Supplementary Material

1 Description of tomographic methods and model properties

The ambient noise tomography model of Chen et al. (2018) uses 2006 one-year data from 123 Hi-net borehole stations in Tohoku. After a procedure to suppress the effects of earthquakes, instrument glitches, and unwanted signals, cross-correlations of vertical-component continuous records were calculated between all possible pairs of stations to establish empirical Green's functions (EGF), which are the Rayleigh waves traveling between pairs of stations. Traditional frequency-time analysis is applied to these EGFs as they were Rayleigh waves from natural earthquakes. The data set is composed of 2242, 3873, 3365, and 1933 phase velocity measurements at periods of 3, 6, 10, and 16 s, respectively. These data are put through an inversion procedure to determine the 3D models of both isotropic and azimuthally anisotropic shear velocity (V_S) variations.

The inversion from inter-station EGFs to a 3D V_S model can be performed with different approaches. We parameterized vertical variation into 13 layers, covering depth ranges of 0-1, 1-3, 3-5, 5-8, 8-12, 12-16, 16-20, 20-24, 24-29, 29-34, 34-41, 41-51, and 51-66 km. Only 9 layers from 1 to 34 km depths are used in the interpretation and discussion. In horizontal variations, we employed a wavelet-based, multiscale inversion technique (Chiao and Kuo, 2001), which makes the best of the heterogeneity of resolution in an unbiased way, exploiting local high resolution for more model details, while retaining stable solutions where resolution is poor. This approach has been applied in both surface-wave and body-wave tomography (Hung et al., 2011; Huang et al., 2015). In principle, the model is built up by stacking different levels of lateral parameterization defined by triangles with characteristic lengths from 382 km (level 1) to 6 km (level 7). The stacking is data-adaptive in that at a particular location, how high the model can afford to go up the scale ladder depends on how dense the raypaths are in the vicinity. Local, high resolution can push to level 7. Poor resolution regions would stay at low level characterized by a V_S not too different from the regional averages. Chen et al. (2018) illustrates how the multiscale tomography works in assembling the final model in their Figure 5a. Characteristic horizontal resolution is roughly 30 km in the upper crust, although in some areas it can be 20 km. Note that the dimensions of the low V_S anomalies in the upper crust that we interpret as intrusive complexes are on the order of 50 km. The vertical resolution is related to the layering scheme, which is described above. The thickness of each layer delimits the maximum vertical resolution at that depth, i.e., 2 – 5 km in the 9 layers presented in the paper. Thin layering enables inversion to locate the peak of the anomalies more accurately before the inversion (including the effect of surface wave kernel and the regularization) spreads the anomalies over depth. The vertical resolution is considered to be 4 - 5 km in upper and mid-crust and probably 20 km in the bottom of the model. We emphasize that the real resolution depends on the model setup, the inversion technique including regularization, the data coverage, and the criterion that defines "resolution". A comparison in resolution solely based on the numbers claimed in each model is not advised.

The resolution of surface-wave tomography downgrades with depth. In contrast, P- or S-wave tomography has resolutions roughly constant along the path. Potential disadvantages of body wave tomography are (1) a lower resolution near the surface as body waves travel almost vertically towards the station, leading to low density of ray crossing, and (2) uncertainty in earthquake locations and uneven distribution of earthquakes. These drawbacks are circumvented in ambient noise tomography, in that the surface waves are employed and stations are treated as earthquakes and, in the case of Tohoku, station (earthquake) distribution is dense and uniform. These advantages allow ambient noise tomography to better map upper crustal structures. In Tohoku, our ambient noise model should be combined with body-wave models, such as Niu et al. (2018), to illuminate the entire crust.

The volume estimation of the subvolcanic intrusive bodies (**Table S1**, see below, and refer to the methods section of the main text for details) has uncertainties related to the inherent resolution and the real size of the bodies. The fact that the bodies can be resolved is because they are larger than the resolution of the model. Once this condition is true, the vertical uncertainty is related to the limiting resolution, or the layer thickness, which is 4 km in the upper crust. This is justified by the apparently sharp top and bottom boundaries of the imaged Vs anomalies. Because the limiting resolution in horizontal direction is level 7 or roughly 7 km, the lateral edges of the subvolcanic intrusive bodies can be resolved better than allowed by the horizontal resolution. The uncertainty in the horizontal dimension of the bodies is estimated to be 10-15 km. The dominant factor is obviously the uncertainty over depth, because the defined volume is vertically thin (*c*. 8 km). An extreme case would be the top or bottom boundary being misplaced by one layer. This would result in a 50% error in the volume estimate. By a statistical rule of thumb, half of the extreme case, i.e. 25%, is considered the uncertainty in volume estimates. Note, however, that this absolute uncertainty of 25% in the volume of the subvolcanic intrusive bodies is much larger than the relative uncertainties between different volcanic centers studied within one tomographic model. Thus, the pattern in Figure 2B, which plots volume ratios (cf. **Table S1**), remains unchanged.

2 Data extraction from the Global Volcanism Program

We collated the eruption history and the associated Volcanic Explosivity Index (VEI) from the Global Volcanism Program (2013). We only considered those records for which the status in the eruption certainty column was "confirmed". In **Table S2** below, the year columns in light-grey indicate eruptions that occurred B.C.; n.d. indicates that no VEI was provided in the database.

