Image processing on meso-scale photographs of brittle shear zones

Poorvi Hebbar[1], Soumyajit Mukherjee[2]*, Narayan Bose[2]

1. Department of Computer Science and Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400 076, Maharashtra, INDIA

2. Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, Mumbai 400 076, Maharashtra, INDIA

***Author for correspondence:** smoumyajitm@gmail.com, smukherjee@iitb.ac.in

Statement: This article *is a non-peer reviewed preprint, submitted to EarthArXi. The article has been submitted to the Journal of Earth System Science for peer review.*

Image processing on meso-scale photographs of brittle shear zones

Poorvi Hebbar[1], Soumyajit Mukherjee[2]*, Narayan Bose[2]

1. Department of Computer Science and Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400 076, Maharashtra, INDIA

2. Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, Mumbai 400 076, Maharashtra, INDIA

***Author for correspondence: smoumyajitm@gmail.com, smukherjee@iitb.ac.in

Abstract

Study of structures and fabrics from different scales of observation is an indispensible first step in structural geology and other branches of geoscience. We process three selected images of brittle shear zones from quartzite, limestone and schist samples using various methods, steps and filters. Such exercises more effectively detect brittle planes when the planes are not too close-spaced and devoid of white fault gouge. Edge detection methods using fuzzy logic seems to be one of the best methods to detect brittle shear planes more distinctly in meso-scale from photographs acquired from ordinary cameras. Notwithstanding, structural geologists' identification and categorization of structures in the field with naked yet *"trained"* eyes or in other scales of observation continues to be indispensible.

Words: 119

Keywords: Image interpretation; mathematical method; shear zone; structures

Highlights:

I. Image processing techniques applied to brittle shear zones photographs, to enhance images
II. Discussion made on usefulness of such exercise in better identification of shear planes

1. Introduction

Correct geological interpretation of structures documented in field or from other scales of observations (Mukherjee 2021) has been of paramount importance in structural geology. Field-sketches were done profusely by the field geologists (Genge 2020) before cameras became handy. Subsequently, with the advent of digital cameras and smart phones (Novakova and Pavlis 2017), photography and other structural geological activities in the field became quite easy. Having a huge space in the electronic device, geologists now take numerous photographs of geological structures. However, after getting back from field, one may note that not all photographs are of good quality, or in few images a very detail of structures are required to be presented. In such cases, geological snaps can be required to undertake image processing. However, if the primary image is poor, chances are that image analysis can help to recover features with a limit (Heilbronner and Barrett 2014). One of the main outcomes of image analysis in structural geology is to enhance the geological feature of key interest (Bjørnerud and Boyer 1996) in an unbiased, reproducible, quantitative and time-saving way (Bons and Jessell 1996).

In applied structural geological contexts, images have been processed for seismic (Misra and Mukherjee 2018), boreholes (e.g., Cornet 2013), microstructures (e.g., Mokhles *et al.* 2019), remote sensing (e.g., Sulaksana and Hamdani 2014) etc. Matlab programme has recently been developed to study fracture patters (Healy *et al.* 2017). Image analyses if done carefully can produce a good number of following outcomes (Bjørnerud and Boyer 1996) calculation of object areas, perimeters/lengths, color/grayscale magnitudes, and for lenticular objects- axial lengths, orientations, *x*-*y* centers, point-counting, strain analysis, areal estimation and assessment of lattice and grain-shape preferred orientation.

This work first time applies several standard image processing methods on structural geological images take from meso-scale. These methods are image segmentation, fuzzy logic image processing, bilateral filtering and comparison amongst various fracture detection filter techniques. We finally compare different methods/techniques and comment on the practice to get the best possible interpretation of geological photographs. Specifically speaking, photographs of brittle sheared rocks were analyzes. The aim was to identify the brittle shear planes correctly that can lead to correct interpretation of shear sense. The aim is important in structural geology since, incorrect interpretation of shear sense can lead to misleading tectonic models (review in Dutta and Mukherjee 2019). Fig. 1 presents the brittle shear plane terminologies well established in structural geology.

