3D Classified GPR Facies Models From Multi-Frequency Data Volumes: A Synthetic Study

Philipp Koyan and Jens Tronicke

University of Potsdam, Karl-Liebknecht-Straße 24-25, 14476 Potsdam, Germany

Correspondence: koyan@uni-potsdam.de

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Summary

Modern GPR systems allow for acquiring densely sampled data sets also using different antenna frequencies. Here, we consider such a multi-frequency approach to image near-surface sedimentary structures at different spatial scales. Despite the steady technical development of GPR data acquisition, today's interpretation techniques largely rely on single-frequency data sets typically interpreted in a manual and, thus, subjective and non-reproducible manner. To pave the way toward a more objective and reproducible interpretation of multi-frequency GPR data sets, we develop an attribute-based multi-scale workflow. We evaluate our flow by integrating information of synthetic 50 and 200 MHz GPR volumes modeled across complex sedimentary structures showing heterogeneities at multiple spatial scales. Our strategy results in a multi-scale facies model comprising major structural variations as characterized by the 50 MHz volume and structural details as resolved by the 200 MHz data. We conclude that this attribute-based workflow poses an efficient and reliable tool to interpret both single- and multi-frequency GPR data and, thus, can either be an alternative or a guide for typical manual interpretation approaches. For further background information and relevant literature, we refer to the corresponding Proceedings Paper. The versatility of our approach is demonstrated on **Poster 122** where it is used to interpret GPR data collected along railway tracks.

Workflow

A – Synthetic Multi-Frequency GPR data
Processed, ready-to-interpret, 50 and 200 MHz data sets

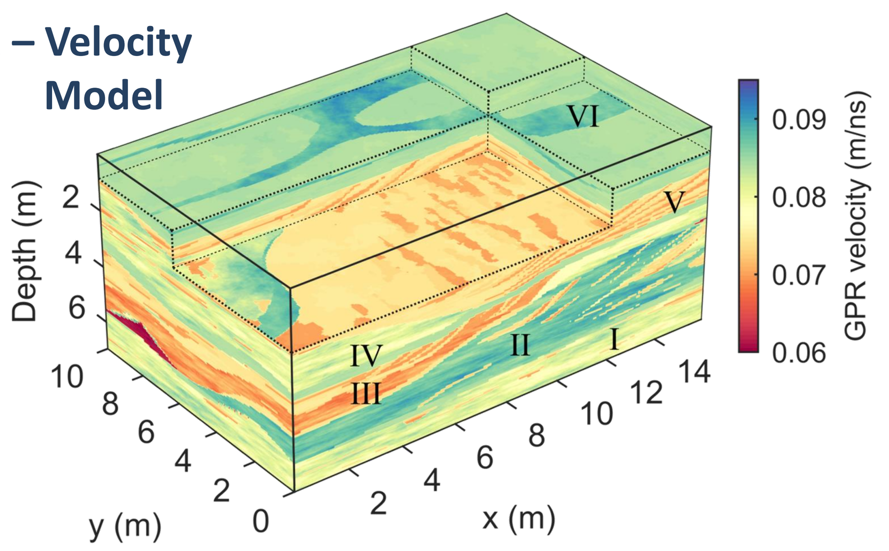
→ **B – Attribute Database**
Filtered 50 and 200 MHz texture and structural attributes

