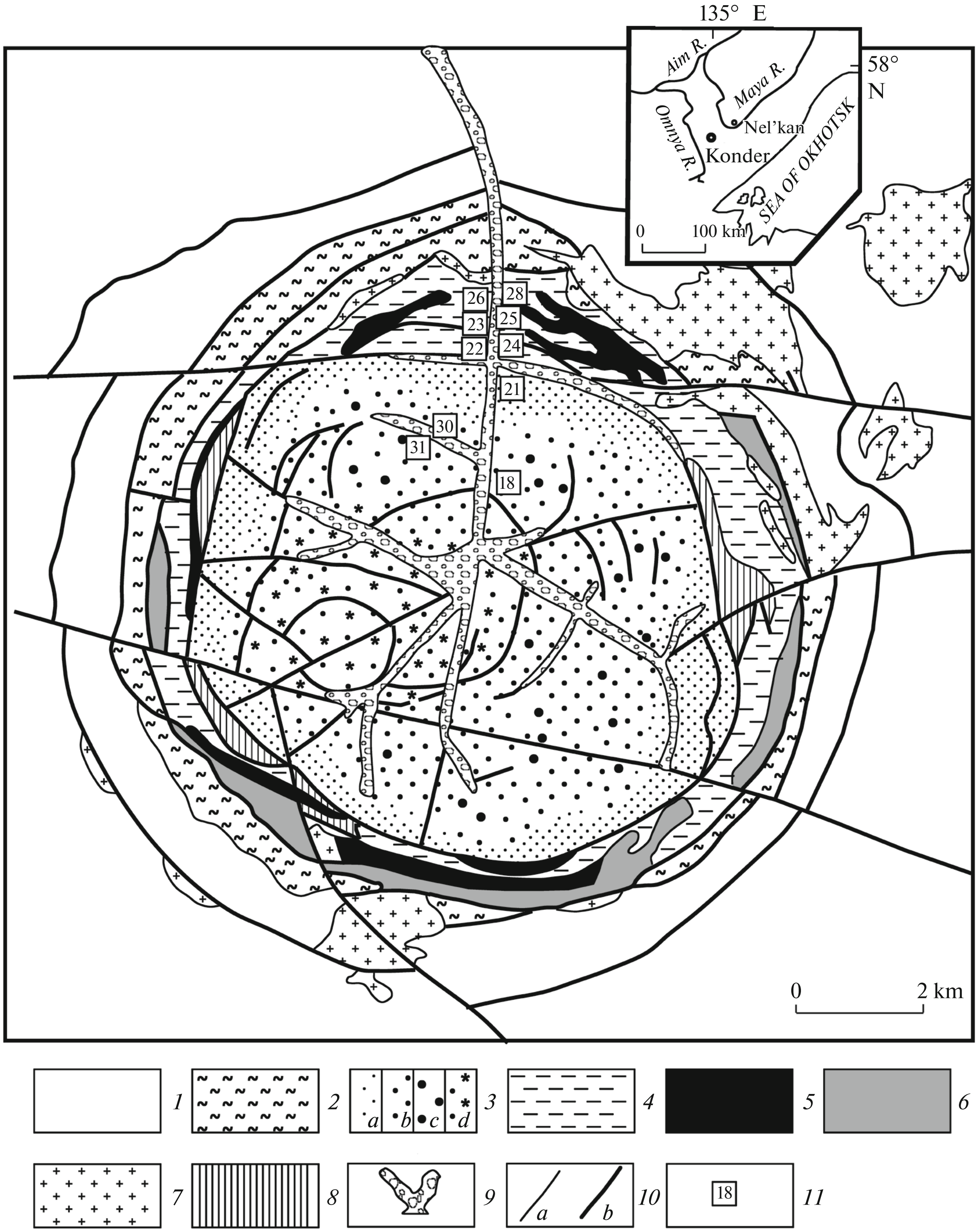

Fig. 1. Geological structure of the Konder massif on the Aldan Shield, compiled using the geological maps 1 : 10000 and 1 : 25000 (PGO Dal'geologiya [1]). (*1*) Middle Riphean sedimentary rocks (aleurolite and sandstone); (*2*) Archean granite and metamorphic rocks (gneiss, crystalline schist, marble, etc.); (*3*) dunite: (*a*) fine-granular, (*b*) fine-, medium-, and coarse-granular, (*c*) pegmatoid, and (*d*) metasomatically altered; (*4*) pyroxenite; (*5*) kosvite; (*6*) gabbro; (*7*) subalkaline diorite and monzodiorite; (*8*) olivine–diopside metasomatic rocks; (*9*) PGE placers; (*10*) boundaries and faults: (*a*) geological boundaries, (*b*) faults; (*11*) places of sampling and sample numbers.

We performed the Rb–Sr and Sm–Nd isotope–geochemical study of clinopyroxenes from dunite, wehrlite, pyroxenite, and kosvite from the Konder massif for direct estimation of their age, as well as for establishment of the source of ultrabasic rocks and their likely genetic links to the sources of the later intrusive phases. Clinopyroxenes (Cpx) of ultrabasic rocks are the major hosts for incompatible elements.

Table 1. Chemical composition of clinopyroxene from ultrabasic rocks of the Konder massif (wt %)

Rock	1			2	3			4	5
Sample	18	21	30	31	22	25	26	23	28
Comp.	X(6)	X(7)	X(7)	X(10)	X(7)	X(24)	X(16)	X(20)	X(25)
SiO_2	54.23	54.02	54.06	53.92	53.02	53.63	53.62	53.32	52.72
TiO_2	0.08	0.12	0.08	0.16	0.27	0.20	0.23	0.28	0.34
Al_2O_3	0.88	0.62	0.86	0.84	1.27	1.05	1.08	1.21	1.60
Cr_2O_3	0.68	0.51	1.04	0.55	0.19	0.33	0.43	0.24	0.11
FeO	2.34	2.50	1.94	3.24	5.07	4.13	3.92	4.67	6.16
MnO	0.04	0.04	0.08	0.10	0.07	0.11	0.12	0.12	0.13
MgO	15.52	15.63	15.54	15.90	14.72	15.42	15.77	15.16	14.15
CaO	25.91	26.39	26.04	25.16	25.20	25.03	24.65	24.89	24.62
Na_2O	0.32	0.16	0.37	0.14	0.18	0.10	0.19	0.13	0.16
Mg#	0.922	0.918	0.935	0.897	0.838	0.869	0.878	0.853	0.803