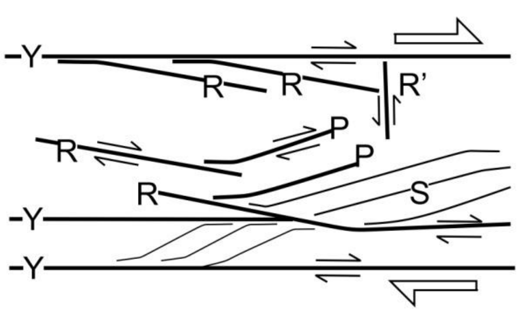

Fig. 1. *Brittle shear plane nomenclature (reproduced from fig. 5.34 of Passchier and Trouw 1996).*

2. Scope of work

2.1. Samples and Photography:

Three images (Figs. 2a, 3a, 4a) of brittle shear zones with Y- and P-planes developed in different degrees were processed by standard techniques. These photographs were captured using a *Canon PowerShot SX150 IS* digital camera, and they come from the Inner Lesser Himalaya along the Bhagirathi river section, Uttarakhand, western Himalaya, India. Low-grade meta-sedimentary rocks, mostly quartzites (Fig. 2a) and low-grade metamorphosed limestones (Figs. 3a, 4a) and thinly layered schists are present along this traverse. Detail of structural geology of the location can be found in Bose *et al.* (2018), Bose and Mukherjee (2019), Biswas and Mukherjee (2022) and Biswas et al. (2022). Sigmoid P-planes are bound by Y-planes were found from these images in naked eyes, and in the field a top-to-N/NE back-shear is indicated. The timing of this specific deformation from this Himalayan section has remained unknown till date. Shear zones observed in (sub)vertical natural rock sections were photographed within around 11 a.m. to 02 p.m., i.e. when maximum sun light is available. Rock sections perpendicular to the primary shear Y-planes and parallel to the dip direction of such planes were photographed.

