

## Gamma-enhancement of reflected light images as a routine method for assessment of compositional heterogeneity in common low-reflectance Fe-bearing minerals

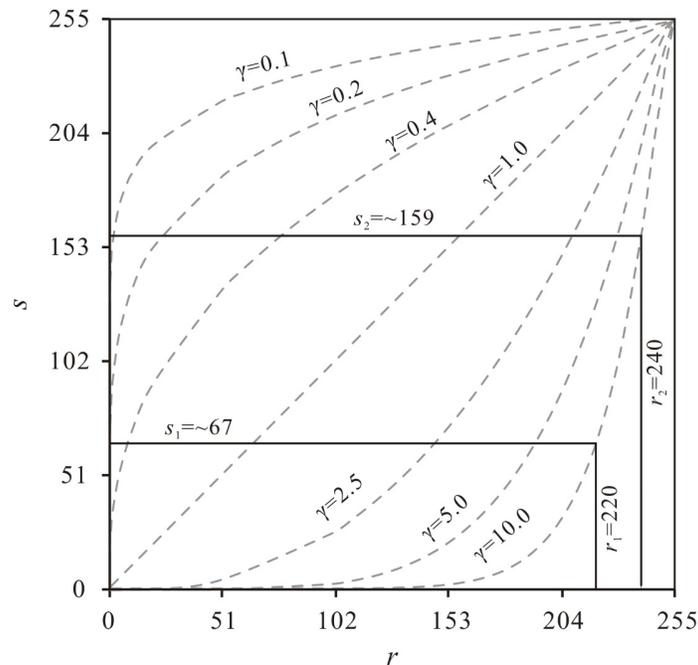
### Appendix A

#### Background on gamma correction

Gamma correction, also called power-law transformation, is a digital image enhancement method that changes the gray values of input and therefore improves the contrast in images for human viewers (e.g., Gonzalez and Woods 2008; Maini and Aggarwal 2010; Heilbronner and Barrett 2014). The transformation function for  $\gamma$  correction is usually defined as:

$$s = C \times r^\gamma,$$

where  $s$  and  $r$  are the gray values (between 0 and 255) of output and input, respectively;  $C$  is a positive weighting constant and used to limit the gray values of  $s$  between 0 and 255, and  $\gamma$  is the exponent defining the gamma correction (Heilbronner and Barrett 2014). Both  $C$  and  $\gamma$  are built-in parameters of display equipment or software with certain ranges (Gonzalez and Woods 2008; Maini and Aggarwal 2010).



**Figure A1.** Plot of gamma correction result for various  $\gamma$  using different values of constant  $C$  to scale each curve to fit the range shown. Figure after Zhu et al (2021).

The transformation functions of gamma correction are shown graphically in Figure A1. The parameter  $\gamma$  controls the contrast adjustment. The condition  $0 < \gamma < 1$  produces overall contrast enhancement resulting in a brightened image. This condition is suitable for underexposed images. If  $\gamma > 1$ , the gray values lower than the local mean will be stretched toward black (low gray values) while others are stretched toward

white (high gray values), resulting in a balanced image for bright images (Vimal and Thiruvikraman 2012; Heilbronner and Barrett 2014). For example, if the input gray values are chosen as 220 and 240, we expect output values of  $\sim 67$  and  $\sim 159$ , respectively, when using  $g = 10$  and  $C = 2.51 \times 10^{-22}$  in Figure A1. In this case, the difference of input gray values is stretched from 8.33 to 57.86% when using higher values of  $\gamma$ , resulting in significant variation of gray values that are sufficient to distinguish distinct domains that originally had similar gray values.

It is worth noting that different sorts of software will have different values for constant  $C$  and  $\gamma$  range, thus the same  $\gamma$  value may not produce comparable enhancements. Some sorts of software may even use the equation  $s = C \times r^{1/\gamma}$ , which would lead to an opposite enhancement effect since we use the equation  $s = C \times r^\gamma$  in the present study.

