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Roughened Surfaces in Micro- and Nano-Structures

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Roughened Surfaces
in Micro- and Nano-Structures
(nano geometry)

1 microstructoloy

2 roughening of a surface (Sandstrahlen)

3 orientation and boundaries on a surface of grains

4 hot drops and roughened surfaces

0. Introduction

There exist different kinds of surfaces - two of these are

- **surfaces in the differential geometry (line-geometry)**
- **surfaces of real objects (point-geometry)**

Especially the characterisation of the surface

of an iron plate during different steps of a plastic deformation

needs a geometric description of point-geometry, because microscopy gives point-information in a coordinate-system of micro- or nanometers.

When we examine the microstructure of a material we are looking at a very small sample of the structure. From this limited view we try to understand how the properties of the material relate to structure - if there is a relation (remember the cracks in the wheels of trains).

But, when we measure the properties of the material (such as tensile strength[1]), hardness, density or electrical conductivity), we use a much larger specimen, so that the measured properties refer to something hundreds or thousands of times larger than our microscopic view.

It should not be surprising, therefore, that it is difficult thus to establish correlations between properties and microstructure.

[1]) tensile strength= Zugprobe

3 orientation and boundaries on a surface of grains

3.1 grains and its boundaries (motivation)

What happens during cold deformation of a metal?

Fig. 3.1.1 shows the grain-structure of a metal. We deform this metal in very small steps and look for possible changes of the grain structure. Our aim is to find out a statement in the form

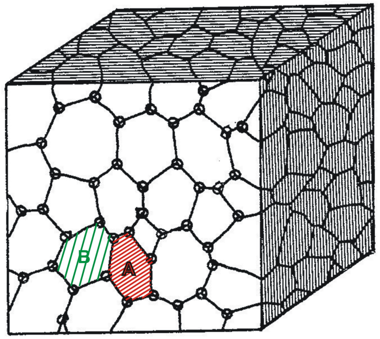
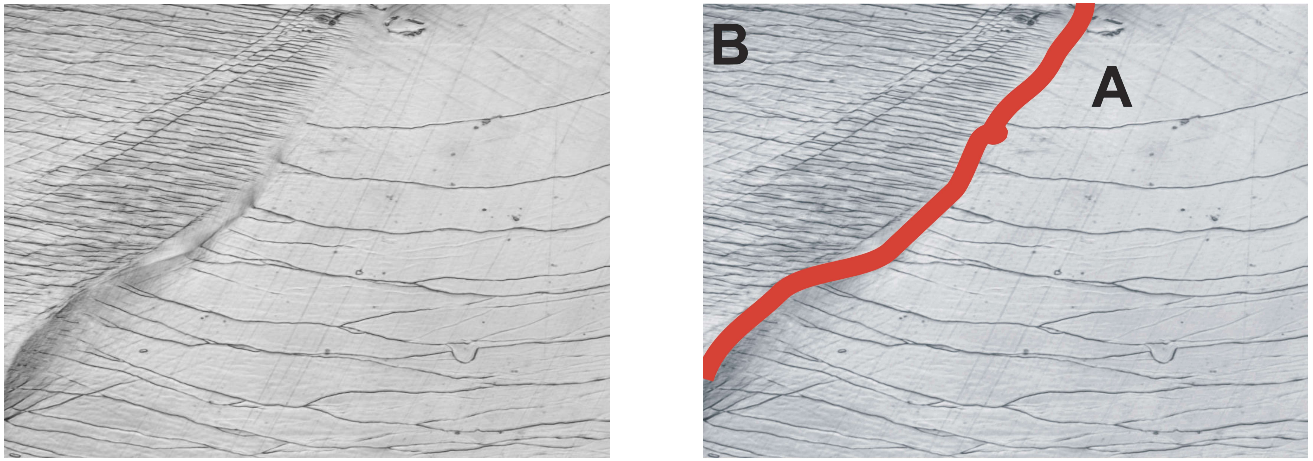


fig. 3.1.1: **grains grain A and grain B with different orientations**

$(50 \times 50 \times 50\,\mu m^3)$

„In this microscopy we have grains A and B.
The grain A has during the first cold deformation of 5%
the main orientation of 90°.
with respect to a „north"-orientation"



The black curves are the valleys in the surface

The red curve is the boundary

fig. 3.1.2: structure of the surface (detail of fig. 3.1.1) - $(10 \times 10\mu\, m^2)$

During many steps of a cold deformation of metal we are interested in those zones where grains change their orientation with respect to valleys.

We are interested in a possible dependency between the structure of grains and the degree of (cold) deformation.