X is the average value (the number of analyzed grains is given in parentheses); Mg# = 100Mg/(Mg + Fe), at %. (1) Dunite with accessory chrome spinellide; (2) vein clinopyroxenite; (3) olivine clinopyroxenite; (4) wehrlite in clinopyroxenite; (5) kosvite.

This allowed us to perform their isotope analysis with an acceptable accuracy.

The samples were collected from the "dunite core," as well as from pyroxenite in the marginal part of the Konder massif. The places of sampling were selected in the areas where dunite and pyroxenite were subjected to the lowest degree of influence of the later intrusive rocks (Fig. 1). The chemical composition of Cpx was studied at the Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences, on a JSM-6510LA electron microscope equipped with a JED-220 energy-dispersive spectrometer.

All samples of dunite and pyroxenite have insignificant signs of secondary alterations: replacement of olivine with serpentine, the presence of secondary biotite. The collected Cpx monofractions contain a high portion of grains with the products of postcrystallization alterations as well, mostly represented by biotite overgrowths. Because of this, we carried out leaching of Cpx monofractions in 50% solution of HF for 15 min at a room temperature. Then, after removal of the solution, Cpx monofractions were washed in ultrapure water three times and were kept in the 2-N solution of HCl on a hot plate for an hour. As a result, examination of Cpx under a microscope indicated complete removal of the products of secondary alterations. The losses were up to 30 wt % of the initial Cpx monofraction. Then, we performed decomposition of Cpx monofractions in a mixture of concentrated acids $HF-HNO_3-HClO_4$ in the proportion of 5 : 1 : 1 using fluoroplastic vessels at 130°C for 24 h. After decomposition, we extracted Rb, Sr, Sm, and Nd, according to the methodology [9], with further isotope analysis.