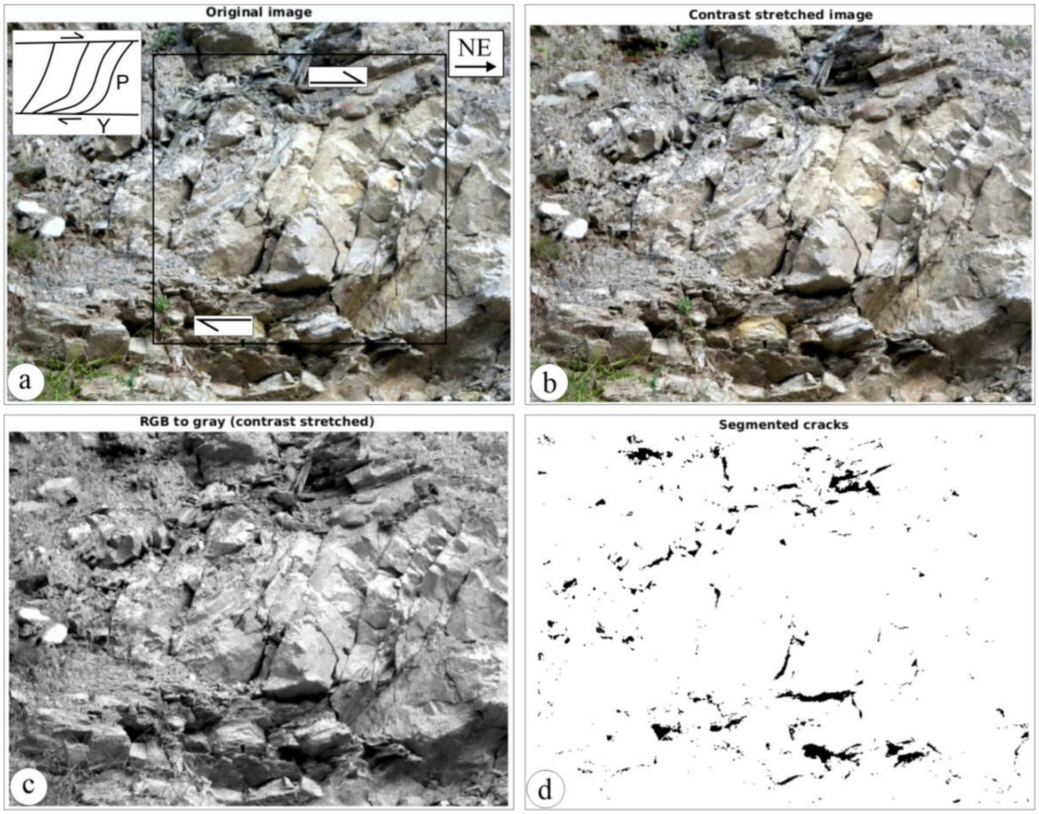

Fig. 2. *See **Table 1** for the codes. **(a)** Aaa; **(b)** Aab, **(c)** AAc **(d)** Aad, Width of image ~ 3m. Berinag Formation. Quartzite exposed at 30.8136 °N, 78.6205 °E.*

2.2. Image processing technique

2.3.

While interpreting, figures have been named as *"Xyz"* in both main text as well as in Repository 1. Here *X* stands for the methods applied, *y* denotes figure number (*a* for Fig. 2a, *b* for Fig. 3a and *c* for Fig. 4a), and *z* represents steps used in the applied methods (Table 1). For example, *Abc* will mean image segmentation applied on image *b* with RGB to greyscale step involved. Matlab programs were written for each of the image enhancement process (Repository 1). The image analyses did not have any preferred choice for some specific fractures. For example, the grain boundaries were also enhanced along with the brittle P- and Y-planes. Repository 2 presents altogether 61 interpreted images, with about 20 each from the given 3 uninterpreted images. In Section-3 "Discussions", we present few key images in order to compare the output.

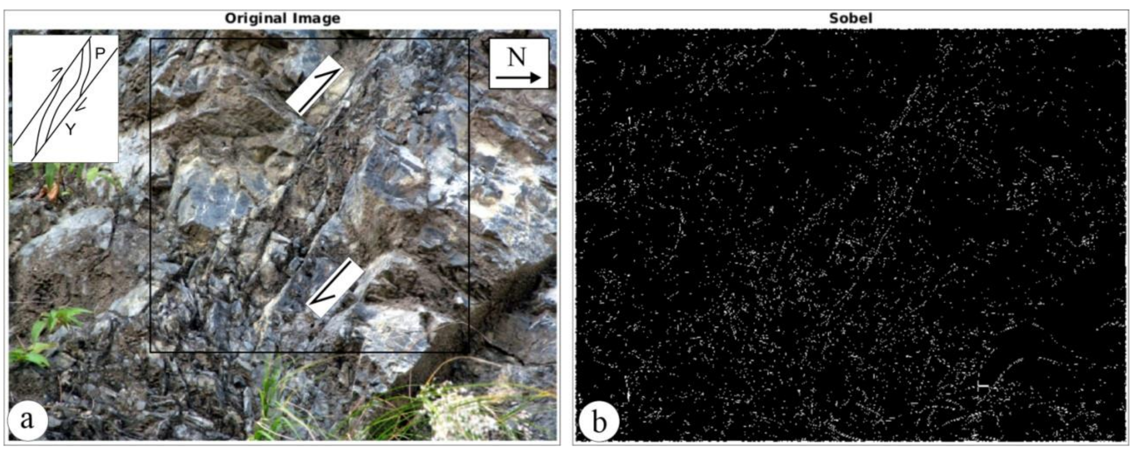

Fig. 3. *See* ***Table 1*** *for the codes.* ***(a)*** *Aba,* ***(b)*** *Dbc. Width of image ~ 3m. Mandhali Formation. Limestone exposed at 30.6802°N, 78.3497°E.*

Table 1: Methods and Steps used in different methods.

