Modelos Quantitativos de Bacias Sedimentares

AGG0314

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O que é um **Modelo**?

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(O que é um modelo científico?)

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Wikipedia (tradução livre de *Scientific modelling*)
O objetivo [do modelo] é fazer com que uma parte específica do mundo seja mais fácil de entender, definir, quantificar, visualizar ou simular, referenciando-o ao conhecimento existente e comumente aceito.

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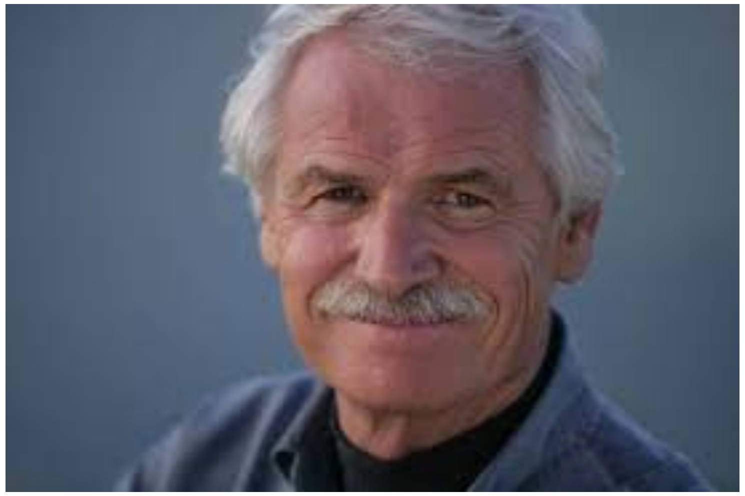
Kurt Stüwe (tradução livre *Geodynamics of the Lithosphere*)
Modelos são ferramentas que nós usamos para descrever o mundo ao nosso redor de forma simplificada tal que nós possamos entendê-lo melhor.

Como representar o ser humano?


Como representar o ser humano?

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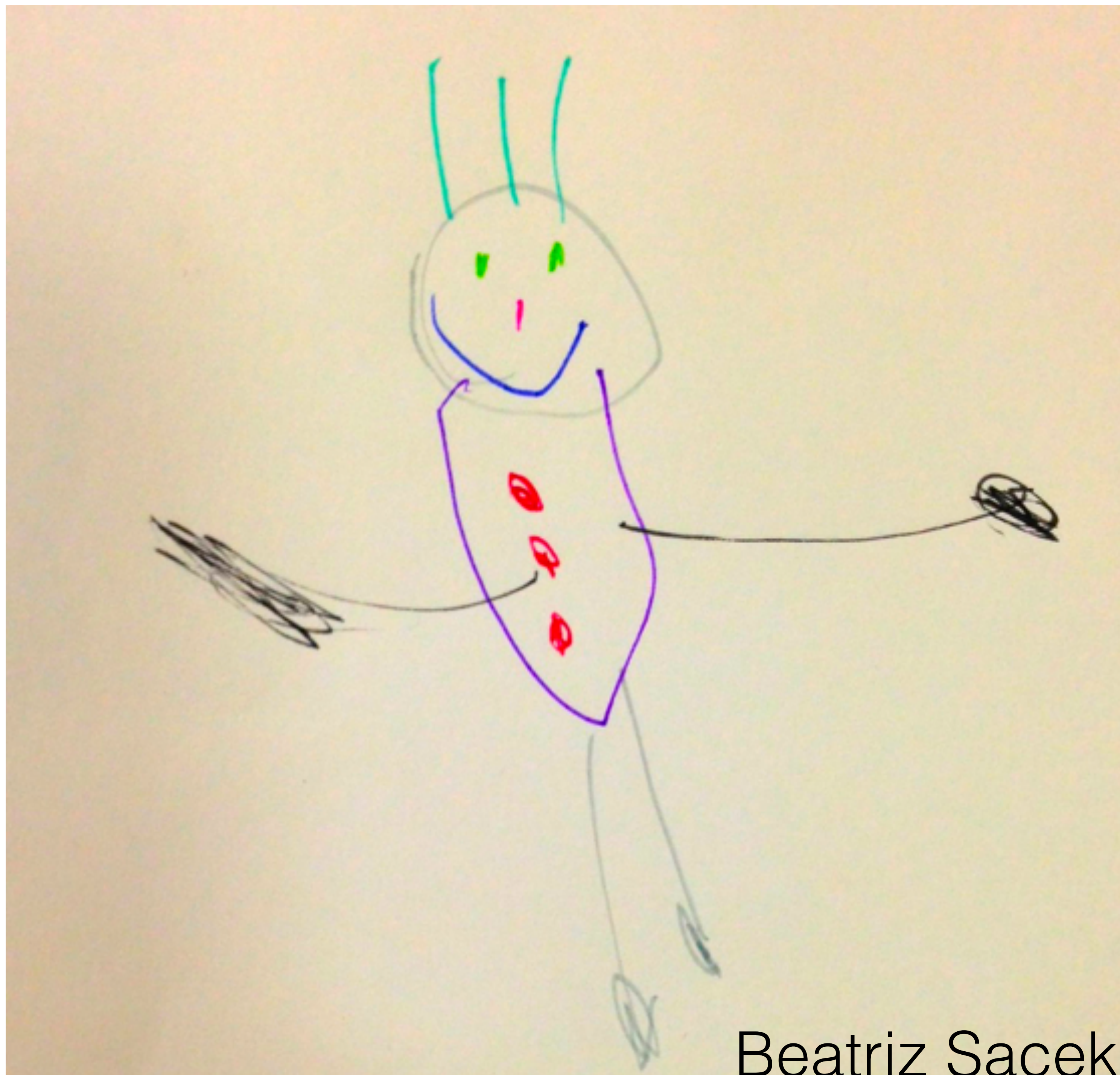
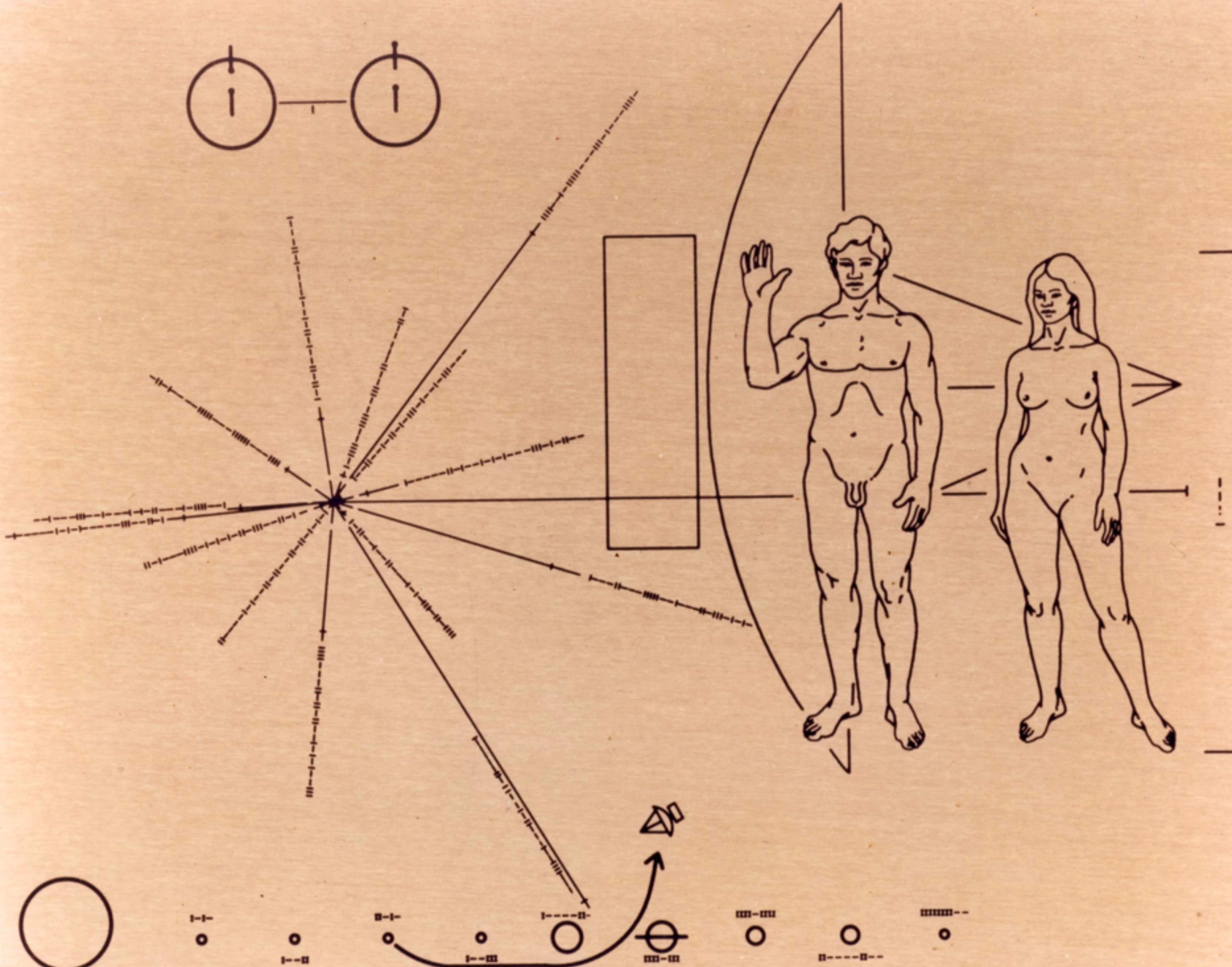
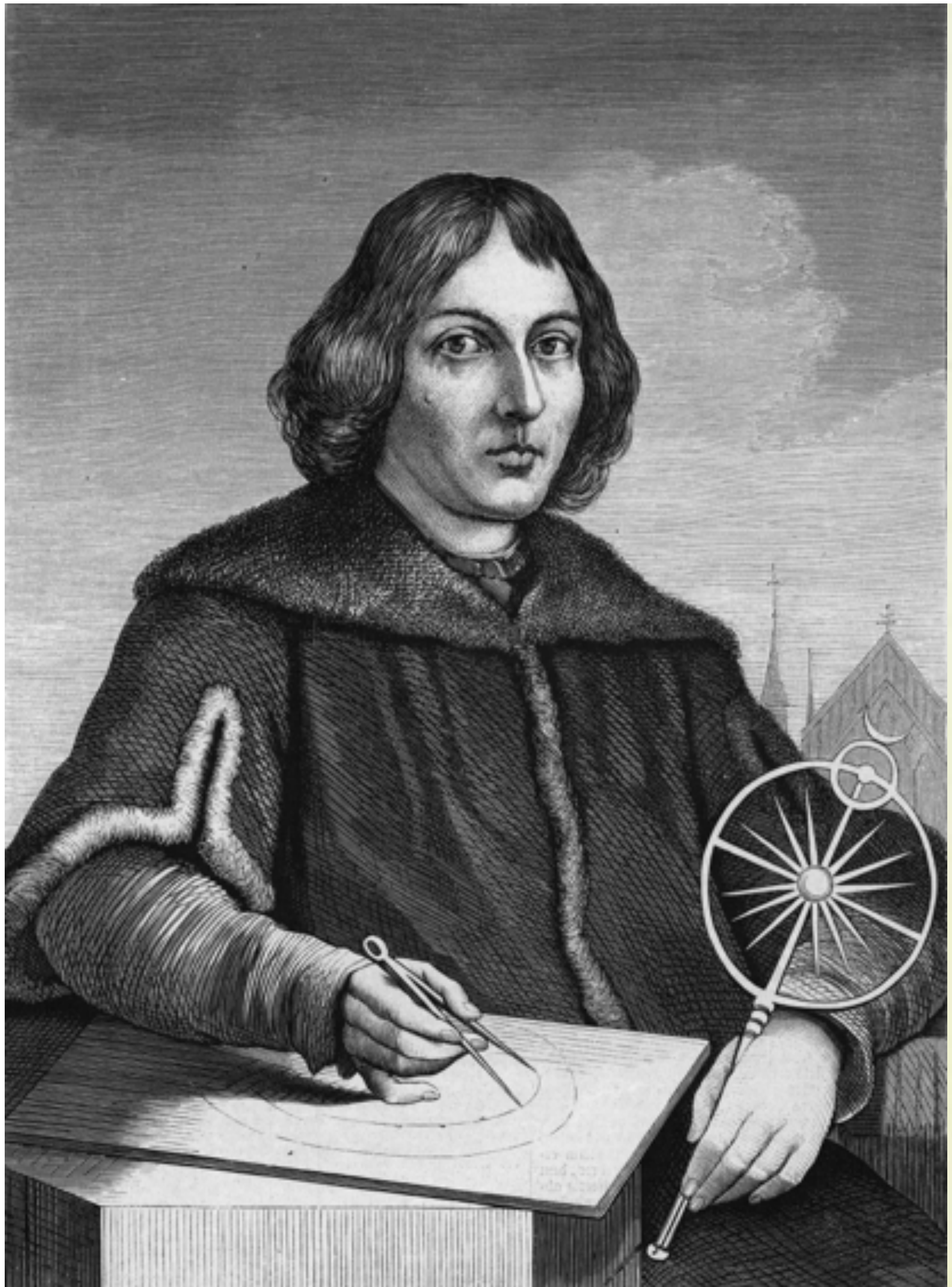
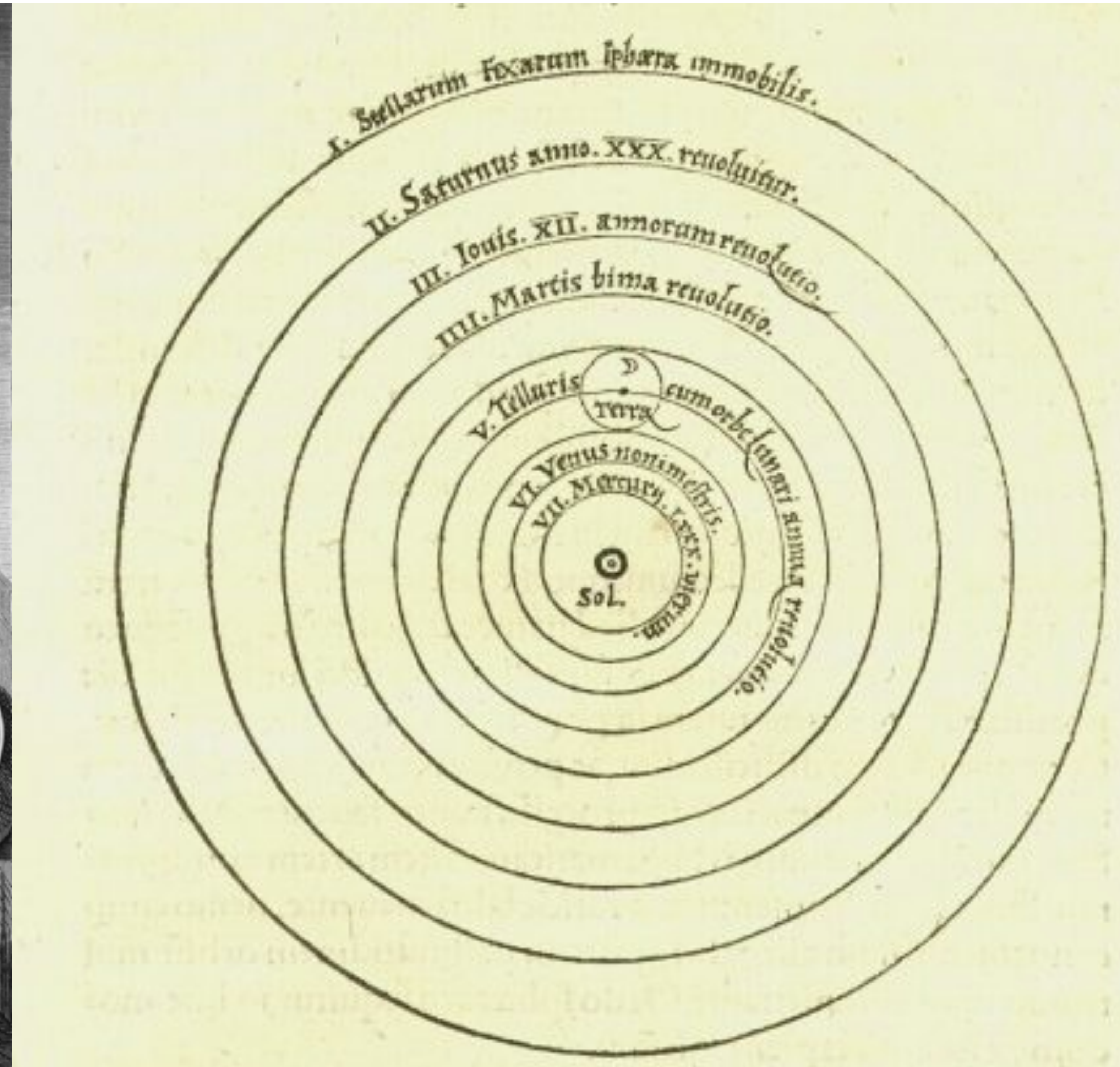