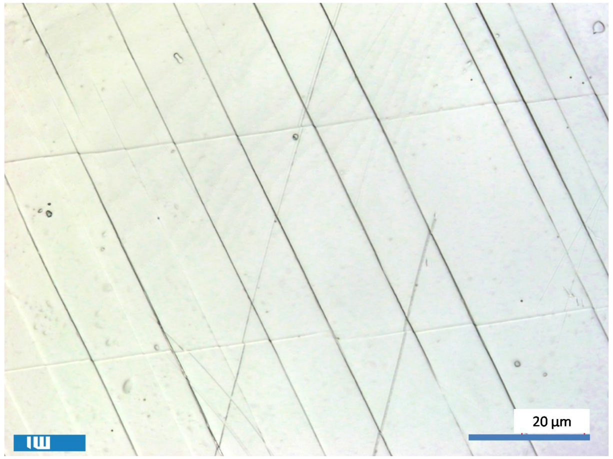


fig. 3.1.3a):
Al, $100 \times 70\,\mu m$
$\varphi_Z = -0.05$, **95%**

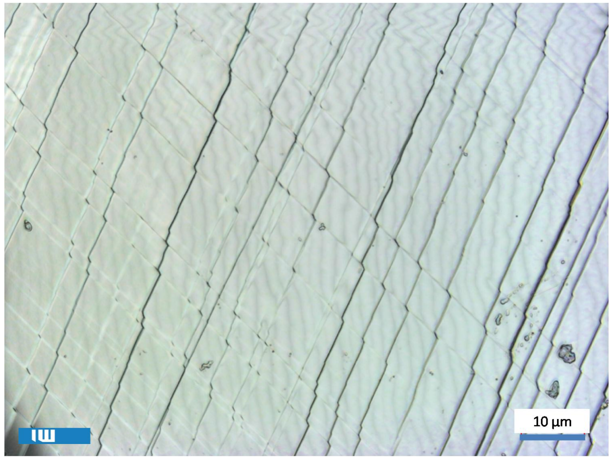


fig. 3.1.3b):
Al, $88 \times 62\,\mu m$
$\varphi_Z = -0.10$, **90%**

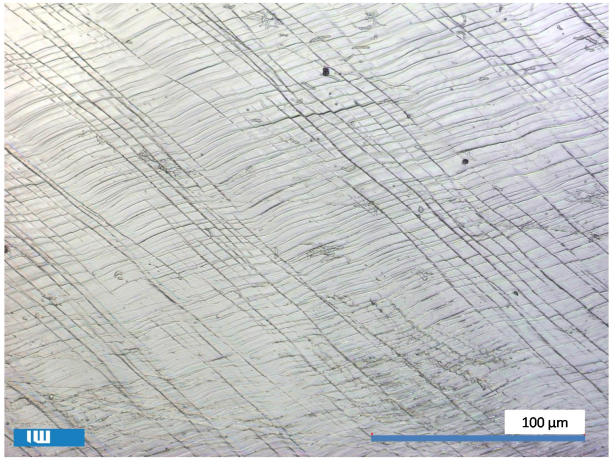


fig. 3.1.3c):
Al, $285 \times 200\,\mu m$
$\varphi_Z = -0.16$, **85%**

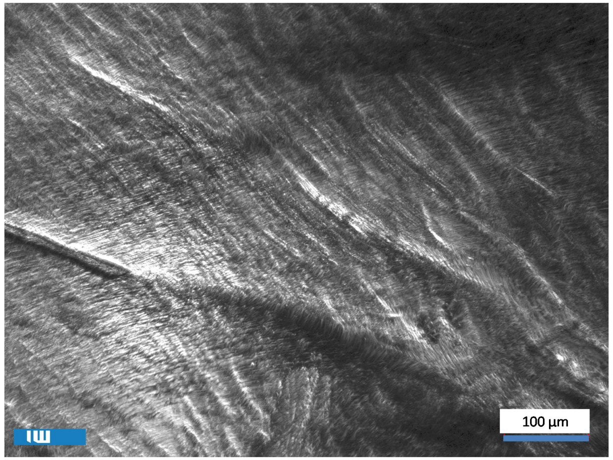


fig. 3.1.3d):
Al, $800 \times 560\,\mu m$
$\varphi_Z = -0.43$, **65%**

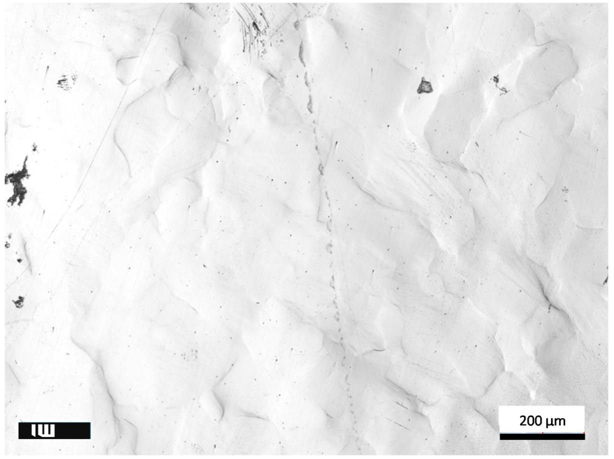


fig. 3.1.4a):
Fe, $1600 \times 1120\,\mu m$
$\varphi_Z = -0.02$**, 98%**

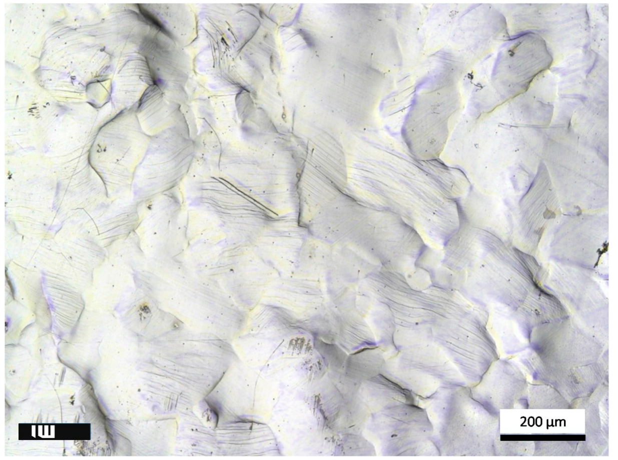


fig. 3.1.4b):
Fe, $1600 \times 1120\,\mu m$
$\varphi_Z = -0.04$**, 96%**

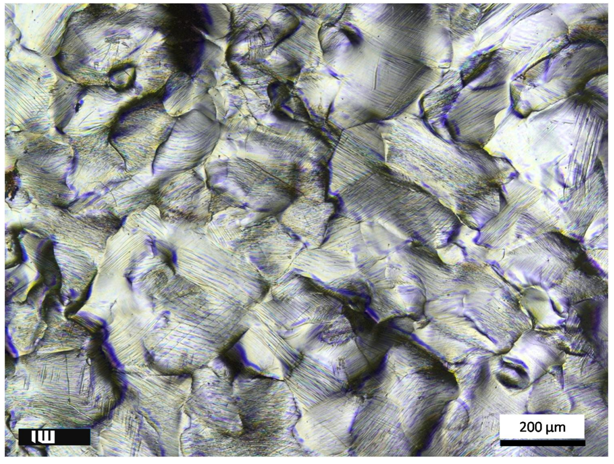


fig. 3.1.4c):
Fe, $1600 \times 1120\,\mu m$
$\varphi_Z = -0.15$**, 86%**

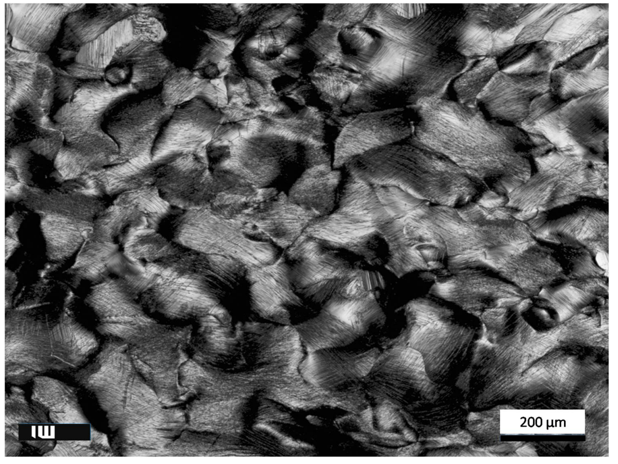


fig. 3.1.4d):
Fe, $1600 \times 1120\,\mu m$
$\varphi_Z = -0.32$**, 73%**

3.2 orientation (example)

Let us start with a simplification:
We construct a „landscape“ which consists of the heights of 30 columns an 20 rows. Here we can find hills and valleys, and we will define an „orientation of a valley“ and the detection of boundaries between different orientations.

3.2 Simplification: landscape with hills and valleys

6	6	5	5	4	4	3	2	0	0	1	2	1	0	0	2	4	6	8	9	9	8	7	5	3	1	0	0	1	2
5	5	4	4	3	3	2	1	0	1	1	2	1	0	0	1	5	7	9	8	7	6	5	3	2	0	1	1	1	2
4	4	4	3	4	3	2	1	0	1	1	2	2	1	0	3	6	9	9	8	7	4	2	0	0	1	2	2	2	3
4	4	4	5	5	4	3	2	0	1	1	2	1	0	2	4	7	9	7	5	3	1	0	0	1	2	3	3	3	4
3	4	5	6	6	5	4	3	0	2	2	1	1	0	2	4	7	9	7	4	2	0	0	1	1	2	3	4	4	5
4	5	6	6	7	7	6	6	5	0	1	2	1	0	3	5	7	9	8	6	4	2	0	1	1	2	3	4	5	6
5	6	8	8	8	8	7	8	8	6	0	1	1	0	2	5	8	9	8	7	5	3	0	1	2	3	4	5	6	7
7	8	9	9	9	9	9	9	9	9	5	0	1	1	0	4	6	9	7	6	4	2	1	0	1	2	3	4	5	6
9	9	8	8	8	9	9	8	8	9	9	4	0	0	0	3	7	9	8	6	5	3	2	0	0	1	2	3	4	5
8	8	7	6	6	7	8	8	7	8	9	9	4	2	0	4	7	9	9	7	6	5	3	1	0	1	2	3	4	5
7	6	5	5	5	6	7	7	7	8	8	9	9	5	2	0	5	7	9	8	7	5	4	2	1	0	1	2	3	3
5	4	2	3	4	3	6	5	6	5	7	8	9	9	6	2	0	2	9	9	8	8	7	5	3	1	0	1	2	2
3	1	0	1	2	1	4	4	5	4	6	7	9	9	6	3	0	0	3	9	8	7	6	5	3	2	1	0	0	0
3	2	1	0	0	1	2	2	3	4	5	7	9	9	7	4	2	0	1	4	9	7	6	6	5	4	3	1	1	1
2	2	1	0	0	0	0	2	3	3	5	7	9	9	7	4	3	2	0	5	9	9	8	7	6	5	4	3	2	2
3	3	2	1	1	1	1	0	1	2	4	6	8	9	9	8	6	4	2	0	4	9	9	8	7	6	5	4	4	3
4	4	3	2	2	1	1	0	2	3	5	7	8	9	9	8	5	3	1	0	2	5	7	9	7	7	7	6	5	5
5	5	4	3	3	2	1	0	1	3	5	7	8	9	9	8	6	4	2	1	0	1	2	8	9	9	8	8	7	8
4	5	5	4	4	2	0	2	3	4	6	7	8	9	9	7	6	5	3	2	1	0	2	5	7	9	9	9	7	7
3	5	7	5	3	1	0	1	3	5	7	8	8	9	9	7	6	5	4	3	2	0	1	3	5	6	7	9	9	8

Tab 3.2.1: **„landscape“, constructed from the heights of 30 columns and 20 rows**

6	6	5	5	4	4	3	2	0	0	1	2	1	0	0	2	4	6	8	9	9	8	7	5	3	1	0	0	1	2
5	5	4	4	3	3	2	1	0	1	1	2	1	0	0	1	5	7	9	8	7	6	5	3	2	0	1	1	1	2
4	4	4	3	4	3	2	1	0	1	1	2	2	1	0	3	6	9	9	8	7	4	2	0	0	1	2	2	2	3
4	4	4	5	5	4	3	2	0	1	1	2	1	0	2	4	7	9	7	5	3	1	0	0	1	2	3	3	3	4
3	4	5	6	6	5	4	3	0	2	2	1	1	0	2	4	7	9	7	4	2	0	0	1	1	2	3	4	4	5
4	5	6	6	7	7	6	6	5	0	1	2	1	0	3	5	7	9	8	6	4	2	0	1	1	2	3	4	5	6
5	6	8	8	8	8	7	8	8	6	0	1	1	0	2	5	8	9	8	7	5	3	0	1	2	3	4	5	6	7
7	8	9	9	9	9	9	9	9	9	5	0	1	1	0	4	6	9	7	6	4	2	1	0	1	2	3	4	5	6
9	9	8	8	8	9	9	8	8	9	9	4	0	0	0	3	7	9	8	6	5	3	2	0	0	1	2	3	4	5
8	8	7	6	6	7	8	8	7	8	9	9	4	2	0	4	7	9	9	7	6	5	3	1	0	1	2	3	4	5
7	6	5	5	5	6	7	7	7	8	8	9	9	5	2	0	5	7	9	8	7	5	4	2	1	0	1	2	3	3
5	4	2	3	4	3	6	5	6	5	7	8	9	9	6	2	0	2	9	9	8	8	7	5	3	1	0	1	2	2
3	1	0	1	2	1	4	4	5	4	6	7	9	9	6	3	0	0	3	9	8	7	6	5	3	2	1	0	0	0
3	2	1	0	0	1	2	2	3	4	5	7	9	9	7	4	2	0	1	4	9	7	6	6	5	4	3	1	1	1
2	2	1	0	0	0	0	2	3	3	5	7	9	9	7	4	3	2	0	5	9	9	8	7	6	5	4	3	2	2
3	3	2	1	1	1	1	0	1	2	4	6	8	9	9	8	6	4	2	0	4	9	9	8	7	6	5	4	4	3
4	4	3	2	2	1	1	0	2	3	5	7	8	9	9	8	5	3	1	0	2	5	7	9	7	7	7	6	5	5
5	5	4	3	3	2	1	0	1	3	5	7	8	9	9	8	6	4	2	1	0	1	2	8	9	9	8	8	7	8
4	5	5	4	4	2	0	2	3	4	6	7	8	9	9	7	6	5	3	2	1	0	2	5	7	9	9	9	7	7
3	5	7	5	3	1	0	1	3	5	7	8	8	9	9	7	6	5	4	3	2	0	1	3	5	6	7	9	9	8

