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Is it relevant to talk about “mountain” and “valley” folds?

David Dureisseix, Jérôme Cavoret
INSA Lyon

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A question of vocabulary

Current codification and vocabulary for origami diagrams often make use of mountain and valley folds. It is a lively description to distinguish the two types of fold (one can switch from one to another while turning over the paper sheet).

This is a mental picture of a landscape model, even for a curved crease. But is it similar for a truly real fold on a real paper sheet? Try to mark a fold, then unfold it: can we classify what is seen into a mountain or a valley? When looking at classical eye distance in the neighboring of the fold, the answer is: yes, especially when using grazing light. Indeed, due to the bending paper elasticity, the residual strain after folding process makes the mountain and the valley visible, Figure 1. But what about the sole fold itself? A closer look is then necessary.

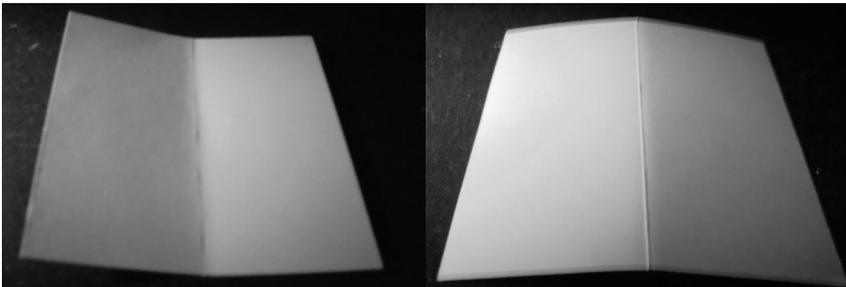


Figure 1. Macroscopic view of and unfolded crease with grazing light (paper edge length is 7 cm).

Let's get close to the fold

For a better view of the question, let us use powerful observation facilities. First, what is within the thickness of the paper? Precise X-rays studies allow to “see” within the paper thickness, but we need a source of X-rays, for instance the ESRF¹ in Grenoble [2], Figure 2.

¹ European Synchrotron Radiation Facility

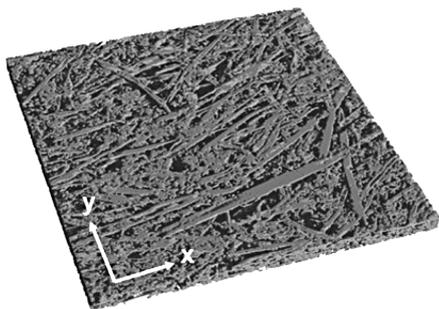


Figure 2. 3D view of a paper sample (the largest edge length is 0.7 mm), after [2], with permission of EDP Sciences

Paper then reveals its components: cellulose fibers, from various wood varieties, with different diameters and lengths, as well as variable proportions of particles. Fibers are mainly arranged parallel to a plane, but are entangled [10].

Concerning the crease itself, an optical view of the surface of the paper, using a Sensofar™ optical profilometer at INSA Lyon, allows to imagine what happened, Figure 3. The folding process may well change the local material state of the paper in the vicinity of the crease. For the selected pictures, the experimental protocol was the following: the paper sheet is folded in half, using the thumb, from the fold center up to the two end points, then again on all its length from one end to the other. Then the sheet is unfolded using a 5 kg roller, then folded again using the same roller.

Even when following carefully this procedure, we never get exactly the same thing each time. An illustration of this variability lies in the stiffness measure of the fold, as in [1], [8]. Nevertheless, qualitatively, the observations may be representative enough, Figure 3.

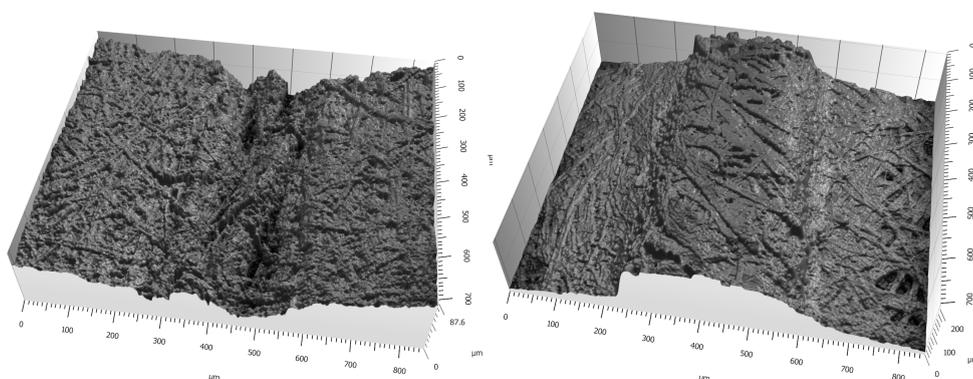


Figure 3. Views from each face of the same paper crease. Left: valley side, right: mountain side (the edge length is 0.7 mm).

