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Characterizing microstructures of Earth materials: **Reconstructing** higher-order correlation functions using deep generative adversarial networks (GANs)

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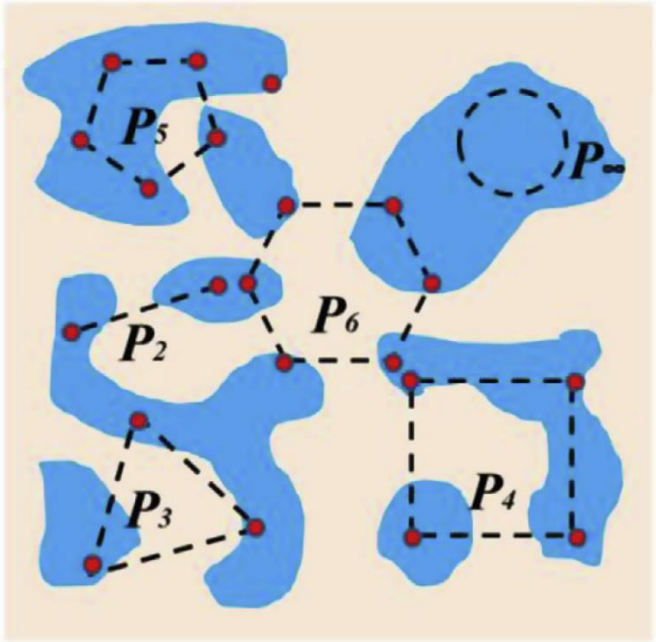
Characterization

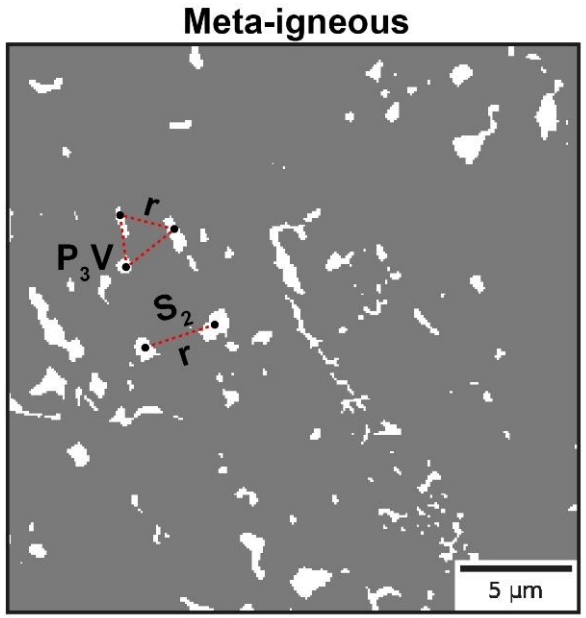
❖ Statistical representation of geomaterials using spatial correlation functions.

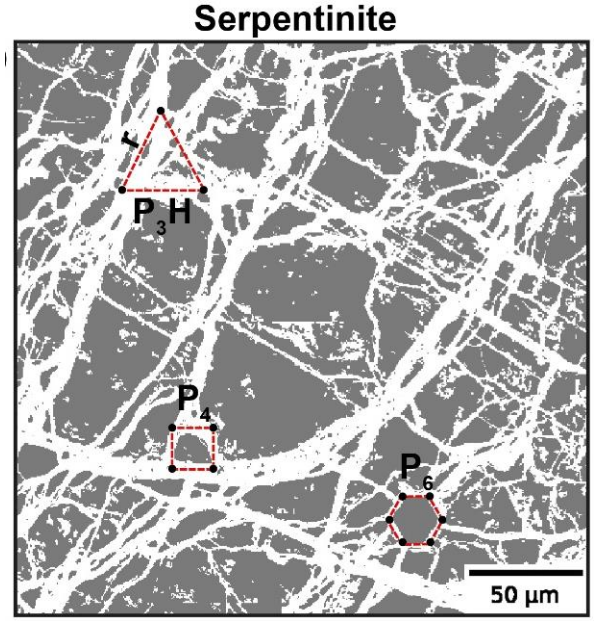
Statistical microstructure descriptors (SMDs)

