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Multi-Scale Spatial Texture Characterization in Earth Systems using Topological Data Analysis

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I. Modeling Multi-scale Geological Features

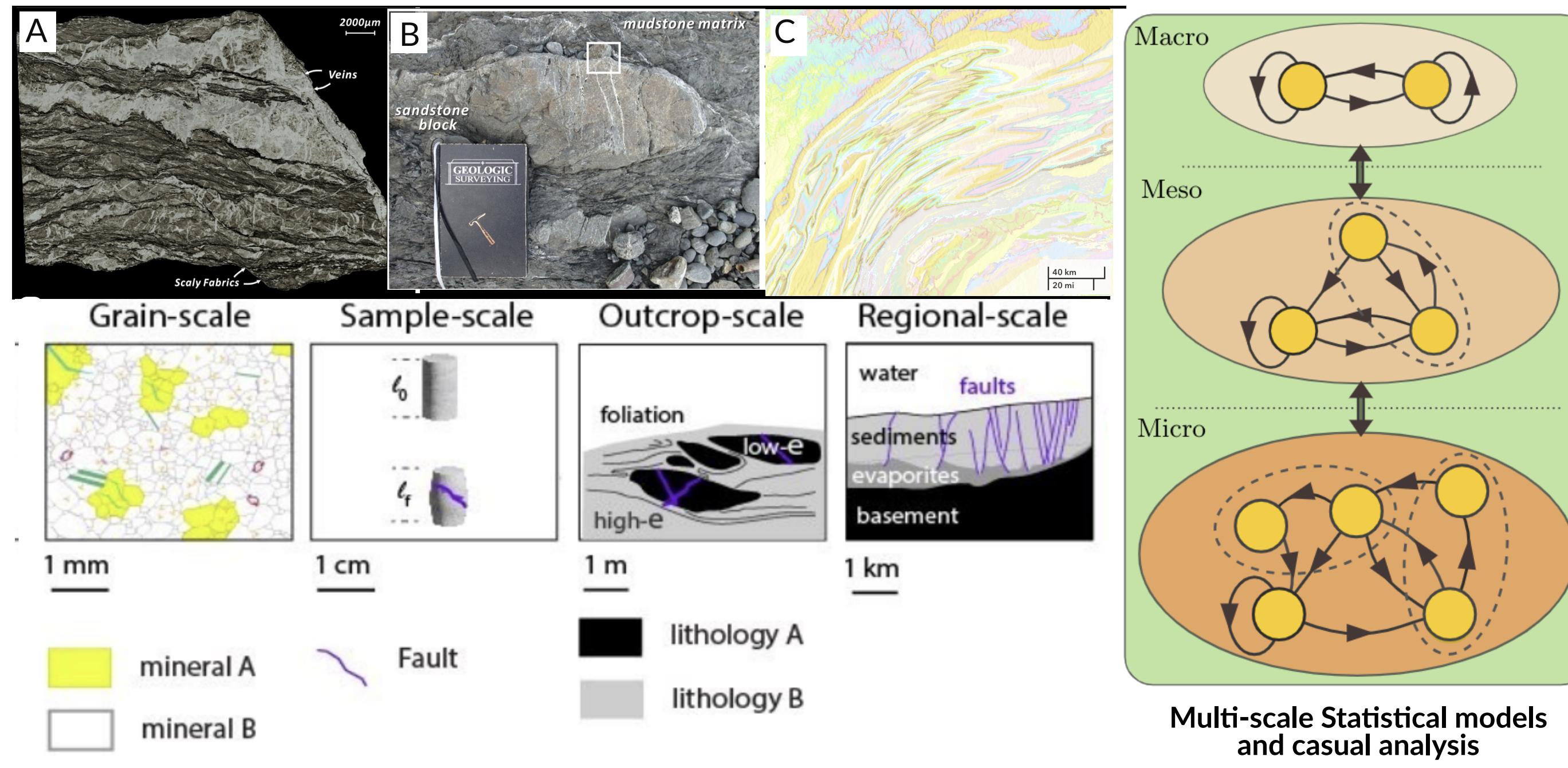
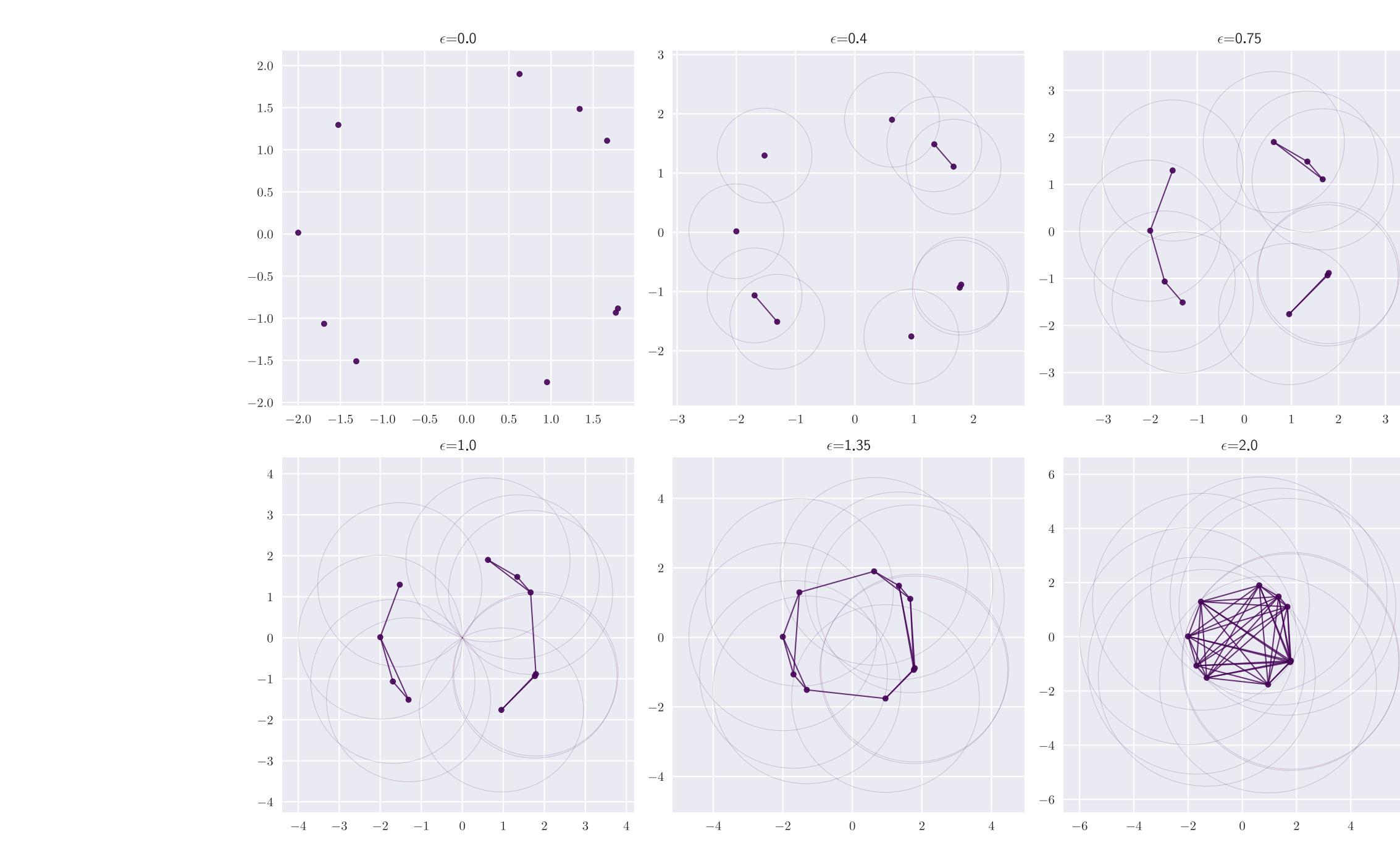
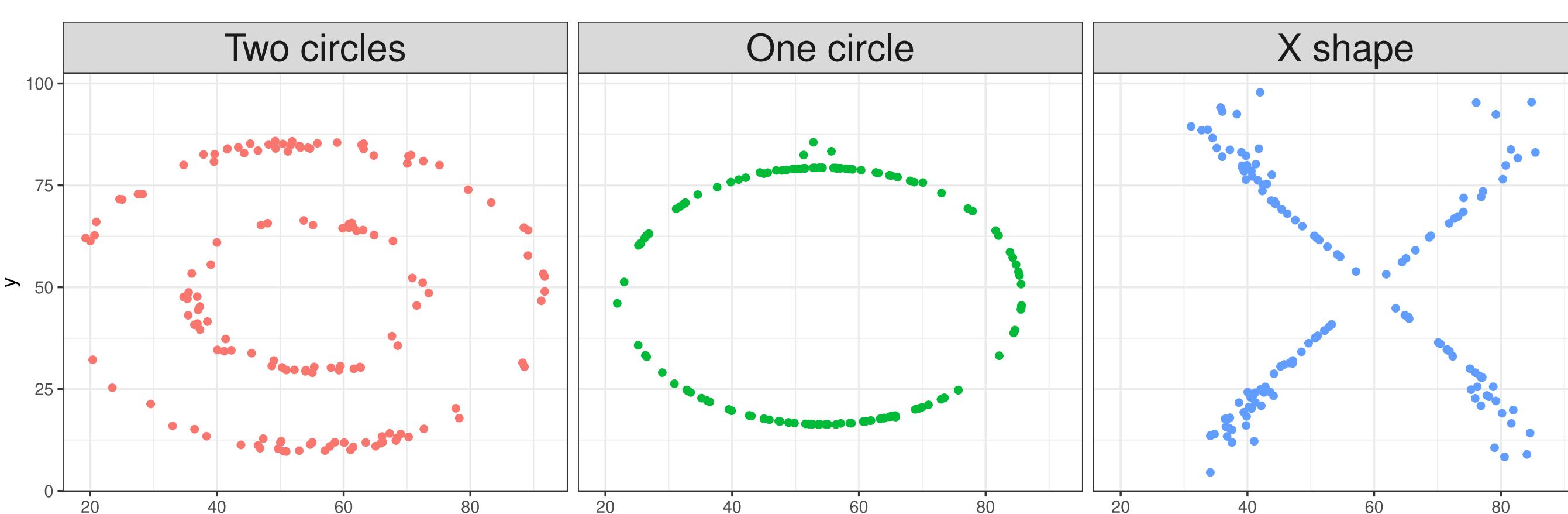


