FINAL TECHNICAL REPORT

CENTRAL UNITED STATES SEISMIC OBSERVATORY: PHASE I, BOREHOLE INSTALLATION

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ABSTRACT

Estimating earthquake ground motions of earthquake engineering interest in the thick soil/sediment deposits in the upper Mississippi embayment is problematic. The problems can include: 1) site effects due to thick (>100 m) layers of low shear-wave velocity sediments, 2) non-linearity, 3) attenuation along propagation paths (lateral and vertical) between the seismic source and the surface, and 4) ground motion differences between lowland sites (i.e., floodplain) in northeastern Arkansas and southeastern Missouri and upland sites (i.e., loess bluffs) in western Tennessee (including Memphis) and Kentucky.

In order to better address these issues we will install a borehole seismic observatory with instrumentation beneath, within, and atop the thick sediment overburden. This study completed the first phase of the observatory construction, the borehole installation. Specifically, a 595-m borehole was drilled, cased, and logged (both geophysical and geological) for the future establishment of the vertical observatory. The borehole penetrated the entire sediment overburden (586 m) and was terminated 9 meters into limestone bedrock. The hole was cased from the ground surface to a depth of 589 meters with 102-mm diameter steel casing. Stainless steel casing of the same diameter was extended from 589 meters to the bottom of the hole. Prior to casing the hole, electrical, sonic velocity (P- and S-wave), and deviation logs were completed.

The instrumented observatory will ultimately evaluate the soil transfer function of the poorly lithified post-Paleozoic sediments at the site near the center of the New Madrid seismic zone (NMSZ). In addition to constraining existing and future site response models in the region, the final array will act as a calibration site for regional seismic stations. The observatory site is near the most active part of the NMSZ; therefore, it should provide the maximum amount of data in the shortest period of time. The site also consists of two shallow (250m and 30m) operating vertical arrays.

NONTECHNICAL SUMMARY

The thick Mississippi embayment soil/sediment deposits are expected to alter the amplitude, duration, and frequency content of a significant earthquake. Estimating the ground motions of earthquake engineering interest in these thick deposits is problematic, however. To address these issues, we have completed Phase I of constructing a seismic observatory that penetrates the thick sediment overburden by installing a 595 meter cased borehole near the central segment of the New Madrid seismic zone that can be instrumented with a vertical seismic array. The completed borehole is capable of housing instrumentation beneath, within, and atop a 586-m sediment overburden, and will allow researchers to evaluate the effects deep soils have on earthquake ground motions. In addition, the instrumented observatory will allow characterization the dynamic soil properties responsible for the effects, validation of geotechnical techniques currently being used to characterize deep soil sites, and calibration of the numerous free-field strong-motion stations throughout the Mississippi embayment.

INTRODUCTION

The thick Mississippi embayment soil/sediment deposits are expected to produce significant earthquake site effects. Consequently, the primary objective of this ongoing research is to ultimately rigorously evaluate the soil transfer function of the post-Paleocene sediments at a site near the center of the New Madrid seismic zone (NMSZ) for the purpose of constraining existing and future site response models in the region (Fig. 1). The site of the new borehole for the Central U.S. Seismic Observatory (CUSSO) is near the most active part of the NMSZ; therefore, it should provide the maximum amount of data in the shortest period of time. The location of the site is typical of what Toro et al. (1992) referred to as Embayment Lowlands (i.e., floodplains) that cover much of the northern embayment (Fig. 2).