Tab 3.2.2: **„landscape“, constructed from the heights of 30 columns and 20 rows, colored:**

0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9

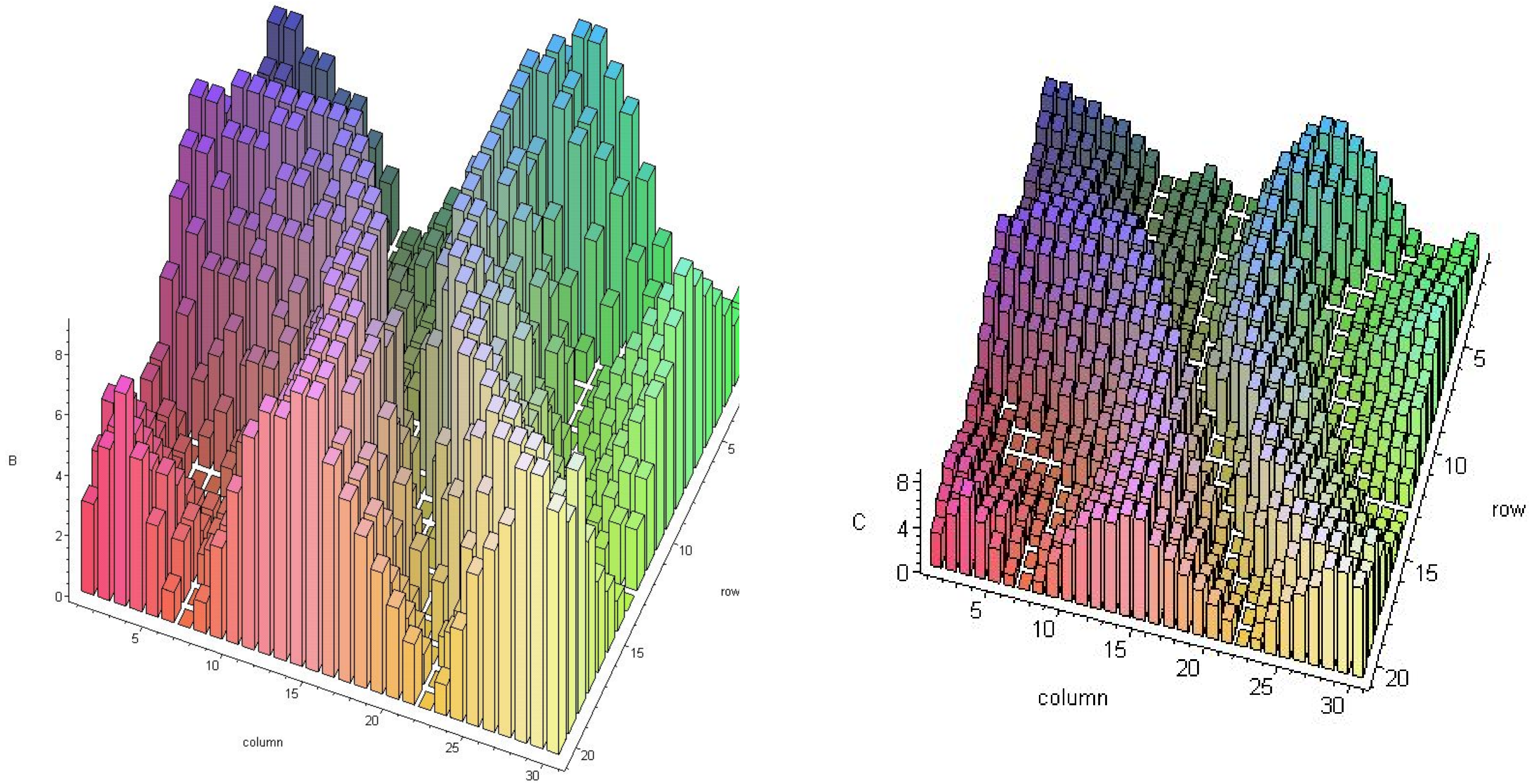


fig. 3.2.1: **„landscape 3D“, constructed from the heights of 30 columns and 20 rows**

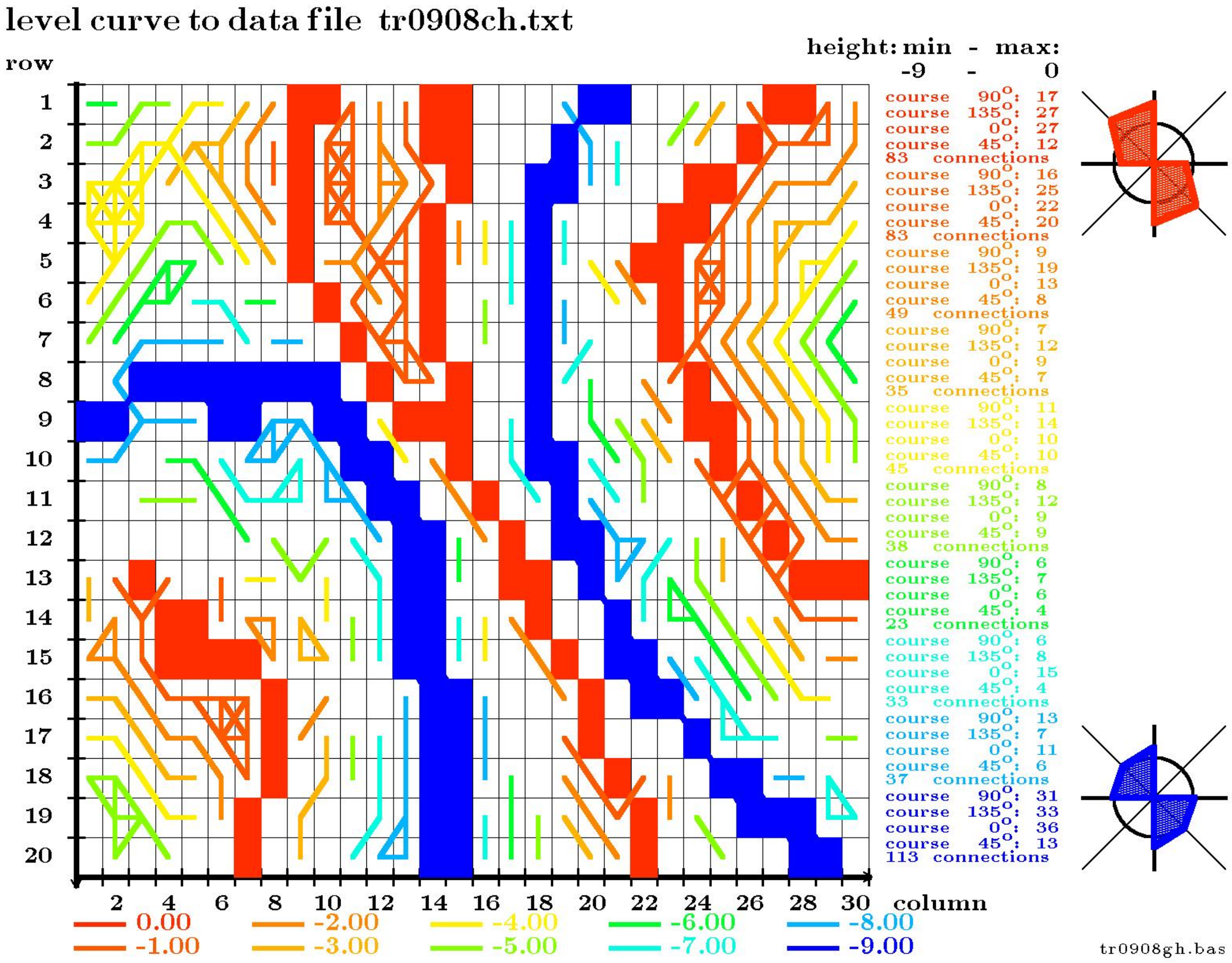


fig 3.2.2: **„landscape“, constructed from the heights of 30 columns and 20 rows**

<u>additional:</u> lines as connection between neighbor-pixels with the same height
<u>for each class of height:</u> number of lines with the same course

3.3 limits of grains

<u>definition 3.3.1:</u> A „landscape $L(s,z)$“ is a rectangle of s columns and z rows, if for each (a,b) with $1 \le a \le s$ and $1 \le b \le z$ there exists a real number $h(a,b) \in \mathbb{R}$ which we will call the „height of the pixel (a,b)“. We look at a „landscape $L(s,z)$“ of s columns and z rows with hills and valleys, and we want to find boundaries of this landscape (or grain).