→ **C1 – Large-Scale Facies Model**
Classification of 50 MHz attributes

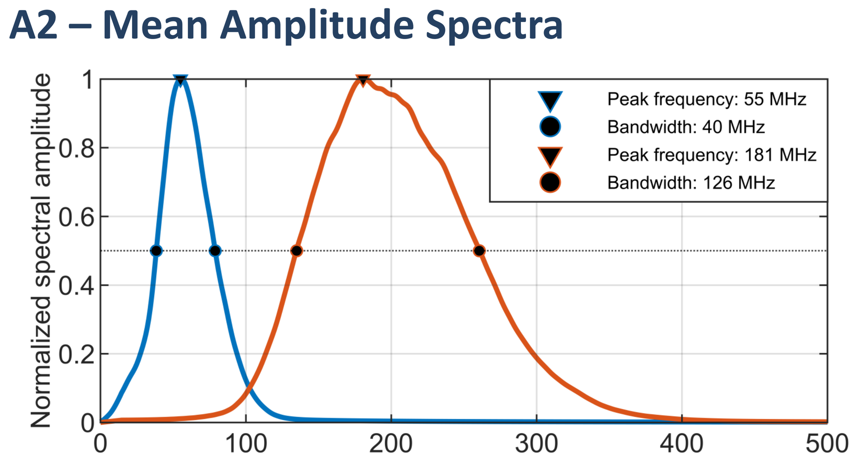
→ **C2 – Multi-Scale Facies Model**
Classification of 200 MHz attributes constrained by large-scale facies model

