

ex oriente lux
 after darkness light
 mehr licht
 wer arbeitet verliert die übersicht
 per aspera ad astra

after some time of 'darkness' - this is the 'light'

CALIBRATING

In order to deduce crystallographic orientation - in particular inclination - from images taken on the polarizing microscope under conditions of crossed polarizers with lambda plate and circular polarization (- which can either be true circular polarization, i.e. with 2 quarterwave plates between crossed polarizers, or calculated circular polarization from the superposition of rotated crossed polarized images - the latter being the better if more tedious way - because more precisely achievable in contrast to finding the exact 45° superposition)...

... in order to deduce orientations, five major corrections (or conversions) have to be carried out.

These corrections are due to

1

possible thickness variations of the thin section:

The intensity of polarized light passing through a birefringent material depends on the optical path length, i.e. on the product of refractive index times length of path. i.e. thickness of crystal. In other words, for a given crystallographic orientation w/r to the vibration direction of the light (i.e., the orientation of the polarizers), the intensity of light varies with the thickness (see for example quartz wedge or other compensators, or see Michel Levy Chart)

2

uneven lighting conditions:

one the so-called background - which is due to improper centering of the microscope lamp and condensor (improper Köhler illumination) - and one the so-called flare - which is due to the fact that the incoming light - after having been reflected on the 45 ° mirror - is pre-polarized and hence - if the polarizers are toruned with respect to the light, an intensity difference can be noted. Background corrections can be severe (depending on the care taken while centering the microscope), flare corrections are usually minor.

3

the camera response:

CCDs are usually linear, and when tested actually perform very close to linear. The linearity holds between the recorded gray values or brightness values and the exposure. Now, exposure is the product of intensity times time: $E = I \cdot t$. In order to verify if a given camera works in a linear mode, one best uses a series of images

taken at different exposure times and measures the resulting gray values: GV as $f(t)$ or B as $f(t)$. On a log-log plot - $\log(B)$ versus $\log(t)$ - the lines must be straight and have a slope of 1.00, ... unless, a 'gamma correction' was applied during the recording of the images (if this is the case, turn the 'gamma correction' off, set the camera to linear). In any case, it is advisable to check whether a given camera works in linear mode, and, in particular if this is also true for the nearly monochrome conditions (660, 680 or 700 nm) under which the CIP input images are recorded.

For a given image, time is constant, and selected at a level such that the darkest part (minimum or zero exposure) records as 0 brightness (or 255 density) and the brightest part (maximum exposure) as 255 brightness (or 0 density). In other words the To find the original intensity (I) from the recorded gray values, i.e., from the linear recording of the exposure (E), the brightness values have to be linearized using a log function. When calibrating the camera, i.e., for practical purposes, the log function - $I = \log(B)$ - is usually 'softened' to a function of the form $I = B^n$, where n assumes a value of -2 (square root) to -4.

4

the limits of the intensity histograms:

Ideally, the histogram should start at zero for zero intensity and end at 255 for maximum intensity. But nothing is ideal - histograms have a way of fading out at either end - and therefore we have to select the limits and define which part of the (intensity) histogram we really want to use. Identifying the limits (I_{min} and I_{max}) is often not very difficult - we can also decide that we want to discard a certain percentage - say 1% at either end -, but what to do with the intensities that are outside the limits? Should we set all $I > I_{max}$ to I_{max} and all $I < I_{min}$ to I_{min} ? And thus derive for all $I > I_{max}$ an inclination of 90° and for all $I < I_{min}$ one of 0° ? Obviously, this is not such a good idea, because (a) we would obtain artificially high densities for the 0° and 90° inclinations and (b) any grain lying close to either the periphery or the center of the pole figure would have no internal variations of inclination - and this - we know - is unrealistic.

What to do? The solution is a pragmatic one: the 'excess intensities' are 'mirrored' at the limits (and the tilt index, T_{index} file, is reversed), thus causing the inclinations to be 'wrapped' around the periphery or across the center to the side of the half space. This procedure creates the slightly awkward situation where the c-axes of the brightest grains may not be exactly at the periphery of the polefigure, i.e., parallel to the image plane, instead, they may be pointing slightly above or below. On the other hand, this trick ensures that internal orientation variations of grains with \pm horizontal c-axes are not completely 'flattened', in other words, they are not artificially turned into perfect little single crystals with perfectly parallel c-axes at every point (every pixel)... The absolute inclination may be wrong but the relative internal orientation variations are preserved, and probably very close to being correctly rendered.

5

the inclination - intensity relation:

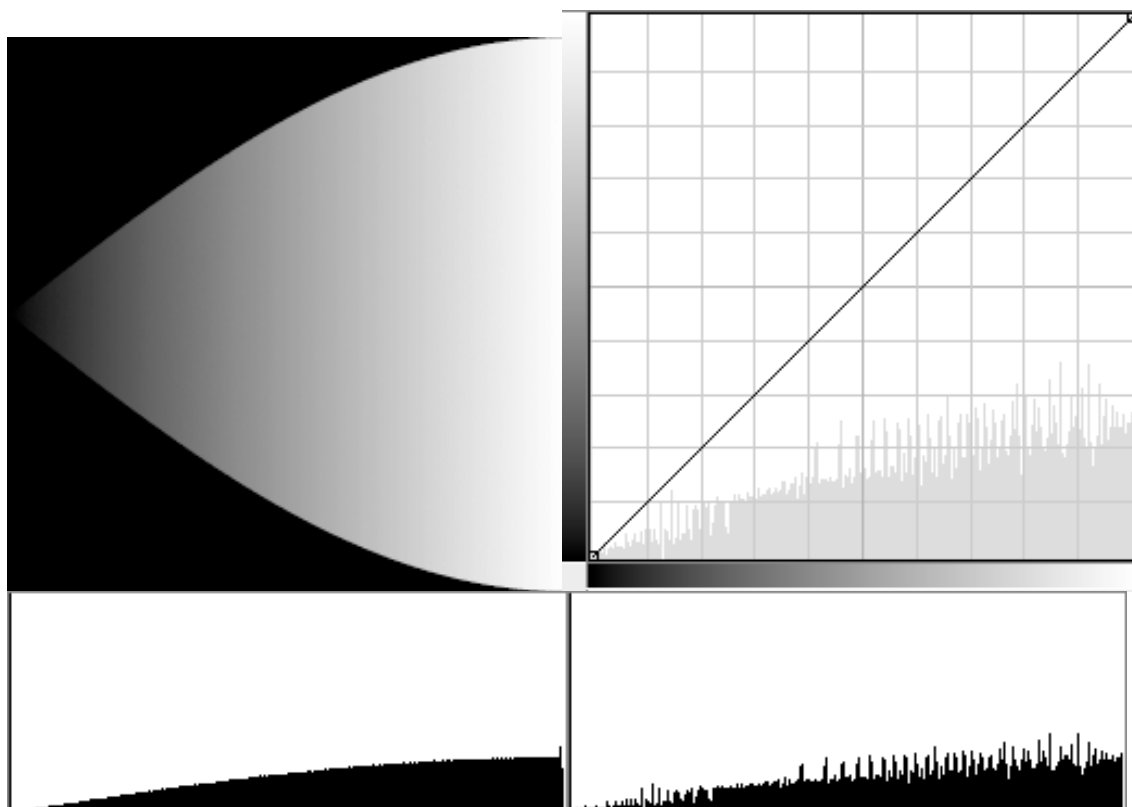
As a first approximation, the the intensity on a circular polarized image, is said to depend as a sine square function on the inclination of the crystal axis w/r to the microscope axis (but I don't remember the reference to this, possibly Burri, 1950 or so). The crystal appears dark if the inclination of the optical axis = 0° (parallel to the

