Advances in Geospatial Modeling of Seismic Hazards
Poster # 24

Geology based f_0 model of New England

Marshall Pontrelli[1], Dr. Laurie Baise[1], Dr. John Ebel[2], Dr. Steve Mabee[3], Dr. Weiwei Zhan[1]

Tufts University[1], Boston College[2], UMASS Amherst/Mass Geological Survey[3]

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Abstract

In this research, we develop a broad understanding of soil amplification in glaciated terrain by classifying each surficial geologic unit in the New England region with an f_0 distribution. We group 1625 f_0 measurements, computed using Nakamura's HVSR technique (Nakamura, 1989), by surficial geologic unit from the Conterminous US surficial geology map (Soller et al. 2009) using the methodology that Wills and Clahan (2006) used to group Vs30 measurements. We then calculate measures of central tendency and dispersion for each unit. Using this approach, we observe that thick proglacial sediments on Cape Cod and Long Island tend to have the lowest f_0 measurements, consistent with a deep soil profile. We also see that the marine clays in Boston, the coast of Lake Champlain and the alluvial sediments in the Connecticut River Valley tend to have the next lowest frequencies, which we attribute to sediment thicknesses less than what is observed on Cape Cod and Long Island. Finally, we observe that the blanket of till covering the majority of New England tends to have high f_0 values in the region, indicating shallow sediments. We also establish estimates of sediment shear-wave velocity for each of the surficial geologic units based on a combination of in-situ measurements and expert opinion. Using the common relationship of $f_0 = Vs/4d$ which relates f_0 to shear wave velocity and depth, we discuss what our f_0 distributions mean for soil amplification and site response prediction in New England.

Dataset

To develop our f_0 database, we compiled HVSR measurements from prior projects and then supplemented with out own collection

- 570 stations in the Greater Boston area from Yilar et al. (2017)
- 198 stations on Cape Cod from Fairchild et al. (2013).
- 545 stations from Steve Mabee (Massachusetts geological survey, personal communication) across Massachusetts and in the Connecticut River Valley.
- 487 stations of our own field campaign covering New England using major highways to targeting geologic deposits where we expected local amplification of seismic shaking.