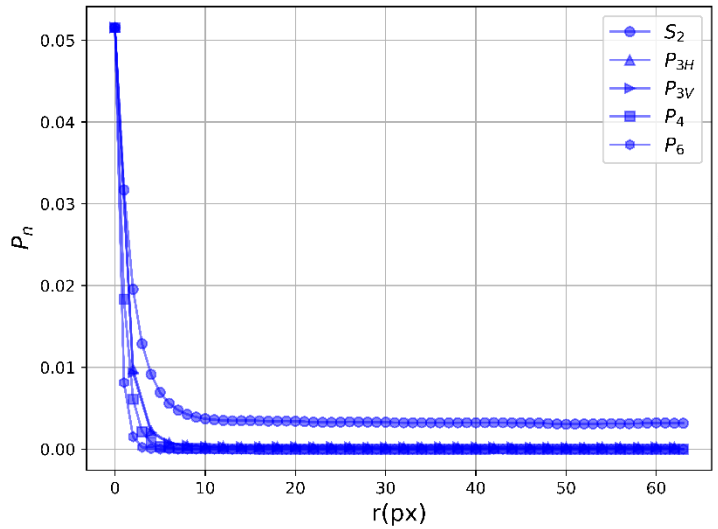


(Chen et al., 2019)

Probability of ***n*** random points of distance ***r*** to lie in the same phase of interest







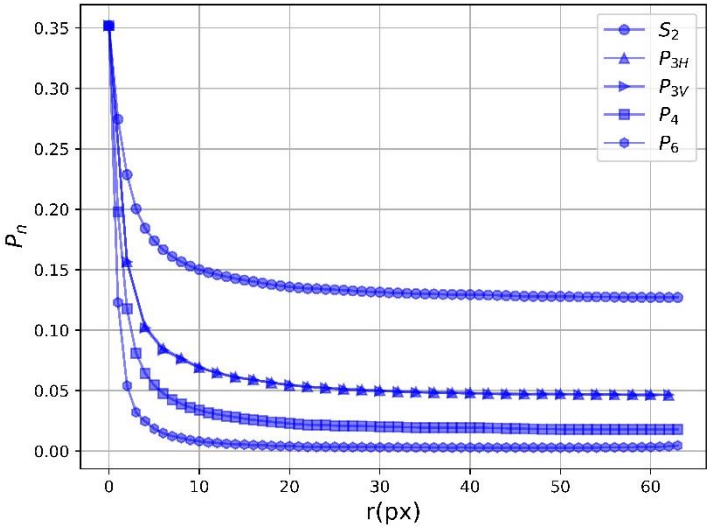
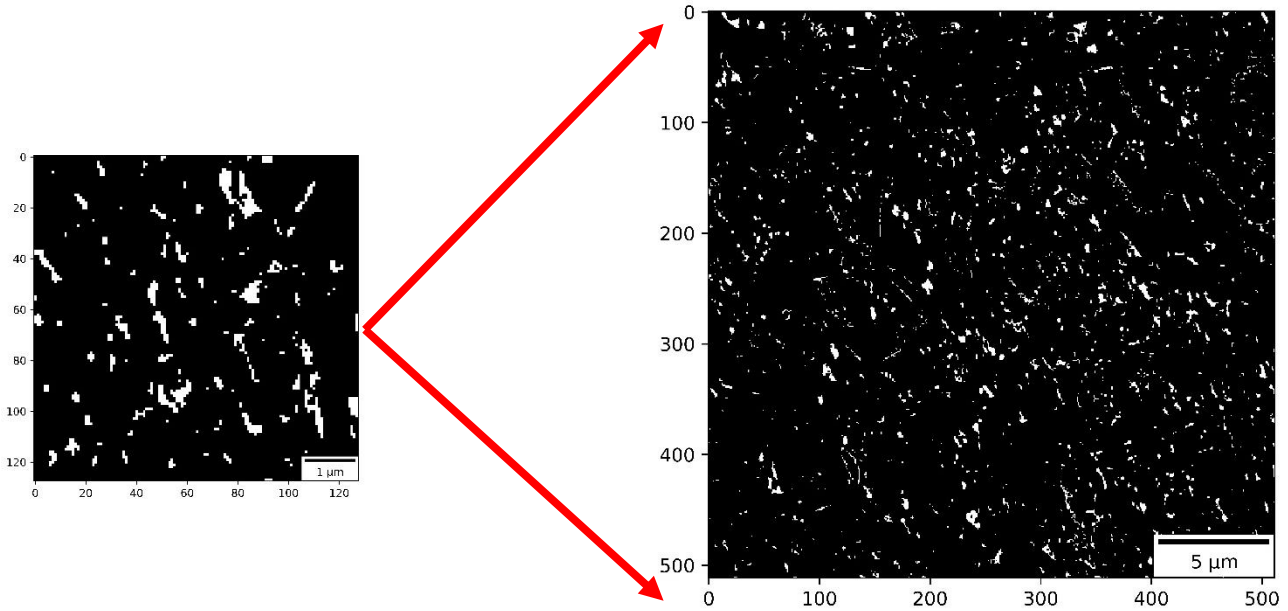


