Sm-Nd метод

$$^{147}Sm \rightarrow {}^{143}Nd + \alpha + 2.23\ Mev$$

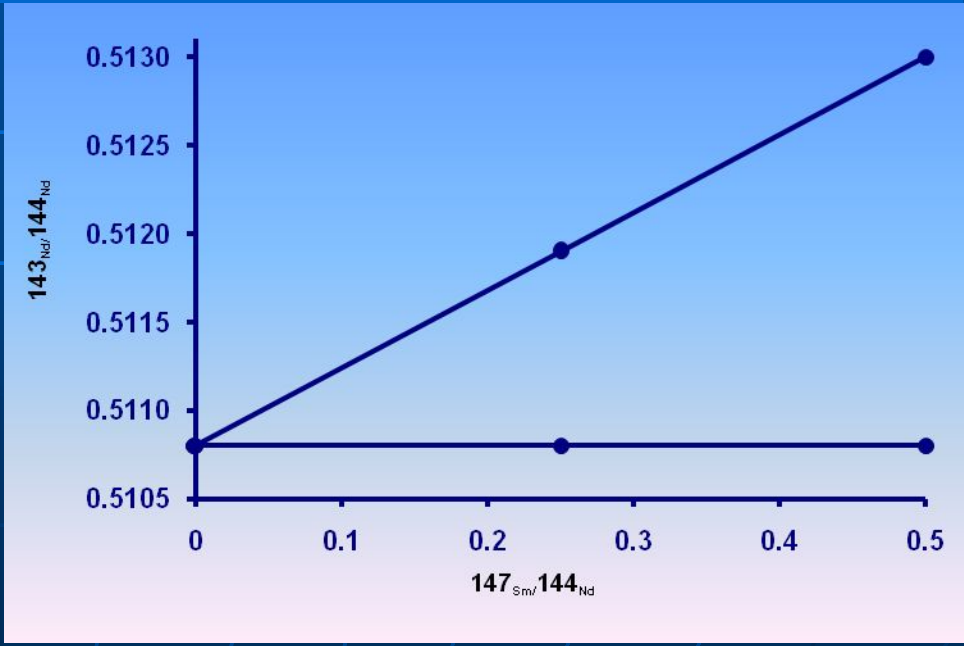
$$\lambda = 6.54 \times 10^{-12}\ год^{-1} \quad \rightarrow \quad T_{1/2} = 106\ млрд.лет$$

Lugmair G.W. Sm-Nd ages: a new dating method (abs). // Meteoritics. 1974. V.9. P. 369.

$$\frac{^{143}Nd}{^{144}Nd} = \left(\frac{^{143}Nd}{^{144}Nd}\right)_0 + \left(\frac{^{147}Sm}{^{144}Nd}\right) \cdot [\exp(\lambda \cdot t) - 1]$$

$$t = \frac{1}{\lambda} \ln\left[\frac{\frac{^{143}Nd}{^{144}Nd} - \left(\frac{^{143}Nd}{^{144}Nd}\right)_0}{\frac{^{147}Sm}{^{144}Nd}} + 1\right]$$

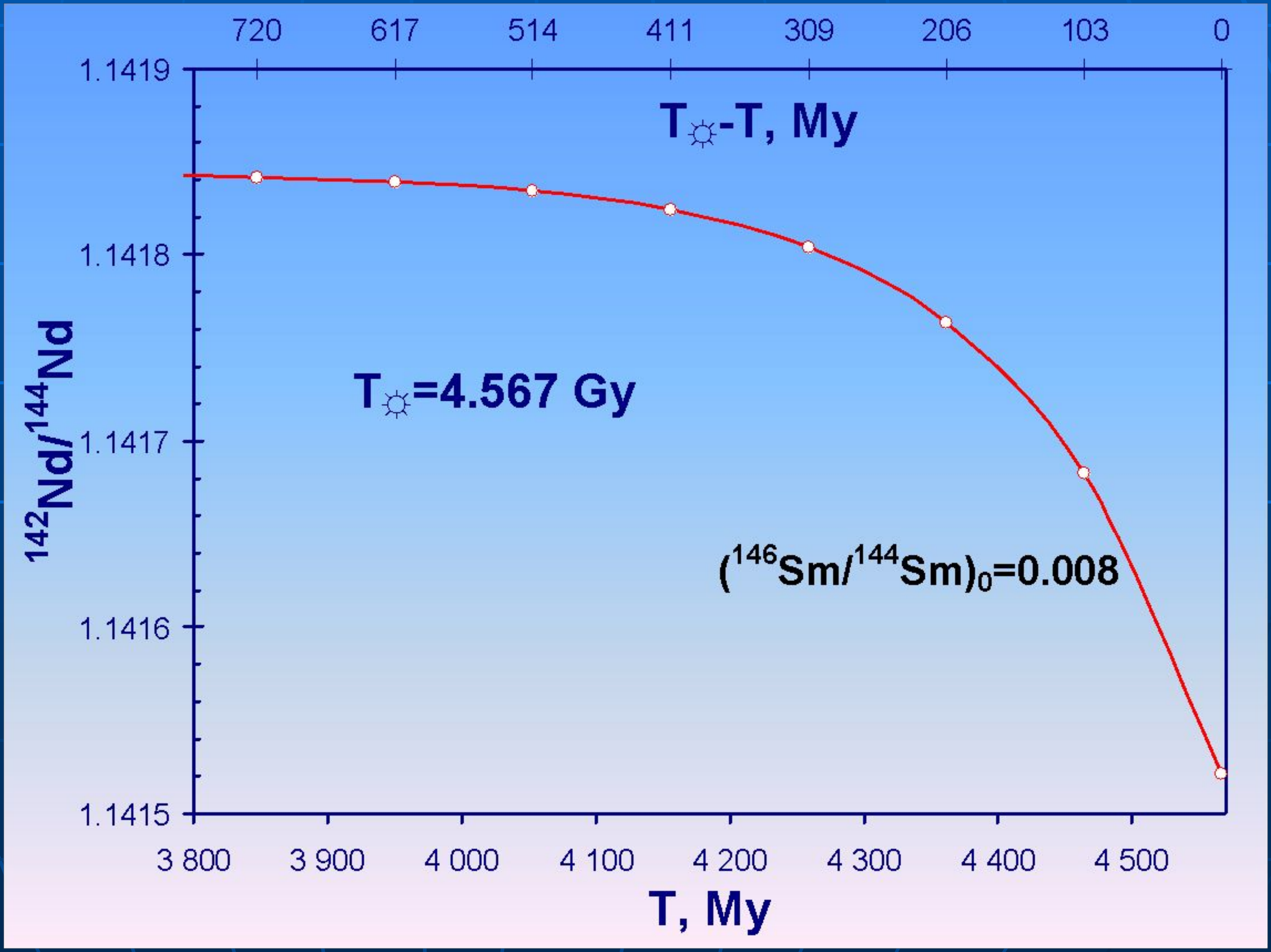
$$t = \frac{1}{\lambda} \ln\left[\frac{\left(\frac{^{143}Nd}{^{144}Nd}\right)_1 - \left(\frac{^{143}Nd}{^{144}Nd}\right)_2}{\left(\frac{^{147}Sm}{^{144}Nd}\right)_1 - \left(\frac{^{147}Sm}{^{144}Nd}\right)_2} + 1\right]$$



$$^{146}Sm \xrightarrow{\alpha} {}^{142}Nd$$

$$\lambda = 6.74 \times 10^{-9}\ \text{год}^{-1}$$

$$T_{1/2} = 103\ \text{млн.лет}$$



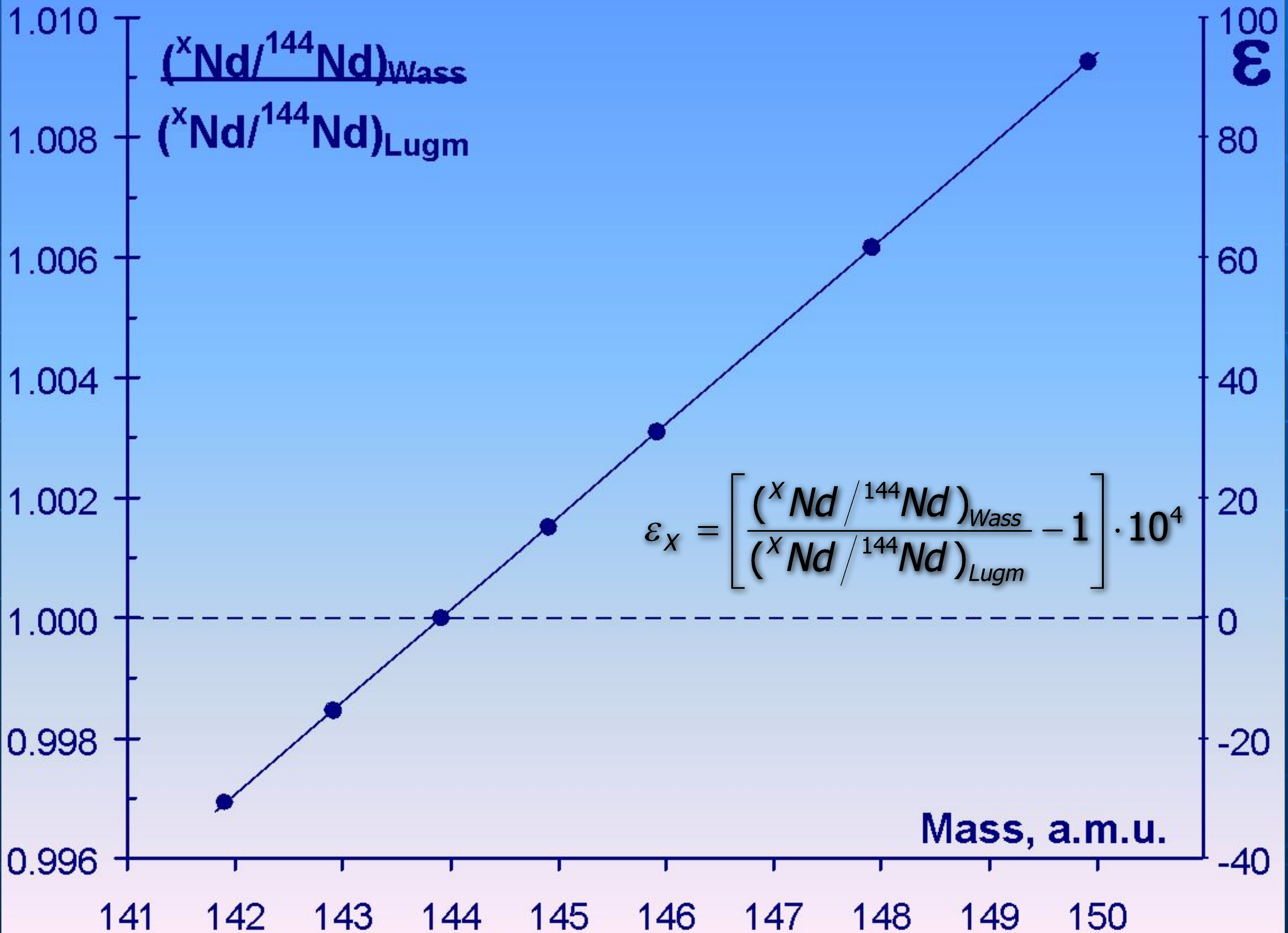
Изотопный состав Sm и Nd

$^{144}Sm/^{154}Sm=$	0.13516
$^{147}Sm/^{154}Sm=$	0.65918
$^{148}Sm/^{154}Sm\equiv$	0.49419
$^{149}Sm/^{154}Sm=$	0.6075
$^{150}Sm/^{154}Sm=$	0.3244
$^{152}Sm/^{154}Sm=$	1.17537

	At.%	AW
^{144}Sm	3.075%	143.91207
^{147}Sm	14.996%	146.91493
^{148}Sm	11.242%	147.91485
^{149}Sm	13.820%	148.91721
^{150}Sm	7.380%	149.91730
^{152}Sm	26.738%	151.91976
^{154}Sm	22.749%	153.92222
Sm		150.3656

	University of California, San Diego, La Jolla (UCSD), G.W.Lugmair	California Institute of Technology, Pasadena (CIT), G.J.Wasserburg		At.%	AW
$^{142}Nd/^{144}Nd=$	1.141817	1.138305	^{142}Nd	27.168%	141.9077
$^{143}Nd/^{144}Nd=$	(0.512638)	(0.511847)	^{143}Nd	12.198%	142.9099
			^{144}Nd	23.794%	143.9101
$^{145}Nd/^{144}Nd=$	0.348404	0.348933	^{145}Nd	8.290%	144.9126
$^{146}Nd/^{144}Nd\equiv$	0.7219	0.724137	^{146}Nd	17.177%	145.9132
$^{148}Nd/^{144}Nd=$	0.241572	0.243062	^{148}Nd	5.748%	147.9169
$^{150}Nd/^{144}Nd=$	0.236431	0.238621	^{150}Nd	5.626%	149.9209
			Nd		144.240

$$(^{147}Sm/^{144}Nd)_{at} = (Sm/Nd)_W \cdot 0.60456$$



$\frac{(^{x}Nd/^{144}Nd)_{Wass}}{(^{x}Nd/^{144}Nd)_{Lugm}}$
ε
$\varepsilon_X = \left[\frac{(^{X}Nd/^{144}Nd)_{Wass}}{(^{X}Nd/^{144}Nd)_{Lugm}} - 1 \right] \cdot 10^4$
Mass, a.m.u.
1.010
1.008
1.006
1.004
1.002
1.000
0.998
0.996
100
80
60
40
20
0
-20
-40
141
142
143
144
145
146
147
148
149
150

$$\varepsilon_{Nd}^{T} = \left[\frac{({}^{143}Nd / {}^{144}Nd)_{Sample}^{T}}{({}^{143}Nd / {}^{144}Nd)_{CHUR}^{T}} - 1 \right] \cdot 10^4$$

где:

$$\left(\frac{{}^{143}Nd}{{}^{144}Nd} \right)_{Sample}^{T} = \frac{{}^{143}Nd}{{}^{144}Nd} - \left(\frac{{}^{147}Sm}{{}^{144}Nd} \right) \cdot [\exp(\lambda \cdot t) - 1]$$

$$\left(\frac{{}^{143}Nd}{{}^{144}Nd} \right)_{CHUR}^{T} = \left(\frac{{}^{143}Nd}{{}^{144}Nd} \right)_{CHUR} - \left(\frac{{}^{147}Sm}{{}^{144}Nd} \right)_{CHUR} \cdot [\exp(\lambda \cdot t) - 1]$$

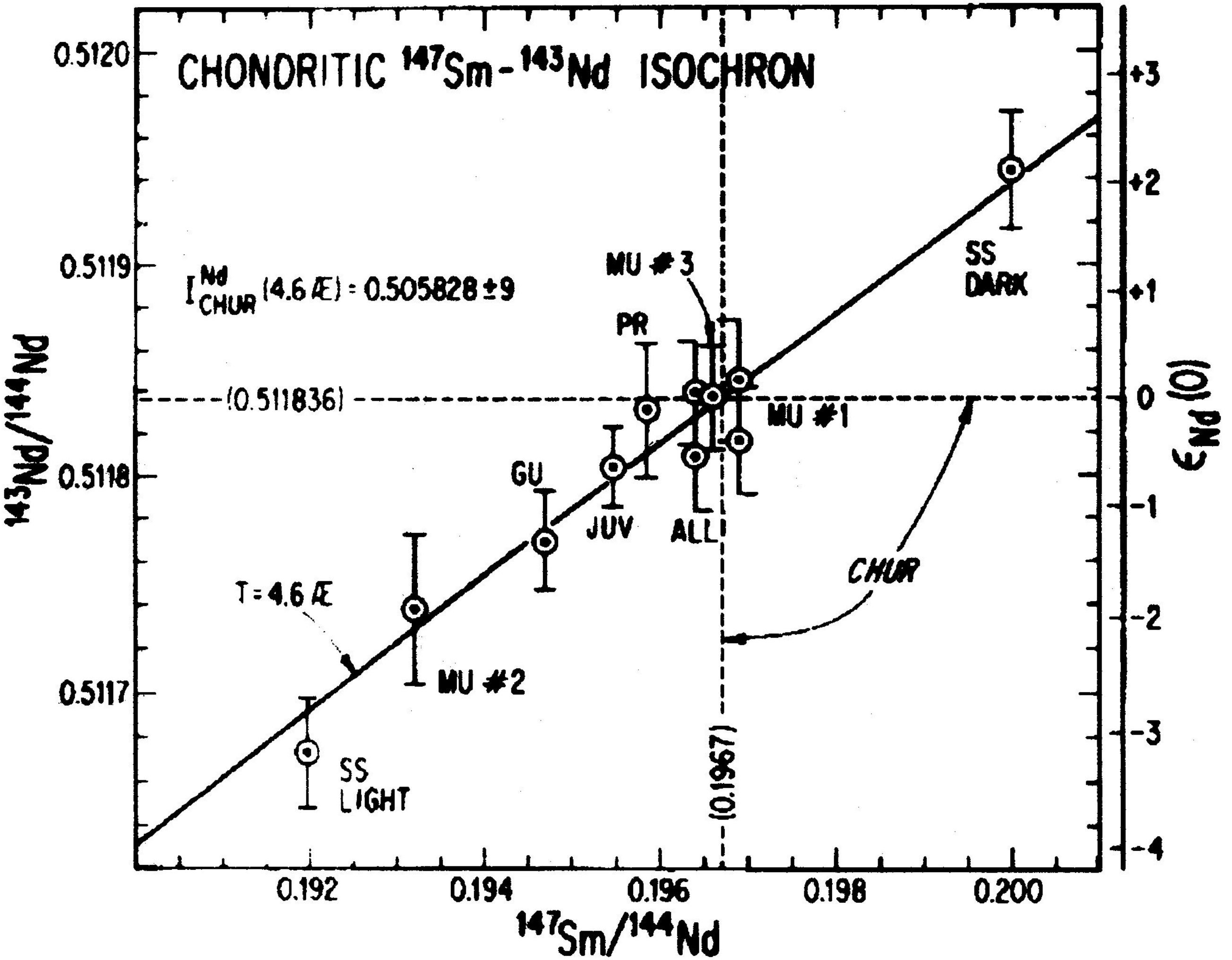


Fig. 2. Sm-Nd evolution diagram for chondrite samples and Juvinas. A reference line with a slope of 4.6 AE is shown. The dashed lines represent the new values selected for average chondrites (CHUR).

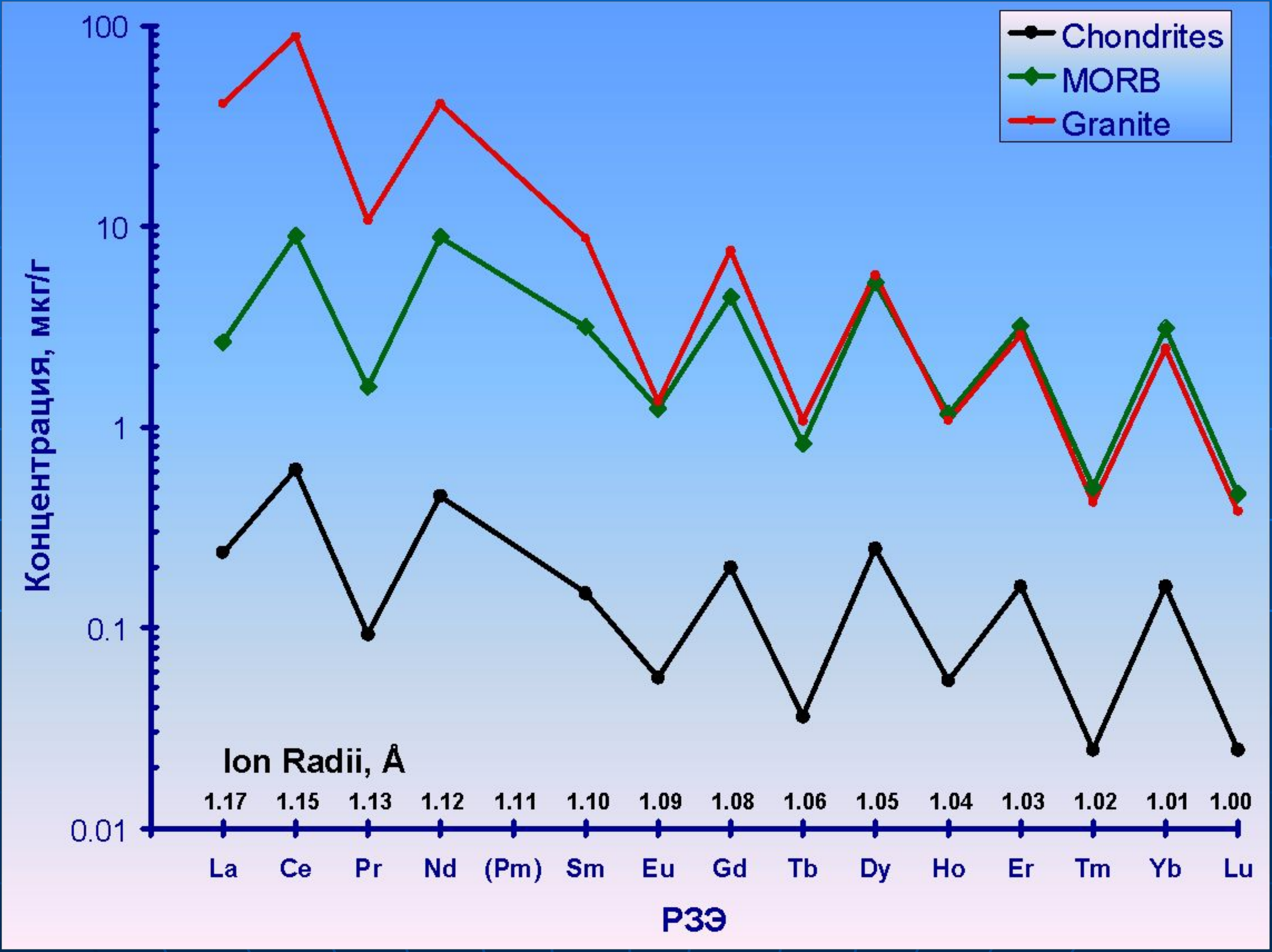
Jacobsen S.B., Wasserburg G.J., Sm-Nd isotopic evolution of chondrites. // Earth and Planetary Science Letters, 1980. 50: 139-155.

CHUR = Chondritic Uniform Reservoir

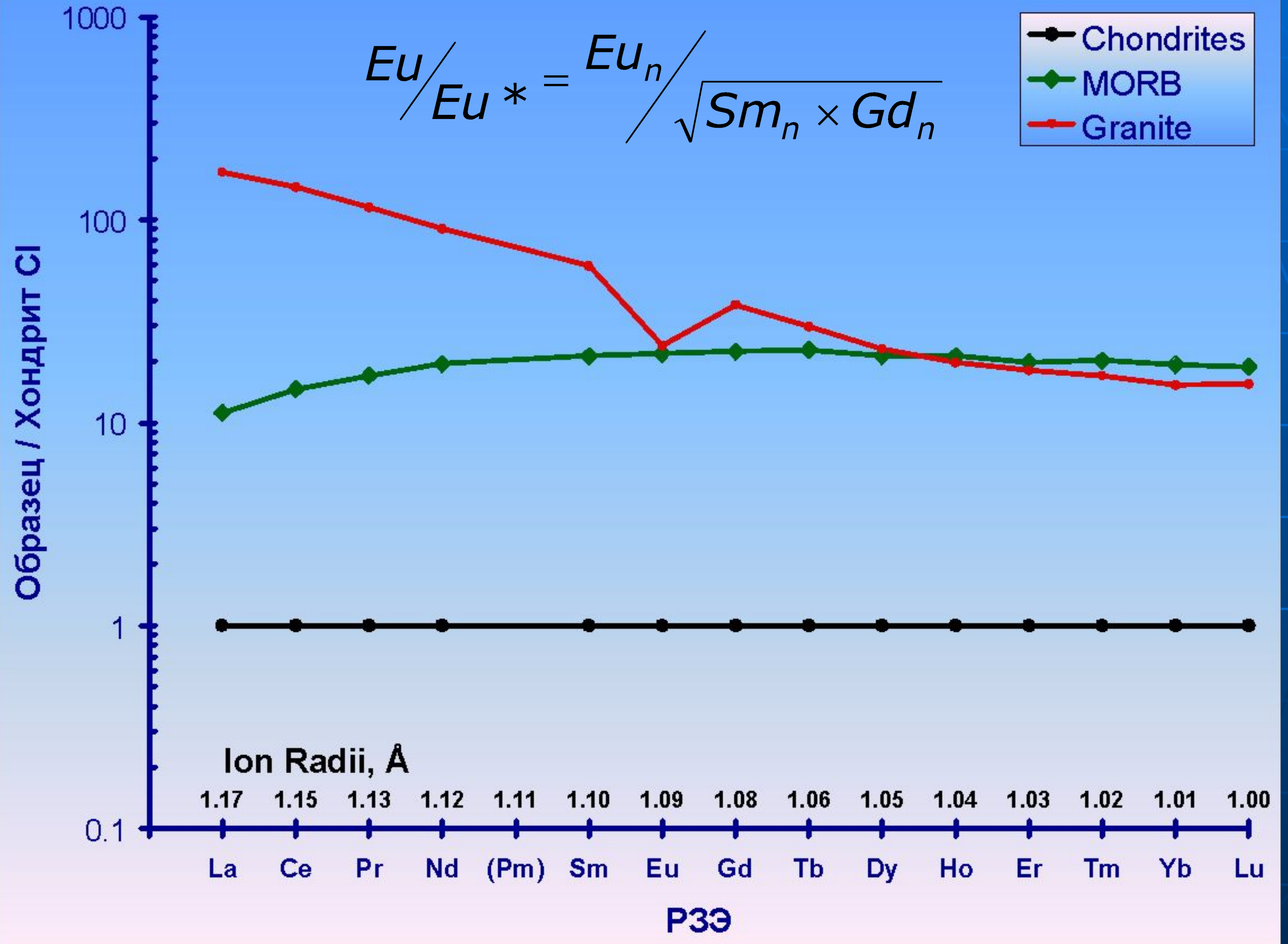
$$\left(\frac{^{143}Nd}{^{144}Nd}\right)^{t=0}_{CHUR} = 0.512638 \quad \textit{или} \quad 0.511847\ (Wass)$$

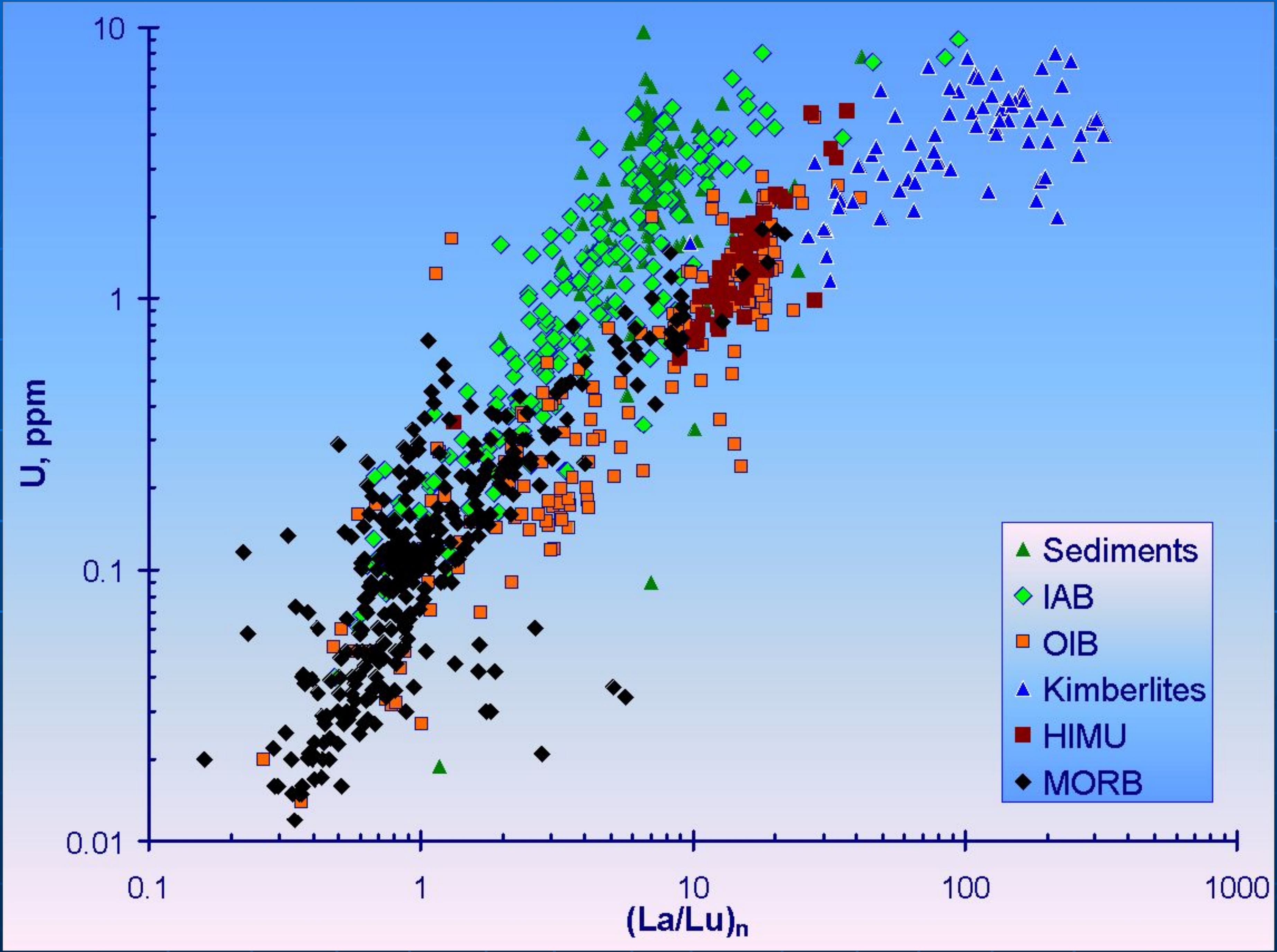
$$\left(\frac{^{147}Sm}{^{144}Nd}\right)_{CHUR} = 0.1967$$

$$\left(\frac{^{143}Nd}{^{144}Nd}\right)^{t=4.5}_{CHUR} = 0.506763 \quad \textit{или} \quad 0.505972$$

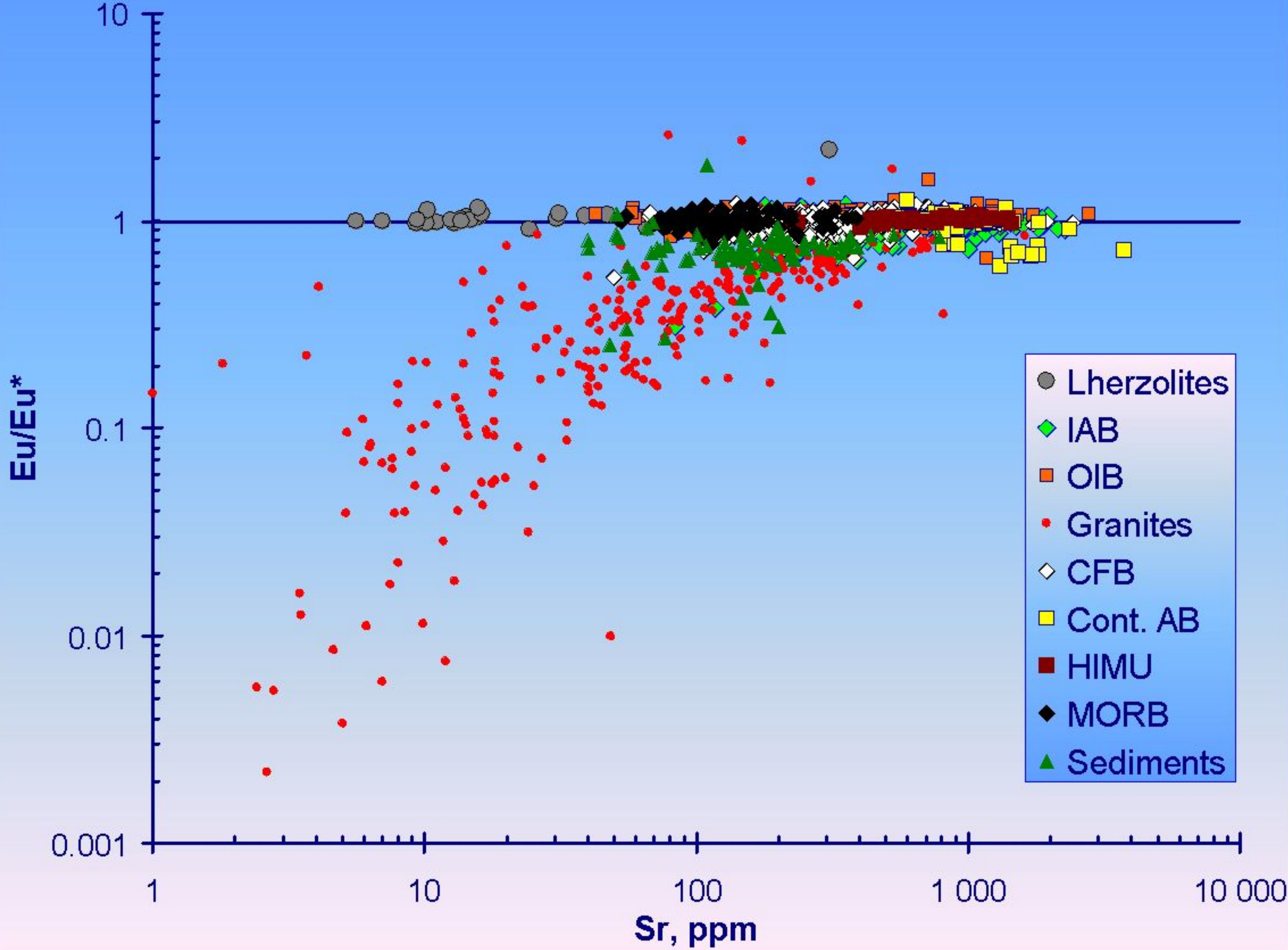

Chondrites
MORB
Granite
100
10
1
0.1
0.01
Концентрация, мкг/г
Ion Radii, Å
1.17
1.15
1.13
1.12
1.11
1.10
1.09
1.08
1.06
1.05
1.04
1.03
1.02
1.01
1.00
La
Ce
Pr
Nd
(Pm)
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
РЗЭ

$$Eu/Eu^* = Eu_n / \sqrt{Sm_n \times Gd_n}$$





U, ppm
10
1
0.1
0.01
0.1
1
10
100
1000
(La/Lu)n
Sediments
IAB
OIB
Kimberlites
HIMU
MORB



Eu/Eu*
10
1
0.1
0.01
0.001
1
10
100
1 000
10 000
Sr, ppm
Lherzolites
IAB
OIB
Granites
CFB
Cont. AB
HIMU
MORB
Sediments

Задача 10. Построить графики нормированных РЗЭ, рассчитать Eu/Eu* и $(La/Lu)_n$

	Chond-rites	82LI4Aa, Carbo-natite	907-3, Raumid granite-1	972-1, Raumid granite-7	GL49S, Basalt glass (N.Chile)
La	0.367	698	39.7	10.1	1.3
Ce	0.957	1500	77.6	29.9	4.9
Pr	0.137	184	8.0	5.0	1.04
Nd	0.711	705	25.9	24.8	6.2
Sm	0.231	113	4.06	9.49	2.4
Eu	0.087	30.6	0.506	0.015	0.97
Gd	0.306	79.0	2.97	7.74	3.4
Tb	0.058	9.64	0.44	1.79	0.65
Dy	0.381	45.3	2.47	15.2	4.3
Ho	0.0851	7.36	0.53	3.27	0.95
Er	0.249	17.1	1.63	8.13	2.7
Tm	0.036	1.96	0.27	1.93	0.38
Yb	0.248	11.5	1.91	15.5	2.5
Lu	0.0381	1.03	0.3	1.89	0.35

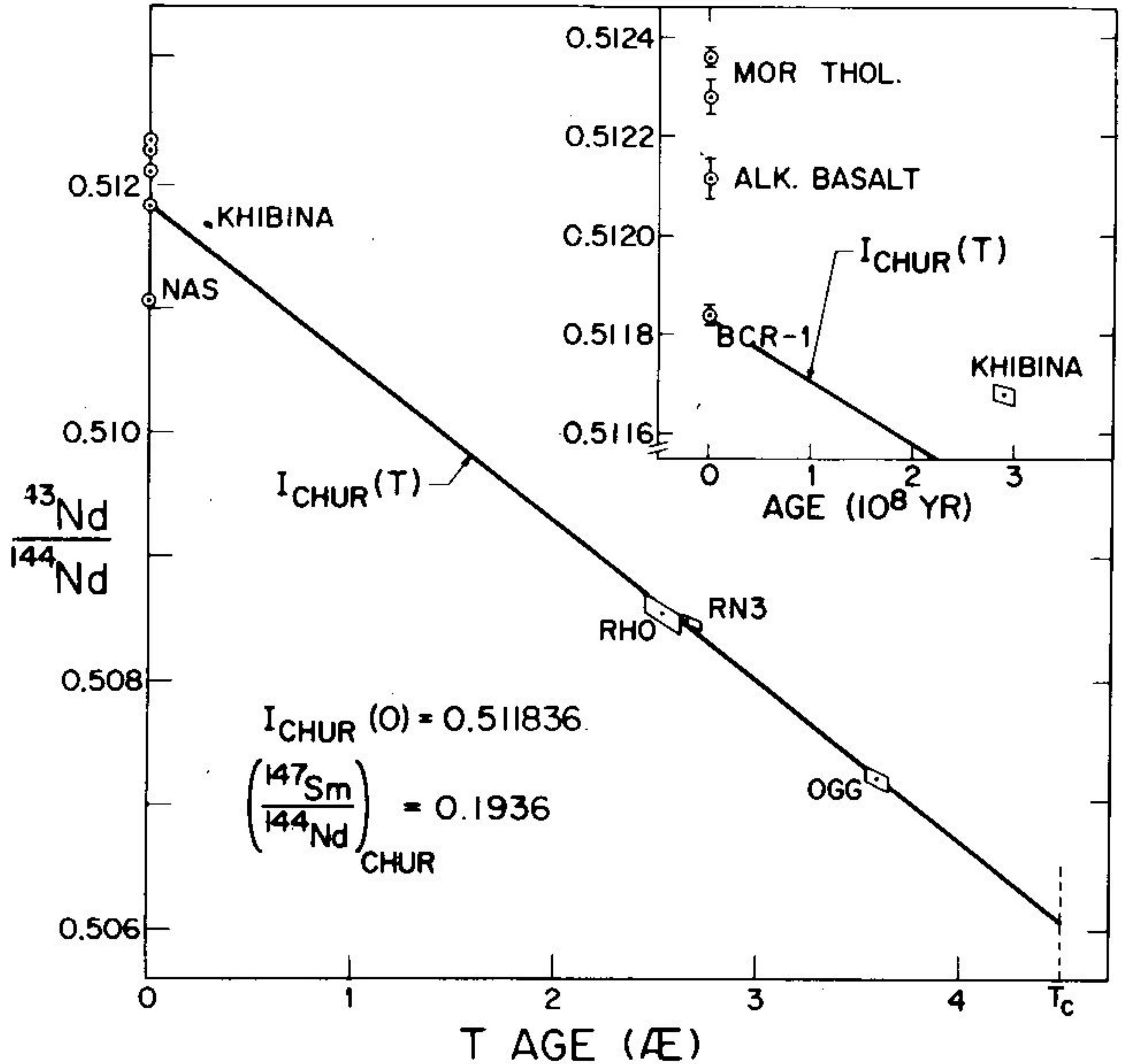


Fig. 2: Observed initial $^{143}Nd/^{144}Nd$ versus time. $I_{CHUR}(T)$ represents evolution of $^{143}Nd/^{144}Nd$ in a reservoir with chondritic Sm/Nd.

DePaolo D.J., Wasserburg G.J., Nd isotopic variations and petrogenetic models. // Geophysical Research Letters, 1976. 3(5): 249-252.