References

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Table S1 | Subvolcanic intrusion volume estimates (in km^3) for NE Japan's arc front volcanoes

Radius	4 km	5 km	6 km	7 km	8 km	9 km	10 km	11 km	12 km	13 km	Volume ratio w.r.t. Zao	
Volcano name											*Average*	*St.Dev.*
Adatarayama	481	746	1073	1370	1725	2068	2474	2894	3279	3751	2.84	0.34
Akita-Komagatake	550	858	1220	1644	2119	2642	3233	3866	4569	5266	3.54	0.14
Akita-Yakeyama	503	772	1114	1489	1934	2422	2983	3569	4194	4822	3.24	0.11
Azumayama	539	880	1265	1716	2211	2794	3470	4152	4853	5601	3.70	0.10
Bandaisan	550	880	1243	1705	2216	2789	3402	4055	4790	5517	3.67	0.11
Hachimantai	561	869	1232	1687	2125	2638	3197	3807	4500	5214	3.55	0.19
Iwatesan	429	669	960	1343	1772	2195	2641	3141	3679	4196	2.85	0.10
Kurikomayama	572	858	1243	1683	2222	2797	3444	4111	4824	5598	3.69	0.08
Naruko	217	345	507	713	953	1269	1592	1985	2408	2848	1.64	0.13
Towada	295	485	688	893	1156	1463	1794	2103	2433	2886	1.94	0.10
Zao	150	228	330	456	594	762	930	1122	1353	1572	1.00	0.00

Table S2 | Holocene eruption record of NE Japan's arc front volcanoes

Hakkodasan		Towada		Akita-Yakeyama		Hachimantai	
Year	VEI	Year	VEI	Year	VEI	Year	VEI
1550	1	915	5	1997	1	-5350	n.d.
1340	1	-750	4	1997	1	-7900	n.d.
450	1	-4150	5	1957	1		
-50	1	-5550	3	1951	1		
-1150	1	-6250	4	1950	1		
-2250	3	-7250	5	1949	1		
-2850	2	-8250	5	1948	1		
		-9490	3	1929	2		
				1890	2		
				1887	2		
				1867	n.d.		
				1678	2		
				1390	n.d.		
				570	n.d.		
				-1250	n.d.		
				-3050	n.d.		

Iwatesan		Akita-Komagatake		Kurikomayama		Naruko	
Year	VEI	Year	VEI	Year	VEI	Year	VEI
1919	1	1970	2	1950	2	837	1
1732	2	1932	2	1946	2	-800	n.d.
1686	3	1902	1	1944	1	-1350	n.d.
1450	n.d.	1890	2	1744	2	-1400	n.d.
1300	3	1100	2	1726	1	-4400	n.d.
150	n.d.	807	3	1450	1		
-350	n.d.	400	n.d.	-3450	n.d.		
-450	n.d.	-50	2				
-1150	n.d.	-200	n.d.				
-1250	3	-350	3				
-1500	n.d.	-1450	n.d.				
-1650	n.d.	-5950	3				
-2000	n.d.	-6150	n.d.				
-2050	n.d.	-6350	3				
-2700	n.d.	-7100	n.d.				
-2950	n.d.	-7850	4				
-3050	n.d.	-8300	4				
-3250	0	-8800	3				
-3750	n.d.						
-4350	n.d.						
-4450	0						
-4850	n.d.						
-4900	n.d.						
-5650	n.d.						
-6300	n.d.						
-6450	n.d.						

Zao		Azumayama		Adatarayama		Bandaisan	
Year	VEI	Year	VEI	Year	VEI	Year	VEI
1940	1	1977	1	1996	1	1888	4
1905	1	1950	1	1900	2	1808	2
1896	1	1895	1	1899	2	1787	2
1895	2	1894	1	950	n.d.	806	3
1895	1	1893	1	-50	n.d.	-550	n.d.
1894	2	1893	1	-590	3	-1800	n.d.
1873	1	1800	n.d.	-1550	n.d.	-3850	n.d.
1867	2	1711	1	-2600	3	-4650	n.d.
1833	2	1331	1	-4300	3	-5050	n.d.
1831	2	600	n.d.	-6150	3	-6350	n.d.
1830	2	-150	n.d.	-6650	3	-7450	n.d.
1822	n.d.	-950	n.d.	-8050	3		
1821	2	-1800	n.d.				
1809	2	-2750	n.d.				
1806	2	-3000	1				
1804	2	-4150	3				
1796	2	-4550	n.d.				
1794	2	-5400	1				
1694	2	-5700	2				
1670	2						
1669	3						
1668	2						
1641	2						
1630	2						
1623	3						
1622	2						
1620	2						
1400	3						
1230	2						
1227	3						
1183	2						
884	3						
300	4						
-1600	n.d.						
-2000	n.d.						
-2300	n.d.						
-2600	n.d.						
-3350	n.d.						
-3850	n.d.						
-4150	n.d.						
-5500	n.d.						
-5600	n.d.						
-7600	n.d.						