Beatriz Sacek



Modelo de Copérnico



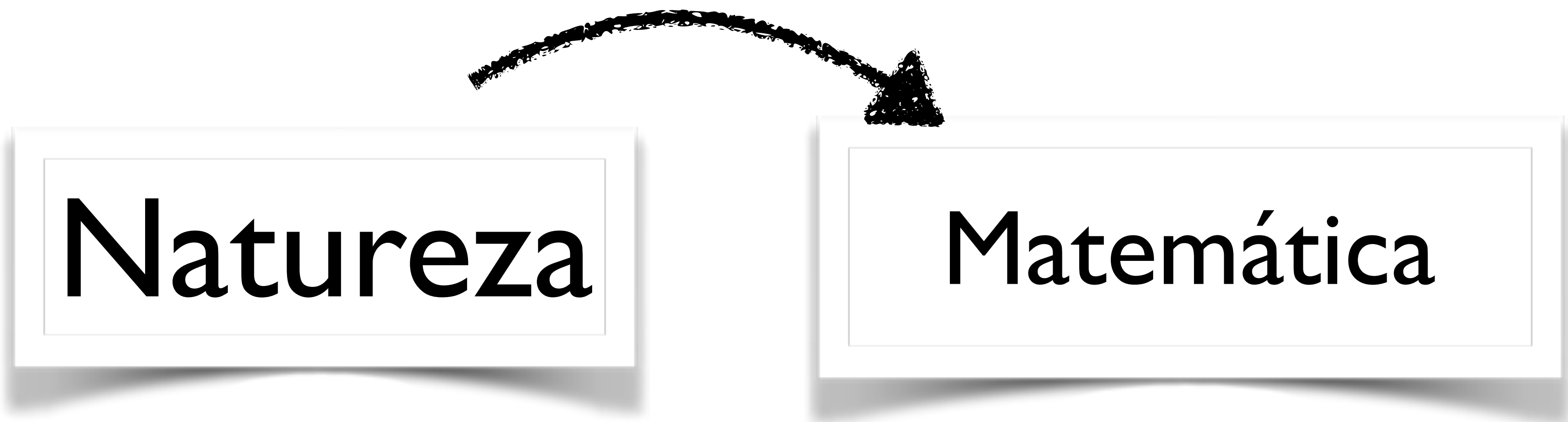


O que é **Quantitativo**?

O que é **Quantitativo**?

Wikipedia (tradução livre de *Quantitative research*)
Nas ciências naturais e nas ciências sociais, a pesquisa quantitativa é a investigação empírica sistemática de fenômenos observáveis através de técnicas estatísticas, matemáticas ou computacionais. O objetivo da pesquisa quantitativa é desenvolver e empregar modelos matemáticos, teorias e hipóteses relativas aos fenômenos.

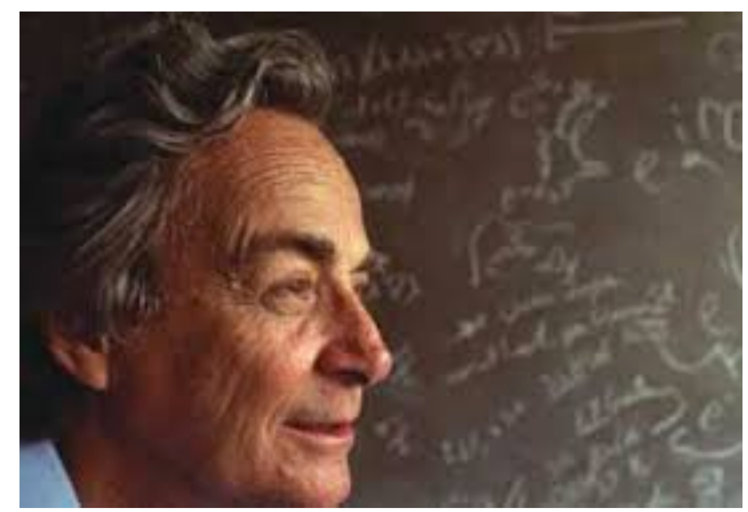
Natureza


Natureza
Matemática

Natureza → Matemática

…não saber matemática é uma limitação severa para entender o mundo.

Richard Feynman



Natureza → Matemática → Modelos computacionais

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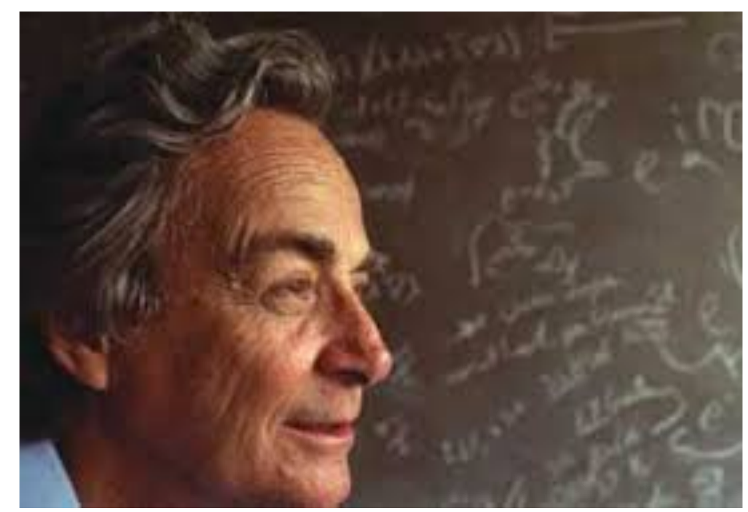

