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Nikolai Bagdassarov
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Fundamentals of Rock Physics

Rock physics encompasses practically all aspects of solid- and fluid-state physics. This book provides a unified presentation of the underlying physical principles of rock physics, covering elements of mineral physics, petrology and rock mechanics. After a short introduction on rocks and minerals, the subsequent chapters cover rock density, porosity, stress and strain relationships, permeability, poroelasticity, acoustics, conductivity, polarizability, magnetism, thermal properties and natural radioactivity. Each chapter includes problem sets and focus boxes with in-depth explanations of the physical and mathematical aspects of underlying processes. The book is also supplemented by online MATLAB exercises to help students apply their knowledge to numerically solve rock physics problems. Covering laboratory and field-based measurement methods as well as theoretical models, this textbook is ideal for upper-level undergraduate and graduate courses in rock physics. It will also make a useful reference for researchers and professional scientists working in geoscience and petroleum engineering.

Nikolai Bagdassarov is a professor in the Department of Earth Sciences at Goethe University, Germany. He is a fellow of the Humboldt Foundation, Head of the Rock Physics Laboratory and Professor of Geophysics at Frankfurt University, and has been a member of the American Geophysical Union since 1991. He has more than 60 peer-reviewed publications in the field of rock physics and is an experienced lecturer, having taught courses on geophysics and rock physics, physics of magmas and volcanoes, and rock mechanics at Goethe University Frankfurt since 1995.

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NIKOLAI BAGDASSAROV
Goethe University Frankfurt

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To my parent-geologists,
Galina and Shahen.

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Preface

Why have another book about rock physics? There are so many of this variety!

To answer this question, I refer the reader to the student joke about the preciseness of some definitions in geosciences:

If one asks a mathematician what is the opposite term to “parallelism,” the unique answer will be “orthogonality.” To the same question a physicist would definitely give the answer “sequence,” and the geologist’s answer will probably be “obliqueness,” “slant,” etc. The old wisdom is that any unclear geological answer always needs to be explained by using formal mathematical and physical definitions!

My parents were geologists, which explains my passion for rocks and their properties. When I was a young boy, my father used to explain to me that “geology is generally speaking not a science” but more like “a way of life.” And I was pretty much convinced of this statement, observing how my parents prepared themselves in winter for summer field seasons, and that was quite an absorbing business, as I remember. So the combination of “the geologist way of life” and my interest in mathematics and physics predefined my future passion for rock physics.

Physics and mathematics are required for understanding rock properties and their origin and evolution on the Earth and in our solar system. The few geoscience students from Frankfurt University whom I have dealt with in my lectures were astonished to find these subjects to be as important for them as for future geologists.

To interest geoscience students in engineering and mathematical descriptions of natural phenomena, I traditionally began my classes with the example of one of the well-known Moscow puzzles (see Kordemsky, 1992):

Imagine that we are in a new residential district in the outskirts of Moscow. The area is built up of many dull similar apartment blocks constructed according to a rectangular grid pattern of size $n \times m$ shown in Figure P.1. The dashed line indicates a path from point A to point B having the length of n horizontal and m vertical stretches. It is surely not the only way to come from A to B. The question is how many similar identical-length routes from A to B can be found in Figure P.1 moving only downward and to the right.

For grid 1×1 or one block, the answer is evident: there are two routes. For the size 2×2, many kids aged less than 7 give the correct answer almost immediately: 6. With adults, and especially with German geoscience students, it takes much longer. For a larger grid, someone can become confused very fast by trying to draw all possible paths. How to find the solution of the problem?

1. *Engineering method.* We denote the starting point as (1, 1) and any node of grid by indices (i, j). There is only one route to reach the adjacent node (1, 2) or (2, 1) starting from the point (1, 1). In order to reach the node (2, 2) there are $2 = 1 + 1$ paths. Then, to reach (1, 3) or (3, 1), there are $3 = 1 + 2$ paths, etc. The number of routes in each node is the sum of the route number at the left node plus the route number in the upper node. Therefore, the route number S to reach a particular node (i, j) equals the sum of paths to reach $(i - 1, j)$ and $(i, j - 1)$. So we compose matrix $S(i, j)$