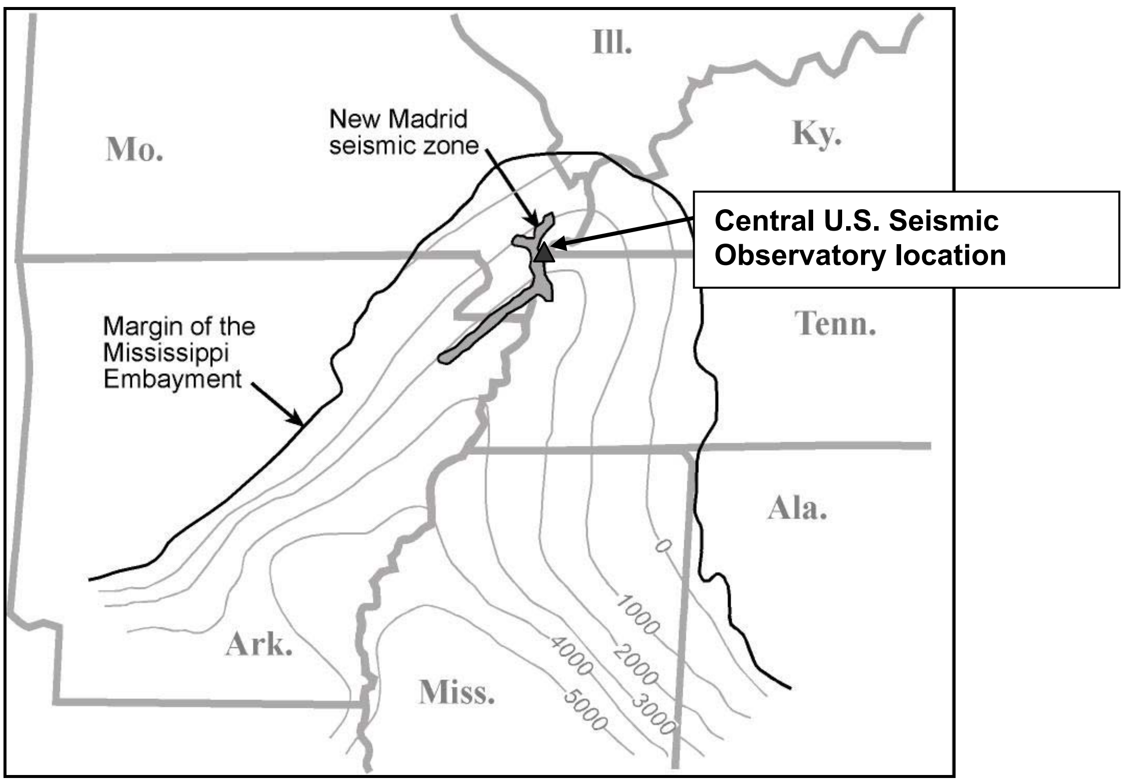

Figure 1. Map showing the location of the new 595-m borehole for the central U.S. seismic observatory. Also, located at the site is strong-motion array, VSAS. The site is located near the central segment of the New Madrid seismic zone. The contours show sediment thickness in feet below mean sea level.

The upper Mississippi embayment is a south-plunging synclinal trough characterized by gently dipping post-Paleozoic sediments that thicken to the south. The drilled depth to the Paleozoic bedrock at the site was 585 m. This depth was anticipated from a walkaway seismic sounding adjacent to the well site prior to drilling. This report describes the results of the drilling, geophysical logging, and interpretations. Detailed information regarding equipment, acquisition parameters and instrumentation can be obtained from the PI's.