1. Geometria complicada

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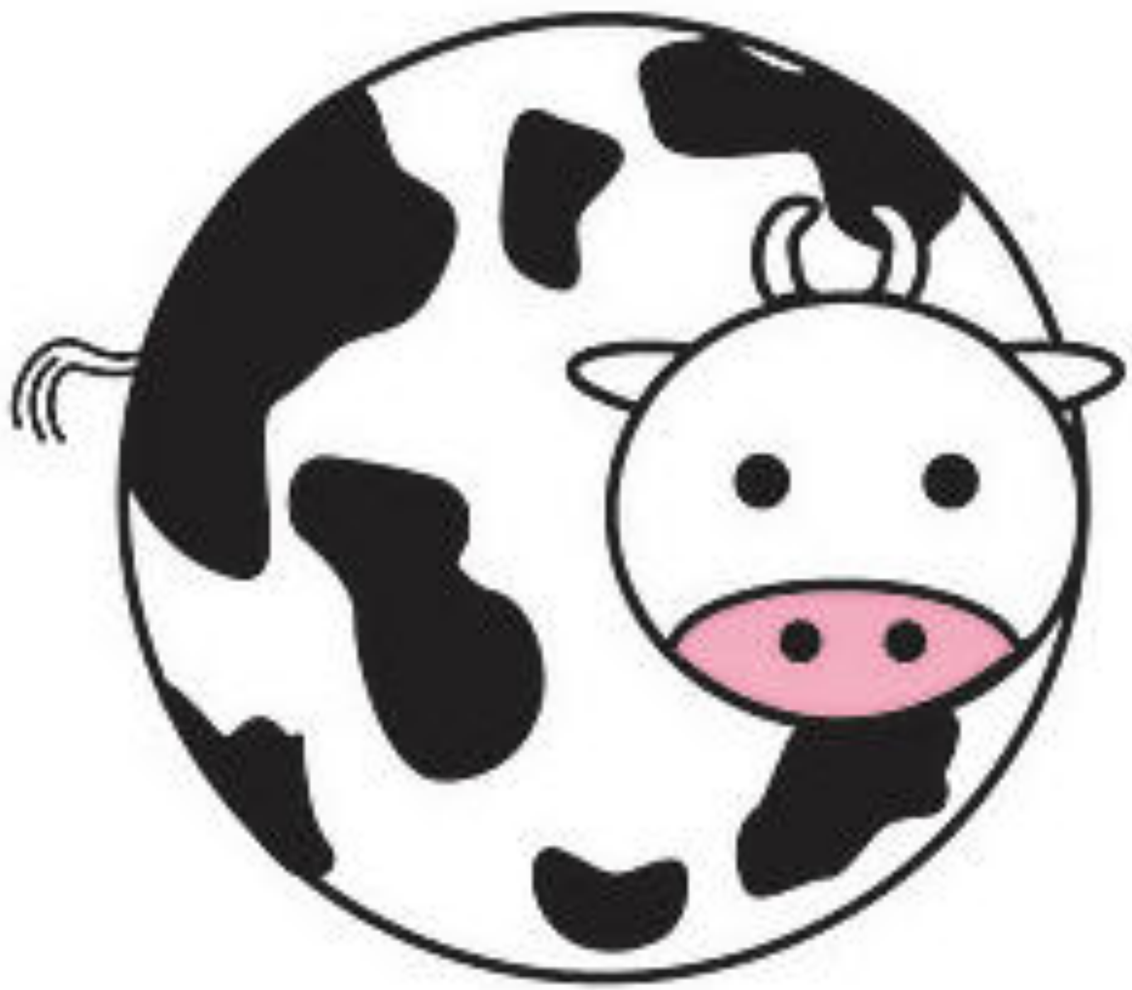

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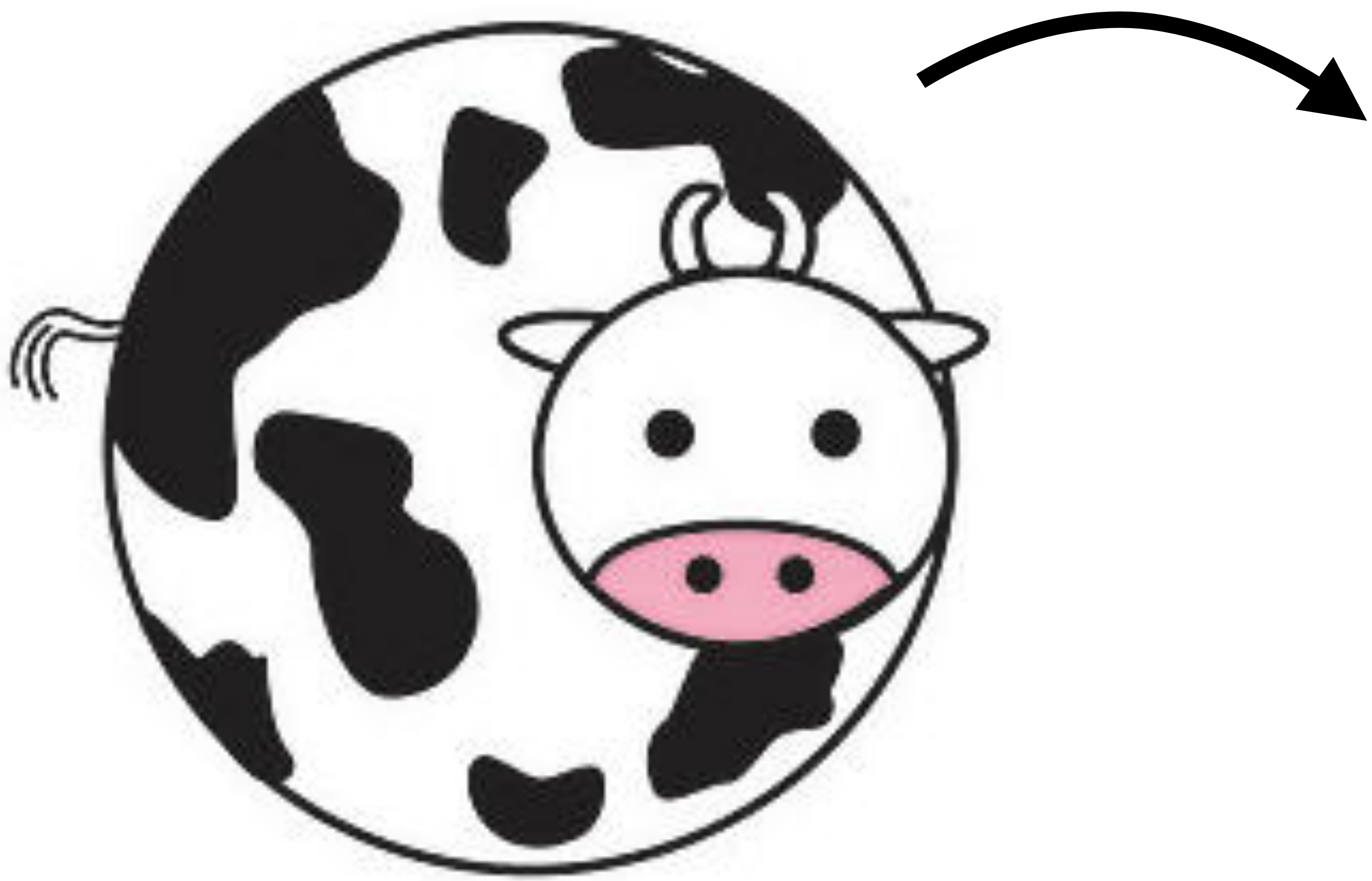

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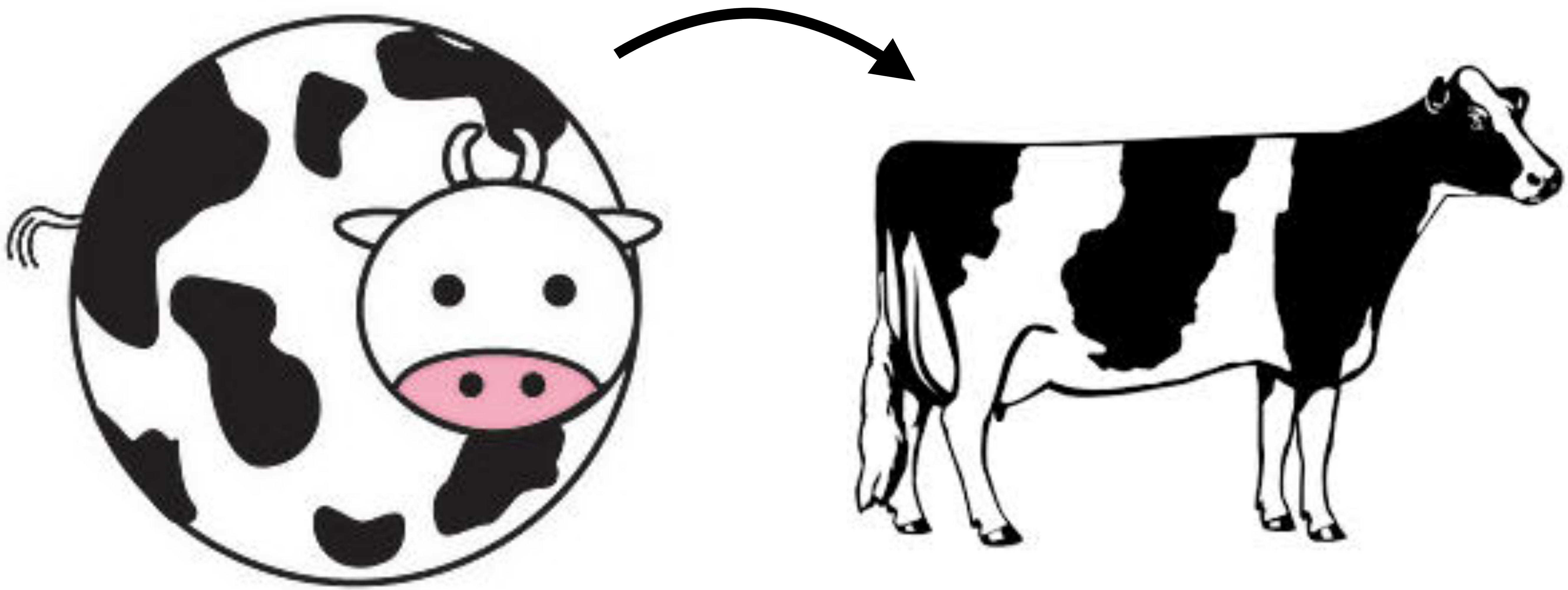

2. Acoplamento entre diferentes processos

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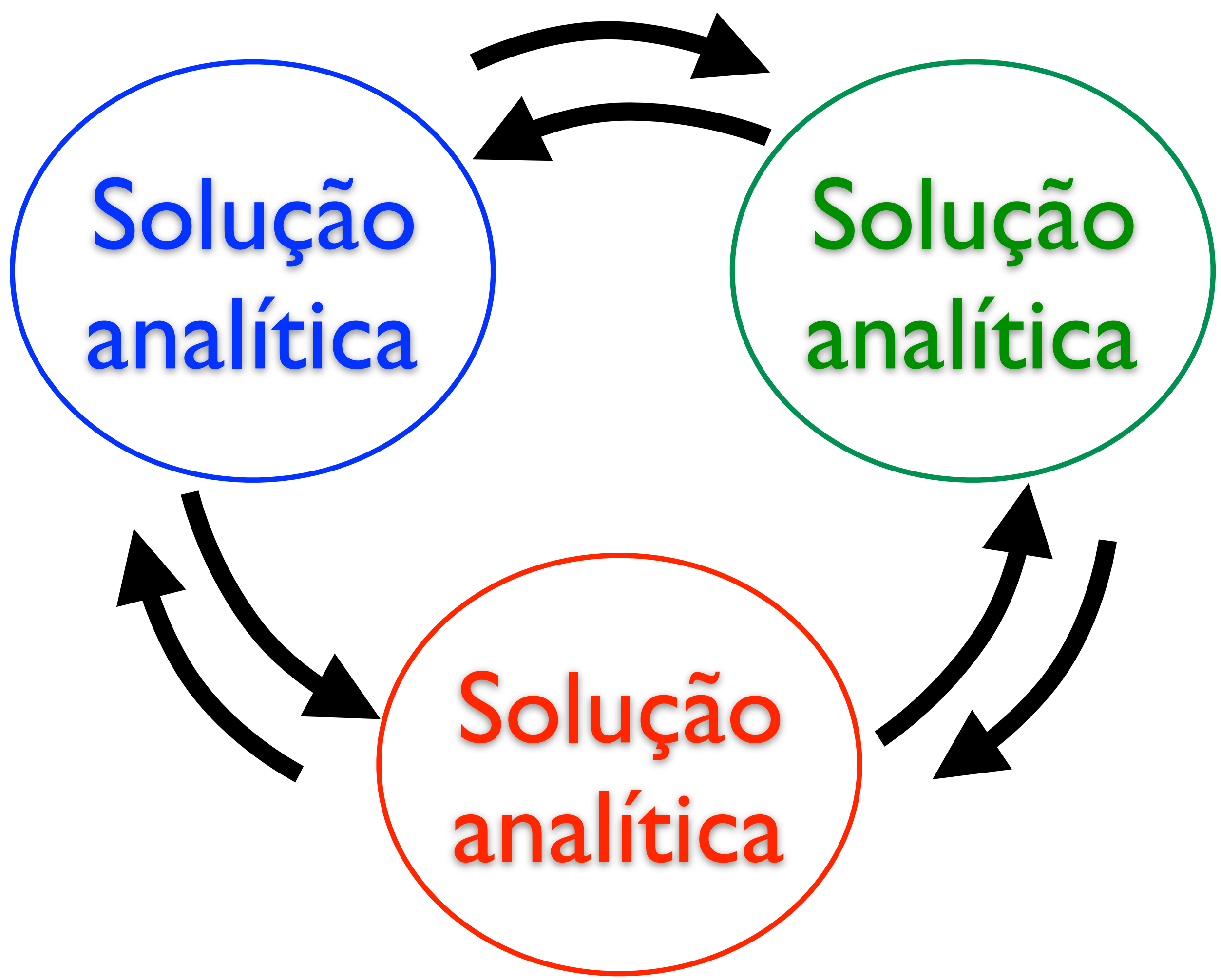