microscope axis) and brightest if the inclination = 90° (in the plane of the thin section). When calculating the exact function, however, one finds that the inclination-intensity function varies with the thickness of the thin section (and the recording wave length). Therefore, to derive the inclinations more precisely, a calculated, thickness-dependent conversion should be used. The preparation of good B-to-INC conversion functions is very difficult because - while the exact function can be calculated more or less easily (from the polstacks),, a practical conversion has to consider the problems associated with the very sensitive dependence of INC on B at the extremes.

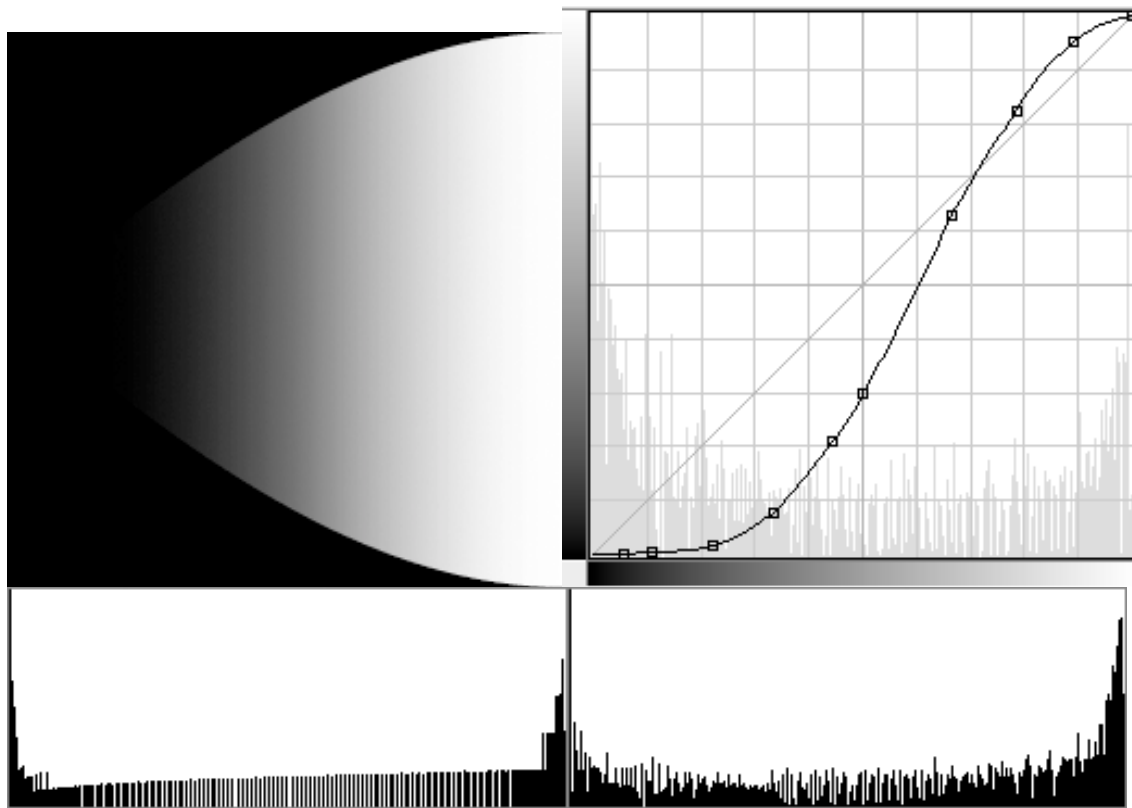
FROM CRYSTALLOGRAPHIC ORIENTATIONS TO GRAYVALUES....

To understand what has been outlined above, we want to go through a forward simulation of how a thin section (with a random texture) is recorded and how crystallographic orientations, in particular, the inclination distribution function (histogram of inclinations) is transformed to a brightness histogram on the cirpol image. We concentrate on the relation between inclinations and the brightness of the circular polarization image because the derivation of azimuths from rotation images presents (almost) no problem.

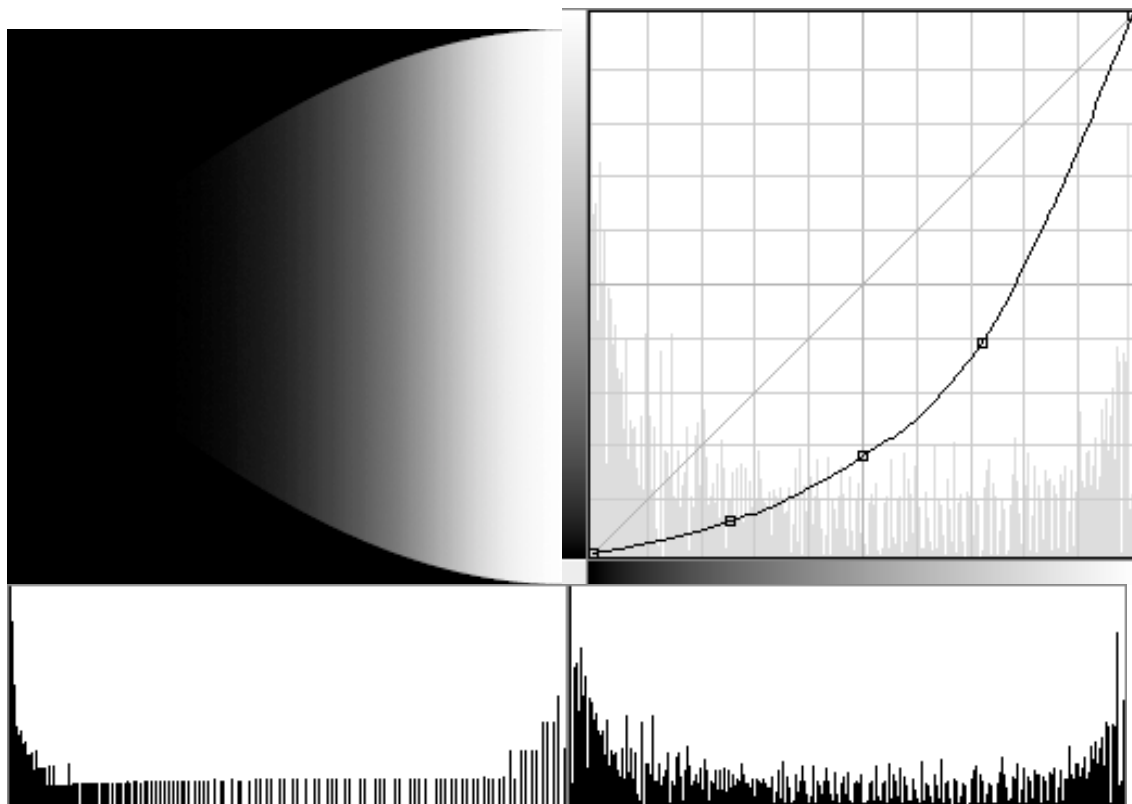
INCLINATIONS OF RANDOM ORIENTATION (SINE FUNCTION)