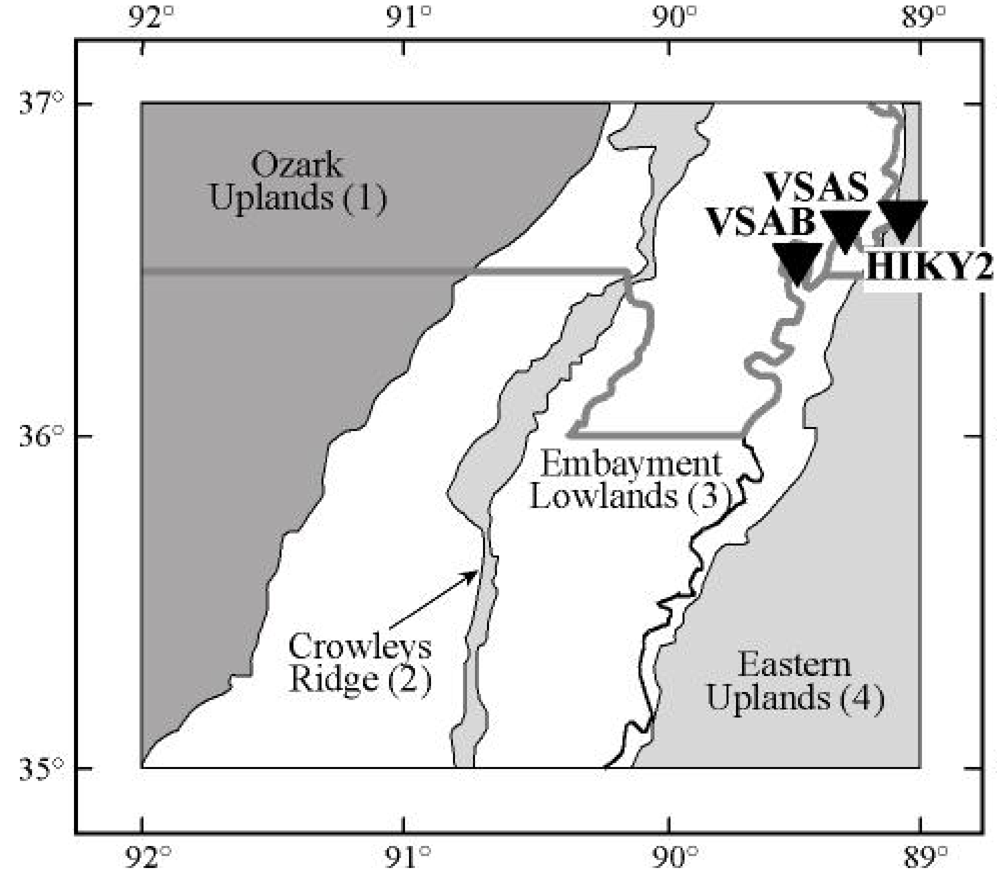

Figure 2. Four soil regions discussed by Toro et al. (1992). The new borehole site (CUSSO) is located adjacent to the vertical accelerometer array VSAS, and is situated between existing strong-motion stations VSAB and HIKY2.

Five significant contributions to the NEHRP program are expected from the completed CUSSO array.

- Evaluation of the effect of deep soil conditions on earthquake ground motions in the NMSZ.
- Characterization of the dynamic soil properties of the post-Paleozoic sediments in the central NMSZ.
- Validation of techniques currently being used to characterize deep soil sites.
- Evaluation of NEHRP Recommended Provisions, as they pertain to the NMSZ.
- Evaluation of path effects between stations VSAB, VSAS, and HIKY.
- Calibration for the numerous free-field stations in the Mississippi embayment.

PHASE I RESULTS

Location: A Fulton County, Kentucky landowner (Mr. Austin Voorhees) has granted the University of Kentucky a 25-year right-of-entry (with extension option) to a small parcel of land for the purpose of installation and operation of the CUSSO and existing vertical strong-motion seismic array, VSAS. Specifically, CUSSO and VSAS are sited in the community of Sassafras Ridge, Kentucky, at coordinates N 36º33.139’, W 89º19.784’.

Drilling: A mud rotary drilling rig advanced a 15 inch (381 mm) diameter borehole through the alluvium to a depth of 150 ft (45.7 m) below ground surface. The second phase of drilling telescoped down to a 10 inch (254 mm) diameter boring that was extended through the remaining poorly lithified sediment, terminating 9 meters into limestone bedrock. Cutting were collected at the well head and saved for stratigraphic interpretation at the Kentucky Geological Survey's Well Sample and Core Library. The geological interpretation of the cuttings is shown in Figure 3.

Stratigraphic and Geophysical ELog Interpretations: The contact between the surficial alluvium and the underlying Jackson Formation is interpreted to be at 155 feet (47.2 m) below the surface at an elevation of 135 feet (41.1 m) msl. This boundary marks a distinct lithologic change between the overlying coarse sand and gravel and underlying black clay. There is also a distinctive change in the gamma and spontaneous potential logs (Fig. 3). Reported palynomorph assemblages in the Jackson Formation represent deposition in a continental lacustrine environment, however some marine forms are also present in some localities (Olive, 1980).

The contact between the Jackson Formation and the underlying Claiborne Formation was placed approximately 430 feet below the surface at elevation -140 feet (-42.6 m) msl. A lithologic change was interpreted from the driller's log, as well as the electric logs. Lithologically, the underlying green sandy clay of the Claiborne Formation is glauconitic and evidence for marine environment deposition. There was also a significant change in the electric logs as further evidence for a stratigraphic boundary (Fig. 3).