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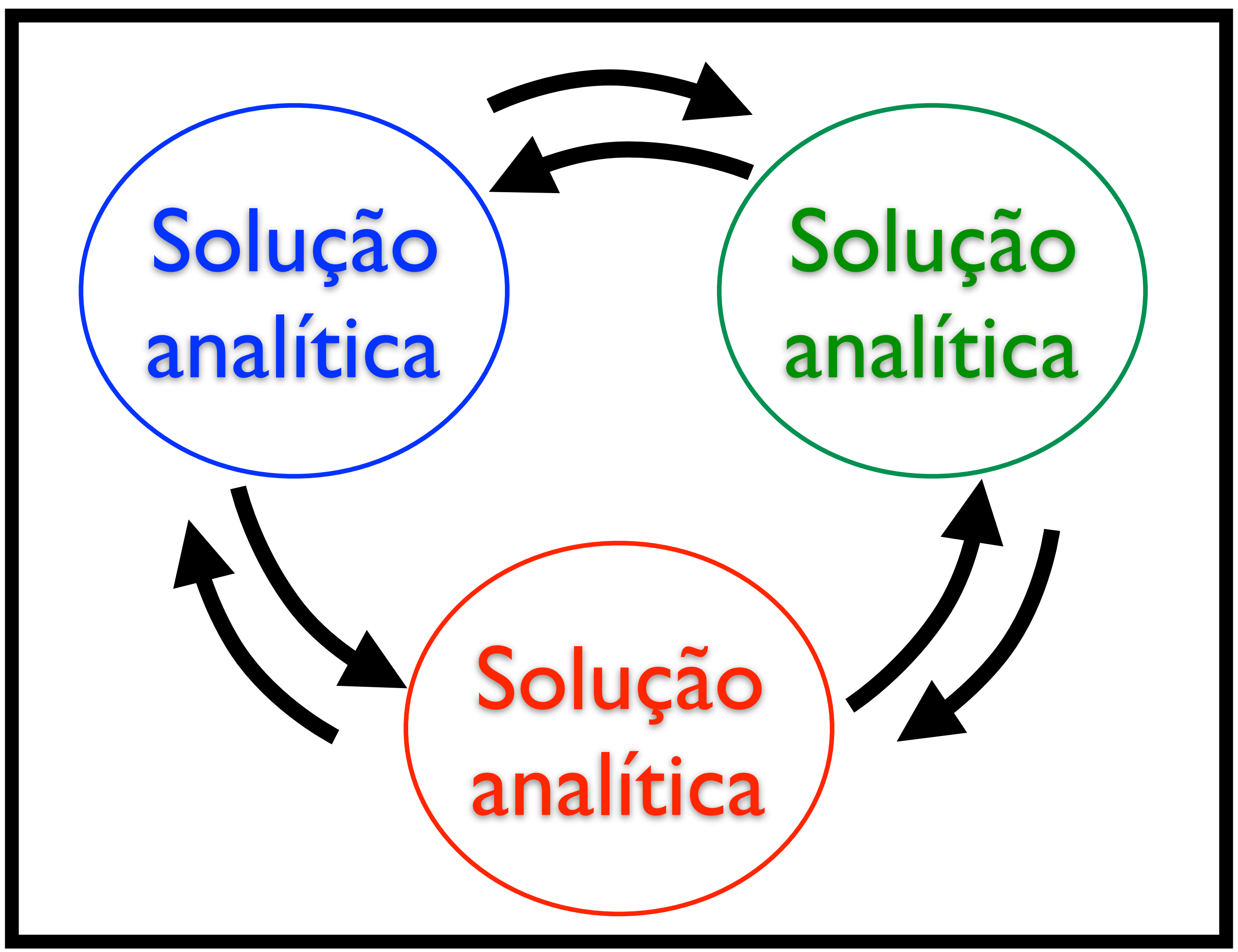

Solução numérica

O que é **Bacia Sedimentar**?

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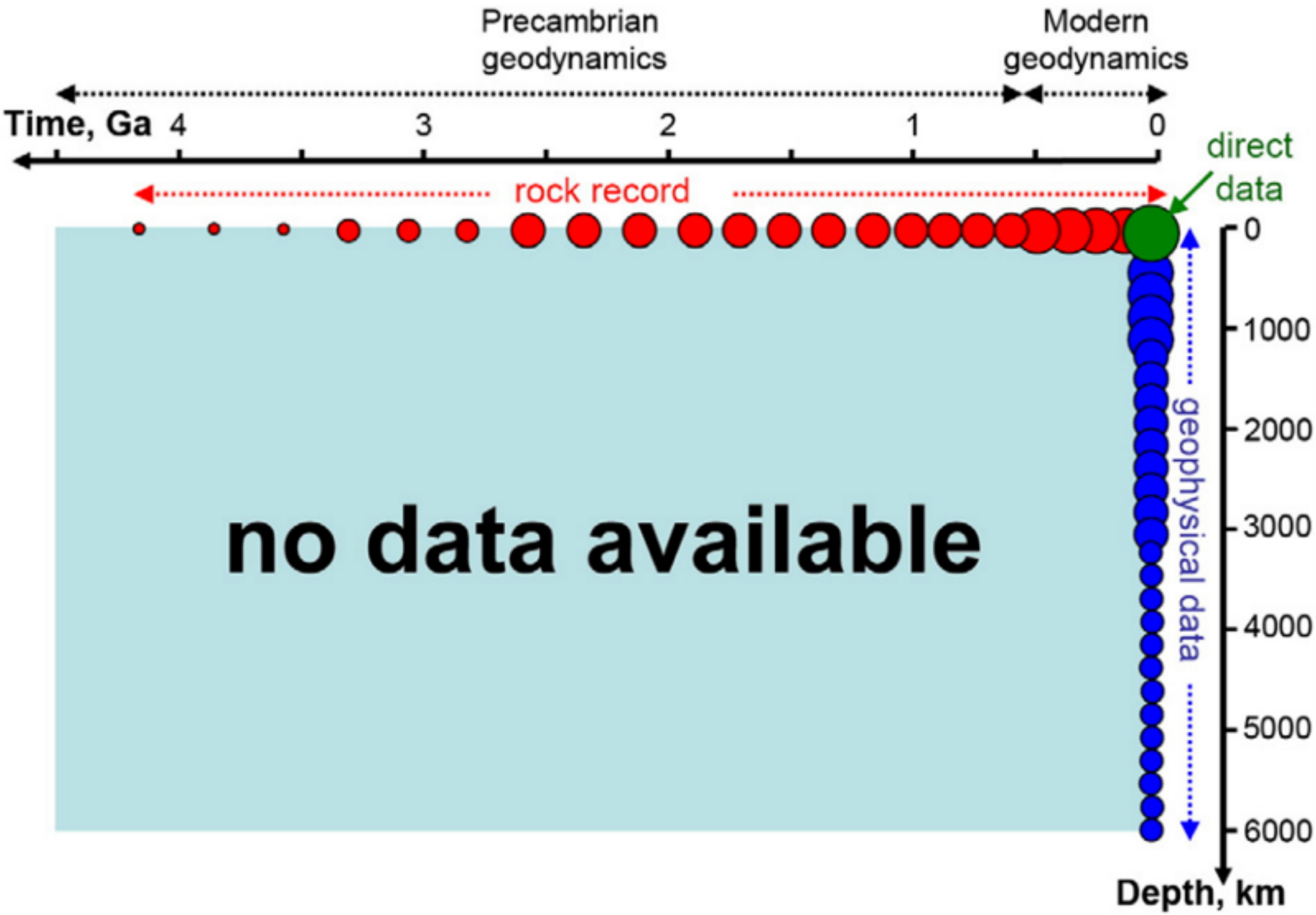
Dicionário enciclopédico inglês-português (Geof. & Geol)
Área deprimida da crosta terrestre, preenchida por rochas sedimentares.

O que é **Bacia Sedimentar**?

Dicionário enciclopédico inglês-português (Geof. & Geol)
Área deprimida da crosta terrestre, preenchida por rochas sedimentares.

Basin Analysis
Vale a pena estudar as bacias sedimentares pois elas contêm o registro de processos na superfície terrestre que operaram durante inúmeros milênios. Elas também contêm em sua geometria a evolução tectônica e a história estratigráfica, pistas valiosas sobre a forma como a litosfera se deforma. Elas são, portanto, repositórios principais de informações geológicas. As bacias sedimentares passadas e presentes também são os locais de quase todos os hidrocarbonetos comerciais do mundo.



Taras Gerya (2012)

O que é Geodinâmica?

Google Books Ngram Viewer

Google Books Ngram Viewer

Graph these comma-separated phrases: geology ☐ case-insensitive

between 1800 and 2000 from the corpus English with smoothing of 3. Search lots of books

(click on line/label for focus)

Search in Google Books:

1800 - 1841	1842 - 1894	1895 - 1910	1911 - 1981	1982 - 2000	geology	English

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Graph these comma-separated phrases: geophysics,geology case-insensitive

between 1800 and 2000 from the corpus English with smoothing of 3. Search lots of books

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Search in Google Books:

1800 - 1939	1940 - 1982	1983 - 1987	1988 - 1993	1994 - 2000	geophysics	English
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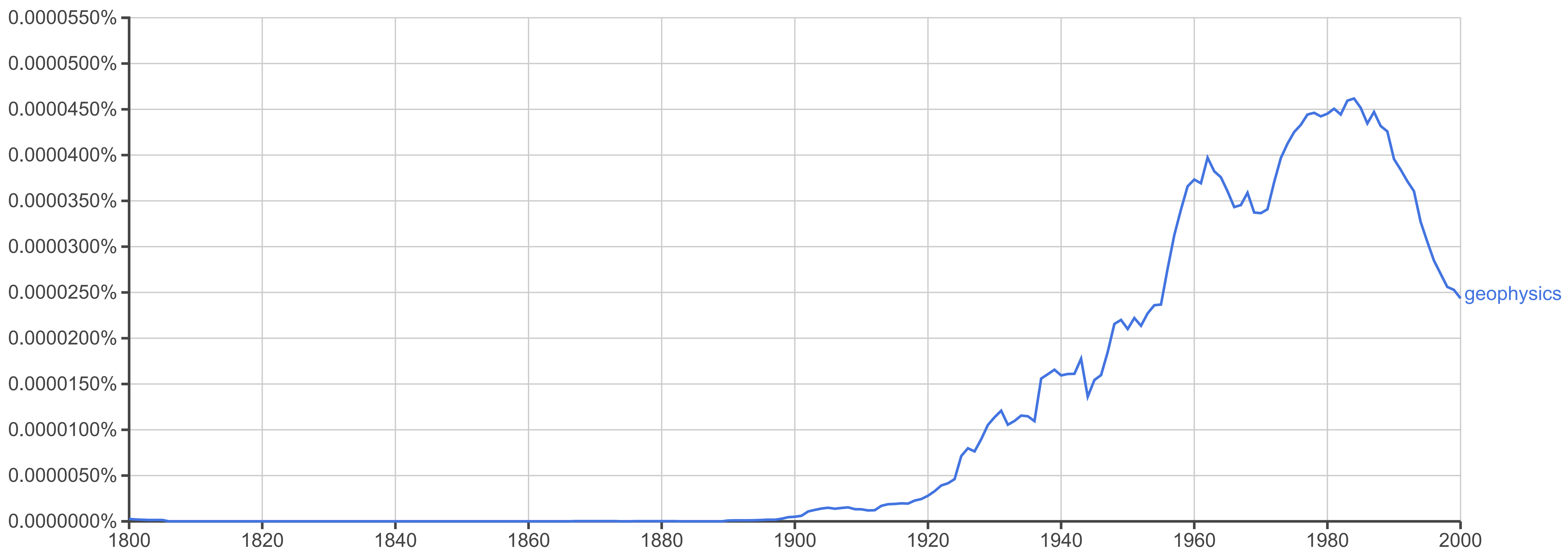