X* in fig. code *Xyz	**Method**	***z* in fig. code *Xyz***	**Standard Approach** (Internet ref)
A	Image segmentation	a. Original uninterpreted image	
		b. Contrast stretched	Contrast is augmented in the image: Stretches the intensity range to span a desired range of magnitudes.
		c. RGB to greyscale	Alters RGB Images into gray scale. Average value of the three colors per pixel is taken.
		d. Segmented cracks	Alters the grayscale image into a binary image. Pixels in the input image are altered with a luminance more than a threshold level with the value 1 (white). Other pixels with the magnitude 0 (black).
		e. Cleaned image	Deletes isolated pixels (individual 1's surrounded by 0's or vice-versa).
		f. Thinned image	It removes pixels so that an object without holes shrinks to a minimally connected stroke, and an object with holes shrinks to a connected ring halfway between each hole and the outer boundary.
B	Fuzzy logic image processing	a. Original uninterpreted image	
		b. RGB to greyscale	See *A-c* above
		c. I_x: Gradient of intensities	Gradient of the intensities of image pixels along x-direction.
		d. I_y: Gradient of intensities	Gradient of the intensities of image pixels along y-direction.
		e. Degree of membership	A membership function is assigned with the specified type and parameters. Designates a zero-mean Gaussian membership function for each input. For gradient value for a pixel to be 0, it belongs to the zero membership function with a degree = 1. If sx and sy are the

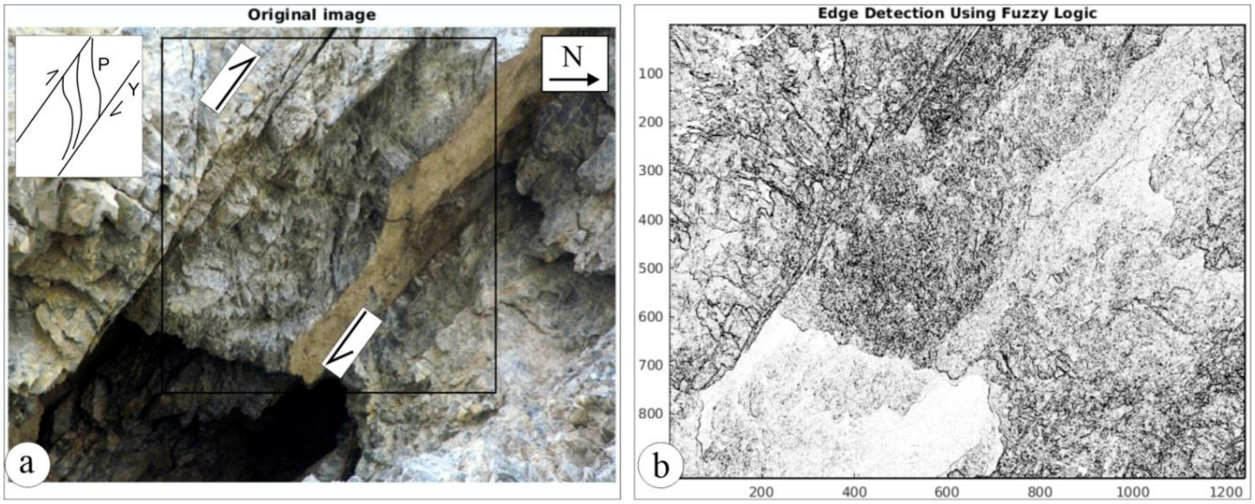

Fig. 4. *See* ***Table 1*** *for the codes.* ***(a)*** *Aca,* ***(b)*** *Bcf. Width of image ~ 1.5 m. Mandhali Formation. Limestone exposed at 30.6802°N, 78.3497°E.*

3. Discussions

In the image segmentation method (method *A*), no significant differences are found amongst the uninterpreted image (Fig. 2a), the contrast stretched image (Fig. 2b), and the greyscale image (Fig. 2c). No significant improvement is found also for fuzzy logic image processing (method *B*) when the RGB to greyscale conversion was made (image *Bab* in Repository 2). However, in case of the segmented crack approach under method *B*, curvature of the P-plane is clearly visible near the middle part of the image (Fig. 2d). The cleaned image (Fig. 2e) under method *B* shows fractures with equal ease as that of the Fig. 2d. When Fuzzy logic image processing (method *B*) with I_X: gradient of intensities is applied, shear zones take an appearance (Fig. 2f), which perhaps only a structural geologist who has seen the field exposure (Fig. 2a) earlier can interpret. However, when Fuzzy logic image processing (method *B*) with I_y: gradient of intensities is applied, the shear planes are not at all decipherable (image *Bad* in Repository 2), even though we have a prior idea about the original uninterpreted image (Fig. 2a). One of the best manifestations of P and Y planes appear when edge detection using fuzzy logic is applied (Fig. 2g). In this case, the right portion of the image demonstrates both the P and the Y planes quite distinctly. When bilateral filtering (method *C*) is done and different steps applied, there is no significant improvement in identifying the brittle planes Y and P in the obtained images (image *Caa* up to *Cae* in Repository 2) when compared with the uninterpretd image (Fig. 2a). The LoG (image *Dag* in Repository 2) and the zerocross (image *Dah* in Repository 2) processes yield clumsy output and can be more difficult to identify the planes Y and P, than the simple uninterpreted image (Fig. 2a). The Prewitt filter (Fig. 2h) and the Roberts filter (Fig. 2i) filter give better and cleaner images.

