Understanding shallow marine clastic reservoir heterogeneity from modern analogues resolved by GPR and drone imagery

Patrick Duff
University of South Carolina

Abstract

Clastic deposition in the continental and near shore environment is widely recognized as complex, and is controlled by allogenic processes such as eustasy and tectonics and autogenic processes influenced by fluvial discharge, and morphologic inheritance. The dynamic nature of the processes that drive fluvial to shallow marine deposition results in deposits that exhibit abrupt lateral and vertical discontinuities in facies that juxtapose porous and permeable units with impermeable ones. The complex geometries and stacking patterns that form the depositional architecture of preserved continental and near shore depositional systems represent significant obstacles to applying many of the conceptual and stochastic models utilized in exploration and reservoir modeling. Close examination of modern fluvial to shallow marine deposits of reservoir quality sand can assist in predicting the occurrence of these deposits in the subsurface, as well as understanding their internal structure.

To establish a proof of concept, a series of vibracore samples, GPR reflection lines, and rotary-wing drone surveys will be acquired on the coastal plain of South Carolina to investigate the internal structure and stratigraphy of strand-plain/barrier-island sand deposits, to define the morphological expression of these features, and to estimate their reservoir characteristics. A 3D GPR reflection grid, as well as a common midpoint survey and borehole survey will be collected in 100 and 200 MHz within a paleo-shoreface deposit at the University of South Carolina's Baruch Institute for coastal science research. These near surface geophysical data will be integrated with vibracore data and drone imagery to resolve the geometry and internal structure of the deposit, including bedform types and scales, as well as internal surfaces, such as unconformity, flooding, and accretionary surfaces. Stratigraphic units are differentiable on the basis of vibracores, as well as radar sections, with observed changes in radar velocity and facies correlative to structural and/or stratigraphic interfaces. Raw subsurface data will be processed to develop data products such as a depth converted GPR volume, a GPR velocity log for the borehole, digital core logs and photos for the continuous cored interval within the GPR volume, and a DEM and digital orthomosaic of the land surface. These data products will be used to construct a 3D near surface model of the deposit using Schlumberger Petrel software. The results will establish the suitability of the imaged deposit as a reservoir analogue for ancient equivalents. The high resolution imaging (centimeter scale) of modern deposits made possible by GPR and fixed-wing drones will allow the 3D near surface model to be used to condition subsurface reservoir models by defining internal geometries not imaged by seismic data and assisting the estimation of reservoir heterogeneity.

Technical Approach and Plan

The equipment used to conduct the proposed research includes a Sensors and Software ground penetrating radar (GPR) system, a DJI Phantom 4 unmanned aerial system (UAS) rotary wing drone air craft, a Leica GPS 1200 real time kinematic (RTK) GPS, and a vibracore sediment sampling system. GPR is a noninvasive technique for imaging the shallow subsurface to ~25 m depth. The system consists of transmitting and receiving antennas that propagate electromagnetic (EM) energy into the subsurface. When the incident wave encounters an interface across which there is a significant difference in EM properties, the incident wave is reflected back to the surface. The resulting data can be processed into an image that resolves structural and stratigraphic features of the subsurface, including faults, folds, bedforms, depositional surfaces, and lithofacies. GPR surveys can also define the velocity structure of the near-surface; these data can be used to refine or confirm interpretations made on the basis of reflection data or as an independent constraint on geology. Velocity information is also used for time to depth conversion of reflection data, and to perform a GPR to well tie.

UAS drone derived structure from motion (SfM) photogrammetry is a scale-invariant method for producing 3D models of the land surface, such as digital elevation models, which can be overlain with high resolution imagery. The highly accurate survey coordinate system produced from SfM image restitution can be registered to a real world coordinate system via ground control points surveyed in using RTK GPS, which delivers centimeter scale accuracy in 3D. The combination of these datasets permits high resolution morphometric analyses and change detection (for time transgressive 4D data). Vibracore and push core sediment sampling, which involves either a high frequency weighted vibrator used to force a 4” core barrel into the subsurface, or a smaller handheld instrument such as a Dutch gouge allows the user to directly sample a vertical column of sediment in order to correlate geophysical observations and provide additional data to resolve stratigraphic and lithologic relationships.

Data products derived from raw near surface geophysical data and core will be used to construct a 3D near surface reservoir analogue model of the strand-plain/barrier-island deposit using Schlumberger Petrel software. The static reservoir analogue model can be used to condition subsurface reservoir models by defining internal geometries not imaged by seismic data and assisting the estimation of reservoir heterogeneity.

The combination of the technology and methods described above is ideally suited to achieve the goals of the proposed research. The research method is flexible, noninvasive, and amphibious, and the datasets produced offer a resolution and geospatial accuracy appropriate to answer the research questions suggested by the accompanying abstract. Furthermore, given the dynamic nature of shallow marine deposits, and the ease and low cost of collecting these data, field sites can be reoccupied in order to produce 4D datasets that will shed light on the various processes responsible for producing the observed sedimentary structures and stratigraphic architecture. There are limitations associated with the proposed methods, however. These include the sensitivity of GPR to salinity in ground water or surface water, and the difficulty of achieving high resolution GPS data under a dense canopy of trees. While the former can be addressed by choosing preserved Holocene equivalents of modern deposits, which should reside in a freshwater domain, the latter can be addressed by using GPS reference station and rover techniques, along with the post-processing of data in order ensure high geospatial accuracy in difficult field conditions.

The timeline for the project targets field acquisition at the strand-plain/barrier island field site in the coastal plain of South Carolina and associated data processing and integration within a time frame of 14 months. Critical milestones include completion of field data acquisition by month 6, completion of data processing and integration by month nine, and completion of data analysis/synthesis by month 12. Months 13 and 14 will be used to produce final data products and write up results in the form of at least one peer- reviewed manuscript.