Image reconstruction

❖ **Image reconstruction** is the process of generating statistically equivalent microstructures but with **larger size** and/or **additional dimensions**.

Why image reconstruction?

✓ Upsampling and upscaling.



✓ **High-resolution**

✖ **Small field of view**

✓ **High-resolution**

✓ **Representative size**

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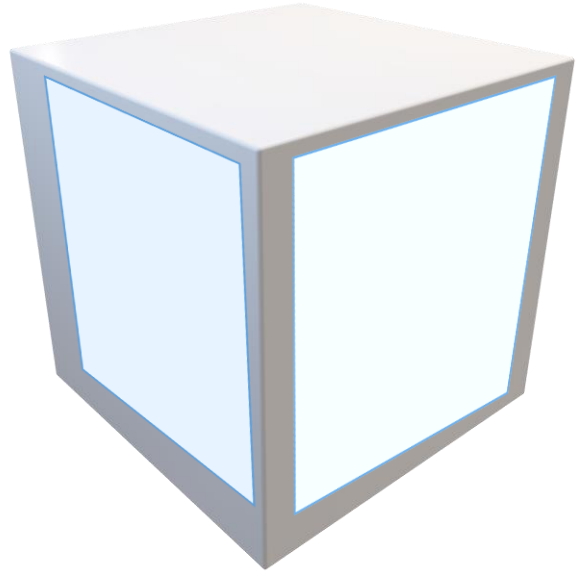
Why image reconstruction?



✓ Upsampling and upscaling.

✓ 2D to 3D reconstruction

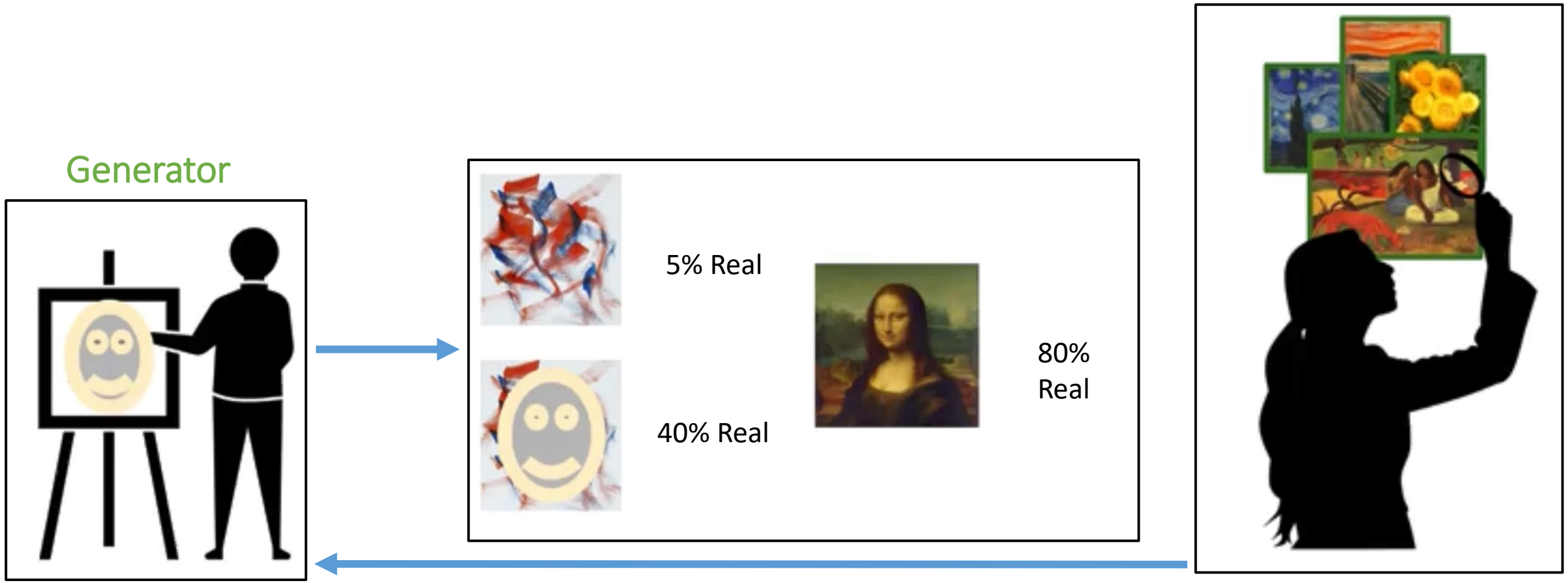
Methods:

✓ Stochastic: two-point correlation + optimization method (simulated annealing).
✓ **Deep-learning based generative models**: Generative adversarial network (GAN).

Generative adversarial network (GAN)

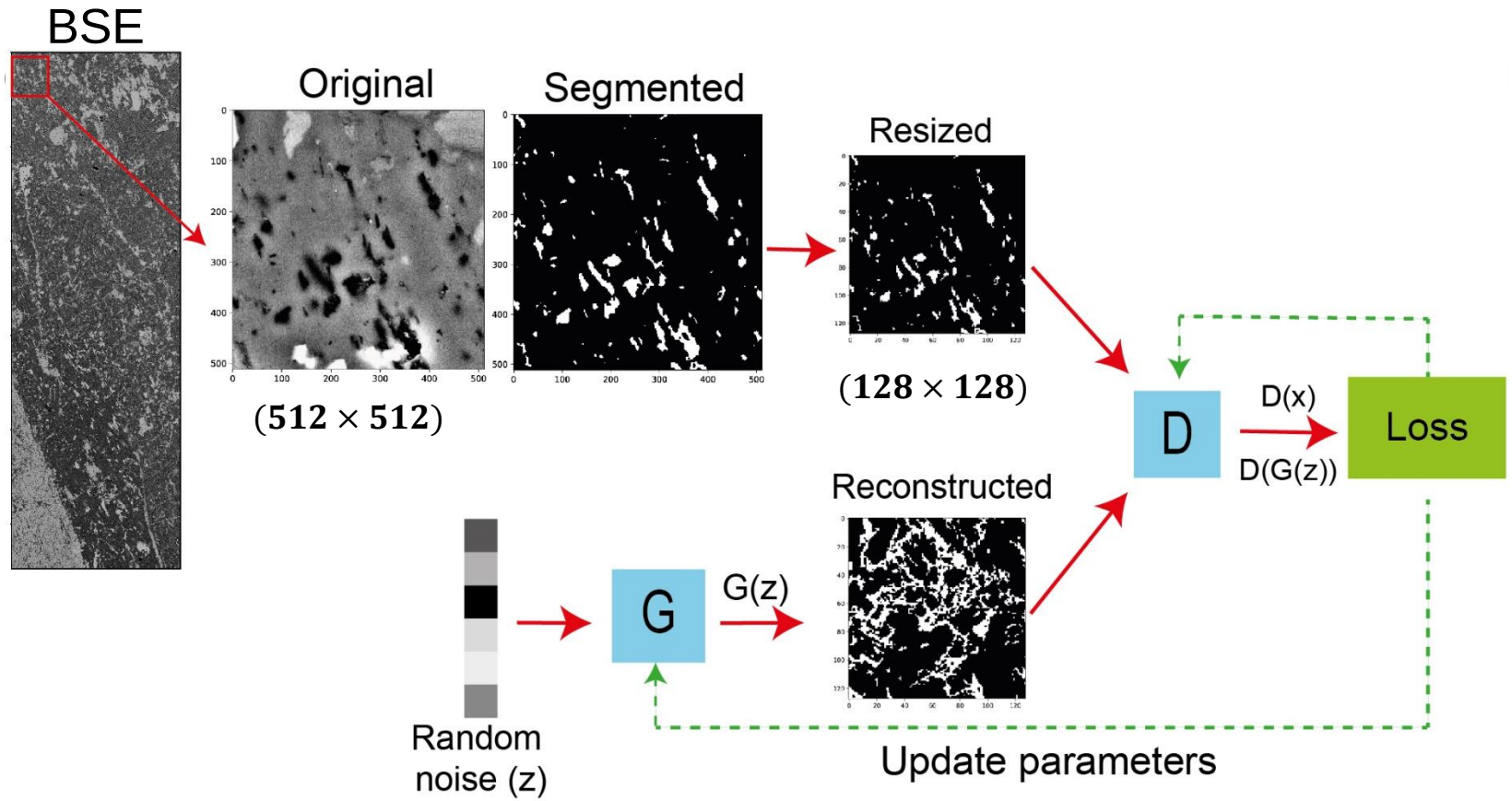
❖ **2 convolutional neural networks (CNN):**