We can indeed observe different things depending on the face we look at. For the present case, Arjowiggins Conqueror CX22™ paper, we can also define a fold width: the process zone of folding is 300 microns (0.3 mm), which correspond to about 2.3 times the paper thickness; grammage is 116 grams par meter square, and the mean fiber diameter is 30 microns.

What happens in the crease can have an influence on the complete folding; the mechanics of the material is quite rough in the folding process: fiber reorientation and/or fiber rupture, delamination... as it can be easily seen for the cardboard [6].

Crease mechanics

Even when using classical paper sheets, some differences are observed depending on the kind of paper. Paperfolders know that the color is not the sole criteria for choosing a suited paper to fold. At least, they are also concerned with the grammage (mass per surface unit), and the thickness. But this is often not enough: the composite and multilayer nature, the manufacturing process... have consequences on the paper behavior.

Depending on the profession that uses the paper, other properties are involved, for instance: stiffness, foldability, strength, tearing, shape forming... (packaging, [2], [4], [1], [11]), friction, hygroscopic behavior, dye uptake... (printing, [1], [2]), quality, fragility, aging... (cultural heritage, [5]), biodegradability, recyclability, etc. For industry, there are some standardization issues, as ISO² standards, for instance about water penetration resistance (ISO 5633:1983), foldability (ISO 5626:1993), traction (ISO 1924-x), fracture toughness (ISO 17958:2013), delamination (ISO 16260:2016), tearing resistance (ISO 1974:1990), bursting strength (ISO 2758:2001), and, as mentioned before, grammage and thickness (ISO 536:2012, ISO 534:2011), friction (ISO 15359:1999), roughness (ISO 8791-x), bending stiffness (5628:2019)...

Go for a trek?

So, what about mountains and valleys of origami landscape? This depends on the observation scale: we discover a new world at small scale. From pictures of Figure 3, we may imagine a hill on the mountain side, and meanders that evoke a river within the valley. Therefore, we indeed can talk about mountain and valley folds!

Now, we can wonder about what happens if we cause a change in the landscape: we revert the previous fold (switching between the mountain and valley side). Figure 4 shows that a new prominent bump has been created in the meanders of the previous valley side, and the shape of the previous mountain side has changed. We now see hills on both sides of the paper. Therefore, within the paper thickness, some delamination occurs as an underground cavern in the new landscape. The valley is about to disappear...

We may well imagine that if we continue the fold reversals, we will end up to create a crevasse: the paper is torn. The landscape is therefore not so quiet...

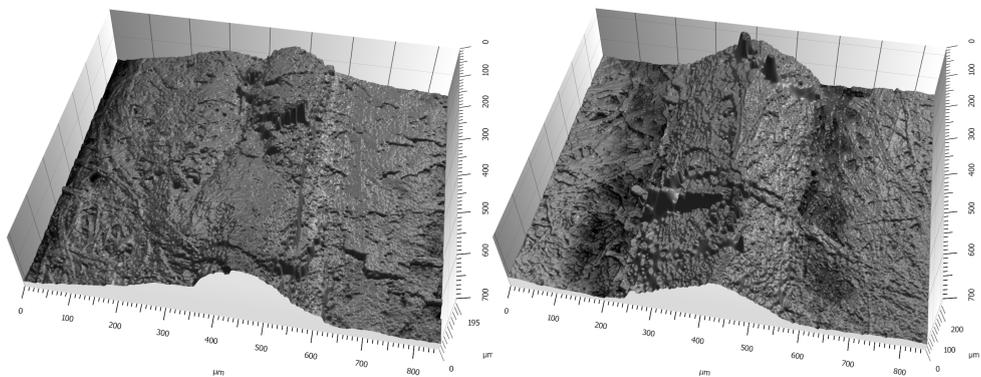


Figure 4. Views of the two sides of the paper, after reversing the previous fold. Left: former valley fold, right: former mountain fold (the paper side length is 0.7 mm).

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² International Organization for Standardization

cf <http://perso.3sr-grenoble.fr/users/jfbloch/> (last access: 2020-01-30)

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