The boundary separating the Claiborne Formation and the underlying Wilcox Formation is approximately 900 feet (274.3 m) below the surface at elevation of -610 feet (-185.9 m) msl. The contact was interpreted from litholigic differences and a distinctive change in the gamma log. The sand and cemented sand is correlative with the Claiborne Formation, and the underlying clay is correlative with the Wilcox Formation.

The Wilcox Formation is separated from the underlying Porters Creek Clay at approximately 1300 feet (396 m) below the surface at elevation -1010 feet (-307.8) msl, and is relatively easy to identify lithologically and geophysically. The Porters Creek Clay is a distinctive, thick sequence of clay and underlies the sandy clay lithology of the Wilcox Formation. This lithologic change is also evident in the gamma and spontaneous potential logs.

The contact between the Porters Creek Clay and the underlying Clayton and McNairy Formations is approximately 1590 feet (484.6 m) below the surface or at an elevation of -1290 feet (-393.2 m) msl. Lithologically, there is distinct contrast between the overly clays and the underlying sand and clays of the Clayton and McNairy formations. This lithologic distinction is exhibited well by the spontaneous potential log (Fig 3).

The Clayton and McNairy Formations boundary with the underlying Paleozoic bedrock is approximately 1925 feet (586.7 m) below the surface at elevation -1625 feet (-495.3 m). The contact is exhibited well by the gamma and spontaneous potential logs (Fig. 3). The limestone is likely Mississippian in age, but the exact age and formation is equivocal.