The Nd and Sr isotope composition was studied on a Triton multicollector solid-phase mass spectrometer at the Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences. The concentrations of Rb, Sr, Sm, and Nd were analyzed by the method of isotope dilution using mixed isotope indicators $^{150}Nd-^{149}Sm$ and $^{84}Sr-^{85}Rb$.

The Nd and Sr isotope composition of Cpx was analyzed in three samples of dunite, four samples of pyroxenite, and one sample of wehrlite. In addition, we analyzed the Nd and Sr bulk isotope composition in the kosvite sample (Fig. 1, Table 1). According to Mg# and the concentration of TiO_2 and other mineral-forming oxides in Cpx from ultrabasic rocks of the Konder massif, there is the following regular series corresponding to the magmatic differentiation (Fig. 2): recrystallized dunite → fine-granular subhedral dunite → vein clinopyroxenite → wehrlite and clinopyroxenite → kosvite. This allows us to suggest that ultrabasic rocks of the Konder massif have a magmatic (cumulative) nature.

The figurative points of the isotope compositions of Cpx (Table 2) from dunite form a trend with the slope corresponding to an age of 128 ± 40 Ma with an initial $\varepsilon_{Nd}(t) = +3.5$ on the Sm–Nd diagram (Fig. 3). The compositions of Cpx from wehrlite and pyroxenite plot significantly lower than those from dunite on the Sm–Nd diagram (Fig. 3) and do not provide a direct age estimate by the Sm–Nd method. The value of $\varepsilon_{Nd}(t)$ for wehrlite and pyroxenite recalculated for the age of dunite ranges from –1.9 to –0.6. The isotope characteristics of Nd in dunite, wehrlite, and pyroxenite are characterized by a negative correlation with the isotope characteristics of Sr (Fig. 4). The initial values of $\varepsilon_{Sr}(t)$ in Cpx from dunite vary from –17 to

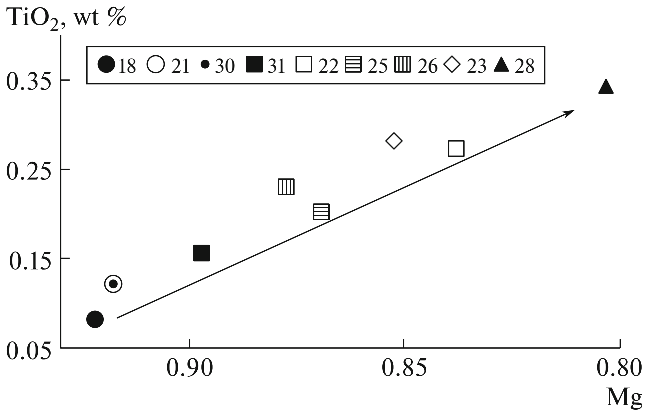

Fig. 2. Compositional variations of Cpx (Mg# and TiO_2 content). Numerals in the legend correspond to sample numbers in Table 1. An arrow shows the assumed trend of magmatic differentiation for ultrabasic rocks.