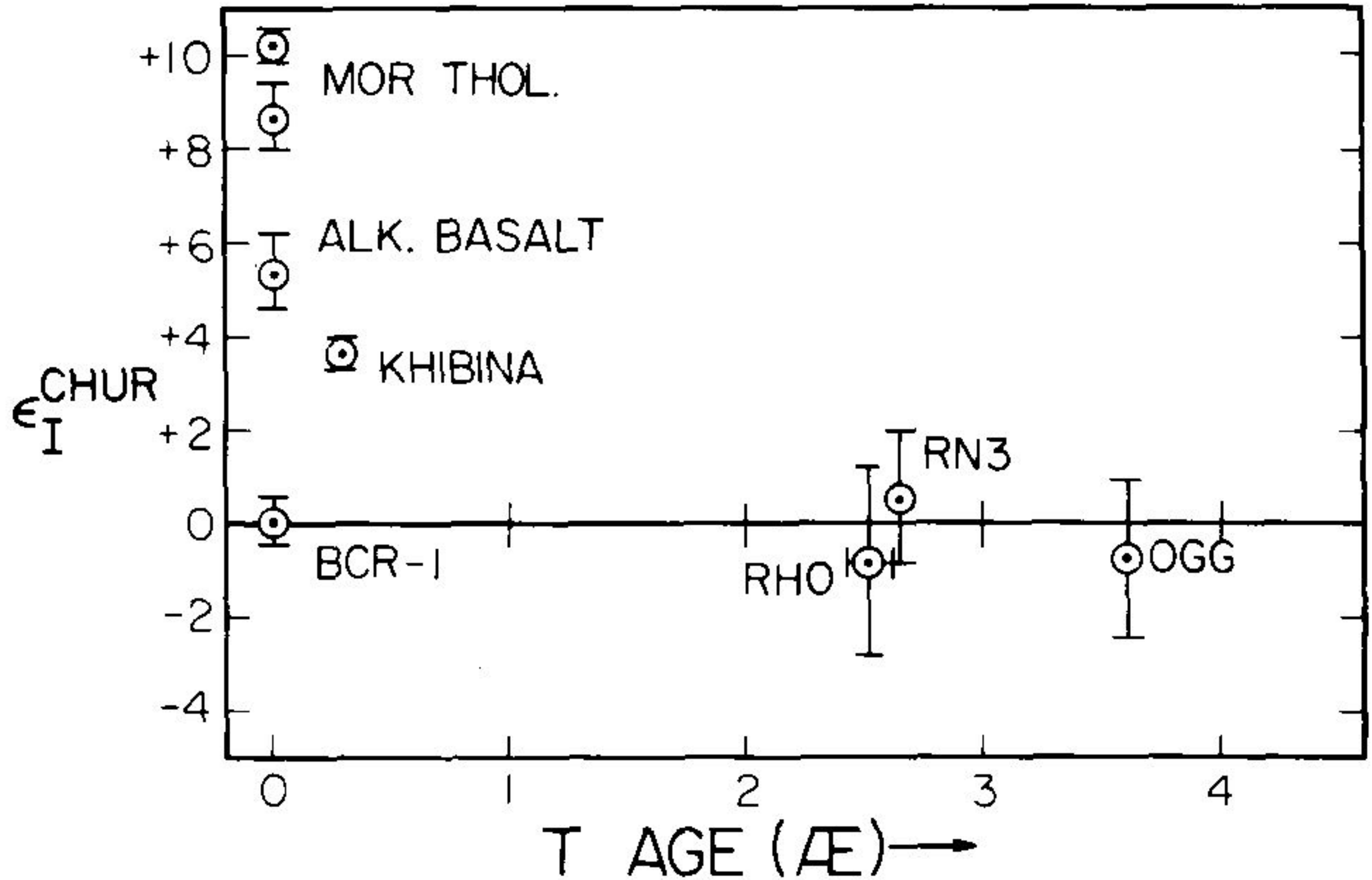
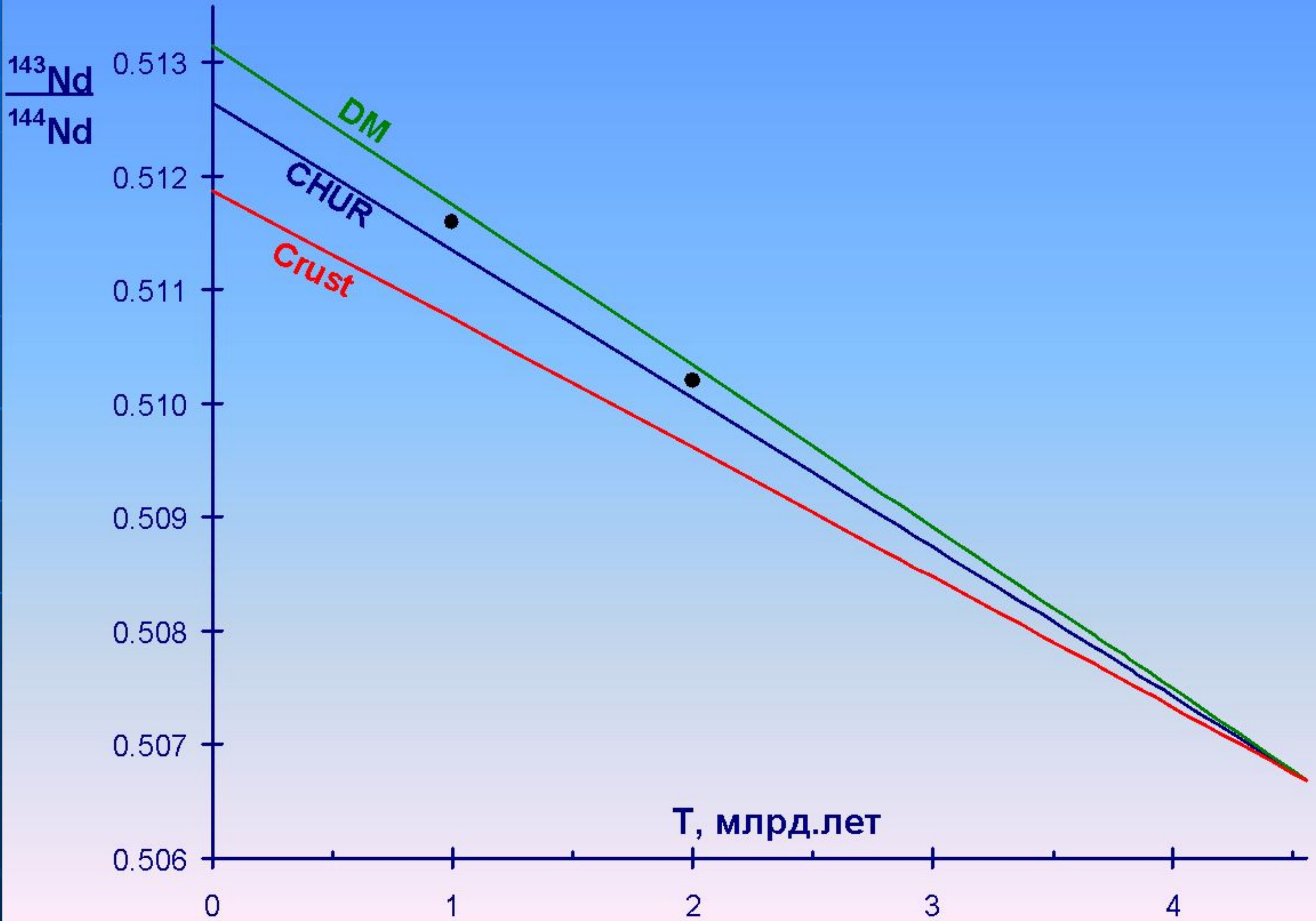


Fig. 3: Fractional deviations in parts in 10^4 of initial $^{143}Nd/^{144}Nd$ from evolution in a chondritic Sm/Nd reservoir (CHUR) vs. time.



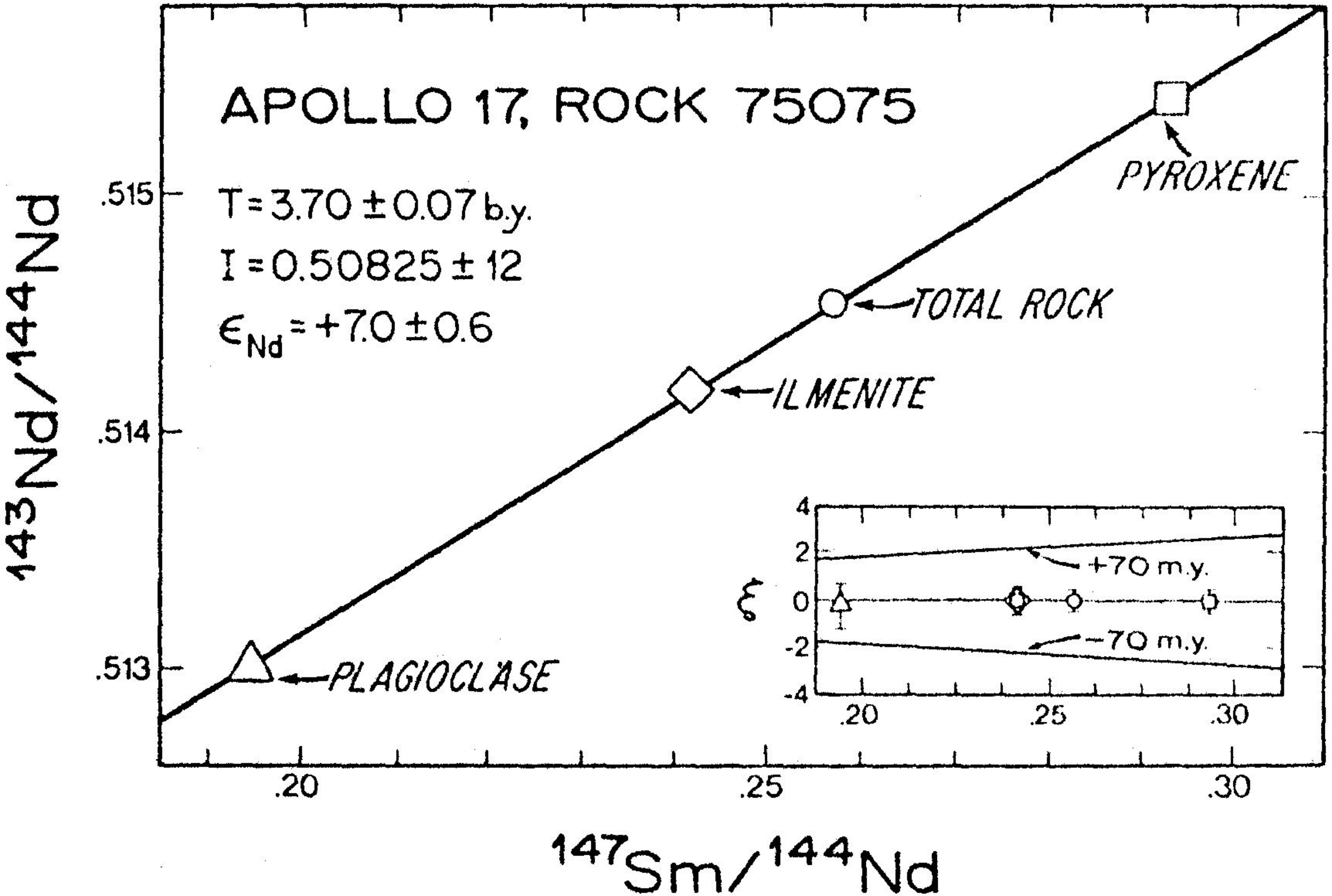
$^{143}Nd / ^{144}Nd$
0.513
0.512
0.511
0.510
0.509
0.508
0.507
0.506
DM
CHUR
Crust
T, млрд.лет
0
1
2
3
4

$$\left(\frac{^{143}Nd}{^{144}Nd}\right)^{t=1.0\ \text{млрд.лет}} = 0.511399$$

$$\varepsilon_{Nd} = ?$$

$$\left(\frac{^{143}Nd}{^{144}Nd}\right)_{CHUR}^{t=1\ \text{млрд.лет}} = 0.512638 - 0.1967 \cdot [\exp(0.00654 \cdot 1.0) - 1]$$

$$\varepsilon_{Nd} = \left(0.511399/0.511347 - 1\right) \cdot 10^4 = 1.0$$



Mineral isochron for lunar basalt 75075 (Lugmair et al. 1975)

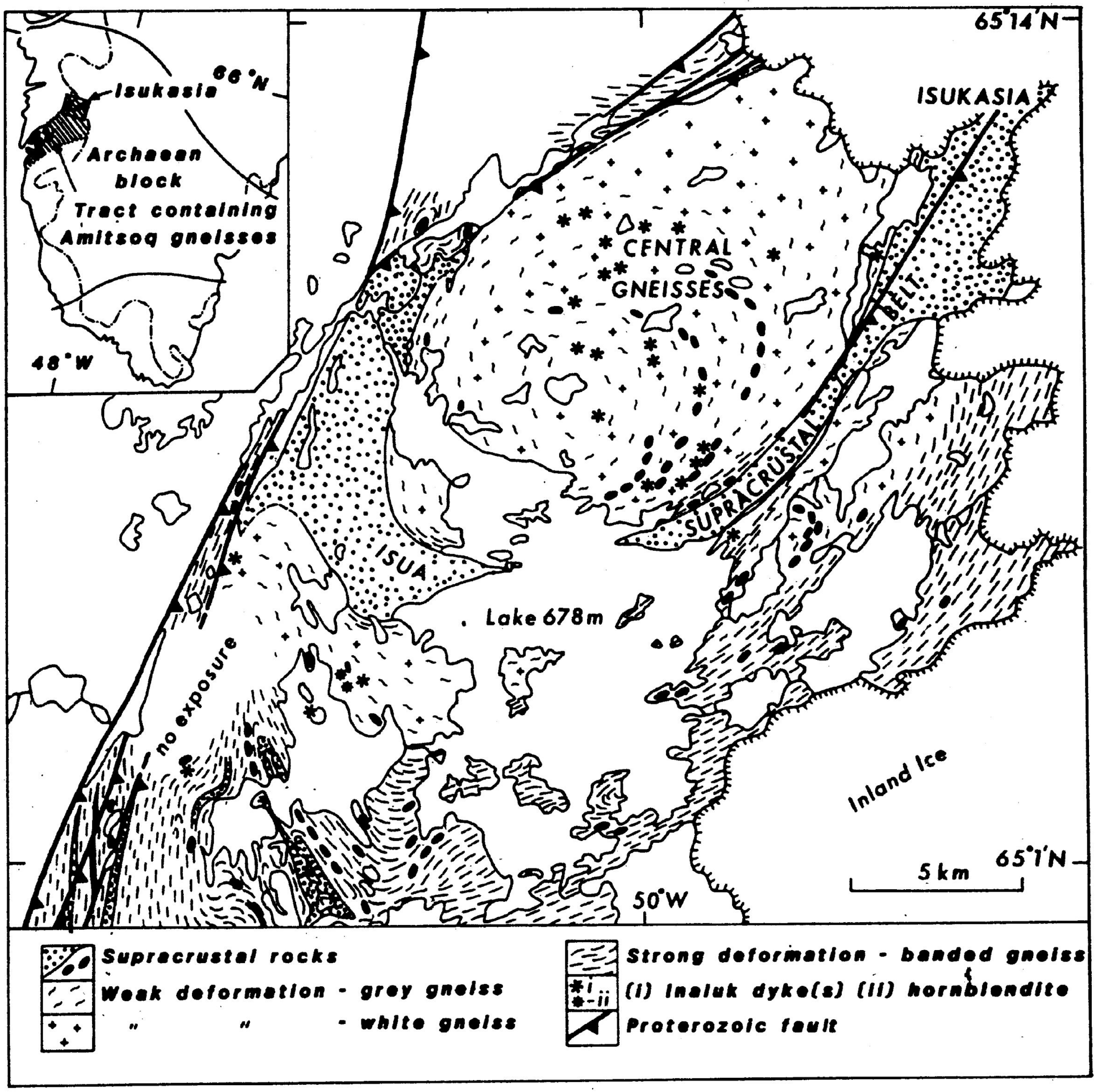
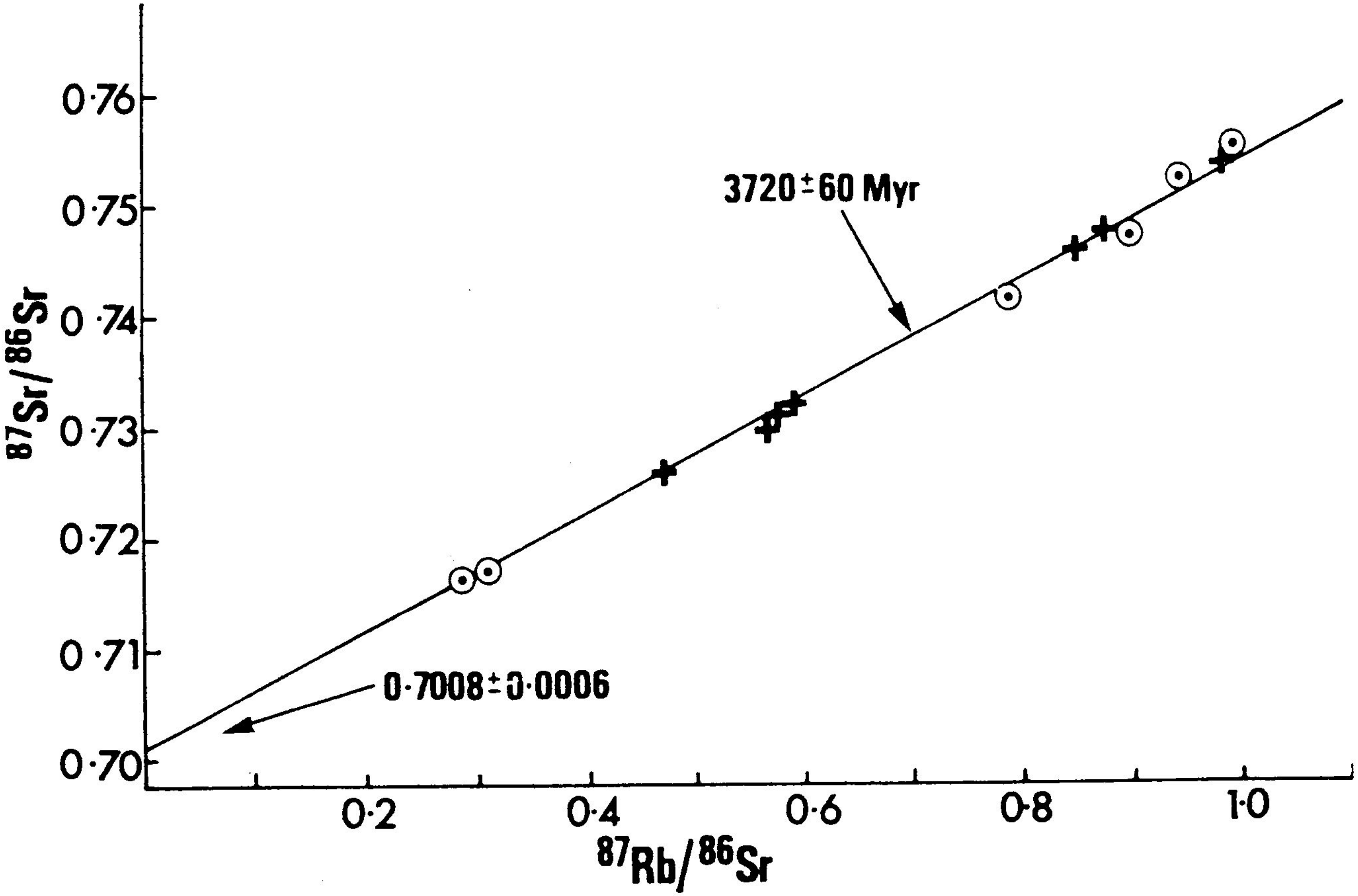


FIG. 1. Geological sketch map of the Isukasia area.

described elsewhere[8]. Rb/Sr ratios were determined by a precise X-ray fluorescence technique[9]. The decay constant of ^{87}Rb was taken as 1.39×10^{-11} yr^{-1}.

Fig. 2 Rb–Sr whole rock isochron plot for Amitsoq gneisses from Isua. ⊙, Gneissic veins cutting supracrustals (Group 1, Table 1) and Gneisses far away from contact with supracrustals (Group 2, Table 1). +, Gneisses from near contact with supracrustals (for full details and analytical data, see ref. 6).



Moorbath, S, Allaart, JH, Bridgwater, D and McGregor, VR (1977). "Rb-Sr ages of early Archaean supracrustal rocks and Amitsoq gneisses at Isua." Nature 270: 43-45.

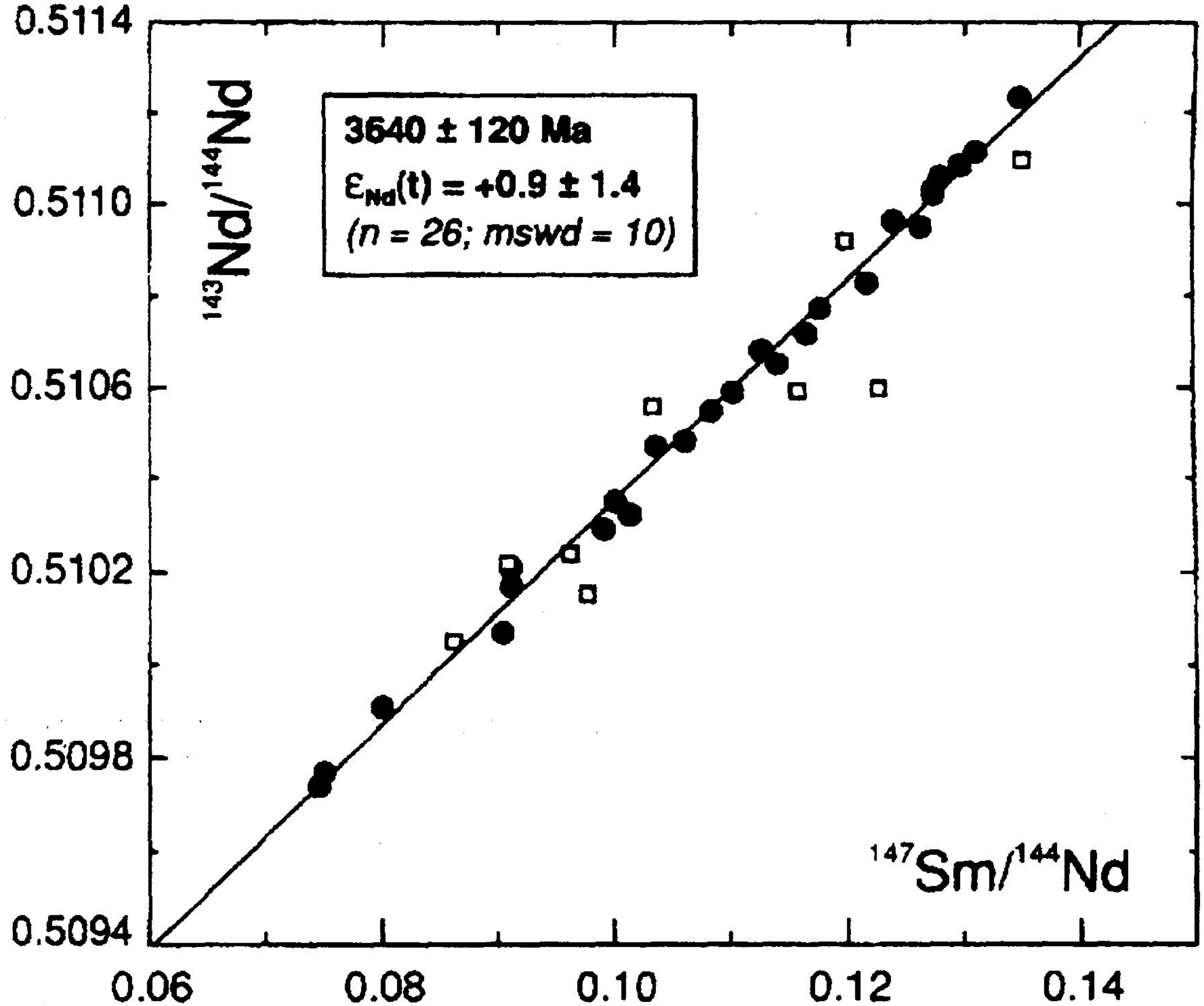
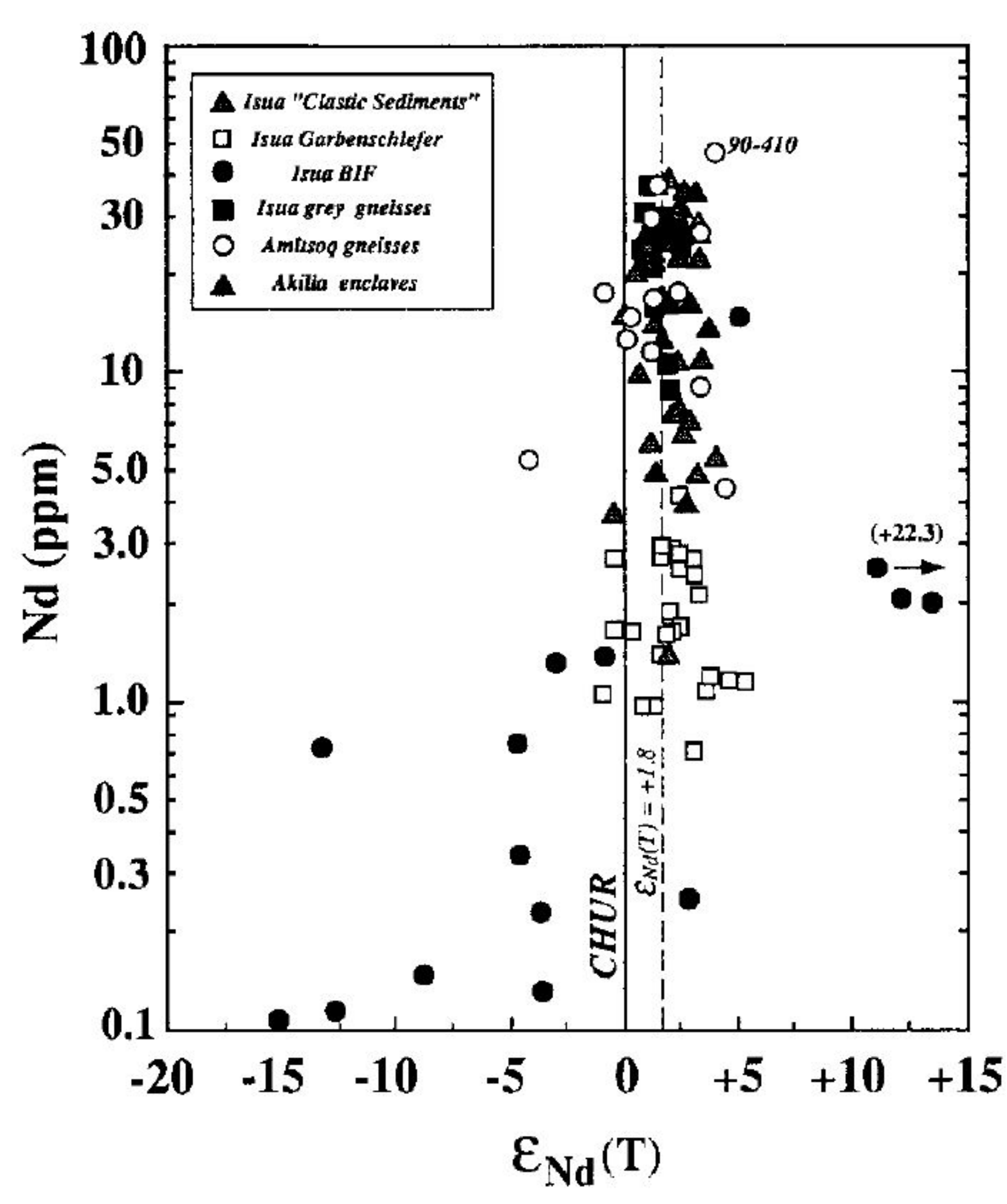


Fig. 6. Combined Sm–Nd regression (*filled circles*) for Amîtsoq gneiss samples from Baadsgaard et al. (1986b), Moorbath et al. (1986), and Shimizu et al. (1988). The Amîtsoq gneiss data of Bennett et al. (1993) are shown for comparison (*open squares*), and omitted from the regression calculation.

Moorbath, S, Whitehouse, MJ and Kamber, BS (1997). "Extreme Nd-Isotope Heterogeneity in the Early Archean - Fact or Fiction - Case-Histories from Northern Canada and West Greenland." Chemical Geology 135(3-4): 213-231.



Gruau G., Rosing M., Bridgwater D., Gill R.C.O. Resetting of Sm-Nd systematics during metamorphism of >3.7 Ga rocks: implications for isotopic models of early Earth differentiation. Chemical Geology. 1996. V.133. P.225-240.

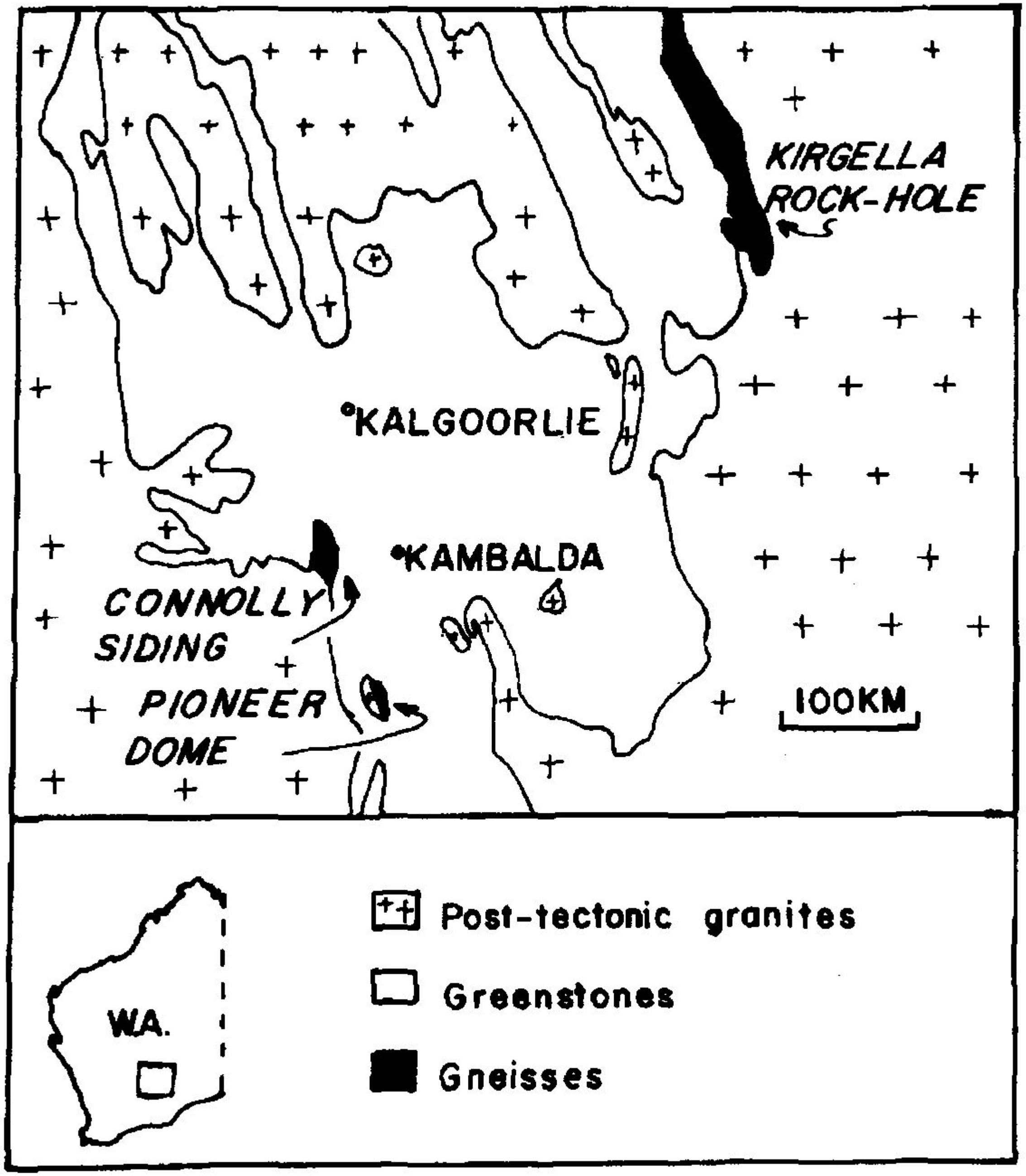


Fig. 1. Map of the eastern Yilgarn Block of Western Australia, showing the gneiss localities.

McCulloch M.T., Compston W., Froude D.
Sm-Nd and Rb-Sr dating of Archaean gneisses, eastern Yilgarn Block, Western Australia. // Journal of the Geological Society of Australia, 1983. 30: 149-153.

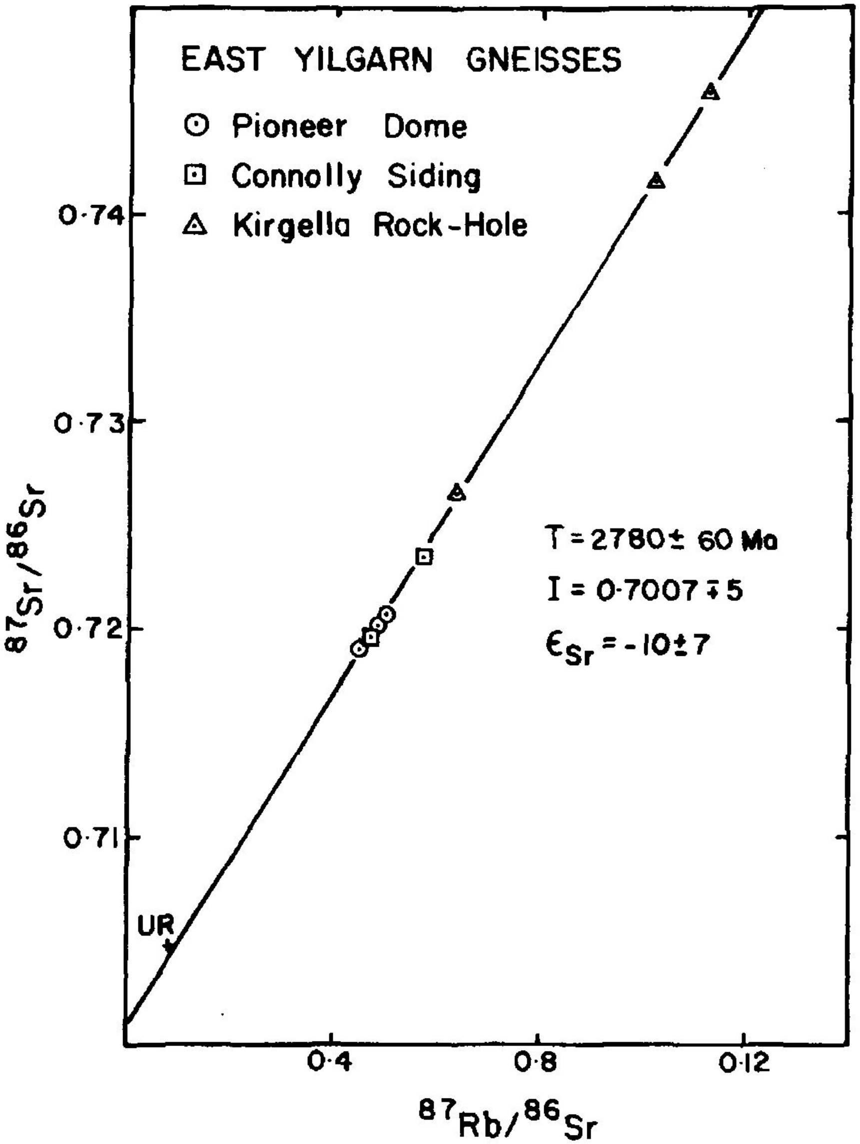


Fig. 2. Rb-Sr whole-rock isochron for the eastern Yilgarn gneisses. Despite the regional sampling, all points lie close to a single line. The cross shows the present-day bulk earth point (UR).

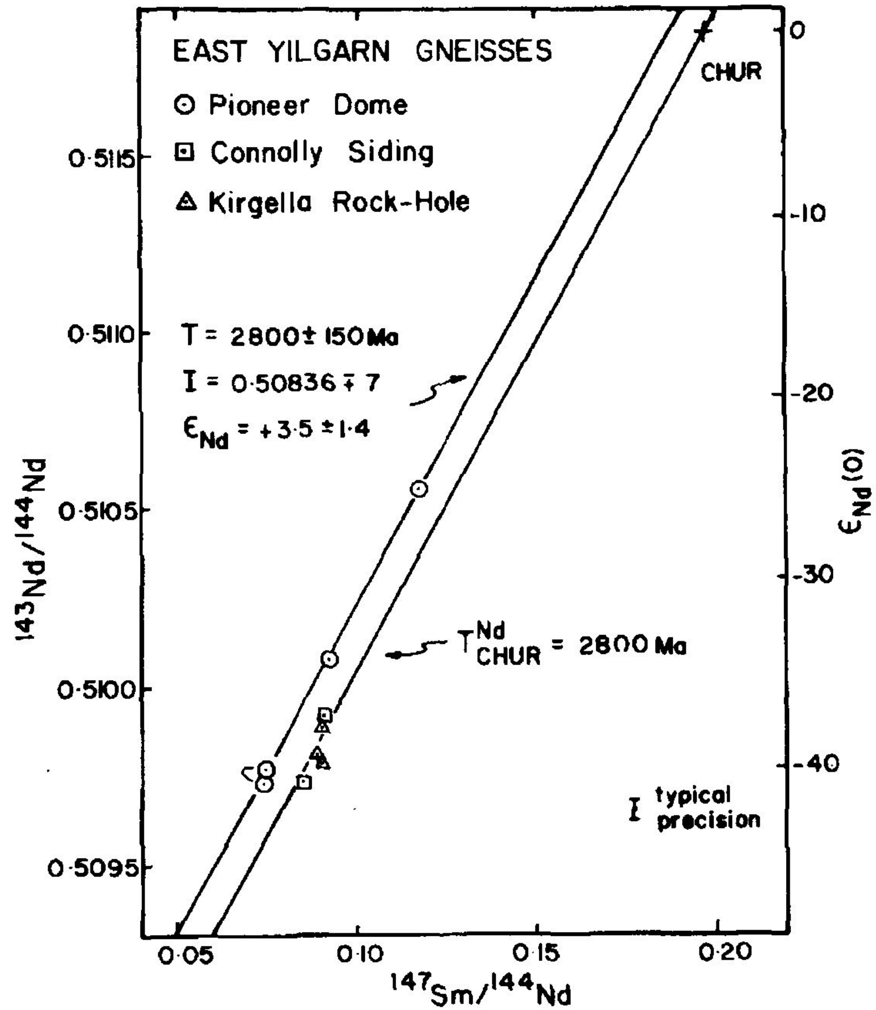


Fig. 3. Sm-Nd isochron diagram for the eastern Yilgarn gneisses. In contrast to Rb-Sr, the points do not define a single array, although individual localities form broadly coherent groups. This disparity is consistent with the Pioneer Dome gneisses being derived from a depleted Nd/Sm source at *c.* 2800 Ma, whereas the Connolly Siding and Kirgella Rock-hole gneisses were derived from a chondritic Nd/Sm source (CHUR) at approximately the same time. The cross shows the present-day bulk earth point (CHUR).

Frost C.D., Frost B.R. Open-System dehydration of amphibolite, Morton Pass, Wyoming - elemental and Nd and Sr isotopic effects. // Journal of Geology. 1995. 103(3): 269-284.

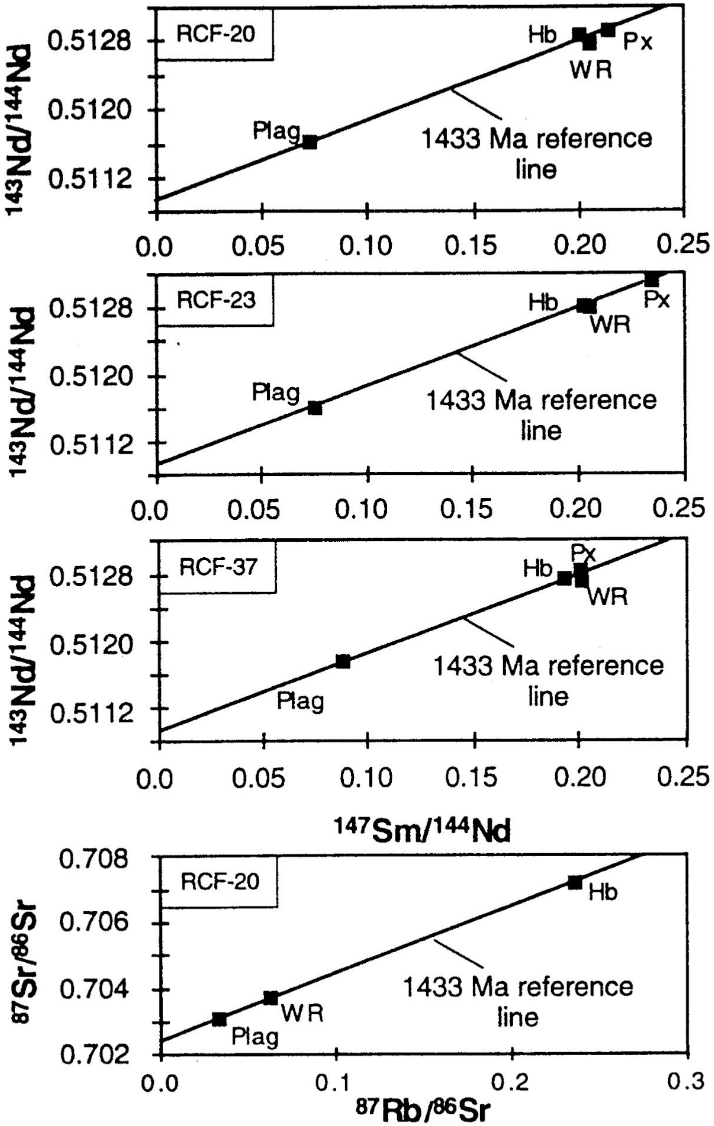


Figure 10. Sm-Nd and Rb-Sr mineral isochrons for metabasite samples RCF-20, RCF-23 and RCF-37. Isochron fits using the ISOPLOT program (Ludwig 1989) gave the following results: RCF-20 Sm-Nd = 1.40 ± 0.23 Ga, MSWD = 37; RCF-23 Sm-Nd = 1433 ± 17 Ma, MSWD = 1.0; RCF-37 Sm-Nd = 1.40 ± 0.23 Ga, MSWD = 23; RCF-20 Rb-Sr = 1385 ± 31 Ma, MSWD = 1.2. All errors are calculated at the 95% confidence level.