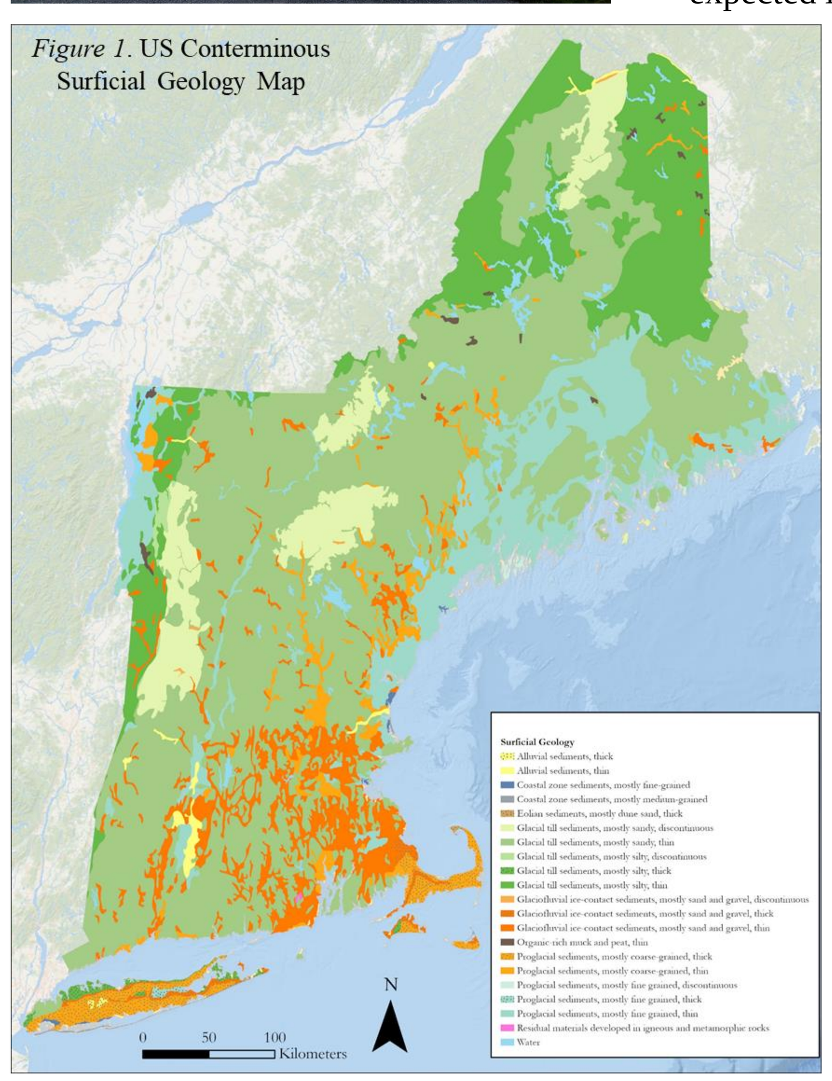

Figure 1. US Conterminous Surficial Geology Map

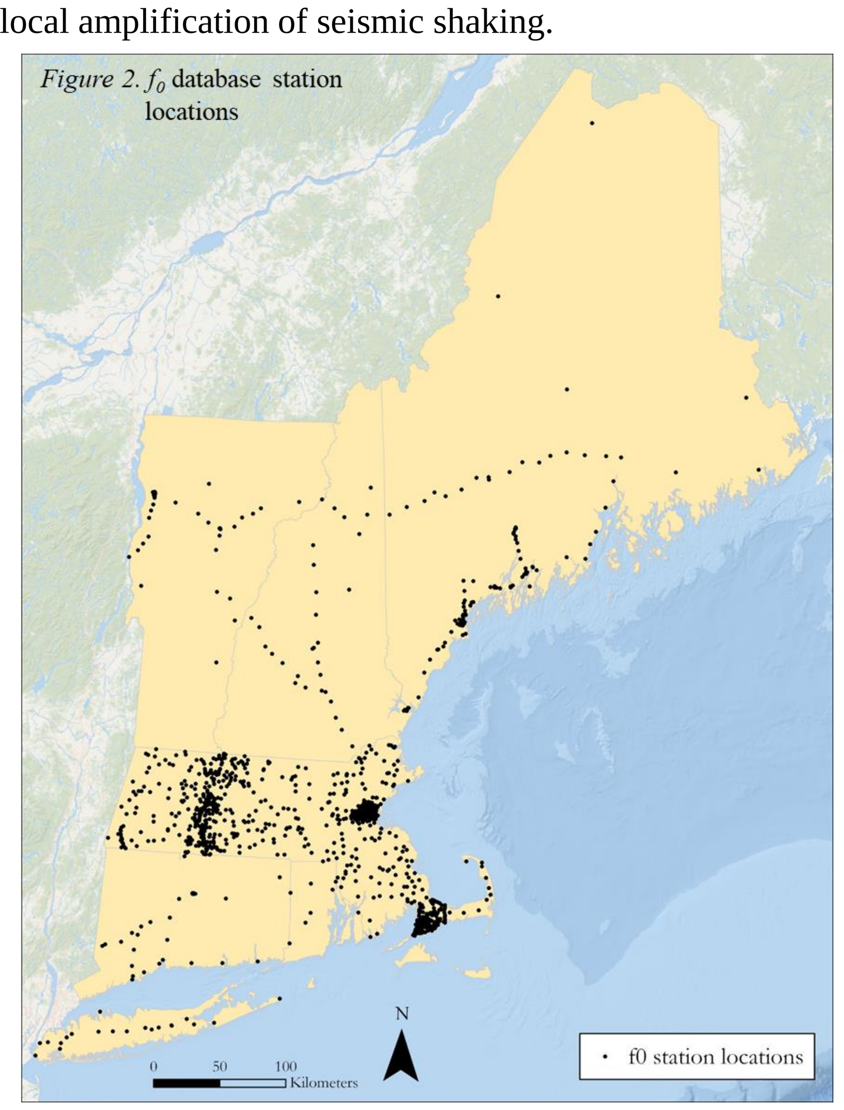

Figure 2. f_0 database station locations

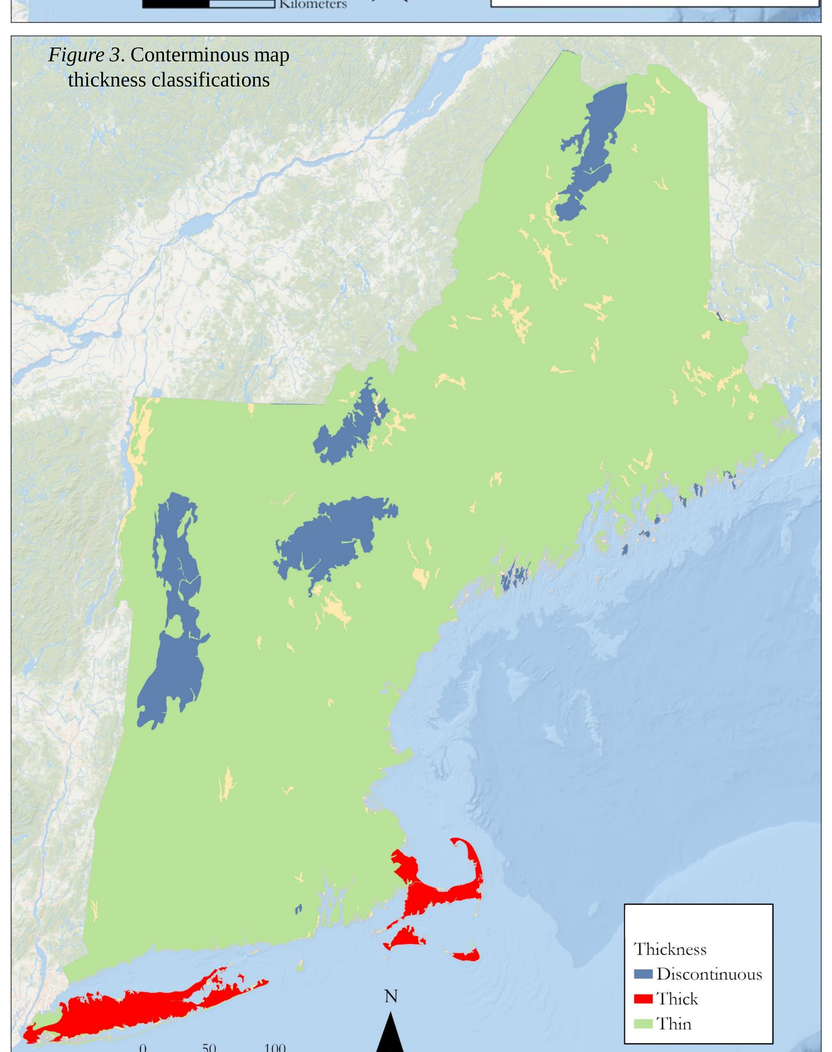

Figure 3. Conterminous map thickness classifications

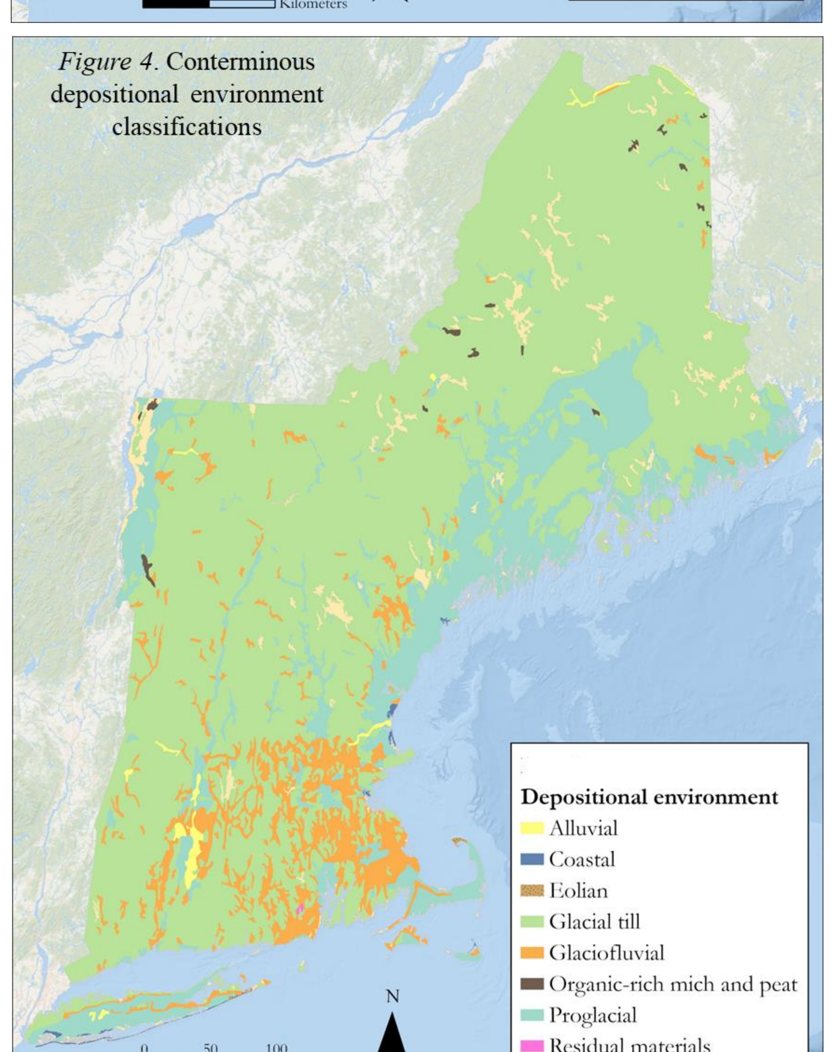

Figure 4. Conterminous depositional environment classifications

Methods

Grouping f_0 points by surficial geology

1. Spatial join the f_0 dataset to the Conterminous geology dataset.
2. Count the number of stations in each unit.
3. Find the units with few stations in them (not enough to make a distribution).
4. Logically combine units with few stations with units with many stations (Table 1).