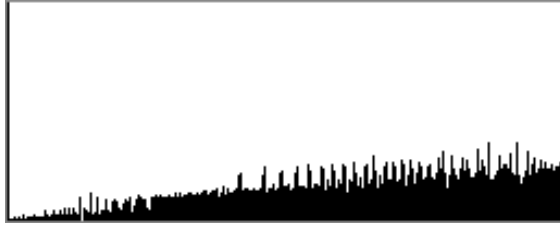
INCLINATIONS TO INTENSITIES



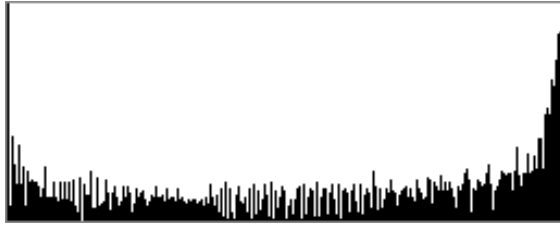
INTENSITIES TO BRIGHTNESS VALUES



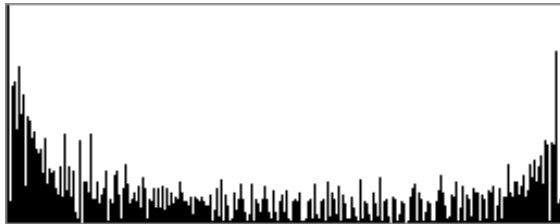
Summary:



inclinations (0 - 90)



intensities (0 - 255)



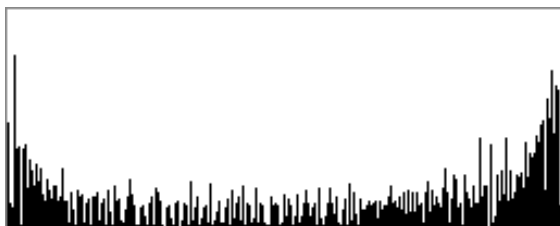
brightness value (B) of recorded brightness

... AND BACK AGAIN

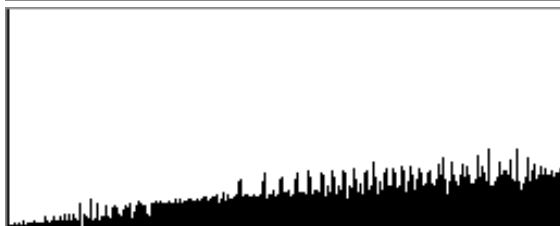
Four basic corrections or conversion have to be performed before the input images can be processed by the CIP program - before gray values can be turned into c-axis orientations.

A practical consideration: Changes in the thickness of the thin section and uneven lighting conditions have to be corrected for each recording individually, however, the camera calibration and the B-to-INC conversion can be prepared in advance.

The final task is to transform from GV of recorded brightness to inclinations



gray value (GV) of recorded brightness



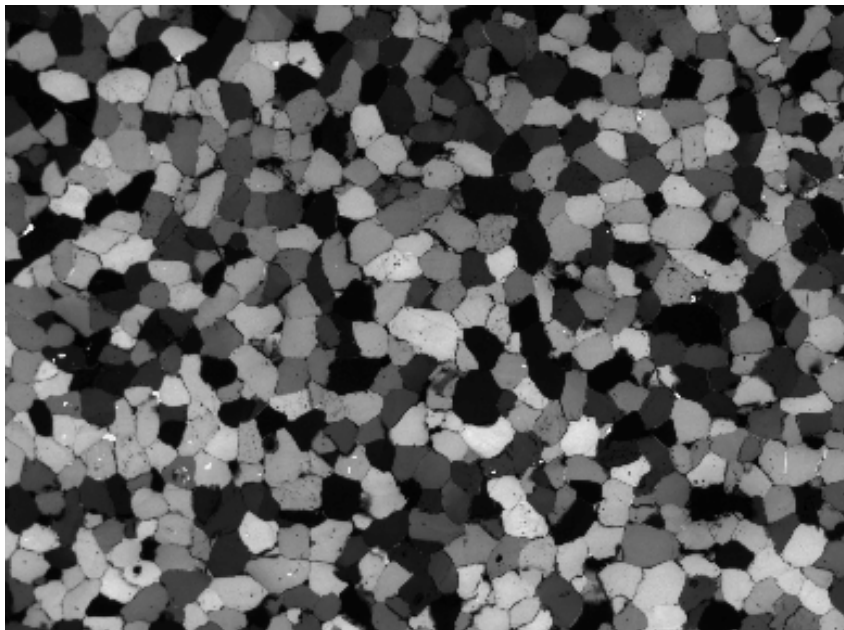
inclinations (0-90)

