Ground Penetrating Radar Assisted Characterization and Quantification using Frequency Domain Full Waveform Inversion of Varied Sedimentary Facies

Mrinal Kanti Layek

Supervisor: Dr. Probal Sengupta

Department of Geology and Geophysics

Abstract

The geophysical prospecting and modeling of the shallow subsurface require a high-resolution, cost-effective and non-invasive geophysical method like ground penetrating radar (GPR). The principle of GPR is based on the propagation of the electromagnetic (EM) pulse (10MHz to 2GHz) into the subsurface. The interpretation of GPR data poses a critical issue for different sedimentary subsurface exploration and modeling. The work presented here employed the qualitative and quantitative analyses of GPR data collected from different sedimentary environments. After comparing with the other techniques (like attribute analysis, travel time tomography, etc.), radar facies (RF) analysis and finite difference frequency domain (FDFD) full waveform inversion (FWI) seems to be more suitable and convenient for GPR data interpretation. The most common objectives of this Ph.D. work are as follows: (1) characterization of different sedimentary facies in lossy to low loss medium using RF analysis, (2) formulation and implementation of improved and efficient forward modeling method for GPR data and (3) testing the applicability and effectiveness of the newly developed numerical scheme in FDFD FWI.

To fulfill the first objective, three study sites of different sedimentary settings are considered. In the first part, Chandipur intertidal zone (Odisha, India), categorized as a high lossy medium, is investigated. A combination of geophysical study including GPR and vertical electrical sounding (VES) was done to identify different shallow-subsurface features like intertidal dunes, buried palaeo-channels, erosional surface, water table, eolian deposit of sand, washover delta and erosional surfaces, which are all present in this intertidal coast of the eastern parts of India, adjoining the Bay of Bengal (BoB). Consequently, based on the data, a conceptual model of the depositional and erosional history of the sedimentation of the area, as well as, the coastal hydrogeological disposition, was conceived. A moderate to low loss sedimentary setting of Paradeep coastal barrier (Odisha, India) is investigated with 200 MHz GPR antenna. GPR reflection survey was done to delineate the shapes and sizes of the sedimentary features, erosional surfaces, channels, scour-and-fill structures, progradational beddings and internal geometry of the beach ridge deposits. Here, cyclicity of erosion and accretion has been established from this study. To test the applicability of RF analysis of fluvio-GPR data, the point bar adjoint to the river Ganga in Varanasi (Uttar Pradesh, India) is selected as study area. Here, the groundwater table (2-2.5 m below ground surface (bgs)) becomes shallower in both cliffside and riverside while getting relatively deeper in the middle part of the point bar. The fluvial deposits, like coarse to fine sand, act as potential local groundwater storages.

For the second objective, forward modeling of GPR data has been presented which plays an important role in the inversion/modeling of the observed data. So, the selection of a better FD grid is most important. For this reason, six unstaggered grid and two staggered grid formulations with the perfectly matched layer (PML) are employed. Among these stencils, a new nine-point staggered grid with complex frequency stretched PML (CFSPML) technique has been proposed and applied to the subsurface models using MATLAB programming. This proposed scheme has been proven to be the best FD-grid technique for forward modeling.

Finally, for the last objective, the guideline for better multiparameter imaging for GPR data, especially collected from varied sediments, is established using the quasi-Newton method and simultaneous frequency sampling strategy of irregular sampling. The full waveform inversion (FWI) is an optimization technique which involves in search of the minima between recorded and predicted data. In the FWI, the effectiveness of the proposed technique is also tested. Several numerical experiments with a synthetic model have established the fact that the new grid formulation produces a faster converging rate and required less computation time. This method is also very much effective for the realistic sedimentary model of the lossy medium. The proposed method is also applicable for modeling of the acoustic wave with some necessary modifications.

Keywords – Ground Penetrating Radar (GPR), Radar facies (RF) analysis, Sedimentology, Finite difference frequency domain (FDFD), Full waveform inversion (FWI).