<u>definition 3.3.2:</u> Let $L(s,z)$ be a landscape and $A = (a_0, b_0) \in L(s,z)$. Then a „rectangle“ $R_{a,b}(A)$ is defined by
$R_{a,b}(A) := \{(x,y)\,,\; a_0 \le x \le a_0 + a$ **and** $\;-b_0 - b \le y \le -b_0\}$,
with $A = (a_0, -b_0)$.

<u>definition 3.3.3:</u> A pixel $p = (x, y) \in R_{a,b}(a_0, b_0)$ with $a_0 < x < a_0 + a$ and $-b_0 - b < y < -b_0$ has the „orientation 0° with respect to a valley“, if the pixel p <u>and</u> the pixel 2 (or the pixel 6) in *fig 3.2.3* have the lowest height of the rectangle $R_{a,b}(A)$.

p has the „orientation 45° with respect to a valley“, if the pixel p <u>and</u> the pixel 3 (or the pixel 7) in *fig 3.2.3* have the lowest height of the rectangle $R_{a,b}(A)$.

p has the „orientation 90° with respect to a valley“, if the pixel p <u>and</u> the pixel 4 (or the pixel 8) in *fig 3.2.3* have the lowest height of the rectangle $R_{a,b}(A)$.

p has the „orientation 135° with respect to a valley“, if the pixel p <u>and</u> the pixel 5 (or the pixel 9) in *fig 3.2.3* have the lowest height of the rectangle $R_{a,b}(A)$.

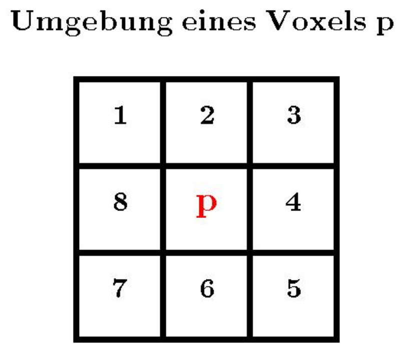


fig 3.3.1: „orientation“

In the same way we define the „orientation 0°“, the „orientation 45°“, the „orientation 90°“ and the „orientation 135°“ „with respect to a hill“.

We want to look for a boundary in our landscape $L := L(30, 20)$ which we used in tab. 3.2.1, tab. 3.2.2 and tab. 3.2.3.
Therefore we start with a rectangle $R := R_{12,10}((1, -1)) \in L(30, 20)$ of 12×10 pixels. Within this rectangle we hope to find one (or more) valleys.

For each pixel $p \in R$ mith the minimal height of L we look for neighbor-pixels of p which have the same height (that means which have minimal height as p).

<u>definition 3.3.4:</u> the „main orientation $\mathcal{O}^v_{a,b}(A)$ of a valley in a rectangle $R_{a,b}(A)$“ is the orientation with respect to a valley of the most pixels of R - or the orientation with the most connections in the lowest height (or deepest valley) in $R_{a,b}(A)$.

In the same way we define

definition 3.3.5: the „main orientation $\mathcal{O}^h_{a,b}(A)$ of a hill in a rectangle $R_{a,b}(A)$" is the orientation with respect of a hill of the most pixels of R - or the orientation with the most connections in the largest height (or highest hill) in $R_{a,b}(A)$.

	1	2	3	4	5	6	7	8	9	10	11	12
1	6	6	5	5	4	4	3	2	0	0	1	2
2	5	5	4	4	3	3	2	1	0	1	1	2
3	4	4	4	3	4	3	2	1	0	1	1	2
4	4	4	4	5	5	4	3	2	0	1	1	2
5	3	4	5	6	6	5	4	3	0	2	2	1
6	4	5	6	6	7	7	6	6	5	0	1	2
7	5	6	8	8	8	8	7	8	8	6	0	1
8	7	8	9	9	9	9	9	9	9	9	5	0
9	9	9	8	8	8	9	9	8	8	9	9	4
10	8	8	7	6	6	7	8	8	7	8	9	9

Tab 3.3.1: **„landscape" $R_{12,10}(A)$ with heights of 12 columns and 10 rows (part of the tab 3.2.2)**
colored:
0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9

From fig. 3.2.3 we get the main orientation at maximal height and at minimal height.

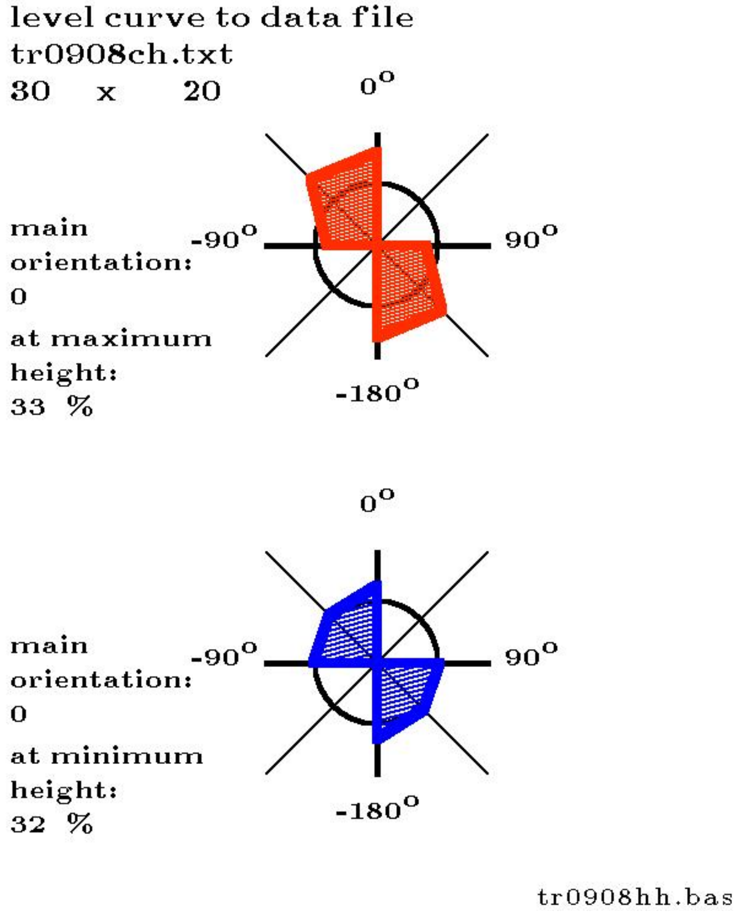


fig. 3.3.2 main orientation

$$\mathcal{O}_{30,20}(A) = 0^\circ$$

3.4 orientation

In a next step we expand our rectangle to $R_{12,10}(A)$ (including the pixel A) and try to determine a criterion for valley-orientation, which is responsible for grain-continuity:

tolerance-criterion

two rectangles $R_{a,b}(A)$ and $R_{c,d}(A)$

„belong to the same grain (or rectangle) with pixel A"

if

$$\mathcal{O}_{a,b}(A) \qquad ? \qquad \mathcal{O}_{c,d}(A)$$

Looking for a tolerance criterion it is necessary to decide if the main orientation

- **of the maximum height, or**
- **of the minimum height**

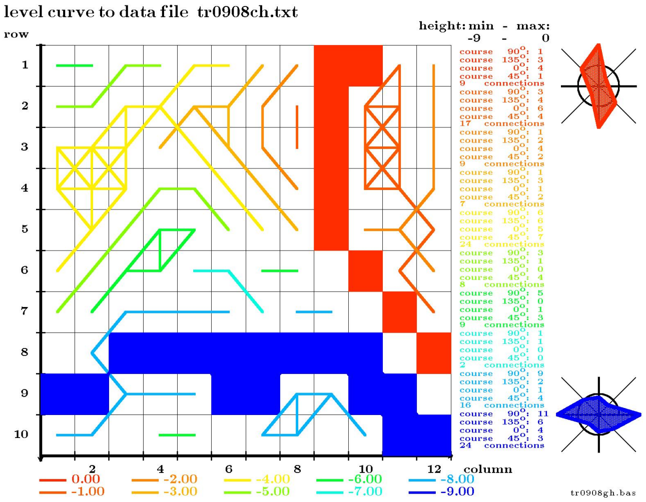
has to be continous. (In *fig. 3.1.2* the minimum height (valleys) has to be contious in a grain.)