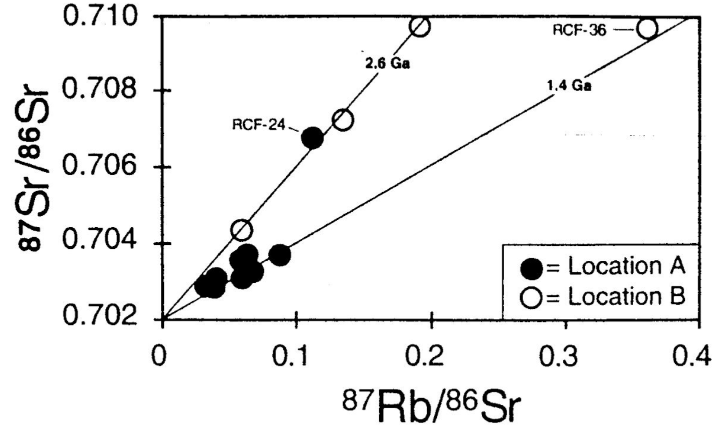


Figure 11. Rb-Sr isochron diagram for whole rock metabasite samples from Morton Pass. Samples containing more than 35% hornblende plot along a 2.6 Ga reference line, whereas samples in which greater amounts of hornblende has broken down plot near a 1.4 Ga reference line.

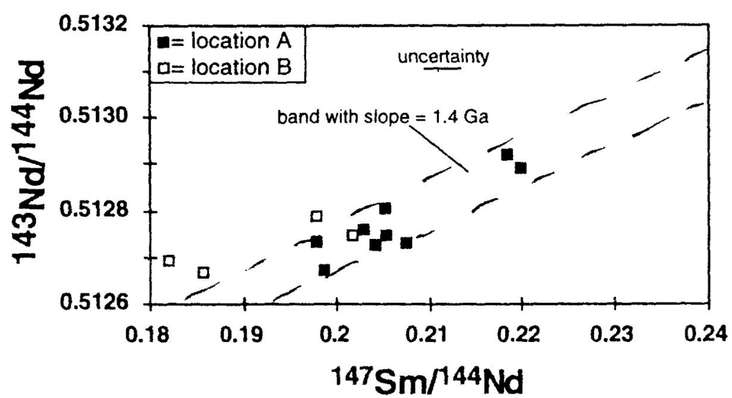


Figure 9. Sm-Nd whole rock isochron diagram for metabasites from location A (filled squares) and location B (open squares). The slope of the shaded band corresponds to an age of 1.4 Ga.

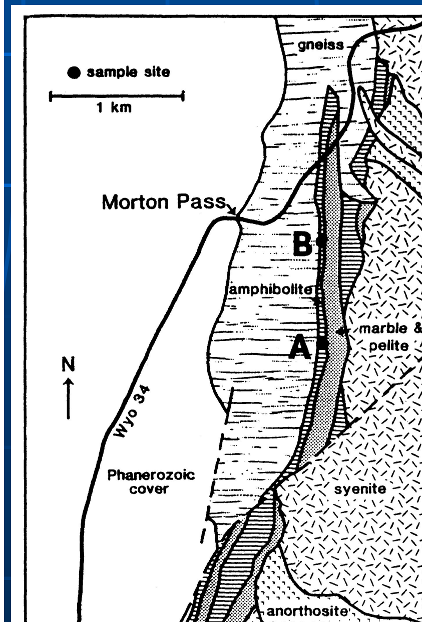


Figure 2. Geologic map of the Morton Pass area. Filled circles locate the two sample localities discussed in the text.

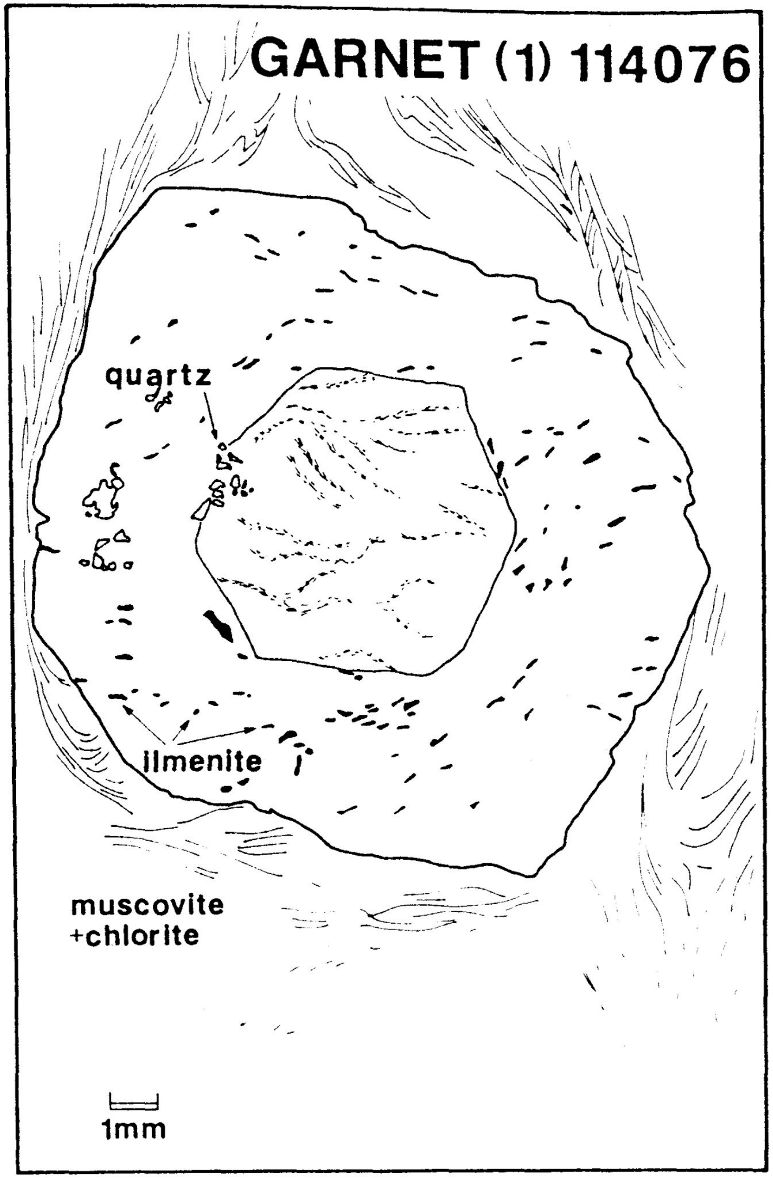
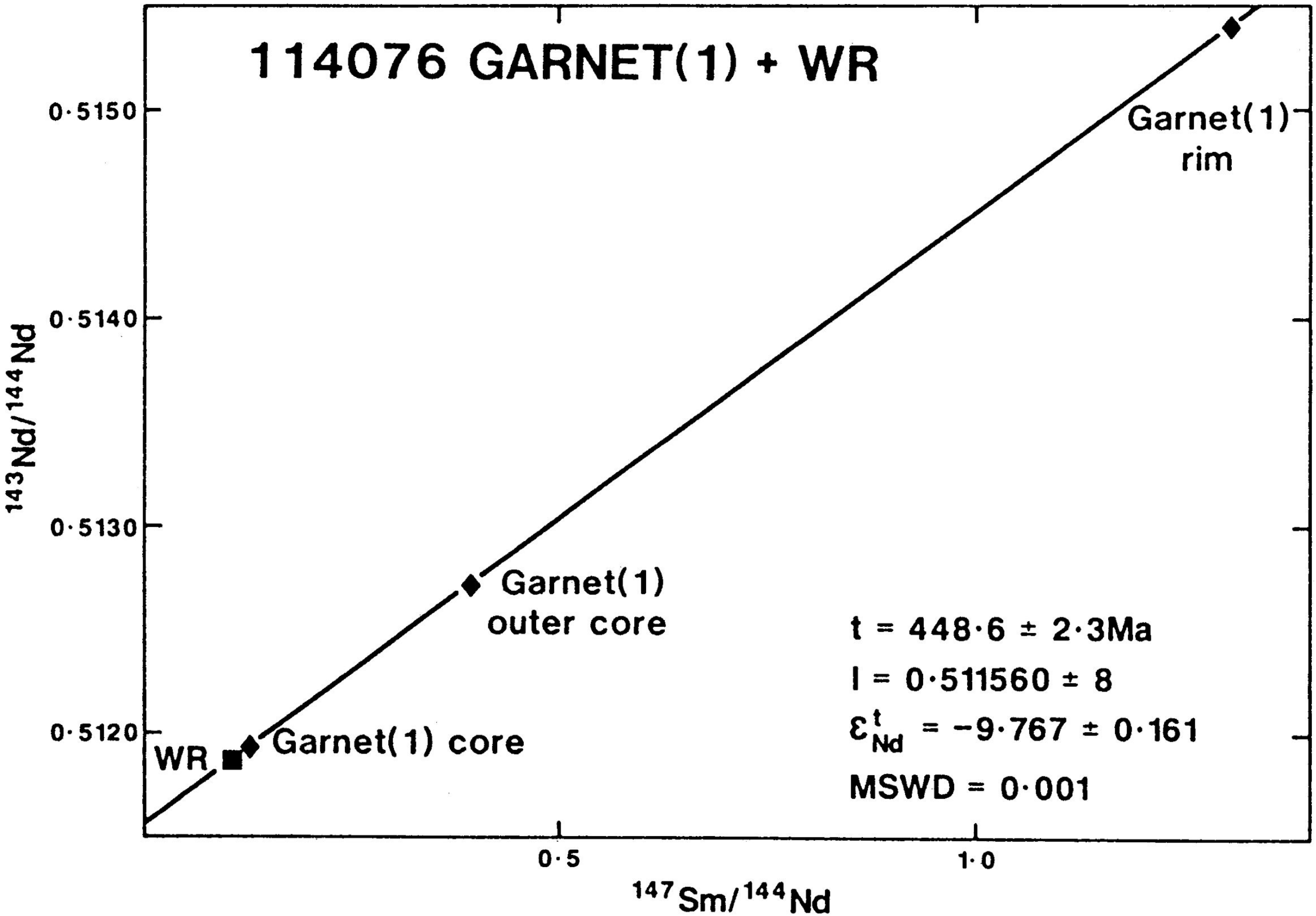
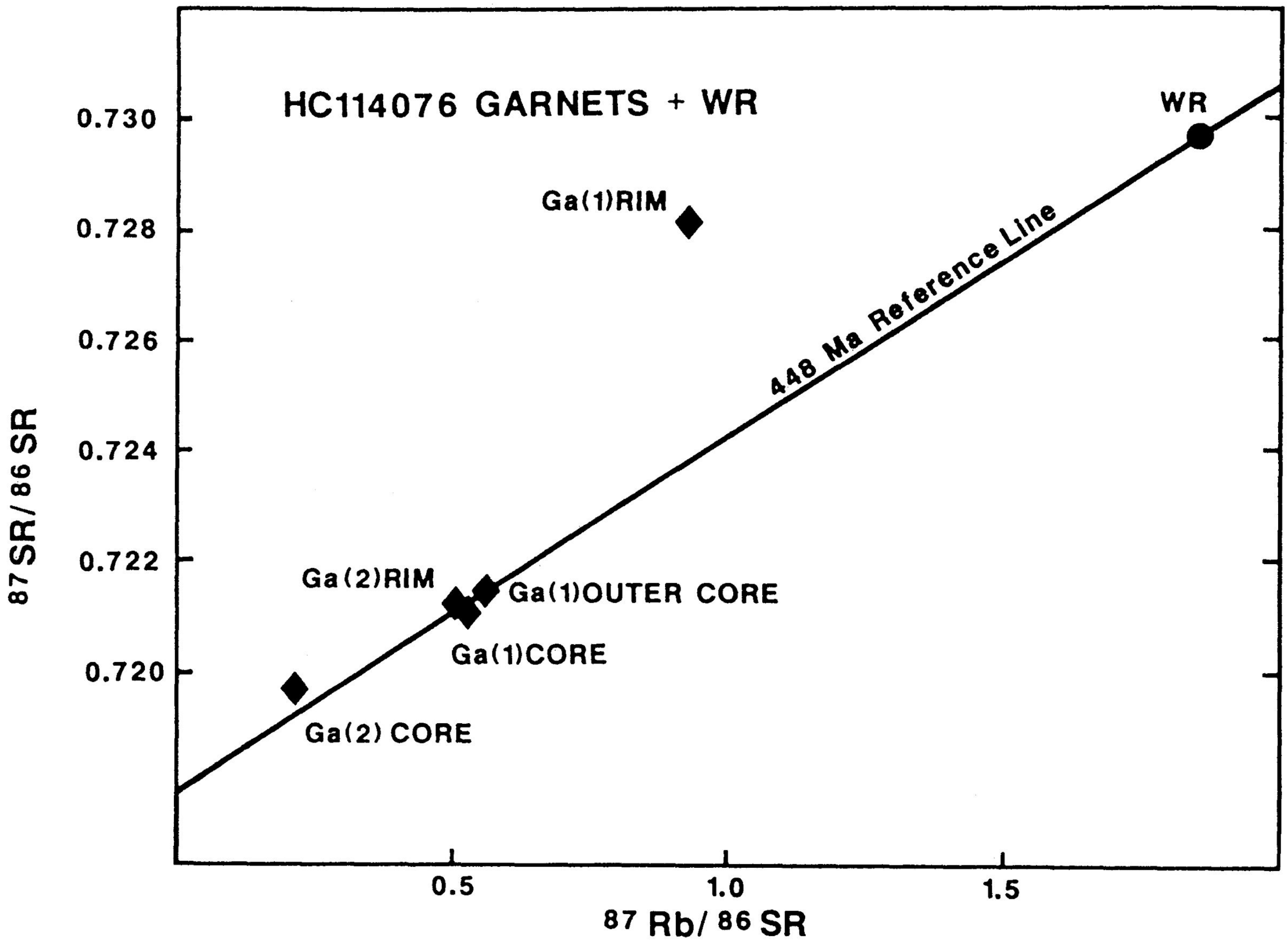


Fig. 1. Sketch of 114076 Garnet(1), Pigeon Island, Newfoundland, showing the inclusion-rich core containing needles of rutile and epidote < 50 μm long, and an optically clear outer core with 0.5 mm inclusions of ilmenite. The matrix is largely retrogressed to muscovite and chlorite.

Vance D., O'Nions R.K. Isotopic Chronometry of Zoned Garnets - Growth-Kinetics and Metamorphic Histories. // Earth and Planetary Science Letters. 1990. 97(3-4): 227-240.



Sm–Nd evolution diagram showing results for the whole rock (WR) and the three fractions for sample HC114076 Garnet(1).



Rb–Sr evolution diagram for garnets in HC114076 and the whole rock (WR). The garnet samples all fall close to the 448 Ma reference line (calculated using the whole rock, and presumed to be the time of growth as given by the Sm–Nd data) except for Garnet(1) rim, which is also the only garnet showing a retrograde rim zonation pattern.

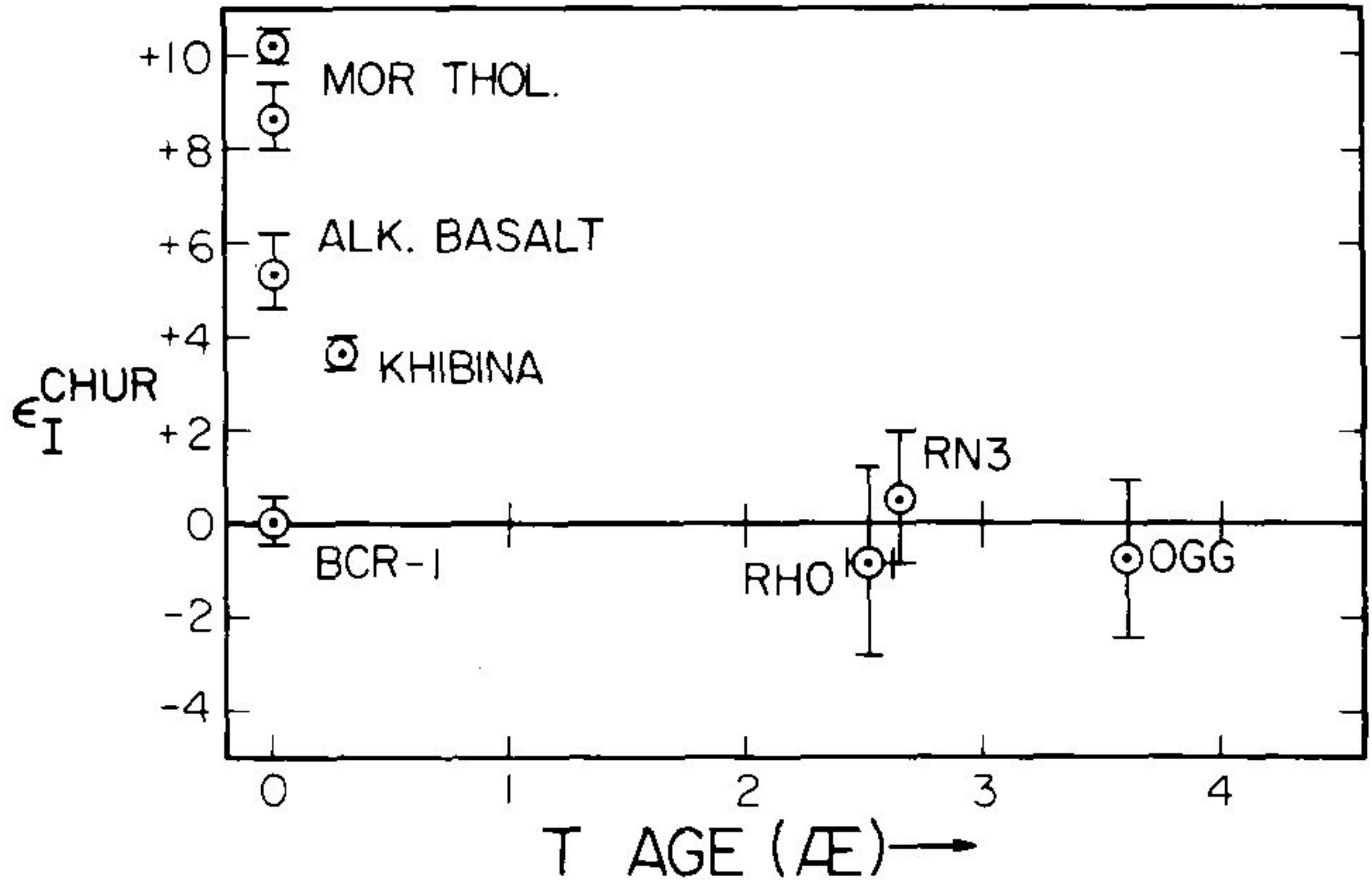


Fig. 3: Fractional deviations in parts in 10^4 of initial $^{143}Nd/^{144}Nd$ from evolution in a chondritic Sm/Nd reservoir (CHUR) vs. time.

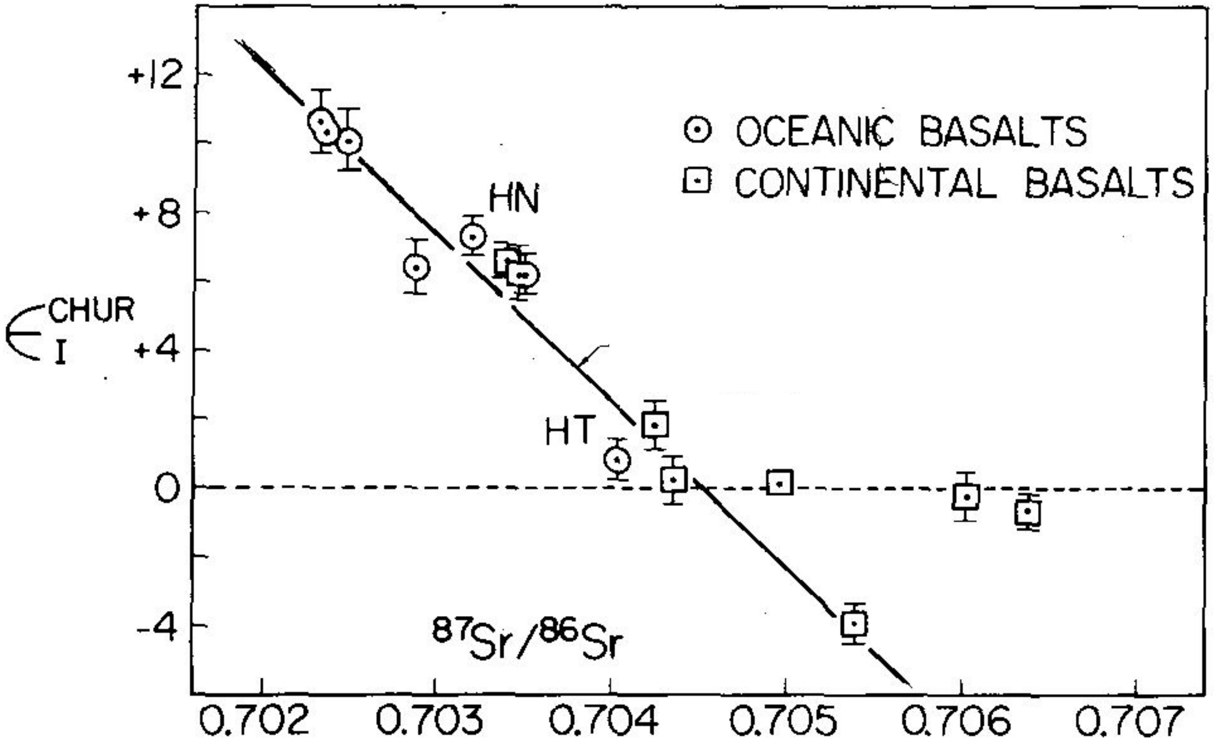
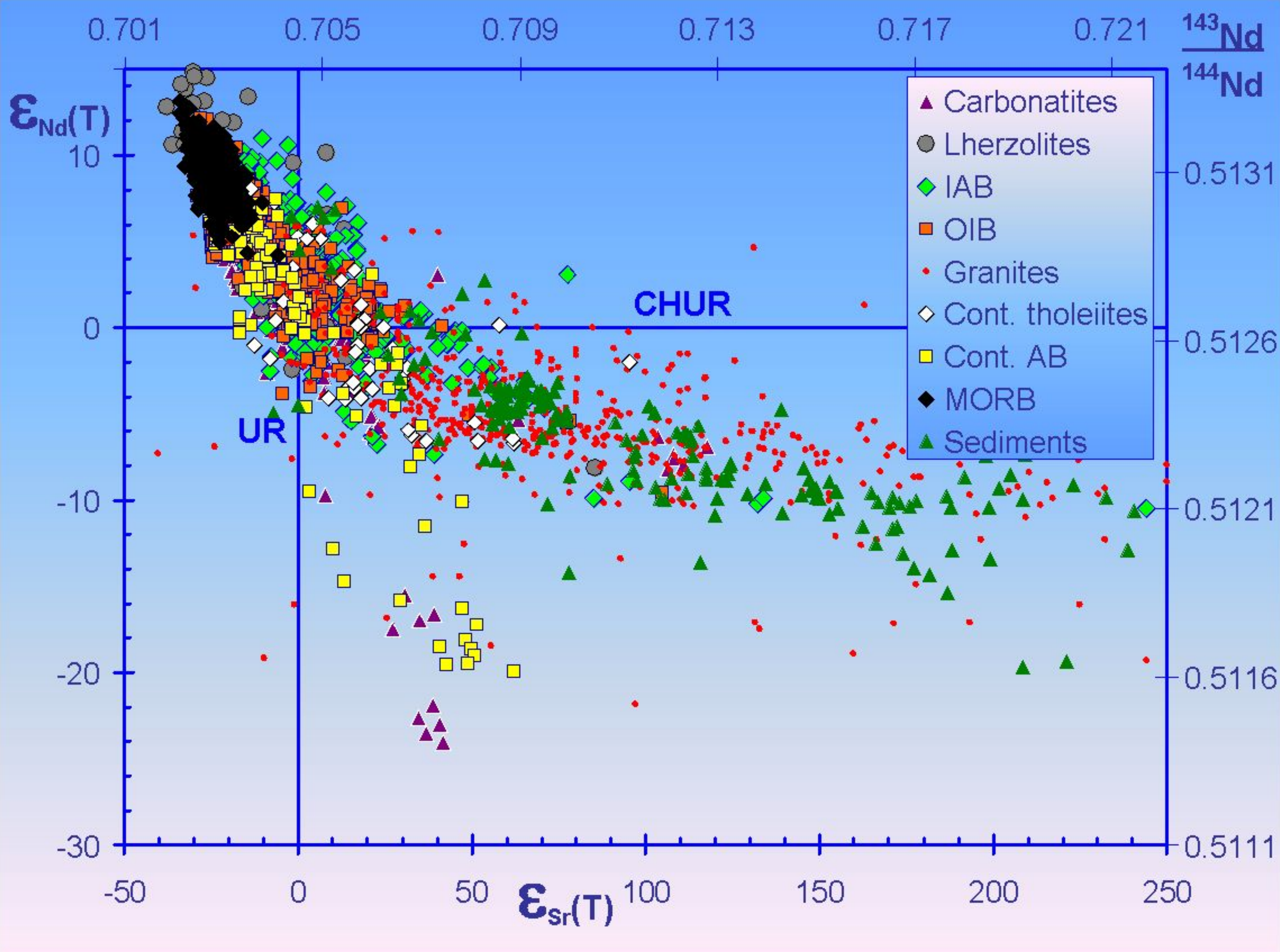
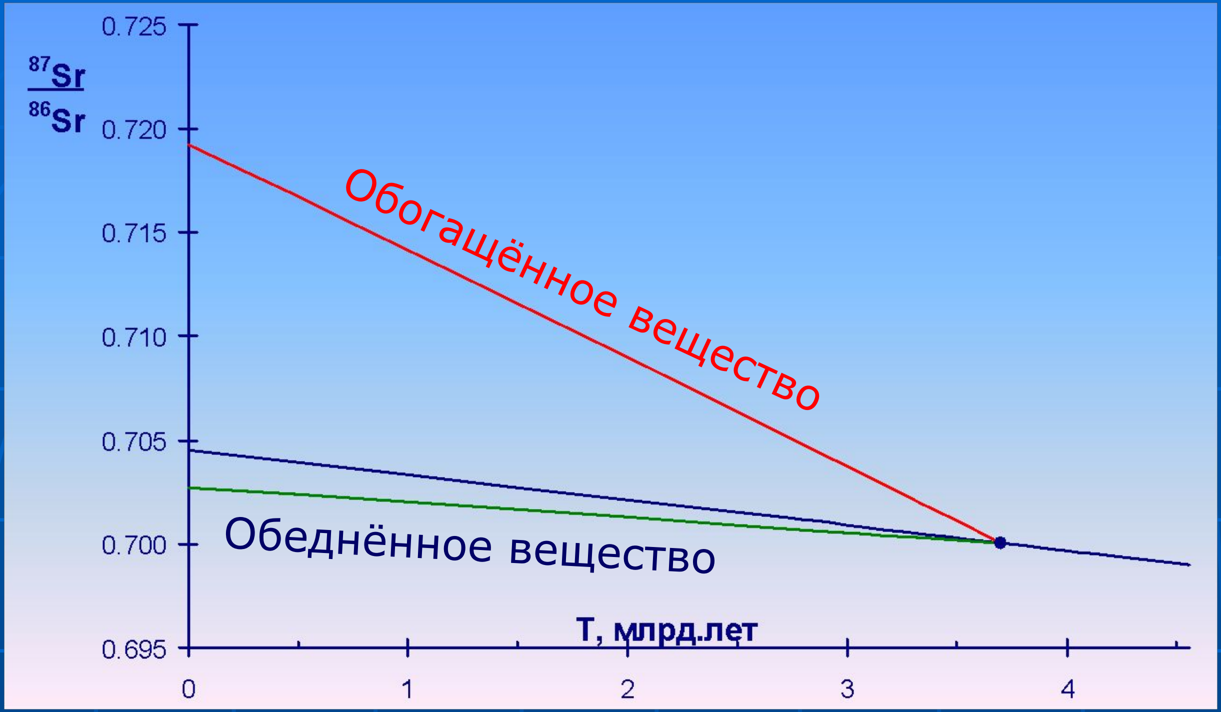


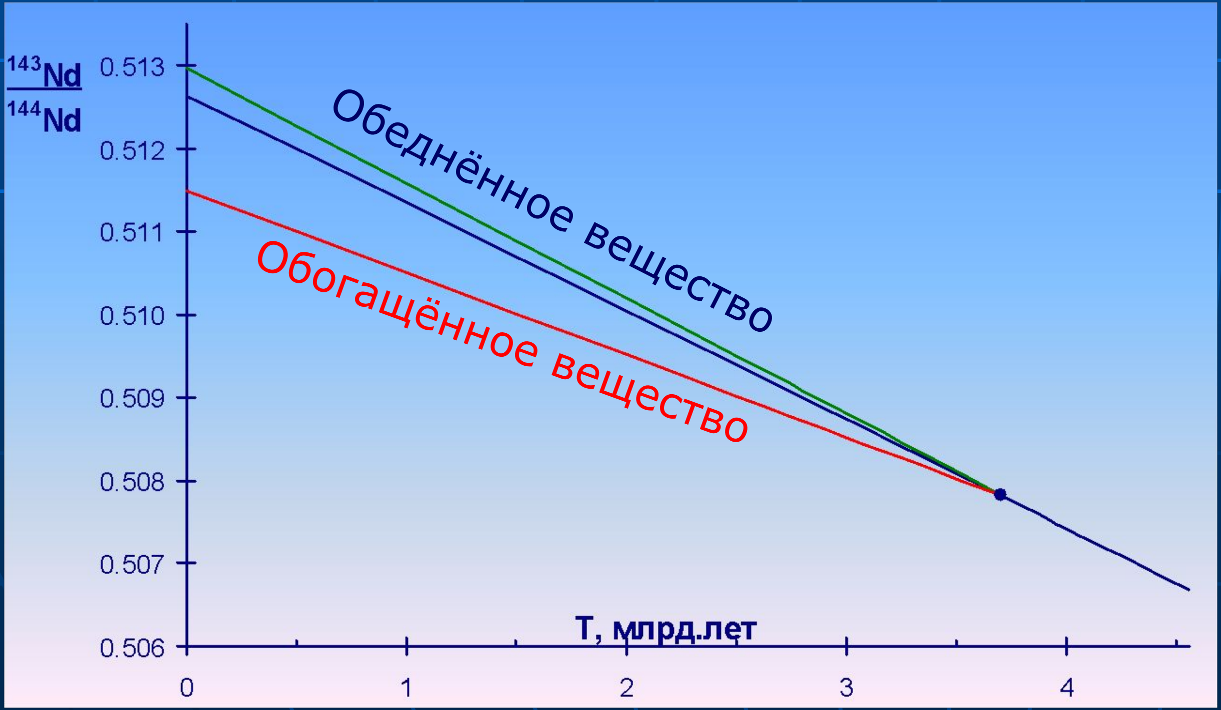
Fig. 4: ϵ_I^{CHUR} *vs.* initial $^{87}Sr/^{86}Sr$ for young basalts. Included are two samples from *Richard*, et. al. (1976) (PD1P, ARP74) and BCR-1 ($^{87}Sr/^{86}Sr$ for BCR-1 from *Pankhurst* and *O'Nions*, 1973). The solid line shows the inferred trend of the correlation and the relative magnitudes of correlated variations of Rb/Sr and Sm/Nd necessary to produce such a trend. The dashed line indicates the trend defined by four continental basalt samples which have $\epsilon_I^{CHUR} \approx 0$ but different $^{87}Sr/^{86}Sr$, all lying to the right of the main correlation line. This trend may result from contamination of magmas with crustal radiogenic Sr or indicate the existence of magma sources which have become enriched in Rb relative to Sr, but have retained unchanged Sm/Nd. Should new data populate the correlation line to values of ϵ_I^{CHUR} much less than zero, it would require serious revision of the simple two-reservoir model.

DePaolo D.J., Wasserburg G.J. Inferences about magma sources and mantle structure from variations of $^{143}Nd/^{144}Nd$. // Geophysical Research Letters, 1976. 3(12): 743-746.

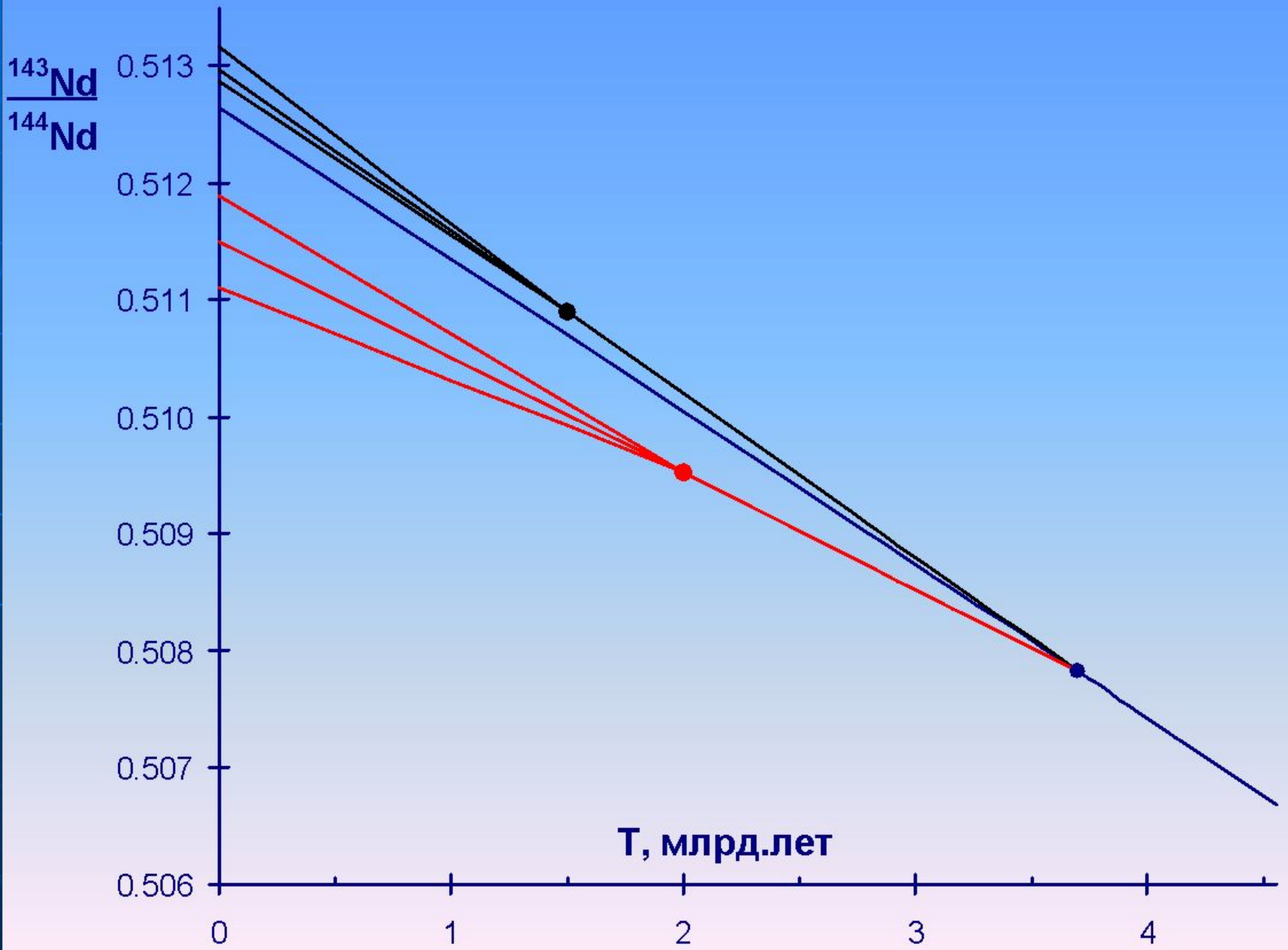

0.701
0.705
0.709
0.713
0.717
0.721
$^{143}Nd/^{144}Nd$
$\varepsilon_{Nd}(T)$
10
0
-10
-20
-30
0.5131
0.5126
0.5121
0.5116
0.5111
Carbonatites
Lherzolites
IAB
OIB
Granites
Cont. tholeiites
Cont. AB
MORB
Sediments
CHUR
UR
-50
0
50
100
150
200
250
$\varepsilon_{Sr}(T)$



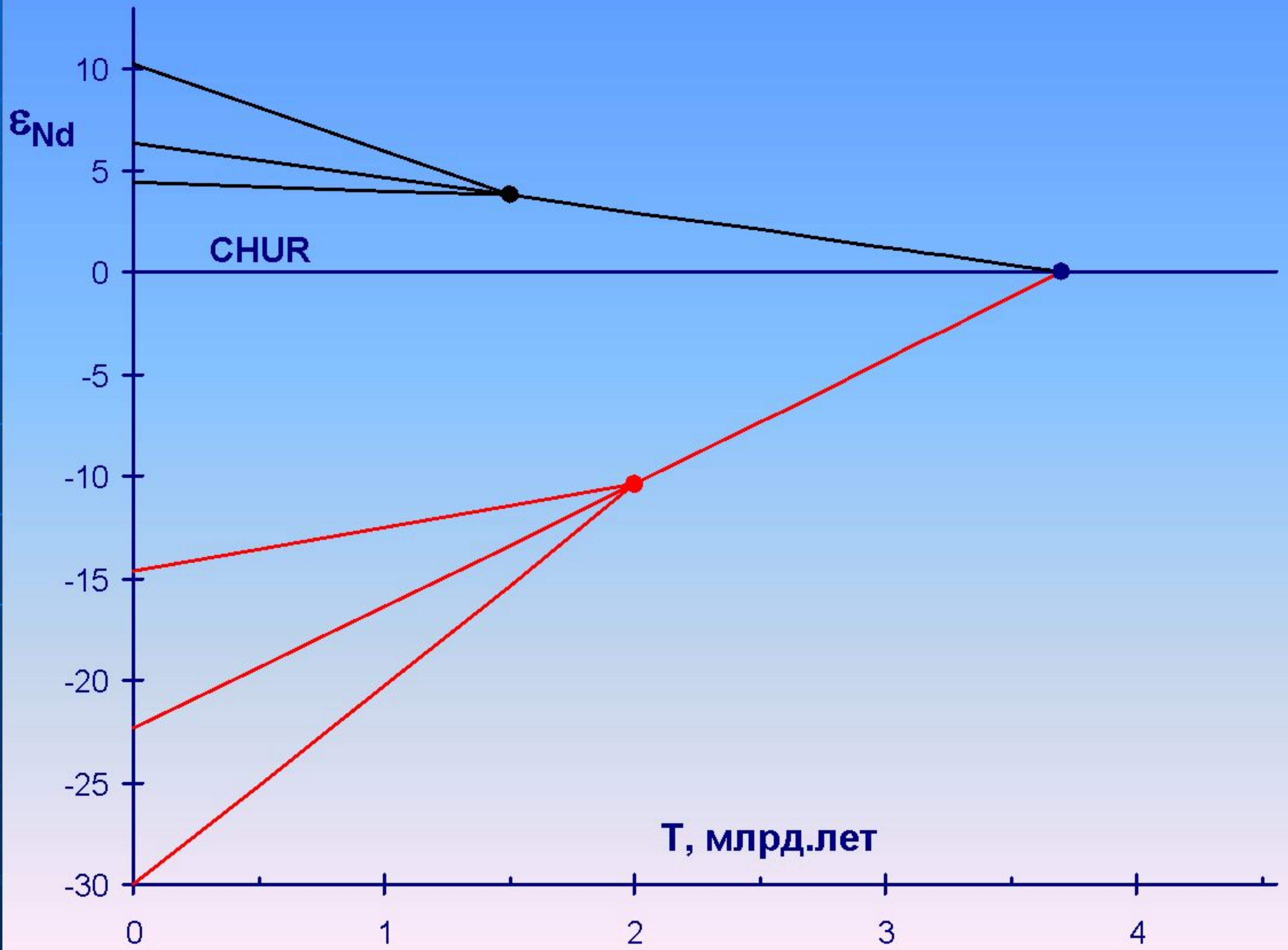
$^{87}Sr / ^{86}Sr$
0.725
0.720
0.715
0.710
0.705
0.700
0.695
Обогащённое вещество
Обеднённое вещество
T, млрд.лет
0
1
2
3
4