5. After units are combined, perform the spatial join again and calculate the median and interquartile range of each unit's f_0 distribution.

New surficial name	Surficial unit groups	Thickness
Glaciofluvial ice-contact sediments, thin	Glaciofluvial ice-contact sediments, mostly sand and gravel, thin; Glaciofluvial ice-contact sediments, mostly sand and gravel, discontinuous	Thin
Proglacial sediments, fine grained, thin	Proglacial sediments, mostly fine grained, thin; Proglacial sediments, mostly fine grained, discontinuous	Thin
Glacial till	Glacial till sediments, mostly sandy, thin; Glacial till sediments, mostly sandy, discontinuous; Glacial till sediments, mostly silty, thin; Glacial till sediments, mostly silty, discontinuous	Thin
Proglacial sediments, thick	Proglacial sediments, mostly coarse-grained, thick; Proglacial sediments, mostly fine grained, thick; Alluvial sediments, thick; Glacial till sediments, mostly silty, thick; Eolian sediments, mostly dune sand, thick	Thick
Proglacial sediments, coarse grained, thin	Proglacial sediments, mostly coarse-grained, thin	Thin
Alluvial sediments, thin	Alluvial sediments, thin	Thin
Glaciofluvial ice-contact sediments, thick	Glaciofluvial ice-contact sediments, mostly sand and gravel, thick	Thick
Coastal zone sediments	Coastal zone sediments, mostly fine-grained; Coastal zone sediments, mostly medium-grained	Thin
Organic-rich muck and peat, thin	Organic-rich muck and peat, thin	Thin
Residual materials	Residual materials developed in igneous and metamorphic rocks	Thin