### **Analytical conditions of electron microprobe analysis**

Analytical conditions for spot analysis of magnetite, garnet, and wolframite were 15kV/20nA using a beam diameter of 1 to 5  $\mu\text{m}$ . On-peak count times were set at 10 s and 5 s off-peak background for all elements. X-ray lines and standards for magnetite were as follows: SiO<sub>2</sub> K $\alpha$  (quartz), TiO<sub>2</sub> K $\alpha$  (rutile), Al<sub>2</sub>O<sub>3</sub> K $\alpha$  (Al<sub>2</sub>SiO<sub>5</sub>), V<sub>2</sub>O<sub>3</sub> K $\alpha$  (Ca<sub>3</sub>(VO<sub>4</sub>)<sub>2</sub>), FeO K $\alpha$  (magnetite), MnO K $\alpha$  (pyrophanite), MgO K $\alpha$  (olivine), CaO K $\alpha$  (wollastonite), CoO K $\alpha$ (CoO), Na<sub>2</sub>O K $\alpha$  (albite), K<sub>2</sub>O K $\alpha$ (KTiOPO<sub>4</sub>). X-ray lines and standards for magnetite and garnet were as follows: SiO<sub>2</sub> K $\alpha$  (quartz), TiO<sub>2</sub> K $\alpha$  (rutile), Al<sub>2</sub>O<sub>3</sub> K $\alpha$  (Al<sub>2</sub>SiO<sub>5</sub>), Cr<sub>2</sub>O<sub>3</sub> K $\alpha$  (Cr<sub>2</sub>O<sub>3</sub>), FeO K $\alpha$  (magnetite), MnO K $\alpha$  (pyrophanite), MgO K $\alpha$  (olivine), CaO K $\alpha$  (wollastonite), Na<sub>2</sub>O K $\alpha$  (albite). Site allocations of cations were calculated using the Microsoft Excel spreadsheet of Grew et al. (2013). The Microsoft Excel spreadsheet introduced by Locock (2008) was used to calculate garnet end-member proportions from the resultant cations. X-ray lines and standards for wolframite were as follows: FeO K $\alpha$  (magnetite), MnO K $\alpha$  (pyrophanite), Na<sub>2</sub>O K $\alpha$  (albite), WO<sub>3</sub> M $\alpha$  (scheelite). Qualitative X-ray mapping of compositional zoning in magnetite and wolframite was undertaken using a JXA-iHP200F Hyper Probe microanalyzer. X-ray lines were Si K $\alpha$ , Al K $\alpha$ , and K K $\alpha$  for magnetite, and Fe K $\alpha$ , Mn K $\alpha$ , and Nb L $\alpha$  for wolframite, respectively. These elements were collected on separate spectrometers at 15 kV and 100 nA. The spatial resolution was  $\sim 1.0 \mu\text{m}$ . Analytical conditions for spot analysis of tetrahedrite-tennantite were 20 kV/20 nA using a beam size of  $\sim 1 \mu\text{m}$ . Count-times were 10 s for unknowns and 5 s background for all elements. X-ray lines and standards for tetrahedrite-tennantite were S K $\alpha$  (pyrite), Pb M $\alpha$  (galena), As L $\alpha$  (gallium arsenide), Fe K $\alpha$  (pyrite), Cu K $\alpha$  (chalcopyrite), Zn L $\alpha$  (sphalerite), Ag L $\alpha$  (sanguinite), Sb L $\alpha$  (stibnite), Bi M $\alpha$  (bismuth sulfide), Cd L $\alpha$  (CdS).

## References cited

- Gonzalez, R.C., and Woods, R.E. (2008) *Digital Image Processing*, 3<sup>rd</sup> ed., 976 p. Prentice Hall International.
- Grew, E.S., Locock, A.J., Mills, S.J. Galuskina, I.O., Galuskin, E.V., and Hålenius, U. (2013) Nomenclature of the garnet supergroup. *American Mineralogist*, 98, 785–811.
- Heilbronner, R., and Barrett, S. (2014) *Image Analysis in Earth Sciences: Microstructures and textures of earth materials*. Springer-Verlag.
- Locock, A.J. (2008) An Excel spreadsheet to recast analyses of garnet into end-member components, and a synopsis of the crystal chemistry of natural silicate garnets. *Computers & Geosciences*, 34, 1769–1780.
- Maini, R., and Aggarwal, H. (2010) A comprehensive review of image enhancement techniques. *Journal of Computing*, 2(3), 8–13
- Vimal, S.P., and Thiruvikraman, P.K. (2012) Automated image enhancement using power law transformations. *Sādhanā*, 37, 739–745.
- Zhu, Q.Q., Cook, N.J., Xie, G.Q., Ciobanu, C.L., Jian, W., Wade, B.P., and Xu, J. (2021) Gamma-enhancement of reflected light images: A rapid, effective tool for assessment of compositional heterogeneity in pyrite. *American Mineralogist*, 106, 497–505.