Bedrock Depth Determination and Mapping by Characterizing Shear Wave Velocity and Fundamental Resonance of the Glacial Drift Surface Layer at a Site in NE Ohio

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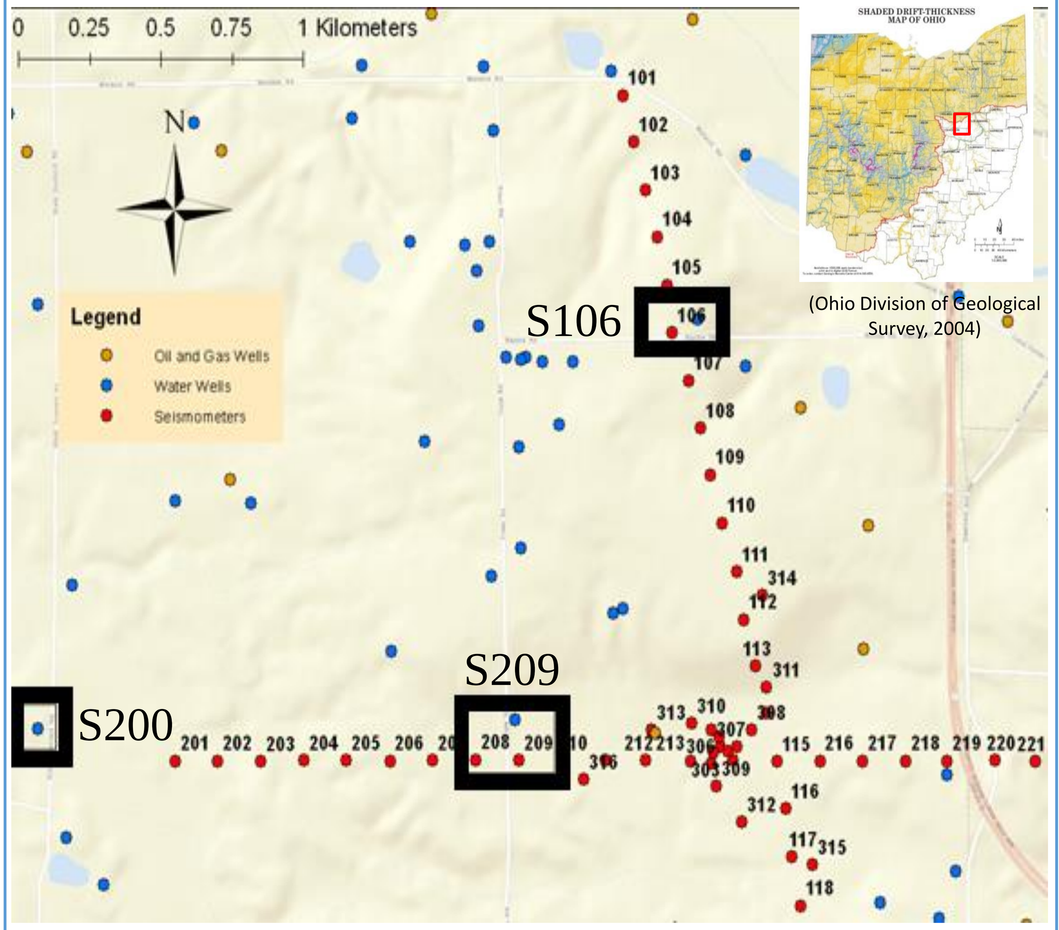
Abstract