Figure 1: Multi-scale textures and hierarchical dependence in geological images

- Mineral spatial arrangements create multi-scale rock texture that fundamentally controls reactive fluid flow in subsurface systems.
- Mineral transects encode multi-scale texture and hierarchical dependence information that needs to be quantitatively characterized and modeled.
- Predictive models diverge from observations because they inadequately account for rock texture

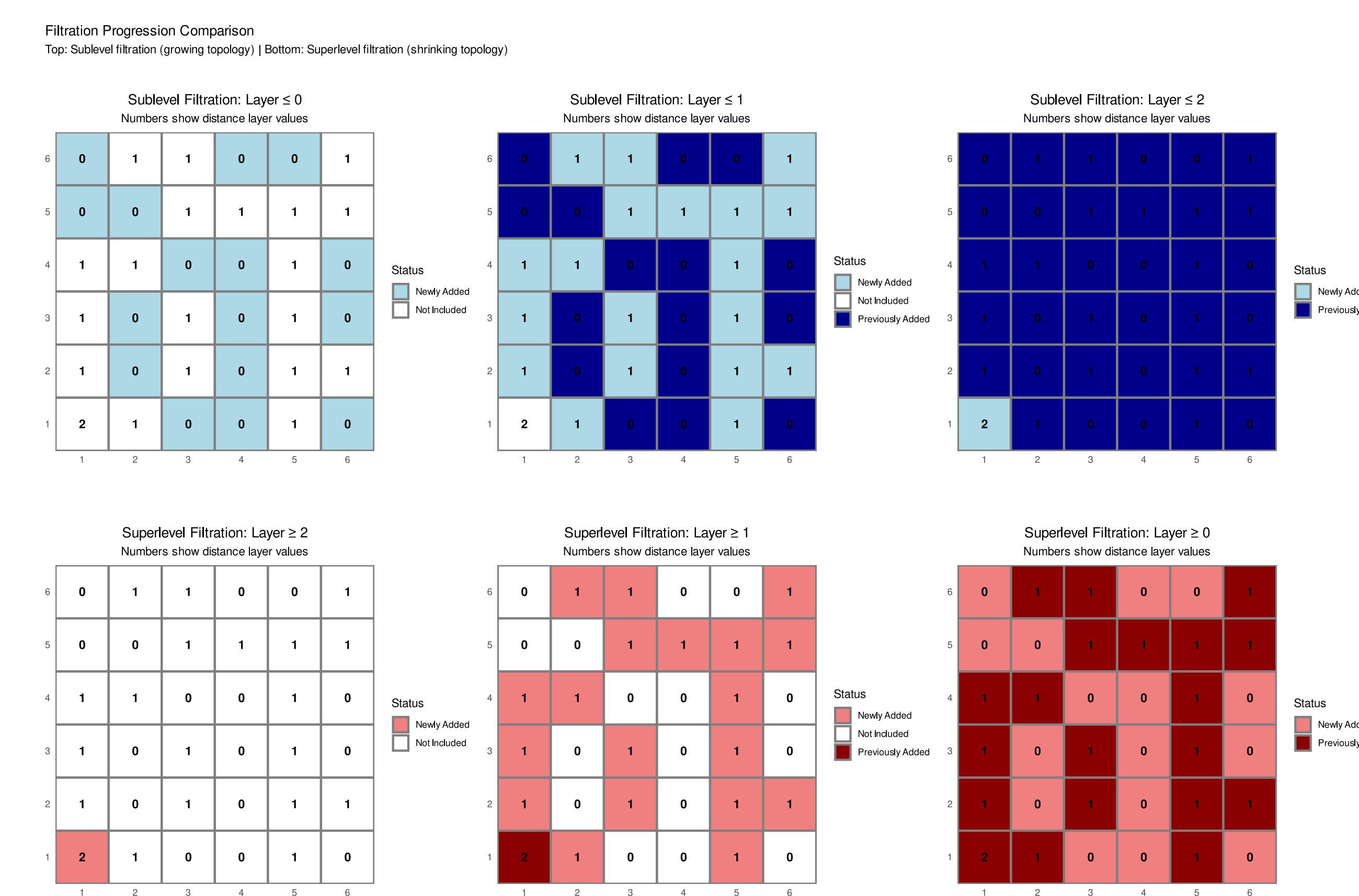
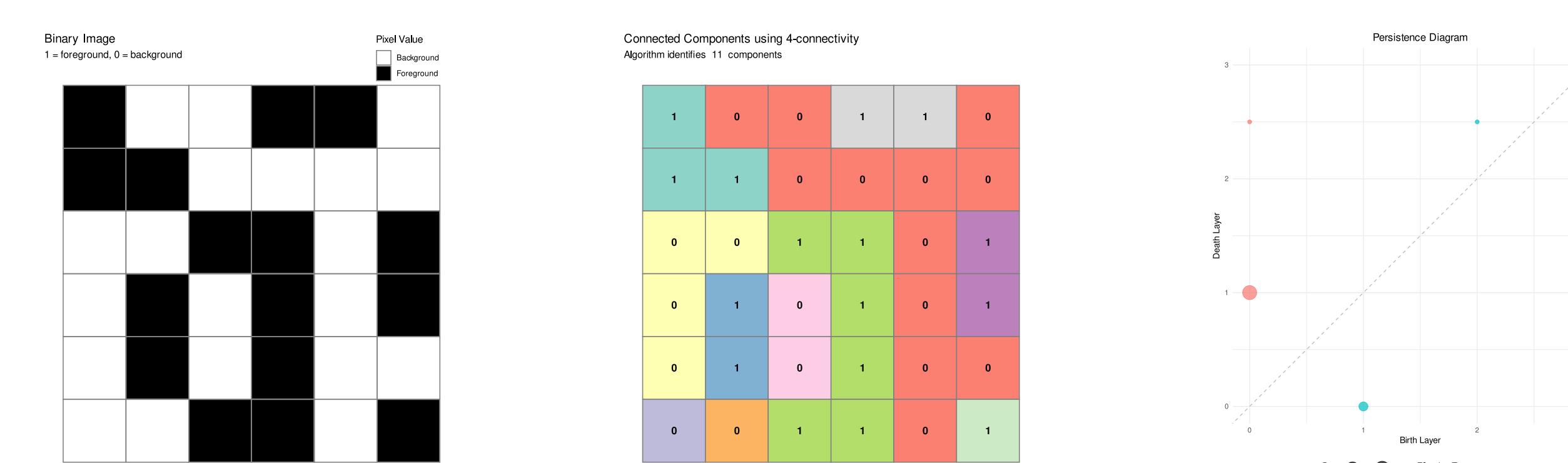
II. Topological Data Analysis