Interestingly, when we apply image the segmentation method (method *A*) over another uninterpreted image (Fig. 3a), segmented crack (image *Abd* in Repository 2) and cleaned images (image *abe* in Repository 2) are impossible to decipher for Y and P planes and the shear sense. All the approaches of fuzzy logic image processing (method B) applied on Fig. 3a gives unsatisfactory images (images *Bba* to *Bbf* in Repository 2) that cannot be interpreted for Y and P planes. The same is true for the resultant images (images *Cba* to *Cbe*) in Repository 2) when bilateral filtering method is applied on Fig. 3a. Comparison between various fracture detection filter techniques (method D) when applied on Fig. 3a, LoG (image *Dbg* in Repository 2) and Zerocross filters (image *Dbh* in Repository 2) give the worst results. The Sobel filter here can produce an image where few of the shear planes are visible (Fig. 3b), but still difficult to interpret than the simple visual interpretation of Fig. 3a.

In case of the field photograph Fig. 4a, following the image segmentation method (method *A*) the segmented crack and the cleaned crack filters give white patches at the place where P- and Y planes are found otherwise. In Fuzzy logic image processing (method *B*), only the edge detection technique reveals P and Y planes somewhat clearly (Fig. 4b). The same problem persists in all the output images (images *Dca* to *Dch* in Repository 2) in using the method of comparison between various fracture detection filter techniques (method *D*). In bilateral filtering method (method *C*), none of the output images (images *Cca* to *Cce* in Repository 2) give clear-cut P and Y planes. The different techniques applied for image analyses in this study needs to be cross-checked for other rock types such as gneisses.

The main difference between the two field snaps Figs. 2a and 3a is that in the later, the P-planes are more closely spaced than the former one. Possibly because of this, Fig. 2a after image processing, gave more distinct appearance of P and Y planes in few cases. Fig. 4a is a case with white fault gouge developed where P- and Y planes are found. Because of this white colour, many of the filtering approaches failed to pick up the Y and the P-planes, even though those are visible to the eyes of a trained structural geologist! For all the three starting images Figs. 2a, 3a and 4a, their greyscale images deduced by various means do not significantly ease the detection of P and Y planes. In some of the methods, the thinned images and the zerocross images (e.g., images *Aaf* and *Dch*, respectively, in Repository 2) completely fail to bring out the Y and the P-planes.

4. Conclusions

A number of image enhancement methods, techniques and filters are available. Testing them on meso-scale photographs of brittle shear zones, led to understand the followings.

(i) One of the best manifestation of P and Y planes appear when edge detection using fuzzy logic is applied.

(ii) The zerocross and the thinned image techniques usually give poor ouput.

(iii) Greyscale images do not significantly enhance the photographs.

(iv) If the rock consists of white fine grained contents such as gouge material, image enhancement to detect brittle planes may not work well.

(v) Image enhancement on close-spaced planes possibly does not ease detection of those planes. For cases *(ii)* to *(v)*, a trained structural geologist's visual interpretation on field snaps can be more useful! In case, image processing also give ambiguous results, it will be better to undertake conventional thin-section studies of rocks to detect P and Y planes in microscale.