An experiment was conducted at a location of variable thickness glacial drift southwest of Clinton, Ohio, where an extensive earlier dataset of 3-component passive seismic data was available. The goal was to examine the relationship $f_0 = Vs/4h$ between the fundamental resonant frequency (f_0) of the drift surface layer, its shear wave velocity (Vs) and thickness (h), and attempt to produce maps of bedrock depth and bedrock topography for the area. Three sites were examined with MASW and shear wave refraction surveys to independently determine the local drift Vs and depth to bedrock for comparison with local well data and the f_0 determined from 3-component passive seismic data at each site. The surveys indicate that the variation of the average Vs of the glacial drift of the three sites is approximately 10% of the mean despite a bedrock depth variation of over 100% of the mean. A theoretical f_0 calculated at the three survey sites, using the local average drift Vs and depth to bedrock, compared well with the H/V peak spectral frequency (f_0) determined using the associated 3-component seismometer data. However, the average Vs determined using MASW, rather than the shear wave refraction survey, appeared to better model the bedrock depths using the f_0 determined from the 3-component passive data. As a result of these surveys an average Vs was deemed suitable to be used to solve for h at the several prior sites of 3-component seismometers in the area in order to produce drift thickness and bedrock topography maps. ArcGIS® was used to produce a drift thickness map using local water and gas well information. These maps include the depths calculated from the average Vs of drift and the f_0 determined from the prior 3-component passive data. The bedrock depths calculated from the 3-component seismometer array correlate well with the major trends indicated by the surrounding water and gas wells. Final contour maps of bedrock depth and topography incorporated depth to bedrock both observed in the water and gas wells as well as that calculated from geophysical methods. This study demonstrates how studies of surface layer resonance can effectively map variations of bedrock depth and topography in an area of significant bedrock topography.

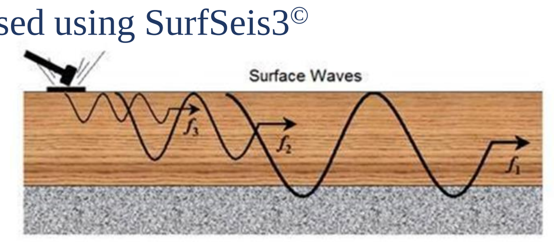
Objectives

- Conduct three shear wave velocity (Vs) surveys to determine an average Vs
- Assess Vs variability
- Validate the relationship; $f_o=Vs/(4*h)$ (Mahajan et al., 2012)
- Use Vs and horizontal to vertical spectral ratio (HVSR) of 3-component seismometers to calculate bedrock depth at each and compare with local water and gas wells
- Produce isopach and bedrock topography maps



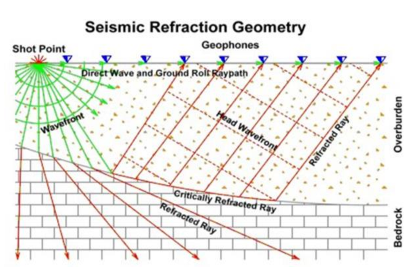
Methods

- Multichannel analysis of surface waves (MASW) (Park, 2003)
  - Frequency and surface wave (phase) velocity measured at the surface indicate shear wave velocity and depth of propagation
  - Processed using SurfSeis3©



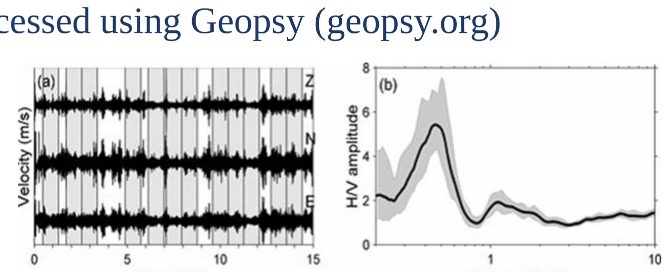
(Park Seismic LLC)

- Shear wave refraction (Interpex Limited, 2010)
  - Refracted arrivals indicate the velocity of the refracting material
  - Crossover distance and time indicate the depth of the refractor
  - Processed using IXRefraX™



(Enviroscan, Inc., 2016)

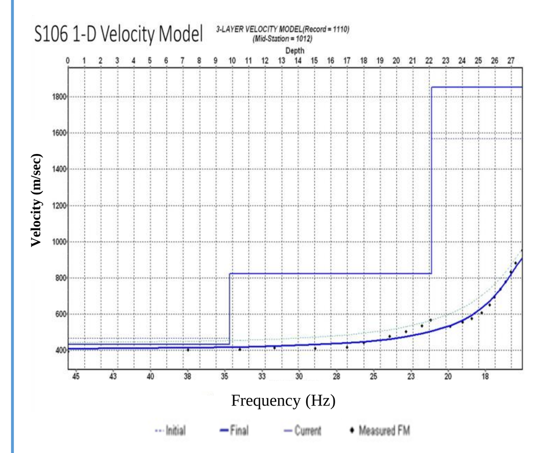
- Horizontal to vertical spectral ratio (HVSR) (Bonnefoy-Claudet et al., 2009)
  - Horizontal component amplitude of seismic motion is divided by the vertical component amplitude measured by a 3-component seismometer
  - Indicates the frequency for which the horizontal component is amplified most and provides a fundamental resonance estimate
  - Processed using Geopsy (geopsy.org)