Let us decide that we look for the valleys in a rectangle $R_{a,b}(A)$.
Then we look for possible changes of the main orientation when the rectangle $R_{a,b}(A)$ becomes an enlarged rectangle $R_{a+1,b}(A)$ or $R_{a,b+1}(A)$:

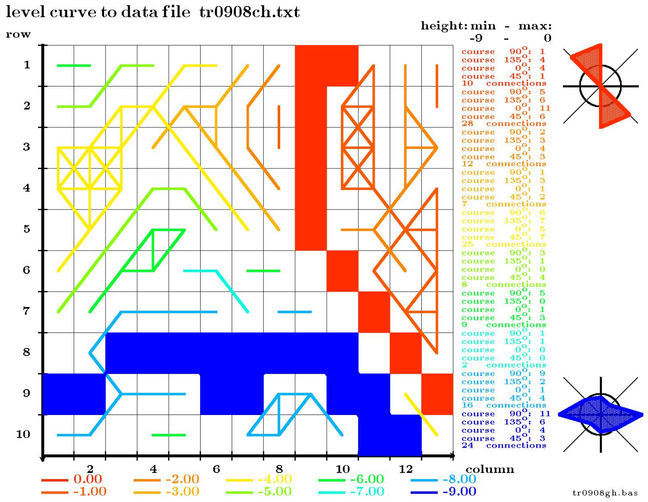
- **If the main orientation from rectangle $R_{a,b}(A)$ changes during horizontal enlarging of the rectangle to $R_{a+1,b}(A)$ (or during vertical enlarging of the rectangle to $R_{a,b+1}(A)$), then we stop the process and start with a new starting point B and a new rectangle $R_{1,1}(B)$.new orientation.**

- **If the main orientation does not change, but if the percentage change**

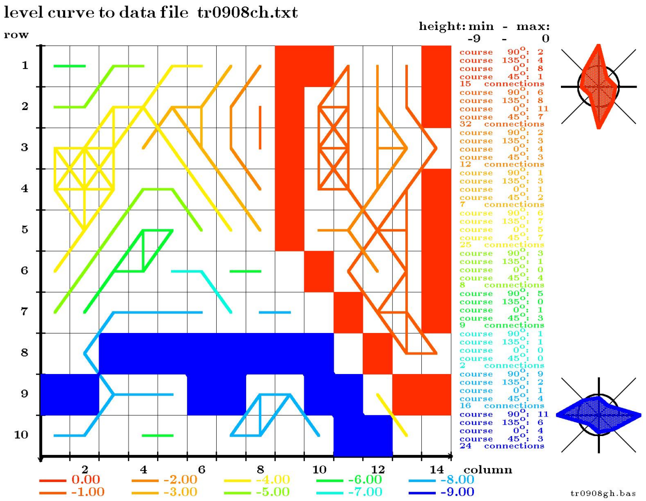
3.4.1 horizontal dilatation



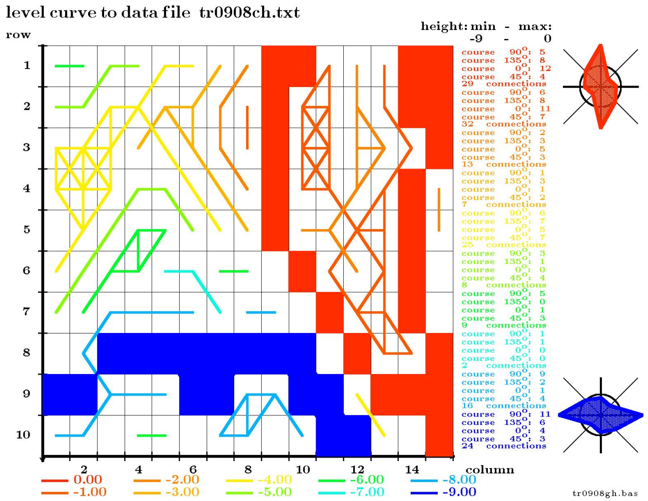
12 $\times$ 10 **units:** $R_{12,10}(A)$