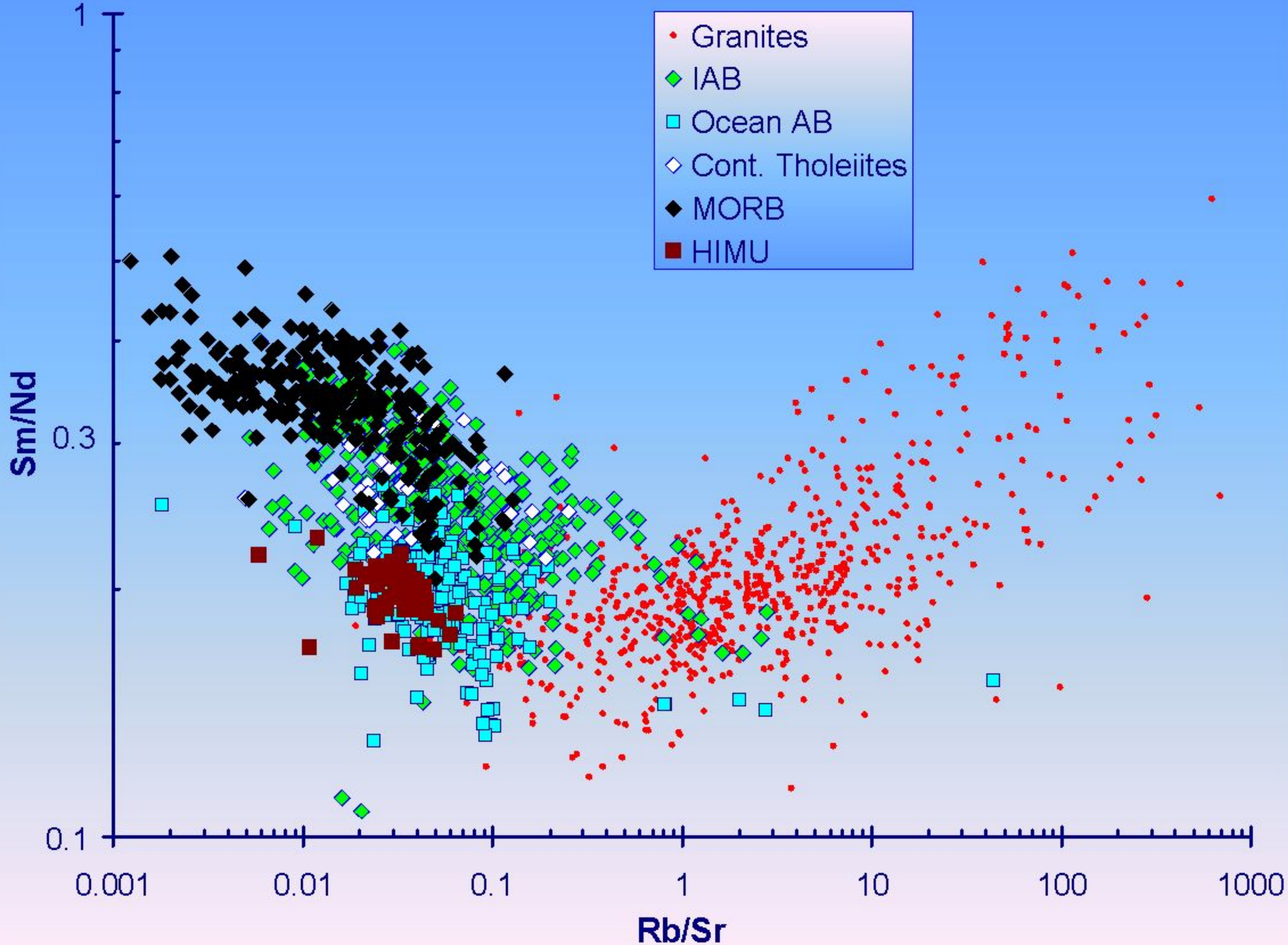
$^{143}Nd / ^{144}Nd$
0.513
0.512
0.511
0.510
0.509
0.508
0.507
0.506
Обеднённое вещество
Обогащённое вещество
T, млрд.лет
0
1
2
3
4



$^{143}Nd/^{144}Nd$
0.513
0.512
0.511
0.510
0.509
0.508
0.507
0.506
T, млрд.лет
0
1
2
3
4



εNd
10
5
0
-5
-10
-15
-20
-25
-30
CHUR
T, млрд.лет
0
1
2
3
4

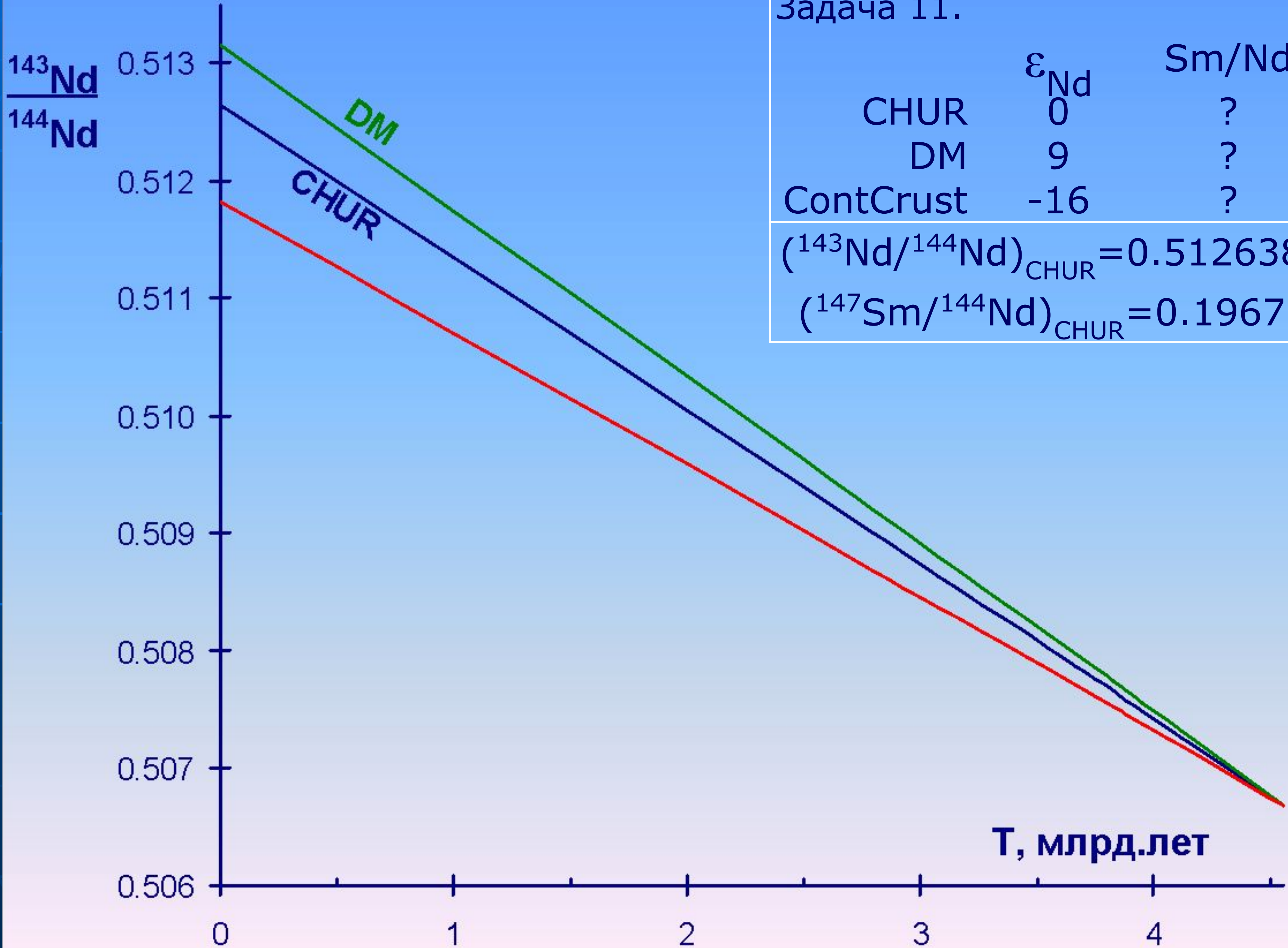

Granites
IAB
Ocean AB
Cont. Tholeiites
MORB
HIMU
Sm/Nd
1
0.3
0.1
0.001
0.01
0.1
1
10
100
1000
Rb/Sr

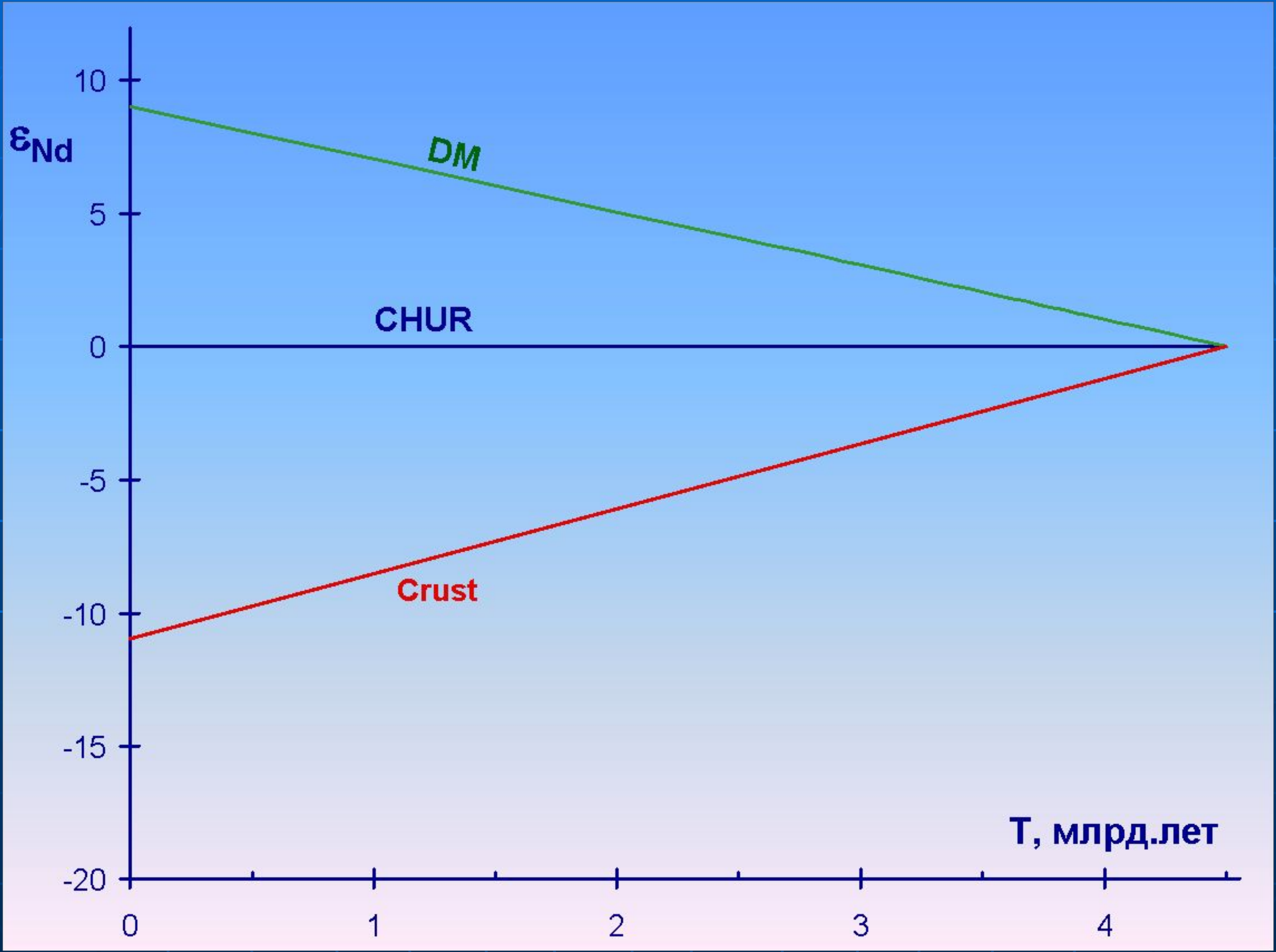
Задача 11.

	ε_{Nd}	Sm/Nd
CHUR	0	?
DM	9	?
ContCrust	-16	?

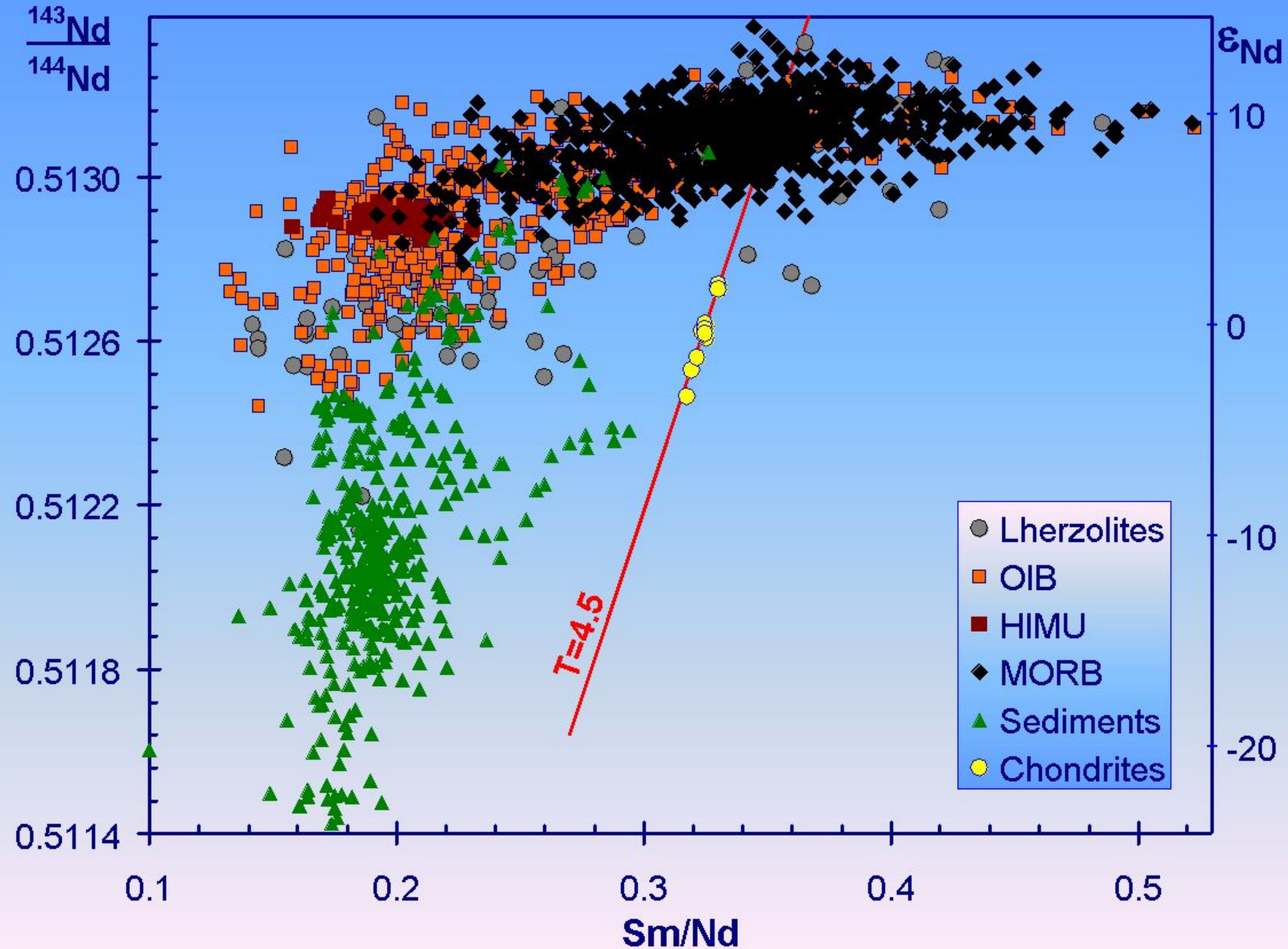
$(^{143}Nd/^{144}Nd)_{CHUR}=0.512638$

$(^{147}Sm/^{144}Nd)_{CHUR}=0.1967$

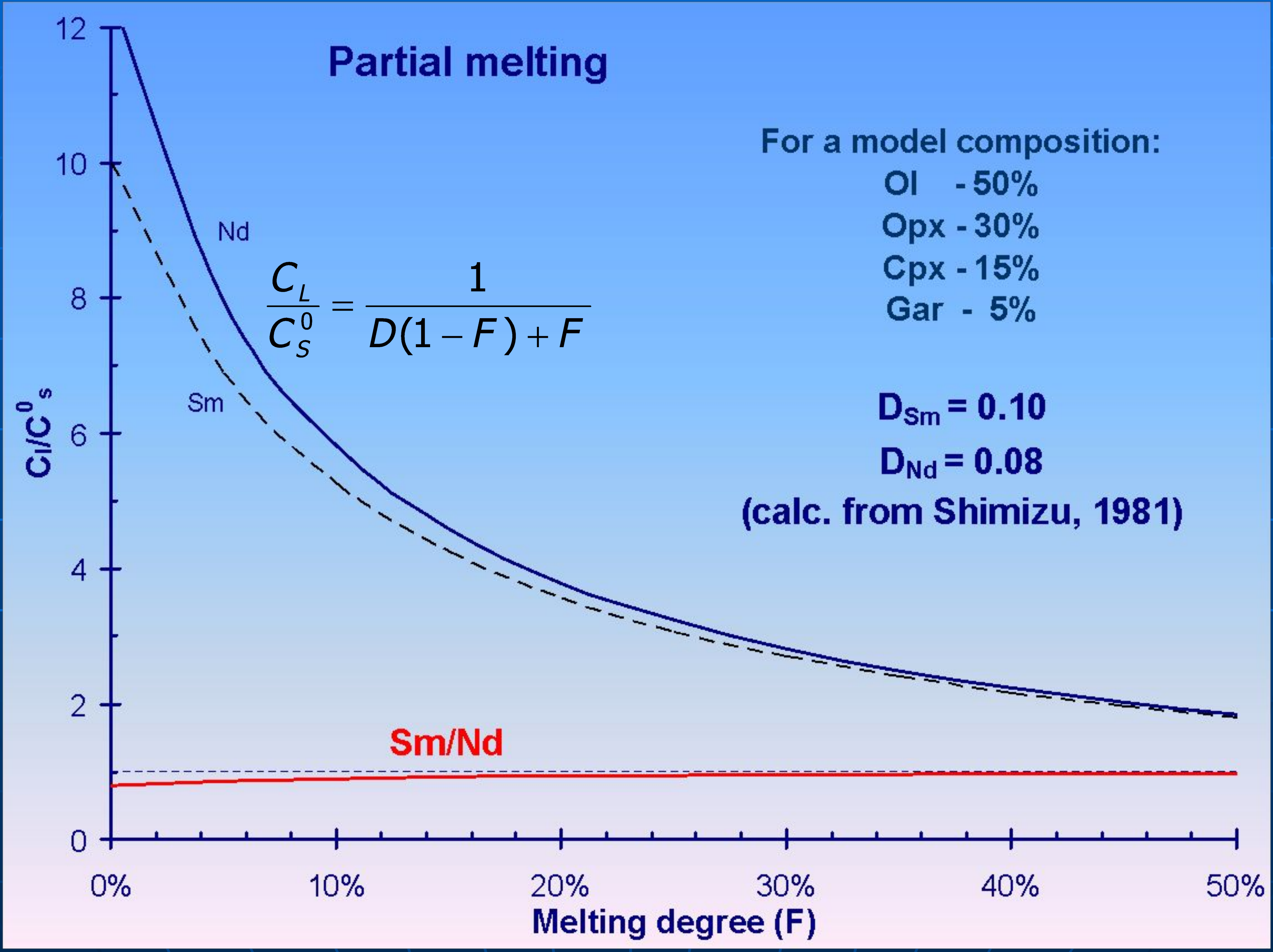




10
5
0
-5
-10
-15
-20
εNd
DM
CHUR
Crust
T, млрд.лет
0
1
2
3
4



143Nd/144Nd
εNd
0.5130
0.5126
0.5122
0.5118
0.5114
10
0
-10
-20
0.1
0.2
0.3
0.4
0.5
Sm/Nd
T=4.5
Lherzolites
OIB
HIMU
MORB
Sediments
Chondrites



Partial melting
For a model composition:
Ol - 50%
Opx - 30%
Cpx - 15%
Gar - 5%
$D_{Sm} = 0.10$
$D_{Nd} = 0.08$
(calc. from Shimizu, 1981)
$$\frac{C_L}{C_S^0} = \frac{1}{D(1-F)+F}$$
Nd
Sm
Sm/Nd
C_l/C^0_s
12
10
8
6
4
2
0
0%
10%
20%
30%
40%
50%
Melting degree (F)

Модельный возраст
в Sm-Nd системе

- Позволяет оценить время отделения породы (или её протолита) от мантийного источника

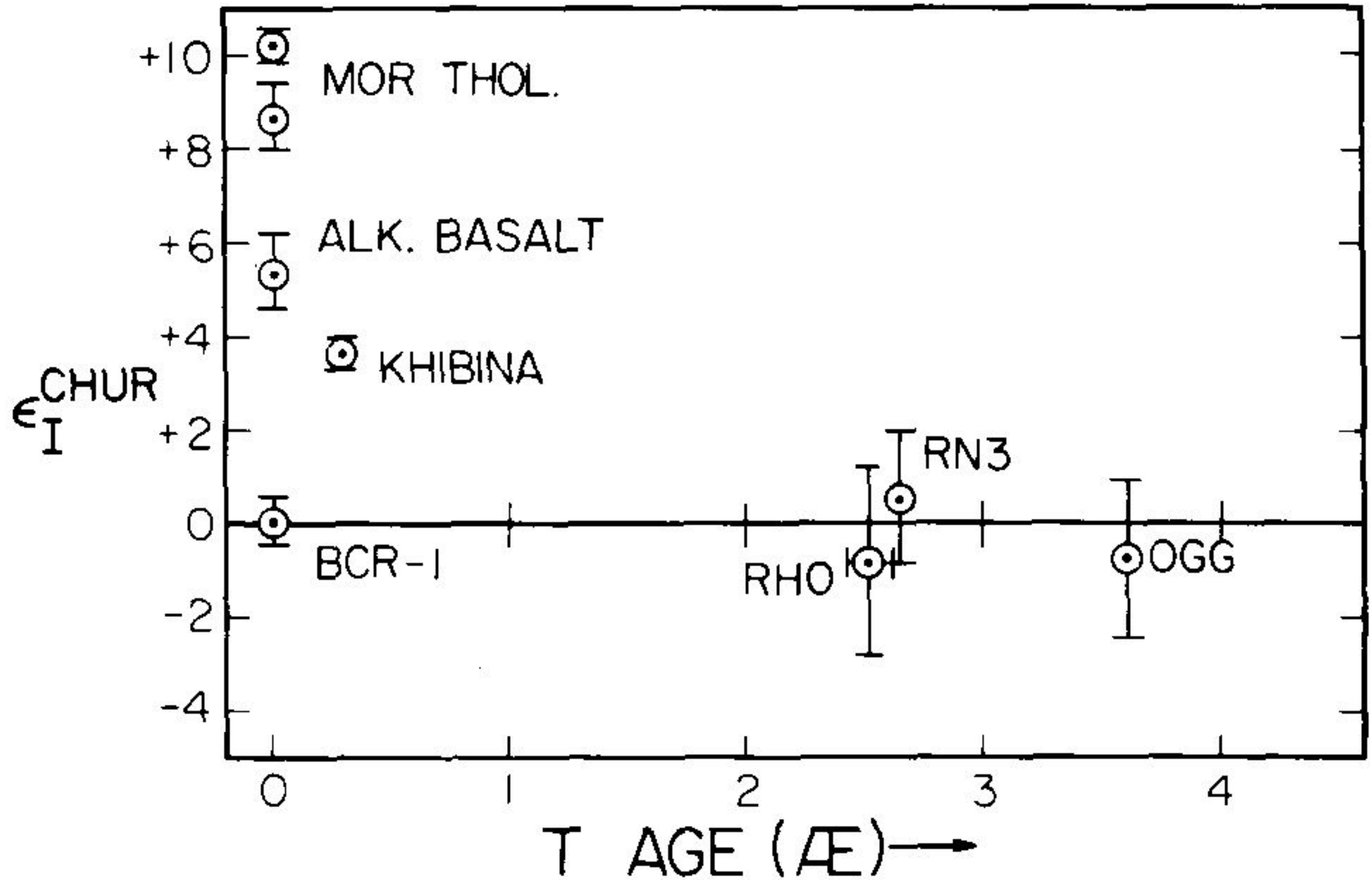
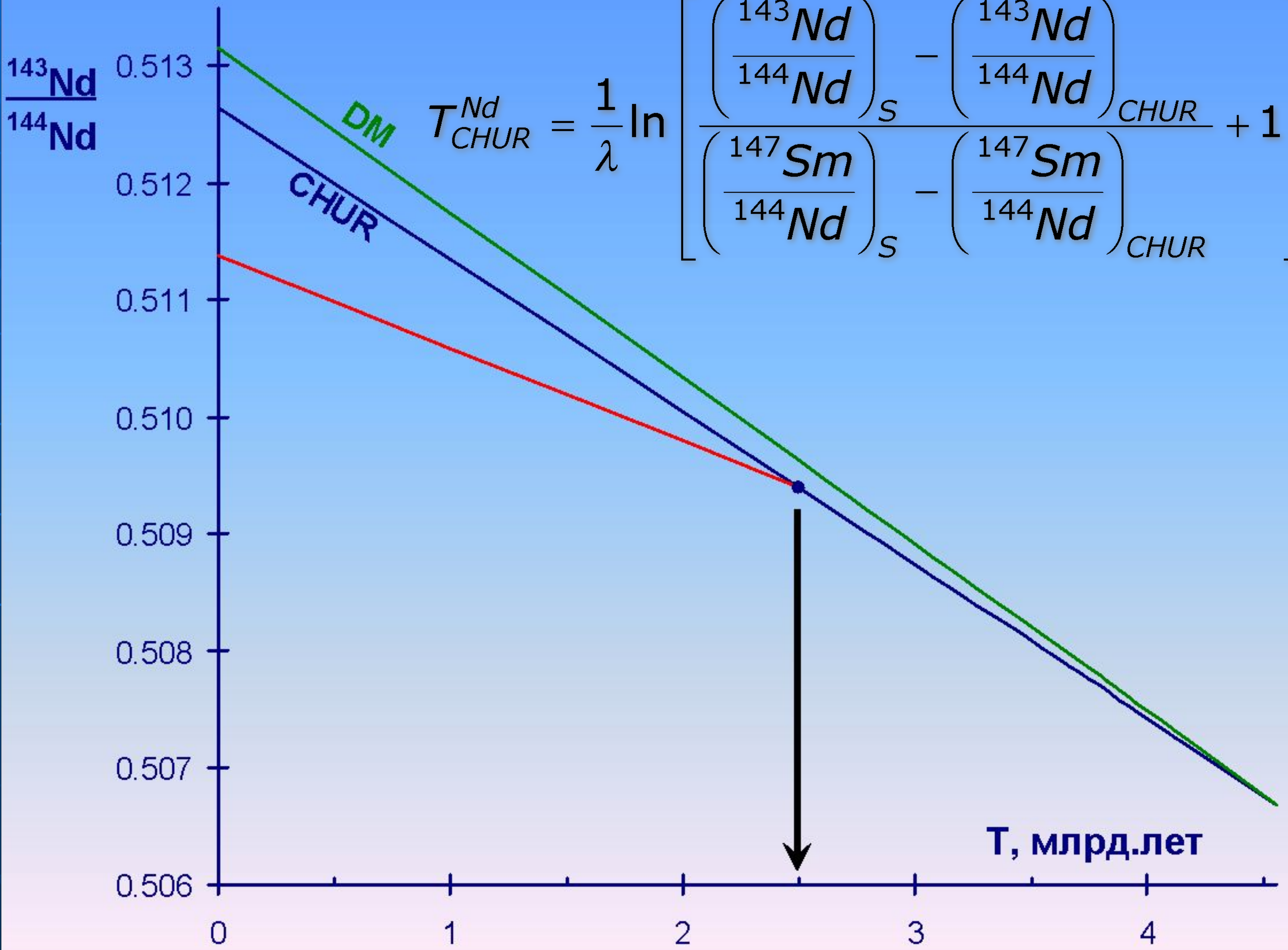


Fig. 3: Fractional deviations in parts in 10^4 of initial $^{143}Nd/^{144}Nd$ from evolution in a chondritic Sm/Nd reservoir (CHUR) vs. time.



$$T_{CHUR}^{Nd} = \frac{1}{\lambda}\ln\left[\frac{\left(\frac{^{143}Nd}{^{144}Nd}\right)_S - \left(\frac{^{143}Nd}{^{144}Nd}\right)_{CHUR}}{\left(\frac{^{147}Sm}{^{144}Nd}\right)_S - \left(\frac{^{147}Sm}{^{144}Nd}\right)_{CHUR}} + 1\right]$$

Smith A.D., Ludden J.N. Nd isotopic evolution of the Precambrian mantle. // Earth and Planetary Science Letters. 1989. 93: 14-22.

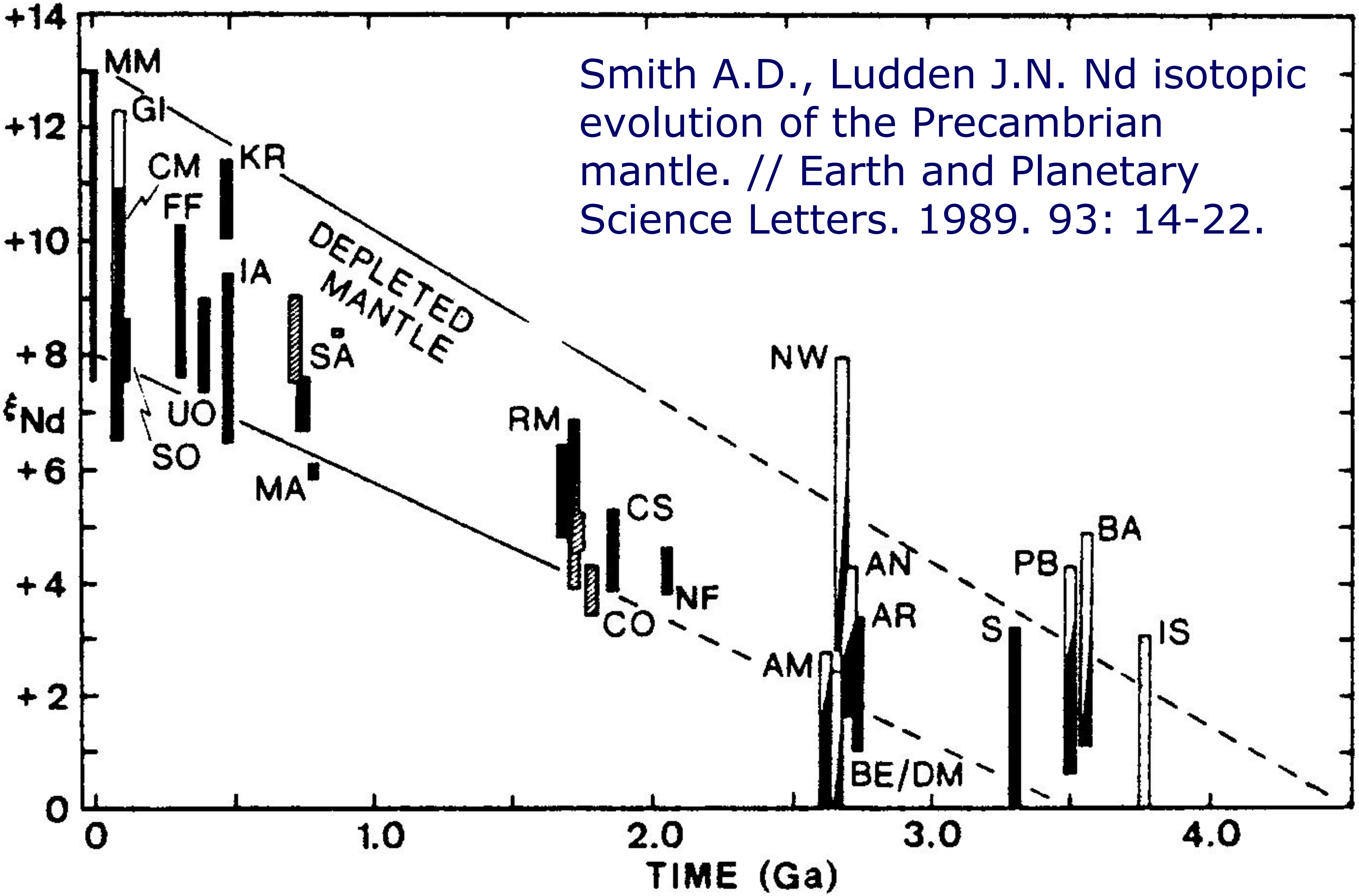
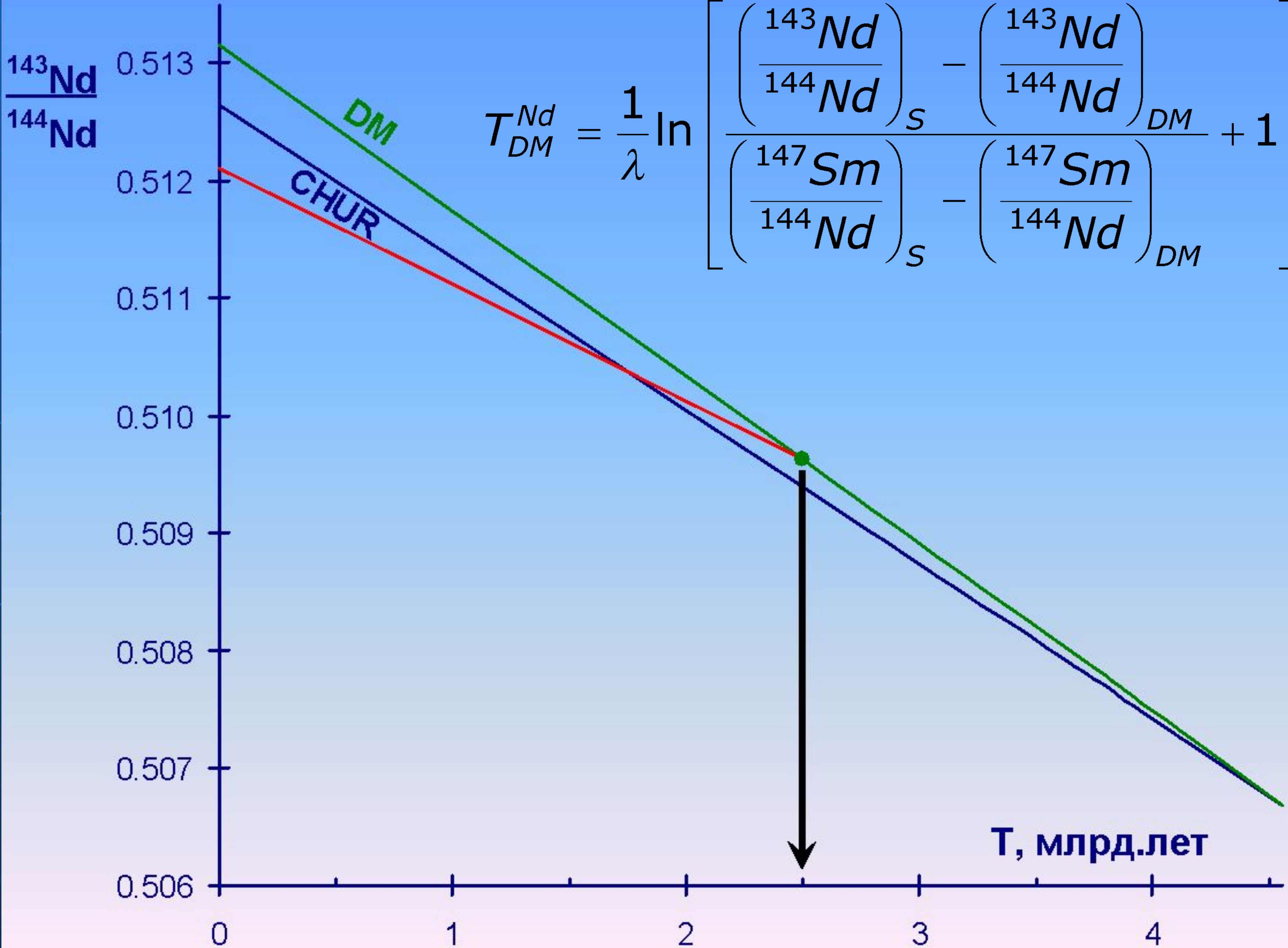
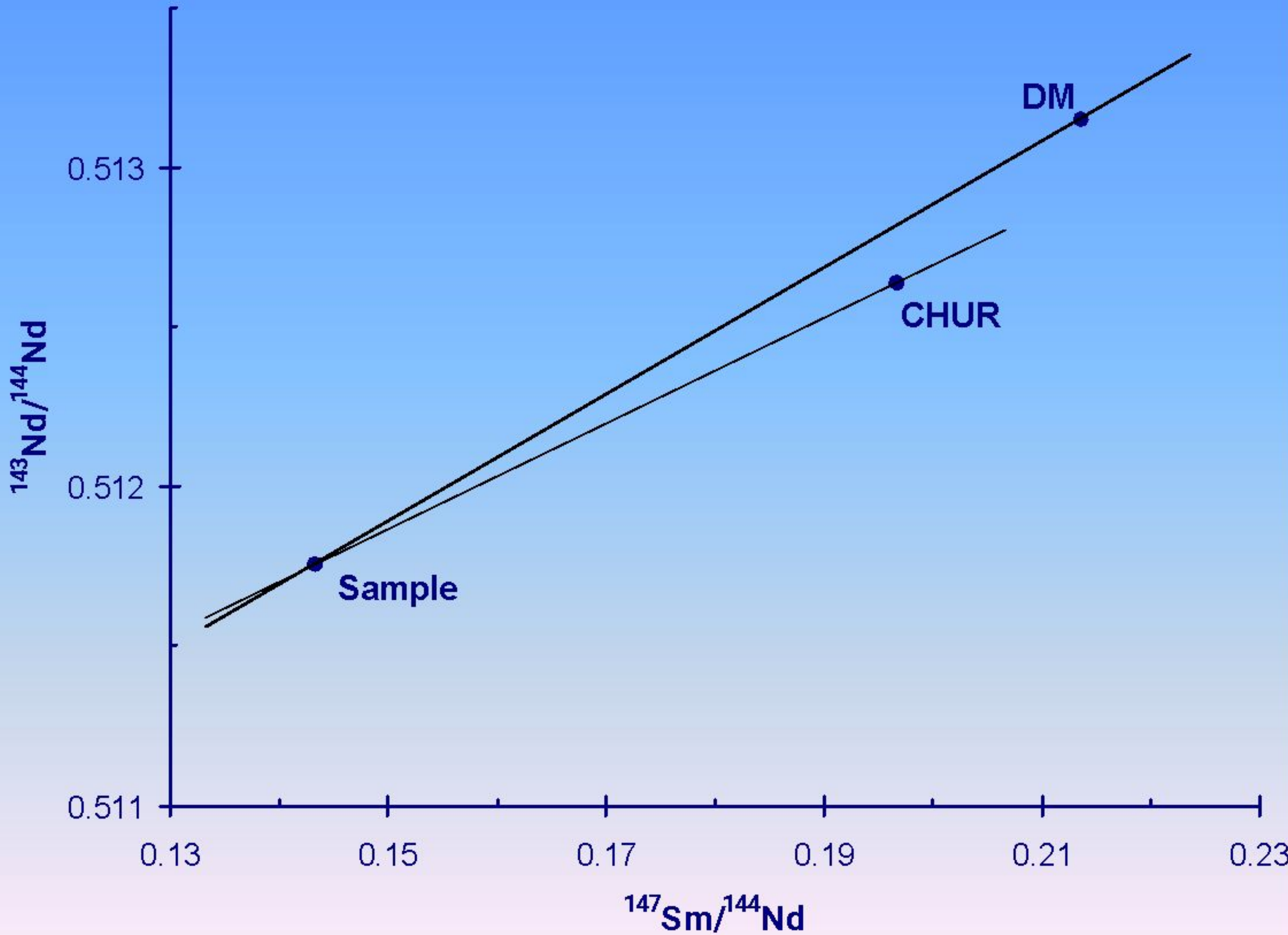


Fig. 3. Variation in ϵ_{Nd} with time for mantle-derived rocks (unshaded: komatiites; shaded: tholeiites; hatched: primitive island arc volcanics) and sediments (stippled).