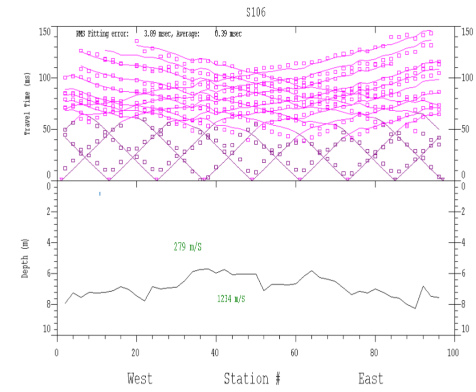
(Bonnefoy-Claudet et al., 2009)

Results

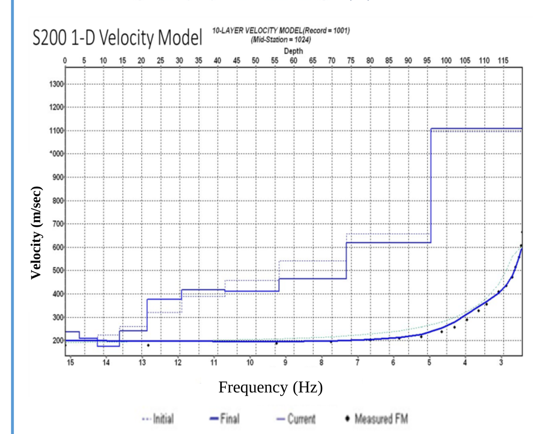
S106 MASW



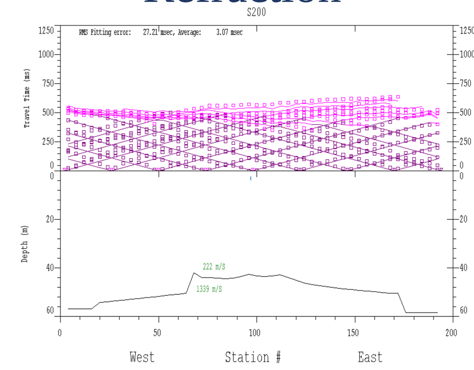
S106 Shear Wave Refraction



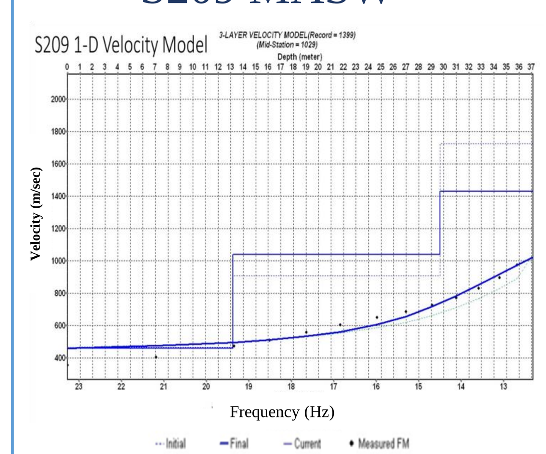
S200 MASW



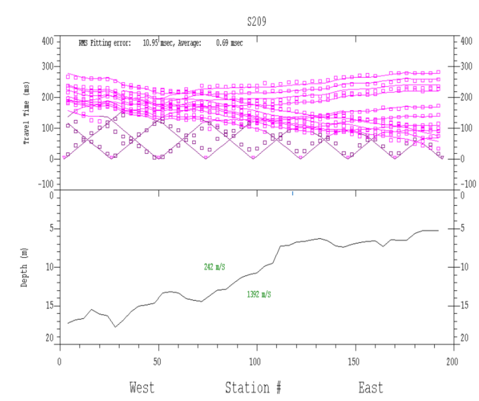
S200 Shear Wave Refraction



S209 MASW



S209 Shear Wave Refraction

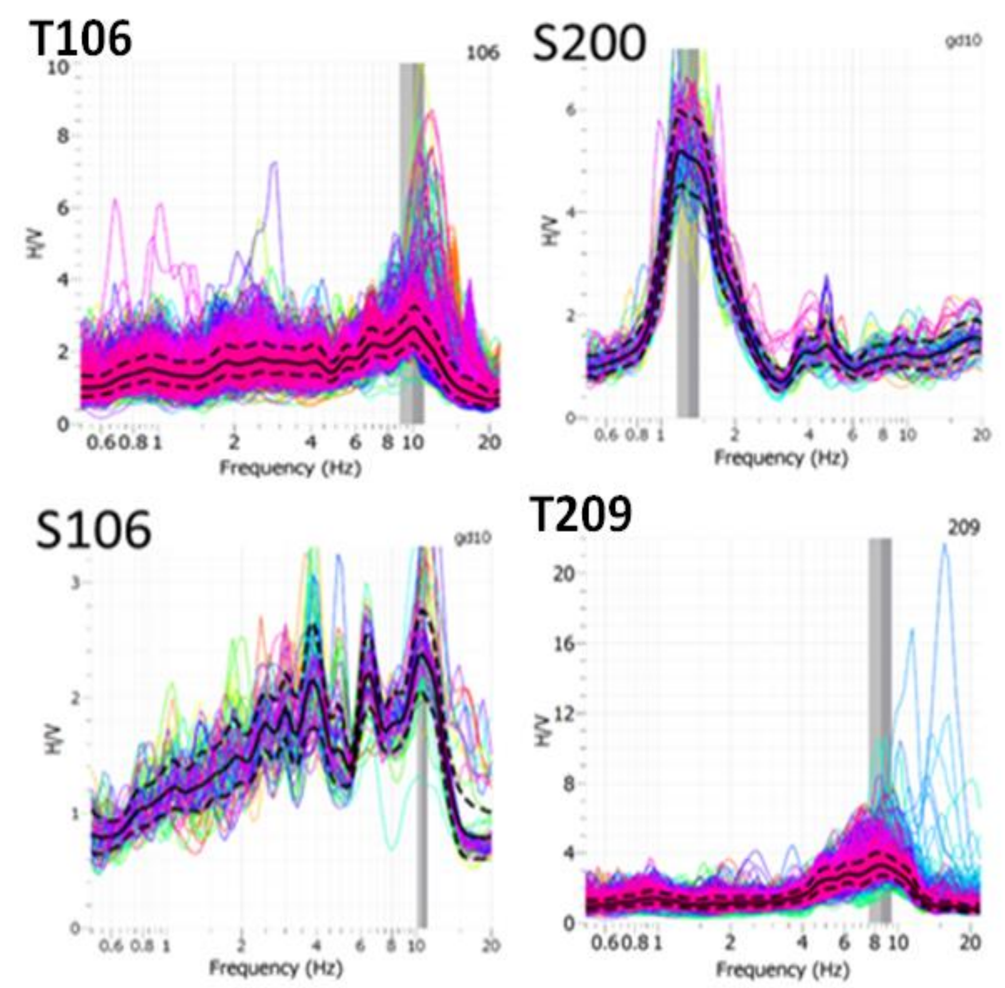