13 $\times$ 10 **units:** $R_{13,10}(A)$

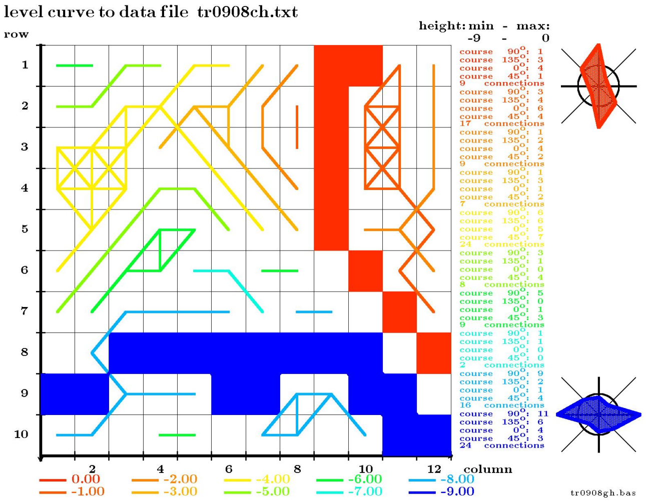


14 $\times$ 10 **units:** $R_{14,10}(A)$

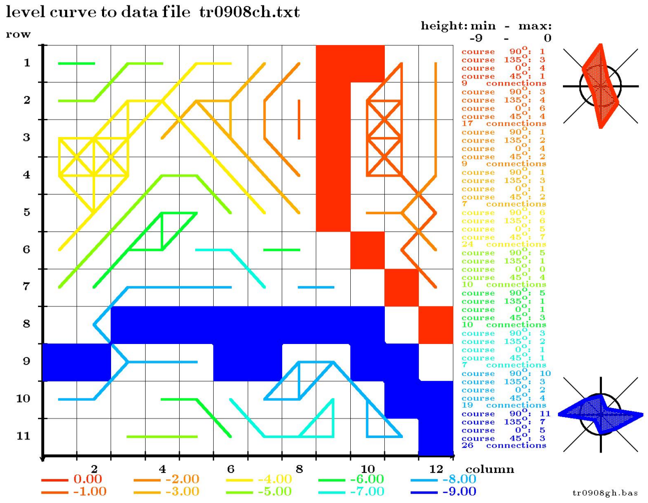


15 $\times$ 10 **units:** $R_{15,10}(A)$

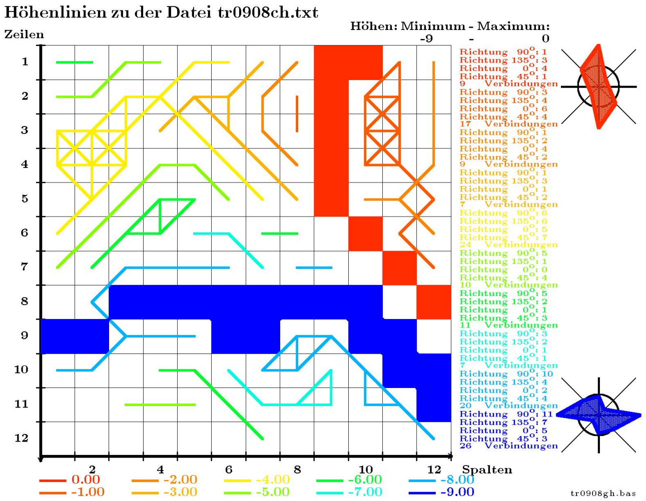
3.4.2 vertical dilatation



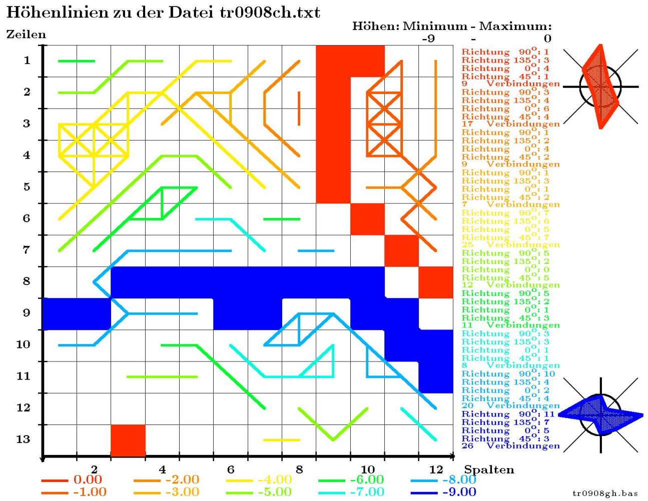
12×10 **units:** $R_{12,10}(A)$



12×11 **units:** $R_{12,11}(A)$



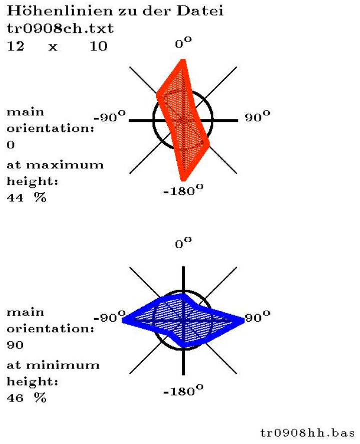
12×12 **units:** $R_{12,12}(A)$



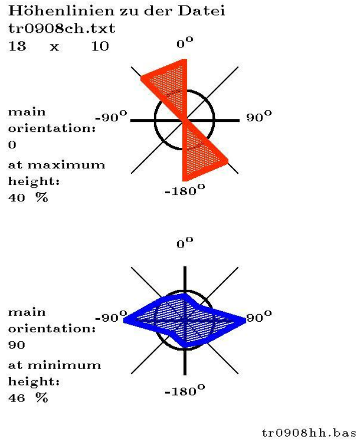
12×13 **units:** $R_{12,13}(A)$

3.4.3 orientations of hills and valleys

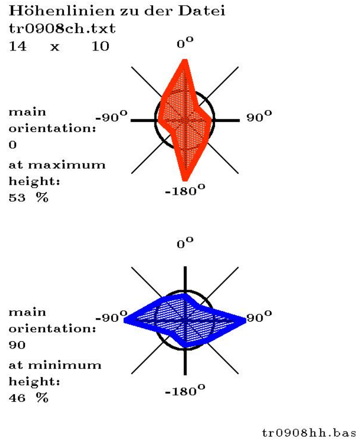
horizontal



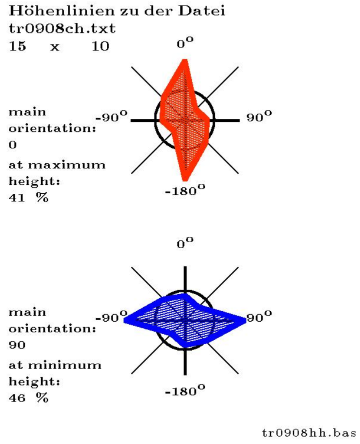
12 × 10 **units**



13 × 10 **units**

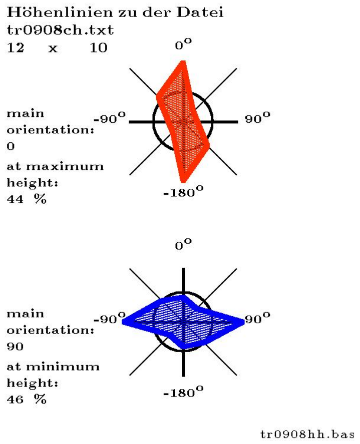


14 × 10 **units**

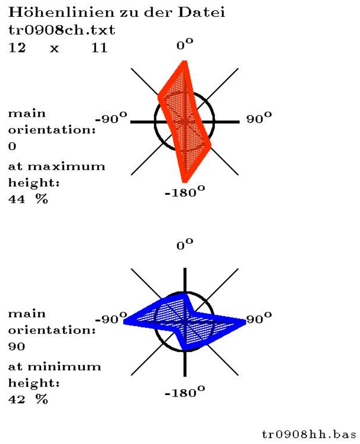


15 × 10 **units**

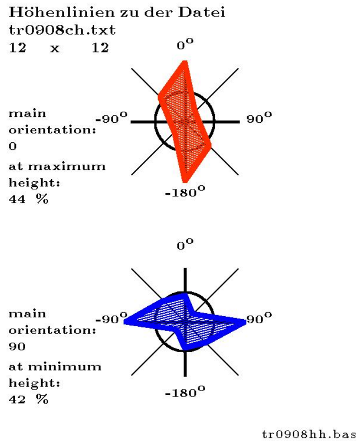
vertical



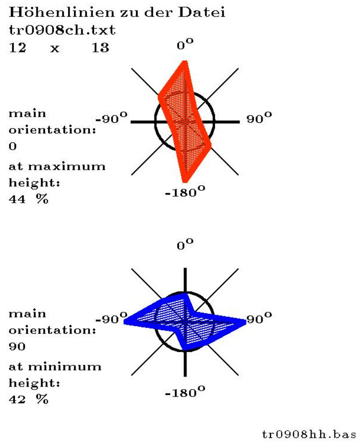
12 × 10 **units**



12 × 11 **units**



12 × 12 **units**



12 × 13 **units**

3.5 laser spectroscopy

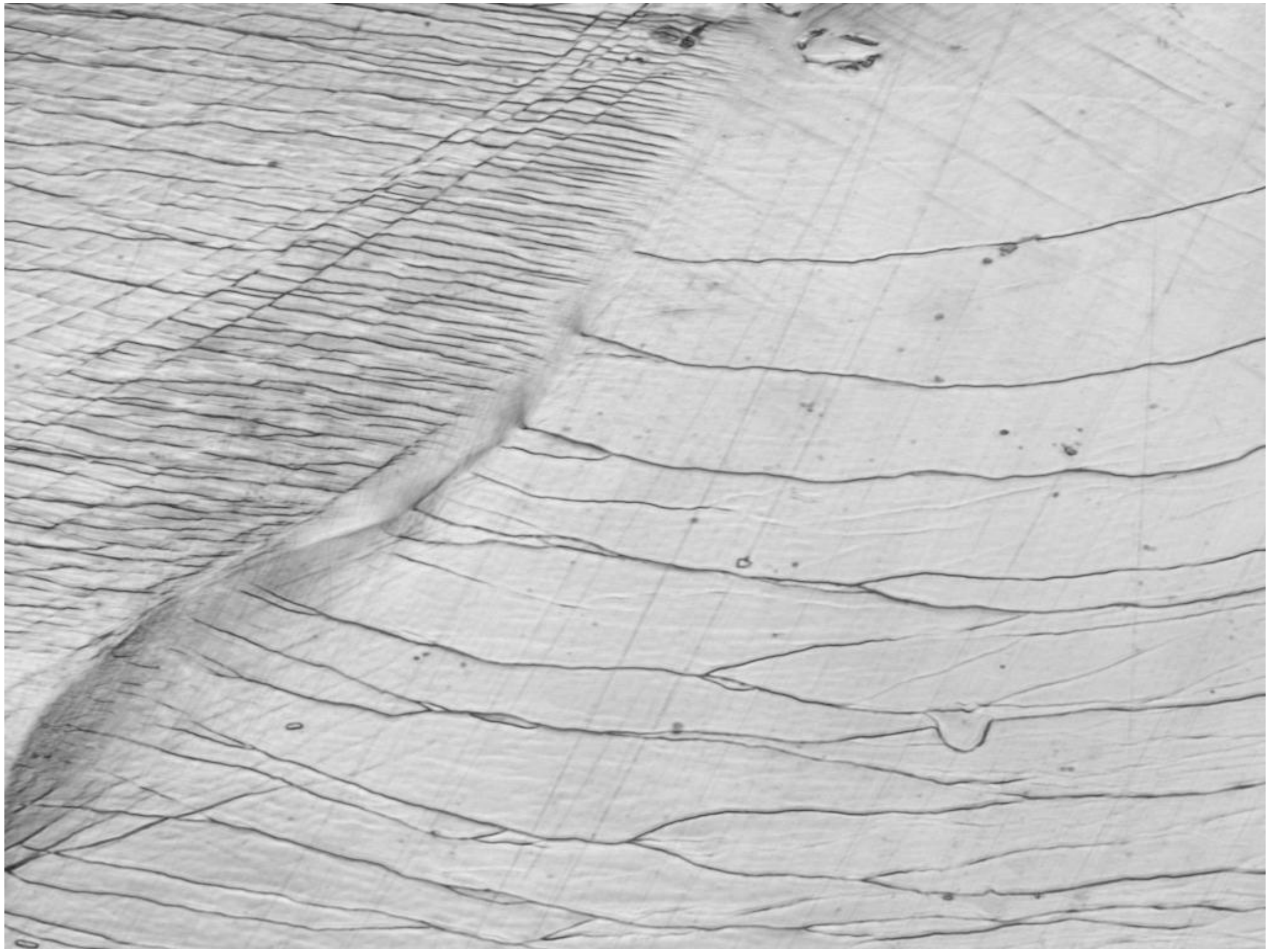


fig 3.1.2: **XY-Calibration:** 2048×1536 **pixels, 71** nm**/pixel. - Z Calibration: 1** nm**/pixel**