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1800 - 1939 1940 - 1982 1983 - 1987 1988 - 1993 1994 - 2000 geophysics English

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Graph these comma-separated phrases: geophysics,seismology ☐ case-insensitive

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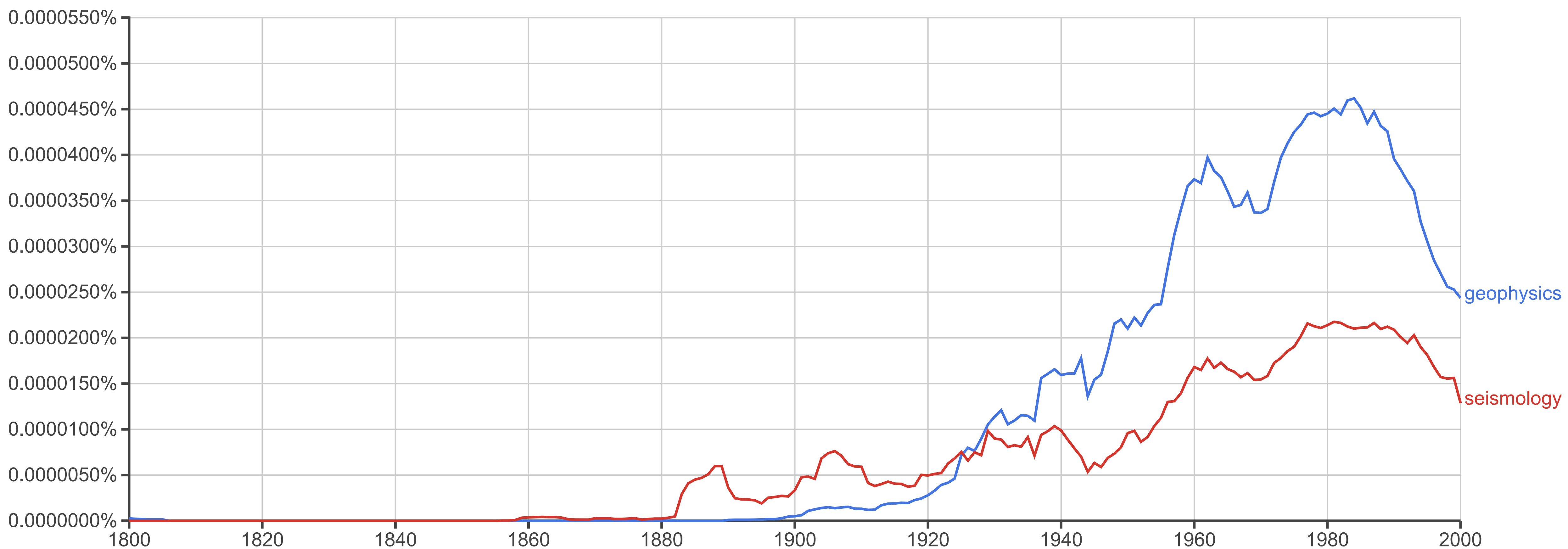

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Search in Google Books:

1800 - 1939	1940 - 1982	1983 - 1987	1988 - 1993	1994 - 2000	geophysics	English
1800 - 1909	1910 - 1981	1982 - 1987	1988 - 1993	1994 - 2000	seismology	English

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Graph these comma-separated phrases: geophysics,seismology,gravimetry ☐ case-insensitive

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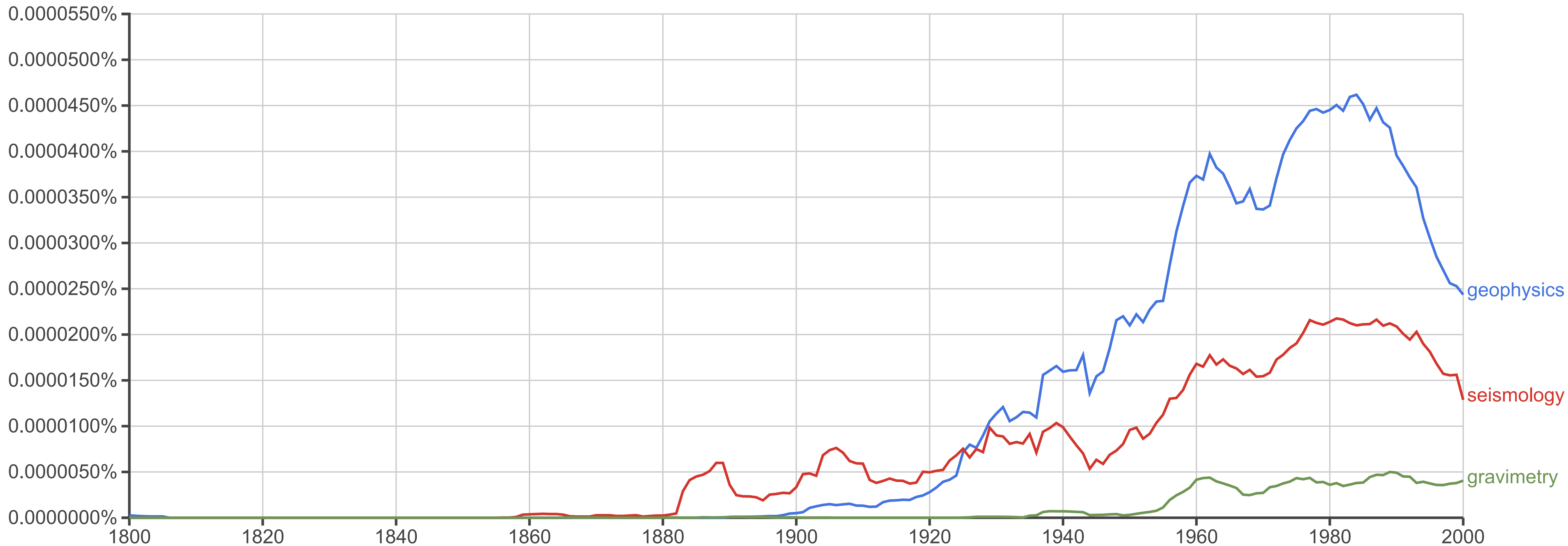

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Search in Google Books:

1800 - 1939	1940 - 1982	1983 - 1987	1988 - 1993	1994 - 2000	geophysics	English
1800 - 1909	1910 - 1981	1982 - 1987	1988 - 1993	1994 - 2000	seismology	English
1800 - 1958	1959 - 1987	1988 - 1991	1992 - 1996	1997 - 2000	gravimetry	English

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Graph these comma-separated phrases: geophysics,seismology,gravimetry,geodynamics ☐ case-insensitive

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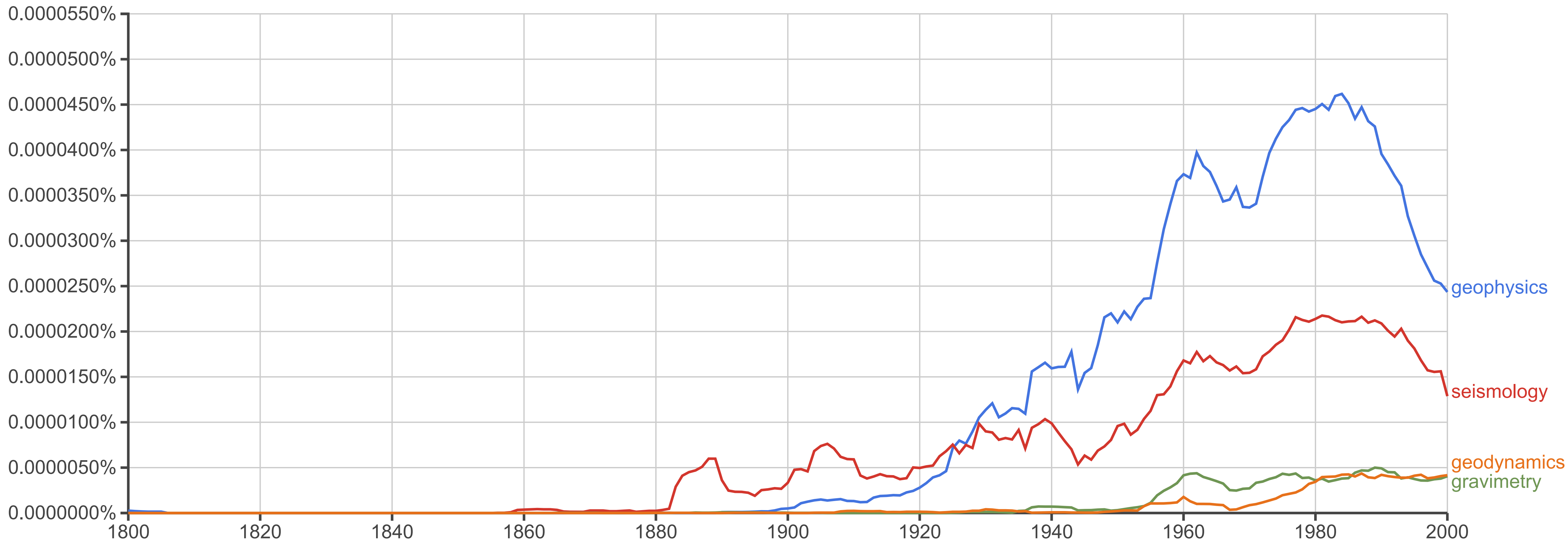

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Search in Google Books:

1800 - 1939	1940 - 1982	1983 - 1987	1988 - 1993	1994 - 2000	geophysics	English
1800 - 1909	1910 - 1981	1982 - 1987	1988 - 1993	1994 - 2000	seismology	English
1800 - 1958	1959 - 1987	1988 - 1991	1992 - 1996	1997 - 2000	gravimetry	English
1800 - 1957	1958 - 1990	1991 - 1993	1994 - 1996	1997 - 2000	geodynamics	English

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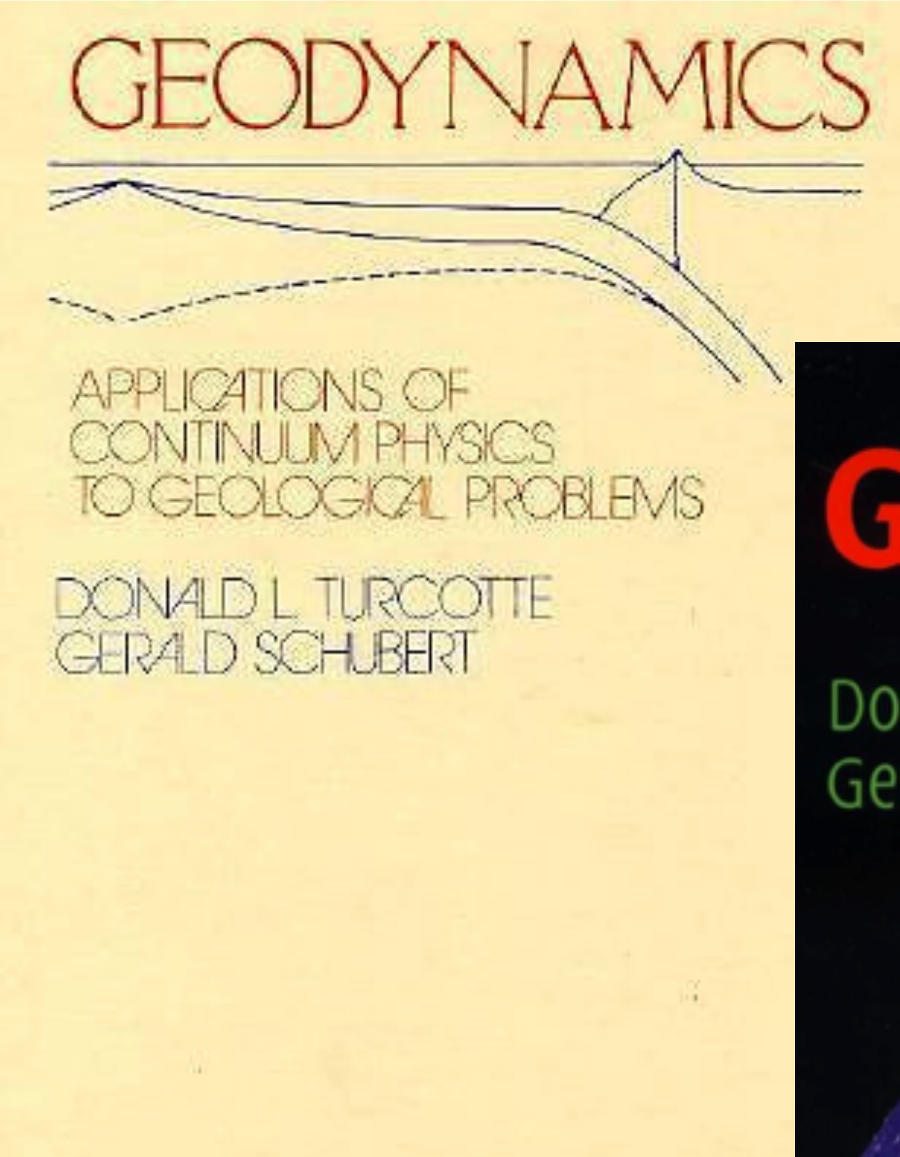