Shear Wave Velocity and Bedrock Depth Results

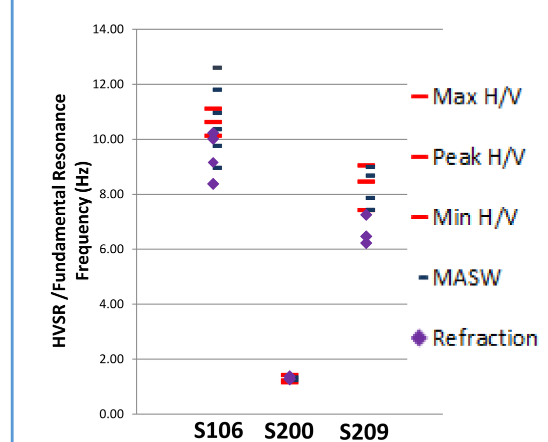
Site #	MASW Vs (m/s)	MASW Depth (m)	Refraction Vs (m/s)	Refraction Depth (m)	Well Depth (m)
S106	431.04	9.84	278.10	6.80	5
S200	370.16	74.57	221.70	42.60	59
S209	458.11	13.20	229.90	7.10	5
Average	419.77	32.54	243.23	18.83	23
Standard Deviation	45.04	36.44	30.47	20.58	24
Percent	10.73%	111.99%	12.53%	109.29%	104%

Results (Cont.)