korn5x100_shd.jpg

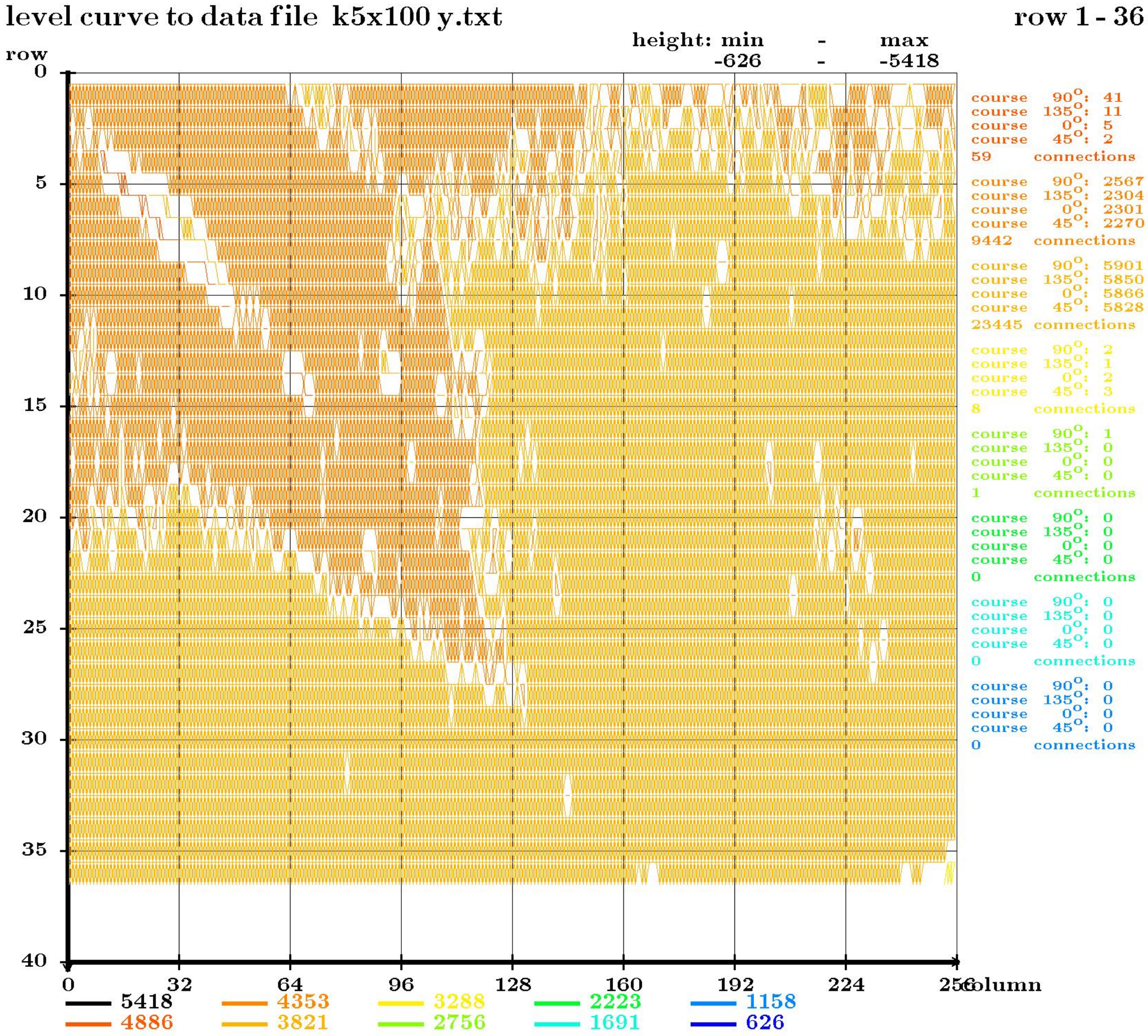


fig 3.3.2: row 1 to 36 from *fig. 3.3.1*

k5x100_1-36.jpg

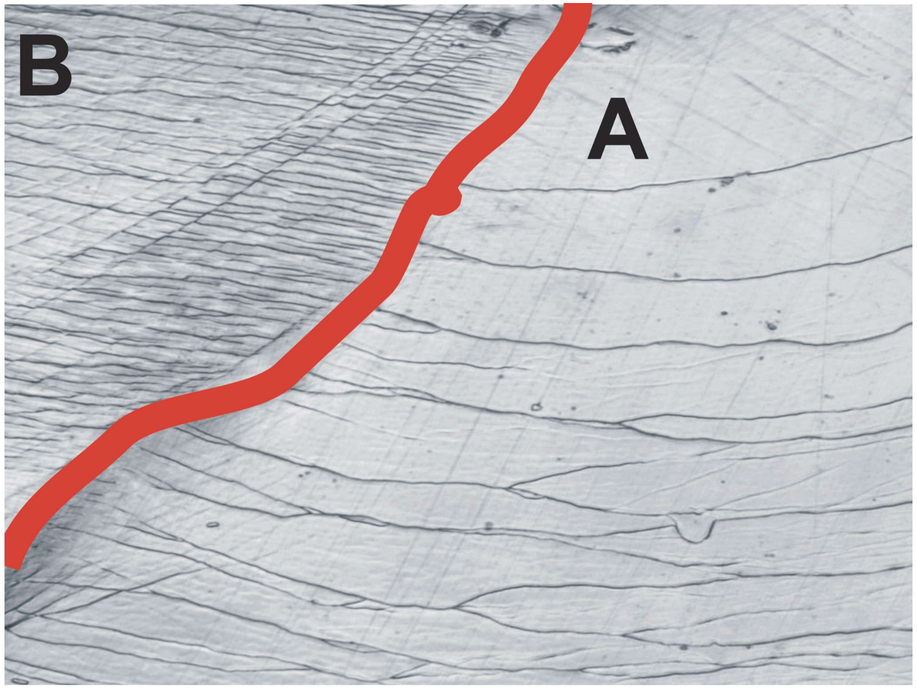


fig. 3.1.2: **Measurement**

korn_T.jpg

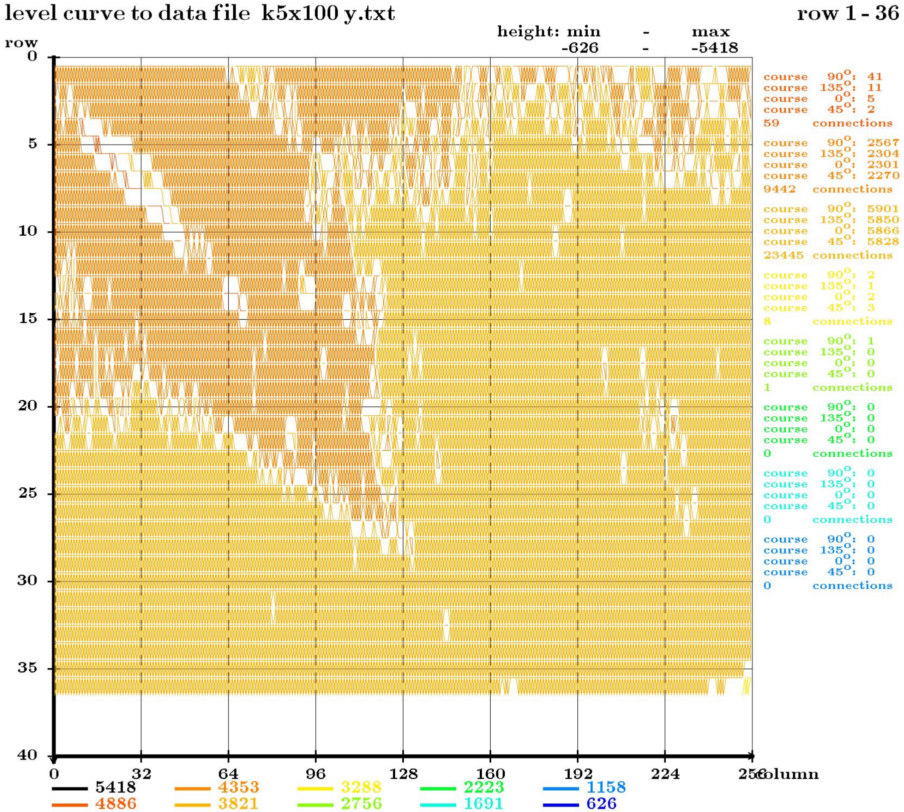


fig 3.3.2: **row 1 to 36 from** ***fig. 3.3.1***