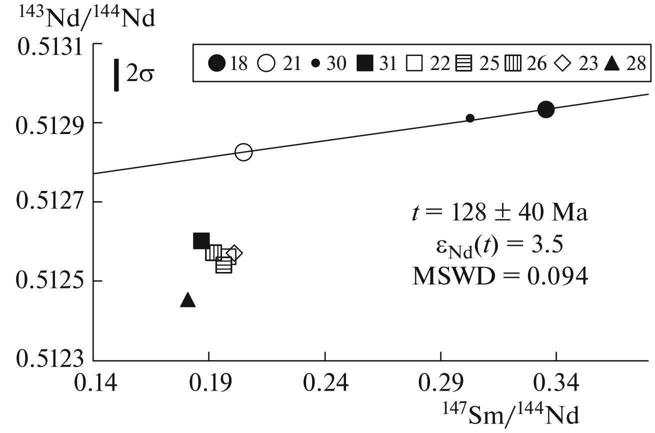

Fig 3. $^{147}Sm/^{144}Nd$–$^{143}Nd/^{144}Nd$ diagram for Cpx from ultrabasic rocks of the Konder massif (Table 2). The regression line is plotted using the data for Cpx from dunite. The black rectangle in the upper left-hand corner characterizes the errors of the measured ratios $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$ within 2σ. See Fig. 2 for other symbols.

–8.5; in Cpx from wehrlite and pyroxenite, from –7.3 to –4.8. Kosvite is characterized by the lowest value of $\varepsilon_{Nd}(t)$ = –3.4 and by the highest value of $\varepsilon_{Sr}(t)$ = –0.5 in comparison with other rocks.

Since Cpx has a cumulative genesis, variations in the Nd and Sr isotope characteristics may be explained by two reasons: the different participation of mantle sources (depleted and enriched) and various degrees of melt contamination with host rocks.

According to the previously suggested model, the dunite core of the Konder massif crystallized from the picritic melt in the mantle and intruded into the continental crust as a consolidated body [8]. In this case, the observed variations in the isotope characteristics of Nd and Sr in Cpx from dunite and clinopyroxenite should result in differences in the mantle sources of these rocks. However, as was shown above, the composition of Cpx from rocks of the dunite–pyroxenite complex corresponds to a single magmatic trend. Therefore, it is most likely that the observed variations in the isotope characteristics of Sr and Nd in these rocks (Fig. 4) are controlled by contamination of

Table 2. Sm–Nd and Rb–Sr isotope characteristics of clinopyroxenes from ultrabasic rocks of the Konder massif

Rock	Sample	Sm, ppm	Nd, ppm	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	+/–2σ	$\varepsilon_{Nd}(t)$	Rb, ppm	Sr, ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	+/–2σ	$\varepsilon_{Sr}(t)$
1	18	0.12	0.22	0.3356	0.512933	61	3.5	0.001	22.11	0.0001	0.703643	6	–10.0
1	21	0.27	0.80	0.2049	0.512825	9	3.5	0.02	26.06	0.0023	0.703753	6	–8.5
1	30	0.30	0.60	0.3029	0.512911	7	3.5	2.28	17.61	0.3741	0.703853	7	–16.9
2	31	0.55	1.78	0.1869	0.512600	8	–0.6	0.02	79.27	0.0009	0.703835	4	–7.3
3	22	0.86	2.61	0.1983	0.512560	5	–1.5	0.00	83.48	0.0001	0.704013	7	–4.8
3	25	0.75	2.31	0.1969	0.512540	5	–1.9	0.001	77.46	0.0001	0.703902	6	–6.4
3	26	0.63	1.97	0.1925	0.512571	4	–1.2	0.001	83.94	0.0001	0.703923	3	–6.1
4	23	0.81	2.43	0.2012	0.512570	4	–1.4	0.001	84.47	0.0001	0.703990	8	–5.1
5	28	1.95	6.49	0.1813	0.512452	3	–3.4	4.68	125.55	0.1078	0.704516	5	–0.5