A - Synthetic Multi-Frequency GPR Data

A1 – Velocity Model

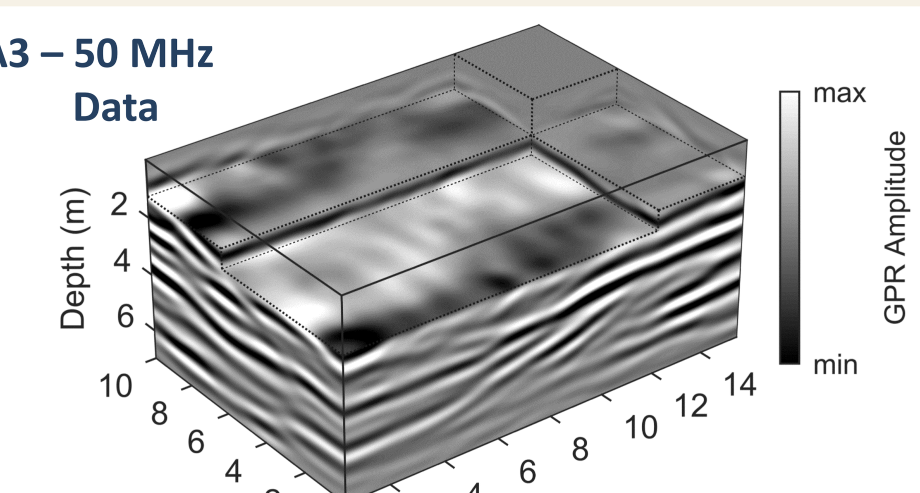


A2 – Mean Amplitude Spectra

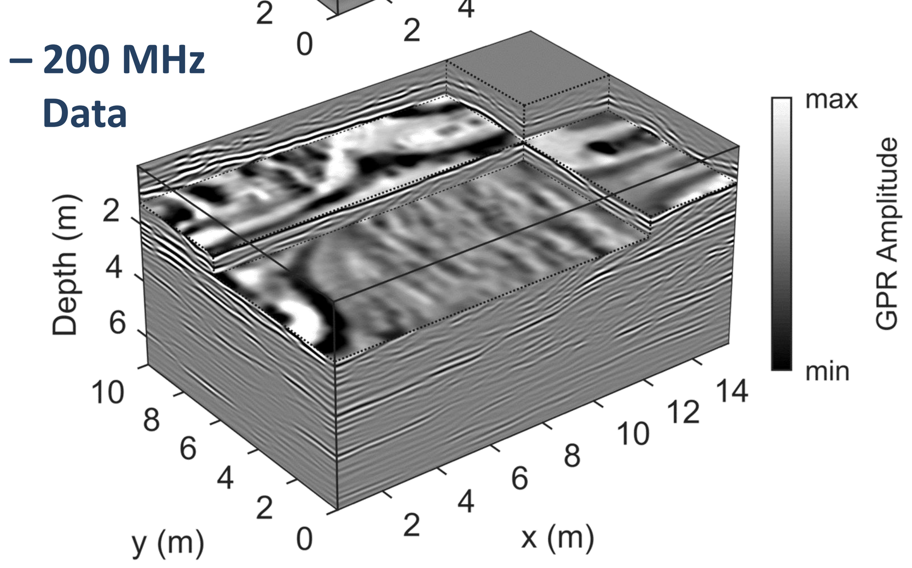


Free HDF5 and VTK versions of input model and selected synthetic GPR data

A3 – 50 MHz Data



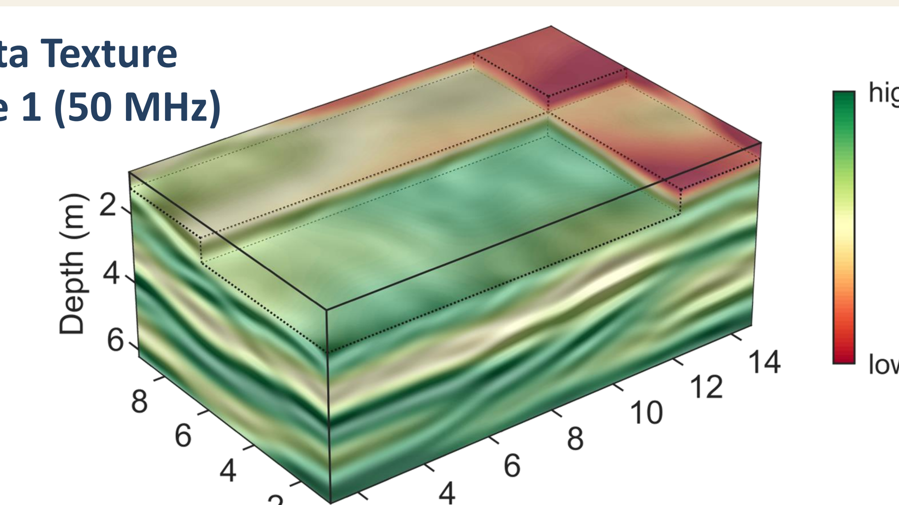
A4 – 200 MHz Data



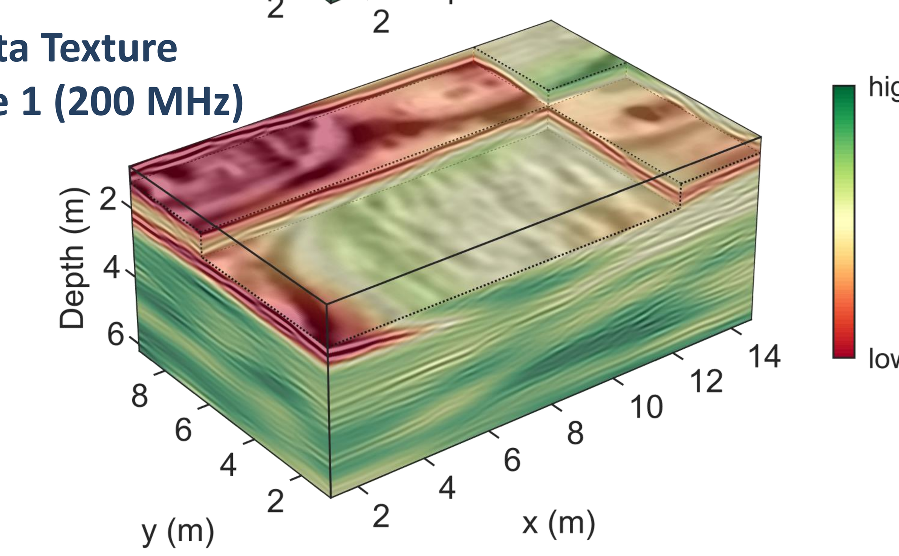
- **A1** Realistic sedimentary input model in terms of GPR velocity with main genetic units labeled from I to VI
- Unit VI: structurally rather homogeneous, large-scale undulating, small-amplitude velocity variations
- Units I, II, and IV: more heterogeneous regions characterized by local small-scale, high-amplitude velocity variations partly dipping towards lower *x* values
- Units III and V: alternating sequences showing small-scale, medium-amplitude velocity variations dipping towards lower *x* values
- **A2** Mean amplitude spectra of synthetic GPR data volumes simulated across A1 using a center frequency of 50 (blue) and 200 MHz (orange)
- **A3** Migrated 50 MHz volume imaging large-scale structures and major zonation
- **A4** Migrated 200 MHz volume resolving structural details
- Multi-frequency GPR volumes complement each other in terms of imaged spatial scales
- Integrated interpretation strategy desirable to better understand such complex sedimentary settings