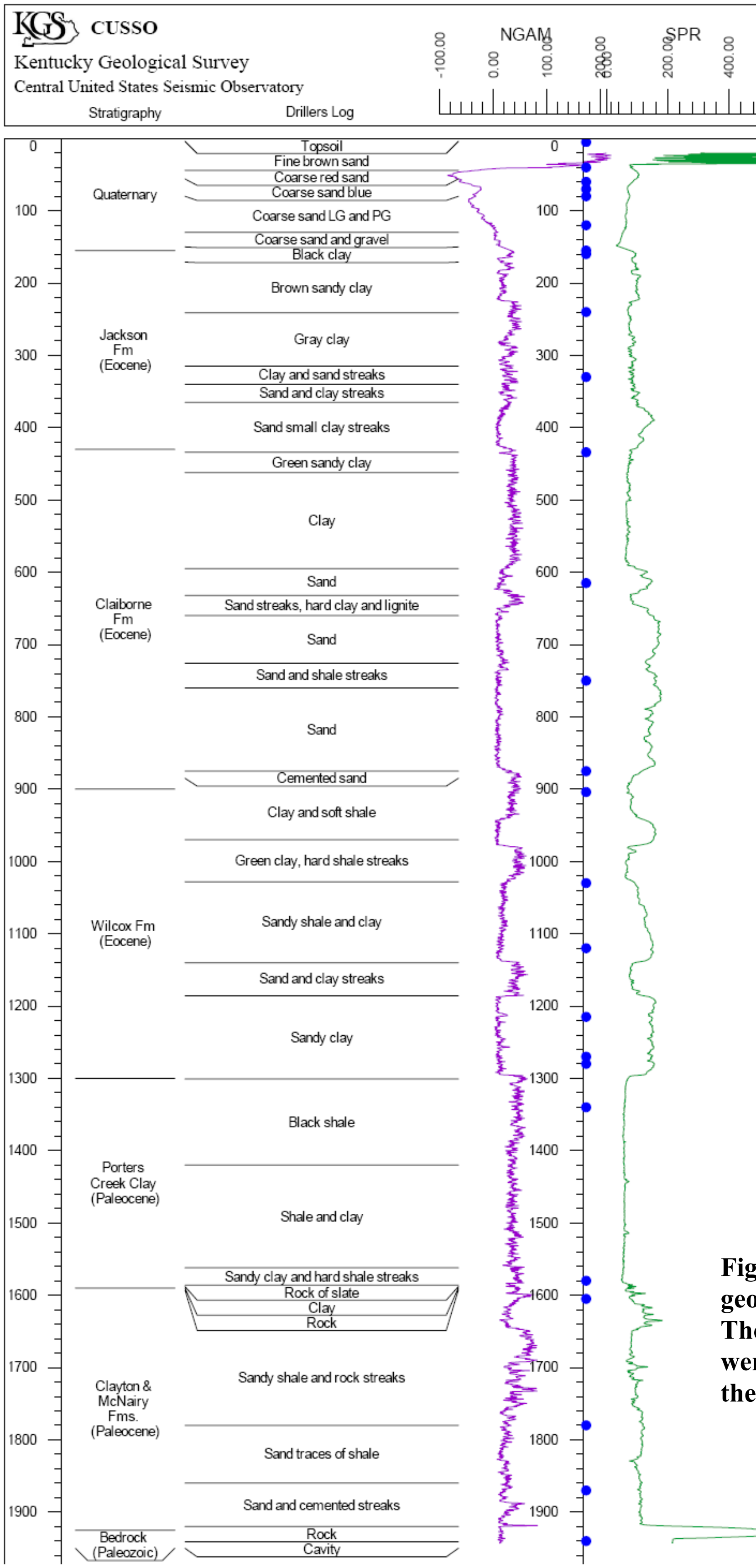

Figure 3. Stratigraphic and geophysical well log interpretations. The stratigraphic interpretations were made from cuttings collected at the well head.

There are three industry wells near the CUSSO site on Sassafras Ridge in the Bondurant Quadrangle. The stratigraphic tops of the formations are listed on the Bondurant GQ, and the driller's logs are available via the Kentucky Geological Survey oil and gas database. These holes include KGS oil and gas record numbers 8740, 8741, and 8742. Record number 8740 is approximately 2.4 km southwest of Sassafras Ridge. Record number 8741 is approximately 4.0 km east, and record number 8742 is approximately 3.6 km south of Sassafras Ridge, respectively.

Stratigraphic interpretations from the CUSSO hole were correlated with the stratigraphic interpretation of the nearby deep-holes. The depth to the top of the Jackson Formation is consistent in all the holes. The Claiborne Formation is hard to distinguish from the Jackson Formation, therefore that stratigraphic interval is not identified in the 3 holes near the Sassafras Ridge hole. The Wilcox Formation is of variable in thickness and is deposited on an irregular surface; however the elevation of this formation on Sassafras Ridge is consistent with the other deep-holes given the regional dip of the strata in this part of the Mississppian Embayment. The elevation of the top of the Porters Creek Clay, Clayton and McNairy Formations, and Paleozoic bedrock are all consistent with the elevation of the nearby deep-holes.

<u>P- and S-Wave Velocity Suspension Logs:</u> The P- and S-wave velocity logs were interpreted to yield 12 layers. The boundary contacts, thicknesses, and measured velocities are given in Table 1. More detailed information regarding procedures, equipment, and acquisition parameters can be obtained from the PI's (see contact information at beginning and end of report).

	Layer Depth			Layer Velocity	
Layer Number	Top	Bottom	Thickness	V_s	V_p
	(ft)	(ft)	(ft)	(ft/s)	(ft/s)
1	12.3	79.6	67.3	684	5281
2	79.6	140.3	60.7	969	5563
3	140.3	191.9	51.7	351	5369
4	191.9	431.4	239.5	604	5188
5	431.4	588.9	157.5	1675	6056
6	588.9	867.8	278.9	820	5595
7	867.8	1038.4	170.6	1274	5970
8	1038.4	1274.6	236.2	1648	5916
9	1274.6	1399.3	124.7	1455	5859
10	1399.3	1599.6	200.3	1779	6365
11	1599.6	1933.2	333.7	2860	7515
12	1933.2	1938.2	4.9	4763	10726

Table 1. Results of the P- and S-wave suspension velocity log.

Deviation Log: The borehole was inclined at less than 0.1 degree from vertical, and the error in depth value was1.2 feet in 1948.3 ft, or 0.06 percent, as presented in Figure 4. This error is less than depth errors from other causes, and no adjustment of log depth is indicated.