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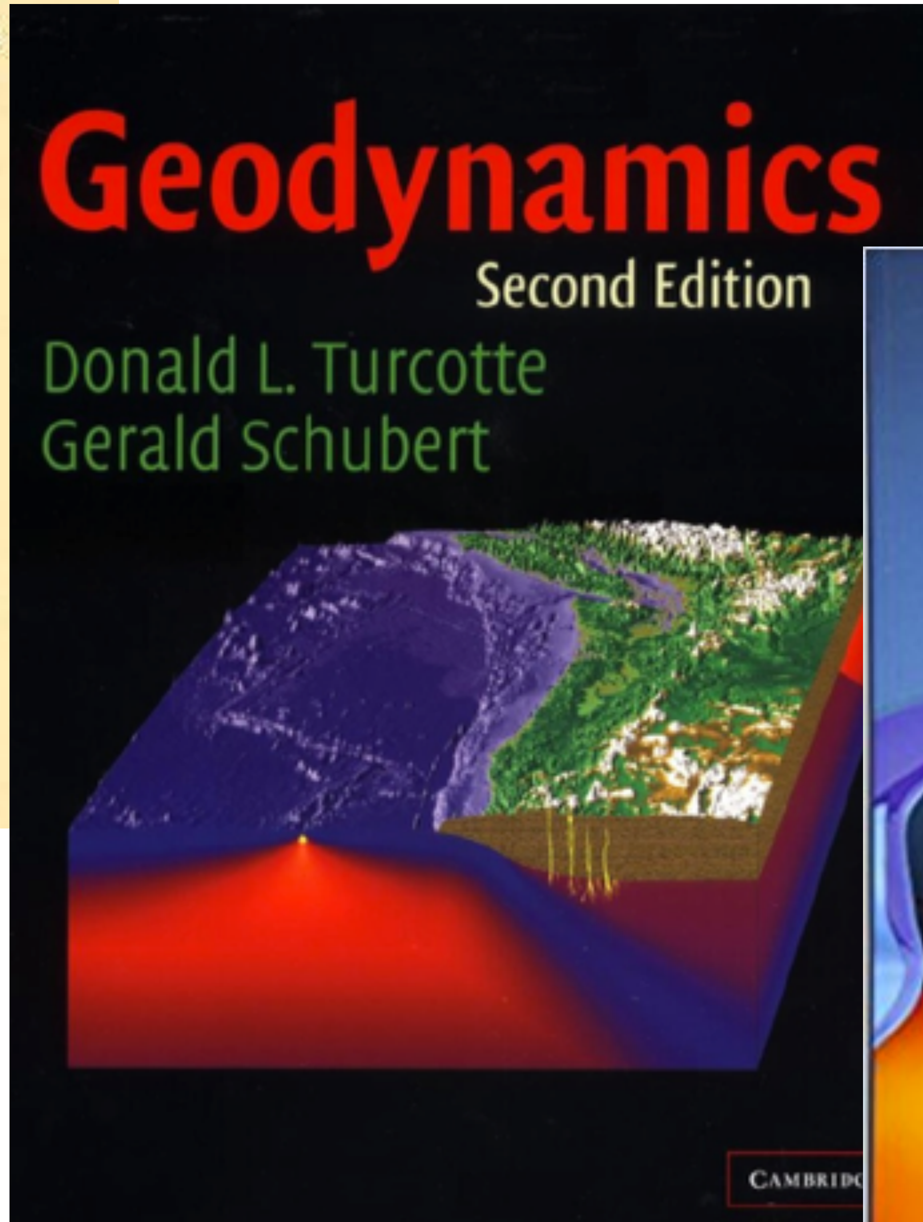

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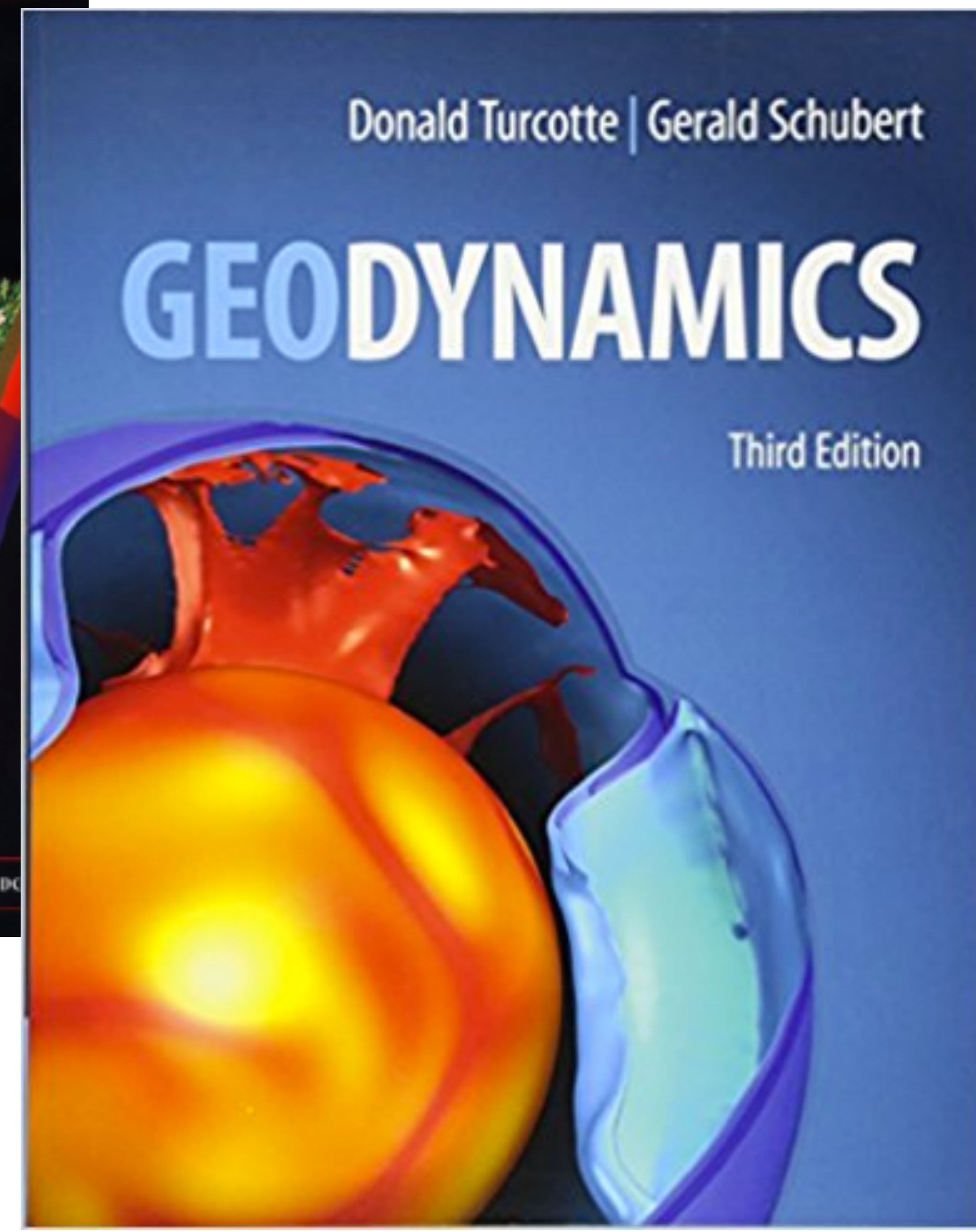


2014

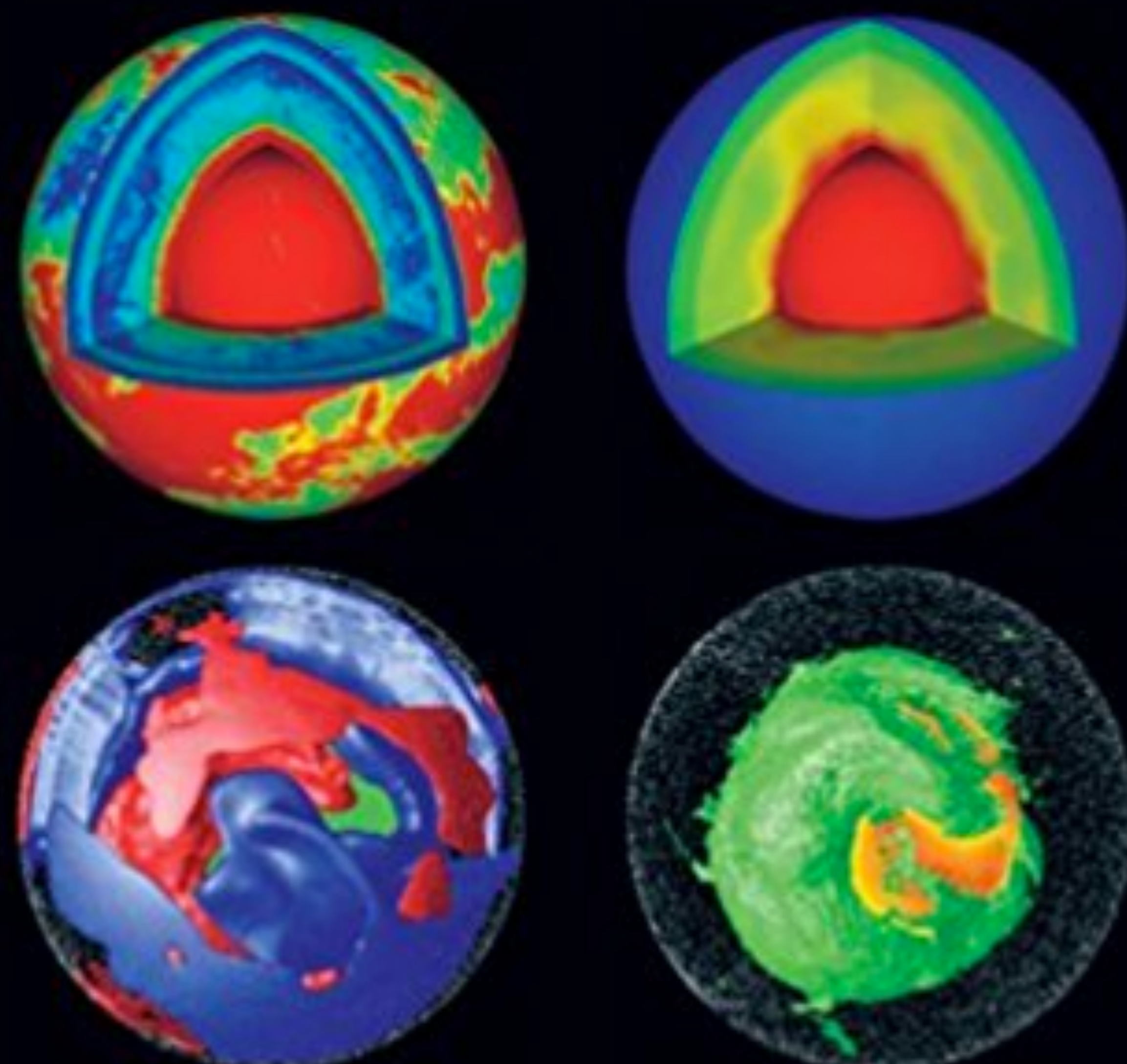
Preface

This textbook deals with the fundamental physical processes necessary for an understanding of plate tectonics and a variety of geological phenomena. We believe that the appropriate title for this material is *geodynamics*. The contents of this textbook evolved from a series of courses given at Cornell University and UCLA to students with a wide range of backgrounds in geology, geophysics, physics, mathematics, chemistry, and engineering. The level of the students ranged from advanced undergraduate to graduate.