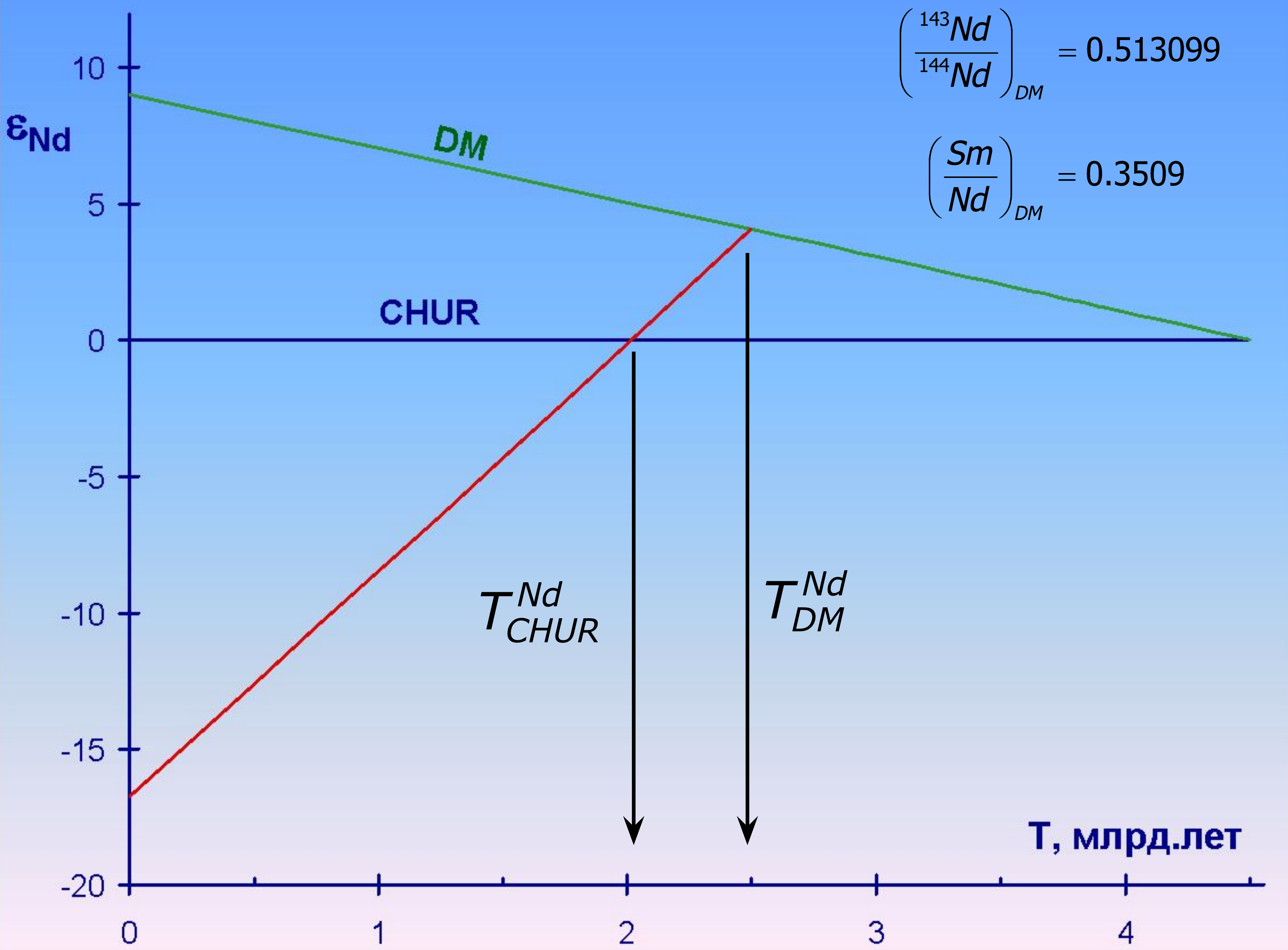
Fig. 3. Variation in ϵ_{Nd} with time for mantle-derived rocks (unshaded: komatiites; shaded: tholeiites; hatched: primitive island arc volcanics) and sediments (stippled). In order of increasing age: *MM* = modern MORB [17,18]; *GI* = Gorgona Island [19]; *CM* = Cretaceous MORB [20]; *SO* = Semail ophiolite [21]; *FF* = Fennel Formation [22]; *UO* = Urals ophiolite [23]; *KR* = Kings River ophiolite [24]; *IA* = Iapetus basalts [25,26]; *SA* = Saudi Arabian ophiolites and arcs [27–29]; *MA* = Matchless Amphibolite [30]; *RM* = Rocky Mountain greenstones [16]; *CO* = Colorado Front Range greenstones [15]; *CS* = Circum-Superior Belt ([8,12], this study); *NF* = Jouttiaapa Formation [14]; *DM/BE* = Belingwe [31] and Diemals-Marda [32]; *AM* = Abitibi, Munro Township [33]; *AN* = Abitibi, Newton Township [12,34]; *AR* = Abitibi, Rainy Lake [35]; *NW* = Norseman-Wiluna [36–38]; *S* = Saglek [39]; *PB* = Pilbara [40,41]; *BA* = Barberton [42,43]; *IS* = Isua [1].

$$T_{DM}^{Nd} = \frac{1}{\lambda}\ln\left[\frac{\left(\frac{^{143}Nd}{^{144}Nd}\right)_S - \left(\frac{^{143}Nd}{^{144}Nd}\right)_{DM}}{\left(\frac{^{147}Sm}{^{144}Nd}\right)_S - \left(\frac{^{147}Sm}{^{144}Nd}\right)_{DM}} + 1\right]$$

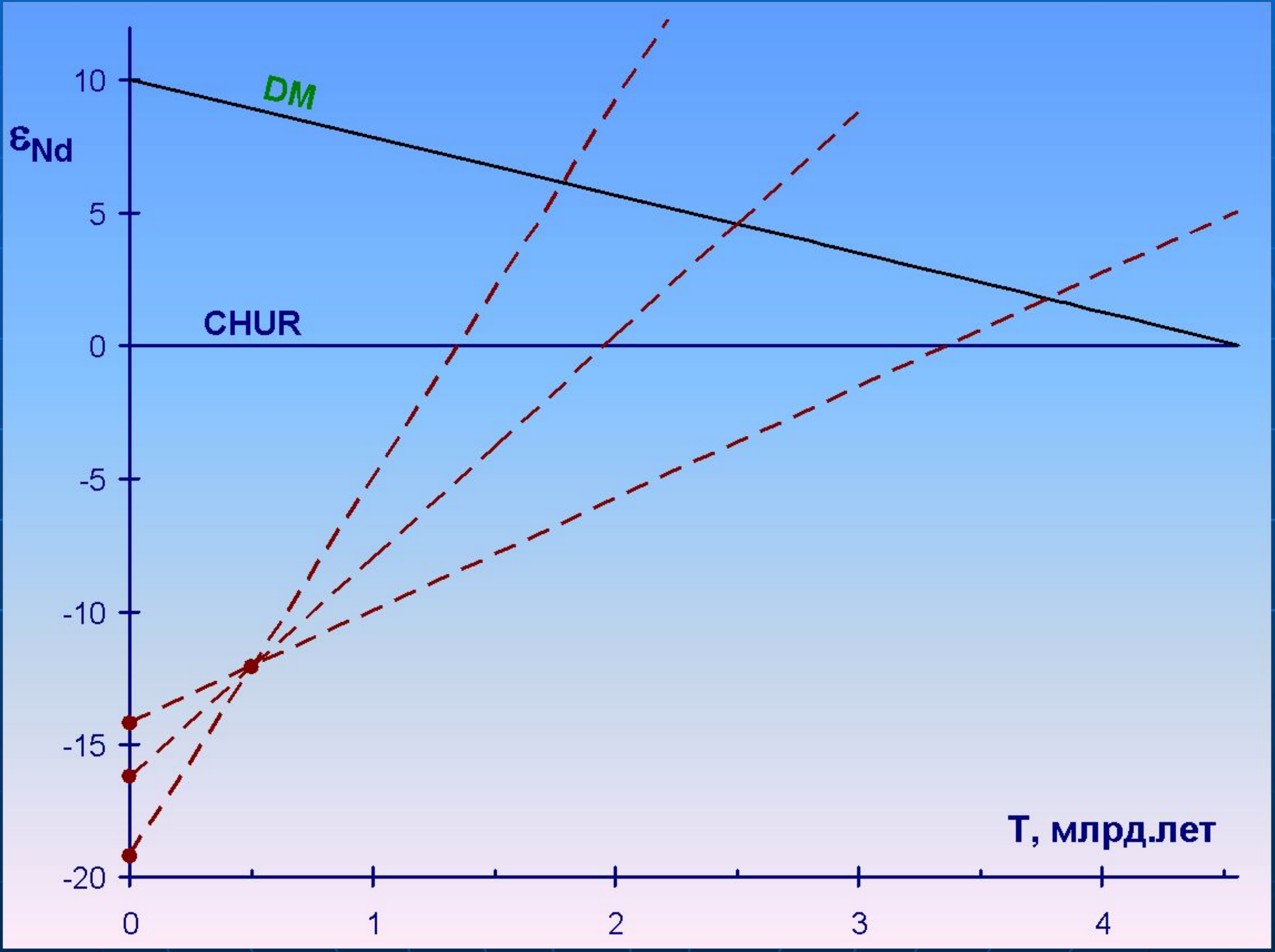




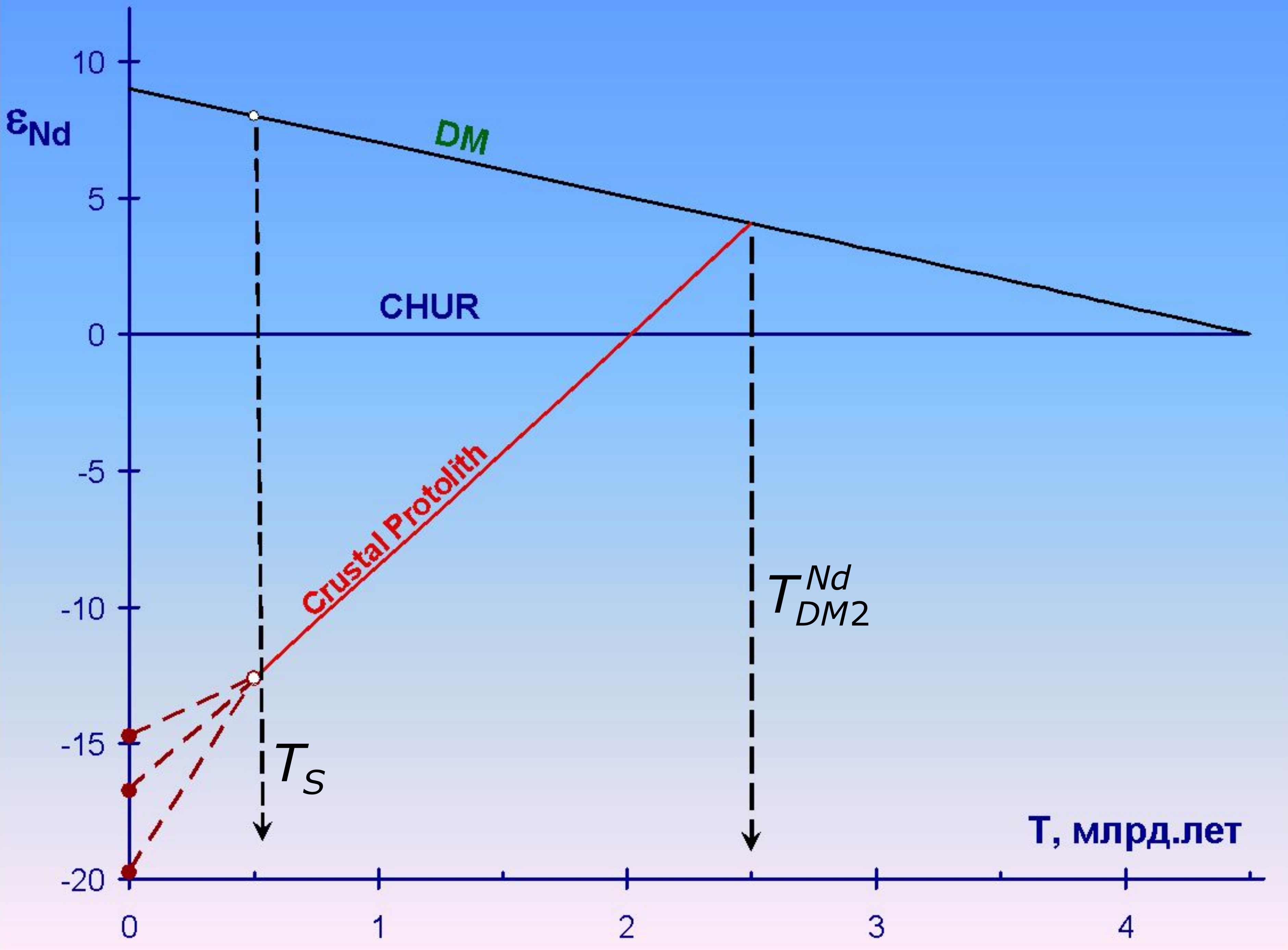
DM
CHUR
Sample
0.513
0.512
0.511
0.13
0.15
0.17
0.19
0.21
0.23
$^{143}Nd/^{144}Nd$
$^{147}Sm/^{144}Nd$



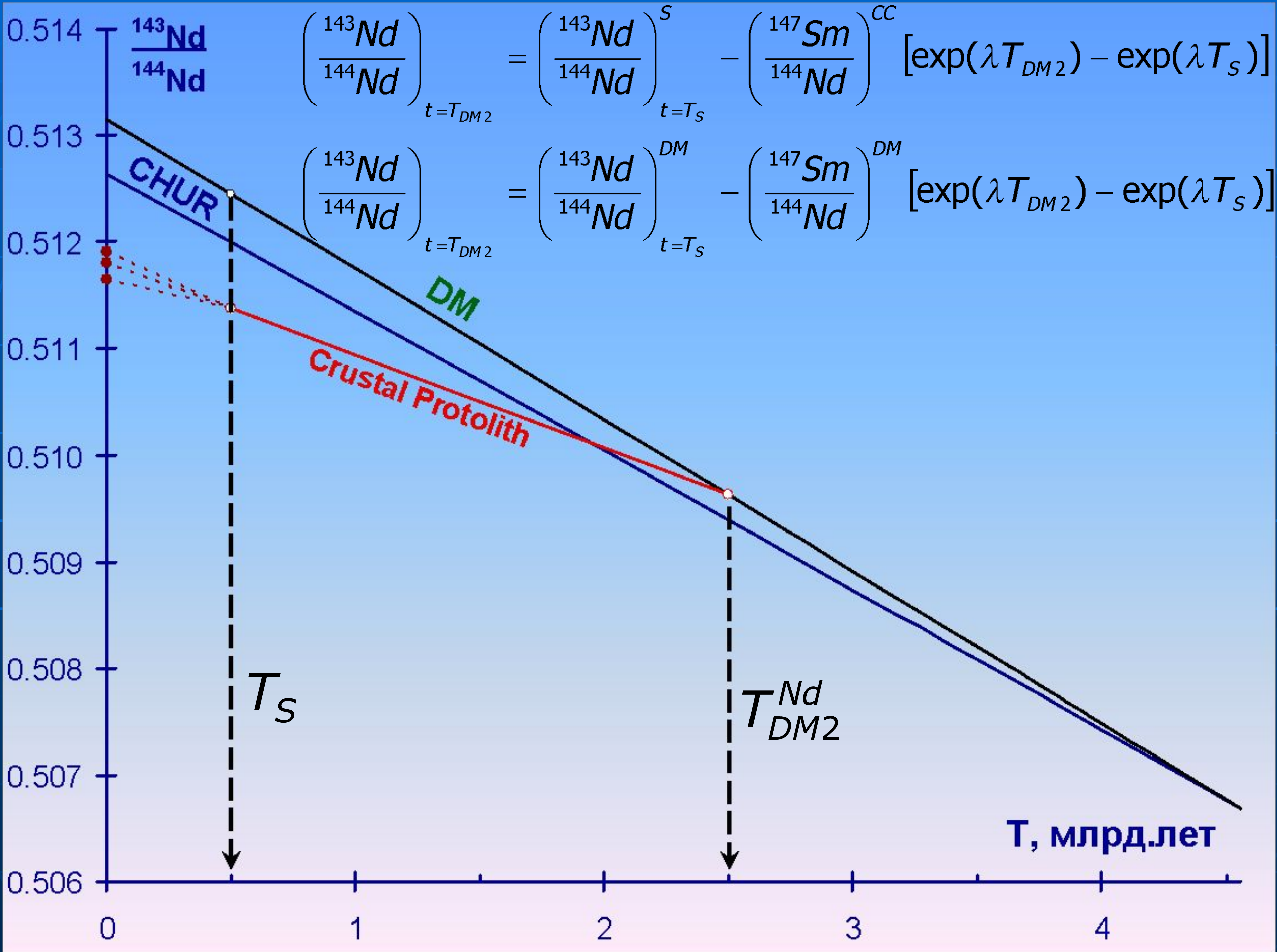
$\left(\frac{^{143}Nd}{^{144}Nd}\right)_{DM} = 0.513099$
$\left(\frac{Sm}{Nd}\right)_{DM} = 0.3509$
ε_{Nd}
10
5
0
-5
-10
-15
-20
DM
CHUR
T_{CHUR}^{Nd}
T_{DM}^{Nd}
T, млрд.лет
0
1
2
3
4



εNd
10
5
0
-5
-10
-15
-20
DM
CHUR
T, млрд.лет
0
1
2
3
4



εNd
10
5
0
-5
-10
-15
-20
DM
CHUR
Crustal Protolith
T_{DM2}^{Nd}
T_S
T, млрд.лет
0
1
2
3
4



$$\left(\frac{^{143}Nd}{^{144}Nd}\right)_{t=T_{DM2}} = \left(\frac{^{143}Nd}{^{144}Nd}\right)^{S}_{t=T_S} - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{CC}\left[\exp(\lambda T_{DM2}) - \exp(\lambda T_S)\right]$$
$$\left(\frac{^{143}Nd}{^{144}Nd}\right)_{t=T_{DM2}} = \left(\frac{^{143}Nd}{^{144}Nd}\right)^{DM}_{t=T_S} - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{DM}\left[\exp(\lambda T_{DM2}) - \exp(\lambda T_S)\right]$$
$^{143}Nd/^{144}Nd$
0.514
0.513
0.512
0.511
0.510
0.509
0.508
0.507
0.506
CHUR
DM
Crustal Protolith
T_S
T_{DM2}^{Nd}
T, млрд.лет
0
1
2
3
4

$$\frac{\left(\frac{^{143}Nd}{^{144}Nd}\right)^{DM}_{t=T_S} - \left(\frac{^{143}Nd}{^{144}Nd}\right)^{S}_{t=T_S}}{\left(\frac{^{147}Sm}{^{144}Nd}\right)^{DM} - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{CC}} = \left[\exp(\lambda T_{DM2}) - \exp(\lambda T_S)\right]$$

$$T^{Nd}_{DM2} = \frac{1}{\lambda}\ln\left[\frac{\left(\frac{^{143}Nd}{^{144}Nd}\right)^{DM}_{t=T_S} - \left(\frac{^{143}Nd}{^{144}Nd}\right)^{S}_{t=T_S}}{\left(\frac{^{147}Sm}{^{144}Nd}\right)^{DM} - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{CC}} + \exp(\lambda T_S)\right]$$

где

$$\left(\frac{^{143}Nd}{^{144}Nd}\right)^{DM}_{t=T_S} = \left(\frac{^{143}Nd}{^{144}Nd}\right)^{DM}_{t=0} - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{DM}\left[\exp(\lambda T_S) - 1\right]$$

$$\left(\frac{^{143}Nd}{^{144}Nd}\right)^{S}_{t=T_S} = \left(\frac{^{143}Nd}{^{144}Nd}\right)^{S}_{t=0} - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{S}\left[\exp(\lambda T_S) - 1\right]$$

$$T_{DM2}^{Nd} = \frac{1}{\lambda}\ln\left[\frac{\left(\frac{^{143}Nd}{^{144}Nd}\right)^{DM} + \left(\frac{^{147}Sm}{^{144}Nd}\right)^{DM} - \left(\frac{^{143}Nd}{^{144}Nd}\right)^{S} + \left(\frac{^{147}Sm}{^{144}Nd}\right)^{S}\left[\exp(\lambda T_S) - 1\right] - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{CC} \cdot \exp(\lambda T_S)}{\left(\frac{^{147}Sm}{^{144}Nd}\right)^{DM} - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{CC}}\right]$$

$$\frac{\left(\frac{^{143}Nd}{^{144}Nd}\right)^{DM}_{t=T_S} - \left(\frac{^{143}Nd}{^{144}Nd}\right)^{S}_{t=T_S}}{\left(\frac{^{147}Sm}{^{144}Nd}\right)^{DM} - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{CC}} \cong [\lambda T_{DM2} - \lambda T_S]$$

$$\exp(\lambda t) = 1 + \lambda t + \frac{(\lambda t)^2}{2!} + \frac{(\lambda t)^3}{3!} + \ldots$$

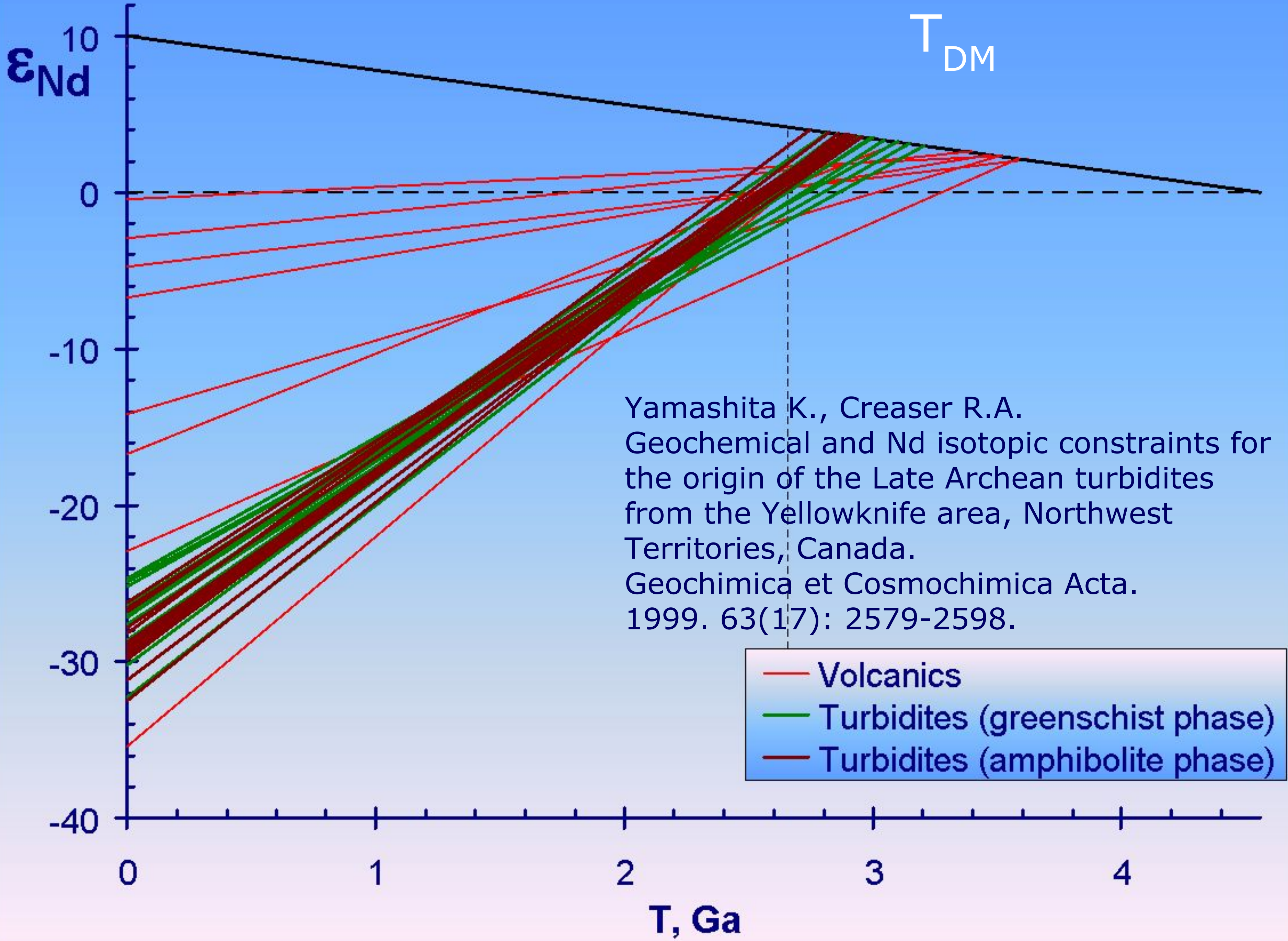
если $\lambda t << 1,$

$$D_{rad} \cong N\lambda t$$

$$T^{Nd}_{DM2} \cong T_S + \frac{1}{\lambda} \cdot \frac{\left(\frac{^{143}Nd}{^{144}Nd}\right)^{DM}_{t=T_S} - \left(\frac{^{143}Nd}{^{144}Nd}\right)^{S}_{t=T_S}}{\left(\frac{^{147}Sm}{^{144}Nd}\right)^{DM} - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{CC}}$$

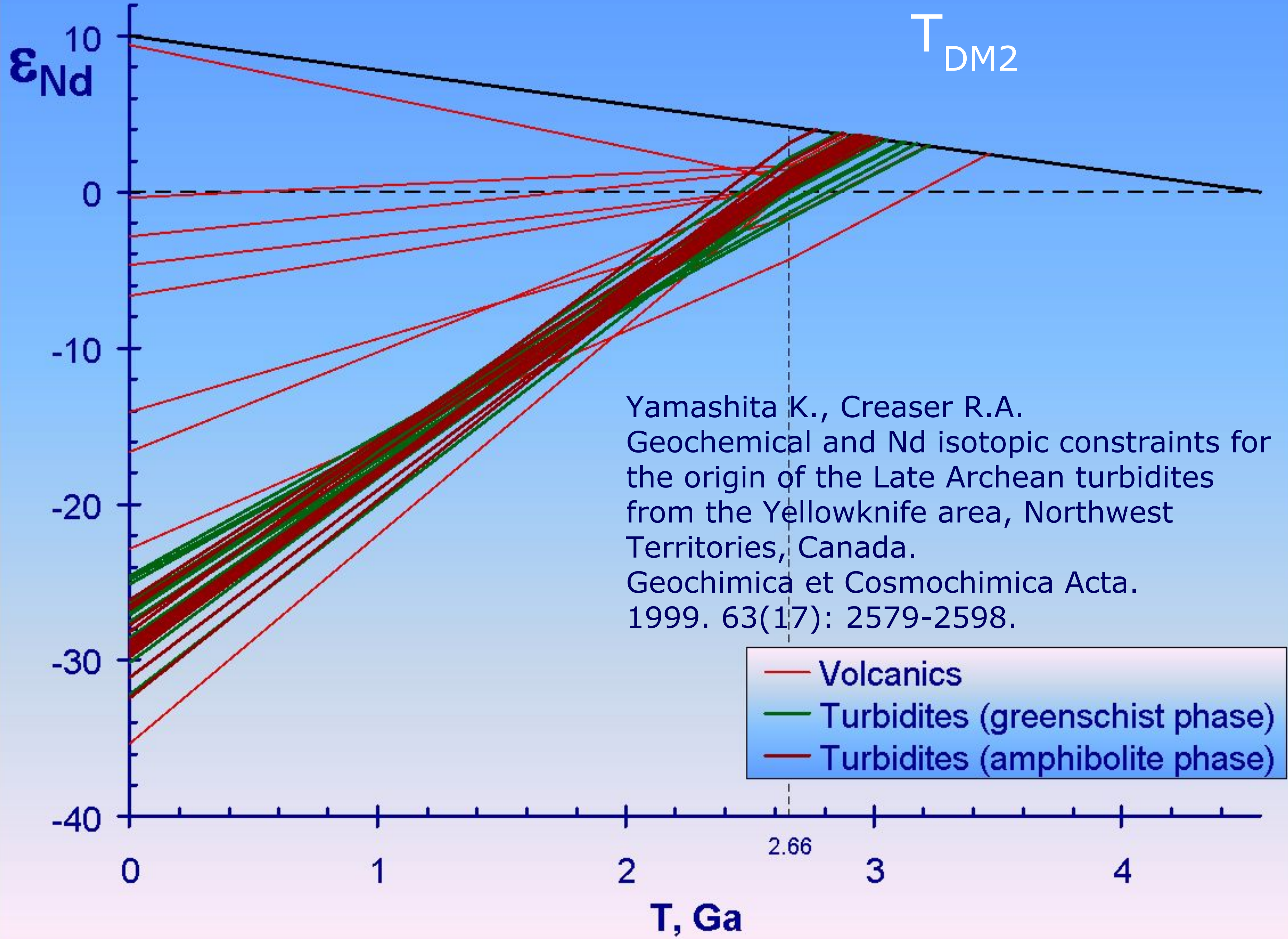
$$T^{Nd}_{DM2} \cong T_S + \frac{1}{\lambda} \cdot \frac{\left(\frac{^{143}Nd}{^{144}Nd}\right)^{DM}_{t=0} - \left(\frac{^{143}Nd}{^{144}Nd}\right)^{S}_{t=0} - \left[\left(\frac{^{147}Sm}{^{144}Nd}\right)^{DM} - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{S}\right]\lambda T_S}{\left(\frac{^{147}Sm}{^{144}Nd}\right)^{DM} - \left(\frac{^{147}Sm}{^{144}Nd}\right)^{CC}}$$

T_{DM}



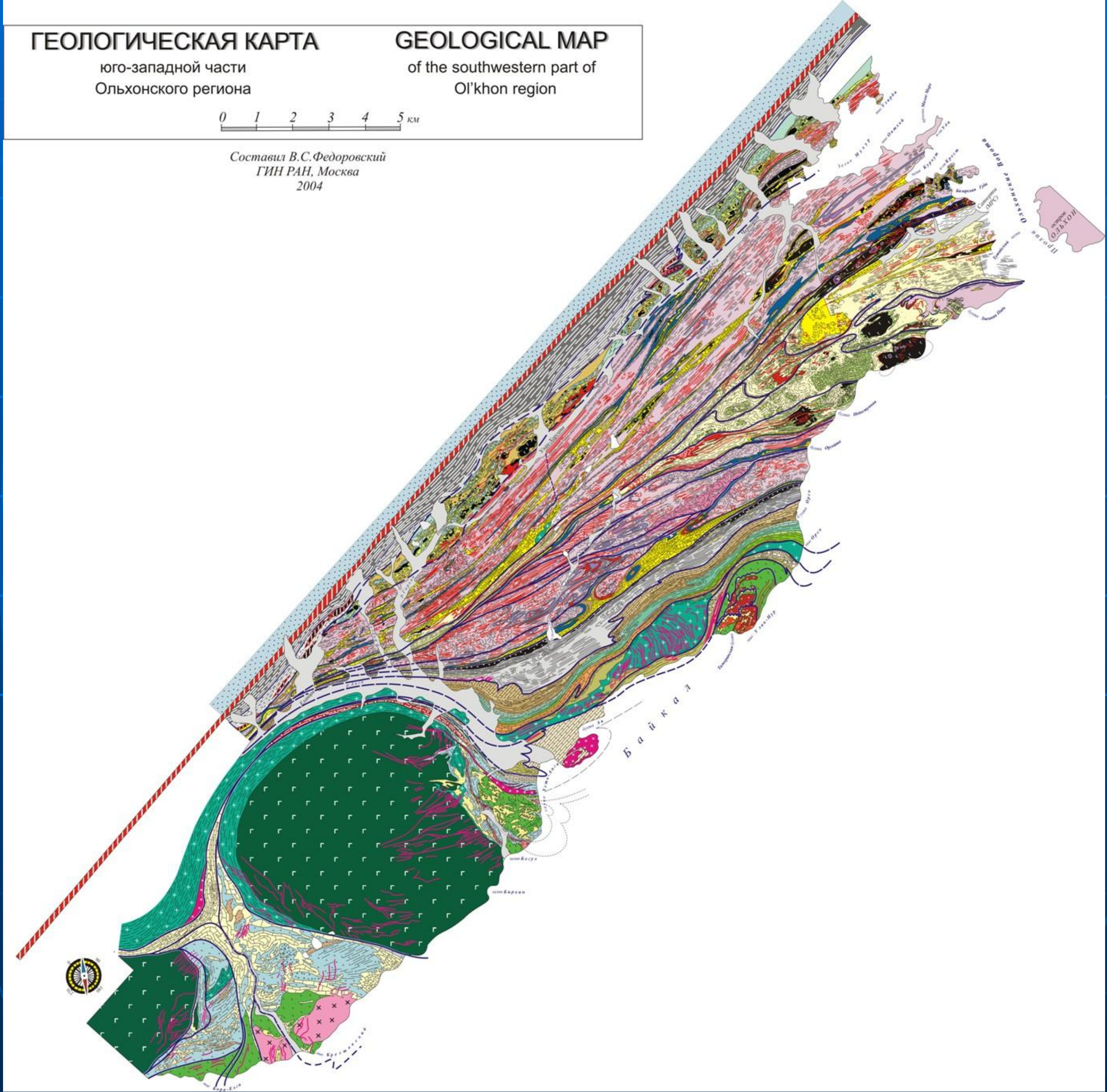
Yamashita K., Creaser R.A.
Geochemical and Nd isotopic constraints for the origin of the Late Archean turbidites from the Yellowknife area, Northwest Territories, Canada.
Geochimica et Cosmochimica Acta.
1999. 63(17): 2579-2598.

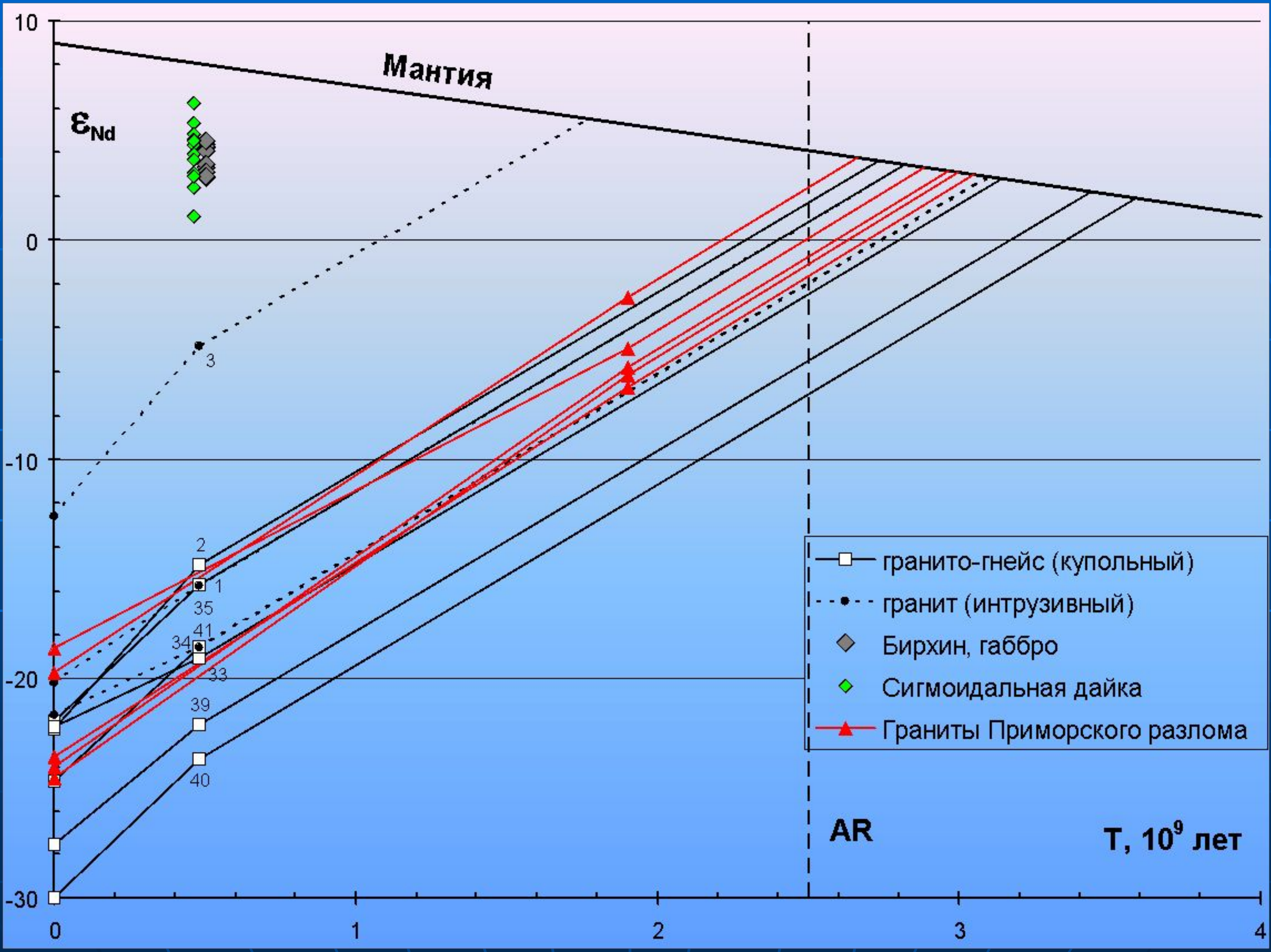
T_{DM2}



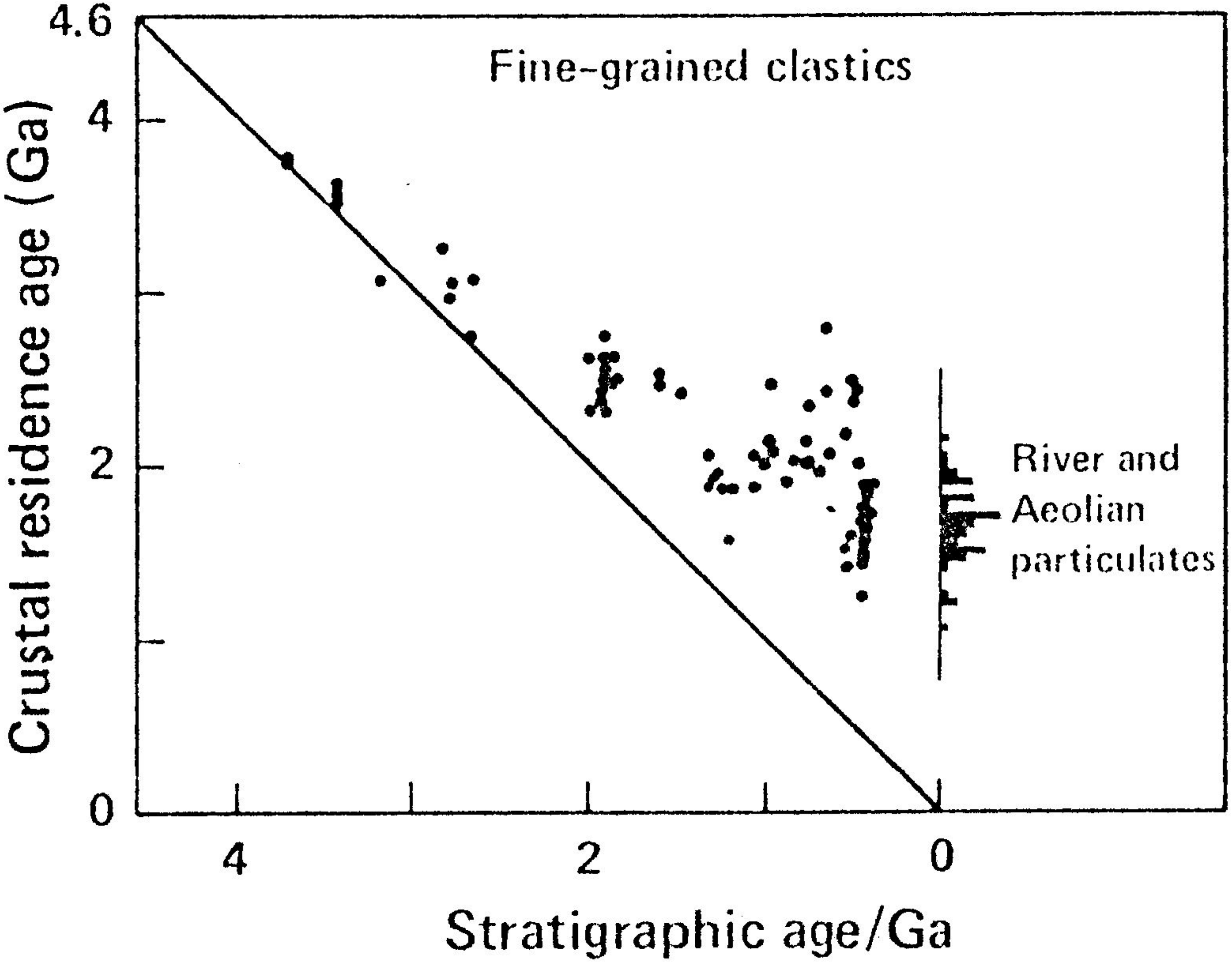
Yamashita K., Creaser R.A.
Geochemical and Nd isotopic constraints for the origin of the Late Archean turbidites from the Yellowknife area, Northwest Territories, Canada.
Geochimica et Cosmochimica Acta.
1999. 63(17): 2579-2598.