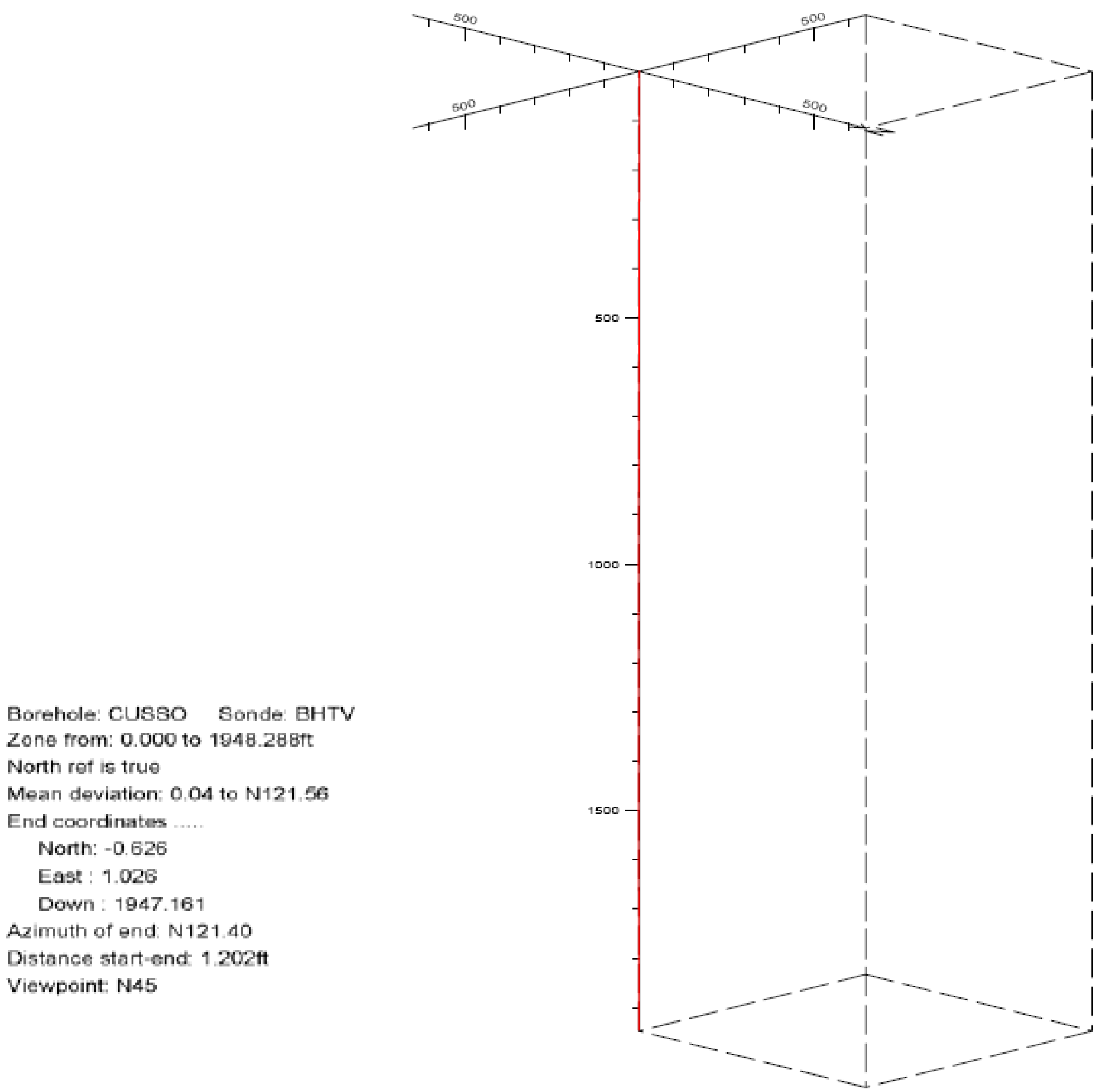

Figure 4. An orthographic projection of the deviation survey and error is shown.

The Kentucky Geological Survey at the University of Kentucky has the detailed attributes from the geological and geophysical datasets stored in standard formats. They are available upon request. Requests for the information should be directed to:

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