k5x100_1-36.jpg

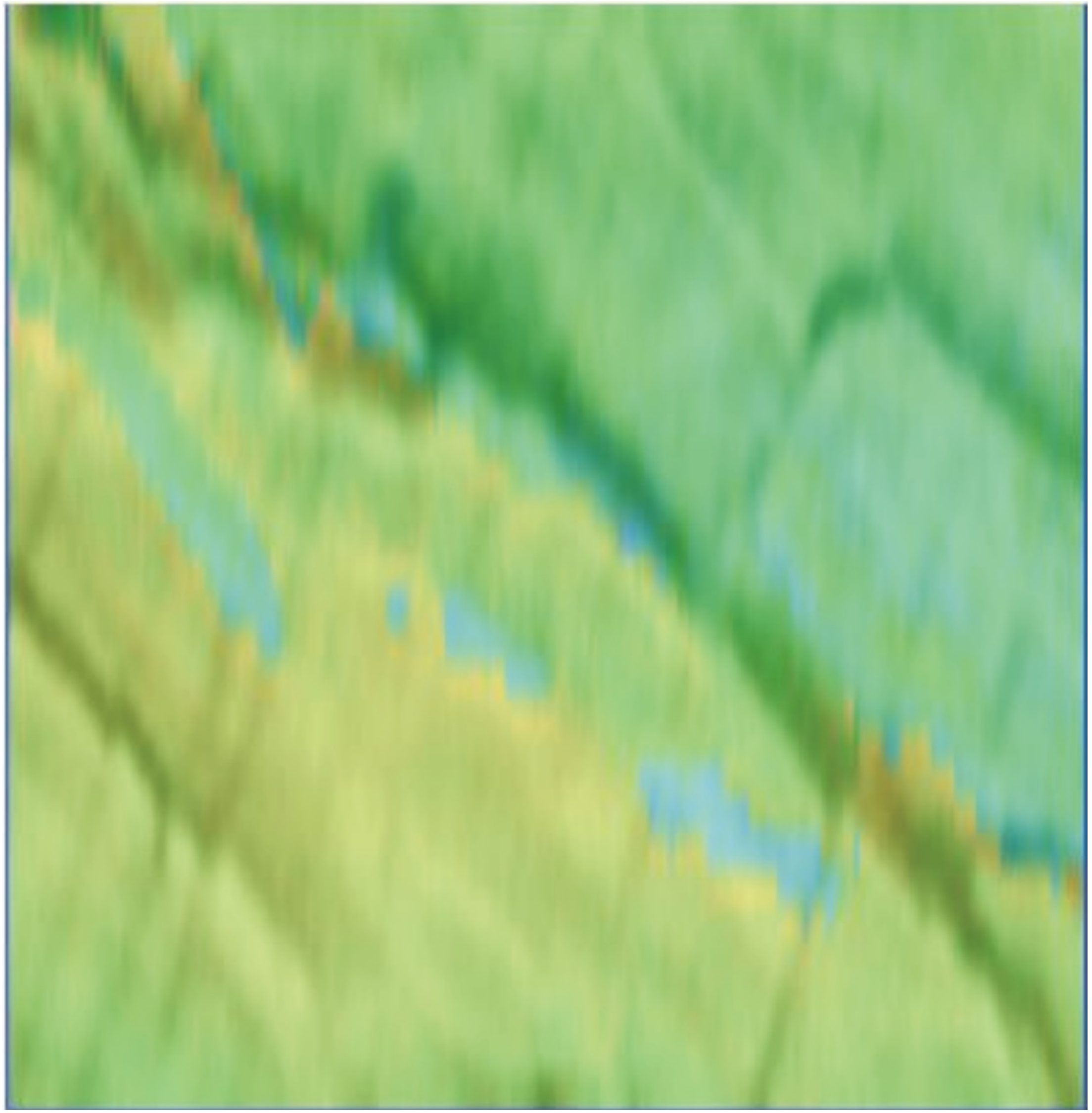


fig 3.3.3: **fig. 3.1.2 and fig. 3.3.2**
korn_1+1.jpg

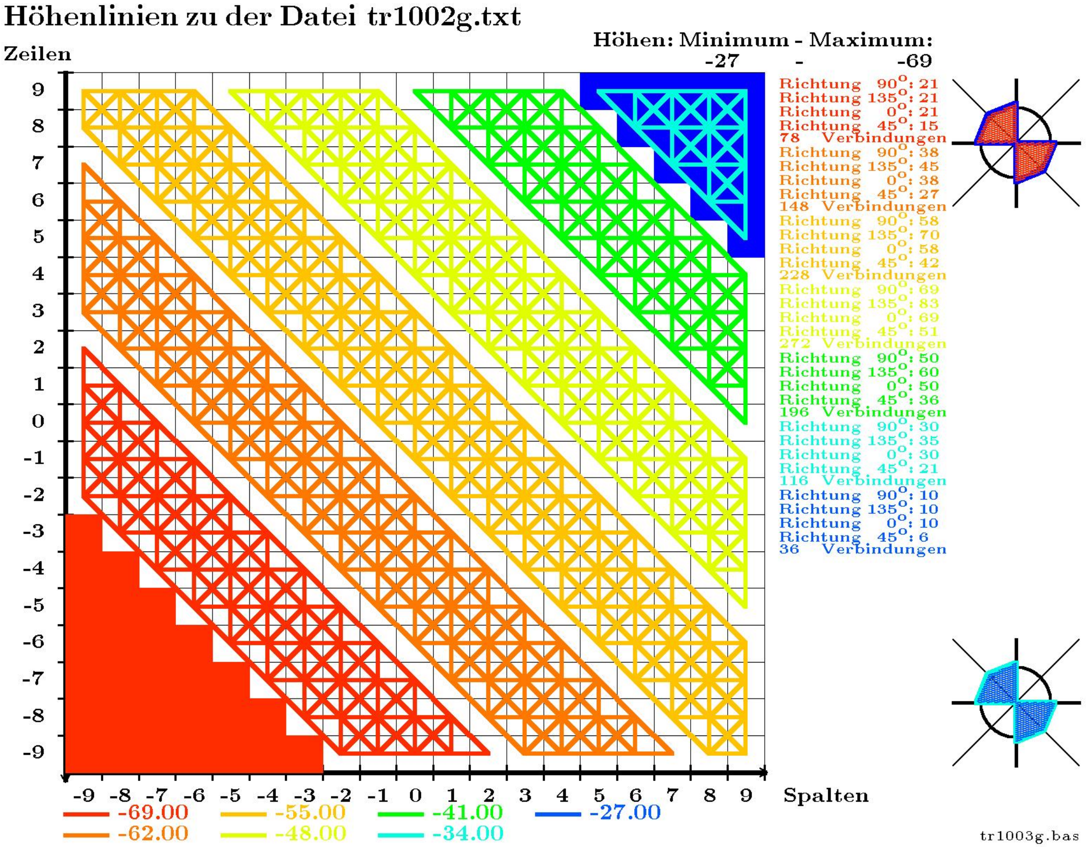


fig 3.4.1:

land3_1.jpg

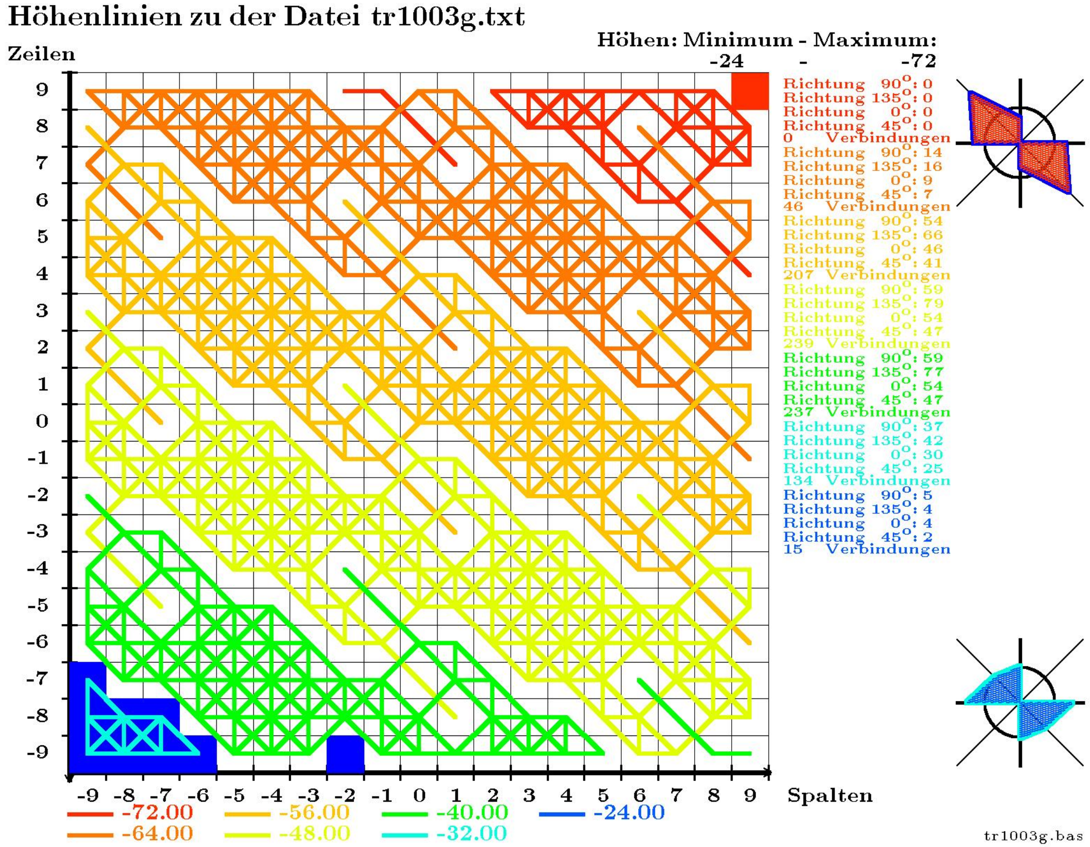


fig 3.4.2:

land3_2.jpg