Table 1. Surficial geologic groupings

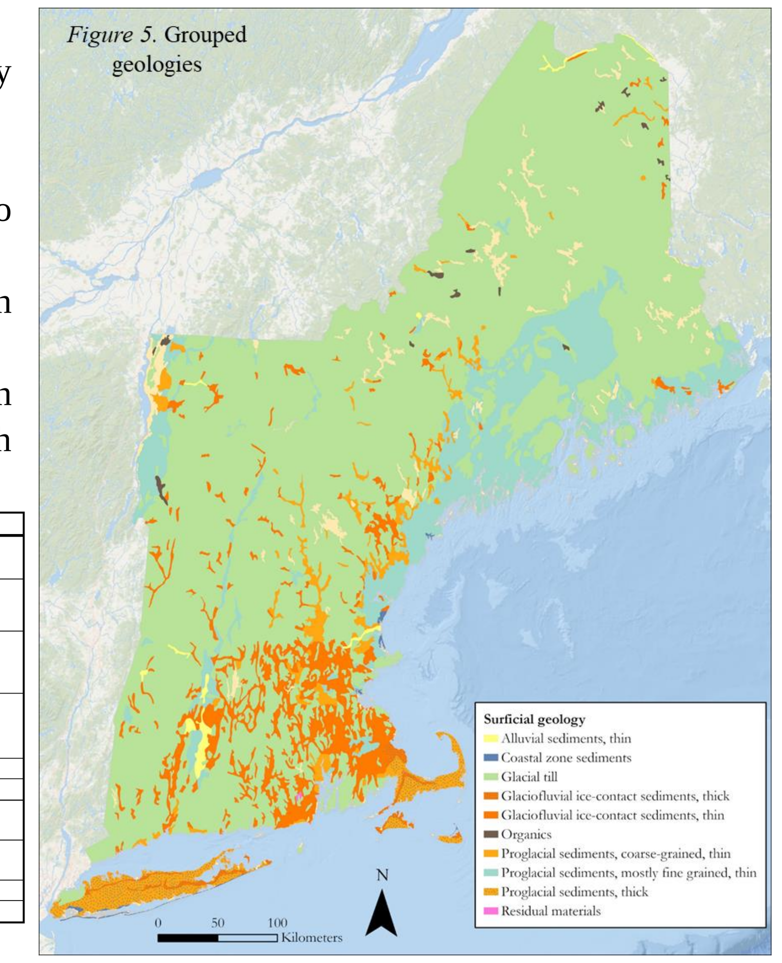

Figure 5. Grouped geologies

Results

After joining the f_0 dataset to the grouped Conterminous surficial map, we get an f_0 distribution for each unit. Table 2 shows the number of f_0 stations in each unit with the unit's respective f_0 median and interquartile range as well as an estimate for the unit's range of velocity values. The map shows the distribution of f_0 medians in space.

Surficial unit	Thickness	# Stations	Median (Hz)*	IQR (HZ)*	Vs_{avg} (m/s)$^{\tau}$
Glaciofluvial ice-contact sediments, thin	Thin	461	4.00	6.60	220-300
Proglacial sediments, mostly fine grained, thin	Thin	381	2.70	3.65	150-220
Glacial till	Thin	359	6.16	10.15	300-500
Proglacial sediments, thick	Thick	182	1.03	0.28	180-250
Proglacial sediments, coarse-grained, thin	Thin	74	3.70	3.47	220-300
Alluvial sediments, thin	Thin	62	1.83	1.59	170-250
Glaciofluvial ice-contact sediments, thick	Thick	32	1.06	0.23	180-250
Coastal zone sediments, mostly fine-grained	Thin	26	3.31	1.60	150-220

Table 2. f_0 medians, IQRs and average shear wave velocity estimates for each unit, along with that unit's # of stations and thickness. We compiled these Vs estimates from various sources and using engineering judgement (Thompson et al 2014, NH State Geological Survey, MA Geological Survey, Hager Geosciences).