УСЛОВНЫЕ ЗНАКИ
ИРКУТСК
АНГАРСК
Масштаб 1:1 000 000


ГЕОЛОГИЧЕСКАЯ КАРТА
юго-западной части
Ольхонского региона
GEOLOGICAL MAP
of the southwestern part of
Ol'khon region
0 1 2 3 4 5 км
Составил В.С.Федоровский
ГИН РАН, Москва
2004
Байкал



Мантия
εNd
AR
T, 10^9 лет
гранито-гнейс (купольный)
гранит (интрузивный)
Бирхин, габбро
Сигмоидальная дайка
Граниты Приморского разлома
10
0
-10
-20
-30
0
1
2
3
4
3
2
1
35
41
34
33
39
40



Model age versus depositional age
for sediments worldwide (O'Nions 1984)

Задача 12. Вычислить T_{DM} и T_{DM2}

Sample	Sm/Nd	$^{143}Nd/^{144}Nd$	Age
1	0.1467	0.512030	0.80
2	0.1500	0.512014	0.82
3	0.1533	0.511999	0.84
4	0.1566	0.511984	0.86
5	0.1599	0.511969	0.88
6	0.1633	0.511955	0.90
7	0.1666	0.511942	0.92
8	0.1699	0.511929	0.94
9	0.1732	0.511916	0.96
10	0.1765	0.511904	0.98
…	…	…	…
31	0.2460	0.511774	1.40
32	0.2493	0.511774	1.42
33	0.2526	0.511774	1.44
34	0.2559	0.511774	1.46

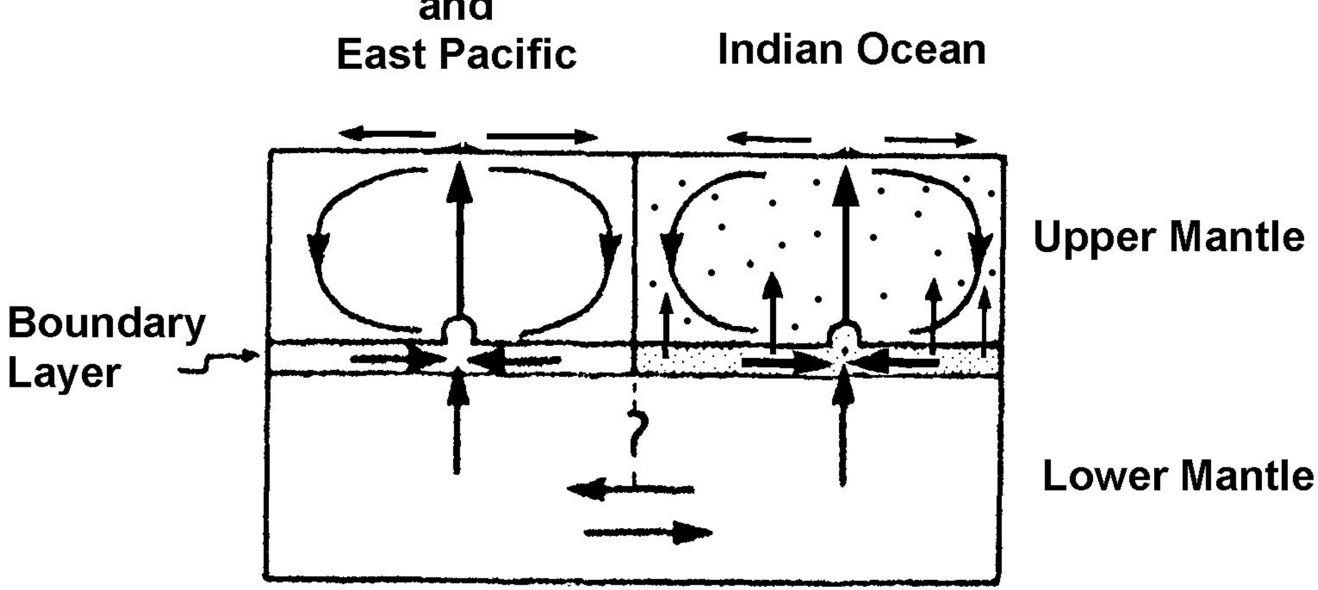
Остальные варианты в файле Ex12.xls на сайте wiki.web.ru

DM:
$\varepsilon_{Nd}(0)=+9$
$\varepsilon_{Nd}(4.5)=0$

Cont.Crust:
[Sm]=3.5 ppm
[Nd]=16.0 ppm

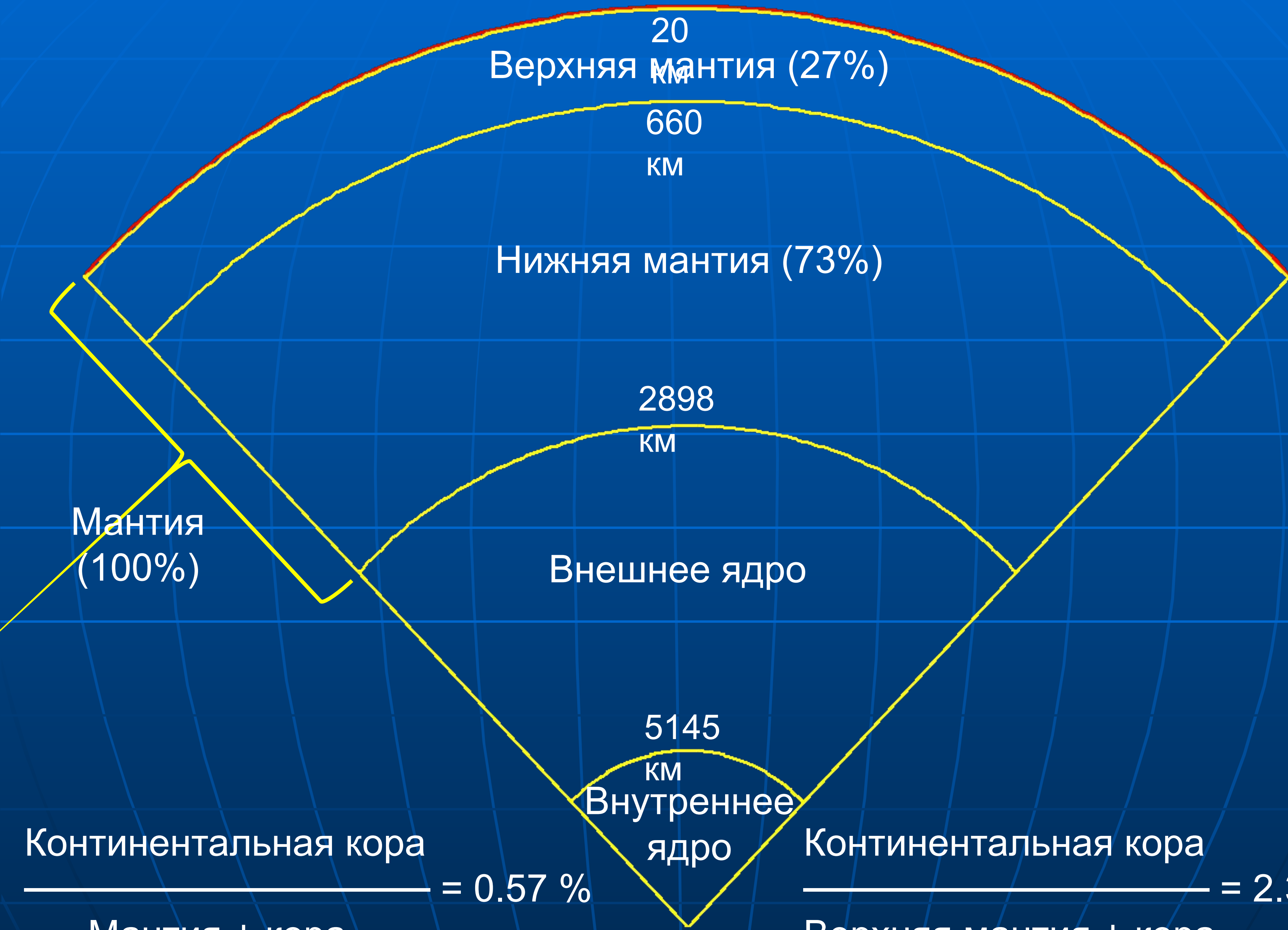
Проблема баланса кора-мантия

Hamelin & Allègre, 1985



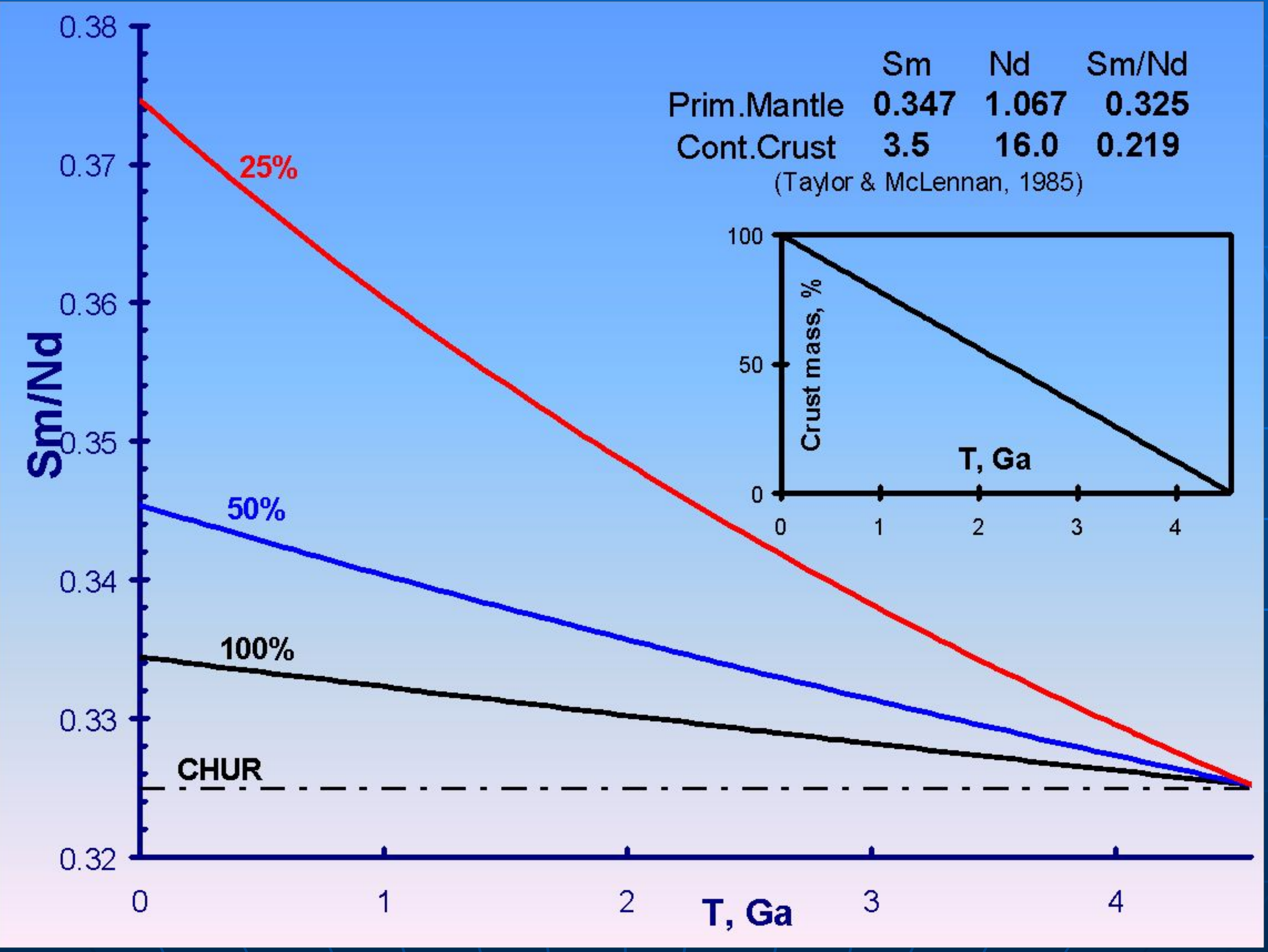
BOX MODEL OF MANTLE CIRCULATION

Fig. 5 Possible scheme of mantle dynamics. The upper mantle is divided in different discontinuous boxes, according to the SWIR MORB isotope results. The model where ocean island basalts originate in the boundary layer between upper and lower mantle[38] is illustrated as an example. Since the Indian Ocean island basalt source material (dotted area) is different from other parts of the world, the sub-Indian upper mantle is contaminated specifically by these Indian blobs, some of which reach the surface and others becoming progressively mixed within the upper mantle convection cell.



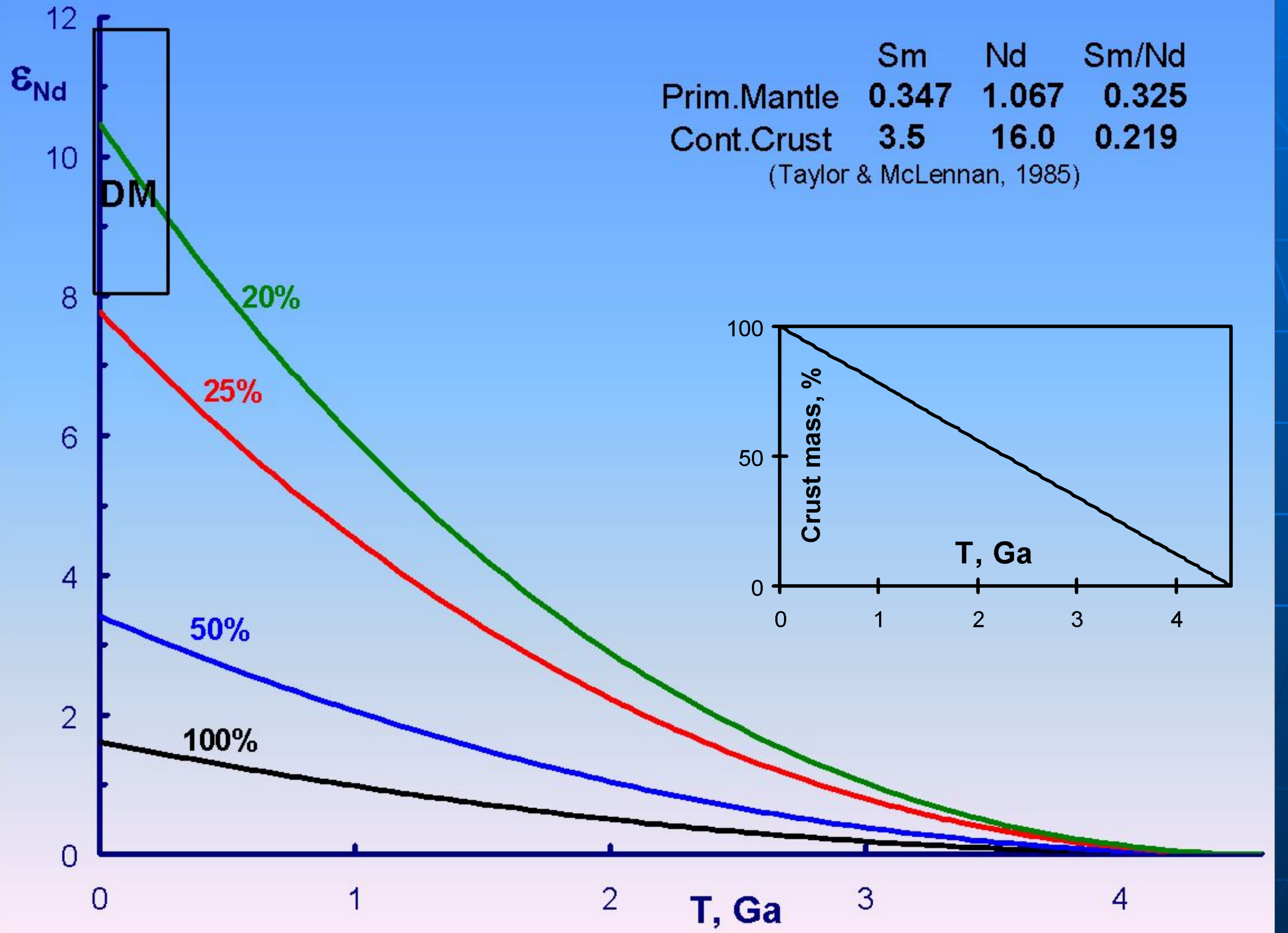
$$\frac{\text{Континентальная кора}}{\text{Мантия + кора}} = 0.57\ \%$$

$$\frac{\text{Континентальная кора}}{\text{Верхняя мантия + кора}} = 2.3\ \%$$



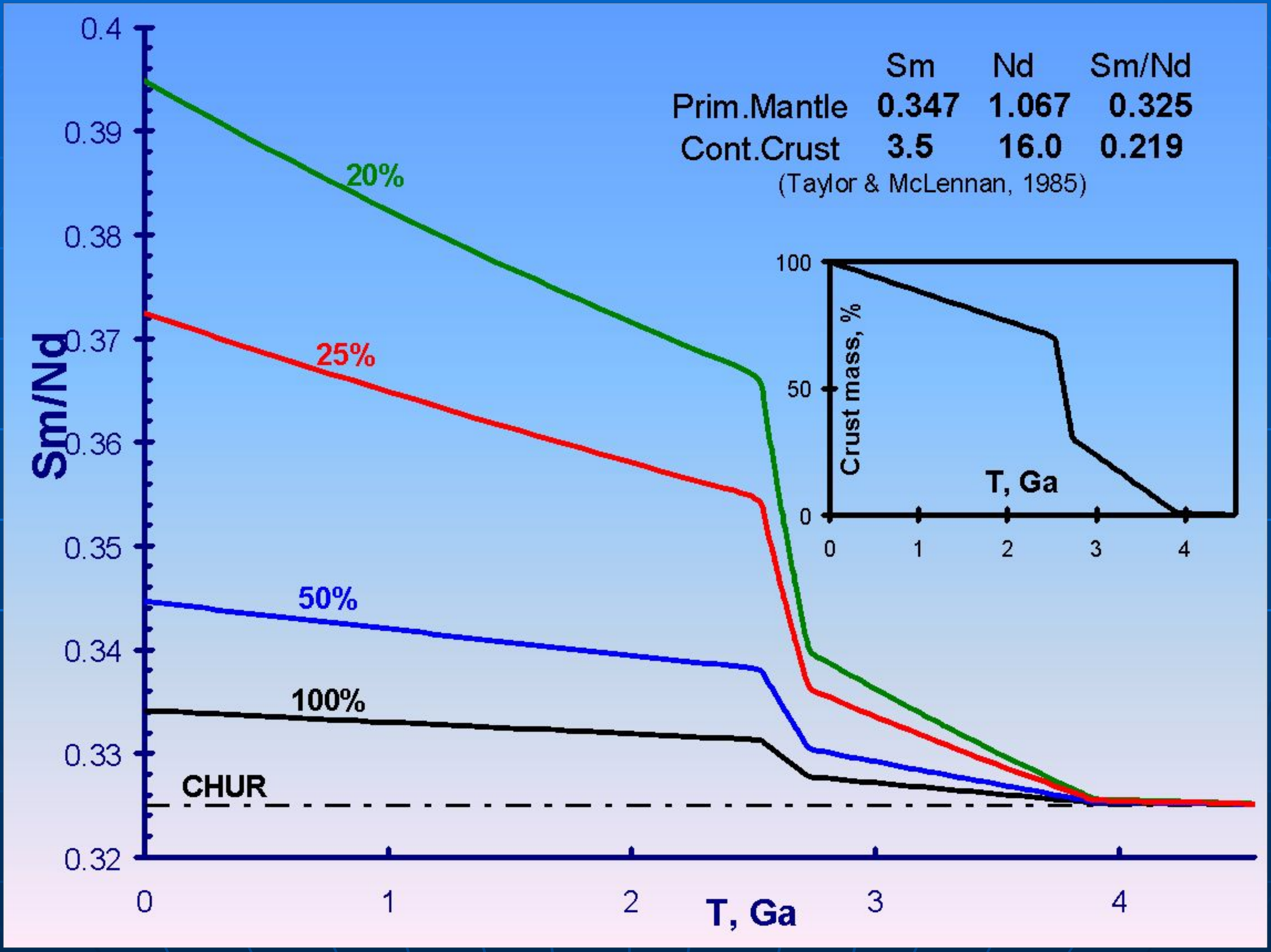
	Sm	Nd	Sm/Nd
Prim.Mantle	**0.347**	**1.067**	**0.325**
Cont.Crust	**3.5**	**16.0**	**0.219**

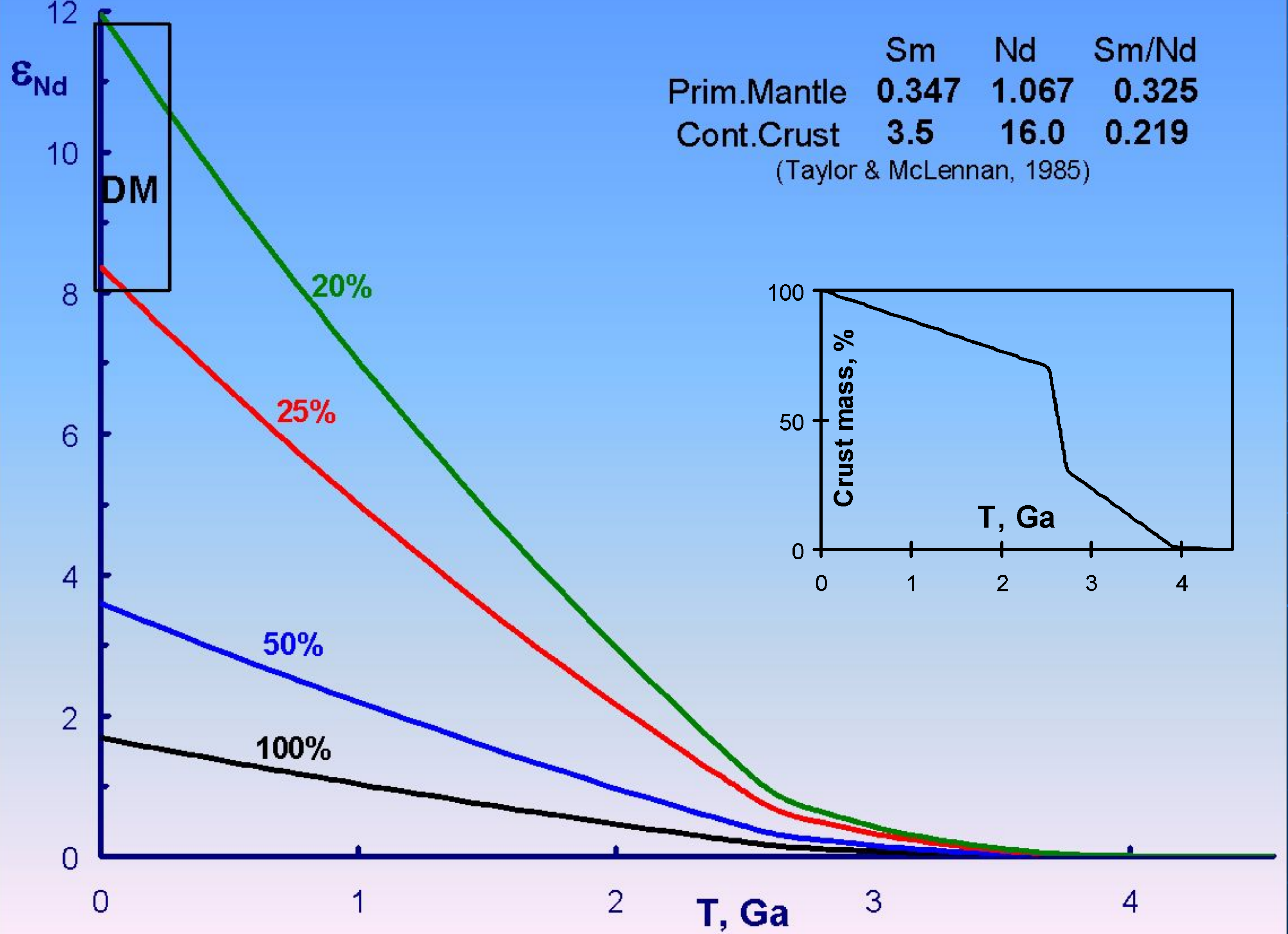
(Taylor & McLennan, 1985)



	Sm	Nd	Sm/Nd
Prim.Mantle	0.347	1.067	0.325
Cont.Crust	3.5	16.0	0.219

(Taylor & McLennan, 1985)


Sm Nd Sm/Nd
Prim.Mantle 0.347 1.067 0.325
Cont.Crust 3.5 16.0 0.219
(Taylor & McLennan, 1985)
Sm/Nd
0.4
0.39
0.38
0.37
0.36
0.35
0.34
0.33
0.32
20%
25%
50%
100%
CHUR
0
1
2
3
4
T, Ga
Crust mass, %
100
50
0
T, Ga



	Sm	Nd	Sm/Nd
Prim.Mantle	**0.347**	**1.067**	**0.325**
Cont.Crust	**3.5**	**16.0**	**0.219**

(Taylor & McLennan, 1985)

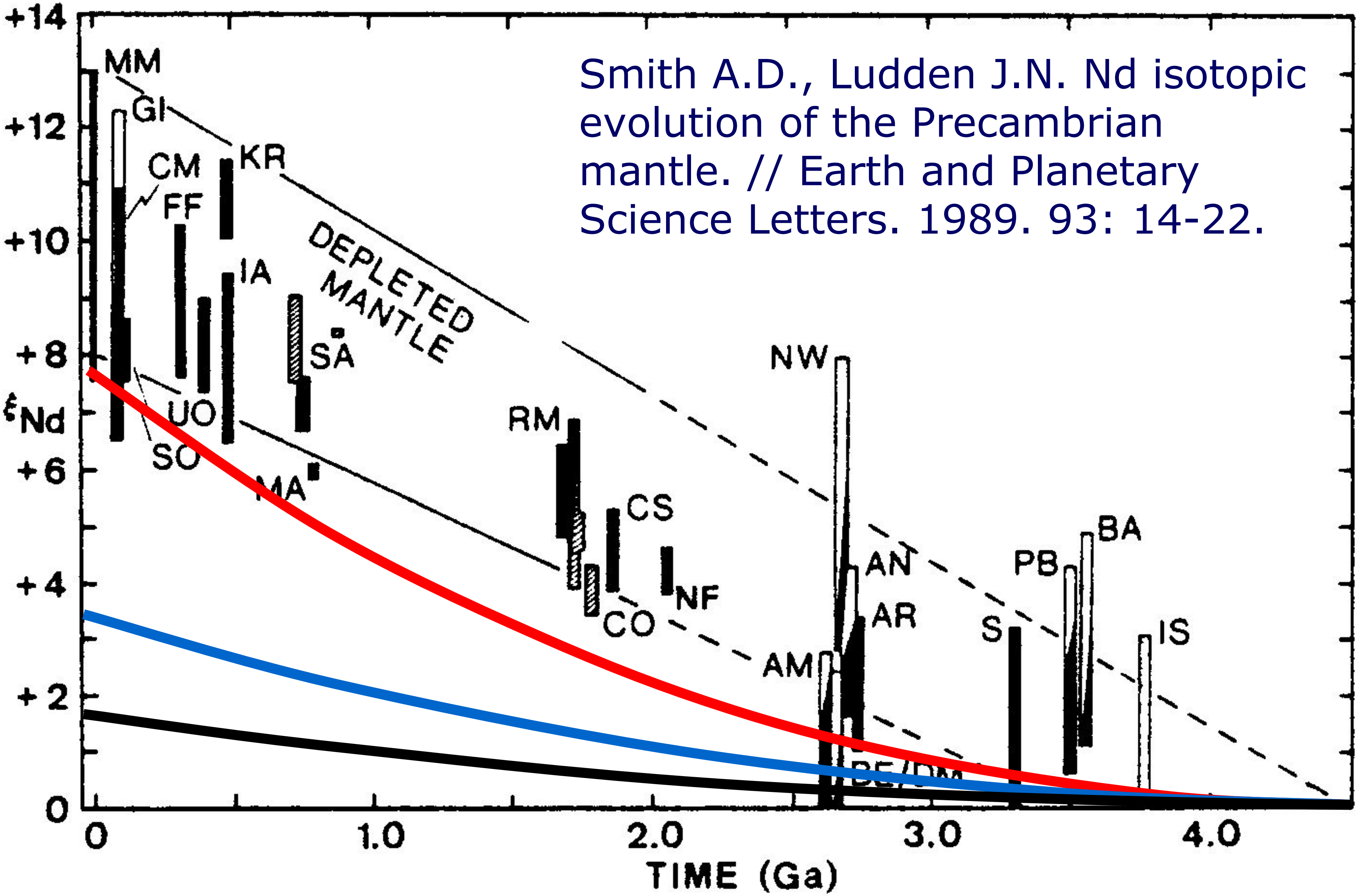
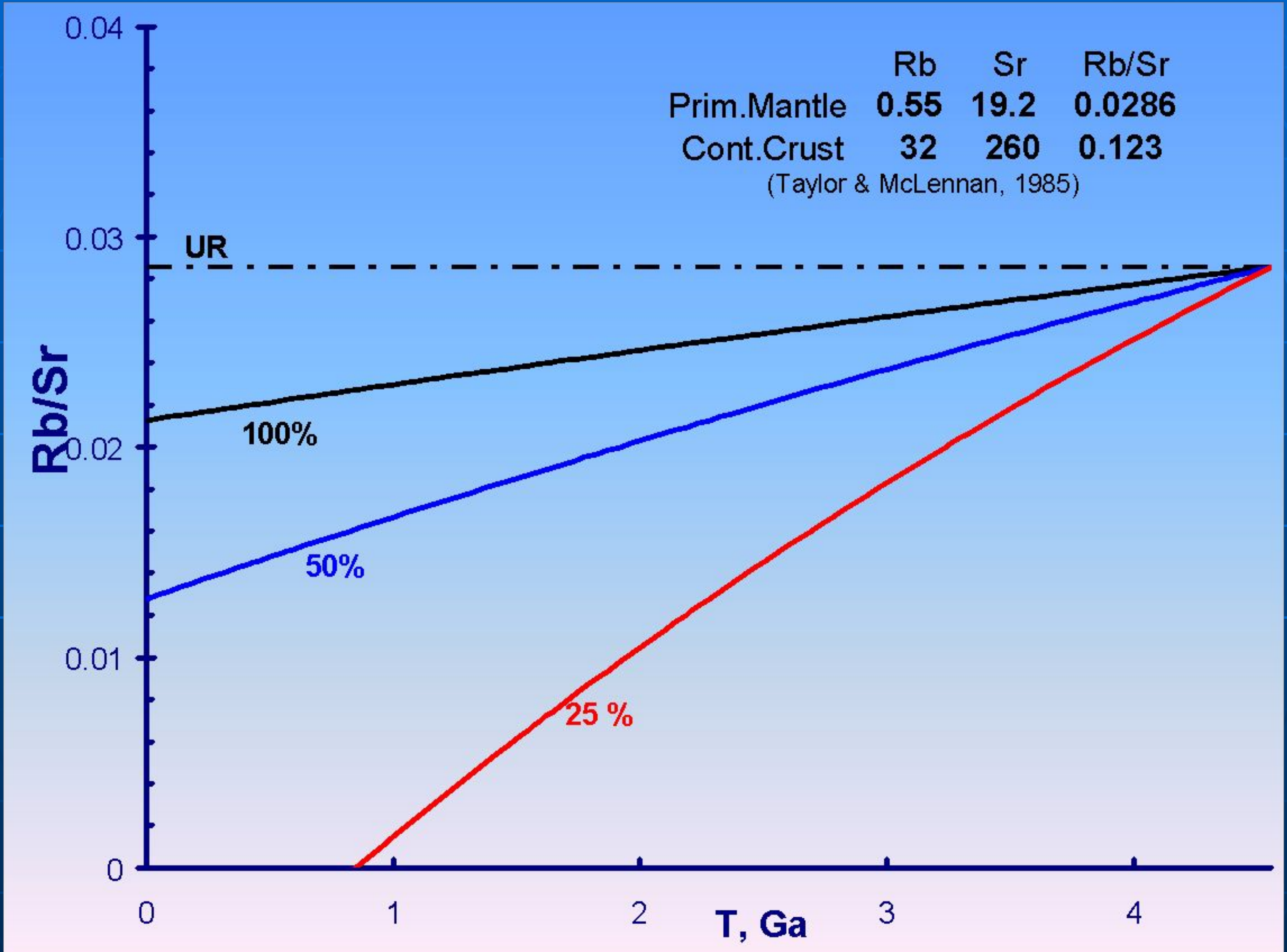
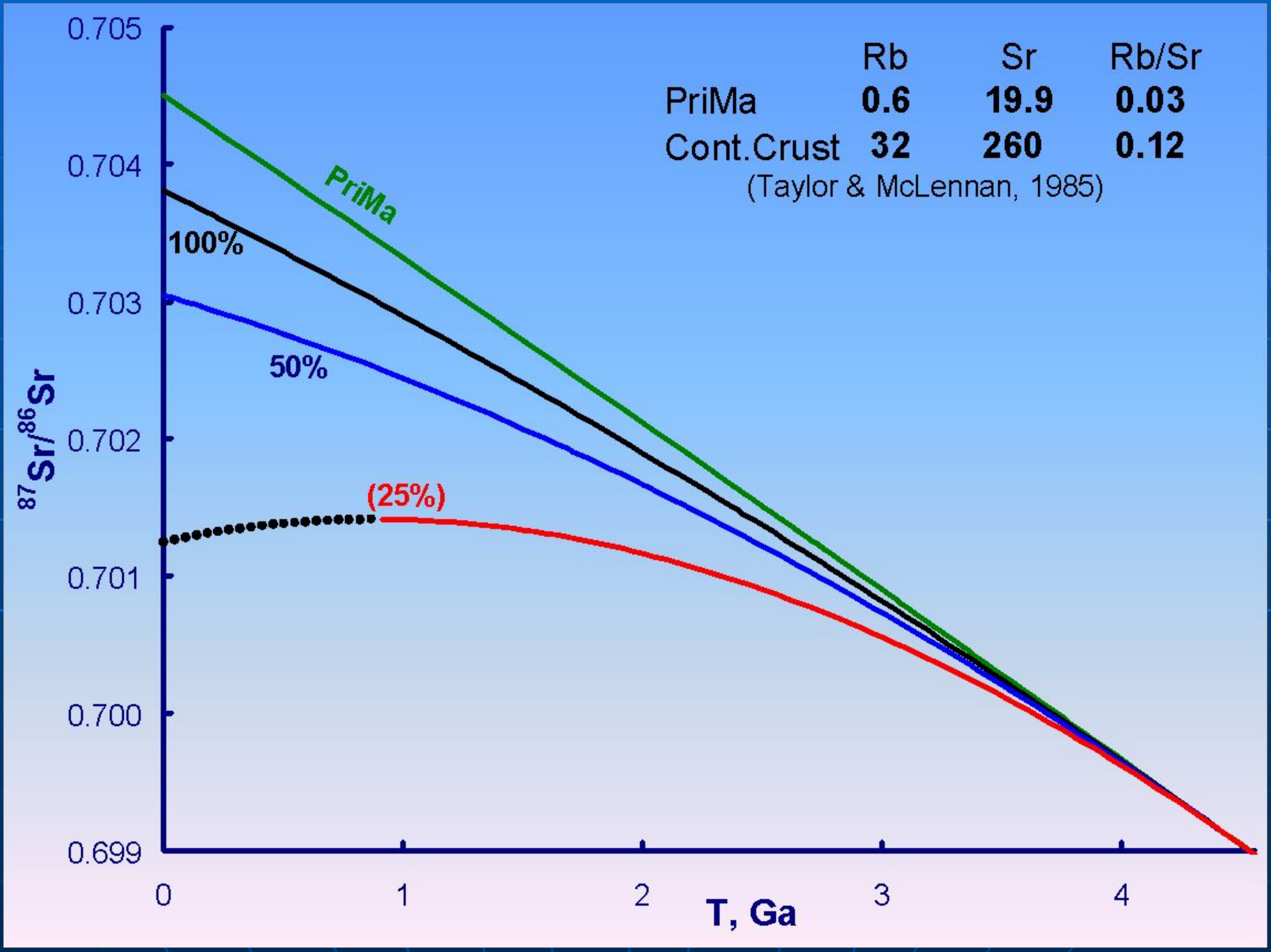


Fig. 3. Variation in ϵ_{Nd} with time for mantle-derived rocks (unshaded: komatiites; shaded: tholeiites; hatched: primitive island arc volcanics) and sediments (stippled).