- Generator
- Discriminator



(Coursera.com)

Generative adversarial network (GAN)



Non-cooperative game (Minimax game)

Wasserstein loss with Gradient penalty (WGAN-GP):

Regularization term

$$\underbrace{min}_{G}\ \underbrace{max}_{C}\ E(c(x) - E(c(g(z)) + \lambda E(\|\nabla(c(\hat{x})\|_2 - 1)^2$$

(Gulrajani et al., 2017)

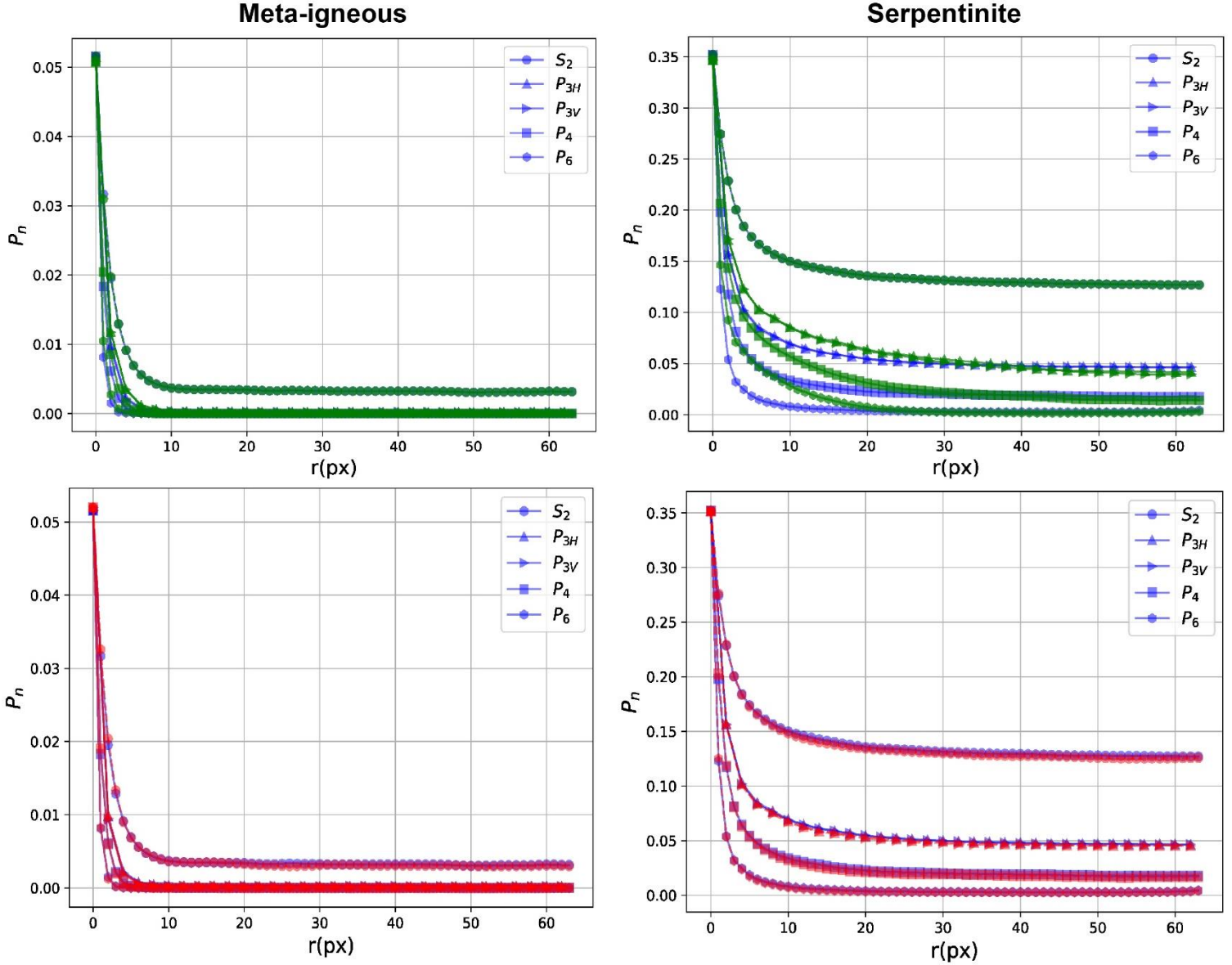
WGAN-GP vs Stochastic

Stochastic reconstruction

S_2 + Simulated annealing

WGAN-GP

Trained with thousands of images

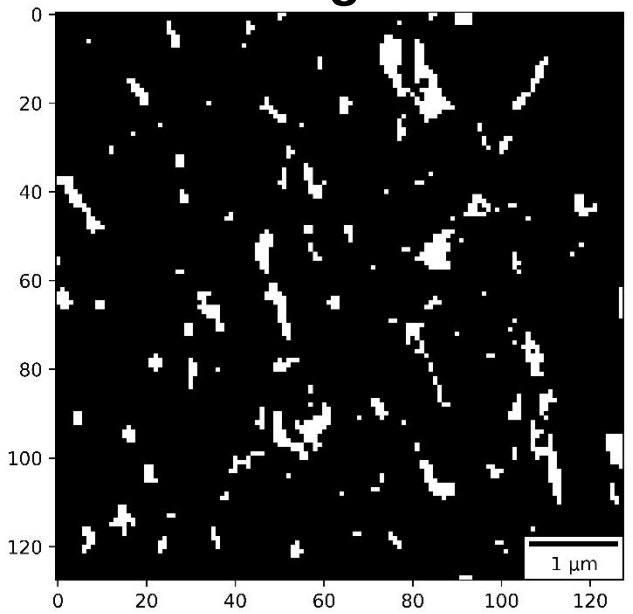


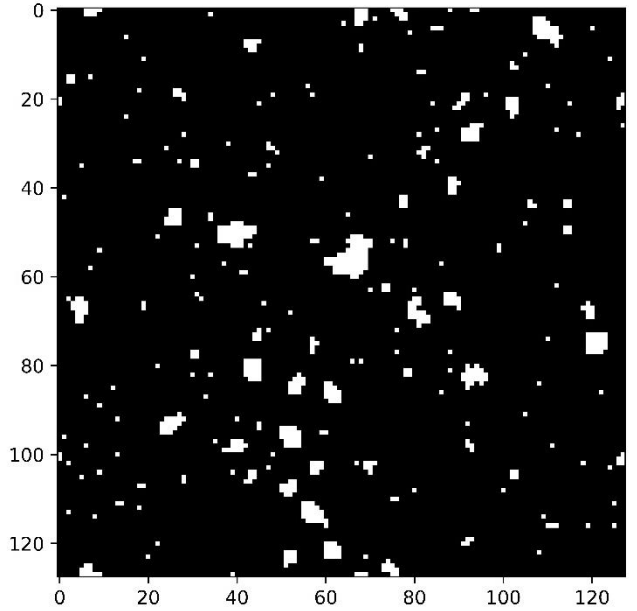
Blue: Original **Green**: Stochastic **Red**: Our WGAN-GP