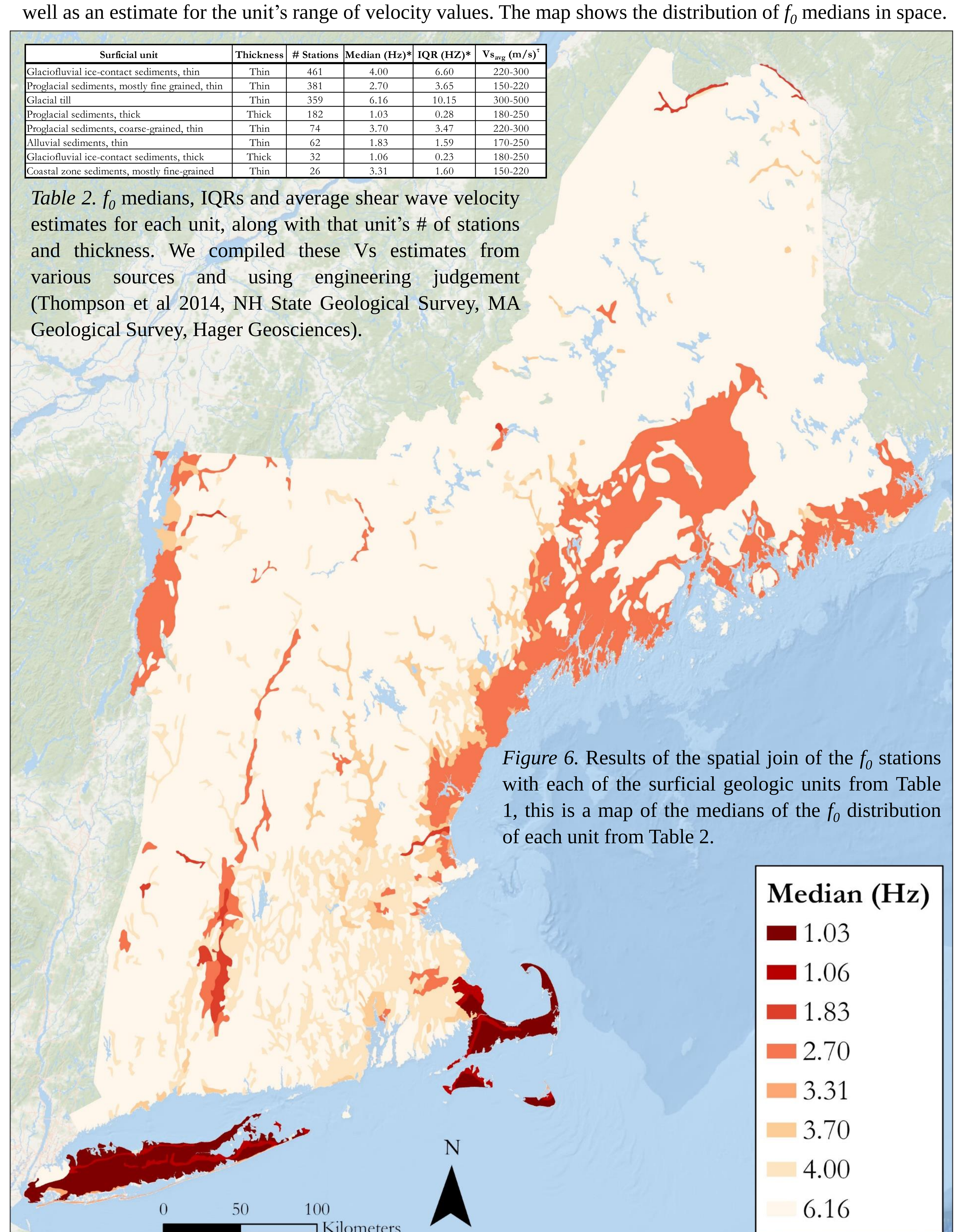

Figure 6. Results of the spatial join of the f_0 stations with each of the surficial geologic units from Table 1, this is a map of the medians of the f_0 distribution of each unit from Table 2.

Discussion

Main results from the analysis

- Glacial till tends to have the highest f_0 values.
- The thick classified sediments (Proglacial and glaciofluvial) tend to have the lowest f_0 values and are located on Cape Cod and Long Island.
- Fine-grained proglacial and coastal zone sediments have median f_0 values of 2.7 and 3.3 Hz respectively and are located on the Maine coast, Lake Champlain coast, and Boston Basin
- Alluvial sediments have a median f_0 value of 1.83 Hz and are located predominately in the Connecticut River Valley.