AND NOW THE WHOLE STORY IN REAL LIFE

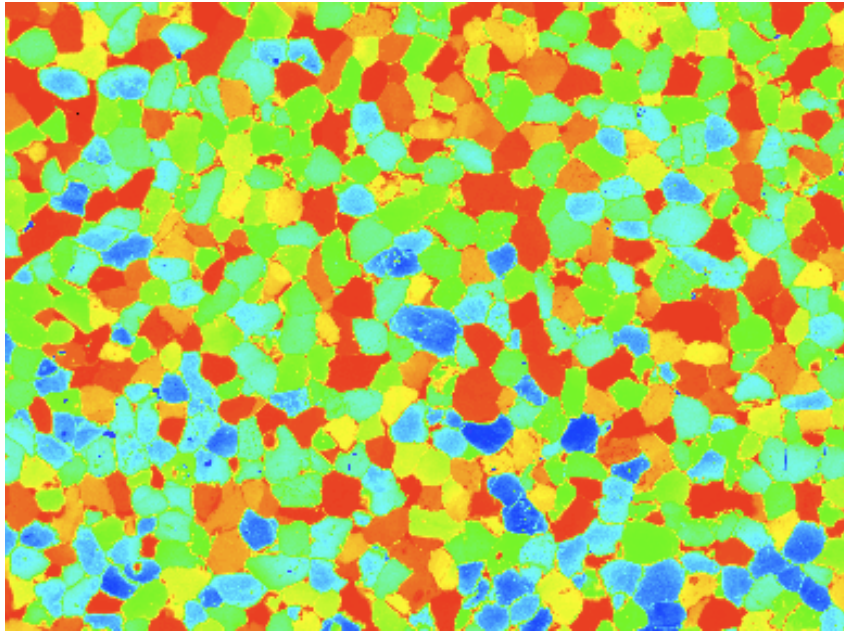
We will use a thin section of Black Hills Quartzite (BHQ) which is texture-free, i.e., which has a random crystallographic orientation. It has been recorded in Image SXM (HALF grabs)- The sample is called bhq5x wombat HALF on account of a grain in the center that looks much like a wombat. The Black Hills quartzite has no texture (that we know of) and therefore the sample is very well used to test the various calibrations and conversions. The aim, obviously, is to create an orientation image that has NO preferred orientation and a polefigure that is homogeneously populated...

1 FROM MOUNTAINS AND VALLEYS TO FLATLAND

Uneven thickness of the section is (... best avoided altogether ... but if unavoidable) best determined by looking at the circular polarization image, using a Rainbow LUT. Thickness changes are not visible in unpolarized images - what may be noted there, are uneven lighting conditions.



circular polarization



+ Rainbow LUT

The section is thickest in the bottom half or bottom right quarter (blue = lower GV = brighter).

In other words we are close to the center of the thin section - slightly above it - , and it is very common that thin sections are thickest in the center with the thickness tapering away towards the edges. The taper depends on the quality the lapping machine and/or the care the technician put into preparing the section.

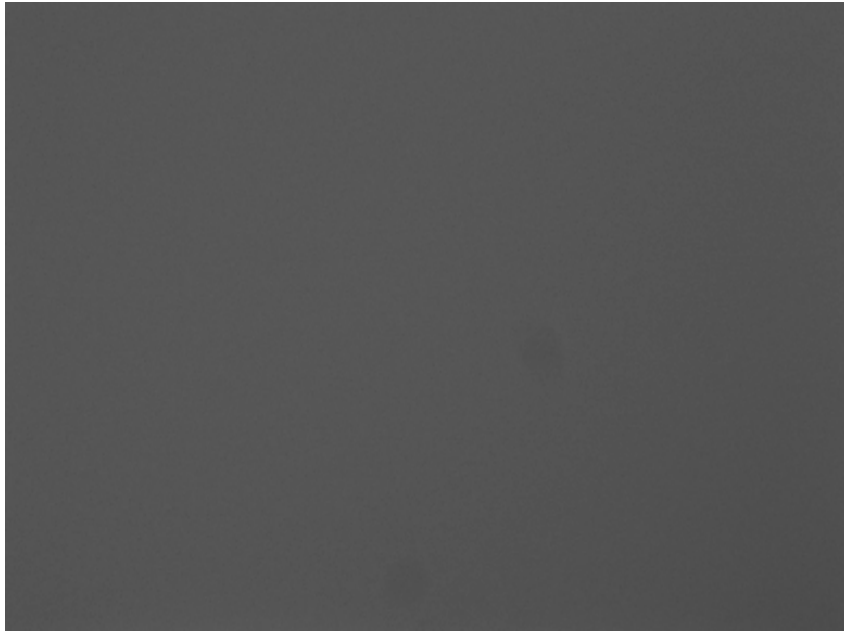
Using the lazy lighting macro, one finds that the upper 1/6 of the image has an average brightness of 181 and the lower 1/6 a mean of 144, the difference being 37 GV, while the left-right difference is $(160 - 167 =)$ 7 GV.

A thickness mask might be a wedge of 37 gray values and used to 'divide out' the thickness

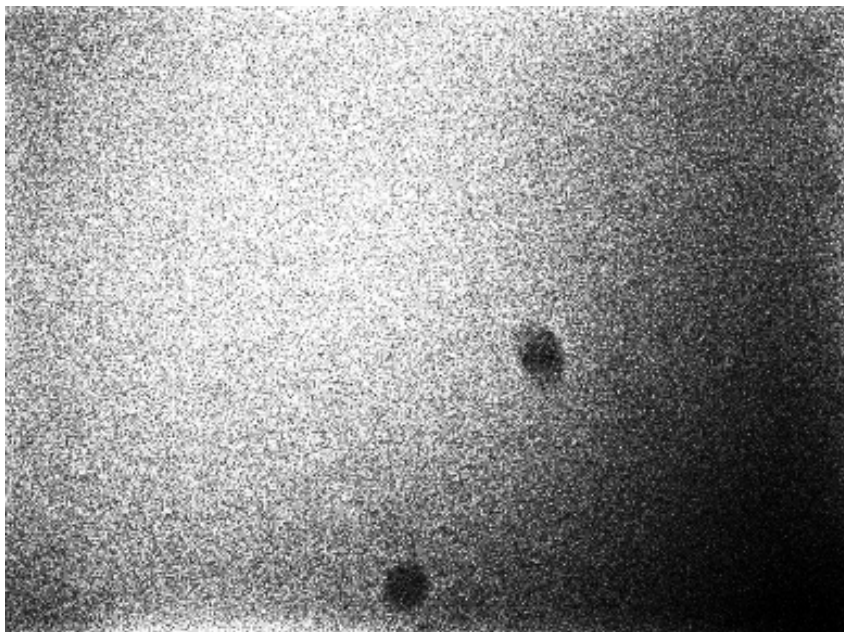
An error is introduced, of course, because the contrast is increased as a result of the numerical operation - not as would be for truly increasing thickness. However, the contrast increases for increasing section thickness and for increasing image brightness, and the difference between the increases may be negligible...

2 FROM CHAOTIC DARKNESS TO EVEN LIGHT

The background - uneven lighting, dirt, smudges, scratches etc. - can be corrected by so-called image flattening, i.e. division of image by background image. The horrible state of affairs is best seen in an equalized version of the image.