In all cases we present the material with a minimum of mathematical complexity. We have not introduced mathematical concepts unless they are essential to the understanding of physical principles. For example, our treat-

ALIK ISMAIL-ZADEH AND PAUL TACKLEY

Computational Methods for GEODYNAMICS



CAMBRIDGE

Prefácio para *Computational Methods for Geodynamics* por Gerald Schubert

"Geodynamics is the application of the basic principles of physics, chemistry and mathematics to understanding how the internal activity of the Earth results in all the geological phenomena and structures apparent at the surface, including seafloor spreading and continental drift, mountain building, volcanoes, earthquakes, sedimentary basins, faulting, folding, and more. Geodynamics also deals with how the Earth's internal activity and structure reveals itself externally in ways both geophysical, its gravitational and magnetic fields, and geochemical, the mineralogy of its rocks and the isotopic composition of its rocks, atmosphere, and ocean. […]

Google Books Ngram Viewer

Graph these comma-separated phrases: geodynamics,plate tectonics case-insensitive

between 1800 and 2000 from the corpus English with smoothing of 3. Search lots of books

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Search in Google Books:

1800 - 1957	1958 - 1990	1991 - 1993	1994 - 1996	1997 - 2000	geodynamics	English
1800 - 1975	1976 - 1993	1994 - 1996	1997 - 1999	2000	plate tectonics	English

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Geodinâmica computacional

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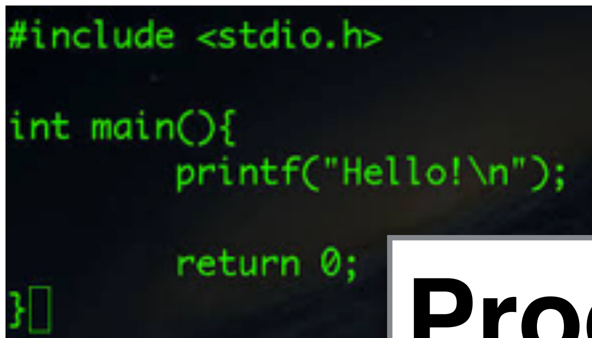
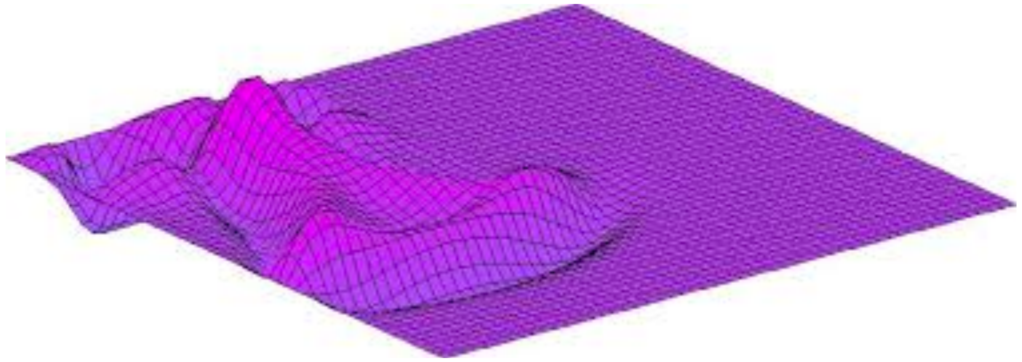


Programming

Geodinâmica computacional

Programming

Numerical methods



Geodinâmica computacional

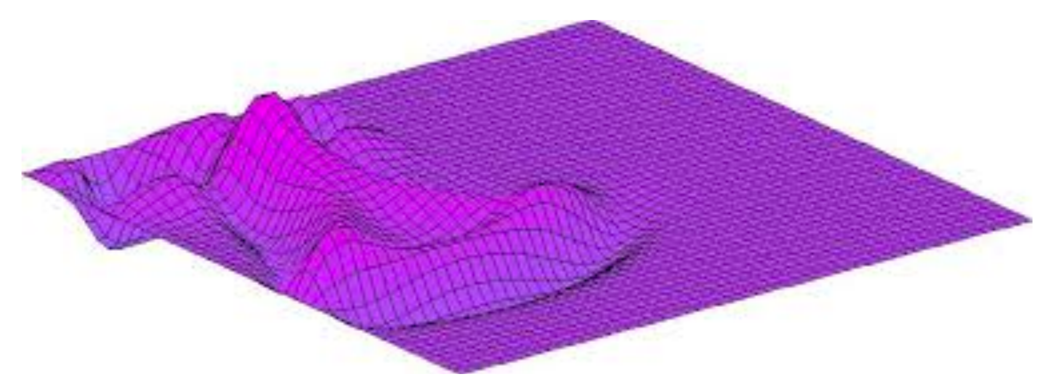
```
#include <stdio.h>

int main(){
        printf("Hello!\n");

        return 0;
}
```

Programming

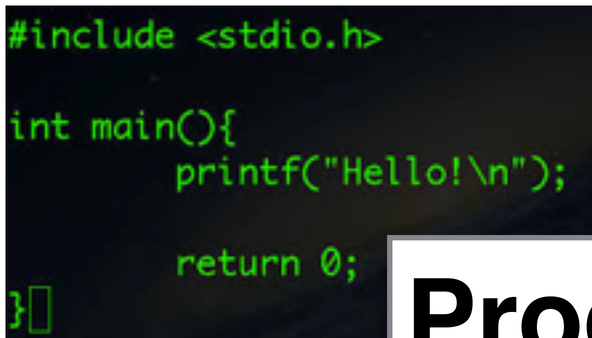
Physics

Numerical methods

$$\vec{F} = \frac{d\vec{p}}{dt}$$



Geodinâmica computacional



Programming

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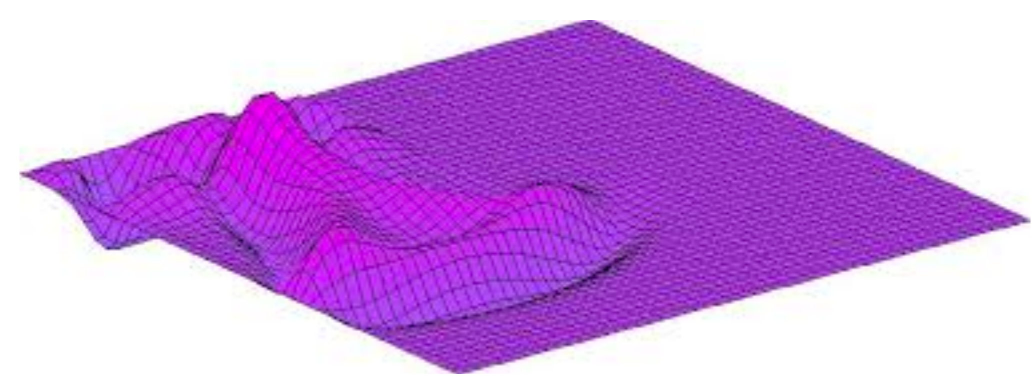
Numerical methods



VOL. 76, NO. 5 JOURNAL OF GEOPHYSICAL RESEARCH FEBRUARY 10, 1971

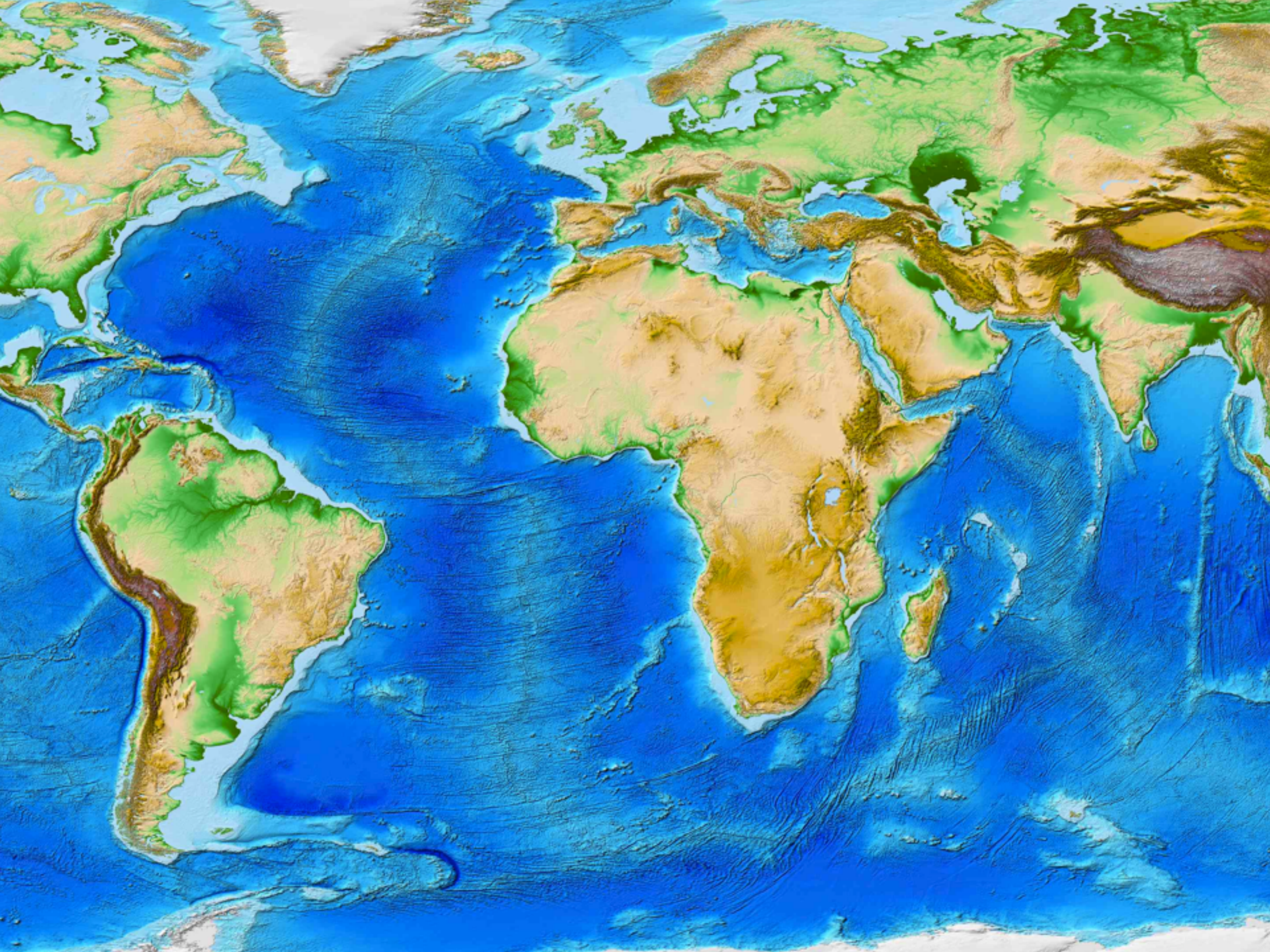
Structure of Convection Cells in the Mantle

K. E. TORRANCE AND D. L. TURCOTTE

Cornell University, Ithaca, New York 14850

This paper demonstrates the feasibility of using numerical calculations to determine the structure of convection cells within the mantle. A temperature and depth-dependent viscosity appropriate for diffusion creep is employed. The upper boundary is a rigid surface moving at constant speed; this boundary condition is compatible with plate tectonics. It is found that large flow velocities and small temperature differences are associated with ascending convection, and significant flows extend to a depth of 300 km. The surface heat flow and topography are determined and are in reasonable agreement with observations.