Acknowledgements: This work is a part of PH's research assignment for the course *GS 407: Structural Geology* taught by SM. CPDA grant (IIT Bombay) supported SM. An anonymous reviewer commented. Handled by Saibal Gupta. This article is dedicated to Prof. W-C Dullo and his wife Monika Dullo for decades of selfless service for the International Journal of Earth Sciences (formerly Geologische Rundschau) as Chief Editor and Managing Editor, respectively.

Author credit statement:

PH: Programming and output images. **SM:** Supervision, manuscript writing, fieldwork. **NB:** Fieldwork, photography, commenting on the draft.

References

Biswas T, Bose N, Dutta D and Mukherjee S 2022 Arc-parallel shears in collisional orogens: Global review and paleostress analyses from the NW Lesser Himalayan Sequence (Garhwal region, Uttarakhand, India); *Marine Petrol. Geol.* in press.

Biswas T, Mukherjee S 2022 Non-Uniform B-spline curve analyses of sigmoid brittle shear P- and ductile shear S-planes; *Int. J. Earth Sci.* in press.

Bjørnerud M G and Boyer B. 1996 Image Analysis in Structural Geology Using NIH Image; In: *Structural Geology and Personal Computers* (ed.) De Paor D, Pergamon Press. Oxford. ISBN: 0 08 042430 9. pp. 105-122.

Bons P D and Jessell M 1996 Image Analysis in Structural Geology Using NIH Image; In: *Structural Geology and Personal Computers* (ed.) De Paor D, Pergamon Press. Oxford. ISBN: 0 08 042430 9. pp. 135-166.

Bose N, Dutta D and Mukherjee S 2018 Role of grain-size in phyllonitisation: Insights from mineralogy, microstructures, strain analyses and numerical modeling; *J. Struct. Geol.* **112** 39-52.

Bose N and Mukherjee S 2019 Field documentation and genesis of the back-structures from the Garhwal Lesser Himalaya, Uttarakhand, India. In: Crustal Architecture and Evolution of the Himalaya-Karakoram-Tibet Orogen. (eds) Sharma R, Villa I M and Kumar S, *Geol. Soc. London Spec. Publ.* **481** 111–125.

Dutta D and Mukherjee S 2019 Opposite shear senses: Geneses, global occurrences, numerical simulations and a case study from the Indian Western Himalaya; *J. Struct. Geol.* **126** 357-392.

Genge M J 2020 *Geological Field Sketches and Illustrations: A Practical Guide*. Oxford University Press. ISBN 978–0–19–883592–9. pp. 1-293.

Healy D et al 2017 FracPaQ: A MATLAB™ toolbox for the quantification of fracture patterns; *J. Struct. Geol.* **95** 1-16.

Heilbronner R and Barrett S 2014 *Image Analysis in Earth Sciences: Microstructures and Textures of Earth Materials*. Springer-Verlag. Berlin. pp. 13. ISBN: 978-3-642-10342-1.

Internet ref: www.mathworks.com (Accessed on 25-May-2021)

Misra A A and Mukherjee S 2018 Seismic Structural Analysis. In: *Atlas of Structural Geological Interpretation from Seismic Images* (eds.) Misra A A, Mukherjee S, Wiley Blackwell. ISBN: 978-1-119-15832-5. pp. 15-26.

Mokhles M, Fatai A and Mohammed M 2019 *Advances in Rock Petrography: Image Processing Techniques for Automated Textural Thin Section Analysis*; Society of Petroleum Engineers. SPE-194835-MS.

Mukherjee S 2021 *Atlas of Structural Geology*. Second Edition. Elsevier. Amsterdam. ISBN: 978012816802. pp. 1-260.

Novakova L and Pavlis T L 2017 Assessment of the precision of smart phones and tablets for measurement of planar orientations: A case study; *J. Struct. Geol.* **97** 93-103.

Passchier C W and Trouw R A J 1996 *Microtectonics*. Springer. pp. 128. ISBN: 978-3-662-08736-7.

Sulaksana N and Hamdani A M 2014 The Analysis of Remote Sensing Imagery for Predicting Structural Geology in Berau Basin East Kalimantan; *Int. J. Sci. Res.* 18-21. Article id: 020131349.

Repository material: On request to the author S Mukherjee (soumyajitm@gmail.com, msoumyajit@yahoo.com , repository item will be shared)