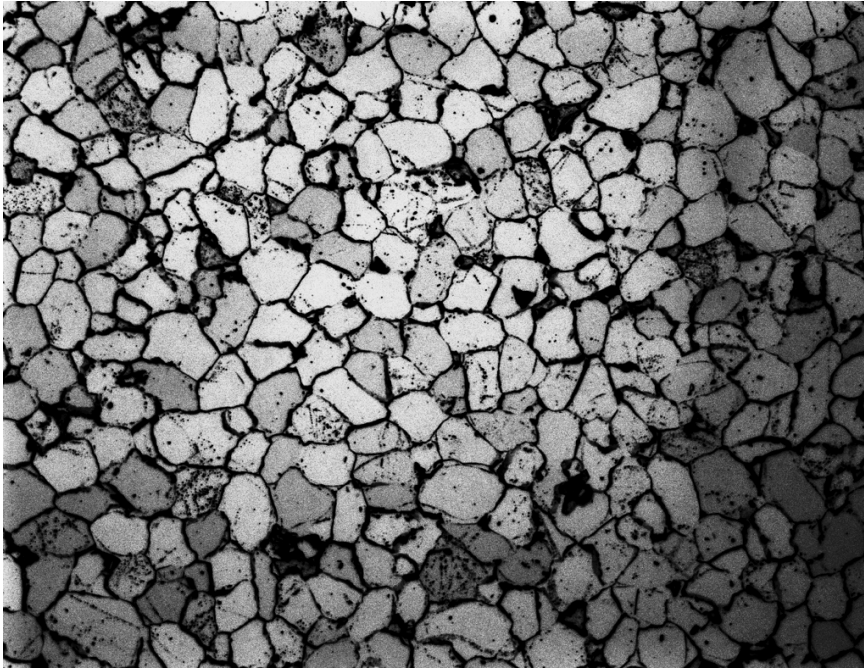


background

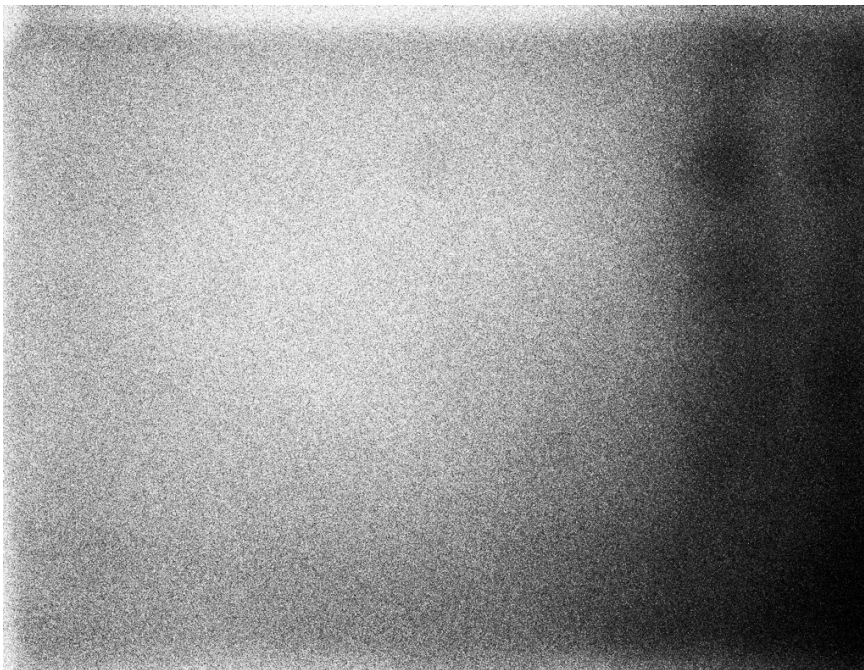


equalized background

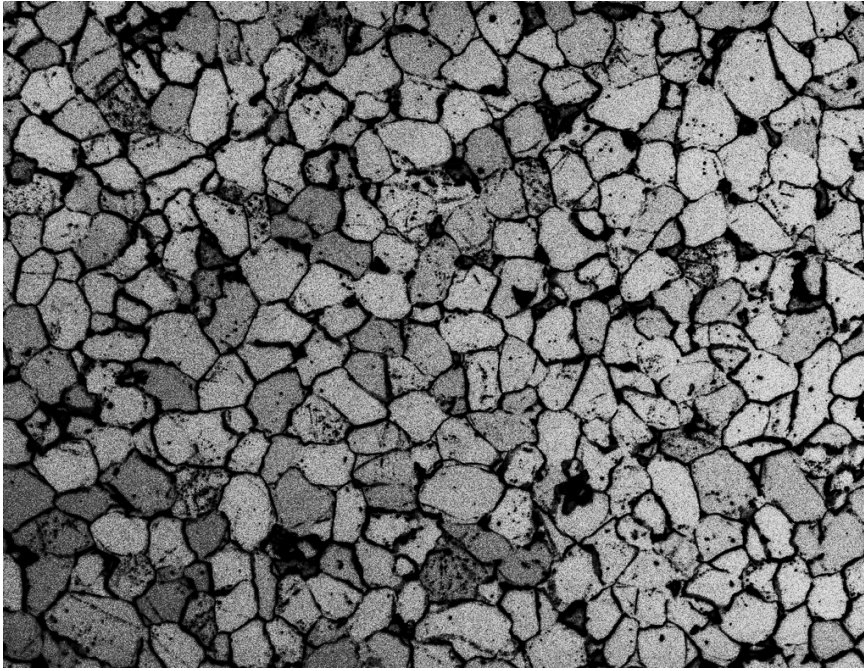
The background correction should be done first.



nopol equalized



background equalized

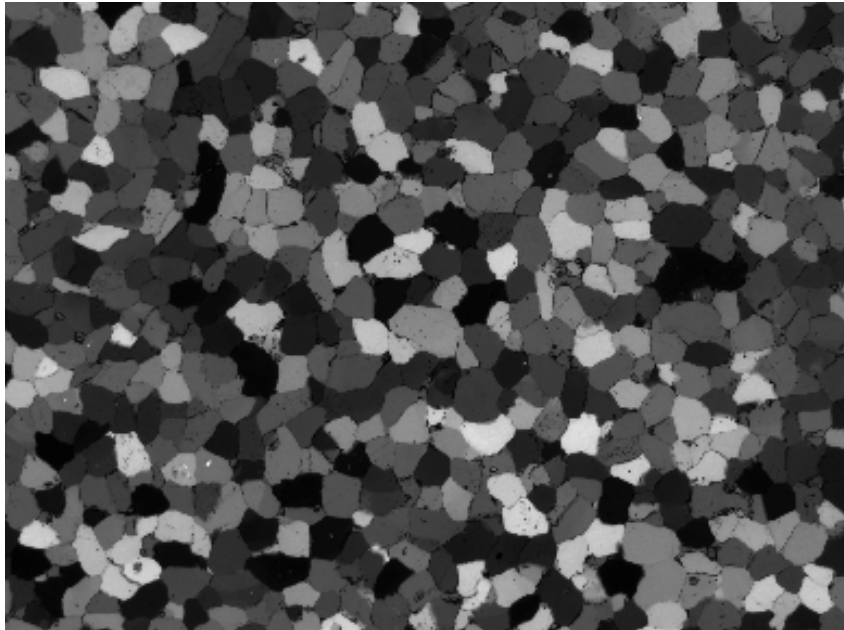


nopol flattened equ.

