

Sui, S., Shen, W., Mahan, K., and Schulte-Pelkum, V., 2022, Constraining the crustal composition of the continental U.S. using seismic observables: GSA Bulletin, <https://doi.org/10.1130/B36229.1>.

Supplemental Material

Supplemental Text.

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Figure S2. SiO_2 wt% profiles with uncertainties for station F12A calculated by using polynomial-fitting V_s - V_p/V_s - SiO_2 wt% relationships.

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1. A smoothed surface vs. analytical formats

In addition to the smoothed interpolation surface we construct in this study, there are other approaches to obtain the smooth trend between the SiO₂ wt% and seismic properties. Here we show the comparison between the surface we use in this study and the trend made by the least-square polynomial fitting technique. In **Fig. S1 A-C**, we show the surface in the main manuscript and the misfit of individual rock samples (defined as the surface-predicted SiO₂ wt% subtracting laboratory-measured SiO₂ wt%).

Fig. S1 D-F presents a surface created by fitting the trend with the second-order polynomials using the **Eq. S1**:

$$SiO_2 \text{ wt\%} = a_1(V_s)^2 + a_2V_s(V_p/V_s) + a_3(V_p/V_s)^2 + b_1V_s + b_2(V_p/V_s) + c \quad (S1)$$

By performing the least squares fitting, the coefficients are: $a_1=-39.23$; $a_2=45.68$; $a_3=221.46$; $b_1=183.26$; $b_2=-1060.67$; $c=805.58$.

In this test, we note the 2nd order polynomials least-square fitting result in greater misfit, especially for the rocks with felsic/mafic composition (**Fig. S1 F**). This is mostly due to the fact that the SiO₂-Vs-Vp/Vs trend is more complicated than a smooth surface represented by low order polynomials. In addition, **Fig. S1 G-I** presents the result from another test that fits the trend with a third-order polynomials function (**Eq. S2**):

$$SiO_2 \text{ wt\%} = a_1(V_s)^3 + a_2(V_s)^2(V_p/V_s) + a_3V_s(V_p/V_s)^2 + a_4(V_p/V_s)^3 + b_1(V_s)^2 + b_2V_s(V_p/V_s) + b_3(V_p/V_s)^2 + c_1V_s + c_2(V_p/V_s) + d \quad (S2)$$

The resulting coefficients are: $a_1=333.28$; $a_2=506.34$; $a_3=-1319.33$; $a_4=-4405.02$; $b_1=-4666.15$; $b_2=963.83$; $b_3=28884.64$; $c_1=16574.62$; $c_2=-54169.45$; $d=12256.80$.

The misfits for the rock samples look reasonable for the intermediate Vs and Vp/Vs ranges. However, this relationship suffers from edge effects where the model space is not constrained by lab-measurements (e.g., Vs ~ 3.4-3.5 km/sec and Vp/Vs ~ 1.6-1.7), which introduces unlikely SiO₂ wt% when the Vs (or Vp/Vs) have extreme values. For example, when we apply the 3rd order polynomial-fit surface to station F12A (average Vs ~ 3.5 km/s; Vp/Vs ~ 1.62), a SiO₂ profile with upper crust > 100 wt% shows up in the shallow crust (**Fig. S2**).

We also test high-order polynomials and bicubic B-spline fitting. The major trends are also captured by these functions, but strong edge effects are observed and they require a large number of coefficients ($N(N+1)/2$ for Nth order polynomial fitting and at least 30 for bicubic B-spline fitting). As a result, we conclude that the surface function we employ in the manuscript is suitable for this application.

2. Quality control on receiver functions (RFs)

To reduce the noise in receiver functions, we apply the signal-to-noise ratio (SNR) criteria of 5 to the P-wave signals, which is defined as the amplitude of P arrival over the standard deviation of amplitudes for waveform 10-20 sec before the P arrival. RFs are calculated from seismograms with SNR>5, and undergo a 5-stage quality control (QC) before the H-k stacking: 1) The ray parameter of the event is required to be between 0.04-0.1 s/km. 2) The P-arrival signal amplitude of the RF should be lower than 1. 3) The P arrival in the RF should be positive. 4) The fitness (defined by the time domain deconvolution algorithm, quantifying the robustness of the deconvolution process, Ligorria and Ammon 1999) should be larger than 80%. 5) The RFs' average integrated amplitude between 20 and 40 sec should always be lower than that of the first 5 sec, which allows us to remove the RFs with ringing wiggles. One example of the 5 stage QC for M26A is shown in **Fig. S3**, for which the final accepted number of RFs is 19, only ~ 10% of the number of raw RFs. Because of the rigorous quality control, 302 stations do not report robust Vp/Vs results that are meaningful enough for us to perform the compositional analysis. Many of these stations are located in the midwestern region, for which their distance to the West Pacific seismic belt is in the shadow zone of direct P arrival.

3. Vp/Vs comparison to Earthscope Automatic Receiver Survey (EARS)

In this section, we present the crystalline crustal Vp/Vs for 1406 stations from this study and crustal Vp/Vs from EARS in **Fig. S4** (Crotwell and Owens, 2005). The scatter plot in **Fig. S4 A** shows that Vp/Vs from this study and EARS are mostly distributed in the range of 1.65-1.85. **Fig. S4 B** shows that EARS Vp/Vs have more extreme values than this study.