B – Attribute Database

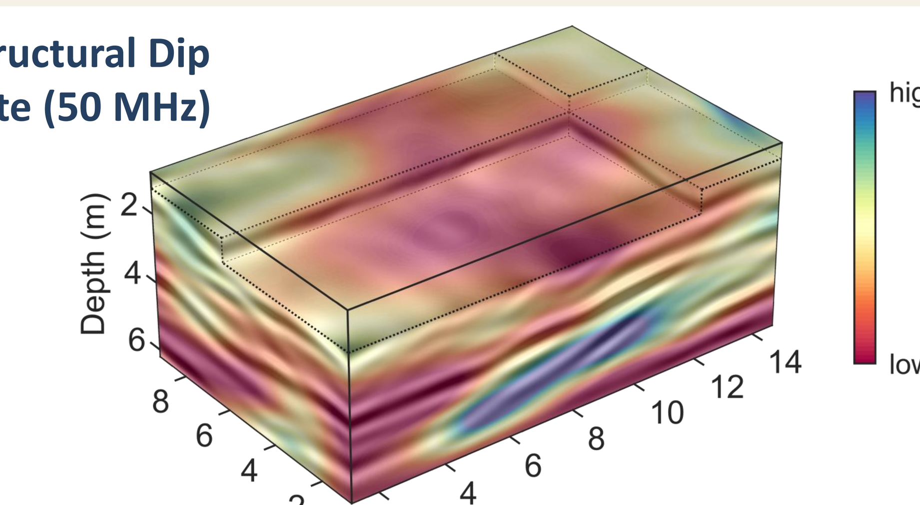
B1 – Meta Texture Attribute 1 (50 MHz)



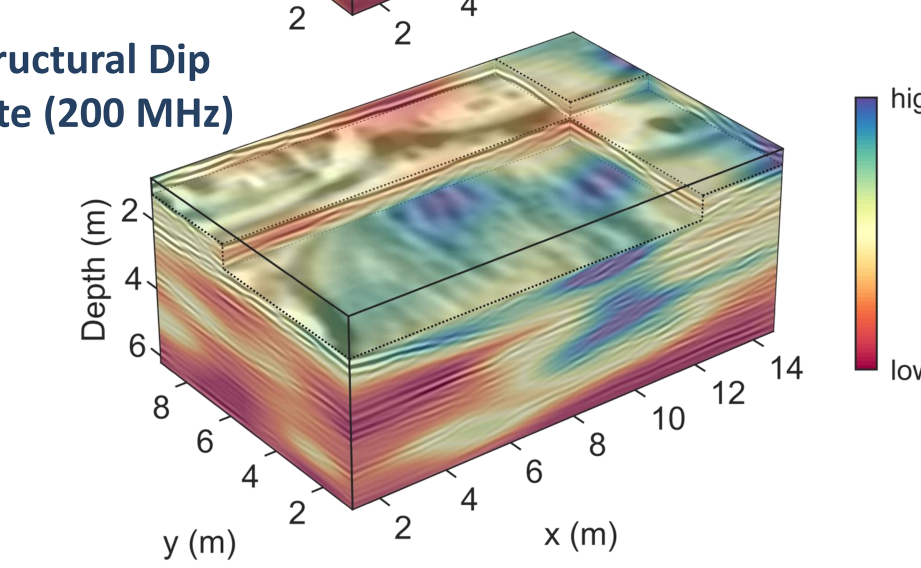
B2 – Meta Texture Attribute 1 (200 MHz)



B3 – Structural Dip Attribute (50 MHz)



B4 – Structural Dip Attribute (200 MHz)