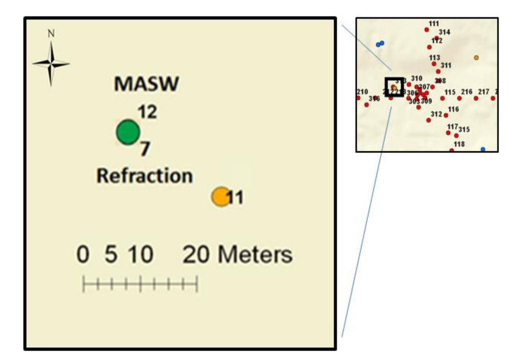
HVSR



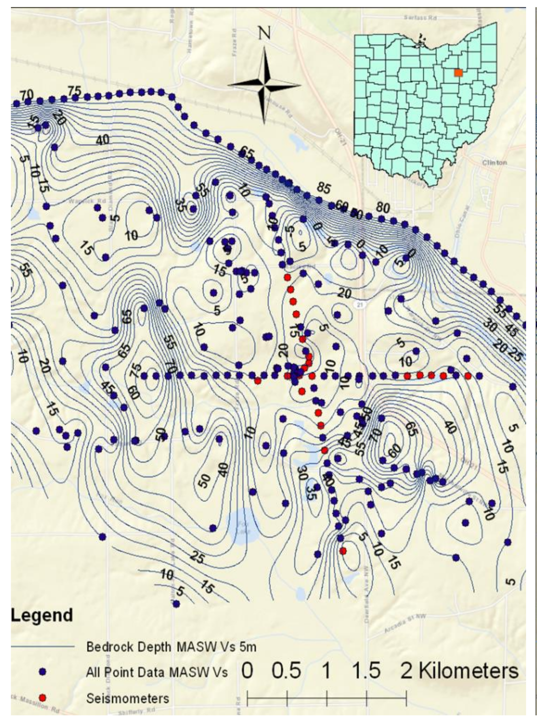
Theoretical Fundamental Resonance and HVSR



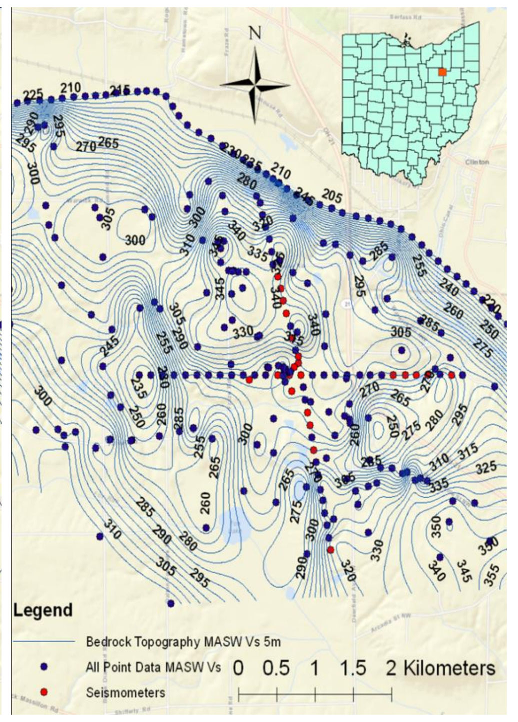
MASW Shear Wave Refraction Comparison



Surface Thickness



Bedrock Topography



Conclusions

- Shear wave velocity did not vary significantly
- The relationship; $f_o=Vs/(4*h)$ is valid at this site
- For the closest comparison, MASW provided the best bedrock depth approximation
- Mapping bedrock is possible at sites where shear wave velocity can be determined and data from an array of 3-component seismometers are available

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