Dan McKenzie



Earth and Planetary Science Letters, 40 (1978) 25–32

[6]

SOME REMARKS ON THE DEVELOPMENT OF SEDIMENTARY BASINS

DAN McKENZIE

Department of Geodesy and Geophysics, Madingley Rise, Madingley Road, Cambridge (England)

Received December 14, 1977
Revised version received March 27, 1978

A simple model for the development and evolution of sedimentary basins is proposed. The first event consists of a rapid stretching of continental lithosphere, which produces thinning and passive upwelling of hot asthenosphere. This stage is associated with block faulting and subsidence. The lithosphere then thickens by heat conduction to the surface, and further slow subsidence occurs which is not associated with faulting. The slow subsidence and the heat flow depend only on the amount of stretching, which can be estimated from these quantities and from the change in thickness of the continental crust caused by the extension. The model is therefore easily tested. Preliminary investigations of the Great Basin, the Aegean, the North Sea and the Michigan Basin suggest that the model can account for the major events in their evolution.

] avoided this difficulty ...ges, but added little to the ... question. ... the mechanism which heats ...re. Haxby et al. [8] offered ...sed on mantle diapirs, which ... to intrude and replace the ...phere with hot rock without ...mation at the surface. In ...t flow anomalies have yet been ...aire variations in temperature in ...he lithosphere. Both the heat ...ciated with ridges [9] and with ...[11] can be produced by a simple ...ain by an isothermal mantle. ...ceanic heat flow anomalies are ...xtensive than those found in conti... ...herefore be surprising if continental, ...nic, heat flow anomalies required the ...al heat sources beneath the litho-

...ace and the heating problem are ... basin is produced by stretching con... ... over a large region. Such a model has ...sed to account for the normal faulting ...hinning observed in rifted regions ...t the thermal consequences of the ...ave received little attention. An exten... ...el of this type can account for the present ...on and heat flow in the Aegean Sea region ...ugh, since the deformation is still occurring, ...ormed sedimentary basin has yet developed. ...he models of Voight [12] and Makris [15], ...mal anomalies associated with basin formation ...uired in the asthenosphere. The prupose of the ...pment below is to examine the surface flow ...bsidence produced by arbitrary amounts of ...hing. The results are then compared with the ...ation of several basins and used to suggest how ...stretching model can be tested.

Model calculations

The simplest stretching model is illustrated in Fig. 1. At time $t = 0$ a unit length of continental lithosphere is suddenly extended to a length β, causing upwelling of hot asthenosphere. The resultant thermal

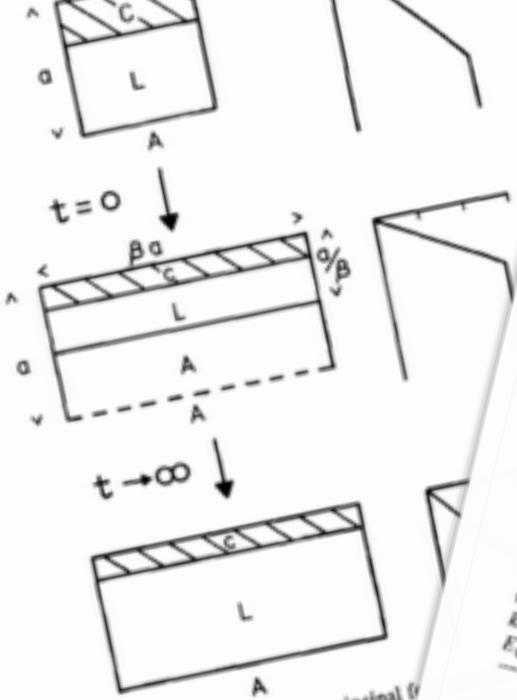


Fig. 1. Sketch to show the principal f... dence model. At time $t = 0$ a piece o... continental lithosphere is extended... ture of the material remains unch... isostatic compensation causes u... sphere. Cooling of this hot ma... the temperature perturbation... assumed to be conserved du... ity neglected. The disconti... between the lithosphere a... of the model which coul... details of the convecti... However, the heat flu...

perturbation g... Isostatic com... simplest mo... tal rocks a... correspo... sphere i... exami... scure...

TABLE 1

Values of parameters used (mostly taken from Parsons and Sclater [9])

a	=	125 km
ρ_0	=	3.33 g cm^{-3}
ρ_c	=	2.8 g cm^{-3}
ρ_w	=	1.0 g cm^{-3}
α	=	3.28×10^{-5} °C^{-1}
T_1	=	1333°C
τ	=	62.8 My
kT_1/a	=	0.8 μcal cm^{-2} s^{-1}
E_0	=	3.2 km

both before and after extension, there is an initial subsidence S_i given by:

$$S_i = \frac{a\left[(\rho_0 - \rho_c)\frac{t_c}{a}\left(1 - \alpha T_1 \frac{t_c}{a}\right) - \frac{\alpha T_1 \rho_0}{2}\right]\left(1 - \frac{1}{\beta}\right)}{\rho_0(1 - \alpha T_1) - \rho_w} \quad (1)$$

where a is the thickness of the lithosphere and t_c the initial thickness of the continental crust, ρ_0 the density of the mantle, ρ_c that of the continent both at 0°C. ρ_w is the density of seawater, α the thermal expansion coefficient of both the mantle and the crust and T_1, the temperature of the astenosphere. The surface of the continent is taken to be at or below sea level, and continental crust is assumed to be conserved. The sign of S_i depends on t_c and is independent of β. Using values for the quantities in (1) in Table 1, taken from Parsons and Sclater [9], S_i is positive if $t_c \geq 18$ km. Hence land areas will subside but regions with thin crust can be elevated by the stretching, though not sufficiently to emerge above sea level. It is of course possible that uncompensated islands may be produced during the extension by block faulting as has happened in the Aegean, or that vulcanism may cause the volume of the continental crust to increase. These processes can elevate part or all of a stretched basin above sea level during extension which would otherwise sink. The stretching increases the heat flow by β at $t = 0$ if it occurs instantaneously. After the extension the temperature variation is:

$$T = T_1\,, \qquad 0 < \frac{z}{a} < \left(1 - \frac{1}{\beta}\right)$$

wh... litho... denc... solve...

$$\frac{\partial T}{\partial t} = \kappa \ldots$$

where κ is ... ditions:

$T = 0\,,$ ...

$= T_1\,,$ ...

and initial conditio... Fourier expansion, ... given by Lubimova a... ature structure in an o... is:

$$\frac{T}{T_1} = 1 - \frac{z}{a} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^n}{n} \ldots$$

$$\times \exp\left(\frac{-n^2 t}{\tau}\right)\sin\frac{n\pi z}{a}$$

where:

$$\tau = \frac{a^2}{\pi^2 \kappa}$$

As $\beta \to \infty$ the term in square brackets ... the solution is that for an oceanic ridge ... the heat is conducted vertically [9]. The ... flux, F, is easily obtained from (5):

$$F(t) = \frac{kT_1}{a}\left(1 + 2\sum_{n=1}^{\infty}\left[\frac{\beta}{n\pi}\sin\frac{n\pi}{\beta}\right]\exp\left(-\frac{n^2 t}{\tau}\right) \ldots\right.$$

The elevation, $e(t)$, above the final depth to which the upper surface of the lithosphere sinks is:

$$e(t) = \frac{a\rho_0\alpha T_1}{\rho_0 - \rho_w}\left(\frac{4}{\pi^2}\sum_{m=0}^{\infty}\frac{1}{(2m+1)^2} \times \left[\frac{\beta}{(2m+1)\pi}\sin\frac{(2m+1)\pi}{\beta}\right]\exp\left(-(2m+1)^2\frac{t}{\tau}\right)\right) \quad (8)$$

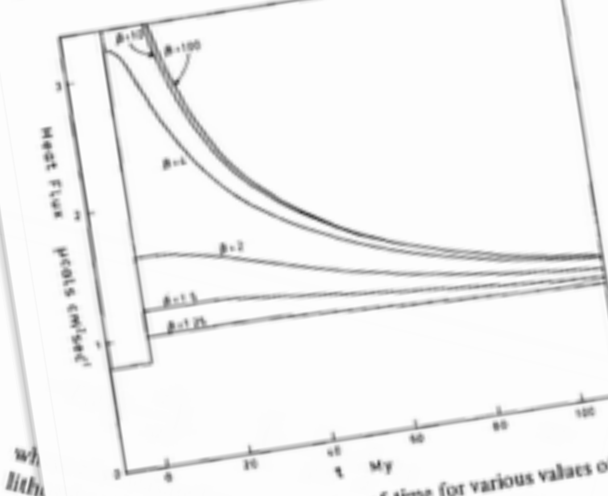


Fig. 2. Heat flux as a function of time for various values of β, obtained from equation (7).

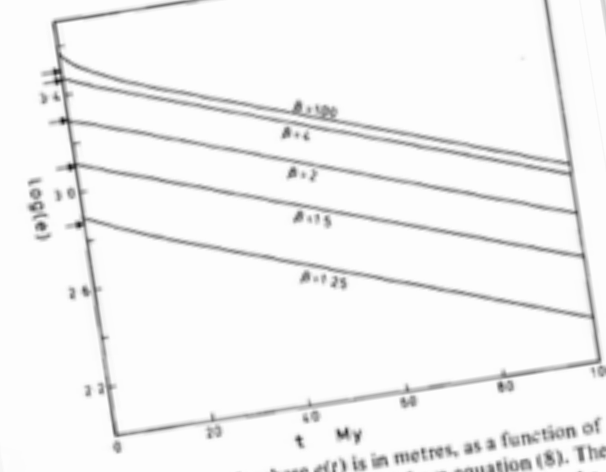


Fig. 3. $\log_{10}[e(t)]$, where $e(t)$ is in metres, as a function of time for various values of β obtained from equation (8). The arrows mark the positions where straight lines fitted to the curves for values of $t > 20$ My intersect the $t = 0$ axis.

The heat flux is a function of time for various values of β in Fig. 2 shows a strong dependence on β for time less than about 50 My if β is between 1 and 4. However the heat flux is insensitive to β when β is large because almost all the region between $z = 0$ and $z = a$ is replaced with asthenosphere during extension, and the thin remnant of the original lithosphere has little influence. Extension increases the heat flux by a factor β. After a time which depends on the thermal time constant of the stretched lithosphere, τ/β^2, the heat flux starts to decrease. The behaviour at large times, $t \gtrsim 30$ My, can be described by the first term of the summation in (7): (9)

$$F(t) = \frac{kT_1}{a}\left[1 + 2r\exp\left(-\frac{t}{\tau}\right)\right] \quad (10)$$

where $r = (\beta/\pi)\sin(\pi/\beta)$ is the fraction by which the time-dependent part of the heat flux is reduced below the ridge model. Since the heat flux is reduced below the ridge model. Since $\beta > 1, 0 < r \leqslant 1$. Hence when $t \ll \tau/\beta^2$ the ratio of the heat flux after stretching to that before gives β directly.

At times between 0 and 30 My β can only be obtained from F by using (7), but for later times (9) is sufficient. When $t \gtrsim \tau$ the heat flow anomaly is small and will not be easy to observe, and for values of $\beta \leq 1.5$ the anomaly will be difficult to observe at all times.

The behaviour of the elevation anomaly is diffe... ent. Fig. 3 shows $\log_{10}(e)$ as a function of t for va... ous values of β. The curves are almost straight lin... when $\beta < 4$ for all values of t. The reason for this ... clear from (8): for such values of β the second te... the summation is very small and:

$$e(t) \simeq E_0 r \exp(-t/\tau)$$

where:

$$E_0 = \frac{4a\rho_0\alpha T_1}{\pi^2(\rho_0 - \rho_w)}$$

Parsons and Sclater [9] give a value of 3.2 k... When β is large and $r \to 1$ the corresponding ... sion to (11) is valid only for $t \gtrsim 20$ My. The ... sidence since extension, S_t, is sometimes m... measured than e:

$$S_t = e(0) - e(t)$$

The total subsidence S is the sum of S_t an... Following Parsons and Sclater [9], S_t ... function of $\sqrt{t}$ in Fig. 4. An approximat... for S_t, σ_t, may be obtained from (11):

$$\sigma_t = E_0 r[1 - \exp(-x^2/\tau)]$$

where:

$$x^2 = t$$

LHC: €7.5 billion