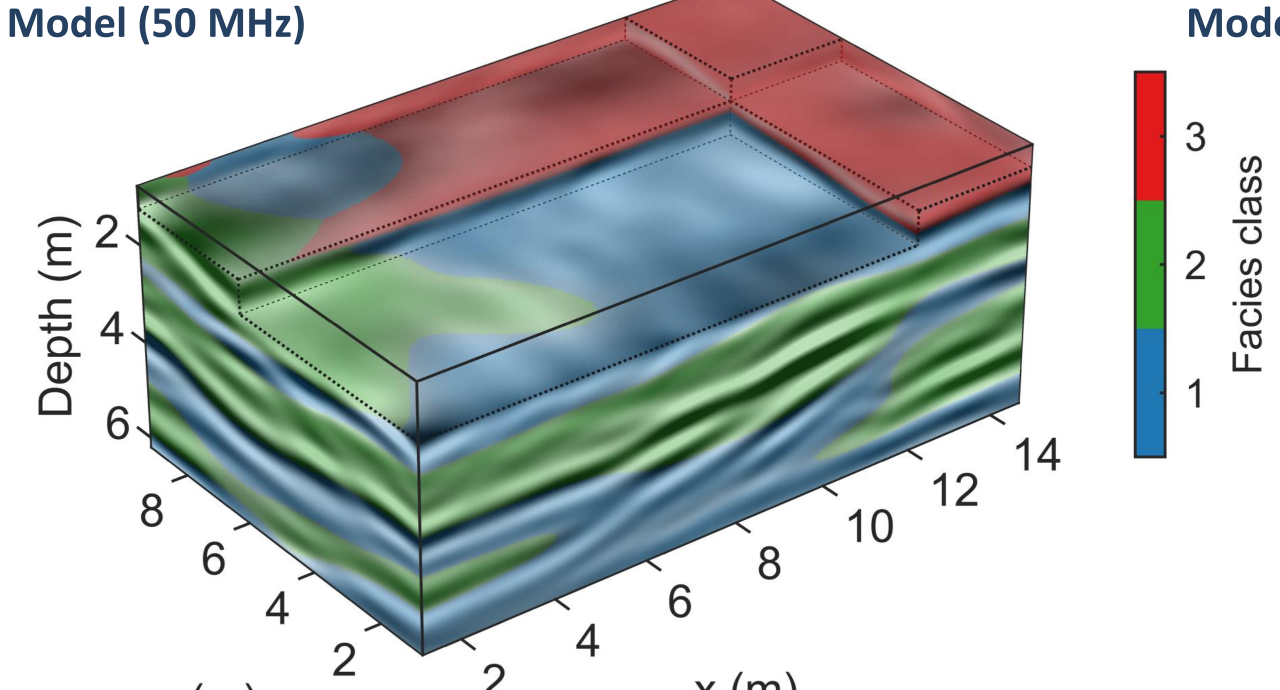


- 17 texture attributes calculated in 3D using gray-level co-occurrence matrix (GLCM)
- Principal component analysis to reduce database dimensionality and eliminate correlated information
- Meta texture attributes 1, 2, and 3 (i.e., the first three principal components) used for further analyses
- 3D structural dip attribute (i.e., geological dip angle) calculated from gradient structure tensor
- Scale-based filter strategy to focus on target spatial scales
- **B1, B2** Meta texture attribute 1 of 50 MHz and 200 MHz database as transparent overlay on corresponding data set
- **B3, B4** Structural dip attribute calculated from 50 MHz and 200 MHz GPR data sets (A3 and A4)
- 50 MHz attributes (B1, B3) comprise information on large-scale stratification indicating three major zones
- 200 MHz attributes (B2, B4) reveal details not resolved by 50 MHz data and attributes (e.g., within the alternating sequences found in units III and V)