A second kind of lighting problem may occur if the polarizers and the wave plate are rotated (while the section remains fixed). The resulting (slight) change of overall intensity of the illumination, i.e., the change of incoming intensity, I_0 , is corrected by multiplying the images according to their orientation (azimuth of rotation) by a factor that is proportional to the azimuthal weakening. For historical reasons, this correction is called 'flare correction' because - as in photography - it contributed an overall brightness to the image, i.e., it is not localized such as the background or thickness correction.

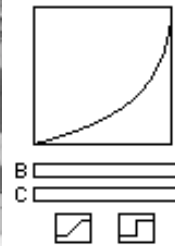
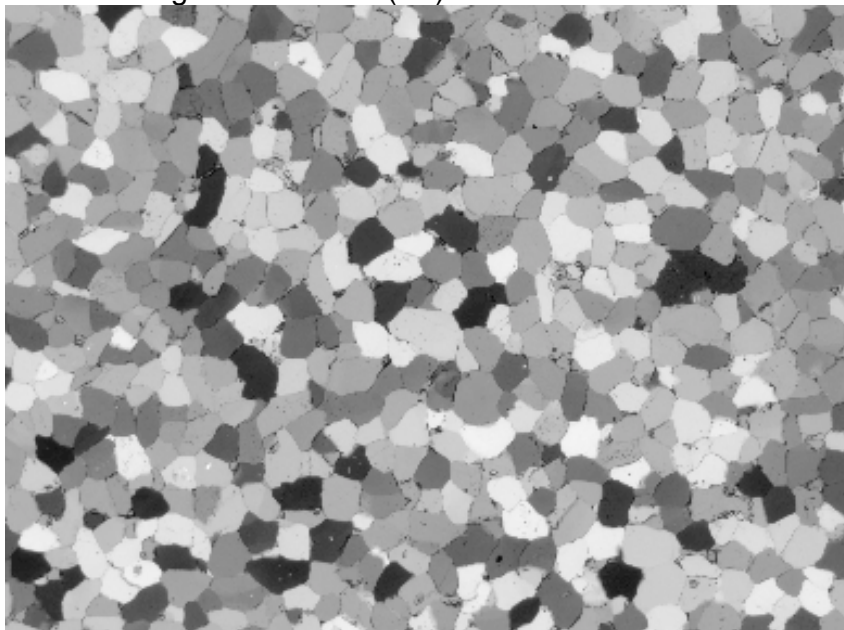
3 FROM BRIGHTNESS TO INTENSITY

The camera correction - it is basically a linearization (slightly adapted to the technical limitations of the camera) and should be called B-to-I conversion - is performed by applying a so-called camera calibration LUT, some form of a log or negative power law. How to best prepare a B-to-I conversion LUT is described in the next section.

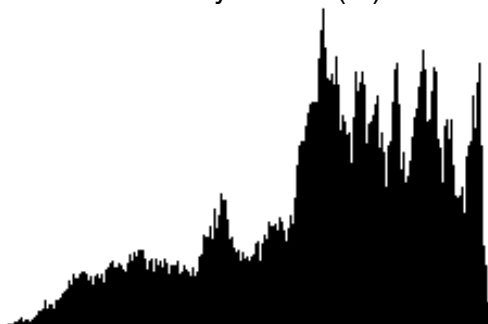


rotation.000

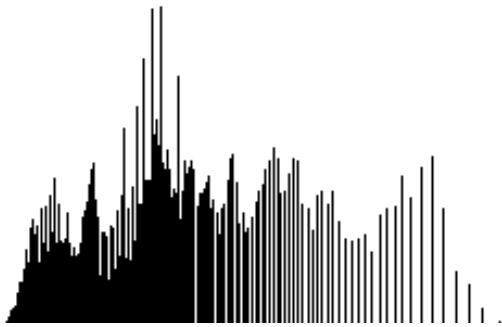
recorded brightness values (B)



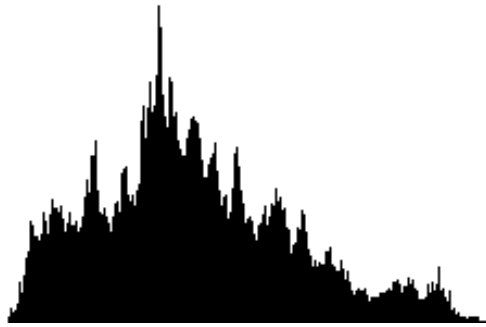
recalculated intensity values (I)



histogram of rotation.000



histogram of corr. (Palette axio-660nm.CAL)