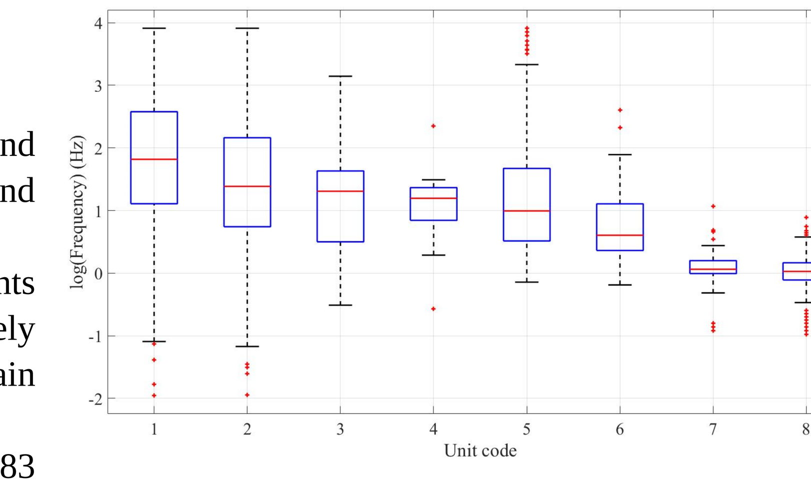

Figure 7. Box and whisker plot of each surficial unit's f_0 distribution in units of ln(Hz).

Surficial unit	Unit code	Thickness	# Stations	ln(median)	ln(IQR)	Median (Hz)	IQR (Hz)	Vs_{avg} (m/s)
Glacial till	1	Thin	359	1.82	1.47	6.16	10.15	180-250
Glaciofluvial ice-contact sediments, thin	2	Thin	461	1.39	1.42	4.00	6.60	220-300
Proglacial sediments, coarse-grained, thin	3	Thin	74	1.31	1.13	3.70	3.47	180-250
Coastal zone sediments, mostly fine-grained	4	Thin	26	1.20	0.52	3.31	1.60	300-500
Proglacial sediments, mostly fine grained, thin	5	Thin	381	0.99	1.16	2.70	3.65	150-220
Alluvial sediments, thin	6	Thin	62	0.61	0.74	1.83	1.59	150-220
Glaciofluvial ice-contact sediments, thick	7	Thick	32	0.06	0.21	1.06	0.23	170-250
Proglacial sediments, thick	8	Thick	182	0.03	0.27	1.03	0.28	220-300

Table 3. Median and IQR f_0 values and average Vs estimates for each surficial unit. Each unit has a code which corresponds to the Box and Whisker plot x-axis label.