Rb Sr Rb/Sr
Prim.Mantle 0.55 19.2 0.0286
Cont.Crust 32 260 0.123
(Taylor & McLennan, 1985)
UR
100%
50%
25 %
Rb/Sr
0.04
0.03
0.02
0.01
0
0
1
2
3
4
T, Ga



0.705
0.704
0.703
0.702
0.701
0.700
0.699
$^{87}Sr/^{86}Sr$
Rb Sr Rb/Sr
PriMa 0.6 19.9 0.03
Cont.Crust 32 260 0.12
(Taylor & McLennan, 1985)
PriMa
100%
50%
(25%)
0
1
2
3
4
T, Ga

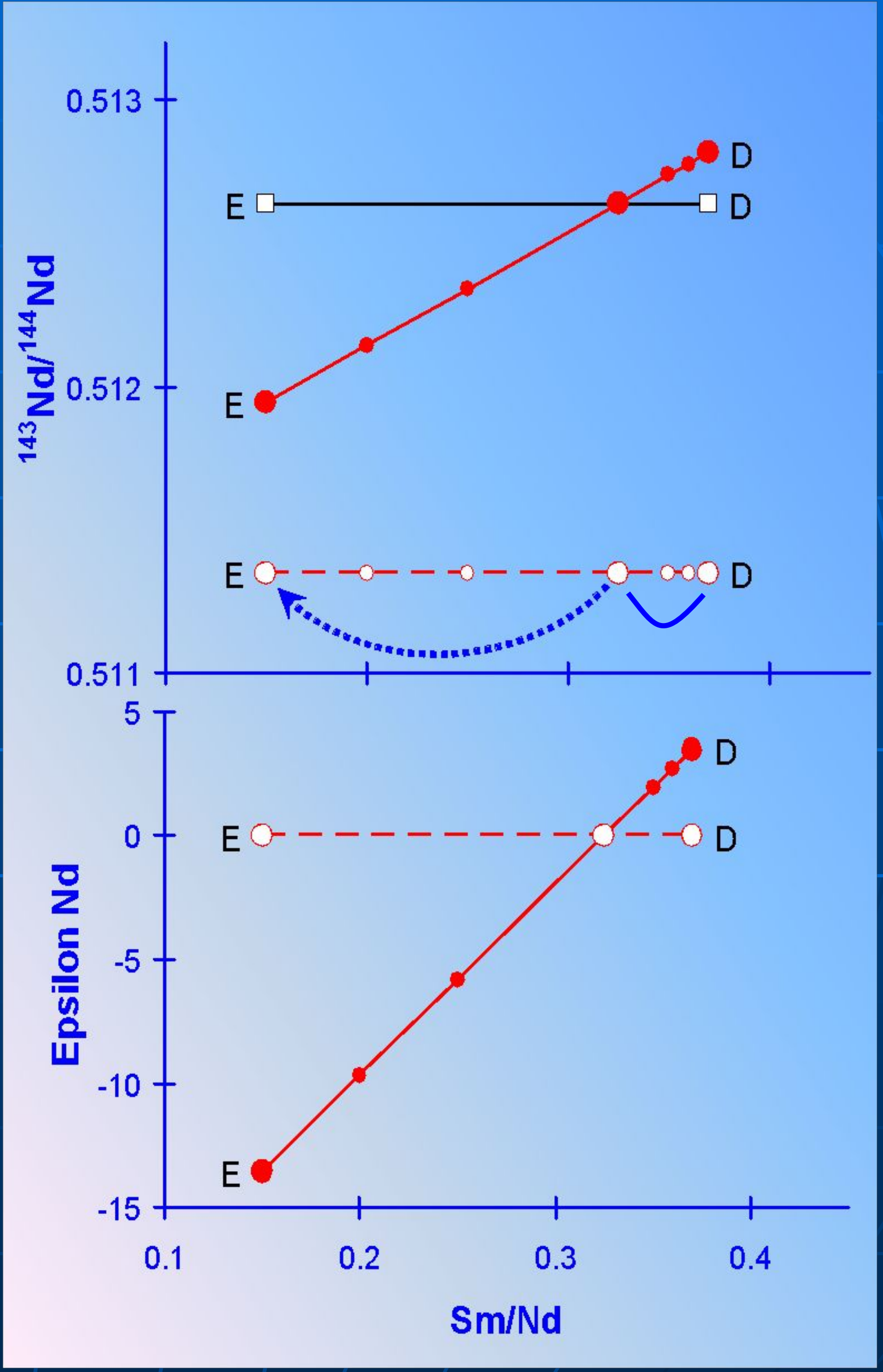
- Прямые выплавки (E) из примитивной мантии и рестит (D) должны иметь начальный изотопный состав этого источника и комплементарные отношения Sm/Nd

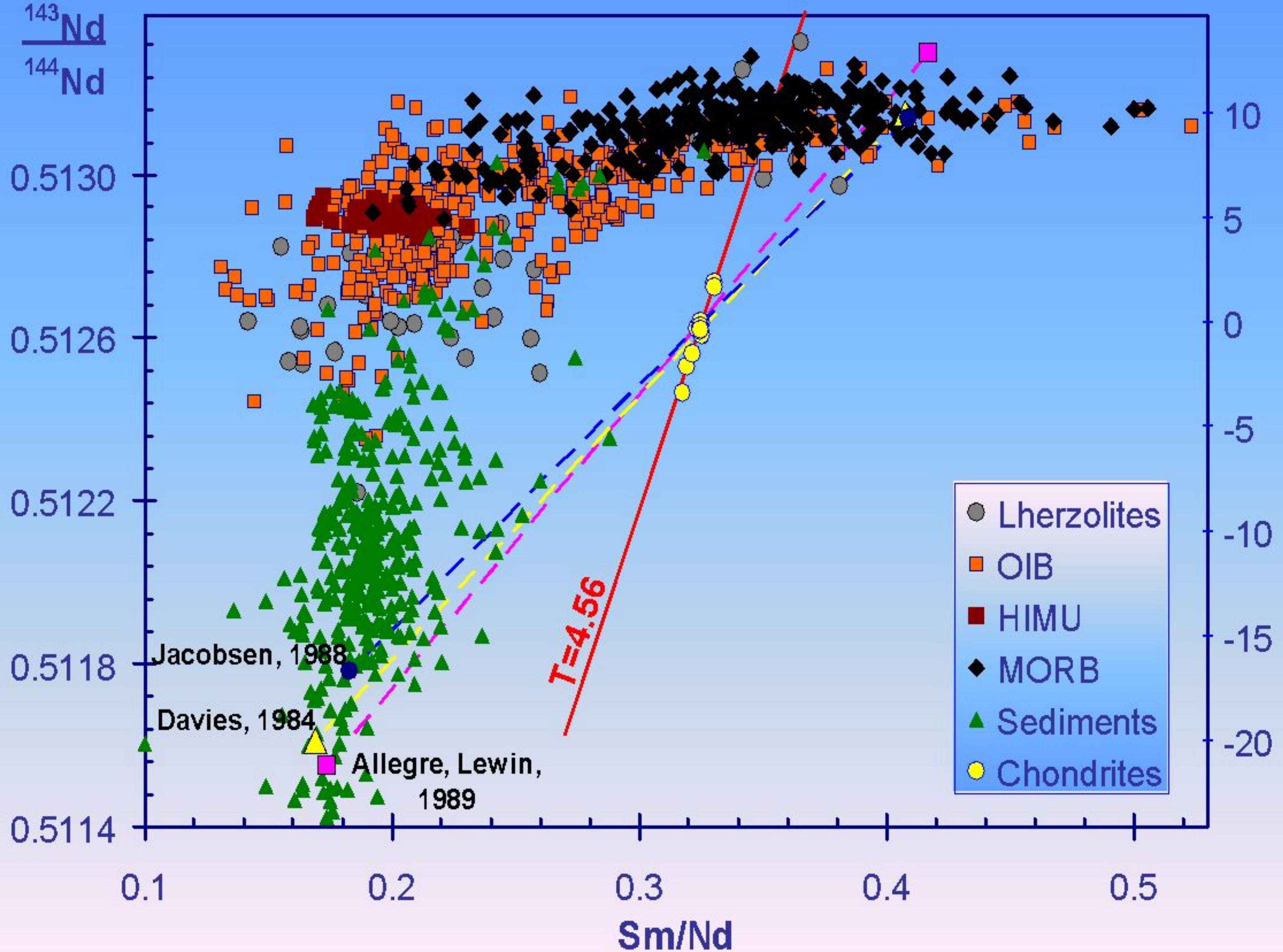
- Линии смешения обеднённого и обогащённого вещества в этих координатах – прямые, проходящие через исходный (примитивный) источник

- Прямые выплавки толеитов из CHUR должны иметь:

$\varepsilon_{Nd} \approx 0$

Sm/Nd ≈ 0.325





143Nd/144Nd
0.5130
0.5126
0.5122
0.5118
0.5114
10
5
0
-5
-10
-15
-20
0.1
0.2
0.3
0.4
0.5
Sm/Nd
T=4.56
Jacobsen, 1988
Davies, 1984
Allegre, Lewin, 1989
Lherzolites
OIB
HIMU
MORB
Sediments
Chondrites

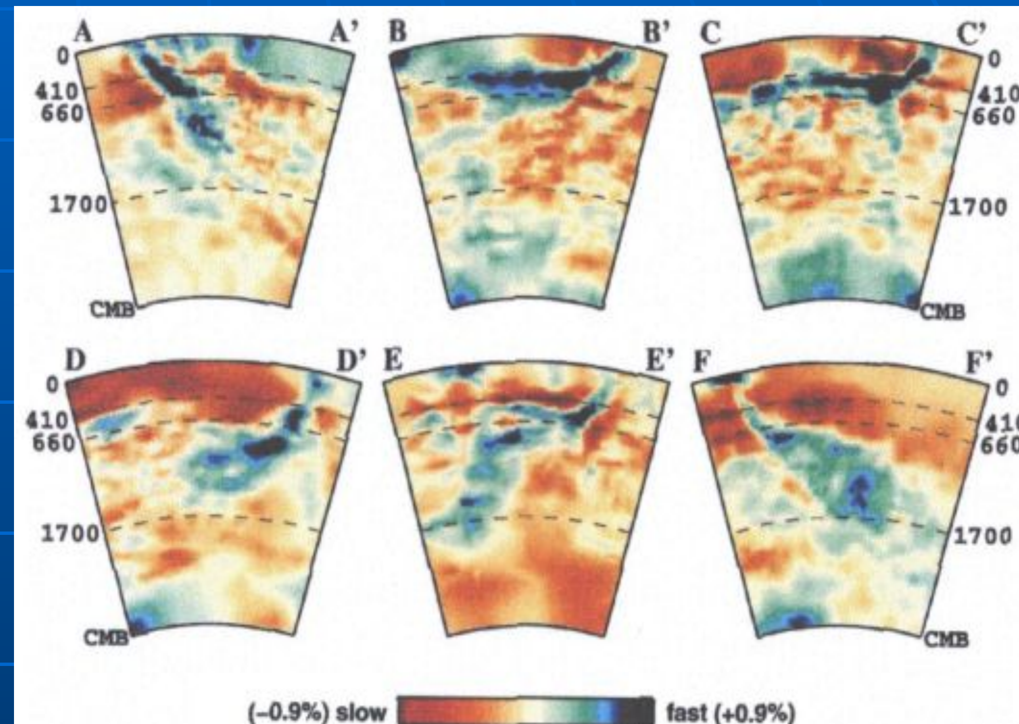
Альтернатива:

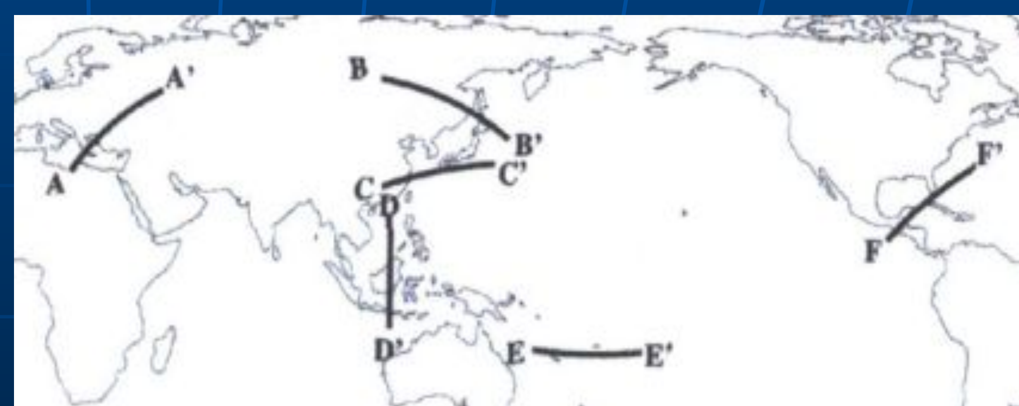
- Мантия Земли в целом имеет отличное от хондритов Sm/Nd отношение

  или

- Примитивное (необеднённое) вещество, в объёме нижней мантии, <u>полностью</u> изолировано на глубине

D.C.Rubie, R.D. van der Hilst,
Physics of the Earth and Planetary Interiors. 2001. V.127. P. 1-7.





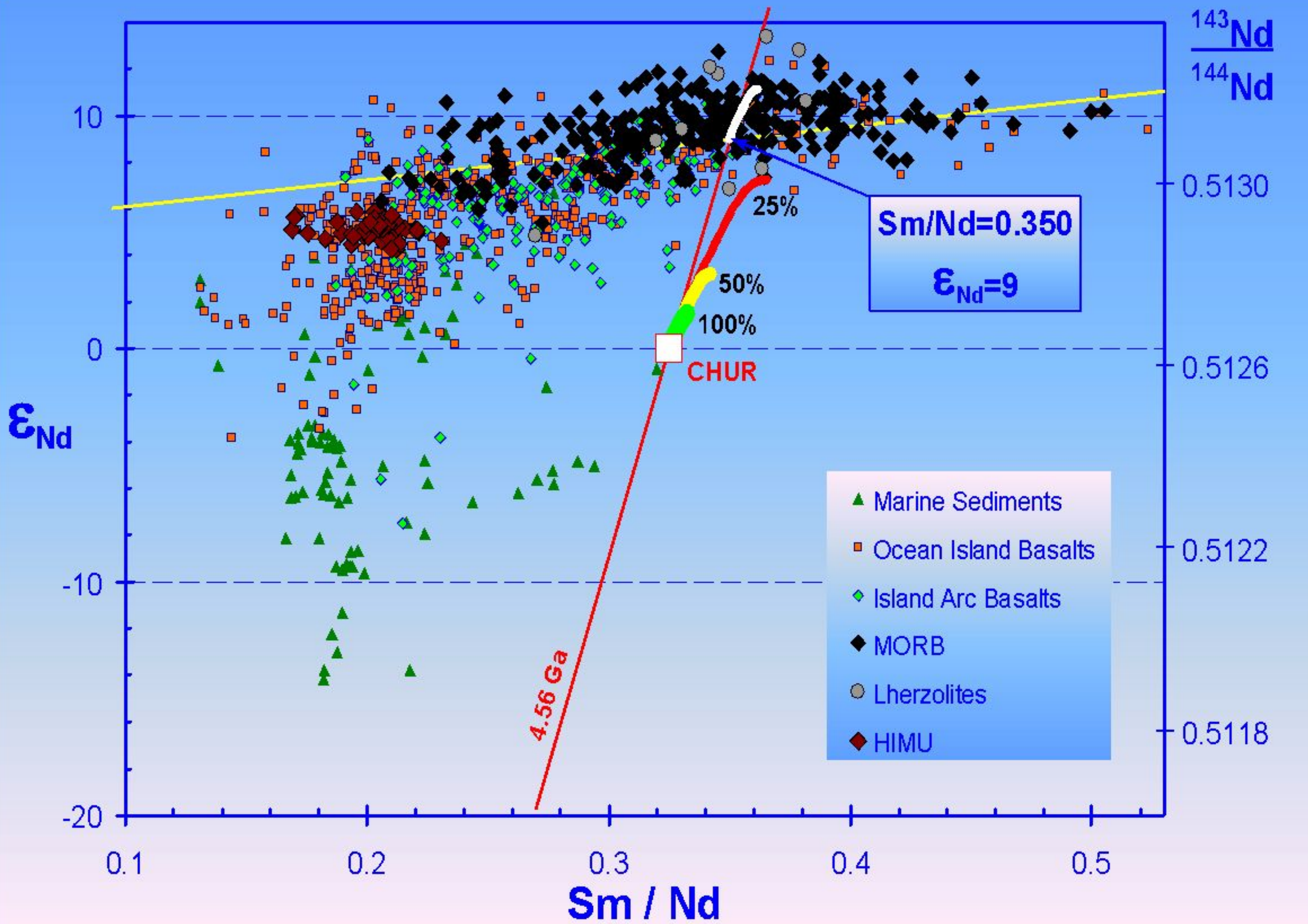
Поток вещества в нижнюю мантию фиксируется сейсмотомографией.

Значит есть и обратный поток – из нижней мантии к поверхности Земли

Вывод:

- Мантия Земли имеет отличное от хондритов Sm/Nd отношение

Какое?



10
0
-10
-20
εNd
0.1
0.2
0.3
0.4
0.5
Sm / Nd
143Nd
144Nd
0.5130
0.5126
0.5122
0.5118
25%
50%
100%
CHUR
4.56 Ga
Sm/Nd=0.350
εNd=9
Marine Sediments
Ocean Island Basalts
Island Arc Basalts
MORB
Lherzolites
HIMU

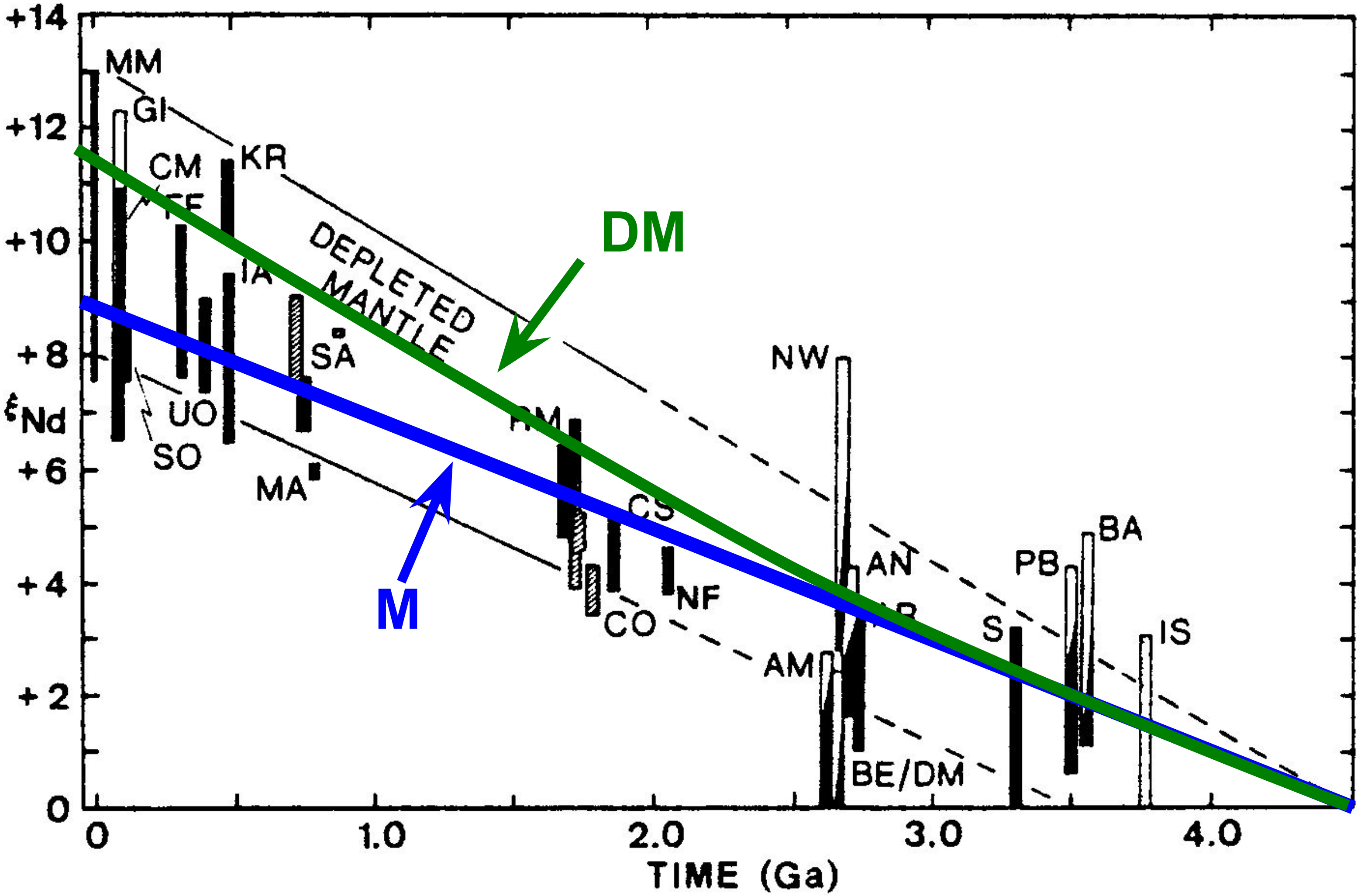
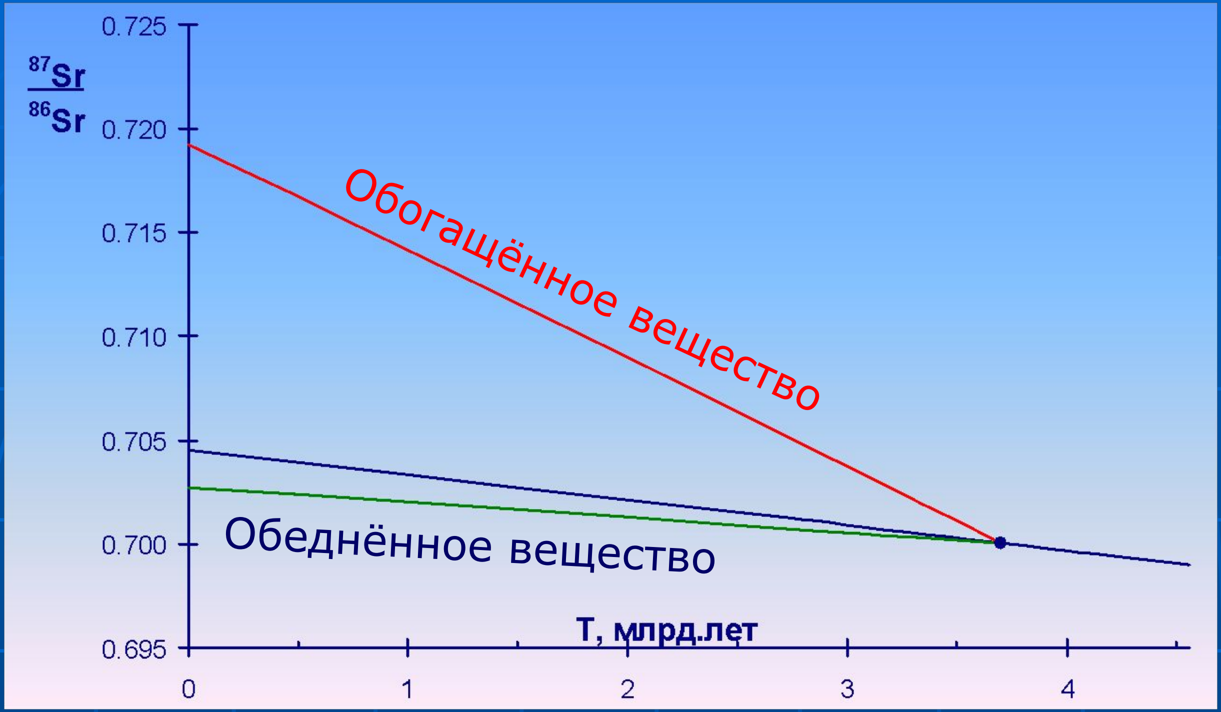


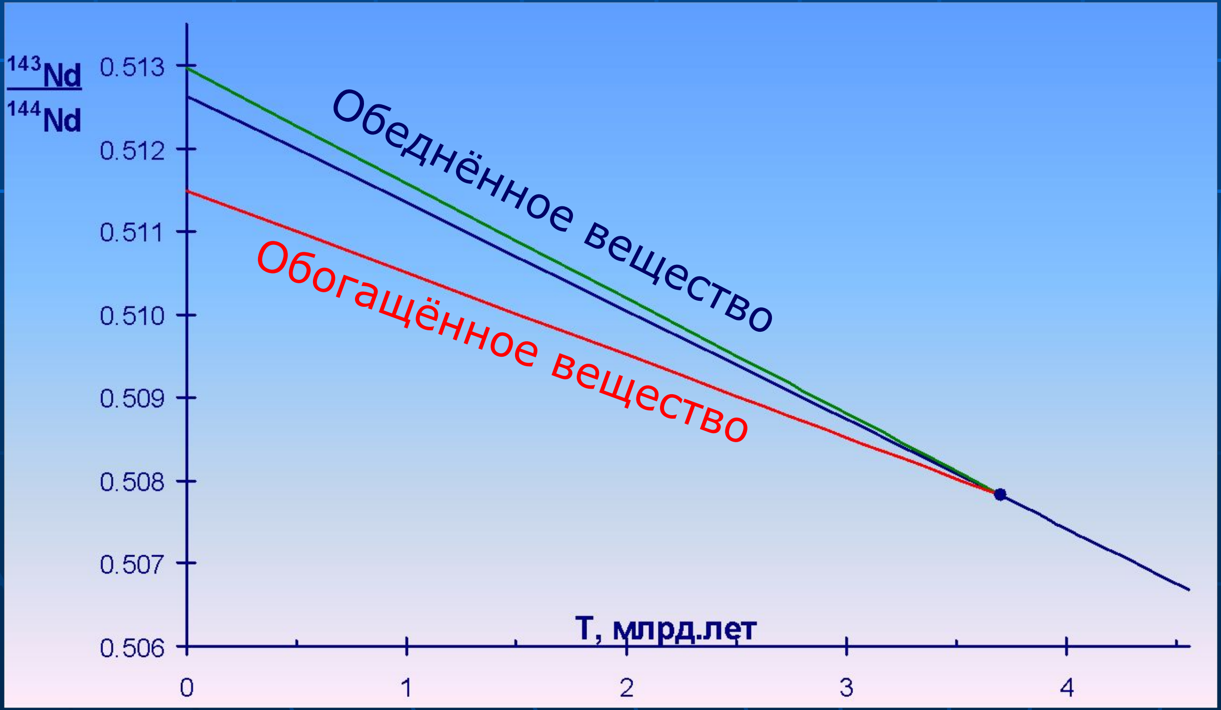
Fig. 3. Variation in ϵ_{Nd} with time for mantle-derived rocks (unshaded: komatiites; shaded: tholeiites; hatched: primitive island arc volcanics) and sediments (stippled).

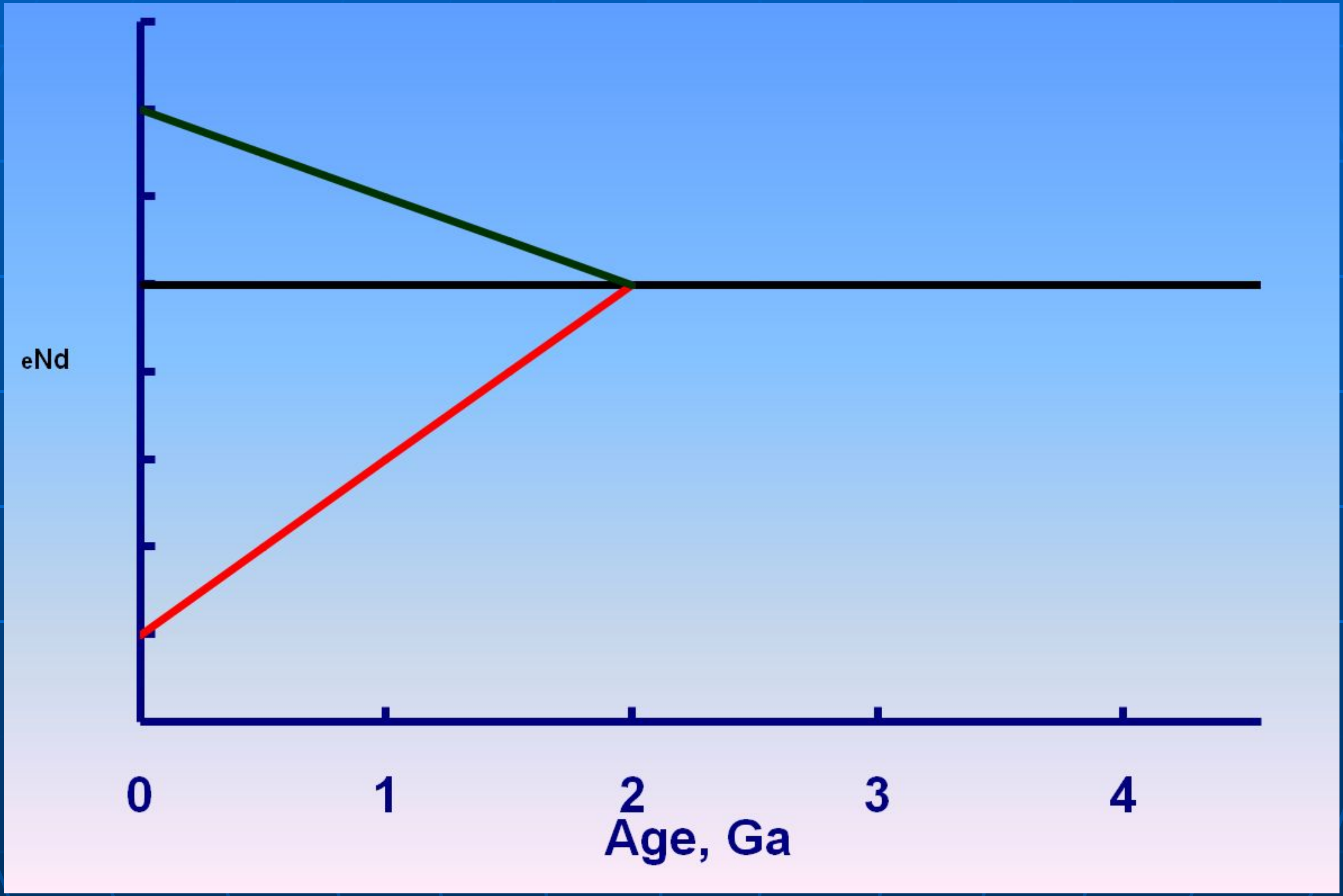
Задача 13

- Рассчитать изотопный состав обеднённой мантии (DM) при следующих допущениях:
  - DM образовалась в результате отделения вещества континентальной коры от примитивной мантии
  - средний возраст коры – по вариантам (файл Ex13.xls на wiki.web.ru)
- Рассмотреть два случая:
  - а) источник коры – вся мантия
  - б) источник коры – верхняя мантия

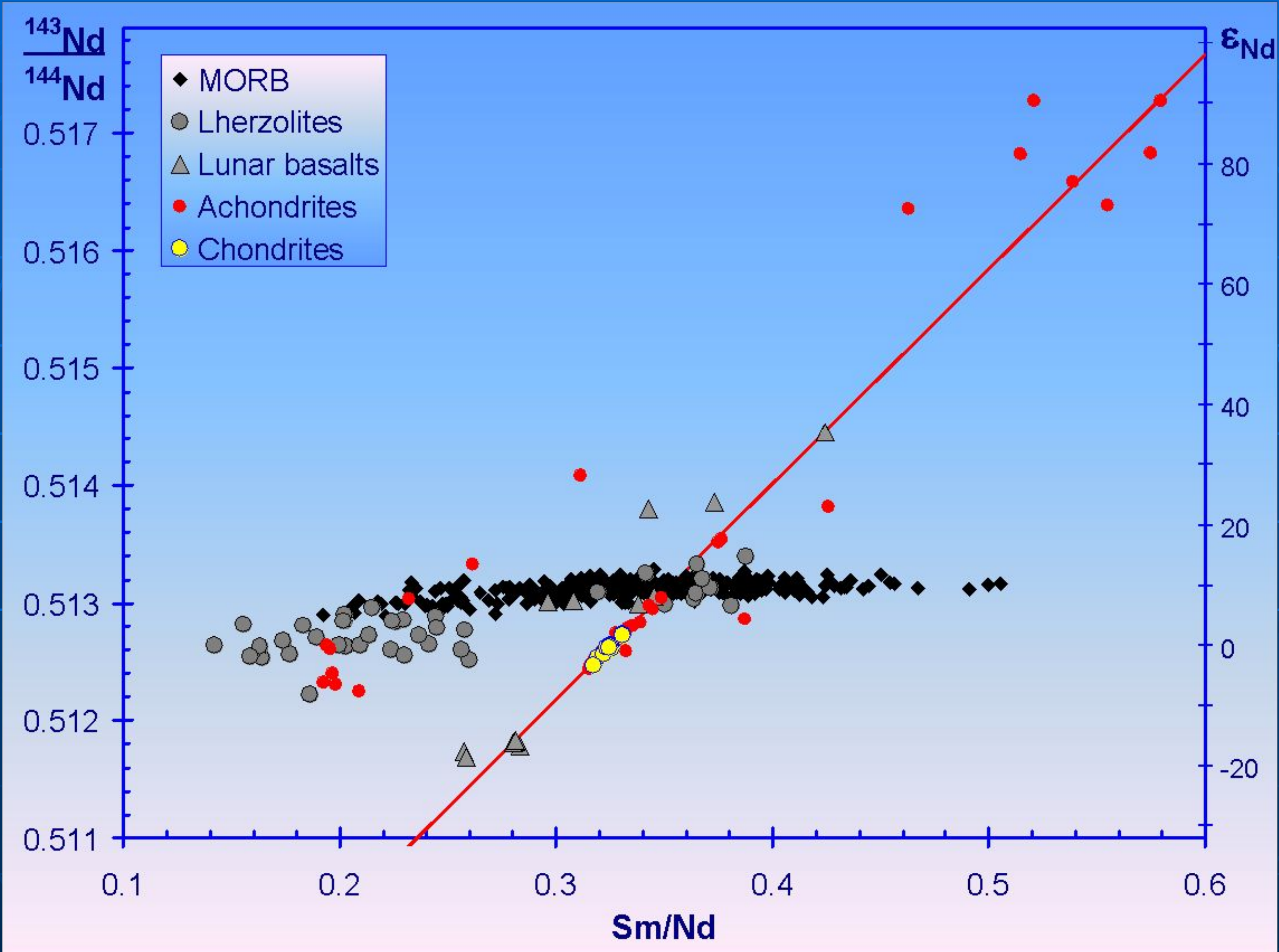
	Пиролит (примитивная мантия)	Континентальная кора	DM
Rb, ppm	0.55	32	
Sr, ppm	19.25	260	
$^{87}Rb/^{86}Sr$	0.0827		
$^{87}Sr/^{86}Sr$	0.7045		
ε_{Sr}	0.0		?
Sm, ppm	0.347	3.5	
Nd, ppm	1.067	16	
$^{147}Sm/^{144}Nd$	0.1967		
$^{143}Nd/^{144}Nd$	0.512638		
ε_{Nd}	0.0		?


87Sr/86Sr
0.725
0.720
0.715
0.710
0.705
0.700
0.695
Обогащённое вещество
Обеднённое вещество
T, млрд.лет
0
1
2
3
4


143Nd/144Nd
0.513
0.512
0.511
0.510
0.509
0.508
0.507
0.506
Обеднённое вещество
Обогащённое вещество
T, млрд.лет
0
1
2
3
4



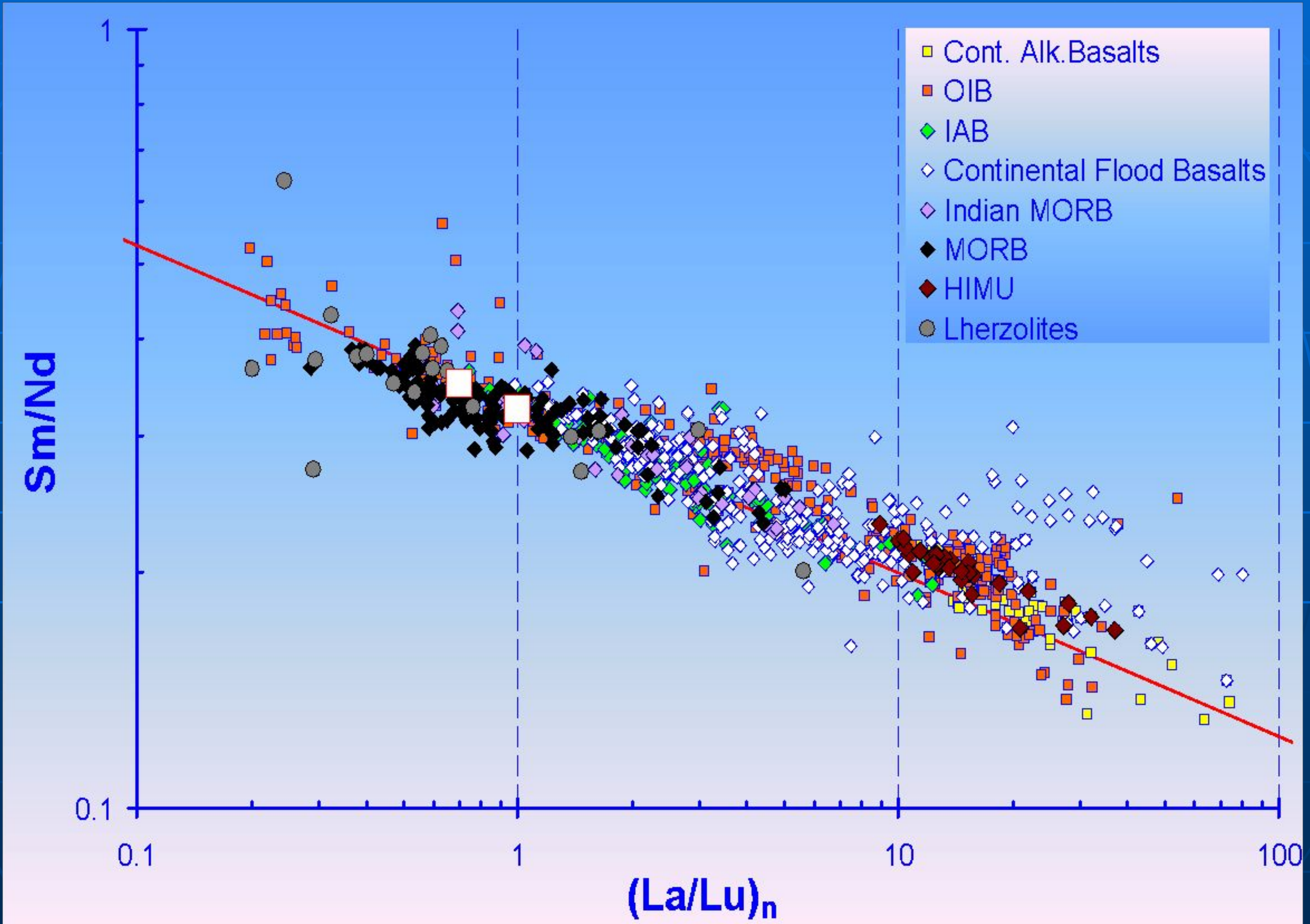
eNd
0
1
2
3
4
Age, Ga



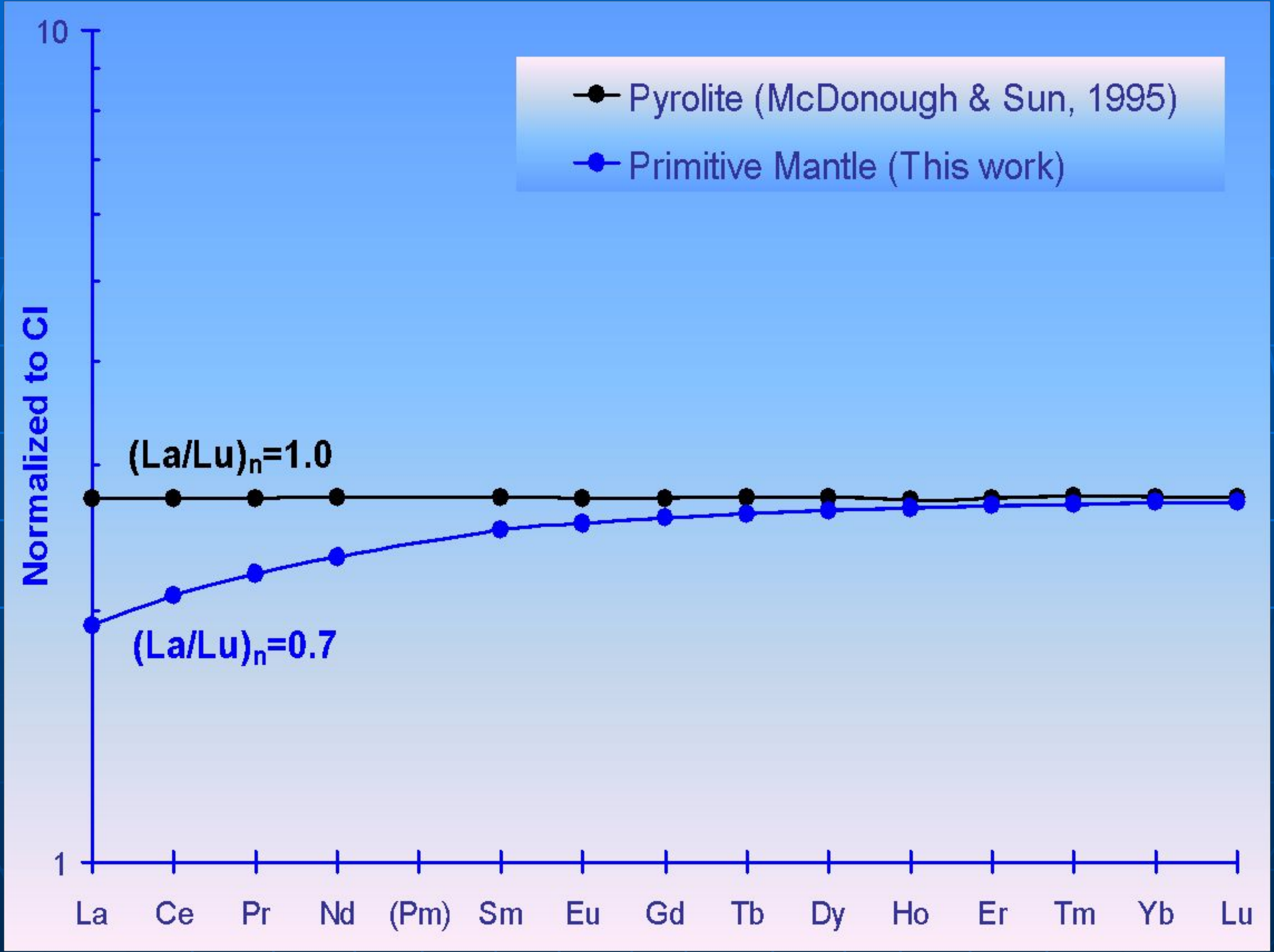
143Nd/144Nd
εNd
MORB
Lherzolites
Lunar basalts
Achondrites
Chondrites
0.517
0.516
0.515
0.514
0.513
0.512
0.511
80
60
40
20
0
-20
0.1
0.2
0.3
0.4
0.5
0.6
Sm/Nd