- Topology studies properties of objects under continuous deformation.
- TDA quantifies the structural information contained in a filtration by “filling gaps” between points that are “close enough”.



Dataset	Avg(X)	Avg(Y)	SD(X)	SD(Y)	Cor(X,Y)
two_circles	54.3	47.8	16.8	26.9	-0.0641
circle	54.3	47.8	16.8	26.9	-0.0686
X_shape	54.3	47.8	16.8	26.9	-0.0683

- **Method Overview:** We quantify the scale and topology of mineral connectivity and distribution across all spatial resolutions within an image, generating translation-invariant structural summaries.



III. Application to texture data

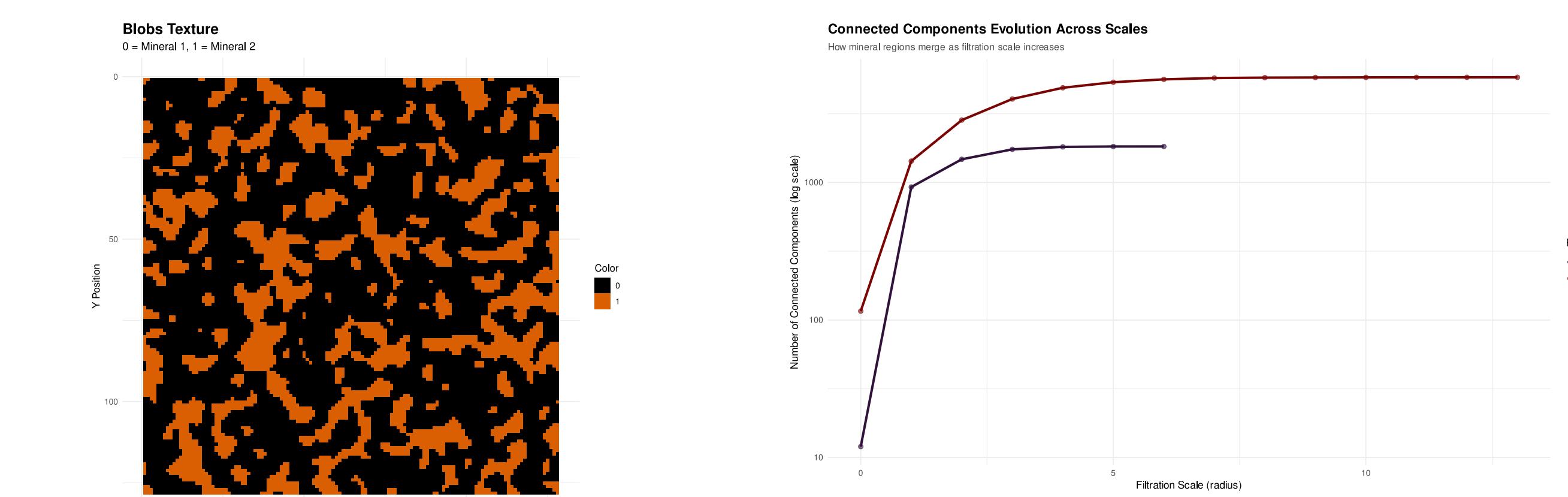
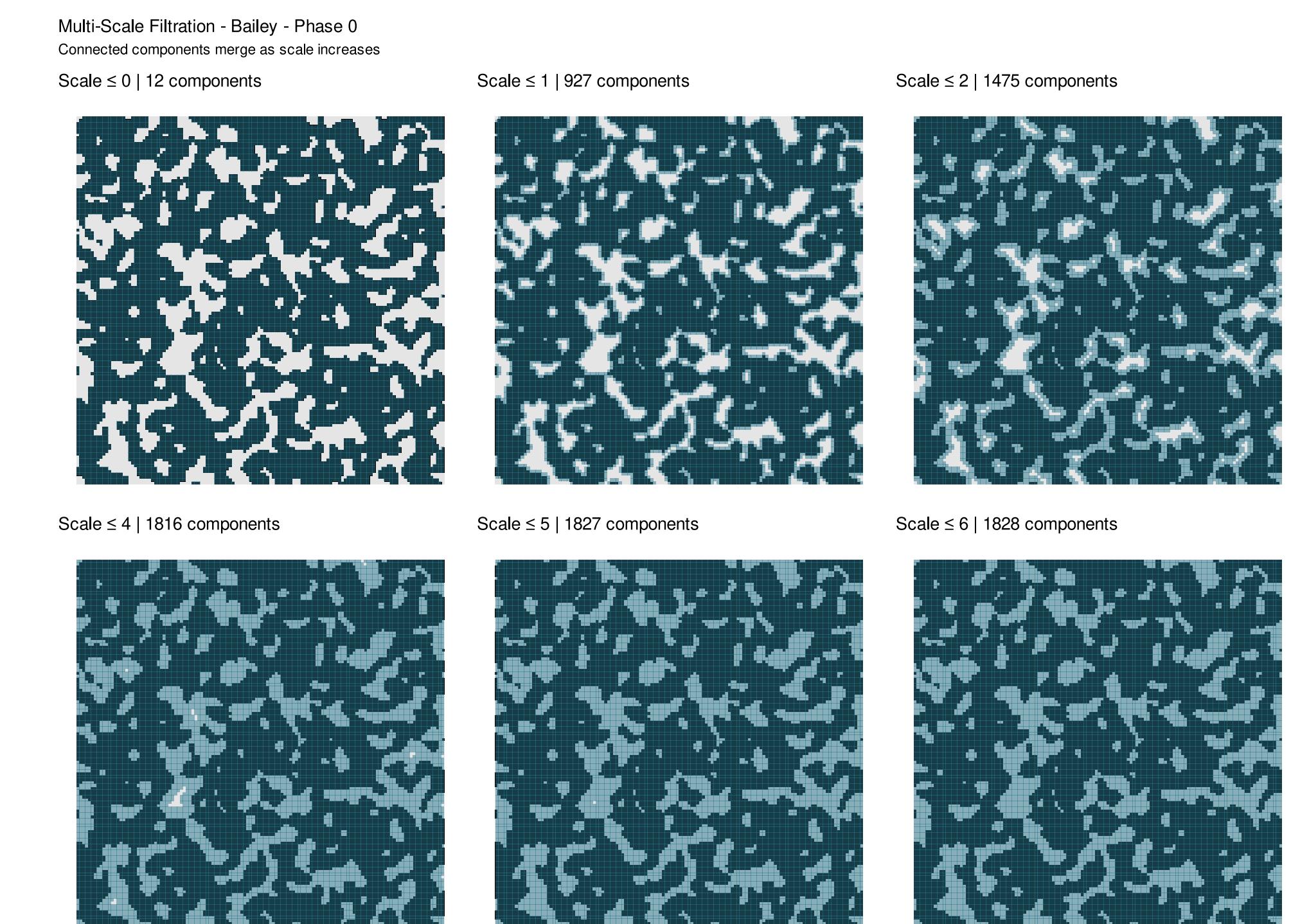


Figure 1: Number of connected components identified at different levels of dilation

- Multi-scale filtration shows how connected components merge and holes appear and disappear as scale increases.



- Each scale captures different aspects of mineral connectivity and pore structure.