(1–5) Rocks from Table 1. The $\varepsilon_{Nd}(t)$ and $\varepsilon_{Sr}(t)$ values are calculated for the age obtained by regression of clinopyroxenes from dunite (128 Ma). The following parameters were used for calculation of $\varepsilon_{Nd}(t)$ and $\varepsilon_{Sr}(t)$: $^{147}Sm/^{144}Nd_{CHUR}$ = 0.1968, $^{143}Nd/^{144}Nd_{CHUR}$ = 0.512638, $^{87}Rb/^{86}Sr_{UR}$ = 0.0816, $^{87}Sr/^{86}Sr_{UR}$ = 0.7045 [11]. The values of the bulk run were 0.05 ng for Rb, 0.02 ng for Sr, 0.03 ng for Sm, and 0.05 ng for Nd. Reproducibility of isotope analyses was controlled by measurement of the composition of the La Jolla and SRM-987 standards. In the period of Sr measurements, $^{87}Sr/^{86}Sr$ in the SRM-987 standard was 0.710241 ± 15 (2σ, 10 analyses) and the $^{143}Nd/^{144}Nd$ value in the La Jolla standard was 0.511847 ± 8 (2σ, 12 analyses). The Sr isotope composition is normalized for $^{88}Sr/^{86}Sr$ = 8.37521; the Nd isotope composition, for $^{146}Nd/^{144}Nd$ = 0.7219. The error in determination of the $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$ ratios estimated from ten measurements of the BCR-2 standard is 0.3 and 0.003%, respectively. The data for kosvite are given for bulk rock.

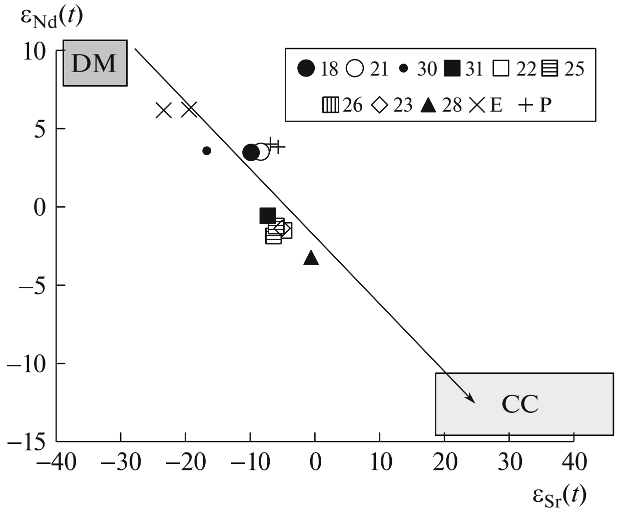

Fig. 4. $\varepsilon_{Sr}(t)$–$\varepsilon_{Nd}(t)$ diagram for rocks from the Konder massif. DM, depleted mantle; CC, ancient continental crust [11]; E, isotope characteristics of apatite–phlogopite–magnetite pyroxenite [4]; P isotope characteristics of alkaline syenite [3]. See Fig. 2 for other symbols.

picritic melt with rocks of the continental crust in the course of its crystallization.

The isotope characteristics of dunite representing a cumulate indicate the parameters of the melt at the early stage of its magmatic evolution, when olivine crystallized. Pyroxenite and wehrlite characterize the isotope parameters of the residual melt. The isotope characteristics of Sr and Nd for the sample of kosvite are on the continuation of the isotope trend from dunite to pyroxenite (Fig. 4). As the compositions of Cpx from this sample plot on the continuation of a single magmatic trend of ultrabasic rocks (Fig. 2), igneous kosvite from the Konder massif may be considered as a later product of crystallization of the melt common with dunite and pyroxenite. Therefore, estimates of the dunite age based on the isotope dating of zircons extracted from this rock [4, 5], in our opinion, may be explained by the xenogenic nature of zircons.

The results obtained allow us to make the following conclusions:

(1) The Sm–Nd isotope characteristics of Cpx from dunite of the Konder massif correspond to the regression with an age of 128 ± 40 Ma. This allowed us to substantiate the same age of rocks from the "dunite core" and alkaline rocks of the later intrusive stage in the Konder massif. The age obtained is in agreement with age estimate for native platinum from the Konder massif (112 ± 7) previously obtained by the Pt–He method [10].

(2) Variations in the Sr and Nd characteristics in dunite, wehrlite, pyroxenite, and kosvite result from contamination of the initial picritic melt with rocks of the continental crust in the course of its crystallization. This excludes the model of diapiric intrusion of mantle dunite.

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