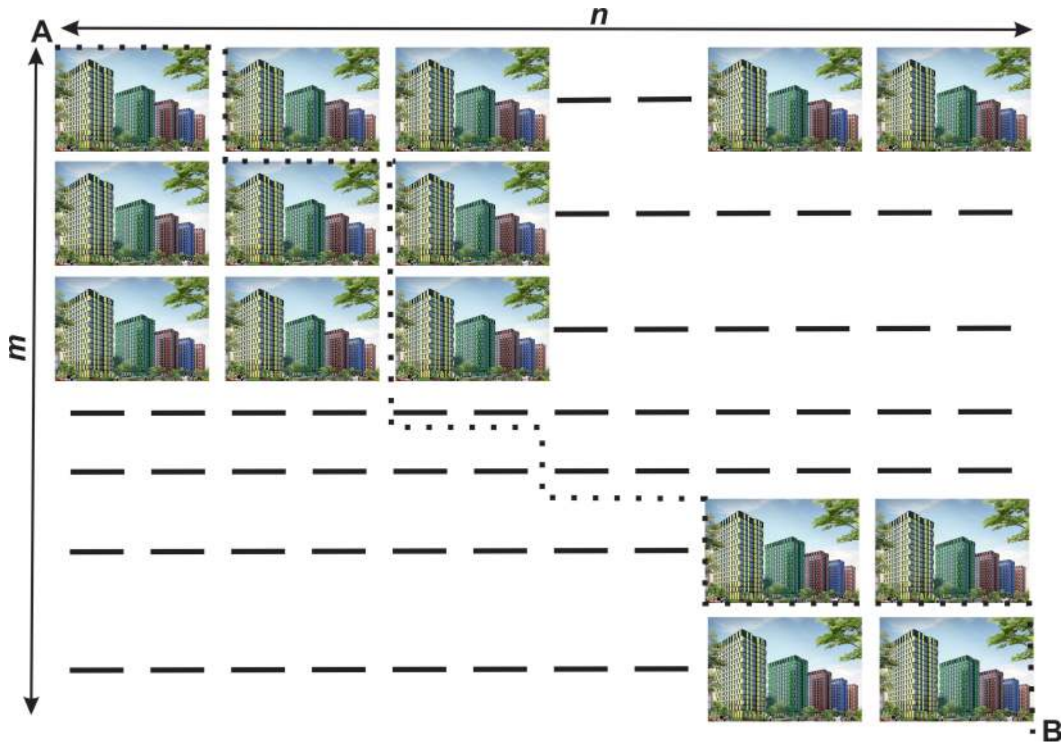

Figure P.1 The Moscow puzzle "How many routes?"

whose elements are route numbers at nodes (i, j). The matrix S is of size $(n+1 \times m+1)$ filled with 1s at $(1, j)$ and $(i, 1)$ nodes because at the edge, there is always only one possible route to reach the node (Figure P.2).

The scheme to build the Moscow puzzle matrix $S(i, j)$ may be realized through the simple algorithm $S(1, 1) = 1$; $S(i, j) = S(i-1, j) + S(i, j-1)$ or using MATLAB code:

```
clc; % clear screen
prompt='Input number of columns n: ';% print to input n on screen
n=input(prompt)% print n on screen
prompt='Input number of lines m: ';%print input m on screen
m=input(prompt) % print m on screen
n=n+1; m=m+1; S=ones(n,m); %create matrix filled with 1 of size (n+1 x m+1)
S(1,1)=0;% starting point 0 routes
for i=2:n
    for j=2:m
        S(i,j)=S(i-1,j)+S(i,j-1);% calculate the sum of routes
    end
end
S % print the result on screen
```

2. *Mathematical method.* From the mathematical point of view, the problem must be reduced to an already solved similar problem whose solution is well known (undeniable truth in mathematics!). The length of any path is $m + n$, because it consists of m stretches down and n stretches to the left.

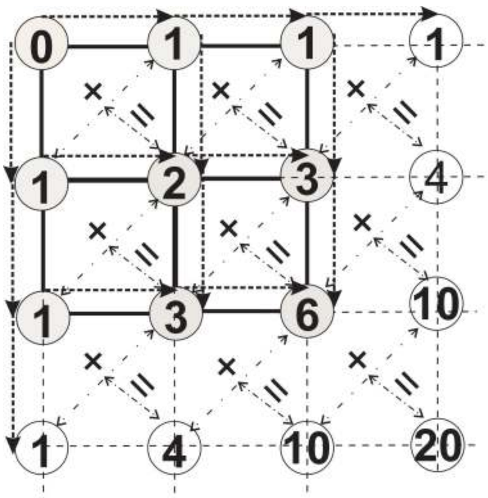

Figure P.2 Solution of Moscow puzzle "How many routes?" The node labels in the rectangular grid are the number of routes to reach this node.

The routes of the same length differ only by alternating positions of horizontal and vertical stretches. How many possible permutations of n horizontal and m vertical stretches are possible among $n + m$ positions? The answer is well known: $\frac{(n+m)!}{n! \cdot m!}$. Here, $n!$ means the factorial product $1 \cdot 2 \cdot \cdots (n-1) \cdot n$. The interesting point is that in order to calculate a factorial, computer resources need to be much larger than for using the two loops of summation used in the engineering solution. For example, MATLAB cannot calculate factorials larger than 170, although by using the summation code it is not a problem at all!

This Moscow puzzle may have some sense for rock physics when one puts the question in this way: how many possible ways are there to break a ribbed bar of chocolate, when trying to break it along a diagonal line? Instead of a chocolate bar, one may imagine a rock slab, the grains of which are of the same size, and think about a fault zone.

Exercise: The size of a ribbed bar of chocolate is $n \times m$. For a given point with indices (i, j), what is the probability that a diagonal crack splitting the bar in two parts passes through this point? Plot contour maps of probabilities using MATLAB.

Literature

Kordemsky, B. A. (1992). *The Moscow puzzles*. Dover Publ. Inc., NY, 310 pp.