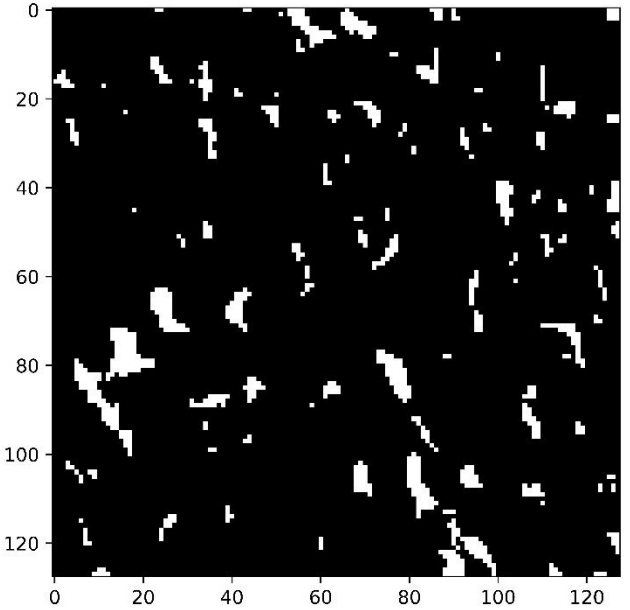
WGAN-GP vs Stochastic method

Original | **Stochastic** | **WGAN-GP**

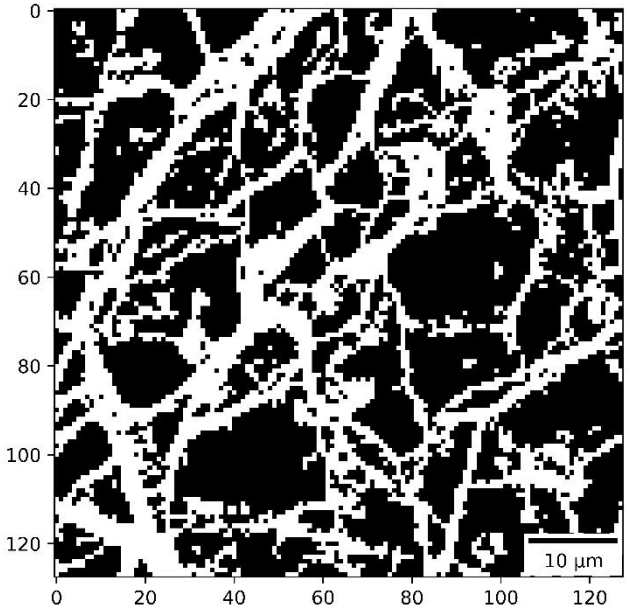
Meta-igneous Pore network

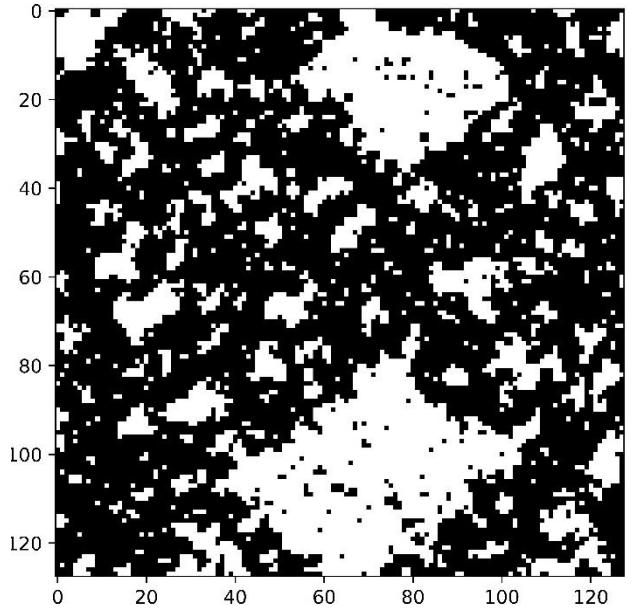


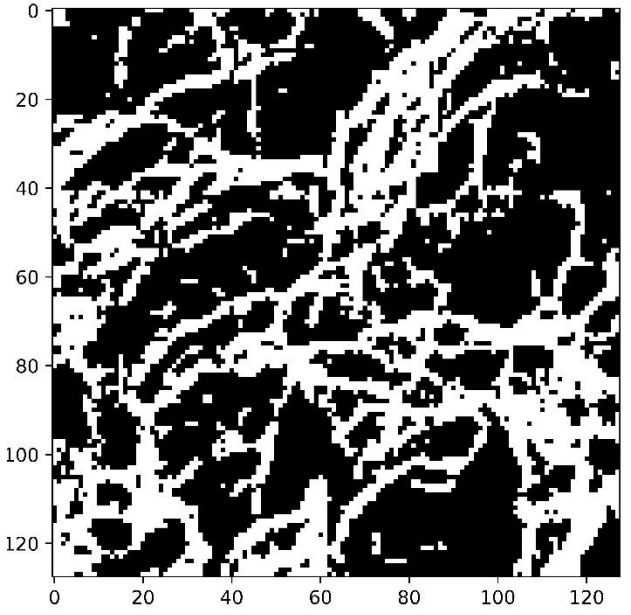




Serpentinite fracture network







Conclusion

- Spatial correlations should be coupled with image reconstruction, especially in the case of anisotropic heterogeneous microstructures and when transport modelling is the next step!

- Github: https://github.com/hamediut/GeoWGAN-GP

- Images are freely accessible: https://public.yoda.uu.nl/geo/UU01/ACSDR4.html