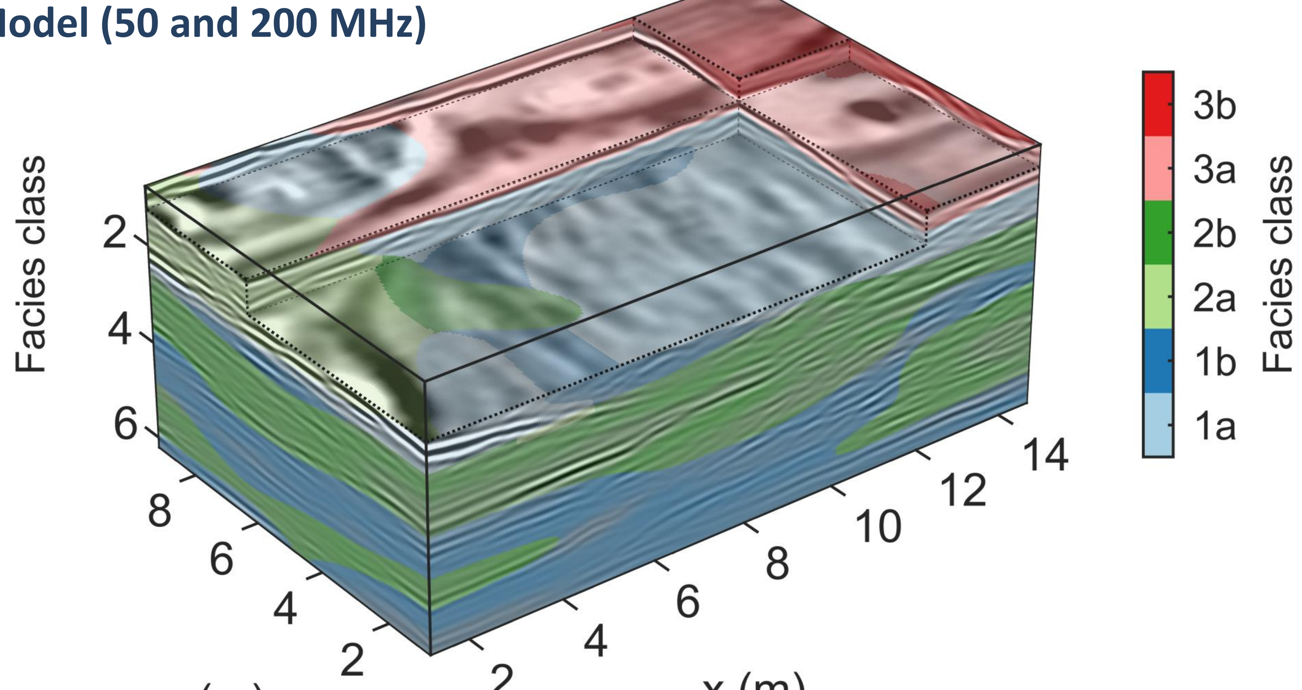
C - Attribute Classification Results And Interpretation

- Unsupervised fuzzy *c*-means cluster analysis to produce classified facies models also including degree of membership to each class for each datum
- Meta texture attributes 1 to 3 and structural dip attribute used as input for classification
- Number of classes/facies based on observations in GPR data sets (A), attributes (B) and further testing, e.g., using cluster validity measures
- **C1** Three-class facies model resulting from classifying 50 MHz attributes (color saturation reflects degree of membership)
- Meaningful zonation of major structural variations by three continuous facies with high memberships; e.g., facies 3 mainly comprises shallow, structurally most homogeneous region (unit VI in A1)

C1 – Large-scale Facies Model (50 MHz)



C2 – Multi-Scale Facies Model (50 and 200 MHz)



- Integration of details resolved by 200 MHz attribute database into large-scale facies model
- In large-scale facies model (C1), each facies class is subdivided into two detailed ones resulting in multi-scale facies model **C2**
- Multi-scale facies model reasonably delineates six continuous classes with high memberships
- Facies 3a distinguishes undulating layer embedded in largely homogeneous facies 3b
- Facies 2a distinguishes regions with subtle heterogeneities from zones showing small-scale, high-amplitude velocity variations found in facies 2b
- Facies 1a delineates alternating dipping sequences of unit V from less heterogeneous parts characterizing facies class 1b