Состав примитивной мантии

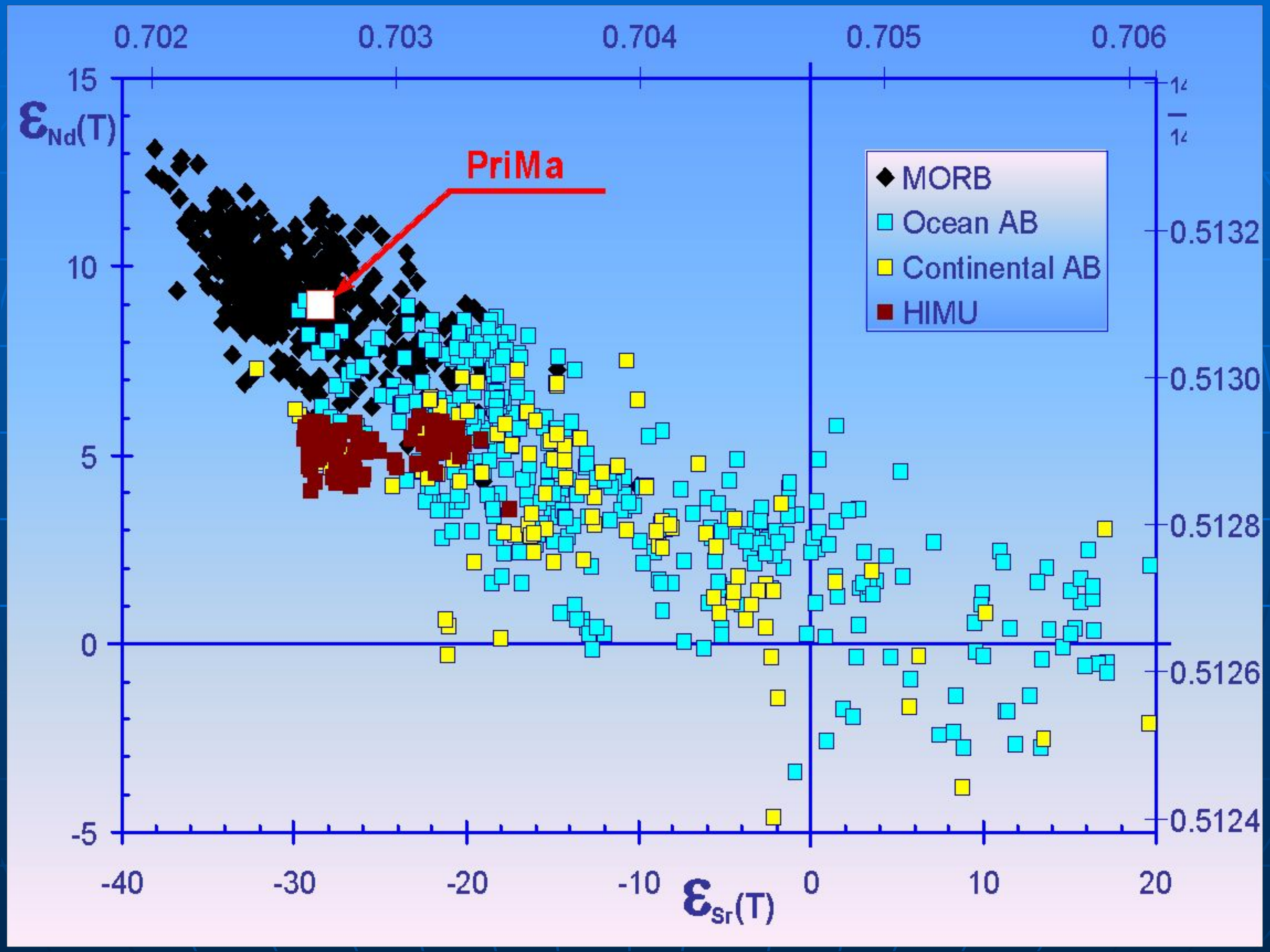
- Sm/Nd = 0.350 и $^{143}Nd/^{144}Nd$ = 0.51310 ε_{Nd} = 9
  ☟
- Rb/Sr = 0.020 ☜ $^{87}Sr/^{86}Sr$ = 0.7028 ε_{Sr} = −28
  $(^{87}Sr/^{86}Sr)_{BABI}$ = 0.699



Sm/Nd
1
0.1
0.1
1
10
100
(La/Lu)n
Cont. Alk.Basalts
OIB
IAB
Continental Flood Basalts
Indian MORB
MORB
HIMU
Lherzolites



Pyrolite (McDonough & Sun, 1995)
Primitive Mantle (This work)
Normalized to CI
10
1
(La/Lu)n=1.0
(La/Lu)n=0.7
La
Ce
Pr
Nd
(Pm)
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu

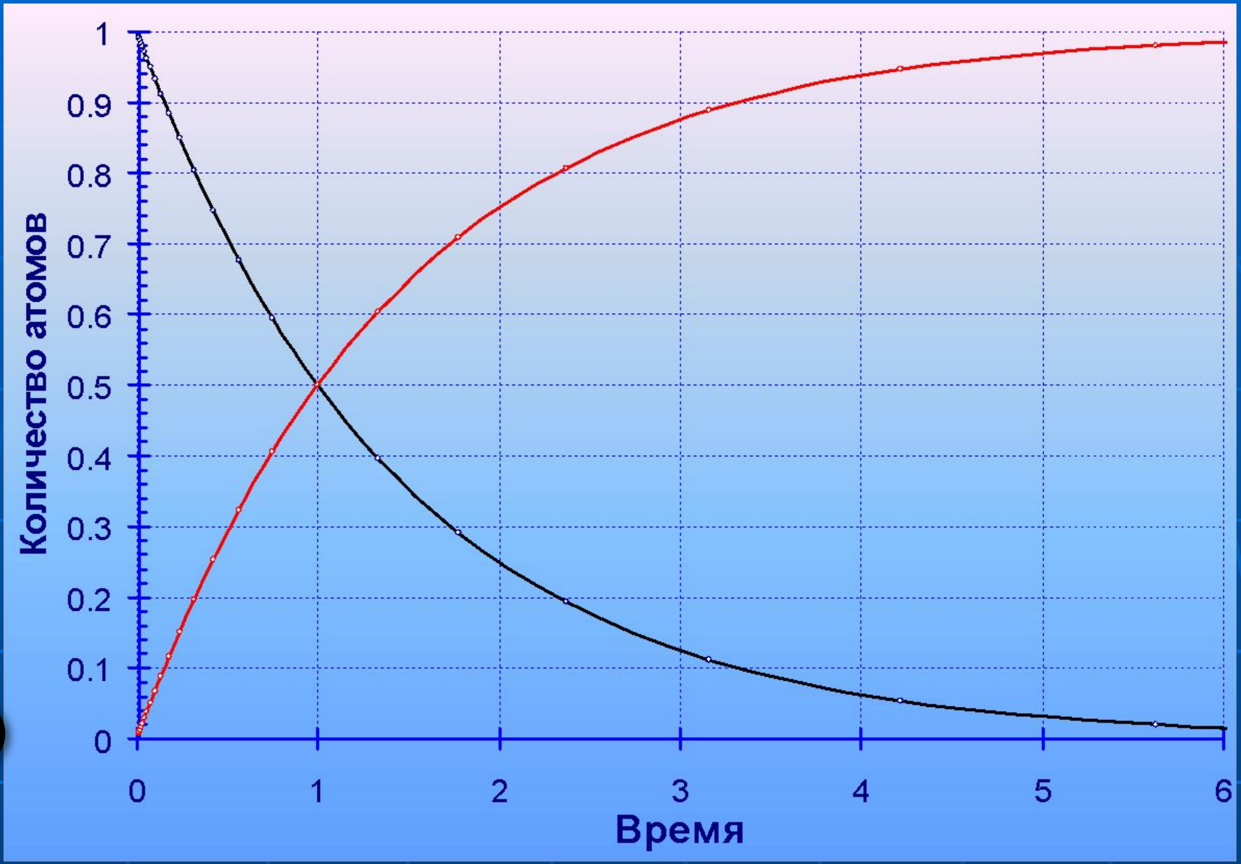


0.702
0.703
0.704
0.705
0.706
15
10
5
0
-5
$\varepsilon_{Nd}(T)$
PriMa
MORB
Ocean AB
Continental AB
HIMU
0.5132
0.5130
0.5128
0.5126
0.5124
-40
-30
-20
-10
0
10
20
$\varepsilon_{Sr}(T)$

$$^{146}Sm \xrightarrow{\alpha} {}^{142}Nd$$

$$\lambda = 6.74 \times 10^{-9}\ \text{год}^{-1}$$

$$T_{1/2} = 103\ \text{млн.лет}$$



$$N_0 = N \exp(\lambda t)$$

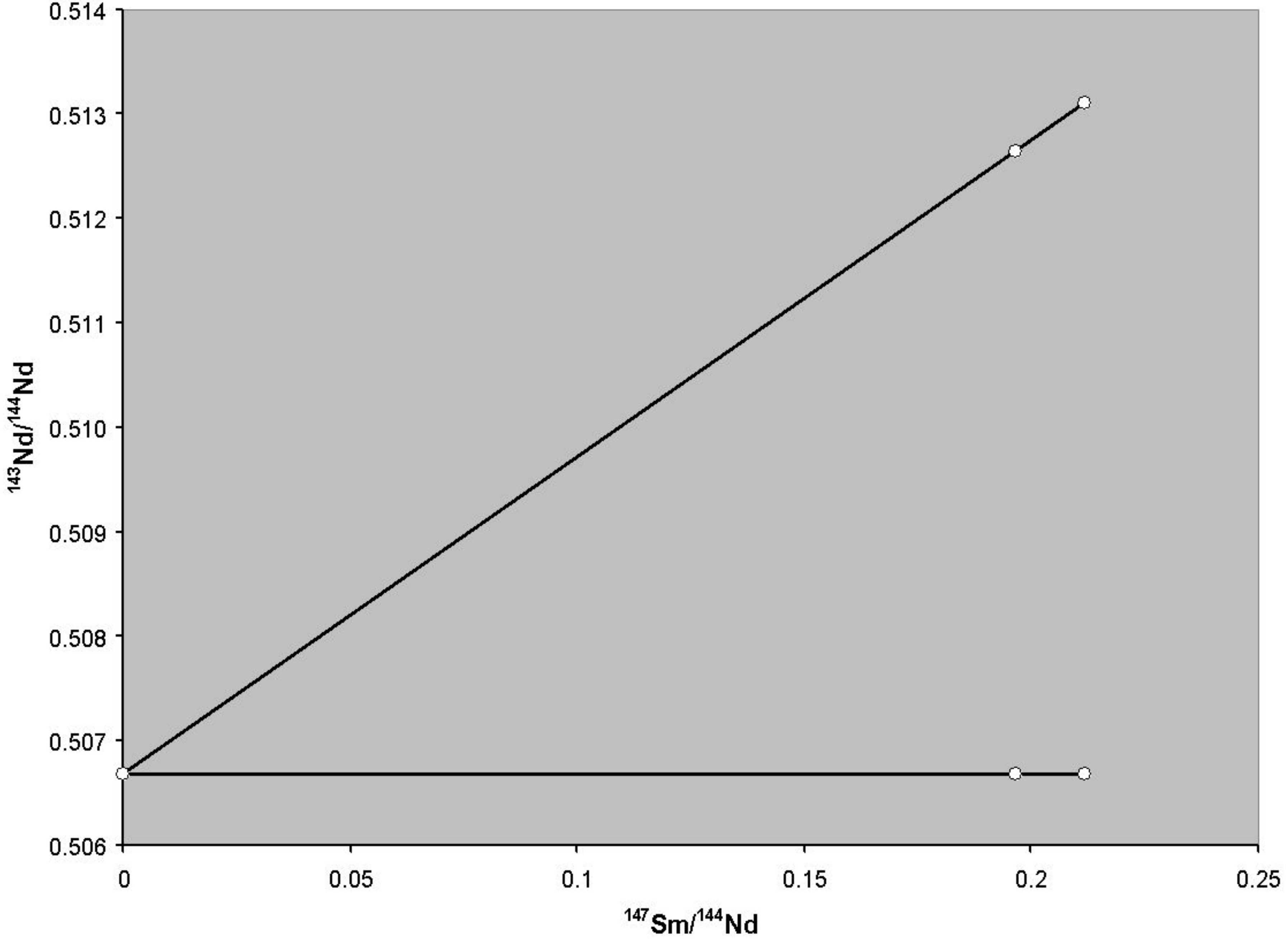
$$N = N_0 \exp(-\lambda t)$$

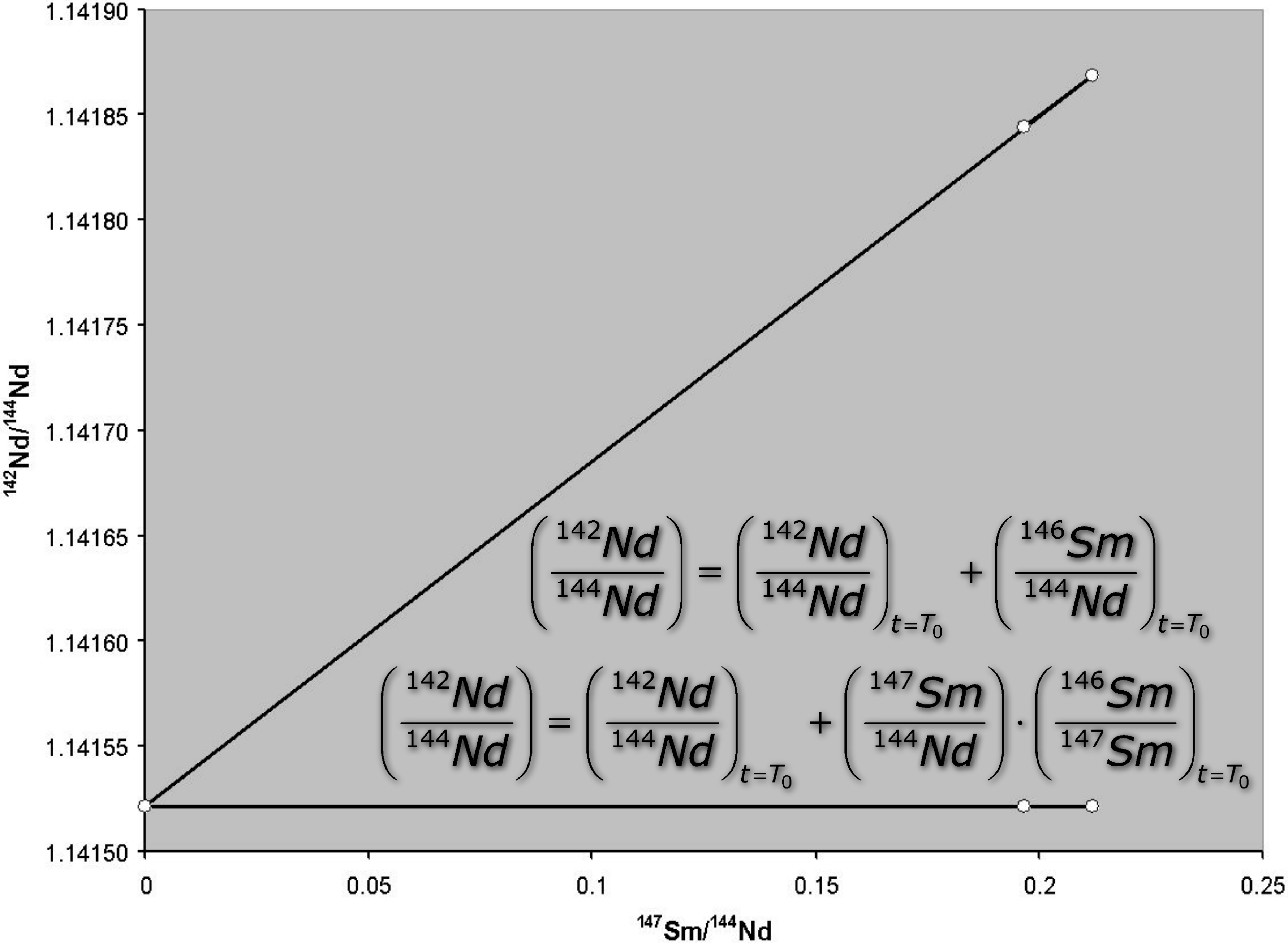
$$^{146}Sm = {}^{146}Sm_0 \cdot \exp(-\lambda t)$$

когда $t \gg T_{1/2}$

$$^{142}Nd_{rad} = {}^{146}Sm_0$$

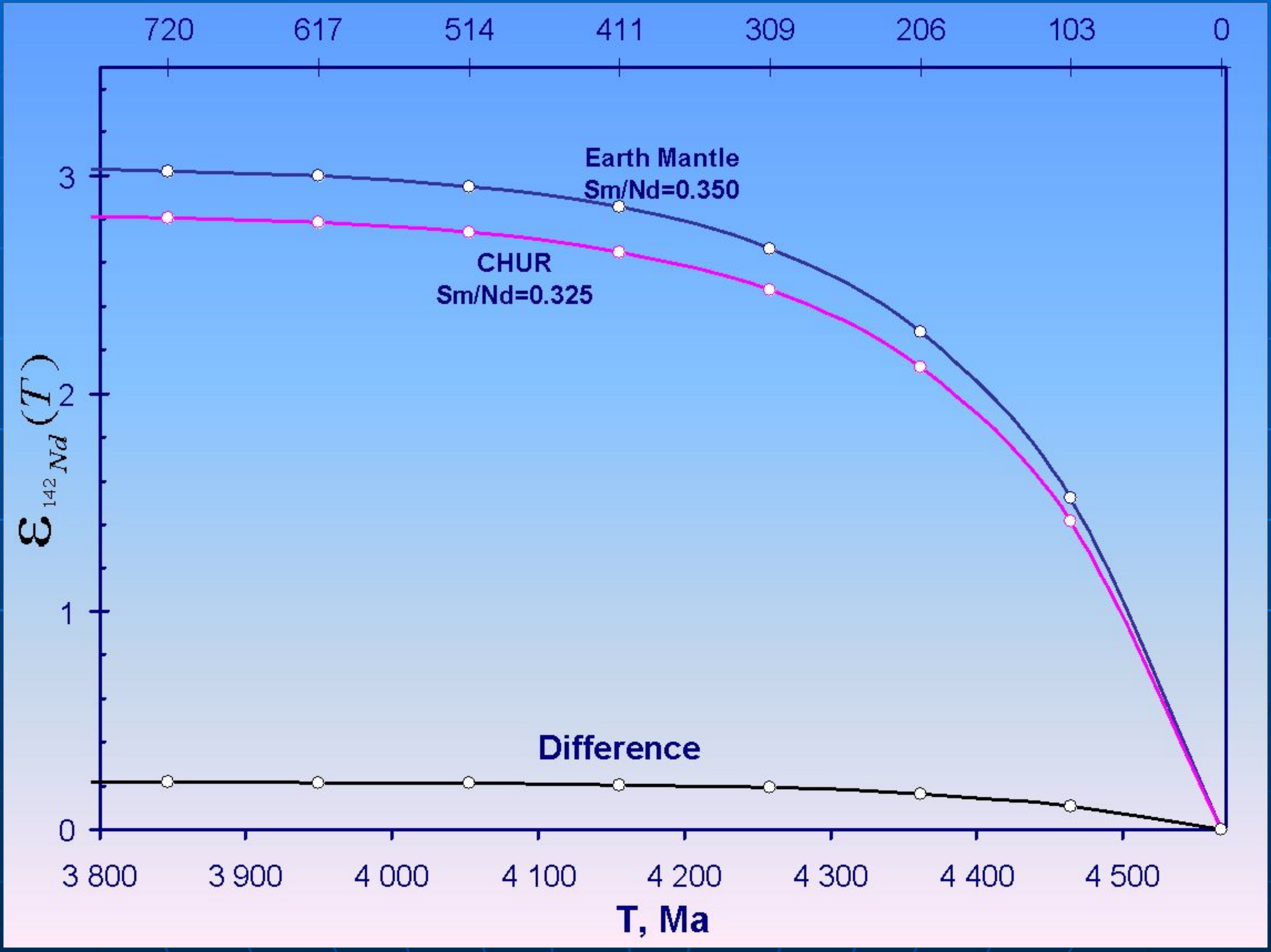
$$\left(\frac{^{142}Nd}{^{144}Nd}\right) = \left(\frac{^{142}Nd}{^{144}Nd}\right)_{t=T_0} + \left(\frac{^{146}Sm}{^{144}Nd}\right)_{t=T_0}$$


0.514
0.513
0.512
0.511
0.510
0.509
0.508
0.507
0.506
0
0.05
0.1
0.15
0.2
0.25
$^{143}Nd/^{144}Nd$
$^{147}Sm/^{144}Nd$



$$\left(\frac{^{142}Nd}{^{144}Nd}\right) = \left(\frac{^{142}Nd}{^{144}Nd}\right)_{t=T_0} + \left(\frac{^{146}Sm}{^{144}Nd}\right)_{t=T_0}$$

$$\left(\frac{^{142}Nd}{^{144}Nd}\right) = \left(\frac{^{142}Nd}{^{144}Nd}\right)_{t=T_0} + \left(\frac{^{147}Sm}{^{144}Nd}\right) \cdot \left(\frac{^{146}Sm}{^{147}Sm}\right)_{t=T_0}$$



720
617
514
411
309
206
103
0
3
2
1
0
Earth Mantle
Sm/Nd=0.350
CHUR
Sm/Nd=0.325
Difference
$\varepsilon_{^{142}Nd}(T)$
3 800
3 900
4 000
4 100
4 200
4 300
4 400
4 500
T, Ma

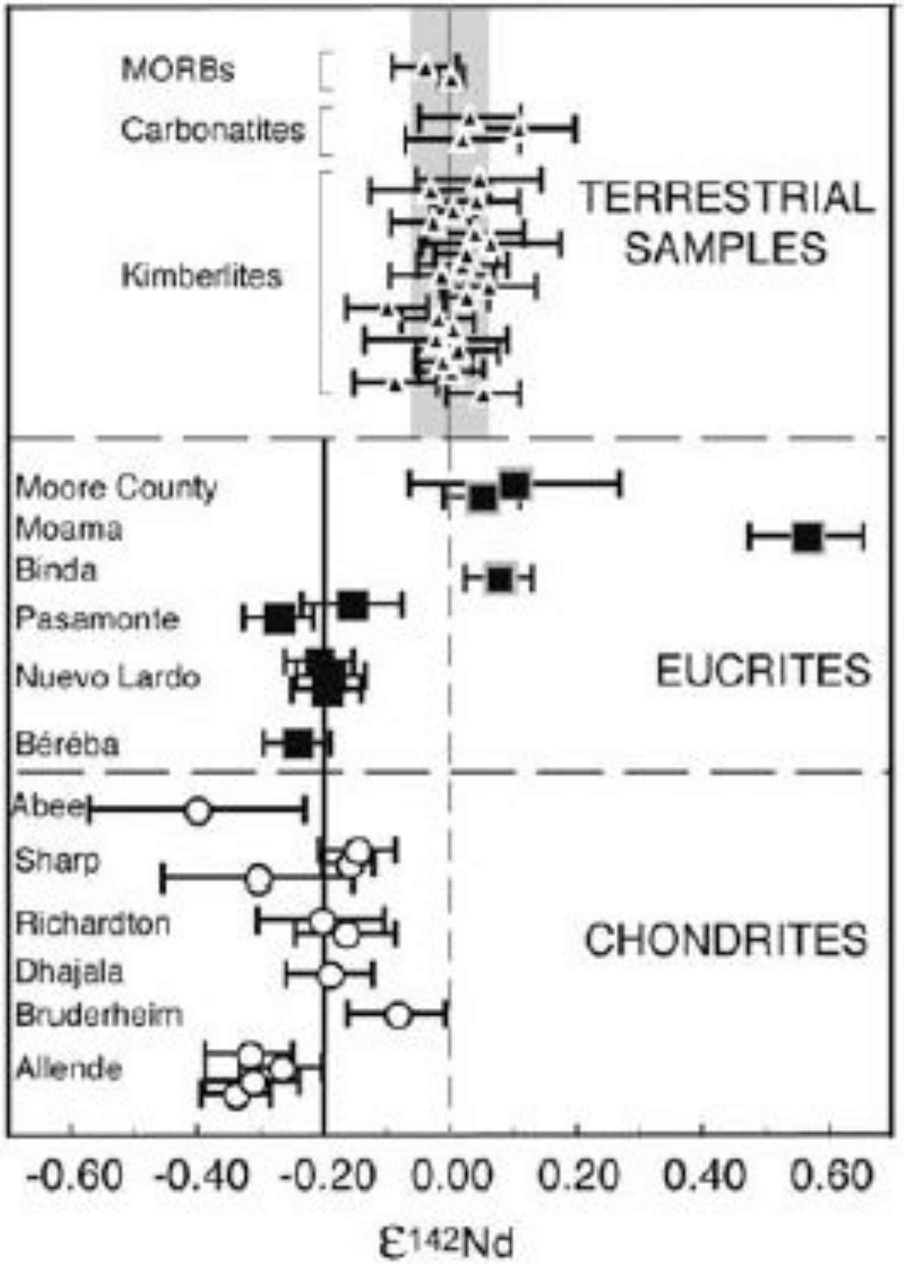
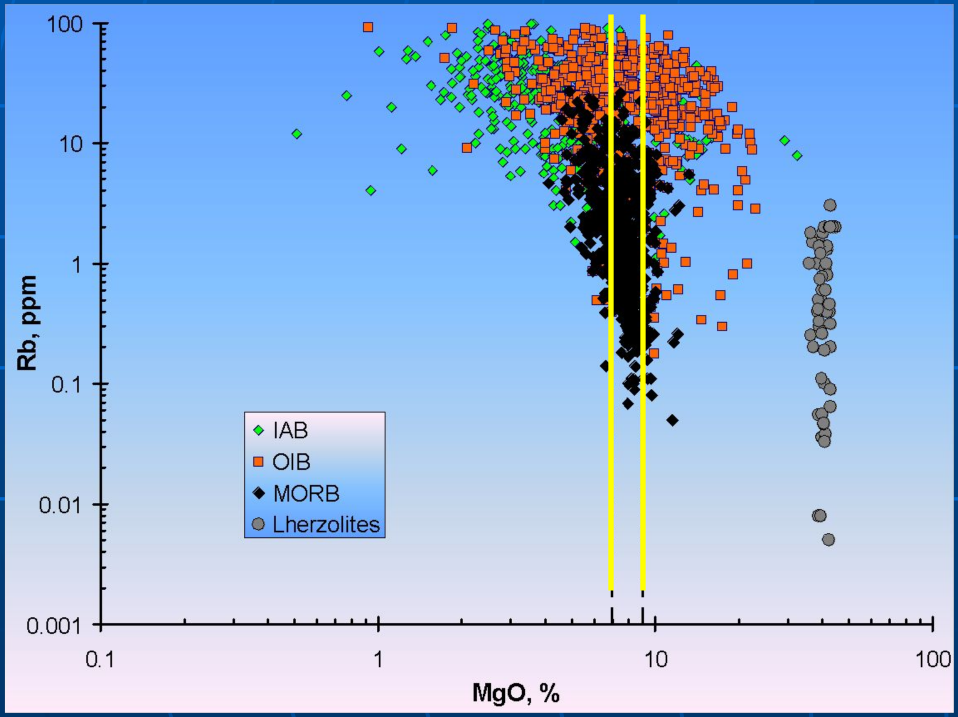


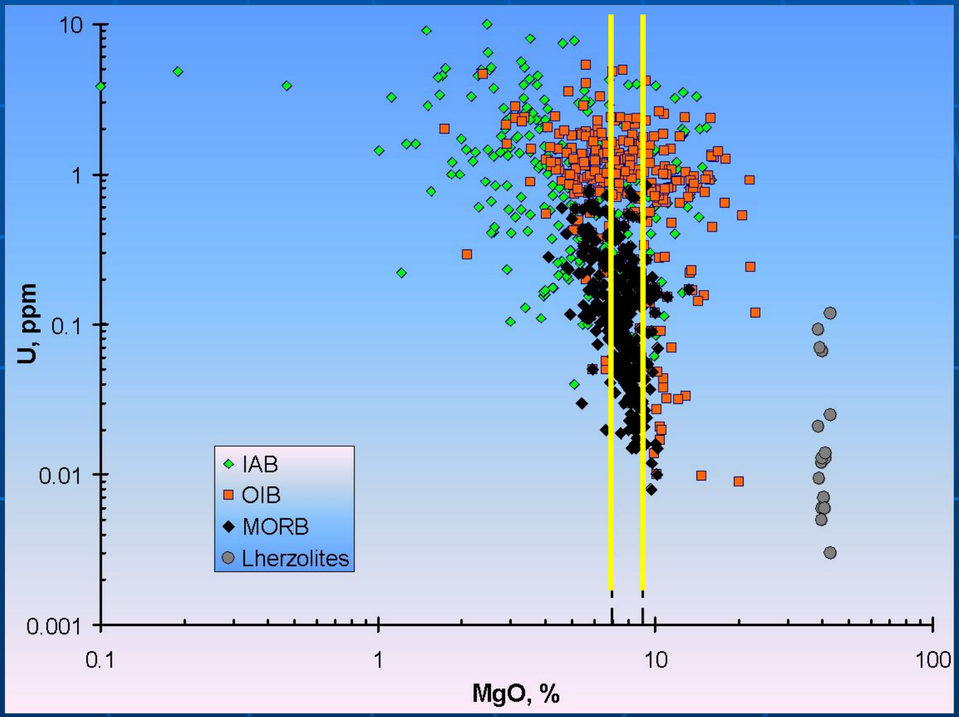
Fig. 1. $^{142}Nd/^{144}Nd$ ratios measured for chondrites and eucrites compared to the La Jolla terrestrial Nd standard ($\varepsilon^{142}Nd$). All chondrites and basaltic eucrites have negative $\varepsilon^{142}Nd$ values outside the external analytical error of $\pm$ 0.07 ε units (2σ) (shaded area). Cumulate eucrites have positive $\varepsilon^{142}Nd$ values in agreement with their high Sm/Nd, resulting from igneous processes on their parent body. The error bars correspond to the internal precision ($2\sigma_{mean}$). Terrestrial samples (MORBs, kimberlites, and carbonatites of different ages and collected in diverse locations) measured using the same procedure (27) have been added to demonstrate the significant excess of 0.2 ε units in all the terrestrial material (samples and standard) relative to the mean chondritic value. All terrestrial samples were measured several times using the same procedures as were used for the chondrites. The uncertainties reported on the mean are 2σ.

M.Boyet, R.W.Carlson. ^{142}Nd evidence for early (>4.53 Ga) global differentiation of the silicate Earth. Science. 2005. Vol.309. P.576-581.

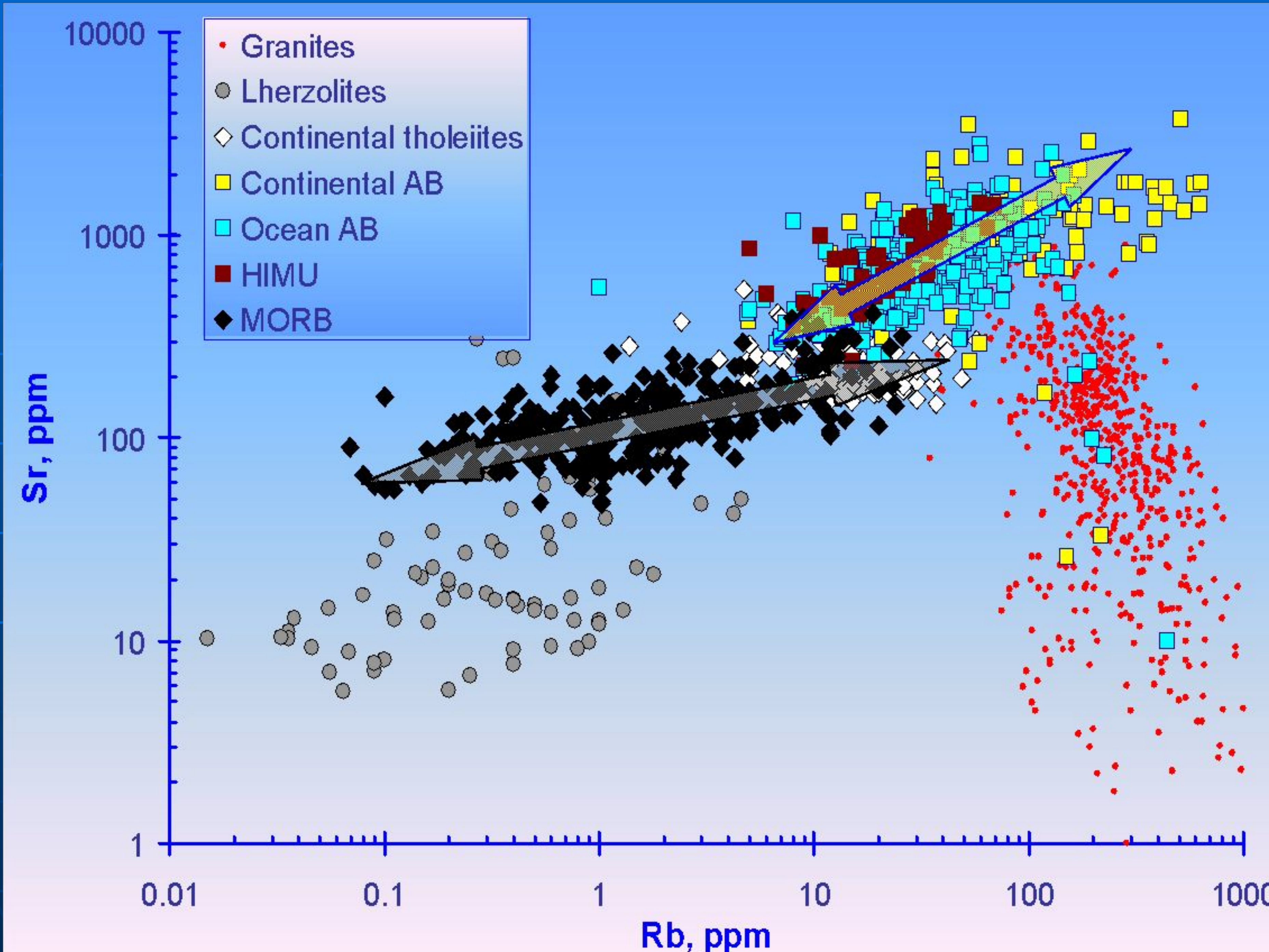
Причины изотопной гетерогенности мантии в Rb-Sr и Sm-Nd изотопных системах

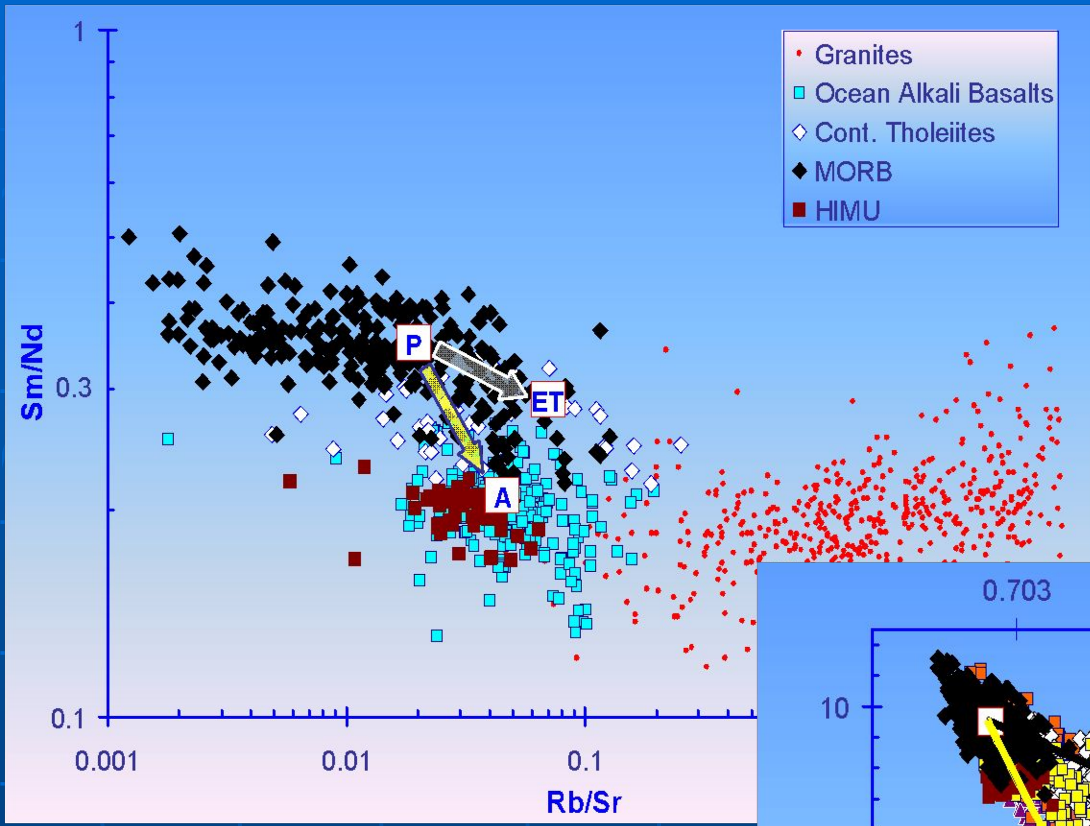
Насколько мантийный источник может быть гетерогенным в отношении элементов-примесей?

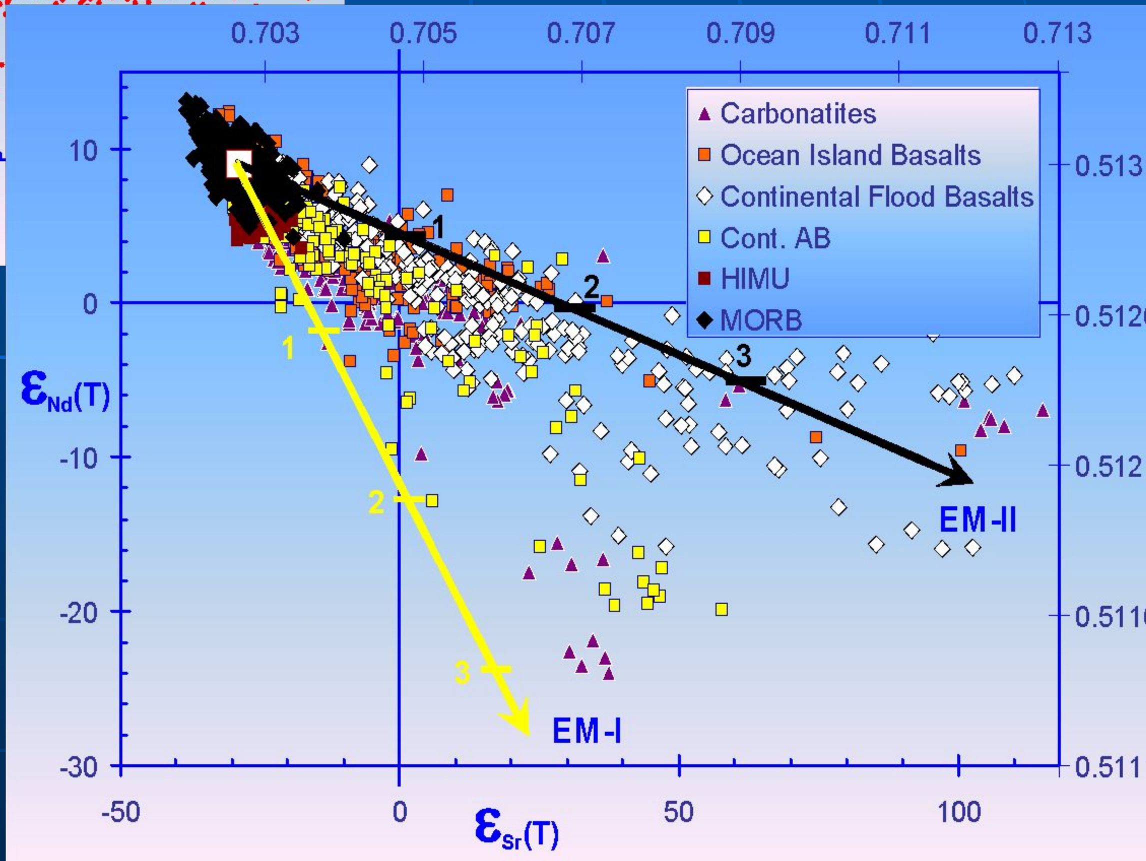




Если в мантии имеют место вариации Rb/Sr, Sm/Nd, U/Th/Pb, Lu/Hf отношений, то со временем это должно привести к изотопной гетерогенности Sr, Nd, Pb, Hf


Granites
Lherzolites
Continental tholeiites
Continental AB
Ocean AB
HIMU
MORB
10000
1000
100
10
1
Sr, ppm
0.01
0.1
1
10
100
1000
Rb, ppm


Granites
Ocean Alkali Basalts
Cont. Tholeiites
MORB
HIMU
P
ET
A
Sm/Nd
Rb/Sr
1
0.3
0.1
0.001
0.01
0.1


Carbonatites
Ocean Island Basalts
Continental Flood Basalts
Cont. AB
HIMU
MORB
0.703
0.705
0.707
0.709
0.711
0.713
10
0
-10
-20
-30
0.5131
0.5126
0.5121
0.5116
0.5111
-50
0
50
100
1
2
3
EM-I
EM-II
$\varepsilon_{Nd}(T)$
$\varepsilon_{Sr}(T)$