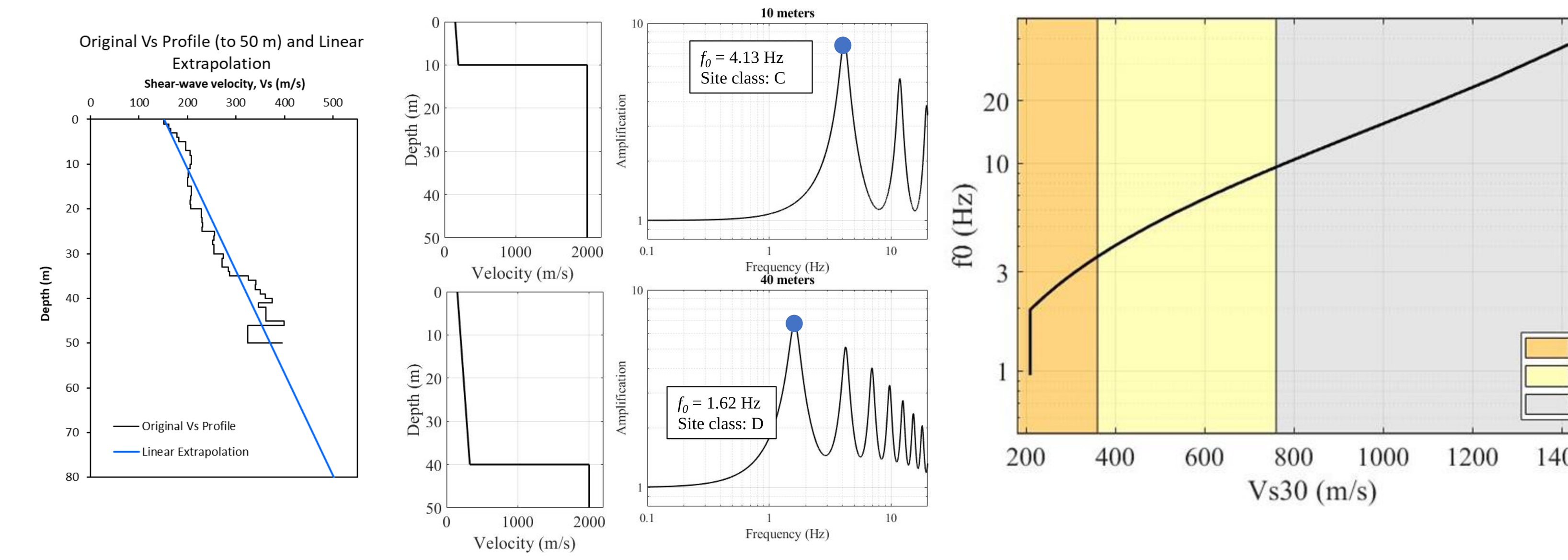

Figure 8. Every velocity profile has a Vs_{avg}, an f_0, a Vs30 and a depth. It is therefore possible to relate f_0 to Vs30-based site class by estimating the overburden Vs_{avg} using the surficial geology (Table 3 average velocities). A low f_0 value from one of our maps indicates a deep deposit with a range of possible velocity values depending on the deposit geology. This derivation is also shown in Hassani and Atkinson (2016).

Conclusion

1. New England glaciated terrain consistently has high impedance contrasts due to high velocity bedrock and the soft, unconsolidated nature of many of the typical glaciated terrain deposits.
2. When grouping the f_0 measurements by surficial geology, the large, unconsolidated surficial units display lower f_0 values than the typical till veneer in the rest of the region.
3. Cape Cod and Long Island have the lowest f_0 values in our study region, which we interpret as being the deepest thicknesses of sediments in the region, a statement that is consistent with the thickness classifications from the conterminous US surficial map (Figure 3).
4. The marine clay sediments in the Boston Basin, the coast of Lake Champlain and the Maine coast tend to have low f_0 values. These f_0 values are very driven by depth to bedrock and therefore can vary widely in short distances.
5. The thin, mostly fine-grained proglacial sediments in Maine tend to have higher f_0 values than the rest of the thin, mostly fine-grained proglacial sediments. In future work, we will treat the Maine Coast independently.
6. The river floodplain/glacial lake structure in the Connecticut River Valley also has low frequencies.

References

Fairchild, G.M., Lane, J.W., Jr., Voytek, E.B., and LeBlanc, D.R., 2013, Bedrock topography of western Cape Cod, Massachusetts, based on bedrock altitudes from geologic borings and analysis of ambient seismic noise by the horizontal-to-vertical spectral-ratio method: U.S. Geological Survey Scientific Investigations Map 3233.

Hassani, B., Atkinson, G.M. (2016) Applicability of the Site Fundamental Frequency as a VS_{30} Proxy for Central and Eastern North America. *Bulletin of the Seismological Society of America* 2016; 106 (2): 653–664. doi: https://doi.org/10.1785/0120150259

Nakamura, Y. (1989) A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface. Railway Technical Research Institute 30(1): 25-33.

Soller, D.R., Reheis, M.C., Garrity, C.P., and Van Sistine, D.R., 2009, Map database for surficial materials in the conterminous United States: U.S. Geological Survey Data Series 425, scale 1:5,000,000 [https://pubs.usgs.gov/ds/425/].

Thompson, E.M., Carkin, B., Baise, L.G., and Kayen, R.E., 2014, Surface wave site characterization at 27 locations near Boston, Massachusetts, including 2 strong-motion stations: U.S. Geological Survey Open-File Report 2014–1232, 27 p., *http://dx.doi.org/10.3133/ofr20141232*

Wills, C. J., and K. B. Clahan (2006). Developing a map of geologically defined site-conditions categories for California, Bull. Seismol. Soc. Am. 96, 1483–1501.

Yilar, E., Baise, L.G., Ebel, J.E. (2017) Using H/V measurements to determine depth to bedrock and Vs30 in Boston, Massachusetts. Engineering Geology 217, 12-22