An ultra high-density, high-resolution multi-component seismic reflection program for near-surface characterization of the Upper Mississippian Embayment.

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SUMMARY

An ultra-high-density 6C, 2D seismic reflection program has been implemented to characterize the near-surface unlithified sediments of the Upper Mississippi Embayment. This program is a collaboration between the University of Kentucky, Collier Geophysics and Explor and was specifically designed for near-surface characterization of Quaternary clastic sediments and upper Cretaceous deltaic sediments overlying Mississippian carbonate bedrock. The work presented will describe the geologic setting, the design and implementation of the acquisition program and share preliminary results of the shear-wave reflection imaging.

INTRODUCTION

The near-surface Quaternary sediments of the Mississippi embayment in western Kentucky are complex. The depositional environment consists of sediments that have been influenced by the paleo-fluvial interactions of the ancestral Tennessee, Ohio and Mississippi Rivers. A variety of different clastic components are represented ranging from highly plastic materials to cobbles and the stratigraphy is further complicated by a surface layer of fine loess deposited during the last glacial retreat. The complex fluvial clastic sequence contrasts sharply (below) with partially indurated (and fractured) high impedance Cretaceous deltaic sediments. These are affected by intraplate tectonics associated with the Reelfoot rift and Rough Creek Graben.

There is a large body of historical work dedicated to resolving structural features within the Upper Mississippi Embayment. Woolery et al, (2009) and Woolery and Almayahi, (2014a) among others provide ample evidence that shear and mode converted reflection imaging is best suited for resolving the complex combination of low on top of high impedance sediments.

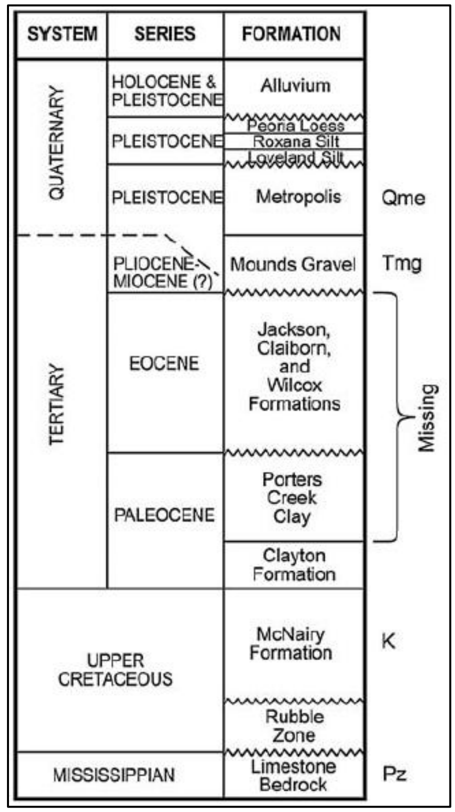

Figure 1. Stratigraphic column of near surface sequences; Eocene and Paleocene units were removed at the site by ancestral Tennessee River (Woolery and Almayahi, 2014a).

The current program is an extension of these efforts and is composed of two grids of six (6) high density 2D lines. Each 2D line is approximately one (1) km long and consists of three-component recording (3C) and a two-component source effort (2C) at 1m source and receiver spatial sampling. It is believed that this program represents the highest density production reflection survey ever acquired within the Upper Mississippi Embayment.

OVERVIEW OF THE FIELD PROGRAM

The data program will consider compressional, mode converted and shear data for resolving the soft loose impedance of Quaternary and stiff Cretaceous sediments. The ultra high-density geometry is necessary to avoid aliasing the imaging of near-surface alluvium sequences as shallow as 5-10m depth. In comparison, the upper sections of the heavily weathered Mississippi carbonate unit are expected to manifest between 100 and 200m below surface. The regional depositional environment for the northernmost embayment is summarized by the representative stratigraphic column provided in Figure 1 courtesy of Woolery and Almayahi (2014a).

The field program requirements for high density acquisition constrained the selection of recording instruments and source effort. Although there are numerous vendors that provide options for 3C recording, there are few vendors that were able to provide the necessary volume of channels (and spares). Given their availability in large quantities, the Stryde node was selected for the receiver effort. These 1C nodes were developed by BP for dense, low-cost high-density field recording (Manning et al, 2019).

The Stryde node is a compact device consisting of battery, single component sensor, GPS and communications electronics in a case roughly 5in in length and 1.5in in diameter. The Stryde node weighs 150g and employs a piezo electric sensor with a dynamic range of 1-125Hz (stryde.io). As a 1C node, it may be coupled with two other nodes in an orthogonal configuration using a metal jig. A spike may be added to the jig to help with coupling to the solid Earth (Figure 2). In this case, we used the 3C converter patented by Explor (Châtenay, et. al, 2022).

In a similar fashion, although compressional sources are common, the same is not true of shear energy sources. As the program includes a substantially large number of compressional and shear source locations, a minimum pair of primary and spare Vibroseis units were not found in sufficient proximity to the project site.

Figure 2. Field deployment of three single component Stryde nodes configured as a 3C receiver. The photo shows two (2) separate 3C receiver stations at the 1m receiver interval used on the project.