4. Rock samples and Perple_X parameters used in synthetic tests in Section 2.3.

Table S1 shows the chemical compositions of the rock samples used in synthetic tests (Kern et al., 1996, 1999) discussed in the main manuscript. **Table S2** lists the solid solution models used in Perple_X calculation (Connolly & Petrini, 2002). **Table S3** shows the resulting major mineral volume proportions. The calculations are made at 870 MPa and 600 °C (~ 30 km deep) using the thermodynamics database *hpha02ver.dat* (Holland & Powell, 2003; Connolly & Kerrick, 2002). The chemical system is assumed to consist of SiO₂ - TiO₂ - Al₂O₃ - FeO - MgO - CaO - Na₂O - K₂O - H₂O (Fe₂O₃ is converted into FeO) during the calculations. For certain samples (WSZ1, JN3), the water content (H₂O) is not reported. In this case, we assume the amount of water that would bring the total oxide to be 100 wt%. We choose the liquid equation of state from Holland & Powell (1998) with the assumption that there is no saturated fluid or components. In this case, sample HT1 requires 1.2 wt% of water, and sample D95-10 requires 1.6 wt% of water.

Table S1. Reported chemical compositions (wt%) for the 4 samples used in the synthetic test

Rock sample	WSZ1	HT1	D95-10	JN3
SiO ₂	71.52	63.5	54.8	49.52
TiO ₂	0.41	0.6	0.9	1.35
Al ₂ O ₃	13.42	13.2	17.3	13.26
Fe ₂ O ₃	4.26	0.6	2.8	15.98
FeO	-	7.2	5.2	-
MgO	2.04	6.9	3.9	5.74
CaO	1.49	1.7	6.3	10.05
Na ₂ O	3.25	2.3	3.8	3.04
K ₂ O	3.09	2.1	2.4	0.83
H ₂ O	-	1.2	1.6	-

Table S2. Solution models and endmembers*

Solution model	Endmembers
Pl(h)	abh,an
Bio(HP)	ann,phl,east,spdh
Gt(HP)	alm,py,gr
Cpx(HP)	di,hed,jd,cats
Opx(HP)	en,fs,mgts,fets
Amph(DPW)	tr,fttr,parg,ts,gl

* : See *Perple_X* documentation (<http://www.perplex.ethz.ch>) for solution model references and abbreviations used here.

Table S3. Perple_X calculated mineral proportions (vol%)

Rock sample/minerals*	WSZ1	HT1	D95-10	JN3
Biotite	15.23	19.72	22.13	8.28
Muscovite	4.65	3.57	-	-
Garnet	-	12.51	0.1	3.21
Clinopyroxene	-	-	1.11	4.19
Amphibole	-	10.27	9.81	52.7
Epidote	-	-	3.53	-
Na/Ca-feldspar	35.86	17.06	48.49	23.3
K-feldspar	4.75	-	-	-
Quartz	35.86	34.44	11.88	4.84
Rutile	0.26	0.42	-	-
Titanite	-	-	1.8	2.92
H ₂ O	-	-	1.14	0.57

*All phases are calculated at 30 km depth and 600 °C for the reported composition of the lower crustal samples used in test case 1 (Kern et al., 1996, 1999). We use the thermodynamic modeling software Perple_X (version 6.9.1, Connolly & Petrini, 2002; thermodynamic database hpha02ver.dat, Holland & Powell, 2003; Connolly & Kerrick, 2002).

Figure S1. Relationships of the rock Vs-Vp/Vs-SiO₂ wt% trend generated from the smoothed surface we use and two least-square polynomial fittings. (A) A smoothed surface derived from the rocks noted by the dots (Hacker et al., 2015) and squares (Christensen, 1996) highlights the trend. The color of the surface and rocks represent the SiO₂ wt%. (B) The misfit between the surface-predicted SiO₂ wt% and laboratory-measured SiO₂ wt% for the individual crustal rocks color-coded by misfit. (C) A scatter plot of

laboratory-measured and predicted SiO₂ wt%. The solid line marks where the measured and predicted SiO₂ wt% are the same. The dashed lines show misfits of ± 5 wt% . (D-F) Similar to subplot A-C, the trend is characterized by second order polynomials instead. (G-I) Third order polynomials are applied.

Figure S2. SiO₂ wt% profiles with uncertainties for station F12A calculated by using polynomial-fitting Vs-Vp/Vs-SiO₂ wt% relationships. Blue dashed line and corridor represent the average SiO₂ wt% profile and one standard deviation from the smoothed surface employed in the main manuscript. Red dashed line and corridor are the average SiO₂ wt% profile and one standard deviation from the trend fit with third-order polynomials.

Figure S3. 5-stage quality control applied at station M26A. The direct P arrivals of RFs are aligned at zero seconds and plotted against the back-azimuth of the events. There are 202 Raw receiver functions before the QC. (A) 192 RFs with the ray parameters between 0.04-0.1. (B) 112 RFs with P-arrival signal amplitudes < 1. (C) 75 RFs with positive P arrivals. (D) 29 RFs with the fitness > 80%. (E) 19 RFs with fewer ringing wiggles are finally accepted.

Figure S4. Vp/Vs of the stations incorporated in this study and Vp/Vs from EARS. (A) The Vp/Vs for individual stations are presented by a scatter plot. The solid line represents where Vp/Vs from two studies are the same. (B) Vp/Vs distributions from this study and EARS are shown in blue and brown histograms, respectively.

Reference in Supplemental text only

1. Holland T, Baker J, Powell R (1998) Mixing properties and activity-composition relationships of chlorites in the system MgO-FeO-Al₂O₃-SiO₂-H₂O. *European Journal of Mineralogy* **10**:395-406.