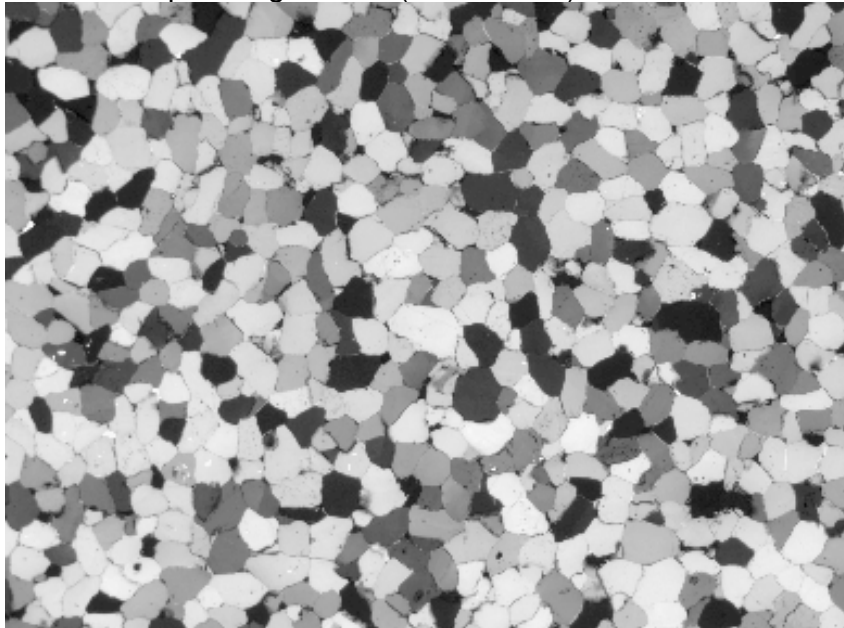


histogramm of corrected after smoothing

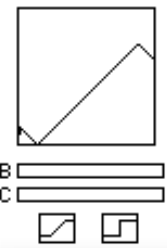
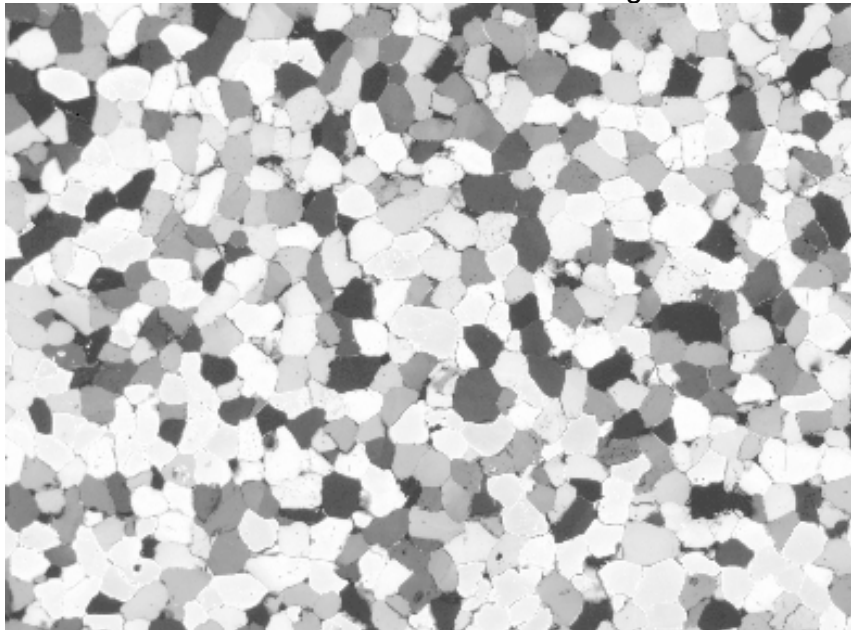
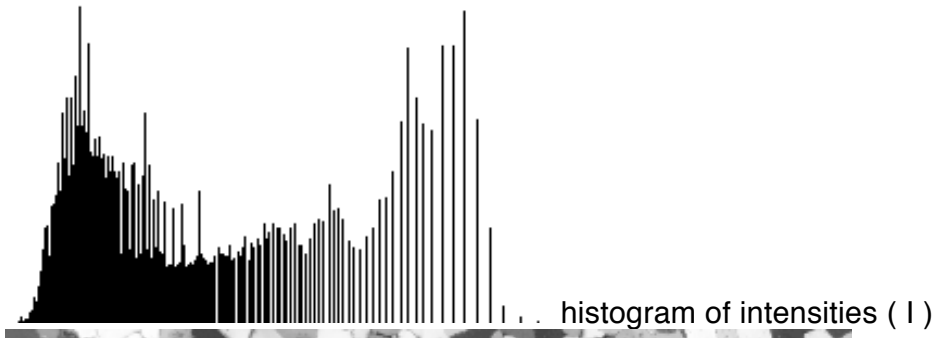
4 CROPPING AND WRAPPING

This step requires some trial and error runs. Whether or not a histogram is correctly cropped is best determined... in hindsight - by examining the pole figure. In other words, it may take a number of rounds of cropping the intensity histogram - calculating the primary inclination (0-90) - calculating the full inclination (0-180) - examining the pole figure - and back to cropping again...

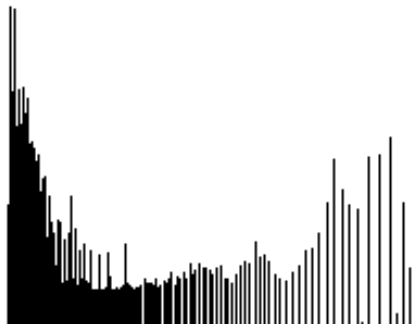
Take the cirpol image of the (texture-free) BHQ:



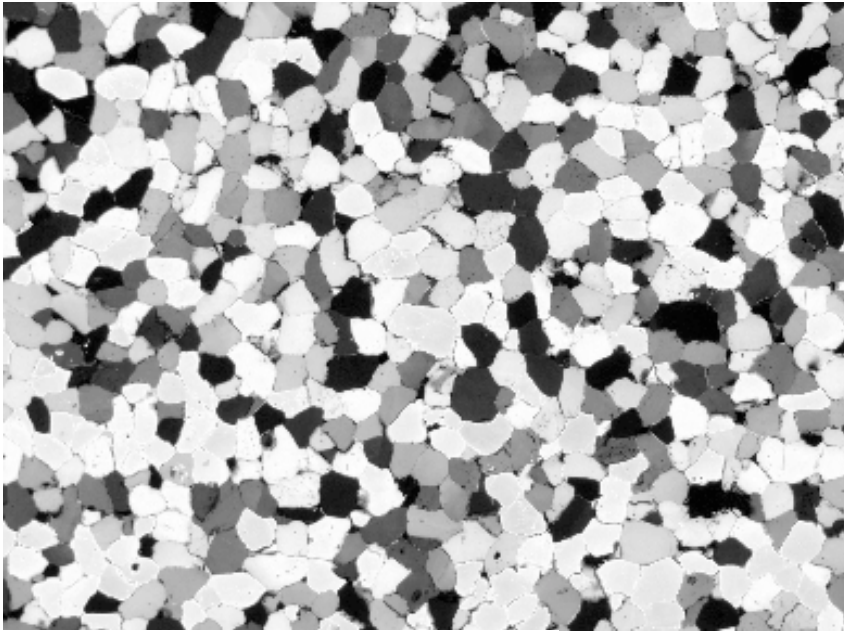
cirpol B-to-I corrected



Select the limits, here: 35 at the lower end (modal valaue) and 222 at upper end:



histogram of cropped / wrapped intensities

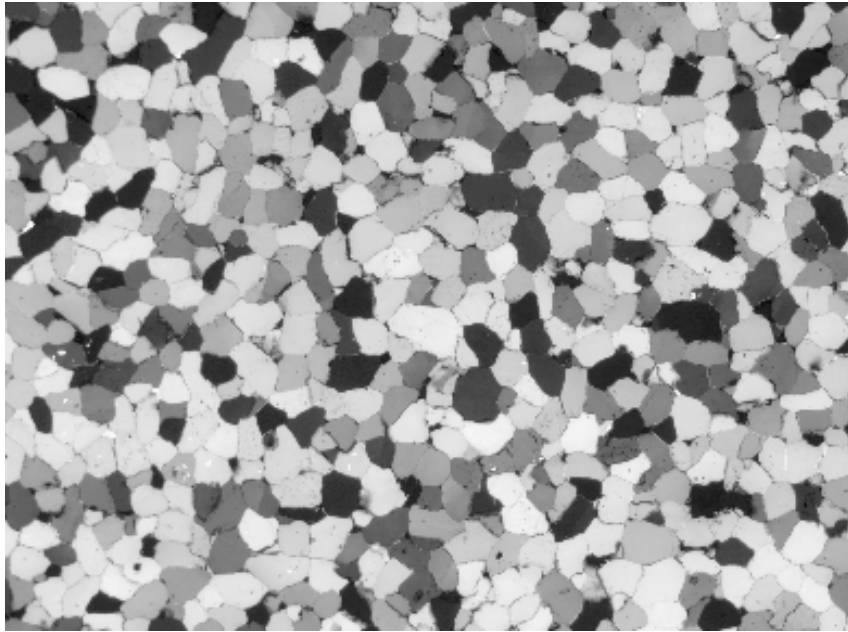


intensities histogram of wrapped and stretched

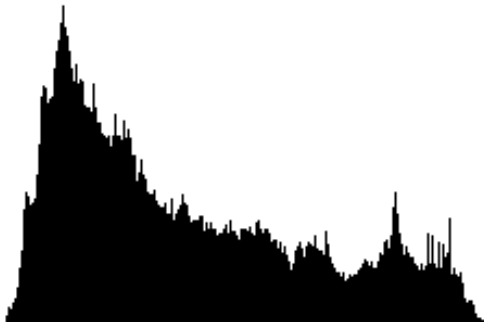
5 FROM INTENSITY TO INCLINATION

The conversion of intensities to inclination is the most difficult. Actually, it is not the conversion that is difficult, but the preparation of a good LUT. How to best prepare a I-to-INC conversion LUT is described in the next section.

Take the cirpol image of the (texture-free) BHQ:

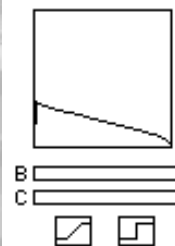
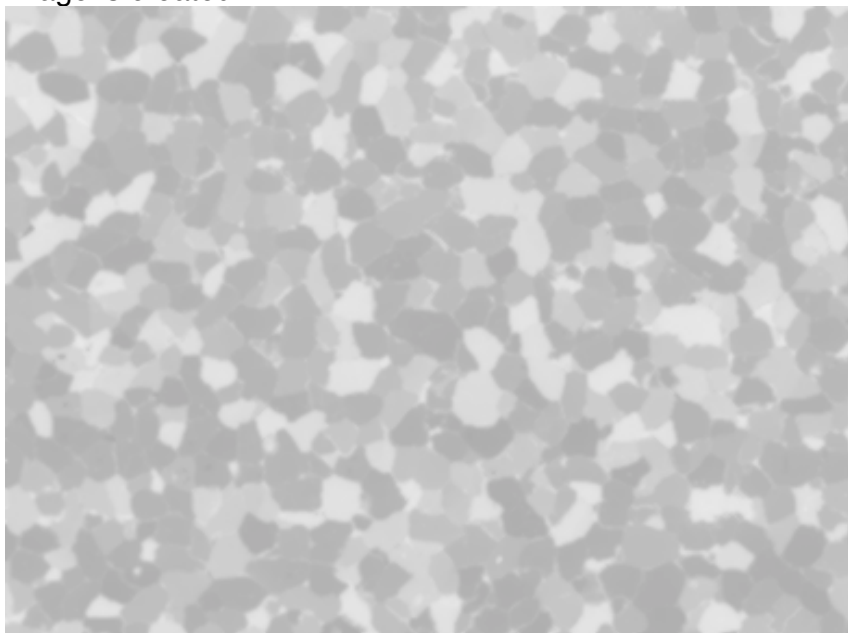


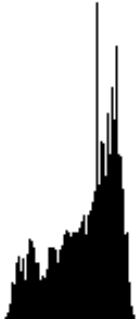
cirpol B-to-I corrected



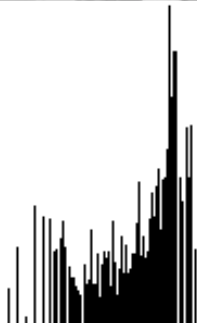
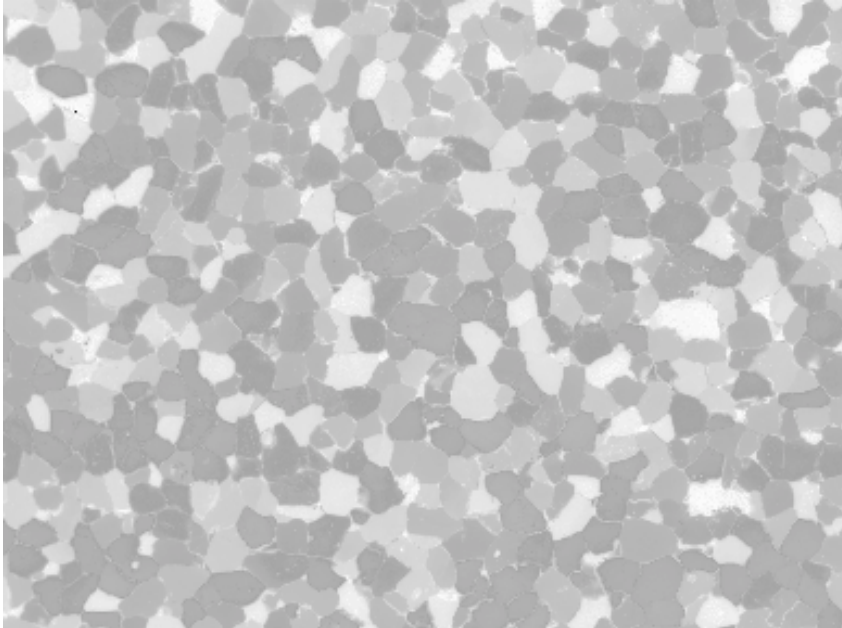
histogram of intensities (I), smoothed

Using the I-to-INC conversion (Palette incl-step-20-GV-90) the following inclination image is created:





histogram INC, from 0 - 90, no wrap



histogram of INC, from 0-90, wrapped intens.

... AND WHAT ABOUT THE AZIMUTH ?

Deriving the azimuth from rotation images is easy in the sense that does not depend on any of the above corrections: given a reasonable clean section and a reasonably even illumination, a maximum brightness (as function of rotation) is always found, even if the B values are un-corrected.

... AND THE TILT IMAGES ?

The determination of the tilt index (see Tindex image in the CIP program) depends

more critically on correctly determined brightness values (remember: the tilt images are used to determine if an axis points above ($0^\circ < \text{INC} < 90^\circ$) or below the image plane ($90^\circ < \text{INC} < 180^\circ$)). However, at any given pixel - where the comparison between the rotation.180 image and the EUP and the SUP tilt images is performed - the lighting conditions etc. are constant for each of these three images. In other words, since the comparison only involves the determination of relative brightness changes, the absolute values need not be precise. Even if they are -locally- all too dark or too bright, the relative changes can still be determined. Much more critical than a correct brightness calibration is a perfect (spatial) matching of the images, making sure that the correct EUP, SUP and rot.180 pixels are compared.

Basel, Feb 22 2011 RH