In lieu of Vibroseis, several other types of field sources were considered. The first type of source considered for *both* compressional and shear energy is an electro-fluidic impulsive source developed by Explor in collaboration with HyFold (Calgary, Canada), named 'LightSpeed'. The LightSpeed device is still a tool in development and was originally designed as a fast and repeatable compressional source. As a compressional source, it was successfully deployed for 80% of the program until forced to retire due to equipment fatigue. It was replaced for the remainder of the program by a simple weight drop system (Figure 4). The deployment of LightSpeed as a shear source was previously untested. As a shear source it was tested on two lines but was ultimately proven to be unreliable.

The remainder of the shear program was acquired using a simple hammer and I-beam (Figure 5). This final choice was based upon the considerable previous success of imparting shear energy with hammer and I-beam in the Upper Mississippi Embayment (Woolery and Street, 2002; Woolery and Almayahi, 2014a). As the large body of historical work has suggested, this type of source proved to be exceptionally effective in the current reflection imaging environment and program.

Seismic acquisition and imaging of multi-component data is a complex process, very time consuming and expensive. Consideration of all six combinations of the recorded wavefield was beyond scope and only three (3) modes were considered for imaging. The three primary products consisted of: (P-P) P wave source and vertical geophone, (SH-SH) transverse shear source and transverse (orthogonal) receiver and (P-SV) P wave source and mode converted shear on the radial (in-line) receiver.

Figure 3: "LightSpeed" electro-fluids impulsive source.

DATA PRCOCESSING CONSIDERATIONS

Given the significant investment in acquiring high-fidelity, high-resolution, multi-component reflection data, a dual data processing program is being employed for pre-stack time imaging of the data. Two different seismic processing partners were selected to validate data efficacy: Stryde (stryde.io) and GeoTomo (geotomo.com). Both processing partners have independent software tools and high-performance computing environments. Each processing partner is expected to pursue a similar but independent workflow for preparing raw field data, attenuating undesirable signals and constructing an image of the subsurface. A deeper investigation of the processing results will be presented once complete.

An initial preliminary imaging result is presented in Figure 6 courtesy of GeoTomo. This SH-SH reflection imaging example demonstrates the effectiveness of the transverse shear I-beam and hammer source with the transverse receiver. The vertical axis represents 100ms of two-way travel-time. The length of the line is approximately 1000m.

Figure 4: Compressional weight drop source.

As can be observed, numerous reflections have been captured and imaged spanning shallow Quaternary sediments to deeper basement stratigraphy. A planned future interpretation of the seismic imaging results will consider calibration of the subsurface impedance with regional well control.

CONCLUSIONS

A high density 6C program has been acquired in the Upper Mississippi Embayment. The program captured three primary wavefields (P-P, SH-SH and P-SV). Initial imaging results demonstrate the effectiveness of the data acquisition program. Future work will explore the various nuances of compressional and shear imaging of the data. Additional work will investigate the subsurface azimuthal response and calibration with regional well control.

Figure 5: Shear energy I-beam and hammer source.

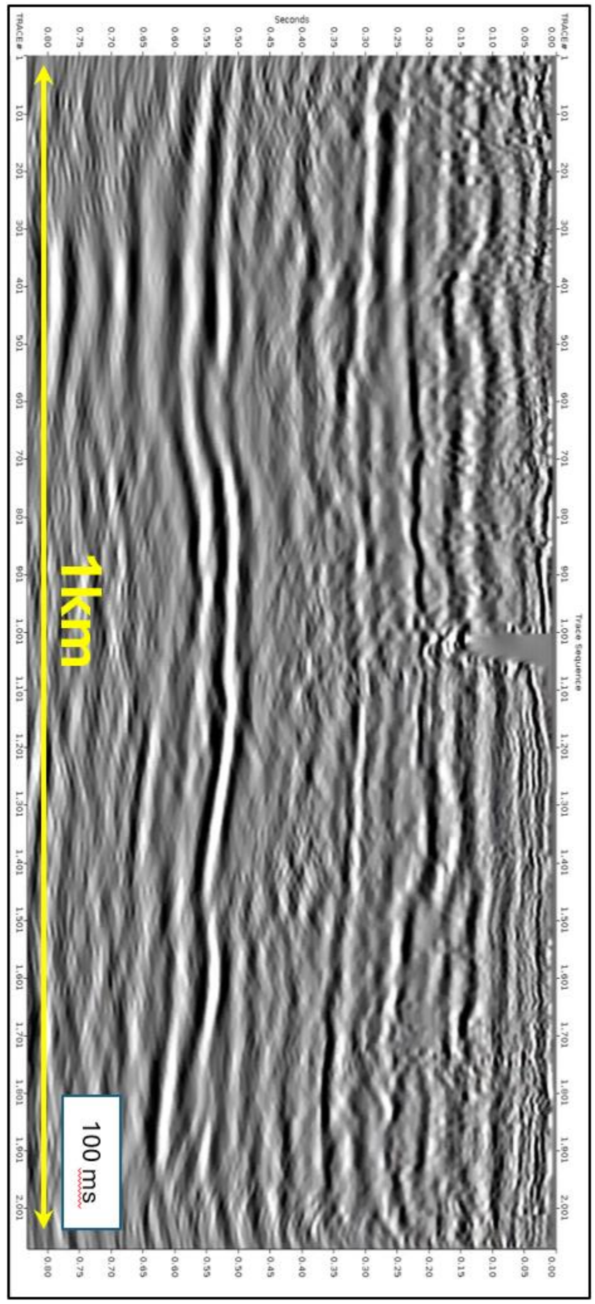

Figure 6: A representative SH reflection imaging example. Image courtesy of GeoTomo.

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